South Downs Mercury

The monthly circular of South Downs Astronomical Society
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Main Talk Julian Onions Observing using the Isaac Newton Telescope, You just press the button, right? An observing trip to the Isaac Newton telescope. I got a chance to do some observing with the 2.5 m Isaac Newton telescope, should be straightforward? Just click and point? Not quite! So, what does it actually take to set up and use a professional telescope? How do you plan and execute an observing run?

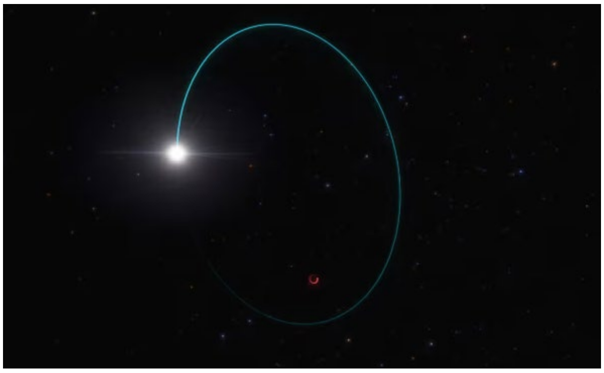
BIOGRAPHY

Julian has always had an interest in astronomy, and after many years as an amateur studied for a Phd in astrophysics at the University of Nottingham. There he studies computer models of galaxy formation using some of the biggest computers in the world, building model universes using mostly dark matter. He also helps out with undergraduate teaching and various outreach activities.

Please support a raffle we are organizing this month.

❖ Most massive stellar black hole in our galaxy found

Date: April 16, 2024
Source: ESO



Artist’s impression shows the orbits of both the star and the black hole around their common centre of mass. Photograph: ESO/L Calçada

Astronomers have identified the most massive stellar black hole yet discovered in the Milky Way galaxy. This black hole was spotted in data from the European Space Agency's Gaia mission because it imposes an odd 'wobbling' motion on the companion star orbiting it. Data from the European Southern Observatory's Very Large Telescope (ESO's VLT) and other ground-based observatories were used to verify the mass of the black hole, putting it at an impressive 33 times that of the Sun.

Stellar black holes are formed from the collapse of massive stars and the ones previously identified in the Milky Way are on average about 10 times as massive as the Sun. Even the next most massive stellar black hole known in our galaxy, Cygnus X-1, only reaches 21 solar masses, making this new 33-solar-mass observation exceptional [1]. Remarkably, this black hole is also extremely close to us -- at a mere 2000 light-years away in the constellation Aquila, it is the second-closest known black hole to Earth. Dubbed Gaia BH3 or BH3 for short, it was found while the team were reviewing Gaia observations in preparation for an upcoming data release. "No one was expecting to find a high-mass black hole lurking nearby, undetected so far," says Gaia collaboration member Pasquale Panuzzo, an astronomer at the Observatoire de Paris, part of France's National Centre for Scientific Research (CNRS). "This is the kind of discovery you make once in your research life."

To confirm their discovery, the Gaia collaboration used data from ground-based observatories, including from the Ultraviolet and Visual Echelle Spectrograph (UVES) instrument on ESO's VLT, located in Chile's Atacama Desert [2]. These observations revealed key properties of the companion star, which, together with Gaia data, allowed astronomers to precisely measure the mass of BH3.

Astronomers have found similarly massive black holes outside our galaxy (using a different detection method), and have theorised that they may form from the collapse of stars with very few elements heavier than hydrogen and helium in their chemical composition. These so-called metal-poor stars are thought to lose less mass over their lifetimes and hence have more material left over to produce high-mass black holes after their death. But evidence directly linking metal-poor stars to high-mass black holes has been lacking until now.

Stars in pairs tend to have similar compositions, meaning that BH3's companion holds important clues about the star that collapsed to form this exceptional black hole. UVES data showed that the companion was a very metal-poor star, indicating that the star that collapsed to form BH3 was also metal-poor -- just as predicted.

The research study, led by Panuzzo, is published today in Astronomy & Astrophysics. "We took the exceptional step of publishing this paper based on preliminary data ahead of the forthcoming Gaia release because of the unique nature of the discovery," says co-author Elisabetta Caffau, also a Gaia collaboration member from the CNRS Observatoire de Paris. Making the data available early will let other astronomers start studying this black hole right now, without waiting for the full data release, planned for late 2025 at the earliest.

Further observations of this system could reveal more about its history and about the black hole itself. The GRAVITY instrument on ESO's VLT Interferometer, for example, could help astronomers find out whether this black hole is pulling in matter from its surroundings and better understand this exciting object.

Notes

[1] This is not the most massive black hole in our galaxy -- that title belongs to Sagittarius A*, the supermassive black hole at the Milky Way's centre, which has about four million times the mass of the Sun. But Gaia BH3 is the most massive black hole known in the Milky Way that formed from the collapse of a star.

[2] Aside from UVES on ESO's VLT, the study relied on data from: the HERMES spectrograph at the Mercator Telescope operated at La Palma (Spain) by Leuven University, Belgium, in collaboration with the Observatory of the University of Geneva, Switzerland; and the SOPHIE high-precision spectrograph at the Observatoire de Haute-Provence -- OSU Institut Pythéas.

- How Pluto got its heart

Date: April 15, 2024
Source: University of Bern

Artistic representation of the huge, slow impact on Pluto that led to the heart-shaped structure on its surface.

The mystery of how Pluto got a giant heart-shaped feature on its surface has finally been solved by an international team of astrophysicists led by the University of Bern and members of the National Centre of Competence in Research (NCCR) PlanetS. The team is the first to successfully reproduce the unusual shape with numerical simulations, attributing it to a giant and slow oblique-angle impact.

Ever since the cameras of NASA's New Horizons mission discovered a large heart-shaped structure on the surface of the dwarf planet Pluto in 2015, this "heart" has puzzled scientists because of its unique shape, geological composition, and elevation. A team of scientists from the University of Bern, including several members of the NCCR PlanetS, and the University of Arizona in Tucson have used numerical simulations to investigate the origins of Sputnik Planitia, the western teardrop-shaped part of Pluto's "heart" surface feature. According to their research, Pluto's early history was marked by a cataclysmic event that formed Sputnik Planitia: a collision with a planetary body about 700 km in diameter, roughly twice the size of Switzerland from east to west. The team's findings, which were recently published in *Nature Astronomy*, also suggest that the inner structure of Pluto is different from what was previously assumed, indicating that there is no subsurface ocean.

A divided heart

The "heart," also known as the Tombaugh Regio, captured the public's attention immediately upon its discovery. But it also immediately caught the interest of scientists because it is covered in a high-albedo material that reflects more light than its surroundings, creating its whiter colour. However, the "heart" is not composed of a single element. Sputnik Planitia (the western part) covers an area of 1200 by 2000 kilometres, which is equivalent to a quarter of Europe or the United States. What is striking, however, is that this region is three to four kilometres lower in elevation than most of Pluto's surface. "The bright appearance of Sputnik Planitia is due to it being predominantly filled with white nitrogen ice that moves and convects to constantly smooth out the surface. This nitrogen most likely accumulated quickly after the impact due to the lower altitude," explains Dr. Harry Ballantyne from the University of Bern, lead author of the study. The eastern part of the "heart" is also covered by a similar but much thinner layer of nitrogen ice, the origin of which is still unclear to scientists, but is probably related to Sputnik Planitia.

An oblique impact

"The elongated shape of Sputnik Planitia strongly suggests that the impact was not a direct head-on collision but rather an oblique one," points out Dr. Martin Jutzi of the University of Bern, who initiated the study. So, the team, like several others around the world, used their Smoothed Particle Hydrodynamics (SPH) simulation software to digitally recreate such impacts, varying both the composition of Pluto and its impactor, as well as the velocity and angle of the impactor. These simulations confirmed the scientists' suspicions about the oblique angle of impact and determined the composition of the impactor.

"Pluto's core is so cold that the rocks remained very hard and did not melt despite the heat of the impact, and thanks to the angle of impact and the low velocity, the core of the impactor did not sink into Pluto's core, but remained intact as a splat on it," explains Harry Ballantyne. "Somewhere beneath Sputnik is the remnant core of another massive body, that Pluto never quite digested," adds co-author Erik Asphaug from the University of Arizona. This core strength and relatively low velocity were key to the success of these simulations: lower strength would result in a very symmetrical leftover surface feature that does not look like the teardrop shape observed by New Horizons.

"We are used to thinking of planetary collisions as incredibly intense events where you can ignore the details except for things like energy, momentum and density. But in the distant Solar System, velocities are so much slower, and solid ice is strong, so you have to be much more precise in your calculations. That's where the fun starts," says Erik Asphaug. The two teams have a long record of collaborations together, exploring since 2011 already the idea of planetary "splats" to explain, for instance, features on the far side of the Moon. After our moon and Pluto, the University of Bern team plans to explore similar scenarios for other outer Solar System bodies such as the Pluto-like dwarf planet Haumea.

No subsurface ocean on Pluto

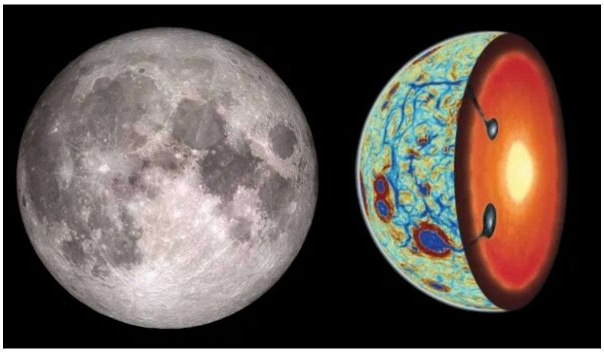
The current study sheds new light on Pluto's internal structure as well. In fact, a giant impact like the one simulated is much more likely to have occurred very early in Pluto's history. However, this poses a problem: a giant depression like Sputnik Planitia is expected to slowly move towards the pole of the dwarf planet over time due to the laws of physics, since it has a mass deficit. Yet it is paradoxically near the equator. The previous theorized explanation was that Pluto, like several other planetary bodies in the outer Solar System, has a subsurface liquid water ocean. According to this previous explanation, Pluto's icy crust would be thinner in the Sputnik Planitia region, causing the ocean to bulge there, and since liquid water is denser than ice, you would end up with a mass surplus that induces migration toward the equator.

However, the new study offers an alternative perspective. "In our simulations, all of Pluto's primordial mantle is excavated by the impact, and as the impactor's core material splats onto Pluto's core, it creates a local mass excess that can explain the migration toward the equator without a subsurface ocean, or at most a very thin one," explains Martin Jutzi. Dr. Adeene Denton from the University of Arizona, also co-author of the study, is currently conducting a new research project to estimate the speed of this migration. "This novel and inventing origin for Pluto's heart-shaped feature may lead to a better understanding of Pluto's origin," she concludes.

- How the moon turned itself inside out

Scientists combined computer simulations and spacecraft data to solve a long-standing mystery surrounding the moon's 'lopsided' geology

Date: April 8, 2024
Source: University of Arizona



(Left) a detailed image of the moon (Right) Schematic illustration with a gravity gradient map of the lunar nearside and a cross-section showing two ilmenite-bearing cumulate downwellings from lunar mantle overturn. (Image credit: NASA/Adrien Broquet/University of Arizona & Audrey Lasbordes)

About 4.5 billion years ago, a small planet smashed into the young Earth, flinging molten rock into space. Slowly, the debris coalesced, cooled and solidified, forming our moon. This scenario of how the Earth's moon came to be is the one largely agreed upon by most scientists. But the details of how exactly that happened are "more of a choose-your-own adventure novel," according to researchers in the University of Arizona Lunar and Planetary Laboratory who published a paper in *Nature Geoscience*. The findings offer important insights into the evolution of the lunar interior, and potentially for planets such as the Earth or Mars.

Most of what is known about the origin of the moon comes from analyses of rock samples, collected by Apollo astronauts more than 50 years ago, combined with theoretical models. The samples of basaltic lava rocks brought back from the moon showed surprisingly high concentrations of titanium. Later satellite observations found that these titanium-rich volcanic rocks are primarily located on the moon's nearside, but how and why they got there has remained a mystery -- until now.

Because the moon formed fast and hot, it was likely covered by a global magma ocean. As the molten rock gradually cooled and solidified, it formed the moon's mantle and the bright crust we see when we look up at a full moon at night. But deeper below the surface, the young moon was wildly out of equilibrium. Models suggest that the last dregs of the magma ocean crystallized into dense minerals including ilmenite, a mineral containing titanium and iron.

"Because these heavy minerals are denser than the mantle underneath, it creates a gravitational instability, and you would expect this layer to sink deeper into the moon's interior," said Weigang Liang, who led the research as part of his doctoral work at LPL. Somehow, in the millennia that followed, that dense material did sink into the interior, mixed with the mantle, melted and returned to the surface as titanium-rich lava flows that we see on the surface today.

"Our moon literally turned itself inside out," said co-author and LPL associate professor Jeff Andrews-Hanna. "But there has been little physical evidence to shed light on the exact sequence of events during this critical phase of lunar history, and there is a lot of disagreement in the details of what went down -- literally."

Did this material sink as it formed a little at a time, or all at once after the moon had fully solidified? Did it sink into the interior globally and then rise up on the near side, or did it migrate to the near side and then sink? Did it sink in one big blob, or several smaller blobs?

"Without evidence, you can pick your favourite model. Each model holds profound implications for the geologic evolution of our moon," said co-lead author Adrien Broquet of the German Aerospace Centre in Berlin, who did the work during his time as a postdoctoral research associate at LPL.

In a previous study, led by Nan Zhang at Peking University in Beijing, who is also a co-author on the latest paper, models predicted that the dense layer of titanium-rich material beneath the crust first migrated to the near side of the moon, possibly triggered by a giant impact on the far side, and then sunk into the interior in a network of sheetlike slabs, cascading into the lunar interior almost like waterfalls. But when that material sank, it left behind a small remnant in a geometric pattern of intersecting linear bodies of dense titanium-rich material beneath the crust.

"When we saw those model predictions, it was like a lightbulb went on," said Andrews-Hanna, "because we see the exact same pattern when we look at subtle variations in the moon's gravity field, revealing a network of dense material lurking below the crust."

In the new study, the authors compared simulations of a sinking ilmenite-rich layer to a set of linear gravity anomalies detected by NASA's GRAIL mission, whose two spacecraft orbited the moon between 2011 and 2012, measuring tiny variations in its gravitational pull. These linear anomalies surround a vast dark region of the lunar near side covered by volcanic flows known as mare (Latin for "sea").

The authors found that the gravity signatures measured by the GRAIL mission are consistent with ilmenite layer simulations, and that the gravity field can be used to map out the distribution of the ilmenite remnants left after the sinking of the majority of the dense layer.

"Our analyses show that the models and data are telling one remarkably consistent story," Liang said. "Ilmenite materials migrated to the near side and sunk into the interior in sheetlike cascades, leaving behind a vestige that causes anomalies in the moon's gravity field, as seen by GRAIL."

The team's observations also constrain the timing of this event: The linear gravity anomalies are interrupted by the largest and oldest impact basins on the near side and therefore must have formed earlier. Based on these cross-cutting relationships, the authors suggest that the ilmenite-rich layer sank prior to 4.22 billion years ago, which is consistent with it contributing to later volcanism seen on the lunar surface.

"Analysing these variations in the moon's gravity field allowed us to peek under the moon's surface and see what lies beneath," said Broquet, who worked with Liang to show that the anomalies in the moon's gravitational field match what would be expected for the zones of dense titanium-rich material predicted by computer simulation models of lunar overturn.

Lopsided moon

While the detection of lunar gravity anomalies provides evidence for the sinking of a dense layer in the moon's interior and allows for a more precise estimate of how and when this event occurred, what we see on the surface of the moon adds even more intrigue to the story, according to the research team.

"The moon is fundamentally lopsided in every respect," Andrews-Hanna said, explaining that the near side facing the Earth, and particularly the dark region known as Oceanus Procellarum region, is lower in elevation, has a thinner crust, is largely covered in lava flows, and has high concentrations of typically rare elements like titanium and thorium. The far side differs in each of these respects. Somehow, the overturn of the lunar mantle is thought to be related to the unique structure and history of the near side Procellarum region. But the details of that overturn have been a matter of considerable debate among scientists.

"Our work connects the dots between the geophysical evidence for the interior structure of the moon and computer models of its evolution," Liang added.

"For the first time we have physical evidence showing us what was happening in the moon's interior during this critical stage in its evolution, and that's really exciting," Andrews-Hanna said. "It turns out that the moon's earliest history is written below the surface, and it just took the right combination of models and data to unveil that story."

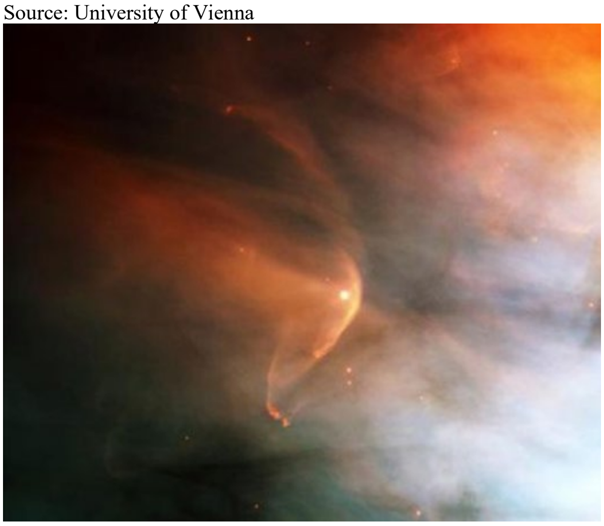
"The vestiges of early lunar evolution are present below the crust today, which is mesmerizing," Broquet said. "Future missions, such as with a seismic network, would allow a better investigation of the geometry of these structures."

Liang added: "When the Artemis astronauts eventually land on the moon to begin a new era of human exploration, we will have a very different understanding of our neighbour than we did when the Apollo astronauts first set foot on it."

- Stellar winds of three sun-like stars detected for the first time

Astrophysicists were able to quantify the mass loss of stars via their stellar winds

Date: April 12, 2024
Source: University of Vienna



© NASA/JPL-Caltech; NASA and The Hubble Heritage Team (STScI/AURA); C. R. O'Dell, Vanderbilt University

An international research team led by a researcher from the University of Vienna has for the first time directly detected stellar winds from three Sun-like stars by recording the X-ray emission from their astrospheres, and placed constraints on the mass loss rate of the stars via their stellar winds. The study is currently published in *Nature Astronomy.*

Astrospheres, stellar analogues of the heliosphere that surrounds our solar system, are very hot plasma bubbles blown by stellar winds into the interstellar medium, a space filled with gas and dust. The study of the stellar winds of low-mass stars similar to the Sun allows us to understand stellar and planetary evolution, and ultimately the history and future of our own star and solar system. Stellar winds drive many processes that evaporate planetary atmospheres into space and therefore lead to atmospheric mass loss. Although escape rates of planets over an hour or even a year are tiny, they operate over long geological periods. The losses accumulate and can be a decisive factor for a planet evolving into a habitable world or an airless rock. Despite their importance for the evolution of both stars and planets, winds of Sun-like stars are notoriously difficult to constrain. Mainly composed of protons and electrons, they also contain a small quantity of heavier highly charged ions (e.g. oxygen, carbon). It is these ions which, by capturing electrons from the neutrals of the interstellar medium around the star, emit X-rays.

X-ray emission from astrospheres detected

An international research team led by Kristina Kislyakova, Senior Scientist at the Department of Astrophysics of the University of Vienna, has detected for the first time the X-ray emission from the astrospheres around three sun-like stars, so called main sequence stars which are stars in the prime of their life, and has thus recorded such winds for the first time directly, allowing them to place constraints on the mass loss rate of the stars via their stellar winds.

These results, based on observations with the XMM-Newton space telescope, are currently published in *Nature Astronomy*. The researchers observed the spectral fingerprints (so-called spectral lines) of the oxygen ions with XMM-Newton and were able to determine the quantity of oxygen and ultimately the total mass of stellar wind emitted by the stars. For the three stars with detected astrospheres, named 70 Ophiuchi, epsilon Eridani, and 61 Cygni, the researchers estimated their mass loss rates to be 66.5±11.1, 15.6±4.4, and 9.6±4.1 times the solar mass loss rate, respectively. This means that the winds from these stars are much stronger than the solar wind, which might be explained by stronger magnetic activity of these stars.

"In the solar system, solar wind charge exchange emission has been observed from planets, comets, and the heliosphere and provides a natural laboratory to study the solar wind's composition," explains the lead author of the study, Kristina Kislyakova. "Observing this emission from distant stars is much trickier due to the faintness of the signal. In addition to that, the distance to the stars makes it very difficult to disentangle the signal emitted by the astrosphere from the actual X-ray emission of the star itself, part of which is "spread" over the field-of-view of the telescope due to instrumental effects. We have developed a new algorithm to disentangle the stellar and the atmospheric contributions to the emission and detected charge exchange signals originating from stellar wind oxygen ions and the surrounding neutral interstellar medium of three main-sequence stars. This has been the first time X-ray charge exchange emission from astrospheres of such stars has been detected. Our estimated mass loss rates can be used as a benchmark for stellar wind models and expand our limited observational evidence for the winds of Sun-like stars."

Co-author Manuel Güdel, also of the University of Vienna, adds, "there have been world-wide efforts over three decades to substantiate the presence of winds around Sun-like stars and measure their strengths, but so far only indirect evidence based on their secondary effects on the star or its environment alluded to the existence of such winds; our group previously tried to detect radio emission from the winds but could only place upper limits to the wind strengths while not detecting the winds themselves. Our new X-ray based results pave the way to finding and even imaging these winds directly and studying their interactions with surrounding planets."

"In the future, this method of direct detection of stellar winds in X-rays will be facilitated thanks to future high-resolution instruments, like the X-IFU spectrometer of the European Athena mission. The high spectral resolution of X-IFU will resolve the finer structure and emission ratio of the oxygen lines (as well as other fainter lines), that are hard to distinguish with XMM's CCD resolution, and provide additional constraints on the emission mechanism; thermal emission from the stars, or non-thermal charge exchange from the astrospheres." -- explains CNRS researcher Dimitra Koutroumpa, a co-author of the study.

- Beautiful nebula, violent history: Clash of stars solves stellar mystery

Date: April 11, 2024

Source: ESO

This image, taken with the VLT Survey Telescope hosted at ESO's Paranal Observatory, shows the beautiful nebula NGC 6164/6165, also known as the Dragon's Egg. The nebula is a cloud of gas and dust surrounding a pair of stars called HD 148937. Credit: ESO/VPHAS+ team. Acknowledgement: CASU

When astronomers looked at a stellar pair at the heart of a stunning cloud of gas and dust, they were in for a surprise. Star pairs are typically very similar, like twins, but in HD 148937, one star appears younger and, unlike the other, is magnetic. New data from the European Southern Observatory (ESO) suggest there were originally three stars in the system, until two of them clashed and merged. This violent event created the surrounding cloud and forever altered the system's fate.

"When doing background reading, I was struck by how special this system seemed," says Abigail Frost, an astronomer at ESO in Chile and lead author of the study published today in *Science*. The system, HD 148937, is located about 3800 light-years away from Earth in the direction of the Norma constellation. It is made up of two stars much more massive than the Sun and surrounded by a beautiful nebula, a cloud of gas and dust. "A nebula surrounding two massive stars is a rarity, and it really made us feel like something cool had to have happened in this system. When looking at the data, the coolness only increased."

"After a detailed analysis, we could determine that the more massive star appears much younger than its companion, which doesn't make any sense since they should have formed at the same time!" Frost says. The age difference -- one star appears to be at least 1.5 million years younger than the other -- suggests something must have rejuvenated the more massive star.

Another piece of the puzzle is the nebula surrounding the stars, known as NGC 6164/6165. It is 7500 years old, hundreds of times younger than both stars. The nebula also shows very high amounts of nitrogen, carbon and oxygen. This is surprising as these elements are normally expected deep inside a star, not outside; it is as if some violent event had set them free.

To unravel the mystery, the team assembled nine years' worth of data from the PIONIER and GRAVITY instruments, both on ESO's Very Large Telescope Interferometer (VLTI), located in Chile's Atacama Desert. They also used archival data from the FEROS instrument at ESO's La Silla Observatory.

"We think this system had at least three stars originally; two of them had to be close together at one point in the orbit whilst another star was much more distant," explains Hugues Sana, a professor at KU Leuven in Belgium and the principal investigator of the observations. "The two inner stars merged in a violent manner, creating a magnetic star and throwing out some material, which created the nebula. The more distant star formed a new orbit with the newly merged, now-magnetic star, creating the binary we see today at the centre of the nebula."

"The merger scenario was already in my head back in 2017 when I studied nebula observations obtained with the European Space Agency's Herschel Space Telescope," adds co-author Laurent Mahy, currently a senior researcher at the Royal Observatory of Belgium. "Finding an age discrepancy between the stars suggests that this scenario is the most plausible one and it was only possible to show it with the new ESO data."

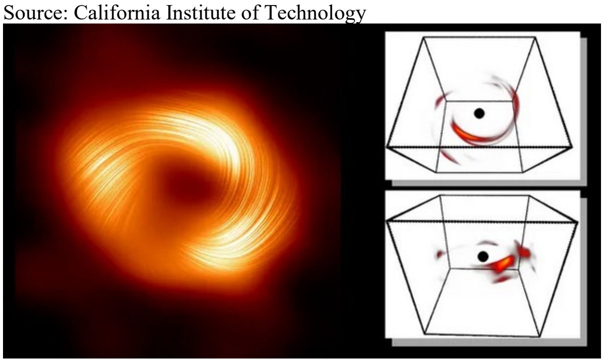
This scenario also explains why one of the stars in the system is magnetic and the other is not -- another peculiar feature of HD 148937 spotted in the VLTI data.

At the same time, it helps solve a long-standing mystery in astronomy: how massive stars get their magnetic fields. While magnetic fields are a common feature of low-mass stars like our Sun, more massive stars cannot sustain magnetic fields in the same way. Yet some massive stars are indeed magnetic. Astronomers had suspected for some time that massive stars could acquire magnetic fields when two stars merge. But this is the first-time researchers find such direct evidence of this happening. In the case of HD 148937, the merger must have happened recently.

"Magnetism in massive stars isn't expected to last very long compared to the lifetime of the star, so it seems we have observed this rare event very soon after it happened," Frost adds.

❖ AI and physics combine to reveal the 3D structure of a flare erupting around a black hole

Date: April 22, 2024
Source: California Institute of Technology



(Left) The Milky Way's central supermassive black hole Sagittarius A* (Right) screenshots from a 3D simulation of flares around Sgr A* (Image credit: EHT Collaboration/Aviad Levis)

Scientists believe the environment immediately surrounding a black hole is tumultuous, featuring hot magnetized gas that spirals in a disk at tremendous speeds and temperatures. Astronomical observations show that within such a disk, mysterious flares occur up to several times a day, temporarily brightening and then fading away.

Now a team led by Caltech scientists has used telescope data and an artificial intelligence (AI) computer-vision technique to recover the first three-dimensional video showing what such flares could look like around Sagittarius A* (Sgr A*, pronounced sadge-ay-star), the supermassive black hole at the heart of our own Milky Way galaxy.

The 3D flare structure features two bright, compact features located about 75 million kilometres (or half the distance between Earth and the Sun) from the centre of the black hole. It is based on data collected by the Atacama Large Millimetre Array (ALMA) in Chile over a period of 100 minutes directly after an eruption seen in X-ray data on April 11, 2017.

"This is the first three-dimensional reconstruction of gas rotating close to a black hole," says Katie Bouman, assistant professor of computing and mathematical sciences, electrical engineering and astronomy at Caltech, whose group led the effort described in a new paper in *Nature Astronomy*.

Aviad Levis, a postdoctoral scholar in Bouman's group and lead author on the new paper, emphasizes that while the video is not a simulation, it is also not a direct recording of events as they took place. "It is a reconstruction based on our models of black hole physics. There is still a lot of uncertainty associated with it because it relies on these models being accurate," he says.

Using AI informed by physics to figure out possible 3D structures

To reconstruct the 3D image, the team had to develop new computational imaging tools that could, for example, account for the bending of light due to the curvature of space-time around objects of enormous gravity, such as a black hole.

The multidisciplinary team first considered if it would be possible to create a 3D video of flares around a black hole in June 2021. The Event Horizon Telescope (EHT) Collaboration, of which Bouman and Levis are members, had already published the first image of the supermassive black hole at the core of a distant galaxy, called M87, and was working to do the same with EHT data from Sgr A*. Pratul Srinivasan of Google Research, a co-author on the new paper, was at the time visiting the team at Caltech. He had helped develop a technique known as neural radiance fields (NeRF) that was then just starting to be used by researchers; it has since had a huge impact on computer graphics. NeRF uses deep learning to create a 3D representation of a scene based on 2D images. It provides a way to observe scenes from different angles, even when only limited views of the scene are available.

The team wondered if, by building on these recent developments in neural network representations, they could reconstruct the 3D environment around a black hole. Their big challenge: From Earth, as anywhere, we only get a single viewpoint of the black hole.

The team thought that they might be able to overcome this problem because gas behaves in a somewhat predictable way as it moves around the black hole. Consider the analogy of trying to capture a 3D image of a child wearing an inner tube around their waist. To capture such an image with the traditional, NeRF method, you would need photos taken from multiple angles while the child remained stationary. But in theory, you could ask the child to rotate while the photographer remained stationary taking pictures. The timed snapshots, combined with information about the child's rotation speed, could be used to reconstruct the 3D scene equally well.

Similarly, by leveraging knowledge of how gas moves at different distances from a black hole, the researchers aimed to solve the 3D flare reconstruction problem with measurements taken from Earth over time.

With this insight in hand, the team built a version of NeRF that takes into account how gas moves around black holes. But it also needed to consider how light bends around massive objects such as black holes. Under the guidance of co-author Andrew Chael of Princeton University, the team developed a computer model to simulate this bending, also known as gravitational lensing.

With these considerations in place, the new version of NeRF was able to recover the structure of orbiting bright features around the event horizon of a black hole. Indeed, the initial proof-of-concept showed promising results on synthetic data.

A flare around Sgr A* to study

But the team needed some real data. That's where ALMA came in. The EHT's now famous image of Sgr A* was based on data collected on April 6-7, 2017, which were relatively calm days in the environment surrounding the black hole. But astronomers detected an explosive and sudden brightening in the surroundings just a few days later, on April 11. When team member Maciek Wielgus of the Max Planck Institute for Radio Astronomy in Germany went back to the ALMA data from that day, he noticed a signal with a period matching the time it would take for a bright spot within the disk to complete an orbit around Sgr A*. The team set out to recover the 3D structure of that brightening around Sgr A*.

ALMA is one of the most powerful radio telescopes in the world. However, because of the vast distance to the galactic centre (more than 26,000 light-years), even ALMA does not have the resolution to see Sgr A*'s immediate surroundings. What ALMA measures are light curves, which are essentially videos of a single flickering pixel, which are created by collecting all of the radio-wavelength light detected by the telescope for each moment of observation.

Recovering a 3D volume from a single-pixel video might seem impossible. However, by leveraging an additional piece of information about the physics that are expected for the disk around black holes, the team was able to get around the lack of spatial information in the ALMA data.

Strongly polarized light from the flares provided clues

ALMA doesn't just capture a single light curve. In fact, it provides several such "videos" for each observation because the telescope records data relating to different polarization states of light. Like wavelength and intensity, polarization is a fundamental property of light and represents which direction the electric component of a light wave is oriented with respect to the wave's general direction of travel. "What we get from ALMA is two polarized single-pixel videos," says Bouman, who is also a Rosenberg Scholar and a Heritage Medical Research Institute Investigator. "That polarized light is actually really, really informative."

Recent theoretical studies suggest that hot spots forming within the gas are strongly polarized, meaning the light waves coming from these hot spots have a distinct preferred orientation direction. This is in contrast to the rest of the gas, which has a more random or scrambled orientation. By gathering the different polarization measurements, the ALMA data gave the scientists information that could help localize where the emission was coming from in 3D space.

Introducing Orbital Polarimetric Tomography

To figure out a likely 3D structure that explained the observations, the team developed an updated version of its method that not only incorporated the physics of light bending and dynamics around a black hole but also the polarized emission expected in hot spots orbiting a black hole. In this technique, each potential flare structure is represented as a continuous volume using a neural network. This allows the researchers to computationally progress the initial 3D structure of a hotspot over time as it orbits the black hole to create a whole light curve. They could then solve for the best initial 3D structure that, when progressed in time according to black hole physics, matched the ALMA observations.

The result is a video showing the clockwise movement of two compact bright regions that trace a path around the black hole. "This is very exciting," says Bouman. "It didn't have to come out this way. There could have been arbitrary brightness scattered throughout the volume. The fact that this looks a lot like the flares that computer simulations of black holes predict is very exciting."

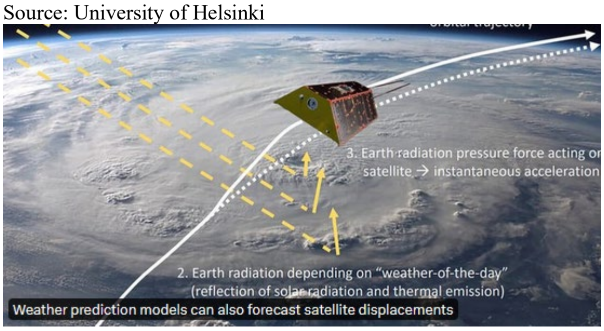
Levis says that the work was uniquely interdisciplinary: "You have a partnership between computer scientists and astrophysicists, which is uniquely synergetic. Together, we developed something that is cutting edge in both fields -- both the development of numerical codes that model how light propagates around black holes and the computational imaging work that we did."

The scientists note that this is just the beginning for this exciting technology. "This is a really interesting application of how AI and physics can come together to reveal something that is otherwise unseen," says Levis. "We hope that astronomers could use it on other rich time-series data to shed light on complex dynamics of other such events and to draw new conclusions."

- Weather prediction models can also forecast satellite displacements

New research finds that modern weather models can accurately predict satellite movements due to the energy emitted and reflected by the Earth.

Date: April 19, 2024
Source: University of Helsinki



Researchers at the Institute for Atmospheric and Earth System Research (INAR) at the University of Helsinki have found that modern weather models can accurately predict the energy that Earth emits and reflects into space, which directly affects the movements of low Earth-orbiting (LEO) satellites. By leveraging these models, the researchers gained insights into how LEO satellites respond to weather events below, such as tropical cyclones with tall and reflective clouds. The results were published in the *Journal of Geophysical Research* in April.

In the study, the researchers utilized numerical weather models. They are sophisticated computer simulators that predict future atmospheric conditions based on current observations and laws of physics.

"Numerical weather models not only simulate weather patterns but also calculate various parameters, including the Earth's energy emissions and reflections under various weather conditions. By analysing these simulations, we sought to understand how changes in weather, such as cloud cover and storms, influence the movement of satellites, affecting their ability to fulfil their intended duties," says Sanam Motlaghzadeh, lead author of the study and doctoral researcher at INAR, funded by the Nessling Foundation.

Improved satellite operations

The significance of the findings lies in their potential to enhance satellite tracking and control, improving the efficiency and reliability of satellite operations.

"Understanding how weather affects satellites also enhances the accuracy of satellite-based measurements used in climate studies. These findings address a critical challenge in satellite data reliability, namely, determining the precise orbits of satellites, on which the weather events have effect," Motlaghzadeh explains.

Satellites play a crucial role in monitoring vegetation, tracking water resources, and observing glacier evolution through various measurement techniques. These measurements, including image capture and height and gravity field measurements, are essential for studying climate change and its impacts.

A better understanding of satellite movements can also aid in climate monitoring and disaster management. Utilizing advanced weather models can further refine satellite-based measurements, facilitating more effective study and mitigation of environmental issues.

"Understanding how satellites interact with Earth's atmosphere offers valuable insights into our planet and how it changes over time. The findings contribute to more accurate satellite-based monitoring of terrestrial water resources, and hence to food security, Motlaghzadeh says.

- Physicists solve puzzle about ancient galaxy found by Webb telescope

Study offers an explanation for dark matter distribution in a massive quiescent galaxy

Date: April 12, 2024
Source: University of California – Riverside

Last September, the James Webb Space Telescope, or JWST, discovered JWST-ER1g, a massive ancient galaxy that formed when the universe was just a quarter of its current age. Surprisingly, an Einstein ring is associated with this galaxy. That's because JWST-ER1g acts as a lens and bends light from a distant source, which then appears as a ring -- a phenomenon called strong gravitational lensing, predicted in Einstein's theory of general relativity.

The total mass enclosed within the ring has two components: stellar and dark matter components.

"If we subtract the stellar mass from the total mass, we get the dark matter mass within the ring," said Hai-Bo Yu, a professor of physics and astronomy at the University of California, Riverside, whose team has published new work about JWST-ER1g in the journal *The Astrophysical Journal Letters*. "But the value for the dark matter mass seems higher than expected. This is puzzling. In our paper, we offer an explanation."

A dark matter halo is the halo of invisible matter that permeates and surrounds a galaxy like JWST-ER1g. Although dark matter has never been detected in laboratories, physicists are confident dark matter, which makes up 85% of the universe's matter, exists.

"When ordinary matter -- pristine gas and stars -- collapses and condenses into the dark matter halo of JWST-ER1g, it may be compressing the halo, leading to a high density," said Demao Kong, a second-year graduate student at UCR, who led the analysis. "Our numerical studies show that this mechanism can explain the high dark matter density of JWST-ER1g -- more dark matter mass in the same volume, resulting in higher density."

According to Daneng Yang, a postdoctoral researcher at UCR and co-author on the paper, JWST-ER1g, formed 3.4 billion years after the Big Bang, provides "a great chance to learn about dark matter."

"This strong lensing object is unique because it has a perfect Einstein ring, from which we can obtain valuable information about the total mass within the ring, a critical step for testing dark matter properties," he said.

Launched on Christmas Day in 2021, NASA's JWST is an orbiting infrared observatory. Also called Webb, it is designed to answer questions about the universe. It is the largest, most complex, and powerful space telescope ever built.

"JWST provides an unprecedented opportunity for us to observe ancient galaxies formed when the universe was young," Yu said. "We expect to see more surprises from JWST and learn more about dark matter soon."

The study was supported by the John Templeton Foundation and the U.S. Department of Energy.

The title of the open access research paper is "Cold Dark Matter and Self-interacting Dark Matter Interpretations of the Strong Gravitational Lensing Object JWST-ER1."

- Astronomers uncover methane emission on a cold brown dwarf

James Webb Space Telescope data pinpoints possible aurorae on isolated world in our solar neighbourhood

Date: April 17, 2024
Source: American Museum of Natural History

An illustration of a brown dwarf and its infrared emissions as seen by the James Webb Space Telescope. (Image credit: NASA, ESA, CSA, LEAH HUSTAK (SPACE TELESCOPE SCIENCE INSTITUTE)

Using new observations from the James Webb Space Telescope (JWST), astronomers have discovered methane emission on a brown dwarf, an unexpected finding for such a cold and isolated world. Published in the journal *Nature*, the findings suggest that this brown dwarf might generate aurorae similar to those seen on our own planet as well as on Jupiter and Saturn.

More massive than planets but lighter than stars, brown dwarfs are ubiquitous in our solar neighbourhood, with thousands identified.

Last year, Jackie Faherty, a senior research scientist and senior education manager at the American Museum of Natural History, led a team of researchers who were awarded time on JWST to investigate 12 brown dwarfs. Among those was CWISEP J193518.59-154620.3 (or W1935 for short) -- a cold brown dwarf 47 light years away that was co-discovered by Backyard Worlds: Planet 9 citizen science volunteer Dan Caselden and the NASA CatWISE team. W1935 is a cold brown dwarf with a surface temperature of about 400° Fahrenheit, or about the temperature at which you'd bake chocolate chip cookies. The mass for W1935 isn't well known but it likely ranges between 6-35 times the mass of Jupiter.

After looking at a number of brown dwarfs observed with JWST, Faherty's team noticed that W1935 looked similar but with one striking exception: it was emitting methane, something that's never been seen before on a brown dwarf.

"Methane gas is expected in giant planets and brown dwarfs but we usually see it absorbing light, not glowing," said Faherty, the lead author of the study. "We were confused about what we were seeing at first but ultimately that transformed into pure excitement at the discovery."

Computer modelling yielded another surprise: the brown dwarf likely has a temperature inversion, a phenomenon in which the atmosphere gets warmer with increasing altitude. Temperature inversions can easily happen to planets orbiting stars, but W1935 is isolated, with no obvious external heat source.

"We were pleasantly shocked when the model clearly predicted a temperature inversion," said co-author Ben Burningham from the University of Hertfordshire. "But we also had to figure out where that extra upper atmosphere heat was coming from."

To investigate, the researchers turned to our solar system. In particular, they looked at studies of Jupiter and Saturn, which both show methane emission and have temperature inversions. The likely cause for this feature on solar system giants is aurorae, therefore, the research team surmised that they had uncovered that same phenomenon on W1935.

Planetary scientists know that one of the major drivers of aurorae on Jupiter and Saturn are high-energy particles from the Sun that interact with the planets' magnetic fields and atmospheres, heating the upper layers. This is also the reason for the aurorae that we see on Earth, commonly referred to as the Northern or Southern Lights since they are most extraordinary near the poles. But with no host star for W1935, a solar wind cannot contribute to the explanation.

There is an enticing additional reason for the aurora in our solar system. Both Jupiter and Saturn have active moons that occasionally eject material into space, interact with the planets, and enhance the auroral footprint on those worlds. Jupiter's moon Io is the most volcanically active world in the solar system, spewing lava fountains dozens of miles high, and Saturn's moon Enceleadus ejects water vapor from its geysers that simultaneously freezes and boils when it hits space. More observations are needed, but the researchers speculate that one explanation for the aurora on W1935 might be an active, yet-to-be discovered moon.

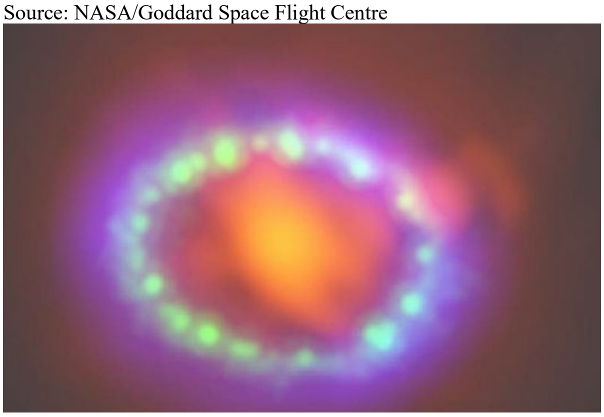
"Every time an astronomer points JWST at an object, there's a chance of a new mind-blowing discovery," said Faherty. "Methane emission was not on my radar when we started this project but now that we know it can be there and the explanation for it so enticing I am constantly on the look-out for it. That's part of how science moves forward."

Other authors on the study include Jonathan Gagne, Institute for Research on Exoplanets and Université de Montréal; Genaro Suarez, Dan Caselden, Austin Rothermich, and Niall Whiteford, American Museum of Natural History; Johanna Vos, Trinity College Dublin; Sherelyn Alejandro Merchan, City University of New York; Caroline Morley, University of Texas; Melanie Rowland and Brianna Lacy, University of Texas, Austin; Rocio Kiman, Charles Beichman, Federico Marocco, and Christopher Gelino, California Institute of Technology; Davy Kirkpatrick, IPAC; Aaron Meisner, NOIRLab; Adam Schneider, USNO; Marc Kuchner and Ehsan Gharib-Nezhad, NASA; Daniella Bardalez Gagliuffi, Amherst; Peter Eisenhardt, Jet Propulsion Laboratory; and Eileen Gonzales, San Francisco State University.

This work was supported in part by NASA and the Space Telescope Science Institute.

❖ No gamma rays seen coming from nearby supernova

Date: April 16, 2024
Source: NASA/Goddard Space Flight Centre



A composite image of SN 1987A from Hubble, Chandra, and ALMA. Credit: ALM

A nearby supernova in 2023 offered astrophysicists an excellent opportunity to test ideas about how these types of explosions boost particles, called cosmic rays, to near light-speed. But surprisingly, NASA's Fermi Gamma-ray Space Telescope detected none of the high-energy gamma-ray light those particles should produce.

On May 18, 2023, a supernova erupted in the nearby Pinwheel galaxy (Messier 101), located about 22 million light-years away in the constellation Ursa Major. The event, named SN 2023ixf, is the most luminous nearby supernova discovered since Fermi launched in 2008.

"Astrophysicists previously estimated that supernovae convert about 10% of their total energy into cosmic ray acceleration," said Guillem Martí-Devesa, a researcher at the University of Trieste in Italy. "But we have never observed this process directly. With the new observations of SN 2023ixf, our calculations result in an energy conversion as low as 1% within a few days after the explosion. This doesn't rule out supernovae as cosmic ray factories, but it does mean we have more to learn about their production."

The paper, led by Martí-Devesa while at the University of Innsbruck in Austria, will appear in a future edition of Astronomy and Astrophysics.

Trillions of trillions of cosmic rays collide with Earth's atmosphere every day. Roughly 90% of them are hydrogen nuclei -- or protons -- and the remainder are electrons or the nuclei of heavier elements.

Scientists have been investigating cosmic ray origins since the early 1900s, but the particles can't be traced back to their sources. Because they're electrically charged, cosmic rays change course as they travel to Earth thanks to magnetic fields they encounter.

"Gamma rays, however, travel directly to us," said Elizabeth Hays, the Fermi project scientist at NASA's Goddard Space Flight Centre in Greenbelt, Maryland. "Cosmic rays produce gamma rays when they interact with matter in their environment. Fermi is the most sensitive gamma-ray telescope in orbit, so when it doesn't detect an expected signal, scientists must explain the absence. Solving that mystery will build a more accurate picture of cosmic ray origins."

Astrophysicists have long suspected supernovae of being top cosmic ray contributors.

These explosions occur when a star at least eight times the Sun's mass runs out of fuel. The core collapses and then rebounds, propelling a shock wave outward through the star. The shock wave accelerates particles, creating cosmic rays. When cosmic rays collide with other matter and light surrounding the star, they generate gamma rays.

Supernovae greatly impact a galaxy's interstellar environment. Their blast waves and expanding cloud of debris may persist for more than 50,000 years. In 2013, Fermi measurements showed that supernova remnants in our own Milky Way galaxy were accelerating cosmic rays, which generated gamma-ray light when they struck interstellar matter. But astronomers say the remnants aren't producing enough high-energy particles to match scientists' measurements on Earth.

One theory proposes that supernovae may accelerate the most energetic cosmic rays in our galaxy in the first few days and weeks after the initial explosion.

But supernovae are rare, occurring only a few times a century in a galaxy like the Milky Way. Out to distances of around 32 million light-years, a supernova occurs, on average, just once a year.

After a month of observations, starting when visible light telescopes first saw SN 2023ixf, Fermi had not detected gamma rays.

"Unfortunately, seeing no gamma rays doesn't mean there are no cosmic rays," said co-author Matthieu Renaud, an astrophysicist at the Montpellier Universe and Particles Laboratory, part of the National Centre for Scientific Research in France. "We have to go through all the underlying hypotheses regarding acceleration mechanisms and environmental conditions in order to convert the absence of gamma rays into an upper limit for cosmic ray production."

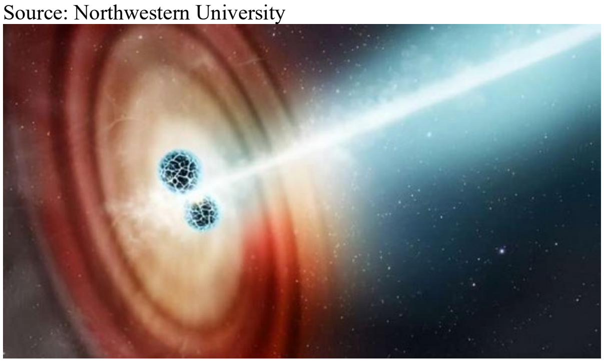
The researchers propose a few scenarios that may have affected Fermi's ability to see gamma rays from the event, like the way the explosion distributed debris and the density of material surrounding the star.

Fermi's observations provide the first opportunity to study conditions right after the supernova explosion. Additional observations of SN 2023ixf at other wavelengths, new simulations and models based on this event, and future studies of other young supernovae will help astronomers home in on the mysterious sources of the universe's cosmic rays.

- ❖ Brightest gamma-ray burst of all time came from the collapse of a massive star

Observations show no sign of heavy elements

Date: April 12, 2024
Source: Northwestern University



This artist's illustration shows two neutron stars colliding. Known as a "kilonova" event, they're the only confirmed location of the r-process that forges heavy elements. Credits: Elizabeth Wheatley (STScI)

In October 2022, an international team of researchers, including Northwestern University astrophysicists, observed the brightest gamma-ray burst (GRB) ever recorded, GRB 221009A.

Now, a Northwestern-led team has confirmed that the phenomenon responsible for the historic burst -- dubbed the B.O.A.T. ("brightest of all time") -- is the collapse and subsequent explosion of a massive star. The team discovered the explosion, or supernova, using NASA's James Webb Space Telescope (JWST).

While this discovery solves one mystery, another mystery deepens.

The researchers speculated that evidence of heavy elements, such as platinum and gold, might reside within the newly uncovered supernova. The extensive search, however, did not find the signature that accompanies such elements. The origin of heavy elements in the universe continues to remain as one of astronomy's biggest open questions.

The research will be published on Friday (April 12) in the journal *Nature Astronomy*.

"When we confirmed that the GRB was generated by the collapse of a massive star, that gave us the opportunity to test a hypothesis for how some of the heaviest elements in the universe are formed," said Northwestern's Peter Blanchard, who led the study. "We did not see signatures of these heavy elements, suggesting that extremely energetic GRBs like the B.O.A.T. do not produce these elements. That doesn't mean that all GRBs do not produce them, but it's a key piece of information as we continue to understand where these heavy elements come from. Future observations with JWST will determine if the B.O.A.T.'s 'normal' cousins produce these elements."

Blanchard is a postdoctoral fellow at Northwestern's Centre for Interdisciplinary Exploration and Research in Astrophysics (CIERA), where he studies super luminous supernovae and GRBs. The study includes co-authors from the Centre for Astrophysics | Harvard & Smithsonian; University of Utah; Penn State; University of California, Berkeley; Radbound University in the Netherlands; Space Telescope Science Institute; University of Arizona/Steward Observatory; University of California, Santa Barbara; Columbia University; Flatiron Institute; University of Greifswald and the University of Guelph.

Birth of the B.O.A.T.

When its light washed over Earth on Oct. 9, 2022, the B.O.A.T. was so bright that it saturated most of the world's gamma-ray detectors. The powerful explosion occurred approximately 2.4 billion light-years away from Earth, in the direction of the constellation Sagitta and lasted a few hundred seconds in duration. As astronomers scrambled to observe the origin of this incredibly bright phenomenon, they were immediately hit with a sense of awe.

"As long as we have been able to detect GRBs, there is no question that this GRB is the brightest we have ever witnessed by a factor of 10 or more," Wen-fai Fong, an associate professor of physics and astronomy at Northwestern's Weinberg College of Arts and Sciences and member of CIERA, said at the time.

"The event produced some of the highest-energy photons ever recorded by satellites designed to detect gamma rays," Blanchard said. "This was an event that Earth sees only once every 10,000 years. We are fortunate to live in a time when we have the technology to detect these bursts happening across the universe. It's so exciting to observe such a rare astronomical phenomenon as the B.O.A.T. and work to understand the physics behind this exceptional event."

A 'normal' supernova

Rather than observe the event immediately, Blanchard, his close collaborator Ashley Villar of Harvard University and their team wanted to view the GRB during its later phases. About six months after the GRB was initially detected, Blanchard used the JWST to examine its aftermath.

"The GRB was so bright that it obscured any potential supernova signature in the first weeks and months after the burst," Blanchard said. "At these times, the so-called afterglow of the GRB was like the headlights of a car coming straight at you, preventing you from seeing the car itself. So, we had to wait for it to fade significantly to give us a chance of seeing the supernova."

Blanchard used the JWST's Near Infrared Spectrograph to observe the object's light at infrared wavelengths. That's when he saw the characteristic signature of elements like calcium and oxygen typically found within a supernova. Surprisingly, it wasn't exceptionally bright -- like the incredibly bright GRB that it accompanied.

"It's not any brighter than previous supernovae," Blanchard said. "It looks fairly normal in the context of other supernovae associated with less energetic GRBs. You might expect that the same collapsing star producing a very energetic and bright GRB would also produce a very energetic and bright supernova. But it turns out that's not the case. We have this extremely luminous GRB, but a normal supernova."

Missing: Heavy elements

After confirming -- for the first time -- the presence of the supernova, Blanchard and his collaborators then searched for evidence of heavy elements within it. Currently, astrophysicists have an incomplete picture of all the mechanisms in the universe that can produce elements heavier than iron.

The primary mechanism for producing heavy elements, the rapid neutron capture process, requires a high concentration of neutrons. So far, astrophysicists have only confirmed the production of heavy elements via this process in the merger of two neutron stars, a collision detected by the Laser Interferometer Gravitational-Wave Observatory (LIGO) in 2017. But scientists say there must be other ways to produce these elusive materials. There are simply too many heavy elements in the universe and too few neutron-star mergers.

"There is likely another source," Blanchard said. "It takes a very long time for binary neutron stars to merge. Two stars in a binary system first have to explode to leave behind neutron stars. Then, it can take billions and billions of years for the two neutron stars to slowly get closer and closer and finally merge. But observations of very old stars indicate that parts of the universe were enriched with heavy metals before most binary neutron stars would have had time to merge. That's pointing us to an alternative channel."

Astrophysicists have hypothesized that heavy elements also might be produced by the collapse of a rapidly spinning, massive star -- the exact type of star that generated the B.O.A.T. Using the infrared spectrum obtained by the JWST, Blanchard studied the inner layers of the supernova, where the heavy elements should be formed.

"The exploded material of the star is opaque at early times, so you can only see the outer layers," Blanchard said. "But once it expands and cools, it becomes transparent. Then you can see the photons coming from the inner layer of the supernova."

"Moreover, different elements absorb and emit photons at different wavelengths, depending on their atomic structure, giving each element a unique spectral signature," Blanchard explained. "Therefore, looking at an object's spectrum can tell us what elements are present. Upon examining the B.O.A.T.'s spectrum, we did not see any signature of heavy elements, suggesting extreme events like GRB 221009A are not primary sources. This is crucial information as we continue to try to pin down where the heaviest elements are formed."

Why so bright?

To tease apart the light of the supernova from that of the bright afterglow that came before it, the researchers paired the JWST data with observations from the Atacama Large Millimetre/Submillimetre Array (ALMA) in Chile.

"Even several months after the burst was discovered, the afterglow was bright enough to contribute a lot of light in the JWST spectra," said Tanmoy Laskar, an assistant professor of physics and astronomy at the University of Utah and a co-author on the study. "Combining data from the two telescopes helped us measure exactly how bright the afterglow was at the time of our JWST observations and allow us to carefully extract the spectrum of the supernova."

Although astrophysicists have yet to uncover how a "normal" supernova and a record-breaking GRB were produced by the same collapsed star, Laskar said it might be related to the shape and structure of the relativistic jets. When rapidly spinning, massive stars collapse into black holes, they produce jets of material that launch at rates close to the speed of light. If these jets are narrow, they produce a more focused -- and brighter -- beam of light.

"It's like focusing a flashlight's beam into a narrow column, as opposed to a broad beam that washes across a whole wall," Laskar said. "In fact, this was one of the narrowest jets seen for a gamma-ray burst so far, which gives us a hint as to why the afterglow appeared as bright as it did. There may be other factors responsible as well, a question that researchers will be studying for years to come."

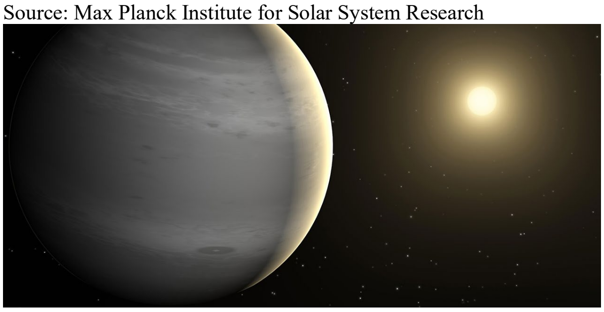
Additional clues also may come from future studies of the galaxy in which the B.O.A.T. occurred. "In addition to a spectrum of the B.O.A.T. itself, we also obtained a spectrum of its 'host' galaxy," Blanchard said. "The spectrum shows signs of intense star formation, hinting that the birth environment of the original star may be different than previous events."

Team member Yijia Li, a graduate student at Penn State, modelled the spectrum of the galaxy, finding that the B.O.A.T.'s host galaxy has the lowest metallicity, a measure of the abundance of elements heavier than hydrogen and helium, of all previous GRB host galaxies. "This is another unique aspect of the B.O.A.T. that may help explain its properties," Li said.

The study, "JWST detection of a supernova associated with GRB 221009A without an r-process signature," was supported by NASA (award number JWST-GO-2784) and the National Science Foundation (award numbers AST-2108676 and AST-2002577). This work is based on observations made with the NASA/ESA/CSA James Webb Space Telescope.

- Exoplanets true to size

Date: April 12, 2024
Source: Max Planck Institute for Solar System Research



Artist's impression of a "hot Jupiter" orbiting close to a Sun-like star.
Credit: NASA

A star's magnetic field must be considered in order to correctly determine the characteristics of their exoplanets from observations by space telescopes such as Kepler, James Webb, or PLATO. This is demonstrated by new model calculations presented today in the journal *Nature Astronomy* by a research group led by the Max Planck Institute for Solar System Research (MPS) in Germany. The researchers show that the distribution of the star's brightness over its disk depends on the star's level of magnetic activity. This, in turn, affects the signature of an exoplanet in observational data. The new model must be used in order to properly interpret the data from the latest generation of space telescopes pointed at distant worlds outside our Solar System.

700 light years away from Earth in the constellation Virgo, the planet WASP-39b orbits the star WASP-39. The gas giant, which takes little more than four days to complete one orbit, is one of the best-studied exoplanets: Shortly after its commissioning in July 2022, NASA's James Webb Space Telescope turned its high-precision gaze on the distant planet. The data revealed evidence of large quantities of water vapor, of methane and even, for the first time, of carbon dioxide in the atmosphere of WASP-39b. A minor sensation! But there is still one fly in the ointment: researchers have not yet succeeded in reproducing all the crucial details of the observations in model calculations. This stands in the way of an even more precise analyses of the data. In the new study led by the MPS, the authors, including researchers from the Massachusetts Institute of Technology (USA), the Space Telescope Science Institute (USA), Keele University (United Kingdom), and the University of Heidelberg (Germany), show a way to overcome this obstacle.

"The problems arising when interpreting the data from WASP-39b are well known from many other exoplanets -- regardless whether they are observed with Kepler, TESS, James Webb, or the future PLATO spacecraft," explains MPS scientist Dr. Nadiia Kostogryz, first author of the new study. "As with other stars orbited by exoplanets, the observed light curve of WASP-39 is flatter than previous models can explain," she adds.

Researchers define a light curve as a measurement of the brightness of a star over a longer period of time. The brightness of a star fluctuates constantly, for example because its luminosity is subject to natural fluctuations. Exoplanets can also leave traces in the light curve. If an exoplanet passes in front of its star as seen by an observer, it dims the starlight. This is reflected in the light curve as a regularly recurring drop in brightness. Precise evaluations of such curves provide information about the size and orbital period of the planet. Researchers can also obtain information about the composition of the planet's atmosphere, if the light from the star is split into its different wavelengths or colours.

A close look at a star's brightness distribution

The limb of a star, the edge of the stellar disk, plays a decisive role in the interpretation of its light curve. Just as in the case of the Sun, the limb appears darker to the observer than the inner area. However, the star does not actually shine less brightly further out. "As the star is a sphere and its surface curved, we look into higher and therefore cooler layers at the limb than in the centre," explains coauthor and MPS-Director Prof. Dr. Laurent Gizon. "This area therefore appears darker to us," he adds.

It is known that the limb darkening affects the exact shape of the exoplanet signal in the light curve: The dimming determines how steeply the brightness of a star falls during a planetary transit and then rises again. However, it has not been possible to reproduce observational data accurately using conventional models of the stellar atmosphere. The decrease of brightness was always less abrupt than the model calculations suggested. "It was clear that we were missing a crucial piece of the puzzle to precisely understand the exoplanets' signal," says MPS-Director Prof. Dr. Sami Solanki, coauthor of the current study.

Magnetic field is the missing piece of the puzzle

As the calculations published today show, the missing piece of the puzzle is the stellar magnetic field. Like the Sun, many stars generate a magnetic field deep in their interior through enormous flows of hot plasma. For the first time, the researchers were now able to include the magnetic field in their models of limb darkening. They could show that the strength of the magnetic field has an important effect: The limb darkening is pronounced in stars with a weak magnetic field, while it is weaker in those with a strong magnetic field.

The researchers were also able to prove that the discrepancy between observational data and model calculations disappears if the star's magnetic field is included in the computations. To this end, the team turned to selected data from NASA's Kepler Space Telescope, which captured the light of thousands and thousands of stars from 2009 to 2018. In a first step, the scientists modelled the atmosphere of typical Kepler stars in the presence of a magnetic field. In a second step, they then generated "artificial" observational data from these calculations. As a comparison with the real data showed, by including the magnetic field, the Kepler data is successfully reproduced.

The team also extended its considerations to data from the James Webb Space Telescope. The telescope is able to split the light of distant stars into its various wavelengths and thus search for the characteristic signs of certain molecules in the atmosphere of the discovered planets. As it turns out, the magnetic field of the parent star influences the stellar limb darkening differently at different wavelengths -- and should therefore be taken into account in future evaluations in order to achieve even more precise results.

From telescopes to models

"In the past decades and years, the way to move forward in exoplanet research was to improve the hardware, the space telescopes designed to search for and characterize new worlds. The James Webb Space Telescope has pushed this development to new limits," says Dr. Alexander Shapiro, coauthor of the current study and head of an ERC-funded research group at the MPS. "The next step is now to improve and refine the models to interpret this excellent data," he adds.

To further advance this development, the researchers now want to extend their analyses to stars that are clearly different from the Sun. In addition, their findings offer the possibility of using the light curves of stars with exoplanets to infer the strength of the stellar magnetic field, which is otherwise often hard to measure.