South Downs Mercury

The monthly circular of South Downs Astronomical Society
Issue: 565 – June 3rd 2022 Editor: Roger Burgess
Main Speaker 19:30 19:30 Owen Brazell Observing Planetary Nebula
The meeting will be Zoom only

Lisa Lacey is standing down as Secretary by the end of August, we need a replacement to take over from her before she stands down

- New study indicates limited water circulation late in the history of Mars

Date: May 13, 2022
Source: Lund University

A research team led by Lund University in Sweden has investigated a meteorite from Mars using neutron and X-ray tomography. The technology, which will probably be used when NASA examines samples from the Red Planet in 2030, showed that the meteorite had limited exposure to water, thus making life at that specific time and place unlikely.
In a cloud of smoke, NASA's spacecraft Perseverance parachuted onto the dusty surface of Mars in February 2021. For several years, the vehicle will skid around and take samples to try to answer the question posed by David Bowie in Life on Mars in 1971. It isn't until around 2030 that Nasa actually intends to send the samples back to Earth, but material from Mars is already being studied -- in the form of meteorites. In a new study published in *Science Advances*, an international research team has studied an approximately 1.3 billion-year-old meteorite using advanced scanning.
"Since water is central to the question of whether life ever existed on Mars, we wanted to investigate how much of the meteorite reacted with water when it was still part of the Mars bedrock," explains Josefin Martell, geology doctoral student at Lund University.
To answer the question of whether there was any major hydrothermal system, which is generally a favourable environment for life to occur, the researchers used neutron and X-ray tomography. X-ray tomography is a common method of examining an object without damaging it. Neutron tomography was used because neutrons are very sensitive to hydrogen.
This means that if a mineral contains hydrogen, it is possible to study it in three dimensions and see where in the meteorite the hydrogen is located. Hydrogen (H) is always of interest when scientists study material from Mars, because water (H2O) is a prerequisite for life as we know it. The results show that a fairly small part of the sample seems to have reacted with water, and that it therefore probably wasn't a large hydrothermal system that gave rise to the alteration.
"A more probable explanation is that the reaction took place after small accumulations of underground ice melted during a meteorite impact about 630 million years ago. Of course, that doesn't mean that life couldn't have existed in other places on Mars, or that there couldn't have been life at other times," says Josefin Martell.
The researchers hope that the results of their study will be helpful when NASA brings back the first samples from Mars around 2030, and there are many reasons to believe that the current technology with neutron and X-ray tomography will be useful when this happens.
"It would be fun if we had the opportunity to study these samples at the research facility European Spallation Source, ESS in Lund,

which by then will be the world's most powerful neutron source," concludes Josefin Martell.

- Researchers use galaxy as a 'cosmic telescope' to study heart of the young universe

Date: May 18, 2022
Source: North Carolina State University

A unique new instrument, coupled with a powerful telescope and a little help from nature, has given researchers the ability to peer into galactic nurseries at the heart of the young universe.

After the big bang some 13.8 billion years ago, the early universe was filled with enormous clouds of neutral diffuse gas, known as Damped Lyman-α systems, or DLAs. These DLAs served as galactic nurseries, as the gasses within slowly condensed to fuel the formation of stars and galaxies. They can still be observed today, but it isn't easy.

"DLAs are a key to understanding how galaxies form in the universe, but they are typically difficult to observe since the clouds are too diffuse and don't emit any light themselves," says Rongmon Bordoloi, assistant professor of physics at North Carolina State University and corresponding author of the research.

Currently, astrophysicists use quasars -- supermassive black holes that emit light -- as "backlight" to detect the DLA clouds. And while this method does allow researchers to pinpoint DLA locations, the light from the quasars only acts as small skewers through a massive cloud, hampering efforts to measure their total size and mass.

But Bordoloi and John O'Meara, chief scientist at the W.M. Keck Observatory in Kamuela, Hawaii, found a way around the problem by using a gravitationally lensed galaxy and integral field spectroscopy to observe two DLAs -- and the host galaxies within -- that formed around 11 billion years ago, not long after the big bang.

"Gravitationally lensed galaxies refers to galaxies that appear stretched and brightened," Bordoloi says. "This is because there is a gravitationally massive structure in front of the galaxy that bends the light coming from it as it travels toward us. So we end up looking at an extended version of the object -- it's like using a cosmic telescope that increases magnification and gives us better visualization.

"The advantage to this is twofold: One, the background object is extended across the sky and bright, so it is easy to take spectrum readings on different parts of the object. Two, because lensing extends the object, you can probe very small scales. For example, if the object is one light year across, we can study small bits in very high fidelity."

Spectrum readings allow astrophysicists to "see" elements in deep space that are not visible to the naked eye, such as diffuse gaseous DLAs and the potential galaxies within them. Normally, gathering the readings is a long and painstaking process. But the team solved that issue by performing integral field spectroscopy with the Keck Cosmic Web Imager.

Integral field spectroscopy allowed the researchers to obtain a spectrum at every single pixel on the part of the sky it targeted, making spectroscopy of an extended object on the sky very efficient. This innovation combined with the stretched and brightened gravitationally lensed galaxy allowed the team to map out the diffuse DLA gas in the sky at high fidelity. Through this method the researchers were able to determine not only the size of the two DLAs, but also that they both contained host galaxies.

"I've waited most of my career for this combination: a telescope and instrument powerful enough, and nature giving us a bit of lucky alignments to study not one but two DLAs in a rich new way," O'Meara says. "It's great to see the science come to fruition."

The DLAs are huge, by the way. With diameters greater than 17.4 kiloparsecs, they're more than two thirds the size of the Milky Way galaxy today. For comparison, 13 billion years ago, a typical galaxy would have a diameter of less than 5 kiloparsecs. A parsec is 3.26 light years, and a kiloparsec is 1,000 parsecs, so it would take light about 56,723 years to travel across each DLA.

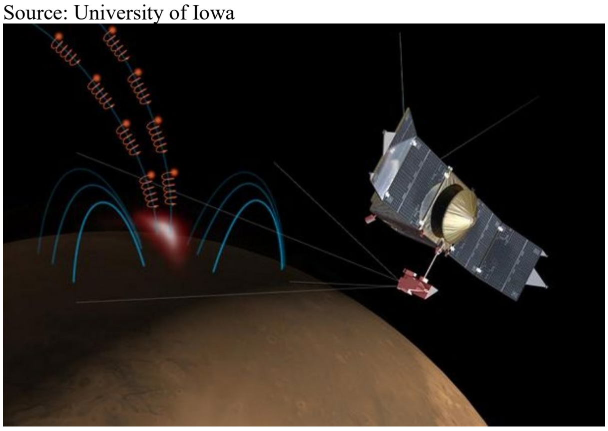
"But to me, the most amazing thing about the DLAs we observed is that they aren't unique -

- they seem to have similarities in structure, host galaxies were detected in both, and their masses indicate that they contain enough fuel for the next generation of star formation," Bordoloi says. "With this new technology at our disposal, we are going to be able to dig deeper into how stars formed in the early universe."

The work appears in *Nature* and was supported by the National Aeronautics and Space Administration, the W.M. Keck Foundation and the National Science Foundation. The Australian Research Council Centre of Excellence for All Sky Astrophysics in 3 Dimensions (ASTRO 3D) also contributed to the work.

- ❖ Physicists explain how type of aurora on Mars is formed

Date: May 18, 2022
Source: University of Iowa



Physicists led by the University of Iowa have learned how a type of aurora on Mars is formed.

In a new study, the physicists studied discrete aurora, a light-in-the-sky display that occurs mostly during the night in the red planet's southern hemisphere. While scientists have known about discrete aurora on Mars-which also occur on Earth -- they did not know how they formed. That's because Mars does not have a global magnetic field like Earth, which is a main trigger for aurora, also called the northern and southern lights on our planet. Instead, the physicists report, discrete aurora on Mars are governed by the interaction between the solar wind -- the constant jet of charged particles from the sun -- and magnetic fields generated by the crust at southern latitudes on Mars. It's the nature of this localized interaction between the solar wind and the crustal magnetic fields that lead to discrete aurora, the scientists find.

"We have the first detailed study looking at how solar wind conditions affect aurora on Mars," says Zachary Girazian, associate research scientist in the Department of Physics and Astronomy and the study's corresponding author. "Our main finding is that inside the strong crustal field region, the aurora occurrence rate depends mostly on the orientation of the solar wind magnetic field, while outside the strong crustal field region, the occurrence rate depends mostly on the solar wind dynamic pressure."

The findings come from more than 200 observations of discrete aurora on Mars by the NASA-led Mars Atmosphere and Volatile EvolutioN (MAVEN) spacecraft. One of the instruments used to make the observations, the Solar Wind Ion Analyzer, is led by Jasper Halekas, associate professor in the Department of Physics and Astronomy and a co-author on the study.

"Now is a very fruitful and exciting time for researching aurora at Mars. The database of discrete aurora observations we have from MAVEN is the first of its kind, allowing us to understand basic features of the aurora for the first time," Girazian says.

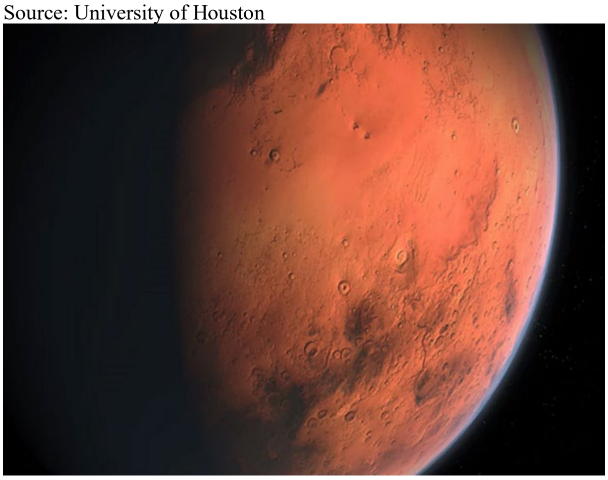
Contributing authors are Nick Schneider, Zachariah Milby, Xiaohua Fang, Sonal Kumar Jain, and Justin Deighan from the University of Colorado-Boulder; Tristan Weber from NASA Goddard Space Flight Centre; Jean-Claude Gerard and Lucas Soret from the Universite de Liege in Belgium; and Christina Lee from the University of California-Berkeley.

NASA funded the research.

- ❖ Mars' emitted energy and seasonal energy imbalance

Traces of long-ago climate change could foretell Earth's own climate troubles

Date: May 16, 2022
Source: University of Houston



A seasonal imbalance in the amount of solar energy absorbed and released by the planet Mars is a likely cause of the dust storms that have long intrigued observers, a team of researchers reports.

Mars' extreme imbalance in energy budget (a term referring to the measurement of solar energy a planet takes in from the sun then releases as heat) was documented by University of Houston researchers Liming Li, associate professor of physics; Xun Jiang, professor of atmospheric science; and Ellen Creecy, doctoral student and lead author of an article to be published this week in the *Proceedings of the National Academy of Sciences* (*PNAS*).

"One of our most interesting findings is that the energy excess -- more energy being absorbed than emitted -- could be one of the generating mechanisms of Mars' dust storms. Understanding how this works on Mars might provide clues about the roles Earth's energy budget takes in the development of severe storms, including hurricanes, on our own planet," Creecy said.

A thin atmosphere and very elliptical orbit make Mars especially susceptible to wide temperature differences. It absorbs extreme amounts of solar heat when it swings closest to the sun in its perihelion seasons (spring and summer for Mars' southern hemisphere), which is the same extreme part of the orbit when its dust storms appear. As its orbit takes Mars further away from the sun, less solar energy is absorbed by the planet. This same phenomenon happens on Earth, too, but the researchers found it to be especially extreme on Mars.

On Earth, energy imbalances can be measured according to season and year, and they play a critical role in our global warming and climate change. In a separate project, Creecy and her colleagues are examining if energy imbalance on Mars also exists on longer time scales, and if it does what the implications would be on the planet's climate change.

"Mars is not a planet that has any kind of real energy storage mechanisms, like we have on Earth. Our large oceans, for example, help to equilibrate the climate system," Creecy said. Yet, Mars bears signs that oceans, lakes and rivers were once abundant. So what happened? The facts are unsettled as to why or when the planet dried into a hot, dusty globe with an abundance of iron oxide -- rust, actually, whose tawny colour inspired observers from centuries ago to call it the Red Planet.

"Mars had oceans and lakes in the past, but it later experienced global warming and climate change. Somehow, Mars lost its oceans and lakes. We know that climate change is happening on Earth now. So what do the lessons of Mars' experience hold for the future of Earth?," Li asked.

Creecy and her colleagues reached their conclusions by comparing four years of data (those are Martian years, roughly equivalent to eight Earth years) of Mars' orbits and temperatures to conditions as documented by NASA missions.

For planetary enthusiasts, they note that much of the data can be accessed free from NASA's Planetary Data Systems website, although some information is available only to researchers. They also collaborated with NASA scientists, including several who have been key members of past missions, including the Mars Global Surveyor and two rovers, Curiosity and Insight, which are still operating on site.

"If we open our eyes to a wide field, Earth is just one planet. With just one point, we never can see a complete picture. We have to look at all points, all planets, to get a complete picture of the evolution of our own Earth. There are many things we can learn from the other planets," Li said. "By studying the history of Mars we gain a lot. What is climate change? What's the future phase for our planet? What's the evolution of Earth? So many things we can learn from other planets."

Joining Creecy, Li and Jiang as co-authors of the article were Michael Smith of NASA Goddard Space Flight Centre in Greenbelt, MD; David Kass and Armin Kleinböhl, both of the Jet Propulsion Laboratory at the California Institute of Technology; and Germán Martínez from the Lunar and Planetary Institute in Houston.

- Hubble reaches new milestone in mystery of universe's expansion rate

Date: May 24, 2022
Source: NASA/Goddard

Completing a nearly 30-year marathon, NASA's Hubble Space Telescope has calibrated more than 40 "milepost markers" of space and time to help scientists precisely measure the expansion rate of the universe -- a quest with a plot twist.

Pursuit of the universe's expansion rate began in the 1920s with measurements by astronomers Edwin P. Hubble and Georges Lemaître. In 1998, this led to the discovery of "dark energy," a mysterious repulsive force accelerating the universe's expansion. In recent years, thanks to data from Hubble and other telescopes, astronomers found another twist: a discrepancy between the expansion rate as measured in the local universe compared to independent observations from right after the big bang, which predict a different expansion value.

The cause of this discrepancy remains a mystery. But Hubble data, encompassing a variety of cosmic objects that serve as distance markers, support the idea that something weird is going on, possibly involving brand new physics.

"You are getting the most precise measure of the expansion rate for the universe from the gold standard of telescopes and cosmic mile markers," said Nobel Laureate Adam Riess of the Space Telescope Science Institute (STScI) and the Johns Hopkins University in Baltimore, Maryland.

Riess leads a scientific collaboration investigating the universe's expansion rate called SH0ES, which stands for Supernova, H0, for the Equation of State of Dark Energy.

"This is what the Hubble Space Telescope was built to do, using the best techniques we know to do it. This is likely Hubble's magnum opus, because it would take another 30 years of Hubble's life to even double this sample size," Riess said.

Riess's team's paper, to be published in the Special Focus issue of *The Astrophysical Journal* reports on completing the biggest and likely last major update on the Hubble constant. The new results more than double the prior sample of cosmic distance markers. His team also reanalysed all of the prior data, with the whole dataset now including over 1,000 Hubble orbits.

When NASA conceived of a large space telescope in the 1970s, one of the primary justifications for the expense and extraordinary technical effort was to be able to resolve Cepheids, stars that brighten and dim periodically, seen inside our Milky Way and external galaxies. Cepheids have long been the gold standard of cosmic mile markers since their utility was discovered by astronomer Henrietta Swan Leavitt in 1912. To calculate much greater distances, astronomers use exploding stars called Type Ia supernovae.

Combined, these objects built a "cosmic distance ladder" across the universe and are essential to measuring the expansion rate of the universe, called the Hubble constant after Edwin Hubble. That value is critical to estimating the age of the universe and provides a basic test of our understanding of the universe.

Starting right after Hubble's launch in 1990, the first set of observations of Cepheid stars to refine the Hubble constant was undertaken by two teams: the HST Key Project led by Wendy Freedman, Robert Kennicutt, Jeremy Mould, and Marc Aaronson, and another by Allan Sandage and collaborators, that used Cepheids as milepost markers to refine the distance measurement to nearby galaxies. By the early 2000s the teams declared "mission accomplished" by reaching an accuracy of 10 percent for the Hubble constant, 72 plus or minus 8 kilometres per second per megaparsec.

In 2005 and again in 2009, the addition of powerful new cameras onboard the Hubble telescope launched "Generation 2" of the Hubble constant research as teams set out to refine the value to an accuracy of just one percent. This was inaugurated by the SH0ES program. Several teams of astronomers using Hubble, including SH0ES, have converged on a Hubble constant value of 73 plus or minus 1 kilometre per second per megaparsec. While other approaches have been used to investigate the Hubble constant question, different teams have come up with values close to the same number.

The SH0ES team includes long-time leaders Dr. Wenlong Yuan of Johns Hopkins University, Dr. Lucas Macri of Texas A&M University, Dr. Stefano Casertano of STScI, and Dr. Dan Scolnic of Duke University. The project was designed to bracket the universe by matching the precision of the Hubble constant inferred from studying the cosmic microwave background radiation leftover from the dawn of the universe.

"The Hubble constant is a very special number. It can be used to thread a needle from the past to the present for an end-to-end test of our understanding of the universe. This took a phenomenal amount of detailed work," said

Dr. Licia Verde, a cosmologist at ICREA and the ICC-University of Barcelona, speaking about the SH0ES team's work.

The team measured 42 of the supernova milepost markers with Hubble. Because they are seen exploding at a rate of about one per year, Hubble has, for all practical purposes, logged as many supernovae as possible for measuring the universe's expansion. Riess said, "We have a complete sample of all the supernovae accessible to the Hubble telescope seen in the last 40 years." Like the lyrics from the song "Kansas City," from the Broadway musical Oklahoma, Hubble has "gone about as far as it can go!"

Weird Physics?

The expansion rate of the universe was predicted to be slower than what Hubble actually sees. By combining the Standard Cosmological Model of the Universe and measurements by the European Space Agency's Planck mission (which observed the relic cosmic microwave background from 13.8 billion years ago), astronomers predict a lower value for the Hubble constant: 67.5 plus or minus 0.5 kilometres per second per megaparsec, compared to the SH0ES team's estimate of 73.

Given the large Hubble sample size, there is only a one-in-a-million chance astronomers are wrong due to an unlucky draw, said Riess, a common threshold for taking a problem seriously in physics. This finding is untangling what was becoming a nice and tidy picture of the universe's dynamical evolution. Astronomers are at a loss for an explanation of the disconnect between the expansion rate of the local universe versus the primeval universe, but the answer might involve additional physics of the universe.

Such confounding findings have made life more exciting for cosmologists like Riess. Thirty years ago they started out to measure the Hubble constant to benchmark the universe, but now it has become something even more interesting. "Actually, I don't care what the expansion value is specifically, but I like to use it to learn about the universe," Riess added.

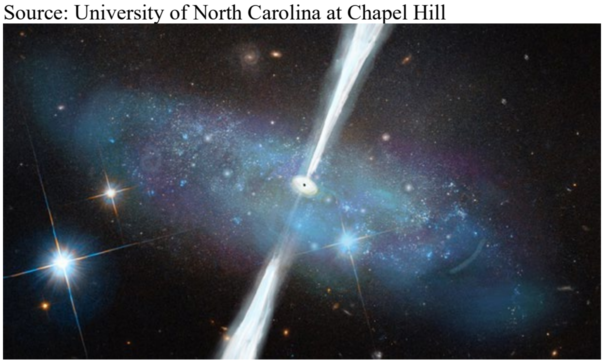
NASA's new Webb Space Telescope will extend on Hubble's work by showing these cosmic milepost markers at greater distances or sharper resolution than what Hubble can see.

The Hubble Space Telescope is a project of international cooperation between NASA and ESA (European Space Agency). NASA's Goddard Space Flight Centre in Greenbelt, Maryland, manages the telescope. The Space Telescope Science Institute (STScI) in Baltimore, Maryland, conducts Hubble science operations. STScI is operated for NASA by the Association of Universities for Research in Astronomy in Washington, D.C.

- Astronomers find hidden trove of massive black holes

Newfound black holes in dwarf galaxies shed light on the origin of our galaxy's supermassive black hole

Date: May 24, 2022
Source: University of North Carolina at Chapel Hill



A team led by researchers at the University of North Carolina at Chapel Hill has found a previously overlooked treasure trove of massive black holes in dwarf galaxies. The newly discovered black holes offer a glimpse into the life story of the supermassive black hole at the centre of our own Milky Way galaxy.

As a giant spiral galaxy, the Milky Way is believed to have been built up from mergers of many smaller dwarf galaxies. For example, the Magellanic Clouds seen in the southern sky are dwarf galaxies that will merge into the Milky Way. Each dwarf that falls in may bring with it a central massive black hole, tens or hundreds of thousands of times the mass of our sun, potentially destined to be swallowed by the Milky Way's central supermassive black hole.

But how often dwarf galaxies contain a massive black hole is unknown, leaving a key gap in our understanding of how black holes and galaxies grow together. New research published in the *Astrophysical Journal* helps to fill in this gap by revealing that massive black holes are many times more common in dwarf galaxies than previously thought.

"This result really blew my mind because these black holes were previously hiding in plain sight," said Mugdha Polimera, lead author of the study and a UNC-Chapel Hill Ph.D. student.

Sending mixed messages

Black holes are typically detected when they are actively growing by ingesting gas and stardust swirling around them, which makes them glow intensely.

UNC-Chapel Hill Professor Sheila Kannappan, Polimera's Ph.D. advisor and co-author of the study, compared black holes to fireflies.

"Just like fireflies, we see black holes only when they're lit up -- when they're growing -- and the lit-up ones give us a clue to how many we can't see."

The problem is, while growing black holes glow with distinctive high-energy radiation, young new born stars can too. Traditionally, astronomers have differentiated growing black holes from new star formation using diagnostic tests that rely on detailed features of each galaxy's visible light when spread out into a spectrum like a rainbow.

The path to discovery began when undergraduate students working with Kannappan tried to apply these traditional tests to galaxy survey data. The team realized that some of the galaxies were sending mixed messages -- two tests would indicate growing black holes, but a third would indicate only star formation.

"Previous work had just rejected ambiguous cases like these from statistical analysis, but I had a hunch they might be undiscovered black holes in dwarf galaxies," Kannappan said. She suspected that the third, sometimes contradictory, test was more sensitive than the other two to typical properties of dwarfs: their simple elemental composition (mainly primordial hydrogen and helium from the Big Bang) and their high rate of forming new stars.

Study co-author Chris Richardson, an associate professor at Elon University, confirmed with theoretical simulations that the mixed-message test results exactly matched what theory would predict for a primordial-composition, highly star-forming dwarf galaxy containing a growing massive black hole. "The fact that my simulations lined up with what the Kannappan group found made me excited to explore the implications for how galaxies evolve," Richardson said.

A census of growing black holes

Polimera took on the challenge of constructing a new census of growing black holes, with attention to both traditional and mixed-message types. She obtained published measurements of visible light spectral features to test for black holes in thousands of galaxies found in two surveys led by Kannappan, RESOLVE and ECO. These surveys include ultraviolet and radio data ideal for studying star formation, and they have an unusual design: Whereas most astronomical surveys select samples that favour big and bright galaxies, RESOLVE and ECO are complete inventories of huge volumes of the present-day universe in which dwarf galaxies are abundant.

"It was important to me that we didn't bias our black hole search toward dwarf galaxies," Polimera said. "But in looking at the whole census, I found that the new type of growing black holes almost always showed up in dwarfs. I was taken aback by the numbers when I first saw them."

More than 80 percent of all growing black holes she found in dwarf galaxies belonged to the new type.

The result seemed too good. "We all got nervous," Polimera said. "The first question that came to my mind was: Have we missed a way that extreme star formation alone could explain these galaxies?" She led an exhaustive search for alternative explanations involving star formation, modelling uncertainties, or exotic astrophysics. In the end, the team was forced to conclude that the newly identified black holes were real.

"We're still pinching ourselves," Kannappan said. "We're excited to pursue a zillion follow-up idea. The black holes we've found are the basic building blocks of supermassive black holes like the one in our own Milky Way. There's so much we want to learn about them."

This research was funded in part by the National Science Foundation.

- Planets of binary stars as possible homes for alien life

Date: May 23, 2022
Source: University of Copenhagen - Faculty of Science

Nearly half of Sun-size stars are binary. According to University of Copenhagen research, planetary systems around binary stars may be very different from those around single stars. This points to new targets in the search for extra-terrestrial life forms.
Since the only known planet with life, the Earth, orbits the Sun, planetary systems around stars of similar size are obvious targets for astronomers trying to locate extra-terrestrial life. Nearly every second star in that category is a binary star. A new result from research at University of Copenhagen indicate that planetary systems are formed in a very different way around binary stars than around single stars such as the Sun.
"The result is exciting since the search for extra-terrestrial life will be equipped with several new, extremely powerful instruments within the coming years. This enhances the significance of understanding how planets are formed around different types of stars. Such results may pinpoint places which would be especially interesting to probe for the existence of life," says Professor Jes Kristian Jørgensen, Niels Bohr Institute, University of Copenhagen, heading the project.
The results from the project, which also has participation of astronomers from Taiwan and USA, are published in the journal *Nature.*

Bursts shape the planetary system

The new discovery has been made based on observations made by the ALMA telescopes in Chile of a young binary star about 1,000 lightyears from Earth. The binary star system, NGC 1333-IRAS2A, is surrounded by a disc consisting of gas and dust. The observations can only provide researchers with a snapshot from a point in the evolution of the binary star system. However, the team has complemented the observations with computer simulations reaching both backwards and forwards in time.
"The observations allow us to zoom in on the stars and study how dust and gas move towards the disc. The simulations will tell us which physics are at play, and how the stars have evolved up till the snapshot we observe, and their future evolution," explains Postdoc Rajika L. Kuruwita, Niels Bohr Institute, second author of the Nature article.
Notably, the movement of gas and dust does not follow a continuous pattern. At some points in time -- typically for relatively shorts periods of ten to one hundred years every thousand years -- the movement becomes very strong. The binary star becomes ten to one hundred times brighter, until it returns to its regular state.
Presumably, the cyclic pattern can be explained by the duality of the binary star. The two stars encircle each other, and at given intervals their joint gravity will affect the surrounding gas and dust disc in a way which causes huge amounts of material to fall towards the star.
"The falling material will trigger a significant heating. The heat will make the star much brighter than usual," says Rajika L. Kuruwita, adding:
"These bursts will tear the gas and dust disc apart. While the disc will build up again, the bursts may still influence the structure of the later planetary system."

Comets carry building blocks for life

The observed stellar system is still too young for planets to have formed. The team hopes to obtain more observational time at ALMA, allowing to investigate the formation of planetary systems.
Not only planets but also comets will be in focus:
"Comets are likely to play a key role in creating possibilities for life to evolve. Comets often have a high content of ice with presence of organic molecules. It can well be imagined that the organic molecules are preserved in comets during epochs where a planet is barren, and that later comet impacts will introduce the molecules to the planet's surface," says Jes Kristian Jørgensen.
Understanding the role of the bursts is important in this context:
"The heating caused by the bursts will trigger evaporation of dust grains and the ice surrounding them. This may alter the chemical composition of the material from which planets are formed."
Thus, chemistry is a part of the research scope:
"The wavelengths covered by ALMA allow us to see quite complex organic molecules, so molecules with 9-12 atoms and containing

carbon. Such molecules can be building blocks for more complex molecules which are key to life as we know it. For example, amino acids which have been fund in comets."

Powerful tools join the search for life in space

ALMA (Atacama Large Millimetre/submillimetre Array) is not a single instrument but 66 telescopes operating in coordination. This allows for a much better resolution than could have been obtained by a single telescope.

Very soon the new James Webb Space Telescope (JWST) will join the search for extra-terrestrial life. Near the end of the decade, JWST will be complemented by the ELT (European Large Telescope) and the extremely powerful SKA (Square Kilometre Array) both planned to begin observing in 2027. The ELT will with its 39-meter mirror be the biggest optical telescope in the world and will be poised to observe the atmospheric conditions of exoplanets (planets outside the Solar System, ed.). SKA will consist of thousands of telescopes in South Africa and in Australia working in coordination and will have longer wavelengths than ALMA.

"The SKA will allow for observing large organic molecules directly. The James Webb Space Telescope operates in the infrared which is especially well suited for observing molecules in ice. Finally, we continue to have ALMA which is especially well suited for observing molecules in gas form. Combining the different sources will provide a wealth of exciting results," Jes Kristian Jørgensen concludes.

Background

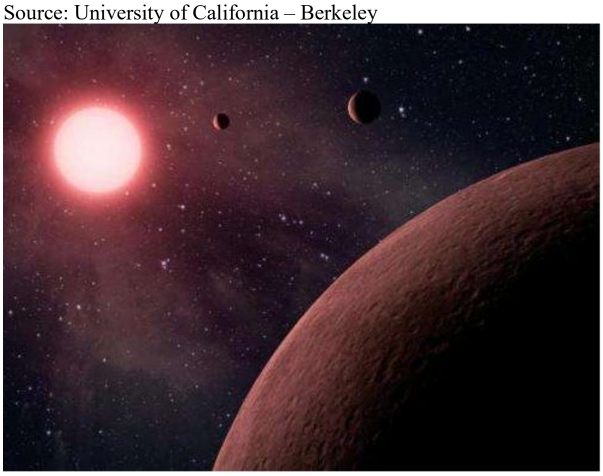
The team has had observation time on the ALMA telescopes in Chile to observe the binary star system NGC 1333-IRAS2A in the Perseus molecular cloud. The distance from Earth to the binary star is about 1,000 lightyears which is a quite short distance in an astronomical context. Formed some 10,000 years ago, it is a very young star.

The two stars of the binary system are 200 astronomical units (AUs) apart. An AU equals the distance from Earth to the Sun. In comparison, the furthest planet of the Solar System, Neptune, is 30 AUs from the Sun.

- AI reveals unsuspected math underlying search for exoplanets

Machine learning algorithm points to problems in mathematical theory for interpreting micro lenses

Date: May 24, 2022
Source: University of California – Berkeley



Artificial intelligence (AI) algorithms trained on real astronomical observations now outperform astronomers in sifting through massive amounts of data to find new exploding stars, identify new types of galaxies and detect the mergers of massive stars, accelerating the rate of new discovery in the world's oldest science.

But AI, also called machine learning, can reveal something deeper, University of California, Berkeley, astronomers found: unsuspected connections hidden in the complex mathematics arising from general relativity -- in particular, how that theory is applied to finding new planets around other stars.

In a paper appearing this week in the journal *Nature Astronomy*, the researchers describe how an AI algorithm developed to more quickly detect exoplanets when such planetary systems pass in front of a background star and briefly brighten it -- a process called gravitational microlensing -- revealed that the decades-old theories now used to explain these observations are woefully incomplete.

In 1936, Albert Einstein himself used his new theory of general relativity to show how the light from a distant star can be bent by the gravity of a foreground star, not only brightening it as seen from Earth, but often splitting it into several points of light or distorting it into a ring, now called an Einstein ring. This is similar to the way a hand lens can focus and intensify light from the sun.

But when the foreground object is a star with a planet, the brightening over time -- the light curve -- is more complicated. What's more, there are often multiple planetary orbits that can explain a given light curve equally well -- so called degeneracies. That's where humans simplified the math and missed the bigger picture.

The AI algorithm, however, pointed to a mathematical way to unify the two major kinds of degeneracy in interpreting what telescopes detect during microlensing, showing that the two "theories" are really special cases of a broader theory that, the researchers admit, is likely still incomplete.

"A machine learning inference algorithm we previously developed led us to discover something new and fundamental about the equations that govern the general relativistic effect of light- bending by two massive bodies," Joshua Bloom wrote in a blog post last year when he uploaded the paper to a preprint server, arXiv. Bloom is a UC Berkeley professor of astronomy and chair of the department.

He compared the discovery by UC Berkeley graduate student Keming Zhang to connections that Google's AI team, DeepMind, recently made between two different areas of mathematics. Taken together, these examples show that AI systems can reveal fundamental associations that humans miss.

"I argue that they constitute one of the first, if not the first time that AI has been used to directly yield new theoretical insight in math and astronomy," Bloom said. "Just as Steve Jobs suggested computers could be the bicycles of the mind, we've been seeking an AI framework to serve as an intellectual rocket ship for scientists."

"This is kind of a milestone in AI and machine learning," emphasized co-author Scott Gaudi, a professor of astronomy at The Ohio State University and one of the pioneers of using gravitational microlensing to discover exoplanets. "Keming's machine learning algorithm uncovered this degeneracy that had been missed by experts in the field toiling with data for decades. This is suggestive of how research is going to go in the future when it is aided by machine learning, which is really exciting."

Discovering exoplanets with microlensing

More than 5,000 exoplanets, or extrasolar planets, have been discovered around stars in the Milky Way, though few have actually been seen through a telescope -- they are too dim. Most have been detected because they create a Doppler wobble in the motions of their host stars or because they slightly dim the light from the host star when they cross in front of it -- transits that were the focus of NASA's Kepler mission. Little more than 100 have been discovered by a third technique, microlensing.

One of the main goals of NASA's Nancy Grace Roman Space Telescope, scheduled to launch by 2027, is to discover thousands more exoplanets via microlensing. The technique has an advantage over the Doppler and transit techniques in that it can detect lower-mass planets, including those the size of Earth, that are far from their stars, at a distance equivalent to that of Jupiter or Saturn in our solar system.

Bloom, Zhang and their colleagues set out two years ago to develop an AI algorithm to analyse microlensing data faster to determine the stellar and planetary masses of these planetary systems and the distances the planets are orbiting from their stars. Such an algorithm would speed analysis of the likely hundreds of thousands of events the Roman telescope will detect in order to find the 1% or fewer that are caused by exoplanetary systems.

One problem astronomers encounter, however, is that the observed signal can be ambiguous. When a lone foreground star passes in front of a background star, the brightness of the background stars rises smoothly to a peak and then drops symmetrically to its original brightness. It's easy to understand mathematically and observationally.

But if the foreground star has a planet, the planet creates a separate brightness peak within the peak caused by the star. When trying to reconstruct the orbital configuration of the exoplanet that produced the signal, general relativity often allows two or more so-called degenerate solutions, all of which can explain the observations.

To date, astronomers have generally dealt with these degeneracies in simplistic and artificially distinct ways, Gaudi said. If the distant starlight passes close to the star, the observations could be interpreted either as a wide or a close orbit for the planet -- an ambiguity astronomers can often resolve with other data. A second type of degeneracy occurs when the background starlight passes close to the planet. In this case, however, the

two different solutions for the planetary orbit are generally only slightly different.
According to Gaudi, these two simplifications of two-body gravitational microlensing are usually sufficient to determine the true masses and orbital distances. In fact, in a paper published last year, Zhang, Bloom, Gaudi and two other UC Berkeley co-authors, astronomy professor Jessica Lu and graduate student Casey Lam, described a new AI algorithm that does not rely on knowledge of these interpretations at all. The algorithm greatly accelerates analysis of microlensing observations, providing results in milliseconds, rather than days, and drastically reducing the computer crunching.
Zhang then tested the new AI algorithm on microlensing light curves from hundreds of possible orbital configurations of star and exoplanet and noticed something unusual: There were other ambiguities that the two interpretations did not account for. He concluded that the commonly used interpretations of microlensing were, in fact, just special cases of a broader theory that explains the full variety of ambiguities in microlensing events.
"The two previous theories of degeneracy deal with cases where the background star appears to pass close to the foreground star or the foreground planet," Zhang said. "The AI algorithm showed us hundreds of examples from not only these two cases, but also situations where the star doesn't pass close to either the star or planet and cannot be explained by either previous theory. That was key to us proposing the new unifying theory."
Gaudi was sceptical, at first, but came around after Zhang produced many examples where the previous two theories did not fit observations and the new theory did. Zhang actually looked at the data from two dozen previous papers that reported the discovery of exoplanets through microlensing and found that, in all cases, the new theory fit the data better than the previous theories.
"People were seeing these microlensing events, which actually were exhibiting this new degeneracy but just didn't realize it," Gaudi said. "It was really just the machine learning looking at thousands of events where it became impossible to miss."
Zhang and Gaudi have submitted a new paper that rigorously describes the new mathematics based on general relativity and explores the theory in microlensing situations where more than one exoplanet orbits a star.
The new theory technically makes interpretation of microlensing observations more ambiguous, since there are more degenerate solutions to describe the observations. But the theory also demonstrates clearly that observing the same microlensing event from two perspectives -- from Earth and from the orbit of the Roman Space Telescope, for example -- will make it easier to settle on the correct orbits and masses. That is what astronomers currently plan to do, Gaudi said.
"The AI suggested a way to look at the lens equation in a new light and uncover something really deep about the mathematics of it," said Bloom. "AI is sort of emerging as not just this kind of blunt tool that's in our toolbox, but as something that's actually quite clever. Alongside an expert like Keming, the two were able to do something pretty fundamental."

- Extra-terrestrial stone brings first supernova clues to Earth

Date: May 16, 2022
Source: University of Johannesburg

New chemistry 'forensics' indicate that the stone named Hypatia from the Egyptian desert could be the first tangible evidence found on Earth of a supernova type Ia explosion. These rare supernovas are some of the most energetic events in the universe.
This is the conclusion from a new study published in the journal *Icarus*, by Jan Kramers, Georgy Belyanin and Hartmut Winkler of the University of Johannesburg, and others.
Since 2013, Belyanin and Kramers have discovered a series of highly unusual chemistry clues in a small fragment of the Hypatia Stone.
In the new research, they eliminate 'cosmic suspects' for the origin of the stone in a

painstaking process. They have pieced together a timeline stretching back to the early stages of the formation of Earth, our Sun and the other planets in our solar system.

A cosmic timeline

Their hypothesis about Hypatia's origin starts with a star: A red giant star collapsed into a white dwarf star. The collapse would have happened inside a gigantic dust cloud, also called a nebula.

That white dwarf found itself in a binary system with a second star. The white dwarf star eventually 'ate' the other star. At some point the 'hungry' white dwarf exploded as a supernova type Ia inside the dust cloud.

After cooling, the gas atoms which remained of the supernova Ia started sticking to the particles of the dust cloud.

"In a sense we could say, we have 'caught' a supernova Ia explosion 'in the act', because the gas atoms from the explosion were caught in the surrounding dust cloud, which eventually formed Hypatia's parent body," says Kramers.

A huge 'bubble' of this supernova dust-and-gas-atoms mix never interacted with other dust clouds.

Millions of years would pass, and eventually the 'bubble' would slowly become solid, in a 'cosmic dust bunny' kind of way. Hypatia's 'parent body' would become a solid rock sometime in the early stages of formation of our solar system.

This process probably happened in a cold, uneventful outer part of our solar system -- in the Oort cloud or in the Kuiper belt.

At some point, Hypatia's parent rock started hurtling towards Earth. The heat of entry into earth's atmosphere, combined with the pressure of impact in the Great Sand Sea in south-western Egypt, created micro-diamonds and shattered the parent rock.

The Hypatia stone picked up in the desert must be one of many fragments of the original impactor.

"If this hypothesis is correct, the Hypatia stone would be the first tangible evidence on Earth of a supernova type Ia explosion. Perhaps equally important, it shows that an individual anomalous 'parcel' of dust from outer space could actually be incorporated in the solar nebula that our solar system was formed from, without being fully mixed in," says Kramers.

"This goes against the conventional view that dust which our solar system was formed from, was thoroughly mixed."

Three million volts for a tiny sample

To piece together the timeline of how Hypatia may have formed, the researchers used several techniques to analyse the strange stone.

In 2013, a study of the argon isotopes showed the rock was not formed on earth. It had to be extra-terrestrial. A 2015 study of noble gases in the fragment indicated that it may not be from any known type of meteorite or comet.

In 2018 the UJ team published various analyses, which included the discovery of a mineral, nickel phosphide, not previously found in any object in our solar system.

At that stage Hypatia was proving difficult to analyse further. The trace metals Kramers and Belyanin were looking for, couldn't really be 'seen in detail' with the equipment they had. They needed a more powerful instrument that would not destroy the tiny sample.

Kramers started analysing a dataset that Belyanin had created a few years before.

In 2015, Belyanin had done a series of analyses on a proton beam at the iThemba Labs in Somerset West. At the time, Dr Wojciech Przybylowicz kept the three-million Volt machine humming along.

In search of a pattern

"Rather than exploring all the incredible anomalies Hypatia presents, we wanted to explore if there is an underlying unity. We wanted to see if there is some kind of consistent chemical pattern in the stone" says Kramers.

Belyanin carefully selected 17 targets on the tiny sample for analysis. All were chosen to be well away from the earthly minerals that had formed in the cracks of the original rock after its impact in the desert.

"We identified 15 different elements in Hypatia with much greater precision and accuracy, with the proton microprobe. This gave us the chemical 'ingredients' we needed, so Jan could start the next process of analysing all the data," says Belyanin.

Proton beam also rules out solar system

The first big new clue from the proton beam analyses was the surprisingly low level of silicon in the Hypatia stone targets. The silicon, along with chromium and manganese, were less than 1% to be expected for something formed within our inner solar system.

Further, high iron, high sulphur, high phosphorus, high copper and high vanadium were conspicuous and anomalous, adds Kramers.

"We found a consistent pattern of trace element abundances that is completely different from anything in the solar system, primitive or evolved. Objects in the asteroid belt and meteors don't match this either. So next we looked outside the solar system," says Kramers.

Not from our neighbourhood

Then Kramers compared the Hypatia element concentration pattern with what one would expect to see in the dust between stars in our solar arm of the Milky Way galaxy.

"We looked to see if the pattern we get from average interstellar dust in our arm of the Milky Way galaxy fits what we see in Hypatia. Again, there was no similarity at all," adds Kramers.

At this point, the proton beam data had also ruled out four 'suspects' of where Hypatia could have formed.

Hypatia did not form on earth, was not part of any known type of comet or meteorite, did not form from average inner solar system dust, and not from average interstellar dust either.

Not a red giant

The next simplest possible explanation for the element concentration pattern in Hypatia, would be a red giant star. Red giant stars are common in the universe.

But the proton beam data ruled out mass outflow from a red giant star too: Hypatia had too much iron, too little silicon and too low concentrations of heavy elements heavier than iron.

Nor a supernova Type II

The next 'suspect' to consider was a supernova type II. Supernovas of type II cook up a lot of iron. They are also a relatively common type of supernova.

Again, the proton beam data for Hypatia ruled out a promising suspect with 'chemistry forensics'. A supernova type II was highly unlikely as the source of strange minerals like nickel phosphide in the pebble. There was also too much iron in Hypatia compared to silicon and calcium.

It was time to closely examine the predicted chemistry of one of the most dramatic explosions in the universe.

Heavy metal factory

A rarer kind of supernova also makes a lot of iron. Supernovas of the type Ia only happen once or twice per galaxy per century. But they manufacture most of the iron (Fe) in the universe. Most of the steel on earth was once the element iron created by Ia supernovas.

Also, established science says that some Ia supernovas leave very distinctive 'forensic chemistry' clues behind. This is because of the way some Ia supernovas are set up.

First, a red giant star at the end of its life collapses into a very dense white dwarf star. White dwarf stars are usually incredibly stable for very long periods and most unlikely to explode. However, there are exceptions to this.

A white dwarf star could start 'pulling' matter off another star in a binary system. One can say the white dwarf star 'eats up' its companion star. Eventually the white dwarf gets so heavy, hot and unstable, it explodes in a supernova Ia.

The nuclear fusion during the supernova Ia explosion should create highly unusual element concentration patterns, accepted scientific theoretical models predict.

Also, the white dwarf star that explodes in a supernova Ia is not just blown to bits, but literally blown to atoms. The supernova Ia matter is delivered into space as gas atoms.

In an extensive literature search of star data and model results, the team could not identify any similar or better chemical fit for the Hypatia stone than a specific set of supernova Ia models.

Forensic elements evidence

"All supernova Ia data and theoretical models show much higher proportions of iron compared to silicon and calcium than supernova II models," says Kramers.

"In this respect, the proton beam laboratory data on Hypatia fit to supernova Ia data and models."

Altogether, eight of the 15 elements analysed conform to the predicted ranges of proportions relative to iron. Those are the elements silicon, sulphur, calcium, titanium, vanadium, chromium, manganese, iron and nickel.

Not all 15 of the analysed elements in Hypatia fit the predictions though. In six of the 15 elements, proportions were between 10 and 100 times higher than the ranges predicted by theoretical models for supernovas of type 1A. These are the elements aluminium, phosphorus, chlorine, potassium, copper and zinc.

"Since a white dwarf star is formed from a dying red giant, Hypatia could have inherited these element proportions for the six elements from a red giant star. This phenomenon has been observed in white dwarf stars in another research," adds Kramers.
If this hypothesis is correct, the Hypatia stone would be the first tangible evidence on Earth of a supernova type Ia explosion, one of the most energetic events in the universe.
The Hypatia stone would be a clue of a cosmic story started during the early formation of our solar system, and be found many years later in a remote desert strewn with other pebbles.

- Hyperfast white dwarf stars provide clues for understanding supernovae

Date: May 13, 2022
Source: RIKEN

Scientists from the RIKEN Cluster for Pioneering Research have used computer modelling to show how a hypothesized type of supernova would evolve on the scale of thousands of years, giving researchers a way to look for examples of supernovae of this model, known as "D^6."
Supernovae are important for cosmology, as one type, Ia, is used as a "standard candle" that allows distance to be measured, and in fact they were used for the measurements that showed, surprisingly to initial observers, that the expansion of the universe is accelerating. It is generally accepted that type Ia supernovae arise from the explosion of degenerate stars known as white dwarfs -- stars that have burned through their hydrogen and shrunk into compact objects -- but the mechanism that causes the explosions is not well understood.
Recently, the discovery of white dwarfs that are moving extremely rapidly has given added credibility to one proposed mechanism for the origin of these supernovae, D^6. In this scenario, one of two white dwarfs in a binary system undergoes what is known as a "double detonation," where a surface layer of helium first explodes, then igniting a larger explosion in the carbon-oxygen core of the star. This leads to the obliteration of the star, and the companion, suddenly freed from the gravitational attraction of the exploding star, is flung out at enormous velocity.
However, very little is known about what shape the remnant of such an event would look like long after the initial explosion. To explore this, the team decided to simulate the long-term evolution, in the form of a supernova remnant, for thousands of years after the explosion. In fact, they were able to observe some features in the progenitor system that would be specific to this scenario, thus offering a way to probe supernova physics, including a "shadow" or dark patch surrounded by a bright ring. They also concluded that the remnants of type Ia explosions are not necessarily symmetric, as is commonly believed.
According to Gilles Ferrand, the first author of the study, "The D^6 supernova explosion has a specific shape. We were not confident that it would be visible in the remnant long after the initial event, but actually we found that there is a specific signature that we can still see thousands of years after the explosion."
Shigehiro Nagataki, the leader of the Astrophysical Big Bang Laboratory at RIKEN, says, "This is a very important finding, because it could have an impact on the use of Ia supernovae as cosmic yardsticks. They were once believed to originate from a single phenomenon, but if they are diverse, then it might require a revaluation of how we use them."
Ferrand continues, "Moving forward, we plan to learn how to more precisely compute the X-ray emission, taking into account the composition and state of the shocked plasma, in order to make direct comparisons with observations. We hope that our paper will give new ideas to observers, of what to look for in supernova remnants."
The research, done in conjunction from an international group including researchers from the University of Manitoba, was published in *The Astrophysical Journal*.

- Astronomers reveal first image of the black hole at the heart of our galaxy

Date: May 12, 2022
Source: European Southern Observatory


Atacama Large Millimetre/submillimetre Array (stock image).
Credit: © mdtc / stock.adobe.com

Today, at simultaneous press conferences around the world, including at the European Southern Observatory (ESO) headquarters in Germany, astronomers have unveiled the first image of the supermassive black hole at the centre of our own Milky Way galaxy. This result provides overwhelming evidence that the object is indeed a black hole and yields valuable clues about the workings of such giants, which are thought to reside at the centre of most galaxies. The image was produced by a global research team called the Event Horizon Telescope (EHT) Collaboration, using observations from a worldwide network of radio telescopes.

The image is a long-anticipated look at the massive object that sits at the very centre of our galaxy. Scientists had previously seen stars orbiting around something invisible, compact, and very massive at the centre of the Milky Way. This strongly suggested that this object -- known as Sagittarius A* (Sgr A*, pronounced "sadge-ay-star") -- is a black hole, and today's image provides the first direct visual evidence of it.

Although we cannot see the black hole itself, because it is completely dark, glowing gas around it reveals a tell-tale signature: a dark central region (called a shadow) surrounded by a bright ring-like structure. The new view captures light bent by the powerful gravity of the black hole, which is four million times more massive than our Sun.

"We were stunned by how well the size of the ring agreed with predictions from Einstein's Theory of General Relativity," said EHT Project Scientist Geoffrey Bower from the Institute of Astronomy and Astrophysics, Academia Sinica, Taipei. "These unprecedented observations have greatly improved our understanding of what happens at the very centre of our galaxy, and offer new insights on how these giant black holes interact with their surroundings." The EHT team's results are being published today in a special issue of The Astrophysical Journal Letters.

Because the black hole is about 27 000 light-years away from Earth, it appears to us to have about the same size in the sky as a doughnut on the Moon. To image it, the team created the powerful EHT, which linked together eight existing radio observatories across the planet to form a single "Earth-sized" virtual telescope [1]. The EHT observed Sgr A* on multiple nights in 2017, collecting data for many hours in a row, similar to using a long exposure time on a camera.

In addition to other facilities, the EHT network of radio observatories includes the Atacama Large Millimetre/submillimetre Array (ALMA) and the Atacama Pathfinder EXperiment (APEX) in the Atacama Desert in Chile, co-owned and co-operated by ESO on behalf of its member states in Europe. Europe also contributes to the EHT observations with other radio observatories -- the IRAM 30-meter telescope in Spain and, since 2018, the NOrthern Extended Millimetre Array (NOEMA) in France -- as well as a supercomputer to combine EHT data hosted by the Max Planck Institute for Radio Astronomy in Germany. Moreover, Europe contributed with funding to the EHT consortium project through grants by the European Research Council and by the Max Planck Society in Germany.

"It is very exciting for ESO to have been playing such an important role in unravelling the mysteries of black holes, and of Sgr A* in particular, over so many years," commented ESO Director General Xavier Barcons. "ESO not only contributed to the EHT observations through the ALMA and APEX facilities but also enabled, with its other observatories in Chile, some of the previous breakthrough observations of the Galactic centre." [2]

The EHT achievement follows the collaboration's 2019 release of the first image of a black hole, called M87*, at the centre of the more distant Messier 87 galaxy.

The two black holes look remarkably similar, even though our galaxy's black hole is more than a thousand times smaller and less massive than M87* [3]. "We have two completely different types of galaxies and two very different black hole masses, but close to the edge of these black holes they look amazingly similar," says Sera Markoff, Co-

Chair of the EHT Science Council and a professor of theoretical astrophysics at the University of Amsterdam, the Netherlands. "This tells us that General Relativity governs these objects up close, and any differences we see further away must be due to differences in the material that surrounds the black holes."

This achievement was considerably more difficult than for M87*, even though Sgr A* is much closer to us. EHT scientist Chi-kwan ('CK') Chan, from Steward Observatory and Department of Astronomy and the Data Science Institute of the University of Arizona, USA, explains: "The gas in the vicinity of the black holes moves at the same speed -- nearly as fast as light -- around both Sgr A* and M87*. But where gas takes days to weeks to orbit the larger M87*, in the much smaller Sgr A* it completes an orbit in mere minutes. This means the brightness and pattern of the gas around Sgr A* were changing rapidly as the EHT Collaboration was observing it -- a bit like trying to take a clear picture of a puppy quickly chasing its tail."

The researchers had to develop sophisticated new tools that accounted for the gas movement around Sgr A*. While M87* was an easier, steadier target, with nearly all images looking the same, that was not the case for Sgr A*. The image of the Sgr A* black hole is an average of the different images the team extracted, finally revealing the giant lurking at the centre of our galaxy for the first time.

The effort was made possible through the ingenuity of more than 300 researchers from 80 institutes around the world that together make up the EHT Collaboration. In addition to developing complex tools to overcome the challenges of imaging Sgr A*, the team worked rigorously for five years, using supercomputers to combine and analyse their data, all while compiling an unprecedented library of simulated black holes to compare with the observations.

Scientists are particularly excited to finally have images of two black holes of very different sizes, which offers the opportunity to understand how they compare and contrast. They have also begun to use the new data to test theories and models of how gas behaves around supermassive black holes. This process is not yet fully understood but is thought to play a key role in shaping the formation and evolution of galaxies.

"Now we can study the differences between these two supermassive black holes to gain valuable new clues about how this important process works," said EHT scientist Keiichi Asada from the Institute of Astronomy and Astrophysics, Academia Sinica, Taipei. "We have images for two black holes -- one at the large end and one at the small end of supermassive black holes in the Universe -- so we can go a lot further in testing how gravity behaves in these extreme environments than ever before."

Progress on the EHT continues: a major observation campaign in March 2022 included more telescopes than ever before. The ongoing expansion of the EHT network and significant technological upgrades will allow scientists to share even more impressive images as well as movies of black holes in the near future.

Notes

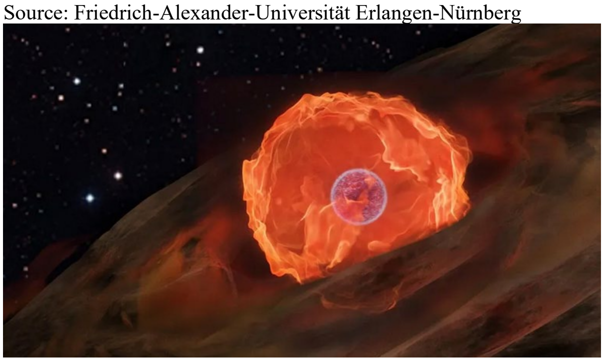
[1] The individual telescopes involved in the EHT in April 2017, when the observations were conducted, were: the Atacama Large Millimetre/submillimetre Array (ALMA), the Atacama Pathfinder EXperiment (APEX), the IRAM 30-meter Telescope, the James Clerk Maxwell Telescope (JCMT), the Large Millimetre Telescope Alfonso Serrano (LMT), the Submillimetre Array (SMA), the UArizona Submillimetre Telescope (SMT), the South Pole Telescope (SPT). Since then, the EHT has added the Greenland Telescope (GLT), the NOrthern Extended Millimetre Array (NOEMA) and the UArizona 12-meter Telescope on Kitt Peak to its network.

ALMA is a partnership of the European Southern Observatory (ESO; Europe, representing its member states), the U.S. National Science Foundation (NSF), and the National Institutes of Natural Sciences (NINS) of Japan, together with the National Research Council (Canada), the Ministry of Science and Technology (MOST; Taiwan), Academia Sinica Institute of Astronomy and Astrophysics (ASIAA; Taiwan), and Korea Astronomy and Space Science Institute (KASI; Republic of Korea), in cooperation with the Republic of Chile. The Joint ALMA Observatory is operated by ESO, the Associated Universities, Inc./National Radio Astronomy Observatory (AUI/NRAO) and the National Astronomical Observatory of Japan (NAOJ). APEX, a collaboration between the Max Planck Institute for Radio Astronomy (Germany), the Onsala Space

Observatory (Sweden) and ESO, is operated by ESO. The 30-meter Telescope is operated by IRAM (the IRAM Partner Organizations are MPG [Germany], CNRS [France] and IGN [Spain]). The JCMT is operated by the East Asian Observatory on behalf of The National Astronomical Observatory of Japan; ASIAA; KASI; the National Astronomical Research Institute of Thailand; the Centre for Astronomical Mega-Science and organisations in the United Kingdom and Canada. The LMT is operated by INAOE and UMass, the SMA is operated by Centre for Astrophysics | Harvard & Smithsonian and ASIAA and the UArizona SMT is operated by the University of Arizona. The SPT is operated by the University of Chicago with specialised EHT instrumentation provided by the University of Arizona.
The Greenland Telescope (GLT) is operated by ASIAA and the Smithsonian Astrophysical Observatory (SAO). The GLT is part of the ALMA-Taiwan project, and is supported in part by the Academia Sinica (AS) and MOST. NOEMA is operated by IRAM and the UArizona 12-meter telescope at Kitt Peak is operated by the University of Arizona.
[2] A strong basis for the interpretation of this new image was provided by previous research carried out on Sgr A*. Astronomers have known the bright, dense radio source at the centre of the Milky Way in the direction of the constellation Sagittarius since the 1970s. By measuring the orbits of several stars very close to our galactic centre over a period of 30 years, teams led by Reinhard Genzel (Director at the Max -Planck Institute for Extra-terrestrial Physics in Garching near Munich, Germany) and Andrea M. Ghez (Professor in the Department of Physics and Astronomy at the University of California, Los Angeles, USA) were able to conclude that the most likely explanation for an object of this mass and density is a supermassive black hole. ESO's facilities (including the Very Large Telescope and the Very Large Telescope Interferometer) and the Keck Observatory were used to carry out this research, which shared the 2020 Nobel Prize in Physics.
[3] Black holes are the only objects we know of where mass scales with size. A black hole a thousand times smaller than another is also a thousand times less massive.
Supplement in *Astrophysical Journal Letters,* "Focus on First Sgr A* Results from the Event Horizon Telescope"
https://iopscience.iop.org/journal/2041-8205/page/Focus_on_First_Sgr_A_Results

❖ Explosion on a white dwarf observed

Date: May 12, 2022
Source: Friedrich-Alexander-Universität Erlangen-Nürnberg



When stars like our Sun use up all their fuel, they shrink to form white dwarfs. Sometimes such dead stars flare back to life in a super-hot explosion and produce a fireball of X-ray radiation. A research team led by FAU has now been able to observe such an explosion of X-ray light for the very first time.
"It was to some extent a fortunate coincidence, really," explains Ole König from the Astronomical Institute at FAU in the Dr. Karl Remeis observatory in Bamberg, who has published an article about this observation in the journal *Nature*, together with Prof. Dr. Jörn Wilms and a research team from the Max Planck Institute for Extra-terrestrial Physics, the University of Tübingen, the Universitat Politécnica de Catalunya in Barcelona und the Leibniz Institute for Astrophysics Potsdam.
"These X-ray flashes last only a few hours and are almost impossible to predict, but the observational instrument must be pointed directly at the explosion at exactly the right time," explains the astrophysicist.
The instrument in this case is the eROSITA X-ray telescope, which is currently located one and a half million kilometres from Earth and has been surveying the sky for soft X-rays since 2019. On July 7, 2020 it measured strong X-ray radiation in an area of the sky that had been completely inconspicuous four hours previously. When the X-ray telescope surveyed the same position in the sky four hours later, the radiation had disappeared. It follows that the X-ray flash that had previously completely overexposed the centre of the detector must have lasted less than eight hours.
X-ray explosions such as this were predicted by theoretical research more than 30 years ago, but have never been observed directly until now. These fireballs of X-rays occur on the surface of stars that were originally

comparable in size to the Sun before using up most of their fuel made of hydrogen and later helium deep inside their cores. These stellar corpses shrink until "white dwarfs" remain, which are similar to Earth in size but contain a mass that can be similar to that of our Sun. "One way to picture these proportions is to think of the Sun being the same size as an apple, which means Earth would be the same size as a pin head orbiting around the apple at a distance of 10 meters," explains Jörn Wilms.

Stellar corpses resemble gemstones

On the other hand, if you were to shrink an apple to the size of a pin head, this tiny particle would retain the comparatively large weight of the apple. "A teaspoon of matter from the inside of a white dwarf easily has the same mass as a large truck," Jörn Wilms continues. Since these burnt out stars are mainly made up of oxygen and carbon, we can compare them to gigantic diamonds that are the same size as Earth floating around in space. These objects in the form of precious gems are so hot they glow white. However, the radiation is so weak that it is difficult to detect from Earth.

Unless the white dwarf is accompanied by a star that is still burning, that is, and when the enormous gravitational pull of the white dwarf draws hydrogen from the shell of the accompanying star. "In time, this hydrogen can collect to form a layer only a few meters thick on the surface of the white dwarf," explains FAU astrophysicist Jörn Wilms. In this layer, the huge gravitational pull generates enormous pressure that is so great that it causes the star to reignite. In a chain reaction, it soon comes to a huge explosion during which the layer of hydrogen is blown off. The X-ray radiation of an explosion like this is what hit the detectors of eROSITA on July 7, 2020 producing an overexposed image.

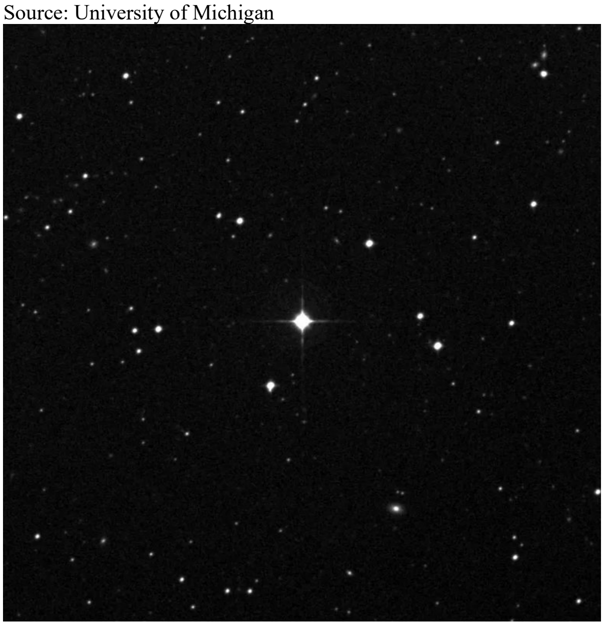
"Using the model calculations we originally drew up while supporting the development of the X-ray instrument, we were able to analyse the overexposed image in more detail during a complex process to gain a behind the scenes view of an explosion of a white dwarf, or nova," explains Jörn Wilms. According to the results, the white dwarf has around the mass of our Sun and is therefore relatively large. The explosion generated a fireball with a temperature of around 327,000 degrees, making it around sixty times hotter than the Sun.

Since these novae run out of fuel quite quickly, they cool rapidly and the X-ray radiation becomes weaker until it eventually becomes visible light, which reached Earth half a day after the eROSITA detection and was observed by optical telescopes. "A seemingly bright star then appeared, which was actually the visible light from the explosion, and so bright that it could be seen on the night sky by the bare eye," explains Ole König. Seemingly "new stars" such as this one have been observed in the past and were named "nova stella," or "new star" on account of their unexpected appearance. Since these novae are only visible after the X-ray flash, it is very difficult to predict such outbreaks and it is mainly down to chance when they hit the X-ray detectors. "We were really lucky," says Ole König.

Short video: https://youtu.be/cIz3zBG4bI0

- Astronomers find 'gold standard' star in Milky Way

Date: May 10, 2022
Source: University of Michigan



In our sun's neighbourhood of the Milky Way Galaxy is a relatively bright star, and in it, astronomers have been able to identify the widest range of elements in a star beyond our solar system yet.

The study, led by University of Michigan astronomer Ian Roederer, has identified 65 elements in the star, HD 222925. Forty-two of the elements identified are heavy elements that are listed along the bottom of the periodic table of elements.

Identifying these elements in a single star will help astronomers understand what's called the "rapid neutron capture process," or one of the major ways by which heavy elements in the universe were created. Their results are posted on arXiv and have been accepted for publication in the *Astrophysical Journal Supplement Series*.

"To the best of my knowledge, that's a record for any object beyond our solar system. And what makes this star so unique is that it has a very high relative proportion of the elements listed along the bottom two-thirds of the periodic table. We even detected gold," Roederer said. "These elements were made by the rapid neutron capture process. That's really the thing we're trying to study: the physics in understanding how, where and when those elements were made."

The process, also called the "r-process," begins with the presence of lighter elements such as iron. Then, rapidly -- on the order of a second -- neutrons are added to the nuclei of the lighter elements. This creates heavier elements such as selenium, silver, tellurium, platinum, gold and thorium, the kind found in HD 222925, and all of which are rarely detected in stars, according to the astronomers.

"You need lots of neutrons that are free and a very high energy set of conditions to liberate them and add them to the nuclei of atoms," Roederer said. "There aren't very many environments in which that can happen -- two, maybe."

One of these environments has been confirmed: the merging of neutron stars. Neutron stars are the collapsed cores of supergiant stars, and are the smallest and densest known celestial objects. The collision of neutron star pairs causes gravitational waves and in 2017, astronomers first detected gravitational waves from merging neutron stars. Another way the r-process might occur is after the explosive death of massive stars.

"That's an important step forward: recognizing where the r-process can occur. But it's a much bigger step to say, 'What did that event actually do? What was produced there?" Roederer said. "That's where our study comes in."

The elements Roederer and his team identified in HD 222925 were produced in either a massive supernova or a merger of neutron stars very early in the universe. The material was ejected and thrown back into space, where it later reformed into the star Roederer is studying today.

This star can then be used as a proxy for what one of those events would have produced. Any model developed in the future that demonstrates how the r-process or nature produces elements on the bottom two-thirds of the periodic table must have the same signature as HD 222925, Roederer says.

Crucially, the astronomers used an instrument on the Hubble Space Telescope that can collect ultraviolet spectra. This instrument was key in allowing the astronomers to collect light in the ultraviolet part of the light spectrum -- light that is faint, coming from a cool star such as HD 222925.

The astronomers also used one of the Magellan telescopes -- a consortium of which U-M is a partner -- at Las Campanas Observatory in Chile to collect light from HD 222925 in the optical part of the light spectrum.

These spectra encode the "chemical fingerprint" of elements within stars, and reading these spectra allows the astronomers not only to identify the elements contained in the star, but also how much of an element the star contains.

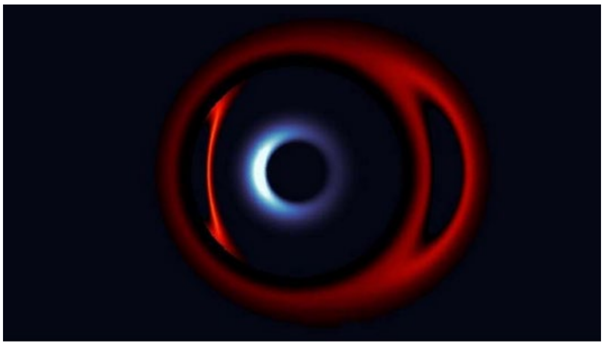
Anna Frebel is a co-author of the study and professor of physics at the Massachusetts Institute of Technology. She helped with the overall interpretation of the HD 222925's element abundance pattern and how it informs our understanding of the origin of the elements in the cosmos.

"We now know the detailed element-by-element output of some r-process event that happened early in the universe," Frebel said. "Any model that tries to understand what's going on with the r-process has to be able to reproduce that."

Many of the study co-authors are part of a group called the R-Process Alliance, a group of astrophysicists dedicated to solving the big questions of the r-process. This project marks one of the team's key goals: identifying which elements, and in what amounts, were produced in the r-process in an unprecedented level of detail.

- ❖ In a pair of merging supermassive black holes, a new method for measuring the void

Date: May 9, 2022
Source: Columbia University



Three years ago, the first ever image of a black hole stunned the world. A black pit of nothingness enclosed by a fiery ring of light. That iconic image of the black hole at the centre of galaxy Messier 87 came into focus thanks to the Event Horizon Telescope, a global network of synchronized radio dishes acting as one giant telescope.

Now, a pair of Columbia researchers have devised a potentially easier way of gazing into the abyss. Outlined in complementary studies in *Physical Review Letters* and *Physical Review D,* their imaging technique could allow astronomers to study black holes smaller than M87's, a monster with a mass of 6.5 billion suns, harboured in galaxies more distant than M87, which at 55 million light-years away, is still relatively close to our own Milky Way.

The technique has just two requirements. First, you need a pair of supermassive black holes in the throes of merging. Second, you need to be looking at the pair at a nearly side-on angle. From this sideways vantage point, as one black hole passes in front of the other, you should be able to see a bright flash of light as the glowing ring of the black hole farther away is magnified by the black hole closest to you, a phenomenon known as gravitational lensing.

The lensing effect is well known, but what the researchers discovered here was a hidden signal: a distinctive dip in brightness corresponding to the "shadow" of the black hole in back. This subtle dimming can last from a few hours to a few days, depending on how massive the black holes, and how closely entwined their orbits. If you measure how long the dip lasts, the researchers say, you can estimate the size and shape of the shadow cast by the black hole's event horizon, the point of no exit, where nothing escapes, not even light.

"It took years and a massive effort by dozens of scientists to make that high-resolution image of the M87 black holes," said the study's first author, Jordy Davelaar, a postdoc at Columbia and the Flatiron Institute's Centre for Computational Astrophysics. "That approach only works for the biggest and closest black holes -- the pair at the heart of M87 and potentially our own Milky Way."

He added, "with our technique, you measure the brightness of the black holes over time, you don't need to resolve each object spatially. It should be possible to find this signal in many galaxies."

The shadow of a black hole is both its most mysterious and informative feature. "That dark spot tells us about the size of the black hole, the shape of the space-time around it, and how matter falls into the black hole near its horizon," said co-author Zoltan Haiman, a physics professor at Columbia.

Black hole shadows may also hold the secret to the true nature of gravity, one of the fundamental forces of our universe. Einstein's theory of gravity, known as general relativity, predicts the size of black holes. Physicists, therefore, have sought them out to test alternative theories of gravity in an effort to reconcile two competing ideas of how nature works: Einstein's general relativity, which explains large scale phenomena like orbiting planets and the expanding universe, and quantum physics, which explains how tiny particles like electrons and photons can occupy multiple states at once.

The researchers became interested in flaring supermassive black holes after spotting a suspected pair of supermassive black holes at the centre of a far-off galaxy in the early universe. NASA's planet-hunting Kepler space telescope was scanning for the tiny dips in brightness corresponding to a planet passing in front of its host star. Instead, Kepler ended up detecting the flares of what Haiman and his colleagues claim are a pair of merging black holes.

They named the distant galaxy "Spikey" for the spikes in brightness triggered by its suspected black holes magnifying each other on each full rotation via the lensing effect. To learn more about the flare, Haiman built a model with his postdoc, Davelaar.

They were confused, however, when their simulated pair of black holes produced an unexpected, but periodic, dip in brightness each time one orbited in front of the other. At first, they thought it was a coding mistake. But further checking led them to trust the signal.

As they looked for a physical mechanism to explain it, they realized that each dip in

brightness closely matched the time it took for the black hole closest to the viewer to pass in front of the shadow of the black hole in back.
The researchers are currently looking for other telescope data to try and confirm the dip they saw in the Kepler data to verify that Spikey is, in fact, harbouring a pair of merging black holes. If it all checks out, the technique could be applied to a handful of other suspected pairs of merging supermassive black holes among the 150 or so that have been spotted so far and are awaiting confirmation.
As more powerful telescopes come online in the coming years, other opportunities may arise. The Vera Rubin Observatory, set to open this year, has its sights on more than 100 million supermassive black holes. Further black hole scouting will be possible when NASA's gravitational wave detector, LISA, is launched into space in 2030.
"Even if only a tiny fraction of these black hole binaries has the right conditions to measure our proposed effect, we could find many of these black hole dips," Davelaar said.