South Downs Mercury

The monthly circular of South Downs Astronomical Society
Issue: 563 – April 1st 2022 Editor: Roger Burgess
Main Speaker 19:30 Main Andrew Mowbray How Long is a Day
The meeting will be accessible via Zoom

Last month's Covid-19 rules still apply at the planetarium but may change
A reminder to member who have not yet renewed subscriptions were due in December

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❖ Meteorites that helped form Earth may have formed in the outer solar system

Date: March 12, 2022
Source: Tokyo Institute of Technology

Asteroids in space, illustration (stock image).
Credit: © JohanSwanepoel / stock.adobe.com

Our Solar System is believed to have formed from a cloud of gas and dust, the so-called solar nebula, which began to condense on itself gravitationally ~ 4.6 billion years ago. As this cloud contracted, it began to spin and shaped itself into a disk revolving about the highest gravity mass at its centre, which would become our Sun. Our solar system inherited all of its chemical composition from an earlier star or stars which exploded as supernovae. Our Sun scavenged a general sample of this material as it formed, but the residual material in the disk began to migrate based on its propensity to freeze at a given temperature. As the Sun grew dense enough to initiate nuclear fusion reactions and become a star, it scavenged a general sample of this material as it formed, but the residuals in the disk formed solid materials to form planetary bodies based on its propensity to freeze at a given temperature. As the Sun irradiated the surrounding disk, it created a heat gradient in the early solar system. For this reason, the inner planets, Mercury, Venus, Earth and Mars, are mostly rock (mostly composed of heavier elements, such as iron, magnesium and silicon), while the outer planets are largely composed of lighter elements, especially hydrogen, helium, carbon, nitrogen and oxygen.

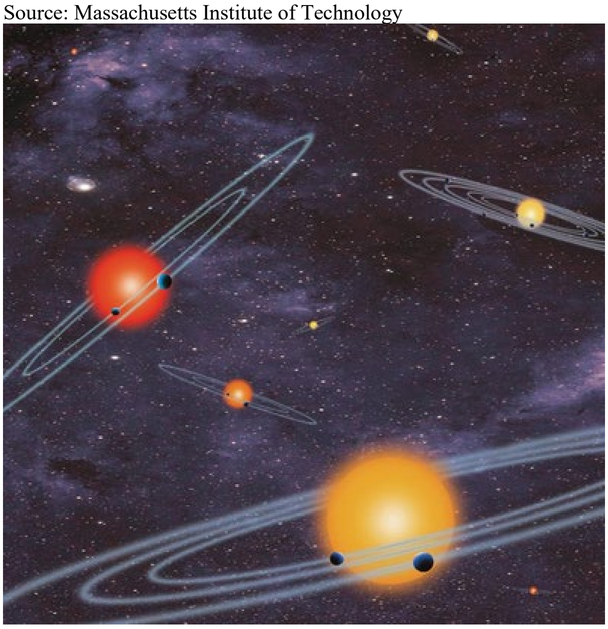
Earth is believed to have formed partly from carbonaceous meteorites, which are thought to come from outer main-belt asteroids. Telescopic observations of outer main-belt asteroids reveal a common 3.1 ?m reflectance feature that suggests their outer layers host either water ices or ammoniated clays, or both, which are only stable at very low temperatures. Interestingly, though several lines of evidence suggest carbonaceous meteorites are derived from such asteroids, the meteorites recovered on Earth generally lack this feature. The asteroid belt thus poses many questions for astronomers and planetary scientists.

A new study led by researchers at the Earth-Life Science Institute (ELSI) at Tokyo Institute of Technology suggests these asteroidal materials may have formed very far out in the early Solar System then been transported into the inner Solar System by chaotic mixing processes. In this study, a combination of asteroid observations using the Japanese AKARI space telescope and theoretical modelling of chemical reactions in asteroids suggests that the surface minerals present on outer main-belt asteroids, especially ammonia (NH_3)-bearing clays, form from starting materials containing NH_3 and CO_2 ice that are stable only at very low temperature, and under water-rich conditions. Based on these results, this new study proposes that outer main-belt asteroids formed in distant orbits and differentiated to form different minerals in water-rich mantles and rock-dominated cores.

To understand the source of the discrepancies in the measured spectra of carbonaceous meteorites and asteroids, using computer simulations, the team modelled the chemical evolution of several plausible primitive mixtures designed to simulate primitive asteroidal materials. They then used these computer models to produce simulated reflectance spectra for comparison to the telescopically obtained ones.
Their models indicated that in order to match the asteroid spectra, the starting material had to contain a significant amount of water and ammonia, a relatively low abundance of CO_2, and react at temperatures below 70?, suggesting the asteroids formed much further out than their present locations in the early solar system. In contrast, the lack of the 3.1 mm feature in meteorites can be attributed to reaction possibly deeper inside asteroids where temperatures reached higher values thus, recovered meteorites may sample deeper portions of asteroids.
If true, this study suggests that Earth's formation and unique properties result from peculiar aspects of the Solar System's formation. There will be several opportunities to test this model, for example, this study provides predictions for what the analysis of Hayabusa 2 returned samples will find. This distant origin of asteroids, if correct, predicts that there will be ammoniated salts and minerals in Hayabusa 2's returned samples. A further check on this model will be provided by the analyses of returned materials from NASA's OSIRIS-Rex mission.
This study also examined whether the physical and chemical conditions in outer main-belt asteroids should be able to form the observed minerals. The cold and distant origin of asteroids proposed suggests there should be a significant similarity between asteroids and comets and raises questions about how each of these types of bodies formed.
This study suggests the materials that formed the Earth may have formed very far out in the early Solar System and then been brought in during the especially turbulent early history of the solar system. Recent observations of protoplanetary disks by the Atacama Large Millimetre/submillimetre Array (ALMA) have found many ringed structures, which are believed to be direct observations of planetesimal formation. As lead author Hiroyuki Kurokawa summarises the work, "Whether our solar system's formation is a typical outcome remains to be determined, but numerous measurements suggest we may be able to place our cosmic history in context soon."

- ❖ Look! Up in the sky! Is it a planet? Nope, just a star

Date: March 15, 2022
Source: Massachusetts Institute of Technology



The first worlds beyond our solar system were discovered three decades ago. Since then, close to 5,000 exoplanets have been confirmed in our galaxy. Astronomers have detected another 5,000 planetary candidates -- objects that might be planets but have yet to be confirmed. Now, the list of planets has shrunk by at least three.
In a study appearing in the *Astronomical Journal*, MIT astronomers report that three, and potentially four, planets that were originally discovered by NASA's Kepler Space Telescope are in fact misclassified. Instead, these suspected planets are likely small stars.
The team used updated measurements of planet-hosting stars to double-check the size of the planets, and identified three that are simply too big to be planets. With new and better estimates of stellar properties, the researchers found that the three objects, which are known as Kepler-854b, Kepler-840b, and Kepler-699b, are now estimated to be between two and four times the size of Jupiter.
"Most exoplanets are Jupiter-sized or much smaller. Twice [the size of] Jupiter is already suspicious. Larger than that cannot be a planet, which is what we found," says the study's first author Prajwal Niraula, a graduate student in MIT's Department of Earth, Atmospheric, and Planetary Sciences.

A fourth planet, Kepler-747b, is about 1.8 times Jupiter's size, which is comparable to the very largest confirmed planets. But Kepler-747b is relatively far from its star, and the amount of light it receives is too small to sustain a planet of its size. Kepler-747b's planetary status, the team concludes, is suspect but not entirely implausible.
"Overall, this study makes the current list of planets more complete," says study author Avi Shporer, a research scientist at MIT's Kavli Institute for Astrophysics and Space Research. "People rely on this list to study the population of planets as a whole. If you use a sample with a few interlopers, your results may be inaccurate. So, it's important that the list of planets is not contaminated."
The study's co-authors also include Ian Wong, NASA Postdoctoral Program Fellow at NASA Goddard Space Flight Centre, and MIT Assistant Professor Julien de Wit.

Stellar updates

Rooting out planetary imposters was not the team's initial goal. Niraula originally intended to look for systems with signs of tidal distortion.
"If you have two objects close to each other, the gravitational pull of one will cause the other to be egg-shaped, or ellipsoidal, which gives you an idea of how massive the companion is," Niraula explains. "So you could determine whether it's a star-star or star-planet system, just based on that tidal pull."
When combing through the Kepler catalogue, he came upon a signal from Kepler-854b that appeared too large to be true.
"Suddenly we had a system where we saw this ellipsoidal signal which was huge, and pretty immediately we knew this could not be from a planet," Shporer says. "Then we thought, something doesn't add up."
The team then took a second look at both the star and the planetary candidate. As with all Kepler-detected planets, Kepler-854b was spotted through a transit detection -- a periodic dip in starlight that signals a possible planet passing in front of its star. The depth of that dip represents the ratio between the size of the planet and that of its star. Astronomers can calculate the planet's size based on what they know of the star's size. But as Kepler-854b was discovered in 2016, its size was based on stellar estimates that were less precise than they are today.
Currently, the most accurate measurements of stars comes from the European Space Agency's Gaia mission, a space-based observatory that is designed to precisely measure and map the properties and paths of stars in the Milky Way. In 2016, Gaia's measurements of Kepler-854 were not yet available. Given the stellar information that was available, the object seemed to be a plausible-sized planet. But Niraula found that with Gaia's improved estimates, Kepler-854b turned out to be much larger, at three times the size of Jupiter.
"There's no way the universe can make a planet of that size," Shporer says. "It just doesn't exist."

Tiny corrections

The team confirmed that Kepler-854b was a planetary "false positive" -- not a planet at all, but instead, a small star orbiting a larger host star. Then they wondered: Could there be more?
Niraula searched through the Kepler catalogue’s more than 2,000 planets, this time for significant updates to the size of stars provided by Gaia. He ultimately discovered three stars whose sizes significantly changed based on Gaia's improved measurements. From these estimates, the team recalculated the size of the planets orbiting each star, and found them to be about two to four times Jupiter's size.
"That was a very big flag," Niraula says. "We now have three objects that are now not planets, and the fourth is likely not a planet."
Going forward, the team anticipates that there won't be many more such corrections to existing exoplanet catalogues.
"This is a tiny correction," Shporer says. "It comes from the better understanding of stars, which is only improving all the time. So, the chances of a star's radius being so incorrect are much smaller. These misclassifications are not going to happen many times more."
This research was supported in part by NASA.

- ❖ Comet 67P’s abundant oxygen more of an illusion, new study suggests

Date: March 14, 2022
Source: Johns Hopkins University Applied Physics Laboratory

When the European Space Agency's Rosetta spacecraft discovered abundant molecular oxygen bursting from comet 67P/Churyumov-Gerasimenko (67P) in 2015, it puzzled scientists. They had never seen a comet emit oxygen, let alone in such abundance. But most alarming were the deeper implications: that researchers had to account for so much oxygen, which meant reconsidering everything they thought they already knew about the chemistry of the early solar system and how it formed.
A new analysis, however, led by planetary scientist Adrienn Luspay-Kuti at the Johns Hopkins Applied Physics Laboratory (APL) in Laurel, Maryland, shows Rosetta's discovery may not be as strange as scientists first imagined. Instead, it suggests the comet has two internal reservoirs that make it seem like there's more oxygen than is actually there.
"It's kind of an illusion," Luspay-Kuti said. "In reality, the comet doesn't have this high oxygen abundance, at least not as far as its formation goes, but it has accumulated oxygen that gets trapped in the upper layers of the comet, which then gets released all at once."
While common on Earth, molecular oxygen (two oxygen atoms doubly linked to each other) is markedly uncommon throughout the universe. It quickly binds to other atoms and molecules, especially the universally abundant atoms hydrogen and carbon, so oxygen appears only in small amounts in just a few molecular clouds. That fact led many researchers to conclude any oxygen in the protosolar nebula that formed our solar system likely had been similarly scooped up.
When Rosetta found oxygen pouring out of comet 67P, however, everything turned on its head. Nobody had seen oxygen in a comet before, and as the fourth most abundant molecule in the comet's bright coma (after water, carbon dioxide and carbon monoxide), it needed some explanation. The oxygen seemed to come off the comet with water, causing many researchers to suspect the oxygen was either primordial -- meaning it got tied up with water at the birth of the solar system and amassed in the comet when it later formed -- or formed from water after the comet had formed.
But Luspay-Kuti and her team were sceptical. As the comet's dumbbell shape gradually rotates, each "bell" (or hemisphere) faces the Sun at various points, meaning the comet has seasons so the oxygen-water connection might not be present all the time. On short time frames, volatiles could potentially turn on and off as they thaw and refreeze with the seasons.

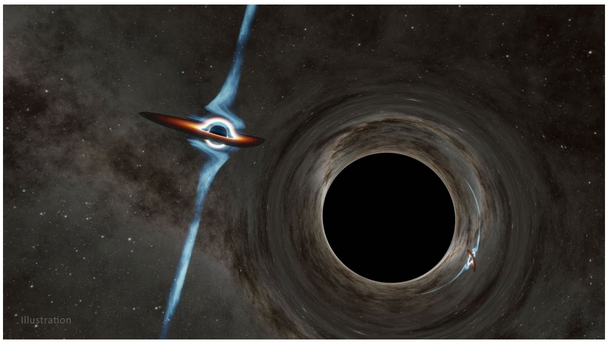
Now You See It, Now You Don't

Taking advantage of these seasons, the team examined the molecular data on short- and long-time periods just before the comet's southern hemisphere entered summer and then again just as its summer ended. As reported in their study, published March 10 in *Nature Astronomy*, the team found that as the southern hemisphere turned away and was sufficiently far from the Sun, the link between oxygen and water disappeared. The amount of water coming off the comet dropped precipitously, so instead the oxygen seemed strongly linked to carbon dioxide and carbon monoxide, which the comet was still emitting.
"There's no way that should be possible under the previous explanations suggested," Luspay-Kuti said. "If oxygen were primordial and tied to water in its formation, there shouldn't be any time that oxygen strongly correlates with carbon monoxide and carbon dioxide but not water."
The team instead proposed the comet's oxygen doesn't come from water but from two reservoirs: one made of oxygen, carbon monoxide and carbon dioxide deep inside the comet's rocky nucleus, and a shallower pocket closer to the surface where oxygen chemically combines with water ice molecules.
The idea goes like this: A deep reservoir of oxygen, carbon monoxide and carbon dioxide ice is constantly emitting gases because oxygen, carbon dioxide and carbon monoxide all vaporize at very low temperatures. As oxygen traverses from the comet's interior toward the surface, however, some chemically inserts into water ice (a major constituent of the comet's nucleus) to form a second, shallower oxygen reservoir. But water ice vaporizes at a much higher temperature than oxygen, so until the Sun sufficiently heats the

surface and vaporizes the water ice, the oxygen is stuck.
The consequence is that oxygen can accumulate in this shallow reservoir for long periods until the comet surface is finally warmed enough for water ice to vaporize, releasing a plume far richer in oxygen than was actually present in the comet.
"Put another way, the oxygen abundances measured in the comet's coma aren't necessarily reflecting its abundances in the comet's nucleus," Luspay-Kuti explained.
The comet would consequently also vacillate with the seasons between strongly associating with water (when the Sun heats the surface) and strongly associating with carbon dioxide and carbon monoxide (when that surface faces away from the Sun and the comet is sufficiently far) -- exactly what Rosetta observed.
"This isn't just one explanation: It's *the* explanation because there is no other possibility," said Olivier Mousis, a planetary scientist from France's Aix-Marseille Université and a study co-author. "If oxygen were just coming from the surface, you wouldn't see these trends observed by Rosetta."
The major implication, he said, is that it means comet 67P's oxygen is, in fact, oxygen that accreted at the beginning of the solar system. It's just that it's only a fraction of what people had thought.
Luspay-Kuti said she wants to probe the topic more deeply by examining the comet's minor molecular species, such as methane and ethane, and their correlation with molecular oxygen and other major species. She suspects this will help researchers get a better idea of the type of ice that the oxygen was incorporated into.
"You still have to come up with a way to incorporate the oxygen into the comet," Luspay-Kuti said, considering that the amount of oxygen is still higher than seen in most molecular clouds. But she said she expected a majority of researchers will welcome the study and its conclusions with a sigh of relief.

- Scientists announce discovery of supermassive binary black holes

Two black holes orbiting one another eventually will merge
Date: March 11, 2022
Source: Purdue University



A team of researchers from Purdue University and other institutions have discovered a supermassive black hole binary system, one of only two known such systems. The two black holes, which orbit each other, likely weigh 100 million suns each. One of the black holes powers a massive jet that moves outward at very close to the speed of light. The system is so far away that the visible light seen today was emitted 8.8 billion years ago.
The two are only between 200 AU and 2,000 AU apart (one AU is the distance from the Earth to the sun), at least 10 times closer than the only other known supermassive binary black hole system.
The close separation is significant because such systems are expected to merge eventually. That event will release a massive amount of energy in the form of gravitational waves, causing ripples in space in every direction (and oscillations in matter) as the waves pass through.
Finding systems like this is also important for understanding the processes by which galaxies formed and how they ended up with massive black holes at their centres.
Methods
Researchers serendipitously discovered the system when they noticed a repeating sinusoidal pattern in its radio brightness emission variations over time, based on data taken after 2008. A subsequent search of historical data revealed that the system also was varying in the same manner in the late 1970s to early 1980s. That type of variation is exactly what researchers would expect if the jetted emission from one black hole is affected by the Doppler effect due to its orbital motion as it swings around the other black hole.
Matthew Lister in the College of Science at Purdue University and his team imaged the system from 2002 to 2012, but the team's radio telescope lacks the resolution to resolve the individual black holes at such a large distance. His imaging data supports the binary black hole scenario and also provides the

orientation angle of the jetted outflow, which is a critical component in the paper's model for the Doppler-induced variations.

- Powerful warm winds seen blowing from a neutron star as it rips up its companion

Date: March 2, 2022
Source: University of Southampton

Depiction of neutron star blowing out warm and cold winds.
Credit: Gabriel

Using the most powerful telescopes on Earth and in space, a team of astronomers has found for the first time blasts of hot, warm and cold winds from a neutron star whilst it consumes matter from a nearby star. The discovery provides new insight into the behaviours of some of the most extreme objects in the universe.

Low-mass X-ray binaries (LMXBs) are systems containing a neutron star or black hole. They are fuelled by material ripped from a neighbouring star; a process known as accretion. Most accretion occurs during violent eruptions where the systems brighten dramatically. At the same time, some of the material that spirals in is propelled back into space in the form of disc winds and jets.

The most common signs of outflowing material from astronomical objects are associated with "warm" gas. Despite this, only winds of "hot" or "cold" gas have been observed in transient X-ray binaries, until now.

In this new study, a team of researchers from eleven countries, led by the University of Southampton, studied the recent eruption of the X-ray binary known as Swift J1858. They used a combination of telescopes, including NASA's Hubble Space Telescope (HST), the European Space Agency's XMM-Newton satellite, the European Southern Observatory Organisation's Very Large Telescope (VLT) and the Spanish Gran Telescopio Canarias (GTC).

The results, published in the journal *Nature*, showed persistent signatures of a warm wind at ultraviolet wavelengths occurring at the same time as signatures of a cold wind at optical wavelengths. This is the first time that winds from such a system have been seen across different bands of the electromagnetic spectrum.

Lead author Dr Noel Castro Segura, of the University of Southampton said: "Eruptions like this are rare, and each of them is unique. Normally they are heavily obscured by interstellar dust, which makes observing them really difficult. Swift J1858 was special, because even though it is located on the other side of our galaxy, the obscuration was small enough to allow for a full multiwavelength study."

"Only one other system -- the black hole X-ray binary, V404 Cyg -- has shown similar properties. However, our attempt to perform the same experiment on that system was unsuccessful, because the eruption ended before we could get the ground-based and space-based telescopes to observe it simultaneously," co-Author Dr Hernández Santisteban from University of St Andrews said.

Swift J1858 is a newly discovered X-ray transient event that displays extreme variability across the electromagnetic spectrum, which presented a rare opportunity.

"All the astronomers in the field were incredibly excited, to the point that we combined our efforts to cover the full spectrum, from radio to X-ray using state-of-art observatories on Earth and in space," Dr Castro Segura continued.

Co-author Nathalie Degenaar, from the University of Amsterdam added, "Neutron stars have an immensely strong gravitational pull that allows them to gobble up gas from other stars. The stellar cannibals are, however, messy eaters and much of the gas that neutron stars pull towards them is not consumed, but flung into space at high speed. This behaviour has a large impact both on the neutron star itself, and on its immediate surroundings. In this paper we report on a new discovery that provides key information about the messy eating patterns of these cosmic cookie monsters."

"This time we had cosmic luck on our side, as we were able to co-ordinate ten telescopes and point them towards the J1858, all while it was fully active. This allows us to obtain much more information, since we can use different

techniques at different wavelengths," Dr Hernández Santisteban said.
Dr Degenaar added, "designing such an ambitious observing campaign -- built around the best telescopes on Earth and in space -- was a huge challenge. So, it is incredibly exciting that all this work has paid off and allowed us to make a key discovery that would not have been possible otherwise."
As well as discovering the different types of winds, the team were able to study the temporal evolution of the gas that flows out. They found that the warm wind was not affected by the strong variations in the brightness of the system. The absence of such a response had previously been an unconfirmed theoretical prediction based on sophisticated simulations.
"In this research we combined the unique capabilities of the HST with the best ground-based telescopes, such as the VLT and GTC, to obtain a complete picture of the dynamics of the gas in the system, from the near-infrared to ultraviolet wavelengths. This allowed us to unveil for first time the true nature of these powerful outflows," Dr Castro Segura said.
"The new insights provided by our results are key to understanding how these objects interact with their environment. By shedding energy and matter into the galaxy, they contribute to the formation of new generations of stars, and to the evolution of the galaxy itself," Dr Castro Segura concluded.
The study was funded by grants from agencies including the Science and Technology Facilities Council (STFC) and NASA among others.

❖ The new, improved Dragonfly is a galactic gas detector

Date: March 10, 2022
Source: Yale University

Roberto Abraham and the Dragonfly Telescope. credit: Peter Van Dokkum via University of Toront

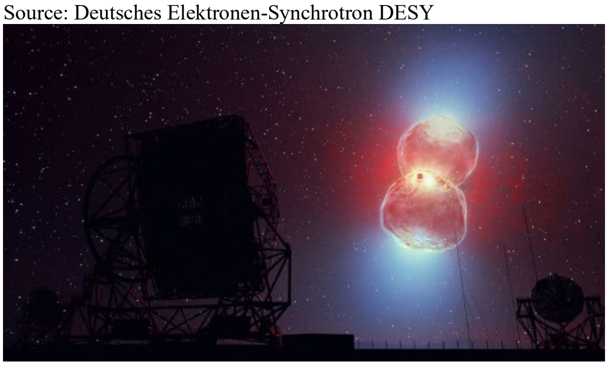
The Dragonfly telescope is undergoing a metamorphosis.
For the past decade, the Dragonfly Telephoto Array -- designed by Yale's Pieter van Dokkum and the University of Toronto's Roberto Abraham and located in New Mexico -- has conducted ground-breaking science by detecting faint starlight within dimly lit parts of the night sky. The telescope uses clusters of telephoto lenses to create images, much the way a dragonfly's eyes gather visual data.
The telescope has spotted previously unseen "fluffy" galaxies, diffuse dwarf galaxies, and galaxies with little or no dark matter.
Now Dragonfly is setting its sights on extragalactic gas.
With the help of a special filter mounted in front of each lens, the Dragonfly telescope is able to block most of the light emitted by stars -- leaving just the faint glow of light-emitting, ionized gas. The Dragonfly team built a "pathfinder" version of the new telescope, with three lenses instead of the original Dragonfly's 48 lenses, as a proof-of-concept device.
The results are even better than expected, the researchers say.
"There are going to be some incredible images from Dragonfly in the next few years," said van Dokkum, the Sol Goldman Family Professor of Astronomy in Yale's Faculty of Arts and Sciences. "This new method of detecting gas clouds is opening up a whole new regime of science to explore."
In a pair of new studies, the Dragonfly team describes previously hidden features within the gas surrounding a group of galaxies located about 12 million light-years from Earth. The researchers chose this area, in part, because it has been studied by other telescopes and provides a number of established, celestial signposts to gauge Dragonfly's accuracy.
"The Messier 81 galaxy group is one of the nearest to our own, making it one of the best to study," said Yale graduate student Imad Pasha, first author of one of the new studies. "We're returning to many such well-known, nearby galaxies with this new instrument to add pieces to the puzzle of how gas gets in and out of galaxies."
Although it has long been known that gas is the fuel for creating stars and planets in galaxies, the dynamics for how this gas actually gets into and out of galaxies are not well understood. Being able to isolate images

of gas structures around galaxies has become a priority for researchers.
For example, Pasha's study, published in *Astrophysical Journal Letters,* describes a nascent dwarf galaxy forming in a tidal arm of the galaxy Messier 82. Essentially, a new galaxy is being formed by the gas ripped away from M82 when M82 flew past its neighbour, M81.
"This type of galaxy is difficult to detect by traditional observations," Pasha said. "We may well find more of these 'baby' galaxies around well-studied groups in the future."
The second new study, which has been accepted by the *Astrophysical Journal*, describes a giant cloud of ionized gas -- 180,000 light years long and 30,000 light years wide. Although the cloud's origin remains a mystery, the researchers theorize that it may have been pulled away from M82 during a close encounter with its larger, companion galaxy, Messier 81, or blown away from M82 by strong "super winds."
"This cloud had never been seen before," said first author Deborah Lokhorst, a former graduate student at the University of Toronto. "Our image was the first with the sensitivity required and a wide enough field of view to detect it. We almost didn't believe it was real!"
Now that the Dragonfly "pathfinder" has proven to be successful, the researchers are building a bigger Dragonfly Spectral Line Mapper instrument with 120 lenses. The telescope is being assembled over the next year in New Mexico.
Co-author Seery Chen, a University of Toronto graduate student who worked on instrumentation development for the new Dragonfly, said part of the project's ethos is to conduct ground-breaking science using readily available materials -- including commercially available telephoto lenses. Eventually, the team plans to make all of its instrument designs and data open-sourced and available to other researchers.
"It makes science more accessible to more people," Chen said.
Co-authors of the new studies include Yale graduate students Tim Miller, Erin Lippitt, Ava Polzin, Zili Shen, and Michael Keim, and former Yale researchers Shany Danieli, now at Princeton, and Allison Merritt, now at the Max-Planck-Institut für Astronomie in Germany.

❖ Cosmic particle accelerator at its limit

Gamma ray observatory H.E.S.S. reveals a cosmic particle acceleration process in unprecedented detail

Date: March 10, 2022
Source: Deutsches Elektronen-Synchrotron DESY



Artist's impression of the RS Ophiuchi Nova outburst. The fast shockwaves form an hourglass shape as they expand, in which gamma rays are produced. This gamma-ray emission is then detected by the H.E.S.S. telescopes (shown in the foreground). Image: DESY/H.E.S.S., Science Communication Lab

With the help of special telescopes, researchers have observed a cosmic particle accelerator as never before. Observations made with the gamma ray observatory H.E.S.S. in Namibia show for the first time the course of an acceleration process in a stellar process called a nova, which comprises powerful eruptions on the surface of a white dwarf. A nova creates a shock wave that tears through the surrounding medium, pulling particles with it and accelerating them to extreme energies. Surprisingly, the nova "RS Ophiuchi" seems to cause particles to accelerate at speeds reaching the theoretical limit, corresponding to ideal conditions. The research has been published in the journal *Science*.
White dwarves are burned-out old stars that have collapsed in on themselves and develop into extremely compact objects. Novae events occur, for example, when a white dwarf is in a binary system with a large star, and the white dwarf gathers material from its more massive companion due to its gravity. Once the gathered material goes over a critical level, it spurs a thermonuclear explosion on the surface of the white dwarf. Some novae are known to repeat. RS Ophiuchi is one of these recurrent novae; there is an explosion on its surface every 15 to 20 years. "The stars forming the system are at approximately the same distance from each other as the Earth and the Sun," explains Alison Mitchell, researcher at Friedrich-Alexander-Universität Erlangen-Nürnberg and principal investigator of the H.E.S.S Nova programme. "When the nova exploded in August 2021, the H.E.S.S.

telescopes allowed us to observe a galactic explosion in very-high-energy gamma rays for the first time," she continues.
The research group observed that the particles were accelerated to energies several hundreds of times higher than previously observed in novae. Additionally, the energy released as a result of the explosion was transformed extremely efficiently into accelerated protons and heavy nuclei, such that the particle acceleration reached the maximum speeds calculated in theoretical models. According to Ruslan Konno, one of the lead authors of the study and a doctoral candidate at DESY in Zeuthen, "The observation that the theoretical limit for particle acceleration can actually be reached in genuine cosmic shock waves has enormous implications for astrophysics. It suggests that the acceleration process could be just as efficient in their much more extreme relatives, supernovae."
During the eruption of RS Ophiuchi, the researchers were able for the first time to follow the development of the nova in real time, allowing them to observe and study cosmic particle acceleration as if they were watching a film. The researchers were able to measure high-energy gamma rays up to one month after the explosion. "This is the first time we have ever been able to carry out observations like this, and it will allow us to gain even more accurate future insights into how cosmic explosions work," explains Dmitry Khangulyan, a theoretical astrophysicist at Rikkyo University in Tokyo, Japan. "We may, for example, discover that novae contribute to the ever-present sea of cosmic rays and therefore have a considerable effect on the dynamics of their immediate surroundings." Cosmic rays are immense showers of energetic subatomic particles that come from every direction in space at the same time, and which have an unclear exact origin.
Specific telescopes were required for these measurements. The H.E.S.S. facility (which stands for High Energy Stereoscopic System) in Namibia consists of five Cherenkov telescopes that are used to investigate gamma rays from space. A new, highly sensitive state-of-the-art camera -- known as FlashCam -- was recently installed in the largest telescope. The FlashCam design is currently being further developed for the next generation gamma-ray observatory, the Cherenkov Telescope Array (CTA). "The new camera has been in use since late 2019, and this measurement shows just how much potential the latest generation of cameras has," explains Simon Steinmaßl, a doctoral candidate at the Max Planck Institute for Nuclear Physics in Heidelberg, who was involved in analysing the camera data.
The telescopes were pointed towards the nova at very short notice after amateur astronomers first reported the nova to the astrophysics community. The success of the observation was due in no small part to the rapid reaction of the researchers and the wider astronomical community, paving the way for extensive subsequent observations. H.E.S.S. Director Stefan Wagner, a professor at the regional observatory in Heidelberg, explains, "Over the next few years, research using the CTA telescopes will show whether this type of nova is special." In addition, researchers now have a clearer idea of what to look for. This gives rise to a number of new possibilities for gaining a better understanding and being better able to explain events linked to novae. "This measurement is a further success in gamma-ray astronomy and an encouraging sign that we will be able to study many more cosmic explosions with H.E.S.S. and gamma-ray telescopes of the future."

- Black hole billiards in the centres of galaxies

Date: March 9, 2022
Source: University of Copenhagen - Faculty of Science

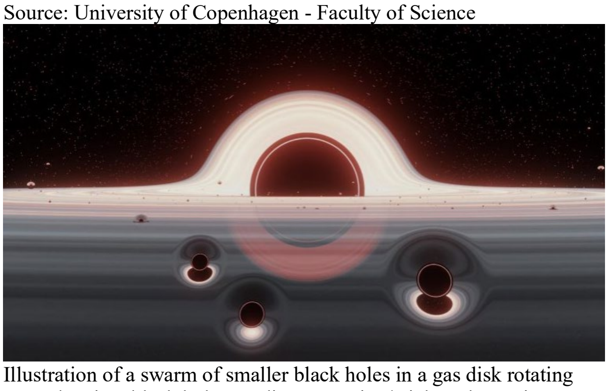


Illustration of a swarm of smaller black holes in a gas disk rotating around a giant black hole. Credit: J. Samsing/Niels Bohr Institute

Researchers provide the first plausible explanation to why one of the most massive black hole pairs observed to date by gravitational waves also seemed to merge on a non-circular orbit. Their suggested solution, now published in *Nature*, involves a chaotic triple drama inside a giant disk of gas around a super massive black hole in a galaxy far, far away.
Black holes are one of the most fascinating objects in the Universe, but our knowledge of

them is still limited -- especially because they do not emit any light. Up until a few years ago, light was our main source of knowledge about our universe and its black holes, until the Laser Interferometer Gravitational Wave Observatory (LIGO) in 2015 made its breakthrough observation of gravitational waves from the merger of two black holes.

"But how and where in our Universe do such black hole's form and merge? Does it happen when nearby stars collapse and both turn into black holes, is it through close chance encounters in star clusters, or is it something else? These are some of the key questions in the new era of Gravitational Wave Astrophysics," says Assist. Prof. Johan Samsing from the Niels Bohr Institute at the University of Copenhagen, lead author of the paper.

He and his collaborators may have now provided a new piece to the puzzle, which possibly solves the last part of a mystery that astrophysicists have struggled with for the past few years.

Unexpected Discovery in 2019

The mystery dates back to 2019, when an unexpected discovery of gravitational waves was made by the LIGO and Virgo observatories. The event named *GW190521* is understood to be the merger of two black holes, which not only were heavier than previously thought physically possible, but had in addition produced a flash of light. Possible explanations have since been provided for these two characteristics, but the gravitational waves also revealed a third astonishing feature of this event -- namely that the black holes did not orbit each other along a circle in the moments before merging.

"The gravitational wave event *GW190521* is the most surprising discovery to date. The black holes' masses and spins were already surprising, but even more surprising was that they appeared not to have a circular orbit leading up to the merger," says co-author Imre Bartos, Prof. at the University of Florida.

But why is a non-circular orbit so unusual and unexpected?

"This is because of the fundamental nature of the gravitational waves emitted, which not only brings the pair of black holes closer for them to finally merge but also acts to circularize their orbit." explains co-author Zoltan Haiman, a Professor at Columbia University.

This observation made many people around the world, including Johan Samsing in Copenhagen, wonder,

"It made me start thinking about how such non-circular (known as "eccentric") mergers can happen with the surprisingly high probability as the observation suggests," says Johan Samsing.

It Takes Three to Tango

A possible answer would be found in the harsh environment in the centres of galaxies harbouring a giant black hole millions of times the mass of the Sun surrounded by a flat, rotating disk of gas.

"In these environments the typical velocity and density of black holes is so high that smaller black holes bounce around as in a giant game of billiards and wide circular binaries cannot exist," points out co-author Prof. Bence Kocsis from the University of Oxford.

But as the group further argued, a giant black hole is not enough, "New studies show that the gas disk plays an important role in capturing smaller black holes, which over time move closer to the centre and also closer to one other. This not only implies they meet and form pairs, but also that such a pair might interact with another, third, black hole, often leading to a chaotic tango with three black holes flying around, " explains astrophysicist Hiromichi Tagawa from Tohoku University, co-author of the study.

However, all previous studies up to observation of *GW190521* indicated that forming eccentric black hole mergers is relatively rare. This naturally brings up the question: Why did the already unusual gravitational wave source *GW190521* also merge on an eccentric orbit?

Two Dimensional Black Hole Billiards

Everything that has been calculated so far was based on the notion that the black hole interactions are taking place in three dimensions, as expected in the majority of stellar systems considered so far.

"But then we started thinking about what would happen if the black hole interactions were instead to take place in a flat disk, which is closer to a two-dimensional environment. Surprisingly, we found in this limit that the probability of forming an eccentric merger increases by as much as 100 times, which leads to about half of all black hole mergers in such disks possibly being eccentric," says Johan Samsing and continues:

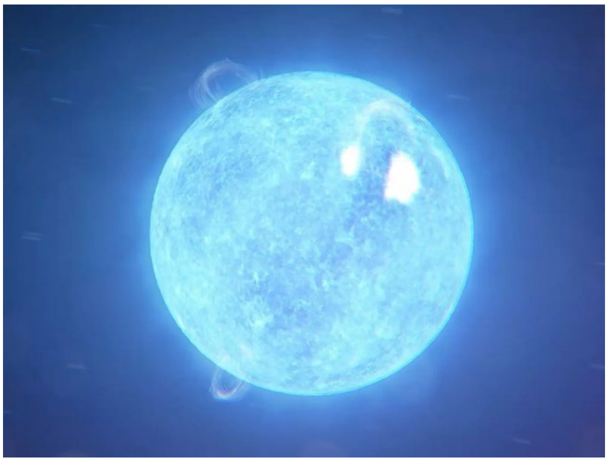
"And that discovery fits incredibly well with the observation in 2019, which all in all now points in the direction that the otherwise spectacular properties of this source are not so strange again, if it was created in a flat gas disk surrounding a super massive black hole in a galactic nucleus."
This possible solution also adds to a century-old problem in mechanics, "The interaction between 3 objects is one of the oldest problems in physics, which both Newton, myself, and others have intensely studied. That this now seems to play a crucial role in how black holes merge in some of the most extreme places of our Universe is incredibly fascinating ," says co-author Nathan W. Leigh, Prof. at Universidad de Concepción, Chile.

Black Holes in Gaseous Disks

The theory of the gas disk also fits with other researchers' explanations of the other two puzzling properties of *GW190521*. The large masses of the black hole have been reached by successive mergers inside the disk, while the emission of light could originate from the ambient gas.
"We have now shown that there can be a huge difference in the signals emitted from black holes that merge in flat, two-dimensional disks, versus those we often consider in three-dimensional stellar systems, which tells us that we now have an extra tool that we can use to learn about how black holes are created and merge in our Universe, " says Johan Samsing.
But this study is only the beginning, "People have been working on understanding the structure of such gas disks for many years, but the problem is difficult. Our results are sensitive to how flat the disk is, and how the black holes move around in it. Time will tell whether we will learn more about these disks, once we have a larger population of black hole mergers, including more unusual cases similar to *GW190521*. To enable this, we must build on our now published discovery, and see where it leads us in this new and exciting field" concludes co-author Zoltan Haiman.

- NASA's NICER telescope sees hot spots merge on a magnetar

Date: March 8, 2022
Source: NASA/Goddard Space Flight Centre


The merging spots on the magnetar. (Image credit: NASA)

For the first time, NASA's Neutron star Interior Composition Explorer (NICER) has observed the merging of multimillion-degree X-ray spots on the surface of a magnetar, a super magnetized stellar core no larger than a city.
"NICER tracked how three bright, X-ray-emitting hot spots slowly wandered across the object's surface while also decreasing in size, providing the best look yet at this phenomenon," said George Younes, a researcher at George Washington University in Washington and NASA's Goddard Space Flight Centre in Greenbelt, Maryland. "The largest spot eventually coalesced with a smaller one, which is something we haven't seen before."
This unique set of observations, described in a paper led by Younes and published Jan. 13 in The Astrophysical Journal Letters, will help guide scientists to a more complete understanding of the interplay between the crust and magnetic field of these extreme objects.
A magnetar is a type of isolated neutron star, the crushed core left behind when a massive star explodes. Compressing more mass than the Sun's into a ball about 12 miles (20 kilometres) across, a neutron star is made of matter so dense that a teaspoonful would weigh as much as a mountain on Earth.
What sets magnetars apart is that they sport the strongest magnetic fields known, up to 10 trillion times more intense than a refrigerator magnet's and a thousand times stronger than a typical neutron stars. The magnetic field represents an enormous storehouse of energy that, when disturbed, can power an outburst of enhanced X-ray activity lasting from months to years.
On Oct. 10, 2020, NASA's Neil Gehrels Swift Observatory discovered just such an outburst

from a new magnetar, called SGR 1830-0645 (SGR 1830 for short). It's located in the constellation Scutum, and while its distance is not precisely known, astronomers estimate that the object lies about 13,000 light-years away. Swift turned its X-Ray Telescope to the source, detecting repeated pulses that revealed the object was rotating every 10.4 seconds. NICER measurements from the same day show that the X-ray emission exhibited three close peaks with every rotation. They were caused when three individual surface regions much hotter than their surroundings spun into and out of our view.
NICER observed SGR 1830 almost daily from its discovery to Nov. 17, after which the Sun was too close to the field of view for safe observation. Over this period, the emission peaks gradually shifted, occurring at slightly different times in the magnetar's rotation. The results favour a model where the spots form and move as a result of crustal motion, in much the same way as the motion of tectonic plates on Earth drives seismic activity.
"The crust of a neutron star is immensely strong, but a magnetar's intense magnetic field can strain it beyond its limits," said Sam Lander, an astrophysicist at the University of East Anglia in Norwich, United Kingdom, and a co-author of the paper. "Understanding this process is a major challenge for theorists, and now NICER and SGR 1830 have brought us a much more direct look at how the crust behaves under extreme stress."
The team thinks these observations reveal a single active region where the crust has become partially molten, slowly deforming under magnetic stress. The three moving hot spots likely represent locations where coronal loops -- similar to the bright, glowing arcs of plasma seen on the Sun -- connect to the surface. The interplay between the loops and crustal motion drives the drifting and merging behaviour.
"Changes in pulse shape, including decreasing numbers of peaks, previously have been seen only in a few 'snapshot' observations widely separated in time, so there was no way to track their evolution," said Zaven Arzoumanian, the NICER science lead at Goddard. "Such changes could have occurred suddenly, which would be more consistent with a lurching magnetic field than wandering hot spots."
NICER is an Astrophysics Mission of Opportunity within NASA's Explorers Program, which provides frequent flight opportunities for world-class scientific investigations from space utilizing innovative, streamlined, and efficient management approaches within the heliophysics and astrophysics science areas. NASA's Space Technology Mission Directorate supports the SEXTANT component of the mission, demonstrating pulsar-based spacecraft navigation.

- Astronomers discover largest molecule yet in a planet-forming disc

Date: March 8, 2022
Source: ESO

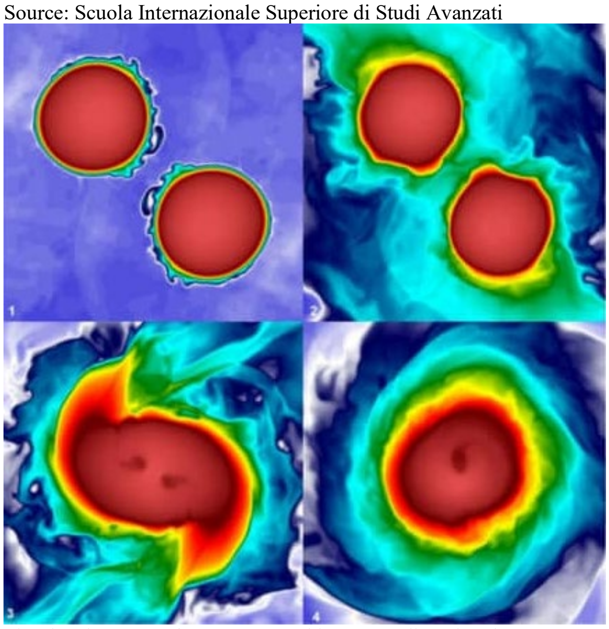

Protoplanetary disc formation, illustration.

Using the Atacama Large Millimetre/submillimetre Array (ALMA) in Chile, researchers at Leiden Observatory in the Netherlands have for the first time detected dimethyl ether in a planet-forming disc. With nine atoms, this is the largest molecule identified in such a disc to date. It is also a precursor of larger organic molecules that can lead to the emergence of life.
"From these results, we can learn more about the origin of life on our planet and therefore get a better idea of the potential for life in other planetary systems. It is very exciting to see how these findings fit into the bigger picture," says Nashanty Brunken, a Master's student at Leiden Observatory, part of Leiden University, and lead author of the study published today in *Astronomy & Astrophysics*.
Dimethyl ether is an organic molecule commonly seen in star-forming clouds, but had never before been found in a planet-forming disc. The researchers also made a tentative detection of methyl formate, a complex molecule similar to dimethyl ether that is also a building block for even larger organic molecules.
"It is really exciting to finally detect these larger molecules in discs. For a while we thought it might not be possible to observe them," says co-author Alice Booth, also a researcher at Leiden Observatory.

The molecules were found in the planet-forming disc around the young star IRS 48 (also known as Oph-IRS 48) with the help of ALMA, an observatory co-owned by the European Southern Observatory (ESO). IRS 48, located 444 light-years away in the constellation Ophiuchus, has been the subject of numerous studies because its disc contains an asymmetric, cashew-nut-shaped "dust trap." This region, which likely formed as a result of a newly born planet or small companion star located between the star and the dust trap, retains large numbers of millimetre-sized dust grains that can come together and grow into kilometre-sized objects like comets, asteroids and potentially even planets.
Many complex organic molecules, such as dimethyl ether, are thought to arise in star-forming clouds, even before the stars themselves are born. In these cold environments, atoms and simple molecules like carbon monoxide stick to dust grains, forming an ice layer and undergoing chemical reactions, which result in more complex molecules. Researchers recently discovered that the dust trap in the IRS 48 disc is also an ice reservoir, harbouring dust grains covered with this ice rich in complex molecules. It was in this region of the disc that ALMA has now spotted signs of the dimethyl ether molecule: as heating from IRS 48 sublimates the ice into gas, the trapped molecules inherited from the cold clouds are freed and become detectable.
"What makes this even more exciting is that we now know these larger complex molecules are available to feed forming planets in the disc," explains Booth. "This was not known before as in most systems these molecules are hidden in the ice."
The discovery of dimethyl ether suggests that many other complex molecules that are commonly detected in star-forming regions may also be lurking on icy structures in planet-forming discs. These molecules are the precursors of prebiotic molecules such as amino acids and sugars, which are some of the basic building blocks of life.
By studying their formation and evolution, researchers can therefore gain a better understanding of how prebiotic molecules end up on planets, including our own. "We are incredibly pleased that we can now start to follow the entire journey of these complex molecules from the clouds that form stars, to planet-forming discs, and to comets. Hopefully with more observations we can get a step closer to understanding the origin of prebiotic molecules in our own Solar System," says Nienke van der Marel, a Leiden Observatory researcher who also participated in the study.
Future studies of IRS 48 with ESO's Extremely Large Telescope (ELT), currently under construction in Chile and set to start operations later this decade, will allow the team to study the chemistry of the very inner regions of the disc, where planets like Earth may be forming.

- Dark energy: Neutron stars will tell us if it's only an illusion

Date: March 3, 2022
Source: Scuola Internazionale Superiore di Studi Avanzati



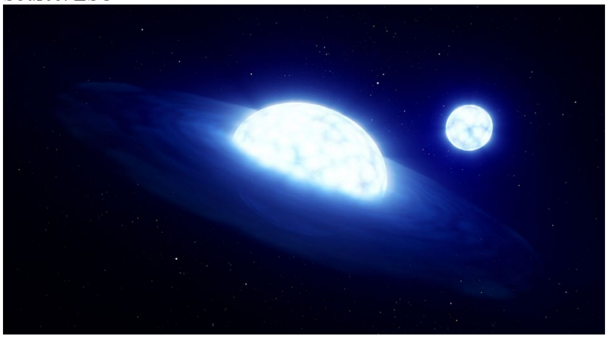
Simulated merger of a neutron star binary. Credit: Miguel Bezares—GRAMS group SISSA

A huge amount of mysterious dark energy is necessary to explain cosmological phenomena, such as the accelerated expansion of the Universe, with Einstein's theory. But what if dark energy was just an illusion and general relativity itself had to be modified? A new SISSA study, published in *Physical Review Letters*, offers a new approach to answer this question. Thanks to huge computational and mathematical effort, scientists produced the first simulation ever of merging binary neutron stars in theories beyond general relativity that reproduce a dark- energy like behaviour on cosmological scales. This allows the comparison of Einstein's theory and modified versions of it, and, with sufficiently accurate data, may solve the dark energy mystery.
For about 100 years now, general relativity has been very successful at describing gravity on a variety of regimes, passing all

experimental tests on Earth and the solar system. However, to explain cosmological observations such as the observed accelerated expansion of the Universe, we need to introduce dark components, such as dark matter and dark energy, which still remain a mystery.
Enrico Barausse, astrophysicist at SISSA (Scuola Internazionale Superiore di Studi Avanzati) and principal investigator of the ERC grant GRAMS (GRavity from Astrophysical to Microscopic Scales) questions whether dark energy is real or, instead, it may be interpreted as a breakdown of our understanding of gravity. "The existence of dark energy could be just an illusion," he says, "the accelerated expansion of the Universe might be caused by some yet unknown modifications of general relativity, a sort of 'dark gravity'."
The merger of neutron stars offers a unique situation to test this hypothesis because gravity around them is pushed to the extreme. "Neutron stars are the densest stars that exist, typically only 10 kilometres in radius, but with a mass between one or two times the mass of our Sun," explains the scientist. "This makes gravity and the spacetime around them extreme, allowing for abundant production of gravitational waves when two of them collide. We can use the data acquired during such events to study the workings of gravity and test Einstein's theory in a new window."
In this study, published in *Physical Review Letters*, SISSA scientists in collaboration with physicists from Universitat de les Illes Balears in Palma de Mallorca, produced the first simulation of merging binary neutron stars in theories of modified gravity relevant for cosmology: "This type of simulations is extremely challenging," clarifies Miguel Bezares, first author of the paper, "because of the highly non-linear nature of the problem. It requires a huge computational effort -months of run in supercomputers -- that was made possible also by the agreement between SISSA and CINECA consortium as well as novel mathematical formulations that we developed. These represented major roadblocks for many years till our first simulation."
Thanks to these simulations, researchers are finally able to compare general relativity and modified gravity. "Surprisingly, we found that the 'dark gravity' hypothesis is equally good as general relativity at explaining the data acquired by the LIGO and Virgo interferometers during past binary neutron star collisions. Indeed, the differences between the two theories in these systems are quite subtle, but they may be detectable by next-generation gravitational interferometers, such as the *Einstein telescope* in Europe and *Cosmic Explorer* in USA. This opens the exciting possibility of using gravitational waves to discriminate between dark energy and 'dark gravity'," Barausse concludes.

- 'Closest black hole' system found to contain no black hole

Date: March 2, 2022
Source: ESO



In 2020 a team led by European Southern Observatory (ESO) astronomers reported the closest black hole to Earth, located just 1000 light-years away in the HR 6819 system. But the results of their study were contested by other researchers, including by an international team based at KU Leuven, Belgium. In a paper published today, these two teams have united to report that there is in fact no black hole in HR 6819, which is instead a "vampire" two-star system in a rare and short-lived stage of its evolution.
The original study on HR 6819 received significant attention from both the press and scientists. Thomas Rivinius, a Chile-based ESO astronomer and lead author on that paper, was not surprised by the astronomy community's reception to their discovery of the black hole. "Not only is it normal, but it should be that results are scrutinised," he says, "and a result that makes the headlines even more so."
Rivinius and his colleagues were convinced that the best explanation for the data they had, obtained with the MPG/ESO 2.2-metre telescope, was that HR 6819 was a triple system, with one star orbiting a black hole every 40 days and a second star in a much wider orbit. But a study led by Julia Bodensteiner, then a PhD student at KU Leuven, Belgium, proposed a different explanation for the same data: HR 6819 could

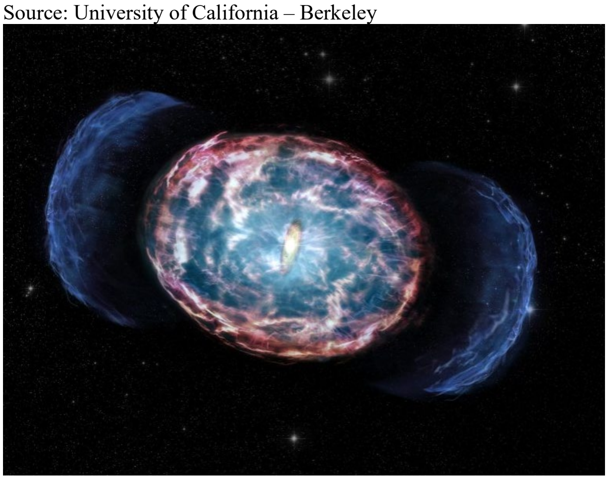
also be a system with only two stars on a 40-day orbit and no black hole at all. This alternative scenario would require one of the stars to be "stripped," meaning that, at an earlier time, it had lost a large fraction of its mass to the other star.
"We had reached the limit of the existing data, so we had to turn to a different observational strategy to decide between the two scenarios proposed by the two teams," says KU Leuven researcher Abigail Frost, who led the new study published today in *Astronomy & Astrophysics*.
To solve the mystery, the two teams worked together to obtain new, sharper data of HR 6819 using ESO's Very Large Telescope (VLT) and Very Large Telescope Interferometer (VLTI). "The VLTI was the only facility that would give us the decisive data we needed to distinguish between the two explanations," says Dietrich Baade, author on both the original HR 6819 study and the new *Astronomy & Astrophysics* paper. Since it made no sense to ask for the same observation twice, the two teams joined forces, which allowed them to pool their resources and knowledge to find the true nature of this system.
"The scenarios we were looking for were rather clear, very different and easily distinguishable with the right instrument," says Rivinius. "We agreed that there were two sources of light in the system, so the question was whether they orbit each other closely, as in the stripped-star scenario, or are far apart from each other, as in the black hole scenario."
To distinguish between the two proposals, the astronomers used both the VLTI's GRAVITY instrument and the Multi Unit Spectroscopic Explorer (MUSE) instrument on ESO's VLT. "MUSE confirmed that there was no bright companion in a wider orbit, while GRAVITY's high spatial resolution was able to resolve two bright sources separated by only one-third of the distance between the Earth and the Sun," says Frost. "These data proved to be the final piece of the puzzle, and allowed us to conclude that HR 6819 is a binary system with no black hole."
"Our best interpretation so far is that we caught this binary system in a moment shortly after one of the stars had sucked the atmosphere off its companion star. This is a common phenomenon in close binary systems, sometimes referred to as "stellar vampirism" in the press," explains Bodensteiner, now a fellow at ESO in Germany and an author on the new study. "While the donor star was stripped of some of its material, the recipient star began to spin more rapidly."
"Catching such a post-interaction phase is extremely difficult as it is so short," adds Frost. "This makes our findings for HR 6819 very exciting, as it presents a perfect candidate to study how this vampirism affects the evolution of massive stars, and in turn the formation of their associated phenomena including gravitational waves and violent supernova explosions."
The newly formed Leuven-ESO joint team now plans to monitor HR 6819 more closely using the VLTI's GRAVITY instrument. The researchers will conduct a joint study of the system over time, to better understand its evolution, constrain its properties, and use that knowledge to learn more about other binary systems.
As for the search for black holes, the team remains optimistic. "Stellar-mass black holes remain very elusive owing to their nature," says Rivinius. "But order-of-magnitude estimates suggest there are tens to hundreds of millions of black holes in the Milky Way alone," Baade adds. It is just a matter of time until astronomers discover them.
More information
This research was presented in the paper "HR 6819 is a binary system with no black hole: Revisiting the source with infrared interferometry and optical integral field spectroscopy" to appear in *Astronomy & Astrophysics*.
It has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement number 772225: MULTIPLES; PI: Hugues Sana).
The team is composed of A. J. Frost (Institute of Astronomy, KU Leuven, Belgium [KU Leuven]), J. Bodensteiner (European Southern Observatory, Garching, Germany [ESO]), Th. Rivinius (European Southern Observatory, Santiago, Chile [ESO Chile]), D. Baade (ESO), A. Mérand (ESO), F. Selman (ESO Chile), M. Abdul-Masih (ESO Chile), G. Banyard (KU Leuven), E. Bordier (KU Leuven, ESO Chile), K. Dsilva (KU Leuven), C. Hawcroft (KU Leuven), L. Mahy (Royal Observatory of Belgium, Brussels, Belgium), M. Reggiani (KU Leuven), T. Shenar (Anton Pannekoek Institute for Astronomy, University of Amsterdam, The Netherlands), M. Cabezas

(Astronomical Institute, Academy of Sciences of the Czech Republic, Prague, Czech Republic [ASCR]), P. Hadrava (ASCR), M. Heida (ESO), R. Klement (The CHARA Array of Georgia State University, Mount Wilson Observatory, Mount Wilson, USA) and H. Sana (KU Leuven).

- Did rapid spin delay 2017 collapse of merged neutron stars into black hole?

Excess X-ray emissions from remnant four years after merger hint at bounce from delayed collapse

Date: March 1, 2022
Source: University of California – Berkeley



In this artist's representation, the merger of two neutron stars to form a black hole (hidden within bright bulge at centre of image) generated opposing, high-energy jets of particles (blue) that heated up material around the stars, making it emit X-rays (reddish clouds). The Chandra X-ray Observatory is still detecting X-rays from the event today. They could be produced by a shock wave in the material around the black hole, or by material falling violently into the black hole (yellowish disk around central bulge). Credit: X-ray data from NASA, CXC and Northwestern Univ./A. Hajela; visual by NASA/CXC/M. Weiss

When two neutron stars spiral into one another and merge to form a black hole -- an event recorded in 2017 by gravitational wave detectors and telescopes worldwide -- does it immediately become a black hole? Or does it take a while to spin down before gravitationally collapsing past the event horizon into a black hole?

Ongoing observations of that 2017 merger by the Chandra X-ray Observatory, an orbiting telescope, suggests the latter: that the merged object stuck around, likely for a mere second, before undergoing ultimate collapse.

The evidence is in the form of an X-ray afterglow from the merger, dubbed GW170817, that would not be expected if the merged neutron stars collapsed immediately to a black hole. The afterglow can be explained as a rebound of material off the merged neutron stars, which ploughed through and heated the material around the binary neutron stars. This hot material has now kept the remnant glowing steadily more than four years after the merger threw material outward in what's referred to as a kilonova. X-ray emissions from a jet of material that was detected by Chandra shortly after the merger would otherwise be dimming by now.

While the excess X-ray emissions observed by Chandra could come from debris in an accretion disk swirling around and eventually falling into the black hole, astrophysicist Raffaella Margutti of the University of California, Berkeley, favours the delayed collapse hypothesis, which is predicted theoretically.

"If the merged neutron stars were to collapse directly to a black hole with no intermediate stage, it would be very hard to explain this X-ray excess that we see right now, because there would be no hard surface for stuff to bounce off and fly out at high velocities to create this afterglow," said Margutti, UC Berkeley associate professor of astronomy and of physics. "It would just fall in. Done. The true reason why I'm excited scientifically is the possibility that we are seeing something more than the jet. We might finally get some information about the new compact object."

Margutti and her colleagues, including first author Aprajita Hajela, who was Margutti's graduate student when she was at Northwestern University before moving to UC Berkeley, report their analysis of the X-ray afterglow in a paper recently accepted for publication in *The Astrophysical Journal Letters*.

The radioactive glow of a kilonova

Gravitational waves from the merger were first detected on Aug. 17, 2017, by the Advanced Laser Interferometer Gravitational-wave Observatory (LIGO) and the Virgo collaboration. Satellite- and ground-based telescopes quickly followed up to record a burst of gamma rays and visible and infrared emissions that together confirmed the theory that many heavy elements are produced in the aftermath of such mergers inside hot ejecta that produces a bright kilonova. The kilonova glows because of light emitted during the decay of radioactive elements, like platinum and gold, that are produced in the merger debris.

Chandra, too, pivoted to observe GW170817, but saw no X-rays until nine days later, suggesting that the merger also produced a narrow jet of material that, upon colliding with the material around the neutron stars, emitted a cone of X-rays that initially missed Earth.

Only later did the head of the jet expand and begin emitting X-rays in a broader jet visible from Earth.
The X-ray emissions from the jet increased for 160 days after the merger, after which they steadily grew fainter as the jet slowed down and expanded. But Hajela and her team noticed that from March 2020 -- about 900 days after the merger -- until the end of 2020, the decline stopped, and the X-ray emissions remained approximately constant in brightness.
"The fact that the X-rays stopped fading quickly was our best evidence yet that something in addition to a jet is being detected in X-rays in this source," Margutti said. "A completely different source of X-rays appears to be needed to explain what we're seeing."
The researchers suggest that the excess X-rays are produced by a shock wave distinct from the jets produced by the merger. This shock was a result of the delayed collapse of the merged neutron stars, likely because its rapid spin very briefly counteracted the gravitational collapse. By sticking around for an extra second, the material around the neutron stars got an extra bounce that produced a very fast tail of kilonova ejecta that created the shock.
"We think the kilonova afterglow emission is produced by shocked material in the circumbinary medium," Margutti said. "It is material that was in the environment of the two neutron stars that was shocked and heated up by the fastest edge of the kilonova ejecta, which is driving the shock wave."
The radiation is reaching us only now because it took time for the heavy kilonova ejecta to be decelerated in the low-density environment and for the kinetic energy of the ejecta to be converted into heat by shocks, she said. This is the same process that produces radio and X-rays for the jet, but because the jet is much, much lighter, it is immediately decelerated by the environment and shines in the X-ray and radio from the very earliest times.
An alternative explanation, the researchers note, is that the X-rays come from material falling towards the black hole that formed after the neutron stars merged.
"This would either be the first time we've seen a kilonova afterglow or the first time we've seen material falling onto a black hole after a neutron star merger," said co-author Joe Bright, a UC Berkeley postdoctoral researcher. "Either outcome would be extremely exciting."
Chandra is now the only observatory still able to detect light from this cosmic collision. Follow-up observations by Chandra and radio telescopes could distinguish between the alternative explanations, however. If it is a kilonova afterglow, radio emission is expected to be detected again in the next few months or years. If the X-rays are being produced by matter falling onto a newly formed black hole, then the X-ray output should stay steady or decline rapidly, and no radio emission will be detected over time.
Margutti hopes that LIGO, Virgo and other telescopes will capture gravitational waves and electromagnetic waves from more neutron star mergers so that the series of events preceding and following the merger can be pinned down more precisely and help reveal the physics of black hole formation. Until then, GW170817 is the only example available for study.
"Further study of GW170817 could have far-reaching implications," said co-author Kate Alexander, a postdoctoral researcher who also is from Northwestern University. "The detection of a kilonova afterglow would imply that the merger did not immediately produce a black hole. Alternatively, this object may offer astronomers a chance to study how matter falls onto a black hole a few years after its birth."
Margutti and her team recently announced that the Chandra telescope had detected X-rays in observations of GW170817 performed in December 2021. Analysis of that data is ongoing. No radio detection associated with the X-rays has been reported.

- NASA's Roman Mission could snap first image of a Jupiter-like world

Date: February 24, 2022
Source: NASA/Goddard Space Flight Centre

The telescope is named after Nancy Grace Roman, NASA's first Chief of Astronomy

NASA's Nancy Grace Roman Space Telescope, now under construction, will test new technologies for space-based planet hunting. The mission aims to photograph worlds and dusty disks around nearby stars

with detail up to a thousand times better than possible with other observatories.
Roman will use its Coronagraph Instrument -- a system of masks, prisms, detectors, and even self-flexing mirrors built to block out the glare from distant stars and reveal the planets in orbit around them -- to demonstrate that direct imaging technologies can perform even better in space than they have with ground-based telescopes.
"We will be able to image worlds in visible light using the Roman Coronagraph," said Rob Zellem, an astronomer at NASA's Jet Propulsion Laboratory (JPL) in Southern California who is co-leading the observation calibration plan for the instrument. JPL is building Roman's Coronagraph Instrument. "Doing so from space will help us see smaller, older, and colder planets than direct imaging usually reveals, bringing us a giant leap closer to imaging planets like Earth."

A home far away from home

Exoplanets -- planets beyond our solar system -- are so distant and dim relative to their host stars that they're practically invisible, even to powerful telescopes. That's why nearly all of the worlds discovered so far have been found indirectly through effects they have on their host stars. However, recent advancements in technology allow astronomers to actually take images of the reflected light from the planets themselves.
Analysing the colours of planetary atmospheres helps astronomers discover what the atmospheres are made of. This, in turn, can offer clues about the processes occurring on the imaged worlds that may affect their habitability. Since living things modify their environment in ways we might be able to detect, such as by producing oxygen or methane, scientists hope this research will pave the way for future missions that could reveal signs of life.
If Roman's Coronagraph Instrument successfully completes its technology demonstration phase, its polarimetry mode will allow astronomers to image the disks around stars in polarized light, familiar to many as the reflected glare blocked by polarized sunglasses. Astronomers will use polarized images to study the dust grains that make up the disks around stars, including their sizes, shapes, and possibly mineral properties. Roman may even be able to reveal structures in the disks, such as gaps created by unseen planets. These measurements will complement existing data by probing fainter dust disks orbiting nearer to their host stars than other telescopes can see.

Bridging the gap

Current direct imaging efforts are limited to enormous, bright planets. These worlds are typically super-Jupiters that are less than 100 million years old -- so young that they glow brightly thanks to heat left over from their formation, which makes them detectable in infrared light. They also tend to be very far away from their host stars because it's easier to block the star's light and see planets in more distant orbits. The Roman Coronagraph could complement other telescopes' infrared observations by imaging young super-Jupiters in visible light for the first time, according to a study by a team of scientists.
But astronomers would also like to directly image planets that are similar to our own one day -- rocky, Earth-sized planets orbiting Sun-like stars within their habitable zones, the range of orbital distances where temperatures allow liquid water to exist on a planet's surface. To do so, astronomers need to be able to see smaller, cooler, dimmer planets orbiting much closer to their host stars than current telescopes can. By photographing worlds in visible light, Roman will be able to image mature planets spanning ages up to several billion years -- something that has never been done before.
"To image Earth-like planets, we'll need 10,000 times better performance than today's instruments provide," said Vanessa Bailey, an astronomer at JPL and the instrument technologist for the Roman Coronagraph. "The Coronagraph Instrument will perform several hundred times better than current instruments, so we will be able to see Jupiter-like planets that are more than 100 million times fainter than their host stars."
A team of scientists recently simulated a promising target for Roman to image, called Upsilon Andromedae d. "This gas giant exoplanet is slightly larger than Jupiter, orbits within a Sun-like star's habitable zone, and is relatively close to Earth -- just 44 light-years away," said Prabal Saxena, an assistant research scientist at the University of Maryland, College Park and NASA's Goddard Space Flight Centre in Greenbelt, Maryland, and the lead author of a paper describing the results. "What's really exciting is that Roman may be able to help us explore hazes and clouds in Upsilon Andromedae d's atmosphere

and may even be able to act as a planetary thermometer by putting constraints on the planet's internal temperature!"

Opening a new frontier

The Coronagraph Instrument will contain several state-of-the-art components that have never flown aboard a space-based observatory before. For example, it will use specially designed coronagraph masks to block the glare from host stars but allow the light from dimmer, orbiting planets to filter through. These masks have innovative, complex shapes that block starlight more effectively than traditional masks.

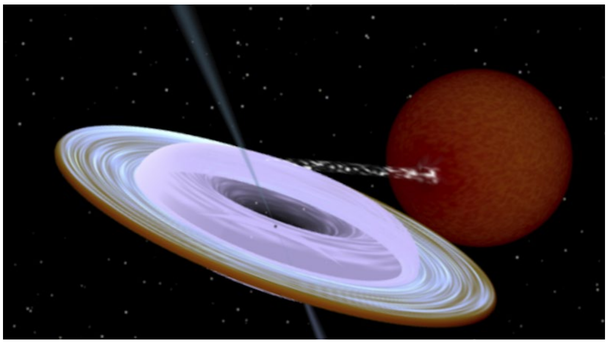
The Roman Coronagraph will also be equipped with deformable mirrors, which help counteract small imperfections that reduce image quality. These special mirrors will measure and subtract starlight in real time, and technicians on the ground can also send commands to the spacecraft to adjust them. This will help counteract effects like temperature changes, which can slightly alter the shape of the optics.

Using this technology, Roman will observe planets so faint that special detectors will count individual photons of light as they arrive, seconds or even minutes apart. No other observatory has done this kind of imaging in visible light before, providing a vital step toward discovering habitable planets and possibly learning whether we are alone in the universe.

The Nancy Grace Roman Space Telescope is managed at NASA's Goddard Space Flight Centre in Greenbelt, Maryland, with participation by NASA's Jet Propulsion Laboratory and Caltech/IPAC in Southern California, the Space Telescope Science Institute in Baltimore, and a science team comprising scientists from various research institutions. The primary industrial partners are Ball Aerospace and Technologies Corporation in Boulder, Colorado; L3Harris Technologies in Melbourne, Florida; and Teledyne Scientific & Imaging in Thousand Oaks, California.

- Death spiral: A black hole spins on its side

Date: February 25, 2022
Source: University of Turku



Artist impression of the X-ray binary system MAXI J1820+070 containing a black hole (small black dot at the centre of the gaseous disk) and a companion star. A narrow jet is directed along the black hole spin axis, which is strongly misaligned from the rotation axis of the orbit. Image produced with Binsim. CREDIT: R. Hynes

Researchers from the University of Turku, Finland, found that the axis of rotation of a black hole in a binary system is tilted more than 40 degrees relative to the axis of stellar orbit. The finding challenges current theoretical models of black hole formation.

The observation by the researchers from Tuorla Observatory in Finland is the first reliable measurement that shows a large difference between the axis of rotation of a black hole and the axis of a binary system orbit. The difference between the axes measured by the researchers in a binary star system called MAXI J1820+070 was more than 40 degrees.

Often for the space systems with smaller objects orbiting around the central massive body, the own rotation axis of this body is to a high degree aligned with the rotation axis of its satellites. This is true also for our solar system: the planets orbit around the Sun in a plane, which roughly coincides with the equatorial plane of the Sun. The inclination of the Sun rotation axis with respect to orbital axis of the Earth is only seven degrees.

"The expectation of alignment, to a large degree, does not hold for the bizarre objects such as black hole X-ray binaries. The black holes in these systems were formed as a result of a cosmic cataclysm -- the collapse of a massive star. Now we see the black hole dragging matter from the nearby, lighter companion star orbiting around it. We see bright optical and X-ray radiation as the last sigh of the infalling material, and also radio emission from the relativistic jets expelled from the system," says Juri Poutanen, Professor of Astronomy at the University of Turku and the lead author of the publication.

By following these jets, the researchers were able to determine the direction of the axis of rotation of the black hole very accurately. As the amount of gas falling from the companion

star to the black hole later began to decrease, the system dimmed, and much of the light in the system came from the companion star. In this way, the researchers were able to measure the orbit inclination using spectroscopic techniques, and it happened to nearly coincide with the inclination of the ejections.
"To determine the 3D orientation of the orbit, one additionally needs to know the position angle of the system on the sky, meaning how the system is turned with respect to the direction to the North on the sky. This was measured using polarimetric techniques," says Juri Poutanen.
The results published in the *Science* magazine open interesting prospects towards studies of black hole formation and evolution of such systems, as such extreme misalignment is hard to get in many black hole formation and binary evolution scenarios.
"The difference of more than 40 degrees between the orbital axis and the black hole spin was completely unexpected. Scientists have often assumed this difference to be very small when they have modelled the behaviour of matter in a curved time space around a black hole. The current models are already really complex, and now the new findings force us to add a new dimension to them," Poutanen states.
The key finding was made using the in-house built polarimetric instrument DIPol-UF mounted at the Nordic Optical Telescope, which is owned by the University of Turku jointly with the Aarhus University in Denmark.

- Deep neural network to find hidden turbulent motion on the sun

Date: February 25, 2022
Source: National Institutes of Natural Sciences


The team found that the AI developed by them can function rather accurately with just temperature and vertical flow data. It can accurately predict horizontal motion. (Credits: Reuters)

Scientists developed a neural network deep learning technique to extract hidden turbulent motion information from observations of the Sun. Tests on three different sets of simulation data showed that it is possible to infer the horizontal motion from data for the temperature and vertical motion. This technique will benefit solar astronomy and other fields such as plasma physics, fusion science, and fluid dynamics.
The Sun is important to the Sustainable Development Goal of Affordable and Clean Energy, both as the source of solar power and as a natural example of fusion energy. Our understanding of the Sun is limited by the data we can collect. It is relatively easy to observe the temperature and vertical motion of solar plasma, gas so hot that the component atoms break down into electrons and ions. But it is difficult to determine the horizontal motion.
To tackle this problem, a team of scientists led by the National Astronomical Observatory of Japan and the National Institute for Fusion Science created a neural network model, and fed it data from three different simulations of plasma turbulence. After training, the neural network was able to correctly infer the horizontal motion given only the vertical motion and the temperature.
The team also developed a novel coherence spectrum to evaluate the performance of the output at different size scales. This new analysis showed that the method succeeded at predicting the large-scale patterns in the horizontal turbulent motion, but had trouble with small features. The team is now working to improve the performance at small scales. It is hoped that this method can be applied to future high resolution solar observations, such as those expected from the SUNRISE-3 balloon telescope, as well as to laboratory plasmas, such as those created in fusion science research for new energy.