South Downs Mercury

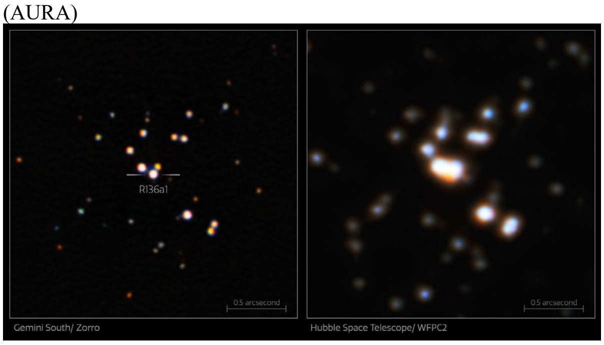
The monthly circular of South Downs Astronomical Society
Issue: 567 – September 2nd 2022 Editor: Roger Burgess
Main Speaker 19:30 19:30 Dr David Whitehouse The Alien Perspective
The meeting will be available via Zoom

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

- Seeing universe's most massive known star

Ground-breaking observation from Gemini Observatory suggests this and possibly other colossal stars are less massive than previously thought

Date: August 18, 2022
Source: Association of Universities for Research in Astronomy (AURA)



By harnessing the capabilities of the 8.1-meter Gemini South telescope in Chile, which is part of the International Gemini Observatory operated by NSF's NOIRLab, astronomers have obtained the sharpest image ever of the star R136a1, the most massive known star in the Universe. Their research, led by NOIRLab astronomer Venu M. Kalari, challenges our understanding of the most massive stars and suggests that they may not be as massive as previously thought.

Astronomers have yet to fully understand how the most massive stars -- those more than 100 times the mass of the Sun -- are formed. One particularly challenging piece of this puzzle is obtaining observations of these giants, which typically dwell in the densely populated hearts of dust-shrouded star clusters. Giant stars also live fast and die young, burning through their fuel reserves in only a few million years. In comparison, our Sun is less than halfway through its 10 billion year lifespan. The combination of densely packed stars, relatively short lifetimes, and vast astronomical distances makes distinguishing individual massive stars in clusters a daunting technical challenge.

By pushing the capabilities of the Zorro instrument on the Gemini South telescope of the International Gemini Observatory, operated by NSF's NOIRLab, astronomers have obtained the sharpest-ever image of R136a1 -- the most massive known star. This colossal star is a member of the R136 star cluster, which lies about 160,000 light-years from Earth in the centre of the Tarantula Nebula in the Large Magellanic Cloud, a dwarf companion galaxy of the Milky Way.

Previous observations suggested that R136a1 had a mass somewhere between 250 to 320 times the mass of the Sun. The new Zorro observations, however, indicate that this giant star may be only 170 to 230 times the mass of the Sun. Even with this lower estimate, R136a1 still qualifies as the most massive known star.

Astronomers are able to estimate a star's mass by comparing its observed brightness and temperature with theoretical predictions. The sharper Zorro image allowed NSF's NOIRLab astronomer Venu M. Kalari and his colleagues to more accurately separated the brightness of R136a1 from its nearby stellar companions, which led to a lower estimate of its brightness and therefore its mass.

"Our results show us that the most massive star we currently know is not as massive as we had previously thought," explained Kalari, lead author of the paper announcing this result. "This suggests that the upper limit on stellar masses may also be smaller than previously thought."

This result also has implications for the origin of elements heavier than helium in the Universe. These elements are created during the cataclysmically explosive death of stars more than 150 times the mass of the Sun in events that astronomers refer to as pair-instability supernovae. If R136a1 is less massive than previously thought, the same could be true of other massive stars and consequently pair instability supernovae may be rarer than expected.

The star cluster hosting R136a1 has previously been observed by astronomers using the NASA/ESA Hubble Space Telescope and a variety of ground-based telescopes, but none of these telescopes could obtain images sharp enough to pick out all the individual stellar members of the nearby cluster.

Gemini South's Zorro instrument was able to surpass the resolution of previous observations by using a technique known as speckle imaging, which enables ground-based telescopes to overcome much of the blurring effect of Earth's atmosphere [1]. By taking many thousands of short-exposure images of a bright object and carefully processing the data, it is possible to cancel out almost all this blurring [2]. This approach, as well as the use of adaptive optics, can dramatically increase the resolution of ground-based telescopes, as shown by the team's sharp new Zorro observations of R136a1 [3].

"This result shows that given the right conditions an 8.1-meter telescope pushed to its limits can rival not only the Hubble Space Telescope when it comes to angular resolution, but also the James Webb Space Telescope," commented Ricardo Salinas, a co-author of this paper and the instrument scientist for Zorro. "This observation pushes the boundary of what is considered possible using speckle imaging."

"We began this work as an exploratory observation to see how well Zorro could observe this type of object," concluded Kalari. "While we urge caution when interpreting our results, our observations indicate that the most massive stars may not be as massive as once thought."

Zorro and its twin instrument `Alopeke are identical imagers mounted on the Gemini South and Gemini North telescopes, respectively. Their names are the Hawaiian and Spanish words for "fox" and represent the telescopes' respective locations on Maunakea in Hawai'i and on Cerro Pachón in Chile. These instruments are part of the Gemini Observatory's Visiting Instrument Program, which enables new science by accommodating innovative instruments and enabling exciting research. Steve B. Howell, current chair of the Gemini Observatory Board and senior research scientist at the NASA Ames Research Centre in Mountain View, California, is the principal investigator on both instruments.

"Gemini South continues to enhance our understanding of the Universe, transforming astronomy as we know it. This discovery is yet another example of the scientific feats we can accomplish when we combine international collaboration, world-class infrastructure, and a stellar team," said NSF Gemini Program Officer Martin Still.

Notes

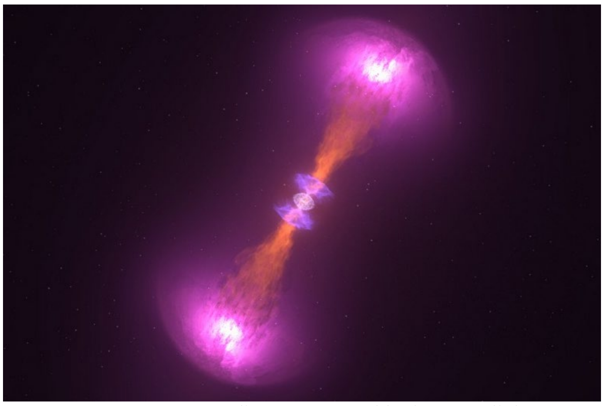
[1] The blurring effect of the atmosphere is what makes stars twinkle at night, and astronomers and engineers have devised a variety of approaches to dealing with atmospheric turbulence. As well as placing observatories at high, dry sites with stable skies, astronomers have equipped a handful of telescopes with adaptive optics systems, assemblies of computer-controlled deformable mirrors and laser guide stars that can correct for atmospheric distortion. In addition to speckle imaging, Gemini South is able to use its Gemini Multi-Conjugate Adaptive Optics System to counteract the blurring of the atmosphere.

[2] The individual observations captured by Zorro had exposure times of just 60 milliseconds, and 40,000 of these individual observations of the R136 cluster were captured over the course of 40 minutes. Each of these snapshots is so short that the atmosphere didn't have time to blur any individual exposure, and by carefully combining all 40,000 exposures the team could build up a sharp image of the cluster.

[3] When observing in the red part of the visible electromagnetic spectrum (about 832 nanometres), the Zorro instrument on Gemini South has an image resolution of about 30 milliarcseconds. This is slightly better resolution than NASA/ESA/CSA's James Webb Space Telescope and about three-times sharper resolution achieved by the Hubble Space Telescope at the same wavelength.

- Looking inside a neutron star -- new model will improve insights gleaned from gravitational waves

Date: August 18, 2022
Source: University of Birmingham


A neutron star merger. Credit: NASA's Goddard Space Flight Centre/CI Lab

The unique oscillations in binary neutron stars right before they merge could have big implications for the insights scientists can glean from gravitational wave detection. Researchers at the University of Birmingham have demonstrated the way in which these vibrations, caused by the interactions between the two stars' tidal fields as they get close together, affect gravitational-wave observations. The study is published in *Physical Review Letters.*

Taking these movements into account could make a huge difference to our understanding of the data taken by the Advanced LIGO and Virgo instruments, set up to detect gravitational waves -- ripples in time and space -- produced by the merging of black holes and neutron stars.

The researchers aim to have a new model ready for Advanced LIGO's next observing run and even more advanced models for the next generation of Advanced LIGO instruments, called A+, which are due to begin their first observing run in 2025.

Since the first gravitational waves were detected by the LIGO Scientific Collaboration and Virgo Collaboration in 2016, scientists have been focused on advancing their understanding of the massive collisions that produce these signals, including the physics of a neutron star at supra nuclear densities.

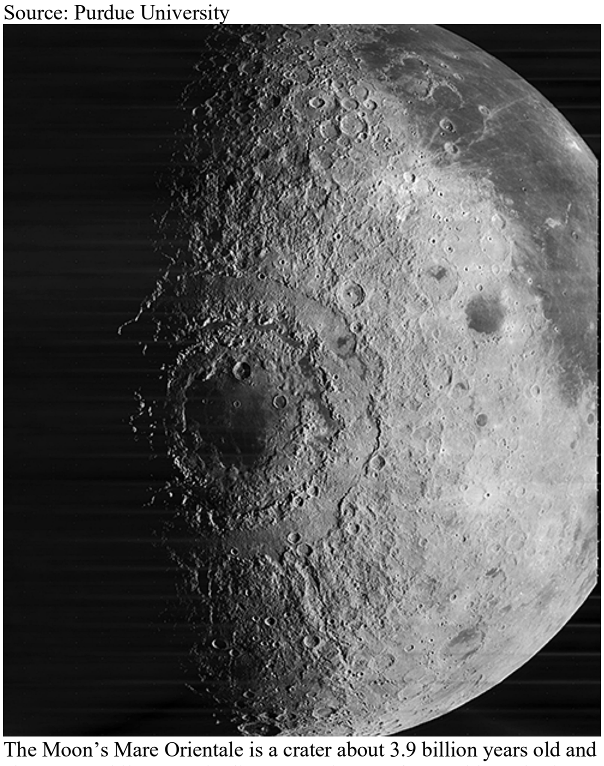
Dr Geraint Pratten, of the Institute for Gravitational Wave Astronomy at University of Birmingham, is lead-author on the paper. He said: "Scientists are now able to get lots of crucial information about neutron stars from the latest gravitational wave detections. Details such as the relationship between the star's mass and its radius, for example, provide crucial insight into fundamental physics behind neutron stars. If we neglect these additional effects, our understanding of the structure of the neutron star as a whole can become deeply biased."

Dr Patricia Schmidt, co-author on the paper and Associate Professor at the Institute for Gravitational Wave Astronomy, added: "These refinements are really important. Within single neutron stars we can start to understand what's happening deep inside the star's core, where matter exists at temperatures and densities we cannot produce in ground-based experiments. At this point we might start to see atoms interacting with each other in ways we have not yet seen -- potentially requiring new laws of physics."

The refinements devised by the team represent the latest contribution from the University of Birmingham to the Advanced LIGO programme. Researchers in the University's Institute for Gravitational Wave Astronomy have been deeply involved in design and development of the detectors since the programme's earliest stages. Looking ahead, PhD student Natalie Williams is already progressing work on calculations to further refine and calibrate the new models.

- Breaking in a new planet

Date: August 18, 2022
Source: Purdue University


The Moon’s Mare Orientale is a crater about 3.9 billion years old and about 1,000 kilometres in diameter. It is one of several large basins that account for most of the porosity of the Moon’s crust. (NASA Image)

The harder you hit something -- a ball, a walnut, a geode -- the more likely it is to break open. Or, if not break open, at least lose a little bit of its structural integrity, the way baseball players pummel new gloves to make them softer and more flexible. Cracks, massive or tiny, form and bear a silent, permanent witness to the impact.

Studying how those impacts affect planetary bodies, asteroids, moons and other rocks in space helps planetary scientists including Brandon Johnson, associate professor, and Sean Wiggins, postdoctoral researcher, in the College of Science's Department of Earth, Atmospheric, and Planetary Sciences at Purdue University, understand extraplanetary geology, especially where to look for precious matter including water, ice and even, potentially, microbial life.
Every solid body in the solar system is constantly pummelled by impacts, both large and small. Even on Earth, every single spot has been affected by at least three big impacts.
Using the moon as a test subject, Johnson, Wiggins and their team set out to quantify the relationship between impacts and a planet's porosity.
The researchers used extensive lunar gravity data and detailed modelling and found that when large objects hit the moon or any other planetary body, that impact can affect surfaces and structures, even very far away from the point of impact and deep into the planet or moon itself. This finding, detailed in their new study published in the journal *Nature Communications*, explains existing data on the moon that had puzzled scientists. The research was partially funded by funded by NASA's Lunar Data Analysis Program.
"NASA's GRAIL (Gravity Recovery and Interior Laboratory) mission measured the gravity of the moon and showed that the moon crust is very porous to very great depths," Johnson said. "We didn't have a description of how the moon would get so porous. This is the first work that really shows that large impacts are capable of fracturing the moon's crust and introducing this porosity."
Understanding where planets and moons have fractured, and why, can help direct space exploration and tell scientists where the best place to look for life might be. Anywhere that rock, water and air meet and interact, there is a potential for life.
"There's a lot to be excited about," Wiggins said. "Our data explains a mystery. This research has implications for the early Earth and for Mars. If life existed back then, there were these intermittently big impacts that would sterilize the planet and boil off the oceans. But if you had life that could survive in pores and interstices a few hundred feet or even a few miles down, it could have survived. They could have provided these refuges where life could hide out from these kinds of impacts.
"These findings have a lot of potential for directing future missions on Mars or elsewhere. It can help direct searches, tell us where to look."

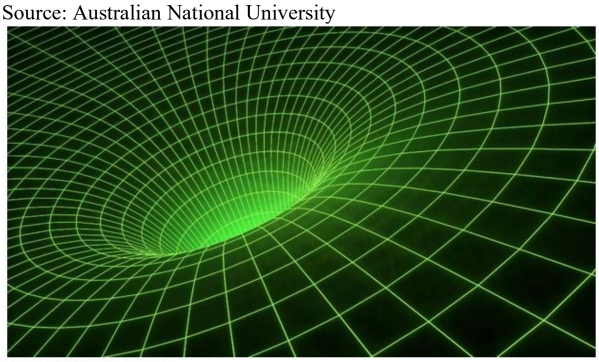
- ❖ Black hole collisions could help us measure how fast the universe is expanding

Astronomers propose 'spectral siren' method to understand evolution of the universe
Date: August 17, 2022
Source: University of Chicago
A black hole is usually where information goes to disappear -- but scientists may have found a trick to use its last moments to tell us about the history of the universe. In a new study, two University of Chicago astrophysicists laid out a method for how to use pairs of colliding black holes to measure how fast our universe is expanding -- and thus understand how the universe evolved, what it is made out of, and where it's going. In particular, the scientists think the new technique, which they call a "spectral siren," may be able to tell us about the otherwise elusive "teenage" years of the universe.
A cosmic ruler
A major ongoing scientific debate is exactly how fast the universe is expanding -- a number called the Hubble constant. The different methods available so far yield slightly different answers, and scientists are eager to find alternate ways to measure this rate. Checking the accuracy of this number is especially important because it affects our understanding of fundamental questions like the age, history and makeup of the universe.
The new study offers a way to make this calculation, using special detectors that pick up the cosmic echoes of black hole collisions.
Occasionally, two black holes will slam into each other -- an event so powerful that it literally creates a ripple in space-time that travels across the universe. Here on Earth, the U.S. Laser Interferometer Gravitational-Wave Observatory (LIGO) and the Italian observatory Virgo can pick up those ripples, which are called gravitational waves.
Over the past few years, LIGO and Virgo have collected the readings from almost 100 pairs of black holes colliding.
The signal from each collision contains information about how massive the black holes were. But the signal has been traveling across space, and during that time the

universe has expanded, which changes the properties of the signal. "For example, if you took a black hole and put it earlier in the universe, the signal would change and it would look like a bigger black hole than it really is," explained UChicago astrophysicist Daniel Holz, one of the two authors on the paper.
If scientists can figure out a way to measure how that signal changed, they can calculate the expansion rate of the universe. The problem is calibration: How do they know *how much* it changed from the original?
In their new paper, Holz and first author Jose María Ezquiaga suggest that they can use our newfound knowledge about the whole population of black holes as a calibration tool. For example, current evidence suggests that most of the detected black holes have between five and 40 times the mass of our sun. "So we measure the masses of the nearby black holes and understand their features, and then we look further away and see how much those further ones appear to have shifted," said Ezquiaga, a NASA Einstein Postdoctoral Fellow and Kavli Institute for Cosmological Physics Fellow working with Holz at UChicago. "And this gives you a measure of the expansion of the universe."
The authors dub it the "spectral siren" method, a new approach to the 'standard siren' method which Holz and collaborators have been pioneering. (The name is a reference to the 'standard candle' methods also used in astronomy.)
The scientists are excited because in the future, as LIGO's capabilities expand, the method may provide a unique window into the "teenage" years of the universe -- about 10 billion years ago -- that are hard to study with other methods.
Researchers can use the cosmic microwave background to look at the very earliest moments of the universe, and they can look around at galaxies near our own galaxy to study the universe's more recent history. But the in-between period is harder to reach, and it's an area of special scientific interest.
"It's around that time that we switched from dark matter being the predominant force in the universe to dark energy taking over, and we are very interested in studying this critical transition," said Ezquiaga.
The other advantage of this method, the authors said, is that there are fewer uncertainties created by gaps in our scientific knowledge. "By using the entire population of black holes, the method can calibrate itself, directly identifying and correcting for errors," Holz said. The other methods used to calculate the Hubble constant rely on our current understanding of the physics of stars and galaxies, which involves a lot of complicated physics and astrophysics. This means the measurements might be thrown off quite a bit if there's something we don't yet know.
By contrast, this new black hole method relies almost purely on Einstein's theory of gravity, which is well-studied and has stood up against all the ways scientists have tried to test it so far.
The more readings they have from all black holes, the more accurate this calibration will be. "We need preferably thousands of these signals, which we should have in a few years, and even more in the next decade or two," said Holz. "At that point it would be an incredibly powerful method to learn about the universe."

- Mars model provides method for landing humans on Red Planet

Date: August 17, 2022
Source: Australian National University



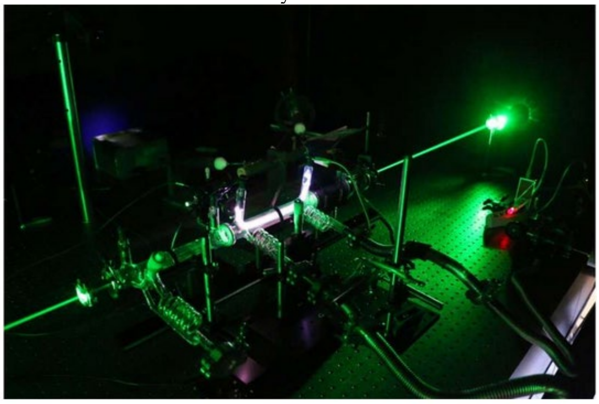
Credit: CC0 Public Domain

A mathematical model developed by space medicine experts from The Australian National University (ANU) could be used to predict whether an astronaut can safely travel to Mars and fulfil their mission duties upon stepping foot on the Red Planet.
The ANU team simulated the impact of prolonged exposure to zero gravity on the cardiovascular system to determine whether the human body can tolerate Mars' gravitational forces -- which aren't as strong as on Earth -- without fainting or suffering a medical emergency when stepping out of a spacecraft.
The model could be used to assess the impact of short and long duration space flight on the body and could serve as another important

piece of the puzzle in helping land humans on Mars.
Dr Lex van Loon, a Research Fellow from the ANU Medical School, said although there are multiple risks associated with travelling to Mars, the biggest concern is prolonged exposure to microgravity -- near zero gravity -- which, combined with exposure to damaging radiation from the Sun, could cause "fundamental" changes to the body.
"We know it takes about six to seven months to travel to Mars and this could cause the structure of your blood vessels or the strength of your heart to change due to the weightlessness experienced as a result of zero gravity space travel," Dr van Loon, who is also the lead author of the paper, said.
"With the rise of commercial space flight agencies like Space X and Blue Origin, there's more room for rich but not necessarily healthy people to go into space, so we want to use mathematical models to predict whether someone is fit to fly to Mars."
Astrophysicist and emergency medicine registrar Dr Emma Tucker said prolonged exposure to zero gravity can cause the heart to become lazy because it doesn't have to work as hard to overcome gravity in order to pump blood around the body.
"When you're on Earth, gravity is pulling fluid to the bottom half of our body, which is why some people find their legs begin to swell up toward the end of the day. But when you go into space that gravitational pull disappears, which means the fluid shifts to the top half of your body and that triggers a response that fools the body into thinking there's too much fluid," Dr Tucker said.
"As a result, you start going to the toilet a lot, you start getting rid of extra fluid, you don't feel thirsty and you don't drink as much, which means you become dehydrated in space.
"This is why you might see astronauts on the news faint when they step foot on Earth again. This is quite a common occurrence as a result of space travel, and the longer you're in space the more likely you are to collapse when you return to gravity.
"The purpose of our model is to predict, with great accuracy, whether an astronaut can safely arrive on Mars without fainting. We believe it's possible."
Due to a communication delay in relaying messages between Mars and Earth, astronauts must be able to out their duties without receiving immediate assistance from support crews. Dr van Loon said this window of radio silence differs depending on the alignment of the Sun, Earth and Mars in its orbit, but could last for at least 20 minutes.
"If an astronaut faints when they first step out of the spacecraft or if there's a medical emergency, they'll be nobody on Mars to help them," Dr van Loon said.
"This is why we must be absolutely certain the astronaut is fit to fly and can adapt to Mars' gravitational field. They must be able to operate effectively and efficiently with minimal support during those crucial first few minutes."
The model uses an algorithm based on astronaut data collected from past space expeditions, including the Apollo Missions, to simulate the risks involved with travelling to Mars.
Although the space data used to inform the parameters of the model is derived from middle-aged and well-trained astronauts, the researchers hope to expand its capabilities by simulating the impact of prolonged space travel on relatively unhealthy individuals with pre-existing heart conditions. This would provide the researchers with a more holistic picture of what would happen if an "everyday" person was to travel into space.

- Harvesting resources on Mars with plasmas

A plasma-based method may one day convert carbon dioxide into oxygen and produce fuels, fertilizers on the red planet
Date: August 16, 2022
Source: American Institute of Physics



Carbon dioxide plasma created at the Laboratoire de Physique des Plasma...

An international team of researchers came up with a plasma-based way to produce and separate oxygen within the Martian environment. It's a complementary approach to NASA's Mars Oxygen In-Situ Resource Utilization Experiment, and it may deliver

high rates of molecule production per kilogram of instrumentation sent to space. Such a system could play a critical role in the development of life-support systems on Mars and the feedstock and base chemicals necessary for processing fuels, building materials, and fertilizers.
In the *Journal of Applied Physics*, from AIP Publishing, the team from the University of Lisbon, the Massachusetts Institute of Technology, Sorbonne University, Eindhoven University of Technology, and the Dutch Institute for Fundamental Energy Research presented a method for harnessing and processing local resources to generate products on Mars. Natural conditions on the red planet are nearly ideal for in situ resource utilization by plasmas, since the atmosphere is primarily formed by carbon dioxide that can be split to produce oxygen and its pressure is favourable for plasma ignition.
Two big hurdles stand in the way of producing oxygen on Mars.
"First, the decomposition of carbon dioxide molecules to extract oxygen. It's a very difficult molecule to break," said author Vasco Guerra, of the University of Lisbon. "Second, the separation of the produced oxygen from a gas mixture that also contains, for example, carbon dioxide and carbon monoxide. We're looking at these two steps in a holistic way to solve both challenges at the same time. This is where plasmas can help."
Plasma is the fourth natural state of matter, and it contains free charged particles, such as electrons and ions. Electrons are light and easily accelerated up to very high energies with electric fields.
"When bulletlike electrons collide with a carbon dioxide molecule, they can directly decompose it or transfer energy to make it vibrate," Guerra said. "This energy can be channelled, to a large extent, into carbon dioxide decomposition. Together with our colleagues in France and the Netherlands, we experimentally demonstrated the validity of these theories. Moreover, the heat generated in the plasma is also beneficial for the separation of oxygen."
Oxygen is key to creating a breathable environment, as well as the starting point to produce fuels and fertilizers for future Martian agriculture. Local production of fuels will be important for future missions. All are essential for future human settlement on Mars.
By dissociating carbon dioxide molecules to produce green fuels and recycle chemicals, the plasma technology may also aid in addressing climate change on Earth.

- ESO telescope images a spectacular cosmic dance

Date: August 17, 2022
Source: ESO

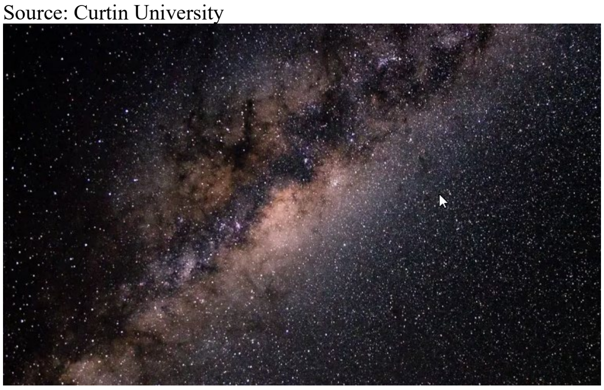
Galaxy NGC 7727 was born from the merger of two galaxies

ESO's Very Large Telescope (VLT) has imaged the result of a spectacular cosmic collision -- the galaxy NGC 7727. This giant was born from the merger of two galaxies, an event that started around a billion years ago. At its centre lies the closest pair of supermassive black holes ever found, two objects that are destined to coalesce into an even more massive black hole.
Just as you may bump into someone on a busy street, galaxies too can bump into each other. But while galactic interactions are much more violent than a bump on a busy street, individual stars don't generally collide since, compared to their sizes, the distances between them are very large. Rather, the galaxies dance around each other, with gravity creating tidal forces that dramatically change the look of the two dance partners. 'Tails' of stars, gas and dust are spun around the galaxies as they eventually form a new, merged galaxy, resulting in the disordered and beautifully asymmetrical shape that we see in NGC 7727.
The consequences of this cosmic bump are spectacularly evident in this image of the galaxy, taken with the FOcal Reducer and low dispersion Spectrograph 2 (FORS2) instrument at ESO's VLT. While the galaxy was previously captured by another ESO telescope, this new image shows more

intricate details both within the main body of the galaxy and in the faint tails around it.
In this ESO VLT image we see the tangled trails created as the two galaxies merged, stripping stars and dust from each other to create the spectacular long arms embracing NGC 7727. Parts of these arms are dotted with stars, which appear as bright blue-purplish spots in this image.
Also visible in this image are two bright points at the centre of the galaxy, another tell-tale sign of its dramatic past. The core of NGC 7727 still consists of the original two galactic cores, each hosting a supermassive black hole. Located about 89 million light-years away from Earth, in the constellation of Aquarius, this is the closest pair of supermassive black holes to us.
The black holes in NGC 7727 are observed to be just 1600 light-years apart in the sky and are expected to merge within 250 million years, the blink of an eye in astronomical time. When the black holes merge they will create an even more massive black hole.
The search for similarly hidden supermassive black hole pairs is expected to make a great leap forward with ESO's upcoming Extremely Large Telescope (https://elt.eso.org/) (ELT), set to start operating later this decade in Chile's Atacama Desert. With the ELT, we can expect many more of these discoveries at the centres of galaxies.
Our home galaxy, which also sports a supermassive black hole at its centre, is on a path to merge with our closest large neighbour, the Andromeda Galaxy, billions of years from now. Perhaps the resulting galaxy will look something similar to the cosmic dance we see in NGC 7727, so this image could be giving us a glimpse into the future.

- Comet impacts formed continents when Solar System entered arms of Milky Way

Date: August 24, 2022
Source: Curtin University



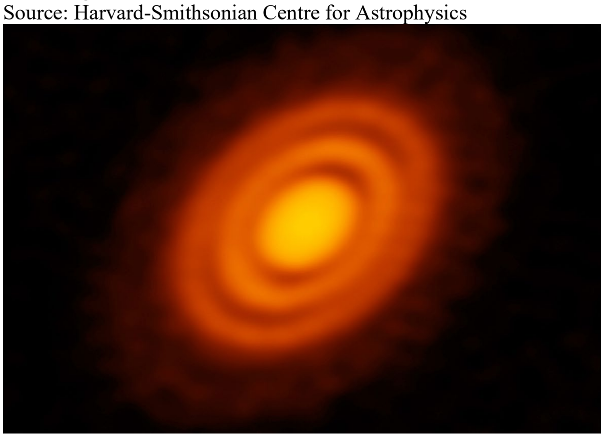
New Curtin research has found evidence that Earth's early continents resulted from being hit by comets as our Solar System passed into and out of the spiral arms of the Milky Way Galaxy, turning traditional thinking about our planet's formation on its head.
The new research, published in *Geology*, challenges the existing theory that Earth's crust was solely formed by processes inside our planet, casting a new light on the formative history of Earth and our place in the cosmos.
Lead researcher Professor Chris Kirkland, from the Timescales of Mineral Systems Group within Curtin's School of Earth and Planetary Sciences, said studying minerals in the Earth's crust revealed a rhythm of crust production every 200 million years or so that matched our Solar System's transit through areas of the galaxy with a higher density of stars.
"The Solar System orbits around the Milky Way, passing between the spiral arms of the galaxy approximately every 200 million years," Professor Kirkland said.
"From looking at the age and isotopic signature of minerals from both the Pilbara Craton in Western Australia and North Atlantic Craton in Greenland, we see a similar rhythm of crust production, which coincides with periods during which the Solar System journeyed through areas of the galaxy most heavily populated by stars."
"When passing through regions of higher star density, comets would have been dislodged from the most distant reaches of the Solar System, some of which impacted Earth.
"Increased comet impact on Earth would have led to greater melting of the Earth's surface to produce the buoyant nuclei of the early continents."
Professor Kirkland said the findings challenged the existing theory that crust production was entirely related to processes internal to the Earth.
"Our study reveals an exciting link between geological processes on Earth and the movement of the Solar System in our galaxy," Professor Kirkland said.
"Linking the formation of continents, the landmasses on which we all live and where we find the majority of our mineral resources, to the passage of the Solar System through the Milky Way casts a whole new light on the formative history of our planet and its place in the cosmos."

Professor Kirkland is affiliated with The Institute for Geoscience Research (TIGeR), Curtin's flagship Earth Sciences research institute.

Also contributing to the study were researchers from the University of Lincoln, the Astromaterials Research and Exploration Science Division within NASA's Johnson Space Centre and the Geological Survey of Western Australia.

- Case solved: Missing carbon monoxide found hiding in the ice

Date: August 22, 2022
Source: Harvard-Smithsonian Centre for Astrophysics



Astronomers frequently observe carbon monoxide in planetary nurseries. The compound is ultra-bright and extremely common in protoplanetary disks -- regions of dust and gas where planets form around young stars -- making it a prime target for scientists.

But for the last decade or so, something hasn't been adding up when it comes to carbon monoxide observations, says Diana Powell, a NASA Hubble Fellow at the Centre for Astrophysics | Harvard & Smithsonian.

A huge chunk of carbon monoxide is missing in all observations of disks, if astronomers' current predictions of its abundance are correct.

Now, a new model -- validated by observations with ALMA -- has solved the mystery: carbon monoxide has been hiding in ice formations within the disks. The findings are described today in the journal *Nature Astronomy*.

"This may be one of the biggest unsolved problems in planet-forming disks," says Powell, who led the study. "Depending on the system observed, carbon monoxide is three to 100 times less than it should be; it's off by a really huge amount."

And carbon monoxide inaccuracies could have huge implications for the field of astrochemistry.

"Carbon monoxide is essentially used to trace everything we know about disks -- like mass, composition and temperature," Powell explains. "This could mean many of our results for disks have been biased and uncertain because we don't understand the compound well enough."

Intrigued by the mystery, Powell put on her detective hat and leaned on her expertise in the physics behind phase changes -- when matter morphs from one state to another, like a gas changing into a solid.

On a hunch, Powell made alterations to an astrophysical model that's currently used to study clouds on exoplanets, or planets beyond our solar system.

"What's really special about this model is that it has detailed physics for how ice forms on particles," she explains. "So how ice nucleates onto small particles and then how it condenses. The model carefully tracks where ice is, on what particle it's located on, how big the particles are, how small they are and then how they move around."

Powell applied the adapted model to planetary disks, hoping to generate an in-depth understanding of how carbon monoxide evolves over time in planetary nurseries. To test the model's validity, Powell then compared its output to real ALMA observations of carbon monoxide in four well-studied disks -- TW Hya, HD 163296, DM Tau and IM Lup.

The results and models worked really well, Powell says.

The new model lined up with each of the observations, showing that the four disks weren't actually missing carbon monoxide at all -- it had just morphed into ice, which is currently undetectable with a telescope.

Radio observatories like ALMA allow astronomers to view carbon monoxide in space in its gas phase, but ice is much harder to detect with current technology, especially large formations of ice, Powell says.

The model shows that unlike previous thinking, carbon monoxide is forming on large particles of ice -- especially after one million years. Prior to a million years, gaseous carbon monoxide is abundant and detectable in disks.

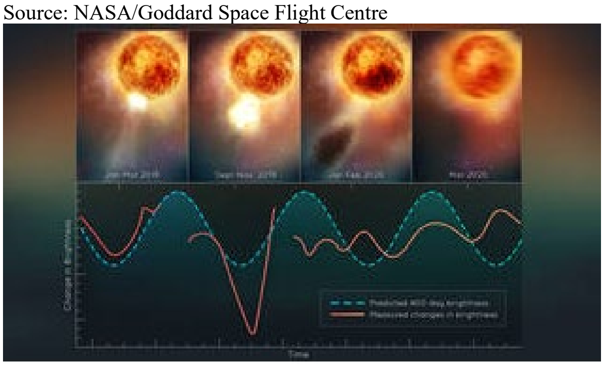
"This changes how we thought ice and gas were distributed in disks," Powell says. "It also shows that detailed modelling like this is important to understand the fundamentals of these environments."

Powell hopes her model can be further validated using observations with NASA's Webb Telescope -- which may be powerful enough to finally detect ice in disks, but that remains to be seen.
Powell, who loves phase changes and the complicated processes behind them, says she is in awe of their influence. "Small-scale ice formation physics influences disk formation and evolution -- now that's really cool."

- Hubble sees red supergiant star Betelgeuse slowly recovering after blowing its top

Analysing data from NASA's Hubble Space Telescope and several other observatories, astronomers have concluded that the bright red supergiant star Betelgeuse quite literally blew its top in 2019

Date: August 11, 2022
Source: NASA/Goddard Space Flight Centre



This illustration plots changes in the brightness of the red supergiant star Betelgeuse, following the titanic mass ejection of a large piece of its visible surface. The escaping material cooled to form a cloud of dust that temporarily made the star look dimmer, as seen from Earth. This unprecedented stellar convulsion disrupted the monster star's 400-day-long oscillation period that astronomers had measured for more than 200 years. The interior may now be jiggling like a plate of gelatine dessert.
Credits: NASA, ESA, Elizabeth Wheatley (STScI)

The star Betelgeuse appears as a brilliant, ruby-red, twinkling spot of light in the upper right shoulder of the winter constellation Orion the Hunter. But when viewed close up, astronomers know it as a seething monster with a 400-day-long heartbeat of regular pulsations. This aging star is classified as a supergiant because it has swelled up to an astonishing diameter of approximately 1 billion miles. If placed at the centre of our solar system it would reach out to the orbit of Jupiter. The star's ultimate fate is to explode as a supernova. When that eventually happens it will be briefly visible in the daytime sky from Earth. But there are a lot of fireworks going on now before the final detonation.
Astronomers using Hubble and other telescopes have deduced that the star blew off a huge piece of its visible surface in 2019. This has never before been seen on a star. Our petulant Sun routinely goes through mass ejections of its outer atmosphere, the corona. But those events are orders of magnitude weaker than what was seen on Betelgeuse.
The first clue came when the star mysteriously darkened in late 2019. An immense cloud of obscuring dust formed from the ejected surface as it cooled. Astronomers have now pieced together a scenario for the upheaval. And the star is still slowly recovering; the photosphere is rebuilding itself. And the interior is reverberating like a bell that has been hit with a sledgehammer, disrupting the star's normal cycle. This doesn't mean the monster star is going to explode any time soon, but the late-life convulsions may continue to amaze astronomers.
Analysing data from NASA's Hubble Space Telescope and several other observatories, astronomers have concluded that the bright red supergiant star Betelgeuse quite literally blew its top in 2019, losing a substantial part of its visible surface and producing a gigantic Surface Mass Ejection (SME). This is something never before seen in a normal star's behaviour.
Our Sun routinely blows off parts of its tenuous outer atmosphere, the corona, in an event known as a Coronal Mass Ejection (CME). But the Betelgeuse SME blasted off 400 billion times as much mass as a typical CME!
The monster star is still slowly recovering from this catastrophic upheaval. "Betelgeuse continues doing some very unusual things right now; the interior is sort of bouncing," said Andrea Dupree of the Centre for Astrophysics | Harvard & Smithsonian in Cambridge, Massachusetts.
These new observations yield clues as to how red stars lose mass late in their lives as their nuclear fusion furnaces burn out, before exploding as supernovae. The amount of mass loss significantly affects their fate. However, Betelgeuse's surprisingly petulant behaviour is not evidence the star is about to blow up anytime soon. So the mass loss event is not necessarily the signal of an imminent explosion.
Dupree is now pulling together all the puzzle pieces of the star's petulant behaviour before, after, and during the eruption into a coherent story of a never-before-seen titanic convulsion in an aging star.

This includes new spectroscopic and imaging data from the STELLA robotic observatory, the Fred L. Whipple Observatory's Tillinghast Reflector Echelle Spectrograph (TRES), NASA's Solar Terrestrial Relations Observatory spacecraft (STEREO-A), NASA's Hubble Space Telescope, and the American Association of Variable Star Observers (AAVSO). Dupree emphasizes that the Hubble data was pivotal to helping sort out the mystery.
"We've never before seen a huge mass ejection of the surface of a star. We are left with something going on that we don't completely understand. It's a totally new phenomenon that we can observe directly and resolve surface details with Hubble. We're watching stellar evolution in real time."
The titanic outburst in 2019 was possibly caused by a convective plume, more than a million miles across, bubbling up from deep inside the star. It produced shocks and pulsations that blasted off the chunk of the photosphere leaving the star with a large cool surface area under the dust cloud that was produced by the cooling piece of photosphere. Betelgeuse is now struggling to recover from this injury.
Weighing roughly several times as much as our Moon, the fractured piece of photosphere sped off into space and cooled to form a dust cloud that blocked light from the star as seen by Earth observers. The dimming, which began in late 2019 and lasted for a few months, was easily noticeable even by backyard observers watching the star change brightness. One of the brightest stars in the sky, Betelgeuse is easily found in the right shoulder of the constellation Orion.
Even more fantastic, the supergiant's 400-day pulsation rate is now gone, perhaps at least temporarily. For almost 200 years astronomers have measured this rhythm as evident in changes in Betelgeuse's brightness variations and surface motions. Its disruption attests to the ferocity of the blowout.
The star's interior convection cells, which drive the regular pulsation may be sloshing around like an imbalanced washing machine tub, Dupree suggests. TRES and Hubble spectra imply that the outer layers may be back to normal, but the surface is still bouncing like a plate of gelatine dessert as the photosphere rebuilds itself.
Though our Sun has coronal mass ejections that blow off small pieces of the outer atmosphere, astronomers have never witnessed such a large amount of a star's visible surface get blasted into space. Therefore, surface mass ejections and coronal mass ejections may be different events.
Betelgeuse is now so huge now that if it replaced the Sun at the centre of our solar system, its outer surface would extend past the orbit of Jupiter. Dupree used Hubble to resolve hot spots on the star's surface in 1996. This was the first direct image of a star other than the Sun.
NASA's Webb Space Telescope may be able to detect the ejected material in infrared light as it continues moving away from the star.

- Astronomers confirm star wreck as source of extreme cosmic particles

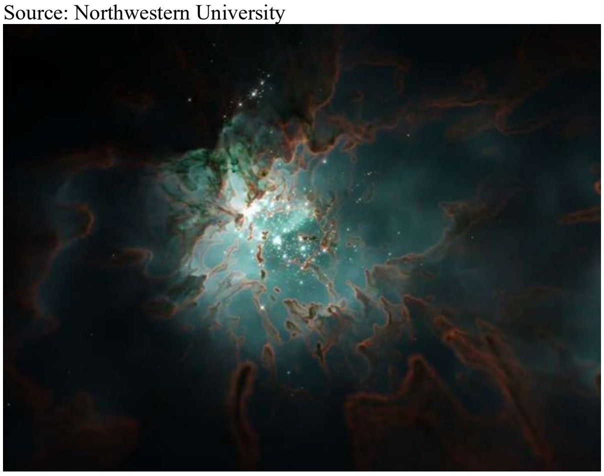
Date: August 11, 2022
Source: NASA/Goddard Space Flight Centre

Astronomers have long sought the launch sites for some of the highest-energy protons in our galaxy. Now a study using 12 years of data from NASA's Fermi Gamma-ray Space Telescope confirms that one supernova remnant is just such a place.
Fermi has shown that the shock waves of exploded stars boost particles to speeds comparable to that of light. Called cosmic rays, these particles mostly take the form of protons, but can include atomic nuclei and electrons. Because they all carry an electric charge, their paths become scrambled as they whisk through our galaxy's magnetic field. Since we can no longer tell which direction they originated from, this masks their birthplace. But when these particles collide with interstellar gas near the supernova remnant, they produce a tell-tale glow in gamma rays -- the highest-energy light there is.
"Theorists think the highest-energy cosmic ray protons in the Milky Way reach a million billion electron volts, or PeV energies," said Ke Fang, an assistant professor of physics at the University of Wisconsin, Madison. "The

precise nature of their sources, which we call PeVatrons, has been difficult to pin down."
Trapped by chaotic magnetic fields, the particles repeatedly cross the supernova's shock wave, gaining speed and energy with each passage. Eventually, the remnant can no longer hold them, and they zip off into interstellar space.
Boosted to some 10 times the energy mustered by the world's most powerful particle accelerator, the Large Hadron Collider, PeV protons are on the cusp of escaping our galaxy altogether.
Astronomers have identified a few suspected PeVatrons, including one at the centre of our galaxy. Naturally, supernova remnants top the list of candidates. Yet out of about 300 known remnants, only a few have been found to emit gamma rays with sufficiently high energies.
One particular star wreck has commanded a lot of attention from gamma-ray astronomers. Called G106.3+2.7, it's a comet-shaped cloud located about 2,600 light-years away in the constellation Cepheus. A bright pulsar caps the northern end of the supernova remnant, and astronomers think both objects formed in the same explosion.
Fermi's Large Area Telescope, its primary instrument, detected billion-electron-volt (GeV) gamma rays from within the remnant's extended tail. (For comparison, visible light's energy measures between about 2 and 3 electron volts.) The Very Energetic Radiation Imaging Telescope Array System (VERITAS) at the Fred Lawrence Whipple Observatory in southern Arizona recorded even higher-energy gamma rays from the same region. And both the High-Altitude Water Cherenkov Gamma-Ray Observatory in Mexico and the Tibet AS-Gamma Experiment in China have detected photons with energies of 100 trillion electron volts (TeV) from the area probed by Fermi and VERITAS.
"This object has been a source of considerable interest for a while now, but to crown it as a PeVatron, we have to prove its accelerating protons," explained co-author Henrike Fleischhack at the Catholic University of America in Washington and NASA's Goddard Space Flight Centre in Greenbelt, Maryland. "The catch is that electrons accelerated to a few hundred TeV can produce the same emission. Now, with the help of 12 years of Fermi data, we think we've made the case that G106.3+2.7 is indeed a PeVatron."
A paper detailing the findings, led by Fang, was published Aug. 10 in the journal *Physical Review Letters.*
The pulsar, J2229+6114, emits its own gamma rays in a lighthouse-like beacon as it spins, and this glow dominates the region to energies of a few GeV. Most of this emission occurs in the first half of the pulsar's rotation. The team effectively turned off the pulsar by analysing only gamma rays arriving from the latter part of the cycle. Below 10 GeV, there is no significant emission from the remnant's tail.
Above this energy, the pulsar's interference is negligible and the additional source becomes readily apparent. The team's detailed analysis overwhelmingly favours PeV protons as the particles driving this gamma-ray emission.
"So far, G106.3+2.7 is unique, but it may turn out to be the brightest member of a new population of supernova remnants that emit gamma rays reaching TeV energies," Fang notes. "More of them may be revealed through future observations by Fermi and very-high-energy gamma-ray observatories."
Video: https://youtu.be/oYm-0MX_3HE

- ❖ Stars determine their own masses

Simulations show why stars formed in different environments have similar masses
Date: August 9, 2022
Source: Northwestern University



Simulation of a star-forming region, where massive stars destroy their parent cloud. Credit: STARFORGE

Last year, a team of astrophysicists including key members from Northwestern University launched STARFORGE, a project that produces the most realistic, highest-resolution 3D simulations of star formation to date.
Now, the scientists have used the highly detailed simulations to uncover what determines the masses of stars, a mystery that has captivated astrophysicists for decades.
In a new study, the team discovered that star formation is a self-regulatory process. In other

words, stars themselves set their own masses. This helps explain why stars formed in disparate environments still have similar masses. The new finding may enable researchers to better understand star formation within our own Milky Way and other galaxies.

The study was published last week in the *Monthly Notices of the Royal Astronomical Society*. The collaborative team included experts from Northwestern, University of Texas at Austin (UT Austin), Carnegie Observatories, Harvard University and the California Institute of Technology. The lead author of the new study is Dávid Guszejnov, a postdoctoral fellow at UT Austin.

"Understanding the stellar initial mass function is such an important problem because it impacts astrophysics across the board -- from nearby planets to distant galaxies," said Northwestern's Claude-André Faucher-Giguère, a study co-author. "This is because stars have relatively simple DNA. If you know the mass of a star, then you know most things about the star: how much light it emits, how long it will live and what will happen to it when it dies. The distribution of stellar masses is thus critical for whether planets that orbit stars can potentially sustain life, as well as what distant galaxies look like."

Faucher-Giguère is an associate professor of physics and astronomy in Northwestern's Weinberg College of Arts and Sciences and a member of the Centre for Interdisciplinary Exploration and Research in Astrophysics (CIERA).

Outer space is filled with giant clouds, consisting of cold gas and dust. Slowly, gravity pulls far-flung specks of this gas and dust toward each other to form dense clumps. Materials in these clumps fall inward, crashing and sparking heat to create a new born star.

Surrounding each of these "protostars" is a rotating disk of gas and dust. Every planet in our solar system was once specks in such a disk around our new born sun. Whether or not planets orbiting a star could host life is dependent on the mass of the star and how it formed. Therefore, understanding star formation is crucial to determining where life can form in the universe.

"Stars are the atoms of the galaxy," said Stella Offner, associate professor of astronomy at UT Austin. "Their mass distribution dictates whether planets will be born and if life might develop."

Every subfield in astronomy depends on the mass distribution of stars -- or initial mass function (IMF) -- which has proved challenging for scientists to model correctly. Stars much bigger than our sun are rare, making up only 1% of new born stars. And, for every one of these stars there are up to 10 sun-like stars and 30 dwarf stars. Observations found that no matter where we look in the Milky Way these ratios (i.e., the IMF) are the same, for both newly formed star clusters and for those that are billions of years old.

This is the mystery of the IMF. Every population of stars in our galaxy, and in all the dwarf galaxies that surround us, has this same balance -- even though their stars were born under wildly different conditions over billions of years. In theory, the IMF should vary dramatically, but it is virtually universal, which has puzzled astronomers for decades.

"For a long time, we have been asking why," Guszejnov said. "Our simulations followed stars from birth to the natural endpoint of their formation to solve this mystery."

The new simulations, however, showed that stellar feedback, in an effort to oppose gravity, pushes stellar masses toward the same mass distribution. These simulations are the first to follow the formation of individual stars in a collapsing giant cloud, while also capturing how these newly formed stars interact with their surroundings by giving off light and shedding mass via jets and winds -- a phenomenon referred to as "stellar feedback."

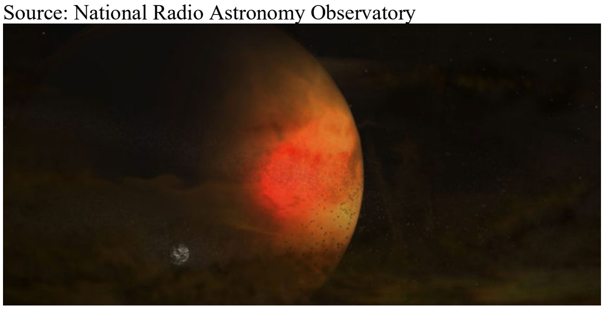
The STARFORGE project is a multi-institutional initiative, co-led by Guszejnov and Michael Grudić of Carnegie Observatories. Grudić was a CIERA postdoctoral fellow at Northwestern when the project was initiated. STARFORGE simulations are the first to simultaneously model star formation, evolution and dynamics while accounting for stellar feedback, including jets, radiation, wind and nearby supernovae activity. While other simulations have incorporated individual types of stellar feedback, STARFORGE puts them all together to simulate how these various processes interact to affect star formation.

The collaboration is funded by the National Science Foundation, NASA, the Research Corporation for Science Advancement, the

Extreme Science and Engineering Discovery Environment, CIERA and Harvard's Institute for Theory and Computation. Research was completed on two supercomputers at UT Austin's Texas Advanced Computing Centre. Video: https://youtu.be/XaZp0prvWGU

- Planet formation: ALMA detects gas in a circumplanetary disk

Date: August 9, 2022
Source: National Radio Astronomy Observatory



Scientists using the Atacama Large Millimetre/submillimetre Array (ALMA) -- in which the National Radio Astronomy Observatory (NRAO) is a partner -- to study planet formation have made the first-ever detection of gas in a circumplanetary disk. What's more, the detection also suggests the presence of a very young exoplanet. The results of the research are published in *The Astrophysical Journal Letters*.
Circumplanetary disks are an amassing of gas, dust, and debris around young planets. These disks give rise to moons and other small, rocky objects, and control the growth of young, giant planets. Studying these disks in their earliest stages may help shed light on the formation of our own Solar System, including that of Jupiter's Galilean moons, which scientists believe formed in a circumplanetary disk of Jupiter around 4.5 billion years ago.
While studying AS 209 -- a young star located roughly 395 light-years from Earth in the constellation Ophiuchus -- scientists observed a blob of emitted light in the middle of an otherwise empty gap in the gas surrounding the star. That led to the detection of the circumplanetary disk surrounding a potential Jupiter-mass planet. Scientists are watching the system closely, both because of the planet's distance from its star and the star's age. The exoplanet is located more than 200 astronomical units, or 18.59 billion miles, away from the host star, challenging currently accepted theories of planet formation. And if the host star's estimated age of just 1.6 million years holds true, this exoplanet could be one of the youngest ever detected. Further study is needed, and scientists hope that upcoming observations with the James Webb Space Telescope will confirm the planet's presence.
"The best way to study planet formation is to observe planets while they're forming. We are living in a very exciting time when this happens thanks to powerful telescopes, such as ALMA and JWST," said Jaehan Bae, a professor of astronomy at the University of Florida and the lead author of the paper.
Scientists have long suspected the presence of circumplanetary disks around exoplanets, but until recently were unable to prove it. In 2019, ALMA scientists made the first-ever detection of a circumplanetary, moon-forming disk while observing the young exoplanet PDS 70c, and confirmed the find in 2021. The new observations of gas in a circumplanetary disk at AS 209 may shed further light on the development of planetary atmospheres and the processes by which moons are formed.
The National Radio Astronomy Observatory is a facility of the National Science Foundation, operated under cooperative agreement by Associated Universities, Inc.

- Signs of disturbance in nearby dwarf galaxies indicate an alternative gravity theory

Date: August 5, 2022
Source: University of Bonn

Dwarf galaxies are small, faint galaxies that can usually be found in galaxy clusters or near larger galaxies. Because of this, they might be affected by the gravitational effects of their larger companions. "We introduce an innovative way of testing the standard model based on how much dwarf galaxies are disturbed by gravitational ‚tides' from nearby larger galaxies," said Elena Asencio, a PhD student at the University of Bonn and the lead author of the story. Tides arise when gravity from one body pulls differently on different parts of another body. These are similar to tides on Earth, which arise because the moon pulls more strongly on the side of Earth which faces the moon.
The Fornax Cluster has a rich population of dwarf galaxies. Recent observations show that some of these dwarfs appear distorted, as if they have been perturbed by the cluster environment. "Such perturbations in the Fornax dwarfs are not expected according to the Standard Model," said Pavel Kroupa, Professor at the University of Bonn and Charles University in Prague. "This is because, according to the standard model, the

dark matter halos of these dwarfs should partly shield them from tides raised by the cluster."

The authors analysed the expected level of disturbance of the dwarfs, which depends on their internal properties and their distance to the gravitationally powerful cluster centre. Galaxies with large sizes but low stellar masses and galaxies close to the cluster centre are more easily disturbed or destroyed. They compared the results with their observed level of disturbance evident from photographs taken by the VLT Survey Telescope of the European Southern Observatory.

"The comparison showed that, if one wants to explain the observations in the standard model" - said Elena Asencio - "the Fornax dwarfs should already be destroyed by gravity from the cluster centre even when the tides it raises on a dwarf are sixty-four times weaker than the dwarf's own self-gravity." Not only is this counter-intuitive, she said, it also contradicts previous studies, which found that the external force needed to disturb a dwarf galaxy is about the same as the dwarf's self-gravity.

Contradiction to the standard model

From this, the authors concluded that, in the standard model, it is not possible to explain the observed morphologies of the Fornax dwarfs in a self-consistent way. They repeated the analysis using Milgromian dynamics (MOND). Instead of assuming dark matter halos surrounding galaxies, the MOND theory proposes a correction to Newtonian dynamics by which gravity experiences a boost in the regime of low accelerations.

"We were not sure that the dwarf galaxies would be able to survive the extreme environment of a galaxy cluster in MOND, due to the absence of protective dark matter halos in this model - admitted Dr Indranil Banik from the University of St Andrews - "but our results show a remarkable agreement between observations and the MOND expectations for the level of disturbance of the Fornax dwarfs."

"It is exciting to see that the data we obtained with the VLT survey telescope allowed such a thorough test of cosmological models," said Aku Venhola from the University of Oulu (Finland) and Steffen Mieske from the European Southern Observatory, co-authors of the study.

This is not the first time that a study testing the effect of dark matter on the dynamics and evolution of galaxies concluded that observations are better explained when they are not surrounded by dark matter. "The number of publications showing incompatibilities between observations and the dark matter paradigm just keeps increasing every year. It is time to start investing more resources into more promising theories," said Pavel Kroupa, member of the Transdisciplinary Research Areas "Modelling" and "Matter" at the University of Bonn.

Dr. Hongsheng Zhao from the University of St Andrews added: "Our results have major implications for fundamental physics. We expect to find more disturbed dwarfs in other clusters, a prediction which other teams should verify."

Participating institutions and funding:

In addition to the University of Bonn, the study involved the University of Saint Andrews (Scotland), the European Southern Observatory (ESO), the University of Oulu (Finland), and Charles University in Prague (Czech Republic). The study was supported by the University of Bonn, the UK Science and Technology Facilities Council and the German Academic Exchange Service.