South Downs Mercury

The monthly circular of South Downs Astronomical Society
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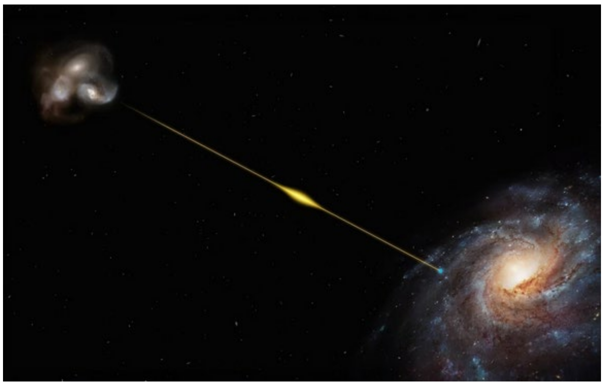
Main Talk Ian Sharp FRAS *"*Detection of Exoplanets in PCEB binary systems using Eclipse Time Variations (ETVs)." Ian will describe how amateur astronomers can measure the times of eclipses of these Post Common Envelope Binary Systems and contribute to the science of the possible discovery of exoplanets that may be orbiting around them. The speaker will summarise the subject and demonstrate the practical techniques that are required to get involved.

Please support a raffle we are organizing this month

- Astronomers detect most distant fast radio burst to date

Date: October 19, 2023
Source: ESO



An artist's impression (not to scale) illustrates the path of the fast radio burst FRB 20220610A, from the distant galaxy where it originated all the way to Earth, in one of the Milky Way's spiral arms. It's so far away its light took eight billion years to reach us, making FRB 20220610A the most distant fast radio burst found to date. Image: ESO/M.Kornmesser

An international team has spotted a remote blast of cosmic radio waves lasting less than a millisecond. This 'fast radio burst' (FRB) is the most distant ever detected. Its source was pinned down by the European Southern Observatory's (ESO) Very Large Telescope (VLT) in a galaxy so far away that its light took eight billion years to reach us. The FRB is also one of the most energetic ever observed; in a tiny fraction of a second it released the equivalent of our Sun's total emission over 30 years.

The discovery of the burst, named FRB 20220610A, was made in June last year by the ASKAP radio telescope in Australia [1] and it smashed the team's previous distance record by 50 percent.

"Using ASKAP's array of dishes, we were able to determine precisely where the burst came from," says Stuart Ryder, an astronomer from Macquarie University in Australia and the co-lead author of the study published today in *Science*. "Then we used [ESO's VLT] in Chile to search for the source galaxy, [2] finding it to be older and further away than any other FRB source found to date and likely within a small group of merging galaxies."

The discovery confirms that FRBs can be used to measure the 'missing' matter between galaxies, providing a new way to 'weigh' the Universe.

Current methods of estimating the mass of the Universe are giving conflicting answers and challenging the standard model of cosmology. "If we count up the amount of normal matter in the Universe -- the atoms that we are all made of -- we find that more than half of what should be there today is missing," says Ryan Shannon, a professor at the Swinburne University of Technology in Australia, who also co-led the study. "We think that the missing matter is hiding in the space between galaxies, but it may just be so hot and diffuse that it's impossible to see using normal techniques."

"Fast radio bursts sense this ionised material. Even in space that is nearly perfectly empty they can 'see' all the electrons, and that allows us to measure how much stuff is between the galaxies," Shannon says.

Finding distant FRBs is key to accurately measuring the Universe's missing matter, as shown by the late Australian astronomer Jean-Pierre ('J-P') Macquart in 2020. "J-P showed that the further away a fast radio burst is, the more diffuse gas it reveals between the galaxies. This is now known as the Macquart relation. Some recent fast radio bursts appeared to break this relationship. Our measurements confirm the Macquart relation holds out to beyond half the known Universe," says Ryder.

"While we still don't know what causes these massive bursts of energy, the paper confirms that fast radio bursts are common events in the cosmos and that we will be able to use them to detect matter between galaxies, and better understand the structure of the Universe," says Shannon.

The result represents the limit of what is achievable with telescopes today, although astronomers will soon have the tools to detect even older and more distant bursts, pin down their source galaxies and measure the Universe's missing matter. The international Square Kilometre Array Observatory is currently building two radio telescopes in South Africa and Australia that will be capable of finding thousands of FRBs, including very distant ones that cannot be detected with current facilities. ESO's Extremely Large Telescope, a 39-metre telescope under construction in the Chilean Atacama Desert, will be one of the few telescopes able to study the source galaxies of bursts even further away than FRB 20220610A.

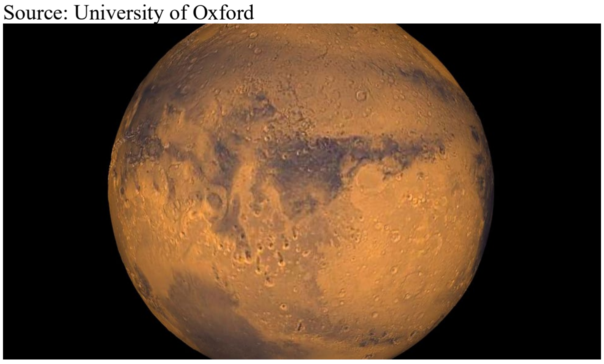
Notes

[1] The ASKAP telescope is owned and operated by CSIRO, Australia's national science agency, on Wajarri Yamaji Country in Western Australia.

[2] The team used data obtained with the FOcal Reducer and low dispersion Spectrograph 2 (FORS2), the X-shooter and the High Acuity Wide-field K-band Imager (HAWK-I) instruments on ESO's VLT. Data from the Keck Observatory in Hawai'i, US, was also used in the study.

- Source of largest ever Mars quake revealed

Date: October 17, 2023
Source: University of Oxford



A global team of scientists have announced the results of an unprecedented collaboration to search for the source of the largest ever seismic event recorded on Mars. The study, led by the University of Oxford, rules out a meteorite impact, suggesting instead that the quake was the result of enormous tectonic forces within Mars' crust.

The quake, which had a magnitude of 4.7 and caused vibrations to reverberate through the planet for at least six hours, was recorded by NASA's InSight lander on May 4 2022. Because its seismic signal was similar to previous quakes known to be caused by meteoroid impacts, the team believed that this event (dubbed 'S1222a') might have been caused by an impact as well, and launched an international search for a fresh crater.

Although Mars is smaller than Earth, it has a similar land surface area because it has no oceans. In order to survey this huge amount of ground -- 144 million km^2 -- study lead Dr Benjamin Fernando of the University of Oxford sought contributions from the European Space Agency, the Chinese National Space Agency, the Indian Space Research Organisation, and the United Arab Emirates Space Agency. This is thought to be the first time that all missions in orbit around Mars have collaborated on a single project. Each group examined data from their satellites orbiting Mars to look for a new crater, or any other tell-tale signature of an impact (e.g., a dust cloud appearing in the hours after the quake).

After several months of searching, the team announced today that no fresh crater was found. They conclude that the event was instead caused by the release of enormous tectonic forces within Mars' interior. The results, published today in the journal *Geophysical Research Letters*, indicate that the planet is much more seismically active than previously thought.

Dr Fernando said: 'We still think that Mars doesn't have any active plate tectonics today, so this event was likely caused by the release of stress within Mars' crust. These stresses are the result of billions of years of evolution; including the cooling and shrinking of different parts of the planet at different rates. We still do not fully understand why some parts of the planet seem to have higher stresses than others, but results like these help us to investigate further. One day, this information may help us to understand where it would be safe for humans to live on Mars and where you might want to avoid!'

He added: 'This project represents a huge international effort to help solve the mystery of S1222a, and I am incredibly grateful to all the missions who contributed. I hope this project serves as a template for productive international collaborations in deep space.'
Dr Daniela Tirsch, Science Coordinator for the High-Resolution Stereo Camera on board the European Space Agency's Mars Express Spacecraft said: 'This experiment shows how important it is to maintain a diverse set of instruments at Mars, and we are very glad to have played our part in completing the multi-instrumental and international approach of this study.'
From China, Dr Jianjun Liu (National Astronomical Observatories, Chinese Academy of Sciences) added: 'We are willing to collaborate with scientists around the world to share and apply this scientific data to get more knowledge about Mars, and are proud to have provided data from the colour imagers on Tianwen-1 to contribute to this effort.'
Dr Dimitra Atri, Group Leader for Mars at New York University Abu Dhabi and contributor of data from the UAE's Hope Spacecraft, said: 'This has been a great opportunity for me to collaborate with the InSight team, as well as with individuals from other major missions dedicated to the study of Mars. This really is the golden age of Mars exploration!'
Dr Constantinos Charalambous of Imperial College London, a co-author on the study, said: 'The absence of a crater in our image search for S1222a marks a significant milestone in interpreting seismic signals on Mars, crucial for distinguishing impact events from tectonic forces on the Red Planet.'
S1222a was one of the last events recorded by InSight before its end of mission was declared in December 2022. The team are now moving forward by applying knowledge from this study to future work, including upcoming missions to the Moon and Saturn's moon Titan.

About InSight

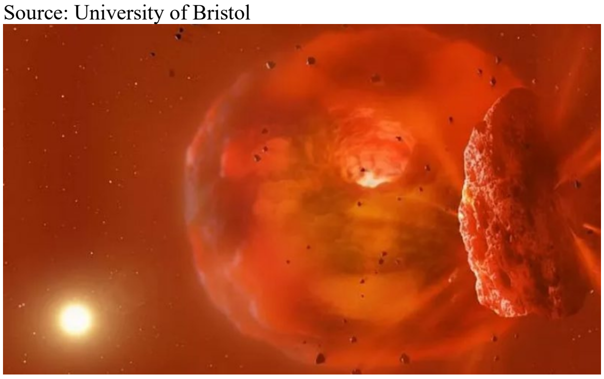
- InSight was a NASA mission dedicated to the study of the Martian interior through geophysics, especially seismology (the study of Earthqukes).
- It launched from California in May 2018 and landed on Mars in November of that year. The last data were returned in December 2022, after the spacecraft lost power due to increasing dust accumulation on its solar panels.
- External partners to the InSight mission included the UK, France, Germany, and Switzerland. Within the UK, Imperial College London and the University of Oxford are lead institutions.
- During its time on Mars, InSight recorded over 1,300 mars quake events. Of these, at least 8 were from meteoroid impact events. The largest two formed craters around 150m in diameter. If the S1222a event was formed by an impact, we would expect the crater to be at least 300m in diameter.

This project involved all other active missions currently orbiting Mars, who contributed their data and expertise. These include:

- The MAVEN, Mars Reconnaissance Orbiter (MRO), and Mars Odyssey spacecraft of NASA
- The ExoMars Trace Gas Orbiter (TGO) and Mars Express (MEX) spacecraft of ESA
- The Emirates Mars Mission (Hope) of the United Arab Emirates Space Agency
- The Tianwen-1 Mission of the Chinese National Space Agency
- The Mangalyaan (MOM) mission of the Indian Space Research Organisation, which ended in September 2022. The MOM data were searched but no relevant images were taken before the end of mission

- ❖ Researchers capture first-ever afterglow of huge planetary collision in outer space

Date: October 11, 2023
Source: University of Bristol

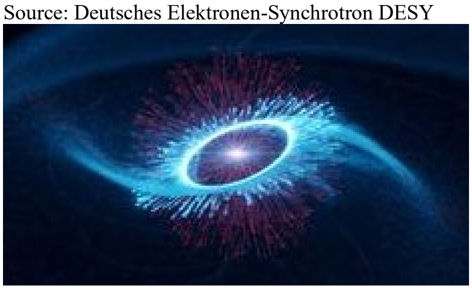


The study, published today in *Nature,* reports the sighting of two ice giant exoplanets colliding around a sun-like star, creating a blaze of light and plumes of dust. Its findings

show the bright heat afterglow and resulting dust cloud, which moved in front of the parent star dimming it over time.
The international team of astronomers was formed after an enthusiast viewed the light curve of the star and noticed something strange. It showed the system doubled in brightness at infrared wavelengths some three years before the star started to fade in visible light.
Co-lead author Dr Matthew Kenworthy, from Leiden University, said: "To be honest, this observation was a complete surprise to me. When we originally shared the visible light curve of this star with other astronomers, we started watching it with a network of other telescopes.
"An astronomer on social media pointed out that the star brightened up in the infrared over a thousand days before the optical fading. I knew then this was an unusual event."
The network of professional and amateur astronomers studied the star intensively including monitoring changes in the star's brightness over the next two years. The star was named ASASSN-21qj after the network of telescopes that first detected the fading of the star at visible wavelengths.
The researchers concluded the most likely explanation is that two ice giant exoplanets collided, producing the infrared glow detected by NASA's NEOWISE mission, which uses a space telescope to hunt for asteroids and comets.
Co-lead author Dr Simon Lock, Research Fellow in Earth Sciences at the University of Bristol, said: "Our calculations and computer models indicate the temperature and size of the glowing material, as well as the amount of time the glow has lasted, is consistent with the collision of two ice giant exoplanets."
The resultant expanding debris cloud from the impact then travelled in front of the star some three years later, causing the star to dim in brightness at visible wavelengths.
Over the next few years, the cloud of dust is expected to start smearing out along the orbit of the collision remnant, and a tell-tale scattering of light from this cloud could be detected with both ground-based telescopes and NASA's largest telescope in space, known as JWST.
The astronomers plan on watching closely what happens next in this system.
Co-author Dr Zoe Leinhardt, Associate Professor of Astrophysics at the University of Bristol, added: "It will be fascinating to observe further developments. Ultimately, the mass of material around the remnant may condense to form a retinue of moons that will orbit around this new planet."

- Scientists discover the highest energy gamma-rays ever from a pulsar

H.E.S.S. observatory records 20 tera-electronvolts photons from the Vela pulsar
Date: October 5, 2023
Source: Deutsches Elektronen-Synchrotron DESY



Scientists using the H.E.S.S. observatory in Namibia have detected the highest energy gamma rays ever from a dead star called a pulsar. The energy of these gamma rays clocked in at 20 tera-electronvolts, or about ten trillion times the energy of visible light. This observation is hard to reconcile with the theory of the production of such pulsed gamma rays, as the international team reports in the journal *Nature Astronomy*.
Pulsars are the left-over corpses of stars that spectacularly exploded in a supernova. The explosions leave behind a tiny, dead star with a diameter of just some 20 kilometres, rotating extremely fast and endowed with an enormous magnetic field. "These dead stars are almost entirely made up of neutrons and are incredibly dense: a teaspoon of their material has a mass of more than five billion tonnes, or about 900 times the mass of the Great Pyramid of Giza," explains H.E.S.S. scientist Emma de Oña Wilhelmi, a co-author of the publication working at DESY.
Pulsars emit rotating beams of electromagnetic radiation, somewhat like cosmic lighthouses. If their beam sweeps across our solar system, we see flashes of radiation at regular time intervals. These flashes, also called pulses of radiation, can be searched for in different energy bands of the electromagnetic spectrum. Scientists think that the source of this radiation are fast electrons produced and accelerated in the pulsar's magnetosphere, while traveling towards its periphery. The magnetosphere is made up of plasma and electromagnetic fields that surround and co-rotate with the star. "On

their outward journey, the electrons acquire energy and release it in the form of the observed radiation beams," says Bronek Rudak from the Nicolaus Copernicus Astronomical Centre (CAMK PAN) in Poland, also a co-author.
The Vela pulsar, located in the Southern sky in the constellation Vela (sail of the ship), is the brightest pulsar in the radio band of the electromagnetic spectrum and the brightest persistent source of cosmic gamma rays in the giga-electronvolts (GeV) range. It rotates about eleven times per second. However, above a few GeV, its radiation ends abruptly, presumably because the electrons reach the end of the pulsar's magnetosphere and escape from it.
But this is not the end of the story: using deep observations with H.E.S.S., a new radiation component at even higher energies has now been discovered, with energies of up to tens of tera-electronvolts (TeV). "That is about 200 times more energetic than all radiation ever detected before from this object," says co-author Christo Venter from the North-West University in South Africa. This very high-energy component appears at the same phase intervals as the one observed in the GeV range. However, to attain these energies, the electrons might have to travel even farther than the magnetosphere, yet the rotational emission pattern needs to remain intact.
"This result challenges our previous knowledge of pulsars and requires a rethinking of how these natural accelerators work," says Arache Djannati-Atai from the Astroparticle & Cosmology (APC) laboratory in France, who led the research. "The traditional scheme according to which particles are accelerated along magnetic field lines within or slightly outside the magnetosphere cannot sufficiently explain our observations. Perhaps we are witnessing the acceleration of particles through the so-called magnetic reconnection process beyond the light cylinder, which still somehow preserves the rotational pattern? But even this scenario faces difficulties to explain how such extreme radiation is produced."
Whatever the explanation, next to its other superlatives, the Vela pulsar now officially holds the record as the pulsar with the highest-energy gamma rays discovered to date. "This discovery opens a new observation window for detection of other pulsars in the tens of teraelectronvolt range with current and upcoming more sensitive gamma-ray telescopes, hence paving the way for a better understanding of the extreme acceleration processes in highly magnetised astrophysical objects," says Djannati-Atai.

- Black holes could come in 'perfect pairs' in an ever-expanding Universe

Date: October 19, 2023
Source: University of Southampton

Artist concept of supermassive black hole. Credit: NASA/JPL-Caltech

Researchers from the University of Southampton, together with colleagues from the universities of Cambridge and Barcelona, have shown it's theoretically possible for black holes to exist in perfectly balanced pairs -- held in equilibrium by a cosmological force -- mimicking a single black hole.
Black holes are massive astronomical objects that have such a strong gravitational pull that nothing, not even light, can escape. They are incredibly dense. A black hole could pack the mass of the Earth into a space the size of a pea.
Conventional theories about black holes, based on Einstein's theory of General Relativity, typically explain how static or spinning black holes can exist on their own, isolated in space. Black holes in pairs would eventually be thwarted by gravity attracting and colliding them together.
However, this is true if one assumes the Universe is standing still. But what about one which is constantly moving? Could pairs of black holes exist in harmony in an ever-expanding Universe, perhaps masquerading as one?
"The standard model of cosmology assumes that the Big Bang brought the Universe into existence and that, approximately 9.8 billion years ago, it became dominated by a mysterious force, coined 'dark energy', which accelerates the Universe at a constant rate," says Professor Oscar Dias of the University of Southampton.

Scientists refer to this mysterious force as a 'cosmological constant'. In a Universe explained by Einstein's theory with a cosmological constant, black holes are immersed in a cosmological accelerated background. This moves the theoretical goal posts over how black holes can interact and exist together.
Through complex numerical methods, the team behind this latest study show that two static (non-spinning) black holes can exist in equilibrium -- their gravitational attraction offset by the expansion associated with a cosmological constant. Even in the acceleration of an ever-expanding Universe, the black holes remain locked at a fixed distance from one another. As hard as expansion may try to pull them apart, the gravitational attraction compensates.
"Viewed from a distance, a pair of black holes whose attraction is offset by cosmic expansion would look like a single black hole. It might be hard to detect whether it is a single black hole or a pair of them," comments Professor Dias.
Professor Jorge Santos of the University of Cambridge adds: "Our theory is proven for a pair of static black holes, but we believe it could be applied to spinning ones too. Also, it seems plausible that our solution could hold true for three or even four black holes, opening up a whole range of possibilities."
This study was conducted by Professor Oscar Dias (University of Southampton), Professor Gary Gibbons (University of Cambridge), Professor Jorge Santos (University of Cambridge) and Dr Benson Way (University of Barcelona). Their paper 'Static Black Binaries in de Sitter Space' is published in the journal *Physical Review Letters* and reviewed as a Viewpoint article.

- ❖ Grasping the three-dimensional morphology of kilonovae

Date: October 18, 2023
Source: GSI Helmholtzzentrum für Schwerionenforschung GmbH

An advanced new three-dimensional (3D) computer simulation of the light emitted following a merger of two neutron stars has produced a similar sequence of spectroscopic features to an observed kilonova. "The unprecedented agreement between our simulations and the observation of kilonova AT2017gfo indicates that we understand broadly what has taken place in the explosion and aftermath," says Luke Shingles, scientist at GSI/FAIR and the leading author of the publication in *The Astrophysical Journal Letters*. Recent observations that combine both gravitational waves and visible light have pointed to neutron star mergers as the major site of this element production. The research was performed by scientists at GSI Helmholtzzentrum für Schwerionenforschung and Queen's University Belfast.
The interactions between electrons, ions, and photons within the material ejected from a neutron-star merger determine the light that we can see through telescopes. These processes and the emitted light can be modelled with computer simulations of radiative transfer. Researchers have recently produced, for the first time, a three-dimensional simulation that self-consistently follows the neutron-star merger, neutron-capture nucleosynthesis, energy deposited by radioactive decay, and radiative transfer with tens of millions of atomic transitions of heavy elements.
Being a 3D model, the observed light can be predicted for any viewing direction. When viewed nearly perpendicular to the orbital plane of the two neutron stars (as observational evidence indicates for the kilonova AT2017gfo) the model predicts a sequence of spectral distributions that look remarkably similar to what has been observed for AT2017gfo. "Research in this area will help us to understand the origins of elements heavier than iron (such as platinum and gold) that were mainly produced by the rapid neutron capture process in neutron star mergers," says Shingles.
About half of the elements heavier than iron are produced in an environment of extreme temperatures and neutron densities, as achieved when two neutron stars merge with each other. When they eventually spiral in toward each other and coalesce, the resulting explosion leads to the ejection of matter with the appropriate conditions to produce unstable neutron-rich heavy nuclei by a sequence of neutron captures and beta-decays. These nuclei decay to stability, liberating energy that

powers an explosive 'kilonova' transient, a bright emission of light that rapidly fades in about a week.
The 3D simulation combines together several areas of physics, including the behaviour of matter at high densities, the properties of unstable heavy nuclei, and atom-light interactions of heavy elements. Further challenges remain, such as accounting for the rate at which the spectral distribution changes, and the description of material ejected at late times. Future progress in this area will increase the precision with which we can predict and understand features in the spectra and will further our understanding of the conditions in which heavy elements were synthesized. A fundamental ingredient for these models is high quality atomic and nuclear experimental data as will be provided by the FAIR facility.

- Scientists, philosophers identify nature's missing evolutionary law

Date: October 16, 2023
Source: Carnegie Science Earth and Planets Laboratory

As Earth formed, new geologic processes, especially those related to the interaction of hot fluids with rock during igneous activity and plate tectonics, gave birth to over 1500 new mineral species (4.55 to 2.5 billion years ago). At 2.5 billion years ago, emerging biological life introduced oxygen into the atmosphere. This was a time of pivotal change, when photosynthesis began and the interaction of iron with oxygen-based minerals changed ancient life, providing the blueprint for our future evolution, together with minerals. Credit: Dr. Robert Lavinsky

A paper in the journal *Proceedings of the National Academy of Sciences* today describes "a missing law of nature," recognizing for the first time an important norm within the natural world's workings.
In essence, the new law states that complex natural systems evolve to states of greater patterning, diversity, and complexity. In other words, evolution is not limited to life on Earth, it also occurs in other massively complex systems, from planets and stars to atoms, minerals, and more.
Authored by a nine-member team -- leading scientists from the Carnegie Institution for Science, the California Institute of Technology (Caltech) and Cornell University, and philosophers from the University of Colorado -- the work was funded by the John Templeton Foundation.
"Macroscopic" laws of nature describe and explain phenomena experienced daily in the natural world. Natural laws related to forces and motion, gravity, electromagnetism, and energy, for example, were described more than 150 years ago.
The new work presents a modern addition -- a macroscopic law recognizing evolution as a common feature of the natural world's complex systems, which are characterised as follows:

- They are formed from many different components, such as atoms, molecules, or cells, that can be arranged and rearranged repeatedly
- Are subject to natural processes that cause countless different arrangements to be formed
- Only a small fraction of all these configurations survives in a process called "selection for function."

Regardless of whether the system is living or non-living, when a novel configuration works well and function improves, evolution occurs.
The authors' "Law of Increasing Functional Information" states that the system will evolve "if many different configurations of the system undergo selection for one or more functions."
"An important component of this proposed natural law is the idea of 'selection for function,'" says Carnegie astrobiologist Dr. Michael L. Wong, first author of the study.
In the case of biology, Darwin equated function primarily with survival -- the ability to live long enough to produce fertile offspring.
The new study expands that perspective, noting that at least three kinds of function occur in nature.
The most basic function is stability -- stable arrangements of atoms or molecules are selected to continue. Also chosen to persist are dynamic systems with ongoing supplies of energy.
The third and most interesting function is "novelty" -- the tendency of evolving systems

to explore new configurations that sometimes lead to startling new behaviours or characteristics.

Life's evolutionary history is rich with novelties -- photosynthesis evolved when single cells learned to harness light energy, multicellular life evolved when cells learned to cooperate, and species evolved thanks to advantageous new behaviours such as swimming, walking, flying, and thinking.

The same sort of evolution happens in the mineral kingdom. The earliest minerals represent particularly stable arrangements of atoms. Those primordial minerals provided foundations for the next generations of minerals, which participated in life's origins. The evolution of life and minerals are intertwined, as life uses minerals for shells, teeth, and bones.

Indeed, Earth's minerals, which began with about 20 at the dawn of our Solar System, now number almost 6,000 known today thanks to ever more complex physical, chemical, and ultimately biological processes over 4.5 billion years.

In the case of stars, the paper notes that just two major elements -- hydrogen and helium -- formed the first stars shortly after the big bang. Those earliest stars used hydrogen and helium to make about 20 heavier chemical elements. And the next generation of stars built on that diversity to produce almost 100 more elements.

"Charles Darwin eloquently articulated the way plants and animals evolve by natural selection, with many variations and traits of individuals and many different configurations," says co-author Robert M. Hazen of Carnegie Science, a leader of the research.

"We contend that Darwinian theory is just a very special, very important case within a far larger natural phenomenon. The notion that selection for function drives evolution applies equally to stars, atoms, minerals, and many other conceptually equivalent situations where many configurations are subjected to selective pressure."

The co-authors themselves represent a unique multi-disciplinary configuration: three philosophers of science, two astrobiologists, a data scientist, a mineralogist, and a theoretical physicist.

Says Dr. Wong: "In this new paper, we consider evolution in the broadest sense -- change over time -- which subsumes Darwinian evolution based upon the particulars of 'descent with modification.'"

"The universe generates novel combinations of atoms, molecules, cells, etc. Those combinations that are stable and can go on to engender even more novelty will continue to evolve. This is what makes life the most striking example of evolution, but evolution is everywhere."

Among many implications, the paper offers:

1. Understanding into how differing systems possess varying degrees to which they can continue to evolve. "Potential complexity" or "future complexity" have been proposed as metrics of how much more complex an evolving system might become
2. Insights into how the rate of evolution of some systems can be influenced artificially. The notion of functional information suggests that the rate of evolution in a system might be increased in at least three ways: (1) by increasing the number and/or diversity of interacting agents, (2) by increasing the number of different configurations of the system; and/or 3) by enhancing the selective pressure on the system (for example, in chemical systems by more frequent cycles of heating/cooling or wetting/drying).
3. A deeper understanding of generative forces behind the creation and existence of complex phenomena in the universe, and the role of information in describing them
4. An understanding of life in the context of other complex evolving systems. Life shares certain conceptual equivalencies with other complex evolving systems, but the authors point to a future research direction, asking if there is something distinct about how life processes information on functionality.
5. Aiding the search for life elsewhere: if there is a demarcation between life and non-life that has to do with selection for function, can we identify the "rules of life" that allow us to discriminate that biotic dividing line in Astro biological investigations?
6. At a time when evolving AI systems are an increasing concern, a predictive law of information that characterizes

how both natural and symbolic systems evolve is especially welcome

Laws of nature -- motion, gravity, electromagnetism, thermodynamics -- etc. codify the general behaviour of various macroscopic natural systems across space and time.

The "law of increasing functional information" published today complements the 2nd law of thermodynamics, which states that the entropy (disorder) of an isolated system increases over time (and heat always flows from hotter to colder objects).

- Signatures of the Space Age: Spacecraft metals left in the wake of humanity's path to the stars

Airplane-based research by Purdue scientists detects unprecedented levels of alloy aerosols in the atmosphere

Date: October 16, 2023
Source: Purdue University

The Space Age is leaving fingerprints on one of the most remote parts of the planet -- the stratosphere -- which has potential implications for climate, the ozone layer and the continued habitability of Earth.

Using tools hitched to the nose cone of their research planes and sampling more than 11 miles above the planet's surface, researchers have discovered significant amounts of metals in aerosols in the atmosphere, likely from increasingly frequent launches and returns of spacecraft and satellites. That mass of metal is changing atmospheric chemistry in ways that may impact Earth's atmosphere and ozone layer.

"We are finding this human-made material in what we consider a pristine area of the atmosphere," said Dan Cziczo, one of a team of scientists who published a study on these results in the *Proceedings of the National Academy of Sciences*. "And if something is changing in the stratosphere -- this stable region of the atmosphere -- that deserves a closer look." Cziczo, professor and head of the Department of Earth, Atmospheric, and Planetary Sciences in Purdue's College of Science, is an expert in atmospheric science who has spent decades studying this rarefied region.

Led by Dan Murphy, an adjunct professor in the Department of Earth, Atmospheric, and Planetary Sciences and a researcher at the National Oceanic and Atmospheric Administration, the team detected more than 20 elements in ratios that mirror those used in spacecraft alloys. They found that the mass of lithium, aluminium, copper and lead from spacecraft re-entry far exceeded those metals found in natural cosmic dust. Nearly 10% of large sulfuric acid particles -- the particles that help protect and buffer the ozone layer -- contained aluminium and other spacecraft metals.

Scientists estimate that as many as 50,000 more satellites may reach orbit by 2030. The team calculates that means that, in the next few decades, up to half of stratospheric sulfuric acid particles would contain metals from re-entry. What effect that could have on the atmosphere, the ozone layer and life on Earth is yet to be understood.

Scientists have long suspected that spacecraft and satellites were changing the upper atmosphere, but studying the stratosphere, where we don't live and even the highest flights enter only briefly, is challenging.

As part of NASA's Airborne Science Program, Murphy and his group fly a WB-57 airplane to sample the atmosphere 11.8 miles (19 km) above the ground in Alaska, where circumpolar clouds tend to form. Similar measurements were made by Cziczo and his group from an ER-2 aircraft over the continental United States. Both groups use instruments hitched to the nose cone to ensure that only the freshest, most undisturbed air is sampled.

The sheltering sky

Like the view of the unruffled surface of the ocean, the stratosphere appears untroubled -- at least to human eyes. Life and civilization take place mostly on the planet's surface and in the troposphere, the atmosphere's very lowest layer. The stratosphere is a surprisingly stable and seemingly serene layer of the atmosphere.

The stratosphere is also the realm of the ozone layer: that gaseous marvel that acts as a global tent to shield the planet and all life on it from the searing, scorching rays of ultraviolet radiation. Without the ozone layer, life would likely never have arisen on Earth. And without it, life is unlikely to be able to continue.

The last decades have been eventful for the stratosphere. The ozone layer came under threat from chlorofluorocarbons in the 1980s, and only coordinated, sustained global efforts of governments and corporations have begun to bear fruit in repairing and replenishing it.

"Shooting stars streak through the atmosphere," Cziczo said. "Often, the meteor burns up in the atmosphere and doesn't even become a meteorite and reach the planet. So, the material it was made from stays in the atmosphere in the form of ions. They form very hot gas, which starts to cool and condense as molecules and fall into the stratosphere. The molecules find each other and knit together and form what we call meteorite smoke. Scientists recently started noticing that the chemical fingerprint of these meteoritic particles was starting to change, which made us ask, 'Well, what changed?' because meteorite composition hasn't changed. But the number of spacecraft has."

What goes up

Spacecraft launches, and returns, were once international events. The launches of Sputnik and the Mercury missions were front-page news. Now, a quickening tide of innovation and loosening regulation means that dozens of countries and corporations are able to launch satellites and spacecraft into orbit. All those satellites have to be sent up on rockets -- and most of that material, eventually, comes back down.

Like the wakes of great ships trolling through the ocean, rockets leave behind them a trail of metals that may change the atmosphere in ways scientists don't yet understand.

"Just to get things into orbit, you need all this fuel and a huge body to support the payload," Cziczo said. "There are so many rockets going up and coming back and so many satellites falling back through the atmosphere that it's starting to show up in the stratosphere as these aerosol particles."

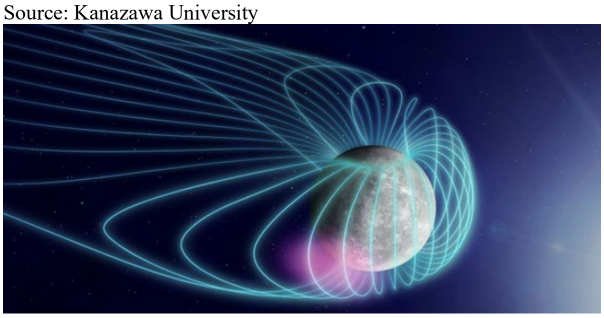
Of course, shooting stars were the first space-delivery system. Meteorites fall through the atmosphere every day. The heat and friction of the atmosphere peel material off them, just as they do off human-made artifacts.

However, while hundreds of meteors enter the Earth's atmosphere every day, they are increasingly being rivalled by the mass of metals that comprise the tons of Falcon, Ariane and Soyuz rockets that boost spacecraft into space and return again to Earth's surface.

"Changes to the atmosphere can be difficult to study and complex to understand," Cziczo said. "But what this research shows us is that the impact of human occupation and human spaceflight on the planet may be significant -- perhaps more significant than we have yet imagined. Understanding our planet is one of the most urgent research priorities there is."

- Source of electron acceleration and X-ray aurora of Mercury local chorus waves detected

Date: October 10, 2023
Source: Kanazawa University



Observations during two flybys by the Mio spacecraft as part of the BepiColombo International Mercury Exploration Project have revealed that chorus waves occur quite locally in the dawn sector of Mercury. Mercury's magnetic field is about 1% of that of Earth, and it was unclear whether chorus waves would be generated like on Earth. The present study reveals that the chorus waves are the driving source of Mercury's X-ray auroras, whose mechanism was not understood.

Since Mercury is the closest planet to the Sun among the solar system planets, it is strongly influenced by the solar wind, a high-speed (several hundred km/s) stream of plasma blowing from the Sun. Explorations of Mercury was first carried out by the Mariner 10 spacecraft in 1974 and 1975, which revealed that Mercury has a magnetic field, and thus a magnetosphere, similar to that of Earth. In the 2000s, the MESSENGER spacecraft provided a detailed picture of the Mercury's magnetic field and magnetosphere, and revealed that Mercury's magnetic field centre is shifted northward from the planet's centre by approximately 0.2 RM (RM is Mercury's radius of 2,439.7 km). The third exploration of Mercury is currently being made by the BepiColombo International Mercury Exploration Project*1) thanks to the Mio spacecraft (Project Scientist, Dr. Murakami) and the Mercury Planetary Orbiter (MPO). In particular, unlike Mariner 10 and MESSENGER, the Mio spacecraft is equipped with a full suite of plasma wave instrument (PWI, Principal Investigator Prof. Kasaba) designed specifically to investigate for the first time the electromagnetic environment around Mercury.

Electromagnetic waves can efficiently accelerate plasma particles (electrons, protons, heavier ions); as such, they play an important role in the Mercury's magnetospheric dynamics.

The present study was performed by an international joint research team consisting of scientists from Kanazawa University, Tohoku University, Kyoto University, MagneDesign Corporation, Laboratoire de Physique des Plasmas, France with support from CNES (French Space Agency), and the Institute of Space and Astronautical Science, the Japan Aerospace Exploration Agency (JAXA).

The Mio spacecraft, launched on October 20, 2018, is currently on its way to Mercury, with a final insertion in orbit around the planet scheduled for December 2025. Although getting Mio into Mercury's orbit is technically extremely difficult due to the strong gravity of the Sun as compared to that of Mercury, it is scheduled to enter into orbit around Mercury in 2025 after several flybys*2) of Earth, Venus, and Mercury for gravity assist manoeuvres. During the Mercury flybys that occurred on October 1, 2021 and June 23, 2022, the Mio spacecraft had approached the planet at an altitude of approximately 200 km. The stowed configuration of the spacecraft during the journey to Mercury is not optimal for measuring electromagnetic waves because of the interference noise coming from the spacecraft itself. However, the Mio spacecraft was developed to lower as much as possible its electromagnetic noise level, and thus has been certified as an electromagnetically clean spacecraft through EMC tests*3). Alternating current magnetic field sensors that can cope with the scorching environment of Mercury have been developed jointly by Japan and France and have allowed the first electromagnetic wave observations around Mercury without being contaminated by the noise from the spacecraft itself. This has revealed the local generation of chorus waves, such as those that are frequently detected in the magnetosphere of Earth. The existence of chorus waves in the magnetosphere of Mercury, which is now confirmed, was predicted (frequency range, intensity, etc.) since 2000s when the plasma wave instrument (PWI) of the Mio spacecraft was designed. What most surprised the international joint research team, including Dr. Ozaki of Kanazawa University, was the "spatial locality" of the chorus waves, which were detected only in an extremely limited region in the dawn sector of the Mercury's magnetosphere during the two flybys. This means that there is a physical mechanism that tends to generate chorus waves only in the dawn sector of the magnetosphere of Mercury. In order to investigate the cause of the generation of chorus waves in the dawn sector, the international joint research team used the nonlinear growth theory of chorus waves established by Prof. Omura, Kyoto University, to evaluate the effect of curvature of the magnetic field of Mercury, which is strongly distorted by the solar wind. The magnetic field lines in the night sector are stretched by the solar wind pressure, while the magnetic field lines in the dawn sector are less affected resulting in a smaller curvature. Based on the characteristics of the magnetic field lines and the nonlinear growth theory, it is revealed that in the dawn sector, energy is efficiently transferred from electrons to electromagnetic waves along magnetic field lines, creating conditions that favour chorus wave generation. The effect is also confirmed in a numerical simulation of the Mercury environment using a high-performance computer. In this study, the team has revealed the importance of the planetary magnetic field lines, which are strongly affected by the solar wind, on the locality of chorus wave generation thanks to a strong synergy between "spacecraft observation," "theory" and "simulation."

Future Prospects

In the Mercury flyby observations, the team prepared for the comprehensive electromagnetic environment survey using the planned Mio spacecraft probe in orbit around Mercury. Chorus waves, which were expected to be detected at the time of planning, are observed in a quite local manner, i.e., in the dawn sector of Mercury, which was not expected, and the results show various fluctuations in the magnetosphere of Mercury. The data demonstrate the existence of energetic electrons on Mercury that can generate chorus waves, the possibility of generating active electrons efficiently accelerated by chorus waves, and the generation of X-ray auroras by electrons forcibly precipitating from Mercury's magnetosphere to the surface of Mercury driven by chorus waves. These observations will have a wide impact on the scientific understanding of Mercury's environment. The

Mio spacecraft is on its way to carry out a comprehensive exploration of Mercury. Based on flyby observations we have found that magnetic field distortion is responsible for the local (i.e., dawn sector) generation of the chorus waves. The comprehensive exploration of the electromagnetic environment by the Mio spacecraft in Mercury's orbit will contribute not only to understanding the plasma environment of the entire Mercury's magnetosphere but also to a deep understanding of the magnetospheric dynamics in general. The magnetosphere acts as a barrier preventing life-threatening cosmic radiations on the planets of the solar system. Comparison of data from Mercury and Earth will strengthen our understanding of this important natural shielding of our home planet.

Glossary

*1) BepiColombo International Mercury Exploration Project
Comprehensive exploration project for Mercury using two spacecraft probes (Mio and MPO) by Japan-Europe cooperation. In particular, Japan is in charge of the Mercury magnetosphere probe Mio, equipped with electromagnetic wave observation instruments, etc.

*2) Flyby
With a spacecraft probe passing in proximity to a planet. The orbit of the spacecraft probe is to be changed in a desired manner by using the gravity of the planet.

*3) EMC (electromagnetic compatibility) test
Evaluation test to check whether unnecessary electromagnetic noise is emitted and whether the equipment is designed and manufactured in such a way that it will not malfunction even if it receives unwanted electromagnetic noise.

Reference

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Funders

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- Removal of magnetic spacecraft contamination within extraterrestrial samples easily carried out, researchers say

Date: October 11, 2023
Source: Stanford University

For decades, scientists have pondered the mystery of the moon's ancient magnetism. Based on analyses of lunar samples, its now-deceased magnetic field may have been active for more than 1.5 billion years -- give or take a billion years. Scientists believe it was generated like the Earth's via a dynamo process, whereby the spinning and churning of conductive liquid metal within a rocky planet's core generates a magnetic field. However, researchers have grappled with how such a small planetary body could have sustained a long-lived magnetic field. Some have even questioned the legitimacy of return samples that point to the existence of an ancient dynamo, suggesting magnetism may have been acquired via exposure to strong magnetic fields onboard spacecraft during the return mission or from plasmas produced by massive impacts on the moon.
Stanford University scientists have now demonstrated that the magnetism in lunar samples is not adversely altered by the spacecraft journey back to Earth or certain laboratory procedures, disproving one of the two major oppositions to the ancient dynamo theory. The findings, published in *Geophysical Research Letters* Oct. 11, bode well for research stemming from other sample-return missions from space, since any magnetic contamination acquired during flight or on Earth can likely be easily removed.
"You want to know that the spacecraft returning your sample is not magnetically frying your rock, essentially," said lead study author Sonia Tikoo, an assistant professor of geophysics at the Stanford Doerr School of Sustainability. "We simulated a long-term exposure of a sample to a stronger magnetic field than what the Earth has -- something that might be realistic for a spacecraft -- and found that for nearly all samples, including several we had previously studied in the context of lunar dynamo records, we could remove that contamination quite easily."

Reproducing contamination

The study authors conducted two sets of lab experiments on eight samples from four different Apollo missions. They used a magnet to expose the samples to a field strength of about 5 millitesla -- about 100 times stronger than the Earth's magnetic field -- for two days to approximately replicate the length of a return journey from the moon. Then, they took the samples into a magnetically shielded lab room to measure how quickly the contamination decayed and test how easily it could be removed using standard techniques. The research shows that basalts (rocks formed by the cooling of lava flows) are generally less susceptible to acquiring magnetic contamination than glass-bearing lunar rocks, but in nearly all cases the resulting contamination could be easily removed using standard methods.

"As a global community, we're starting to send more sample-return missions to other bodies, so it's good to know that as long as we're careful to ensure spacecraft fields are not too high -- and it doesn't have to be zero, necessarily -- we can still do paleomagnetism studies along with other research," said Tikoo, who also holds a courtesy appointment in Earth and planetary sciences. "You don't always have to send up a heavy magnetic shield that's going to take up a lot of room and a lot of mass at the expense of other science."

Paleomagnetism is a branch of geophysics that uses remanent magnetization in rocks from the time of their formation to reconstruct the direction and/or strength of the geomagnetic field. The magnetic history of the moon is important for understanding the evolution of interior thermal history over time, in addition to how a global dynamo field may have controlled the delivery and retention of volatile substances, such as water, at the lunar surface. "An ancient lunar field may even have aided atmospheric retention on the early Earth," the study authors write.

"Paleomagnetism is a very powerful tool for understanding core processes since we cannot go to the core of the planets, and also to learn about the past behaviour of the core," said study co-author Ji-In Jung, a PhD student in geophysics.

Dynamo theory

Magnetic fields may protect planets' surfaces from harmful solar radiation and space weather, enabling the long-term preservation of atmospheres. While various other mechanisms for generating a magnetic field have been proposed, the dynamo theory is the widely accepted explanation of this phenomenon on Earth. Scientists think Earth's magnetic field may have been essential for the development of conditions that support life, so learning about their presence around other planets and moons is part of the search for evidence of extraterrestrial life.

"In order to know about the internal structures of planetary bodies and their interaction with the atmosphere or other systems, we need to know about planetary dynamo processes," Jung said.

Magnetic fields can also reveal the overall cooling history of a planetary body, which can, in turn, affect its volcanism and its tectonic regime. For asteroids, researchers want to understand how magnetic fields may have helped material come together in the early solar nebula and eventually build up into larger planets.

The moon's magnetic history is of particular interest because geophysicists do not understand how a small planetary body like the moon could have generated a long-lived magnetic field, given that it has a small core that would likely have cooled quickly. As a next step, Tikoo aims to continue ongoing work to discriminate between the dynamo and impact hypotheses.

"This study proves that we can do extraterrestrial paleomagnetism with mission-returned samples," Tikoo said. "I don't think anybody doubts the ability to do Earth paleomagnetism and I'm happy that we can do it for space, too."

This research was funded by a grant from NASA.

- NASA's Webb captures an ethereal view of NGC 346

Date: October 11, 2023
Source: NASA/Goddard Space Flight Centre

This new infrared image of NGC 346 from NASA's James Webb Space Telescope's Mid-Infrared Instrument (MIRI) traces emission from cool gas and dust. In this image blue represents silicates and sooty chemical molecules known as polycyclic aromatic hydrocarbons, or PAHs. More diffuse red emission shines from warm dust heated by the brightest and most massive stars in the heart of the region. Bright patches and filaments mark areas with abundant numbers of protostars. This image includes 7.7-micron light shown in blue, 10 microns in cyan, 11.3 microns in green, 15 microns in yellow, and 21 microns in red (770W, 1000W, 1130W, 1500W, and 2100W filters, respectively).
Credit: NASA, ESA, CSA, STScI, N. Habel (JPL). Image Processing: P. Kavanagh (Maynooth University).

Filaments of dust and gas festoon this star-forming region in a new infrared image from MIRI.
One of the greatest strengths of NASA's James Webb Space Telescope is its ability to give astronomers detailed views of areas where new stars are being born. The latest example, showcased here in a new image from Webb's Mid-Infrared Instrument (MIRI), is NGC 346 -- the brightest and largest star-forming region in the Small Magellanic Cloud.
The Small Magellanic Cloud (SMC) is a satellite galaxy of the Milky Way, visible to the unaided eye in the southern constellation Tucana. This small companion galaxy is more primeval than the Milky Way in that it possesses fewer heavy elements, which are forged in stars through nuclear fusion and supernova explosions, compared to our own galaxy.
Since cosmic dust is formed from heavy elements like silicon and oxygen, scientists expected the SMC to lack significant amounts of dust. However, the new MIRI image, as well as a previous image of NGC 346 from Webb's Near-Infrared Camera released in January, show ample dust within this region.
In this representative-colour image, blue tendrils trace emission from material that includes dusty silicates and sooty chemical molecules known as polycyclic aromatic hydrocarbons, or PAHs. More diffuse red emission shines from warm dust heated by the brightest and most massive stars in the heart of the region. An arc at the centre left may be a reflection of light from the star near the arc's centre. (Similar, fainter arcs appear associated with stars at lower left and upper right.)
Lastly, bright patches and filaments mark areas with abundant numbers of protostars. The research team looked for the reddest stars, and found 1,001 pinpoint sources of light, most of them young stars still embedded in their dusty cocoons.
By combining Webb data in both the near-infrared and mid-infrared, astronomers are able to take a fuller census of the stars and protostars within this dynamic region. The results have implications for our understanding of galaxies that existed billions of years ago, during an era in the universe known as "cosmic noon," when star formation was at its peak and heavy element concentrations were lower, as seen in the SMC.*The James Webb Space Telescope is the world's premier space science observatory.*

- 'Starquakes' could explain mystery signals

Fast radio bursts from distant neutron stars resemble earthquakes rather than solar flares
Date: October 11, 2023
Source: University of Tokyo

Neutron star, Star formed of compressed neutrons, believed to be the residue of a supernova explosion. (Photo by: QAI Publishing/Universal Images Group via Getty Images)

Fast radio bursts, or FRBs, are an astronomical mystery, with their exact cause and origins still unconfirmed. These intense bursts of radio energy are invisible to the human eye, but show up brightly on radio telescopes. Previous studies have noted broad similarities between the energy distribution of repeat FRBs, and that of earthquakes and solar flares. However, new research at the University of Tokyo has looked at the time and energy of FRBs and found distinct differences between FRBs and solar flares, but several notable similarities between FRBs and earthquakes. This supports the theory that FRBs are caused by "starquakes" on the surface of neutron stars. This discovery could help us better understand earthquakes, the behaviour of high-density matter and aspects of nuclear physics.

The vastness of space holds many mysteries. While some people dream of boldly going where no one has gone before, there is a lot we can learn from the comfort of Earth. Thanks to technological advances, we can explore the surface of Mars, marvel at Saturn's rings and pick up mysterious signals from deep space. Fast radio bursts are hugely powerful, bright bursts of energy which are visible on radio waves. First discovered in 2007, these bursts can travel billions of light years but typically last mere thousandths of a second. It has been estimated that as many as 10,000 FRBs may happen every day if we could observe the whole sky. While the sources of most bursts detected so far appear to emit a one-off event, there are about 50 FRB sources which emit bursts repeatedly. The cause of FRBs is unknown, but some ideas have been put forward, including that they might even be alien in origin. However, the current prevailing theory is that at least some FRBs are emitted by neutron stars. These stars form when a supergiant star collapses, going from eight times the mass of our sun (on average) to a superdense core only 20-40 kilometres across. Magnetars are neutron stars with extremely strong magnetic fields, and these have been observed to emit FRBs.

"It was theoretically considered that the surface of a magnetar could be experiencing a starquake, an energy release similar to earthquakes on Earth," said Professor Tomonori Totani from the Department of Astronomy at the Graduate School of Science. "Recent observational advances have led to the detection of thousands more FRBs, so we took the opportunity to compare the now large statistical data sets available for FRBs with data from earthquakes and solar flares, to explore possible similarities."

So far, statistical analysis of FRBs has focused on the distribution of wait times between two successive bursts. However, Totani and co-author Yuya Tsuzuki, a graduate student in the same department, point out that calculating only the wait-time distribution does not take into account correlations that might exist across other bursts. So, the team decided to calculate correlation across two-dimensional space, analysing the time and emission energy of nearly 7,000 bursts from three different repeater FRB sources. They then applied the same method to examine the time-energy correlation of earthquakes (using data from Japan) and of solar flares (using records from the Hinode international mission to study the sun), and compared the results of all three phenomena.

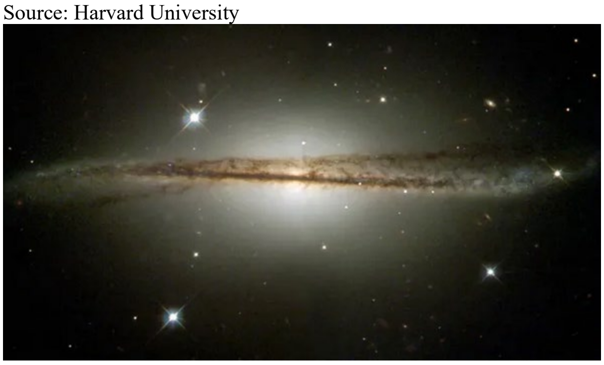
Totani and Tsuzuki were surprised that, in contrast to other studies, their analysis showed a striking similarity between FRBs and earthquake data, but a distinct difference between FRBs and solar flares. Totani explained: "The results show notable similarities between FRBs and earthquakes in the following ways: First, the probability of an aftershock occurring for a single event is 10-50%; second, the aftershock occurrence rate decreases with time, as a power of time; third, the aftershock rate is always constant even if the FRB-earthquake activity (mean rate) changes significantly; and fourth, there is no correlation between the energies of the main shock and its aftershock."

This strongly suggests the existence of a solid crust on the surface of neutron stars, and that starquakes suddenly occurring on these crusts releases huge amounts of energy which we see as FRBs. The team intends to continue analysing new data on FRBs, to verify that the similarities they have found are universal. "By studying starquakes on distant ultra dense stars, which are completely different environments from Earth, we may gain new insights into earthquakes," said Totani. "The interior of a neutron star is the densest place in the universe, comparable to that of the interior of an atomic nucleus. Starquakes in neutron stars have opened up the possibility of gaining new insights into very high-density matter and the fundamental laws of nuclear physics."

- ❖ Finding explanation for Milky Way's warp

Astronomers' results bolster hypothesis of how galaxy evolved

Date: October 10, 2023
Source: Harvard University



The Milky Way is sort of twisted like this galaxy pictured here. (Image credit: NASA/Space Telescope Science Institute)

The Milky Way is often depicted as a flat, spinning disk of dust, gas, and stars. But if you could zoom out and take an edge-on photo, it actually has a distinctive warp -- as if you tried to twist and bend a vinyl LP.
Though scientists have long known through observational data that the Milky Way is warped and its edges are flared like a skirt, no one could explain why.
Now, Harvard astronomers at the Centre for Astrophysics | Harvard and Smithsonian (CfA) have performed the first calculations that fully explain this phenomenon, with compelling evidence pointing to the Milky Way's envelopment in an off-kilter halo of dark matter. The work also bolsters current thinking about how the galaxy evolved and may offer clues into some of the mysteries of dark matter.
The new calculations were led by Jiwon Jesse Han, a Griffin Graduate School of Arts and Sciences student affiliated with the CfA. Published in *Nature Astronomy*, the work includes co-authors Charlie Conroy and Lars Hernquist, both faculty members at the CfA and in the Department of Astronomy.
Our galaxy is located inside a diffuse cloud called the stellar halo, which extends much farther out into the universe. In groundbreaking work published last year, the Harvard team deduced that the stellar halo is tilted and elliptical in shape, like a zeppelin or football.
Building on that, the team assumed the same shape for the dark matter halo, the larger entity that encompasses everything in and around the Milky Way. Dark matter makes up 80 percent of the galaxy's mass but is invisible because it doesn't interact with light, so the shape of that halo must be inferred. Using models to calculate the orbits of stars within a tilted, oblong dark matter halo, the team found a near-perfect match to existing observations of a warped, flared galaxy.
"A tilted dark halo is actually fairly common in simulations, but no one had explored its effect on the Milky Way," Conroy said. "It turns out that the tilt is an elegant way to explain both the magnitude and direction of our galaxy's wobbly disk."
Scientists had long surmised that the Milky Way formed due to a galactic collision; the astronomers' work further underscores that hypothesis.
"If the galaxy was just evolving on its own, it would have had this nice, spherical halo, this nice, flat disk," Han said. "So, the fact that the halo is tilted and has a football-like shape suggests that our galaxy experienced a merger event, where two galaxies collide."
Their calculation of the dark matter halo's probable shape may also provide clues as to the properties and particle nature of dark matter itself, which remain unsolved mysteries in physics. "The fact that the galaxy is not spherical in our data implies that there is some limit to which dark matter can interact with itself," Han explained.
Confidence in these findings might lead to better ways to cleverly study the unobservable dark matter that makes up most of the universe. This includes new ways to pick up on kinematic signatures of dark sub-halos, which are miniature dark matter halos zipping around the galaxy.

- ❖ Stellar fountain of youth with turbulent formation history in the centre of our galaxy

Date: October 10, 2023
Source: University of Cologne

Researchers have discovered that the star cluster IRS13 near the supermassive black hole Sagittarius A* in our galaxy is much younger than anticipated. This challenges existing theories about star formation near black holes. The team suggests IRS13 had a turbulent formation, which may have led to the unexpected presence of young stars in its vicinity.

An unexpectedly high number of young stars has been identified in the direct vicinity of a supermassive black hole and water ice has been detected at the centre of our galaxy.

An international team led by Dr Florian Peißker at the University of Cologne's Institute of Astrophysics has analysed in detail a young star cluster in the immediate vicinity of the super massive black hole Sagittarius A* (Sgr A*) in the centre of our galaxy and showed that it is significantly younger than expected. This cluster, known as IRS13, was discovered more than twenty years ago, but only now has it been possible to determine the cluster members in detail by combining a wide variety of data -- taken with various telescopes over a period of several decades. The stars are a few 100,000 years old and therefore extraordinarily young for stellar conditions. By comparison, our sun is about 5 billion years old. Due to the high-energy radiation as well as the tidal forces of the galaxy, it should in fact not be possible for such a large number of young stars to be in the direct vicinity of the super massive black hole.

The study was conducted under the title 'The Evaporating Massive Embedded Stellar Cluster IRS 13 Close to Sgr A*. I. Detection of a Rich Population of Dusty Objects in the IRS13 Cluster' and has now appeared in *The Astrophysical Journal*.

In connection with the current study, a further outstanding result has also been published. For the first time, the James Webb Space Telescope (JWST) was used to record a spectrum free of atmospheric interference from the Galactic Centre. A prism on board the telescope was developed at the Institute of Astrophysics in the working group led by Professor Dr Andreas Eckart, a co-author of the publication. The present spectrum shows that there is water ice in the Galactic Centre. This water ice, which is often found in the dusty discs around very young stellar objects, is another independent indicator of the young age of some stars near the black hole.

In addition to the unexpected detection of young stars and water ice by the JWST, the researchers led by Dr Peißker have also found that IRS13 has a turbulent history of formation behind it. The study results suggest that IRS13 migrated toward the super massive black hole through friction with the interstellar medium, collisions with other star clusters, or internal processes. From a certain distance, the cluster was then 'captured' by the gravitation of the black hole. In this process, a bow shock may have formed at the top of the cluster from the dust surrounding the cluster, similar to the tip of a ship in the water. The associated increase in dust density then stimulated further star formation. This is an explanation why these young stars are above all in the top or front of the cluster.

"The analysis of IRS13 and the accompanying interpretation of the cluster is the first attempt to unravel a decade-old mystery about the unexpectedly young stars in the Galactic Centre," according to Dr Peißker. "In addition to IRS13, there is a star cluster, the so-called S-cluster, which is even closer to the black hole and also consists of young stars. They are also significantly younger than would be possible according to accepted theories." The findings on IRS13 provide the opportunity in further research to establish a connection between the direct vicinity of the black hole and regions several light years away. Dr Michal Zajaček, second author of the study and scientist at Masaryk University in Brno (Czech Republic), added: "The star cluster IRS13 seems to be the key to unravelling the origin of the dense star population at the centre of our galaxy. We have gathered extensive evidence that very young stars within the range of the super massive black hole may have formed in star clusters such as IRS13. This is also the first time we have been able to identify star populations of different ages -- hot main sequence stars and young emerging stars -- in the cluster so close to the centre of the Milky Way."