South Downs Mercury

The monthly circular of South Downs Astronomical Society
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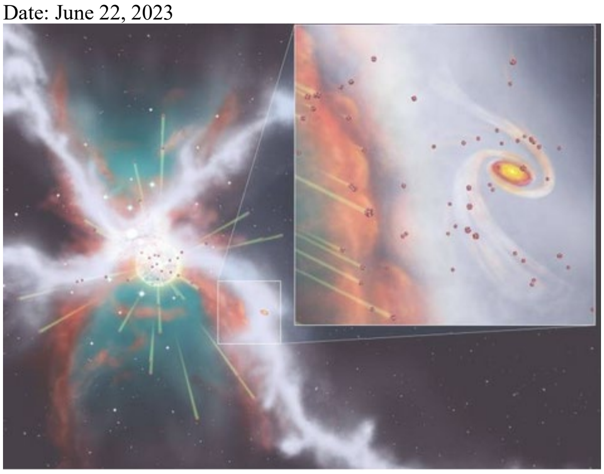
Main Talk Mike John Mallett FRAS. “Measuring the brightness of stars, planets and supernova to enable more accurate measurements” Measuring the brightness of stars, planets and supernova are key to understanding the processes of evolving astronomical systems. We will look at the photometric techniques in astronomy that have enabled us to improve the accuracy of measurements over the past 20 years. I will use our prior research as an example of the improvements.

Please support a raffle we are organizing this month

- Molecular filament shielded young solar system from supernova

Date: June 22, 2023



Artist’s impression of the blast wave from a supernova colliding with the molecular cloud filament where the sun is forming. Credit: NAOJ
Source: National Institutes of Natural Sciences

Isotope ratios found in meteorites suggest that a supernova exploded nearby while the Sun and Solar System were still forming. But the blast wave from a supernova that close could have potentially destroyed the nascent Solar System. New calculations shows that a filament of molecular gas, which is the birth cocoon of the Solar System, aided the capture of the isotopes found in the meteorites, while acting as a buffer protecting the young Solar System from the nearby supernova blast.
Primitive meteorites preserve information about the conditions at the birth of the Sun and planets. The meteorite components show an inhomogeneous concentration of a radioactive isotope of aluminium. This variation suggests that an additional amount of the radioactive aluminium was introduced shortly after the Solar System started forming. A nearby supernova explosion is the best candidate for this injection of new radioactive isotopes. But a supernova that was close enough to deliver the amount of isotopes seen in meteorites would have also created a blast wave strong enough to rip the nascent Solar System apart.
A team led by Doris Arzoumanian at the National Astronomical Observatory of Japan proposed a new explanation of how the Solar System acquired the amount of isotopes measured in meteorites while surviving the supernova shock. Stars form in large groups called clusters inside giant clouds of molecular gas. These molecular clouds are filamentary. Small stars like the Sun usually form along the filaments and large stars, which will explode in a supernova, usually form at the hubs where multiple filaments cross.
Assuming that the Sun formed along a dense molecular gas filament, and a supernova exploded at a nearby filament hub, the team's calculation showed that it would take at least 300,000 years for the blast wave to break up the dense filament around the forming Solar System. The components of meteorites enriched in radioactive isotopes formed in approximately the first 100,000 years of Solar System formation inside the dense filament. The parent filament may have acted as a buffer to protect the young Sun and helped catch the radioactive isotopes from the supernova blast wave and channel them into the still forming Solar System.

- Never-before-seen way to annihilate a star

Date: June 22, 2023
Source: Association of Universities for Research in Astronomy (AURA)

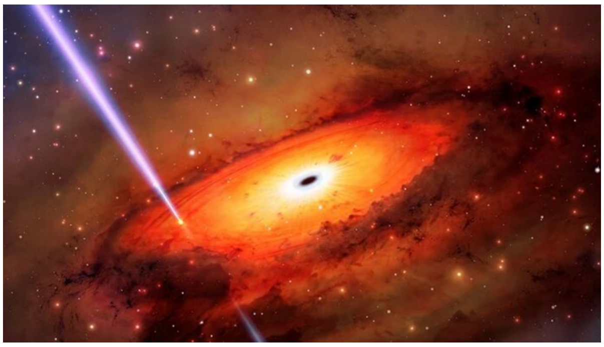


Image Credit: International Gemini Observatory/NOIRLab/NSF/AURA/M. Garlick/M. Zamani

International Gemini Observatory traces gamma-ray burst to nucleus of ancient galaxy, suggesting stars can undergo demolition-derby-like collisions.

Astronomers studying a powerful gamma-ray burst (GRB) with the Gemini South telescope, operated by NSF's NOIRLab, may have detected a never-before-seen way to destroy a star. Unlike most GRBs, which are caused by exploding massive stars or the chance mergers of neutron stars, astronomers have concluded that this GRB came instead from the collision of stars or stellar remnants in the jam-packed environment surrounding a supermassive black hole at the core of an ancient galaxy.

Most stars in the Universe die in predictable ways, depending on their mass. Relatively low-mass stars like our Sun slough off their outer layers in old age and eventually fade to become white dwarf stars. More massive stars burn brighter and die sooner in cataclysmic supernova explosions, creating ultra dense objects like neutron stars and black holes. If two such stellar remnants form a binary system, they also can eventually collide. New research, however, points to a long-hypothesized, but never-before-seen, fourth option.

While searching for the origins of a long-duration gamma-ray burst (GRB), astronomers using the Gemini South telescope in Chile, part of the International Gemini Observatory operated by NSF's NOIRLab, and other telescopes [1], have uncovered evidence of a demolition-derby-like collision of stars or stellar remnants in the chaotic and densely packed region near an ancient galaxy's supermassive black hole.

"These new results show that stars can meet their demise in some of the densest regions of the Universe where they can be driven to collide," said Andrew Levan, an astronomer with Radboud University in The Netherlands and lead author of a paper appearing in the journal Nature Astronomy. "This is exciting for understanding how stars die and for answering other questions, such as what unexpected sources might create gravitational waves that we could detect on Earth."

Ancient galaxies are long past their star-forming prime and would have few, if any, remaining giant stars, the principal source of long GRBs. Their cores, however, are teeming with stars and a menagerie of ultra-dense stellar remnants, such as white dwarf stars, neutron stars, and black holes. Astronomers have long suspected that in the turbulent beehive of activity surrounding a supermassive black hole, it would only be a matter of time until two stellar objects collide to produce a GRB. Evidence for that type of merger, however, has been elusive.

The first hints that such an event had occurred were seen on 19 October 2019 when NASA's Neil Gehrels Swift Observatory detected a bright flash of gamma rays that lasted for a little more than one minute. Any GRB lasting more than two seconds is considered "long." Such bursts typically come from the supernova death of stars at least 10 times the mass of our Sun -- but not always.

The researchers then used Gemini South to make long-term observations of the GRB's fading afterglow to learn more about its origins. The observations allowed the astronomers to pinpoint the location of the GRB to a region less than 100 light-years from the nucleus of an ancient galaxy, which placed it very near the galaxy's supermassive black hole. The researchers also found no evidence of a corresponding supernova, which would leave its imprint on the light studied by Gemini South.

"Our follow-up observation told us that rather than being a massive star collapsing, the burst was most likely caused by the merger of two compact objects," said Levan. "By pinpointing its location to the centre of a previously identified ancient galaxy, we had the first tantalizing evidence of a new pathway for stars to meet their demise."

In normal galactic environments, the production of long GRBs from colliding stellar remnants such as neutron stars and black holes is thought to be vanishingly rare. The cores of ancient galaxies, however, are anything but normal and there may be a million or more stars crammed into a region just a few light-years across. Such extreme population density may be great enough that occasional stellar collisions can occur, especially under the titanic gravitational influence of a supermassive black hole, which would perturb the motions of stars and send them careening in random directions. Eventually, these wayward stars would intersect and merge, triggering a titanic explosion that could be observed from vast cosmic distances.

It is possible that such events occur routinely in similarly crowded regions across the Universe but have gone unnoticed until this point. A possible reason for their obscurity is that galactic centres are brimming with dust and gas, which could obscure both the initial flash of the GRB and the resulting afterglow. This particular GRB, identified as GRB 191019A, may be a rare exception, allowing astronomers to detect the burst and study its after effects.

The researchers would like to discover more of these events. Their hope is to match a GRB detection with a corresponding gravitational-wave detection, which would reveal more about their true nature and confirm their origins, even in the murkiest of environments. The Vera C. Rubin Observatory, when it comes online in 2025, will be invaluable in this kind of research.

"Studying gamma-ray bursts like these is a great example of how the field is really advanced by many facilities working together, from the detection of the GRB, to the discoveries of afterglows and distances with telescopes like Gemini, through to detailed dissection of events with observations across the electromagnetic spectrum," said Levan.

"These observations add to Gemini's rich heritage developing our understanding of stellar evolution," says Martin Still, NSF's program director for the International Gemini Observatory. "The time sensitive observations are a testament to Gemini's nimble operations and sensitivity to distant, dynamic events across the Universe."

- Earth was created much faster than we thought: This makes the chance of finding other habitable planets in the Universe more likely

Date: June 14, 2023
Source: University of Copenhagen - The Faculty of Health and Medical Sciences

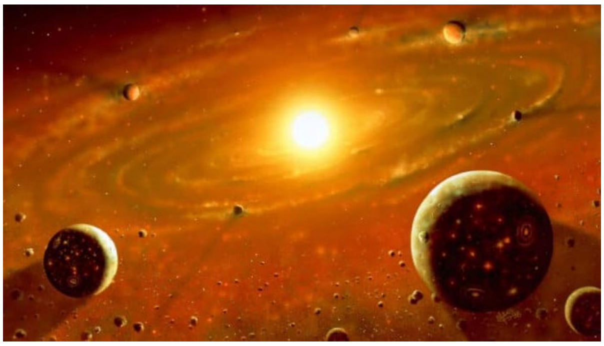


Illustration of a planet forming disk surrounding the young Sun. Rocky planets grow from the rapid accumulation of small pebbles. Credit: University of Copenhagen

Over the past decades, researchers thought Earth was created over a period of more than 100 million years. However, a new study from UCPH suggests that the creation of Earth was much more rapid, and that water and other essential ingredients for life were delivered to Earth very early on.

When we walk around in our everyday life, we might not think of the Earth itself very often. But this planet is the foundation of our life. The air we breathe, the water we drink and the gravity that pins us to the ground.

Up until now, researchers believed that it took more than 100 million years for the Earth to form. And it was also common belief that water was delivered by lucky collisions with water-rich asteroids like comets.

However, a new study from the University of Copenhagen suggests that it might not have happened entirely by chance.

"We show that the Earth formed by the very fast accumulation of small millimetre-sized pebbles. In this mechanism, the Earth was formed in just a few million years. Based on our findings, it appears that the presence of water on Earth is a byproduct of its formation" says Martin Bizzarro, who is a Professor at Globe Institute and one of the researchers behind the new study.

The results of the research not only show that the Earth was created much faster than previously thought, but that the presence of water is a predicted outcome of its formation process. This is important knowledge because it tells us something about planets outside our own Solar System.

"With this new planet formation mechanism, the chance of having habitable planets in the galaxy is much higher than we previously thought," says Martin Bizzarro.

A greater chance of water on other planets

Habitability is the potential for a planet to have the right ingredients at its surface for life to develop. One key ingredient for habitability is water.

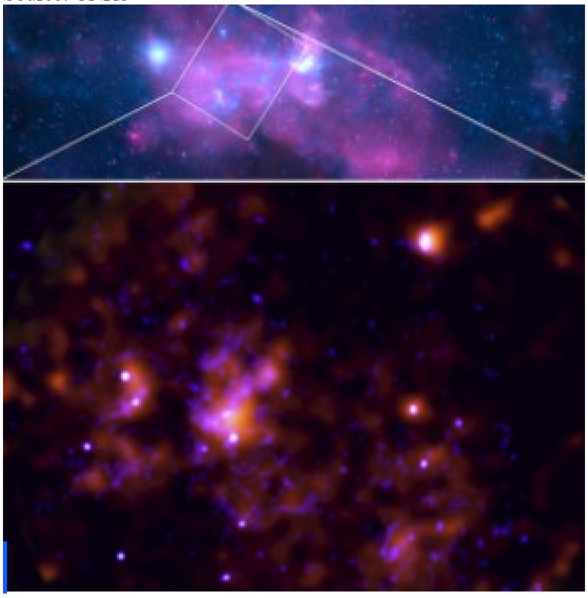
"People have debated how planets form for a long time. One theory is that planets are formed by the gradual collision of bodies, progressively increasing their size over 100 million years. In this scenario, the presence of water on Earth would need a sort of chance event," says Associate Professor Martin Schiller who is also behind the new study.
An example of this could be if comets, which are icy bodies, bombarded the surface of Earth towards the end of its formation.
"If that is how Earth was formed, then it is pretty lucky that we have water on Earth. This makes the chances that there is water on planets outside our Solar System very low," says Martin Schiller.
Instead, the researchers behind the new study suggests a new theory of how Earth was created.
"There was a disk around the young Sun where the planets were growing. The disk was filled with small dust particles. Once a planet reaches a certain size, it sorts of act like a vacuum cleaner, sucking up all that dust very quickly. And that makes it grow to the size of Earth in just a few million years," says Ph.D. student Isaac Onyett, who is the corresponding author of the study.
This vacuuming of small dust particles not only played a vital role in Earth's formation but made sure that water was delivered to our planet.
"The disk also contains many icy particles. As the vacuum cleaner effect draws in the dust, it also captures a portion of the ice. This process contributes to the presence of water during Earth's formation, rather than relying on a chance event delivering water 100 million years later," says Isaac Onyett.
With the new knowledge and understanding of the mechanisms there is a much greater chance of water being present on other planets.
"This theory would predict that whenever you form a planet like Earth, you will have water on it. If you go to another planetary system where there is a planet orbiting a star the size of the Sun, then the planet should have water if it is in the right distance," says Martin Bizzarro.

How the researchers did

The researchers used silicon isotopes as a tool to understand the mechanisms and timescales of planet formation. By analysing the isotopic composition of more than 60 different meteorites and planetary bodies, the researchers were able to establish genetic relationships between rocky planets like Earth and Mars and other celestial objects. This approach allowed the researchers to of the type of building blocks that assembled to form Earth, and the process by which they came together.

- ❖ Detection of an echo emitted by our Galaxy's black hole 200 years ago

Date: June 21, 2023
Source: CNRS



An international team of scientists has discovered that Sagittarius A* (Sgr A*)[1], the supermassive black hole at the centre of the Milky Way, emerged from a long period of dormancy some 200 years ago. The team, led by Frédéric Marin[2], a CNRS researcher at the Astronomical Strasbourg Observatory (CNRS/University of Strasbourg), has revealed the past awakening of this gigantic object, which is four million times more massive than the Sun. Their work is published in *Nature* on 21 June. Over a period of one year at the beginning of the 19th century, the black hole gobbled up cosmic objects that got a little too close to it, before once more entering a state of quiescence.
No effect was felt on Earth, as the distance between Sgr A* and our planet is too great (about two billion times the distance from the Earth to the Sun). However, the X-ray echo detected, which was emitted about 200 years ago, reveals that the original intensity was at least a million times greater than that currently emitted by Sgr A*. To get an idea of the increase in intensity of the X-ray emission when the black hole emerged from its quiescent state, it is as if a single glow-worm hidden in a forest suddenly became as bright as the Sun. These findings explain why galactic molecular clouds near Sgr A* are

shining more brightly than usual: it is because they are reflecting the X-rays emitted by Sgr A* 200 years ago.
To carry out their research, the scientists used NASA's IXPE (*Imaging X-ray Polarimetry Explorer)* satellite[3], which was for the very first time able to detect the polarisation of this X-ray light with great precision and also determine its source, something that had previously proved impossible. Rather like a compass, the polarised X-ray light[4] points directly to its source, Sgr A*, even though the latter is now virtually extinct. The scientists are continuing their work on Sgr A* to try to determine the physical mechanisms required for a black hole to switch from a quiescent state to an active one.

Footnotes

1. Pronounced 'Sagittarius A star'.
2. The scientists are from laboratories in Japan, the United States, Italy, Hong Kong, Canada, Russia, Germany, the Czech Republic, the United Kingdom, Finland, Spain, the Netherlands, China and France (Observatoire Astronomique de Strasbourg (CNRS/Université de Strasbourg) and Institut de Planétologie et d 'Astrophysique de Grenoble (CNRS/Université Grenoble Alpes)).
3. They combined this data with that obtained from the European Space Agency's XMM-Newton and NASA's Chandra missions.
4. Polarisation refers to the preferred direction of the oscillations of the electric field of a light wave.

- Einstein and Euler put to the test at the edge of the Universe

Date: June 22, 2023
Source: Université de Genève

Credit: CC0 Public Domain

The cosmos is a unique laboratory for testing the laws of physics, in particular those of Euler and Einstein. Euler described the movements of celestial objects, while Einstein described the way in which celestial objects distort the Universe. Since the discovery of dark matter and the acceleration of the Universe's expansion, the validity of their equations has been put to the test: are they capable of explaining these mysterious phenomena? A team from the University of Geneva (UNIGE) has developed the first method to find out. It considers a never-before-used measure: time distortion. The results are published in *Nature Astronomy*.
The theories of Leonhard Euler (1707-1783) and Albert Einstein (1879-1955) revolutionised our understanding of the Universe. With the famous equation that bears his name, Euler gave scientists a powerful tool for calculating the movements of galaxies in the Universe. With his theory of general relativity, Einstein demonstrated that the Universe is not a static framework: it can be distorted by star clusters and galaxies. Physicists have tested these equations in all sorts of ways, which have so far proved successful. However, two discoveries continue to put these models to the test: the acceleration of the Universe's expansion and the existence of invisible dark matter, which is thought to account for 85% of all matter in the cosmos. Do these mysterious phenomena still obey the equations of Einstein and Euler? Researchers are still unable to answer this question.

The missing ingredient

"The problem is that current cosmological data do not allow us to differentiate between a theory that breaks Einstein's equations and one that breaks Euler's equation. This is what we demonstrate in our study. We also present a mathematical method for solving this problem. This is the culmination of ten years of research," explains Camille Bonvin, associate professor in the Department of Theoretical Physics in the UNIGE Faculty of Science and first author of the study.
Researchers were unable to differentiate between the validity of these two equations at the very edge of the Universe because they were missing an "ingredient": the measurement of time distortion. "Until then, we only knew how to measure the speed of celestial objects and the sum of the distortion of time and space. We have developed a method for accessing this additional measurement, and it's a first," says Camille Bonvin.

If the time distortion is not equal to the sum of time and space -- i.e., the result produced by the theory of general relativity -- this means that Einstein's model does not work. If the time distortion does not correspond to the speed of the galaxies calculated with the Euler equation, this means that the latter is not valid. "This will allow us to discover whether new forces or matter, which violate these two theories, exist in the Universe," explains Levon Pogosian, professor in the Department of Physics at Simon Fraser University, in Canada, and co-author of the study.

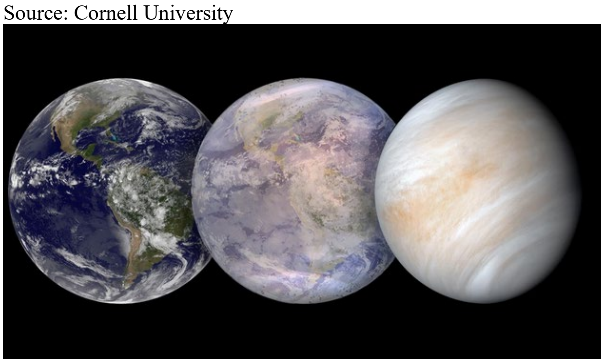
Reality check

These results will make a crucial contribution to several missions whose aim is to determine the origin of the accelerated expansion of the Universe and the nature of dark matter. These include the EUCLID space telescope, which will be launched in July 2023 by the European Space Agency (ESA), in collaboration with the UNIGE, and the Dark Energy Spectroscopic Instrument (DESI), which began its 5-year mission in 2021 in Arizona. There is also the international SKA (Square Kilometre Array) giant radio telescope project in South Africa and Australia, which will begin observations in 2028/29.

"Our method will be integrated into these different missions. This is already the case for DESI, whom we have become external collaborators thanks to this research," Camille Bonvin enthuses. The research team has successfully tested its model on synthetic catalogues of galaxies. The next stage will involve testing it using the first data supplied by DESI, as well as identifying the obstacles and minimising the systematic features that could hamper its application.

- Exoplanet may reveal secrets about the edge of habitability

Date: June 21, 2023
Source: Cornell University



Artist impression showing the exoplanet LP 890-9c's potential evolution from a hot Earth to a desiccated Venus. Credit: R. Payne/Carl Sagan Institute.

How close can a rocky planet be to a star, and still sustain water and life? A recently discovered exoplanet may be key to solving that mystery.

"Super-Earth" LP 890-9c (also named SPECULOOS-2c) is providing important insights about conditions at the inner edge of a star's habitable zone and why Earth and Venus developed so differently, according to new research led by Lisa Kaltenegger, associate professor of astronomy at Cornell University.

Her team found LP 890-9c, which orbits close to the inner edge of its solar system's habitable zone, would look vastly different depending on whether it still had warm oceans, a steam atmosphere, or if it had lost its water -- assuming it once had oceans like Earth's.

"Looking at this planet will tell us what's happening on this inner edge of the habitable zone -- how long a rocky planet can maintain habitability when it starts to get hot," Kaltenegger said. "It will teach us something fundamental about how rocky planets evolve with increasing starlight, and about what will one day happen to us and Earth."

Kaltenegger is the lead author of "Hot Earth or Young Venus? A Nearby Transiting Rocky Planet Mystery," published in *Monthly Notices of the Royal Astronomical Society: Letters.*

LP 890-9c is one of two super-Earths orbiting a red dwarf star located 100 light years from Earth, researchers announced last year. They said liquid water or an atmosphere rich in water vapor was possible on LP 890-9c, which is about 40% larger than Earth and circles the small, cool star in 8.5 days.

Those criteria suggested it to be one of the best targets for JWST to study among the known, potentially habitable terrestrial planets, in addition to the TRAPPIST-1 system.

The team's models are the first to detail differences in the chemical signatures generated by rocky planets near the habitable zone's interior boundary, based on variables including the planet's size, mass, chemical makeup, surface temperature and pressure, atmospheric height and cloud cover. The calculations were key to estimating how much time JWST would need to confirm the basic composition of an atmosphere -- if there is one.

The models span several scenarios thought to reflect stages of rocky planets' evolution, ranging from a "hot Earth" where life might still be possible, to a desolate Venus featuring a carbon dioxide atmosphere. In between are phases Earth is expected to experience as the sun grows brighter and hotter with age, causing the oceans to gradually evaporate and fill the atmosphere with steam before boiling off entirely.

How long those processes might take is unknown, and the astronomers say LP 890-9c provides a rare opportunity to explore that evolution.

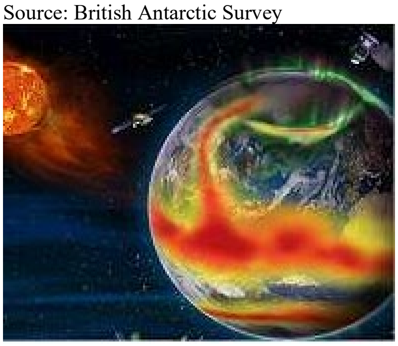
"This planet is the first target where we can test these different scenarios," Kaltenegger said. "If it's still a hotter Earth -- hot, but with liquid water and conditions for life -- then the timeline is slower than we thought. If we see that it's already a full-blown Venus, then the water gets lost fast."

It's possible that LP 890-9c has no atmosphere and hosts no life, or that it resembles a Venus with thick clouds that would block light from reflecting and thus yield little information. Deeper investigation promises to provide valuable clues, Kaltenegger said.

"We don't know what this planet on the edge of habitability could be like, so we have to look," she said. "This is what real exploration is about."

- Scientists report 'benchmarks' for extreme space weather

Date: June 15, 2023
Source: British Antarctic Survey



High-energy 'relativistic' electrons -- so-called "killer" electrons -- are a major source of radiation damage to satellites and so understanding their patterns of activity is crucial. Bursts of charged particles and magnetic fields from the Sun can tear open the Earth's magnetic field, giving rise to geomagnetic storms. During these events the number of killer electrons in the outer radiation belt can increase by orders of magnitude and become a significant space weather hazard.

Dr Nigel Meredith of BAS led an international team who analysed 20 years of data from a US GPS satellite to determine the 1 in 10, 1 in 50, and 1 in 100-year event levels. A 1 in 100-year event is an event of a size that will be equalled or exceeded on average once every 100 years.

Satellite operators, manufacturers, insurers, and governments need to prepare and mitigate against the risks posed by these electrons.

Society is increasingly reliant on satellites for a variety of applications including communication, navigation, Earth observation and defence. As of April 2022, there were 5,465 operational satellites in Earth orbit, and most are exposed to energetic electrons for at least some of their orbit. In 2021, the overall global space economy generated revenues of $386 billion, an increase of four percent compared to the previous year.

Dr Nigel Meredith, space weather scientist and lead author of the study says:

"The 1 in 100-year event levels reported in this study are important for industry and government. They serve as benchmarks against which to compare other extreme space weather events and to assess the potential impact of an extreme event."

These findings are vitally important to the satellite industry as engineers and operators require realistic estimates of the largest electron fluxes encountered in GPS orbit to prepare for the impacts of these extreme events and to improve the resilience of future satellites. The findings are essential for satellite insurers to help them ensure satellite operators are doing all they can to reduce risk and to evaluate realistic disaster scenarios

The difference between the 1 in 10 year and 1 in 100-year event varies depending on the energy of the electrons and the distance from Earth. These differences are largest at the highest energies furthest from the planet, varying between a factor of 3 and 10 for some of the highest electron energies over 35,000 km from the Earth's surface. Such substantial increases could pose a significant additional risk to satellites operating in this region.

Like weather on our planet, space weather can vary greatly over minutes, days, seasons and the 11-year solar cycle. The researchers found that the majority of these killer electron events occurred during the solar cycle's declining phases -- seen twice during the 20-year period they studied -- but the largest event was elsewhere, showing that extreme events can happen at any time.

Severe space weather was added to the UK National Risk Register of Civil Emergencies in 2011. The impacts of space weather on satellites can range from momentary interruptions of service to total loss of capabilities. In 2003 a major storm caused 47 satellites to experience anomalies, over 10 to be out of action for more than a day and one was a complete loss.

- Weigh a quasar's galaxy with precision

Date: June 3, 2023
Source: Ecole Polytechnique Fédérale de Lausanne

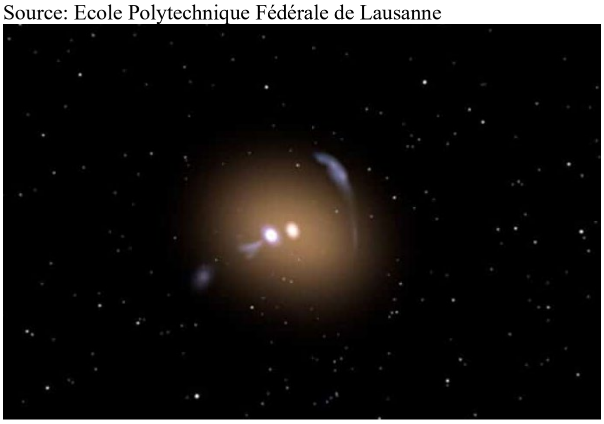


Illustration of quasar lensing. CREDIT: EPFL / Austin Peel

A team of researchers from EPFL have found a way to use the phenomenon of strong gravitational lensing to determine with precision -- about 3 times more precise than any other technique -- the mass of a galaxy containing a quasar, as well as their evolution in cosmic time. Knowing the mass of quasar host galaxies provides insight into the evolution of galaxies in the early universe, for building scenarios of galaxy formation and black hole development. The results are published in *Nature Astronomy*.

"The unprecedented precision and accuracy achieved with gravitational lensing provide a new avenue for obtaining robust mass estimates in the distant Universe, where conventional techniques lack precision and are susceptible to biases," says EPFL astrophysicist Frédéric Courbin, senior author of the study.

"The masses of host galaxies have been measured in the past, but thanks to gravitational lensing, this is the first time that the measurement is so precise in the distant Universe," explains Martin Millon, lead author of the study and currently at Stanford University on an SNF grant.

Combining gravitational lensing and quasars

A quasar is a luminous manifestation of a supermassive black hole that accretes surrounding matter, sitting at the centre of a host galaxy. It is generally difficult to measure how heavy a quasar's host galaxy is because quasars are very distant objects, and also because they are so bright that they overshine anything within its vicinity.

Gravitational lensing allows us to compute the mass of the lensing object. Thanks to Einstein's theory of gravitation, we know how massive objects in the foreground of the night sky -- the gravitational lens -- can bend light coming from background objects. Resulting are strange rings of light, that are actually distortions of the background object's light by the gravitational lens.

Courbin was cycling to the Sauverny Observatory, over a decade ago, when he realized that he could combine the two -- quasars and gravitational lensing -- to measure the mass of a quasar's host galaxy. For this, he had to find a quasar in a galaxy that also acts as a gravitational lens.

A handful of gravitational lensing quasars observed so far

The Sloan Digital Sky Survey (SDSS) database was a great place to search for gravitational lensing quasars candidates, but to be sure, Courbin had to see the lensing rings. In 2010, he and colleagues commissioned time on the Hubble Space Telescope to observe 4 candidates of which 3 showed lensing. Of the three, one stood out due to its characteristic gravitational lensing rings: SDSS J0919+2720.

The HST image of SDSS J0919+2720 shows two bright objects in the foreground that each act as a gravitational lens, "probably two galaxies in the process of merging," explains Courbin. The one on the left is a bright quasar, within a host galaxy too dim to be observed. The bright object on the right is another galaxy, the main gravitational lens. A faint object on the far left is a companion galaxy. The characteristic rings are deformed light coming from a background galaxy.

Computational lens modelling to the rescue

By carefully analysing the gravitationally lensed rings in SDSS J0919+2720, it is possible to determine the mass of the two bright objects… in principle. Disentangling the masses of the various objects would have been impossible without the recent development of a wavelet-based lens modelling technique by co-author Aymeric Galan, currently at the Technical University of Münich (TUM), also on an SNF grant.

"One of the biggest challenges in astrophysics is to understand how a supermassive black hole forms," explains Galan. "Knowing its mass, how it compares to its host galaxy and how it evolves through cosmic times, are what allows us to discard or validate certain formation theories."

"In the local Universe, we observe that the most massive galaxies also host the most massive black holes at their centre. This could suggest that the growth of galaxies is regulated by the amount of energy radiated by their central black hole and injected into the galaxy. However, to test this theory, we still need to study these interactions not only locally but also in the distant Universe," explains Millon.

Gravitational lensing events are very rare, with one galaxy in a thousand unveiling the phenomenon. Since quasars are seen in about one every thousand galaxies a quasar acting as a lens is one in a million. The scientists expect to detect hundreds of these lensing quasars with the ESA-NASA mission Euclid, to be launched this summer with a Falcon-9 SpaceX rocket.

- Researchers demystify the unusual origin of the Geminids meteor shower

Date: June 15, 2023
Source: Princeton University

The Geminids meteor shower. (Image Credit: NASA).

The Geminids meteoroids light up the sky as they race past Earth each winter, producing one of the most intense meteor showers in our night sky.

Mysteries surrounding the origin of this meteoroid stream have long fascinated scientists because, while most meteor showers are created when a comet emits a tail of ice and dust, the Geminids stem from an asteroid -- a chunk of rock that normally does not produce a tail. Until recently, the Geminids had only been studied from Earth.

Now, Princeton researchers used observations from NASA's Parker Solar Probe mission to deduce that it was likely a violent, catastrophic event -- such as a high-speed collision with another body or a gaseous explosion -- that created the Geminids. The findings, which were published in the *Planetary Science Journal* on June 15, narrow down hypotheses about this asteroid's composition and history that would explain its unconventional behaviour.

"Asteroids are like little time capsules for the formation of our solar system," said Jamey Szalay, research scholar at the Princeton University space physics laboratory and co-author on the paper. "They were formed when our solar system was formed, and understanding their composition gives us another piece of the story."

An unusual asteroid

Unlike most known meteor showers that come from comets, which are made of ice and dust, the Geminids stream seems to originate from an asteroid -- a chunk of rock and metal -- called 3200 Phaethon.

"Most meteoroid streams are formed via a cometary mechanism, it's unusual that this one seems to be from an asteroid," said Wolf Cukier, undergraduate class of 2024 at Princeton and lead author on the paper. "Additionally, the stream is orbiting slightly outside of its parent body when it's closest to the sun, which isn't obvious to explain just by looking at it," he added, referring to a recent study with Parker Solar Probe images of the Geminids led by Karl Battams of the Naval Research Laboratory.

When a comet travels close to the Sun it gets hotter, causing the ice on the surface to release a tail of gas, which in turn drags with it little pieces of ice and dust. This material continues to trail behind the comet as it stays within the Sun's gravitational pull. Over time, this repeated process fills the orbit of the parent body with material to form a meteoroid stream.

But because asteroids like 3200 Phaethon are made of rock and metal, they are not typically affected by the Sun's heat the way comets are, leaving scientists to wonder what causes the formation of 3200 Phaethon's stream across the night sky.

"What's really weird is that we know that 3200 Phaethon is an asteroid, but as it flies by the Sun, it seems to have some kind of temperature-driven activity," Szalay said. "Most asteroids don't do that."

Some researchers have suggested that 3200 Phaethon may actually be a comet that lost all of its snow, leaving only a rocky core resembling an asteroid. But the new Parker Solar Probe data show that although some of 3200 Phaethon's activity is related to temperature, the creation of the Geminids stream was likely not caused by a cometary mechanism, but by something much more catastrophic.

Opening the time capsule

To learn about the origin of the Geminids stream, Cukier and Szalay used the new Parker Solar Probe data to model three possible formation scenarios, then compared these models to existing models created from Earth-based observations.

"There are what's called the 'basic' model of formation of a meteoroid stream, and the 'violent' creation model," Cukier said. "It's called 'basic' because it's the most straight-forward thing to model, but really these processes are both violent, just different degrees of violence."

These different models reflect the chain of events that would transpire according to the laws of physics based on different scenarios. For example, Cukier used the basic model to simulate all of the chunks of material releasing from the asteroid with zero relative velocity -- or with no speed or direction relative to 3200 Phaethon -- to see what the resulting orbit would look like and compare it to the orbit shown by the Parker Solar Probe data.

He then used the violent creation model to simulate the material releasing from the asteroid with a relative velocity of up to one kilometre per hour, as if the pieces were knocked loose by a sudden, violent event.

He also simulated the cometary model -- the mechanism behind the formation of most meteoroid streams. The resulting simulated orbit matched the least with the way the Geminids orbit actually appears according to the Parker Solar Probe data, so they ruled out this scenario.

In comparing the simulated orbits from each of the models, the team found that the violent models were most consistent with the Parker Solar Probe data, meaning it's likely that a sudden, violent event -- such as a high-speed collision with another body or a gaseous explosion, among other possibilities -- created the Geminids stream.

The research builds on the work of Szalay and several colleagues of the Parker Solar Probe mission, built and assembled at the Johns Hopkins Applied Physics Laboratory (APL) in Laurel, Maryland, to assemble a picture of the structure and behaviour of the large cloud of dust that swirls through the innermost solar system.

They took advantage of Parker's flight path -- an orbit that swings it just millions of miles from the Sun, closer than any spacecraft in history -- to get the best direct look at the dusty cloud of grains shed from passing comets and asteroids.

Although the probe doesn't measure dust particles directly, it can track dust grains in a clever way: as dust grains pelt the spacecraft along its path, the high-velocity impacts create plasma clouds. These impact clouds produce unique signals in electric potential that are picked up by several sensors on the probe's FIELDS instrument, which is designed to measure the electric and magnetic fields near the Sun.

"The first-of-its-kind data our spacecraft is gathering now will be analysed for decades to come," said Nour Raouafi, Parker Solar Probe project scientist at APL. "And it's exciting to see scientists of all levels and skills digging into it to shed light on the Sun, the solar system and the universe beyond."

Reaching for the stars

Cukier said his passion for learning about outer space combined with departmental support are what motivated him to pursue this project.

After taking a hands-on lab class offered by the Princeton space physics laboratory -- where he gained practical experience building space instruments, like those currently sampling the Sun's environment aboard Parker Solar Probe -- and serving as treasurer for the undergraduate astronomy club, he decided he wanted to pursue extracurricular research.

He was met with enthusiasm when he reached out to scientists in the Princeton Space Physics group. "Everyone is very supportive of undergraduate research, especially in astrophysics, because it's really part of the departmental culture," he said.

"It's always wonderful when our students like Wolf can contribute so strongly to this sort of space research," said David McComas, head of the Space Physics group and vice president

for the Princeton Plasma Physics Laboratory (PPPL). "Many of us have been in awe of the Geminids meteor displays for years and it is awesome to finally have the data and research to show how they likely formed."
Cukier said that he's been drawn to watching the sky since he was a kid. "Planetary science is surprisingly accessible," he said. "For the Geminids, for instance, anyone can go outside on December 14 this year at night and look up. It's visible from Princeton, and some of the meteors are really bright. I'd highly recommend seeing it."
"Formation, Structure, and Detectability of the Geminids Meteoroid Stream" by W.Z. Cukier and J.R. Szalay was published June 15, 2023 by Planetary Science Journal (DOI 10.3847/PSJ/acd538). The research was supported by the Parker Solar Probe Guest Investigator Program (80NSSC21K1764). Parker Solar Probe is part of NASA's Living with a Star program to explore aspects of the Sun-Earth system that directly affect life and society. The program is managed by NASA's Goddard Space Flight Centre for the Heliophysics Division of NASA's Science Mission Directorate. APL manages the Parker Solar Probe mission for NASA.

- Discovery of white dwarf pulsar sheds light on star evolution

Date: June 15, 2023
Source: University of Warwick

Artist's impression of a white dwarf pulsar. In this binary star system, a rapidly spinning white dwarf (right) accelerates electrons to nearly the speed of light. These high-energy particles produce bursts of radiation that strike the accompanying red dwarf star (left), causing the entire system to pulsate from the radio to the X-ray range.

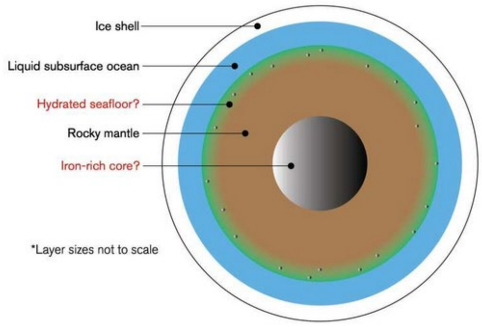
Credit: M. Garlick/University of Warwick/ESO

The discovery of a rare type of white dwarf star system provides new understanding into stellar evolution.
White dwarfs are small, dense stars typically the size of a planet. They are formed when a star of low mass has burnt all its fuel, losing its outer layers. Sometimes referred to as "stellar fossils," they offer insight into different aspects of star formation and evolution.
A rare type of white dwarf pulsar has been discovered for the second time only, in research led by the University of Warwick. White dwarf pulsars include a rapidly spinning, burnt-out stellar remnant called a white dwarf, which lashes its neighbour -- a red dwarf -- with powerful beams of electrical particles and radiation, causing the entire system to brighten and fade dramatically over regular intervals. This is owing to strong magnetic fields, but scientists are unsure what causes them.
A key theory which explains the strong magnetic fields is the "dynamo model" -- that white dwarfs have dynamos (electrical generators) in their core, as does the Earth, but much more powerful. But for this theory to be tested, scientists needed to search for other white dwarf pulsars to see if their predictions held true.
Published today in *Nature Astronomy*, scientists funded by the UK Science and Technology Facilities Council (STFC) describe the newly detected white dwarf pulsar, J191213.72-441045.1 (J1912-4410 for short). It is only the second time such a star system has been found, following the discovery of AR Scorpii (AR Sco) in 2016.
773 light years away from Earth and spinning 300 times faster than our planet, the white dwarf pulsar has a size similar to the Earth, but a mass at least as large as the Sun. This means that a teaspoon of white dwarf material would weigh around 15 tons. White dwarfs begin their lives at extremely hot temperatures before cooling down over billions of years, and the low temperature of J1912−4410 points to an advanced age.
Dr Ingrid Pelisoli, University of Warwick's Department of Physics, said: "The origin of magnetic fields is a big open question in many fields of astronomy, and this is particularly true for white dwarf stars. The magnetic fields in white dwarfs can be more than a million times stronger than the magnetic field of the Sun, and the dynamo model helps to explain why. The discovery of J1912−4410 provided a critical step forward in this field.
"We used data from a few different surveys to find candidates, focusing on systems that had similar characteristics to AR Sco. We followed up any candidates with ULTRACAM, which detects the very fast light variations expected of white dwarf pulsars. After observing a couple dozen candidates, we found one that showed very

similar light variations to AR Sco. Our follow-up campaign with other telescopes revealed that every five minutes or so, this system sent a radio and X-ray signal in our direction.
"This confirmed that there are more white dwarf pulsars out there, as predicted by previous models. There were other predictions made by the dynamo model, which were confirmed by the discovery of J1912−4410. Due to their old age, the white dwarfs in the pulsar system should be cool. Their companions should be close enough that the gravitational pull of the white dwarf was in the past strong enough to capture mass from the companion, and this causes them to be fast spinning. All of those predictions hold for the new pulsar found: the white dwarf is cooler than 13,000K, spins on its axis once every five minutes, and the gravitational pull of the white dwarf has a strong effect in the companion.
"This research is an excellent demonstration that science works -- we can make predictions and put them to test, and that is how any science progresses."
Dr Pelisoli is one of the first group of research fellows and PhD students supported by a £3.5 million private philanthropic donation from a Warwick alumnus. One of the largest gifts towards the study of astronomy and astrophysics in the UK, the donation is enabling the next generation of astronomers to explore the furthest reaches of our universe.
Axel Schwope, Leibniz Institute for Astrophysics Potsdam (AIP), who is leading a complementary study published as a letter in Astronomy and Astrophysics, added: "We are excited to have independently found the object in the X-ray all-sky survey performed with SRG/eROSITA. The follow-up investigation with the ESA satellite XMM-Newton revealed the pulsations in the high-energy X-ray regime, thus confirming the unusual nature of the new object and firmly establishing the white dwarf pulsars as a new class."

- Jupiter's moon Europa may have had a slow evolution

Date: June 17, 2023
Source: Arizona State University



Internal evolution of Europa. Credit: Kevin Trinh/ASU

Jupiter's moon, Europa, is slightly smaller than Earth's Moon and is one of the most promising places to search for alien life.
Amid the Jovian system, Europa is of particular interest to scientists because of the strong evidence for nutrients, water and energy to potentially provide a habitable environment for some form of life beyond Earth. In addition, Europa is believed to be made up into four layers (from surface to centre): an ice shell, salt water ocean, rocky mantle, and metallic core.
Like Earth, Europa's ocean touches the rocky seafloor, which may allow for rock-water chemistry favourable for life. Some scientists also believe that the seafloor may host volcanoes, which can provide more energy and nutrients for a potential biosphere.
ASU scientists Kevin Trinh, Carver Bierson and Joe O'Rourke of the School of Earth and Space Exploration investigated the consequences of Europa forming with low initial temperatures, using computer code that Trinh wrote. Their findings have been recently published in *Science Advances.*

Hydrated rocks may be a key ingredient

Europa may have a metamorphic origin for the ocean. While some scientists speculated this, Trinh and his team show that if Europa indeed formed from hydrated rocks (i.e., rocks have hydrogen and oxygen), then enough of Europa's interior should get hot enough to release water directly from the hydrated rocks to form the ocean and ice shell.
"The origin of Europa's ocean is important because the moon's potential to support life ultimately depends on the chemical ingredients and physical conditions during the ocean formation process," said Kevin Trinh, graduate associate at ASU's School of Earth and Space Exploration.

Metallic core formation requires high temperatures

Many scientists studying this icy moon assumed that Europa formed with a metallic

core during or shortly after accretion. This ASU study contradicts that prediction, instead arguing that Europa may not have started forming its metallic core until billions of years after accretion (if it happened at all).
"For most worlds in the solar system we tend to think of their internal structure as being set shortly after they finish forming. This work is very exciting because it reframes Europa as a world whose interior has been slowly evolving over its whole lifetime. This opens doors for future research to understand how these changes might be observed in the Europa we see today," said Carver Bierson, postdoctoral research scholar at ASU's School of Earth and Space Exploration.
The existence of a metallic core is deeply tied to Europa's internal heat, which may also be used to drive seafloor volcanism and contribute to a habitable seafloor environment. However, it is unclear whether Europa generated enough heat to form such a core. Trinh's code calculates how heat is generated and distributed throughout a moon, which uses the same governing equations that many geodynamicists used for decades. The team's novel result, however, comes from challenging the assumptions common to Europa modelling: A small moon like Europa could form as a cold mixture of ice, rock, and metal.
However, all of these processes require a hot interior. A small moon like Europa (~1% of Earth's mass) may not have enough energy to trigger or sustain Earth-like processes -- metallic core formation, seafloor volcanism, and ongoing rock-water geochemistry -- which implies that Europa's habitable potential is uncertain. The exact time at which Europa formed determines how much heat is available from the radioactive decay of a short-lived isotope of aluminium. Tidal heating (from gravitational interactions with Jupiter and other moons) also governs how quickly Europa's interior separates into distinct layers.

Europa's seafloor may be cool, hydrated, and experience limited (if any) seafloor volcanism

This study implies that there may be limited hydrothermal activity and seafloor volcanism at Europa, which may hinder habitability. However, confident predictions require more data.
"Europa is not just a wet, baby Earth. It is its own special world, full of mysteries to unravel," said Joseph O'Rourke, Assistant Professor at ASU's School of Earth and Space Exploration. In October 2024, NASA plans to launch a spacecraft called Europa Clipper, which should arrive at Europa in April 2030. With the recent work by Trinh, Bierson and O'Rourke, scientists will be better equipped to interpret incoming data from Europa Clipper, whose main objective is to evaluate Jupiter's icy moon Europa for the potential conditions to host life.

- Long missions, frequent travel take a toll on astronauts' brains

Date: June 8, 2023
Source: University of Florida

Illustration of an expeditionary crew on Mars setting up drilling gear in a quest to use ice for sustaining a human presence on the Red Planet. Long space missions, like the trek to Mars, have measurable effects on the human brain, the implications of which remain unclear. (Image credit: NASA)

As we enter a new era in space travel, a study looking at how the human brain reacts to traveling outside Earth's gravity suggests frequent flyers should wait three years after longer missions to allow the physiological changes in their brains to reset.
Researchers studied brain scans of 30 astronauts from before and after space travel. Their findings, reported today in *Scientific Reports*, reveal that the brain's ventricles expand significantly in those who completed longer missions of at least six months, and that less than three years may not provide enough time for the ventricles to fully recover.
Ventricles are cavities in the brain filled with cerebrospinal fluid, which provides protection, nourishment and waste removal to the brain. Mechanisms in the human body effectively distribute fluids throughout the body, but in the absence of gravity, the fluid shifts upward, pushing the brain higher within the skull and causing the ventricles to expand.
"We found that the more time people spent in space, the larger their ventricles became," said Rachael Seidler, a professor of applied physiology and kinesiology at the University of Florida and an author of the study. "Many astronauts travel to space more than one time,

and our study shows it takes about three years between flights for the ventricles to fully recover."

Seidler, a member of the Norman Fixel Institute for Neurological Diseases at UF Health, said based on studies so far, ventricular expansion is the most enduring change seen in the brain resulting from spaceflight.

"We don't yet know for sure what the long-term consequences of this is on the health and behavioural health of space travellers," she said, "so allowing the brain time to recover seems like a good idea."

Of the 30 astronauts studied, eight travelled on two-week missions, 18 were on six-month missions, and four were in space for approximately one year. The ventricular enlargement tapered off after six months, the study's authors reported.

"The biggest jump comes when you go from two weeks to six months in space," Seidler said. "There is no measurable change in the ventricles' volume after only two weeks."

With increased interest in space tourism in recent years, this is good news, as shorter space junkets appear to cause little physiological changes to the brain, she said.

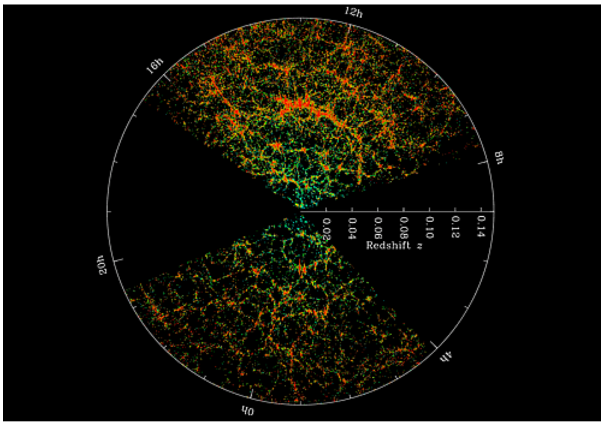
While researchers cannot yet study astronauts who have been in space much longer than a year, Seidler said it's also good news that the expansion of the brain's ventricles levels off after about six months.

"We were happy to see that the changes don't increase exponentially, considering we will eventually have people in space for longer periods," she said.

The results of the study, which was funded by NASA, could impact future decision-making regarding crew travel and mission planning, Seidler said.

- Astronomers discover new link between dark matter and clumpiness of the universe

Date: June 14, 2023
Source: University of Toronto



Sloan Digital Sky Survey

In a study published today in the *Journal of Cosmology and Astroparticle Physics,* researchers at the University of Toronto reveal a theoretical breakthrough that may explain both the nature of invisible dark matter and the large-scale structure of the universe known as the cosmic web. The result establishes a new link between these two longstanding problems in astronomy, opening new possibilities for understanding the cosmos.

The research suggests that the "clumpiness problem," which centres on the unexpectedly even distribution of matter on large scales throughout the cosmos, may be a sign that dark matter is composed of hypothetical, ultra-light particles called axions. The implications of proving the existence of hard-to-detect axions extend beyond understanding dark matter and could address fundamental questions about the nature of the universe itself.

"If confirmed with future telescope observations and lab experiments, finding axion dark matter would be one of the most significant discoveries of this century," says lead author Keir Rogers, Dunlap Fellow at the Dunlap Institute for Astronomy & Astrophysics in the Faculty of Arts & Science at the University of Toronto. "At the same time, our results suggest an explanation for why the universe is less clumpy than we thought, an observation that has become increasingly clear over the last decade or so, and currently leaves our theory of the universe uncertain."

Dark matter, comprising 85 percent of the universe's mass, is invisible because it does not interact with light. Scientists study its gravitational effects on visible matter to understand how it is distributed in the universe.

A leading theory proposes that dark matter is made of axions, described in quantum mechanics as "fuzzy" due to their wave-like behaviour. Unlike discrete point-like particles, axions can have wavelengths larger than entire galaxies. This fuzziness influences the formation and distribution of dark matter, potentially explaining why the universe is less clumpy than predicted in a universe without axions.

This lack of clumpiness has been observed in large galaxy surveys, challenging the other prevailing theory that dark matter consists only of heavy, weakly interacting sub-atomic particles called WIMPs. Despite experiments like the Large Hadron Collider, no evidence supporting the existence of WIMPs has been found.

"In science, it's when ideas break down that new discoveries are made and age-old problems are solved," says Rogers.

For the study, the research team -- led by Rogers and including members of associate professor Renée Hložek's research group at the Dunlap Institute, as well as from the University of Pennsylvania, Institute for Advanced Study, Columbia University and King's College London -- analysed observations of relic light from the Big Bang, known as the Cosmic Microwave Background (CMB), obtained from the Planck 2018, Atacama Cosmology Telescope and South Pole Telescope surveys. The researchers compared these CMB data with galaxy clustering data from the Baryon Oscillation Spectroscopic Survey (BOSS), which maps the positions of approximately a million galaxies in the nearby universe. By studying the distribution of galaxies, which mirrors the behaviour of dark matter under gravitational forces, they measured fluctuations in the amount of matter throughout the universe and confirmed its reduced clumpiness compared to predictions.

The researchers then conducted computer simulations to predict the appearance of relic light and the distribution of galaxies in a universe with long dark matter waves. These calculations aligned with CMB data from the Big Bang and galaxy clustering data, supporting the notion that fuzzy axions could account for the clumpiness problem.

Future research will involve large-scale surveys to map millions of galaxies and provide precise measurements of clumpiness, including observations over the next decade with the Rubin Observatory. The researchers hope to compare their theory to direct observations of dark matter through gravitational lensing, an effect where dark matter clumpiness is measured by how much it bends the light from distant galaxies, akin to a giant magnifying glass. They also plan to investigate how galaxies expel gas into space and how this affects the dark matter distribution to further confirm their results.

Understanding the nature of dark matter is one of the most pressing fundamental questions and key to understanding the origin and future of the universe.

Presently, scientists do not have a single theory that simultaneously explains gravity and quantum mechanics -- a theory of everything. The most popular theory of everything over the last few decades is string theory, which posits another level below the quantum level, where everything is made of string-like excitations of energy. According to Rogers, detecting a fuzzy axion particle could be a hint that the string theory of everything is correct.

"We have the tools now that could enable us to finally understand something experimentally about the century-old mystery of dark matter, even in the next decade or so -- and that could give us hints to answers about even bigger theoretical questions," says Rogers. "The hope is that the puzzling elements of the universe are solvable."

- A scorching-hot exoplanet scrutinized by astronomers

Date: June 14, 2023
Source: University of Montreal

The ultra-hot giant exoplanet WASP-76 b, studied here, is an extremely hot world orbiting very close to its giant star. Credit: NOIRLab

An international team led by Stefan Pelletier, a Ph.D. student at Université de Montréal's Trottier Institute for Research on Exoplanets announced today having made a detailed study of the extremely hot giant exoplanet WASP-76 b.

Using the MAROON-X instrument on the Gemini-North Telescope, the team was able to identify and measure the abundance of 11 chemical elements in the atmosphere of the planet.
Those include rock-forming elements whose abundances are not even known for giant planets in the Solar System such as Jupiter or Saturn. The team's study is published in the journal *Nature*.
"Truly rare are the times when an exoplanet hundreds of light years away can teach us something that would otherwise likely be impossible to know about our own Solar System," said Pelletier. "This is the case with this study."

A big, hot, strange world

WASP-76 b is a strange world. It reaches extreme temperatures because it is very close to its parent star, a massive star 634 light-years away in the constellation of Pisces: approximately 12 times closer than Mercury is to the Sun. With a mass similar to that of Jupiter, but almost six times bigger by volume, it is quite "puffy."
Since its discovery by the Wide-Angle Search for Planets (WASP) program in 2013, many teams have studied it and identified various elements in its atmosphere. Notably, in a study also published in *Nature* in March 2020, a team found an iron signature and hypothesised that there could be iron rain on the planet.
Aware of these studies, Pelletier became motivated to obtain new, independent observations of WASP-76 b using the MAROON-X high-resolution optical spectrograph on the Gemini-North 8-metre Telescope in Hawai'i, part of the International Gemini Observatory, operated by NSF's NOIRLab.
"We recognized that the powerful new MAROON-X spectrograph would enable us to study the chemical composition of WASP-76 b with a level of detail unprecedented for any giant planet," says UdeM astronomy professor Björn Benneke, co-author of the study and Stefan Pelletier's PhD research supervisor.

A composition similar to the Sun's

Within the Sun, the abundances of almost all elements in the periodic table are known with great accuracy. In the giant planets in our Solar System, however, that's true for only a handful of elements, whose compositions remain poorly constrained. And this has hampered understanding of the mechanisms governing the formation of these planets.
As it is so close to its star, WASP-76 b has a temperature well above 2000°C. At these degrees, many elements that would normally form rocks here on Earth (like magnesium and iron) are vaporised and present in gaseous form in the upper atmosphere. Studying this peculiar planet enables unprecedented insight into the presence and abundance of rock-forming elements in giant planets, since in colder giant planets like Jupiter these elements are lower in the atmosphere and impossible to detect.
The abundance of many elements measured by Pelletier and his team in the exoplanet's atmosphere -- such as manganese, chromium, magnesium, vanadium, barium and calcium -- matches those of its host star as well as of our own Sun very closely.
These abundances are not random: they are the direct product of the Big Bang, followed by billions of years of stellar nucleosynthesis, so scientists measure roughly the same composition in all stars. It is, however, different from the composition of rocky planets like Earth, which are formed in a more complex manner.
The results of this new study indicate that giant planets could maintain an overall composition that reflects that of the protoplanetary disc from which they formed.

Depletion of other elements very interesting

However, other elements were depleted in the planet compared to the star -- a result Pelletier found particularly interesting.
"These elements that appear to be missing in WASP-76 b's atmosphere are precisely those that require higher temperatures to vaporise, like titanium and aluminium, " he said. "Meanwhile, the ones that matched our predictions, like manganese, vanadium, or calcium, all vaporise at slightly lower temperatures."
The discovery team's interpretation is that the observed composition of the upper atmospheres of giant planets can be extremely sensitive to temperature. Depending on an element's temperature of condensation, it will be in gas form and present in the upper part of the atmosphere, or condense into liquid form where it will sink to deeper layers. When in gas form, it plays an important role in absorbing light and can be seen in astronomers' observations. When condensed, it cannot be detected by astronomers and

becomes completely absent from their observations.

"If confirmed, this finding would mean that two giant exoplanets that have slightly different temperatures from one another could have very different atmospheres, " said Pelletier. "Kind of like two pots of water, one at -1°C that is frozen, and one that is at +1°C that is liquid. For example, calcium is observed on WASP-76 b, but it may not be on a slightly colder planet."

First detection of vanadium oxide

Another interesting finding by Pelletier's team is the detection of a molecule called vanadium oxide. This is the first time it has been unambiguously detected on an exoplanet, and is of great interest to astronomers because they know it can have a big impact on hot giant planets.

"This molecule plays a similar role to ozone in Earth's atmosphere: it is extremely efficient at heating up the upper atmosphere," explained Pelletier. "This causes the temperatures to increase as a function of altitude, instead of decreasing as is typically seen on colder planets."

One element, nickel, is clearly more abundant in the exoplanet's atmosphere than what the astronomers were expecting. Many hypotheses could explain that; one is that WASP-76 b could have accreted material from a planet similar to Mercury. In our Solar System, the small rocky planet is enriched with metals like nickel because of how it was formed.

Pelletier's team also found that the asymmetry in iron absorption between the east and west hemispheres of WASP-76 b reported in previous studies is similarly present for many other elements. This means the underlying phenomenon causing this is thus probably a global process such as a difference in temperature or clouds being present on one side of the planet but not the other, rather than being the result of condensation into liquid form as was previously suggested.

Confirming and leveraging lessons learned

Pelletier and his team are very keen to learn more about this exoplanet and other ultra-hot giant planets, in part to confirm their hypothesis about the vastly different atmospheres that could prevail on planets differing slightly in temperature.

They also hope other researchers will leverage what they learned from this giant exoplanet and apply it to better our understanding of our own Solar System planets and how they came to be.

"Generations of researchers have used Jupiter, Saturn, Uranus, and Neptune's measured abundances for hydrogen and helium to benchmark formation theories of gaseous planets," said Benneke. "Likewise, the measurements of heavier elements such as calcium or magnesium on WASP-76 b will help further understanding the formation of gaseous planets.