South Downs Mercury

The monthly circular of South Downs Astronomical Society
Issue: 589 – September 6th 2024 Editor: Roger Burgess

Main **Talk Owen Brazell "Globular Clusters"**

Abstract:
Globular clusters are one of the most interesting and enigmatic types of astronomical object. In this talk we will look at the history of discovery and what our current understanding of them is as well as what are the best ones to observe and some of the tools you might use to find them.

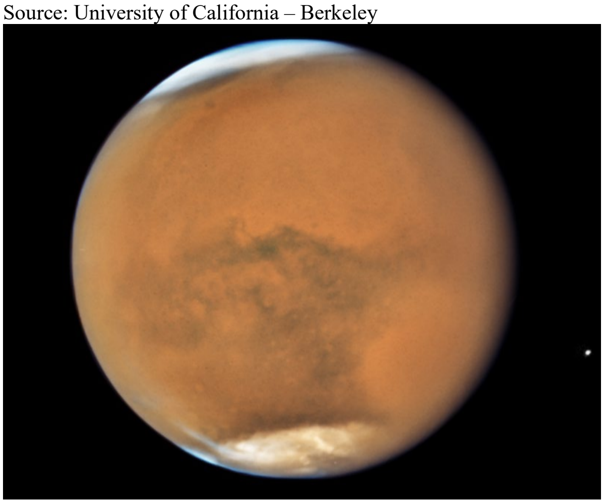
Bio:
Owen has been interested in astronomy from an early age and got his first telescope when he was ten years old so has been involved in astronomy for over 50 years. He did an astronomy O level, probably the only time he used a Patrick Moore book, and this led to him doing an Honours degree in Astronomy at St Andrews University and then a part time MSc from Queen Mary college but has spent his working life in the oil exploration industry. Nevertheless, he has found time to be on the council of the British Astronomical Association a number of times and was deputy director of its deep sky section for 20 years. He now holds the post of President of the Webb Society and is also chairman of Abingdon AS. He has also been on the council of the FAS. His main interests are in visual deep sky observing which he does with a variety of telescopes up to 22" in aperture. He also has an interest in observing comets and in solar observing. He has given talks on various aspects deep sky observing to many societies and has written a monthly deep sky column in the Astronomy Now magazine for many years. He also writes a monthly Galaxy of the Month column for the Webb Society website. He has also contributed material to a number of books. Owen has also been a keen attendee at star parties and he has been at some of the best sites in the world for these.

Please support a raffle we are organizing this month.

I am pleased to say that building work on the Planetarium extension is now complete and access will be via the improved main entrance inside the gates. There are limited parking spaces there but if those are full the two "overflow" parking areas can still be used.
(Entry to the Planetarium is no longer possible via the back door to the meeting room)

- Scientists find oceans of water on Mars: It's just too deep to tap

Seismic data from the Insight lander indicates deep, porous rock filled with liquid water
Date: August 12, 2024
Source: University of California – Berkeley

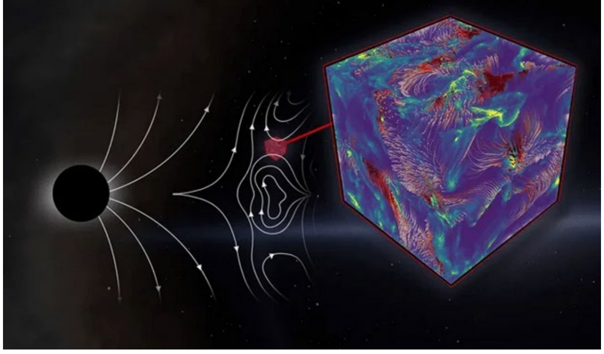


Using seismic activity to probe the interior of Mars, geophysicists have found evidence for a large underground reservoir of liquid water -- enough to fill oceans on the planet's surface. The data from NASA's Insight lander allowed the scientists to estimate that the amount of groundwater could cover the entire planet to a depth of between 1 and 2 kilometres, or about a mile.
While that's good news for those tracking the fate of water on the planet after its oceans disappeared more than 3 billion years ago, the reservoir won't be of much use to anyone trying to tap into it to supply a future Mars colony. It's located in tiny cracks and pores in rock in the middle of the Martian crust, between 11.5 and 20 kilometres below the surface. Even on Earth, drilling a hole a kilometre deep is a challenge.
The finding does pinpoint another promising place to look for life on Mars, however, if the reservoir can be accessed. For the moment, it

helps answer questions about the geological history of the planet.
"Understanding the Martian water cycle is critical for understanding the evolution of the climate, surface and interior," said Vashan Wright, a former UC Berkeley postdoctoral fellow who is now an assistant professor at UC San Diego's Scripps Institution of Oceanography. "A useful starting point is to identify where water is and how much is there."
Wright, alongside colleagues Michael Manga of UC Berkeley and Matthias Morzfeld of Scripps Oceanography, detailed their analysis in a paper that will appear this week in the journal *Proceedings of the National Academy of Sciences*.
The scientists employed a mathematical model of rock physics, identical to models used on Earth to map underground aquifers and oil fields, to conclude that the seismic data from Insight are best explained by a deep layer of fractured igneous rock saturated with liquid water. Igneous rocks are cooled hot magma, like the granite of the Sierra Nevada.
"Establishing that there is a big reservoir of liquid water provides some window into what the climate was like or could be like," said Manga, a UC Berkeley professor of earth and planetary science. "And water is necessary for life as we know it. I don't see why [the underground reservoir] is not a habitable environment. It's certainly true on Earth -- deep, deep mines host life, the bottom of the ocean hosts life. We haven't found any evidence for life on Mars, but at least we have identified a place that should, in principle, be able to sustain life."
Manga was Wright's postdoctoral adviser. Morzfeld was a former postdoctoral fellow in UC Berkeley's mathematics department and is now an associate professor of geophysics at Scripps Oceanography.
Manga noted that lots of evidence -- river channels, deltas and lake deposits, as well as water-altered rock -- supports the hypothesis that water once flowed on the planet's surface. But that wet period ended more than 3 billion years ago, after Mars lost its atmosphere. Planetary scientists on Earth have sent many probes and landers to the planet to find out what happened to that water -- the water frozen in Mars' polar ice caps can't account for it all -- as well as when it happened, and whether life exists or used to exist on the planet.
The new findings are an indication that much of the water did not escape into space but filtered down into the crust.
The Insight lander was sent by NASA to Mars in 2018 to investigate the crust, mantle, core and atmosphere, and it recorded invaluable information about Mars' interior before the mission ended in 2022.
"The mission greatly exceeded my expectations," Manga said. "From looking at all the seismic data that Insight collected, they've figured out the thickness of the crust, the depth of the core, the composition of the core, even a little bit about the temperature within the mantle."
Insight detected Mars quakes up to about a magnitude of 5, meteor impacts and rumblings from volcanic areas, all of which produced seismic waves that allowed geophysicists to probe the interior.
An earlier paper reported that above a depth of about 5 kilometres, the upper crust did not contain water ice, as Manga and others suspected. That may mean that there's little accessible frozen groundwater outside the polar regions.
The new paper analysed the deeper crust and concluded that the "available data are best explained by a water-saturated mid-crust" below Insight's location. Assuming the crust is similar throughout the planet, the team argued, there should be more water in this mid-crust zone than the "volumes proposed to have filled hypothesized ancient Martian oceans."
The Canadian Institute for Advanced Research, the National Science Foundation and the U.S. Office of Naval Research supported the work.

- Explanation found for X-ray radiation from black holes

Date: August 20, 2024
Source: University of Helsinki



Researchers at the University of Helsinki have succeeded in something that has been pursued since the 1970s: explaining the X-ray radiation from the black hole surroundings. The radiation originates from the combined effect of the chaotic movements of magnetic fields and turbulent plasma gas.

Using detailed supercomputer simulations, researchers at the University of Helsinki modelled the interactions between radiation, plasma, and magnetic fields around black holes. It was found that the chaotic movements, or turbulence, caused by the magnetic fields heat the local plasma and make it radiate.

Focus on the X-ray radiation from accretion disks

A black hole is created when a large star collapses into such a dense concentration of mass that its gravity prevents even light from escaping its sphere of influence. This is why, instead of direct observation, black holes can only be observed through their indirect effects on the environment.

Most of the observed black holes have a companion star, with which they form a binary star system. In the binary system, the two objects orbit each other, and the matter of the companion star slowly spirals into the black hole. This slowly flowing stream of gas often forms an accretion disk around the black hole, a bright, observable source of X-rays.

Since the 1970s, attempts have been made to model the radiation from the accretion flows around the black holes. At the time, X-rays were already thought to be generated through the interaction of the local gas and magnetic fields, similar to how the Sun's surroundings are heated by its magnetic activity via solar flares.

"The flares in the accretion disks of black holes are like extreme versions of solar flares," says Associate Professor Joonas Nättilä. Nättilä heads the Computational Plasma Astrophysics research group at the University of Helsinki, which specializes in modelling precisely this kind of extreme plasma.

Radiation-plasma interaction

The simulations demonstrated that the turbulence around the black holes is so strong that even quantum effects become important for the plasma dynamics.

In the modelled mixture of electron-positron plasma and photons, the local X-ray radiation can turn into electrons and positrons, which can then annihilate back into radiation, as they come in contact.

Nättilä describes how electrons and positrons, antiparticles to one another, usually do not occur in the same place. However, the extremely energetic surroundings of black holes make even this possible. In general, radiation does not interact with plasma either. However, photons are so energetic around black holes that their interactions are important to plasma, too.

"In everyday life, such quantum phenomena where matter suddenly appears in place of extremely bright light are, of course, not seen, but near black holes, they become crucial," Nättilä says.

"It took us years to investigate and add to the simulations all quantum phenomena occurring in nature, but ultimately, it was worth it," he adds.

An accurate picture of the origins of radiation

The study demonstrated that turbulent plasma naturally produces the kind of X-ray radiation observed from the accretion disks. The simulation also made it possible, for the first time, to see that the plasma around black holes can be in two distinct equilibrium states, depending on the external radiation field. In one state, the plasma is transparent and cold, while in the other, it is opaque and hot.

"The X-ray observations of black hole accretion disks show exactly the same kind of variation between the so-called soft and hard states," Nättilä points out.

The study was published in the journal *Nature Communications*. The simulation used in the study is the first plasma physics model to include all the important quantum interactions between radiation and plasma. The study is part of a project headed by Nättilä and funded with a €2.2 million Starting Grant from the European Research Council, which aims to understand interactions between plasma and radiation.

- ❖ Scientists lay out revolutionary method to warm Mars

Date: August 7, 2024
Source: University of Chicago

Ever since we learned that the surface of planet Mars is cold and dead, people have wondered if there is a way to make it friendlier to life.

In a groundbreaking study published Aug. 7 in *Science Advances*, researchers from the University of Chicago, Northwestern University, and the University of Central Florida have proposed a revolutionary approach towards terraforming Mars. This new method, using engineered dust particles released to the atmosphere, could potentially warm the Red Planet by more than 50 degrees Fahrenheit, to temperatures suitable for microbial life -- a crucial first step towards making Mars habitable.

The proposed method is over 5,000 times more efficient than previous schemes to globally warm Mars, representing a significant leap forward in our ability to modify the Martian environment.

What sets this approach apart is its use of resources readily available on Mars, making it far more feasible than earlier proposals that relied on importing materials from Earth or mining rare Martian resources.

This strategy would take decades. But it appears logistically easier than other plans proposed so far.

"This suggests that the barrier to warming Mars to allow liquid water is not as high as previously thought," said Edwin Kite, an associate professor of geophysical sciences at the University of Chicago and corresponding author on the study. The lead author was Samaneh Ansari, a graduate student in Prof. Hooman Mohseni's group at Northwestern University.

Astronauts still won't be able to breathe Mars' thin air; making the planet suitable for humans to walk on the surface unaided requires much more work. But perhaps groundwork could be laid, by making the planet habitable for microbes and food crops that could gradually add oxygen to the atmosphere -- much as they have done for Earth during its geologic history.

A new approach to an age-old dream

There is a rich history of proposals to make Mars habitable; Carl Sagan himself came up with one back in 1971. These have ranged from outright daydreams, such as science fiction writers depicting turning one of Mars' moons into a sun, to more recent and scientifically plausible ideas, such as engineering transparent gel tiles to trap heat.

Any plan to make Mars habitable must address several hurdles, including deadly UV rays and salty soil. But the biggest is the planet's temperature; the surface of Mars averages about -80 degrees Fahrenheit.

One strategy to warm the planet could be the same method that humans are unintentionally using here on Earth: releasing material into the atmosphere, which would enhance Mars' natural greenhouse effect, trapping solar heat at the surface.

The trouble is that you would need tons of these materials -- literally. Previous schemes depended on bringing gases from Earth to Mars, or attempting to mine Mars for a large mass of ingredients that aren't very common there -- both are costly and difficult propositions. But the team wondered whether it could be done by processing materials that already exist abundantly on Mars.

We know from rovers like Curiosity that dust on Mars is rich in iron and aluminium. By themselves, those dust particles aren't suitable to warm the planet; their size and composition mean they tend to cool the surface slightly rather than warm it. But if we engineered dust particles that had different shapes or compositions, the researchers hypothesized, perhaps they could trap heat more efficiently.

The researchers designed particles shaped like short rods -- similar in size to commercially available glitter. These particles are designed to trap escaping heat and scatter sunlight towards the surface, enhancing Mars' natural greenhouse effect.

"How light interacts with sub-wavelength objects is fascinating. Importantly, engineering
nanoparticles can lead to optical effects that far exceed what is conventionally expected from
such small particles," said Ansari. Mohseni, who is a co-author, believes that they have just scratched the surface: "We believe it is possible to design nanoparticles with higher

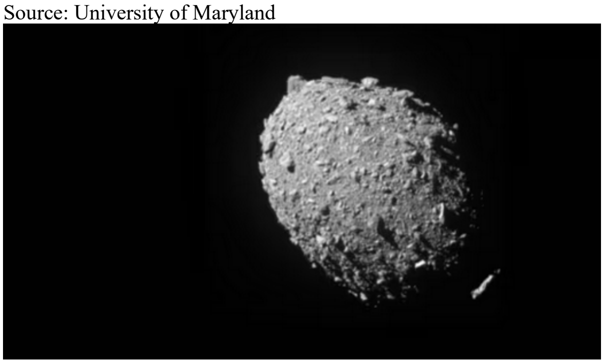
efficiency, and even those that can dynamically change their optical properties."
"You'd still need millions of tons to warm the planet, but that's five thousand times less than you would need with previous proposals to globally warm Mars," said Kite. "This significantly increases the feasibility of the project."
Calculations indicate that if the particles were released into Mars' atmosphere continuously at 30 Liters per second, the planet would warm by more than 50 degrees Fahrenheit -- and the effect could be noticeable within as soon as months. Similarly, the warming would be reversible, stopping within a few years if release was switched off.

Potential impact and future research

Much work remains to be done, the scientists said. We don't know exactly how fast the engineered dust would cycle out of Mars' atmosphere, for example. Mars does have water and clouds, and, as the planet warms, it's possible that water would increasingly start to condense around the particles and fall back to the surface as rain.
"Climate feedbacks are really difficult to model accurately," Kite cautioned. "To implement something like this, we would need more data from both Mars and Earth, and we'd need to proceed slowly and reversibly to ensure the effects work as intended."
While this method represents a significant leap forward in terraforming research, the researchers emphasize that the study focuses on warming Mars to temperatures suitable for microbial life and possibly growing food crops -- not on creating a breathable atmosphere for humans.
"This research opens new avenues for exploration and potentially brings us one step closer to the long-held dream of establishing a sustainable human presence on Mars," said Kite.
Ansari is the lead author of the study. Other coauthors of the study were Ramses Ramirez of the University of Central Florida and Liam Steele, formerly a postdoctoral researcher at UChicago, now with the European Centre for Medium-Range Weather Forecasts.
The authors used the Quest high-performance computing facility at Northwestern and the University of Chicago Research Computing Centre.

- ❖ NASA's DART impact permanently changed the shape and orbit of asteroid moon

Date: August 23, 2024
Source: University of Maryland



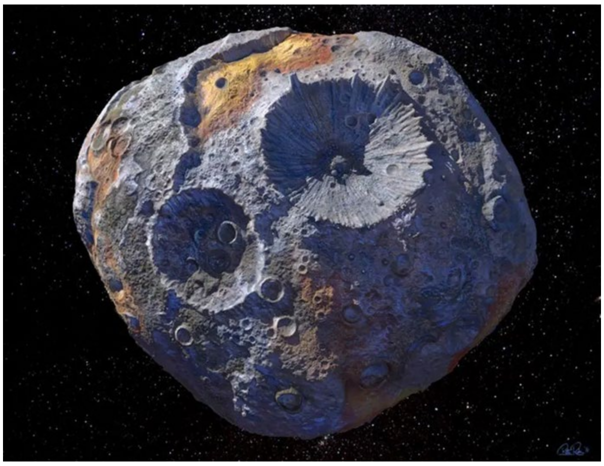
Asteroid moon Dimorphos as seen by the DART spacecraft which completely changed its orbit. NASA/Johns Hopkins APL/Handout via REUTERS

When NASA's Double Asteroid Redirection Test (DART) spacecraft collided with an asteroid moon called Dimorphos in 2022, the moon was significantly deformed -- creating a large crater and reshaping it so dramatically that the moon derailed from its original evolutionary progression -- according to a new study. The study's researchers believe that Dimorphos may start to "tumble" chaotically in its attempts to move back into gravitational equilibrium with its parent asteroid named Didymos.
"For the most part, our original pre-impact predictions about how DART would change the way Didymos and its moon move in space were correct," said Derek Richardson, a professor of astronomy at the University of Maryland and a DART investigation working group lead. "But there are some unexpected findings that help provide a better picture of how asteroids and other small bodies form and evolve over time."
The paper published in *Planetary Science Journal* on August 23, 2024 by a team led by Richardson detailed notable post-impact observations and described possible implications for future asteroid research.
One of the biggest surprises was how much the impact with DART changed the shape of Dimorphos. According to Richardson, the asteroid moon was originally oblate (shaped like a hamburger) but became more prolate (stretched out like a football) after the DART spacecraft collided with it.
"We were expecting Dimorphos to be prolate pre-impact simply because that's generally how we believed the central body of a moon would gradually accumulate material that's been shed off a primary body like Didymos. It would naturally tend to form an elongated

body that would always point its long axis toward the main body," Richardson explained. "But this result contradicts that idea and indicates that something more complex is at work here. Furthermore, the impact-induced change in Dimorphos' shape likely changed how it interacts with Didymos."
Richardson noted that although DART only hit the moon, the moon and the main body are connected through gravity. The debris scattered by the spacecraft on impact also played a role in the disturbed equilibrium between the moon and its asteroid, shortening Dimorphos' orbit around Didymos.
Interestingly, Didymos' shape remained the same -- a finding that indicates that the larger asteroid's body is firm and rigid enough to maintain its form even after losing mass to create its moon.
According to Richardson, Dimorphos' changes have important implications for future exploration efforts, including the European Space Agency's follow-up mission to the Didymos system slated for October 2024.
"Originally, Dimorphos was probably in a very relaxed state and had one side pointing toward the main body, Didymos, just like how Earth's moon always has one face pointing toward our planet," Richardson explained. "Now, it's knocked out of alignment, which means it may wobble back and forth in its orientation. Dimorphos might also be 'tumbling,' meaning that we may have caused it to rotate chaotically and unpredictably."
The team is now waiting to find out when the ejected debris will clear from the system, whether Dimorphos is still tumbling in space and when it will eventually regain its previous stability.
"One of our biggest questions now is if Dimorphos is stable enough for spacecraft to land and install more research equipment on it," he said. "It could take a hundred years to see noticeable changes in the system, but it's only been a few years since the impact. Learning about how long it takes Dimorphos to regain its stability tells us important things about its internal structure, which in turn informs future attempts to deflect hazardous asteroids."
Richardson and his team hope that Hera will provide more information about DART's impact. By late 2026, Hera will arrive at the binary asteroid system containing Dimorphos and Didymos to assess the internal properties of both asteroids for the first time, providing a more detailed analysis of the DART mission and its implications for the future.
"DART gave us insight into complicated gravitational physics that you can't do in a lab, and all of this research helps us calibrate our efforts to defend Earth in the event of an actual threat," Richardson said. "There's a nonzero chance that an asteroid or comet will approach and endanger the planet. Now, we have an additional line of defence against these kinds of external threats."

- SwRI-led team finds evidence of hydration on Asteroid Psyche

Webb telescope data indicate a complex history for the metallic asteroid
Date: August 13, 2024
Source: Southwest Research Institute



NASA’s Webb telescope has confirmed the presence of hydrated minerals on the surface of Psyche

Courtesy of Maxar/ASU/P. Rubin/NASA/JPL-Caltech
Using data from NASA's James Webb Space Telescope, a Southwest Research Institute-led team has confirmed hydroxyl molecules on the surface of the metallic asteroid Psyche. The presence of hydrated minerals suggests a complex history for Psyche, important context for the NASA spacecraft en route to this interesting asteroid orbiting the Sun between Mars and Jupiter.
At about 140 miles in diameter, Psyche is one of the most massive objects in the main asteroid belt. Previous observations indicate that Psyche is a dense, largely metallic object that could be a leftover core from a planet that experienced a catastrophic collision. On Oct. 13, 2023, NASA launched the Psyche spacecraft, which is traveling 2.2 billion miles to arrive at the asteroid in August 2029.
"Using telescopes at different wavelengths of infrared light, the SwRI-led research will provide different but complementary

information to what the Psyche spacecraft is designed to study," said SwRI's Dr. Tracy Becker, second author of a new American Astronomical Society's *Planetary Science Journal* paper discussing these findings.

"Our understanding of solar system evolution is closely tied to interpretations of asteroid composition, particularly the M-class asteroids that contain higher concentrations of metal," said Centre for Astrophysics | Harvard & Smithsonian's Dr. Stephanie Jarmak, the paper's lead author, who conducted much of this research while at SwRI. "These asteroids were initially thought to be the exposed cores of differentiated planetesimals, a hypothesis based on their spectral similarity to iron meteorites."

The Webb data point to hydroxyl and perhaps water on Psyche's surface. The hydrated minerals could result from external sources, including impactors. If the hydration is native or endogenous, then Psyche may have a different evolutionary history than current models suggest.

"Asteroids are leftovers from the planetary formation process, so their compositions vary depending on where they formed in the solar nebula," said SwRI's Dr. Anicia Arredondo, another co-author. "Hydration that is endogenous could suggest that Psyche is not the remnant core of a protoplanet. Instead, it could suggest that Psyche originated beyond the 'snow line,' the minimum distance from the Sun where protoplanetary disc temperatures are low enough for volatile compounds to condense into solids, before migrating to the outer main belt."

However, the paper found the variability in the strength of the hydration features across the observations implies a heterogeneous distribution of hydrated minerals. This variability suggests a complex surface history that could be explained by impacts from carbonaceous chondrite asteroids thought to be very hydrated.

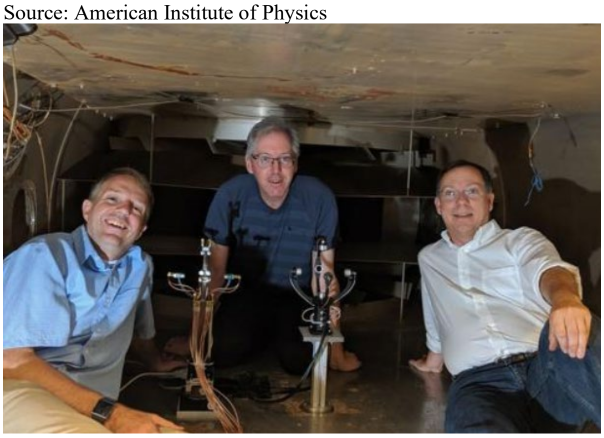
Understanding the location of asteroids and their compositions tells us how materials in the solar nebula were distributed and have evolved since formation. How water is distributed in our solar system will provide insight into the distribution of water in other solar systems and, because water is necessary for all life on Earth, will drive where to look for potential life, both in our solar system and beyond.

NASA's Webb telescope, developed in partnership with the European and Canadian space agencies, is part of the Space Telescope Science Institute, operated by the Association of Universities for Research in Astronomy. The Psyche mission is led by Arizona State University. NASA's Jet Propulsion Laboratory is responsible for mission management, operations and navigation.

- ❖ Measuring Martian winds with sound

Novel anemometer tracks sound travel for speedier, more precise wind speed calculations on the red planet

Date: August 13, 2024
Source: American Institute of Physics



Authors Robert White (left), Ian Neeson (centre) and Don Banfield (right) in the Mars Simulation Wind Tunnel at the University of Aarhus, Denmark in 2019, preparing to test early prototypes of the Mars sonic anemometer, visible in the centre.

Mars has a notoriously inhospitable environment, with temperatures that fluctuate dramatically over the course of a Martian day and average minus 80 degrees Fahrenheit. Its surface is mostly covered in red dust, with terrain typified by craters, canyons, and volcanoes. And its atmosphere is extremely thin, comprising only about 1% of the density of Earth's.

Needless to say, measuring wind speeds on the red planet is challenging. Martian landers have been able capture measurements -- some gauging the cooling rate of heated materials when winds blow over them, others using cameras to image "tell-tales" that blow in the wind. Both anemometric methods have yielded valuable insight into the planet's climate and atmosphere.

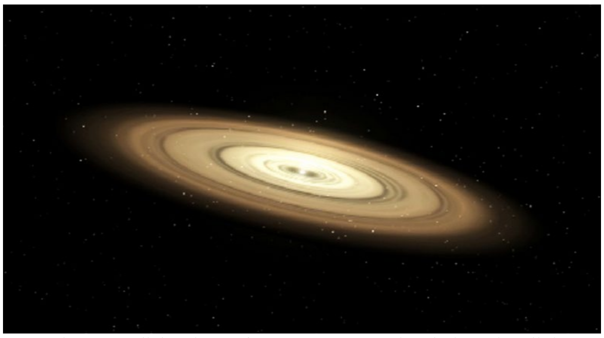
But there's still room for improvement in the astronomical toolshed, especially as plans to send astronauts to Mars unfold in the coming years.

In *JASA*, published on behalf of the Acoustical Society of America by AIP

Publishing, researchers from Canada and the U.S. demonstrated a novel sonic anemometric system featuring a pair of narrowband piezoelectric transducers to measure the travel time of sound pulses through Martian air. The study accounted for variables including transducer diffraction effects and wind direction.
"By measuring sound travel time differences both forward and backward, we can accurately measure wind in three dimensions," said author Robert White. "The two major advantages of this method are that it's fast and it works well at low speeds."
The researchers hope to be able to measure up to 100 wind speeds per second and at speeds as low as 1 cm/s, a remarkable contrast to previous methods that could register only about 1 wind speed per second and struggled to track speeds below 50 cm/s.
"By measuring quickly and accurately, we hope to be able to measure not only mean winds, but also turbulence and fluctuating winds," said White. "This is important for understanding atmospheric variables that could be problematic for small vehicles such as the Ingenuity helicopter that flew on Mars recently."
The researchers characterized ultrasonic transducers and sensors over a wide range of temperatures and a narrow range of pressures in carbon dioxide, the primary atmospheric gas on Mars. With their selections, they showed only nominal error rates would result from temperature and pressure changes.
"The system we're developing will be 10 times faster and 10 times more accurate than anything previously used," said White. "We hope it will produce more valuable data as future missions to Mars are considered and provide useful information on the Martian climate, perhaps also with implications for better understanding the climate of our own planet."

- Meteor showers shed light on where comets formed in the early solar system

Date: August 22, 2024
Source: SETI Institute



Protoplanetary disk. Figure from a computer simulation visualizing the formation of planets (https://svs.gsfc.nasa.gov/12278). Photo: NASA/JPL-Caltech

An international team of 45 researchers studying meteor showers has found that not all comets crumble the same way when they approach the Sun. In a paper published in the journal Icarus this week, they ascribe the differences to the conditions in the protoplanetary disk where comets formed 4.5 billion years ago.
"The meteoroids we see as meteors in the night sky are the size of small pebbles," said lead author and SETI Institute and NASA Ames meteor astronomer Peter Jenniskens. "They are, in fact, the same size as the pebbles that collapsed into comets during the formation of our solar system."
As our solar system formed, tiny particles in the disk around the young Sun gradually grew larger until they became the size of small pebbles.
"Once pebbles grow large enough to no longer travel along with the gas, they are destroyed by mutual collisions before they can grow much bigger," said NASA Ames planetary scientist and co-author Paul Estrada. "Comets and primitive asteroids instead were formed when clouds of these pebbles locally collapsed into kilometre-sized and larger bodies." /p>
Fast forward 4.5 billion years: when comets approach the Sun today, they crumble into smaller pieces called meteoroids. Those meteoroids co-orbit with the comet for a while and can later create meteor showers when they hit Earth's atmosphere.
"We hypothesized that comets crumble into the sizes of the pebbles they are made of," said Jenniskens. "In that case, the size distribution and the physical and chemical properties of young meteoroid streams still contain information about the conditions in the protoplanetary disk during this collapse."
Jenniskens and his team of professional and amateur astronomers use special low-light video cameras in networks all over the world to track meteors in a NASA-sponsored project

called "CAMS" -- or Cameras for Allsky Meteor Surveillance (http://cams.seti.org). "These cameras measure the meteoroids' paths, how high they are when they first light up, and how they slowdown in Earth's atmosphere," said Jenniskens. "Specialized cameras measured the composition of some of these meteoroids."

The team studied 47 young meteor showers. Most are the crumbs of two types of comets: Jupiter-family comets from the Scattered Disk of the Kuiper Belt beyond Neptune and long-period comets from the Oort Cloud surrounding our solar system. Long-period comets move on much wider orbits than the Jupiter-family comets and are much more loosely held by the Sun's gravity.

"We found that long-period (Oort Cloud) comets often crumble into sizes indicative of gentle accretion conditions," said Jenniskens. "Their meteoroids have a low density. The meteoroid streams contain a fairly constant 4% of a type of solid meteoroids that were heated in the past and now only brighten deeper in Earth's atmosphere and typically are poor in the element sodium."

On the other hand, Jupiter-family comets usually crumble into smaller, denser meteoroids. They also have a higher 8% of solid materials on average and show more diversity in that content.

"We concluded that these Jupiter-family comets are composed of pebbles that had reached the point where fragmentation became important in their size evolution," said Estrada. "The higher admixture of materials that were heated in the past are expected closer to the Sun."

Primitive asteroids formed even closer to the Sun, although still outside the orbit of Jupiter. These asteroids produce meteor showers with even smaller particles, showing their pebble building blocks experienced even more aggressive fragmentation.

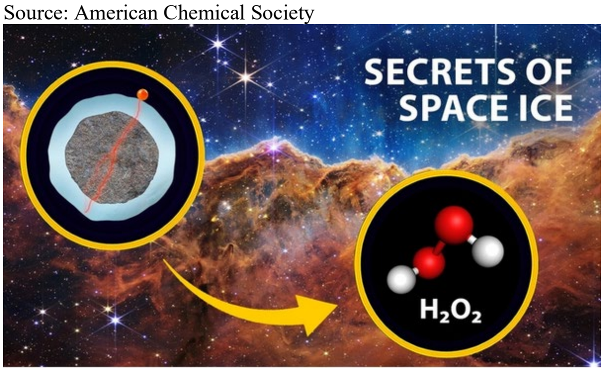
"While there are exceptions in both groups, the implication is that most long-period comets formed under more gentle particle growth conditions, possibly near the 30 AU edge of the Trans Neptunian Disk," said Estrada. "Most Jupiter family comets formed closer to the Sun where pebbles reached or passed the fragmentation barrier, while primitive asteroids formed in the region where the cores of the giant planets formed."

How is this possible? While the giant planets were growing, Neptune moved outward and scattered comets and asteroids out of the remaining protoplanetary disk. This outward movement likely created both the Scattered Disk of the Kuiper Belt and the Oort Cloud. That would predict that both long period and Jupiter-family comets have the same properties, but the team found otherwise.

"It is possible that stars and molecular clouds in the birth region of the Sun perturbed the wide orbits of Oort Cloud comets early on, and the long-period comets we see today were scattered into such orbits only at a time when the Sun had moved out of this region," said Jenniskens. "In contrast, Jupiter-family comets have always been on shorter orbits and sample all objects scattered by Neptune on its way out."

- ❖ Extraterrestrial chemistry with earthbound possibilities

Date: August 21, 2024
Source: American Chemical Society



Who are we? Why are we here? As the Crosby, Stills, Nash & Young song suggests, we are stardust, the result of chemistry occurring throughout vast clouds of interstellar gas and dust. To better understand how that chemistry could create prebiotic molecules -- the seeds of life on Earth and possibly elsewhere -- researchers investigated the role of low-energy electrons created as cosmic radiation traverses through ice particles. Their findings may also inform medical and environmental applications on our home planet.

Undergraduate student Kennedy Barnes will present the team's results at the fall meeting of the American Chemical Society (ACS).

"The first detection of molecules in space was made by Wellesley College alum Annie Jump Cannon more than a hundred years ago," says Barnes, who, with fellow undergraduate Rong Wu, led this study at Wellesley, mentored by chemistry professor Christopher Arumainayagam and physics professor James Battat. Since Cannon's discovery, scientists have been interested in finding out how extraterrestrial molecules form. "Our goal is to explore the relative importance of low-energy electrons versus photons in instigating the chemical reactions responsible for the extraterrestrial synthesis of these prebiotic molecules," Barnes explains.

The few studies that previously probed this question suggested that both electrons and photons can catalyse the same reactions. Studies by Barnes and colleagues, however, hint that the prebiotic molecule yield from low-energy electrons and photons could be significantly different in space. "Our calculations suggest that the number of cosmic-ray-induced electrons within cosmic ice could be much greater than the number of photons striking the ice," Barnes explains. "Therefore, electrons likely play a more significant role than photons in the extraterrestrial synthesis of prebiotic molecules."

Aside from cosmic ice, her research into low-energy electrons and radiation chemistry also has potential applications on Earth. Barnes and colleagues recently studied the radiolysis of water, finding evidence of electron-stimulated release of hydrogen peroxide and hydroperoxyl radicals, which destroy stratospheric ozone and act as damaging reactive oxygen species in cells.

"A lot of our water radiolysis research findings could be used in medical applications and medical simulations," Barnes shares, offering the example of using high-energy radiation to treat cancer. "I once had a biochemistry professor say that humans are basically bags of water. So, other scientists are investigating how low-energy electrons produced in water affect our DNA molecules."

She also says the team's findings are applicable to environmental remediation efforts where wastewater is being treated with high-energy radiation, which produces large numbers of low-energy electrons that are assumed to be responsible for the destruction of hazardous chemicals.

Back to space chemistry, in attempting to better understand prebiotic molecule synthesis, the researchers didn't limit their efforts to mathematical modelling; they also tested their hypothesis by mimicking the conditions of space in the lab. They use an ultrahigh-vacuum chamber containing an ultrapure copper substrate that they can cool to ultralow temperatures, along with an electron gun that produces low-energy electrons and a laser-driven plasma lamp that produces low-energy photons. The scientists then bombard nanoscale ice films with electrons or photons to see what molecules are produced.

"Although we have previously focused on how this research is applicable to interstellar submicron ice particles, it is also relevant to cosmic ice on a much larger scale, like that of Jupiter's moon Europa, which has a 20-mile-thick ice shell," says Barnes.

Thus, she suggests their research will help astronomers understand data from space exploration missions such as NASA's James Webb Space Telescope as well as the Europa Clipper, initially expected to launch in October 2024. Barnes hopes that their findings will inspire other researchers to incorporate low-energy electrons into their astrochemistry models that simulate what happens within cosmic ices.

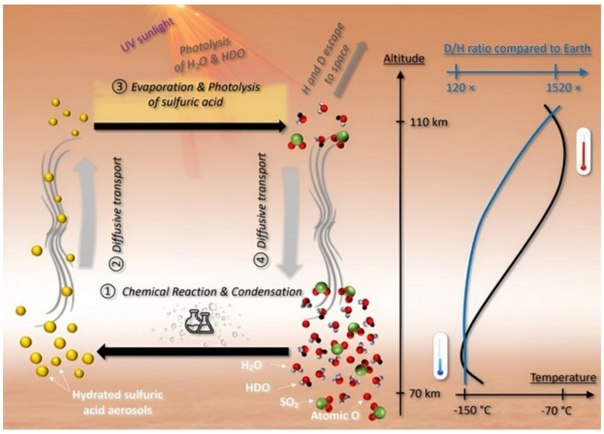
Barnes and colleagues are also varying the molecular composition of ice films and exploring atom addition reactions to see if low-energy electrons can produce other prebiotic chemistries. This work is being performed in collaboration with researchers at the Laboratory for the Study of Radiation and Matter in Astrophysics and Atmospheres in France.

"There's a lot that we're on the cusp of learning, which I think is really exciting and interesting," says Barnes, touting what she describes as a new Space Age.

The research was funded by the U.S. National Science Foundation, Arnold and Mabel Beckman Foundation, Wellesley College Faculty Awards, Brachman Hoffman grants, and the Nancy Harrison Kolodny '64 Professorship.

- Spectacular increase in the deuterium/hydrogen ratio in Venus' atmosphere

Date: August 20, 2024
Source: Tohoku University



Thanks to observations by the Solar Occultation in the Infrared (SOIR) instrument on the Venus Express space probe of the European Space Agency (ESA), researchers have discovered an unexpected increase in the abundances of two water molecule variants -- H_2O and HDO -- and their ratio HDO/H_2O in Venus' mesosphere. This phenomenon challenges our understanding of Venus' water history and the potential that it was once habitable in the past.

Currently, Venus is a dry, hostile planet. Venus has pressures nearly 100 times higher than Earth and temperatures around 460°C. Its atmosphere, covered by thick clouds of sulphuric acid and water droplets, is extremely dry. Most water is found below and within these cloud layers. However, Venus may have once supported just as much water as Earth.

"Venus is often called Earth's twin due to its similar size," remarks Hiroki Karyu, a researcher at Tohoku University, "Despite the similarities between the two planets, it has evolved differently. Unlike Earth, Venus has extreme surface conditions."

Investigating the abundances of H_2O and its deuterated counterpart HDO (isotopologues) reveals insights into Venus' water history. It is generally accepted that Venus and Earth initially had a similar HDO/H_2O ratio. However, the ratio observed in Venus' bulk atmosphere (below 70 km) is 120 times higher, indicating significant deuterium enrichment over time. This enrichment is primarily due to solar radiation breaking down water isotopologues in the upper atmosphere, producing hydrogen (H) and deuterium (D) atoms. Since H atoms escape into space more readily due to their lower mass, the HDO/H_2O ratio gradually increases.

To figure out how much H and D are escaping into space, it is crucial to measure the water isotopologue amounts at heights where sunlight can break them down, which occurs above the clouds at altitudes larger than ~70 km. The study found two surprising results: the concentrations of H_2O and HDO increase with altitude between 70 and 110 km, and the HDO/H_2O ratio rises significantly by an order of magnitude over this range, reaching levels over 1500 times higher than in Earth's oceans.

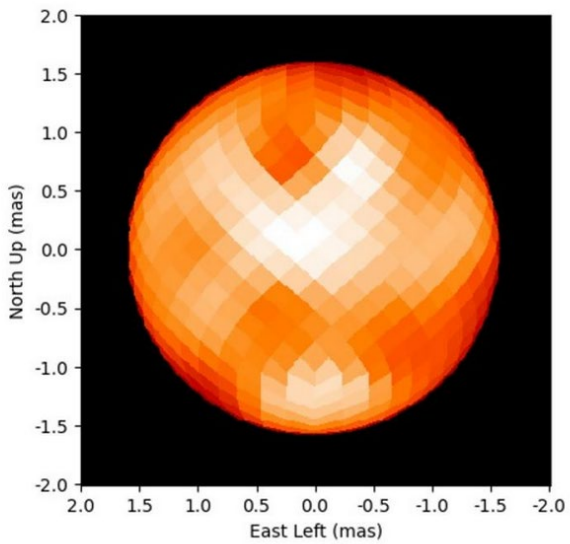
A proposed mechanism to explain these findings involves the behaviour of hydrated sulphuric acid (H_2SO_4) aerosols. These aerosols form just above the clouds, where temperatures drop below the sulphurated water dew point, leading to the formation of deuterium-enriched aerosols. These particles rise to higher altitudes, where increased temperatures cause them to evaporate, releasing more significant fraction of HDO compared to H_2O. The vapour then is transported downwards, restarting the cycle.

The study emphasizes two key points. First, variations in altitude play a crucial role in locating the D and H reservoirs. Second, the increased HDO/H_2O ratio ultimately increases deuterium release, impacting long-term evolution of the D/H ratio. These findings encourage the incorporation of altitude-dependent processes into models to make accurate predictions about D/H evolution.

Understanding the evolution of Venus' habitability and water history will help us understand the factors that make a planet become inhabitable, so that we know how to avoid letting the Earth follow in its' twin's footsteps.

- ❖ New view of North Star reveals spotted surface

Date: August 20, 2024
Source: Georgia State University



CHARA Array false-colour image of Polaris from April 2021 that reveals large bright and dark spots on the surface. Polaris appears about 600,000 times smaller than the Full Moon in the sky.

Researchers using Georgia State University's Centre for High Angular Resolution Astronomy (CHARA) Array have identified new details about the size and appearance of the North Star, also known as Polaris. The new research is published in *The Astrophysical Journal*.

Earth's North Pole points to a direction in space marked by the North Star. Polaris is both a navigation aid and a remarkable star in its own right. It is the brightest member of a triple-star system and is a pulsating variable star. Polaris gets brighter and fainter periodically as the star's diameter grows and shrinks over a four-day cycle.

Polaris is a kind of star known as a Cepheid variable. Astronomers use these stars as "standard candles" because their true brightness depends on their period of pulsation: Brighter stars pulsate slower than fainter stars. How bright a star appears in the sky depends on the star's true brightness and the distance to the star. Because we know the true brightness of a Cepheid based on its pulsation period, astronomers can use them to measure the distances to their host galaxies and to infer the expansion rate of the universe.

A team of astronomers led by Nancy Evans at the Centre for Astrophysics | Harvard & Smithsonian observed Polaris using the CHARA optical interferometric array of six telescopes at Mount Wilson, Calif. The goal of the investigation was to map the orbit of the close, faint companion that orbits Polaris every 30 years.

"The small separation and large contrast in brightness between the two stars makes it extremely challenging to resolve the binary system during their closest approach," Evans said.

The CHARA Array combines the light of six telescopes that are spread across the mountaintop at the historic Mount Wilson Observatory. By combining the light, the CHARA Array acted like a 330-meter telescope to detect the faint companion as it passed close to Polaris. The observations of Polaris were recorded using the MIRC-X camera which was built by astronomers at the University of Michigan and Exeter University in the U.K. The MIRC-X camera has the remarkable ability to capture details of stellar surfaces.

The team successfully tracked the orbit of the close companion and measured changes in the size of the Cepheid as it pulsated. The orbital motion showed that Polaris has a mass five times larger than that of the Sun. The images of Polaris showed that it has a diameter 46 times the size of the Sun.

The biggest surprise was the appearance of Polaris in close-up images. The CHARA observations provided the first glimpse of what the surface of a Cepheid variable looks like.

CHARA Array false-colour image of Polaris from April 2021 that reveals large bright and dark spots on the surface. Polaris appears about 600,000 times smaller than the Full Moon in the sky.

"The CHARA images revealed large bright and dark spots on the surface of Polaris that changed over time," said Gail Schaefer, director of the CHARA Array. The presence of spots and the rotation of the star might be linked to a 120-day variation in measured velocity.

"We plan to continue imaging Polaris in the future," said John Monnier, an astronomy professor at the University of Michigan. "We hope to better understand the mechanism that generates the spots on the surface of Polaris."

The new observations of Polaris were made and recorded as part of the open access program at the CHARA Array, where astronomers from around the world can apply for time through the National Optical-Infrared Astronomy Research Laboratory (NOIRLab).

The CHARA Array is located at the Mount Wilson Observatory in the San Gabriel Mountains of southern California. The six telescopes of the CHARA Array are arranged along three arms. The light from each telescope is transported through vacuum pipes to the central beam combining lab. All the beams converge on the MIRC-X camera in the lab.

The CHARA Array open access program is funded by the National Science Foundation (grant AST-2034336). Institutional support for the CHARA Array is provided by Georgia State's College of Arts & Sciences and the Office of the Vice President for Research and Economic Development.

- Right on schedule: Physicists use modelling to forecast a black hole's feeding patterns with precision

Date: August 16, 2024
Source: Syracuse University

The dramatic dimming of a light source ~ 860 million light-years away from Earth confirms the accuracy of a detailed model developed by a team of astrophysicists, including Syracuse University Professor Eric Coughlin.

Powerful telescopes like NASA's Hubble, James Webb, and Chandra X-ray Observatory provide scientists a window into deep space to probe the physics of black holes. While one might wonder how you can "see" a black hole, which famously absorbs all light, this is made possible by tidal disruption events (TDEs) -- where a star is destroyed by a supermassive black hole and can fuel a "luminous accretion flare." With luminosities thousands of billions of times brighter than the Sun, accretion events enable astrophysicists to study supermassive black holes (SMBHs) at cosmological distances.

TDEs occur when a star is violently ripped apart by a black hole's immense gravitational field. As the star is shredded, its remnants are transformed into a stream of debris that rains back down onto the black hole to form a very hot, very bright disk of material swirling around the black hole, called an accretion disc. Scientists can study these to make direct observations of TDEs, and compare those to theoretical models to relate observations to physical properties of disrupted stars and their disrupting black holes.

A team of physicists from Syracuse University, MIT and the Space Telescope Science Institute used detailed modelling to predict the brightening and dimming of AT2018fyk, which is a repeating partial TDE, meaning the high-density core of the star survived the gravitational interaction with the SMBH, allowing it to orbit the black hole and be shredded more than once. The model predicted that AT2018fyk would "dim" in August 2023, a forecast which was confirmed when the source went dark last summer, providing evidence that their model delivers a new way to probe the physics of black holes. Their results were published in *The Astrophysical Journal Letters.*

A High Energy Source

Thanks to incredibly detailed extragalactic surveys, scientists are monitoring more coming and going light sources than ever before. Surveys pan entire hemispheres in search of sudden brightening or dimming of sources, which tells researchers that something has changed. Unlike the telescope in your living room that can only focus visible light, telescopes such as Chandra can detect light sources in what's referred to as the X-ray spectrum emitted from material that is millions of degrees in temperature.

Visible light and X-rays are both forms of electromagnetic radiation, but X-rays have shorter wavelengths and more energy. Similar to the way in which your stove becomes "red hot" after you turn it on, the gas comprising a disc "glows" at different temperatures, with the hottest material closest to the black hole. However, instead of radiating its energy at optical wavelengths visible to the eye, the hottest gas in an accretion disc emits in the X-ray spectrum. These are the same X-rays used by doctors to image your bones and that can pass through soft tissue, and because of this relative transparency, the detectors used by NASA X-ray telescopes are specifically designed to detect this high-energy radiation.'

A Repeat Performance

In January 2023, a team of physicists, including Eric Coughlin, a professor at Syracuse University's Department of Physics, Dheeraj R. "DJ" Pasham, a research scientist at MIT, and Thomas Wevers, a Fellow at the Space Telescope Science Institute, published a paper in *The Astrophysical Journal Letters* that proposed a detailed model for a repeating partial TDE. Their results were the first to map a star's surprising return orbit about a supermassive black hole -- revealing new information about one of the cosmos' most extreme environments.

The team based their study on a TDE known as AT2018fyk (AT stands for "Astrophysical Transient"), where a star was proposed to be captured by a SMBH through an exchange process known as "Hills capture." Originally part of a binary system (two stars that orbit one another under their mutual gravitational attraction), one of the stars was hypothesized to have been captured by the gravitational field of the black hole and the other (non-captured) star was ejected from the centre of the galaxy at speeds comparable to ~ 1000 km/s.

Once bound to the SMBH, the star powering the emission from AT2018fyk has been repeatedly stripped of its outer envelope each time it passes through its point of closest approach with the black hole. The stripped outer layers of the star form the bright accretion disk, which researchers can study using X-Ray and Ultraviolet /Optical telescopes that observe light from distant galaxies.

While TDEs are usually "once-and-done" because the extreme gravitational field of the SMBH destroys the star, meaning that the SMBH fades back into darkness following the accretion flare, AT2018fyk offered the unique opportunity to probe a repeating partial TDE.

The research team has used a trio of telescopes to make the initial and follow-up detections: Swift and Chandra, both operated by NASA, and XMM-Newton, which is a European mission. First observed in 2018, AT2018fyk is ~ 870 million light years away, meaning that because of the time it takes light to travel, it happened in "real time" ~ 870 million years ago.

The team used detailed modelling to forecast that the light source would abruptly disappear around August 2023 and brighten again when the freshly stripped material accretes onto the black hole in 2025.

Model Validation

Confirming the accuracy of their model, the team reported an X-ray drop in flux over a span of two months, starting on August 14, 2023. This sudden change can be interpreted as the second emission shutoff.

"The observed emission shutoff shows that our model and assumptions are viable, and suggests that we are really seeing a star being slowly devoured by a distant and very massive black hole," says Coughlin. "In our paper last year, we used constraints from the initial outburst, dimming and rebrightening to predict that AT2018fyk should display a sudden and rapid dimming in August of 2023, *if* the star survived the second encounter that fuelled the second brightening."

The fact that the system displayed this predicted shutoff therefore implies several distinctions about the star and the black hole:

- the star survived its second encounter with the black hole;
- the rate of return of stripped debris to the black hole is tightly coupled to the brightness of AT2018fyk;
- and the orbital period of the star about the black hole is ~ 1300 days, or about 3.5 years.

The second cutoff implies that another rebrightening should happen between May and August of 2025, and if the star survived the second encounter, a third shutoff is predicted to occur between January and July of 2027.

As for whether we can count on seeing a rebrightening in 2025, Coughlin says the detection of a second cutoff implies that the star has had more mass freshly stripped, which should return to the black hole to produce a third brightening.

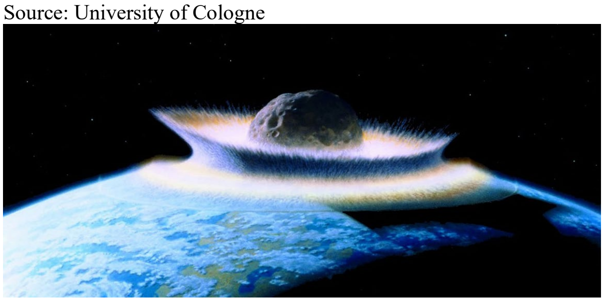
"The only uncertainty is in the peak of the emission," he says. "The second re-brightened peak was considerably dimmer than the first, and it is, unfortunately, possible that the third outburst will be dimmer still. This is the only thing that would limit the detectability of this third outburst."

Coughlin notes that this model signifies an exciting new way to study the incredibly rare occurrences of repeating partial TDEs, which are believed to take place once every million years in a given galaxy. To date, he says scientists have encountered only four to five systems that display this behaviour.

"With the advent of improved detection technology uncovering more repeating partial TDEs, we anticipate that this model will be an essential tool for scientists in identifying these discoveries," he says.

- ❖ Tracking down the asteroid that sealed the fate of the dinosaurs

Date August 16, 2024
Source: University of Cologne



An artist's impression of what an asteroid colliding with Earth might look like. Sixty-six million years ago an event like this, although on a much smaller scale, caused 75% of all animals to die out. Image: Don Davis

Geoscientists from the University of Cologne have led an international study to determine the origin of the huge piece of rock that hit the Earth around 66 million years ago and permanently changed the climate. The scientists analysed samples of the rock layer that marks the boundary between the Cretaceous and Paleogene periods. This period also saw the last major mass extinction event on Earth, in which around 70 percent of all animal species became extinct. The results of the study published in *Science* indicate that the asteroid formed outside Jupiter's orbit during the early development of our solar system.

According to a widely accepted theory, the mass extinction at the Cretaceous-Paleogene boundary was triggered by the impact of an asteroid at least 10 kilometres in diameter near Chicxulub on the Yucatán Peninsula in Mexico. On impact, the asteroid and large quantities of earth rock vaporized. Fine dust particles spread into the stratosphere and obscured the sun. This led to dramatic changes in the living conditions on the planet and brought photosynthetic activity to a halt for several years.

The dust particles released by the impact formed a layer of sediment around the entire globe. This is why the Cretaceous-Paleogene boundary can be identified and sampled in many places on Earth. It contains high concentrations of platinum-group metals, which come from the asteroid and are otherwise extremely rare in the rock that forms the Earth's crust.

By analysing the isotopic composition of the platinum metal ruthenium in the cleanroom laboratory of the University of Cologne's Institute of Geology and Mineralogy, the scientists discovered that the asteroid originally came from the outer solar system. "The asteroid's composition is consistent with that of carbonaceous asteroids that formed outside of Jupiter's orbit during the formation of the solar system," said Dr Mario Fischer-Gödde, first author of the study.

The ruthenium isotope compositions were also determined for other craters and impact structures of different ages on Earth for comparison. This data shows that within the last 500 million years, almost exclusively fragments of S-type asteroids have hit the Earth. In contrast to the impact at the Cretaceous-Paleogene boundary, these asteroids originate from the inner solar system. Well over 80 percent of all asteroid fragments that hit the Earth in the form of meteorites come from the inner solar system. Professor Dr Carsten Münker, co-author of the study, added: "We found that the impact of an asteroid like the one at Chicxulub is a very rare and unique event in geological time. The fate of the dinosaurs and many other species was sealed by this projectile from the outer reaches of the solar system."

- Engineers conduct first in-orbit test of 'swarm' satellite autonomous navigation

Date: August 14, 2024
Source: Stanford University

An artist's visualization of the StarFOX swarm. (Image credit: NASA/Blue Canyon Technologies)

Someday, instead of large, expensive individual space satellites, teams of smaller satellites -- known by scientists as a "swarm" -- will work in collaboration, enabling greater accuracy, agility, and autonomy. Among the scientists working to make these teams a reality are researchers at Stanford University's Space Rendezvous Lab, who recently completed the first-ever in-orbit test of a prototype system able to navigate a swarm of satellites using only visual information shared through a wireless network.

"It's a milestone paper and the culmination of 11 years of effort by my lab, which was founded with this goal of surpassing the current state of the art and practice in distributed autonomy in space," said Simone D'Amico, associate professor of aeronautics and astronautics and senior author of the study. "Starling is the first demonstration ever made of an autonomous swarm of satellites."

The test is known as Starling Formation-Flying Optical Experiment, or StarFOX. In it, the team successfully navigated four small satellites working in tandem using only visual information gathered from onboard cameras to calculate their trajectories (or orbits). The researchers presented their findings from the initial StarFOX test at a gathering of swarm satellite experts at the Small Satellite Conference in Logan, Utah.

All the angles

D'Amico described the challenge as one that has driven his team for more than a decade. "Our team has been advocating for distributed space systems since the lab's inception. Now it has become mainstream. NASA, the Department of Défense, the U.S. Space Force -- all have understood the value of multiple assets in coordination to accomplish objectives which would otherwise be impossible or very difficult to achieve by a single spacecraft," he said. "Advantages include improved accuracy, coverage, flexibility, robustness, and potentially new objectives not yet imagined."

Robust navigation of the swarm presents a considerable technological challenge. Current systems rely on the Global Navigation Satellite System (GNSS), requiring frequent contact with terrestrial systems. Beyond Earth's orbit, there is the Deep Space Network, but it is relatively slow and not easily scalable to future endeavours. What's more, neither system can help satellites avoid what D'Amico calls "non-cooperative objects" like space debris that might knock a satellite out of commission.

The swarm needs a self-contained navigation system that allows a high degree of autonomy and robustness, D'Amico said. Such systems are likewise made more attractive by minimal technical requirements and financial costs of today's miniaturized cameras and other hardware. The cameras used in the StarFOX test are proven, relatively inexpensive 2D cameras called star-trackers found on any satellite today.

"At its core, angles-only navigation requires no additional hardware even when used on small and inexpensive spacecraft," D'Amico said. "And exchanging visual information between swarm members provides a new distributed optical navigation capability."

Written in the stars

StarFOX combines visual measurements from single cameras mounted on each satellite in a swarm. Similar to a mariner of old navigating the high seas with a sextant, the field of known stars in the background is used as reference to extract bearing angles to the swarming satellites. These angles are then processed onboard through accurate physics-based force models to estimate the position and velocity of the satellites with respect to the orbited planet -- in this case, Earth, but the moon, Mars, or other planetary objects would work as well.

StarFOX employs the Space Rendezvous Lab's angles-only Absolute and Relative Trajectory Measurement System -- ARTMS, for short -- which integrates three new space robotics algorithms. An Image Processing algorithm detects and tracks multiple targets in images and computes target-bearing angles -- the angles at which objects, including space debris, are moving toward or away from each other. The Batch Orbit Determination algorithm then estimates each satellite's coarse orbit from these angles. Last but not least, the Sequential Orbit Determination algorithm refines swarm trajectories with the processing of new images through time to potentially feed autonomous guidance, control, and collision avoidance algorithms onboard.

Data is shared over an inter-satellite communication link (or wireless network). It is all used to calculate robust absolute and relative position and velocity to a remarkable degree of accuracy without GNSS. Under the most challenging conditions, using just a single observer satellite, StarFOX was able to calculate relative position -- the position of individual satellites to one another -- to within 0.5% of their distance. When multiple observers were added in, those error rates dropped to just 0.1%.

The Starling test was deemed promising enough that NASA has extended the project, now known as StarFOX+, through 2025 to further explore these improved capabilities and pave the way for future space situational awareness and positioning technologies.

- Galaxies in dense environments tend to be larger, settling one cosmic question and raising others

Date: August 14, 2024
Source: University of Washington

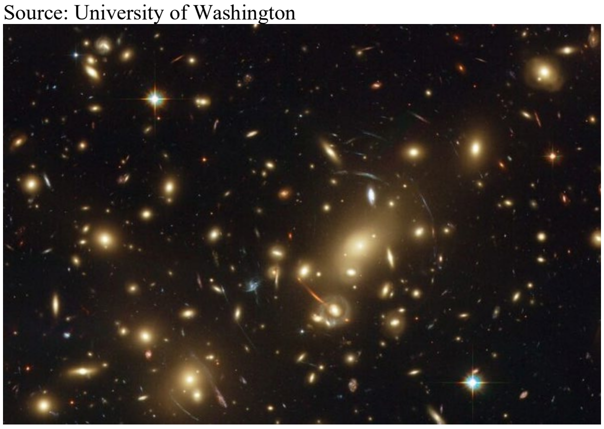


Image of Abell 2218, a dense galactic cluster approximately 2 billion light years from Earth.

For decades, scientists have known that some galaxies reside in dense environments with lots of other galaxies nearby. Others drift through the cosmos essentially alone, with few or no other galaxies in their corner of the universe.

A new study has found a major difference between galaxies in these divergent settings: Galaxies with more neighbours tend to be larger than their counterparts, which have a similar shape and mass, but reside in less dense environments. In a paper published Aug. 14 in the *Astrophysical Journal*, researchers at the University of Washington, Yale University, the Leibniz Institute for Astrophysics Potsdam in Germany and Waseda University in Japan report that galaxies found in denser regions of the

universe are as much as 25% larger than isolated galaxies.
The research, which used a new machine-learning tool to analyse millions of galaxies, helps resolve a long-standing debate among astrophysicists over the relationship between a galaxy's size and its environment. The findings also raise new questions about how galaxies form and evolve over billions of years.
"Current theories of galaxy formation and evolution cannot adequately explain the finding that clustered galaxies are larger than their identical counterparts in less dense regions of the universe," said lead author Aritra Ghosh, a UW postdoctoral researcher in astronomy and an LSST-DA Catalyst Fellow with the UW's DiRAC Institute. "That's one of the most interesting things about astrophysics. Sometimes what the theories predict we should find and what a survey actually finds are not in agreement, and so we go back and try to modify existing theories to better explain the observations."
Past studies that looked into the relationship between galaxy size and environment came up with contradictory results. Some determined that galaxies in clusters were smaller than isolated galaxies. Others came to the opposite conclusion. The studies were generally much smaller in scope, based on observations of hundreds or thousands of galaxies.
In this new study, Ghosh and his colleagues utilized a survey of millions of galaxies conducted using the Subaru Telescope in Hawaii. This endeavour, known as the Hyper Suprime-Cam Subaru Strategic Program, took high-quality images of each galaxy. The team selected approximately 3 million galaxies with the highest-quality data and used a machine learning algorithm to determine the size of each one. Next, the researchers essentially placed a circle -- one with a radius of 30 million light years -- around each galaxy. The circle represents the galaxy's immediate vicinity. They then asked a simple question: How many neighbouring galaxies lie within that circle?
The answer showed a clear general trend: Galaxies with more neighbours were also on average larger.
There could be many reasons why. Perhaps densely clustered galaxies are simply larger when they first form, or are more likely to undergo efficient mergers with close neighbours. Perhaps dark matter -- that mysterious substance that makes up most of the matter in the universe, yet cannot be detected directly by any current means -- plays a role. After all, galaxies form within individual "halos" of dark matter and the gravitational pull from those halos plays a critical role in how galaxies evolve.
"Theoretical astrophysicists will have to perform more comprehensive studies using simulations to conclusively establish why galaxies with more neighbours tend to be larger," said Ghosh. "For now, the best we can say is that we're confident that this relationship between galaxy environment and galaxy size exists."
Utilizing an incredibly large dataset like the Hyper Suprime-Cam Subaru Strategic Program helped the team reach a clear conclusion. But that's only part of the story. The novel machine learning tool they used to help determine the size of each individual galaxy also accounted for inherent uncertainties in the measurements of galaxy size.
"One important lesson we had learned prior to this study is that settling this question doesn't just require surveying large numbers of galaxies," said Ghosh. "You also need careful statistical analysis. A part of that comes from machine learning tools that can accurately quantify the degree of uncertainty in our measurements of galaxy properties."
The machine learning tool that they used is called GaMPEN -- or Galaxy Morphology Posterior Estimation Network. As a doctoral student at Yale, Ghosh led development of GaMPEN, which was unveiled in papers published in 2022 and 2023 in the *Astrophysical Journal*. The tool is freely available online and could be adapted to analyse other large surveys, said Ghosh.
Though this new study focuses on galaxies, it also forecasts the types of research -- cantered on complex analyses of incredibly large datasets -- that will soon take astronomy by storm. When a generation of new telescopes with powerful cameras, including the Vera C. Rubin Observatory in Chile, come online, they will collect massive amounts of data on the cosmos every night. In anticipation, scientists have been developing new tools like GaMPEN that can utilize these large datasets to answer pressing questions in astrophysics.
"Very soon, large datasets will be the norm in astronomy," said Ghosh. "This study is a

perfect demonstration of what you can do with them -- when you have the right tools."

Co-authors on the study are Meg Urry, professor of physics and of astronomy at Yale; Meredith Powell, a research fellow with the Leibniz Institute; Rhythm Shimakawa, associate professor at Waseda University; Frank van den Bosch, a Yale professor of astronomy; Daisuke Nagai, professor of physics and of astronomy at Yale; Kaustav Mitra, a doctoral student at Yale; and Andrew Connolly, professor of astronomy at the UW and faculty member in the DiRAC Institute and the eScience Institute. The research was funded by NASA, the Yale Graduate School of Arts & Sciences, the John Templeton Foundation, the Charles and Lisa Simonyi Fund for Arts and Sciences, the Washington Research Foundation and the UW eScience Institute.