South Downs Mercury

The monthly circular of South Downs Astronomical Society
Issue: 556 – September 3rd 2021 Editor: Roger Burgess
Delayed AGM followed by a Storm Dunlop Talk

We are holding the delayed AGM, we are looking for a new secretary and committee members We are down to 5 members now. The rules laid down by the Planetarium are below.

At the meeting we would like SDAS members to please enter the Planetarium through the rear door of the meeting room via the fire safety gate. This is to avoid contact with people arriving for the public show.

Arriving at the Planetarium

If you are feeling unwell for any reason please do **not** attend.

- Ensure that you are wearing a facemask or other face covering - there are no exceptions
- Please do **not** scan the Planetarium's NHS QR code on the main entrance doors (see below for track and trace instructions)
- Use the hand wash which will be located on the left after you enter the main door.
- Proceed straight to the normal meeting room (the Bunker Room).
- If you have the NHS Covid app on your phone, scan the SDAS NHS QR code on the meeting room door, otherwise make sure you provide your name to the SDAS committee member on duty., including your contact details if you are not an SDAS member.
- After providing your track and trace details, take your seat in the meeting room.
- If you need to use the toilet facilities please be aware that there will also be a public show starting at 7.30 pm, and that entry to the ladies and gents' toilets is strictly one person, or family group, at a time. This will be controlled by Planetarium volunteers.
- In the meeting room there will be a maximum of 40 seats and these will be spaced apart to meet Covid social distancing requirements. Family groups can sit together, or groups of up to 4 people who arrive in the same car.

During the meeting

- Remain seated throughout the meeting, with your facemasks on. **There will be no interval for refreshments**. if individuals do need to take a toilet break during the meeting that is fine of course, but please avoid doing so between 8.30 and 8.45pm as people will be leaving from the public show during that time.
- SDAS members and guest presenters must wear a face covering while speaking at the meeting.
- **At the end of the meeting**
- The meeting should end in time and preferably by 9.30pm at latest .to allow cleaning of surfaces. - At the end of the meeting please leave the building immediately apart from using the toilet facilities if you need to, and maintain social distancing as you leave.

❖ Space scientists reveal secret behind Jupiter's 'energy crisis'

Date: August 4, 2021
Source: University of Leicester

Planet Jupiter (stock image; elements furnished by NASA).
Credit: © Vadimsadovski / stock.adobe.com

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New research published in *Nature* has revealed the solution to Jupiter's 'energy crisis', which has puzzled astronomers for decades.

Space scientists at the University of Leicester worked with colleagues from the Japanese Space Agency (JAXA), Boston University, NASA's Goddard Space Flight Centre and the National Institute of Information and Communications Technology (NICT) to reveal the mechanism behind Jupiter's atmospheric heating.

Now, using data from the Keck Observatory in Hawai'i, astronomers have created the most-detailed yet global map of the gas giant's upper atmosphere, confirming for the first time that Jupiter's powerful aurorae are responsible for delivering planet-wide heating.

Dr James O'Donoghue is a researcher at JAXA and completed his PhD at Leicester, and is lead author for the research paper. He said:

"We first began trying to create a global heat map of Jupiter's uppermost atmosphere at the University of Leicester. The signal was not bright enough to reveal anything outside of Jupiter's polar regions at the time, but with the lessons learned from that work we managed to secure time on one of the largest, most competitive telescopes on Earth some years later.

"Using the Keck telescope we produced temperature maps of extraordinary detail. We found that temperatures start very high within the aurora, as expected from previous work, but now we could observe that Jupiter's aurora, despite taking up less than 10% of the area of the planet, appear to be heating the whole thing.

"This research started in Leicester and carried on at Boston University and NASA before ending at JAXA in Japan. Collaborators from each continent working together made this study successful, combined with data from NASA's Juno spacecraft in orbit around Jupiter and JAXA's Hisaki spacecraft, an observatory in space."

Dr Tom Stallard and Dr Henrik Melin are both part of the School of Physics and Astronomy at the University of Leicester. Dr Stallard added:

"There has been a very long-standing puzzle in the thin atmosphere at the top of every Giant Planet within our solar system. With every Jupiter space mission, along with ground-based observations, over the past 50 years, we have consistently measured the equatorial temperatures as being much too hot.

"This 'energy crisis' has been a long standing issue -- do the models fail to properly model how heat flows from the aurora, or is there some other unknown heat source near the equator?

"This paper describes how we have mapped this region in unprecedented detail and have shown that, at Jupiter, the equatorial heating is directly associated with auroral heating."

Aurorae occur when charged particles are caught in a planet's magnetic field. These spiral along the field lines towards the planet's magnetic poles, striking atoms and molecules in the atmosphere to release light and energy. On Earth, this leads to the characteristic light show that forms the Aurora Borealis and Australis. At Jupiter, the material spewing from its volcanic moon, Io, leads to the most powerful aurora in the Solar System and enormous heating in the polar regions of the planet.

Although the Jovian aurorae have long been a prime candidate for heating the planet's atmosphere, observations have previously been unable to confirm or deny this until now.

Previous maps of the upper atmospheric temperature were formed using images consisting of only several pixels. This is not enough resolution to see how the temperature might be changed across the planet, providing few clues as to the origin of the extra heat.

Researchers created five maps of the atmospheric temperature at different spatial resolutions, with the highest resolution map showing an average temperature measurement for squares two degrees longitude 'high' by two degrees latitude 'wide'.

The team scoured more than 10,000 individual data points, only mapping points with an uncertainty of less than five per cent.

Models of the atmospheres of gas giants suggest that they work like a giant refrigerator, with heat energy drawn from the equator towards the pole, and deposited in the lower atmosphere in these pole regions.

These new findings suggest that fast-changing aurorae may drive waves of energy against this poleward flow, allowing heat to reach the equator.

Observations also showed a region of localised heating in the sub-auroral region that could be interpreted as a limited wave of heat propagating equatorward, which could be

interpreted as evidence of the process driving heat transfer.
Planetary research at the University of Leicester spans the breadth of Jovian system, from the planet's magnetosphere and atmosphere, out to its diverse collection of satellites.
Leicester researchers are members of the Juno mission made up of a global team astronomer observing the giant planet, and are leading Jupiter observations from the forthcoming James Webb Space Telescope. Leicester also plays a leading role in science and instrumentation on the European Space Agency (ESA)'s Jupiter Icy Moons Explorer (JUICE), due for launch in 2022.

- Hubble finds evidence of water vapor at Jupiter's moon Ganymede

Date: July 26, 2021
Source: Space Telescope Science Institute (STScI)

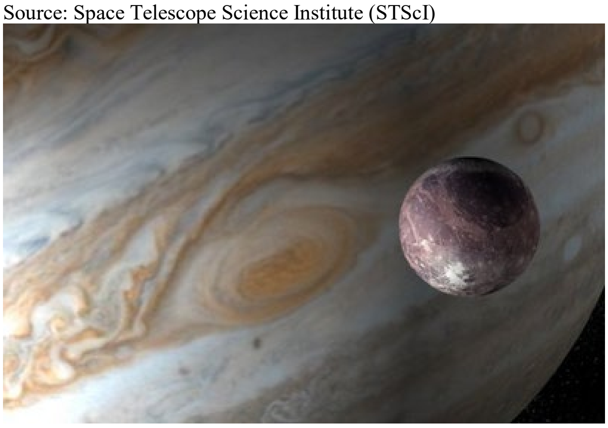

Illustration of the planet Jupiter and moon Ganymede (stock image).
Credit: © ianm35 / stock.adobe.com

For the first time, astronomers have uncovered evidence of water vapor in the atmosphere of Jupiter's moon Ganymede. This water vapor forms when ice from the moon's surface sublimates -- that is, turns from solid to gas.
Scientists used new and archival datasets from NASA's Hubble Space Telescope to make the discovery, published in the journal *Nature Astronomy.*
Previous research has offered circumstantial evidence that Ganymede, the largest moon in the solar system, contains more water than all of Earth's oceans. However, temperatures there are so cold that water on the surface is frozen solid. Ganymede's ocean would reside roughly 100 miles below the crust; therefore, the water vapor would not represent the evaporation of this ocean.
Astronomers re-examined Hubble observations from the last two decades to find this evidence of water vapor.
In 1998, Hubble's Space Telescope Imaging Spectrograph (STIS) took the first ultraviolet (UV) images of Ganymede, which revealed in two images colourful ribbons of electrified gas called auroral bands, and provided further evidence that Ganymede has a weak magnetic field.
The similarities in these UV observations were explained by the presence of molecular oxygen (O_2). But some observed features did not match the expected emissions from a pure O_2 atmosphere. At the same time, scientists concluded this discrepancy was likely related to higher concentrations of atomic oxygen (O).
As part of a large observing program to support NASA's Juno mission in 2018, Lorenz Roth of the KTH Royal Institute of Technology in Stockholm, Sweden led the team that set out to measure the amount of atomic oxygen with Hubble. The team's analysis combined the data from two instruments: Hubble's Cosmic Origins Spectrograph (COS) in 2018 and archival images from the Space Telescope Imaging Spectrograph (STIS) from 1998 to 2010.
To their surprise, and contrary to the original interpretations of the data from 1998, they discovered there was hardly any atomic oxygen in Ganymede's atmosphere. This means there must be another explanation for the apparent differences in these UV aurora images.
Roth and his team then took a closer look at the relative distribution of the aurora in the UV images. Ganymede's surface temperature varies strongly throughout the day, and around noon near the equator it may become sufficiently warm that the ice surface releases (or sublimates) some small amounts of water molecules. In fact, the perceived differences in the UV images are directly correlated with where water would be expected in the moon's atmosphere.
"So far only the molecular oxygen had been observed," explained Roth. "This is produced when charged particles erode the ice surface. The water vapor that we measured now originates from ice sublimation caused by the thermal escape of water vapor from warm icy regions."
This finding adds anticipation to ESA (European Space Agency)'s upcoming mission, JUICE, which stands for JUpiter ICy moons Explorer. JUICE is the first large-class mission in ESA's Cosmic Vision 2015-2025 program. Planned for launch in 2022 and arrival at Jupiter in 2029, it will spend at least three years making detailed observations of Jupiter and three of its largest moons, with

particular emphasis on Ganymede as a planetary body and potential habitat. Ganymede was identified for detailed investigation because it provides a natural laboratory for analysis of the nature, evolution and potential habitability of icy worlds in general, the role it plays within the system of Galilean satellites, and its unique magnetic and plasma interactions with Jupiter and its environment.
"Our results can provide the JUICE instrument teams with valuable information that may be used to refine their observation plans to optimize the use of the spacecraft," added Roth.
Right now, NASA's Juno mission is taking a close look at Ganymede and recently released new imagery of the icy moon. Juno has been studying Jupiter and its environment, also known as the Jovian system, since 2016.
Understanding the Jovian system and unravelling its history, from its origin to the possible emergence of habitable environments, will provide us with a better understanding of how gas giant planets and their satellites form and evolve. In addition, new insights will hopefully be found on the habitability of Jupiter-like exoplanetary systems.
The Hubble Space Telescope is a project of international cooperation between NASA and ESA (European Space Agency). NASA's Goddard Space Flight Centre in Greenbelt, Maryland, manages the telescope. The Space Telescope Science Institute (STScI) in Baltimore, Maryland, conducts Hubble science operations. STScI is operated for NASA by the Association of Universities for Research in Astronomy in Washington, D.C.

- Interstellar comets like Borisov may not be all that rare

Date: August 23, 2021
Source: Harvard-Smithsonian Centre for Astrophysics

In 2019, astronomers spotted something incredible in our backyard: a rogue comet from another star system. Named Borisov, the icy snowball travelled 110,000 miles per hour and marked the first and only interstellar comet ever detected by humans.
But what if these interstellar visitors -- comets, meteors, asteroids and other debris from beyond our solar system -- are more common than we think?
In a new study published Monday in the *Monthly Notices of the Royal Astronomical Society*, astronomers Amir Siraj and Avi Loeb at the Centre for Astrophysics | Harvard & Smithsonian (CfA) present new calculations showing that in the Oort Cloud -- a shell of debris in the farthest reaches of our solar system -- interstellar objects outnumber objects belonging to our solar system.
"Before the detection of the first interstellar comet, we had no idea how many interstellar objects there were in our solar system, but theory on the formation of planetary systems suggests that there should be fewer visitors than permanent residents," says Siraj, a concurrent undergraduate and graduate student in Harvard's Department of Astronomy and lead author of the study. "Now we're finding that there could be substantially more visitors."
The calculations, made using conclusions drawn from Borisov, include significant uncertainties, Siraj points out. But even after taking these into consideration, interstellar visitors prevail over objects that are native to the solar system.
"Let's say I watch a mile-long stretch of railroad for a day and observe one car cross it. I can say that, on that day, the observed rate of cars crossing the section of railroad was one per day per mile," Siraj explains. "But if I have a reason to believe that the observation was not a one-off event -- say, by noticing a pair of crossing gates built for cars -- then I can take it a step further and begin to make statistical conclusions about the overall rate of cars crossing that stretch of railroad."
But if there are so many interstellar visitors, why have we only ever seen one?
We just don't have the technology to see them yet, Siraj says.
Consider, he says, that the Oort Cloud spans a region some 200 billion to 100 trillion miles away from our Sun -- and unlike stars, objects in the Oort Cloud don't produce their own light. Those two factors make debris in the outer solar system incredibly hard to see.
Senior astrophysicist Matthew Holman, who was not involved in the research, says the study results are exciting because they have implications for objects even closer than the Oort Cloud.
"These results suggest that the abundances of interstellar and Oort cloud objects are comparable closer to the Sun than Saturn. This can be tested with current and future solar system surveys," says Holman, who is the former director of the CfA's Minor Planet

Centre, which tracks comets, asteroids and other debris in the solar system.
"When looking at the asteroid data in that region, the question is: are there asteroids that really are interstellar that we just didn't recognize before?" he asks.
Holman explains that there are some asteroids that get detected but aren't observed or followed up on year after year. "We think they are asteroids, then we lose them without doing a detailed look."
Loeb, study co-author and Harvard astronomy professor, adds that "interstellar objects in the planetary region of the solar system would be rare, but our results clearly show they are more common than solar system material in the dark reaches of the Oort cloud."
Observations with next-generation technology may help confirm the team's results.
The launch of the Vera C. Rubin Observatory, slated for 2022, will "blow previous searches for interstellar objects out of the water," Siraj says, and hopefully help detect many more visitors like Borisov.
The Transneptunian Automated Occultation Survey (TAOS II), which is specifically designed to detect comets in the far reaches of our solar system, may also be able to detect one of these passers-by. TAOS II may come online as early as this year.
The abundance of interstellar objects in the Oort Cloud suggests that much more debris is left over from the formation of planetary systems than previously thought, Siraj says.
"Our findings show that interstellar objects can place interesting constraints on planetary system formation processes, since their implied abundance requires a significant mass of material to be ejected in the form of planetesimals," Siraj says. "Together with observational studies of protoplanetary disks and computational approaches to planet formation, the study of interstellar objects could help us unlock the secrets of how our planetary system -- and others -- formed."

- Cosmic rays may be key to understanding galactic dynamics

Date: August 24, 2021
Source: American Institute of Physics

Cosmic rays are charged subnuclear particles that move close to the speed of light, constantly raining down on the Earth. These particles are relativistic, as defined by Albert Einstein's special relativity, and manage to generate a magnetic field that controls the way they move within the galaxy.
Gas within the interstellar medium is composed of atoms, mostly hydrogen and mostly ionized, meaning its protons and electrons are separated. While moving around within this gas, cosmic rays kickstart the background protons, which causes a collective plasma wave movement akin to the ripples on a lake when you toss in a stone.
The big question is how cosmic rays deposit their momentum into the background plasma that composes the interstellar medium. In *Physics of Plasmas*, from AIP Publishing, plasma astrophysicists in France review recent developments within the field of studying the streaming instability triggered by cosmic rays within astrophysical and space plasma.
"Cosmic rays may help explain aspects of our galaxy from its smallest scales, such as protoplanetary disks and planets, to its largest scales, such as galactic winds," said Alexandre Marcowith, from the University of Montpellier.
Until now, cosmic rays were viewed as being a bit apart within galaxy "ecology." But because instability works well and is stronger than expected around cosmic ray sources, such as supernova remnants and pulsars, these particles likely have far more impacts on galactic dynamics and the star formation cycle than previously known.
"This is not really a surprise, but more of a paradigm shift," Marcowith said. "In science and astrophysics, everything is connected."
Supernova shock waves expanding the interstellar/intergalactic medium "are known to accelerate cosmic rays, and because cosmic rays are streaming away, they may have contributed to generating the magnetic field seeds necessary to explain the actual magnetic field strengths we observe around us," said Marcowith.
After the amplitude of a plasma wave is reduced or damped over time, much like those generated by a stone thrown into a lake, it heats the gas of the plasma. Meanwhile, it helps scatter cosmic rays.
For this to occur, the waves need wavelengths of the same order as the cosmic ray gyro radius. Cosmic rays possess a helical (spiral) motion around the magnetic field, and its radius is called the Larmor radius.
"Say you are driving a car on a winding road. If the wavelength is of the same order as your wheel size, it will be difficult to drive," said Marcowith.

Cosmic rays are strongly scattered by these waves, and the main instability at the origin of these perturbations (waves) is the streaming instability associated with the collective streaming motion of cosmic rays.
"There are several fields of research in astrophysics using similar numerical techniques to investigate the impact of this streaming instability within different astrophysical contexts such as supernova remnants and jets," said Marcowith. "This instability and turbulence it creates may be the source of many astrophysical phenomena, and it shows how cosmic rays play a role in the big circus of our Milky Way."

- ❖ Here comes the Sun: Planetary scientists find evidence of solar-driven change on the Moon

Date: August 21, 2021
Source: Northern Arizona University

Tiny iron nanoparticles unlike any found naturally on Earth are nearly everywhere on the Moon -- and scientists are trying to understand why. A new study led by Northern Arizona University doctoral candidate Christian J. Tai Udovicic, in collaboration with associate professor Christopher Edwards, both of NAU's Department of Astronomy and Planetary Science, uncovered important clues to help understand the surprisingly active lunar surface. In an article recently published in *Geophysical Research Letters,* the scientists found that solar radiation could be a more important source of lunar iron nanoparticles than previously thought.
Asteroid impacts and solar radiation affect the Moon in unique ways because it lacks the protective magnetic field and atmosphere that protect us here on Earth. Both asteroids and solar radiation break down lunar rocks and soil, forming iron nanoparticles (some smaller, some larger) that are detectable from instruments on satellites orbiting the Moon.
The study used data from National Aeronautics and Space Administration (NASA) and Japan Aerospace Exploration Agency (JAXA) spacecraft to understand how quickly iron nanoparticles form on the Moon over time.
"We have thought for a long time that the solar wind has a small effect on lunar surface evolution, when in fact it may be the most important process producing iron nanoparticles," Tai Udovicic said. "Since iron absorbs a lot of light, very small amounts of these particles can be detected from very far away -- making them a great indicator of change on the Moon."
Surprisingly, the smaller iron nanoparticles seemed to form at a similar rate as radiation damage in samples returned from the Apollo missions to the Moon, a hint that the Sun has a strong influence in their formation.
"When I saw the Apollo sample data and our satellite data side by side for the first time, I was shocked," Tai Udovicic said. "This study shows that the solar radiation could have a much larger influence in active change on the Moon than previously thought, not only darkening its surface, but it might also create small quantities of water usable in future missions."
As NASA prepares to land the first woman and the next man on the surface of the Moon by 2024 as part of the Artemis mission, understanding the solar radiation environment and possible resources on the Moon are critical. In future work recently awarded a NASA Future Investigators in Space Science and Technology (FINESST) grant, Tai Udovicic plans to broaden his targeted study to the entire Moon, but is also eager to take a closer look at mysterious lunar swirls, one of which was recently selected as a landing site for the upcoming Lunar Vertex rover. He also studies lunar temperatures and water ice stability to inform future missions.
"This work helps us understand, from a bird's eye view, how the lunar surface changes over time," said Tai Udovicic. "While there is still a lot to learn, we want to make sure that when we have boots back on the Moon, that those missions are backed by the best science available. It's the most exciting time to be a lunar scientist since the tail end of the Apollo era in the 70s."

- ❖ New simulation shows how galaxies feed their supermassive black holes

First model to show how gas flows across universe into a supermassive black hole’s centre
Date: August 17, 2021
Source: Northwestern University

Galaxies' spiral arms are responsible for scooping up gas to feed to their central supermassive black holes, according to a new high-powered simulation.
Started at Northwestern University, the simulation is the first to show, in great detail, how gas flows across the universe all the way down to the centre of a supermassive black hole. While other simulations have modelled

black hole growth, this is the first single computer simulation powerful enough to comprehensively account for the numerous forces and factors that play into the evolution of supermassive black holes.
The simulation also gives rare insight into the mysterious nature of quasars, which are incredibly luminous, fast-growing black holes. Some of the brightest objects in the universe, quasars often even outshine entire galaxies.
"The light we observe from distant quasars is powered as gas falls into supermassive black holes and gets heated up in the process," said Northwestern's Claude-André Faucher-Giguère, one of the study's senior authors. "Our simulations show that galaxy structures, such as spiral arms, use gravitational forces to 'put the brakes on' gas that would otherwise orbit galaxy centres forever. This breaking mechanism enables the gas to instead fall into black holes and the gravitational brakes, or torques, are strong enough to explain the quasars that we observe."
The research was published today(Aug. 17) in the *Astrophysical Journal*.
Faucher-Giguèreis an associate professor of physics and astronomy at Northwestern's Weinberg College of Arts and Sciencesand a member of the Centre for Interdisciplinary Exploration and Research in Astrophysics(CIERA). Daniel Anglés-Alcázar, an assistant professor at the University of Connecticut and former CIERA fellow inFaucher-Giguère's group, is the paper's first author.
Equivalent to the mass of millions or even billions of suns, supermassive black holes can swallow 10 times the mass of a sun in just one year. But while some supermassive black holes enjoy a continuous supply of food, others go dormant for millions of years, only to reawaken abruptly with a serendipitous influx of gas. The details about how gas flows across the universe to feed supermassive black holes have remained a long-standing question.
To address this mystery, the research team developed the new simulation, which incorporates many of the key physical processes -- including the expansion of the universe and the galactic environment on large scales, gravity gas hydrodynamics and feedback from massive stars -- into one model.
"Powerful events such as supernovae inject a lot of energy into the surrounding medium, and this influences how the galaxy evolves," Anglés-Alcázar said. "So we need to incorporate all of these details and physical processes to capture an accurate picture."
Building on previous work from the FIRE ("Feedback In Realistic Environments") project, the new technology greatly increases model resolution and allows for following the gas as it flows across the galaxy with more than 1,000 times better resolution than previously possible.
"Other models can tell you a lot of details about what's happening very close to the black hole, but they don't contain information about what the rest of the galaxy is doing or even less about what the environment around the galaxy is doing," Anglés-Alcázar said. "It turns out, it is very important to connect all these processes at the same time."
"The very existence of supermassive black holes is quite amazing, yet there is no consensus on how they formed," Faucher-Giguère said. "The reason supermassive black holes are so difficult to explain is that forming them requires cramming a huge amount of matter into a tiny space. How does the universe manage to do that? Until now, theorists developed explanations relying on patching together different ideas for how matter in galaxies gets crammed into the innermost one millionth of a galaxy's size."
With the new simulations, researchers can finally model how this happens. For example, the new simulation will help researchers understand the origin of the supermassive black hole at the centre of our own Milky Way galaxy as well as the supermassive black hole at the centre of the Messier 87 galaxy, which was famously captured by the Event Horizon Telescopein 2019. Next, the researchers aim to study large statistical populations of galaxies and their central black holes to better understand how black holes can form and grow under various conditions.

- ❖ Fast changes between the solar seasons resolved by new sun clock

Date: August 17, 2021
Source: University of Warwick

Violent activity on our Sun leads to some of the most extreme space weather events on Earth, impacting systems such as satellites, communications systems, power distribution and aviation. The roughly 11 year cycle of solar activity has three 'seasons', each of which affects the space weather felt at Earth differently: (i) solar maximum, the sun is active and disordered, when space weather is stormy and events are irregular (ii) the

declining phase, when the sun and solar wind becomes ordered, and space weather is more moderate and (iii) solar minimum, when activity is quiet.
In a new study led by the University of Warwick and published in *The Astrophysical Journal*, scientists found that the change from solar maximum to the declining phase is fast, happening within a few (27 day) solar rotations. They also showed that the declining phase is twice as long in even-numbered solar cycles as it is in odd-numbered cycles.
No two solar cycles are the same in amplitude or duration. To study the solar seasons, the scientists built a sun clock from the daily sunspot number record available since 1818. This maps the irregular solar cycles onto a regular clock. The magnetic polarity of the sun reverses after each roughly 11 year solar cycle giving a roughly 22 year magnetic cycle (named after George Ellery Hale) and to explore this, a 22 year clock was constructed. The effect on space weather at earth can be tracked back using the longest continuous records of geomagnetic activity over the past 150 years, and once the clock is constructed, it can be used to study multiple observations of seasonal solar activity which affect the earth.
With the greater detail afforded by the sun clock, the scientists could see that the switch from solar maximum to the declining phase is fast, occurring within a few (27 day) solar rotations. There was also a clear difference in the duration of the declining phase when the sun's magnetic polarity is 'up' compared to 'down': in even-numbered cycles it is around twice as long as odd-numbered cycles. As we are about to enter cycle 25, the scientists anticipate that the next declining phase will be short.
Lead author Professor Sandra Chapman of the University of Warwick Department of Physics said: "By combining well known methods in a new way, our clock resolves changes in the Sun's climate to within a few solar rotations. Then you find the changes between some phases can be really sharp.
"If you know you've had a long cycle, you know the next one's going to be short, we can estimate how long it's going to last. Knowing the timing of the climate seasons helps to plan for space weather. Operationally it is useful to know when conditions will be active or quiet, for satellites, power grids, communications."
The results also provide a clue to understanding how the Sun reverses polarity after every cycle.
Professor Chapman adds: "I also think it is remarkable that something the size of the sun can flip its magnetic field every 11 years, and going down-up is different to going up-down. Somehow the sun 'knows which way up it is', and this is an intriguing problem, at the heart of how the sun generates its magnetic field."

- Solving solar puzzle could help save Earth from planet-wide blackouts

Date: August 5, 2021
Source: University of Sydney

Scientists in Australia and in the USA have solved a long-standing mystery about the Sun that could help astronomers predict space weather and help us prepare for potentially devastating geomagnetic storms if they were to hit Earth.
The Sun's internal magnetic field is directly responsible for space weather -- streams of high-energy particles from the Sun that can be triggered by solar flares, sunspots or coronal mass ejections that produce geomagnetic storms. Yet it is unclear how these happen and it has been impossible to predict when these events will occur.
Now, a new study led by Dr Geoffrey Vasil from the School of Mathematics & Statistics at the University of Sydney could provide a strong theoretical framework to help improve our understanding of the Sun's internal magnetic dynamo that helps drive near-Earth space weather.
The Sun is made up of several distinct regions. The convection zone is one of the most important -- a 200,000-kilometre-deep ocean of super-hot rolling, turbulent fluid plasma taking up the outer 30 percent of the star's diameter.
Existing solar theory suggests the largest swirls and eddies take up the convection zone, imagined as giant circular convection cells as pictured here by NASA.
However, these cells have never been found, a long-standing problem known as the 'Convective Conundrum'.
Dr Vasil said there is a reason for this. Rather than circular cells, the flow breaks up into tall spinning cigar-shaped columns 'just' 30,000 kilometres across. This, he said, is caused by a much stronger influence of the Sun's rotation than previously thought.
"You can balance a skinny pencil on its point if you spin it fast enough," said Dr Vasil, an

expert in fluid dynamics. "Skinny cells of solar fluid spinning in the convection zone can behave similarly."
The findings have been published in the *Proceedings of the National Academy of Sciences of the United States of America*.
"We don't know very much about the inside of the Sun, but it is hugely important if we want to understand solar weather that can directly impact Earth," Dr Vasil said.
"Strong rotation is known to completely change the properties of magnetic dynamos, of which the Sun is one."
Dr Vasil and collaborators Professor Keith Julien of the University of Colorado and Dr Nicholas Featherstone at Southwest Research Institute in Boulder, say that this predicted rapid rotation inside the Sun suppresses what otherwise would be larger-scale flows, creating more variegated dynamics for the outer third of the solar depth.
"By properly accounting for rotation, our new model of the Sun fits observed data and could dramatically improve our understanding of the Sun's electromagnetic behaviour," said Dr Vasil, who is the lead author of the study.
In the most extreme cases, solar geomagnetic storms can shower the Earth with pulses of radiation capable of frying our sophisticated global electronics and communication infrastructure.
A huge geomagnetic storm of this type hit Earth in 1859, known as the Carrington Event, but this was before our global reliance on electronics. The fledgling telegraph system from Melbourne to New York was affected.
"A similar event today could destroy trillions of dollars' worth of global infrastructure and take months, if not years, to repair," Dr Vasil said.
A small-scale event in 1989 caused massive blackouts in Canada in what some initially thought might have been a nuclear attack. In 2012 a solar storm similar in scale to the Carrington Event passed by Earth without impacting, missing our orbit around the Sun by just nine days.
"The next solar max is in the middle of this decade, yet we still don't know enough about the Sun to predict if these cyclical events will produce a dangerous storm," Dr Vasil said.
"While a solar storm hitting Earth is very unlikely, like an earthquake, it will eventually happen and we need to be prepared."
Solar storms emerging from within the Sun can take from several hours to days to reach Earth. Dr Vasil said that better knowledge of the internal dynamism of our home star could help planners avoid disaster if they have enough warning to shut down equipment before a blast of energetic particles does the job instead.
"We cannot explain how sunspots form. Nor can we discern what sunspot groups are most prone to violent rupture. Policymakers need to know how often it might be necessary to endure a days-long emergency shutdown to avoid a severe catastrophe," he said.
Dr Vasil and his colleagues' theoretical model will now need to be tested through observation to further improve the modelling of the Sun's internal processes. To do this, scientists will use a technique known as helioseismology, to listen inside the beating heart of the star.
"We hope our findings will inspire further observation and research into the driving forces of the Sun," he said.
This could involve the unprecedented launch of polar orbiter observational satellites outside the elliptical plane of the Solar System.

- ❖ Ocean world: Rocky exoplanet has just half the mass of Venus

Date: August 5, 2021
Source: ESO

A team of astronomers have used the European Southern Observatory's Very Large Telescope (ESO's VLT) in Chile to shed new light on planets around a nearby star, L 98-59, that resemble those in the inner Solar System. Amongst the findings are a planet with half the mass of Venus -- the lightest exoplanet ever to be measured using the radial velocity technique -- an ocean world, and a possible planet in the habitable zone.
"The planet in the habitable zone may have an atmosphere that could protect and support life," says María Rosa Zapatero Osorio, an astronomer at the Centre for Astrobiology in Madrid, Spain, and one of the authors of the study published today in *Astronomy & Astrophysics.*
The results are an important step in the quest to find life on Earth-sized planets outside the Solar System. The detection of biosignatures on an exoplanet depends on the ability to study its atmosphere, but current telescopes are not large enough to achieve the resolution needed to do this for small, rocky planets. The newly studied planetary system, called L 98-59 after its star, is an attractive target for future observations of exoplanet atmospheres. Its orbits a star only 35 light-years away and

has now been found to host rocky planets, like Earth or Venus, which are close enough to the star to be warm.

With the contribution of ESO's VLT, the team was able to infer that three of the planets may contain water in their interiors or atmospheres. The two planets closest to the star in the L 98-59 system are probably dry, but might have small amounts of water, while up to 30% of the third planet's mass could be water, making it an ocean world.

Furthermore, the team found "hidden" exoplanets that had not previously been spotted in this planetary system. They discovered a fourth planet and suspect there is a fifth, in a zone at the right distance from the star for liquid water to exist on its surface.

"We have hints of the presence of a terrestrial planet in the habitable zone of this system," explains Olivier Demangeon, a researcher at the Instituto de Astrofísica e Ciências do Espaço, University of Porto in Portugal and lead author of the new study.

The study represents a technical breakthrough, as astronomers were able to determine, using the radial velocity method, that the innermost planet in the system has just half the mass of Venus. This makes it the lightest exoplanet ever measured using this technique, which calculates the wobble of the star caused by the tiny gravitational tug of its orbiting planets.

The team used the Echelle SPectrograph for Rocky Exoplanets and Stable Spectroscopic Observations (ESPRESSO) instrument on ESO's VLT to study L 98-59. "Without the precision and stability provided by ESPRESSO this measurement would have not been possible," says Zapatero Osorio. "This is a step forward in our ability to measure the masses of the smallest planets beyond the Solar System."

The astronomers first spotted three of L 98-59's planets in 2019, using NASA's Transiting Exoplanet Survey Satellite (TESS). This satellite relies on a technique called the transit method -- where the dip in the light coming from the star caused by a planet passing in front of it is used to infer the properties of the planet -- to find the planets and measure their sizes. However, it was only with the addition of radial velocity measurements made with ESPRESSO and its predecessor, the High Accuracy Radial velocity Planet Searcher (HARPS) at the ESO La Silla 3.6-metre telescope, that Demangeon and his team were able to find extra planets and measure the masses and radii of the first three. "If we want to know what a planet is made of, the minimum that we need is its mass and its radius," Demangeon explains.

The team hopes to continue to study the system with the forthcoming NASA/ESA/CSA James Webb Space Telescope (JWST) , while ESO's Extremely Large Telescope (ELT), under construction in the Chilean Atacama Desert and set to start observations in 2027, will also be ideal for studying these planets. "The HIRES instrument on the ELT may have the power to study the atmospheres of some of the planets in the L 98-59 system, thus complementing the JWST from the ground," says Zapatero Osorio.

"This system announces what is to come," adds Demangeon. "We, as a society, have been chasing terrestrial planets since the birth of astronomy and now we are finally getting closer and closer to the detection of a terrestrial planet in the habitable zone of its star, of which we could study the atmosphere."

- Nearby star resembles ours in its youth

Date: August 4, 2021
Source: NASA/Goddard Space Flight Centre

New research led by NASA provides a closer look at a nearby star thought to resemble our young Sun. The work allows scientists to better understand what our Sun may have been like when it was young, and how it may have shaped the atmosphere of our planet and the development of life on Earth.

Many people dream of meeting with a younger version of themselves to exchange advice, identify the origins of their defining traits, and share hopes for the future. At 4.65 billion years old, our Sun is a middle-aged star. Scientists are often curious to learn exactly what properties enabled our Sun, in its younger years, to support life on nearby Earth. Without a time machine to transport scientists back billions of years, retracing our star's early activity may seem an impossible feat. Luckily, in the Milky Way galaxy -- the glimmering, spiralling segment of the universe where our solar system is located -- there are more than 100 billion stars. One in ten share characteristics with our Sun, and many are in the early stages of development.

"Imagine I want to reproduce a baby picture of an adult when they were one or two years old, and all of their pictures were erased or lost. I would look at a photo of them now, and their close relatives' photos from around that age,

and from there, reconstruct their baby photos," said Vladimir Airapetian, senior astrophysicist in the Heliophysics Division at NASA's Goddard Space Flight Centre in Greenbelt, Maryland, and first author on the new study. "That's the sort of process we are following here -- looking at characteristics of a young star similar to ours, to better understand what our own star was like in its youth, and what allowed it to foster life on one of its nearby planets."
Kappa 1 Ceti is one such solar analogue. The star is located about 30 light-years away (in space terms, that's like a neighbour who lives on the next street over) and is estimated to be between 600 to 750 million years old, around the same age our Sun was when life developed on Earth. It also has a similar mass and surface temperature to our Sun, said the study's second author, Meng Jin, a heliophysicist with the SETI Institute and the Lockheed Martin Solar and Astrophysics Laboratory in California. All of those factors make Kappa 1 Ceti a "twin" of our young Sun at the time when life arose on Earth, and an important target for study.
Airapetian, Jin, and several colleagues have adapted an existing solar model to predict some of Kappa 1 Ceti's most important, yet difficult to measure, characteristics. The model relies on data input from a variety of space missions including the NASA/ESA Hubble Space Telescope, NASA's Transiting Exoplanet Survey Satellite and NICER missions, and ESA's XMM-Newton. The team published their study today in *The Astrophysical Journal.*
Star Power
Like human toddlers, toddler stars are known for their high bursts of energy and activity. For stars, one way this pent-up energy is released is in the form of a stellar wind.
Stellar winds, like stars themselves, are mostly made up of a superhot gas known as plasma, created when particles in a gas have split into positively charged ions and negatively charged electrons. The most energetic plasma, with the help of a star's magnetic field, can shoot off away from the outermost and hottest part of a star's atmosphere, the corona, in an eruption, or stream more steadily toward nearby planets as stellar wind. "Stellar wind is continuously flowing out from a star toward its nearby planets, influencing those planets' environments," Jin said.
Younger stars tend to generate hotter, more vigorous stellar winds and more powerful plasma eruptions than older stars do. Such outbursts can affect the atmosphere and chemistry of planets nearby, and possibly even catalyse the development of organic material -- the building blocks for life -- on those planets.
Stellar wind can have a significant impact on planets at any stage of life. But the strong, highly dense stellar winds of young stars can compress the protective magnetic shields of surrounding planets, making them even more susceptible to the effects of the charged particles.
Our Sun is a perfect example. Compared to now, in its toddlerhood, our Sun likely rotated three times faster, had a stronger magnetic field, and shot out more intense high-energy radiation and particles. These days, for lucky spectators, the impact of these particles is sometimes visible near the planet's poles as aurora, or the Northern and Southern Lights. Airapetian says 4 billion years ago, considering the impact of our Sun's wind at that time, these tremendous lights were likely often visible from many more places around the globe.
That high level of activity in our Sun's nascence may have pushed back Earth's protective magnetosphere, and provided the planet -- not close enough to be torched like Venus, nor distant enough to be neglected like Mars -- with the right atmospheric chemistry for the formation of biological molecules.
Similar processes could be unfolding in stellar systems across our galaxy and universe.
"It's my dream to find a rocky exoplanet in the stage that our planet was in more than 4 billion years ago, being shaped by its young, active star and nearly ready to host life," Airapetian said. "Understanding what our Sun was like just as life was beginning to develop on Earth will help us to refine our search for stars with exoplanets that may eventually host life."
A Solar Twin
Though solar analogues can help solve one of the challenges of peeking into the Sun's past, time isn't the only complicating factor in studying our young Sun. There's also distance.
We have instruments capable of accurately measuring the stellar wind from our own Sun, called the solar wind. However, it's not yet possible to directly observe the stellar wind of other stars in our galaxy, like Kappa 1 Ceti, because they are too far away.
When scientists wish to study an event or phenomenon that they cannot directly observe,

scientific modelling can help fill in the gaps. Models are representations or predictions of an object of study, built on existing scientific data. While scientists have previously modelled the stellar wind from this star, Airapetian said, they used more simplified assumptions.

"Every model needs input to get output," Airapetian said. "To get useful, accurate output, the input needs to be solid data, ideally from multiple sources across time. We have all that data from Kappa 1 Ceti, but we really synthesized it in this predictive model to move past previous purely observational studies of the star."

Airapetian likens his team's model to a doctor's report. To get a full picture of how a patient is doing, a doctor is likely to talk to the patient, gather markers like heart rate and temperature, and if needed, conduct several more specialized tests, like a blood test or ultrasound. They are likely to formulate an accurate assessment of patient well-being with a combination of these metrics, not just one. Similarly, by using many pieces of information about Kappa 1 Ceti gathered from different space missions, scientists are better able to predict its corona and the stellar wind. Because stellar wind can affect a nearby planet's magnetic shield, it plays an important role in habitability. The team is also working on another project, looking more closely at the particles that may have emerged from early solar flares, as well as prebiotic chemistry on Earth.

Our Sun's Past, Written in the Stars

The researchers hope to use their model to map the environments of other Sun-like stars at various life stages.

Specifically, they have eyes on the infant star EK Dra -- 111 light-years away and only 100 million years old -- which is likely rotating three times faster and shooting off more flares and plasma than Kappa 1 Ceti. Documenting how these similar stars of various ages differ from one another will help characterize the typical trajectory of a star's life.

Their work, Airapetian said, is all about "looking at our own Sun, its past and its possible future, through the lens of other stars."

To learn more about our Sun's stormy youth, watch this video and see how energy from our young Sun -- 4 billion years ago -- aided in creating molecules in Earth's atmosphere, allowing it to warm up enough to incubate life.

The basis for the new model of Kappa 1 Ceti by Airapetian, Jin, and colleagues is the Alfvén Wave Solar Model, which is within the Space Weather Modeling Framework developed by the University of Michigan. The model works by inputting known information about a star, including its magnetic field and ultraviolet emission line data, to predict stellar wind activity. When the model has been tested on our Sun, it has been validated and checked against observed data to verify that its predictions are accurate.

"It's capable of modelling our star's winds and corona with high fidelity," Jin said. "And it's a model we can use on other stars, too, to predict their stellar wind and thereby investigate habitability. That's what we did here."

Previous studies have drawn on data gathered by the Transiting Exoplanet Survey Satellite (TESS) and Hubble Space Telescope (HST) to identify Kappa 1 Ceti as a young solar proxy, and to gather the necessary inputs for the model, such as magnetic field and ultraviolet emission line data.

- ❖ Why is this weird, metallic star hurtling out of the Milky Way?

Astronomers analysed light data from a piece of supernova shrapnel to gain clues about where it came from

Date: August 2, 2021
Source: Boston University

About 2,000 light-years away from Earth, there is a star catapulting toward the edge of the Milky Way. This particular star, known as LP 40?365, is one of a unique breed of fast-moving stars -- remnant pieces of massive white dwarf stars -- that have survived in chunks after a gigantic stellar explosion.

"This star is moving so fast that it's almost certainly leaving the galaxy…[it's] moving almost two million miles an hour," says JJ Hermes, Boston University College of Arts & Sciences assistant professor of astronomy. But why is this flying object speeding out of the Milky Way? Because it's a piece of shrapnel from a past explosion -- a cosmic event known as a supernova -- that's still being propelled forward.

"To have gone through partial detonation and still survive is very cool and unique, and it's only in the last few years that we've started to think this kind of star could exist," says Odelia Putterman, a former BU student who has worked in Hermes' lab.

In a new paper published in *The Astrophysical Journal Letters*, Hermes and Putterman uncover new observations about this leftover "star shrapnel" that gives insight to other stars with similar catastrophic pasts.
Putterman and Hermes analysed data from NASA's Hubble Space Telescope and Transiting Exoplanet Survey Satellite (TESS), which surveys the sky and collects light information on stars near and far. By looking at various kinds of light data from both telescopes, the researchers and their collaborators found that LP 40?365 is not only being hurled out of the galaxy, but based on the brightness patterns in the data, is also rotating on its way out.
"The star is basically being slingshotted from the explosion, and we're [observing] its rotation on its way out," says Putterman, who is second author on the paper.
"We dug a little deeper to figure out why that star [was repeatedly] getting brighter and fainter, and the simplest explanation is that we're seeing something at [its] surface rotate in and out of view every nine hours," suggesting its rotation rate, Hermes says. All stars rotate -- even our sun slowly rotates on its axis every 27 days. But for a star fragment that's survived a supernova, nine hours is considered relatively slow.
Supernovas occur when a white dwarf gets too massive to support itself, eventually triggering a cosmic detonation of energy. Finding the rotation rate of a star like LP 40?365 after a supernova can lend clues into the original two-star system it came from. It's common in the universe for stars to come in close pairs, including white dwarfs, which are highly dense stars that form toward the end of a star's life. If one white dwarf gives too much mass to the other, the star being dumped on can self-destruct, resulting in a supernova.
Supernovas are commonplace in the galaxy and can happen in many different ways, according to the researchers, but they are usually very hard to see. This makes it hard to know which star did the imploding and which star dumped too much mass onto its star partner.
Based on LP 40?365's relatively slow rotation rate, Hermes and Putterman feel more confident that it is shrapnel from the star that self-destructed after being fed too much mass by its partner, when they were once orbiting each other at high speed. Because the stars were orbiting each other so quickly and closely, the explosion slingshotted both stars, and now we only see LP 40-365.
"This [paper] adds one more layer of knowledge into what role these stars played when the supernova occurred," and what can happen after the explosion, Putterman says.
"By understanding what's happening with this particular star, we can start to understand what's happening with many other similar stars that came from a similar situation."
"These are very weird stars," Hermes says.
Stars like LP 40-365 are not only some of the fastest stars known to astronomers, but also the most metal-rich stars ever detected. Stars like our sun are composed of helium and hydrogen, but a star that has survived a supernova is primarily composed of metal material, because "what we're seeing are the by-products of violent nuclear reactions that happen when a star blows itself up," Hermes says, making star shrapnel like this especially fascinating to study.

- Astronomers probe layer-cake structure of brown dwarf's atmosphere

Date: July 30, 2021
Source: W. M. Keck Observatory

Maunakea, Hawaii -- Jupiter may be the bully planet of our solar system because it's the most massive planet, but it's actually a runt compared to many of the giant planets found around other stars.
These alien worlds, called super-Jupiters, weigh up to 13 times Jupiter's mass.
Astronomers have analysed the composition of some of these monsters, but it has been difficult to study their atmospheres in detail because these gas giants get lost in the glare of their parent stars.
Researchers, however, have a substitute: the atmospheres of brown dwarfs, so-called failed stars that are up to 80 times Jupiter's mass.
These hefty objects form out of a collapsing cloud of gas, as stars do, but lack the mass to become hot enough to sustain nuclear fusion in their cores, which powers stars.
Instead, brown dwarfs share a kinship with super-Jupiters. Both types of objects have similar temperatures and are extremely massive. They also have complex, varied atmospheres. The only difference, astronomers think, is their pedigree. Super-Jupiters form around stars; brown dwarfs often form in isolation.
A team of astronomers, led by Elena Manjavacas of the Space Telescope Science Institute in Baltimore, Maryland, has tested a

new way to peer through the cloud layers of these nomadic objects. The researchers used an instrument at W. M. Keck Observatory on Maunakea in Hawaii to study in near-infrared light the colours and brightness variations of the layer-cake cloud structure in the nearby, free-floating brown dwarf known as 2MASS J22081363+2921215.
The Keck Observatory instrument, called the Multi-Object Spectrograph for Infrared Exploration (MOSFIRE), also analysed the spectral fingerprints of various chemical elements contained in the clouds and how they change with time. This is the first time astronomers have used MOSFIRE in this type of study.
These measurements offered Manjavacas a holistic view of the brown dwarf's atmospheric clouds, providing more detail than previous observations of this object. Pioneered by Hubble observations, this technique is difficult for ground-based telescopes to do because of contamination from Earth's atmosphere, which absorbs certain infrared wavelengths. This absorption rate changes due to the weather.
"The only way to do this from the ground is by using Keck's high-resolution MOSFIRE instrument because it allows us to observe multiple stars simultaneously with our brown dwarf," said Manjavacas, a former staff astronomer at Keck Observatory and the lead author of the study. "This allows us to correct for the contamination introduced by the Earth's atmosphere and measure the true signal from the brown dwarf with good precision. So, these observations are a proof-of-concept that MOSFIRE can do these types of studies of brown dwarf atmospheres."
She decided to study this particular brown dwarf because it is very young and therefore extremely bright. It has not cooled off yet. Its mass and temperature are similar to those of the nearby giant exoplanet Beta Pictoris b, discovered in 2008 near-infrared images taken by the European Southern Observatory's Very Large Telescope in northern Chile.
"We don't have the ability yet with current technology to analyse in detail the atmosphere of Beta Pictoris b," Manjavacas said. "So, we're using our study of this brown dwarf's atmosphere as a proxy to get an idea of what the exoplanet's clouds might look like at different heights of its atmosphere."
Both the brown dwarf and Beta Pictoris b are young, so they radiate heat strongly in the near-infrared. They are both members of a flock of stars and sub-stellar objects called the Beta Pictoris moving group, which shares the same origin and a common motion through space. The group, which is about 33 million years old, is the closest grouping of young stars to Earth. It is located roughly 115 light-years away.
While they're cooler than bona fide stars, brown dwarfs are still extremely hot. The brown dwarf in Manjavacas' study is a sizzling 2,780 degrees Fahrenheit (1,527 degrees Celsius).
The giant object is about 12 times heavier than Jupiter. As a young body, it is spinning incredibly fast, completing a rotation every 3.5 hours, compared to Jupiter's 10-hour rotation period. So, clouds are whipping around the planet, creating a dynamic, turbulent atmosphere.
Keck Observatory's MOSFIRE instrument stared at the brown dwarf for 2.5 hours, watching how the light filtering up through the atmosphere from the dwarf's hot interior brightens and dims over time. Bright spots that appeared on the rotating object indicate regions where researchers can see deeper into the atmosphere, where it is hotter. Infrared wavelengths allow astronomers to peer deeper into the atmosphere. The observations suggest the brown dwarf has a mottled atmosphere with scattered clouds. If viewed close-up, the planet might resemble a carved Halloween pumpkin, with light escaping from the hot interior.
Its spectrum reveals clouds of hot sand grains and other exotic elements. Potassium iodide traces the object's upper atmosphere, which also includes magnesium silicate clouds. Moving down in the atmosphere is a layer of sodium iodide and magnesium silicate clouds. The final layer consists of aluminium oxide clouds. The atmosphere's total depth is 446 miles (718 kilometres). The elements detected represent a typical part of the composition of brown dwarf atmospheres, Manjavacas said. She and her team used computer models of brown dwarf atmospheres to determine the location of the chemical compounds in each cloud layer.
The study will be published in *The Astronomical Journal*.
Manjavacas' plan is to use Keck Observatory's MOSFIRE to study other atmospheres of brown dwarfs and compare them to those of gas giants. Future telescopes such as NASA's James Webb Space Telescope, an infrared

observatory scheduled to launch later this year, will provide even more information about a brown dwarf's atmosphere.
"JWST will give us the structure of the entire atmosphere, providing more coverage than any other telescope," Manjavacas said.
She hopes that MOSFIRE can be used in tandem with JWST to sample a wide range of brown dwarfs and gain a better understanding of brown dwarfs and giant planets.
"Exoplanets are so much more diverse than what we see locally in the solar system," said Keck Observatory Chief Scientist John O'Meara. "It's work like this, and future work with Keck and JWST, that will give us a fuller picture of the diversity of planets orbiting other stars."

- HR 8799 super-Jupiters' days measured for the first time, gives a new spin on unravelling planet formation mystery

Date: July 29, 2021
Source: W. M. Keck Observatory

Astronomers have captured the first-ever spin measurements of HR 8799, the famed system that made history as the very first exoplanetary system to have its image taken.
Discovered in 2008 by two Maunakea Observatories in Hawaii -- W. M. Keck Observatory and the international Gemini Observatory, a Program of NSF's NOIRLab -- the HR 8799 star system is located 129 light-years away and has four planets more massive than Jupiter, or super-Jupiters: HR 8799 planets b, c, d, and e. None of their rotation periods had ever been measured, until now.
The breakthrough was made possible by a Caltech and Keck Observatory-led science and engineering team that has developed an instrument capable of observing known imaged exoplanets at spectral resolutions that are detailed enough to allow astronomers to decipher how fast the planets are spinning.
Using the state-of-the-art Keck Planet Imager and Characterizer (KPIC) on the Keck II telescope atop Hawaii Island's Maunakea, astronomers found that the minimum rotation speeds of HR 8799 planets d and e clocked in at 10.1 km/s and 15 km/s, respectively. This translates to a length of day that could be as short as three hours or could be up to 24 hours such as on Earth depending on the axial tilts of the HR 8799 planets, which are currently undetermined. For context, one day on Jupiter lasts nearly 10 hours; its rotation speed is about 12.7 km/s.
As for the other two planets, the team was able to constrain the spin of HR 8799 c to an upper limit of less than 14 km/s; planet b's rotation measurement was inconclusive.
The findings are KPIC's first science results, which have been accepted for publication in *The Astronomical Journal*.
"With KPIC, we were able to obtain the highest spectral resolution observations ever conducted of the HR 8799 exoplanets," says Jason Wang, an astronomer at Caltech and lead author of the study. "This allows us to study them with finer granularity than ever before and unlocks the key to gaining a deeper understanding of not just how these four planets formed, but how gas giants in general develop throughout the universe."

DIZZY DATA UNVEILS PLANETS' PAST

How fast a planet spins gives insight into its formation history. Created out of gas and dust kicked up by a new born star, baby planets start spinning faster as they accumulate more material and grow -- a process called core accretion. It is believed that planetary magnetic fields then slow and cap their rotation speed. After the fully-formed planet is finished accreting and cools off, it spins back up.
"The spins of HR 8799 planets d and e are consistent with the theory that the planets' magnetic fields put a brake on their spins in their natal years," says Wang. "The spin measurements also hint at the notion that lower mass planets spin faster because they are less affected by magnetic braking, which might tell us something important about how they form. I find this tantalizing."
Wang stresses this possible trend is unconfirmed; to validate it requires more KPIC spin measurements of lower mass companions. The team's goal is to find a common link between the rotation periods of the HR 8799 planets, the giant planets in our own solar system, Jupiter and Saturn, and other known super-Jupiters and brown dwarfs.
"With enough spin measurements, we'll be able to identify trends that would reveal how the physical processes driving planet formation work," says co-author Jean-Baptiste Ruffio, a David and Ellen Lee Postdoctoral Scholar Research Associate in Astronomy at Caltech. "This is something that people have already started doing, but KPIC is allowing us to do this for the smallest, faintest, and closest imaged alien worlds."

KPIC'S FIRST LIGHT SUCCESS

Commissioned between 2018 to 2020, KPIC's specialty is detecting exoplanets and brown dwarfs that orbit so close to their host stars that the glare from the starlight makes it difficult to 'see' these celestial bodies from Earth. The instrument filters unwanted starlight by way of an innovative fibre injection unit that routes light from the Keck II telescope adaptive optics (AO) system into the Observatory's Near-Infrared Spectrograph (NIRSPEC).

KPIC's first light results are outlined in a technical paper that has been accepted in the *Journal of Astronomical Telescopes, Instruments, and Systems (JATIS)*.

"KPIC is a game-changer in the field of exoplanet characterization," says KPIC Principal Investigator Dimitri Mawet, Professor of Astronomy at Caltech. "It allows us to measure a planet's length of day, orbit, and molecular makeup of its atmosphere."

KPIC made strong detections of water and carbon monoxide, but no methane, in three of the four HR 8799 planets -- c, d, and e -- which is consistent with what is known of the planets' atmospheres.

"It's exciting to see KPIC's superpower manifest," says Keck Observatory AO Scientist/Engineer Jacques Delorme, lead author of the JATIS paper. "Because this is the first technology of its kind, we didn't know if KPIC was going to work as well as it did. Now that we have successfully demonstrated its capabilities, we can move on to Phase 2 of the project to further improve the instrument's overall performance."

"We have yet to unlock KPIC's full science potential," says Caltech Lead Instrument Scientist Nemanja Jovanovic, co-author of the technical paper. "Through more instrument upgrades, we hope to observe exoplanets in the near future with such a high degree of detail, that we'll be able to study weather phenomena and map clouds of gas giant planets."

Phase 2 of the KPIC upgrades are planned for this Winter. If all goes well, Keck Observatory's science community may begin using the technology in the second half of 2022.

- Scientists observe gas re-accretion in dying galaxies for the first time

Date: July 29, 2021
Source: National Radio Astronomy Observatory

A new study from scientists using the Atacama Large Millimetre/submillimetre Array (ALMA) suggests that previously displaced gases can re-accrete onto galaxies, potentially slowing down the process of galaxy death caused by ram pressure stripping, and creating unique structures more resistant to its effects.

"Much of the previous work on ram pressure stripped galaxies is focused on the material that gets stripped out of galaxies. In this new work we see some gas that rather than being thrown out of the galaxy never to return is instead moving like a boomerang, being ejected out but then circling around and falling back to its source," said William Cramer, an astronomer at Arizona State University and the lead author on the new study. "By combining Hubble and ALMA data at very high resolution, we are able to prove that this process is happening."

Ram pressure stripping refers to the process that displaces gas from galaxies, leaving them without the material needed to form new stars. As galaxies move through their galaxy clusters, hot gas known as the intra-cluster medium -- or, the space between -- acts like a forceful wind, pushing gases out of the traveling galaxies. Over time, this leads to the starvation and "death" of once-active star-forming galaxies. Because ram pressure stripping can speed up the normal life cycle of galaxies and alter the amount of molecular gas within them, it is of particular interest to scientists studying the life, maturation, and death of galaxies.

"We've seen in simulations that not all of the gas being pushed by ram pressure stripping escapes the galaxy because it has to reach escape velocity in order to actually escape and not fall back. The re-accretion that we're seeing, we believe is from clouds of gas that were pushed out of the galaxy by ram pressure stripping, and didn't achieve escape velocity, so they're falling back," said Jeff Kenney, an astronomer at Yale University, and the co-author on the study. "If you're trying to predict how fast a galaxy is going to stop forming stars over time and transform into a red, or dead galaxy, then you want to understand how effective ram pressure is at stripping the gas out. If you don't know that gas can fall back onto the galaxy and continue to recycle and form new stars, you're going to overpredict the quenching of the stars. Having proof of this process means more accurate timelines for the lifecycle of galaxies."

The new study focuses on NGC 4921 -- a barred spiral galaxy and the largest spiral galaxy in the Coma Cluster -- located roughly 320 million light-years from Earth in the constellation Coma Berenices. NGC 4921 is of particular interest to scientists studying the effects of ram pressure stripping because evidence of both the process and its aftermath is abundant.

"Ram pressure triggers star formation on the side where it is having the greatest impact on the galaxy," said Cramer. "It's easy to identify in NGC 4921 because there are many young blue stars on the side of the galaxy where it's occurring."

Kenney added that ram pressure stripping in NGC 4921 has created a strong, visible line between where dust still exists in the galaxy and where it doesn't. "There is a strong dust line present, and beyond that there's almost no gas in the galaxy. We think that that part of the galaxy has been almost completely cleaned out by ram pressure."

Using ALMA's Band 6 receiver, scientists were able to resolve carbon monoxide, the key to "seeing" both those areas of the galaxy devoid of gas, as well as those areas where it is re-accreting. "We know that the majority of molecular gas in galaxies is in the form of hydrogen, but molecular hydrogen is very difficult to observe directly," said Cramer. "Carbon monoxide is commonly used as a proxy for studying molecular gas in galaxies because it is much easier to observe."

The ability to see more of the galaxy, even at its faintest, unveiled interesting structures likely created in the process of gas displacement, and further immune to its effects. "Ram pressure appears to form unique structures, or filaments in galaxies that are clues as to how a galaxy evolves under a ram pressure wind. In the case of NGC 4921, they bear a striking resemblance to the famous nebula, the Pillars of Creation, although on a much more massive scale," said Cramer. "We think that they are supported by magnetic fields which are preventing them from being stripped away with the rest of the gas."

Observations revealed that the structures are more than just wisps of gas and dust; the filaments have mass and a lot of it. "These filaments are heavier and stickier -- they hold on to their material more tightly than the rest of the galaxy's interstellar medium can do -- and they seem to be connected to that big dust ridge both in space and in velocity," said Kenney. "They're more like molasses than smoke. If you just blow on something that is smoke, the smoke is light, and it disperses and goes in all directions. But this is much heavier than that."

Although a significant breakthrough, the results of the study are only a starting point for Cramer and Kenney, who examined one small part of just one galaxy. "If we want to predict the death rate of galaxies, and the birth rate of new stars, we need to understand if and how much of the material that forms stars, originally lost to ram pressure, is actually recycled back," said Cramer. "These observations are of just one quadrant of NGC 4921. There is likely even more gas falling back into other quadrants. While we have confirmed that some stripped gas can 'rain' back down, we need more observations to quantify how much gas falls back and how many new stars form as a result."

"A fascinating study, demonstrating the power of ALMA and the benefit of combining its observations with those of a telescope at other wavelengths," added Joseph Pesce, NRAO/ALMA program officer at the NSF. "Ram pressure stripping is an important phenomenon for galaxies in clusters, and understanding the process better allows us to understand galaxy evolution -- and nature -- better."

- ❖ Scientists capture most-detailed radio image of Andromeda galaxy to date

Disk of galaxy identified as region where new stars are born

Date: July 28, 2021
Source: University of British Columbia

Scientists have published a new, detailed radio image of the Andromeda galaxy -- the Milky Way's sister galaxy -- which will allow them to identify and study the regions of Andromeda where new stars are born.

The study -- which is the first to create a radio image of Andromeda at the microwave frequency of 6.6 GHz -- was led by University of British Columbia physicist Sofia Fatigoni, with colleagues at Sapienza University of Rome and the Italian National Institute of Astrophysics. It was published online in *Astronomy and Astrophysics.*

"This image will allow us to study the structure of Andromeda and its content in more detail than has ever been possible," said

Fatigoni, a PhD student in the department of physics and astronomy at UBC.
"Understanding the nature of physical processes that take place inside Andromeda allows us to understand what happens in our own galaxy more clearly -- as if we were looking at ourselves from the outside."
Prior to this study, no maps capturing such a large region of the sky around the Andromeda Galaxy had ever been made in the microwave band frequencies between one GHz to 22 GHz. In this range, the galaxy's emission is very faint, making it hard to see its structure. However, it is only in this frequency range that particular features are visible, so having a map at this particular frequency is crucial to understanding which physical processes are happening inside Andromeda.
In order to observe Andromeda at this frequency, the researchers required a single-dish radio telescope with a large effective area. For the study, the scientists turned to the Sardinia Radio Telescope, a 64-metre fully steerable telescope capable of operating at high radio frequencies.
It took 66 hours of observation with the Sardinia Radio Telescope and consistent data analysis for the researchers to map the galaxy with high sensitivity. They were then able to estimate the rate of star formation within Andromeda, and produce a detailed map that highlighted the disk of the galaxy as the region where new stars are born.
"By combining this new image with those previously acquired, we have made significant steps forward in clarifying the nature of Andromeda's microwave emissions and allowing us to distinguish physical processes that occur in different regions of the galaxy," said Dr. Elia Battistelli, a professor in the department of physics at Sapienza and coordinator of the study.
"In particular, we were able to determine the fraction of emissions due to thermal processes related to the early stations of new star formation, and the fraction of radio signals attributable to non-thermal mechanisms due to cosmic rays that spiral in the magnetic field present in the interstellar medium," Fatigoni said.
For the study, the team developed and implemented software that allowed -- among other things -- to test new algorithms to identify never-before-examined lower emission sources in the field of view around Andromeda at a frequency of 6.6 GHz. From the resulting map, researchers were able to identify a catalogue of about 100 point sources, including stars, galaxies and other objects in the background of Andromeda.

- ❖ First detection of light from behind a black hole

Date: July 28, 2021
Source: Stanford University

Watching X-rays flung out into the universe by the supermassive black hole at the centre of a galaxy 800 million light-years away, Stanford University astrophysicist Dan Wilkins noticed an intriguing pattern. He observed a series of bright flares of X-rays -- exciting, but not unprecedented -- and then, the telescopes recorded something unexpected: additional flashes of X-rays that were smaller, later and of different "colours" than the bright flares.
According to theory, these luminous echoes were consistent with X-rays reflected from behind the black hole -- but even a basic understanding of black holes tells us that is a strange place for light to come from.
"Any light that goes into that black hole doesn't come out, so we shouldn't be able to see anything that's behind the black hole," said Wilkins, who is a research scientist at the Kavli Institute for Particle Astrophysics and Cosmology at Stanford and SLAC National Accelerator Laboratory. It is another strange characteristic of the black hole, however, that makes this observation possible. "The reason we can see that is because that black hole is warping space, bending light and twisting magnetic fields around itself," Wilkins explained.
The strange discovery, detailed in a paper published July 28 in *Nature,* is the first direct observation of light from behind a black hole -- a scenario that was predicted by Einstein's theory of general relativity but never confirmed, until now.
"Fifty years ago, when astrophysicists starting speculating about how the magnetic field might behave close to a black hole, they had no idea that one day we might have the techniques to observe this directly and see Einstein's general theory of relativity in action," said Roger Blandford, a co-author of the paper who is the Luke Blossom Professor in the School of Humanities and Sciences and Stanford and SLAC professor of physics and particle physics.
How to see a black hole

The original motivation behind this research was to learn more about a mysterious feature of certain black holes, called a corona. Material falling into a supermassive black hole powers the brightest continuous sources of light in the universe, and as it does so, forms a corona around the black hole. This light -- which is X-ray light -- can be analysed to map and characterize a black hole.

The leading theory for what a corona is starts with gas sliding into the black hole where it superheats to millions of degrees. At that temperature, electrons separate from atoms, creating a magnetized plasma. Caught up in the powerful spin of the black hole, the magnetic field arcs so high above the black hole, and twirls about itself so much, that it eventually breaks altogether -- a situation so reminiscent of what happens around our own Sun that it borrowed the name "corona."

"This magnetic field getting tied up and then snapping close to the black hole heats everything around it and produces these high energy electrons that then go on to produce the X-rays," said Wilkins.

As Wilkins took a closer look to investigate the origin of the flares, he saw a series of smaller flashes. These, the researchers determined, are the same X-ray flares but reflected from the *back* of the disk -- a first glimpse at the far side of a black hole.

"I've been building theoretical predictions of how these echoes appear to us for a few years," said Wilkins. "I'd already seen them in the theory I've been developing, so once I saw them in the telescope observations, I could figure out the connection."

Future observations

The mission to characterize and understand coronas continues and will require more observation. Part of that future will be the European Space Agency's X-ray observatory, Athena (Advanced Telescope for High-ENergy Astrophysics). As a member of the lab of Steve Allen, professor of physics at Stanford and of particle physics and astrophysics at SLAC, Wilkins is helping to develop part of the Wide Field Imager detector for Athena.

"It's got a much bigger mirror than we've ever had on an X-ray telescope and it's going to let us get higher resolution looks in much shorter observation times," said Wilkins. "So, the picture we are starting to get from the data at the moment is going to become much clearer with these new observatories."

Co-authors of this research are from Saint Mary's University (Canada), Netherlands Institute for Space Research (SRON), University of Amsterdam and The Pennsylvania State University.

This work was supported by the NASA NuSTAR and XMM-Newton Guest Observer programs, a Kavli Fellowship at Stanford University, and the V.M. Willaman Endowment at the Pennsylvania State University.