South Downs Mercury

The monthly circular of South Downs Astronomical Society
Issue: 510 – September 2017 Editor: Roger Burgess

- Next meeting Friday 1st September Lecture room of the South Downs Planetarium, Chichester, at 7.30pm. Please support a raffle we are organizing this month

- Main Talk Jack Martin "Practical Stellar Spectroscopy"

- Ten spacecraft – from Venus Express to Voyager 2 – all tracked same solar flare. We hardly noticed at first, but records revealed plenty about how star-stuff sails solar winds

By Simon Sharwood, APAC Editor 17 Aug 2017 at 07:26

On October 14th, 2014, the Sun decided it was time for a coronal mass ejection, the irregular hiccups that see it belch out astounding quantities of magnetised plasma. And after careful analysis, we've now fingerprinted the plasma's passing using no fewer than ten spacecraft. The event and subsequent analysis are detailed in a paper titled "Interplanetary coronal mass ejection observed at STEREO-A, Mars, comet 67P/Churyumov-Gerasimenko, Saturn, and New Horizons en route to Pluto" published in Space Physics. Coronal mass ejections (CMEs) aren't uncommon and solar observatories often spot them. But this one had the good fortune to happen in a spot that saw its effects cross the paths of ten spacecraft. As explained by the European Space Agency, the event was first spotted by the team running its Mars Express mission when looking at data from Comet Siding Spring's October 2014 close encounter with Mars. As the paper recounts, "Mars' upper atmosphere was disturbed during that time, most likely due to a solar wind event, making the analysis of the comet-related effects more complex than anticipated. It was therefore decided to search for possible solar wind structures that could have been present at Mars during that period." That effort led to detection of the October 14th event and then for a search to figure out how to investigate it. Which is where astronomers got lucky, because we had lots of eyes on the event. Three Sun-watching missions, the ESA's Proba-2, the joint ESA/NASA SOHO satellite and NASA's SDO, all snapped the CME as it happened. NASA's Stereo-A, the ESA's Venus Express, Mars Express and Rosetta, NASA's Mars Odyssey and Maven orbiters and even the Curiosity rover were all in the cone of star-stuff the CME produced. Even further out the Cassini spacecraft was in a handy spot, too. New Horizons and Voyager-2 were also in good places. The latter is thought to have observed something suggesting the CME 17 months after it happened. New Horizons had its own inconclusive encounter three months after the CME. Not all of the craft were able to get a good look at the event, because most weren't told to look for it in advance. Venus Express, for example, was behind the Sun relative to Earth so was out of radio range and had turned off its instruments. But the craft's star tracker was "overwhelmed with radiation at the expected time of passage", giving us useful data about when the CME passed by. Other craft reported marked decreases in cosmic rays for a day or more as the CME passed, confirming observations we've been able to make when CMEs pass Earth. The study has also taught us more about how fast CMEs travel: the paper the data collected suggests "a strong decrease from about 1000 to 580 km/s within 1.5 AU, followed by a gradual decrease down to about 450–500 km/s at ~15 AU." The 15 AU measurement comes from Cassini. New Horizons and Voyager 2's measurement suggest CME plasma holds its speeds after it passes the ringed planet.

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The paper concludes by saying the event could have yielded even more data had some other nearby spacecraft been switched on and/or had the right instruments aboard. The authors therefore "emphasize the importance of a space weather monitoring package, including a magnetometer, to be embarked in all planetary and astronomical missions as a basic payload requirement." They also recommend that "plasma instruments continue to operate during solar superior conjunctions, even if only at a very low data rate, or continue to acquire data for later download."

- Ancient Moon rocks vital clue in space dynamo study

By Katyanna Quach 11 Aug 2017 at 06:31

The Moon's liquid core spun acting like dynamo to produce a magnetic field ... Illustration by Hernán Cañellas

Scientists studying prehistoric lunar rocks have found evidence of a lava-lamp-like dynamo at the heart of our Moon's metallic core that generated a long-lasting magnetic field. The Moon samples were collected in 1971 by astronauts, David Scott and James Irwin, during NASA's Apollo 15 space mission. Now, a paper published in Science Advances this Friday reveals that one particular sample was formed one to 2.5 billion years ago in a relatively weak magnetic field of about five microteslas. Older rocks, said to be about four billion years' old, showed signs that they were formed when the Moon's magnetic field was 100 microteslas. In other words, the Moon's magnetic field weakened from 100 microteslas roughly four billion years ago to five microteslas around two billion years ago. That's a billion years longer than previously thought – it was generally thought the Moon's field strength sharply nosedived about three billion years ago. The paper's authors believe the Moon may once have had a molten metallic core. The slow churn of the liquid acted as a dynamo that powered the magnetic field around Earth's natural satellite. Benjamin Weiss, co-author of the study and professor of planetary sciences at the Massachusetts Institute of Technology in the US, said this week the concept of a planetary magnetic field being produced by a moving liquid core "is only a few decades old." "What powers this motion on Earth and other bodies, particularly on the Moon, is not well-understood," he said.
The researchers have proposed the dynamo is a result of the gravitational pull between the Earth and the Moon. At one point, the Moon was much closer to the Earth, and the gravitational forces present may have been strong enough to rotate the Moon's exterior, dragging its liquid metallic centre into a swirling motion, thus creating a powerful magnetic field. But as the Moon moved further away, the gravitational pull weakened and the Moon's magnetic field started to drop. "As the Moon cools, its core acts like a lava lamp – low-density stuff rises because it's hot or because its composition is different from that of the surrounding fluid," Weiss said. "That's how we think the Earth's dynamo works, and that's what we suggest the late lunar dynamo was doing as well."

How the field strength was detected

Tiny grains of material in the lunar rocks point in a certain direction under the influence of a magnetic field, just like a compass needle. The researchers built an oxygen-free oven to heat the samples close to the temperatures they formed in, and measured how the magnetization changed as the temperature increased. "You see how magnetized it gets from getting heated in that known magnetic field, then you compare that field to the natural magnetic field you measured beforehand, and from that you can figure out what the ancient field strength was," Weiss explained.

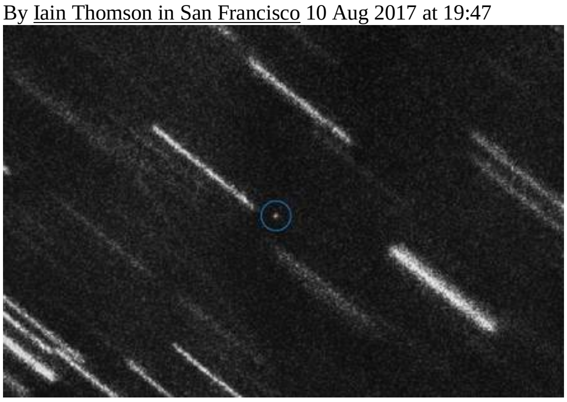
Sonia Tikoo, lead author of the paper and an assistant professor at Rutgers University in the US, told *The Register* on Thursday she hopes more lunar samples will be collected in future to help pinpoint when the Moon's dynamo faded away. "It would be great to obtain more lunar rocks, particularly from locations that were not sampled during the Apollo missions," she said. "There are several missions under development around the world – most in the proposal stage, but some beyond

– that could involve a robotic sample return from the Moon in the next decade or so.
“It would be even more awesome if NASA could send more humans to the Moon but that doesn't seem to be in the cards for the near future. China is aiming to send a crewed mission to the Moon by the mid-2030s. In the meantime, scientists will continue working with the Apollo samples we already have as well as with lunar meteorites that have landed on Earth.” The rocks have, essentially, helped scientists narrow down the timeline of the Moon’s dynamo. "Today the moon's field is essentially zero," Weiss said. "And we now know it turned off somewhere between the formation of this rock and today."

- Cancel the farewell party. Get back to work. That asteroid isn't going to hit Earth in October

ESA tells everyone to calm down and carry on

By Iain Thomson in San Francisco 10 Aug 2017 at 19:47



Clocked ... Asteroid 2012 TC4 spotted in space

The European Space Agency has confirmed there is no danger of asteroid 2012 TC4 hitting Earth in October, despite what some panicky YouTube videos might tell you.
The rock was spotted five years ago when it whizzed past Earth, missing us by 94,800 kilometres (58,900 miles). Last month NASA eggheads reckoned the asteroid may this year come as close as 6,800 kilometers (4,200 miles), a gnat's whisker in cosmic distances.
However, the asteroid's orbit path has now been firmed up, and we're going to be fine: it will skip past our fragile planet in October, missing us 44,000 kilometres (27,340 miles).
"The original observations revealed the asteroid’s next approach to our vicinity would be in October 2017 but its orbit meant that it could not be tracked during the last five years, leaving astronomers unsure on how close it would come," ESA said in a statement today.
"The new observations reveal it will miss Earth by 44,000 kilometres (27,340 miles)."
Shortly after its 2012 flyby, astronomers lost sight of the alien object because it is so small and dark. It was picked up again this year by ESA's European Southern Observatory's 8.2-metre telescopes at its Very Large Telescope Observatory in Chile. Even if 2012 TC4 did hit Earth, it wouldn't be an end-of-civilization event. The rock is only 15 to 30 metres (50-98 feet) wide and after being ablated by air compression on its trip through the atmosphere, the final boulder would be about the same size as the 2013 Chelyabinsk meteorite, which hurt 1,500 folks in Russia when it smashed into our planet but caused no deaths. The asteroid, which is traveling at about 13.4 kilometres per second (30,000 miles per hour), will make its closest approach to Earth on October 12.
Astronomers are gearing up for the event and will be studying the rock closely to work out what it's made of. "Scientists have always appreciated knowing when an asteroid will make a close approach to and safely pass the Earth because they can make preparations to collect data to characterize and learn as much as possible about it," said Michael Kelley, program scientist and NASA Headquarters lead for the TC4 observation campaign.
"This time we are adding in another layer of effort, using this asteroid flyby to test the worldwide asteroid detection and tracking network, assessing our capability to work together in response to finding a potential real asteroid threat."
You may have noticed that this year's flyby distance from Earth will be less than the gap in 2012: astronomers hope to use measurements of the object as it screams by to precisely figure out the rock's path. It looks as though there'll be no impact with our home world until at least 2050, though.

- China can't find anyone smart enough to run its whizzbang $180m 1,640ft radio telescope. 'We need a superhero,' sighs prof – and anyone can apply

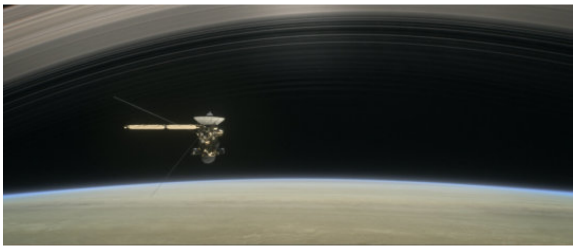
By Iain Thomson in San Francisco 8 Aug 2017 at 06:01

Not so fast, FAST ... the radio telescope in China

There aren't many astronomy jobs that pay very well – but the Chinese authorities are offering just that for the director of scientific operation for its new Five-hundred-metre Aperture Spherical Telescope. At 500m (1,640ft) across, FAST became the world's largest filled-aperture radio telescope when construction finished last year. While the initial building is complete and nearly 10,000 people have been moved away from the instrument to cut down on polluting it with electromagnetic signals, the telescope still needs to be calibrated and fine-tuned. Unfortunately, finding a director with the necessary skills to do the job of managing and running the instrument has proven problematic. So a foreigner is now being sought to bring their experience to bear on the project. "The post is currently open to scientists working outside China only," a human resources official at the Chinese Academy of Sciences told the South China Morning Post. "Candidates can be of any nationality, any race." It's a lucrative role at the 1.2bn yuan (US$178m, £110m) facility. In addition to a funding research award of 8m yuan (US$1.2m, £914k), the director will also receive a very substantial salary, free accommodation (albeit in a rather remote part of the country) and other subsidies. In return they'll be expected to ensure that the project runs smoothly. It's a tough job, managing a facility that complex and handling the competing claims for time on the 'scope from scientists. The Academy of Sciences is asking for a professor with at least 20 years' experience in radio astronomy, as well as management training. "These requirements are very high. It puts most astronomers out of the race. I may be able to count those qualified with my fingers," said Wang Tinggui, professor of astrophysics at the University of Science and Technology of China. "It is not a job for a scientist. It's for a superhero." However, it also gives the person a chance to make history. FAST dwarfs lesser telescopes by more than a factor of two. It will be used to explore the universe for alien life, examine pulsars, and pick up the faintest radio emissions the universe has to offer.

- Cassini to begin final five orbits around Saturn

August 12, Date: 2017
Source: NASA



This artist's rendering shows Cassini as the spacecraft makes one of its final five dives through Saturn's upper atmosphere in August and September 2017.
Credit: NASA/JPL-Caltech

NASA's Cassini spacecraft will enter new territory in its final mission phase, the Grand Finale, as it prepares to embark on a set of ultra-close passes through Saturn's upper atmosphere with its final five orbits around the planet. Cassini will make the first of these five passes over Saturn at 12:22 a.m. EDT Monday, Aug. 14. The spacecraft's point of closest approach to Saturn during these passes will be between about 1,010 and 1,060 miles (1,630 and 1,710 kilometers) above Saturn's cloud tops. The spacecraft is expected to encounter atmosphere dense enough to require the use of its small rocket thrusters to maintain stability -- conditions similar to those encountered during many of Cassini's close flybys of Saturn's moon Titan, which has its own dense atmosphere. "Cassini's Titan flybys prepared us for these rapid passes through Saturn's upper atmosphere," said Earl Maize, Cassini project manager at NASA's Jet Propulsion Laboratory (JPL) in California. "Thanks to our past experience, the team is confident that we understand how the spacecraft will behave at the atmospheric densities our models predict." Maize said the team will consider the Aug. 14 pass nominal if the thrusters operate between 10 and 60 percent of their capability. If the thrusters are forced to work harder -- meaning the atmosphere is denser than models predict -- engineers will increase the altitude of subsequent orbits. Referred to as a "pop-up manoeuvre," thrusters will be used to raise the altitude of closest approach on the next passes, likely by about 120 miles (200 kilometers). If the pop-up manoeuvre is not needed, and the atmosphere is less dense than expected during the first three passes, engineers may alternately use the "pop-down" option to lower the closest approach altitude of the last two orbits, also likely by about 120 miles (200 kilometers). Doing so would enable Cassini's science instruments, especially the ion and neutral mass spectrometer (INMS), to obtain data on the atmosphere even closer to the planet's cloud tops. "As it makes these five dips into Saturn, followed by its final plunge, Cassini will become the first Saturn atmospheric probe," said Linda Spilker, Cassini project scientist at JPL. "It's long been a goal in planetary exploration to send a dedicated probe into the atmosphere of Saturn, and we're laying the groundwork for future exploration with this first foray." Other Cassini instruments will make detailed, high-resolution observations of Saturn's auroras, temperature, and the vortexes at the planet's poles. Its radar will peer deep into the atmosphere to reveal small-scale features as fine as 16 miles (25 kilometers) wide -- nearly 100 times smaller than the spacecraft could observe prior to the Grand Finale. On Sept. 11, a distant encounter with Titan will serve as a gravitational version of a large pop-down manoeuvre, slowing Cassini's orbit around Saturn and bending its path slightly to send the spacecraft toward its Sept. 15 plunge into the planet. During the half-orbit plunge, the plan is to have seven Cassini science instruments, including INMS, turned on and reporting measurements in near real time. The spacecraft is expected to reach an altitude where atmospheric density is about twice what it encountered during its final five passes. Once Cassini reaches that point, its thrusters will no longer be able to work against the push of Saturn's atmosphere to keep the spacecraft's antenna pointed toward Earth, and contact will permanently be lost. The spacecraft will break up like a meteor moments later, ending its long and rewarding journey. The Cassini-Huygens mission is a cooperative project of NASA, ESA (European Space Agency) and the Italian Space Agency. JPL manages the mission for NASA's Science Mission Directorate in Washington. JPL designed, developed and assembled the Cassini spacecraft.

- ❖ New mission going to the space station to explore mysteries of 'cosmic rain'

Date: August 11, 2017
Source: NASA/Goddard Space Flight Centre


From its new vantage point on the International Space Station's Japanese Experiment Module - Exposed Facility, the Cosmic Ray Energetics and Mass (ISS-CREAM) mission, shown in the inset illustration, will study cosmic rays to determine their sources and acceleration mechanisms.
Credit: NASA

A new experiment set for an Aug. 14 launch to the International Space Station will provide an unprecedented look at a rain of particles from deep space, called cosmic rays, that constantly showers our planet. The Cosmic Ray Energetics and Mass mission destined for the International Space Station (ISS-CREAM) is designed to measure the highest-energy particles of any detector yet flown in space. CREAM was originally developed as a part of NASA's Balloon Program, during which it returned measurements from around 120,000 feet in seven flights between 2004 and 2016. "The CREAM balloon experiment achieved a total sky exposure of 191 days, a record for any balloon-borne astronomical experiment," said Eun-Suk Seo, a professor of physics at the University of Maryland in College Park and the experiment's principal investigator. "Operating on the space station will increase our exposure by over 10 times, taking us well beyond the traditional energy limits of direct measurements." Sporting new instruments, as well as refurbished versions of detectors originally used on balloon flights over Antarctica, the refrigerator-sized, 1.4-ton (1,300 kilogram) ISS-CREAM experiment will be delivered to the space station as part of the 12th SpaceX commercial resupply service mission. Once there, ISS-CREAM will be moved to the Exposed Facility platform extending from Kibo, the Japanese Experiment Module. From this orbital perch, ISS-CREAM is expected to study the "cosmic rain" for three years’ time needed to provide unparalleled direct measurements of rare high-energy cosmic rays. At energies above about 1 billion electron volts, most cosmic rays come to us from beyond our solar system. Various lines of evidence, including observations from NASA's Fermi Gamma-ray Space Telescope, support the idea that shock waves from the expanding debris of stars that exploded as supernovas accelerate cosmic rays up to energies of 1,000 trillion electron volts (PeV). That's 10 million times the energy of medical proton beams used to treat cancer. ISS-CREAM data will allow scientists to examine how sources other than supernova remnants contribute to the population of cosmic rays. Protons are the most common cosmic ray particles, but electrons, helium nuclei and the nuclei of heavier elements make up a small percentage. All are direct samples of matter from interstellar space. But because the particles are electrically charged, they interact with galactic magnetic fields, causing them to wander in their journey to Earth. This scrambles their paths and makes it impossible to trace cosmic ray particles back to their sources. "An additional challenge is that the flux of particles striking any detector decreases steadily with higher energies," said ISS-CREAM co-investigator Jason Link, a researcher at NASA's Goddard Space Flight Centre in Greenbelt, Maryland. "So to better explore higher energies, we either need a much bigger detector or much more observing time. Operating on the space station provides us with this extra time." Large ground-based systems study cosmic rays at energies greater than 1 PeV by making Earth's atmosphere the detector. When a cosmic ray strikes the nucleus of a gas molecule in the atmosphere, both explode in a shower of subatomic shrapnel that triggers a wider cascade of particle collisions. Some of these secondary particles reach detectors on the ground, providing information scientists can use to infer the properties of the original cosmic ray. These secondary’s also produce an interfering background that limited the effectiveness of CREAM's balloon operations. Removing that background is another advantage of relocating to orbit. With decreasing numbers of particles at increasing energies, the cosmic ray spectrum vaguely resembles the profile of a human leg. At PeV energies, this decline abruptly steepens, forming a detail scientist’s call the "knee." ISS-CREAM is the first space mission capable of measuring the low flux of cosmic rays at energies approaching the knee. "The origin of the knee and other features remain longstanding mysteries," Seo said. "Many scenarios have been proposed to explain them, but we don't know which is correct." Astronomers don't think supernova remnants are capable of powering cosmic rays beyond the PeV range, so the knee may be shaped in part by the drop-off of their cosmic rays in this region. "High-energy cosmic rays carry a great deal of information about our interstellar neighbourhood and our galaxy, but we haven't been able to read these messages very clearly," said co-investigator John Mitchell at Goddard. "ISS-CREAM represents one significant step in this direction." ISS-CREAM detects cosmic ray particles when they slam into the matter making up its instruments. First, a silicon charge detector measures the electrical charge of incoming particles, then layers of carbon provide targets that encourage impacts, producing cascades of particles that stream into electrical and optical detectors below while a calorimeter determines their energy. Two scintillator-based detector systems provide the ability to discern between singly charged electrons and protons. All told, ISS-CREAM can distinguish electrons, protons and atomic nuclei as massive as iron as they crash through the instruments. ISS-CREAM will join two other cosmic ray experiments already working on the space station. The Alpha Magnetic Spectrometer (AMS-02), led by an international collaboration sponsored by the U.S. Department of Energy, is mapping cosmic rays up to a trillion electron volts, and the Japan-led Calorimetric Electron Telescope (CALET), also located on the Kibo Exposed Facility, is dedicated to studying cosmic ray electrons. Overall management of ISS-CREAM and integration for its space station application was provided by NASA's Wallops Flight Facility on Virginia's Eastern Shore. ISS-CREAM was developed as part of an international collaboration led by the University of Maryland at College Park, which includes teams from NASA Goddard, Penn State University in University Park, Pennsylvania, and Northern Kentucky University in Highland Heights, as well as collaborating institutions in the Republic of Korea, Mexico and France.

- New observations of Crab Nebula and Pulsar reveal polarized emissions

Date: August 10, 2017

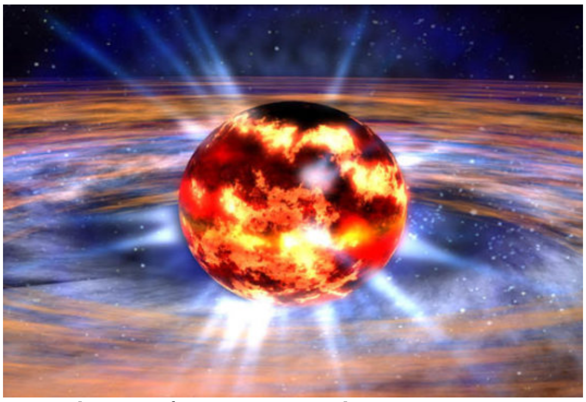
Source: KTH The Royal Institute of Technology

The flight path of the PoGO+ balloon.
Credit: SSC

New observations of polarised X-rays from the Crab Nebula and Pulsar, published today in Scientific Reports, may help explain sudden flares in the Crab's X-ray intensity, as well as provide new data for modelling -- and understanding -- the nebula. Since it was first observed little more than a thousand years ago, the Crab Nebula has been studied by generations of astronomers. Yet new observations by researchers in Sweden show this "cosmic lighthouse" has yet to give up all of its secrets. The researchers' observations of polarised X-rays from the Crab Nebula and Pulsar, published today in *Scientific Reports*, may help explain sudden flares in the Crab's X-ray intensity, as well as provide new data for modelling -- and understanding -- the nebula. The polarisation of Crab X-rays reveals how and where they are produced in the extreme environment of the nebula, says Mark Pearce, Professor of Physics at KTH Royal Institute of Technology and lead author of the study. "Our measurements indicate that the X-rays come from an organized region in the vicinity of the pulsar at the centre of the nebula," Pearce says. "Electrons gyrating around magnetic field lines in this region produce the X-rays. The measurements are made in an unexplored energy range, so they provide new information which will help to solve the puzzle of how high energy radiation is generated." In 1054 CE, Chinese astronomers recorded the appearance of a new bright star on the sky -- an event we now refer to as a supernova, or exploding star. The aftermath of this cataclysmic event was a rapidly rotating neutron star: the Crab pulsar, barely 15 km in diameter but with a mass equal to our solar system's Sun, surrounded by an expanding nebula of particles and radiation. Neutron stars are a kind of ultra-dense zombie sun that forms when a star exhausts its fuel and collapses upon itself due to the force of its own gravity. If they were any denser, they'd be black holes. Pearce says that while detecting the Crab's X-rays is routine business for research satellites, examining the polarisation of these emissions -- that is, the plane in which the radiation waves oscillate -- is new territory. "Neutron stars are fascinating objects," Pearce says. "The Crab pulsar rotates around an axis 30 times per second producing flashes of X-rays -- a sort of cosmic lighthouse. The X-rays arise from the acceleration of electrons in intense magnetic fields (10 trillion times stronger than the earth's magnetic field), up to energies typically a hundred times higher than obtainable at the LHC accelerator." In the paper published in *Scientific Reports* on August 10th 2017 new light is shed on the pulsar through novel measurements conducted by a balloon-borne telescope, PoGO+ ("PoGO plus"), flown at the top of the atmosphere in summer 2016. Just like visible light or radio waves, X-rays are electromagnetic and they can be polarised, or in other words, the electric field can oscillate in a specific plane. Usually, the polarisation cannot be measured by X-ray telescopes, so researchers miss out on some of the information carried by these X-ray messengers, Pearce says. The PoGO+ mission was developed specifically to measure the polarisation of X-rays from the Crab and other celestial bodies, with the aim of opening a new observational window on these objects. Since X-rays are readily absorbed by the earth's atmosphere, observations need to take place high in the stratosphere. In the early hours of July 12 2016, an enormous, 1.1 million-cubic-metre helium balloon carrying a specially built telescope was released from the SSC Esrange Space Centre, near Kiruna in northern Sweden, to do just that. The PoGO measurements are the first-made in the so-called "hard X-ray" band, covering the energy range 20-160 keV, and provide new data for Crab modelling. Results from the PoGO missions are the first from a dedicated X-ray polarimetry mission in more than 40 years. PoGO+ reveals that a relatively high fraction, 21 percent, of Crab X-rays are polarised even though observations encompassed both the pulsar and topologically complex nebula. Pearce says that this indicates the X-rays originate from a compact region with a well-ordered magnetic field. "The angle of the polarisation plane is aligned to the rotation axis of the pulsar, as expected for electrons which generate X-rays through synchrotron processes while trapped in toroidal trajectories around the pulsar," he says. "By accurately determining the arrival time of X-rays, PoGO+ was able to distinguish between X-rays which originate from the nebula and pulsar." The overall emission was found to be dominated by the nebula. Comparing the measured nebula polarisation angle with that measured at optical wavelengths also indicates that the emission site is associated with the torus -- a donut shaped luminous structure in the inner part of the nebula. Pearce says that the lower polarisation angle seen for the pulsar is in line with results at optical wavelengths -- an important confirmation that these more straight-forward measurements are a reasonable proxy for X-ray models. The PoGO+ polarisation results are compatible with those obtained in 2013 from the PoGOLite Pathfinder. The consistency between these results may help to elucidate the cause of sudden increases in the Crab X-ray intensity which were recently observed. Such flares were unexpected for an object which was long considered to be a celestial standard candle for X-rays. The PoGO+ mission was supported in Sweden by The Swedish National Space Board, The Knut and Alice Wallenberg Foundation and The Swedish Research Council. In Japan, support was provided by Japan Society for Promotion of Science and ISAS/JAXA.

- Primordial black holes may have helped to forge heavy elements

Date: August 4, 2017
Source: University of California - San Diego



Artist's depiction of a neutron star. Credit
Credit: NASA

Astronomers like to say we are the by-products of stars, stellar furnaces that long ago fused hydrogen and helium into the elements needed for life through the process of stellar nucleosynthesis. As the late Carl Sagan once put it: "The nitrogen in our DNA, the calcium in our teeth, the iron in our blood, the carbon in our apple pies were made in the interiors of collapsing stars. We are made of star stuff." But what about the heavier elements in the periodic chart, elements such as gold, platinum and uranium? Astronomers believe most of these "r-process elements" -- elements much heavier than iron -- were created, either in the aftermath of the collapse of massive stars and the associated supernova explosions, or in the merging of binary neutron star systems. "A different kind of furnace was needed to forge gold, platinum, uranium and most other elements heavier than iron," explained George Fuller, a theoretical astrophysicist and professor of physics who directs UC San Diego's Centre for Astrophysics and Space Sciences. "These elements most likely formed in an environment rich with neutrons." In a paper published August 7 in the journal *Physical Review Letters*, he and two other theoretical astrophysicists at UCLA -- Alex Kusenko and Volodymyr Takhistov -- offer another means by which stars could have produced these heavy elements: tiny black holes that came into contact with and are captured by neutron stars, and then destroy them. Neutron stars are the smallest and densest stars known to exist, so dense that a spoonful of their surface has an equivalent mass of three billion tons. Tiny black holes are more speculative, but many astronomers believe they could be a by-product of the Big Bang and that they could now make up some fraction of the "dark matter" -- the unseen, nearly non-interacting stuff that observations reveal exists in the universe. If these tiny black holes follow the distribution of dark matter in space and co-exist with neutron stars, Fuller and his colleagues contend in their paper that some interesting physics would occur. They calculate that, in rare instances, a neutron star will capture such a black hole and then devoured from the inside out by it. This violent process can lead to the ejection of some of the dense neutron star matter into space. "Small black holes produced in the Big Bang can invade a neutron star and eat it from the inside," Fuller explained. "In the last milliseconds of the neutron star's demise, the amount of ejected neutron-rich material is sufficient to explain the observed abundances

of heavy elements." "As the neutron stars are devoured," he added, "they spin up and eject cold neutron matter, which decompresses, heats up and make these elements." This process of creating the periodic table's heaviest elements would also provide explanations for a number of other unresolved puzzles in the universe and within our own Milky Way galaxy. "Since these events happen rarely, one can understand why only one in ten dwarf galaxies is enriched with heavy elements," said Fuller. "The systematic destruction of neutron stars by primordial black holes is consistent with the paucity of neutron stars in the galactic centre and in dwarf galaxies, where the density of black holes should be very high." In addition, the scientists calculated that ejection of nuclear matter from the tiny black holes devouring neutron stars would produce three other unexplained phenomenon observed by astronomers. "They are a distinctive display of infrared light (sometimes termed a "kilonova"), a radio emission that may explain the mysterious Fast Radio Bursts from unknown sources deep in the cosmos, and the positrons detected in the galactic centre by X-ray observations," said Fuller. "Each of these represent long-standing mysteries. It is indeed surprising that the solutions of these seemingly unrelated phenomena may be connected with the violent end of neutron stars at the hands of tiny black holes."
Funding for this project was provided by the National Science Foundation (PHY-1614864) at UC San Diego and by the U.S. Department of Energy (DE-SC0009937) at UCLA. Alex Kusenko was also supported, in part, by the World Premier International Research Centre Initiative (WPI), MEXT, Japan.

- Supernova collides with nearby star, taking astrophysicists by surprise

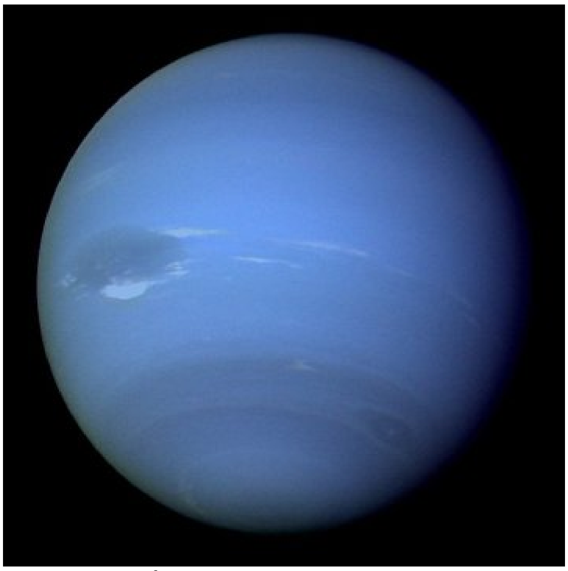
Date: August 14, 2017
Source: University of California - Santa Barbara

Only 55 million lightyears away, this is one of the closest supernovae discovered in recent years.
Credit: Image courtesy of University of California - Santa Barbara

In the 2009 film "Star Trek," a supernova hurtles through space and obliterates a planet unfortunate enough to be in its path. Fiction, of course, but it turns out the notion is not so farfetched. Using the nearby Las Cumbres Observatory (LCO), astrophysicists from UC Santa Barbara have observed something similar: an exploding star slamming into a nearby companion star. What's more, they detected the fleeting blue glow from the interaction at an unprecedented level of detail. Their observations revealed surprising information about the mysterious companion star, a feat made possible by recent advances in linking telescopes into a robotic network. The team's findings appear in the journal *Astrophysical Journal Letters*. The identity of this particular companion has been hotly debated for more than 50 years. Prevailing theory over the last few years has held that the supernovae happen when two white dwarfs spiral together and merge. This new study demonstrates that the supernova collided with the companion star that was not a white dwarf. White dwarf stars are the dead cores of what used to be normal stars like the sun. "We've been looking for this effect -- a supernova crashing into its companion star -- since it was predicted in 2010," said lead author Griffin Hosseinzadeh, a UCSB graduate student. "Hints have been seen before, but this time the evidence is overwhelming." The supernova in question is SN 2017cbv, a thermonuclear Type Ia, which astronomers use to measure the acceleration of the expansion of the universe. This kind of supernova is known to be the explosion of a white dwarf star, though it requires additional mass from a companion star to explode. The UCSB-led research implies that the white dwarf was stealing matter from a much larger companion star -- approximately 20 times the radius of the sun -- which caused the white dwarf to explode. The collision of the supernova and the companion star shocked the supernova material, heating it to a blue glow heavy in ultraviolet light. Such a shock could not have been produced if the companion were another white dwarf star. "The universe is crazier than science fiction authors have dared to imagine," said Andy Howell, a staff scientist at LCO and Hosseinzadeh's Ph.D. adviser. "Supernovae can wreck nearby stars, too, releasing unbelievable amounts of energy in the process." Co-author David Sand, an associate professor at the University of Arizona, discovered the supernova on March 10, 2017, in the galaxy NGC 5643. Only 55 million lightyears away, SN 2017cbv was one of the closest supernovae discovered in recent years, found by the DLT40 survey using the Panchromatic Robotic Optical Monitoring and Polarimetry Telescope (PROMPT) in Chile, which monitors galaxies nightly at distances less than 40 mega parsecs (120 million light-years). This was one of the earliest catches ever -- within a day, perhaps even hours, of its explosion. The DLT40 survey was created by Sand and study co-author Stefano Valenti, an assistant professor at UC Davis; both were previously postdoctoral researchers at LCO. Within minutes of discovery, Sand activated observations with LCO's global network of 18 robotic telescopes, spaced around Earth so that one is always on the night side. This allowed the team to take immediate and near-continuous observations. "With LCO's ability to monitor the supernova every few hours, we were able to see the full extent of the rise and fall of the blue glow for the first time," Hosseinzadeh said. "Conventional telescopes would have had only a data point or two and missed it." Howell likened the event to gaining astronomical superpowers that give astronomers the ability to see the universe in new ways. "These capabilities were just a dream a few years ago," he said. "But now we're living the dream and unlocking the origins of supernovae in the process."

- Scientists probe Neptune's depths to reveal secrets of icy planets

Date: August 11, 2017
Source: University of Edinburgh

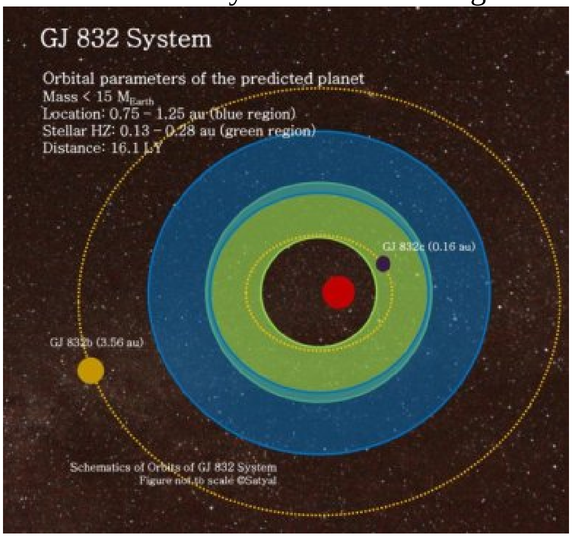


Voyager image of Neptune.
Credit: NASA

Scientists have helped solve the mystery of what lies beneath the surface of Neptune -- the most distant planet in our solar system. A new study sheds light on the chemical make-up of the planet, which lies around 4.5 billion kilometres from the sun. Extremely low temperatures on planets like Neptune -- called ice giants -- mean that chemicals on these distant worlds exist in a frozen state, researchers say. Frozen mixtures of water, ammonia and methane make up a thick layer between the planets' atmosphere and core -- known as the mantle. However, the form in which these chemicals are stored is poorly understood. Using laboratory experiments to study these conditions is difficult, as it is very hard to recreate the extreme pressures and temperatures found on ice giants, researchers say. Instead, scientists at the University of Edinburgh ran large-scale computer simulations of conditions in the mantle. By looking at how the chemicals there react with each other at very high pressures and low temperatures, they were able to predict which compounds are formed in the mantle. The team found that frozen mixtures of water and ammonia inside Neptune -- and other ice giants, including Uranus -- are likely to form a little-studied compound called ammonia hemihydrate. The findings will influence how ice giants are studied in future and could help astronomers classify newly discovered planets as they look deeper into space. The study, published in the journal *Proceedings of the National Academy of Sciences*, was supported by Engineering and Physical Sciences Research Council. The work was carried out in collaboration with scientists at Jilin University, China. Dr Andreas Hermann, of the University of Edinburgh's Centre for Science at Extreme Conditions, said: "This study helps us better predict what is inside icy planets like Neptune. Our findings suggest that ammonia hemihydrate could be an important component of the mantle in ice giants, and will help improve our understanding of these frozen worlds. Computer models are a great tool to study these extreme places, and we are now building on this study to get an even more complete picture of what goes on there."

- ❖ Astrophysicists predict Earth-like planet in star system only 16 light years away

Date: August 17, 2017
Source: University of Texas at Arlington



This is the GJ832 system.
Credit: Suman Satyal

Astrophysicists at the University of Texas at Arlington have predicted that an Earth-like planet may be lurking in a star system just 16 light years away. The team investigated the star system Gliese 832 for additional exoplanets residing between the two currently known alien worlds in this system. Their computations revealed that an additional Earth-like planet with a dynamically stable configuration may be residing at a distance ranging from 0.25 to 2.0 astronomical unit (AU) from the star. "According to our calculations, this hypothetical alien world would probably have a mass between 1 to 15 Earth's masses," said the lead author Suman Satyal, UTA physics researcher, lecturer and laboratory supervisor. The paper is co-authored by John Griffith, UTA undergraduate student and long-time UTA physics professor Zdzislaw Musielak. The astrophysicists published their findings this week as "Dynamics of a probable Earth-Like Planet in the GJ 832 System" in *The Astrophysical Journal*. UTA Physics Chair Alexander Weiss congratulated the researchers on their work, which underscores the University's commitment to data-driven discovery within its Strategic Plan 2020: Bold Solutions | Global Impact. "This is an important breakthrough demonstrating the possible existence of a potential new planet orbiting a star close to our own," Weiss said. "The fact that Dr. Satyal was able to demonstrate that the planet could maintain a stable orbit in the habitable zone of a red dwarf for more than 1 billion years is extremely impressive and demonstrates the world class capabilities of our department's astrophysics group." Gliese 832 is a red dwarf and has just under half the mass and radius of our sun. The star is orbited by a giant Jupiter-like exoplanet designated Gliese 832b and by a super-Earth planet Gliese 832c. The gas giant with 0.64 Jupiter masses is orbiting the star at a distance of 3.53 AU, while the other planet is potentially a rocky world, around five times more massive than the Earth, residing very close its host star -- about 0.16 AU. For this research, the team analysed the simulated data with an injected Earth-mass planet on this nearby planetary system hoping to find a stable orbital configuration for the planet that may be located in a vast space between the two known planets. Gliese 832b and Gliese 832c were discovered by the radial velocity technique, which detects variations in the velocity of the central star, due to the changing direction of the gravitational pull from an unseen exoplanet as it orbits the star. By regularly looking at the spectrum of a star -- and so, measuring its velocity -- one can see if it moves periodically due to the influence of a companion. "We also used the integrated data from the time evolution of orbital parameters to generate the synthetic radial velocity curves of the known and the Earth-like planets in the system," said Satyal, who earned his Ph.D. in Astrophysics from UTA in 2014. "We obtained several radial velocity curves for varying masses and distances indicating a possible new middle planet," the astrophysicist noted. For instance, if the new planet is located around 1 AU from the star, it has an upper mass limit of 10 Earth masses and a generated radial velocity signal of 1.4 meters per second. A planet with about the mass of the Earth at the same location would have radial velocity signal of only 0.14 m/s, thus much smaller and hard to detect with the current technology. "The existence of this possible planet is supported by long-term orbital stability of the system, orbital dynamics and the synthetic radial velocity signal analysis," Satyal said. "At the same time, a significantly large number of radial velocity observations, transit method studies, as well as direct imaging are still needed to confirm the presence of possible new planets in the Gliese 832 system."

- Where is everybody? The implications of cosmic silence

Date: August 11, 2017
Source: University of Arkansas, Fayetteville

This dwarf galaxy is named NGC 5949. It sits at a distance of around 44 million light-years from Earth, placing it within the Milky Way's cosmic neighbourhood.
Credit: ESA/Hubble & NASA

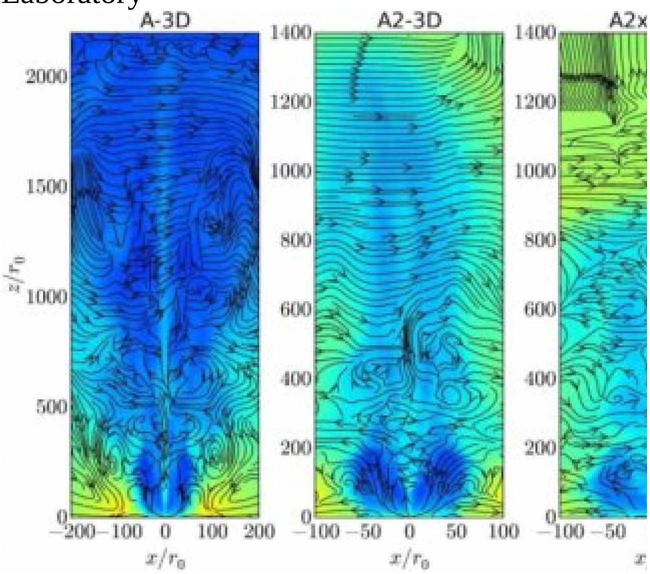
The universe is incomprehensibly vast, with billions of other planets circling billions of other stars. The potential for intelligent life to exist somewhere out there should be enormous.

So, where is everybody?

That's the Fermi paradox in a nutshell. Daniel Whitmire, a retired astrophysicist who teaches mathematics at the University of Arkansas, once thought the cosmic silence indicated we as a species lagged far behind. "I taught astronomy for 37 years," said Whitmire. "I used to tell my students that by statistics, we have to be the dumbest guys in the galaxy. After all we have only been technological for about 100 years while other civilizations could be more technologically advanced than us by millions or billions of years." Recently, however, he's changed his mind. By applying a statistical concept called the principle of mediocrity -- the idea that in the absence of any evidence to the contrary we should consider ourselves typical, rather than atypical -- Whitmire has concluded that instead of lagging behind, our species may be average. That's not good news. In a paper published Aug. 3 in the *International Journal of Astrobiology*, Whitmire argues that if we are typical, it follows that species such as ours go extinct soon after attaining technological knowledge. (The paper is also available on Whitmire's website.) The argument is based on two observations: We are the first technological species to evolve on Earth, and we are early in our technological development. (He defines "technological" as a biological species that has developed electronic devices and can significantly alter the planet.) The first observation seems obvious, but as Whitmire notes in his paper, researchers believe the Earth should be habitable for animal life at least a billion years into the future. Based on how long it took proto-primates to evolve into a technological species that leaves enough time for it to happen again up to 23 times. On that time scale, there could have been others before us, but there's nothing in the geologic record to indicate we weren't the first. "We'd leave a heck of a fingerprint if we disappeared overnight," Whitmire noted. By Whitmire's definition we became "technological" after the industrial revolution and the invention of radio, or roughly 100 years ago. According to the principle of mediocrity, a bell curve of the ages of all extant technological civilizations in the universe would put us in the middle 95 percent. In other words, technological civilizations that last millions of years, or longer, would be highly atypical. Since we are first, other typical technological civilizations should also be first. The principle of mediocrity allows no second acts. The implication is that once species become technological, they flame out and take the biosphere with them. Whitmire argues that the principle holds for two standard deviations, or in this case about 200 years. But because the distribution of ages on a bell curve skews older (there is no absolute upper limit, but the age can't be less than zero), he doubles that figure and comes up with 500 years, give or take. The assumption of a bell-shaped curve is not absolutely necessary. Other assumptions give roughly similar results. There's always the possibility that we are atypical and our species' lifespan will fall somewhere in the outlying 5 percent of the bell curve. If that's the case, we're back to the nugget of wisdom Whitmire taught his astronomy students for more than three decades. "If we're not typical then my initial observation would be correct," he said. "We would be the dumbest guys in the galaxy by the numbers."

- New 3-D simulations show how galactic centres cool their jets

Theories and models show how instabilities develop in extreme energy releases from black holes
Date: August 14, 2017
Source: DOE/Lawrence Berkeley National Laboratory



Side-by-side comparison of density "snapshots" produced in a 3-D simulation of jets beaming out from a black hole (at the base of images). Red shows higher density and blue shows lower density. The black directional lines show magnetic field streamlines. The perturbed magnetic lines reflect both the emergence of irregular magnetic fields in the jets and the large-scale deviations of the jets out of the image plane, both caused by the 3-D magnetic kink instability.
Credit: Berkeley Lab, Purdue University

Some of the most extreme outbursts observed in the universe are the mysterious jets of energy and matter beaming from the centre of galaxies at nearly the speed of light. These narrow jets, which typically form in opposing pairs are believed to be associated with supermassive black holes and other exotic objects, though the mechanisms that drive and dissipate them are not well understood. Now, a small team of researchers has developed theories supported by 3-D simulations to explain what's at work.

Finding common causes for instabilities in space jets

"These jets are notoriously hard to explain," said Alexander "Sasha" Tchekhovskoy, a former NASA Einstein fellow who co-led the new study as a member of the Nuclear Science Division at the Department of Energy's Lawrence Berkeley National Laboratory (Berkeley Lab), and the Astronomy and Physics departments and Theoretical Astrophysics Centre at UC Berkeley. "Why are they so stable in some galaxies and in others they just fall apart?" As much as half of the jets' energy can escape in the form of X-rays and stronger forms of radiation. The researchers showed how two different mechanisms -- both related to the jets' interaction with surrounding matter, known as the "ambient medium" -- serve to reduce about half of the energy of these powerful jets. "The exciting part of this research is that we are now coming to understand the full range of dissipation mechanisms that are working in the jet," no matter the size or type of jet, he said. The study that Tchekhovskoy co-led with Purdue University scientists Rodolfo Barniol Duran and Dimitrios Giannios is published in the Aug. 21 edition of *Monthly Notices of the Royal Astronomical Society*. The study concludes that the ambient medium itself has a lot to do with how the jets release energy. "We were finally able to simulate jets that start from the black hole and propagate to very large distances -- where they bump into the ambient medium," said Duran, formerly a postdoctoral research associate at Purdue University who is now a faculty member at California State University, Sacramento. Tchekhovskoy, who has studied these jets for over a decade, said that an effect known as magnetic kink stability, which causes a sudden bend in the direction of some jets, and another effect that triggers a series of shocks within other jets, appear to be the primary mechanisms for energy release. The density of the ambient medium that the jets encounter serves as the key trigger for each type of release mechanism. "For a long time, we have speculated that shocks and instabilities trigger the spectacular light displays from jets. Now these ideas and models can be cast on a much firmer theoretical ground," said Giannios, assistant professor of physics and astronomy at Purdue. The length and intensity of the jets can illuminate the properties of their associated black holes, such as their age and size and whether they are actively "feeding" on surrounding matter. The longest jets extend for millions of light years into surrounding space. "When we look at black holes, the first things we notice are the central streaks of these jets. You can make images of these streaks and measure their lengths, widths, and speeds to get information from the very centre of the black hole," Tchekhovskoy noted. "Black holes tend to eat in binges of tens and hundreds of millions of years. These jets are like the 'burps' of black holes -- they are determined by the black holes' diet and frequency of feeding." While nothing -- not even light -- can escape a black hole's interior, the jets somehow manage to draw their energy from the black hole. The jets are driven by a sort of accounting trick, he explained, like writing a check for a negative amount and having money appear in your account. In the black hole's case, it's the laws of physics rather than a banking loophole that allow black holes to spew energy and matter even as they suck in surrounding matter. The incredible friction and heating of gases spiralling in toward the black hole cause extreme temperatures and compression in magnetic fields, resulting in an energetic backlash and an outflow of radiation that escapes the black holes strong pull.

A tale of magnetic kinks and sequenced shocks

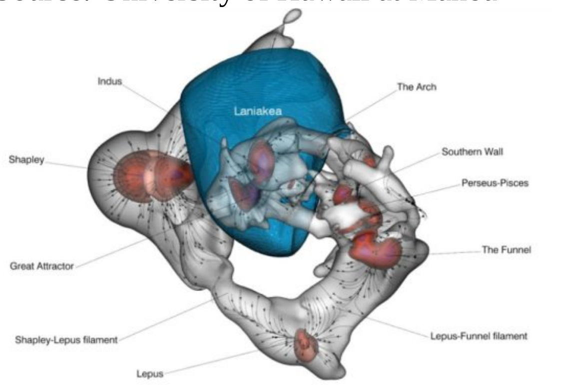
Earlier studies had shown how magnetic instabilities (kinks) in the jets can occur when jets run into the ambient medium. This instability is like a magnetic spring. If you squish the spring from both ends between your fingers, the spring will fly sideways out of your hand. Likewise, a jet experiencing this instability can change direction when it rams into matter outside of the black hole's reach. The same type of instability frustrated scientists working on early machines that attempted to create and harness a superhot, charged state of matter known as a plasma in efforts to develop fusion energy, which powers the sun. The space jets, also known as active galactic nuclei (AGN) jets, also are a form of plasma. The latest study found that in cases where an earlier jet had "pre-drilled" a hole in the ambient medium surrounding a black hole and the matter impacted by the newly formed jet was less dense, a different process is at work in the form of "recollimation" shocks. These shocks form as matter and energy in the jet bounce off the sides of the hole. The jet, while losing energy from every shock, immediately reforms a narrow column until its energy eventually dissipates to the point that the beam loses its tight focus and spills out into a broad area. "With these shocks, the jet is like a phoenix. It comes out of the shock every time," though with gradually lessening energy, Tchekhovskoy said. "This train of shocks cumulatively can dissipate quite a substantial amount of the total energy." The researchers designed the models to smash against different densities of matter in the ambient medium to create instabilities in the jets that mimic astrophysical observations.

Peering deeper into the source of jets

New, higher-resolution images of regions in space where supermassive black holes are believed to exist -- from the Event Horizon Telescope (EHT), for example -- should help to inform and improve models and theories explaining jet behaviour, Tchekhovskoy said, and future studies could also include more complexity in the jet models, such as a longer sequence of shocks. "It would be really interesting to include gravity into these models," he said, "and to see the dynamics of buoyant cavities that the jet fills up with hot magnetized plasma as it drills a hole" in the ambient medium. He added, "Seeing deeper into where the jets come from -- we think the jets start at the black hole's event horizon (a point of no return for matter entering the black hole) -- would be really helpful to see in nature these 'bounces' in repeating shocks, for example. The EHT could resolve this structure and provide a nice test of our work."

- Cosmic velocity web: Motions of thousands of galaxies mapped

Date: August 15, 2017
Source: University of Hawaii at Manoa



The cosmic velocity web is represented by surfaces of knots in red and surfaces of filaments in grey. The black lines with arrows illustrate local velocity flows within filaments and toward knots. The Laniakea Supercluster basin of attraction that includes our Milky Way galaxy is represented by a blue surface. The region being displayed extends across one billion light years. Credit: Daniel Pomarede, Yehuda Hoffman, R. Brent Tully and Helene Courtois. *Credit: Daniel Pomarede, Yehuda Hoffman, R. Brent Tully, Helene Courtois*

The cosmic web -- the distribution of matter on the largest scales in the universe -- has usually been defined through the distribution of galaxies. Now, a new study by a team of astronomers from France, Israel and Hawaii demonstrates a novel approach. Instead of using galaxy positions, they mapped the motions of thousands of galaxies. Because galaxies are pulled toward gravitational attractors and move away from empty regions, these motions allowed the team to locate the denser matter in clusters and filaments and the absence of matter in regions called voids. Matter was distributed almost homogeneously in the very early universe, with only miniscule variations in density. Over the 14-billion-year history of the universe, gravity has been acting to pull matter together in some places and leave other places more and more empty. Today, the matter forms a network of knots and connecting filaments referred to as the cosmic web. Most of this matter is in a mysterious form, the so-called "dark matter." Galaxies have formed at the highest concentrations of matter and act as lighthouses illuminating the underlying cosmic structure. The newly defined cosmic velocity web defines the structure of the universe from velocity information alone. In those regions with abundant observations, the structure of the velocity web and the web inferred from the locations of the galaxy lighthouses are similar. This agreement provides strong confirmation of the fundamental idea that structure developed from the growth of initially tiny fluctuations through gravitational attraction. The cosmic velocity web analysis was led by Daniel Pomarede, Atomic Energy Centre, France, with the collaboration of Helene Courtois at the University of Lyon, France; Yehuda Hoffman at the Hebrew University, Israel; and Brent Tully at the University of Hawaii's Institute for Astronomy. "With the motions of the galaxies, we can infer where all of the mass is located: the galaxies and the 5 times more abundant transparent matter (usually wrongly called dark matter). This total gravitating mass, together with the expansion of the universe, is responsible for the motions that create the architecture of the universe. The gravity from galaxies alone cannot create this network we see," said Dr. Courtois. Dr. Tully adds, "Moreover, a wide swath of the universe is hidden behind the obscuring disk of our own Milky Way galaxy. Our reconstruction of structure with the velocity web is revealing for the first time filaments of matter that stretch all the way around the sky and are easily followed through these regions of obscuration." This definition of the cosmic velocity web was made possible by the large and coherent collection of galaxy distances and velocities in the Cosmic flows series. The current analysis is based on a study of 8,000 galaxies in the second release of cosmic flows. The third release, with over twice as many galaxy distances and velocities is already available, and will reveal the cosmic velocity web in increasingly rich detail. The key element of the program is the acquisition of good distances to galaxies. Several methods are used, such as exploiting the known luminosities of old stars that are just beginning to burn Helium in their cores, and the relationship between the rotation speed of galaxies and the number of stars they possess. The observations have involved dozens of telescopes around the world and in space and at wavelengths from visible light through the infrared to radio. "The velocity web method for mapping the cosmos is analogous to using plate tectonics in geology. It helps understand not just the current layout of the universe, but also the movement of the invisible underlying masses responsible for that topology," said Dr. Courtois. The team has produced an extensive video demonstrating the cosmic velocity web. It first explains the concepts underlying the cosmic velocity web reconstruction, followed by a description of its major elements. The video then shows how cosmic flows are organized within its structure, and how the basin of attraction of the recently mapped Laniakea Supercluster resides within its elements. In the final sequence, the viewer enters an immersive exploration of the filamentary structure of the local universe, navigating inside the filaments and visiting the major nodes such as the Great Attractor. The 11-minute video is linked below and available at https://vimeo.com/pomarede/vweb

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The 3-dimensional map can also be explored in an interactive visualization, using the free online Sketchfab platform. This is a powerful tool to visualize interactively the structure from any viewpoint and compare it with the distribution of galaxies; one can dive inside the filaments and explore them in immersion. With appropriate virtual reality hardware, it can also be used in VR mode. This visualization marks a milestone as the first time such an interactive dataset will be embedded in the online version of the scientific article appearing in the *Astrophysical Journal*. Everyone is invited to interact with the data below, or at https://skfb.ly/667Jr.

How to find us