ISSUE 6

February 2021

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INSIDE THIS ISSUE

"Yellowknife Flurry", captures the intricate structure of snowflakes, the highest resolution to date.
Click here to view more amazing photographs
Credits: Nathan Myhrvold

CAFÉ SCIENTIFIQUE :
THE NEWSLETTER

EDITOR'S NOTE: GABRIEL'S HORN PARADOX

Gabriel's Horn is a particular surface of revolution, formed from rotating the graph of y = 1/x around the x-axis, forming an infinitely long horn. When thinking about the dimensions of this horn, a reasonable and intuitive guess would be that the volume would be infinite too right? However after going through the equations, we observe that the volume of this horn is finite; what's more is that this volume is exactly pi! If you pour pi units of paint into the horn it will fill up exactly, no more paint will be able to fit in, and any less then there would still be room left over; even though it is infinitely long, I can still fill it up. Now this is very weird itself, however this is only the beginning of the paradox!

If we now calculate the surface area of the outer face of Gabriel's horn, we find that this area is infinite! So this shape is infinitely long, has infinite surface area, but finite volume? We can never 'paint' the surface of this horn, but can fill it up. But if we have filled up the inside with paint, surely we have already painted the infinite inner surface area with a finite amount of paint? How does that work?

This is known as the Painter's paradox and is a great thought experiment. Of course it this will never truly make sense to us as humans, as infinitely long horns are not 'real' objects- if they were real then we'd probably have a much greater understanding of infinity. 'A paradox has been described as a truth standing on its head to attract attention. Undoubtedly, paradoxes captivate. They also cajole, provoke, amuse, exasperate and seduce. More importantly they arouse curiosity, stimulate and motivate' (Kleiner and Movshovitz-Hadar, 1994). ~ Shivanshi ☺

MARTIAN MINERAL ON EARTH

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A yellow-brown mineral, called jarosite, requires both water and acidic conditions to form. These are rare conditions on Mars, however after the opportunity rover first discovered it in 2004, the mineral has been seen in several other Martian locations, leaving the puzzling mystery to how the mineral became so common. Some have theorised that when ice covered the planet billions of years ago, dust containing the required minerals (iron, sulphate and potassium) may have been trapped inside as the ice sheets grew, providing the wet environment needed. However scientists have never seen dust and ice chemically reacting to form the mineral. But a recent discovery of jarosite particles locked in Antarctica's ice may support the theory .

After examination the particles with an electron microscope, the team found that the jarosite had formed in pockets within the ice, and were noticeably cracked and devoid of sharp edges, suggesting that the mineral formed in the same way on Mars. However on the Red planet, the jarosite appears in metre-thick deposits, and not just a few grains. These thick slabs may have formed on Mars as it is much dustier than on Antarctica, providing more raw material for the mineral to form. This is just the first step to linking the Martian environment to that of Antarctic ice, and further investigations may lead to answers to whether Martian ice deposits were key in the formation of other minerals.

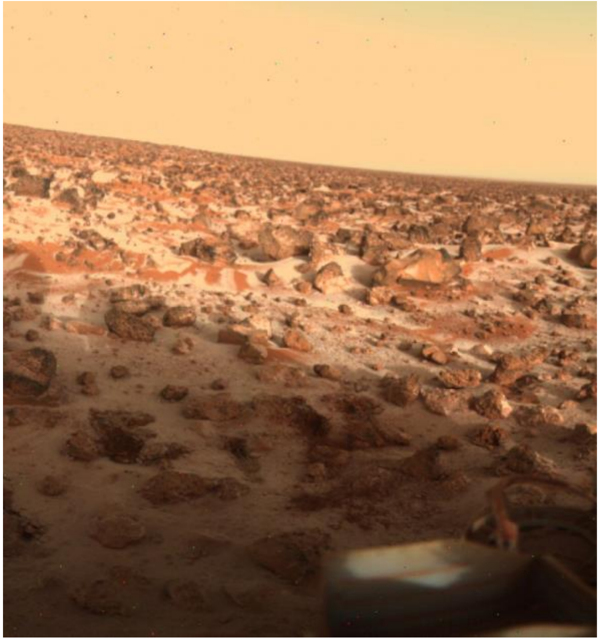

Image of early morning frost at location of the Viking 2 Lander on 18th May 1972. Credit: NASA/JPL

LUMINOSITY IN PARTICLE PHYSICS

Click here to read the full article

When physicists talk about particle collisions, they talk about a measurement called luminosity. This quantity doesn't tell scientists exactly how many particle collisions are happening inside the collider, rather luminosity measures exactly how tightly packed the particles are in the beams that cross; the tighter the 'squeeze', the more likely it is that some of the particles will collide. Why do we do this? Well collisions are complicated, especially at the particle level. Two protons could pass right through each other, and nothing could happen; if two protons interact, does that count as a collision? What about if only their intersecting electromagnetic fields interact and eject a few photons? These are just a few reasons to why talking in terms of luminosity is a better way to describe these events. The rate at which particles are brought together to collide is called instantaneous luminosity. This rate depends on the number of particles in each colliding beam, and the areas of the beams. The units of luminosity are quite interesting--as it is calculated by multiplying the number of protons in each beam, dividing by the beam area , all over time- the units calculate to be centimetres squared per time! This is a rather non intuitive unit, however it gives us exactly the information we need. When scientists load up the LHC with particles to collide, they keep them running as long as the beams are in good enough condition with enough particles left to have a good instantaneous luminosity. Considering an average LHC fill lasts between 10 and 20 hours, the number of potential collisions can climb very quickly, therfore we also need to consider the 'integrated luminosity', the many potential collisions accumulating over the hours of running. For this value, we switch from squared centimetres to a new unit of area, the barn, a reference to the idiom 'Couldn't hit the broad side of the barn'. It was invented in the 1940's and its size (10-24 centimetres squared) was kept classified until the end of World War II, as the size is equivalent to the size of a uranium nucleus, which was a key ingredient in the then-newly developed atomic bomb. The barn then stuck around after the war, and became a standard way to measure area in nuclear and particle physics. With the LH-LHC upgrade, scientists are increasing the number of protons, better aligning their trajectories, and decreasing the diameter of collisions, all to increase the likelihood that they will interact with each other!

DETECTING EMOTIONS WITH AI

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A new study done by researchers at Queen Mary University London suggests that wireless signals could help us reveal our inner emotions. The study demonstrated the use of radio waves to measure heart rate and breathing signal, and predict how someone is feeling, even in the absence of any other visual clues. Participants were initially asked to watch a video selected by researchers for its ability to evoke one of four basic emotions: anger, sadness, joy and pleasure. Whilst the individual was watching the video, the researchers then emitted harmless radio signals, like those transmitted from any wireless system, and measured the signals that bounced back from them; by analysing changes to the signals caused by slight body movements, the researchers were able to reveal 'hidden' information about an individual's heart and breathing rates. For this study, deep learning techniques were employed, rather than classical machine learning approaches. Deep learning involves an artificial neural network learning its own features from time-dependant raw data, which could detect emotions more accurately than the traditional methods. Deep learning has allowed us to assess data in a similar way to how a human brain would work, looking at different layers of information and making connections between them. This has allowed the accurate measuring of emotions in a subject-independent way, where we can look at a whole collection of signals from different individuals and learn from this data and use it to predict the emotions of people from outside a training database. Traditionally, emotion detection has relied on the assessment of visible signals, such as facial expressions, eye movements and gestures. However these can be unreliable as they don't effectively capture an individuals internal emotions. This is why researchers are looking into other ways of emotion detection, for example ECG signals. These detect electrical activity in the heart, providing a link between the nervous system and heart rhythm. This new wireless technology does have some ethical and public acceptance concerns, however it could be an invaluable technology with many practical applications, especially in areas such as human/robot interaction and healthcare and emotional wellbeing.

Click here for a great educational series to learn more about neural networks and deep learning

A portrait of Ramanujan , 'The Man Who Knew Infinity'

AI AND MATHS FORMULAE

Click here to read the full article

Researchers have built the Ramanujan Machine, a machine deigned to find new ways of calculating the digits of mathematical constants, such as e, which are irrational. The AI starts with well known formulae to calculate the digits, say the first few thousand. From those, the algorithm tries to predict a new formula that does the same calculation just as well. The process used a good guess (a conjecture) and then it is up to humans to prove that the formula can accurately calculate the number. The project is named after Srinivasa Ramanujan, an Indian Mathematician who was active in the early 20th century. Ramanujan rarely wrote proofs that appear in conventional maths papers; instead he filled his notebooks with amazing formulae from his dreams. The Ramanujan machine currently has limited applications, as the algorithm can only generate a particular type of formula called continued fractions, which express numbers as an infinite sequence of fractions nested in each other's denominators. Further use and improvement of AI in mathematics could hopefully one day lead us to solving amazing problems in Mathematics, from proving the irrationality of certain numbers such as Catalan's constant to the millennium problems!

DETECTING LIFE-SUSTAINING PLANETS

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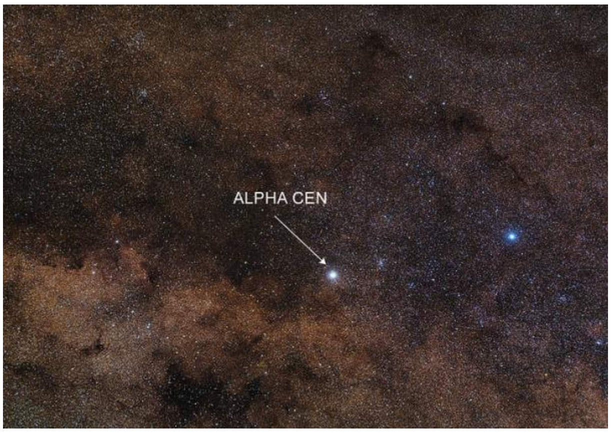
According to a new study, it is now possible to capture images of planets that could potentially sustain life around nearby stars. Using a newly developed system for mid-infrared exoplanet imaging, the study's authors say that they can now use ground-based telescopes to directly capture images of planets about three times the size of Earth, within the habitable zones of nearby systems. Current efforts to directly image exoplanets have been hamstrung due to technological limitations, resulting in a bias toward the detection of easier to see planets that are much larger than Jupiter, and are located around very young stars, and far outside the habitable zone. In order to find planets with suitable conditions for life as we know it, we have to look for rocky planets, roughly the size of Earth, inside habitable zones, and around older, sun-like stars. The method described in the paper provides more than a tenfold improvement over existing capabilities to directly observe exoplanets, and we can now push beneath detection limits for the first time. The team have observed the Alpha Centauri system (triple star system) for nearly 100 hours over the course of a month, and after analysis and removing false signals, the final image revealed a light source designated as 'C1' that could potentially hint at the presence of an exoplanet candidate inside the habitable zone! Simulations of what planets within the data are likely to look like suggest that 'C1' could be a Neptune to Saturn sized planet at a distance from Alpha Centauri A that is similar to that distance between the Earth and the sun. Although we can't yet be certain that 'C1' is a planet however it is a step closer towards trying to find habitable planets within Alpha Centauri, and will be further explored with the next generation of telescopes .



Alpha Centauri: A triple star sytem located just over 4 light years (25 trillion miles) from Earth. Credits: NASA

The Hubble Telescope's best image of Alpha Centauri A and B. Credits: NASA Goddard

INFECTIOUS DISEASES AND THE FROG'S MICROBIOME

Click here to read the full article

Just as beneficial microbes in the human gut can be affected by antibiotics, diet interventions and other disturbances, the microbiomes of other animals can also be upset. In a study published with the University of Hawai'i at Manoa School of Ocean and Earth Science and Technology, they determined that the skin microbiome of an endangered frog was altered when the frogs were infected by a specific fungus, and it didn't recover to its initial state even when the frog was cured of the infection. Batrachochytrium dendrobatidis (Bd) is a fungus that infects the skin of amphibians and since its discovery just over two decades ago, Bd has emerged as a global threat to amphibians. Researchers found that Bd infection disturbed the frog bionome by altering the relative abundances of core bacterial species, but when the frogs were cleared of their infections, the microbiomes did not recover. Conservation of Hawaiian species will now require understanding of how infections diseaes affect its wildlife, including having effects on associated microbiomes.

HOW BACTERIA SLEEP THROUGH ANTIBIOTIC ATTACKS

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Bacteria can survive antibiotic treatment even without antibiotic resistance by slowing down their metabolism and going into a type of 'deep sleep'. Resistant bacteria evade the effects of antibiotics by becoming less susceptible by, for example breaking the drugs down. But some bacteria have another survival strategy: they withstand treatment by going into a sleep-like state that enables them to tolerate antibiotics. Once the therapy is complete, the bacteria 'wake up' and re-establish the infection. This state can result in recurrent and difficult-to-treat infections. The research team worked with the bacterium Staphylococcus aureus, which is found on the skin of many people, and often causes evasive infections. The researchers took bacteria from an infected patient and cultivated them in petri dishes. Certain bacterial colonies turned out to be smaller than others- this tells us that the sample contained persistent bacteria . Unlike other bacteria, persistent bacteria must first 'awaken', leading to delayed growth in the nutrient medium. To determine the conditions under which the bacteria become persistent, the researchers carried out various stress tests; factors included the presence of human immune cells and antibiotics or an acidic environment. They found that the more extreme the stress conditions, the higher the percentage of persistent bacteria. Analysis of the set of bacterial proteins (proteome), showed that comprehensive molecular reprogramming had taken place and slowed metabolism down in persisters. However it did not come to a complete standstill, but the bacteria rather entered a kind of deep sleep, increasing their chances of survival in a hostile environment. They also found that as soon as the environment becomes more hospitable, the bacteria reverse these changes and again become infectious. A better understanding of these mechanisms will contribute to developing new treatments against persistent bacteria, and in turn help further the fight against antibiotic resistance.

'GHOSTLY' NEUTRINO FROM BLACK HOLE

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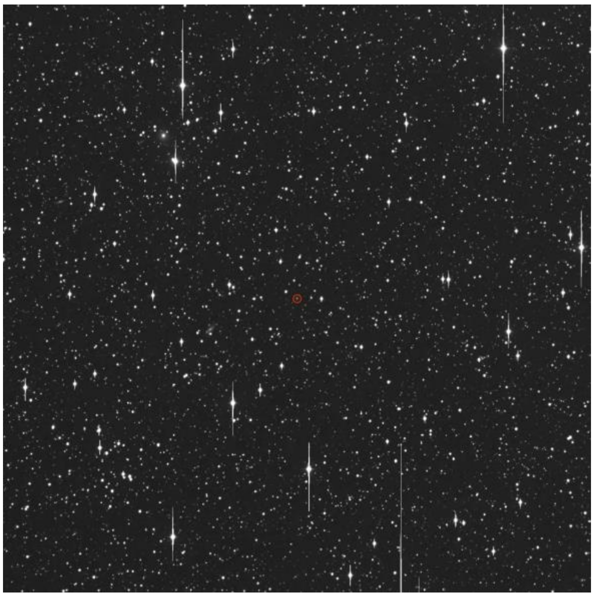
A ghostly particle that smashed into Antarctica in 2019 has been traced back to a black hole tearing apart a star while acting like a giant cosmic particle accelerator. Neutrinos are incredibly lightweight, around 500,000 times lighter than the electron, and poses no charge therefore hardly interact with other particles. As such, they can easily slip through matter, however they do occasionally strike atoms. When this happens, they give off telltale flashes of light, one of which was observed on October 1. 2019, using the IceCube Neutrino Observatory at the South Pole. It smashed into the Antarctic ice with a remarkable energy of more than 100 tera-electronvolts; that's 10 times the maximum energy that can be achieved in the LHC! The researchers traced this neutrino back to a galaxy, which had inside it a black hole shedding star, a so-called tidal disruption. The star had come too close to a supermassive black hole at the centre of the galaxy, and was ripped apart. Half of its debris was hurled into space, whereas the other half settled into a swirling disk, which eventually shone bright enough for astronomers to see it from Earth!



The Zwinky Transient Facilty captured this snapshot of the total disruption (circled). Credits: ZTF/Caltech Optial Observatories

THE PROTON'S INNER ANTIMATTER

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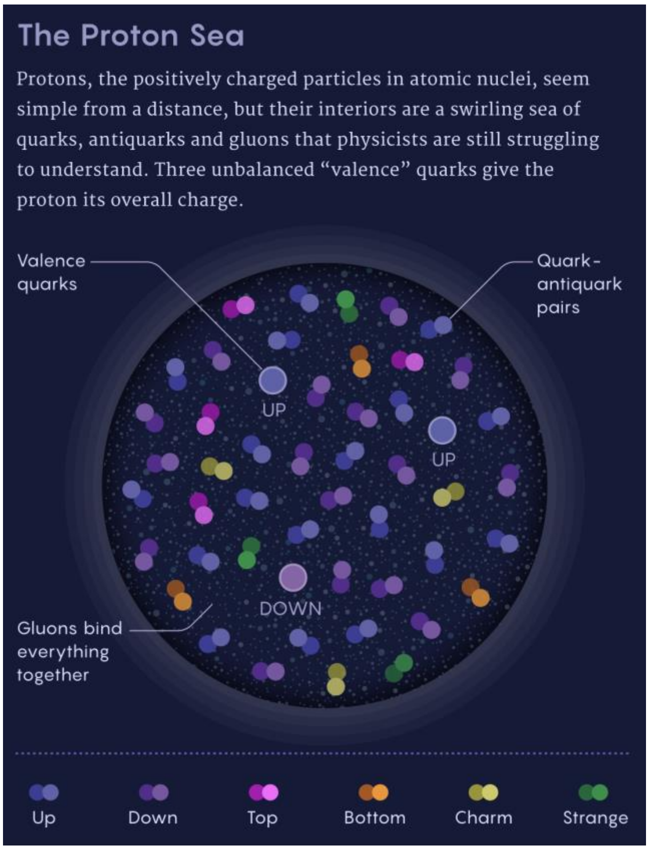
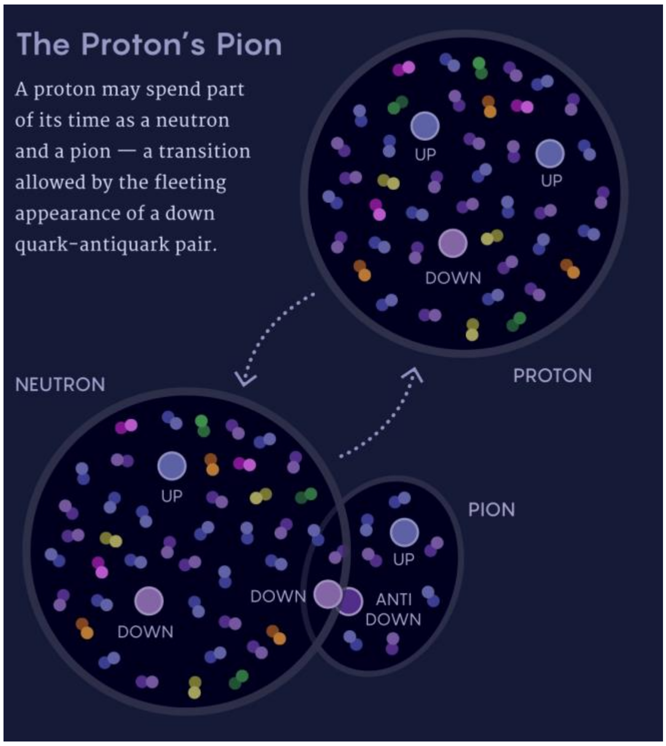
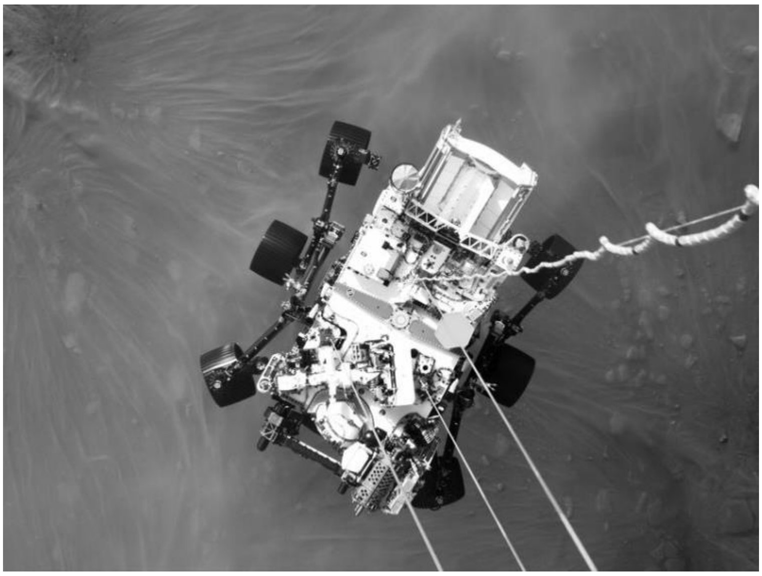
We learn in school that a proton is made of three elementary particles, two up quarks and one down quark, who's electrical charges combine to give the proton its charge of +1. However in reality, the proton's interior swirls with a fluctuating number of six kinds of quarks, their oppositely charged antimatter counterparts, and gluons that bind the others together. Somehow, these fluctuations wind up stable, and mimic a trio of quarks. Thirty years ago, researchers discovered this 'proton sea', which they expected to contain an even spread of different types of antimatter; instead they found that down quarks seemed to significantly outnumber the up quarks, finding that there are, on average, 1.4 down antiquarks for every up antiquark. This evidence immediately favours two theoretical models of the proton sea. One is the 'pion cloud', a popular approach that emphasises the proton's tendency to emit and reabsorb pions. The other model, the so-called statistical model, treats the proton like a container full of gas. For a brief period of time, we thought the quark model of the proton was accurate, however as we stared to measure the properties of these 3 quarks more, we discovered that there were some additional things going on: the quarks' momentum only accounted for a minor fraction of the proton's total mass, and when electrons were fired at at the protons, the researchers saw them ping off more things inside, and more internal particles kept getting revealed. Quantum chromodynamics (QCD) is a theory developed that describes the strong force, and predicts the very maelstrom that the scattering experiments observed. The complications arise as gluons feel the very force they carry; this self-dealing creates a quagmire inside the proton, giving gluons free reign to arise, and split into short-lived quark-anti-quark pairs, which seem to 'cancels out', from afar. However self-dealing gluons leave the QCD equations generally unsolvable, and so we can't calculate its precise predictions. But we still has no reason to think that gluons should split more into one type of quark-antiquark pair than the other, we would expect equal amounts of both. Theorists soon came out with a number of different possibilities to explain the proton's asymmetry, one of which involves the pion model, where the proton morphs into the a neutron and a pion. As the pion contains a down antiquark (as a pion containing an up antiquark can't materialise as easily), the pion cloud idea could explain the surplus of down anti-quarks. Another famous model is the statistical model, which treats the internal particles as if they're gas molecules in a room, flying at a distribution of speeds that depend on whether they possess integer or half amounts of angular momentum. Whatever the actual true model, solving a mystery so deep and obscure as this will forever change the physics landscape, and would give us great insight to how these particles truly work!



The Proton Sea. Credits: Samuel Valasco/Quanta Magazine



The pion cloud theory, where the proton morphs into a neutron and a pion. Credits: Samuel Valasco/Quanta Magazine



‘DARE MIGHTY THINGS’