

# DUNE Discoveries about Solar Neutrinos

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*The Deep Underground Neutrino Experiment (DUNE) is an international research collaboration aimed at exploring topics related to neutrinos and proton decay, which should start collecting data around 2025. [37]*

*This new measurement constitutes an interesting confirmation of the standard cosmological model which links the production of neutrinos one second after the Big Bang to the clustering of galaxies billions of years later. [36]*

*The history of the universe is predicated on the idea that, compared to today, the universe was hotter and more symmetric in its early phase. [35]*

*The universe consists of a massive imbalance between matter and antimatter. [34]*

*Our universe could be the mirror image of an antimatter universe extending backwards in time before the Big Bang. [33]*

*"As you celebrate New Year's Day, cast an eye upward and think for a moment about the amazing things our country and our species can do when we set our minds to it," Stern wrote in the New York Times on Monday. [32]*

*Our senses are stuck in the past. There's a flash of lightning, and then seconds pass until we hear the rumble of distant thunder. We hear the past. [31]*

*ESA's technical centre in the Netherlands has begun running a pulsar-based clock. The "PulChron" system measures the passing of time using millisecond-frequency radio pulses from multiple fast-spinning neutron stars. [30]*

*VR is an almost perfect avenue for this approach, since it has been surging in popularity as both entertainment and an educational tool. [29]*

*Using MAGIC telescopes and NASA's Fermi spacecraft, an international team of astronomers has discovered a new source of very high energy gamma-ray emission around the supernova remnant (SNR) G24.7+0.6. [28]*

*In 1973, Russian physicist A.B. Migdal predicted the phenomenon of pion condensation above a critical, extremely high—several times higher than that for normal matter—nuclear density. [27]*

*Our first glimpses into the physics that exist near the center of a black hole are being made possible using "loop quantum gravity"—a theory that uses quantum mechanics to extend gravitational physics beyond Einstein's theory of general relativity. [26]*

*In the shadowy regions of black holes two fundamental theories describing our world collide. Can these problems be resolved and do black holes really exist? First, we may have to see one and scientists are trying to do just this. [25]*

*The authors suggest that this virtual reality simulation could be useful for studying [24]*

*Every galaxy is thought to harbor a supermassive black hole in the center, or nucleus, of the galaxy, and in active galaxies this black hole is fed by infalling matter. [23]*

*A new study by researchers at the University of Colorado Boulder finds that violent crashes may be more effective at activating black holes than more peaceful mergers. [22]*

*For the first time, a team of astronomers has observed several pairs of galaxies in the final stages of merging together into single, larger galaxies. [21]*

*In a cluster of some of the most massive and luminous [HYPERLINK "https://phys.org/tags/stars/"](https://phys.org/tags/stars/) stars in our galaxy, about 5,000 light years from Earth, astronomers detected particles being accelerated by a rapidly rotating neutron star as it passed by the massive star it orbits only once every 50 years. [20]*

*For the first time astronomers have detected gravitational waves from a merged, hyper-massive neutron star. [19]*

*A group of scientists from the Niels Bohr Institute (NBI) at the University of Copenhagen will soon start developing a new line of technical equipment in order to dramatically improve gravitational wave detectors. [18]*

*A global team of scientists, including two University of Mississippi physicists, has found that the same instruments used in the historic discovery of gravitational waves caused by colliding black holes could help unlock the secrets of dark matter, a mysterious and as-yet-unobserved component of the universe. [17]*

*The lack of so-called "dark photons" in electron-positron collision data rules out scenarios in which these hypothetical particles explain the muon's magnetic moment. [16]*

*By reproducing the complexity of the cosmos through unprecedented simulations, a new study highlights the importance of the possible behaviour of very high-energy photons.*

*In their journey through intergalactic magnetic fields, such photons could be transformed into axions and thus avoid being absorbed. [15]*

*Scientists have detected a mysterious X-ray signal that could be caused by dark matter streaming out of our Sun's core.*

*Hidden photons are predicted in some extensions of the Standard Model of particle physics, and unlike WIMPs they would interact electromagnetically with normal matter.*

*In particle physics and astrophysics, weakly interacting massive particles, or WIMPs, are among the leading hypothetical particle physics candidates for dark matter.*

*The gravitational force attracting the matter, causing concentration of the matter in a small space and leaving much space with low matter concentration: dark matter and energy.*

*There is an asymmetry between the mass of the electric charges, for example proton and electron, can understood by the asymmetrical Planck Distribution Law. This temperature dependent energy distribution is asymmetric around the maximum intensity, where the annihilation of matter and antimatter is a high probability event. The asymmetric sides are creating different frequencies of electromagnetic radiations being in the same intensity level and compensating each other. One of these compensating ratios is the electron – proton mass ratio. The lower energy side has no compensating intensity level, it is the dark energy and the corresponding matter is the dark matter.*

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Author: George Rajna

## **The Big Bang**

The Big Bang caused acceleration created radial currents of the matter, and since the matter is composed of negative and positive charges, these currents are creating magnetic field and attracting forces between the parallel moving electric currents. This is the gravitational force experienced by the matter, and also the mass is result of the electromagnetic forces between the

charged particles. The positive and negative charged currents attracts each other or by the magnetic forces or by the much stronger electrostatic forces!?

The gravitational force attracting the matter, causing concentration of the matter in a small space and leaving much space with low matter concentration: dark matter and energy.

There is an asymmetry between the mass of the electric charges, for example proton and electron, can understood by the asymmetrical Planck Distribution Law. This temperature dependent energy distribution is asymmetric around the maximum intensity, where the annihilation of matter and antimatter is a high probability event. The asymmetric sides are creating different frequencies of electromagnetic radiations being in the same intensity level and compensating each other. One of these compensating ratios is the electron – proton mass ratio. The lower energy side has no compensating intensity level, it is the dark energy and the corresponding matter is the dark matter.

## **The DUNE experiment could lead to new discoveries about solar neutrinos**

The [Deep Underground Neutrino Experiment \(DUNE\)](#) is an international research collaboration aimed at exploring topics related to neutrinos and proton decay, which should start collecting data around 2025. In a recent study featured [in \*Physical Review Letters\*](#), a team of researchers at Ohio State University have showed that DUNE has the potential to deliver groundbreaking results and insight about solar neutrinos.

Neutrino astronomy is a field that studies the different types of neutrinos. Research in this field, such as the recent study carried out by the team at Ohio State University, has increased dramatically over the past few decades.

"As far as we know, neutrinos are elementary particles, meaning that they are not composed by 'smaller pieces,'" Francesco Capozzi, one of the researchers who carried out the study, told Phys.org. "These particles do not possess any electric charge so they cannot interact electromagnetically via the force that keeps electrons and protons together in an atom."

Neutrinos are fascinating particles, as their main properties are very different from those of other [elementary particles](#). For instance, their masses are incredibly small, approximately one-millionth of the next-lightest particles (i.e., electrons).

Another unique characteristic of neutrinos is that they can only interact with other matter via a so-called ['weak interaction'](#). As suggested by its name, this 'weak interaction' is much weaker than the electromagnetic one; so weak that neutrinos can travel through the Earth or sun without ever interacting with other particles. In addition, as they are neutral in charge, neutrinos are not affected by the magnetic fields of the Earth or sun.

"The properties of neutrinos make them unique probes of the universe," Capozzi said. "They can carry information of regions which would be inaccessible otherwise."

There are several sources of neutrinos, and depending on where they are produced, they can differ in fluxes, energies per particle, and other properties. Solar neutrinos, for instance, are produced in

the sun's core, but can then escape to other parts of the solar system. Approximately 60 billion electron neutrinos per square centimeter reach the Earth from the sun every second. Analyzing these particles could allow researchers to uncover real-time information about what is happening at the very center of the sun.

Another type of neutrino comprises those produced during the super energetic explosions of massive stars, supernova neutrinos. These neutrinos reach Earth hours before the light produced in the explosion, and come directly from the innermost part of an exploding star, where the density is so high that even neutrinos can be trapped for a while. These are just a few examples of neutrino sources, but there are countless others, some of which have not yet been detected.

"There even exist neutrinos that have been propagating freely through the universe since about one second after the Big Bang, which carry the imprints of the primordial universe," Capozzi said. "However, we have still been unable to detect these."

Based on what astrophysicists have observed so far, neutrinos come in three main 'flavors': electron neutrinos, muon neutrinos and tau neutrinos. Each of these different 'flavors' is identified based on the charged particle produced during a weak interaction (i.e., electrons, muons or taus).

So far, detecting and studying neutrinos has proved incredibly challenging, mainly due to the fact that they rarely interact with other matter. One way to overcome this limitation is by building large detectors that compensate for the low probability of neutrino interactions by increasing the number of possible particles they can interact with.

The Super-Kamiokande (Super-K) detector in Japan, which essentially consists of a tank filled with 50,000 tons of the purest water available on Earth, is currently the largest detector available for MeV (low-energy) neutrinos. Low-energy neutrinos are those in the MeV energy range, which are mainly produced in nuclear processes, for instance, via fusion reactions in the sun or at the center of exploding stars.

"Another problem is that we cannot see neutrinos themselves using detectors; we can only see the charged particle produced in their interactions," Capozzi explained. In Super-Kamiokande, for instance, we see the light these charged particles emit in water when traveling at almost the speed of light."

The sun is one of the most important natural sources of neutrinos, as they are produced via the same nuclear reactions that allow the sun to shine. When scientists first started detecting [solar neutrinos](#) in the 1960s, they found that there were fewer electron neutrinos than they expected.

"A possible explanation for this anomaly was that neutrinos were changing their flavor while propagating," Capozzi explained. "This phenomenon, now known as neutrino oscillation, is physically possible only if neutrinos have mass. It took about 30 years to confirm that the solar neutrino anomaly was, indeed, due to [neutrino oscillations](#)."

Essentially, although neutrinos come in different flavors, scientists discovered that they can also oscillate and 'change flavors.' The two physicists who discovered this, Takaaki Kajita and Arthur B. McDonald, were awarded the Nobel Prize in Physics in 2015.

"Perhaps the weirdest thing about neutrinos is that they oscillate," Shirley Li, another researcher involved in the study, told Phys.org. "Neutrinos born with one flavor may turn into neutrinos with a different flavor after they propagate over some distance. Imagine how surprised you would be if you bought a cup of chocolate ice cream and see that it turned into strawberry ice cream once you open it at home. Physicists were equally surprised when neutrino oscillation was discovered."

Since the discovery of neutrino oscillations, researchers have been using solar neutrinos to determine the parameters describing their oscillations. Despite the huge efforts to achieve this, many questions remain unanswered.

Firstly, researchers were unable to observe all of the nuclear reactions through the correspondent neutrinos. For instance, 'hep' neutrinos, which are produced from the fusion of a nucleus of Helium and a proton, have proven particularly difficult to observe. In fact, while hep neutrinos are the most energetic among solar neutrinos, they are very small in flux compared to other neutrinos.

In addition, the oscillation parameters determined in solar neutrino experiments are not in complete agreement with the measurements collected in other types of experiments. This could be due to some unknown physical phenomena that only affect solar neutrinos.

"We have not run out of questions about solar neutrinos, we have run out of detector advances," John Beacom, one of the researchers who carried out the study, told Phys.org.

Due to the limitations of existing detectors, most current neutrino experiments will most likely be unable to address unanswered questions. This inspired a large and international team of researchers to start building DUNE, a large detector in a mine in South Dakota that is 4850 feet underground.

"In the past, it has already been discussed that DUNE might be used as a solar neutrino detector, too," Capozzi said. "However, no thorough study in this direction has been performed. We decided to cover this gap, showing that DUNE is actually able to provide the answers to those questions, with basically no extra money investment."

In their recent study, Capozzi, Li, Beacom and their colleague Guanying Zhu set out to prove that the DUNE mine could also be a world-leading solar neutrino detector. In order to do this, they first assessed the mine's amount of background, which is essentially something observed in a detector that mimics the signal that one is looking for, even if it has an entirely different origin. This background can confuse and adversely affect the measurement and detection of neutrinos.

"In the energy range relevant for solar neutrinos, the most important background is coming from natural radioactivity," Capozzi explained. "Since the experiment will be based in a cave in a deep mine, the radioactivity comes from the surrounding rock. In order to make an estimate of the background, we first have to understand the rock composition expected for the detector site."



Simulating background events in DUNE proved somewhat challenging, as these can come from a variety of sources, and thus to identify them requires in-depth analyses. When they first started working on their study, the researchers thus started investigating the background sources for neutrino experiments carried out in the past and computed these rates in the context of DUNE.

"It turns out that their rates are reasonably low compared to the signal rates," Li said. "However, halfway through our study, we discovered in the literature the existence of this particular background only for argon detectors. These are low-energy neutrons produced from radioactivities in surrounding rock. This turns out to be the dominant background for solar neutrino measurement in DUNE."

The researchers based their analyses on past literature that outlines the geological aspects of DUNE's mine, which are of crucial importance to complete proper excavations. Knowing the exact rock composition in the mine, they were then able to carry out a calculation to predict its expected background. Subsequently, they used statistical tools to evaluate the precision that DUNE can reach in measuring the oscillation parameters and the flux of neutrinos escaping from the sun.

Once they identified the possible sources of background in the DUNE experiment, they tried to come up with strategies to eliminate the backgrounds, as their rates are typically much higher than the neutrino signal rates. They came up with two distinct solutions: one that entails surrounding the detector with a layer of plastic and the other collecting data for twice as long to achieve better sensitivity.

"For each step of the experiment, we had to take care of further details," Capozzi said. "For example, we had to treat the neutrino interactions carefully with the detector, which will be made of liquid argon. At the energy relevant for solar neutrinos, a very important interaction is with the entire argon nucleus, which depends on complicated nuclear effects."

Before they set out to assess the potential of DUNE as a detector to discover new things about neutrinos, the researchers reviewed all past research on this topic, comparing results that were obtained using different experimental and theoretical nuclear physics techniques. Ultimately, they selected the technique that they felt was more appropriate and implemented it using local computers at their university.

"We now have a theoretical framework that allows us to compute the probability of neutrinos born with one flavor tuning into a different flavor," Li said. "This depends on the energy of the neutrino and the propagation distance, as well as six oscillation parameters. We wanted to measure as many types of neutrino oscillation as we could, e.g., neutrinos with any of the three flavors oscillating to other flavors, in order to get the most precise measurements of the six oscillation parameters, and most importantly, to evaluate whether our current framework of neutrino oscillation was, indeed, correct."

The DUNE experiment is designed to study neutrinos specifically by measuring a flux of high-energy muon neutrinos oscillating to electron neutrinos reaching a big detector the South Dakota-based underground mine. This could ultimately allow researchers to measure two oscillation parameters that were roughly measured in previous experiments with greater precision.

The detector used in the DUNE experiment is extremely large compared to other existing detectors. It is 40 kilotons of argon with which neutrinos can interact, and it detects particles via a time projection chamber technology, enabling the collection of 3-D images for each neutrino interaction.

"A natural question is, what else can this amazing detector measure?" Li said. "This is how we got the idea to measure solar neutrinos with DUNE. Solar neutrino oscillation is particularly interesting. So far, solar neutrino and reactor neutrino oscillation patterns slightly disagree. This could be due to two reasons: Either there is an unlikely statistical fluctuation in the current data, or our current theoretical understanding of neutrino oscillation is not complete. The second possibility is extremely exciting."

Another experiment called JUNO, planned for 2020, will measure neutrinos coming out of nuclear reactors. Solar neutrinos and reactor neutrinos are, in principle, sensitive to the same oscillation parameters. So if the theoretical framework proposed by the researchers is right, the parameters identified in the JUNO experiment (i.e., for reactor neutrinos) should be aligned with those gathered in the DUNE experiment (i.e., for solar neutrinos).

Past studies have found discrepancies between the oscillation parameters of reactor and solar neutrinos, but the more precise measurements that are set to be collected in the JUNO and DUNE experiments could shed some light on this discrepancy. This could in turn lead to the discovery of new physical phenomena.

So far, there has been some skepticism in the physics world about the DUNE underground mine being an effective solar neutrino detector, primarily due to the large amount of background expected, which could adversely affect results. In their study, however, Capozzi, Li, Zhu and Beacom demonstrated that DUNE could lead to world-leading measurements of solar neutrinos, while also potentially enabling the first-ever precise measurements of 'hep' solar neutrinos.

"Despite the skepticism, we were able to show that this background can be drastically reduced applying some selection criteria to what we will see in the detector," Capozzi said. "The background left will only dominate over the signal at low energies. The high-energy part will be 'untouched,' and we estimated that it will consist of 100,000 solar neutrinos observed in five years."

In addition to demonstrating the huge potential of DUNE, Capozzi, Li, Zhu, and Beacom introduced a series of feasible theoretical and experimental improvements that could enhance the performance of the DUNE detector. These improvements could also benefit the project at large, facilitating the investigation of other physical phenomena.

In order to address unanswered questions, the next generation of neutrino detectors will need to be huge in size and have advanced detection capabilities. Even using these detectors, some of the properties and characteristics of neutrinos will most likely remain a mystery, as there are still numerous technical challenges to overcome.

"Without this measurement in DUNE, we may never know why solar neutrinos appear to mix differently from reactor antineutrinos," Beacom said. "We are not saying that investigating this will be easy, but we are saying that it is important."

The researchers at Ohio State University are now planning to share the results of their calculations and simulations, as well as their suggestions for improvement with the astrophysics community at large. They hope that this will spark conversation and ultimately encourage changes that could further enhance the performance of the DUNE [detector](#) before the experiment is carried out.

"We are excited to see that the DUNE collaboration is looking into the details of our analysis, and hopefully we will see this analysis carried out when DUNE comes online," Li said. "Overall, it is a truly exciting time to study neutrinos, as there are so many interesting measurements and tests one can do in these experiments. I am still trying to come up with measurements that haven't been considered before and study what they can tell us about neutrinos and physics beyond the Standard Model."

One of the core goals of the team's future research will be making the most out of the observations gathered in the DUNE mine or using other large detectors. To do this, the team plans to continue investigating new techniques that could make detectors more sensitive to [neutrinos](#) produced from astrophysical sources. [37]

## Neutrinos seen in the clustering of galaxies

In early times, the universe was an energetic mix of strongly interacting particles. The first particles to break free from this dense soup were neutrinos, the lightest and most weakly interacting particles of the Standard Model of particle physics. These neutrinos are still around us today, but are very hard to detect directly because they are so weakly interacting. An international team of cosmologists, including Daniel Baumann and Benjamin Wallisch from the University of Amsterdam, have now succeeded in measuring the influence of this 'cosmic neutrino background' on the way galaxies have become clustered during the evolution of the universe. The research was published in *Nature Physics* this week.

When a pebble is dropped into a pond, it creates ripples on the surface of the water that travel outwards in concentric circles. Similarly, the regions in the primordial plasma with the largest densities produced shells of [matter](#) (mostly protons and electrons) propagating outwards at almost, but not quite, the speed of light. This outward push of matter was created by the large number of high-energy photons in the early universe.

About 380,000 years after the Big Bang, when the [free electrons](#) were captured by protons to combine into electrically neutral hydrogen atoms, the spreading of these shells of matter stopped because the photons ceased to interact with the electrons. The resulting frozen shells of matter became the dense regions in which an excess of [galaxies](#) would eventually form. This predicts that an enhanced number of pairs of galaxies should be found at a separation of about 500 million light years, corresponding to the size of the frozen shells created in the early universe. In 2005, this effect was indeed observed for the first time in the distribution of galaxies measured by the Sloan Digital Sky Survey (SDSS).

## A neutrino effect

The presence of the cosmic neutrino background affects the picture described above in a subtle, but relevant way. After the neutrinos decoupled from the rest of the primordial matter, they started travelling at the speed of light, slightly faster than the rest of the matter. The shells of neutrinos therefore overtook the shells of matter. Consequently, the gravitational pull of the neutrinos slightly deformed the matter shells, creating small distortions in the seeds for the formation of galaxies at much later times. This influence of the cosmic neutrinos on the large-scale structure of the universe should be detectable by carefully analyzing the clustering of galaxies.

In their paper, Baumann and collaborators studied new SDSS data of about 1.2 million galaxies, out to a distance of about 6 billion [light years](#). Their [statistical analysis](#) confirms the expected signature of the bath of cosmic neutrinos that fills all of space. This new measurement constitutes an interesting confirmation of the standard cosmological model which links the production of [neutrinos](#) one second after the Big Bang to the clustering of galaxies billions of years later. [36]

## New theory illustrates the development of the universe may be different than we thought

The history of the universe is predicated on the idea that, compared to today, the universe was hotter and more symmetric in its early phase. Scientists have thought this because of the Higgs Boson finding—the particle that gives mass to all other fundamental particles. The concept is that as one analyzes time back toward the Big Bang, the universe gets hotter and the Higgs phase changes to one where everything became massless. Now, physicists are presenting a new theory that suggests an alternative history of the universe is possible.

The research, funded in part by the National Science Foundation and the Department of Energy, is led by Patrick Meade, Ph.D., Associate Professor in the C.N. Yang Institute for Theoretical Physics at Stony Brook University and his former Ph.D. student, Harikrishnan Ramani. The findings are published in the latest edition of *Physical Review Letters*.

The researchers propose a theory beyond the Standard Model of particle physics that describes how electroweak symmetry is not restored at high temperatures. If correct, this would lead to many potential consequences during the development of the universe, such as other phases of matter, particles staying massive in primordial plasma, and new possibilities for explaining the matter-antimatter asymmetry. The theory also highlights how the history of the universe could be very counterintuitive compared to many phenomenon on earth that demonstrate symmetry restoration. [35]

## Explaining a universe composed of matter

The universe consists of a massive imbalance between matter and antimatter. Antimatter and matter are actually the same, but have opposite charges, but there's hardly any antimatter in the observable universe, including the stars and other galaxies. In theory, there should be large amounts of antimatter, but the observable universe is mostly matter

"We're here because there's more matter than antimatter in the universe," says Professor Jens Oluf Andersen at the Norwegian University of Science and Technology's (NTNU) Department of Physics. This great imbalance between matter and antimatter is all tangible matter, including life forms, exists, but scientists don't understand why.

Physics uses a standard model to explain and understand how the world is connected. The standard model is a theory that describes all the particles scientists are familiar with. It accounts for quarks, electrons, the Higgs boson particle and how they all interact with each other. But the standard model cannot explain the fact that the world consists almost exclusively of matter. So there must be something we don't yet understand.

When antimatter and matter meet, they annihilate, and the result is light and nothing else. Given equal amounts of matter and antimatter, nothing would remain once the reaction was completed. As long as we don't know why more matter exists, we can't know why the building blocks of anything else exist, either. "This is one of the biggest unsolved problems in physics," says Andersen.

Researchers call this the "baryon asymmetry" problem. Baryons are subatomic particles, including protons and neutrons. All baryons have a corresponding antibaryon, which is mysteriously rare. The standard model of physics explains several aspects of the forces of nature. It explains how atoms become molecules, and it explains the particles that make up atoms.

"The standard model of physics includes all the particles we know about. The newest particle, the Higgs boson, was discovered in 2012 at CERN, says Andersen. With this discovery, an important piece fell into place. But not the final one. The standard model works perfectly to explain large parts of the universe, so researchers are intrigued when something doesn't fit. Baryon asymmetry belongs in this category.

Physicists do have their theories as to why there is more matter, and thus why we undeniably exist. "One theory is that it's been this way since the Big Bang," says Andersen. In other words, the imbalance between matter and antimatter is a basic precondition that has existed more or less from the beginning.

Quarks are among nature's smallest building blocks. An early surplus of quarks relative to antiquarks was propagated as larger units formed. But Andersen doesn't care for this explanation. "We're still not happy with that idea, because it doesn't tell us much," he says.

So why was this imbalance present from the beginning? Why did quarks initially outnumber antiquarks? "In principle, it's possible to generate asymmetry within the standard model of physics—that is, the difference between the amount of matter and antimatter. But we run into two problems," says Andersen.

First of all, scientists have to go way back in time, to just after the Big Bang when everything started—we're talking about 10 picoseconds, or  $10^{-11}$  seconds after the Big Bang.

The second problem is that temperatures have to be around 1 trillion degrees Kelvin, or  $10^{15}$  degrees. That's scorching—consider that the sun's surface is only about 5700 degrees. Regardless, it is not sufficient to explain baryonic matter. "It can't work. In the standard model, we

don't have enough matter," Andersen says. "The problem is that the jump in the expectation value of the Higgs field is too small," he adds for the benefit those with only a minimum grasp of physics.

"It's probably not just our imagination that's imposing limits, but lots of possibilities exist," says Andersen. These possibilities therefore need to work together with the standard model. "What we're really looking for is an extension of the standard model. Something that fits into it."

Neither he nor other physicists doubt that the standard model is right. The model is continuously tested at CERN and other particle accelerators. It's just that the model isn't yet complete. Andersen and his colleagues are investigating various possibilities for the model to fit with the imbalance between matter and antimatter. The latest results were recently published in *Physical Review Letters*.

"Actually, we're talking about phase transitions," says Andersen. His group is considering processes of change in matter, like water turning into steam or ice under changing conditions. They're also considering whether matter came about as a result of an electroweak phase transition (EWPT) and formed a surplus of baryons just after the Big Bang. The electroweak phase transition occurs by the formation of bubbles. The new phase expands, a bit like water bubbles, and takes over the entire universe.

Andersen and his colleagues tested the so-called "two Higgs doublet" model (2HDM), one of the simplest extensions of the standard model. They searched for possible areas where the right conditions are present to create matter. "Several scenarios exist for how the baryon asymmetry was created. We studied the electroweak phase transition using the 2HDM model. This phase transition takes place in the early stage of our universe," says Andersen.

The process is comparable to boiling water. When water reaches 100 degrees Celsius, gas bubbles form and rise up. These gas bubbles contain water vapour which is the gas phase. Water is a liquid. When it transitions from the gas phase to the liquid phase in the early universe during a process in which the universe expands and is cooled, a surplus of quarks is produced compared to antiquarks, generating the baryon asymmetry.

Last but not least, the researchers are also doing mathematics. In order for the models to work in sync, parameters or numerical values have to fit so that both models are right at the same time. So the work is about finding these parameters. In the most recent article in *Physical Review Letters*, Andersen and his colleagues narrowed down the mathematical area in which matter can be created and at the same time correspond to both models. They have now narrowed the possibilities.

"For the new model (2HDM) to match what we already know from CERN, for example, the parameters in the model can't be just anything. On the other hand, to be able to produce enough baryon asymmetry, the parameters also have to be within a certain range. So that's why we're trying to narrow the parameter range. But that's still a long way off," says Andersen. In any case, the researchers have made a bit of headway on the road to understanding why we and everything else are here. [34]

## Our universe has antimatter partner on the other side of the Big Bang, say physicists

Our universe could be the mirror image of an antimatter universe extending backwards in time before the Big Bang. So claim physicists in Canada, who have [devised a new cosmological model positing the existence of an “antiuniverse”](#) which, paired to our own, preserves a fundamental rule of physics called CPT symmetry. The researchers still need to work out many details of their theory, but they say it naturally explains the existence of dark matter.

Standard cosmological models tell us that the universe – space, time and mass/energy – exploded into existence some 14 billion years ago and has since expanded and cooled, leading to the progressive formation of subatomic particles, atoms, stars and planets.

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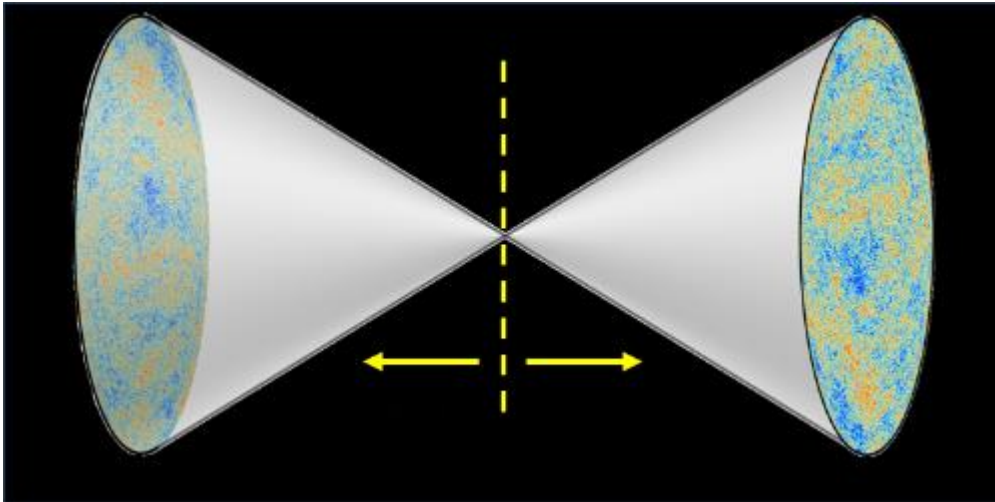
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However, [Neil Turok](#) of the [Perimeter Institute for Theoretical Physics](#) in Ontario reckons that these models’ reliance on ad-hoc parameters means they increasingly resemble Ptolemy’s description of the solar system. One such parameter, he says, is the brief period of rapid expansion known as inflation that can account for the universe’s large-scale uniformity. “There is this frame of mind that you explain a new phenomenon by inventing a new particle or field,” he says. “I think that may turn out to be misguided.”

Instead, Turok and his Perimeter Institute colleague [Latham Boyle](#) set out to develop a model of the universe that can explain all observable phenomena based only on the known particles and fields. They asked themselves whether there is a natural way to extend the universe beyond the Big Bang – a singularity where general relativity breaks down – and then out the other side. “We found that there was,” he says.

The answer was to assume that the universe as a whole obeys CPT symmetry. This fundamental principle requires that any physical process remains the same if time is reversed, space inverted and particles replaced by antiparticles. Turok says that this is not the case for the universe that we

see around us, where time runs forward as space expands, and there's more matter than antimatter.



[In a CPT-symmetric universe, time would run backwards from the Big Bang and antimatter would dominate \(Courtesy: L Boyle/Perimeter Institute of Theoretical Physics\)](#)

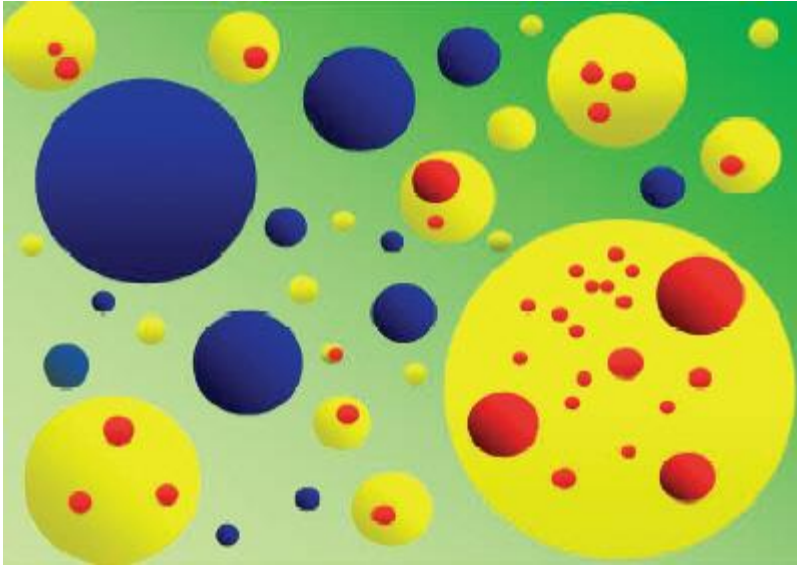
Instead, says Turok, the entity that respects the symmetry is a universe–antiuniverse pair. The antiuniverse would stretch back in time from the Big Bang, getting bigger as it does so, and would be dominated by antimatter as well as having its spatial properties inverted compared to those in our universe – a situation analogous to the creation of electron–positron pairs in a vacuum, says Turok.

Turok, who also collaborated with Kieran Finn of Manchester University in the UK, acknowledges that the model still needs plenty of work and is likely to have many detractors. Indeed, he says that he and his colleagues “had a protracted discussion” with the referees reviewing the paper for *Physical Review Letters* – where it [was eventually published](#) – over the temperature fluctuations in the cosmic microwave background. “They said you have to explain the fluctuations and we said that is a work in progress. Eventually they gave in,” he says.

In very broad terms, Turok says, the fluctuations are due to the quantum-mechanical nature of space–time near the Big Bang singularity. While the far future of our universe and the distant past of the antiuniverse would provide fixed (classical) points, all possible quantum-based permutations would exist in the middle. He and his colleagues counted the instances of each possible configuration of the CPT pair, and from that worked out which is most likely to exist. “It turns out that the most likely universe is one that looks similar to ours,” he says.

Turok adds that quantum uncertainty means that universe and antiuniverse are not exact mirror images of one another – which sidesteps thorny problems such as free will.





### Cyclic universe could explain cosmological constant

But problems aside, Turok says that the new model provides a natural candidate for dark matter. This candidate is an ultra-elusive, very massive particle called a “sterile” neutrino hypothesized to account for the finite (very small) mass of more common left-handed neutrinos. According to Turok, CPT symmetry can be used to work out the abundance of right-handed neutrinos in our universe from first principles. By factoring in the observed density of dark matter, he says that quantity yields a mass for the right-handed neutrino of about  $5 \times 10^8$  GeV – some 500 million times the mass of the proton.

Turok describes that mass as “tantalizingly” similar to the one derived from a couple of anomalous radio signals spotted by the Antarctic Impulsive Transient Antenna (ANITA). The balloon-borne experiment, which flies high over Antarctica, generally observes cosmic rays travelling down through the atmosphere. However, on two occasions ANITA appears to have detected particles travelling up through the Earth with masses between 2 and  $10 \times 10^8$  GeV. Given that ordinary neutrinos would almost certainly interact before getting that far, Thomas Weiler of Vanderbilt University and colleagues recently [proposed that the culprits were instead decaying right-handed neutrinos.](#)

Turok, however, points out a fly in the ointment – which is that the CPT symmetric model requires these neutrinos to be completely stable. But he remains cautiously optimistic. “It is possible to make these particles decay over the age of the universe but that takes a little adjustment of our model,” he says. “So we are still intrigued but I certainly wouldn’t say we are convinced at this stage.” [33]

## **NASA rings in New Year with historic flyby of faraway world**

NASA rang in the New Year on Tuesday with a historic flyby of the farthest, and quite possibly the oldest, cosmic body ever explored by humankind—a tiny, distant world called Ultima Thule—in the hopes of learning more about how planets took shape.

"Go New Horizons!" said lead scientist Alan Stern as a crowd including kids dressed in space costumes blew party horns and cheered at the Johns Hopkins Applied Physics Laboratory in Maryland to mark the moment at 12:33 am (0533 GMT) when the New Horizons spacecraft aimed its cameras at the space rock four billion miles (6.4 billion kilometers) away in a dark and frigid region of space known as the Kuiper Belt.

Offering scientists the first up-close look at an ancient building block of planets, the flyby took place about a billion miles beyond Pluto, which was until now the most faraway world ever visited up close by a spacecraft.

Real-time video of the actual flyby was impossible, since it takes more than six hours for a signal sent from Earth to reach the spaceship, and another six hours for the response to arrive.

The first signal back to Earth should come about 10 hours after the flyby, around 9:45 am (1445 GMT), letting NASA know if New Horizons survived the risky, high-speed encounter.

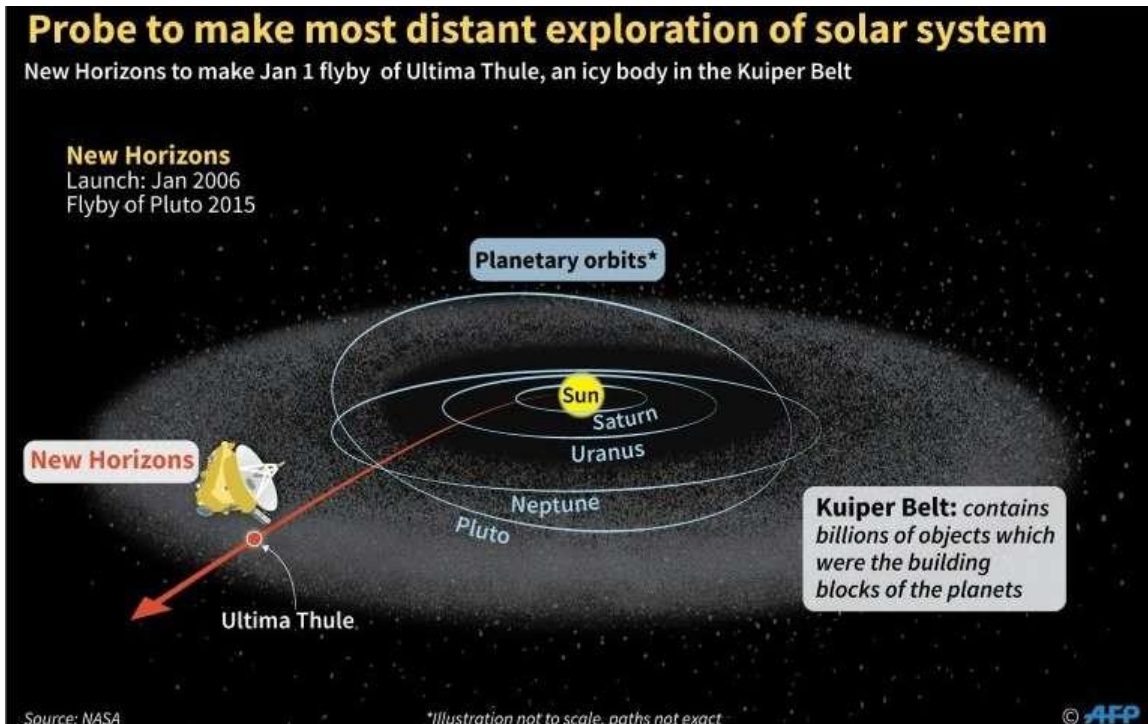
Hurling through space at a speed of 32,000 miles per hour, the spacecraft aimed to make its closest approach within 2,200 miles of the surface of Ultima Thule.

"This is a night none of us are going to forget," said Queen guitarist Brian May—who also holds an advanced degree in astrophysics—and who recorded a solo track to honor the spacecraft and its spirit of exploration.

Stern said Ultima Thule is unique because it is a relic from the early days of the solar system and could provide answers about the origins of other planets.

"The object is in such a deep freeze that it is perfectly preserved from its original formation," he said.

"Everything we are going to learn about Ultima—from its composition to its geology to how it was originally assembled, whether it has satellites and an atmosphere and those kinds of things—are going to teach us about the original formation conditions of objects in the solar system."



NASA's New Horizons spacecraft is heading for a January 1 flyby of Ultima Thule, an icy object in the Kuiper Belt on the outer limits of the solar system

### What does it look like?

Scientists are not sure what Ultima Thule (pronounced TOO-lee) looks like—whether it is cratered or smooth, or even if it is a single object or a cluster.

It was discovered in 2014 with the help of the Hubble Space Telescope, and is believed to be 12-20 miles in size.

A blurred and pixelated image released Monday, taken from 1.2 million miles away, has intrigued scientists because it appears to show an elongated blob, not a round space rock.

The spaceship was to collect 900 images over the course of a few seconds as it shaved by. Even clearer images should arrive over the next three days.

"Now it is just a matter of time to see the data coming down," said deputy project scientist John Spencer of the Southwest Research Institute.

Scientists decided to study Ultima Thule with New Horizons after the spaceship, which launched in 2006, completed its main mission of flying by Pluto in 2015, returning the most detailed images ever taken of the dwarf planet.

Stern said the goal is to take images of Ultima that are three times the resolution the team had for Pluto.

## Frontier of planetary science

Ultima Thule is named for a mythical, far-northern island in medieval literature and cartography, according to NASA.

Project scientist Hal Weaver of the Johns Hopkins Applied Physics Laboratory said humans didn't even know the Kuiper Belt—a vast ring of relics from the formation days of the solar system—existed until the 1990s.

"This is the frontier of planetary science," said Weaver.

"We finally have reached the outskirts of the solar system, these things that have been there since the beginning and have hardly changed—we think. We will find out."

Another NASA spacecraft, OSIRIS-REx, also set a new record on Monday by entering orbit around the asteroid Bennu, the smallest cosmic object—about 1,600 feet (500 meters) in diameter—ever circled by a spacecraft.

NASA said the orbit some 70 million miles (110 million kilometers) away marks "a leap for humankind" because no spacecraft has ever "circled so close to such a small space object—one with barely enough gravity to keep a vehicle in a stable orbit."

The twin planetary feats coincided with the 50th anniversary of the first time humans ever explored another world, when US astronauts orbited the Moon aboard Apollo 8 in December, 1968.

"As you celebrate New Year's Day, cast an eye upward and think for a moment about the amazing things our country and our species can do when we set our minds to it," Stern wrote in the New York Times on Monday. [32]

## When you look up, how far back in time do you see?

Our senses are stuck in the past. There's a flash of lightning, and then seconds pass until we hear the rumble of distant thunder. We hear the past.

We are seeing into the past too.

While sound travels about a kilometre every three seconds, light travels 300,000 kilometres every second. When we see a flash of lightning three kilometres away, we are seeing something that happened a hundredth of a millisecond ago. That's not exactly the distant past.

But as we look further afield, we can peer further back. We can see seconds, minutes, hours and years into the past with our own eyes. Looking through a telescope, we can look even further into the past.

## A second back in time

If you really want to look back in time, you need to look up.

The moon is our nearest celestial neighbour—a world with valleys, mountains and craters.

It's also about 380,000km away, so it takes 1.3 seconds for light to travel from the moon to us. We see the moon not as it is, but as it was 1.3 seconds ago.

The moon doesn't change much from instant to instant, but this 1.3-second delay is perceptible when mission control talks to astronauts on the moon. Radio waves travel at the speed of light, so a message from mission control takes 1.3 seconds to get to the moon, and even the quickest of replies takes another 1.3 seconds to come back.

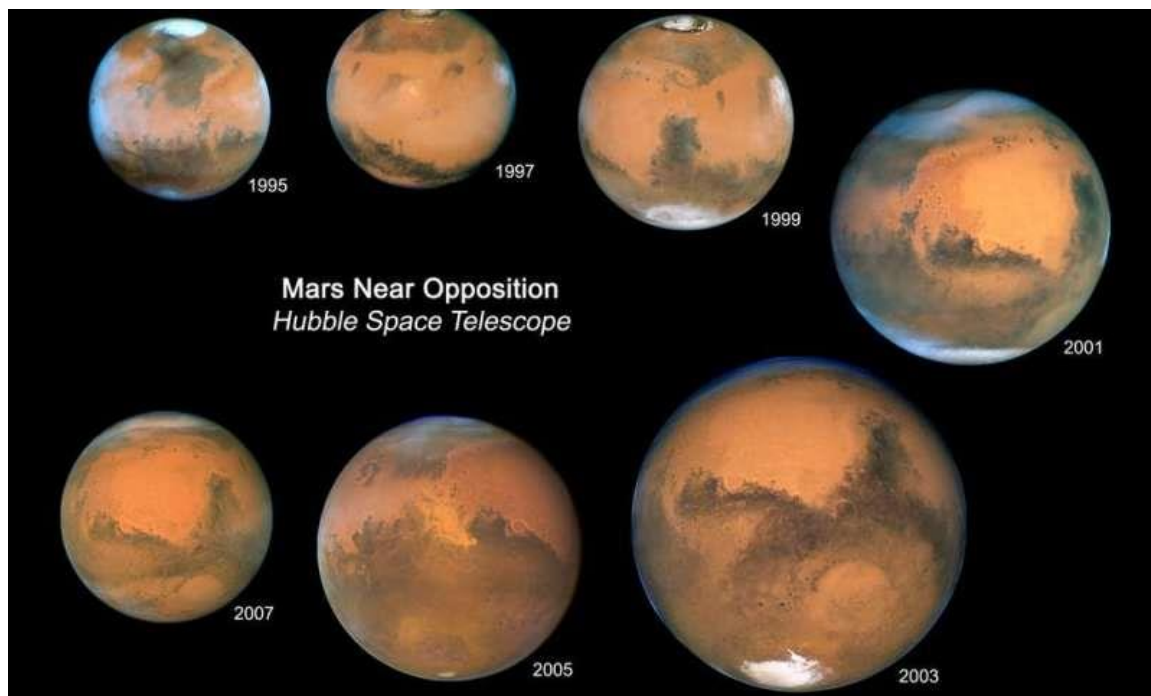
Radio communications to the moon have a perceptible time delay. **Minutes and hours**

It's not hard to look beyond the moon and further back in time. The Sun is about 150 million km away, so we see it as it was about 8 minutes ago.

Even our nearest planetary neighbours, Venus and Mars, are tens of millions of kilometres away, so we see them as they were minutes ago. When [Mars](#) is very close to Earth, we are seeing it as it was about three minutes ago, but at other times light takes more than 20 minutes to travel from Mars to Earth.

This presents some problems if you're [on Earth controlling a Rover on Mars](#). If you're driving the Rover at 1km per hour then the lag, due to the finite [speed of light](#), means the rover could be 200 metres ahead of where you see it, and it could travel another 200 metres after you command it to hit the brakes.

Not surprisingly, Martian Rovers aren't breaking any speed records, [travelling at 5cm per second \(0.18kph or 0.11mph\)](#), and on-board computers help with driving, to prevent rover wrecks.



The light travel time from Mars to Earth changes as the distance to Mars changes. Credit: [NASA](#), [ESA](#), and [Z. Levay \(STScI\)](#), [CC BY](#)

Not surprisingly, Martian Rovers aren't breaking any speed records, travelling at 5cm per second (0.18kph or 0.11mph), with rovers following carefully programmed sequences and using on-board computers to avoid hazards and prevent punctures.

Let's go a bit further out in space. At its closest to Earth, Saturn is still more than a billion kilometres away, so we see it as it was more than an hour ago.

When the world tuned into the Cassini spacecraft's plunge into Saturn's atmosphere in 2017, we were hearing echos from a spacecraft that had already been destroyed more than an hour before.

## Years

The night sky is full of stars, and those stars are incredibly distant. The distances are measured in light years, which corresponds to the distance travelled by light in one year. That's about 9 trillion km.

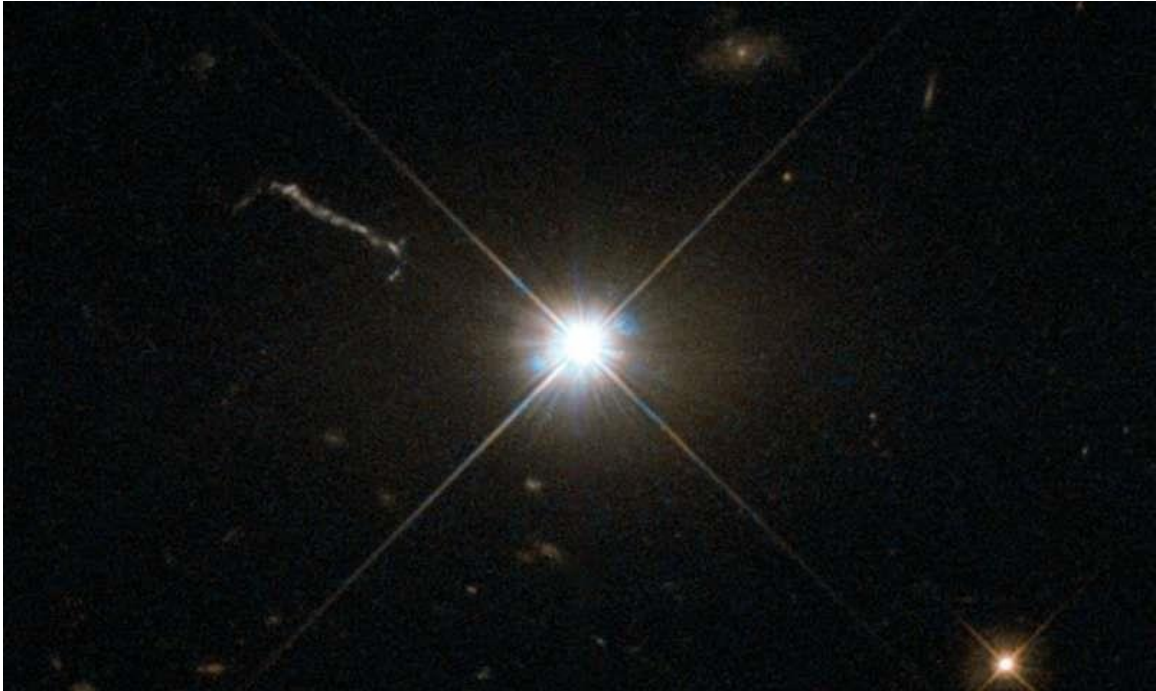
As light moves at finite speed, we can see bursts of light echo off interstellar dust. Alpha Centauri, the nearest star visible to the unaided eye, is at a distance 270,000 times the distance between Earth and the Sun. That's 4 light years, so we see Alpha Centauri as it was 4 years ago.

Some bright stars are much more distant still. Betelgeuse, in the constellation Orion, is about 640 light years away. If Betelgeuse exploded tomorrow (and it will explode one day), we wouldn't know about it for centuries.

Even without a telescope we can see much much further. The Andromeda galaxy and the Magellanic Clouds are relatively nearby galaxies that are bright enough to be seen with the unaided eye.

The Large Magellanic cloud is a mere 160,000 light years away, while Andromeda is 2.5 million light years away. For comparison, modern humans have only walked the Earth for about 300,000 years.





3C 273 can be seen with a small telescope despite being billions of light years away.

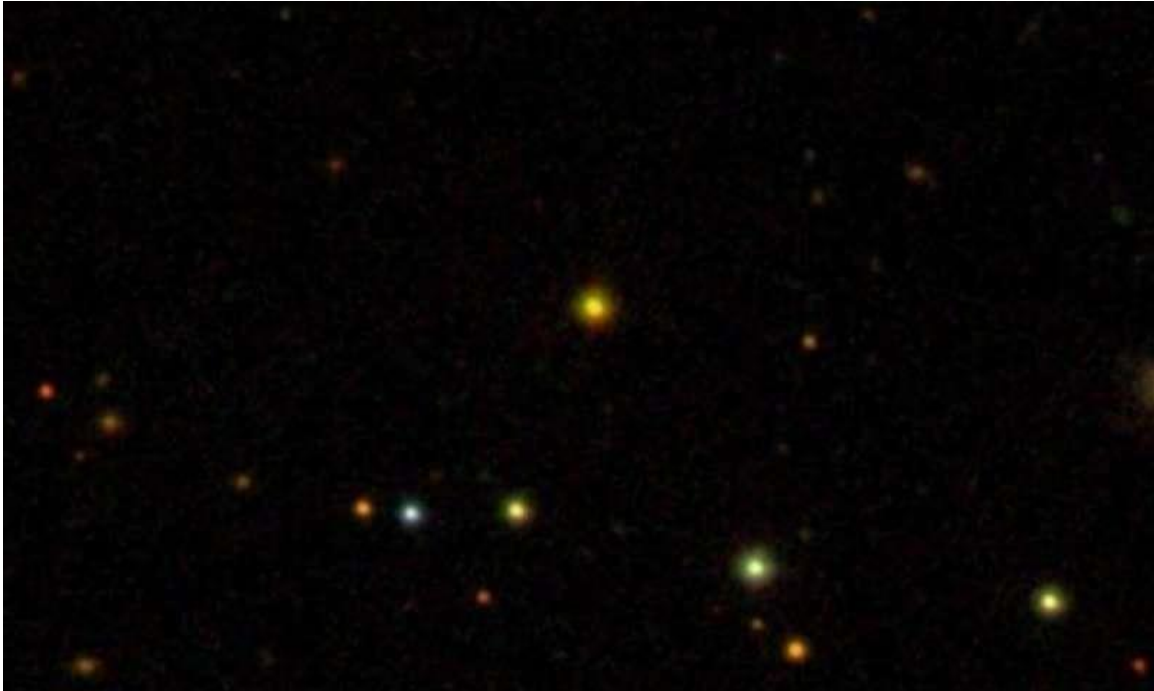
Credit: [ESA/Hubble & NASA](#), [CC BY](#)**Billions**

With the unaided eye you can look millions of years into the past, but how about billions? Well, you can do that at the eyepiece of an amateur telescope.

[Quasar 3C 273](#) is an incredibly luminous object, which is brighter than individual galaxies, and powered by a huge black hole.

But it's 1,000 times fainter than what the unaided eye can see because it's 2.5 billion light years away. That said, you can spot it with a 20cm aperture telescope.

A bigger telescope allows you to peer even further into space, and I once had the pleasure of using an eyepiece on a 1.5-metre diameter telescope. [Quasar APM 08279+5255](#) was just a faint dot, which isn't surprising as it's 12 billion [light](#) years away.



With a big enough telescope you can see quasar APM 08279+5255 and look 12 billion years back in time. Credit: [Sloan Digital Sky Survey](#), [CC BY](#)

Earth is just [4.5 billion years old](#), and even the universe itself is [13.8 billion years old](#). Relatively few people have seen APM 08279+5255 with their own eyes, and in doing so they (and I) have looked back across almost the entire history of our universe.

So when you look up, remember you aren't seeing things as they are now; you're seeing things as they were.

Without really trying, you can see years into the past. And with the aid of a telescope you can see millions or even billions of years into the past with your very own eyes. [31]

### **ESA sets clock by distant spinning stars**

ESA's technical centre in the Netherlands has begun running a pulsar-based clock. The "PulChron" system measures the passing of time using millisecond-frequency radio pulses from multiple fast-spinning neutron stars.

Operating since the end of November, this pulsar-based [timing](#) system is hosted in the Galileo Timing and Geodetic Validation Facility of ESA's ESTEC establishment, at Noordwijk in the Netherlands, and relies on ongoing observations by a five-strong array of radio telescopes across Europe.

Neutron stars are the densest form of observable matter in the cosmos, formed out of the collapsed core of exploding stars. Tiny in cosmic terms, on the order of a dozen kilometres in diameter, they still have a higher mass than Earth's Sun.



A pulsar is a type of rapidly rotating neutron star with a magnetic field that emits a beam of radiation from its pole. Because of their spin – kept steady by their extreme density – pulsars as seen from Earth appear to emit highly regular radio bursts – so much so that in 1967 their discoverer, UK astronomer Jocelyn Bell Burnell, initially considered they might be evidence of 'little green men.'

"PulChron aims to demonstrate the effectiveness of a pulsar-based timescale for the generation and monitoring of [satellite navigation](#) timing in general, and Galileo System Time in particular," explains navigation engineer Stefano Binda, overseeing the PulChron project.



Atomic clocks at ESTEC's Navigation Laboratory: the container on the far right of the image houses an active hydrogen maser atomic clock - an order of magnitude more accurate than the passive hydrogen masers aboard each Galileo satellite, ...[more](#)"A timescale based on pulsar measurements is typically less stable than one using atomic or optical clocks in the short term but it could be competitive in the very long term, over several decades or more, beyond the working life of any individual [atomic clock](#).

"In addition, this pulsar time scale works quite independently of whatever atomic clock technology is employed – it doesn't rely on switches between atomic energy states but the rotation of [neutron stars](#)."

PulChron sources batches of pulsar measurements from the five 100-m class radio telescopes comprising the European Pulsar Timing Array – the Westerbork Synthesis Radio Telescope in the Netherlands, Germany's Effelsberg Radio Telescope, the Lovell Telescope in the UK, France's Nancay Radio Telescope and the Sardinia Radio Telescope in Italy.

This multinational effort monitors 18 highly precise pulsars in the European sky to search out any timing anomalies, potential evidence of gravitational waves – fluctuations in the fabric of spacetime caused by powerful cosmic events.

For PulChron, these [radio telescope](#) measurements are used to steer the output of an active hydrogen maser atomic clock with equipment based in the Galileo Timing and Geodetic Validation Facility – combining its extreme short- and medium-term stability with the longer-term reliability of the pulsars. A 'paper clock' record is also generated out of the measurements, for subsequent post-processing checks.



Setup of the PulChron system, setting an atomic clock using millisecond-scale pulses from fast-spinning pulsars. Radio telescope measurements are used to steer the output of an active hydrogen maser atomic clock with equipment based in [...more](#)

ESA established the Timing and Geodetic Validation Facility in the early days of the Galileo programme, first to prepare for ESA's two GIOVE test satellites and then in support of the world-spanning Galileo system, based on 'Galileo System Time' which needs to remain accurate to a few billionths of a second. The Facility continues to serve as an independent yardstick of Galileo performance, linked to monitoring stations across the globe, as well as a tool for anomaly investigation.

Stefano adds: "The TGVF provided a perfect opportunity to host the PulChron because it is capable of integrating such new elements with little effort, and has a long tradition in time applications, having been used even to synchronise time and frequency offset of the Galileo satellites themselves."

PulChron's accuracy is being monitored down to a few billionths of a second using ESA's adjacent UTC Laboratory, which harnesses three such atomic hydrogen maser clocks plus a trio of caesium clocks to produce a highly-stable timing signal, contributing to the setting of Coordinated Universal Time, UTC – the world's time.

The gradual diversion of [pulsar](#) time from ESTEC's UTC time can therefore be tracked – anticipated at a rate of around 200 trillionths of a second daily. [30]

## **A virtual reality experience of being inside an exploded star**

Cassiopeia A, the youngest known supernova remnant in the Milky Way, is the remains of a star that exploded almost 400 years ago. The star was approximately 15 to 20 times the mass of our sun and sat in the Cassiopeia constellation, almost 11,000 light-years from earth.

Though stunningly distant, it's now possible to step inside a [virtual-reality](#) (VR) depiction of what followed that explosion.

A team led by Kimberly Kowal Arcand from the Harvard-Smithsonian Center for Astrophysics (CfA) and the Center for Computation and Visualization at Brown University has made it possible for astronomers, astrophysicists, space enthusiasts, and the simply curious to experience what it's like inside a dead star. Their efforts are described in a recent paper in *Communicating Astronomy with the Public*.

The VR project—believed to be the first of its kind, using X-ray data from NASA's Chandra X-ray Observatory mission (which is headquartered at CfA), infrared data from the Spitzer Space Telescope, and optical data from other telescopes—adds new layers of understanding to one of the most famous and widely studied objects in the sky.

"Our universe is dynamic and 3-D, but we don't get that when we are constantly looking at things" in two dimensions, said Arcand, the visualization lead at CfA.

The project builds on previous research done on Cas A, as it's commonly known, that first rendered the dead star into a 3-D model using the X-ray and optical data from multiple telescopes. Arcand and her team used that data to convert the model into a VR experience by using MinVR and VTK, two data visualization platforms. The coding work was primarily handled by Brown computer science senior Elaine Jiang, a co-author on the paper.

The VR experience lets users walk inside a colorful digital rendering of the stellar explosion and engage with parts of it while reading short captions identifying the materials they see.

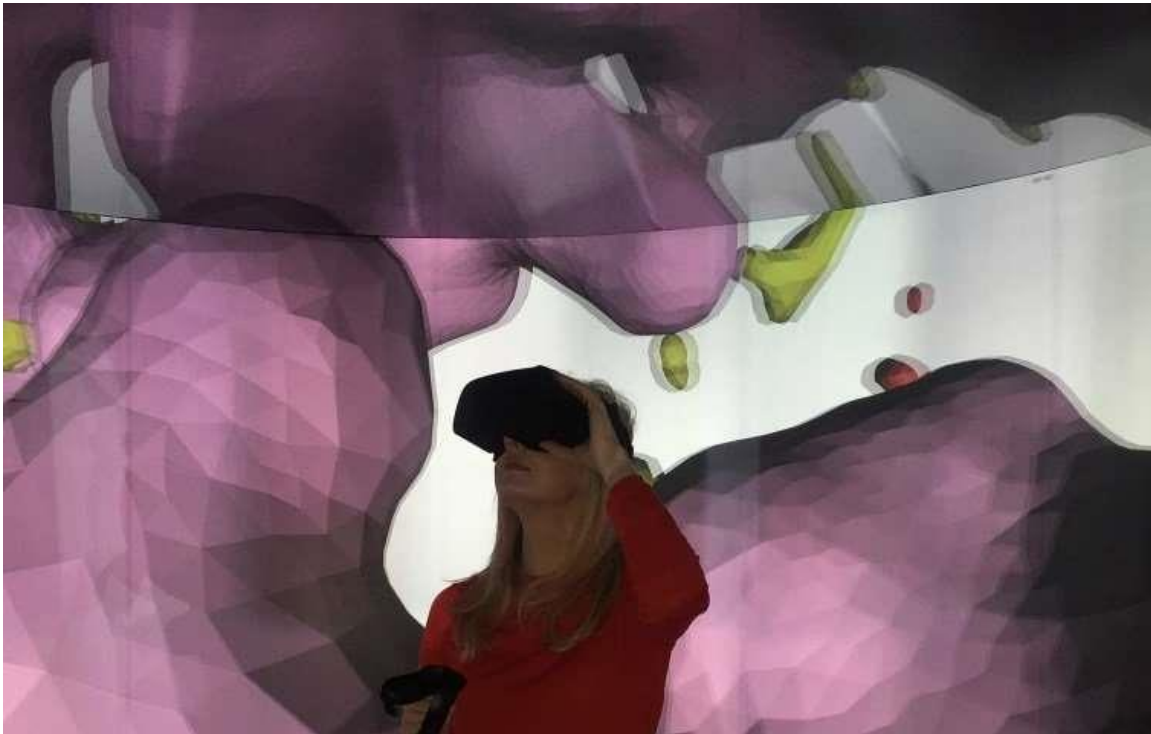
"Astronomers have long studied supernova remnants to better understand exactly how stars produce and disseminate many of the elements observed on Earth and in the cosmos at large," Arcand said.

When stars explode, they expel all of their elements into the universe. In essence, they help create the elements of life, from the iron in our blood to the calcium in our bones. All of that, researchers believe, comes from previous generations of exploded [stars](#).

In the 3-D model of Cas A, and now in the VR model, elements such as iron, silicon, and sulfur are represented by different colors. Seeing it in 3-D throws Cas A into fresh perspective, even for longtime researchers and astronomers who build models of supernova explosions.

"The first time I ever walked inside the same data set that I have been staring at for 20 years, I just immediately was fascinated by things I had never noticed, like how various bits of the iron were in different locations," Arcand said. "The ability to look at something in three dimensions and being immersed in it just kind of opened up my eyes to think about it in different ways."

The VR platforms also opens understanding of the supernova remnant, which is the strongest radio source beyond our solar system, to new audiences. VR versions of Cas A are available by request for a VR cave (a specially made room in which the floors and walls are projection screens), as well as on Oculus Rift, a VR computer platform. As part of this project, the team also created a version that works with Google Cardboard or similar smartphone platforms. In a separate but related project, Arcand and a team from CfA worked with the Smithsonian Learning Lab to create a browser-based, interactive, 3-D application and 360-degree video of Cas A that works with Google Cardboard and similar platforms.



Wearing VR goggles Kim Arcand views a 3-D representation of the Cassiopeia A supernova remnant at the YURT VR Cave at Brown. Credit: NASA/CXC/SAO; NASA/CXC/E.Jiang "My whole career has been looking at data and how we take data and make it accessible or visualize it in a way that adds meaning to it that's still scientific," Arcand said.

VR is an almost perfect avenue for this approach, since it has been surging in popularity as both entertainment and an educational tool. It has been used to help medical staff prepare for surgeries, for example, and video game companies have used it to add excitement and immersion to popular games.

Arcand hopes to make Cas A accessible to even more people, such as the visually impaired, by adding sound elements to the colors in the model.

Reaction to the VR experience has been overwhelmingly positive, Arcand said. Experts and non-experts alike are hit by what Arcand calls "awe moments" of being inside and learning about something so massive and far away.

"Who doesn't want to walk inside a dead star?" Arcand said. [29]

## **New source of very high energy gamma-ray emission detected in the neighborhood of the supernova remnant G24.7+0.6**

Using MAGIC telescopes and NASA's Fermi spacecraft, an international team of astronomers has discovered a new source of very high energy gamma-ray emission around the supernova remnant (SNR) G24.7+0.6. The detection of the new source, designated MAGIC J1835–069, is detailed in a paper published December 12 on the arXiv pre-print server.

Supernova remnants are basically leftovers of massive stars that ended their lives in huge explosions called supernovae. Astronomers generally distinguish three types of SNRs, one of which is the composite SNR—these having rapidly expanding shells from the supernova blast wave accompanied by wind nebulae powered by young pulsars formed in the explosions.

Observations show that composite SNRs are known to accelerate particles to very high energies (VHE), up to hundreds of TeV or beyond, in their expanding shocks or the relativistic wind surrounding the energetic pulsar. Therefore, such objects are excellent targets for observations focused on finding new sources of VHE [emission](#).

Located about 16,300 light years away, SNR G24.7+0.6 is an example of a middle-aged (around 9,500 years old) radio and gamma-ray composite SNR. A group of astronomers have carried out a study of this remnant using the MAGIC (Major Atmospheric Gamma Imaging Cherenkov Telescopes) system at the Roque de los Muchachos Observatory in the Canary Islands and the Large Area Telescope (LAT) onboard NASA's Fermi Gamma-ray Space Telescope.

Data provided by these telescopes allowed the team to identify a VHE emission from an extended source located 0.34 degrees away from the center of G24.7+0.6, which received designation MAGIC J1835–069.

"In this paper, we study the interesting region centered around SNR G24.7+0.6 with Fermi-LAT in the energy range between 60 MeV and 500 GeV. We also explore with the MAGIC telescopes the region around it to investigate the spectral behavior above 150 GeV in order to constrain the emission region observed by Fermi-LAT around the SNR," the researchers wrote in the paper.

The emission from MAGIC J1835–069 was found at energies above 150 GeV and has been detected up to 5 TeV. The spectrum of this source is well-represented by a power-law function with spectral index of 2.74.

The emission from MAGIC J1835–069 also has a projected size of approximately 98 [light years](#) and showcases an extended morphology. The newly found source lies between two known extended



sources detected above 10 GeV by Fermi-LAT, namely FGES J1836.5–0652 and the FGES J1834.1–0706.

The origin of VHE gamma-ray emission from MAGIC J1835–069 remains uncertain due to the complexity of the neighboring region of G24.7+0.6. However, the authors of the paper suggest that it could be explained by cosmic rays accelerated within the remnant interacting via [proton-proton collisions](#) with the carbon monoxide-rich surrounding medium.

"The detected gamma-ray emission can be interpreted as the results of proton-proton interaction between the supernova and the CO-rich surrounding," the researchers concluded. [28]

## **New insights into pion condensation and the formation of neutron stars**

In 1973, Russian physicist A.B. Migdal predicted the phenomenon of pion condensation above a critical, extremely high—several times higher than that for normal matter— nuclear density. Although this condensation has never been observed, it is expected to play a key role in the rapid cooling process of the core of neutron stars. These city-size heavy stellar objects are so dense that on Earth, one teaspoonful would weigh a billion tons.

Recently, researchers from the RIKEN Nishina Center for Accelerator-Based Science and Kyushu University, performing an experiment at the RIKEN RI Beam Factory on a very [neutron-rich](#) tin isotope, investigated whether this process could really occur in neutron stars having the mass of about 1.4 times that of our sun. Similar investigations were conducted previously on [stable isotopes](#), such as  $^{90}\text{Zr}$  or  $^{208}\text{Pb}$ , but this time the researchers decided to study the case of  $^{132}\text{Sn}$ , an isotope of tin. This doubly magic unstable nucleus has a fairly simple structure that makes the theoretical calculations easily compared to other [isotopes](#) with similar mass. Furthermore,  $^{132}\text{Sn}$  with its large neutron excess (it consists of 50 protons and 82 neutrons) provides better conditions than the stable isotopes for extending this study toward the pure neutron matter in the [neutron stars](#).

A secondary cocktail beam containing  $^{132}\text{Sn}$  was produced by projectile fragmentation of a uranium primary beam colliding with thick a beryllium target. Then, a liquid hydrogen target was irradiated with  $^{132}\text{Sn}$ . Resulting in the collective excitation of the neutrons and protons of the tin nuclei, with the neutron spin and proton spin oscillating out of phase. This excitation mode, called "giant resonance," is suitable for studying the short-range interactions that, while being crucial in the onset of pion [condensation](#), are complex and extremely difficult to measure.

According to Masaki Sasano from RIKEN Nishina Center, who is one of the first authors of this study, their result, which was published in the *Physical Review Letters* journal, shows that the pion condensation should occur at around two times normal nuclear density, which can be realized in a neutron star with a mass of 1.4 times that of the sun. Sasano said that in order to understand the possibility of the pion condensation fully, they plan to extend these unique studies of giant resonances to other neutron-rich nuclei that are far beyond the stability line, having large neutron-proton asymmetry. [27]

## Beyond the black hole singularity

Our first glimpses into the physics that exist near the center of a black hole are being made possible using "loop quantum gravity"—a theory that uses quantum mechanics to extend gravitational physics beyond Einstein's theory of general relativity. Loop quantum gravity, originated at Penn State and subsequently developed by a large number of scientists worldwide, is opening up a new paradigm in modern physics. The theory has emerged as a leading candidate to analyze extreme cosmological and astrophysical phenomena in parts of the universe, like black holes, where the equations of general relativity cease to be useful.

Previous work in loop quantum gravity that was highly influential in the field analyzed the quantum nature of the Big Bang, and now two new papers by Abhay Ashtekar and Javier Olmedo at Penn State and Parampreet Singh at Louisiana State University extend those results to black hole interiors. The papers appear as "Editors' suggestions" in the journals *Physical Review Letters* and *Physical Review* on December 10, 2018 and were also highlighted in a Viewpoint article in the journal *Physics*.

"The best theory of gravity that we have today is general relativity, but it has limitations," said Ashtekar, Evan Pugh Professor of Physics, holder of the Eberly Family Chair in Physics, and director of the Penn State Institute for Gravitation and the Cosmos. "For example, general relativity predicts that there are places in the universe where gravity becomes infinite and space-time simply ends. We refer to these places as 'singularities.' But even Einstein agreed that this limitation of general relativity results from the fact that it ignores quantum mechanics."

At the center of a black hole the gravity is so strong that, according to general relativity, space-time becomes so extremely curved that ultimately the curvature becomes infinite. This results in space-time having a jagged edge, beyond which physics no longer exists—the singularity. Another example of a singularity is the Big Bang. Asking what happened before the Big Bang is a meaningless question in general relativity, because space-time ends, and there is no before. But modifications to Einstein's equations that incorporated quantum mechanics through loop quantum gravity allowed researchers to extend physics beyond the Big Bang and make new predictions. The two recent papers have accomplished the same thing for the black hole singularity.

"The basis of loop quantum gravity is Einstein's discovery that the geometry of space-time is not just a stage on which cosmological events are acted out, but it is itself a physical entity that can be bent," said Ashtekar. "As a physical entity the geometry of space-time is made up of some fundamental units, just as matter is made up of atoms. These units of geometry—called 'quantum excitations'—are orders of magnitude smaller than we can detect with today's technology, but we have precise quantum equations that predict their behavior, and one of the best places to look for their effects is at the center of a black hole." According to general relativity, at the center of a black hole gravity becomes infinite so everything that goes in, including the information needed for physical calculations, is lost. This leads to the celebrated 'information paradox' that theoretical physicists have been grappling with for over 40 years. However, the quantum corrections of loop quantum gravity allow for a repulsive force that can overwhelm even the strongest pull of classical gravity and therefore physics can continue to exist. This opens an avenue to show in detail

that there is no loss of information at the center of a blackhole, which the researchers are now pursuing.

Interestingly, even though [loop quantum gravity](#) continues to work where general relativity breaks down—black hole singularities, the Big Bang—its predictions match those of general relativity quite precisely under less extreme circumstances away from the singularity. "It is highly non-trivial to achieve both," said Singh, associate professor of physics at Louisiana State. "Indeed, a number of investigators have explored the quantum nature of the black hole singularity over the past decade, but either the singularity prevailed or the mechanisms that resolved it unleashed unnatural effects. Our new work is free of all such limitations." [26]

## Will we ever see a black hole?

In the shadowy regions of black holes two fundamental theories describing our world collide. Can these problems be resolved and do black holes really exist? First, we may have to see one and scientists are trying to do just this.

Of all the forces in physics there is one that we still do not understand at all: Gravity.

Gravity is where fundamental physics and astronomy meet, and where the two most fundamental theories describing our world—quantum theory and Einstein's theory of spacetime and gravity (aka. the theory of general relativity) – clash head on.

The two theories are seemingly incompatible. And for the most part this isn't a problem. They both live in distinct worlds, where quantum physics describes the very small, and general relativity describes the very largest scales.

Only when you get to very small scales and extreme gravity, do the two theories collide, and somehow, one of them gets it wrong. At least in theory.

But there is once place in the universe where we could actually witness this problem occurring in real life and perhaps even solve it: the edge of a black hole. Here, we find the most extreme gravity. There's just one issue – nobody has ever actually 'seen' a black hole.

## So, what is a black hole?

Imagine that the entire drama of the physical world unfolds in the theatre of spacetime, but gravity is the only 'force' that actually modifies the theatre in which it plays.

The force of gravity rules the universe, but it may not even be a force in the traditional sense. Einstein described it as a consequence of the deformation of spacetime. And perhaps it simply does not fit the standard model of particle physics.

When a very big star explodes at the end of its lifetime, its innermost part will collapse under its own gravity, since there is no longer enough fuel to sustain the pressure working against the force of gravity (yes, gravity feels like a force after all, doesn't it!).

The matter collapses and no force in nature is known to be able to stop that collapse, ever.



In an infinite time, the star will have collapsed into an infinitely small point: a singularity – or to give it another name, a black hole.

Of course, in a finite time the stellar core will have collapsed into something of a finite size and this would still be a huge amount of mass in an insanely small region and it still is called a black hole!

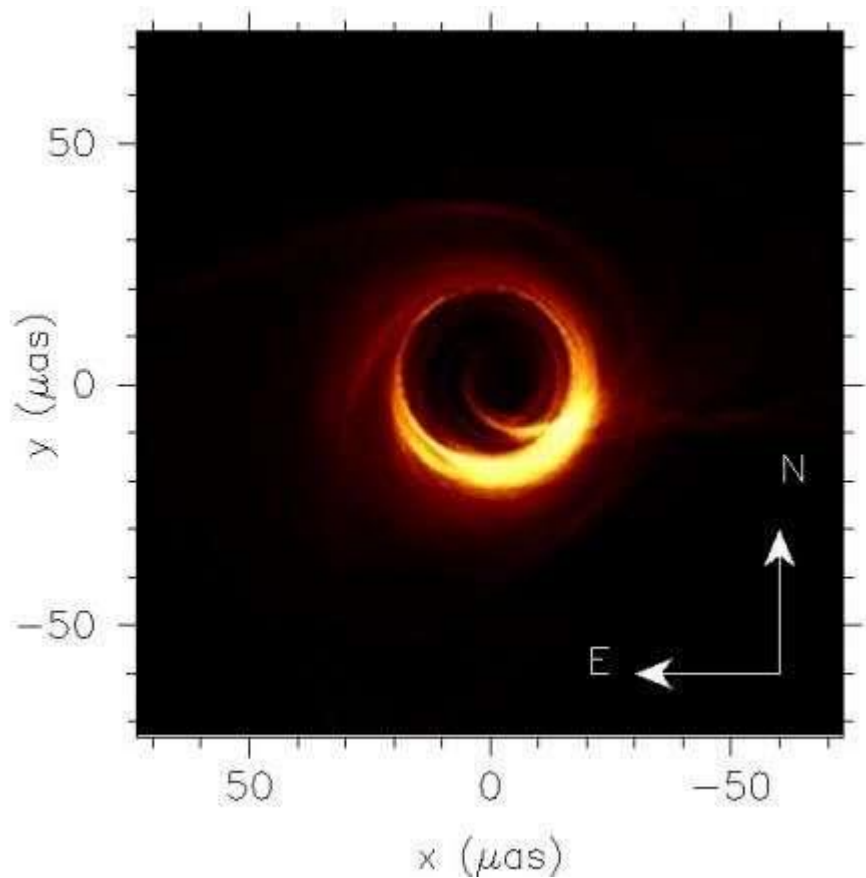
### **Black holes do not suck in everything around them**

Interestingly, it is not true that a black hole will inevitably draw everything in.

In fact, whether you are orbiting a star or a black hole that formed from a star, it does not make a difference, so long as the mass is the same. The good old centrifugal force and your angular momentum will keep you safe and stop you from falling in.

Only when you fire your giant rocket thrusters to brake your rotation, will you start falling inwards.

However, once you fall towards a black hole you will be accelerated to higher and higher speeds, until you eventually reach the speed of light.



Simulated image as predicted for the supermassive black in the galaxy M87 at the frequencies observed with the Event Horizon Telescope (230 GHz). Credit: Moscibrodzka, Falcke, Shiokawa, *Astronomy & Astrophysics*, V. 586, p. 15, 2016, reproduced with permission © ESO

## Why are quantum theory and general relativity incompatible?

At this point everything goes wrong as, according to general relativity, nothing should move faster than the speed of light.

Light is the substrate used in the quantum world to exchange forces and to transport information in the macro world. Light determines how fast you can connect cause and consequences.

If you go faster than light, you could see events and change things before they happen. This has two consequences:

At the point where you reach the speed of light while falling inwards, you would also need to fly out at the speed of light to escape that point, which seems impossible. Hence, conventional physical wisdom will tell you that nothing can escape a black hole, once it has passed that point, which we call the "event horizon."

It also means that suddenly basic principles of quantum information preservation are brutally violated – conserved quantum quantities can simply disappear behind a wall of silence.

Whether that is true and whether and how the theory of gravity (or of quantum physics) needs to be modified is a question of intense debate among physicists, and none of us can say which way the argument will lead in the end.

## Do black holes even exist?

Of course, all this excitement would only be justified, if black holes really existed in this universe. So, do they?

In the last century strong evidence has mounted that certain binary stars with intense X-ray emissions are in fact stars collapsed into black holes.

Moreover, in the centres of galaxies we often find evidence for huge, dark concentrations of mass. These might be supermassive versions of black holes, possibly formed through the merger of many stars and gas clouds that have sunk into the centre of a galaxy.

The evidence is convincing, but circumstantial. At least gravitational waves have let us 'hear' the merger of black holes, but the signature of the event horizon is still elusive and so far, we have never actually 'seen' a black hole – they simply tend to be too small and too far and, in most cases, yes, black...

## So, what would a black hole actually look like?

If you could look straight into a black hole you would see the darkest dark, you can imagine.

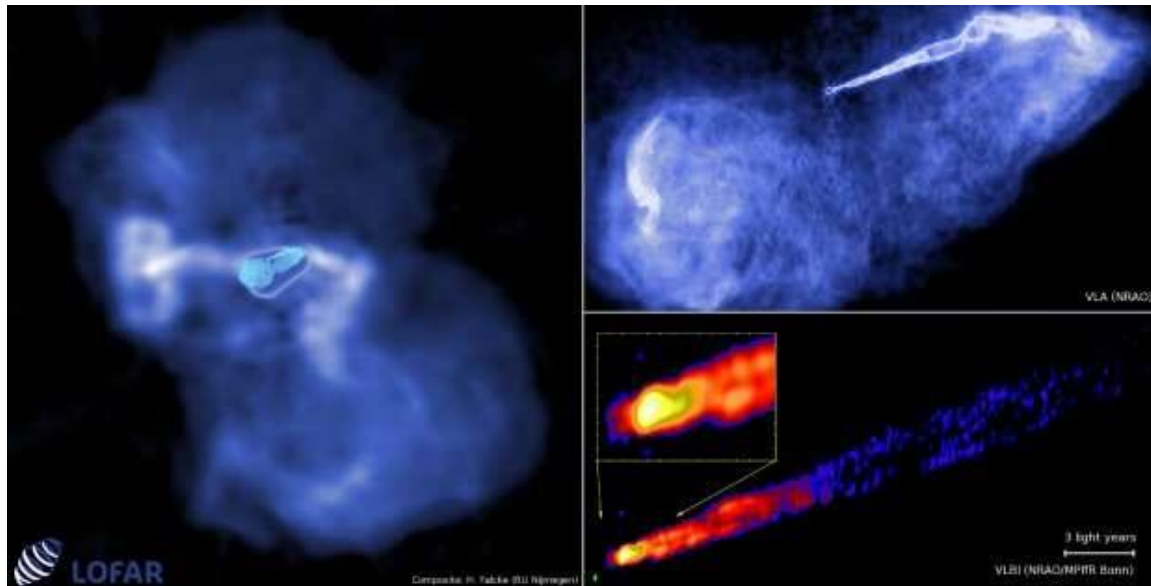
But, the immediate surroundings of a black hole could be bright as gasses spiral inwards –slowed down by the drag of magnetic fields they carry along.

Due to the magnetic friction the gas will heat up to enormous temperatures of up to several tens of billion degrees and start to radiate UV-light and X-rays.

Ultra-hot electrons interacting with the magnetic field in the gas will start producing intense radio emission. Thus, black holes can glow and could be surrounded by a ring of fire that radiates at many different wavelengths.

### A ring of fire with a dark, dark centre

In their very centre, however, the event horizon still lurks and like a bird of prey it catches every photon that gets too close.



Radio images of the jet in the radio galaxy M87 – observed at lower resolution. The left frame is roughly 250,000 light years across. Magnetic fields threading the supermassive black holes lead to the formation of a highly collimated jet ...[more](#)

Since space is bent by the enormous mass of a black hole, light paths will also be bent and even form into almost concentric circles around the black hole, like serpentine around a deep valley. This effect of circling light was calculated already in 1916 by the famous Mathematician David Hilbert only a few months after Albert Einstein finalised his theory of general relativity.

After orbiting the black hole multiple times, some of the light rays might escape while others will end up in the event horizon. Along this complicated light path, you can literally look into the black hole. The nothingness you see is the event horizon.

If you were to take a photo of a black hole, what you would see would be akin to a dark shadow in the middle of a glowing fog of light. Hence, we called this feature the shadow of a black hole .

Interestingly, the shadow appears larger than you might expect by simply taking the diameter of the event horizon. The reason is simply, that the black hole acts as a giant lens, amplifying itself.

Surrounding the shadow will be a thin 'photon ring' due to light circling the black hole almost forever. Further out, you would see more rings of light that arise from near the event horizon, but tend to be concentrated around the black hole shadow due to the lensing effect.

## Fantasy or reality?

Is this pure fantasy that can only be simulated in a computer? Or can it actually be seen in practice? The answer is that it probably can.

There are two relatively nearby supermassive black holes in the universe which are so large and close, that their shadows could be resolved with modern technology.

These are the black holes in the center of our own Milky Way at a distance of 26,000 lightyears with a mass of 4 million times the mass of the sun, and the black hole in the giant elliptical galaxy M87 (Messier 87) with a mass of 3 to 6 billion solar masses.

M87 is a thousand times further away, but also a thousand times more massive and a thousand times larger, so that both objects are expected to have roughly the same shadow diameter projected onto the sky.

## Like seeing a grain of mustard in New York from Europe

Coincidentally, simple theories of radiation also predict that for both objects the emission generated near the event horizon would be emitted at the same radio frequencies of 230 GHz and above.

Most of us come across these frequencies only when we have to pass through a modern airport scanner but some black holes are continuously bathed in them.

The radiation has a very short wavelength of about one millimetre and is easily absorbed by water. For a telescope to observe cosmic millimetre waves it will therefore have to be placed high up, on a dry mountain, to avoid absorption of the radiation in the Earth's troposphere.

Effectively, you need a millimetre-wave telescope that can see an object the size of a mustard seed in New York from as far away as Nijmegen in the Netherlands. That is a telescope a thousand times sharper than the Hubble Space Telescope and for millimetre-waves this requires a telescope the size of the Atlantic Ocean or larger.

## A virtual Earth-sized telescope

Fortunately, we do not need to cover the Earth with a single radio dish, but we can build a virtual [telescope](#) with the same resolution by combining data from telescopes on different mountains across the Earth.

The technique is called Earth rotation synthesis and very long baseline interferometry (VLBI). The idea is old and has been tested for decades already, but it is only now possible at high radio frequencies.

# The Event Horizon Telescope Network



Layout of the Event Horizon Telescope connecting radio telescopes around the world (JCMT & SMA in Hawaii, AMTO in Arizona, LMT in Mexico, ALMA & APEX in Chile, SPT on the South Pole, IRAM 30m in Spain). The red lines are to a proposed [...more](#)

The first successful experiments have already shown that event horizon structures can be probed at these frequencies. Now high-bandwidth digital equipment and large telescopes are available to do this experiment on a large scale.

## Work is already underway

I am one of the three Principal Investigators of the BlackHoleCam project. BlackHoleCam is an EU-funded project to finally image, measure and understand astrophysical black holes. Our European project is part of a global collaboration known as the Event Horizon Telescope consortium – a collaboration of over 200 scientists from Europe, the Americas, Asia, and Africa. Together we want to take the first picture of a black hole.

In April 2017 we observed the Galactic Center and M87 with eight telescopes on six different mountains in Spain, Arizona, Hawaii, Mexico, Chile, and the South Pole.

All telescopes were equipped with precise atomic clocks to accurately synchronise their data. We recorded multiple petabytes of raw data, thanks to surprisingly good weather conditions around the globe at the time.

We are all excited about working with this data. Of course, even in the best of all cases, the images will never look as pretty as the computer simulations. But, at least they will be real and whatever we see will be interesting in its own right.

To get even better images telescopes in Greenland and France are being added. Moreover, we have started raising funds for additional telescopes in Africa and perhaps elsewhere and we are even thinking about telescopes in space.

### **A 'photo' of a black hole**

If we actually succeed in seeing an event horizon, we will know that the problems we have in rhyming [quantum theory](#) and general relativity are not abstract problems, but are very real. And we can point to them in the very real shadowy regions of black holes in a clearly marked region of our universe.

This is perhaps also the place where these problems will eventually be solved.

We could do this by obtaining sharper images of the shadow, or maybe by tracing stars and pulsars as they orbit around black holes, through measuring spacetime ripples as black holes merge, or as is most likely, by using all of the techniques that we now have, together, to probe black holes.

### **A once exotic concept is now a real working laboratory**

As a student, I wondered what to study: particle physics or astrophysics? After reading many popular science articles, my impression was that particle physics had already reached its peak. This field had established an impressive standard model and was able to explain most of the forces and the particles governing our world.

Astronomy though, had just started to explore the depths of a fascinating universe. There was still a lot to be discovered. And I wanted to discover something.

In the end, I chose astrophysics as I wanted to understand gravity. And since you find the most extreme gravity near [black holes](#), I decided to stay as close to them as possible.

Today, what used to be an exotic concept when I started my studies, promises to become a very real and very much visible physics laboratory in the not too distant future. [25]

## **Researchers have created a virtual reality simulation of a supermassive black hole**

The black hole at the centre of our galaxy, Sagittarius A\*, has been visualised in virtual reality for the first time. The details are described in an article published in the open access journal *Computational Astrophysics and Cosmology*.

Scientists at Radboud University, The Netherlands and Goethe University, Germany used recent astrophysical models of Sagittarius A\* to create a series of images that were then put together to create a 360 degree [virtual reality](#) simulation of the black hole, that can be viewed on widely available VR consoles. The authors suggest that this virtual reality simulation could be useful for studying [black holes](#).

Jordy Davelaar, corresponding author, said: "Our virtual reality simulation creates one of the most realistic views of the direct surroundings of the black hole and will help us to learn more about how black holes behave. Traveling to a black hole in our lifetime is impossible, so immersive visualizations like this can help us understand more about these systems from where we are."

The authors also suggest that the virtual reality [simulation](#) could help encourage the general public, including children, to take an interest in astrophysics.

Davelaar said: "The visualisations that we produced have a great potential for outreach. We used them to introduce children to the phenomenon of black holes, and they really learned something from it. This suggests that immersive virtual reality visualizations are a great tool to show our work to a broader audience, even when it involves very complicated systems like black holes."

Heino Falcke, Professor at Radboud University adds: "We all have a picture in our head of how black holes supposedly look, but science has progressed and we can now make much more accurate renderings—and these black holes look quite different from what we are used to. These new visualisations are just the start, more to come in the future." [24]

## **Black holes play hide-and-peek in low-luminosity radio galaxies**

Every galaxy is thought to harbor a supermassive black hole in the center, or nucleus, of the galaxy, and in active galaxies this black hole is fed by infalling matter. This "central engine" is typically surrounded by dusty molecular gas in a doughnut configuration, which hides the black hole and the infalling material from our view along certain viewing directions. The picture of a central engine plus obscuring doughnut is thought to apply to all accreting supermassive black holes, explaining the apparent variety of active galaxies from the very brightest quasars to the lower-luminosity radio galaxies under a single "unified scheme."

However, it has long been known that the weaker [radio galaxies](#) have properties inconsistent with this model, lacking evidence for bright accretion structures and obscuring doughnuts, leading to suggestions that either their black holes or their gas infall mechanisms might be unique. New results from researchers at the University of Manitoba, presented today at the 2018 annual meeting of the Canadian Astronomical Society, show that up to one-third of weak radio [galaxies](#) may in fact have glowing infalling gas with their black holes hidden by dusty doughnuts that shine in the infrared.

To discern this, R. Gleisner, C. O'Dea, J. Gallimore, S. Baum, and S. Wykes fit the Infrared spectrum of a sample of weak radio galaxies with several components including stars, gas, dust, and a dusty torus using special techniques. They found that one-third of the radio galaxies show the classic central engines with accretion structures and doughnuts. They suggest that for the weaker [active galaxies](#), the properties of the central engine are changing dramatically and rapidly. While the [black holes](#) in these galaxies are typically on a diet with low feeding rates, they may periodically go on an occasional binge during which a much larger mass of gas flows into the central black hole causing the creation of the standard bright accretion structure and obscuring torus. [23]



## Tumultuous galaxy mergers better at switching on black holes

A new study by researchers at the University of Colorado Boulder finds that violent crashes may be more effective at activating black holes than more peaceful mergers.

When two galaxies collide, the supermassive black holes that sit at their centers also smash together. But before they do, these galaxies often flicker on, absorbing huge quantities of gas and dust and producing a bright display called an Active Galactic Nucleus (AGN).

But not all mergers are created equal. In some such marriages, only one black hole becomes active, while in others, both do.

The research team led by CU Boulder's Scott Barrows discovered that single activations seem to occur more often in mergers in which the galaxies are mismatched—or when one galaxy is huge and the other puny.

When lopsided galaxies join, "the merger is less violent, and that leads to less gas and dust falling onto the black holes," said Barrows, a postdoctoral research associate in the Center for Astrophysics and Space Astronomy (CASA). "And the less material you have falling onto the black holes, the less likely you are to have two of them become AGNs."

The researchers presented their findings today at a press briefing at the 232nd meeting of the American Astronomical Society, which runs from June 3-7 in Denver, Colorado.

Barrows and his colleagues used data collected by the Chandra X-ray Observatory to systematically scan the night sky for the signatures of AGNs. They spotted mergers in progress by looking for "offset galaxies," or galaxies with a single AGN that sits away from the center of the galaxy. Such a lack of symmetry suggests that a second supermassive black hole, which hasn't been turned on, might be hiding nearby.

Barrows and his colleagues next assembled a sample of 10 offset galaxies and compared that sample to galaxies with a pair of AGNs.

The results were stark: Nine out of the 10 galaxies with only one active black hole came from lopsided mergers, or cases in which one galaxy was more than four times the size of the other. Two-thirds of the galaxies with two active black holes, in contrast, were experiencing clashes among near equals.

Barrows explained that when galaxies of roughly equal size meet, their black holes exert tremendous gravitational forces on each other. Those forces, in turn, send clouds of gas and dust raining onto the black holes.

"It's these torques that extract energy from the gas and dust, allowing it to fall into the nucleus of the black hole," Barrows said. In mismatched mergers, "you simply have smaller forces exerted on the gas and dust in each galaxy."

The team didn't find any rhyme or reason to which black hole activated during a mismatched merger. In some cases, Barrows said, it was the bigger black hole. In other cases, the smaller one.



Next up, he and his colleagues will focus on how the smashing together of two black holes affects the galaxies themselves, including how they create and destroy stars. [22]

## **Astronomers find pairs of black holes at the centers of merging galaxies**

For the first time, a team of astronomers has observed several pairs of galaxies in the final stages of merging together into single, larger galaxies. Peering through thick walls of gas and dust surrounding the merging galaxies' messy cores, the research team captured pairs of supermassive black holes—each of which once occupied the center of one of the two original smaller galaxies—drawing closer together before they coalesce into one giant black hole.

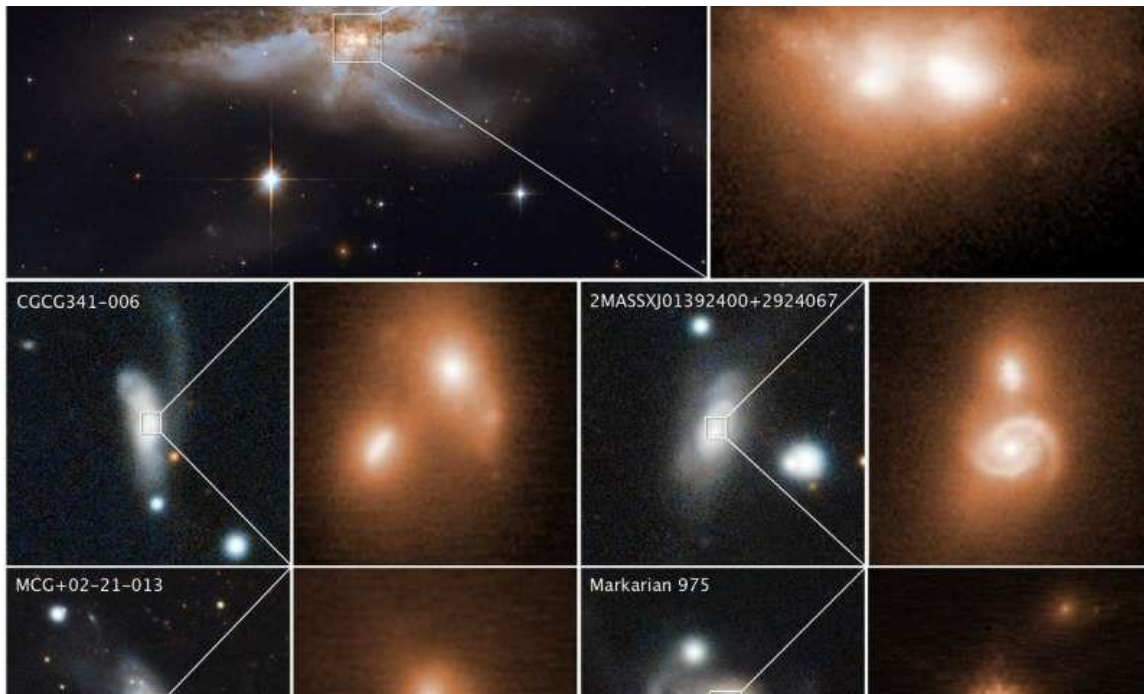
Led by University of Maryland alumnus Michael Koss (M.S. '07, Ph.D. '11, astronomy), a research scientist at Eureka Scientific, Inc., with contributions from UMD astronomers, the team surveyed hundreds of nearby [galaxies](#) using imagery from the W.M. Keck Observatory in Hawaii and NASA's Hubble Space Telescope. The Hubble observations represent more than 20 years' worth of images from the telescope's lengthy archive. The team described their findings in a research paper published on November 8, 2018, in the journal *Nature*.

"Seeing the pairs of merging galaxy nuclei associated with these huge black holes so close together was pretty amazing," Koss said. "In our study, we see two galaxy nuclei right when the images were taken. You can't argue with it; it's a very 'clean' result, which doesn't rely on interpretation."

The high-resolution images also provide a close-up preview of a phenomenon that astronomers suspect was more common in the early universe, when galaxy mergers were more frequent. When the black holes finally do collide, they will unleash powerful energy in the form of gravitational waves—ripples in space-time recently detected for the first time by the twin Laser Interferometer Gravitational-wave Observatory (LIGO) detectors.

The images also presage what will likely happen in a few billion years, when our Milky Way galaxy merges with the neighboring Andromeda galaxy. Both galaxies host [supermassive black holes](#) at their center, which will eventually smash together and merge into one larger black hole.

The team was inspired by a Hubble image of two interacting galaxies collectively called NGC 6240, which later served as a prototype for the study. The team first searched for visually obscured, active black holes by sifting through 10 years' worth of X-ray data from the Burst Alert Telescope (BAT) aboard NASA's Neil Gehrels Swift Observatory.



These images reveal the final stage of a union between pairs of galactic nuclei in the messy cores of colliding galaxies. The image at top left, taken by Hubble's Wide Field Camera 3, shows the merging galaxy NGC 6240. A close-up of the two ...[more](#)"The advantage to using Swift's BAT is that it observes high-energy, 'hard' X-rays," said study co-author Richard Mushotzky, a professor of astronomy at UMD and a fellow of the Joint Space-Science Institute (JSI). "These X-rays penetrate through the thick clouds of dust and gas that surround [active galaxies](#), allowing the BAT to see things that are literally invisible in other wavelengths."

The researchers then combed through the Hubble archive, zeroing in on the [merging galaxies](#) they spotted in the X-ray data. They then used the Keck telescope's super-sharp, near-infrared vision to observe a larger sample of the X-ray-producing black holes not found in the Hubble archive.

The team targeted galaxies located an average of 330 million light-years from Earth—relatively close by in cosmic terms. Many of the galaxies are similar in size to the Milky Way and Andromeda galaxies. In total, the team analyzed 96 galaxies observed with the Keck telescope and 385 galaxies from the Hubble archive.

Their results suggest that more than 17 percent of these galaxies host a pair of black holes at their center, which are locked in the late stages of spiraling ever closer together before merging into a single, ultra-massive black hole. The researchers were surprised to find such a high fraction of late-stage mergers, because most simulations suggest that black hole pairs spend very little time in this phase.

To check their results, the researchers compared the survey galaxies with a control group of 176 other galaxies from the Hubble archive that lack actively growing black holes. In this group, only about one percent of the surveyed galaxies were suspected to host pairs of black holes in the later stages of merging together.

This last step helped the researchers confirm that the luminous galactic cores found in their census of dusty interacting galaxies are indeed a signature of rapidly-growing black hole pairs headed for a collision. According to the researchers, this finding is consistent with theoretical predictions, but until now, had not been verified by direct observations.

"People had conducted studies to look for these close interacting black holes before, but what really enabled this particular study were the X-rays that can break through the cocoon of dust," explained Koss. "We also looked a bit farther in the universe so that we could survey a larger volume of space, giving us a greater chance of finding more luminous, rapidly-growing black holes."

It is not easy to find galactic nuclei so close together. Most prior observations of merging galaxies have caught the coalescing black holes at earlier stages, when they were about 10 times farther away. The late stage of the merger process is so elusive because the interacting galaxies are encased in dense dust and gas, requiring very high-resolution observations that can see through the clouds and pinpoint the two merging nuclei.

"Computer simulations of galaxy smashups show us that black holes grow fastest during the final stages of mergers, near the time when the black holes interact, and that's what we have found in our survey," said Laura Blecha, an assistant professor of physics at the University of Florida and a co-author of the study. Blecha was a JSI Prize Postdoctoral Fellow in the UMD Department of Astronomy prior to joining UF's faculty in 2017. "The fact that [black holes](#) grow faster and faster as mergers progress tells us galaxy encounters are really important for our understanding of how these objects got to be so monstrously big."

Future infrared telescopes such as NASA's highly anticipated James Webb Space Telescope (JWST), slated for launch in 2021, will provide an even better view of mergers in dusty, heavily obscured galaxies. For nearby black hole pairs, JWST should also be capable of measuring the masses, growth rates and other physical parameters for each black hole.

"There might be other objects that we missed. Even with Hubble, many [nearby galaxies](#) at low redshift cannot be resolved—the two nuclei just merge into one," said study co-author Sylvain Veilleux, a professor of astronomy at UMD and a JSI Fellow. "With JWST's higher angular resolution and sensitivity to the infrared, which can pass through the dusty cores of these galaxies, searches for these nearby objects should be easy to do. Also with JWST, we will be able to push toward larger distances, to see objects at higher redshift. With these observations, we can begin to explore the fraction of objects that are merging in the youngest, most distant regions of the universe—which should be fairly frequent." [21]

## **Astronomers detect once-in-a-lifetime gamma rays**

Scientists have discovered something amazing.

In a cluster of some of the most massive and luminous [stars](#) in our galaxy, about 5,000 light years from Earth, astronomers detected particles being accelerated by a rapidly rotating neutron star as it passed by the massive star it orbits only once every 50 years.

The discovery is extremely rare, according to University of Delaware astrophysicist Jamie Holder and [doctoral student](#) Tyler Williamson, who were part of the international team that documented the occurrence.

Holder called this eccentric pair of gravitationally linked stars a "gamma-ray binary system" and likened the once-in-a-lifetime event to the arrival of Halley's comet or last year's U.S. solar eclipse.

Massive stars are among the brightest stars in our galaxy. Neutron stars are extremely dense and energetic stars that result when a massive star explodes.

This binary system is a massive star with a neutron star orbiting around it. Of the 100 billion stars in our galaxy, less than 10 are known to be this type of system.

Even fewer—only two systems, including this one—are known to have an identified neutron star, or pulsar, that emits pulses of radio waves that scientists can measure. This is important because it tells astronomers very accurately how much energy is available to accelerate particles, something scientists know little about.

"You couldn't ask for a better natural laboratory to study particle acceleration in a continually changing environment - at energies far beyond anything we can produce on the Earth," said Holder, a professor in UD's Department of Physics and Astronomy.

The project was led by a team of scientists, including Holder and Williamson, using the VERITAS [telescope](#) array at the Fred Lawrence Whipple Observatory in Arizona, in collaboration with scientists using the MAGIC telescopes at the Roque de los Muchachos Observatory located in La Palma, an island of the Canary Islands, Spain. (VERITAS stands for Very Energetic Radiation Imaging Telescope Array System and MAGIC stands for Major Atmospheric Gamma Imaging Cherenkov telescopes.)



One of the VERITAS telescopes at sunset. Credit: University of Delaware

The researchers recently reported their findings in the *Astrophysical Journal Letters*.

### **Hoping for fireworks**

The natural question, to many minds, is why do scientists care about accelerated particles?

"Because our galaxy is full of them. We call them cosmic rays and they carry as much energy as the light from all the stars," said Holder.

Astronomers discovered more than 100 years ago that accelerated particles exist, yet how or where these particles speed up remains a mystery. Pulsars are among the most extreme objects in the universe and they have magnetic fields around them that are millions of times stronger than anything scientists could hope to build on earth. When a pulsar encounters dust or gas close to a massive star, the particles nearby accelerate—to near speed of light velocities—and collide with what's around them. The result is a beam of high-energy light called gamma-radiation or [gamma rays](#).

Sophisticated telescopes, like those operated by VERITAS and MAGIC, can detect these gamma rays because they emit a blue flash of light when they reach the Earth's atmosphere. While our eyes can't see these flashes of light because they are too quick, only nanoseconds long, these telescopes can.

## Once-in-a-lifetime doctoral experience

Astronomers first discovered gamma rays coming from the pulsar in this unusual pair of stars in 2008. About the size of Newark, Delaware, the pulsar is spinning like the attachment on a kitchen blender, emitting little pulses of gamma rays and radio waves with every rotation.

By measuring these radio pulse frequencies, astronomers were able to tell how fast the pulsar was moving and calculate exactly when it would be closest to the massive star that it was orbiting— Nov. 13, 2017. It's a trip that took 50 years.



UD Professor Jamie Holder is dwarfed by one of the VERITAS cameras. Credit: University of Delaware

The VERITAS and MAGIC teams began monitoring the night sky and tracking the pulsar's orbit in September 2016. At first, they weren't even sure if they would see anything. But in September 2017 the astronomers began to detect a rapid increase in the number of gamma rays hitting the top of the earth's atmosphere.

As they monitored the data coming from the VERITAS telescopes, Holder and Williamson realized that the pulsar was doing something different each day.

"I would wake up every morning and check and see if we had new data, then analyze it as fast as I could, because there were times where the number of gamma rays we were seeing was changing rapidly over a day or two," said Williamson, a fourth-year doctoral student.



During the closest approach between the star and the pulsar in November 2017, Williamson noticed that the VERITAS telescopes had—overnight—recorded ten times the number of gamma rays detected only a few days before.

"I double checked everything before sending the data to our collaborators," Williamson said. "Then one of our partners, Ralph Bird at UCLA, confirmed he'd gotten the same results; that was exciting."

Even more interesting—this observational data did not match what predictive models had predicted.

Generally speaking, Holder said, existing models predicted that as the pulsar approached the massive star it was orbiting, the number of gamma rays produced would slowly accelerate, experience some volatility and then slowly decay over time.

"But our recorded data showed a huge spike in the number of gamma rays instead," Holder said. "This tells us that we need to revise the models of how this particle acceleration is happening."

What's more, according to Holder, while astrophysicists expected the National Aeronautics and Space Administration's (NASA) Fermi gamma-ray space telescope to record these gamma rays, it didn't. Holder said the reason for this is unclear, but that is part of what makes the VERITAS results so interesting.



UD doctoral student Tyler Williamson standing on one of the VERITAS telescope access platforms.  
Credit: University of Delaware

Astrophysicists want to learn just which particles are being accelerated, and what processes are pushing them up to these extreme speeds, in order to understand more about the Universe. Holder said that although gamma-ray binary systems probably don't accelerate a large portion of the



particles in our galaxy, they allow scientists to study the type of acceleration mechanisms which could produce them.

### Charting a promising future

Astronomers won't be able to see this binary system at work again until 2067 when the two stars are once again close together. By then, Williamson joked that he just might be an emeritus professor with time on his hands.

At the moment, Williamson is not worried about running out of things to do. He spent three months at the Arizona-based observatory earlier this year, taking measurements, performing hardware maintenance and devising a remote control to allow the researchers to turn on the telescope's cameras from a computer inside a control room.

"It was a great chance to spend hands-on time with the telescopes and get to know the instrument," said Williamson.

Going forward, he'll spend the remainder of his doctoral studies combing through and analyzing in greater detail the nearly 175 hours of data the VERITAS telescopes collected in 2016 and 2017.

"Tyler is, without a doubt, the luckiest graduate student I've ever met because this event that happens only once every 50 years—one of the most exciting things we've seen with our telescopes in a decade—occurred right in the middle of his doctoral work," said Holder. [20]

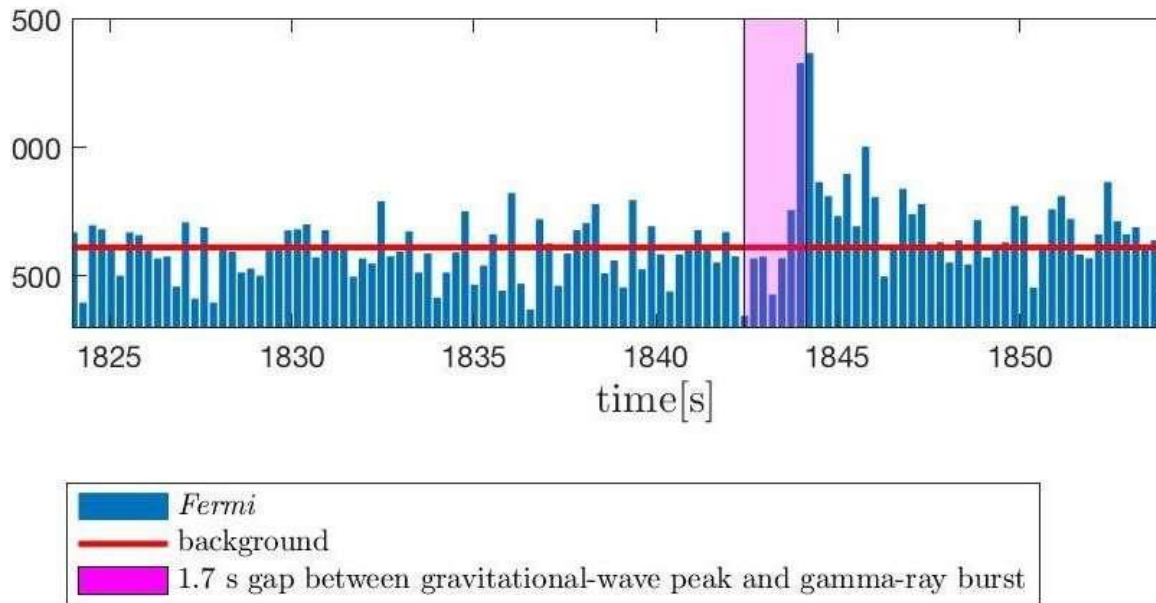
### Gravitational waves from a merged hyper-massive neutron star

For the first time astronomers have detected gravitational waves from a merged, hyper-massive neutron star. The scientists, Maurice van Putten of Sejong University in South Korea, and Massimo della Valle of the Osservatorio Astronomico de Capodimonte in Italy, publish their results in *Monthly Notices of the Royal Astronomical Society: Letters*.

Gravitational waves were predicted by Albert Einstein in his General Theory of Relativity in 1915. The waves are disturbances in space time generated by rapidly moving masses, which propagate out from the source. By the time the waves reach the Earth, they are incredibly weak and their detection requires extremely sensitive equipment. It took scientists until 2016 to announce the first observation of [gravitational waves](#) using the Laser Interferometer Gravitational Wave Observatory (LIGO) detector.

Since that seminal result, gravitational waves have been detected on a further six occasions. One of these, GW170817, resulted from the merger of two stellar remnants known as [neutron stars](#). These objects form after [stars](#) much more massive than the Sun explode as supernovae, leaving behind a core of material packed to extraordinary densities.

At the same time as the burst of gravitational waves from the merger, observatories detected emission in gamma rays, X-rays, ultraviolet, visible light, infrared and radio waves – an unprecedented observing campaign that confirmed the location and nature of the source.



A graph showing gamma-ray counts against time, whose initial peak is 1.7 seconds after the final coalescence of the two neutron stars. This short gamma-ray burst lasts for about three seconds during the period when the gravitational wave ...[more](#)

The initial observations of GW170817 suggested that the two neutron stars merged into a black hole, an object with a gravitational field so powerful that not even light can travel quickly enough to escape its grasp. Van Putten and della Valle set out to check this, using a novel technique to analyse the data from LIGO and the Virgo [gravitational wave detector](#) sited in Italy.

Their detailed analysis shows the H1 and L1 detectors in LIGO, which are separated by more than 3,000 kilometres, simultaneously picked up a descending 'chirp' lasting around 5 seconds. Significantly, this chirp started between the end of the initial burst of gravitational waves and a subsequent burst of gamma rays. Its low frequency (less than 1 KHz, reducing to 49 Hz) suggests the merged object spun down to instead become a larger neutron star, rather than a black hole.

There are other objects like this, with their total mass matching known neutron star binary pairs. But van Putten and della Valle have now confirmed their origin.

Van Putten comments: "We're still very much in the pioneering era of gravitational wave astronomy. So it pays to look at data in detail. For us this really paid off, and we've been able to confirm that two [neutron](#) stars merged to form a larger one."

Gravitational wave astronomy, and eking out the data from every detection, will take another step forward next year, when the Japanese Kamioka Gravitational Wave Detector (KAGRA) comes online. [19]

## Boosting gravitational wave detectors with quantum tricks

A group of scientists from the Niels Bohr Institute (NBI) at the University of Copenhagen will soon start developing a new line of technical equipment in order to dramatically improve gravitational wave detectors.

Gravitational wave detectors are extremely sensitive and can e.g. register colliding neutron stars in space. Yet even higher sensitivity is sought for in order to expand our knowledge about the Universe, and the NBI-scientists are convinced that their equipment can improve the detectors, says Professor Eugene Polzik: "And we should be able to show proof of concept within approximately three years."

If the NBI-scientists are able to improve the gravitational wave detectors as much as they "realistically expect can be done," the detectors will be able to monitor and carry out measurements in an eight times bigger volume of space than what is currently possible, explains Eugene Polzik: "This will represent a truly significant extension."

Polzik is head of Quantum Optics (Quantop) at NBI and he will spearhead the development of the tailor made equipment for gravitational wave detectors. The research – which is supported by the EU, the Eureka Network Projects and the US-based John Templeton Foundation with grants totaling DKK 10 million – will be carried out in Eugene Polzik's lab at NBI.

## A collision well noticed

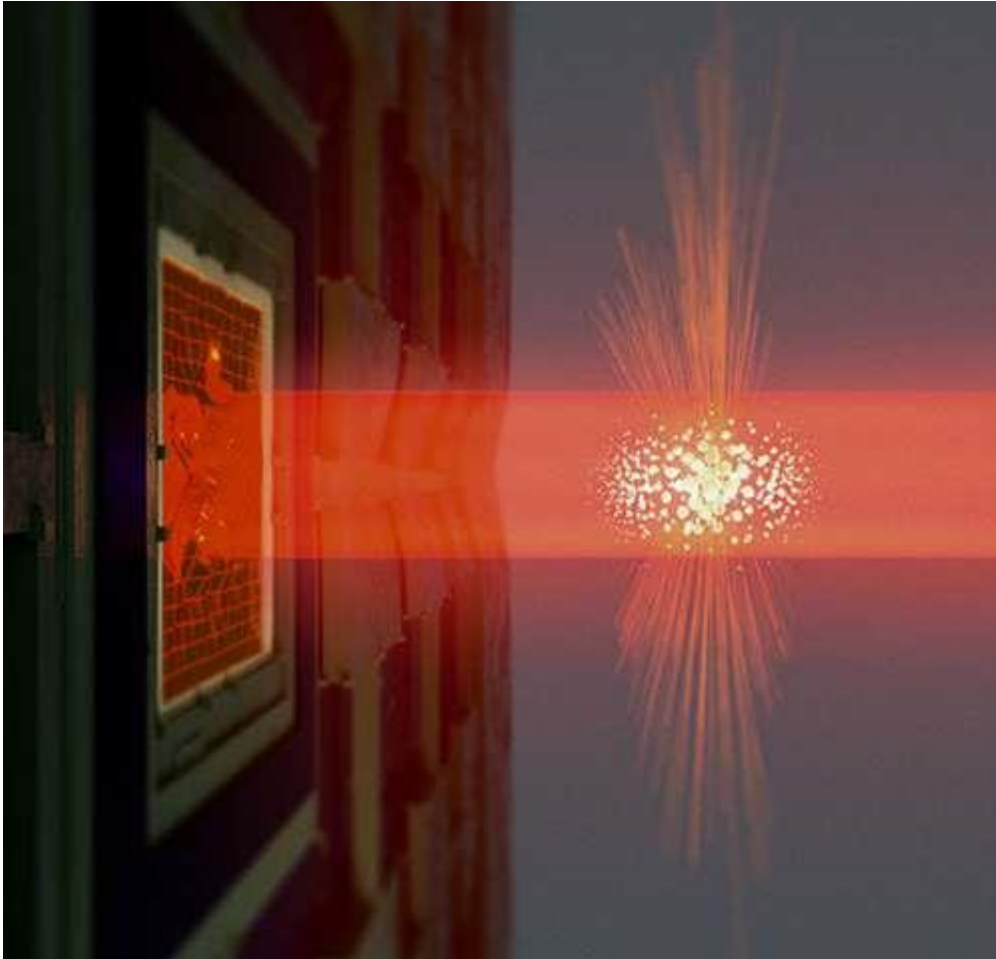
News media all over the world shifted into overdrive in October of 2017 when it was confirmed that a large international team of scientists had indeed measured the collision of two neutron stars; an event which took place 140 million [light](#) years from Earth and resulted in the formation of a kilonova.

The international team of scientists – which also included experts from NBI – was able to confirm the collision by measuring gravitational waves from space – waves in the fabric of spacetime itself, moving at the speed of light. The waves were registered by three gravitational wave detectors: the two US-based LIGO-detectors and the European Virgo-[detector](#) in Italy.

"These gravitational wave detectors represent by far the most sensitive measuring equipment man has yet manufactured – still the detectors are not as accurate as they could possibly be. And this is what we intend to improve," says Professor Eugene Polzik.

How this can be done is outlined in an article which Eugene Polzik and a colleague, Farid Khalili from LIGO collaboration and Moscow State University, have recently published in the scientific journal *Physical Review Letters*. And this is not merely a theoretical proposal, says Eugene Polzik:

"We are convinced this will work as intended. Our calculations show that we ought to be able to improve the precision of measurements carried out by the gravitational wave detectors by a factor of two. And if we succeed, this will result in an increase by a factor of eight of the volume in space which gravitational wave detectors are able to examine at present."



If laser light used to measure motion of a vibrating membrane (left) is first transmitted through an atom cloud (center) the measurement sensitivity can be better than standard quantum limits envisioned by Bohr and Heisenberg. Credit: Bastian Leonhardt Strube and Mads Vadsholt

### **A small glass cell**

In July of last year Eugene Polzik and his team at Quantop published a highly noticed article in *Nature* – and this work is actually the very foundation of their upcoming attempt to improve the gravitational wave detectors.

The article in *Nature* centered on 'fooling' Heisenberg's Uncertainty Principle, which basically says that you cannot simultaneously know the exact position and the exact speed of an object.

This has to do with the fact that observations conducted by shining light on an object inevitably will lead to the object being 'kicked' in random directions by photons, particles of light. This phenomenon is known as Quantum Back Action (QBA) and these random movements put a limit to the accuracy with which measurements can be carried out at the quantum level.

The article in *Nature* in the summer of 2017 made headlines because Eugene Polzik and his team were able to show that it is – to a large extent – actually possible to neutralize QBA.

And QBA is the very reason why gravitational wave detectors – that also operate with light, namely laser light—are not as accurate as they could possibly be," as professor Polzik says.

Put simply, it is possible to neutralize QBA if the light used to observe an object is initially sent through a 'filter.' This was what the article in Nature described – and the 'filter' which the NBI-scientists at Quantop had developed and described consisted of a cloud of 100 million caesium atoms locked-up in a hermetically closed glass cell just one centimeter long, 1/3 of a millimeter high and 1/3 of a millimeter wide.

The principle behind this 'filter' is exactly what Polzik and his team are aiming to incorporate in gravitational wave detectors.

In theory one can optimize measurements of gravitational waves by switching to stronger laser light than the detectors in both Europe and USA are operating with. However, according to quantum mechanics, that is not an option, says Eugene Polzik:

"Switching to stronger laser light will just make a set of mirrors in the detectors shake more because Quantum Back Action will be caused by more photons. These mirrors are absolutely crucial, and if they start shaking, it will in fact increase inaccuracy."

Instead, the NBI-scientists have come up with a plan based on the atomic 'filter' which they demonstrated in the Nature article: They will send the laser light by which the gravitational wave detectors operate through a tailor made version of the cell with the locked-up atoms, says Eugene Polzik: "And we hope that it will do the job." [18]

## **Gravitational wave detectors could shed light on dark matter**

A global team of scientists, including two University of Mississippi physicists, has found that the same instruments used in the historic discovery of gravitational waves caused by colliding black holes could help unlock the secrets of dark matter, a mysterious and as-yet-unobserved component of the universe.

The research findings by Emanuele Berti, UM associate professor of physics and astronomy, Shrobana Ghosh, a graduate student, and their colleagues appears in the September issue of Physical Review Letters, one of the most prestigious peer-reviewed academic journals in the field. "Stochastic and resolvable gravitational waves from ultralight bosons" is co-authored by fellow scientists Richard Brito, Enrico Barausse, Vitor Cardoso, Irina Dvorkin, Antoine Klein and Paolo Pani.

The nature of dark matter remains unknown, but scientists estimate that it is five times as abundant as ordinary matter throughout the universe.

"The nature of dark matter is one the greatest mysteries in physics," Berti said. "It is remarkable that we can now do particle physics – investigate the "very small" – by looking at gravitational-wave emission from black holes, the largest and simplest objects in the universe."

PRL is one of several publications produced by the American Physical Society and American Institute of Physics. It contains papers considered to represent significant advances in research, and therefore, published quickly in short, letter format for a broad audience of physicists.

This paper details calculations by the scientists, who work in Germany, France, Italy, Portugal and the U.S., show that gravitational-wave interferometers can be used to indirectly detect the presence of dark matter.

A companion paper by the team, "Gravitational wave searches for ultralight bosons with LIGO and LISA," also has been accepted and will appear in Physical Review D.

Calculations show that certain types of dark matter could form giant clouds around astrophysical black holes. If ultralight scalar particles exist in nature, fast-spinning black holes would trigger the growth of such scalar "condensates" at the expense of their rotational energy, producing a cloud that rotates around the black hole, now more slowly-spinning, and emits gravitational waves, pretty much like a giant lighthouse in the sky.

"One possibility is that dark matter consists of scalar fields similar to the Higgs boson, but much lighter than neutrinos," Pani said. "This type of dark matter is hard to study in particle accelerators, such as the Large Hadron Collider at CERN, but it may be accessible to gravitational-wave detectors."

The team led by Brito studied gravitational waves emitted by the "black hole plus cloud" system. Depending on the mass of the hypothetical particles, the signal is strong enough to be detected by the Laser Interferometer Gravitational-wave Observatory, with instruments in Louisiana and Washington, and its European counterpart Virgo, as well as by the future space mission Laser Interferometer Space Antenna.

"Surprisingly, gravitational waves from sources that are too weak to be individually detectable can produce a strong stochastic background," Brito said. "This work suggests that a careful analysis of the background in LIGO data may rule out – or detect – ultralight dark matter by gravitational-wave interferometers.

"This is a new, exciting frontier in astroparticle physics that could shed light on our understanding of the microscopic universe."

LIGO has been offline for a few months for upgrades. The team plans to announce new, exciting results from its second observing run soon.

"Our work shows that careful analysis of stochastic gravitational waves in the data they have already taken may be used to place interesting constraints on the nature of dark matter," Berti said.

This innovative work "confirms the high quality of the work in astroparticle physics and gravitationalwave astronomy done by members of the gravitational physics group at UM, widely recognized as one of the leaders in the field," said Luca Bombelli, chair and professor of physics and astronomy at Ole Miss. [17]

## Synopsis: Dark Photon Conjecture Fizzles

The lack of so-called “dark photons” in electron-positron collision data rules out scenarios in which these hypothetical particles explain the muon’s magnetic moment.

Dark photons sound like objects confused about their purpose, but in reality they are part of a comprehensive theory of dark matter. Researchers imagine that dark photons have photon-like interactions with other dark matter particles. And these hypothetical particles have recently gained interest because they might explain why the observed value of the muon’s anomalous magnetic moment disagrees slightly with predictions. However, this muon connection now appears to have been ruled out by the BaBar Collaboration at the SLAC National Accelerator Laboratory in California. The researchers found no signal of dark photons in their electron-positron collision data.

Like the normal photon, the dark photon would carry an electromagnetic-like force between dark matter particles. It could also potentially have a weak coupling to normal matter, implying that dark photons could be produced in high-energy collisions. Previous searches have failed to find a signature, but they have generally assumed that dark photons decay into electrons or some other type of visible particle.

For their new search, the BaBar Collaboration considered a scenario in which a dark photon is created with a normal photon in an electron-positron collision and then decays into invisible particles, such as other dark matter particles. In this case, only one particle—the normal photon—would be detected, and it would carry less than the full energy from the collision. Such missing-energy events can occur in other ways, so the team looked for a “bump” or increase in events at a specific energy that would correspond to the mass of the dark photon. They found no such bump up to masses of 8 GeV. The null result conflicts with models in which a dark photon contribution brings the predicted muon magnetic moment in line with observations. [16]

## Exchanges of identity in deep space

By reproducing the complexity of the cosmos through unprecedented simulations, a new study highlights the importance of the possible behaviour of very high-energy photons. In their journey through intergalactic magnetic fields, such photons could be transformed into axions and thus avoid being absorbed.

Like in a nail-biting thriller full of escapes and subterfuge, photons from far-off light sources such as blazars could experience a continuous exchange of identity in their journey through the universe. This would allow these very tiny particles to escape an enemy which, if encountered, would annihilate them. Normally, very high-energy photons (gamma rays) should “collide” with the background light emitted by galaxies and transform into pairs of matter and antimatter particles, as envisaged by the Theory of Relativity. For this reason, the sources of very high-energy gamma rays should appear significantly less bright than what is observed in many cases.

A possible explanation for this surprising anomaly is that light photons are transformed into hypothetical weakly interacting particles, “axions,” which, in turn, would change into photons, all due to the interaction with magnetic fields. A part of the photons would escape interaction with the intergalactic background light that would make them disappear. The importance of this process is emphasised by a study published in Physical Review Letters, which recreated an extremely



refined model of the cosmic web, a network of filaments composed of gas and dark matter present throughout the universe, and of its magnetic fields. These effects are now awaiting comparison with those obtained experimentally through Cherenkov Telescope Array new generation telescopes.

Through complex and unprecedented computer simulations made at the CSCS Supercomputing Centre in Lugano, scholars have reproduced the so-called cosmic web and its associated magnetic fields to investigate the theory that photons from a light source are transformed into axions, hypothetical elementary particles, on interacting with an extragalactic magnetic field. Axions could then be changed back into photons by interacting with other magnetic fields. Researchers Daniele Montanino, Franco Vazza, Alessandro Mirizzi and Matteo Viel write, "Photons from luminous bodies disappear when they encounter extragalactic background light (EBL). But if on their journey they head into these transformations as envisaged by these theories, it would explain why, in addition to giving very important information on processes that occur in the universe, distant celestial bodies are brighter than expected from an observation on Earth. These changes would, in fact, enable a greater number of photons to reach the Earth."

Thanks to the wealth of magnetic fields present in the cosmic web's filaments, which were recreated with the simulations, the conversion phenomenon would seem much more relevant than predicted by previous models: "Our simulations reproduce a very realistic picture of the cosmos' structure. From what we have observed, the distribution of the cosmic web envisaged by us would markedly increase the probability of these transformations." The next step in the research is to compare simulation results with the experimental data obtained through the use of the Cherenkov Telescope Array Observatories detectors, the new-generation astronomical observatories, one of which is positioned in the Canary Islands and the other in Chile. They will study the universe through very high-energy gamma rays. [15]

## **Astronomers may have detected the first direct evidence of dark matter**

Scientists have detected a mysterious X-ray signal that could be caused by dark matter streaming out of our Sun's core.

Now scientists at the University of Leicester have identified a signal on the X-ray spectrum which appears to be a signature of 'axions' - a hypothetical dark matter particle that's never been detected before.

While we can't get too excited just yet - it will take years to confirm whether this signal really is dark matter - the discovery would completely change our understanding of how the Universe works. After all, dark matter is the force that holds our galaxies together, so learning more about it is pretty important.

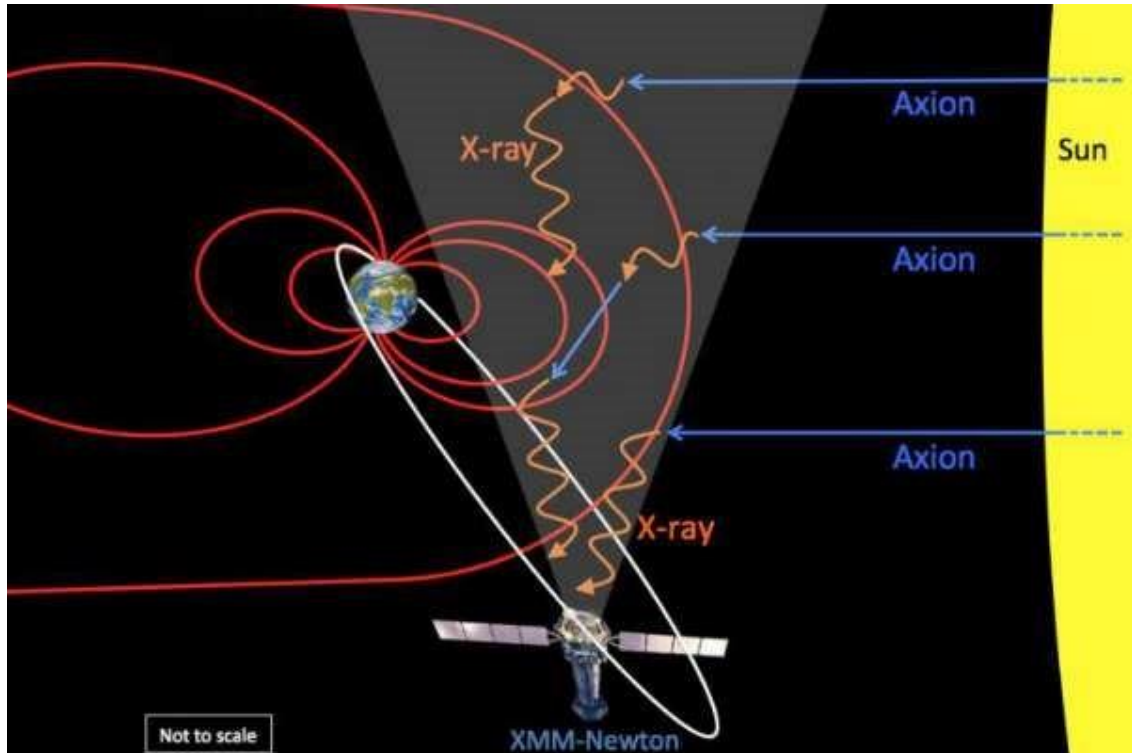
The researchers first detected the signal while searching through 15 years of measurements taking by the European Space Agency's orbiting XMM-Newton space observatory.

Unexpectedly, they noticed that the intensity of X-rays recorded by the spacecraft rose by about 10% whenever XMM-Newton was at the boundary of Earth's magnetic field facing the Sun - even once they removed all the bright X-ray sources from the sky. Usually, that X-ray background is stable. "The X-ray background - the sky, after the bright X-ray sources are removed - appears to be unchanged whenever you look at it," said Andy Read, from the University of Leicester, one of the lead authors on the paper, in a press release. "However, we have discovered a seasonal signal in

this X-ray background, which has no conventional explanation, but is consistent with the discovery of axions."

Researchers predict that axions, if they exist, would be produced invisibly by the Sun, but would convert to X-rays as they hit Earth's magnetic field. This X-ray signal should in theory be strongest when looking through the sunward side of the magnetic field, as this is where the Earth's magnetic field is strongest.

The next step is for the researchers to get a larger dataset from XMM-Newton and confirm the pattern they've seen in X-rays. Once they've done that, they can begin the long process of proving that they have, in fact, detecting dark matter streaming out of our Sun's core.



A sketch (not to scale) shows axions (blue) streaming out of the Sun and then converting into X-rays (orange) in the Earth's magnetic field (red). The X-rays are then detected by the XMM-Newton observatory. [13]

The axion is a hypothetical elementary particle postulated by the Peccei–Quinn theory in 1977 to resolve the strong CP problem in quantum chromodynamics (QCD). If axions exist and have low mass within a specific range, they are of interest as a possible component of cold dark matter. [14]

## Hidden photons

Hidden photons are predicted in some extensions of the Standard Model of particle physics, and unlike WIMPs they would interact electromagnetically with normal matter. Hidden photons also have a very small mass, and are expected to oscillate into normal photons in a process similar to neutrino oscillation. Observing such oscillations relies on detectors that are sensitive to extremely small electromagnetic signals, and a number of these extremely difficult experiments have been built or proposed.

A spherical mirror is ideal for detecting such light because the emitted photons would be concentrated at the sphere's centre, whereas any background light bouncing off the mirror would pass through a focus midway between the sphere's surface and centre. A receiver placed at the centre could then pick up the dark-matter-generated photons, if tuned to their frequency – which is related to the mass of the incoming hidden photons – with mirror and receiver shielded as much as possible from stray electromagnetic waves.

### **Ideal mirror at hand**

Fortunately for the team, an ideal mirror is at hand: a 13 m<sup>2</sup> aluminium mirror used in tests during the construction of the Pierre Auger Observatory and located at the Karlsruhe Institute of Technology. Döbrich and co-workers have got together with several researchers from Karlsruhe, and the collaboration is now readying the mirror by adjusting the position of each of its 36 segments to minimize the spot size of the focused waves. They are also measuring background radiation within the shielded room that will house the experiment. As for receivers, the most likely initial option is a set of low-noise photomultiplier tubes for measurements of visible light, which corresponds to hidden-photon masses of about 1 eV/c<sup>2</sup>. Another obvious choice is a receiver for gigahertz radiation, which corresponds to masses less than 0.001 eV/c<sup>2</sup>; however, this latter set-up would require more shielding.

### **Dark matter composition research - WIMP**

The WIMP (Weakly interactive massive particles) form a class of heavy particles, interacting slightly with matter, and constitute excellent candidates with the nonbaryonic dark matter. The neutralino postulated by the supersymmetric extensions of the standard model of particle physics. The idea of supersymmetry is to associate each boson to a fermion and vice versa. Each particle is then given a super-partner, having identical properties (mass, load), but with a spin which differs by 1/2. Thus, the number of particles is doubled. For example, the photon is accompanied by a photino, the graviton by a gravitino, the electron of a selectron, etc. Following the impossibility to detect a 511 keV boson (the electron partner), the physicists had to re-examine the idea of an exact symmetry. Symmetry is 'broken' and superpartners have a very important mass. One of these superparticles called LSP (Lightest Supersymmetric Particle) is the lightest of all. In most of the supersymmetric theories (without violation of the R-parity) the LSP is a stable particle because it cannot disintegrate in a lighter element. It is of neutral color and electric charge and is then only sensitive to weak interaction (weak nuclear force). It is then an excellent candidate for the not-baryonic dark matter. [11]

### **Weakly interacting massive particles**

In particle physics and astrophysics, weakly interacting massive particles, or WIMPs, are among the leading hypothetical particle physics candidates for dark matter. The term “WIMP” is given to a

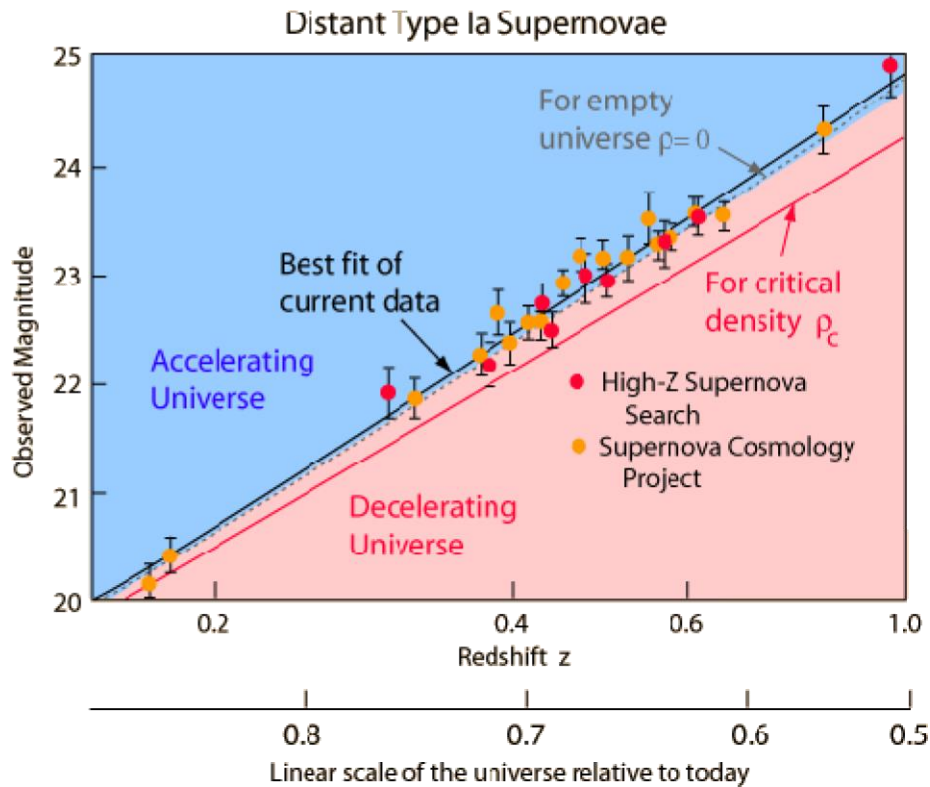
dark matter particle that was produced by falling out of thermal equilibrium with the hot dense plasma of the early universe, although it is often used to refer to any dark matter candidate that interacts with standard particles via a force similar in strength to the weak nuclear force. Its name comes from the fact that obtaining the correct abundance of dark matter today via thermal production requires a self-annihilation cross section, which is roughly what is expected for a new particle in the 100 GeV mass range that interacts via the electroweak force. This apparent coincidence is known as the "WIMP miracle". Because supersymmetric extensions of the standard model of particle physics readily predict a new particle with these properties, a stable supersymmetric partner has long been a prime WIMP candidate. However, recent null results from direct detection experiments including LUX and SuperCDMS, along with the failure to produce evidence of supersymmetry in the Large Hadron Collider (LHC) experiment has cast doubt on the simplest WIMP hypothesis. Experimental efforts to detect WIMPs include the search for products of WIMP annihilation, including gamma

rays, neutrinos and cosmic rays in nearby galaxies and galaxy clusters; direct detection experiments designed to measure the collision of WIMPs with nuclei in the laboratory, as well as attempts to directly produce WIMPs in colliders such as the LHC. [10]

## Evidence for an accelerating universe

One of the observational foundations for the big bang model of cosmology was the observed expansion of the universe. [9] Measurement of the expansion rate is a critical part of the study, and it has been found that the expansion rate is very nearly "flat". That is, the universe is very close to the critical density, above which it would slow down and collapse inward toward a future "big crunch". One of the great challenges of astronomy and astrophysics is distance measurement over the vast distances of the universe. Since the 1990s it has become apparent that type Ia supernovae offer a unique opportunity for the consistent measurement of distance out to perhaps 1000 Mpc. Measurement at these great distances provided the first data to suggest that the expansion rate of the universe is actually accelerating. That acceleration implies an energy density that acts in opposition to gravity which would cause the expansion to accelerate. This is an energy density which we have not directly detected observationally and it has been given the name "dark energy".

The type Ia supernova evidence for an accelerated universe has been discussed by Perlmutter and the diagram below follows his illustration in Physics Today.



The data summarized in the illustration above involve the measurement of the redshifts of the distant supernovae. The observed magnitudes are plotted against the redshift parameter  $z$ . Note that there are a number of Type Ia supernovae around  $z=0.6$ , which with a Hubble constant of 71 km/s/pc is a distance of about 5 billion light years.

### Equation

The cosmological constant  $\Lambda$  appears in Einstein's field equation [5] in the form of

$$R_{\mu\nu} - \frac{1}{2}R g_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4}T_{\mu\nu},$$

where  $R$  and  $g$  describe the structure of spacetime,  $T$  pertains to matter and energy affecting that structure, and  $G$  and  $c$  are conversion factors that arise from using traditional units of measurement. When  $\Lambda$  is zero, this reduces to the original field equation of general relativity. When  $T$  is zero, the field equation describes empty space (the vacuum).

The cosmological constant has the same effect as an intrinsic energy density of the vacuum,  $\rho_{vac}$  (and an associated pressure). In this context it is commonly moved onto the right-hand side of the equation, and defined with a proportionality factor of  $8\pi$ :  $\Lambda = 8\pi\rho_{vac}$ , where unit conventions of general relativity are used (otherwise factors of  $G$  and  $c$  would also appear). It is common to quote values of energy density directly, though still using the name "cosmological constant".

A positive vacuum energy density resulting from a cosmological constant implies a negative pressure, and vice versa. If the energy density is positive, the associated negative pressure will drive an accelerated expansion of the universe, as observed. (See dark energy and cosmic inflation for details.)

## Explanatory models

Models attempting to explain accelerating expansion include some form of dark energy, dark fluid or phantom energy. The most important property of dark energy is that it has negative pressure which is distributed relatively homogeneously in space. The simplest explanation for dark energy is that it is a cosmological constant or vacuum energy; this leads to the Lambda-CDM model, which is generally known as the Standard Model of Cosmology as of 2003-2013, since it is the simplest model in good agreement with a variety of recent observations.

## Dark Matter and Energy

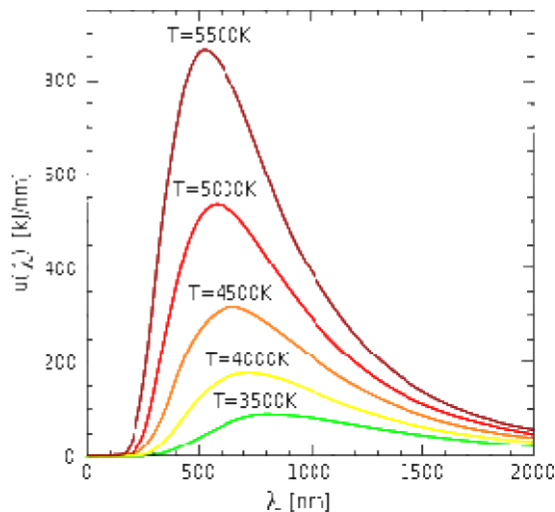
Dark matter is a type of matter hypothesized in astronomy and cosmology to account for a large part of the mass that appears to be missing from the universe. Dark matter cannot be seen directly with telescopes; evidently it neither emits nor absorbs light or other electromagnetic radiation at any significant level. It is otherwise hypothesized to simply be matter that is not reactant to light. Instead, the existence and properties of dark matter are inferred from its gravitational effects on visible matter, radiation, and the large-scale structure of the universe. According to the Planck mission team, and based on the standard model of cosmology, the total mass–energy of the known universe contains 4.9% ordinary matter, 26.8% dark matter and 68.3% dark energy. Thus, dark matter is estimated to constitute 84.5% of the total matter in the universe, while dark energy plus dark matter constitute 95.1% of the total content of the universe. [6]

## Cosmic microwave background

The cosmic microwave background (CMB) is the thermal radiation assumed to be left over from the "Big Bang" of cosmology. When the universe cooled enough, protons and electrons combined to form neutral atoms. These atoms could no longer absorb the thermal radiation, and so the universe became transparent instead of being an opaque fog. [7]

## Thermal radiation

Thermal radiation is electromagnetic radiation generated by the thermal motion of charged particles in matter. All matter with a temperature greater than absolute zero emits thermal radiation. When the temperature of the body is greater than absolute zero, interatomic collisions cause the kinetic energy of the atoms or molecules to change. This results in charge-acceleration and/or dipole oscillation which produces electromagnetic radiation, and the wide spectrum of radiation reflects the wide spectrum of energies and accelerations that occur even at a single temperature. [8]



## Electromagnetic Field and Quantum Theory

Needless to say that the accelerating electrons of the steady stationary current are a simple demystification of the magnetic field, by creating a decreasing charge distribution along the wire, maintaining the decreasing U potential and creating the  $\underline{A}$  vector potential experienced by the electrons moving by  $\underline{v}$  velocity relative to the wire. This way it is easier to understand also the time dependent changes of the electric current and the electromagnetic waves as the resulting fields moving by c velocity.

It could be possible something very important law of the nature behind the self maintaining  $\underline{E}$  accelerating force by the accelerated electrons. The accelerated electrons created electromagnetic fields are so natural that they occur as electromagnetic waves traveling with velocity c. It shows that the electric charges are the result of the electromagnetic waves diffraction.

One of the most important conclusions is that the electric charges are moving in an accelerated way and even if their velocity is constant, they have an intrinsic acceleration anyway, the so called spin, since they need at least an intrinsic acceleration to make possible they movement .

The bridge between the classical and quantum theory is based on this intrinsic acceleration of the spin, explaining also the Heisenberg Uncertainty Principle. The particle – wave duality of the electric charges and the photon makes certain that they are both sides of the same thing. Basing the gravitational force on the accelerating Universe caused magnetic force and the Planck Distribution

Law of the electromagnetic waves caused diffraction gives us the basis to build a Unified Theory of the physical interactions. [4]



## Lorentz transformation of the Special Relativity

In the referential frame of the accelerating electrons the charge density lowering linearly because of the linearly growing way they takes every next time period. From the referential frame of the wire there is a parabolic charge density lowering.

The difference between these two referential frames, namely the referential frame of the wire and the referential frame of the moving electrons gives the relativistic effect. Important to say that the moving electrons presenting the time coordinate, since the electrons are taking linearly increasing way every next time period, and the wire presenting the geometric coordinate. The Lorentz transformations are based on moving light sources of the Michelson - Morley experiment giving a practical method to transform time and geometric coordinates without explaining the source of this mystery.

The real mystery is that the accelerating charges are maintaining the accelerating force with their charge distribution locally. The resolution of this mystery that the charges are simply the results of the diffraction patterns, that is the charges and the electric field are two sides of the same thing. Otherwise the charges could exceed the velocity of the electromagnetic field.

The increasing mass of the electric charges the result of the increasing inductive electric force acting against the accelerating force. The decreasing mass of the decreasing acceleration is the result of the inductive electric force acting against the decreasing force. This is the relativistic mass change explanation, especially importantly explaining the mass reduction in case of velocity decrease.

## The Classical Relativistic effect

The moving charges are self maintain the electromagnetic field locally, causing their movement and this is the result of their acceleration under the force of this field.

In the classical physics the charges will distributed along the electric current so that the electric potential lowering along the current, by linearly increasing the way they take every next time period because this accelerated motion.

## Electromagnetic inertia and Gravitational attraction

Since the magnetic induction creates a negative electric field as a result of the changing acceleration, it works as an electromagnetic inertia, causing an electromagnetic mass.

It looks clear that the growing acceleration results the relativistic growing mass - limited also with the velocity of the electromagnetic wave.

Since  $E = hv$  and  $E = mc^2$ ,  $m = hv/c^2$  that is the  $m$  depends only on the  $v$  frequency. It means that the mass of the proton and electron are electromagnetic and the result of the electromagnetic induction, caused by the changing acceleration of the spinning and moving charge! It could be that the  $m_0$  inertial mass is the result of the spin, since this is the only accelerating motion of the electric charge. Since the accelerating motion has different frequency for the electron in the atom and the proton, they masses are different, also as the wavelengths on both sides of the diffraction pattern, giving equal intensity of radiation.

If the mass is electromagnetic, then the gravitation is also electromagnetic effect caused by the accelerating Universe! The same charges would attract each other if they are moving parallel by the magnetic effect.

The Planck distribution law explains the different frequencies of the proton and electron, giving equal intensity to different lambda wavelengths! Also since the particles are diffraction patterns they have some closeness to each other – can be seen as a gravitational force.

## Electromagnetic inertia and mass

### Electromagnetic Induction

Since the magnetic induction creates a negative electric field as a result of the changing acceleration, it works as an electromagnetic inertia, causing an electromagnetic mass. [1]

### Relativistic change of mass

The increasing mass of the electric charges the result of the increasing inductive electric force acting against the accelerating force. The decreasing mass of the decreasing acceleration is the result of the inductive electric force acting against the decreasing force. This is the relativistic mass change explanation, especially importantly explaining the mass reduction in case of velocity decrease.

### The frequency dependence of mass

Since  $E = h\nu$  and  $E = mc^2$ ,  $m = h\nu/c^2$  that is the  $m$  depends only on the  $\nu$  frequency. It means that the mass of the proton and electron are electromagnetic and the result of the electromagnetic induction, caused by the changing acceleration of the spinning and moving charge! It could be that the  $m_0$  inertial mass is the result of the spin, since this is the only accelerating motion of the electric charge. Since the accelerating motion has different frequency for the electron in the atom and the proton, they masses are different, also as the wavelengths on both sides of the diffraction pattern, giving equal intensity of radiation.

### Electron – Proton mass rate

The Planck distribution law explains the different frequencies of the proton and electron, giving equal intensity to different lambda wavelengths! Also since the particles are diffraction patterns they have some closeness to each other – can be seen as a gravitational force. [1]

There is an asymmetry between the mass of the electric charges, for example proton and electron, can understood by the asymmetrical Planck Distribution Law. This temperature dependent energy distribution is asymmetric around the maximum intensity, where the annihilation of matter and antimatter is a high probability event. The asymmetric sides are creating different frequencies of electromagnetic radiations being in the same intensity level and compensating each other. One of these compensating ratios is the electron – proton mass ratio. The lower energy side has no compensating intensity level, it is the dark energy and the corresponding matter is the dark matter.

## Gravity from the point of view of quantum physics

### The Gravitational force

The gravitational attractive force is basically a magnetic force.

The same electric charges can attract one another by the magnetic force if they are moving parallel in the same direction. Since the electrically neutral matter is composed of negative and positive charges they need 2 photons to mediate this attractive force, one per charges. The Big Bang caused parallel moving of the matter gives this magnetic force, experienced as gravitational force.

Since graviton is a tensor field, it has spin = 2, could be 2 photons with spin = 1 together.

You can think about photons as virtual electron – positron pairs, obtaining the necessary virtual mass for gravity.

The mass as seen before a result of the diffraction, for example the proton – electron mass ratio  $m_p = 1840 m_e$ . In order to move one of these diffraction maximum (electron or proton) we need to intervene into the diffraction pattern with a force appropriate to the intensity of this diffraction maximum, means its intensity or mass.

The Big Bang caused acceleration created radial currents of the matter, and since the matter is composed of negative and positive charges, these currents are creating magnetic field and attracting forces between the parallel moving electric currents. This is the gravitational force experienced by the matter, and also the mass is result of the electromagnetic forces between the charged particles. The positive and negative charged currents attracts each other or by the magnetic forces or by the much stronger electrostatic forces!?

### The Graviton

In physics, the graviton is a hypothetical elementary particle that mediates the force of gravitation in the framework of quantum field theory. If it exists, the graviton is expected to be massless (because the gravitational force appears to have unlimited range) and must be a spin-2 boson. The spin follows from the fact that the source of gravitation is the stress-energy tensor, a second-rank tensor (compared to electromagnetism's spin-1 photon, the source of which is the four-current, a first-rank tensor). Additionally, it can be shown that any massless spin-2 field would give rise to a force indistinguishable from gravitation, because a massless spin-2 field must couple to (interact with) the stress-energy tensor in the same way that the gravitational field does. This result suggests that, if a massless spin-2 particle is discovered, it must be the graviton, so that the only experimental verification needed for the graviton may simply be the discovery of a massless spin-2 particle. [2]

### Conclusions

Researchers predict that axions, if they exist, would be produced invisibly by the Sun, but would convert to X-rays as they hit Earth's magnetic field. This X-ray signal should in theory be strongest when looking through the sunward side of the magnetic field, as this is where the Earth's magnetic

field is strongest. The high frequency of the X-ray and the uncompensated Planck distribution makes the axion a good candidate to be dark matter.

Hidden photons are predicted in some extensions of the Standard Model of particle physics, and unlike WIMPs they would interact electromagnetically with normal matter.

In particle physics and astrophysics, weakly interacting massive particles, or WIMPs, are among the leading hypothetical particle physics candidates for dark matter.

The gravitational force attracting the matter, causing concentration of the matter in a small space and leaving much space with low matter concentration: dark matter and energy.

There is an asymmetry between the mass of the electric charges, for example proton and electron, can understood by the asymmetrical Planck Distribution Law. This temperature dependent energy distribution is asymmetric around the maximum intensity, where the annihilation of matter and antimatter is a high probability event. The asymmetric sides are creating different frequencies of electromagnetic radiations being in the same intensity level and compensating each other. One of these compensating ratios is the electron – proton mass ratio. The lower energy side has no compensating intensity level, it is the dark energy and the corresponding matter is the dark matter. The electric currents causing self maintaining electric potential is the source of the special and general relativistic effects. The Higgs Field is the result of the electromagnetic induction. The Graviton is two photons together. [3]

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