Cold Atom Dynamics

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A research team of multiple institutes, including the National Astronomical Observatory of Japan and University of Tokyo, released an unprecedentedly wide and sharp dark matter map based on the newly obtained imaging data by Hyper Suprime-Cam on the Subaru Telescope. [28]

A signal caused by the very first stars to form in the universe has been picked up by a tiny but highly specialised radio telescope in the remote Western Australian desert. [27]

This week, scientists from around the world who gathered at the University of California, Los Angeles, at the Dark Matter 2018 Symposium learned of new results in the search for evidence of the elusive material in Weakly Interacting Massive Particles (WIMPs) by the DarkSide-50 detector. [26]

If they exist, axions, among the candidates for dark matter particles, could interact with the matter comprising the universe, but at a much weaker extent than previously theorized. New, rigorous constraints on the properties of axions have been proposed by an international team of scientists. [25]

The intensive, worldwide search for dark matter, the missing mass in the universe, has so far failed to find an abundance of dark, massive stars or scads of strange new weakly interacting particles, but a new candidate is slowly gaining followers and observational support. [24]

"We invoke a different theory, the self-interacting dark matter model or SIDM, to show that dark matter self-interactions thermalize the inner halo, which ties ordinary dark matter and dark matter distributions together so that they behave like a collective unit." [23]

Technology proposed 30 years ago to search for dark matter is finally seeing the light. [22]

They're looking for dark matter—the stuff that theoretically makes up a quarter of our universe. [21]

Results from its first run indicate that XENON1T is the most sensitive dark matter detector on Earth. [20]

Scientists at Johannes Gutenberg University Mainz (JGU) in Germany have now come up with a new theory on how dark matter may have been formed shortly after the origin of the universe. [19]

Map of dark matter made from gravitational lensing measurements of 26 million galaxies in the Dark Energy Survey. [18]

CfA astronomers Annalisa Pillepich and Lars Hernquist and their colleagues compared gravitationally distorted Hubble images of the galaxy cluster Abell 2744 and two other clusters with the results of computer simulations of dark matter haloes. [17]

In a paper published July 20 in the journal Physical Review Letters, an international team of cosmologists uses data from the intergalactic medium— the vast, largely empty space between galaxies—to narrow down what dark matter could be. [16]

But a new hypothesis might have gotten us closer to figuring out its identity, because physicists now suspect that dark matter has been changing forms this whole time - from ghostly particles in the Universe's biggest structures, to a strange, superfluid state at smaller scales. And we might soon have the tools to confirm it. [15]

Superfluids may exist inside neutron stars, and some researchers have speculated that space-time itself may be a superfluid. So why shouldn't dark matter have a superfluid phase, too? [14]

"The best result on dark matter so far—and we just got started." This is how scientists behind XENON1T, now the most sensitive dark matter experiment world-wide, commented on their first result from a short 30-day run presented today to the scientific community. [13]

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.

SIMPs would resolve certain discrepancies between simulations of the distribution of dark matter, like this one, and the observed properties of the galaxies.

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

Contents

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!?
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Laser-based prototype probes cold atom dynamics

By tracking the motions of cold atom clouds, astronomers can learn much about the physical processes which play out in the depths of space. To make these measurements, researchers currently use instruments named 'cold atom inertial sensors' which, so far, have largely been operated inside the lab. In new work published in *EPJ D*, a team of physicists at Muquans and LNE-SYRTE (the French national metrology laboratory for time, frequency and gravimetry) present an innovative prototype for a new industrial laser system. Their design paves the way for the development of cold atom inertial sensors in space.

The insights gathered by the team could offer significant improvements in the accuracy of tests of fundamental physics, as well as assessments of the Earth's gravitational field. Studies in the past have made significant strides towards mobile laser systems for cold atom inertial sensing which are more compact, but these have not yet widely proven suitable for measurements in space. In their study, the researchers' updated laser system was implemented onto a ground-based atomic sensor at LNE-SYRTE. This enabled them to prove that their prototype was ready to carry out real experiments measuring the subtle variations in the Earth's gravitational field using matter wave interferometry techniques. Their work was carried out in collaboration with Sodern in the frame of a more general study led by the European Space Agency (ESA), whose objective was to assess and improve the maturity of cold atom technologies.

The design involves industrial lasers which are typically used for telecommunications; with their frequencies doubled. This setup benefited from a wide availability of components, as well as extensive previous research into the properties of the lasers. Through further testing in space-like environments, the team hopes that their system could soon allow researchers to probe various aspects of the physical environment of space in unprecedented levels of detail. [34]

Physicist proposes a new approach in modeling the evolution of the universe

A physicist from RUDN University has proposed a new theoretical model for the interaction of spinor and gravitational fields. He considered the evolution of the universe within one of the variants of the widespread Bianchi cosmological model. In this case, a change in the calculated field parameters led to changes in the evolution of the universe under consideration. Upon reaching certain values, it began to shrink down to the Big Bang. The article was published in the journal *The European Physical Journal Plus*.

The spinor field is characterized by its behavior in interaction with gravitational fields. Dr. Bijan Saha of RUDN University focused on the study of a nonlinear spinor field. With its help, he explained the accelerated expansion of the universe. The study of a spinor field with a non-minimal coupling made it possible to describe not only the expansion of the universe, but also its subsequent contraction and the resulting Big Bang within the framework of the standard Bianchi cosmological model.

The basic calculations performed by Bijan Saha allow moving away from the isotropic model of the Friedman-Robertson-Walker universe (FRW) that is most often used. According to this traditional model, the properties of the universe are independent of the direction in which they are considered. The physicist has put forward an alternative: an anisotropic model in which such dependence exists. On the one hand, the "classical" isotropic model describes the evolution of the modern universe with great precision. On the other hand, there are theoretical arguments and observational data that lead to the conclusion that an anisotropic phase existed in the distant past.

The work of a cosmologist is to model the evolution of the universe theoretically, and in doing so, they pick the models that are simple to solve while giving a more or less realistic picture. In that regard, isotropic FRW model is the best one. But there is no suitable data guaranteeing that the universe was isotropic prior to recombination.

Moreover, there are theoretical arguments in favor of the existence of an anisotropic phase is the remote past, a key factor for the formation of baryonic matter. Since the Bianchi type-I universe is the straightforward generalization of the FRW one, it is customary to consider this model for studying the possible anisotropies of the universe.

The solution of the simplest anisotropic model of the universe in the presence of a spinor field inevitably leads to three options. In the first case, it turns out that space-time corresponds to The Bianchi type-I general model. In the second case, space-time imposes restrictions on the spinor field and turns into locally rotationally symmetric (LRS) Bianchi type-I space-time. That is, isotropy does not apply to the entire universe; it is assumed to have an anisotropic phase. In the third case, the calculations lead to the general case of the isotropic and homogeneous Friedmann-Robertson-Walker (FRW) space-time. But the author does not analyze the evolution of an isotropic and homogeneous universe in the FRW model. He plans to solve this problem in his future publications.

In his article, Saha considers in detail only the first two options for basic calculations. The first one does not give an acceptable answer. The resulting universe turns into a vacuum, and accelerated mode of expansion of evolution is absent. However, in the second case, in which the nonlinearity of a spinor field is considered as a power function, it is possible to simulate the process of evolution of the universe.

In this case, when certain values of a nonlinear spinor field with a non-minimal coupling are reached, the universe begins to shrink down to the Big Crunch.

"While a non-minimally coupled linear spinor field or a minimally coupled nonlinear spinor field in some cases give rise to an open universe, a non-minimally coupled nonlinear spinor field with the same parameters creates a model that is closed, that is, after reaching a certain maximum value, it begins to decrease, and finally, it shrinks down to the Big Crunch," concludes Saha. [33]

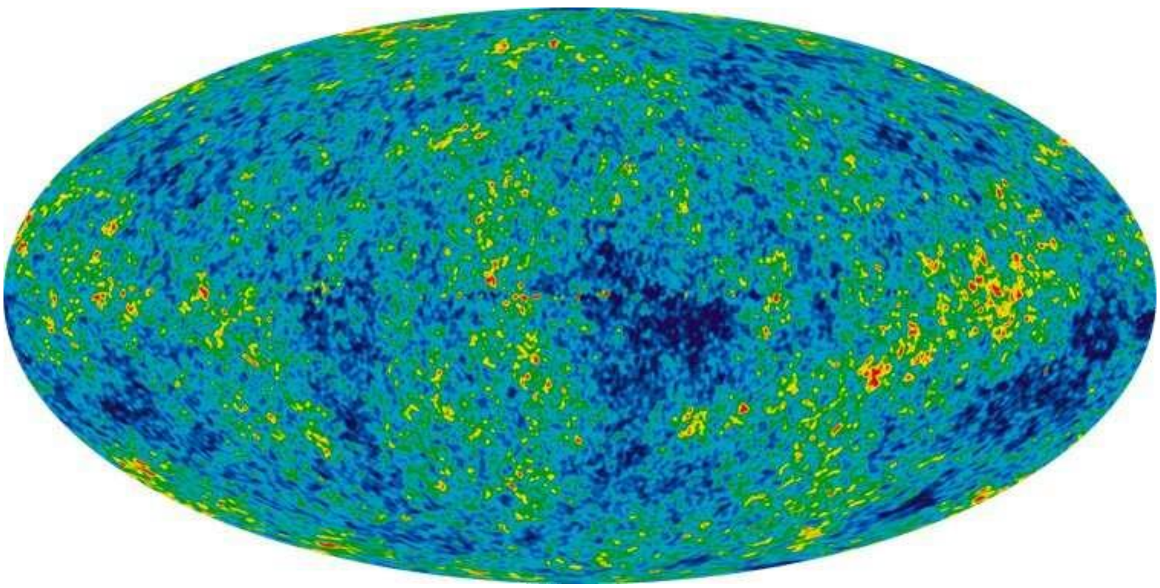
Shape of the universe: study could force us to rethink everything we know about the cosmos

No matter how elegant your theory is, experimental data will have the last word. Observations of the retrograde motion of the planets were fundamental to the Copernican revolution, in which the sun replaced Earth at the centre of the solar system. And the unusual orbit of Mercury provided a spectacular confirmation of the theory of general relativity. In fact, our entire understanding of the universe is built on observed, unexpected anomalies.

Now our new paper, published in *Nature Astronomy*, has come to a conclusion that may unleash a crisis in cosmology—if confirmed. We show that the shape of the universe may actually be curved rather than flat, as previously thought—with a probability larger than 99%. In a curved universe, no matter which direction you travel in, you will end up at the starting point—just like on a sphere. Though the universe has four dimensions, including time.

The result was based on recent measurements of the Cosmic Microwave Background, the light left over from the Big Bang, collected by the Planck Satellite. According to Albert Einstein's theory of general relativity, mass warps space and time around it. As a result, light rays take an apparent turn around a massive object rather than travelling in a straight line—an effect known as gravitational lensing.

There is much more such lensing in the Planck data than there should be, which means the universe could contain more dark matter—an invisible and unknown substance—than we think. In our study, we showed that a closed universe can provide a physical explanation to this effect, because it is able to host a lot more dark matter than a flat universe. Such a universe is perfectly compatible with general relativity.



The Cosmic Microwave Background temperature fluctuations from the seven-year WMAP data over the sky. Credit: NASA/WMAP

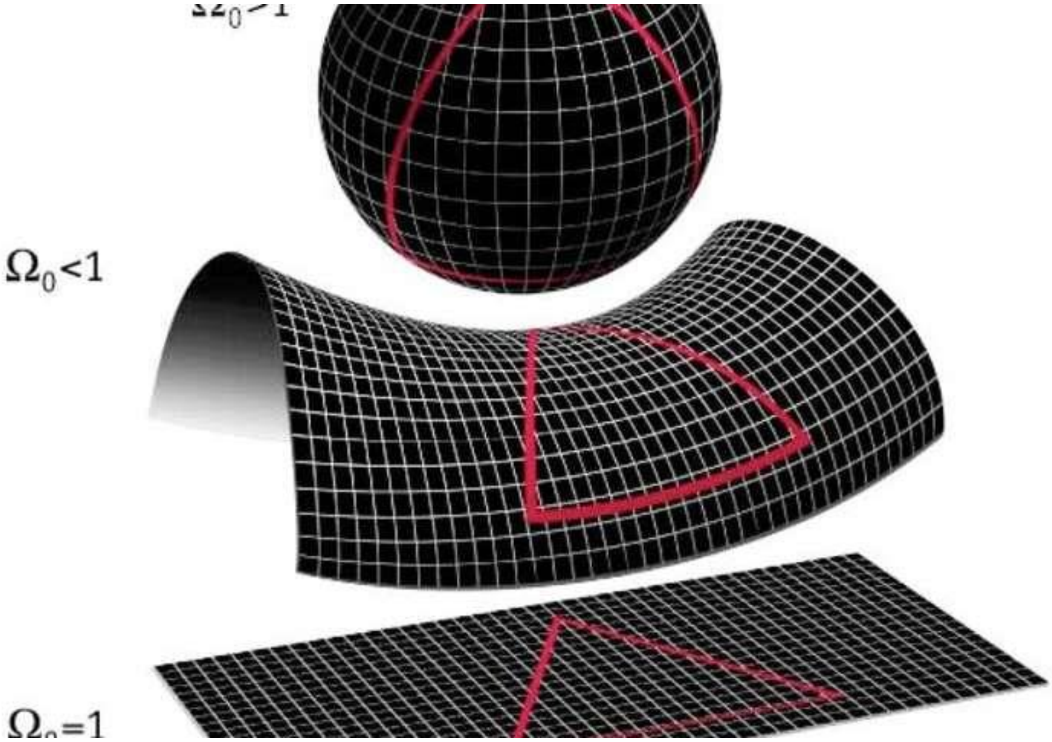
Major headache

Not all cosmologists are convinced by a closed universe though—previous studies have suggested the cosmos is indeed flat. And if a spherical universe is a solution to the lensing anomaly, then we have to deal with several significant consequences. First of all, we have to revise a fundamental cornerstone of cosmology—the theory of cosmological inflation. Inflation describes the first instants after the Big Bang, predicting a period of exponential expansion for the primordial universe.

The theory was developed over the past 40 years to explain why distant parts of the universe look the same and have the same temperature, when they are too far apart to ever have been in contact. Inflation solves the problem because it means that far-flung regions of the universe would once have been connected. But the period of rapid expansion that hurled these regions apart is also thought to have also brought the universe to flatness with exquisite precision.

If the universe is closed, standard inflation is in trouble. And that means we lose our standard explanation for why the universe has the structure it has.

Once we assume that the universe is curved, the Planck data is essentially in disagreement with all other datasets. This all boils down to a real crisis for cosmology, as we say in our paper. For these reasons, cosmologists are cautious—and many of them prefer to attribute the results to a statistical fluke that will resolve when new data from future experiments are available.



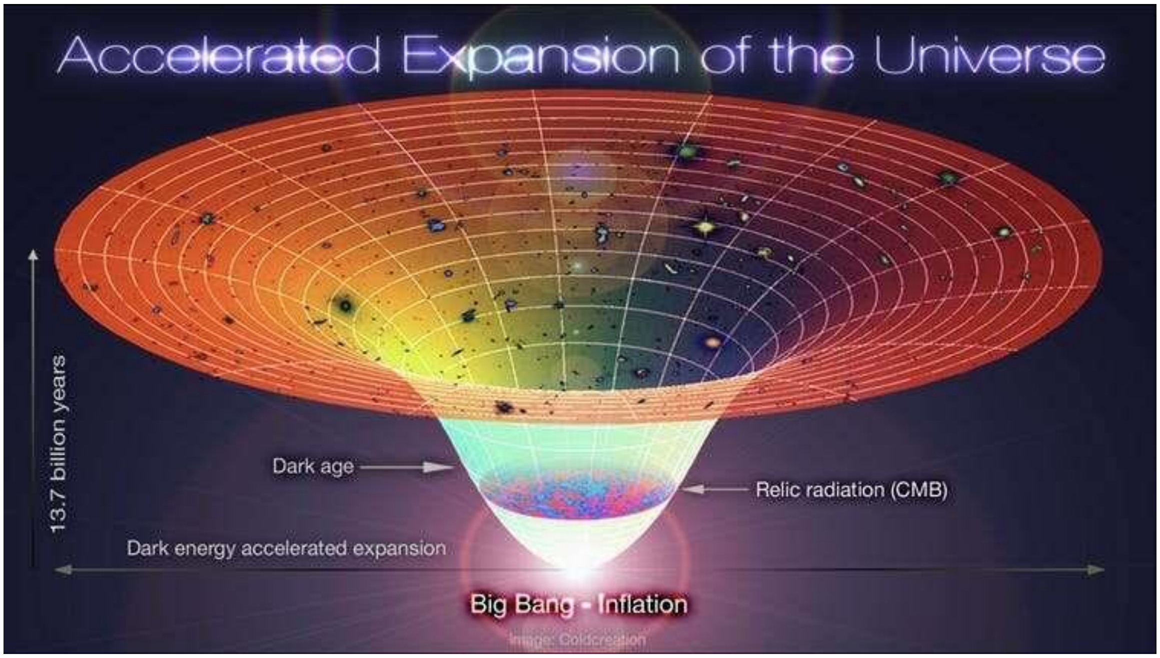
Possible shapes of the universe: top one is curved and closed, as suggested in the new study. Credit: wikipedia

Could we be wrong?

It is certainly possible that we turn out to be wrong. But there is one main reason, in our opinion, why this anomaly should not be merely discarded. In particle physics, a discovery should reach an accuracy of at least five "sigmas" to be accepted by the community. Here we are slightly above three sigmas, so we are clearly below this acceptance level. But while the standard model of particle physics is based on known and proven physics, the standard cosmological model is based on unknown physics.

At the moment, the physical evidence for the three pillars of cosmology—dark matter, dark energy (which causes the universe to expand at an accelerated rate) and inflation—comes solely from cosmology. Their existence can explain many astrophysical observations.

But they are not expected either in the standard model of particle physics that governs the universe on the smallest scales or in the theory of general relativity that operates on the large scales. Instead, these substances belong to the area of unknown physics. Nobody has ever seen either dark matter, dark energy or inflation—in the laboratory or elsewhere.



Credit: coldcreation, CC BY-SA

So while an anomaly in particle physics can be regarded as a hint that we may need to invent completely new physics, an anomaly in cosmology should be regarded as the only way we have to shed light on completely unknown physics.

Therefore, the most interesting result of our paper is not that the universe appears to be curved rather than flat, but the fact that it may force us to rearrange the pieces of the cosmic puzzle in a completely different way. [32]

Physicists simulate critical 'reheating' period that kickstarted the Big Bang

As the Big Bang theory goes, somewhere around 13.8 billion years ago the universe exploded into being, as an infinitely small, compact fireball of matter that cooled as it expanded, triggering reactions that cooked up the first stars and galaxies, and all the forms of matter that we see (and are) today.

Just before the Big Bang launched the universe onto its ever-expanding course, physicists believe, there was another, more explosive phase of the early universe at play: cosmic inflation, which lasted less than a trillionth of a second. During this period, matter—a cold, homogeneous goop—inflated exponentially quickly before processes of the Big Bang took over to more slowly expand and diversify the infant universe.

Recent observations have independently supported theories for both the Big Bang and cosmic inflation. But the two processes are so radically different from each other that scientists have struggled to conceive of how one followed the other.

Now physicists at MIT, Kenyon College, and elsewhere have simulated in detail an intermediary phase of the early universe that may have bridged cosmic inflation with the Big Bang. This phase, known as "reheating," occurred at the end of cosmic inflation and involved processes that wrestled inflation's cold, uniform matter into the ultrahot, complex soup that was in place at the start of the Big Bang.

"The postinflation reheating period sets up the conditions for the Big Bang, and in some sense puts the 'bang' in the Big Bang," says David Kaiser, the Germeshausen Professor of the History of Science and professor of physics at MIT. "It's this bridge period where all hell breaks loose and matter behaves in anything but a simple way."

Kaiser and his colleagues simulated in detail how multiple forms of matter would have interacted during this chaotic period at the end of inflation. Their simulations show that the extreme energy that drove inflation could have been redistributed just as quickly, within an even smaller fraction of a second, and in a way that produced conditions that would have been required for the start of the Big Bang.

The team found this extreme transformation would have been even faster and more efficient if quantum effects modified the way that matter responded to gravity at very high energies, deviating from the way Einstein's theory of general relativity predicts matter and gravity should interact.

"This enables us to tell an unbroken story, from inflation to the postinflation period, to the Big Bang and beyond," Kaiser says. "We can trace a continuous set of processes, all with known physics, to say this is one plausible way in which the universe came to look the way we see it today."

The team's results appear today in *Physical Review Letters*. Kaiser's co-authors are lead author Rachel Nguyen, and John T. Giblin, both of Kenyon College, and former MIT graduate student Evangelos Sfakianakis and Jorinde van de Vis, both of Leiden University in the Netherlands.

"In sync with itself"

The theory of cosmic inflation, first proposed in the 1980s by MIT's Alan Guth, the V.F. Weisskopf Professor of Physics, predicts that the universe began as an extremely small speck of matter, possibly about a hundred-billionth the size of a proton. This speck was filled with ultra-high-energy matter, so energetic that the pressures within generated a repulsive gravitational force—the driving force behind inflation. Like a spark to a fuse, this gravitational force exploded the infant universe outward, at an ever-faster rate, inflating it to nearly an octillion times its original size (that's the number 1 followed by 26 zeroes), in less than a trillionth of a second.

Kaiser and his colleagues attempted to work out what the earliest phases of reheating—that bridge interval at the end of cosmic inflation and just before the Big Bang—might have looked like.

"The earliest phases of reheating should be marked by resonances. One form of high-energy matter dominates, and it's shaking back and forth in sync with itself across large expanses of space, leading to explosive production of new particles," Kaiser says. "That behavior won't last forever, and once it starts transferring energy to a second form of matter, its own swings will get more choppy and uneven across space. We wanted to measure how long it would take for that resonant effect to break up, and for the produced particles to scatter off each other and come to some sort of thermal equilibrium, reminiscent of Big Bang conditions."

The team's computer simulations represent a large lattice onto which they mapped multiple forms of matter and tracked how their energy and distribution changed in space and over time as the scientists varied certain conditions. The simulation's initial conditions were based on a particular inflationary model—a set of predictions for how the early universe's distribution of matter may have behaved during cosmic inflation.

The scientists chose this particular model of inflation over others because its predictions closely match high-precision measurements of the cosmic microwave background—a remnant glow of radiation emitted just 380,000 years after the Big Bang, which is thought to contain traces of the inflationary period.

A universal tweak

The simulation tracked the behavior of two types of matter that may have been dominant during inflation, very similar to a type of particle, the Higgs boson, that was recently observed in other experiments.

Before running their simulations, the team added a slight "tweak" to the model's description of gravity. While ordinary matter that we see today responds to gravity just as Einstein predicted in his theory of general relativity, matter at much higher energies, such as what's thought to have existed during cosmic inflation, should behave slightly differently, interacting with gravity in ways that are modified by quantum mechanics, or interactions at the atomic scale.

In Einstein's theory of general relativity, the strength of gravity is represented as a constant, with what physicists refer to as a minimal coupling, meaning that, no matter the energy of a particular particle, it will respond to gravitational effects with a strength set by a universal constant.

However, at the very high energies that are predicted in cosmic inflation, matter interacts with gravity in a slightly more complicated way. Quantum-mechanical effects predict that the strength of gravity can vary in space and time when interacting with ultra-high-energy matter—a phenomenon known as nonminimal coupling.

Kaiser and his colleagues incorporated a nonminimal coupling term to their inflationary model and observed how the distribution of matter and energy changed as they turned this quantum effect up or down.

In the end they found that the stronger the quantum-modified gravitational effect was in affecting matter, the faster the universe transitioned from the cold, homogeneous matter in inflation to the much hotter, diverse forms of matter that are characteristic of the Big Bang.

By tuning this quantum effect, they could make this crucial transition take place over 2 to 3 "e-folds," referring to the amount of time it takes for the universe to (roughly) triple in size. In this case, they managed to simulate the reheating phase within the time it takes for the universe to triple in size two to three times. By comparison, inflation itself took place over about 60 e-folds.

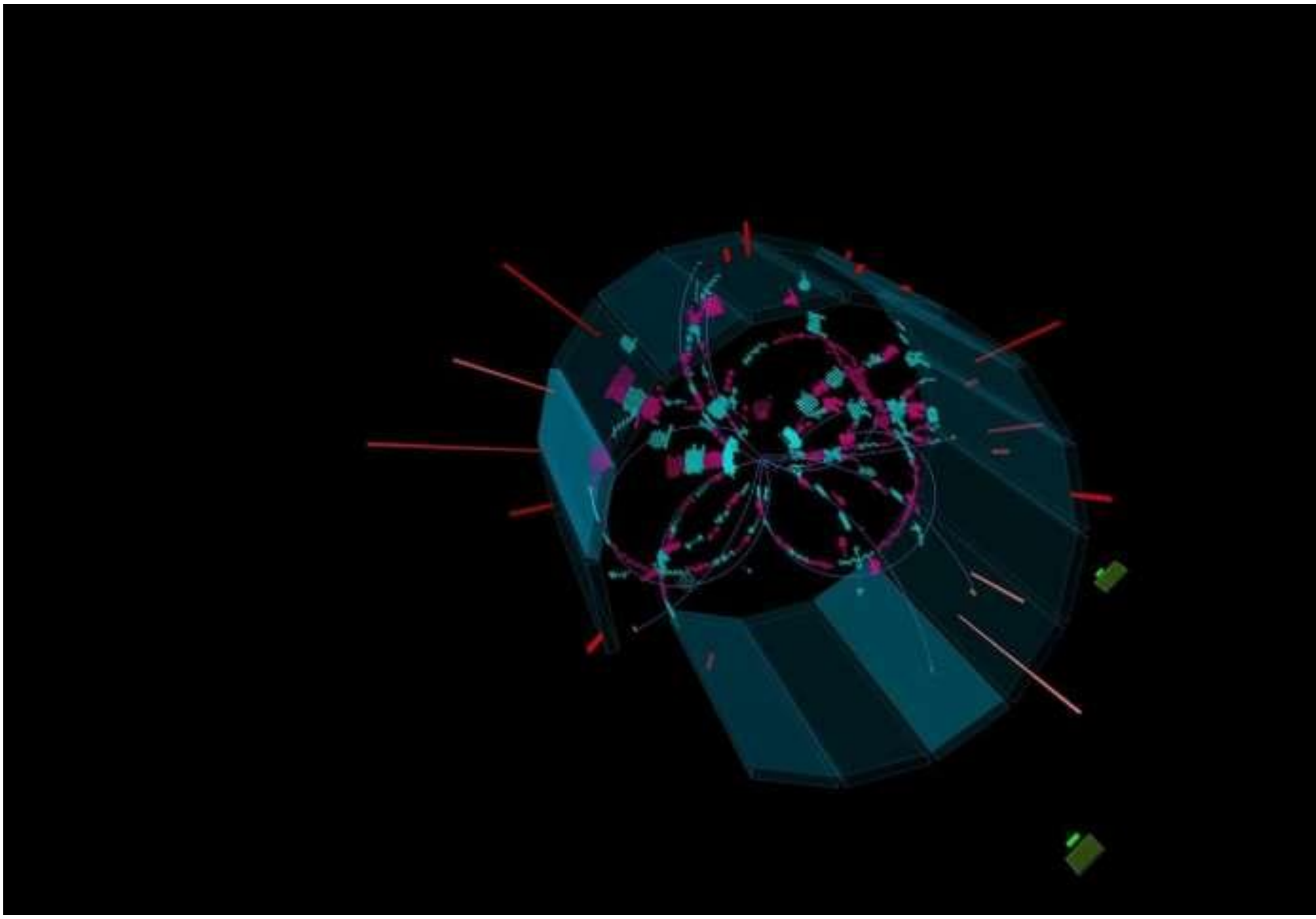
"Reheating was an insane time, when everything went haywire," Kaiser says. "We show that matter was interacting so strongly at that time that it could relax correspondingly quickly as well, beautifully setting the stage for the Big Bang. We didn't know that to be the case, but that's what's emerging from these simulations, all with known physics. That's what's exciting for us." [31]

Secrets of the Big Bang and dark matter

At the Japanese Research Center for Particle Physics KEK, the new particle accelerator experiment Belle II started operation after eight years of construction. Scientists from all over the world eagerly waited for news on the first collisions. 20 researchers of Karlsruhe Institute of Technology (KIT) are involved in the experiment. Based on the Belle II data, they want to study the events after the big bang and to find out the secret of dark matter. Yesterday evening at 5.23 pm German time, first data were measured.

The Belle II detector was conceived in 2010 as the successor of the successful Belle experiment that had been carried out from 1999 to 2010 and enabled some remarkable findings in physical fundamental research. Belle II is located at KEK, a particle physics research center about 55 km northeast of Tokyo in Tsukuba, Ibaraki prefecture, Japan. In this particle accelerator, electrons with opposed anti-particles collide and produce heavy quarks and leptons, particles that no longer exist in today's universe. "While the Large Hadron Collider at CERN is the accelerator with the highest energies – this is where the Higgs boson was discovered in 2012 -, the Japanese super accelerator has the world's highest luminosity, a hundred times higher than that of facilities operated so far," says Florian Bernlochner, Professor at KIT's Institute of Experimental Particle Physics.

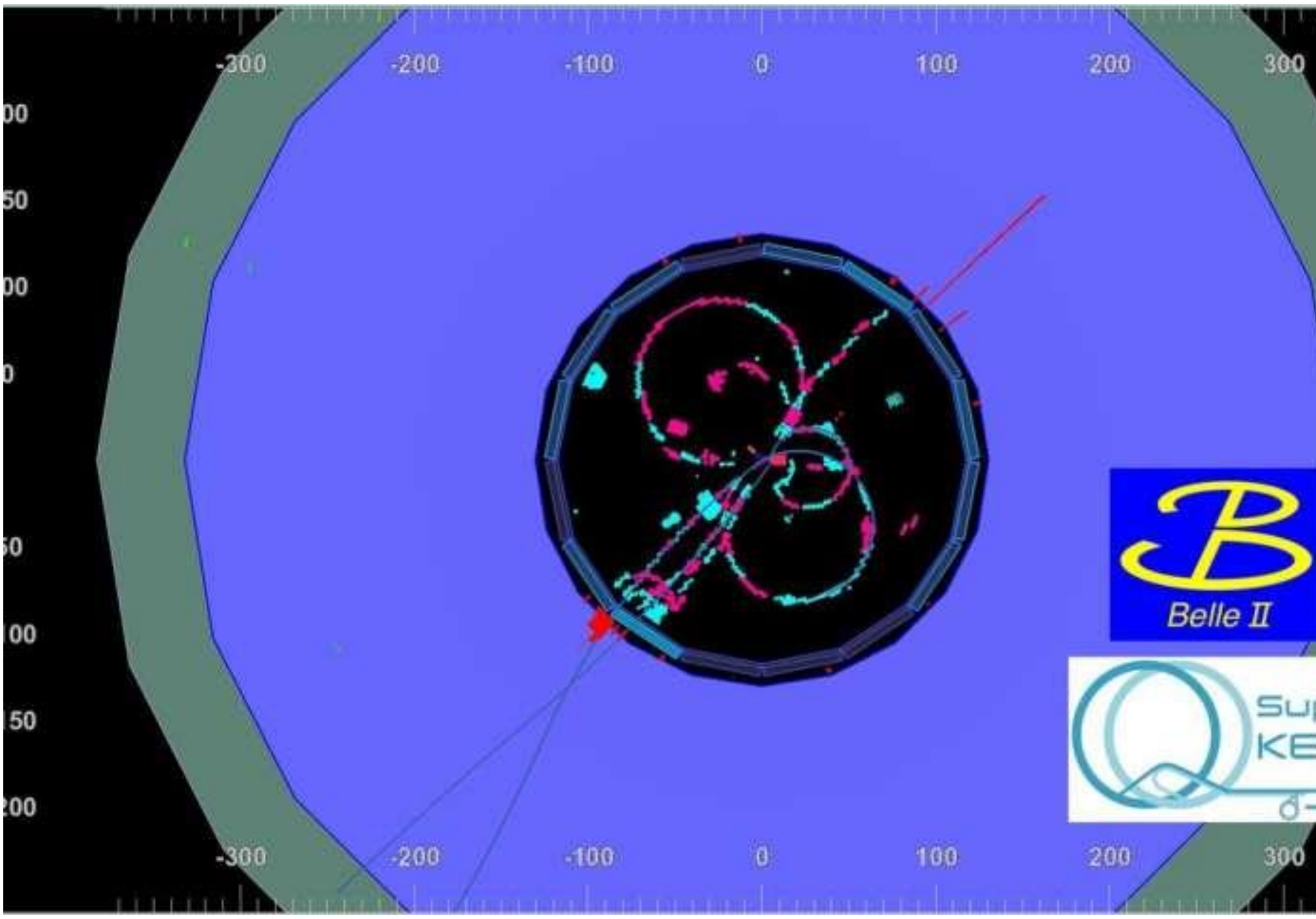
Based on the data, researchers want to explore precisely the events shortly after the big bang. Generation of so-called b-quarks and their anti-particles is of particular interest. Up to 50 billions of these matter-anti-matter pairs are to be produced in the next eight years. After a lifetime of just about one and a half trillionths of a second (10-12s), these heavy quarks decay into lighter, stable particles. Doing this, they violate the so-called CP symmetry (this discovery was granted a Nobel Prize in 2012), as matter and anti-matter show a slightly different behavior during decay.



The blue lines are reconstructed tracks, the magenta and cyan-colored circles are hits in the track chamber, while the red histograms present energy depositions in the Belle II calorimeter. The green boxes are hits in the KL detector (an …more

"This asymmetry, however, is not sufficient to explain why a surplus of matter remained in the early universe after cooling. Today's visible world is composed of this surplus," Professor Bernlochner says.

For this reason, the Belle II experiment searches for new sources of CP violation as well as new phenomena and elementary particles. Searches for dark matter will be of particular importance. Dark matter is not directly visible and only weakly interacts with normal matter: The Belle II experiment will be able to search for medium-light particles with so far unreached precision.



One of the first collision events. Credit: KEK

Several institutes of KIT have made important contributions to the Belle II experiment: The Institute for Theoretical Particle Physics was largely involved in the development of the planned physics program. The Institute of Experimental Particle Physics developed and implemented many algorithms to reconstruct real particles from the electronic signals of the detector. Only with their help can the collisions be analyzed. And the data of the meanwhile completed Belle experiment were used for important preliminary studies relating to the physical phenomena that are to be measured now. The Institute for Information Processing Technology developed new hardware to search for new phenomena in rare decays of tau-leptons. The Institute for Data Processing and Electronics and the ASIC and Detector Laboratory developed the radiation-resistant microchips for the activation and read-out of pixel sensors. [30]

Hunting for dark matter in the smallest galaxies in the Universe

Astrophysicists from the University of Surrey and the University of Edinburgh have created a new method to measure the amount of dark matter at the centre of tiny "dwarf" galaxies.

Dark matter makes up most of the mass of the Universe, yet it remains elusive. Depending on its properties, it can be densely concentrated at the centres of galaxies, or more smoothly distributed over larger scales. By comparing the distribution of dark matter in galaxies with detailed models, researchers can test or rule out different dark matter candidates.

The tightest constraints on dark matter come from the very smallest galaxies in the Universe, "dwarf galaxies". The smallest of these contain just a few thousand or tens of thousands of stars - so-called "ultra-faint" dwarfs. Such tiny galaxies, found orbiting close to the Milky Way, are made up almost entirely of dark matter. If the distribution of dark matter in these tiny galaxies could be mapped out it could provide new and exciting information about its nature. However, being entirely devoid of gas and containing very few stars, until recently there was no viable method for making this measurement.

In a study published by the *Monthly Notices of the Royal Astronomical Society* (*MNRAS*), a team of scientists from the University of Surrey have developed a new method to calculate the inner dark matter density of dwarf galaxies, even if they have no gas and very few stars. The key to the method is to make use of one or more dense star clusters orbiting close to the centre of the dwarf.

Star clusters are gravitationally bound collections of stars that orbit inside galaxies. Unlike galaxies, star clusters are so dense that their stars gravitationally scatter from one another causing them to slowly expand. The research team made the key new insight when they realised that the rate of this expansion depends on the gravitational field that the star cluster orbits in and, therefore, on the distribution of dark matter in the host galaxy. The team used a large suite of computer simulations to show how the structure of star clusters is sensitive to whether dark matter is densely packed at the centre of galaxies, or more smoothly distributed. The team then applied their method to the recently discovered "ultra-faint" dwarf galaxy, Eridanus II, finding much less dark matter in its centre than many models would have predicted.

Dr Filippo Contenta from the University of Surrey and lead author of the study said: "We have developed a new tool to uncover the nature of dark matter and already the results are exciting. Eridanus II, one of the smallest galaxies known, has less dark matter in its centre than expected. If similar results are found for a larger sample of galaxies, this could have wide-ranging implications for the nature of dark matter."

Professor Mark Gieles, Professor of Astrophysics at the University of Surrey and Principal Investigator of the European Research Council (ERC) project that funded the project, added: "We started this ERC project with the hope that we could use star clusters to learn about dark matter so it is very exciting that it worked."

Professor Justin Read, a co-author on the study from the University of Surrey, added: "It is challenging to understand our results for Eridanus II if dark matter comprises a weakly interacting 'cold' particle—the currently-favoured model for dark matter. One possibility is that the dark matter at the very centre of Eridanus II was "heated up" by violent star formation, as suggested by some recent numerical models. More tantalising, however, is the possibility is that dark matter is more complex than we have assumed to date."

Dr Jorge Peñarrubia from the University of Edinburgh's School of Physics and Astronomy said: "These findings lend a fascinating insight into the distribution of dark matter in the most dark matter dominated galaxies in the Universe, and there is great potential for what this new method might uncover in the future." [29]

Unprecedentedly wide and sharp dark matter map

A research team of multiple institutes, including the National Astronomical Observatory of Japan and University of Tokyo, released an unprecedentedly wide and sharp dark matter map based on the newly obtained imaging data by Hyper Suprime-Cam on the Subaru Telescope. The dark matter distribution is estimated by the weak gravitational lensing technique (Figure 1, Movie). The team located the positions and lensing signals of the dark matter halos and found indications that the number of halos could be inconsistent with what the simplest cosmological model suggests. This could be a new clue to understanding why the expansion of the Universe is accelerating.

Mystery of the accelerated Universe

In the 1930's, Edwin Hubble and his colleagues discovered the expansion of the Universe. This was a big surprise to most of the people who believed that the Universe stayed the same throughout eternity. A formula relating matter and the geometry of space-time was required in order to express the expansion of the Universe mathematically. Coincidentally, Einstein had already developed just such a formula. Modern cosmology is based on Einstein's theory for gravity.

It had been thought that the expansion is decelerating over time (blue and red lines in Figure 2) because the contents of the Universe (matter) attract each other. But in the late 1990's, it was found that the expansion has been accelerating since about 8 Giga years ago. This was another big surprise which earned the astronomers who found the expansion a Nobel Prize in 2011. To explain the acceleration, we have to consider something new in the Universe which repels the space.

The simplest resolution is to put the cosmological constant back into Einstein's equation. The cosmological constant was originally introduced by Einstein to realize a static universe, but was abandoned after the discovery of the expansion of the Universe. The standard cosmological model (called LCDM) incorporates the cosmological constant. The expansion history using LCDM is shown by the green line in Figure 2. LCDM is supported by many observations, but the question of what causes the acceleration still remains. This is one of the biggest problems in modern cosmology.

Wide and deep imaging survey using Hyper Suprime-Cam

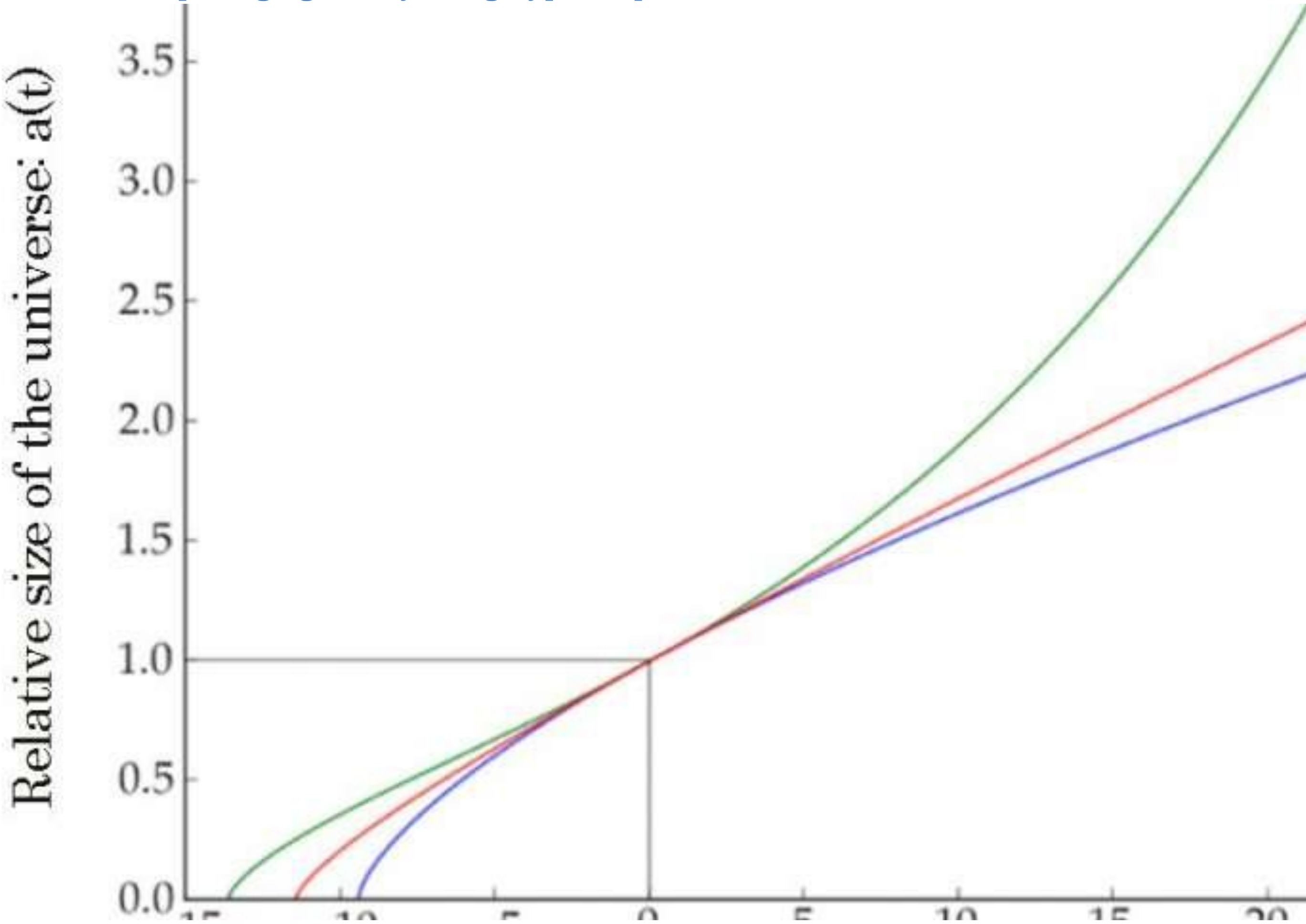


Figure 2: Expansion history of the Universe. The blue line shows what was believed to be likely in the early days of cosmology. Later this cosmological model fell out of favor because it predicts a higher growth rate and more structures, …more

The team is leading a large scale imaging survey using Hyper Suprime-Cam (HSC) to probe the mystery of the accelerating Universe. The key here is to examine the expansion history of the Universe very carefully.

In the early Universe, matter was distributed almost but not quite uniformly. There were slight fluctuations in the density which can now be observed through the temperature fluctuations of the cosmic microwave background. These slight matter fluctuations evolved over cosmic time because of the mutual gravitational attraction of matter, and eventually the large scale structure of the present day Universe become visible. It is known that the growth rate of the structure strongly depends on how the Universe expands. For example, if the expansion rate is high, it is hard for matter to contract and the growth rate is suppressed. This means that the expansion history can be probed inversely through the observation of the growth rate.

It is important to note that growth rate cannot be probed well if we only observe visible matter (stars and galaxies). This is because we now know that nearly 80 % of the matter is an invisible substance called dark matter. The team adopted the 'weak gravitation lensing technique." The images of distant galaxies are slightly distorted by the gravitational field generated by the foreground dark matter distribution. Analysis of the systematic distortion enables us to reconstruct the foreground dark matter distribution.

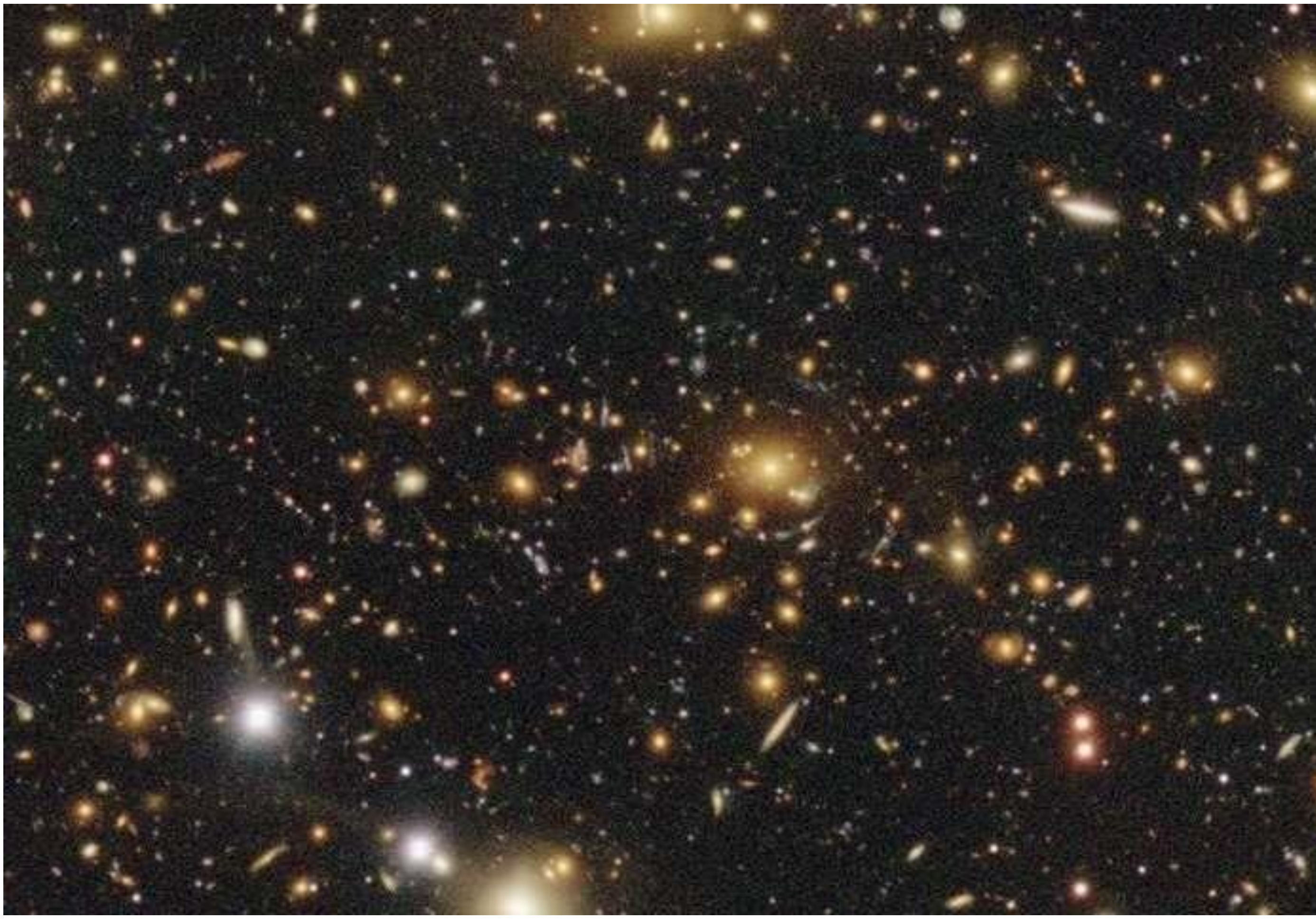


Figure 3: Hyper Suprime-Cam image of a location with a highly significant dark matter halo detected through the weak gravitational lensing technique. This halo is so massive that some of the background (blue) galaxies are stretched …more

This technique is observationally very demanding because the distortion of each galaxy is generally very subtle. Precise shape measurements of faint and apparently small galaxies are required. This motivated the team to develop Hyper Suprime-Cam. They have been carrying out a wide field imaging survey using Hyper Suprime-Cam since March 2014. At this writing in February 2018, 60 % of the survey has been completed.

Unprecedentedly wide and sharp dark matter map

In this release, the team presents the dark matter map based on the imaging data taken by April 2016 (Figure 1). This is only 11 % of the planned final map, but it is already unprecedentedly wide. There has never been such a sharp dark matter map covering such a wide area.

Imaging observations are made through five different color filters. By combining these color data, it is possible to make a crude estimate of the distances to the faint background galaxies (called photometric redshift). At the same time, the lensing efficiency becomes most prominent when the lens is located directly between the distant galaxy and the observer. Using the photometric redshift information, galaxies are grouped into redshift bins. Using this grouped galaxy sample, dark matter distribution is reconstructed using tomographic methods and thus the 3-D distribution can be obtained. Figure 4 shows one such example. Data for 30 square degrees are used to reconstruct the redshift range between 0.1 (~1.3 G light-years) and 1.0 (~8 G light-years). At the redshift of 1.0, the angular span corresponds to 1.0 G x 0.25 G light-years. This 3-D dark matter mass map is also quite new. This is the first time the increase in the number of dark matter halos over time can be seen observationally.

What the dark matter halo count suggests and future prospects

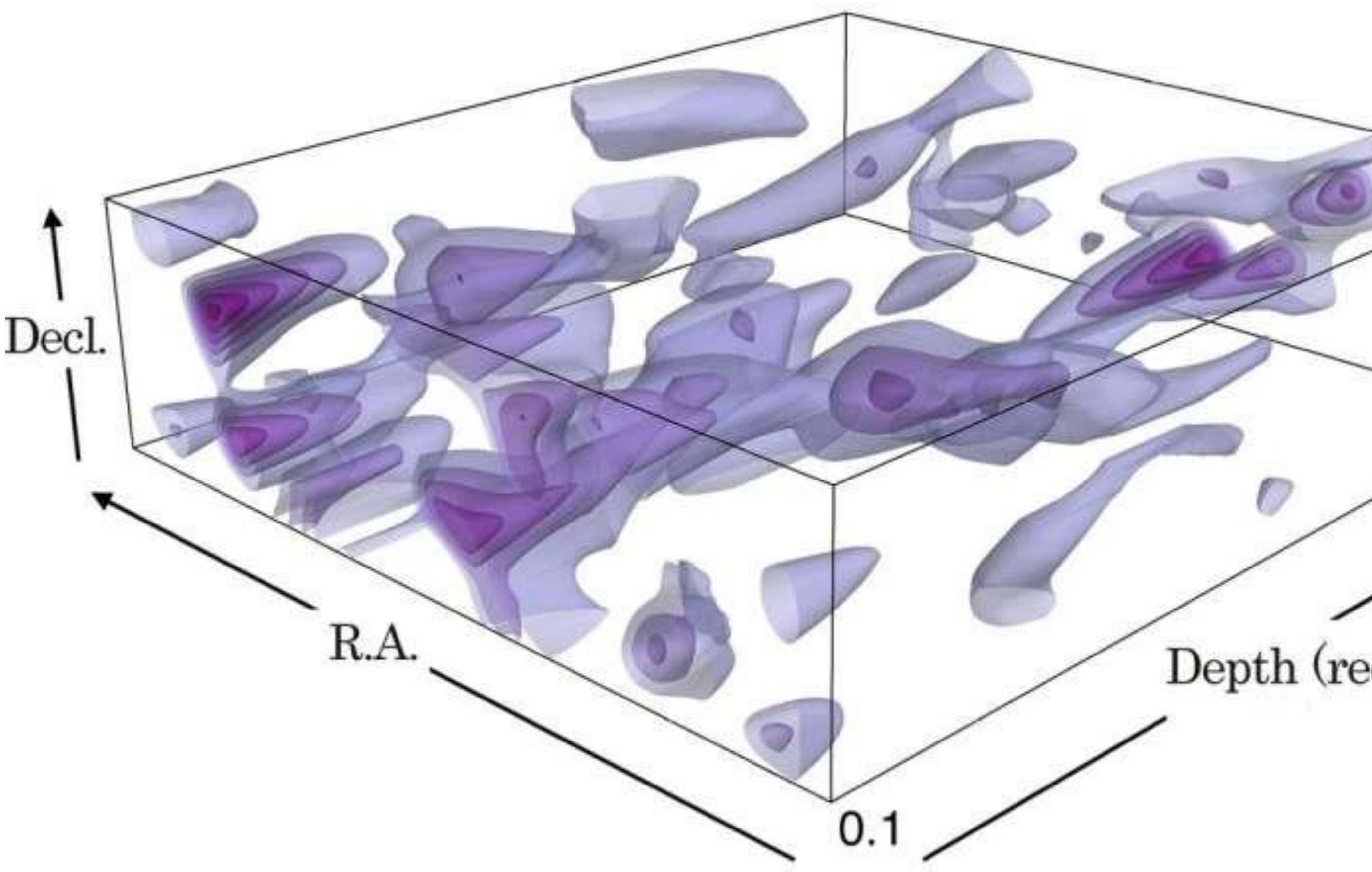


Figure 4: An example of 3D distribution of dark matter reconstructed via tomographic methods using the weak lensing technique combined with the redshift estimates of the background galaxies. All of the 3D maps are available here. Credit: University of Tokyo/NAOJ

The team counted the number of dark matter halos whose lensing signal is above a certain threshold. This is one of the simplest measurements of the growth rate. The histogram (black line) in Figure 5 shows the observed lensing signal strength versus the number of observed halos whereas the model prediction is shown by the solid red line. The model is based on the standard LCDM model using the observation of cosmic microwave background as the seed of the fluctuations. The figure suggests that the number count of the dark matter halos is less than what is expected from LCDM. This could indicate there is a flaw in LCDM and that we might have to consider an alternative rather than the simple cosmological constant.

The statistical significance is, however, still limited as the large error bars (vertical line on the histogram in Figure 5) suggest. There has been no conclusive evidence to reject LCDM, but many astronomers are interested in testing LCDM because discrepancies can be a useful probe to unlock the mystery of the accelerating Universe. Further observation and analysis are needed to confirm the discrepancy with higher significance. There are some other probes of the growth rate and such analysis are also underway (e.g. angular correlation of galaxy shapes) in the team to check the validity of standard LCDM.

These results were published on January 1, 2018 in the HSC special issue of the Publications of the Astronomical Society of Japan. The report is titled "A large sample of shear-selected clusters from the Hyper Suprime-Cam Subaru Strategic Program S16A Wide field mass maps."

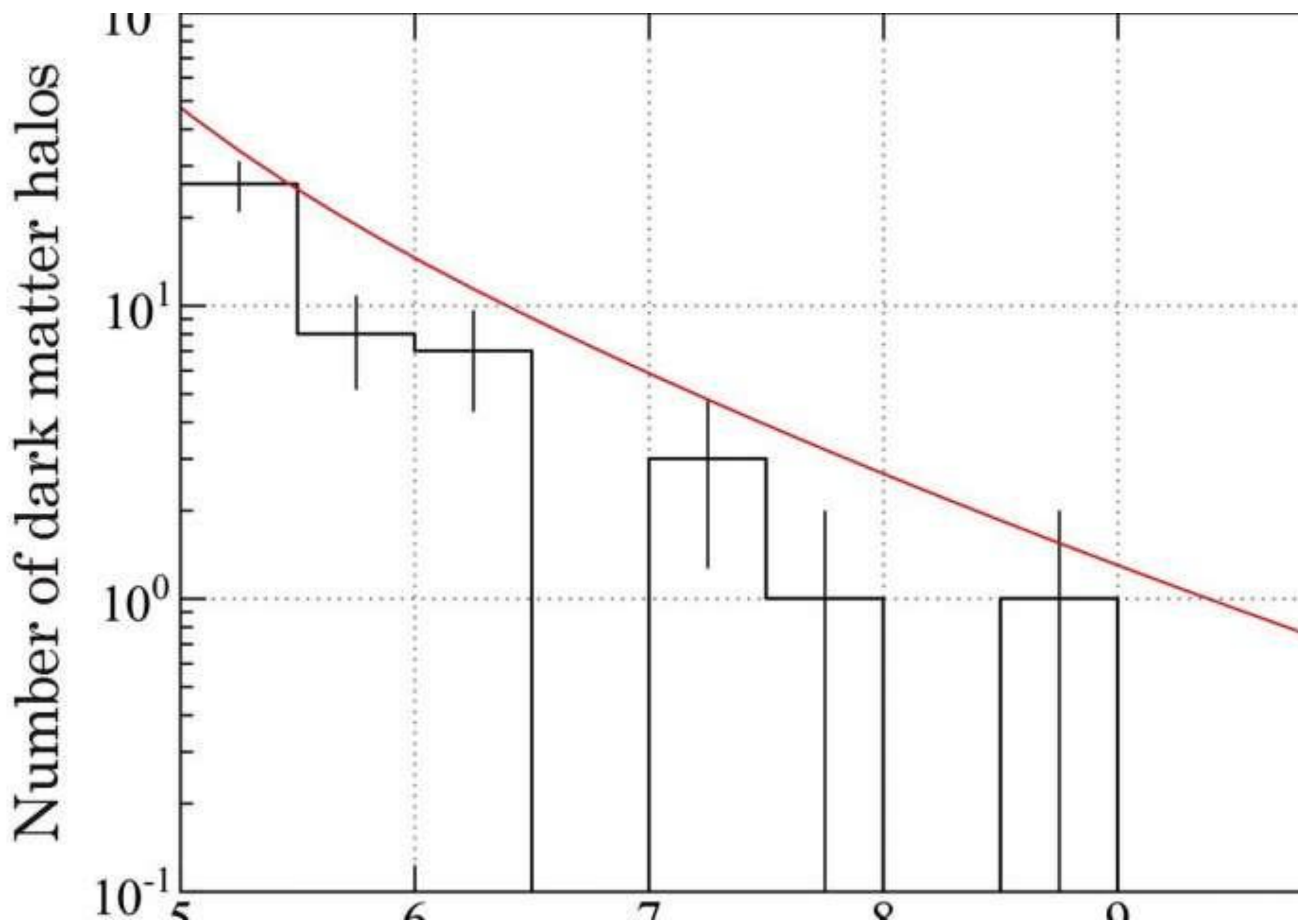


Figure 5: Number of dark matter halos versus their lensing signal strength (black histogram) and number count expected from LCDM and the most recent CMB observation by the Planck satellite. Credit: NAOJ/University of Tokyo [28]

Signal detected from the first stars in the universe, with a hint that dark matter was involved

A signal caused by the very first stars to form in the universe has been picked up by a tiny but highly specialised radio telescope in the remote Western Australian desert.

Details of the detection are revealed in a paper published today in Nature and tell us these stars formed only 180 million years after the Big Bang.

It's potentially one of the most exciting astronomical discoveries of the decade. A second Nature paper out today links the finding to possibly the first detected evidence that dark matter, thought to make up much of the universe, might interact with ordinary atoms.

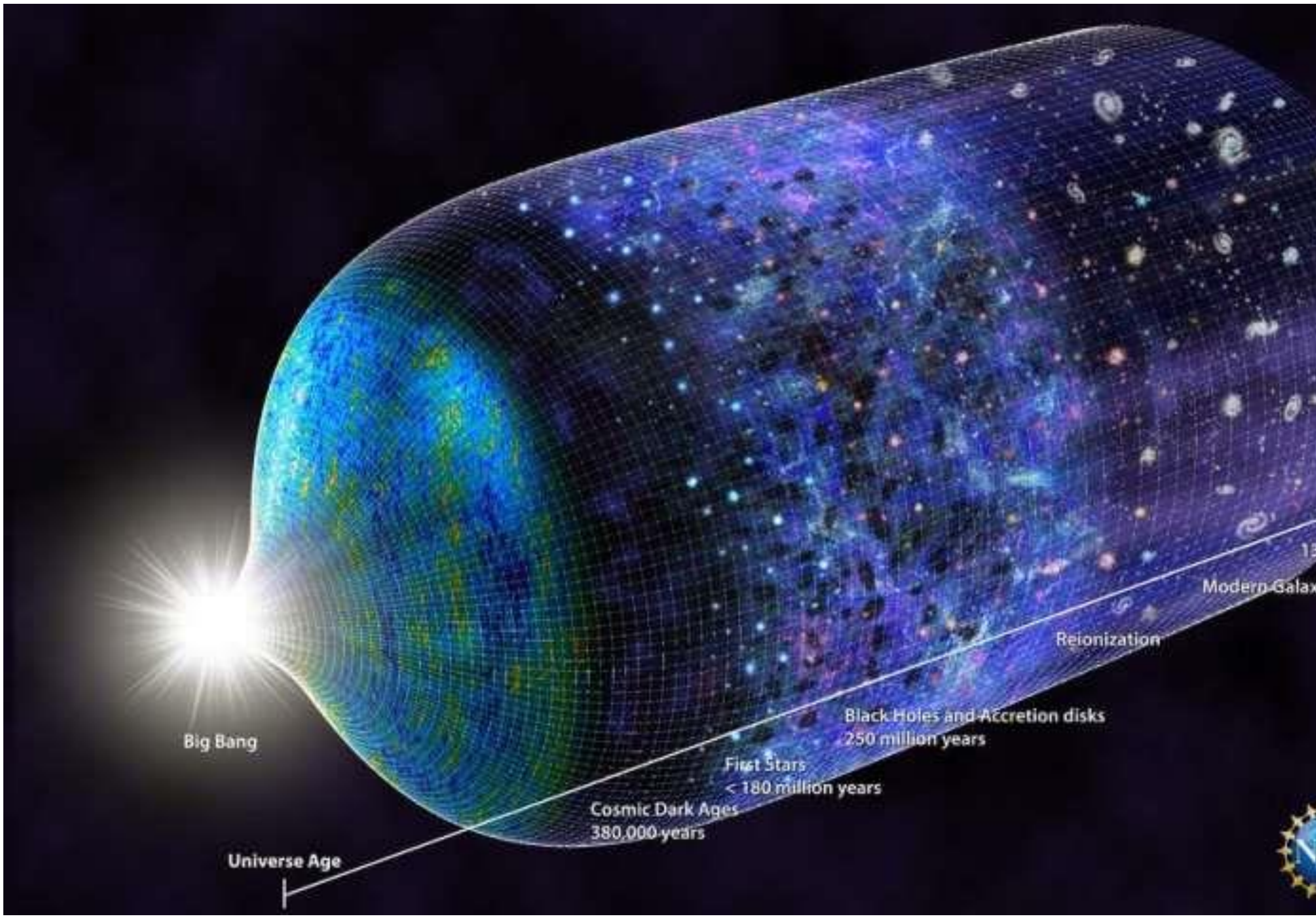
Tuning in to the signal

This discovery was made by a small radio antenna operating in the band of 50-100Mhz, which overlaps some well known FM radio stations (which is why the telescope is located in the remote WA desert).

What has been detected is the absorption of light by neutral atomic hydrogen gas, which filled the early universe after it cooled down from the hot plasma of the Big Bang.

At this time (180 million years after the Big Bang) the early universe was expanding, but the densest regions of the universe were collapsing under gravity to make the first stars.

The formation of the first stars had a dramatic effect on the rest of the universe. Ultraviolet radiation from them changed the electron spin in the hydrogen atoms, causing it to absorb the background radio emission of the universe at a natural resonant frequency of 1,420MHz, casting a shadow so to speak.



A timeline of the universe, updated to show when the first stars emerged emerged by 180 million years after the Big Bang. Credit: N.R. Fuller, National Science Foundation

Now, 13 billion years later, that shadow would be expected at a much lower frequency because the universe has expanded nearly 18-fold in that time.

An early result

Astronomers had been predicting this phenomenon for nearly 20 years and searching for it for ten years. No one quite knew how strong the signal would be or at what frequency to search.

Most expected it would take quite a few more years post 2018.

But the shadow was detected at 78MHz by a team led by astronomer Judd Bowman from Arizona State university.

Amazingly this radio signal detection in 2015-2016 was done by a small aerial (the EDGES experiement), only a few metres in size, coupled to a very clever radio receiver and signal processing system. It's only been published now after rigorous checking.

This is the most important astronomical discovery since the detection of gravitational waves in 2015. The first stars represent the start of everything complex in the universe, the beginning of the long journey to galaxies, solar systems, planets, life and brains.

The EDGES ground-based radio spectrometer, CSIRO's Murchison Radio-astronomy Observatory in Western Australia. Credit: CSIRO

Detecting their signature is a milestone and pinning down the exact time of their formation is an important measurement for cosmology.

This is an amazing result. But it gets better and even more mysterious and exciting.

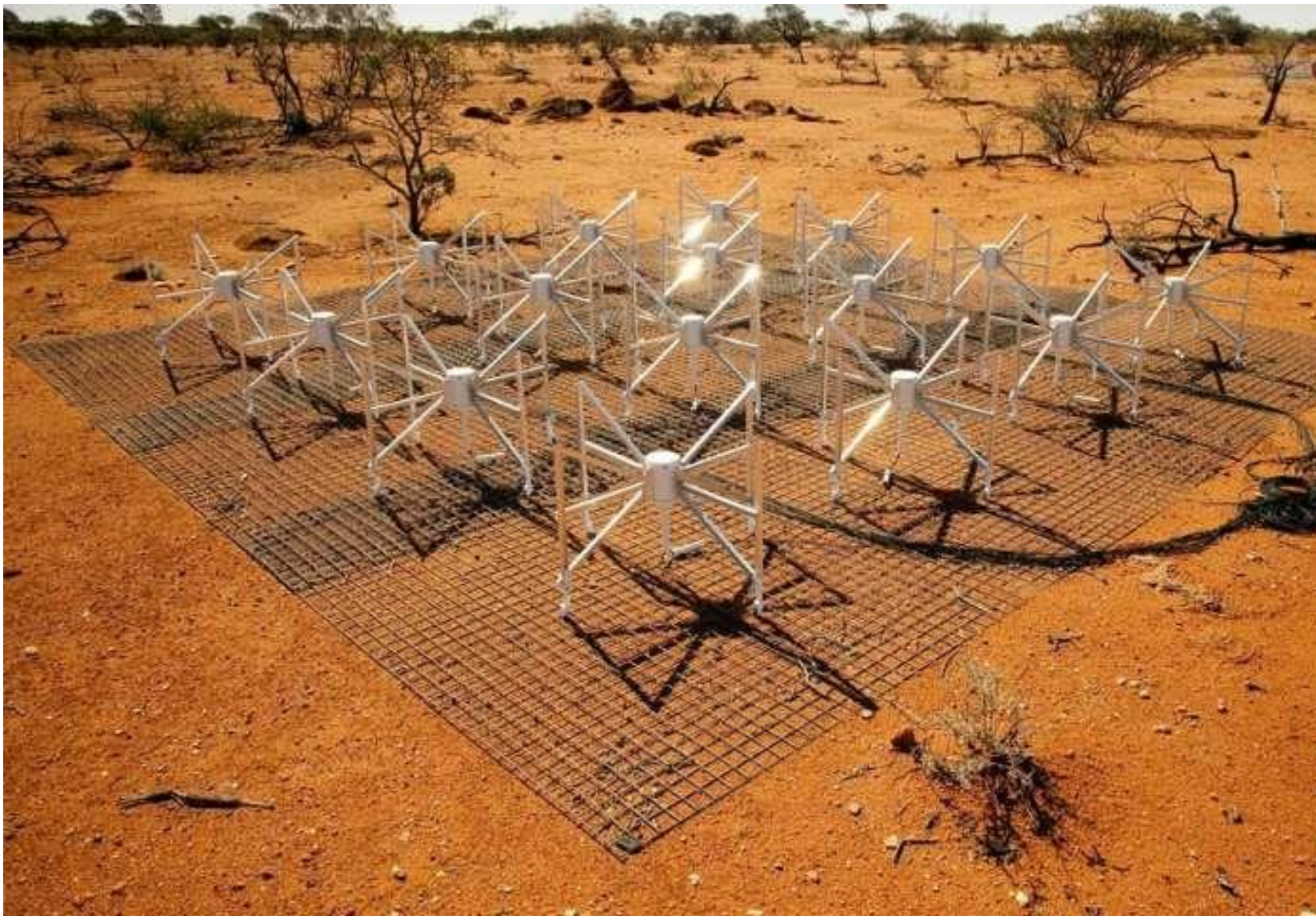
Evidence of dark matter?

The signal is twice as strong as expected, which is why it has been detected so early. In the second Nature paper, astronomer Rennan Barkana, from the Tel Aviv University, said it is quite hard to explain why the signal is so strong, as it tells us the hydrogen gas at this time is significantly colder than expected in the standard model of cosmic evolution.

Astronomers like to introduce new kinds of exotic objects to explain things (e.g. super massive stars, black holes) but these generally produce radiation that makes things hotter instead.

How do you make the atoms colder? You have to put them in thermal contact with something even colder, and the most viable suspect is what is known as cold dark matter.

Cold dark matter is the bedrock of modern cosmology. It was introduced in the 1980s to explain how galaxies rotate—they seemed to spin much faster than could be explained by the visible stars and an extra gravitational force was needed.



One of 128 tiles of the Murchison Widefield Array (MWA) telescope. Credit: Flickr/Australian SKA Office/WA Department of Commerce, CC BY-ND

We now think that dark matter has to be made of a new kind of fundamental particle. There is about six times more dark matter than ordinary matter and if it was made of normal atoms the Big Bang would have looked quite different to what is observed.

As for the nature of this particle, and its mass, we can only guess.

So if cold dark matter is indeed colliding with hydrogen atoms in the early universe and cooling them, this is a major advance and could lead us to pin down its true nature. This would be the first time dark matter has demonstrated any interaction other than gravity.

Here comes the 'but'

A note of caution is warranted. This hydrogen signal is very difficult to detect: it is thousands of times fainter than the background radio noise even for the remote location in Western Australia.

The authors of the first Nature paper have spent more than a year doing a multitude of tests and checks to make sure they have not made a mistake. The sensitivity of their aerial needs to be exquisitely calibrated all across the bandpass. The detection is an impressive technical achievement but astronomers worldwide will be holding their breath until the result is confirmed by an independent experiment.

If it is confirmed then this will open the door to a new window on the early universe and potentially a new understanding of the nature of dark matter by providing a new observational window in to it.

This signal has been detected coming from the whole sky, but in the future it can be mapped on the sky, and the details of the structures in the maps would then give us even more information on the physical properties of the dark matter.

More desert observations

Today's publications are exciting news for Australia in particular. Western Australia is the most radio quiet zone in the world, and will be the prime location for future mapping observations. The Murchison Widefield Array is in operation right now, and future upgrades could provide exactly such a map.

This is also a major science goal of the multi-billion dollar Square Kilometre Array, located in Western Australia, that should be able to provide much greater fidelity pictures of this epoch.

It is extremely exciting to look forward to a time when we will be able to reveal the nature of the first stars and to have a new approach via radio astronomy to tackle dark matter, which has so far proved intractable.

Let's hope the governments of the world, or at least Australia, can keep the frequency of 78 MHz clean of pop music and talk shows so we can continue to observe the birth of the universe.

Physicists contribute to dark matter detector success

In researchers' quest for evidence of dark matter, physicist Andrea Pocar of the University of Massachusetts Amherst and his students have played an important role in designing and building a key part of the argon-based DarkSide-50 detector located underground in Italy's Gran Sasso National Laboratory.

This week, scientists from around the world who gathered at the University of California, Los Angeles, at the Dark Matter 2018 Symposium learned of new results in the search for evidence of the elusive material in Weakly Interacting Massive Particles (WIMPs) by the DarkSide-50 detector. WIMPs have been candidate dark matter particles for decades, but none have been found to date.

Pocar says the DarkSide detector has demonstrated the great potential of liquid argon technology in the search for so-called "heavy WIMPs," those with mass of about 100 to 10,000 times the mass of a proton. Further, he adds, the double-phase argon technique used by the DarkSide-50 detector has unexpected power in the search for "low-mass WIMPs," with only 1-10 times the mass of a proton.

He adds, "The component we made at UMass Amherst, with very dedicated undergraduates involved from the beginning, is working very well. It's exciting this week to see the first report of our success coming out at the symposium." His graduate student Alissa Monte, who has studied surface and radon-related backgrounds using DarkSide-50, will present a poster at the UCLA meeting.

Pocar says, "There is a vibrant community of researchers around the world conducting competing experiments in this 'low mass' WIMP area. Over the past two years we collected data for a measurement we didn't expect to be able to make. At this point we are in a game we didn't think we could be in. We are reporting the high sensitivity we have achieved with the instrument, which is performing better than expected." Sensitivity refers to the instrument's ability to distinguish between dark matter and background radiation.

Dark matter, Pocar explains, represents about 25 percent of the energy content of the universe and while it has mass that can be inferred from gravitational effects, physicists have great difficulty detecting and identifying it because it hardly interacts, if at all, with "regular" matter through other forces. "Dark matter doesn't seem to want to interact much at all with the matter we know about," the physicist notes.

The DarkSide-50 detector uses 50 kg (about 110 lbs.) of liquid argon in a vat, with a small pocket of argon gas at the top, Pocar explains, as a target to detect WIMPs. The researchers hope for a WIMP to hit the nucleus of an argon atom in the tank, which then can be detected by the ionization produced by the nuclear recoil in the surrounding argon medium. Some of the ionization signal, proportional to the energy deposited inside the detector, is collected by applying an electric field to the target, he explains.

A flash of light is also produced in the argon with ionization, Pocar says. For high-enough energy events, the light pulse is bright enough to be used to tell the difference in "signature" between a nuclear recoil like that induced by a WIMP, and electron recoils induced by background or environmental radioactivity.

Pocar's lab designed, made and installed one of the electrodes that apply the electric field. He says, "For low-mass WIMPs, the amount of energy transmitted to the nucleus of argon by a WIMP is incredibly tiny. It's like hitting a billiard ball with a slow ping-pong ball. But a key thing for us is that now with two years of data, we have an exquisite understanding of our detector and we understand all non-WIMP events very well. Once you understand your detector, you can apply all that understanding in search mode, and plan for follow-up experiments."

Cristiano Galbiati, spokesperson for the DarkSide project, said at this week's symposium, "This is the best way to start the adventure of the future experiment DarkSide-20k. The results of DarkSide-50 provide great confidence on our technological choices and on the ability to carry out a compelling discovery program for dark matter. If a detector technology will ever identify convincingly dark matter induced events, this will be it." [26]

The search for dark matter—axions have ever-fewer places to hide

If they exist, axions, among the candidates for dark matter particles, could interact with the matter comprising the universe, but at a much weaker extent than previously theorized. New, rigorous constraints on the properties of axions have been proposed by an international team of scientists.

The latest analysis of measurements of the electrical properties of ultracold neutrons, published in the scientific journal *Physical Review X*, has led to surprising conclusions. On the basis of data collected in the Electric Dipole Moment of Neutron (nEDM) experiment, an international group of physicists demonstrated that axions, hypothetical particles that may comprise cold dark matter, would have to comply with much stricter limitations than previously believed with regard to their mass and manners of interacting with ordinary matter. The results are the first laboratory data imposing limits on the potential interactions of axions with nucleons (i.e. protons or neutrons) and gluons (the particles bonding quarks in nucleons).

"Measurements of the electric dipole moment of neutrons have been conducted by our international group for a good dozen or so years. For most of this time, none of us suspected that any traces associated with potential particles of dark matter might be hidden in the collected data. Only recently, theoreticians have suggested such a possibility and we eagerly took the opportunity to verify the hypotheses about the properties of axions," says Dr. Adam Kozela (IFJ PAN), one of the participants in the experiment.

Dark matter was first proposed to explain the movements of stars within galaxies and galaxies within galactic clusters. The pioneer of statistical research on star movements was the Polish astronomer Marian Kowalski. In 1859, he noticed that the movements of nearby stars could not be explained solely by the movement of the sun. This was the first observational evidence suggesting the rotation of the Milky Way. Kowalski is thus the man who "shook the foundations" of the galaxy. In 1933, the Swiss astronomer Fritz Zwicky went one step further. He analyzed the movements of structures in the Coma galaxy cluster using several methods. He then noticed that they moved as if there were a much larger amount of matter in their surroundings than that observed by astronomers.

Astronomers believe there should be almost 5.5 times as much dark matter in the universe as ordinary matter, as background microwave radiation measurements suggest. But the nature of dark matter is still unknown. Theoreticians have constructed many models predicting the existence of particles that are more or less exotic, which may account for dark matter. Among the candidates are axions. These extremely light particles would interact with ordinary matter almost exclusively via gravity. Current models predict that in certain situations, a photon could change into an axion, and after some time, transform back into a photon. This hypothetical phenomenon is the basis of the famous "lighting through a wall" experiments. These involve directing an intense beam of laser light onto a thick obstacle, and observing those photons that change into axions that penetrate the wall. After passing through, some of the axions could become photons again, with features exactly like those originally directed at the barrier.

Experiments related to measuring the electric dipole moment of neutrons have nothing to do with photons. In experiments conducted for over 10 years, scientists measured changes in the frequency of nuclear magnetic resonance (NMR) of neutrons and mercury atoms in a vacuum chamber in the presence of electric, magnetic and gravitational fields. These measurements enabled the researchers to draw conclusions about the precession of neutrons and mercury atoms, and consequently on their dipole moments.

Theoretical works have appeared in recent years that envisage the possibility of axions interacting with gluons and nucleons. Depending on the mass of the axions, these interactions could result in smaller or larger disturbances with the character of oscillations of dipole electrical moments of nucleons, or even whole atoms. The predictions meant that experiments conducted as part of the nEDM cooperation could contain valuable information about the existence and properties of potential particles of dark matter.

"In the data from the experiments at PSI, our colleagues conducting the analysis looked for frequency changes with periods in the order of minutes, and in the results from ILL—in the order of days. The latter would appear if there was an axion wind, that is, if the axions in the near Earth space were moving in a specific direction. Since the Earth is spinning, at different times of the day our measuring equipment would change its orientation relative to the axion wind, and this should result in cyclical, daily changes in the oscillations recorded by us," explains Dr. Kozela.

The results of the search turned out to be negative. No trace of the existence of axions with masses between 10^{-24} and 10^{-17} electron volts were found (for comparison: the mass of an electron is more than half a million electron volts). In addition, the scientists managed to tighten the constraints imposed by theory on the interaction of axions with nucleons by 40 times. In the case of potential interactions with gluons, the restrictions have increased more than 1000-fold. So if axions do exist, in the current theoretical models, they have fewer places to hide. [25]

MACHOs are dead. WIMPs are a no-show. Say hello to SIMPs: New candidate for dark matter

The intensive, worldwide search for dark matter, the missing mass in the universe, has so far failed to find an abundance of dark, massive stars or scads of strange new weakly interacting particles, but a new candidate is slowly gaining followers and observational support.

Called SIMPs - strongly interacting massive particles - they were proposed three years ago by University of California, Berkeley theoretical physicist Hitoshi Murayama, a professor of physics and director of the Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU) in Japan, and former UC Berkeley postdoc Yonit Hochberg, now at Hebrew University in Israel.

Murayama says that recent observations of a nearby galactic pile-up could be evidence for the existence of SIMPs, and he anticipates that future particle physics experiments will discover one of them.

Murayama discussed his latest theoretical ideas about SIMPs and how the colliding galaxies support the theory in an invited talk Dec. 4 at the 29th Texas Symposium on Relativistic Astrophysics in Cape Town, South Africa.

Astronomers have calculated that dark matter, while invisible, makes up about 85 percent of the mass of the universe. The solidest evidence for its existence is the motion of stars inside galaxies: Without an unseen blob of dark matter, galaxies would fly apart. In some galaxies, the visible stars are so rare that dark matter makes up 99.9 percent of the mass of the galaxy.

Theorists first thought that this invisible matter was just normal matter too dim to see: failed stars called brown dwarfs, burned-out stars or black holes. Yet so-called massive compact halo objects - MACHOs - eluded discovery, and earlier this year a survey of the Andromeda galaxy by the Subaru Telescope basically ruled out any significant undiscovered population of black holes. The researchers searched for black holes left over from the very early universe, so-called primordial black holes, by looking for sudden brightenings produced when they pass in front of background stars and act like a weak lens. They found exactly one - too few to contribute significantly to the mass of the galaxy.

The fundamental structure of the proposed SIMP (strongly interacting massive particle) is similar to that of a pion (left). Pions are composed of an up quark and a down antiquark, with a gluon (g) holding them together. A SIMP would be composed of a quark and an antiquark held together by a gluon (G). Credit: Kavli IPMU graphic

"That study pretty much eliminated the possibility of MACHOs; I would say it is pretty much gone," Murayama said.

WIMPs—weakly interacting massive particles—have fared no better, despite being the focus of researchers' attention for several decades. They should be relatively large - about 100 times heavier than the proton - and interact so rarely with one another that they are termed "weakly" interacting. They were thought to interact more frequently with normal matter through gravity, helping to attract normal matter into clumps that grow into galaxies and eventually spawn stars.

SIMPs interact with themselves, but not others

SIMPs, like WIMPs and MACHOs, theoretically would have been produced in large quantities early in the history of the universe and since have cooled to the average cosmic temperature. But unlike WIMPs, SIMPs are theorized to interact strongly with themselves via gravity but very weakly with normal matter. One possibility proposed by Murayama is that a SIMP is a new combination of quarks, which are the fundamental components of particles like the proton and neutron, called baryons. Whereas protons and neutrons are composed of three quarks, a SIMP would be more like a pion in containing only two: a quark and an antiquark.

The SIMP would be smaller than a WIMP, with a size or cross section like that of an atomic nucleus, which implies there are more of them than there would be WIMPs. Larger numbers would mean that, despite their weak interaction with normal matter - primarily by scattering off of it, as opposed to merging with or decaying into normal matter - they would still leave a fingerprint on normal matter, Murayama said.

He sees such a fingerprint in four colliding galaxies within the Abell 3827 cluster, where, surprisingly, the dark matter appears to lag behind the visible matter. This could be explained, he said, by interactions between the dark matter in each galaxy that slows down the merger of dark matter but not that of normal matter, basically stars.

Conventional WIMP theories predict a highly peaked distribution, or cusp, of dark matter in a small area in the center of every galaxy. SIMP theory predicts a spread of dark matter in the center, which is more typical of dwarf galaxies. …more

"One way to understand why the dark matter is lagging behind the luminous matter is that the dark matter particles actually have finite size, they scatter against each other, so when they want to move toward the rest of the system they get pushed back," Murayama said. "This would explain the observation. That is the kind of thing predicted by my theory of dark matter being a bound state of new kind of quarks."

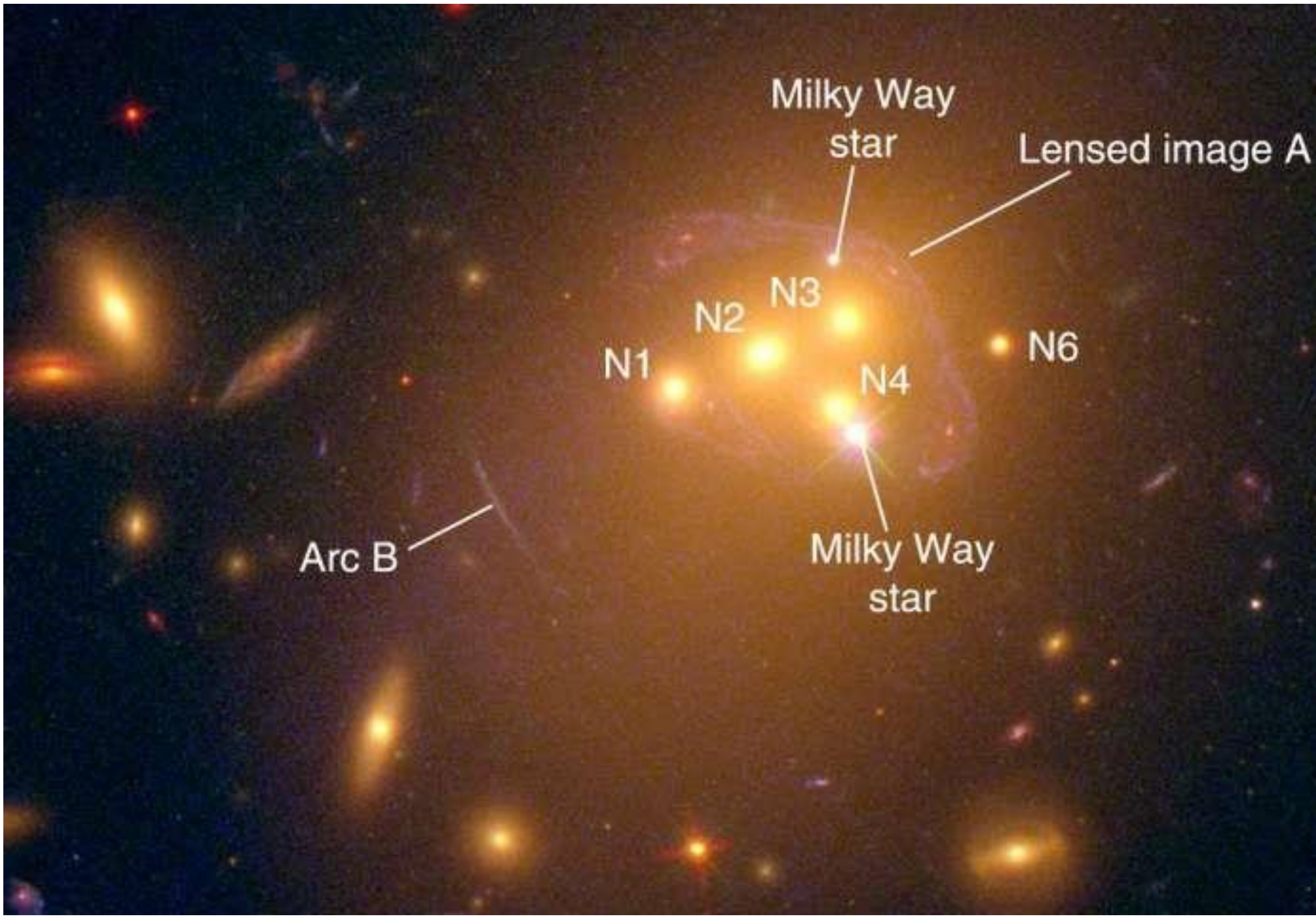
SIMPs also overcome a major failing of WIMP theory: the ability to explain the distribution of dark matter in small galaxies.

"There has been this longstanding puzzle: If you look at dwarf galaxies, which are very small with rather few stars, they are really dominated by dark matter. And if you go through numerical simulations of how dark matter clumps together, they always predict that there is a huge concentration towards the center. A cusp," Murayama said. "But observations seem to suggest that concentration is flatter: a core instead of a cusp. The core/cusp problem has been considered one of the major issues with dark matter that doesn't interact other than by gravity. But if dark matter has a finite size, like a SIMP, the particles can go 'clink' and disperse themselves, and that would actually flatten out the mass profile toward the center. That is another piece of 'evidence' for this kind of theoretical idea."

Ongoing searches for WIMPs and axions

Ground-based experiments to look for SIMPs are being planned, mostly at accelerators like the Large Hadron Collider at CERN in Geneva, where physicists are always looking for unknown particles that fit new predictions. Another experiment at the planned International Linear Collider in Japan could also be used to look for SIMPs.

As Murayama and his colleagues refine the theory of SIMPs and look for ways to find them, the search for WIMPs continues. The Large Underground Xenon (LUX) dark matter experiment in an underground mine in South Dakota has set stringent limits on what a WIMP can look like, and an upgraded experiment called LZ will push those limits further. Daniel McKinsey, a UC Berkeley professor of physics, is one of the co-spokespersons for this experiment, working closely with Lawrence Berkeley National Laboratory, where Murayama is a faculty senior scientist.



This Hubble Space Telescope image of the galaxy cluster Abell 3827 shows the ongoing collision of four bright galaxies and one faint central galaxy, as well as foreground stars in our Milky Way galaxy and galaxies behind the cluster (Arc B …more

Physicists are also seeking other dark matter candidates that are not WIMPs. UC Berkeley faculty are involved in two experiments looking for a hypothetical particle called an axion, which may fit the requirements for dark matter. The Cosmic Axion Spin-Precession Experiment (CASPEr), led by Dmitry Budker, a professor emeritus of physics who is now at the University of Mainz in Germany, and theoretician Surjeet Rajendran, a UC Berkeley professor of physics, is planning to look for perturbations in nuclear spin caused by an axion field. Karl van Bibber, a professor of nuclear engineering, plays a key role in the Axion Dark Matter eXperiment - High Frequency (ADMX-HF), which seeks to detect axions inside a microwave cavity within a strong magnetic field as they convert to photons.

"Of course we shouldn't abandon looking for WIMPs," Murayama said, "but the experimental limits are getting really, really important. Once you get to the level of measurement, where we will be in the near future, even neutrinos end up being the background to the experiment, which is unimaginable."

Neutrinos interact so rarely with normal matter that an estimated 100 trillion fly through our bodies every second without our noticing, something that makes them extremely difficult to detect.

"The community consensus is kind of, we don't know how far we need to go, but at least we need to get down to this level," he added. "But because there are definitely no signs of WIMPs appearing, people are starting to think more broadly these days. Let's stop and think about it again."

Physicists Create Theory on Self-Interacting Dark Matter

Just like identical twins, at first glance, two galaxies can often appear to be very similar, identical even. However, upon closer scrutiny, we see that simply isn't the case. In terms of galaxies, these differences include inner regions that rotate at completely different speeds. So, although they may look the same on the outside, inside is a whole different story. One recent study, led by Hai-Bo Yu of the University of California, Riverside set out to provide us with an explanation for this diversity among galaxies.

Dark matter is the invisible casing that holds galaxies together. The distribution of it is inferred from the motion of gas particles and stars within the galaxy. In Yu's research, the physicists report how the diverse curves and rotation speeds of these galaxies can be explained if dark matter particles do in fact collide with one another near the galaxy's center, in a process called dark matter selfinteraction. “In the prevailing dark matter theory, called Cold Dark Matter or CDM, dark matter particles are assumed to be collisionless, aside from gravity,” confirmed Yu. “We invoke a different theory, the self-interacting dark matter model or SIDM, to show that dark matter self-interactions thermalize the inner halo, which ties ordinary dark matter and dark matter distributions together so that they behave like a collective unit.” In doing this, the self-interacting dark matter halo then becomes much more flexible and easier to accommodate the diverse rotation curves.

These dark matter collisions occur in the inner halo and when the particles collide they thermalize. In galaxies of low-luminosity, the thermalization reduces the density by pushing out the inner dark matter particles. In high-luminous galaxies, such as our very own Milky Way, the thermalization process increases the dark matter density by pulling the particles into the luminous matter. “Our work demonstrates that dark matter may have strong self-interactions, a radical deviation from the prevailing theory,” says Yu.

Around 85 percent of the Universe is dark matter, yet there is still so much we don't know about it. However, what we do know is that it has an unmistakable gravitational imprint on both cosmological and astronomical observations. A lot of Yu's work over the last decade has been on pioneering a new kind of research that will finally conclude what happens when dark matter interacts with itself. He has hypothesized that it would almost certainly affect the dark matter distribution in each halo.

Flip Tanedo is an assistant professor if theoretical particle physics at UC Riverside who's not involved in the study. Here's what he had to say about it: "The compatibility of this hypothesis with observations is a major advance in the field. The SIDM paradigm is a bridge between fundamental particle physics and observational astronomy. The consistency with observations is a big hint that this proposal has a chance of being correct and lays the foundation for future observational, experimental, numerical, and theoretical work. In this way, it is paving the way to new interdisciplinary research." He also added that "Hai-Bo is the architect of modern self-interacting dark matter and how it merges multiple fields: theoretical high-energy physics, experimental highenergy physics, observational, astronomy, numerical simulations of astrophysics, and early universe cosmology and galaxy formation." [23]

The hunt for light dark matter

Technology proposed 30 years ago to search for dark matter is finally seeing the light.

Scientists are using innovative sensors, called skipper CCDs (short for charge-coupled devices) in a new type of dark matter detection project. Scientists will use the project, known as SENSEI, to find the lightest dark matter particles anyone has ever looked for.

Dark matter—so named because it doesn't absorb, reflect or emit light—constitutes 27 percent of the universe, but the jury is still out on what it's made of. The primary theoretical suspect for the main component of dark matter is a particle scientists have descriptively named the weakly interactive massive particle, or WIMP.

But since none of these heavy particles, which are expected to have a mass 100 times that of a proton, have shown up in experiments, it might be time for researchers to think small.

"There is a growing interest in looking for different kinds of dark matter that are additives to the standard WIMP model," said Fermilab scientist Javier Tiffenberg, a leader of the SENSEI collaboration. "Lightweight, or low-mass, dark matter is a very compelling possibility, and for the first time, the technology is there to explore these candidates."

Low-mass dark matter would leave a tiny, difficult-to-see signature when it collides with material inside a detector. Catching these elusive particles requires a dark-matter-detecting master: SENSEI.

Sensing the unseen

In traditional dark matter experiments, scientists look for a transfer of energy that would occur if dark matter particles collided with an ordinary nucleus, but SENSEI is different. It looks for direct interactions of dark matter particles colliding with electrons.

"That is a big difference—you get a lot more energy transferred in this case because an electron is so light compared to a nucleus," Tiffenberg said.

If dark matter has low mass—much smaller than the WIMP model suggests—then it would be many times lighter than an atomic nucleus. So if it were to collide with a nucleus, the resulting energy transfer would be far too small tell us anything. It would be like throwing a ping pong ball at a boulder: the heavy object isn't going anywhere, and there would be no sign the two had come into contact.

An electron is nowhere near as heavy as an atomic nucleus. In fact, a single proton has about 1,836 times more mass than an electron. So the collision of a low-mass dark matter particle with an electron has a much better chance of leaving a mark—more bowling ball than the nucleus's boulder.

Even so, the electron is still a bowling ball compared to the low-mass dark matter particle. An energy transfer between the two would leave only a blip of energy, one either too small for most detectors to pick up or easily overshadowed by noise in the data. There is a small exchange of energy, but, if the detector isn't sensitive enough, it could appear as though nothing happens.

"The bowling ball will move a very tiny amount," said Fermilab scientist Juan Estrada, a SENSEI collaborator. "You need a very precise detector to see this interaction of lightweight particles with something that is much heavier."

That's where SENSEI's sensitive skipper CCDs come in: They will pick up on that tiny transfer of energy.

CCDs have been used for other dark matter detection experiments, such as the Dark Matter in CCDs (or DAMIC) experiment operating at SNOLAB in Canada. These CCDs were a spinoff from sensors developed for use in the Dark Energy Camera in Chile and other dark energy search projects.

CCDs are typically made of silicon divided into pixels. When a dark matter particle passes through the CCD, it collides with silicon's electrons, knocking them free, leaving a net electric charge in each pixel the particle passes through. The electrons then flow through adjacent pixels and are ultimately read as a current in a device that measures the number of electrons freed from each CCD pixel. That measurement tells scientists about the mass and energy of the particle—in this case the dark matter particle—that got the chain reaction going. A massive particle, like a WIMP, would free a gusher of electrons, but a low-mass particle might free only one or two.

Typical CCDs can measure the charge left behind only once, which makes it difficult to decide if a tiny energy signal from one or two electrons is real or an error.

Skipper CCDs are a new generation of the technology that helps eliminate the "iffiness" of a measurement that has a one- or two-electron margin of error. That allows for much higher precision thanks to a unique design.

"In the past, detectors could measure the amount of charge of the energy deposited in each pixel only once," Tiffenberg said. "The big step forward for the skipper CCD is that we are able to measure this charge as many times as we want."

The charge left behind in the skipper CCD by dark matter knocking electrons free can be sampled multiple times and then averaged, a method that yields a more precise measurement of the charge deposited in each pixel than the measure-one-and-done technique. That's the rule of statistics: With more data, you get closer to a property's true value.

SENSEI scientists take advantage of the skipper CCD architecture, measuring the number of electrons in a single pixel a whopping 4,000 times and then averaging them. That minimizes the measurement's error—or noise—and clarifies the signal.

"This is a simple idea, but it took us 30 years to get it to work," Estrada said.

From idea, to reality, to beyond

A small SENSEI prototype is currently running at Fermilab in a detector hall 385 feet below ground, and it has demonstrated that this detector design will work in the hunt for dark matter.

After a few decades existing as only an idea, skipper CCD technology and SENSEI were brought to life by Laboratory Directed Research and Development (LDRD) funds at Fermilab and Lawrence Berkeley National Laboratory (Berkeley Lab). The Fermilab LDRDs were awarded only recently—less than two years ago—but close collaboration between the two laboratories has already yielded SENSEI's promising design, partially thanks to Berkeley lab's previous work in skipper CCD design.

Fermilab LDRD funds allow researchers to test the sensors and develop detectors based on the science, and the Berkeley Lab LDRD funds support the sensor design, which was originally proposed by Berkeley Lab scientist Steve Holland.

"It is the combination of the two LDRDs that really make SENSEI possible," Estrada said.

LDRD programs are intended to provide funding for development of novel, cutting-edge ideas for scientific discovery, and SENSEI technology certainly fits the bill—even beyond its search for dark matter.

Future SENSEI research will also receive a boost thanks to a recent grant from the Heising-Simons Foundation.

"SENSEI is very cool, but what's really impressive is that the skipper CCD will allow the SENSEI science and a lot of other applications," Estrada said. "Astronomical studies are limited by the sensitivity of their experimental measurements, and having sensors without noise is the equivalent of making your telescope bigger—more sensitive."

SENSEI technology may also be critical in the hunt for a fourth type of neutrino, called the sterile neutrino, which seems to be even more shy than its three notoriously elusive neutrino family members.

A larger SENSEI detector equipped with more skipper CCDs will be deployed within the year. It's possible it might not detect anything, sending researchers back to the drawing board in the hunt for dark matter. Or SENSEI might finally make contact with dark matter—and that would be SENSEItional. [22]

Looking at dark matter

The age of discovery is not over. Once, scurvy-riddled Europeans sailed into the unknown to claim foreign, fantastic parts of the world. Now, physicists sit in labs and ask, "Is this all there is?"

No, they aren't suffering a collective existential crisis. They're looking for dark matter—the stuff that theoretically makes up a quarter of our universe. And West Aussie researchers are at the forefront of this search, as part of an Australian-wide project to detect a particle called the axion.

What's the (dark) matter?

If dark matter exists, you are probably sitting in a soup of it right now.

Scientists predict it makes up 26.8% of the universe, which is pretty significant when you consider that everything else we can observe—from hydrogen atoms to black holes—makes up only 5%. (The other 69% is something scientists call dark energy. Don't worry about it.)

There's just one problem. It doesn't interact with electromagnetism—the force between positively and negatively charged particles. It's responsible for practically everything we can observe in day-today life—with the exception of gravity.

Electromagnetic forces present between atoms and molecules in the ground is the reason Earth's gravity doesn't keep pulling us all the way down to its (molten hot) core. The light being emitted from your computer, allowing you to read this story, is generated by interactions of electrically charged particles in your monitor, otherwise known as electricity.

Ordinary matter looks like ordinary matter because of the electromagnetic forces between atoms and molecules. But dark matter doesn't interact with electromagnetism. That means we can't see, smell, taste or touch it. So if dark matter is essentially undetectable, why do we think it exists? And what on Earth are we looking for?

In the dark

Let's start with a basic assumption—gravity exists. Along with electromagnetism, gravity is one of the four basic forces that physicists use to explain almost everything. Gravity says that heavy things attract all other heavy things, so Earth's gravitational pull is the reason we aren't all floating aimlessly in space.

If we peer into all that space, we can see that our Milky Way galaxy is spiral shaped. Smack bang in the galactic centre is a big, bar-shaped bulge from which spiralling arms snake around in a flat circle. Earth sits somewhere in the middle of one of those arms and completes one lap of the galaxy every 225 to 250 million years.

If we think about the entire universe as a giant amusement park, we can imagine our Milky Way to be a carousel. Unlike normal carousels that have plastic ponies fixed in place by poles, the stars, moons and planets that make up our galaxy are disconnected and free to spin around at different speeds.

So if everything is disjointed and spinning, what's keeping us orbiting neatly in our little spiral? Well if we continue with the theme park analogy, we can liken this phenomenon to a swing chair ride.

When swinging in a chair around a tower, a metal chain provides a constant force into the centre of the ride that keeps you spinning round and around that central pole.

The same sort of thing occurs in space, except instead of a chain, we've got gravity. Gravity is provided by the mass of stuff—specifically, the mass of our galactic centre, which scientists believe to be a supermassive black hole. It has so much mass in so little space that it exerts a gravitational force so high it sucks in light.

When you move away from the centre and into the flat galactic halo, we see a lot less stuff. Less stuff means less mass, which means less gravity. We could therefore expect the stuff in the spiral arms to be spinning slower than the stuff closer to the middle.

What astrophysicists actually see is that things on the outer edge of the galaxy are spinning at the same rate as things near the centre of the galaxy—and that's pretty damn fast. If this was the case in our theme park, we would have slipped into a nightmare scenario.

The spinning chair ride would be whirling around so fast that the chain would no longer provide enough force to keep you moving in a circle. The chain would break, and you would be flung to a death worthy of a B-grade horror movie.

Scientists predict the galaxy should rotate like the image on the right. Our galaxy is actually rotating much faster—as on the left. Why then haven't we been flung into space? Probably because of dark matter. Credit: ESO/L. CALÇADA

The fact that Earth has not been slingshotted far and wide suggests that we are surrounded by a lot more mass, which provides a whole bunch of gravity and keeps our galaxy in shape. And most physicists think that mass might just be dark matter.

Dark candidates

Just for a second, forget everything you just read. We're going to stop staring at stars and instead investigate much smaller things—particles. Particle physics is home to this problem called the strong charge parity (CP) problem. It's a very big unexplainable problem in the otherwise successful theory of quantum chromodynamics. Don't worry about it.

Using mathematical equations, particle physicists in the 70s suggested we could solve this strong CP problem with the introduction of a theoretical particle called the axion. And if we do more maths and write a description of what the axion particle should look like, we would find that it has two very exciting qualities—a) it has mass and b) it does not interact with electromagnetism very much at all.

Which sounds suspiciously like the qualities of dark matter. The axion is what physicists call a 'promising candidate' for dark matter. It's like killing two birds with one theoretical, invisible stone.

And if axions are dark matter, we should be surrounded by them right now. If we could only build the right equipment, we could perhaps detect the mysterious mass that's holding our galaxy together. As it happens, some clever scientists at UWA are doing just that.

Dark matter turns light

Physicists at a UWA node of the ARC Centre of Excellence for Engineered Quantum Systems (EQuS) are employing a piece of equipment called a haloscope—so called because it searches for axions in the galactic halo (which you're sitting in right now).

A haloscope is basically an empty copper can (a 'resonant cavity') placed in a very cold, very strong magnetic field. If axions are dark matter and exist all around us, one might enter the resonant cavity, react with the magnetic field and transform into a particle of light—a photon.

Whilst we wouldn't be able to see these photons, scientists are pretty good at measuring them. They're able to measure how much energy it has (its frequency) as it sits inside the resonant cavity. And that frequency corresponds to the mass of the axion that it came from.

The problem is, resonant cavities (those empty copper cans) are created to detect photons with specific frequencies. We don't know how heavy axions are, so we don't know what frequency photon they will produce, which means building the right resonator involves a bit of guesswork.

The search for the axion is more of a process of elimination. What have they been able to exclude so far? Well, mostly due to technical limitations, scientists have previously been looking for axions with a low mass. New theoretical models predict that the axion is a bit heavier. How heavy? We don't know. But Aussie researchers have just been awarded 7 years of funding to try and find out.

Scoping the halo

The Oscillating Resonant Group AxioN (ORGAN) experiment is a nationwide collaboration between members of EQuS and is hosted at UWA. Part of the physicists' work over the next 7 years will be to design resonant cavities that are capable of detecting heavier axions.

They ran an initial experiment over Christmas 2016, the ORGAN Pathfinder, to confirm that their haloscopes were up to the task ahead and that the physicists were capable of analysing their results. This experiment yielded no results—but that doesn't mean that axions don't exist. It only means that they don't exist with the specific mass that they searched for in December 2016 and to a certain level of sensitivity.

The intrepid explorers at UWA will set sail into the next stages of the ORGAN experiment in 2018. And perhaps soon, we'll know exactly what the matter is. [21]

A silent search for dark matter

Results from its first run indicate that XENON1T is the most sensitive dark matter detector on Earth. The sensitivity of the detector—an underground sentinel awaiting a collision that would confirm a hypothesis—stems from both its size and its "silence." Shielded by rock and water, and purified with a sophisticated system, the detector demonstrated a new record low radioactivity level, many orders of magnitude below surrounding material on Earth.

"We are seeing very good quality data from this detector, which tells us that it is running perfectly," said Ethan Brown, a XENON1T Collaboration member, and assistant professor of physics, applied physics, and astronomy at Rensselaer Polytechnic Institute.

Dark matter is theorized as one of the basic constituents of the universe, five times more abundant than ordinary matter. But because it cannot be seen and seldom interacts with ordinary matter, its existence has never been confirmed. Several astronomical measurements have corroborated the existence of dark matter, leading to a worldwide effort to directly observe dark matter particle interactions with ordinary matter. Up to the present, the interactions have proven so feeble that they have escaped direct detection, forcing scientists to build ever-more-sensitive detectors.

Since 2006, the XENON Collaboration has operated three successively more sensitive liquid xenon detectors in the Gran Sasso Underground Laboratory (LNGS) in Italy, and XENON1T is its most powerful venture to date and the largest detector of its type ever built. Particle interactions in liquid xenon create tiny flashes of light, and the detector is intended to capture the flash from the rare occasion in which a dark matter particle collides with a xenon nucleus.

But other interactions are far more common. To shield the detector as much as possible from natural radioactivity in the cavern, the detector (a so-called Liquid Xenon Time Projection Chamber) sits within a cryostat submersed in a tank of water. A mountain above the underground laboratory further shields the detector from cosmic rays. Even with shielding from the outside world, contaminants seep into the xenon from the materials used in the detector. Among his contributions, Brown is responsible for a purification system that continually scrubs the xenon in the detector.

"If the xenon is dirty, we won't see the signal from a collision with dark matter," Brown said. "Keeping the xenon clean is one of the major challenges of this experiment, and my work involves developing new techniques and new technologies to keep pace with that challenge."

Brown also aids in calibrating the detector to ensure that interactions which are recorded can be properly identified. In rare cases, for example, the signal from a gamma ray may approach the expected signal of a dark matter particle, and proper calibration helps to rule out similar false positive signals.

In the paper "First Dark Matter Search Results from the XENON1T Experiment" posted on arXiv.org and submitted for publication, the collaboration presented results of a 34-day run of XENON1T from November 2016 to January 2017. While the results did not detect dark matter particles—known as "weakly interacting massive particles" or "WIMPs" - the combination of record low radioactivity levels with the size of the detector implies an excellent discovery potential in the years to come.

"A new phase in the race to detect dark matter with ultralow background massive detectors on Earth has just began with XENON1T," said Elena Aprile, a professor at Columbia University and project spokesperson. "We are proud to be at the forefront of the race with this amazing detector, the first of its kind." [20]

3 knowns and 3 unknowns about dark matter

What's known:

1. We can observe its effects.

While we can't see dark matter, we can observe and measure its gravitational effects. Galaxies have been observed to spin much faster than expected based on their visible matter, and galaxies move faster in clusters than expected, too, so scientists can calculate the "missing mass" responsible for this motion.

2. It is abundant.

It makes up about 85 percent of the total mass of the universe, and about 27 percent of the universe's total mass and energy.

3. We know more about what dark matter is not.

Increasingly sensitive detectors are lowering the possible rate at which dark mark matter particles can interact with normal matter.

What's unknown

1. Is it made up of one particle or many particles?

Could dark matter be composed of an entire family of particles, such as a theorized "hidden valley" or "dark sector?"

2. Are there "dark forces" acting on dark matter?

Are there forces beyond gravity and other known forces that act on dark matter but not on ordinary matter, and can dark matter interact with itself?

3. Is there dark antimatter?

Could dark matter have an antimatter counterpart, as does normal matter, and is there a similar imbalance that favored dark matter over "dark antimatter" as with normal matter-antimatter? [20]

New theory on the origin of dark matter

Only a small part of the universe consists of visible matter. By far the largest part is invisible and consists of dark matter and dark energy. Very little is known about dark energy, but there are many theories and experiments on the existence of dark matter designed to find these as yet unknown particles. Scientists at Johannes Gutenberg University Mainz (JGU) in Germany have now come up with a new theory on how dark matter may have been formed shortly after the origin of the universe. This new model proposes an alternative to the WIMP paradigm that is the subject of various experiments in current research.

Dark matter is present throughout the universe, forming galaxies and the largest known structures in the cosmos. It makes up around 23 percent of our universe, whereas the particles visible to us that make up the stars, planets, and even life on Earth represent only about four percent of it. The current assumption is that dark matter is a cosmological relic that has essentially remained stable since its creation. "We have called this assumption into question, showing that at the beginning of the universe dark matter may have been unstable," explained Dr. Michael Baker from the Theoretical High Energy Physics (THEP) group at the JGU Institute of Physics. This instability also indicates the existence of a new mechanism that explains the observed quantity of dark matter in the cosmos.

The stability of dark matter is usually explained by a symmetry principle. However, in their paper, Dr. Michael Baker and Prof. Joachim Kopp demonstrate that the universe may have gone through a phase during which this symmetry was broken. This would mean that it is possible for the hypothetical dark matter particle to decay. During the electroweak phase transition, the symmetry that stabilizes dark matter would have been re-established, enabling it to continue to exist in the universe to the present day.

With their new theory, Baker and Kopp have introduced a new principle into the debate about the nature of dark matter that offers an alternative to the widely accepted WIMP theory. Up to now, WIMPs, or weakly interacting massive particles, have been regarded as the most likely components of dark matter, and experiments involving heavily shielded underground detectors have been carried out to look for them. "The absence of any convincing signals caused us to start looking for alternatives to the WIMP paradigm," said Kopp.

The two physicists claim that the new mechanism they propose may be connected with the apparent imbalance between matter and antimatter in the cosmos and could leave an imprint which would be detected in future experiments on gravitational waves. In their paper published in the scientific journal Physical Review Letters, Baker and Kopp also indicate the prospects of finding proof of their new principle at CERN's LHC particle accelerator and other experimental facilities. [19]

Dark Energy Survey reveals most accurate measurement of dark matter structure in the universe

Imagine planting a single seed and, with great precision, being able to predict the exact height of the tree that grows from it. Now imagine traveling to the future and snapping photographic proof that you were right.

If you think of the seed as the early universe, and the tree as the universe the way it looks now, you have an idea of what the Dark Energy Survey (DES) collaboration has just done. In a presentation today at the American Physical Society Division of Particles and Fields meeting at the U.S. Department of Energy's (DOE) Fermi National Accelerator Laboratory, DES scientists will unveil the most accurate measurement ever made of the present large-scale structure of the universe.

These measurements of the amount and "clumpiness" (or distribution) of dark matter in the present-day cosmos were made with a precision that, for the first time, rivals that of inferences from the early universe by the European Space Agency's orbiting Planck observatory. The new DES result (the tree, in the above metaphor) is close to "forecasts" made from the Planck measurements of the distant past (the seed), allowing scientists to understand more about the ways the universe has evolved over 14 billion years.

"This result is beyond exciting," said Scott Dodelson of Fermilab, one of the lead scientists on this result. "For the first time, we're able to see the current structure of the universe with the same clarity that we can see its infancy, and we can follow the threads from one to the other, confirming many predictions along the way."

Most notably, this result supports the theory that 26 percent of the universe is in the form of mysterious dark matter and that space is filled with an also-unseen dark energy, which is causing the accelerating expansion of the universe and makes up 70 percent.

Paradoxically, it is easier to measure the large-scale clumpiness of the universe in the distant past than it is to measure it today. In the first 400,000 years following the Big Bang, the universe was filled with a glowing gas, the light from which survives to this day. Planck's map of this cosmic microwave background radiation gives us a snapshot of the universe at that very early time. Since then, the gravity of dark matter has pulled mass together and made the universe clumpier over time. But dark energy has been fighting back, pushing matter apart. Using the Planck map as a start, cosmologists can calculate precisely how this battle plays out over 14 billion years.

"The DES measurements, when compared with the Planck map, support the simplest version of the dark matter/dark energy theory," said Joe Zuntz, of the University of Edinburgh, who worked on the analysis. "The moment we realized that our measurement matched the Planck result within 7 percent was thrilling for the entire collaboration."

The primary instrument for DES is the 570-megapixel Dark Energy Camera, one of the most powerful in existence, able to capture digital images of light from galaxies eight billion light-years from Earth. The camera was built and tested at Fermilab, the lead laboratory on the Dark Energy Survey, and is mounted on the National Science Foundation's 4-meter Blanco telescope, part of the Cerro Tololo Inter-American Observatory in Chile, a division of the National Optical Astronomy Observatory. The DES data are processed at the National Center for Supercomputing Applications at the University of Illinois at Urbana-Champaign.

Scientists on DES are using the camera to map an eighth of the sky in unprecedented detail over five years. The fifth year of observation will begin in August. The new results released today draw from data collected only during the survey's first year, which covers 1/30th of the sky.

"It is amazing that the team has managed to achieve such precision from only the first year of their survey," said National Science Foundation Program Director Nigel Sharp. "Now that their analysis techniques are developed and tested, we look forward with eager anticipation to breakthrough results as the survey continues."

DES scientists used two methods to measure dark matter. First, they created maps of galaxy positions as tracers, and second, they precisely measured the shapes of 26 million galaxies to directly map the patterns of dark matter over billions of light-years, using a technique called gravitational lensing.

To make these ultraprecise measurements, the DES team developed new ways to detect the tiny lensing distortions of galaxy images, an effect not even visible to the eye, enabling revolutionary advances in understanding these cosmic signals. In the process, they created the largest guide to spotting dark matter in the cosmos ever drawn (see image). The new dark matter map is 10 times the size of the one DES released in 2015 and will eventually be three times larger than it is now.

"It's an enormous team effort and the culmination of years of focused work," said Erin Sheldon, a physicist at the DOE's Brookhaven National Laboratory, who co-developed the new method for detecting lensing distortions.

These results and others from the first year of the Dark Energy Survey will be released today online and announced during a talk by Daniel Gruen, NASA Einstein fellow at the Kavli Institute for Particle Astrophysics and Cosmology at DOE's SLAC National Accelerator Laboratory, at 5 p.m. Central time.

The talk is part of the APS Division of Particles and Fields meeting at Fermilab and will be streamed live.

The results will also be presented by Kavli fellow Elisabeth Krause of the Kavli Insitute for Particle Astrophysics and Cosmology at SLAC at the TeV Particle Astrophysics Conference in Columbus, Ohio, on Aug. 9; and by Michael Troxel, postdoctoral fellow at the Center for Cosmology and AstroParticle Physics at Ohio State University, at the International Symposium on Lepton Photon Interactions at High Energies in Guanzhou, China, on Aug. 10. All three of these speakers are coordinators of DES science working groups and made key contributions to the analysis.

"The Dark Energy Survey has already delivered some remarkable discoveries and measurements, and they have barely scratched the surface of their data," said Fermilab Director Nigel Lockyer. "Today's world-leading results point forward to the great strides DES will make toward understanding dark energy in the coming years." [18]

Mapping dark matter

About eighty-five percent of the matter in the universe is in the form of dark matter, whose nature remains a mystery. The rest of the matter in the universe is of the kind found in atoms. Astronomers studying the evolution of galaxies in the universe find that dark matter exhibits gravity and, because it is so abundant, it dominates the formation of large-scale structures in the universe like clusters of galaxies. Dark matter is hard to observe directly, needless to say, and it shows no evidence of interacting with itself or other matter other than via gravity, but fortunately it can be traced by modeling sensitive observations of the distributions of galaxies across a range of scales.

Galaxies generally reside at the centers of vast clumps of dark matter called haloes because they surround the clusters of galaxies. Gravitational lensing of more distant galaxies by dark matter haloes offers a particularly unique and powerful probe of the detailed distribution of dark matter. So-called strong gravitational lensing creates highly distorted, magnified and occasionally multiple images of a single source; so-called weak lensing results in modestly yet systematically deformed shapes of background galaxies that can also provide robust constraints on the distribution of dark matter within the clusters.

CfA astronomers Annalisa Pillepich and Lars Hernquist and their colleagues compared gravitationally distorted Hubble images of the galaxy cluster Abell 2744 and two other clusters with the results of computer simulations of dark matter haloes. They found, in agreement with key predictions in the conventional dark matter picture, that the detailed galaxy substructures depend on the dark matter halo distribution, and that the total mass and the light trace each other. They also found a few discrepancies: the radial distribution of the dark matter is different from that predicted by the simulations, and the effects of tidal stripping and friction in galaxies are smaller than expected, but they suggest these issues might be resolved with more precise simulations. Overall, however, the standard model of dark matter does an excellent and reassuring job of describing galaxy clustering. [17]

Dark matter is likely 'cold,' not 'fuzzy,' scientists report after new simulations

Dark matter is the aptly named unseen material that makes up the bulk of matter in our universe. But what dark matter is made of is a matter of debate.

Scientists have never directly detected dark matter. But over decades, they have proposed a variety of theories about what type of material—from new particles to primordial black holes—could comprise dark matter and explain its many effects on normal matter. In a paper published July 20 in the journal Physical Review Letters, an international team of cosmologists uses data from the intergalactic medium—the vast, largely empty space between galaxies—to narrow down what dark matter could be.

The team's findings cast doubt on a relatively new theory called "fuzzy dark matter," and instead lend credence to a different model called "cold dark matter." Their results could inform ongoing efforts to detect dark matter directly, especially if researchers have a clear idea of what sorts of properties they should be seeking.

"For decades, theoretical physicists have tried to understand the properties of the particles and forces that must make up dark matter," said lead author Vid Iršic, a postdoctoral researcher in the Department of Astronomy at the University of Washington. "What we have done is place constraints on what dark matter could be—and 'fuzzy dark matter,' if it were to make up all of dark matter, is not consistent with our data."

Scientists had drawn up both the "fuzzy" and "cold" dark-matter theories to explain the effects that dark matter appears to have on galaxies and the intergalactic medium between them.

Cold dark matter is the older of these two theories, dating back to the 1980s, and is currently the standard model for dark matter. It posits that dark matter is made up of a relatively massive, slowmoving type of particle with "weakly interacting" properties. It helps explain the unique, large-scale structure of the universe, such as why galaxies tend to cluster in larger groups.

But the cold dark matter theory also has some drawbacks and inconsistencies. For example, it predicts that our own Milky Way Galaxy should have hundreds of satellite galaxies nearby. Instead, we have only a few dozen small, close neighbors.

The newer fuzzy dark matter theory addressed the deficiencies of the cold dark matter model. According to this theory, dark matter consists of an ultralight particle, rather than a heavy one, and also has a unique feature related to quantum mechanics. For many of the fundamental particles in our universe, their large-scale movements—traveling distances of meters, miles and beyond—can be explained using the principles of "classic" Newtonian physics. Explaining small-scale movements, such as at the subatomic level, requires the complex and often contradictory principles of quantum mechanics. But for the ultralight particle predicted in the fuzzy dark matter theory, movements at incredibly large scales—such as from one end of a galaxy to the other—also require quantum mechanics.

With these two theories of dark matter in mind, Iršic and his colleagues set out to model the hypothetical properties of dark matter based on relatively new observations of the intergalactic medium, or IGM. The IGM consists largely of dark matter—whatever that may be—along with hydrogen gas and a small amount of helium. The hydrogen within IGM absorbs light emitted from distant, bright objects, and astronomers have studied this absorption for decades using Earth-based instruments.

The team looked at how the IGM interacted with light emitted by quasars, which are distant, massive, starlike objects. One set of data came from a survey of 100 quasars by the European Southern Observatory in Chile. The team also included observations of 25 quasars by the Las Campanas Observatory in Chile and the W.M. Keck Observatory in Hawaii.

Using a supercomputer at the University of Cambridge, Iršic and co-authors simulated the IGM—and calculated what type of dark matter particle would be consistent with the quasar data. They discovered that a typical particle predicted by the fuzzy dark matter theory is simply too light to account for the hydrogen absorption patterns in the IGM. A heavier particle—similar to predictions of the traditional cold dark matter theory—is more consistent with their simulations.

"The mass of this particle has to be larger than what people had originally expected, based on the fuzzy dark matter solutions for issues surrounding our galaxy and others," said Iršic.

An ultralight "fuzzy" particle could still exist. But it cannot explain why galactic clusters form, or other questions like the paucity of satellite galaxies around the Milky Way, said Iršic. A heavier "cold" particle remains consistent with the astronomical observations and simulations of the IGM, he added.

The team's results do not address all of the longstanding drawbacks of the cold dark matter model. But Iršic believes that further mining of data from the IGM can help resolve the type—or types—of particles that make up dark matter. In addition, some scientists believe that there are no problems with the cold dark matter theory. Instead, scientists may simply not understand the complex forces at work in the IGM, Iršic added.

"Either way, the IGM remains a rich ground for understanding dark matter," said Iršic.

Co-authors on the paper are Matteo Viel of the International School for Advanced Studies in Italy, the Astronomical Observatory of Trieste and the National Institute for Nuclear Physics in Italy; Martin Haehnelt of the University of Cambridge; James Bolton of the University of Nottingham; and George Becker of the University of California, Riverside. The work was funded by the National Science Foundation, the National Institute for Nuclear Physics in Italy, the European Research Council, the National Institute for Astrophysics in Italy, the Royal Society in the United Kingdom and the Kavli Foundation. [16]

This New Explanation For Dark Matter Could Be The Best One Yet

It makes up about 85 percent of the total mass of the Universe, and yet, physicists still have no idea what dark matter actually is.

But a new hypothesis might have gotten us closer to figuring out its identity, because physicists now suspect that dark matter has been changing forms this whole time - from ghostly particles in the Universe's biggest structures, to a strange, superfluid state at smaller scales. And we might soon have the tools to confirm it.

Dark matter is a hypothetical substance that was proposed almost a century ago to account for the clear imbalance between the amount of matter in the Universe, and the amount of gravity that holds our galaxies together.

We can't directly detect dark matter, but we can see its effects on everything around us - the way galaxies rotate and the way light bends as it travels through the Universe suggests there's far more at play than we're able to pick up.

And now two physicists propose that dark matter has been changing the rules this whole time, and that could explain why it's been so elusive.

"It's a neat idea," particle physicist Tim Tait from the University of California, Irvine, who wasn't involved in the study, told Quanta Magazine.

"You get to have two different kinds of dark matter described by one thing."

The traditional view of dark matter is that it's made up of weakly interacting particles such as axions, which are influenced by the force of gravity in ways that we can observe at large scales.

This 'cold' form of dark matter can be used to predict how massive clusters of galaxies will behave, and fits into what we know about the 'cosmic web' of the Universe - scientists suggest that all galaxies are connected within a vast intergalactic web made up of invisible filaments of dark matter.

But when we scale down to individual galaxies and the way their stars rotate in relation to the galactic centre, something just doesn't add up.

"Most of the mass [in the Universe], which is dark matter, is segregated from where most of the ordinary matter lies," University of Pennsylvania physicist Justin Khoury explains in a press statement.

"On a cosmic web scale, this does well in fitting with the observations. On a galaxy cluster scale, it also does pretty well. However, when on the scale of galaxies, it does not fit."

Khoury and his colleague Lasha Berezhiani, now at Princeton University, suggest that the reason we can't reconcile dark matter's behaviour on both large and small scales in the Universe is because it can shift forms.

We've got the 'cold' dark matter particles for the massive galaxy clusters, but on a singular galactic scale, they suggest that dark matter takes on a superfluid state.

Superfluids are a form of cold, densely packed matter that has zero friction and viscosity, and can sometimes become a Bose-Einstein condensate, referred to as the 'fifth state of matter'.

And as strange as they sound, superfluids are starting to appear more accessible than ever before, with researchers announcing just last week that they were able to create light that acts like a liquid - a form of superfluid - at room temperature for the first time.

The more we come to understand superfluids, the more physicists are willing to entertain the idea that they could be far more common in the Universe than we thought.

"Recently, more physicists have warmed to the possibility of superfluid phases forming naturally in the extreme conditions of space," Jennifer Ouellette explains for Quanta Magazine.

"Superfluids may exist inside neutron stars, and some researchers have speculated that space-time itself may be a superfluid. So why shouldn't dark matter have a superfluid phase, too?"

The idea is that the 'halos' of dark matter that exist around individual galaxies create the conditions necessary to form a superfluid - the gravitational pull of the galaxy ensures that it's densely packed, and the coldness of space keeps the temperature suitably low.

Zoom out to a larger scale, and this gravitational pull becomes too weak to form a superfluid.

The key here is that the existence of superfluid dark matter could explain the strange behaviours of individual galaxies that gravity alone can't explain - it could be creating a second, as-yet-undefined force that acts just like gravity within the dark matter halos surrounding them.

As Ouellette explains, when you disturb an electric field, you get radio waves, and when you disturb a gravitational field, you get gravitational waves. When you disturb a superfluid? You get phonons (sound waves), and this extra force could work in addition to gravity.

"It's nice because you have an additional force on top of gravity, but it really is intrinsically linked to dark matter," Khoury told her. "It's a property of the dark matter medium that gives rise to this force."

We should be clear that this hypothesis is yet to be peer-reviewed, so this is all squarely in the realm of the hypothetical for now. But it's been published on the pre-print website arXiv.org for researchers in the field to pick over.

A big thing it has going for it is the fact that it could also explain 'modified Newtonian dynamics' (MOND) - a theory that says a modification of Newton's laws is needed to account for specific properties that have been observed within galaxies.

"In galaxies, there is superfluid movement of dark matter and MOND applies. However, in galaxy clusters, there is no superfluid movement of dark matter and MOND does not apply," the team suggests in a press statement.

We'll have to wait and see where this hypothesis goes, but the Khoury and Berezhiani say they're close to coming up with actual, testable ways that we can confirm their predictions based on superfluid dark matter.

And if their predictions bear out - we might finally be onto something when it comes to this massive cosmic mystery.

The research is available online at arXiv.org. [15]

Dark Matter Recipe Calls for One Part Superfluid

For years, dark matter has been behaving badly. The term was first invoked nearly 80 years ago by the astronomer Fritz Zwicky, who realized that some unseen gravitational force was needed to stop individual galaxies from escaping giant galaxy clusters. Later, Vera Rubin and Kent Ford used unseen dark matter to explain why galaxies themselves don't fly apart.

Yet even though we use the term "dark matter" to describe these two situations, it's not clear that the same kind of stuff is at work. The simplest and most popular model holds that dark matter is made of weakly interacting particles that move about slowly under the force of gravity. This socalled "cold" dark matter accurately describes large-scale structures like galaxy clusters. However, it doesn't do a great job at predicting the rotation curves of individual galaxies. Dark matter seems to act differently at this scale.

In the latest effort to resolve this conundrum, two physicists have proposed that dark matter is capable of changing phases at different size scales. Justin Khoury, a physicist at the University of Pennsylvania, and his former postdoc Lasha Berezhiani, who is now at Princeton University, say that in the cold, dense environment of the galactic halo, dark matter condenses into a superfluid — an exotic quantum state of matter that has zero viscosity. If dark matter forms a superfluid at the galactic scale, it could give rise to a new force that would account for the observations that don't fit the cold dark matter model. Yet at the scale of galaxy clusters, the special conditions required for a superfluid state to form don't exist; here, dark matter behaves like conventional cold dark matter.

"It's a neat idea," said Tim Tait, a particle physicist at the University of California, Irvine. "You get to have two different kinds of dark matter described by one thing." And that neat idea may soon be testable. Although other physicists have toyed with similar ideas, Khoury and Berezhiani are nearing the point where they can extract testable predictions that would allow astronomers to explore whether our galaxy is swimming in a superfluid sea.

Impossible Superfluids

Here on Earth, superfluids aren't exactly commonplace. But physicists have been cooking them up in their labs since 1938. Cool down particles to sufficiently low temperatures and their quantum nature will start to emerge. Their matter waves will spread out and overlap with one other, eventually coordinating themselves to behave as if they were one big "superatom." They will become coherent, much like the light particles in a laser all have the same energy and vibrate as one. These days even undergraduates create so-called Bose-Einstein condensates (BECs) in the lab, many of which can be classified as superfluids.

Superfluids don't exist in the everyday world — it's too warm for the necessary quantum effects to hold sway. Because of that, "probably ten years ago, people would have balked at this idea and just said 'this is impossible,'" said Tait. But recently, more physicists have warmed to the possibility of superfluid phases forming naturally in the extreme conditions of space. Superfluids may exist inside neutron stars, and some researchers have speculated that space-time itself may be a superfluid. So why shouldn't dark matter have a superfluid phase, too?

To make a superfluid out of a collection of particles, you need to do two things: Pack the particles together at very high densities and cool them down to extremely low temperatures. In the lab, physicists (or undergraduates) confine the particles in an electromagnetic trap, then zap them with lasers to remove the kinetic energy and lower the temperature to just above absolute zero. [14]

XENON1T, the most sensitive detector on Earth searching for WIMP dark matter, releases its first result

"The best result on dark matter so far—and we just got started." This is how scientists behind XENON1T, now the most sensitive dark matter experiment world-wide, commented on their first result from a short 30-day run presented today to the scientific community.

Dark matter is one of the basic constituents of the universe, five times more abundant than ordinary matter. Several astronomical measurements have corroborated the existence of dark matter, leading to a world-wide effort to observe dark matter particle interactions with ordinary matter in extremely sensitive detectors, which would confirm its existence and shed light on its properties. However, these interactions are so feeble that they have escaped direct detection up to this point, forcing scientists to build detectors that are increasingly sensitive. The XENON Collaboration, that with the XENON100 detector led the field for years in the past, is now back on the frontline with the XENON1T experiment. The result from a first short 30-day run shows that this detector has a new record low radioactivity level, many orders of magnitude below surrounding materials on Earth. With a total mass of about 3200kg, XENON1T is the largest detector of this type ever built. The combination of significantly increased size with much lower background implies excellent dark matter discovery potential in the years to come.

The XENON Collaboration consists of 135 researchers from the U.S., Germany, Italy, Switzerland, Portugal, France, the Netherlands, Israel, Sweden and the United Arab Emirates. The latest detector of the XENON family has been in science operation at the LNGS underground laboratory since autumn 2016. The only things you see when visiting the underground experimental site now are a gigantic cylindrical metal tank filled with ultra-pure water to shield the detector at his center, and a three-story-tall, transparent building crowded with equipment to keep the detector running.

The XENON1T central detector, a so-called liquid xenon time projection chamber (LXeTPC), is not visible. It sits within a cryostat in the middle of the water tank, fully submersed in order to shield it as much as possible from natural radioactivity in the cavern. The cryostat keeps the xenon at a temperature of -95°C without freezing the surrounding water. The mountain above the laboratory further shields the detector, preventing perturbations by cosmic rays. But shielding from the outer world is not enough since all materials on Earth contain tiny traces of natural radioactivity. Thus, extreme care was taken to find, select and process the materials of the detector to achieve the lowest possible radioactive content. Laura Baudis, professor at the University of Zürich and professor Manfred Lindner from the Max-Planck-Institute for Nuclear Physics in Heidelberg, emphasize that this allowed XENON1T to achieve record "silence," which is necessary to listen for the very weak voice of dark matter.

A particle interaction in liquid xenon leads to tiny flashes of light. This is what the XENON scientists are recording and studying to infer the position and the energy of the interacting particle, and whether or not it might be dark matter. The spatial information allows the researchers to select interactions occurring in the one-ton central core of the detector.

XENON1T, the most sensitive detector on Earth searching for WIMP dark matter, releases its first result

The surrounding xenon further shields the core xenon target from all materials that already have tiny surviving radioactive contaminants. Despite the shortness of the 30-day science run, the sensitivity of XENON1T has already overcome that of any other experiment in the field, probing unexplored dark matter territory. "WIMPs did not show up in this first search with XENON1T, but we also did not expect them so soon," says Elena Aprile, Professor at Columbia University and spokesperson for the project. "The best news is that the experiment continues to accumulate excellent data, which will allow us to test quite soon the WIMP hypothesis in a region of mass and cross-section with normal atoms as never before. A new phase in the race to detect dark matter with ultra-low background massive detectors on Earth has just began with XENON1T. We are proud to be at the forefront of the race with this amazing detector, the first of its kind." [13]

Out with the WIMPs, in with the SIMPs?

Like cops tracking the wrong person, physicists seeking to identify dark matter—the mysterious stuff whose gravity appears to bind the galaxies—may have been stalking the wrong particle. In fact, a particle with some properties opposite to those of physicists' current favorite dark matter candidate—the weakly interacting massive particle, or WIMP—would do just as good a job at explaining the stuff, a quartet of theorists says. Hypothetical strongly interacting massive particles— or SIMPs—would also better account for some astrophysical observations, they argue.

SIMPs can also provide just the right amount of dark matter, assuming the theorists add a couple of wrinkles. The SIMPs must disappear primarily through collisions in which three SIMPs go in and only two SIMPs come out. These events must be more common than ones in which two SIMPs annihilate each other to produce two ordinary particles. Moreover, the theorists argue, SIMPs must interact with ordinary matter, although much more weakly than WIMPs. That's because the three-to-two collisions would heat up the SIMPs if they could not interact and share heat with ordinary matter.

Moreover, the fact that SIMPs must interact with ordinary matter guarantees that, in principle, they should be detectable in some way, Hochberg says. Whereas physicists are now searching for signs of WIMPs colliding with massive atomic nuclei, researchers would probably have to look for SIMPs smacking into lighter electrons because the bantamweight particles would not pack enough punch to send a nucleus flying.

Compared with WIMPy dark matter, SIMPy dark matter would also have another desirable property. As the universe evolved, dark matter coalesced into clumps, or halos, in which the galaxies then formed. But computer simulations suggest that dark matter that doesn't interact with itself would form myriad little clumps that are very dense in the center. And little "dwarf galaxies" aren't as abundant and the centers of galaxies aren't as dense as the simulations suggest. But strongly interacting dark matter would smooth out the distribution of dark matter and solve those problems, Hochberg says. "This isn't some independent thing that we've just forced into the model," she says. "It just naturally happens."

The new analysis "has the flavor of the WIMP miracle, which is nice," says Jonathan Feng, a theorist at UC Irvine who was not involved in the work. Feng says he's been working on similar ideas and that the ability to reconcile the differences between dark matter simulations and the observed properties of galaxies makes strongly interacting dark matter attractive conceptually.

However, he cautions, it may be possible that, feeble as they may be, the interactions between dark and ordinary matter might smooth out the dark matter distribution on their own. And Feng says he has some doubts about the claim that SIMPs must interact with ordinary matter strongly enough to be detected. So the SIMP probably won't knock WIMP off its perch as the best guess for the dark matter particle just yet, Feng says: "At the moment, it's not as well motivated as the WIMP, but it's definitely worth exploring." [12]

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 supersymetric 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 differes 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 superparticules 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]

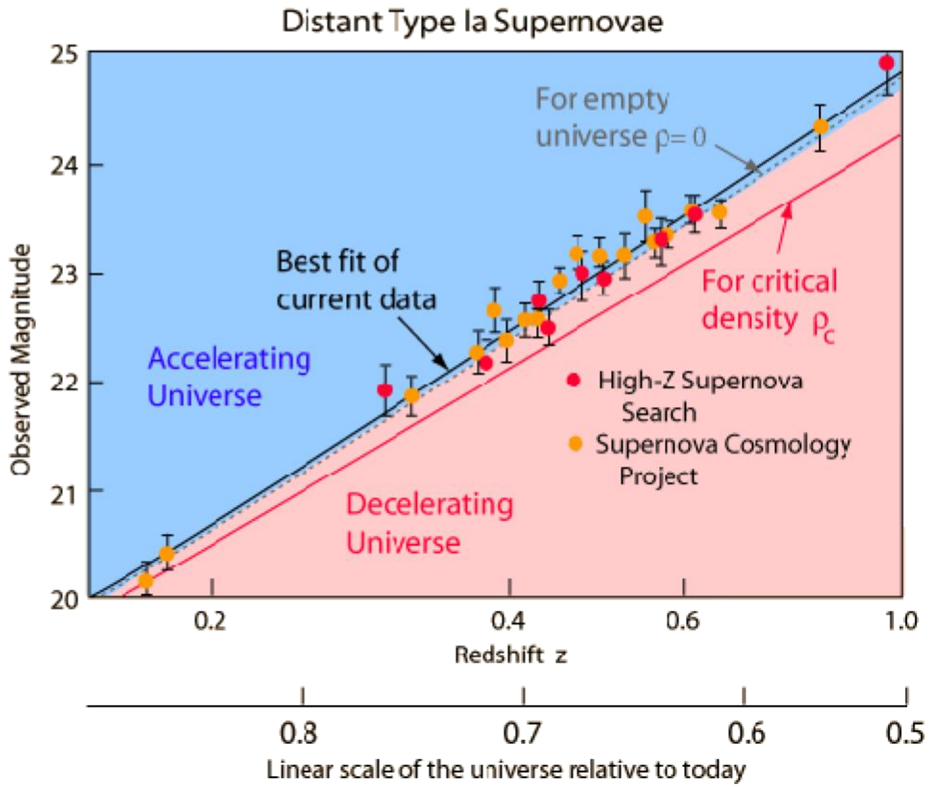
Weakly interacting massive particles

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 1a supernovae around z=.6, which with a Hubble constant of 71 km/s/mpc is a distance of about 5 billion light years.

Equation

The cosmological constant Λ 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 Λ 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, ρ_{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 8π: $\Lambda = 8\pi\rho_{vac}$, 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

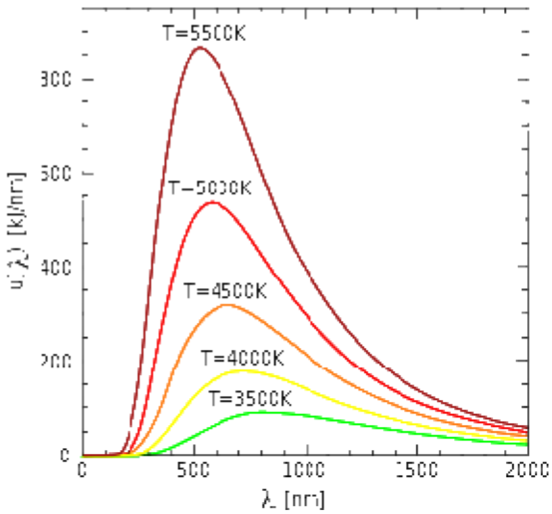
Dark matter is a type of matter hypothesized in astronomy and cosmology to account for a large part of the mass that appears to be missing from the universe. Dark matter cannot be seen directly with telescopes; evidently it neither emits nor absorbs light or other electromagnetic radiation at any significant 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 **A** vector potential experienced by the electrons moving by **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 **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_o 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

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The frequency dependence of mass

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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 Bing 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 rate Mp=1840 Me. 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

SIMPs would resolve certain discrepancies between simulations of the distribution of dark matter, like this one, and the observed properties of the galaxies.
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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