Josephson Vortices

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"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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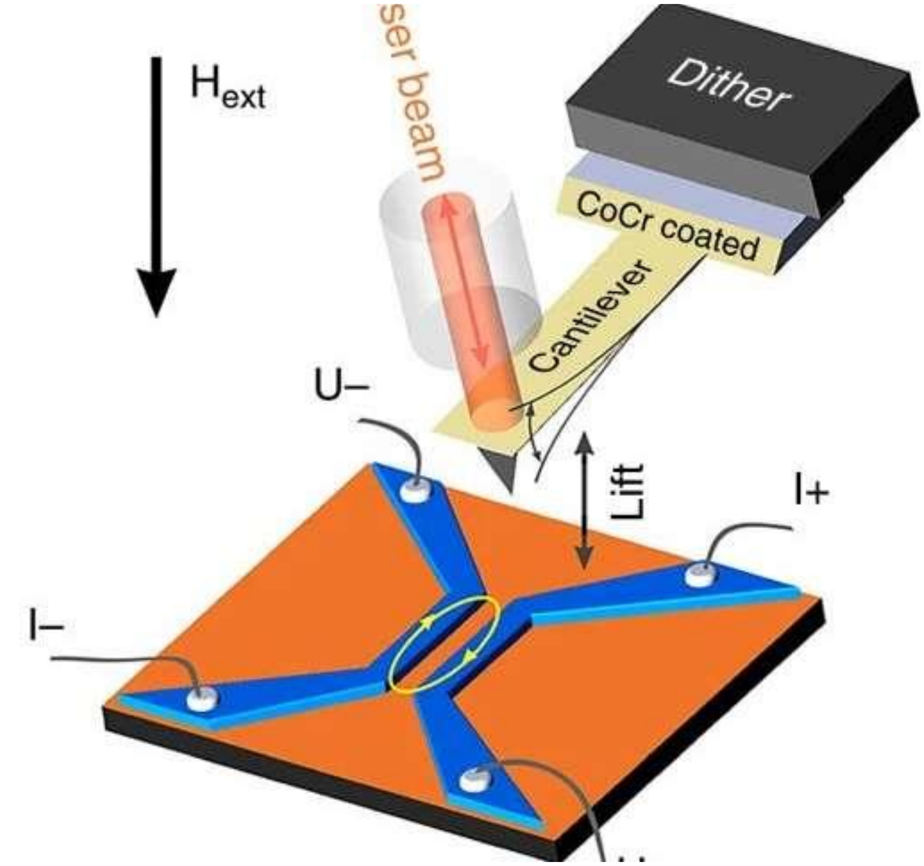
Scientists tame Josephson vortices

MIPT physicists have learned how to locally control Josephson vortices. The discovery can be used for quantum electronics superconducting devices and future quantum processors. The work has been published in the prestigious scientific journal *Nature Communications*.

A Josephson vortex is a vortex of currents occurring in a system of two superconductors separated by a weak link—a dielectric, a normal metal, etc.—in the presence of an external magnetic field. In 1962, Brian Josephson predicted the flow of a supercurrent through a thin layer of insulating material separating two pieces of superconducting material. This current was named the Josephson current, and the coupling of superconductors was dubbed a Josephson junction. A so-called weak link occurs between the two superconductors through a dielectric or a nonsuperconducting metal, and macroscopic quantum coherence develops.

When this system is placed in a magnetic field, the superconductors push the magnetic field out. The greater the magnetic field applied, the more the superconductivity resists the magnetic field penetrating into the Josephson system. However, the weak link is a place in which the field can penetrate in the form of individual Josephson vortices carrying magnetic flux quanta. Josephson vortices are often seen as real topological objects, 2 pi-phase singularities that are hard to observe and manipulate.

Researchers from the MIPT Laboratory of Topological Quantum Phenomena in Superconducting Systems applied a magnetic force microscope to study Josephson vortices in a system of two superconducting niobium contacts interlaid with a copper layer acting as a weak link.



Experimental setup. The blue and orange indicate niobium and copper, respectively. The ellipse marks the area of the Josephson junction. The cobalt-chromium-coated tip oscillates, excited by a piezo element (dither). The optic fiber is used to read out the oscillations. Credit: Viacheslav Dremov et al./Nature Communications

"We have demonstrated that in the planar (flat) superconductor-normal metal-superconductor contacts, Josephson vortices have a unique imprint," said the paper's senior author, Vasily Stolyarov of MIPT. "We found this by observing these structures with a magnetic force microscope. Based on this discovery, we demonstrated the possibility of locally generating Josephson vortices, which can be manipulated by the magnetic cantilever of a microscope. Our research is yet another step toward creating future superconducting quantum computing machines."

The variety of ultrasensitive superconducting devices, qubits, and architectures for quantum computing is growing rapidly. It is expected that superconducting quantum electronic devices will challenge conventional semiconductor devices very soon. These new devices will rely on Josephson junctions like the one indicated by the yellow closed arrow in figure 1.

"It is quite difficult to visualize Josephson vortices, as they are poorly localized," Stolyarov added. "We discovered a way to measure the dissipation that occurs during the creation and destruction of such a vortex in the weak link area. Dissipation is a minor release of energy. In our case, the energy is released when a vortex moves in a planar Josephson contact. Thus, using our magnetic force microscope, we can successfully detect not only the static magnetic portrait of the superconducting structure but also the dynamic processes in it."

The authors of the paper demonstrated a method for remote generation, detection, and manipulation of Josephson vortices in planar Josephson junctions using a low-temperature magnetic force microscope. With certain parameters (probe location, temperature, external magnetic field, electric current flow through the sample), the team observed a particular response of the microscope cantilever. This was followed by the appearance of sharp rings/arcs in the images. The researchers identified these features as bifurcation points between adjacent Josephson states characterized by a different number or position of Josephson vortices inside the junction. The process is accompanied by the exchange of energy between the cantilever and the sample at the bifurcation points and demonstrates that a magnetic force microscope can provide unique information on the state of a Josephson vortex.

It is expected that the results of the research will serve as an impetus and a basis for developing new methods of local noncontact diagnostics and management of modern superconducting devices and superconducting quantum electronics. [27]

A theoretical explanation for an enhanced thermal Hall response in high-temperature superconductors

A few months ago, a team of researchers led by Louis Taillefer at the University of Sherbrooke measured the thermal Hall conductivity in several compounds of copper, oxygen and other elements that are also high-temperature superconductors known as 'cuprates.' In physics, the thermal Hall effect describes heat flow in a direction transverse to a temperature gradient.

Generally, heat flows in the same direction as the temperature gradient, but in the presence of a magnetic field, some flows in the transverse direction, too; this is known as the thermal Hall effect. In their study, Taillefer and his collaborators observed that in the cuprates, this transverse flow can sometimes be very large, which was surprising for many physicists worldwide.

Inspired by this observation, a team of researchers at Harvard University and the University of California recently set out to investigate it further. In their paper, published in *Nature Physics*, they were able to explain these striking findings by taking into account the possibility that the applied magnetic field in the experiment could bring the material close to an exotic phase with a large thermal Hall conductivity.

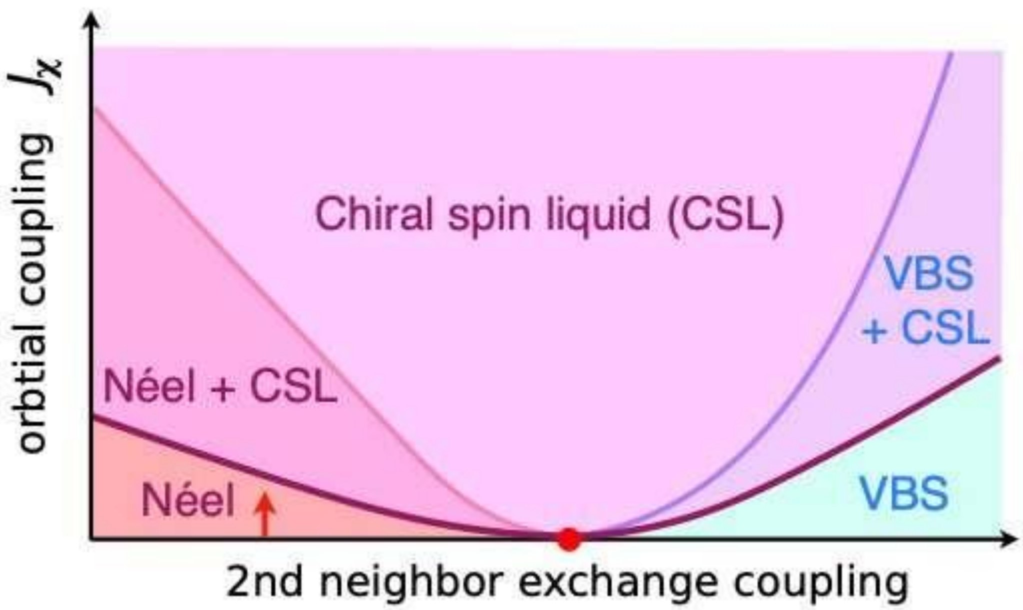
Essentially, the large signal observed by Taillefer and his colleagues indicates the presence of other mobile degrees of freedom that, unlike usual electrons, do not carry an electric charge, but contribute to the thermal Hall conductivity. These additional degrees of freedom only appear to be present in the Néel state and in the so-called 'pseudogap' state.

The Néel state is a state in which there is one electron per square lattice site and electron spins are arranged in opposite directions like black and white squares on a chess board. The pseudogap state, on the other hand, one of the most mysterious states in the phase diagram of high-temperature superconductors, emerges when the Néel order is destroyed by doping the system with holes (i.e., reducing the electronic density from one electron per square lattice site).

"These observations immediately caught our attention since our previous theoretical attempts to understand the phase diagram of the cuprates, which were motivated by a set of very different measurements and numerical simulations, naturally involve mobile 'spinon' excitations inside the pseudogap phase," Mathias Scheurer and Subir Sachdev, two of the researchers who carried out the study, told Phys.org. "Spinons carry spin but no charge, and hence represent a natural source of the observed large thermal Hall response. We were thus eager to analyze whether these theoretical descriptions can quantitatively reproduce the thermal Hall data of Taillefer's group."

To investigate whether the theoretical constructs they devised were aligned with the data gathered by Taillefer and his colleagues, the researchers first focused their theoretical investigations on the undoped cuprates, with one electron per site and Néel order. They chose to study this particular system because undoped experimental samples are the cleanest, and thus, the experimental signatures in Taillefer's data are most likely intrinsic for the undoped samples, rather than a consequence of inhomogeneities in the system. In addition, the observations gathered by Taillefer and his team for the undoped system are also most surprising, as they undermined the previous understanding of the Néel phase.

"Both we and P. Lee's group concluded after detailed investigations that conventional spin-wave theory cannot reproduce the large thermal Hall response seen in experiment," Scheurer and Sachdev said. "Therefore, one is faced with the problem of finding a mechanism for the observed enhanced thermal Hall effect in the Néel phase, which we address in our recent *Nature Physics* article."



In the vicinity of the critical point (red dot) between the Néel state, realized in the undoped cuprates, and a second phase (denoted by VBS which stands for valence bond solid), only a small orbital coupling is required to drive the system into a chiral spin liquid (CSL) phase. The horizontal axis represents a coupling constant between spins located on next-nearest-neighbor copper sites. The red arrow denotes the impact of the experimentally applied magnetic field, driving the Néel state in proximity to the transition to a phase where Néel order and CSL coexists. Credit: Samajdar et al. Figure adapted from Samajdar et al., *Nature Physics* (2019).

One key aspect of the explanation for the thermal Hall effect provided by Scheurer, Sachdev and their colleagues is the orbital coupling J_χ of the magnetic field. In materials with very strong interactions, such as cuprates, this orbital coupling is often neglected, as it is expected to be significantly weaker than the direct coupling of the spin to the magnetic field, which is known as Zeeman coupling. However, in the proximity of a critical point, its effect can be enhanced significantly.

"Our theory is that a small J_χ can drive the system into a chiral spin liquid (CSL) phase in the vicinity of the critical point—an effect we expected to be further enhanced in the presence of spin-orbit coupling," Scheurer and Sachdev said. "CSLs are related to quantum Hall phases, with the crucial difference that the mobile degrees of freedom are not electrons but rather spinons, which only carry spin and no electric charge. As such, they do not exhibit a quantized electric Hall response, but by virtue of carrying energy, yield a quantized thermal Hall response."

The theory devised by Scheurer, Sachdev and their colleagues suggests that the magnetic field applied in experiments investigating the thermal Hall effect drives the Néel phase in proximity to a CSL that coexists with Néel order. In their study, they found that although the undoped system remained in the Néel phase, this proximity yields a large thermal Hall response similar, but somewhat smaller, than that observed in the data of Taillefer's team. The researchers also observed that the dependence they predicted for the thermal Hall conductivity on both temperature and magnetic field agrees well with the measurements.

The theory proposed by the researchers thus represents a natural possible explanation of the striking observations of Taillefer and his colleagues. This thermal Hall conductivity cannot be explained by the spin-wave theory of the Néel state, which was previously believed to capture the physics of the undoped compounds very well.

"Our work indicates that spinon excitations have to be taken into account, even in the Néel phase," Scheurer and Sachdev said. "Our study also illustrates that the orbital coupling of the magnetic field, although expected to be weak compared to the Zeeman coupling, can play a key role."

In addition to providing a feasible explanation for the findings gathered by Taillefer and his colleagues, Scheurer, Sachdev and their colleagues came up with an effective theory for the transition between the Néel state and the CSL. This theory has four different 'dual' formulations. In other words, there are four theories that look very different at first sight (e.g., they contain different types of elementary degrees of freedom), but essentially describe the same physics.

"In our work, we could relate all four theories to the microscopic degrees of freedom of the undoped cuprates," Scheurer and Sachdev explained. "It is quite exciting to see how abstract statements of 'dualities' between theories obtain a concrete representation in a real material with direct consequences for condensed matter experiments. We hope that the insights of our recent work will prove useful for the extension to the doped system."

So far, the team of researchers at Harvard University and the University of California was able to provide a viable theoretical explanation of why the undoped cuprate compounds present an enhanced thermal Hall response. In their future work, they plan to investigate this topic further by elaborating on the four different 'dual theories' they proposed for the enhancement mechanism of the thermal Hall effect.

"As our previous computations are only based one description, we are planning to look into the respective predictions for the thermal Hall conductivity in the three other theories; this is also expected to advance our understanding of the physics behind the underlying dualities," Scheurer and Sachdev said. "Another important problem for future research will be extending our analysis to the doped system. This will likely shed light on the nature of the pseudogap phase." [26]

Twisted physics: Magic angle graphene produces switchable patterns of superconductivity

Last year, scientists demonstrated that twisted bilayer graphene—a material made of two atom-thin sheets of carbon with a slight twist—can exhibit alternating superconducting and insulating regions. Now, a new study in the journal *Nature* by scientists from Spain, the U.S., China and Japan shows that superconductivity can be turned on or off with a small voltage change, increasing its usefulness for electronic devices.

"It's kind of a holy grail of physics to create a material that has superconductivity at room temperature," University of Texas at Austin physicist Allan MacDonald said. "So that's part of the motivation of this work: to understand high-temperature superconductivity better."

The discovery is a significant advance in an emerging field called Twistronics, whose pioneers include MacDonald and engineer Emanuel Tutuc, also from The University of Texas at Austin. It took several years of hard work by researchers around the world to turn MacDonald's original insight into materials with these strange properties, but it was worth the wait.

Finding superconductivity in odd places

In 2011, MacDonald, a theoretical physicist who uses quantum mathematics and computer modeling to study two-dimensional materials, made an unexpected discovery. Along with Rafi Bistritzer, a postdoctoral researcher, he was working on building simple but accurate models of how electrons behave in stacked 2-D materials—materials one atom thick—when one layer is slightly twisted relative to the others. The seemingly un-computable problem, MacDonald believed, could be greatly simplified by focusing on one key parameter of the system.

The strategy MacDonald and Bistritzer employed proved successful. The surprise came later. When they applied their method to twisted bilayer graphene, a system consisting of two layers of carbon atoms, they found that at a very specific angle of about 1.1 degrees—which they dubbed the "magic angle"—the electrons behaved in a strange and extraordinary way, suddenly moving more than 100 times more slowly.

Why this was the case and what it would mean for science would take years to discover.

In the short term, the finding was largely ignored or dismissed. The result seemed too unusual to believe. Moreover, it was not obvious that creating a physical example of such a system, with such a precise placement of the two-dimensional sheets, was physically achievable.

But not everyone was incredulous or intimidated by the results. A few experimentalists around the world took note of the prediction published in the *Proceedings of the National Academy of Sciences* and chose to pursue the "magic angle." When in 2018, for the first time, physicists at the Massachusetts Institute of Technology created a system of layered graphene twisted by 1.1 degrees, they found, as MacDonald had predicted, that it exhibited remarkable properties—in particular, superconductivity at a surprisingly high temperature.

"There's no simple explanation for why electrons suddenly slow down," MacDonald said. "Thanks to recent work by theorists at Harvard, there's now a partial explanation related to models often studied in elementary particle physics. But there's now a whole world of related effects in different layered 2-D materials. Twisted bilayer graphene is just a peek into one part of it."

Superconducting materials have no electrical resistance, allowing electrons to travel endlessly without dissipating energy. They are used in quantum computing and could be game changers for electrical transmission if they did not require expensive refrigeration.

First discovered in 1911, superconductivity has been documented in a number of materials. However, they all require extremely low temperatures to maintain their distinctive characteristics. The emergence of stacked 2-D materials may change this.

The discovery of superconductivity in twisted bilayer graphene has since provided fuel for a flourishing subfield with a catchy name—Twistronics—and a rush to develop the technology further.

This video shows how the idea for twistronics was first developed, how "magic angle" graphen spawns superconductivity and possible applications. Credit: David Steadman/University of Texas at Austin

A decade of dedicated study

Ever since the discovery of graphene by Andre Geim and Konstantin Novoselov at the University of Manchester in 2004 (which ultimately led to a Nobel Prize in physics in 2010), MacDonald has been fascinated with these strange, two-dimensional systems and the new physics they may contain.

He began studying the material almost immediately and, since 2004, has used supercomputers at the Texas Advanced Computing Center (TACC) to explore the electronic structure of graphene and other 2-D materials.

"My work is all about predicting unusual phenomena that haven't been seen before, or trying to understand phenomena that are not well understood," MacDonald said. "I'm drawn to theory that connects directly to things that actually happen, and I'm interested in the power of math and theory to describe the real world."

The strange properties of layered 2-D materials seems to relate to interactions, which become much more crucial when electrons slow down, inducing strong correlations between individual electrons. Typically, electrons circle nearly separately around the nucleus in atomic orbitals, settling into quantum states with the lowest available energies. This does not seem to be the case in magic angle graphene.

"Basically, nothing much interesting can happen when the electrons organize themselves the way they do in an atom by occupying the lowest energy orbitals," MacDonald said. "But once their fate is determined by interactions between the electrons, then interesting things can happen."

How does one even go about studying what happens in layered 2-D systems—known, technically, as van der Waals heterostructures? "Seeing" electrons in motion is next to impossible. Measurements provide clues, but the results are oblique and frequently counterintuitive. Computer models, MacDonald believes, can help add to the emerging picture of confined electrons.

Computer models that represent classical electronic structure are well developed and highly accurate in most cases, but they need to be adjusted in the face of the weird physics of heterojunctions.

Altering these factors means rewriting the prevailing model to mirror the behavior of strongly interacting electrons, a task that MacDonald and researchers in his lab are currently working on, using TACC's Stampede2 supercomputer—one of the most powerful in the world—to test models and run simulations. Moreover, ever-larger numbers of electrons must be included in order to accurately replicate the results that are emerging from labs around the world.

"The real system has billions of electrons," MacDonald explained. "As you increase the number of electrons, you quickly exceed the capability of any computer. So, one of the approaches we're using, in work led by Pawel Potasz—a visitor from Poland—is to solve the electronic problem for small numbers of electrons and extrapolate the behavior to large numbers."

Applying theory to never-before-seen systems

While working to redesign electronic structure models and scale them to ever-greater numbers of electrons, MacDonald still finds time to collaborate with experimental groups around the world, adding his theoretical and computational insights to their findings.

What happens when a supermaterial meets a magic angle? Credit: David Steadman/University of Texas at Austin

For years after the discovery of magic angle, practical difficulties in creating pure forms of layered 2-D materials with precise angles of rotation limited the field. But in 2016, another UT researcher, Emanuel Tutuc, and his graduate student, Kyounghwan Kim, developed a reliable method for creating such systems, not only using graphene, but of a number of different 2-D materials.

"The breakthrough really was a technique that my student introduced, which consists of taking a large layer, splitting it into two and taking one segment and putting it on top of the other one," Tutuc said.

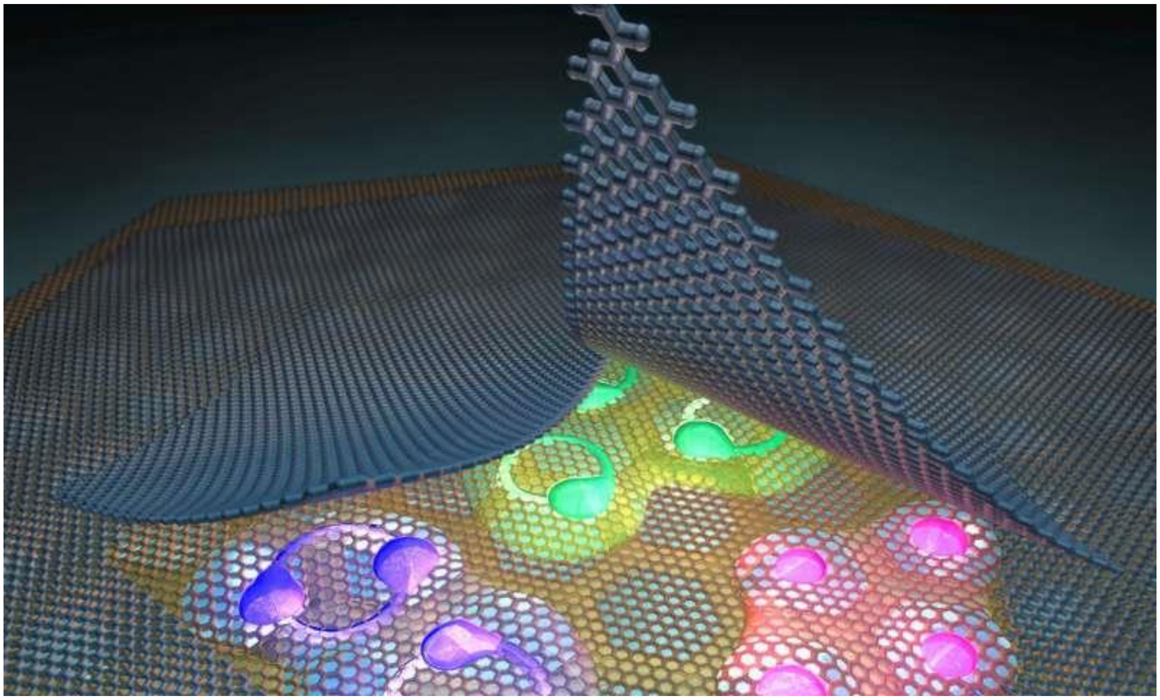
The reason that had not been implemented before is that it is very difficult to pick up a micron-size piece of atom-thick material. Kim invented a sticky, hemispherical handle that can lift up an individual flake, leaving everything else in its proximity intact.

"Once that was done, the possibilities became endless," he continued. "Not long after, the same student said, 'OK, now that we can align them with the really high accuracy, let's go ahead and twist them.' So that was the next step."

In recent years, MacDonald and his team have explored stacks of three, four or five layers of graphene, as well as other promising materials, particularly transition metal chalcogenides, searching for unusual—and potentially useful—phenomena.

Writing in *Nature* in February 2019, MacDonald, Tutuc, UT Austin physicist Elaine Li, and a large international team described the observation of indirect excitons in a molybdenum diselenide/tungsten diselenide (MoSe2/WSe2) heterobilayer with a small twist angle.

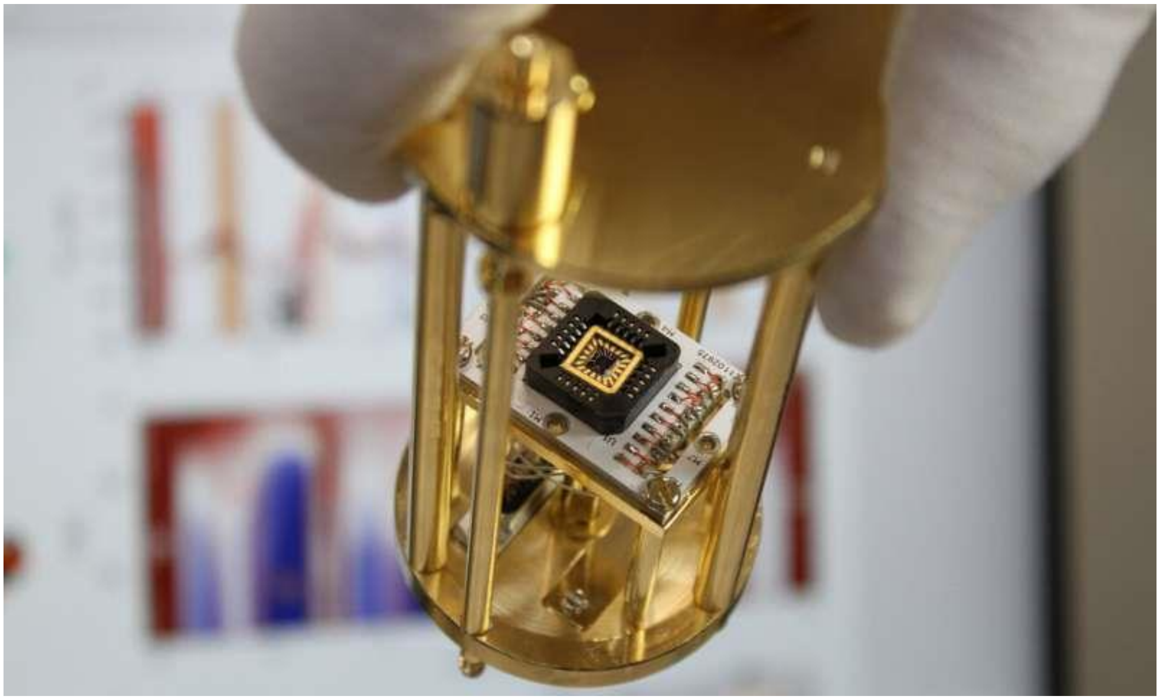
Excitons are quasiparticles that consist of an electron and a hole that attract and hold each other in place. These usually exist within a single layer. However, with certain 2-D materials, it is possible for them to exist on different layers, which greatly increases the length of time they exist. This may enable superfluidity, the unimpeded flow of liquids—a property previously seen only in liquid helium.



Artistic illustration of the bi-layer and the zoo of different states of matter that have been discovered. Credit: © ICFO / F. Vialla

Now, MacDonald and a team from Spain, China and Japan have published a study in *Nature* of magic angle graphene that showed the material can exhibit alternating superconducting and insulating phases that can be turned on or off with a small voltage change, similar to the voltages used in integrated circuits, increasing its usefulness for electronic devices. To achieve this result, team members from the Catalan Institute for Optical Physics produced graphene superlattices with more uniform twists than previously possible. In so doing, they discovered that the pattern of interleaved insulating and superconducting states is even more intricate than predicted.

TACC supercomputers are a critical tool in MacDonald's research and were used for the theoretical modeling of the data in the recent *Nature* paper.



Close-up of the device placed onto the piece that later is adjusted to the experimental setup ©ICFO Credit: ICFO

"Many of the things we do, we could not do without a high-performance computer," he asserted. "We start out running on a desktop and then we quickly get bogged down. So very often, using a supercomputer is the difference between being able to get a satisfactory answer and not being able to get a satisfactory answer."

Though the results of computational experiments may seem less immediate or "real" than those in a lab, as MacDonald has shown, the results can expose new avenues of exploration and help illuminate the mysteries of the universe.

"The thing that's energized my work is that nature is always posing new problems. And when you ask a new type of question, you don't know in advance what the answer is," MacDonald said. "Research is an adventure, a community adventure, a collective random walk, by which knowledge moves forward." [25]

Superconducting nanowires could shed light on dark matter

Superconducting nanowires could be used as both targets and sensors for the direct detection of dark matter, physicists in Israel and the US have shown. Using a prototype nanowire detector, Yonit Hochberg at the Hebrew University of Jerusalem and colleagues demonstrated the possibility of detecting of dark matter particles with masses below about

1 GeV/c^2, while maintaining very low levels of noise. The team says it has already used its prototype to set “meaningful bounds” on interactions between electrons and dark matter.

While dark matter appears to make up about 85% of the matter in the universe, it has not been detected directly – despite the best efforts of physicists working on numerous detectors worldwide. So far, the search has been dominated by efforts to detect weakly-interacting massive particles (WIMPs) – hypothetical dark-matter particles that could be streaming through Earth in very large numbers. WIMP detectors are designed to look for particles with masses greater than 1 GeV/c^2, and are not expected to be sensitive to lower-energy particles.

To extend the search to lower masses, physicists have used several different sensor technologies made from materials including graphene, polar crystals, and superfluid helium. Superconducting nanowires are already used to detect single photons, and Hochberg and colleagues at the Massachusetts Institute of Technology and National Institute of Standards and Technology believe that nanowires should join the hunt for dark matter. If a dark matter particle collides with an electron in a cold, current-carrying superconducting nanowire, the nanowire could heat-up and for a short time cease to be a superconductor. The resulting spike in the nanowire’s resistance would reveal that a dark matter interaction has taken place.

Low noise

The physicists tested their proposal by building a tungsten-silicide nanowire prototype, which had a detection energy threshold of 0.8 eV. During 2.8 h of operation, the detector registered no unwanted background counts, which demonstrates a very low level of intrinsic noise.

The team says the technique has several advantages over other detectors, including ultra-fast detection speeds and very low levels of noise. In addition, the wires could potentially pick up dark matter particles with kinetic energies below 1 eV, which is extremely low for a dark-matter detector, and could also detect “dark photons” with energies less than 1 eV. Dark photons are hypothetical particles that could mediate interactions between dark matter.

The team says their early experiments have already placed meaningful bounds on the interaction between dark matter and electrons including the strongest terrestrial bounds on the absorption of sub-electronvolt dark photons.

In future studies, Hochberg and colleagues now hope to fabricate nanowires on larger scales, and with even lower detection thresholds. When coupled with other detection techniques, they believe their nanowires will allow them to probe for dark matter in previously-unexplored regions of mass and energy.

The research is described in a preprint on *arXiv*. [24]

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

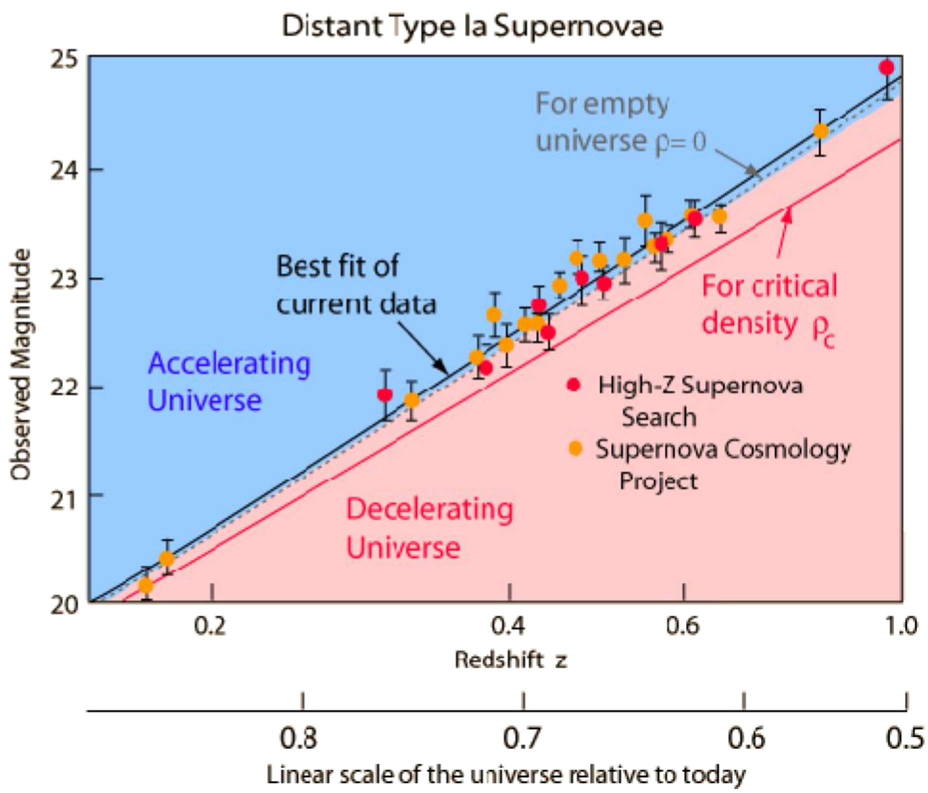
In particle physics and astrophysics, weakly interacting massive particles, or WIMPs, are among the leading hypothetical particle physics candidates for dark matter. The term “WIMP” is given to a dark matter particle that was produced by falling out of thermal equilibrium with the hot dense plasma of 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

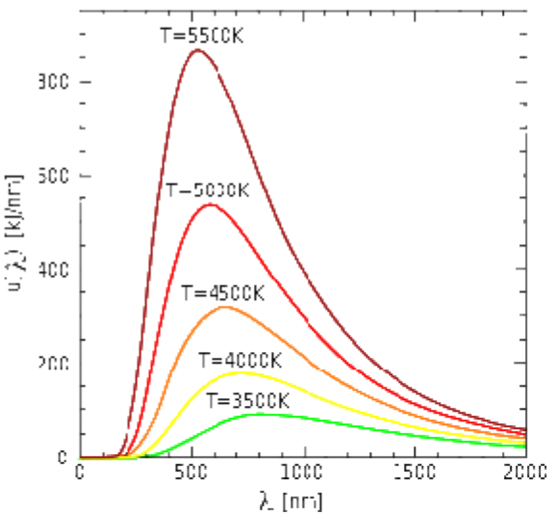
Dark matter is a type of matter hypothesized in astronomy and cosmology to account for a large part of the mass that appears to be missing from the universe. Dark matter cannot be seen directly with telescopes; evidently it neither emits nor absorbs light or other electromagnetic radiation at any significant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