

# Heavy Thermal Dark Matter

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*Today, an international group of researchers, including Carnegie Mellon University's Rachel Mandelbaum, released the deepest wide field map of the three-dimensional distribution of matter in the universe ever made and increased the precision of constraints for dark energy with the Hyper Suprime-Cam survey (HSC). [21]*

*Scientists are hoping to understand one of the most enduring mysteries in cosmology by simulating its effect on the clustering of galaxies. [20]*

*The U.S. Department of Energy has approved nearly \$1 million in funding for the research team, which has been tasked with leveraging large-scale computer simulations and developing new statistical methods to help us better understand these fundamental forces. [19]*

*According to a new study, they could also potentially detect dark matter, if dark matter is composed of a particular kind of particle called a "dark photon." [18]*

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

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

*By reproducing the complexity of the cosmos through unprecedented simulations, a new study highlights the importance of the possible behaviour of very high-energy photons. In their journey through intergalactic magnetic fields, such photons could be transformed into axions and thus avoid being absorbed. [15]*

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

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

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

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

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

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Author: George Rajna

## The Big Bang

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

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

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

### **A new framework could aid the search for heavy thermal dark matter**

Astrophysicists have been searching for dark matter for several decades, but these searches have so far yielded disappointing results. In a recent study, two researchers at Weizmann Institute of Science and the Hebrew University of Jerusalem in Israel have introduced a new theoretical framework outlining a mechanism of elementary thermal dark matter with a mass up to  $10^{14}$  GeV.

The [dark matter](#) considered in their work consists of several almost degenerate particles that scatter in the nearest-neighbor chain in a way that is aligned with the standard model used in dark matter studies. The new framework presented by these researchers, outlined in [a paper published in \*Physical Review Letters\*](#), could ultimately inform future searches for heavy dark matter.

"The nature of dark matter is a longstanding problem in modern day physics," Hyungjin Kim, one of the researchers who carried out the study, told Phys.org. "A particle that is as heavy as Higgs boson, and is involved in interactions whose strength is that of electroweak interaction, is thought to be a particularly well-motivated dark matter candidate, as it often naturally arises when addressing another key problem: the hierarchy between the electroweak scale and the Planck scale."

The particle that is thought to be a good dark matter candidate, known as a weakly interacting massive particle (WIMP), could be produced naturally from interactions between standard model particles in the early universe while they are in [thermal equilibrium](#). This particular process goes by the name of the 'thermal freeze-out mechanism.'

Based on current astrophysics theory, the final abundance of WIMPs in our universe today would thus be insensitive to details of initial conditions or model parameters. However, a common lore originating from [a 1990 paper by Kim Griest and Marc Kamionkowski](#) suggests that this thermal freeze-out mechanism does not work when dark matter is heavier than 100 TeV (i.e., a thousand times heavier than the Higgs boson).

"In our recent paper, we prove this common lore wrong and show that thermal freeze-out is possible even when dark matter is several orders of magnitude heavier than the Higgs mass, if there are a set of dark particles that scatter off the standard model particles with nearest-neighbor interactions," Eric Kuflik, the other researcher behind the study, said. "The relic abundance of the

dark matter is then determined by stochastic interactions between the dark particles and the Standard Model particles."

The mechanism proposed by Kim and Kuflik describes a set of dark matter particles scattering with ordinary matter through nearest-neighbor interactions, which change between species. In other words, it suggests that the dark matter takes a 'random walk' among dark matter species, continuously changing its identity. Based on the framework introduced by the researchers, therefore, the abundance of dark matter is thermally determined in the early universe, enabling extremely heavy dark matter masses.

"We have shown that dark matter can be produced from the [early universe](#) thermal bath while being in thermal equilibrium, even for dark matter masses substantially heavier than conventional wisdom would allow," Kim explained. "Interestingly, the abundance of dark matter particles in our scenario depends only on the interaction strength of the dark particles with the Standard model particles."

The new framework developed by Kim and Kuflik could have important implications for studies investigating the cosmic microwave background, structure formation and cosmic rays. In addition, it could serve as a benchmark for heavy dark matter experimental searches, as it suggests that decays to ordinary matter particles in the late universe could leave interesting astrophysical and cosmological signatures, which researchers could look for when searching for dark matter.

"There are two promising directions we hope to pursue in our future work," Kim said. "First, our mechanism inevitably predicts dark matter particles decaying to Standard Model particles throughout the history of the universe. This could leave interesting astrophysical signatures, such as ultra-high energy cosmic rays and so on. The implications for cosmology are also interesting."

So far, Kim and Kuflik have described the basic idea of superheavy dark matter and provided a 'simple toy [model](#)' of it by parameterizing the interaction strength between dark particles and [standard model](#) particles. In their next studies, however, Kim and Kuflik plan to conduct a detailed study of particle physics theories that could realize their mechanism of superheavy thermal dark matter.

"Explicit realizations in particle physics will help to identify the full suite of experimental signals predicted by the mechanism, which will teach us the best means to either exclude or detect such dark matter," Kuflik added. [23]

## Dark matter on the move

Scientists have found evidence that dark matter can be heated up and moved around, as a result of star formation in galaxies. The findings provide the first observational evidence for the effect known as 'dark matter heating', and give new clues as to what makes up dark matter. The research is published today in the journal *Monthly Notices of the Royal Astronomical Society*.

In the new work, scientists from the University of Surrey, Carnegie Mellon University and ETH Zürich set out to hunt for evidence for [dark matter](#) at the centres of nearby dwarf [galaxies](#). Dwarf galaxies are small, faint galaxies that are typically found orbiting larger galaxies like our own Milky Way. They may hold clues that could help us to better understand the nature of dark [matter](#).

Dark matter is thought to make up most of the mass of the universe. However since it doesn't interact with light in the same way as normal matter, it can only be observed through its gravitational effects. The key to studying it may however lie in how stars are formed in these galaxies.

When stars form, [strong winds](#) can push gas and dust away from the heart of the galaxy. As a result, the galaxy's centre has less mass, which affects how much gravity is felt by the remaining dark matter. With less [gravitational attraction](#), the dark matter gains energy and migrates away from the centre, an effect called 'dark matter heating'.

The team of astrophysicists measured the amount of dark matter at the centres of 16 dwarf galaxies with very different star formation histories. They found that galaxies that stopped forming stars long ago had higher dark matter densities at their centres than those that are still forming [stars](#) today. This supports the theory that the older galaxies had less dark matter heating.

Professor Justin Read, lead author of the study and Head of the Department of Physics at the University of Surrey, said: "We found a truly remarkable relationship between the amount of dark matter at the centres of these tiny dwarfs, and the amount of star formation they have experienced over their lives. The dark matter at the centres of the star-forming dwarfs appears to have been 'heated up' and pushed out."

The findings provide a new constraint on dark matter models: dark matter must be able to form [dwarf galaxies](#) that exhibit a range of central densities, and those densities must relate to the amount of star formation.

Professor Matthew Walker, a co-author from Carnegie Mellon University, added: "This study may be the "smoking gun" evidence that takes us a step closer to understanding what dark matter is. Our finding that it can be heated up and moved around helps to motivate searches for a dark matter particle."

The team hope to expand on this work by measuring the central dark matter density in a larger sample of dwarfs, pushing to even fainter galaxies, and testing a wider range of dark matter models. [22]

## **Hyper Suprime-Cam survey maps dark matter in the universe**

Today, an international group of researchers, including Carnegie Mellon University's Rachel Mandelbaum, released the deepest wide field map of the three-dimensional distribution of matter in the universe ever made and increased the precision of constraints for dark energy with the Hyper Suprime-Cam survey (HSC).

The present-day universe is a pretty lumpy place. As the universe has expanded over the last 14 billion years or so, [galaxies](#) and dark matter have been increasingly drawn together by gravity,

creating a clumpy landscape with large aggregates of matter separated by voids where there is little or no matter.

The gravity that pulls matter together also impacts how we observe astronomical objects. As light travels from distant galaxies towards Earth, the gravitational pull of the other matter in its path, including dark matter, bends the light. As a result, the images of galaxies that telescopes see are slightly distorted, a phenomenon called weak gravitation lensing. Within those distortions is a great amount of information that researchers can mine to better understand the distribution of matter in the universe, and it provides clues to the nature of dark [energy](#).

The HSC map, created from data gathered by Japan's Subaru telescope located in Hawaii, allowed researchers to measure the gravitational distortion in images of about 10 million galaxies.

The Subaru telescope allowed them to see the galaxies further back in time than in other similar surveys. For example, the Dark Energy Survey analyzes a much larger area of the sky at a similar level of precision as HSC, but only surveys the nearby universe. HSC takes a narrower, but deeper view, which allowed researchers to see fainter galaxies and make a sharper map of dark matter distribution.

The research team compared their map with the fluctuations predicted by the European Space Agency Planck satellite's observations of the cosmic microwave background radiation—radiation from the earliest days of the universe. The HSC measurements were slightly lower than, but still statistically consistent with Planck's. The fact that HSC and other weak lensing surveys all find slightly lower results than Planck raises the tantalizing question of whether dark energy truly behaves like Einstein's cosmological constant.

"Our map gives us a better picture of how much dark energy there is and tells us a little more about its properties and how it's making the expansion of the [universe](#) accelerate," Mandelbaum said. "The HSC is a great complement to other surveys. Combining data across projects will be a powerful tool as we try uncover more and more about the nature of dark [matter](#) and dark energy."

Measuring the distortions caused by weak gravitational lensing isn't easy. The effect is quite small and distortions in galaxy shapes can also be caused by the atmosphere, the telescope and the detector. To get precise, accurate results, researchers need to know that they are only measuring effects from weak lensing.

Mandelbaum, associate professor of physics and member of the McWilliams Center for Cosmology at Carnegie Mellon, is an expert at controlling for these outside distortions. She and her team created a detailed image simulation of the HSC survey data based on images from the Hubble Space Telescope. From these simulations, they were able to apply corrections to the galaxy shapes to remove the shape distortions caused by effects other than lensing.

These results come from the HSC survey's first year of data. In all, the HSC [survey](#) will collect five years of data that will yield even more information about the behavior of dark energy and work towards other goals such as studying the evolution of galaxies and massive clusters of galaxies across cosmic time, measuring time-varying objects like supernovae, and even studying our own Milky Way galaxy.

The research will be uploaded to the preprint server [arxiv.org](https://arxiv.org) and will be submitted to the Publication of the Astronomical Society of Japan. [21]

## Dark matter clusters could reveal nature of dark energy

Scientists are hoping to understand one of the most enduring mysteries in cosmology by simulating its effect on the clustering of galaxies.

That mystery is dark [energy](#) – the phenomenon that scientists hypothesise is causing the universe to expand at an ever-faster rate. No-one knows anything about dark energy, except that it could be, somehow, blowing pretty much everything apart.

Meanwhile, dark energy has an equally shady cousin – dark matter. This invisible substance appears to have been clustering around galaxies, and preventing them from spinning themselves apart, by lending them an extra gravitational pull.

Such a clustering effect is in competition with dark energy's accelerating expansion. Yet studying the precise nature of this competition might shed some light on dark energy.

"Many dark energy models are already ruled out with current data," said Dr. Alexander Mead, a cosmologist at the University of British Columbia in Vancouver, Canada, who is working on a project called Halo modelling. "Hopefully in future we can rule more out."

## Gravitational lensing

Currently, the only way dark matter can be observed is by looking for the effects of its gravitational pull on other matter and light. The intense gravitational field it produces can cause light to distort and bend over large distances – an effect known as gravitational lensing.

By mapping the dark matter in distant parts of the cosmos, scientists can work out how much dark matter clustering there is – and in principle how that clustering is being affected by dark energy.

The link between gravitational lensing and dark matter clustering is not straightforward, however. To interpret the data from telescopes, scientists must refer to detailed cosmological models – mathematical representations of complex systems.

Dr. Mead is developing a clustering model that he hopes will have enough accuracy to distinguish between different dark-energy hypotheses.

"An analogy I like a lot is with turbulence. In turbulent fluid flow you can talk about currents and eddies, which are nice words, but the reality of how fluid in a pipe goes from flowing calmly to flowing in a turbulent fashion is extremely complicated."

## Fifth force

One of the more exotic theories is that dark energy is the result of a hitherto undetected fifth force, in addition to nature's four known forces—gravity, electromagnetism, and the strong and weak nuclear forces inside atoms.

A more common hypothesis for dark energy, however, is known as the cosmological constant, which was put forward by Albert Einstein as part of his general theory of relativity. It is often

believed to describe an all-pervading sea of virtual particles that are continually popping into and out of existence throughout the universe.

One way to rule out the cosmological constant hypothesis, of course, is to prove that dark energy is not constant at all. This is the goal of Dr. Pier Stefano Corasaniti of the Paris Observatory in France, who – in a project called EDECS – is approaching dark-matter clustering from a different direction.

Instead of attempting to model clustering from [gravitational lensing](#) data, he is beginning specifically with a dynamical – that is, not constant – hypothesis of dark energy, and trying to predict how dark matter would cluster if this was the case.

### **Pushing the limits**

There are, in principle, infinite ways dark energy can vary in space and time, although many theories have already been ruled out by existing observations. Dr. Corasaniti is focussing his simulations on types of dynamical dark energy that push at the edges of these observational limits, paving the way for tests with future experiments.

The simulations, which trace the evolution of numerous, 'N-body' dark matter particles, require supercomputers running for long periods of time, processing several petabytes (one thousand million million bytes) of data.

"We have run among the largest cosmological N-body simulations ever realised," Dr. Corasaniti said.

Dr. Corasaniti's simulations predict that the way dark energy evolves over time ought to affect [dark matter](#) clustering. This, in turn, alters the efficiency with which galaxies form in ways that would not be the case with constant dark energy.

The predictions his models are making could be tested with the help of forthcoming telescopes such as the Large Synoptic Survey Telescope in Chile and the Square Kilometre Array in Australia and South Africa, as well as by satellite missions such as Euclid (EUropean Cooperation for LighTning Detection) and WFIRST (Wide Field Infrared Survey Telescope).

"If [dark energy](#) turns out to be a dynamical phenomenon this will have a profound implication not only on cosmology, but on our understanding of fundamental physics," said Dr. Corasaniti. [20]

### **Large-scale simulations could shed light on the 'dark' elements that make up most of our cosmos**

If you only account for the matter we can see, our entire galaxy shouldn't exist. The combined gravitational pull of every known moon, planet, and star should not have been strong enough to produce a system as dense and complex as the Milky Way.

So what's held it all together?

Scientists believe there is a large amount of additional matter in the universe that we can't observe directly – so-called "[dark matter](#)." While it is not known what dark matter is made of, its effects on light and gravity are apparent in the very structure of our galaxy. This, combined with the even

more mysterious "[dark energy](#)" thought to be speeding up the universe's expansion, could make up as much as 96 percent of the entire cosmos.

In an ambitious effort directed by Argonne National Laboratory, researchers at the Biocomplexity Institute of Virginia Tech are now attempting to estimate key features of the universe, including its relative distributions of dark matter and dark energy. The U.S. Department of Energy has approved nearly \$1 million in funding for the research team, which has been tasked with leveraging large-scale computer simulations and developing new statistical methods to help us better understand these fundamental forces.

To capture the impact of dark matter and dark energy on current and future scientific observations, the research team plans to build on some of the powerful predictive technologies that have been employed by the Biocomplexity Institute to forecast the global spread of diseases like Zika and Ebola. Using observational data from sources like the Dark Energy Survey, scientists will attempt to better understand how these "dark" elements have influenced the evolution of the universe.

"It sounds somewhat incredible, but we've done similar things in the past by combining statistical methods with supercomputer simulations, looking at epidemics," said Dave Higdon, a professor in the Biocomplexity Institute's Social and Decision Analytics Laboratory and a faculty member in the Department of Statistics, part of the Virginia Tech College of Science.

"Using [statistical methods](#) to combine input data on population, movement patterns, and the surrounding terrain with detailed simulations can forecast how health conditions in an area will evolve quite reliably—it will be an interesting test to see how well these same principles perform on a cosmic scale."

If this effort is successful, results will benefit upcoming cosmological surveys and may shed light on a number of mysteries regarding the makeup and evolution of dark matter and dark energy. What's more, by reverse engineering the evolution of these elements, they could provide unique insights into more than 14 billion years of cosmic history. [19]

## **Gravitational wave detectors to search for dark matter**

Gravitational wave detectors might be able to detect much more than gravitational waves. According to a new study, they could also potentially detect dark matter, if dark matter is composed of a particular kind of particle called a "dark photon." In the future, LIGO (Laser Interferometer Gravitational Wave Observatory) scientists plan to implement a search for dark photons, which will include certain previously unexplored regions of the dark photon parameter space.

A team of physicists, Aaron Pierce, Keith Riles, and Yue Zhao from the University of Michigan, have reported their proposal for using gravitational wave detectors to search for dark matter in a recent paper published in *Physical Review Letters*.

"This proposal nicely bridges the newly born field of gravitational wave astronomy with that of particle physics," Zhao told *Phys.org*. "Without any modifications, a [gravitational wave detector](#) can be used as a very sensitive direct dark matter [detector](#), with the potential for a five-sigma discovery of dark matter."

As the physicists explain in their paper, if dark photons have a very light mass, then they can be considered to behave like an oscillating background field, with the oscillation frequency determined by their mass. Gravitational wave detectors could potentially detect these oscillations because the oscillations may affect test objects placed in the gravitational wave detectors. For example, if two test objects located at different positions in the detector experience different displacements, this difference may be due to the relative phase of the [dark photon](#) field's oscillations at these different positions.

The physicists expect that both present Earth-based gravitational wave detectors such as LIGO, as well as future space-based gravitational wave detectors such as LISA (Laser Interferometer Space Antenna), will have the ability to search for dark [photon](#) dark matter. Using more than one detector would allow for cross-checking and better sensitivity.

In the future, the scientists plan to work on further developing the new [dark matter](#) search method and determining exactly what kind of signal a gravitational wave detector would receive if a dark photon were nearby.

"We plan to push this work well beyond a theoretical proposal," Zhao said. "First, we plan to carry out the data analysis using a simplified signal model and a straightforward search algorithm. Then we will gradually refine our search method and include a detailed simulation of the signal and detector response." [18]

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

This innovative work "confirms the high quality of the work in astroparticle physics and gravitationalwave astronomy done by members of the gravitational physics group at UM, widely

recognized as one of the leaders in the field," said Luca Bombelli, chair and professor of physics and astronomy at Ole Miss. [17]

### **Synopsis: Dark Photon Conjecture Fizzles**

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

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

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

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

### **Exchanges of identity in deep space**

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

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

A possible explanation for this surprising anomaly is that light photons are transformed into hypothetical weakly interacting particles, "axions," which, in turn, would change into photons, all due to the interaction with magnetic fields. A part of the photons would escape interaction with the intergalactic background light that would make them disappear. The importance of this process is emphasised by a study published in Physical Review Letters, which recreated an extremely refined model of the cosmic web, a network of filaments composed of gas and dark matter present throughout the universe, and of its magnetic fields. These effects are now awaiting comparison with those obtained experimentally through Cherenkov Telescope Array new generation telescopes.

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

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

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

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

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

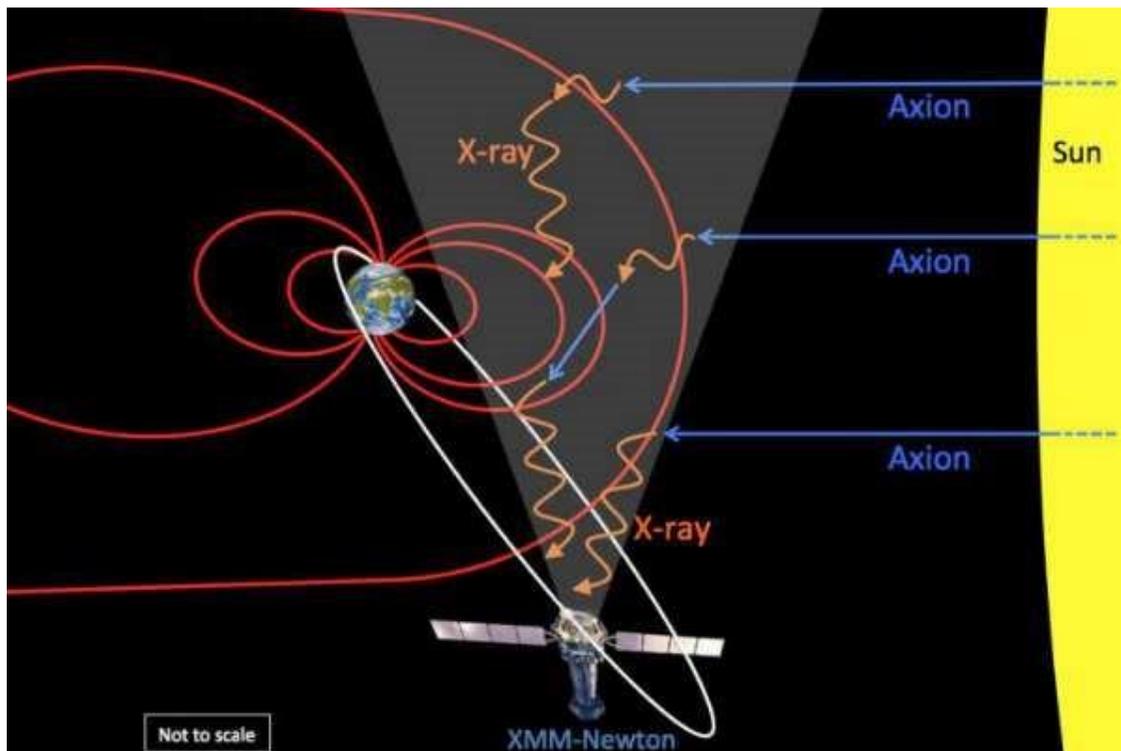
While we can't get too excited just yet - it will take years to confirm whether this signal really is dark matter - the discovery would completely change our understanding of how the Universe works. After all, dark matter is the force that holds our galaxies together, so learning more about it is pretty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

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

Unexpectedly, they noticed that the intensity of X-rays recorded by the spacecraft rose by about 10% whenever XMM-Newton was at the boundary of Earth's magnetic field facing the Sun - even once they removed all the bright X-ray sources from the sky. Usually, that X-ray background is stable. "The X-ray background - the sky, after the bright X-ray sources are removed - appears to be unchanged whenever you look at it," said Andy Read, from the University of Leicester, one of the lead authors on the paper, in a press release. "However, we have discovered a seasonal signal in this X-ray background, which has no conventional explanation, but is consistent with the discovery of axions."

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

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



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

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

## Hidden photons

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

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

## Ideal mirror at hand

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

## Dark matter composition research - WIMP

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

## Weakly interacting massive particles

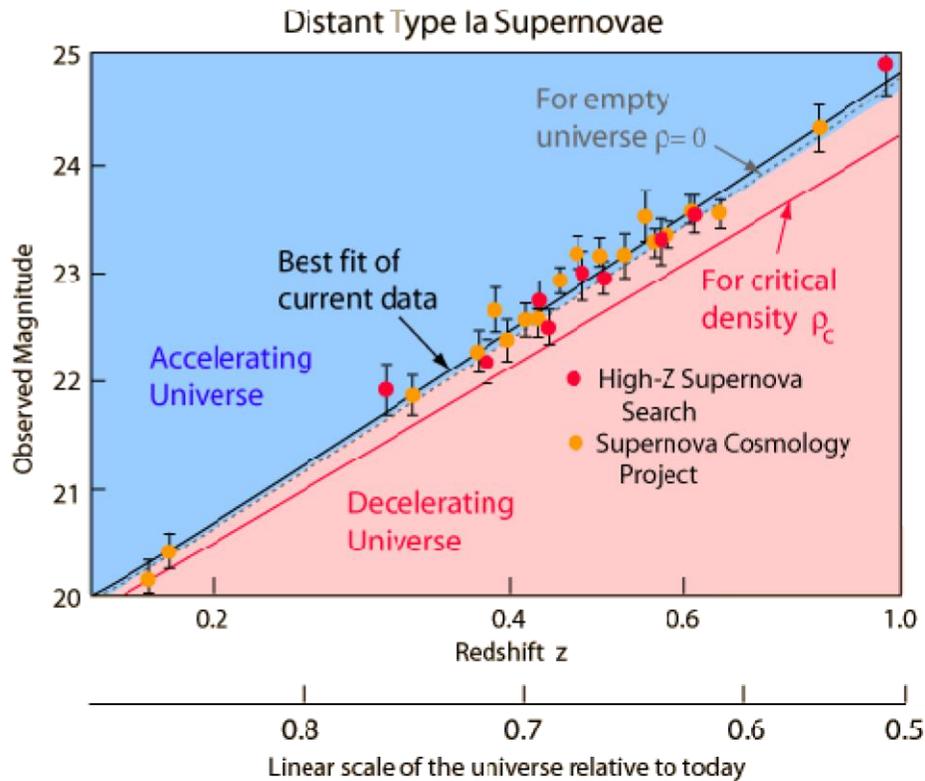
In particle physics and astrophysics, weakly interacting massive particles, or WIMPs, are among the leading hypothetical particle physics candidates for dark matter. The term "WIMP" is given to a dark matter particle that was produced by falling out of thermal equilibrium with the hot dense plasma of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

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

## Evidence for an accelerating universe

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

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



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

### Equation

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

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

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

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

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

## Explanatory models

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

## Dark Matter and Energy

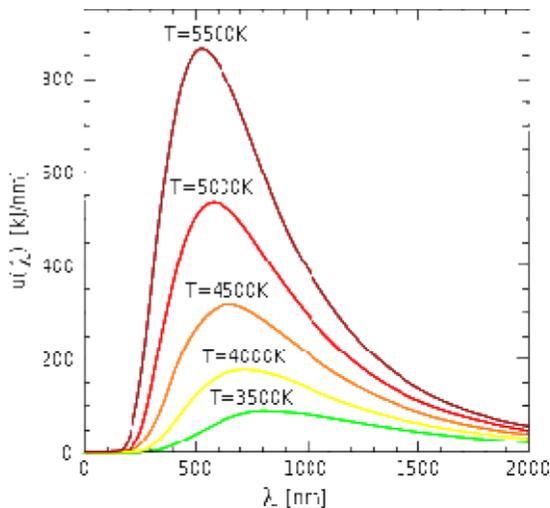
Dark matter is a type of matter hypothesized in astronomy and cosmology to account for a large part of the mass that appears to be missing from the universe. Dark matter cannot be seen directly with telescopes; evidently it neither emits nor absorbs light or other electromagnetic radiation at any significant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

## Cosmic microwave background

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

## Thermal radiation

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



## Electromagnetic Field and Quantum Theory

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

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

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

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

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

## Lorentz transformation of the Special Relativity

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

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

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

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

## The Classical Relativistic effect

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

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

## Electromagnetic inertia and Gravitational attraction

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

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

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

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

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

### Electron – Proton mass rate

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

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

## Gravity from the point of view of quantum physics

### The Gravitational force

The gravitational attractive force is basically a magnetic force.

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

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

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

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

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

### The Graviton

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

### Conclusions

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

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

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

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

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

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

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