

# Monitor Earth's Rotation

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*A team of astronomers from the Inter University Centre for Astronomy & Astrophysics (IUCAA), and Indian Institute of Science Education and Research (IISER), both in Pune, India, and members of two other Indian universities, have identified a previously unknown, extremely large supercluster of galaxies located in the direction of constellation Pisces. [24]*

*Enigmatic 'dark energy', thought to make up 68% of the universe, may not exist at all, according to a Hungarian-American team. [23]*

*Astronomers in the US are setting up an experiment which, if it fails – as others have – could mark the end of a 30-year-old theory. [22]*

*Russian scientists have discovered that the proportion of unstable particles in the composition of dark matter in the days immediately following the Big Bang was no more than 2 percent to 5 percent. Their study has been published in Physical Review D. [21]*

*Researchers from the University of Amsterdam's (UvA) GRAPPA Center of Excellence have just published the most precise analysis of the fluctuations in the gamma-ray background to date. [20]*

*The Dark Energy Spectroscopic Instrument, called DESI, has an ambitious goal: to scan more than 35 million galaxies in the night sky to track the expansion of our universe and the growth of its large-scale structure over the last 10 billion years. [19]*

*If the axion exist and it is the main component of Dark Matter, the very relic axions that would be bombarding us continuously could be detected using microwave resonant (to the axion mass) cavities, immersed in powerful magnetic fields. [18]*

*In yet another attempt to nail down the elusive nature of dark matter, a European team of researchers has used a supercomputer to develop a profile of the yet-to-be-detected entity that appears to pervade the universe. [17]*

*MIT physicists are proposing a new experiment to detect a dark matter particle called the axion. If successful, the effort could crack one of the most perplexing unsolved mysteries in particle physics, as well as finally yield a glimpse of dark matter. [16]*

*Researches at Stockholm University are getting closer to light dark-matter particle models. Observations rule out some axion-like particles in the quest for the content of dark matter. The article is now published in the Physical Review Letters. [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.

## Running light around a tetrahedron

Thanks to an innovative ring laser design, geophysicists at LMU can now measure and monitor Earth's rotation with unprecedented accuracy. The new instrument in Fürstfeldbruck will be formally inaugurated this week.

The world has so far taken relatively little notice of Fürstfeldbruck, a town located about 20 km from Munich. It certainly doesn't rate as a hotspot for cutting-edge science. But that is about to change. For geophysicists based at LMU and the Technical University of Munich (TUM) have built an instrument there which sets a new standard in its field. Buried in an underground bunker built amid cropland and open fields, the device takes up several hundred cubic meters of space. Its purpose is to measure rotational ground motions with greater sensitivity and precision than any other machine in existence.

Even the editors of the leading research journal *Science* are clearly impressed by the dimensions – and the capabilities – of the new instrument. In a news feature that appeared in a recent issue of the magazine, the novel ring laser is referred to as the "most sophisticated" instrument of its kind in the world. The leader of the ROMY (Rotational Motions in Seismology) project is Heiner Igel, Professor of Seismology at LMU. The concept won him one of the richly endowed Advanced Investigator Grants awarded by the European Research Council (ERC), and the LMU went on to supply the additional funding required for its final realization. The initial tests and experiments have been successful, and the instrument will be officially put into service this week.

## Our restless planet

Ring lasers are exquisitely sensitive to rotational motion. They can, for example, measure the Earth's rotation with extremely high precision. Our planet is never at rest, rotating on its own axis every day and orbiting the Sun once a year. But it doesn't follow exactly the same course year for year. Its trajectory is subject to minimal deviations. In fact, it behaves just like a child's spinning top: Neither the orientation of its axis nor the speed of its rotation is constant. It is buffeted by strong winds in the upper atmosphere and by ocean currents at depth, and massive earthquakes knock it out of kilter. But then, the Earth itself is anything but a perfect sphere. No wonder it fails to follow the ideal of perfect circular motion that Aristotle once prescribed for it.

Moreover, quantifying the minimal variations in the many different components of the Earth's motions is not solely a matter of academic interest. For example, all GPS-based navigational systems must be periodically recalibrated in order to take account of these variations, which would otherwise give rise to significant errors in determining one's position on the globe. This task is currently done with the aid of Very Long Baseline Interferometry (VLBI), which uses a network of radio telescopes to determine the distances between the Earth and selected quasars in deep space that are millions of light-years from us. But this method is complicated and it takes days to arrive at the final result. The Munich researchers believe that their new ring laser will enable them to achieve at least the same accuracy in far less time. If they are right, results could be updated within seconds rather than days.

But this is only a small part of Heiner Igel's vision for the new high-end instrument. – He intends to open up a whole new dimension in seismology by using it to carry out more detailed analyses of seismically induced ground motions. For when an earthquake occurs, the ground not only shakes up

and down, and back and forth. Tremors are also characterized by tilting and rotational motions around a fixed point. So far, seismologists have had to ignore such motions, simply because conventional seismometers provide no means of measuring them. However, Igel believes – contrary to received wisdom – that a realistic and complete picture of ground motions during earthquakes requires the acquisition and integration of this information.

Indeed, he and his colleagues hope that the new ring laser will provide answers to a whole series of open questions. For instance, rotation sensors can measure the magnitude of tilting and rotational ground motions, which structural engineers need to enhance the stability of buildings in earthquake zones. Rotation sensors can also provide data that give insights into anomalous magma dynamics in active volcanoes, and thus serve to improve the quality of corresponding modeling studies. In combination with other methods, such measurements permit geophysicists to probe the properties and the dynamics of the Earth's interior, Igel explains. And that's not all. ROMY also promises to shed new light on how the world's oceans interact physically with the planet, causing it to oscillate permanently.

The principle on which the instrument's operation is based was first demonstrated by the French physicist Georges Sagnac shortly before the outbreak of the First World War: He showed a beam of light is directed around a closed course (with the aid of mirrors), the time it takes to complete a circuit is independent of the direction in which it propagates. However, if the apparatus is rotated, the beam travelling in the same sense as the rotation takes slightly longer for each lap – because it has to cover a greater distance than a beam transmitted in the opposite direction. Due to this difference in path-length, two counter-propagating beams will be phase shifted with respect to one another and, when recombined, they produce a typical interference pattern. In exactly the same way, when two notes that are slightly out of tune are sounded together, they produce a characteristic beat note which varies regularly in pitch. Moreover, the rotation rate can be calculated from the frequency of the beat note produced when the counter-propagating beams are superimposed.

Igel and laser physicist Ulrich Schreiber from the TUM made use of this principle in their design for ROMY to measure spin or tilting motions. In this case, the laser beams are propagated along not one but four axes. Each of the four light paths forms the edges of an equilateral triangle with sides 12 m long. At each apex, the light is deflected by mirrors, whose positions can be adjusted with high precision. Together, the four rings form the faces of a regular, inverted tetrahedron whose apex lies 15 m underground. This set-up enables the scientists to measure rotational motions in all directions.

### **Five km of optic fiber, tightly wound**

"It took us two years to work out how to build it," Igel says. To ensure high sensitivity, the ring lasers must be shielded from environmental interference. For example, in order to protect the instrument from ground water, it was enclosed in a tetrahedral concrete shell – like a plant in a flower pot. Igel realized early on that he needed to have his colleague from the TUM onboard to make the project a success – for Schreiber had already designed and built several ring-laser systems in Germany, New Zealand, the USA, Italy and elsewhere. ROMY, however, is undoubtedly his masterpiece. Incorporating computer-controlled precision engineering into an instrument with dimensions of 12 m requires a new level of meticulousness.

Meanwhile, the instrument has not only been tested and calibrated, it has already performed a whole series of measurements which will form the basis for several publications. For example, some of the aftershocks observed after the series of earthquakes in Norcia in Central Italy in October 2016 have been characterized, as well as the seismic noise generated by the Earth's oceans.

Recording the hitherto unquantifiable tilt and rotational motions in the field, i.e. in the vicinity of the seismic focus of an earthquake, will require the use of portable instruments, Igel says – and the researchers responsible for ROMY have already taken a major step towards this goal. They have teamed up with a specialist company in France to develop a portable fibre-optic-based sensor, and the first prototypes were on show at a large geosciences conference held in Vienna in April. These instruments use an extremely thin optic fiber of 5 km in length, which is coiled onto a spool: "A real milestone," Igel enthuses. The initial measurements performed in Central Italy, and on the volcanic island of Stromboli off the north coast of Sicily "look good," he says.

The pioneers in Munich hope that others will follow the example set by ROMY. If so, we should someday have a global network of ring-laser seismometers which can finally provide us with a truly comprehensive picture of the dynamics of the Earth's motions. In such a network, Fürstenfeldbruck's ring would serve as an essential node – a hotspot, so to speak. [27]

## Shedding light on galaxy rotation secrets

The dichotomy concerns the so-called angular momentum (per unit mass) that in physics is a measure of size and rotation velocity. Spiral galaxies are found to be strongly rotating, with an angular momentum higher by a factor of about five than ellipticals. What is the origin of such a difference? An international research team investigated the issue in a study just published in the *Astrophysical Journal*. The team was led by SISSA Ph.D. student JingJing Shi under the supervision of Prof. Andrea Lapi and Luigi Danese, and in collaboration with Prof. Huiyuan Wang from USTC (Hefei) and Dr. Claudia Mancuso from IRA-INAF (Bologna). The researchers inferred from observations the amount of gas fallen into the central region of a developing galaxy, where most of the star formation takes places.

The outcome is that in elliptical galaxies, only about 40 percent of the available gas fell into that central region. More relevantly, this gas fueling star formation was characterized by a rather low angular momentum. This is in stark contrast with the conditions found in spirals, where most of the gas that ends up in stars has an appreciably higher angular momentum. The researchers have traced the dichotomy in the angular momentum of spiral and elliptical galaxies to their different formation histories. Elliptical galaxies form most of their stars in a fast collapse in which angular momentum is dissipated. This process is likely stopped early on by powerful gas outflows from supernova explosions, stellar winds and possibly even from the central supermassive black hole. For spirals, on the other hand, the gas fell slowly, conserving its angular momentum, and stars formed steadily along a timescale comparable to the age of the universe.

"Until recent years, in the paradigm of galaxy formation and evolution, elliptical galaxies were thought to have formed by the merging of stellar disks in the distant universe. Along this line, their angular momentum was thought to be the result of dissipative processes during such merging events," the researchers write. Recently, this paradigm had been challenged by far-infrared/sub-

millimeter observations brought about by the advent of space observatories like Herschel and ground-based interferometers like the Atacama Large Millimeter Array (ALMA).

These observations have the power of penetrating through interstellar dust thus unveiling the star formation processes in the very distant, dusty galaxies that constituted the progenitors of local ellipticals. "The net outcome from these observations is that the stars populating present-day ellipticals are mainly formed in a fast dissipative collapse in the central regions of dusty star-forming galaxies. After a short timescale of less than 1 billion years, the star formation has been quenched by powerful gas outflows." Despite this change of perspective, the origin of the low angular momentum observed in local ellipticals remained unclear.

"This study reconciles the low angular momentum observed in present-day ellipticals with the new paradigm emerging from Herschel and ALMA observations of their progenitors," conclude the scientists. "We demonstrated that the low angular momentum of ellipticals is mainly originated by nature in the central regions during the early galaxy formation process, and not nurtured substantially by the environment via merging events, as envisaged in previous theories." [26]

## **Scientists create first laboratory generation of astrophysical shock waves**

Throughout the universe, supersonic shock waves propel cosmic rays and supernova particles to velocities near the speed of light. The most high-energy of these astrophysical shocks occur too far outside the solar system to be studied in detail and have long puzzled astrophysicists. Shocks closer to Earth can be detected by spacecraft, but they fly by too quickly to probe a wave's formation.

### **Opening the door to new understanding**

Now a team of scientists has generated the first high-energy shock waves in a laboratory setting, opening the door to new understanding of these mysterious processes. "We have for the first time developed a platform for studying highly energetic shocks with greater flexibility and control than is possible with spacecraft," said Derek Schaeffer, a physicist at Princeton University and the U.S. Department of Energy's (DOE) Princeton Plasma Physics Laboratory (PPPL), and lead author of a July paper in *Physical Review Letters* that outlines the experiments.

Schaeffer and colleagues conducted their research on the Omega EP laser facility at the University of Rochester Laboratory for Laser Energetics. Collaborating on the project was PPPL physicist Will Fox, who designed the experiment, and researchers from Rochester and the universities of Michigan and New Hampshire. "This lets you understand the evolution of the physical processes going on inside shock waves," Fox said of the platform.

To produce the wave, scientists used a laser to create a high-energy plasma—a form of matter composed of atoms and charged atomic particles—that expanded into a pre-existing magnetized plasma. The interaction created, within a few billionths of a second, a magnetized shock wave that expanded at a rate of more than 1 million miles per hour, congruent with shocks beyond the solar system. The rapid velocity represented a high "magnetosonic Mach number" and the wave was "collisionless," emulating shocks that occur in outer space where particles are too far apart to frequently collide.



## Discovery by accident

Discovery of this method of generating shock waves actually came about by accident. The physicists had been studying magnetic reconnection, the process in which the magnetic field lines in plasma converge, separate and energetically reconnect. To investigate the flow of plasma in the experiment, researchers installed a new diagnostic on the Rochester laser facility. To their surprise, the diagnostic revealed a sharp steepening of the density of the plasma, which signaled the formation of a high Mach number shock wave.

To simulate the findings, the researchers ran a computer code called "PSC" on the Titan supercomputer, the most powerful U.S. computer, housed at the DOE's Oak Ridge Leadership Computing Facility. The simulation utilized data derived from the experiments and results of the model agreed well with diagnostic images of the shock formation.

Going forward, the laboratory platform will enable new studies of the relationship between collisionless shocks and the acceleration of astrophysical particles. The platform "complements present remote sensing and spacecraft observations," the authors wrote, and "opens the way for controlled laboratory investigations of high-Mach number shocks." [25]

## Researchers describe one of the most massive large-scale structures in the universe

A team of astronomers from the Inter University Centre for Astronomy & Astrophysics (IUCAA), and Indian Institute of Science Education and Research (IISER), both in Pune, India, and members of two other Indian universities, have identified a previously unknown, extremely large supercluster of galaxies located in the direction of constellation Pisces. This is one of the largest known structures in the nearby Universe, and is at a distance of 4,000 million (400 crore) light-years away from us.

This novel discovery is being published in the latest issue of The Astrophysical Journal, the premier research journal of the American Astronomical Society.

Large-scale structures in the Universe are found to be hierarchically assembled, with galaxies, together with associated gas, and dark matter, being clumped in clusters, which are organized with other clusters, smaller groups, filaments, sheets and large empty regions ("voids") in a pattern called the "Cosmic web" which spans the observable Universe.

Superclusters are the largest coherent structures in the Cosmic Web. A Supercluster is a chain of galaxies and galaxy clusters, bound by gravity, often stretching to several hundred times the size of clusters of galaxies, consisting of tens of thousands of galaxies. This newly-discovered 'Saraswati' supercluster, for instance, extends over a scale of 600 million light-years and may contain the mass equivalent of over 20 million billion suns.

When astronomers look far away, they see the Universe from long ago, since light takes a while to reach us. The Saraswati supercluster is observed as it was when the Universe was 10 billion years old.

The long-popular "Cold dark matter" model of the evolution of the Universe predicts that small structures like galaxies form first, which congregate into larger structures. Most forms of this model

do not predict the existence of large structures such as the "Saraswati Supercluster" within the current age of the Universe. The discovery of these extremely large structures thus force astronomers into re-thinking the popular theories of how the Universe got its current form, starting from a more-or-less uniform distribution of energy after the Big Bang. In recent years, the discovery of the present-day Universe being dominated by "Dark Energy", which behaves very differently from Gravitation, might play a role in the formation of these structures.

It is believed that galaxies are formed mostly on the filaments and sheets that are part of the cosmic web, and many of the galaxies travel along these filaments, ending up in the rich clusters, where the crowded environment switches off their star formation and aids in the transformation of galaxies to disk-like blue spiral galaxies to red elliptical galaxies. Since there is an extensive variation of environment within a Supercluster, galaxies travel through these varied environments during their "lifetime". To understand their formation and evolution, one needs to identify these Superclusters and closely study the effect of their environment on the galaxies. This is a very new research area- with the aid of observations of new observational facilities, astronomers are now beginning to understand galaxy evolution. This discovery will greatly enhance this field of research.

"Saraswati" (or "Sarasvati"), a word that has proto-Indo-European roots, is a name found in ancient Indian texts to refer to the major river around which the people of the ancient Indian civilization lived. It is also the name of the celestial goddess who is the keeper of the celestial rivers. In modern India, Saraswati is worshipped as the goddess of knowledge, music, art, wisdom and nature – the muse of all creativity.

Our own galaxy is part of a Supercluster called the Laniakea Supercluster, announced in 2014 by Brent Tully at the University of Hawaii and collaborators.

Interestingly, Somak Raychaudhury, currently Director of IUCAA, Pune, who is a co-author of this paper, also discovered the first massive Supercluster of galaxies on this scale (the "Shapley Concentration"), during his PhD research at the University of Cambridge. In his paper, published in the journal 'Nature' in 1989, he had named the supercluster after the American astronomer Harlow Shapley, in recognition of his pioneering survey of galaxies, from the Southern hemisphere, in which this massive super-structure was first imaged, way back in 1932.

Joydeep Bagchi from IUCAA, the lead author of the paper and co-author Shishir Sankhyayan (PhD scholar at IISER, Pune) said, "We were very surprised to spot this giant wall-like supercluster of galaxies, visible in a large spectroscopic survey of distant galaxies, known as the Sloan Digital Sky Survey (see figure above). This supercluster is clearly embedded in a large network of cosmic filaments traced by clusters and large voids. Previously only a few comparatively large superclusters have been reported, for example the 'Shapley Concentration' or the 'Sloan Great Wall' in the nearby universe, while the 'Saraswati' supercluster is far more distant one. Our work will help to shed light on the perplexing question; how such extreme large scale, prominent matter-density enhancements had formed billions of years in the past when the mysterious Dark Energy had just started to dominate structure formation." [24]

## Explaining the accelerating expansion of the universe without dark energy

Enigmatic 'dark energy', thought to make up 68% of the universe, may not exist at all, according to a Hungarian-American team. The researchers believe that standard models of the universe fail to take account of its changing structure, but that once this is done the need for dark energy disappears. The team publish their results in a paper in *Monthly Notices of the Royal Astronomical Society*.

Our universe was formed in the Big Bang, 13.8 billion years ago, and has been expanding ever since. The key piece of evidence for this expansion is Hubble's law, based on observations of galaxies, which states that on average, the speed with which a galaxy moves away from us is proportional to its distance.

Astronomers measure this velocity of recession by looking at lines in the spectrum of a galaxy, which shift more towards red the faster the galaxy is moving away. From the 1920s, mapping the velocities of galaxies led scientists to conclude that the whole universe is expanding, and that it began life as a vanishingly small point.

In the second half of the twentieth century, astronomers found evidence for unseen 'dark matter' by observing that something extra was needed to explain the motion of stars within galaxies. Dark matter is now thought to make up 27% of the content of universe (in contrast 'ordinary' matter amounts to only 5%).

Observations of the explosions of white dwarf stars in binary systems, so-called Type Ia supernovae, in the 1990s then led scientists to the conclusion that a third component, dark energy, made up 68% of the cosmos, and is responsible for driving an acceleration in the expansion of the universe.

In the new work, the researchers, led by Phd student Gábor Rácz of Eötvös Loránd University in Hungary, question the existence of dark energy and suggest an alternative explanation. They argue that conventional models of cosmology (the study of the origin and evolution of the universe), rely on approximations that ignore its structure, and where matter is assumed to have a uniform density.

"Einstein's equations of general relativity that describe the expansion of the universe are so complex mathematically, that for a hundred years no solutions accounting for the effect of cosmic structures have been found. We know from very precise supernova observations that the universe is accelerating, but at the same time we rely on coarse approximations to Einstein's equations which may introduce serious side-effects, such as the need for dark energy, in the models designed to fit the observational data." explains Dr László Dobos, co-author of the paper, also at Eötvös Loránd University.

In practice, normal and dark matter appear to fill the universe with a foam-like structure, where galaxies are located on the thin walls between bubbles, and are grouped into superclusters. The insides of the bubbles are in contrast almost empty of both kinds of matter.

Using a computer simulation to model the effect of gravity on the distribution of millions of particles of dark matter, the scientists reconstructed the evolution of the universe, including the early clumping of matter, and the formation of large scale structure.

Unlike conventional simulations with a smoothly expanding universe, taking the structure into account led to a model where different regions of the cosmos expand at different rate. The average expansion rate though is consistent with present observations, which suggest an overall acceleration.

Dr Dobos adds: "The theory of general relativity is fundamental in understanding the way the universe evolves. We do not question its validity; we question the validity of the approximate solutions. Our findings rely on a mathematical conjecture which permits the differential expansion of space, consistent with general relativity, and they show how the formation of complex structures of matter affects the expansion. These issues were previously swept under the rug but taking them into account can explain the acceleration without the need for dark energy."

If this finding is upheld, it could have a significant impact on models of the universe and the direction of research in physics. For the past 20 years, astronomers and theoretical physicists have speculated on the nature of dark energy, but it remains an unsolved mystery. With the new model, Csabai and his collaborators expect at the very least to start a lively debate. [23]

## **Will scientists ever prove the existence of dark matter?**

Astronomers in the US are setting up an experiment which, if it fails – as others have – could mark the end of a 30-year-old theory.

Deep underground, in a defunct gold mine in South Dakota, scientists are assembling an array of odd devices: a chamber for holding tonnes of xenon gas; hundreds of light detectors, each capable of pinpointing a single photon; and a vast tank that will be filled with hundreds of gallons of ultra-pure water. The project, the LZ experiment, has a straightforward aim: it is designed to detect particles of an invisible form of matter – called dark matter – as they drift through space.

It is thought there is five times more dark matter than normal matter in the universe, although it has yet to be detected directly. Finding it would solve one of science's most baffling mysteries and explain why galaxies are not ripped apart by stars flying off into deep space.

However, many scientists believe time is running out for the hunt, which has lasted 30 years, cost millions of pounds and produced no positive results. The LZ project – which is halfway through construction – should be science's last throw of the dice, they say. "This generation of detectors should be the last," said astronomer Stacy McGaugh at Case Western Reserve University in Cleveland, Ohio. "If we don't find anything we should accept we are stuck and need to find a different explanation, perhaps by modifying our theories of gravity, to explain the phenomena we attribute to dark matter."

Other researchers reject this view: "Theory indicates we have a really good chance of finding dark matter particles," said Chamkaur Ghag, chair of the Dark Matter UK consortium. "This is certainly not the time to talk of giving up."

The concept of dark matter stems from observations made in the 1970s. Astronomers expected to find that stars rotated more slowly around a galaxy the more distant they were from the galaxy's centre, just as distant planets revolve slowly round the Sun. (Outermost Neptune moves round the Sun at a stately 12,000mph; innermost Mercury does so at 107,082mph.)

That prediction was spectacularly undone by observations, however. Stars at a galaxy's edge orbit almost as fast as those near its centre. According to theory, they should be hurled into space. So astronomers proposed that invisible dark matter must be providing the extra gravity needed to hold galaxies together. Proposed sources of dark matter include burnt-out stars; clouds of dust and gas; and subatomic particles called Wimps – weakly interacting massive particles. All have since been discounted, except Wimps. Many astronomers are now convinced they permeate space and form halos round galaxies to give them the gravitational “muscle” needed to hold fast-flying stars in place.

Getting close to Wimps has not been easy. Scientists have built increasingly sensitive detectors deeper and deeper underground to protect them from subatomic particles that bombard Earth's surface and which would trigger spurious signals. These devices resemble huge Russian dolls: a vast metal tank containing water – to provide added protection against incoming stray particles – is erected and, within this, a giant sphere of an inert gas such as xenon is suspended. Wimps making it through to the final tank should occasionally strike a xenon nucleus, producing a flash of light that can be pinpointed by electronic detectors.

Despite three decades of effort, this approach has had no success, a failure that is starting to worry some researchers. “We are now building detectors containing more and more xenon and which are a million times more sensitive than those we used to hunt Wimps 30 years ago,” said astrophysicist Professor David Merritt, of the Rochester Institute of Technology, New York. “And still we have found nothing.”

Last July, scientists reported that after running their Large Underground Xenon (Lux) experiment for 20 months they had still failed to spot a Wimp. Now an upgraded version of Lux is being built – the LZ detector, a US-UK collaboration – while other devices in Canada and Italy are set to run searches.

The problem facing Wimp hunters is that as their detectors get ever more sensitive, they will start picking up signals from other weakly interacting particles called neutrinos. Tiny, almost massless, these constantly whizz through our planet and our bodies. Neutrinos are not nearly heavy enough to account for the gravitational abnormalities associated with dark matter but are still likely to play havoc with the next generation of Wimp detectors.

“I believe the Wimp hypothesis will be truly dead when we reach that point,” said McGaugh. “It already has serious problems but if we get to the point where we are picking up all this background interaction, the game is up. You will not be able to spot a thing.”

This point is rejected by Ghag. “Yes, occasionally a neutrino will kick a xenon nucleus and produce a result that resembles a Wimp interaction. We will, initially, be in trouble. But as we characterise the collisions we should find ways to differentiate them and concentrate only on those produced by Wimps.”

But there is no guarantee that Wimps – if they exist – will ever interact with atoms of normal matter. “You can imagine a scenario where dark matter particles turn out to be so incredibly weak at interacting with normal matter that our detectors will never see anything,” said cosmologist Andrew Pontzen, of University College London. [22]

## Physicists measure the loss of dark matter since the birth of the universe

Russian scientists have discovered that the proportion of unstable particles in the composition of dark matter in the days immediately following the Big Bang was no more than 2 percent to 5 percent. Their study has been published in Physical Review D.

"The discrepancy between the cosmological parameters in the modern universe and the universe shortly after the Big Bang can be explained by the fact that the proportion of dark matter has decreased. We have now, for the first time, been able to calculate how much dark matter could have been lost, and what the corresponding size of the unstable component would be," says co-author Igor Tkachev of the Department of Experimental Physics at INR.

Astronomers first suspected that there was a large proportion of hidden mass in the universe back in the 1930s, when Fritz Zwicky discovered "peculiarities" in a cluster of galaxies in the constellation Coma Berenices—the galaxies moved as if they were under the effect of gravity from an unseen source. This hidden mass, which is only deduced from its gravitational effect, was given the name dark matter. According to data from the Planck space telescope, the proportion of dark matter in the universe is 26.8 percent; the rest is "ordinary" matter (4.9 percent) and dark energy (68.3 percent).

The nature of dark matter remains unknown. However, its properties could potentially help scientists to solve a problem that arose after studying observations from the Planck telescope. This device accurately measured the fluctuations in the temperature of the cosmic microwave background radiation—the "echo" of the Big Bang. By measuring these fluctuations, the researchers were able to calculate key cosmological parameters using observations of the universe in the recombination era—approximately 300,000 years after the Big Bang.

However, when researchers directly measured the speed of the expansion of galaxies in the modern universe, it turned out that some of these parameters varied significantly—namely the Hubble parameter, which describes the rate of expansion of the universe, and also the parameter associated with the number of galaxies in clusters. "This variance was significantly more than margins of error and systematic errors known to us. Therefore, we are either dealing with some kind of unknown error, or the composition of the ancient universe is considerably different to the modern universe," says Tkachev.

## Russian physicists measure the loss of dark matter since the birth of the universe

The concentration of the unstable component of dark matter  $F$  against the speed of expansion of non-gravitationally bound objects (proportional to the age of the Universe) when examining various combinations of Planck data for several different cosmological phenomena. Credit: MIPT

The discrepancy can be explained by the decaying dark matter (DDM) hypothesis, which states that in the early universe, there was more dark matter, but then part of it decayed.

"Let us imagine that dark matter consists of several components, as in ordinary matter (protons, electrons, neutrons, neutrinos, photons). And one component consists of unstable particles with a rather long lifespan. In the era of the formation of hydrogen, hundreds of thousands of years after the Big Bang, they are still in the universe, but by now (billions of years later), they have

disappeared, having decayed into neutrinos or hypothetical relativistic particles. In that case, the amount of dark matter in the era of hydrogen formation and today will be different," says lead author Dmitry Gorbunov, a professor at MIPT and staff member at INR.

The authors of the study analyzed Planck data and compared them with the DDM model and the standard  $\Lambda$ CDM (Lambda-cold dark matter) model with stable dark matter. The comparison showed that the DDM model is more consistent with the observational data. However, the researchers found that the effect of gravitational lensing (the distortion of cosmic microwave background radiation by a gravitational field) greatly limits the proportion of decaying dark matter in the DDM model.

Using data from observations of various cosmological effects, the researchers were able to give an estimate of the relative concentration of the decaying components of dark matter in the region of 2 percent to 5 percent.

"This means that in today's universe, there is 5 percent less dark matter than in the recombination era. We are not currently able to say how quickly this unstable part decayed; dark matter may still be disintegrating even now, although that would be a different and considerably more complex model," says Tkachev. [21]

## **No trace of dark matter in gamma-ray background**

Researchers from the University of Amsterdam's (UvA) GRAPPA Center of Excellence have just published the most precise analysis of the fluctuations in the gamma-ray background to date. By making use of more than six years of data gathered by the Fermi Large Area Telescope, the researchers found two different source classes contributing to the gamma-ray background. No traces of a contribution of dark matter particles were found in the analysis. The collaborative study was performed by an international group of researchers and is published in the latest edition of the journal *Physical Review D*.

Gamma rays are particles of light, or photons, with the highest energy in the universe and are invisible to the human eye. The most common emitters of gamma rays are blazars: supermassive black holes at the centers of galaxies. In smaller numbers, gamma rays are also produced by a certain kind of stars called pulsars and in huge stellar explosions such as supernovae.

In 2008 NASA launched the Fermi satellite to map the gamma-ray universe with extreme accuracy. The Large Area Telescope, mounted on the Fermi satellite, has been taking data ever since. It continuously scans the entire sky every three hours. The majority of the detected gamma rays is produced in our own Galaxy (the Milky Way), but the Fermi telescope also managed to detect more than 3000 extragalactic sources (according to the latest count performed in January 2016). However, these individual sources are not enough to explain the total amount of gamma-ray photons coming from outside our Galaxy. In fact, about 75% of them are unaccounted for.

## **Isotropic gamma-ray background**

As far back as the late 1960s, orbiting observatories found a diffuse background of gamma rays streaming from all directions in the universe. If you had gamma-ray vision, and looked at the sky, there would be no place that would be dark.

The source of this so-called isotropic gamma-ray background has hitherto remained unknown. This radiation could be produced by unresolved blazars, or other sources too faint to be detected with the Fermi telescope. Parts of the gamma-ray background might also hold the fingerprint of the illustrious dark matter particle, a so-far undetected particle held responsible for the missing 80% of the matter in our universe. If two dark matter particles collide, they can annihilate and produce a signature of gamma-ray photons.

## Fluctuations

Together with colleagues, Dr Mattia Fornasa, an astroparticle physicist at the UvA and lead author of the paper, performed an extensive analysis of the gamma-ray background by using 81 months of data gathered by the Fermi Large Area Telescope – much more data and with a larger energy range than in previous studies. By studying the fluctuations in the intensity of the gamma-ray background, the researchers were able to distinguish two different contributions to the gamma-ray background. One class of gamma-ray sources is needed to explain the fluctuations at low energies (below 1 GeV) and another type to generate the fluctuations at higher energy – the signatures of these two contributions is markedly different.

In their paper the researchers suggest that the gamma rays in the high-energy ranges – from a few GeV up – are likely originating from unresolved blazars. Further investigation into these potential sources is currently being carried out by Fornasa, fellow UvA researcher Shin'ichiro Ando and colleagues from the University of Torino, Italy. However, it seems much harder to pinpoint a source for the fluctuations with energies below 1 GeV. None of the known gamma-ray emitters have a behaviour that is consistent with the new data.

## Constraints on dark matter

To date, the Fermi telescope has not detected any conclusive indication of gamma-ray emission originating from dark-matter particles. Also, this latest study showed no indication of a signal associated with dark matter. Using their data, Fornasa and colleagues were even able to rule out some models of dark matter that would have produced a detectable signal.

'Our measurement complements other search campaigns that used gamma rays to look for dark matter and it confirms that there is little room left for dark matter induced gamma-ray emission in the isotropic gamma-ray background', says Fornasa. [20]

## Ultraprecise measurements in XXL

The Dark Energy Spectroscopic Instrument, called DESI, has an ambitious goal: to scan more than 35 million galaxies in the night sky to track the expansion of our universe and the growth of its large-scale structure over the last 10 billion years. Using DESI—a project led by Lawrence Berkeley National Laboratory—scientists hope to create a 3-D map of a third of the night sky that is more accurate and precise than any other.

A precise map requires that DESI itself be built and assembled with micrometer precision. Fermilab, a Department of Energy national laboratory, is contributing a key piece of the instrument: a large, barrel-shaped device that will hold optical lenses to collect the light from millions of distant galaxies. The smallest deviation in lens alignment could lead to the instrument being permanently out-of-



focus. Every piece of the barrel must be perfectly placed, so the Fermilab team is currently taking every measure to ensure its precise assembly.

The process involves a special machine, meticulous handling and a healthy dose of patience.

### **Precision assembly**

The lens-holding device is a roughly 8-foot-long and 4-foot-wide segmented cylinder—about the size of a small elevator. Once the hulking steel barrel is complete, it will be installed at the Mayall four-meter telescope at the Kitt Peak National Observatory, southwest of Tucson, Arizona.

The lenses will collect the light reflected from the telescope's mirror and focus it into 5,000 optical fibers, through which the light is transported to special detectors, called spectrographs. With the help of 10 such spectrographs, scientists can measure the distance of the galaxies.

In May, a team of specialists at Fermilab began assembling the barrel's five segments carefully, checking that each nut and bolt was perfectly situated. But a nuts-and-bolts-level fit isn't enough. To achieve the precision scientists are aiming for, the DESI barrel and its inner structure must be assembled accurately to within an incredibly tight 20 micrometers. That's one 10th of the thickness of a sheet of paper.

To achieve the required fit, the team has been making small, critical adjustments to the assembled barrel.

### **Accurate alignment**

The barrel adjustments take place in a vacant area the size of a small bedroom. Four tall pillars – nearly seven feet high – stand at the corners of the space.

Above their heads, a rail, similar to train tracks, connects the tops of the two pillars on one side. A second rail connects the other two. A moveable carriage track spans the gap – like a high bridge spans a river – connecting the two rails. The carriage itself glides along the track.

The team guides the carriage so that it stops just above the barrel. The carriage carries a mechanical arm that points towards the floor. It can rotate in all directions in the space within the pillars. At the end of the arm is a highly sensitive and precise sensor, fixed to an articulating motorized probe.

The arm with the sensor comes to life: It reaches down to the barrel and starts feeling for its surfaces. It searches for specific points on the barrel – a corner, an edge, another significant surface marker. When it finds them, it measures the coordinates in the designated space. Very carefully and with tiny movements, it moves over the whole surface of the barrel, measuring up, down and around the surface. As it does, it records the measurement data and saves it for further analysis. Jorge Montes, one of the team members, strategically places markers on the barrel's surface to assist their alignment efforts.

After making the measurement, the scientists return the barrel to an outside area. There they disassemble it, realign all the parts, relying on the previously placed markers. They then reassemble it. With great care they bring the once more fully assembled barrel into the empty space and measure anew the precision of their assembly.

Comparing their performance with their previous assembly, they learn which pieces, if any, are misaligned—even slightly—and where they improved the alignment.

### **Ultraprecise Measurements in XXL**

The barrel will hold the lenses and optics for DESI, which will map one-third of the night sky. To create an accurate map, the barrel's pieces must be accurately assembled to within 20 micrometers. Dial Machine of Rockford, Illinois, ...more

### **A magic machine**

The precise, slow-moving measuring machine that points out the misalignments is called a coordinate measuring machine, or CMM. The group making these point-by-point measurements, led by Fermilab engineering physicist Michael Roman, uses it to ensure the DESI barrel's perfect assembly.

With the help of the CMM, they repeat the whole procedure of assembly, measurement and disassembly again and again, always comparing their performance against previous tries. When they reach their alignment within 10 micrometers—about a 10th the width of a human hair—in a certain number of tries, they are satisfied.

"From early on we knew that the barrel needed high-precision measurements for the assembly and that it would be too large for any of the CMMs at Fermilab to perform such measurements," Roman said.

"In strong support of DESI, Fermilab bought a machine for the dedicated measurements on the barrel," said scientist Gaston Gutierrez, who is one of the DESI project leads at Fermilab.

### **Steady and stable**

To ensure that the CMM's measurements are as precise as they need to be, the CMM is set up in an air-conditioned room, where scientists monitor and control the temperature 24 hours a day. Materials expand when they get warm, affecting the accuracy of CMM's measurements.

So scientists worked out the right control settings for the environmental control system to ensure that the temperature never varied more than one degree from 20 degrees Celsius.

Even the eventual effect of heavy weights on the DESI barrel, including the lenses, can be measured with the new CMM. Scientists place the DESI barrel in the machine and measure it, then add test weights on its sides and remeasure the barrel. The team can see how the barrel shrinks or bends, if at all, and determine whether the lenses will hold steady when the telescope is in motion.

The Fermilab team expects to finish all CMM measurements by early 2017. Then they will disassemble the DESI barrel and send it to the University College London. In London, their colleagues will install the lenses in the support structures. Once the lenses are installed, the barrel will start its journey to its future home in Arizona.

### **Measuring the expansion of the universe**

Scientists have discovered that our universe is growing bigger and bigger—without any end in sight. Like raisins in a rising loaf of bread, the universe's galaxies are being pushed apart from each other.

From previous measurements, scientists have a kind of cosmic ruler, a standard length that goes back to the universe's early beginning. Using this ruler together with the high-precision DESI map, scientists will be able to tell how far galaxies have moved apart and how much our universe has grown throughout its history.

"With the DESI experiment, we want to follow the growing steps of our universe," Gutierrez said. "We start from today and go backwards in time to measure how much the universe has expanded since its early days.

The fabrication, assembly and operation of DESI are small but highly important steps toward precisely understanding the universe. [19]

## **What is the axion? and why it is being searched for by particle physicists? what is its relation with the Dark Matter of the Universe?**

A physical law has CP (charge-parity) symmetry (link is external) if it is equally valid after interchanging each particle by its antiparticle (charge conjugation or C symmetry (link is external)) and -at the same time- inverting the spatial coordinates (parity, "mirror" or P symmetry (link is external)). It is known since some time now that the electroweak interactions do not respect CP symmetry, that is, physicists have observed phenomena that, although only slightly, violate this symmetry.

However, this does not seem to be the case with the strong interactions (link is external) (those responsible for holding together protons and neutrons in the nuclei). The non observation of CP-violating phenomena here impose severe restrictions to input parameters (i.e. parameters not predicted) of the Standard Model, so that they need to be fine-tuned for theory and observation to agree. When this happens in a physical theory usually means that there is something we do not understand and our theory is not complete. This is the strong CP problem.

The Peccei-Quinn mechanism was proposed to solve this problem in a natural way, without required parameter fine-tuning. As a collateral effect, however, a new particle appears, the axion, which may have important observable consequences. In the first place, the axion is a neutral and very light (but not massless) particle, and it does not interact (or does it very weakly) with conventional matter. In some way one can see the axion as a "strange photon". In fact, theory predicts that the axion, if it exists, could transform into a photon (and viceversa) in the presence of electromagnetic fields. This property of the axion is crucial for most of the experimental strategies of axion detection.

This Feynman diagram represents the process of conversion of an axion (dashed line on the left) into a photon (wavy line on the right) in the presence of an electromagnetic field (the wavy line going downwards)

But doubtless one of the most suggestive properties of axions is that, in a natural way, they could be produced in huge numbers soon after the Big Bang. This population of axions would still be present today and could compose the Dark Matter of the Universe. The existence of Dark Matter is widely

accepted in the scientific community, but its nature is still a mystery. Together with WIMPs, the axions are among the most searched candidates in the context of the nature of Dark Matter.

### **Detection of axions**

Thanks to the property of conversion into photons in electromagnetic fields, axions could be produced and detected in the laboratory by using very intense magnets. This type of experiments are being carried out (e.g. ALPS (link is external) in DESY, or OSQAR at CERN), although their sensitivity is still far from "seeing" the axions predicted by the Peccei-Quinn mechanism.

If the axion exist and it is the main component of Dark Matter, the very relic axions that would be bombarding us continuously could be detected using microwave resonant (to the axion mass) cavities, immersed in powerful magnetic fields. This scheme is followed, e.g., by the ADMX (link is external) experiment in the University of Washington. ADMX could detect the axion, if its mass (which is unknown) lies in the sensitivity range of the experiment (around the few microelectronvolts) and if the Dark Matter is mainly composed by axions.

Another promising detection technique, this one independent of the axion being the Dark Matter, is that of the axion helioscope, aiming to detect axions produced at the solar interior. These could be detected, once again, using a powerful magnet, but this time equipped with low background x-ray detectors. The most powerful axion helioscope to-date is the CERN Axion Solar Telescope or CAST, datking data since about a decade at CERN. Although so far there is no sign of the axion, CAST has been the first axion helioscope with enough sensitivity to surpass previous very stringent astrophysical limits on the axion properties, and enter so far unexplored area. In particular, CAST is sensitive to Peccei-Quinn axions with masses in the 0.1-1 eV range approximately.

The International Axion Observatory is a new generation axion helioscope. Its layout is an ambitious extension of CAST's philosophy, using a superconducting magnet of larger dimensions and specifically designed to search for axions, and equipped with x-ray optics and low background detectors. IAXO would have sensitivity to detect axions in the much larger mass range than CAST and thus would explore an important area of parametric space which is also inaccessible by other techniques. In addition, IAXO's magnet could also host other kind of axion experiments, so IAXO could become a sort of a generic infrastructure for axion research. If the axion exists IAXO will have a real opportunity to discover it. [18]

### **Across the universe: simulated distribution of dark matter**

In yet another attempt to nail down the elusive nature of dark matter, a European team of researchers has used a supercomputer to develop a profile of the yet-to-be-detected entity that appears to pervade the universe. Physicists led by Zoltan Fodor of the University of Wuppertal have predicted the masses of dark-matter candidates called axions using the JUQUEEN (Blue Gene/Q) supercomputer at the Forschungszentrum Jülich research institute in Germany. These hypothetical particles are promising dark-matter candidates that are not described by the Standard Model of particle physics but are predicted by an extension to quantum chromodynamics (QCD). Axions are thought to have exceedingly small masses and could, in theory, be detected directly. "However, to find this kind of evidence it would be extremely helpful to know what kind of mass we are looking for," says team-member Andreas Ringwald at DESY in Hamburg. "Otherwise the search could take

decades, because one would have to scan far too large a range." The team's simulations showed that if axions exist, they should have a mass of 50–1500 meV, making them up to 10 billion times lighter than electrons. This would require every cubic centimetre of the universe to contain on average 10 million such ultra-lightweight particles. "The results we are presenting will probably lead to a race to discover these particles," says Fodor. The team says that within the next few years, it should be possible to either confirm or rule out the existence of axions experimentally. The simulations are described in Nature. [17]

## **Team simulates a magnetar to seek dark matter particle**

MIT physicists are proposing a new experiment to detect a dark matter particle called the axion. If successful, the effort could crack one of the most perplexing unsolved mysteries in particle physics, as well as finally yield a glimpse of dark matter.

Axions are hypothetical elementary particles that are thought to be among the lightest particles in the universe—about one-quintillionth the size of a proton. These ultralight particles are virtually invisible, yet if they exist, axions and other yet-unobserved particles may make up 80 percent of the material in the universe, in the form of dark matter.

In a paper published online in Physical Review Letters, the MIT team proposes an experiment to detect axions by simulating an extreme astrophysical phenomenon known as a magnetar—a type of neutron star that generates an immensely powerful magnetic field. The physicists reasoned that in the presence of an axion such a huge magnetic field should waver ever so slightly, producing a second, vastly smaller magnetic field as a signature of the axion itself.

The team consists of MIT associate professor of physics Jesse Thaler, MIT Pappalardo Fellow Benjamin Safdi, and Yonatan Kahn PhD '15, now a postdoc at Princeton University. Together, they designed an experiment to recreate the physics of a magnetar in a controlled laboratory environment, using technology borrowed from magnetic resonance imaging (MRI).

The core of the experiment, which they've named ABRACADABRA (A Broadband/Resonant Approach to Cosmic Axion Detection with an Amplifying B-field Ring Apparatus), consists of a series of magnetic coils, wound in the shape of a toroid, or donut, which is then encased in a layer of superconducting metal and kept in a refrigerator at temperatures just above absolute zero, to minimize external noise. The scientists plan to use a highly sensitive magnetometer, placed inside the donut hole, to detect any signs of axions' influence.

"Axions are very strange, counterintuitive particles," Thaler says. "They're extremely light, with feeble interactions, and yet this particle may dominate the matter budget of the universe and be five times more abundant by mass than ordinary matter. So we really had to think hard on whether these particles are in principle detectable using current technology. It's extremely daunting."

## **A "tantalizing" particle**

If they are detected, axions may also explain an outstanding dilemma in particle physics, known as the Strong CP (charge parity) problem: Since the 1970s, scientists have grown increasingly puzzled

over what Safdi describes as "the indifference of neutrons to electric fields." Neutrons are elementary particles that are found in the nucleus of almost every atom in matter, and they do not carry a net charge.

"We don't expect neutrons to accelerate in the presence of an electric field because they don't carry electric charge, but you might expect them to rotate," Safdi says. "That's because we expect them to have an electric dipole moment, where you can think of a neutron having a plus charge on one side and a minus charge on the other. But from our current understanding, this rotation effect does not exist, whereas theory says it should."

Scientists have hypothesized that this bizarre effect may be explained by the axion, which would somehow remove a neutron's electric dipole moment. If so, the axion would modify electric and magnetic phenomena in a way that could be detectable experimentally.

"It's very tantalizing to say there might be a particle that serves this deep purpose, and even more so if we were to detect the presence of these particles in the form of dark matter," Thaler says.

### **The hunt is on**

Currently, Thaler says most axion hunting has been carried out by researchers at the University of Washington who are running the Axion Dark Matter Experiment, or ADMX. The experiment uses a resonant microwave cavity, set within a large superconducting magnet, to detect very weak conversions of axions to microwave photons. The experiment is tuned to look for axions within a specific range of around one quadrillionth the mass of a proton.

Thaler and his team realized that they could extend this range, and look for much smaller, lighter particles, on the order of one quintillionth the mass of a proton, by recreating the physics of magnetars, in the lab.

"The Strong CP problem is associated with whether a neutron's spin responds to electric effects, and you can kind of think of a magnetar as one gigantic spin with big magnetic fields," Thaler explains. "If axions are coming in and changing the properties of nuclear matter to resolve the Strong CP problem, maybe axions can interact with this magnetar and allow you to see it in a new way. So the subtle effects of axions should be amplified."

The team's prototype design is surprisingly small—"about the palm of your hand," Safdi says. The researchers, who are theoretical physicists by training, are now working with experimentalists at MIT to build the prototype, which is designed to generate a baseline magnetic field of about 1 tesla, comparable to current MRI machines. If axions are present, that field should waver slightly, producing a very tiny oscillation at a frequency that is directly related to the axion's mass. Using a high-precision magnetometer, Thaler hopes to pick up that frequency and ultimately use it to identify the axion's size.

"Only recently have there been many good ideas to search for [low-frequency axions]," says Gray Rybka, an assistant professor of physics at the University of Washington and an ADMX researcher, who was not involved in the research. "The experiment proposed here builds on previous ideas and, if the authors are correct, may be the most practical experimental configuration that can explore some of the plausible lower-frequency axion regimes."

"We have an instrument that's sensitive to many wavelengths, and we can tickle it with an axion of one particular wavelength, and ABRACADABRA will resonate," Thaler says. "And we will be going into uncharted territory, where we could possibly see dark matter from this prototype. That would be amazing." [16]

## **Dark matter does not contain certain axion-like particles**

Physicists are still struggling with the conundrum of identifying more than 80 percent of the matter in the universe. One possibility is that it is made up of extremely light particles that weigh less than a billionth of the mass of an electron. These particles are often called axion-like particles (ALPs). Since ALPs are hard to find, the researchers have not yet been able to test different types of ALPs that could be a constituent of dark matter.

For the first time, the researchers used data from NASA's gamma-ray telescope on the Fermi satellite to study light from the central galaxy of the Perseus galaxy cluster in the hunt for ALPs. The researchers found no traces of ALPs and for the first time, the observations were sensitive enough to exclude certain types of ALPs (ALPs can only constitute dark matter if they have certain characteristics).

ALPs cannot be detected directly, but there is a small chance that they transform into ordinary light and vice versa when traveling through a magnetic field. A research team at Stockholm University used a very bright light source, the central galaxy of the Perseus galaxy cluster, to look for these transformations. The gamma radiation from this galaxy could change its nature to ALPs while traveling through the magnetic field that fills the gas between the galaxies in the cluster.

"The ALPs we have been able to exclude could explain a certain amount of dark matter. What is particularly interesting is that with our analysis we are reaching a sensitivity that we thought could only be obtained with dedicated future experiments on Earth", says Manuel Meyer, post-doc at the Department of Physics, Stockholm University.

Searches for ALPs with the Fermi telescope will continue. More than 80 percent of the matter in the universe is unidentified. Dark matter shows itself only through its gravity, neither absorbing nor radiating any form of light. [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.

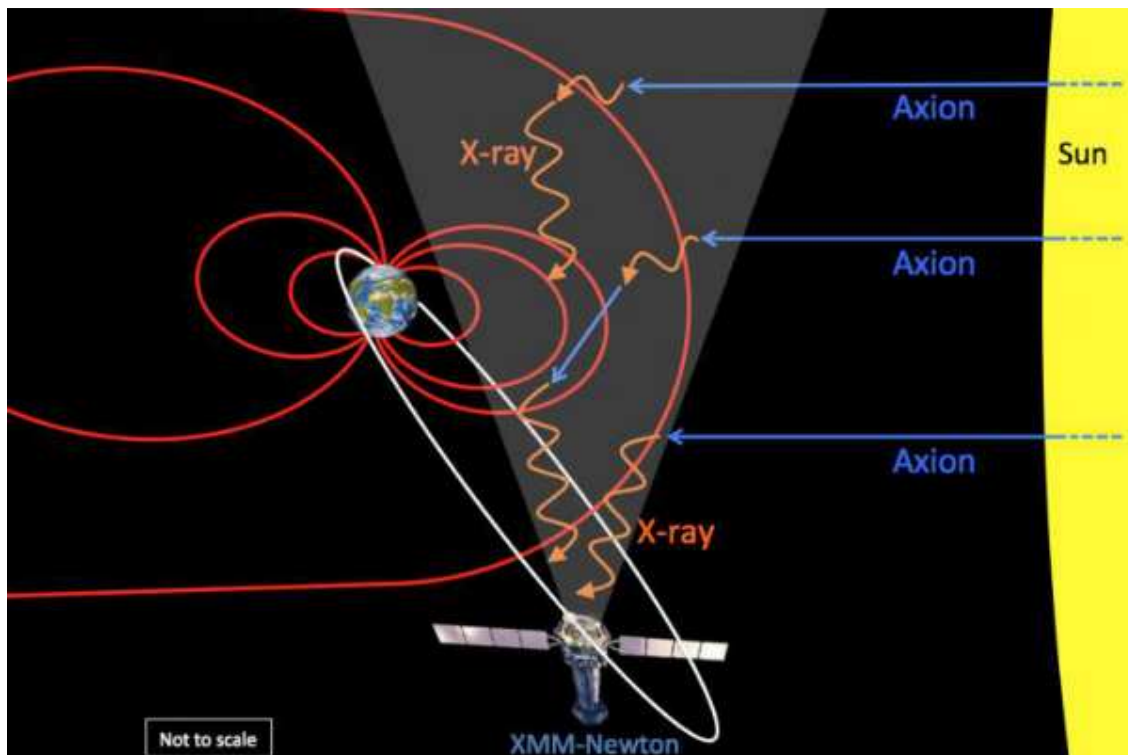
While we can't get too excited just yet - it will take years to confirm whether this signal really is dark matter - the discovery would completely change our understanding of how the Universe works. After all, dark matter is the force that holds our galaxies together, so learning more about it is pretty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

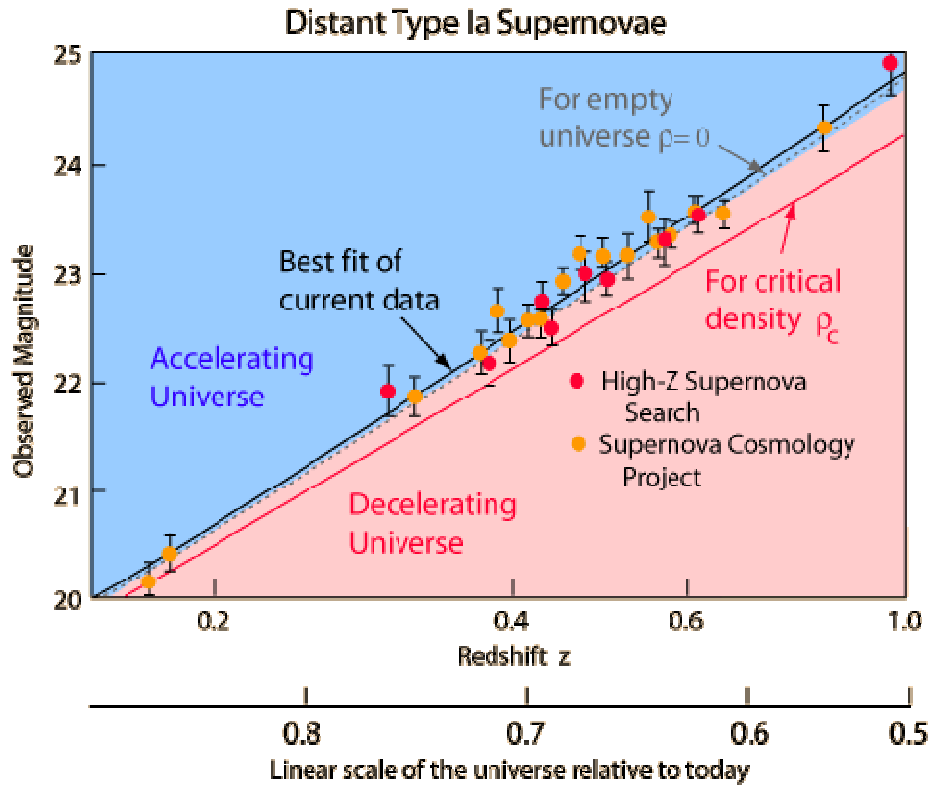
### **Weakly interacting massive particles**

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/mpc 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

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

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,  $\rho_{\text{vac}}$  (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  $8\pi$ :  $\Lambda = 8\pi\rho_{\text{vac}}$ , where unit conventions of general relativity are used (otherwise factors of  $G$  and  $c$  would also appear). It is common to quote values of energy density directly, though still using the name "cosmological constant".

A positive vacuum energy density resulting from a cosmological constant implies a negative pressure, and vice versa. If the energy density is positive, the associated negative pressure will drive

an accelerated expansion of the universe, as observed. (See dark energy and cosmic inflation for details.)

## Explanatory models

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

## Dark Matter and Energy

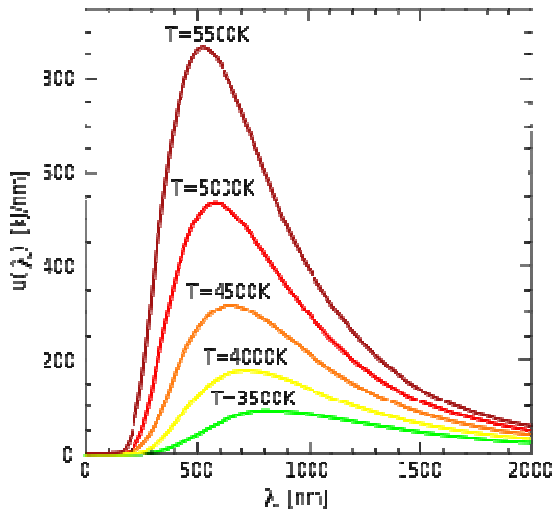
Dark matter is a type of matter hypothesized in astronomy and cosmology to account for a large part of the mass that appears to be missing from the universe. Dark matter cannot be seen directly with telescopes; evidently it neither emits nor absorbs light or other electromagnetic radiation at any significant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

## Cosmic microwave background

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

## Thermal radiation

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



## Electromagnetic Field and Quantum Theory

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

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

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

The bridge between the classical and quantum theory is based on this intrinsic acceleration of the spin, explaining also the Heisenberg Uncertainty Principle. The particle – wave duality of the electric charges and the photon makes certain that they are both sides of the same thing. Basing the gravitational force on the accelerating Universe caused magnetic force and the Planck Distribution Law of the electromagnetic waves caused diffraction gives us the basis to build a Unified Theory of the physical interactions. [4]

## Lorentz transformation of the Special Relativity

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

The difference between these two referential frames, namely the referential frame of the wire and the referential frame of the moving electrons gives the relativistic effect. Important to say that the moving electrons presenting the time coordinate, since the electrons are taking linearly increasing

way every next time period, and the wire presenting the geometric coordinate. The Lorentz transformations are based on moving light sources of the Michelson - Morley experiment giving a practical method to transform time and geometric coordinates without explaining the source of this mystery.

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

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

## The Classical Relativistic effect

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

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

## Electromagnetic inertia and Gravitational attraction

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

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

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

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

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

## Electromagnetic inertia and mass

### Electromagnetic Induction

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

### Relativistic change of mass

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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  $M_p=1840 M_e$ . In order to move one of these diffraction maximum (electron or proton) we need to intervene into the diffraction pattern with a force appropriate to the intensity of this diffraction maximum, means its intensity or mass.

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

## The Graviton

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

## Conclusions

Researchers predict that axions, if they exist, would be produced invisibly by the Sun, but would convert to X-rays as they hit Earth's magnetic field. This X-ray signal should in theory be strongest when looking through the sunward side of the magnetic field, as this is where the Earth's magnetic field is strongest. The high frequency of the X-ray and the uncompensated Planck distribution makes the axion a good candidate to be dark matter.

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

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

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

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



The electric currents causing self maintaining electric potential is the source of the special and general relativistic effects. The Higgs Field is the result of the electromagnetic induction. The Graviton is two photons together. [3]

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