

Pairs of Black Holes

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

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

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

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

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

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

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

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

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

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

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

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Author: George Rajna

The Big Bang

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

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

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

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

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

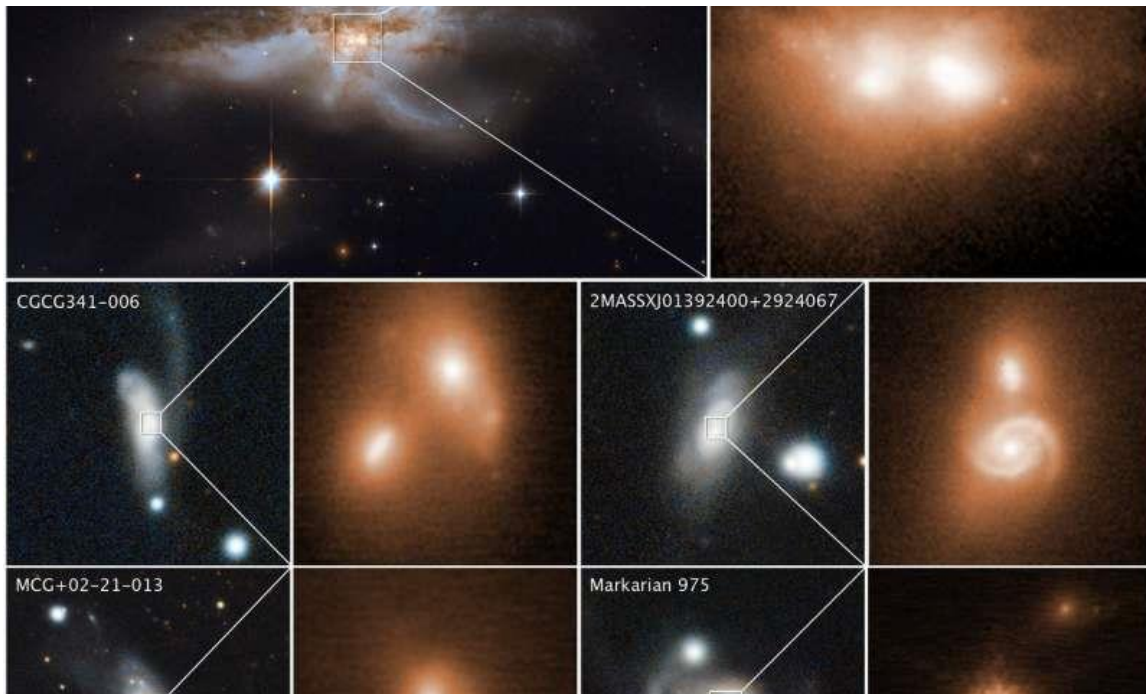
Led by University of Maryland alumnus Michael Koss (M.S. '07, Ph.D. '11, astronomy), a research scientist at Eureka Scientific, Inc., with contributions from UMD astronomers, the team surveyed hundreds of nearby [galaxies](#) using imagery from the W.M. Keck Observatory in Hawaii and NASA's Hubble Space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

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

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

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

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



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

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

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

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

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

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

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

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

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

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

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

Astronomers detect once-in-a-lifetime gamma rays

Scientists have discovered something amazing.

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

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

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

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

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

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

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

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



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

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

Hoping for fireworks

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

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

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

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

Once-in-a-lifetime doctoral experience

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

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



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

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

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

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

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

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

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

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

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

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



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

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

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

Charting a promising future

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

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

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

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

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

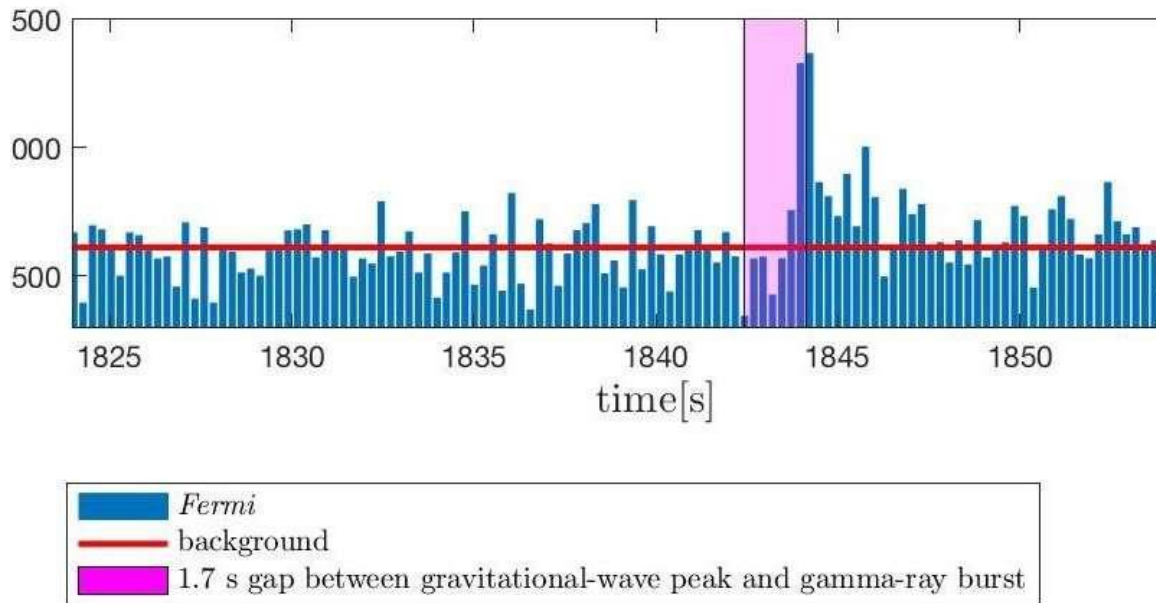
Gravitational waves from a merged hyper-massive neutron star

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

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

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

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



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

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

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

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

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

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

Boosting gravitational wave detectors with quantum tricks

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

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

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

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

A collision well noticed

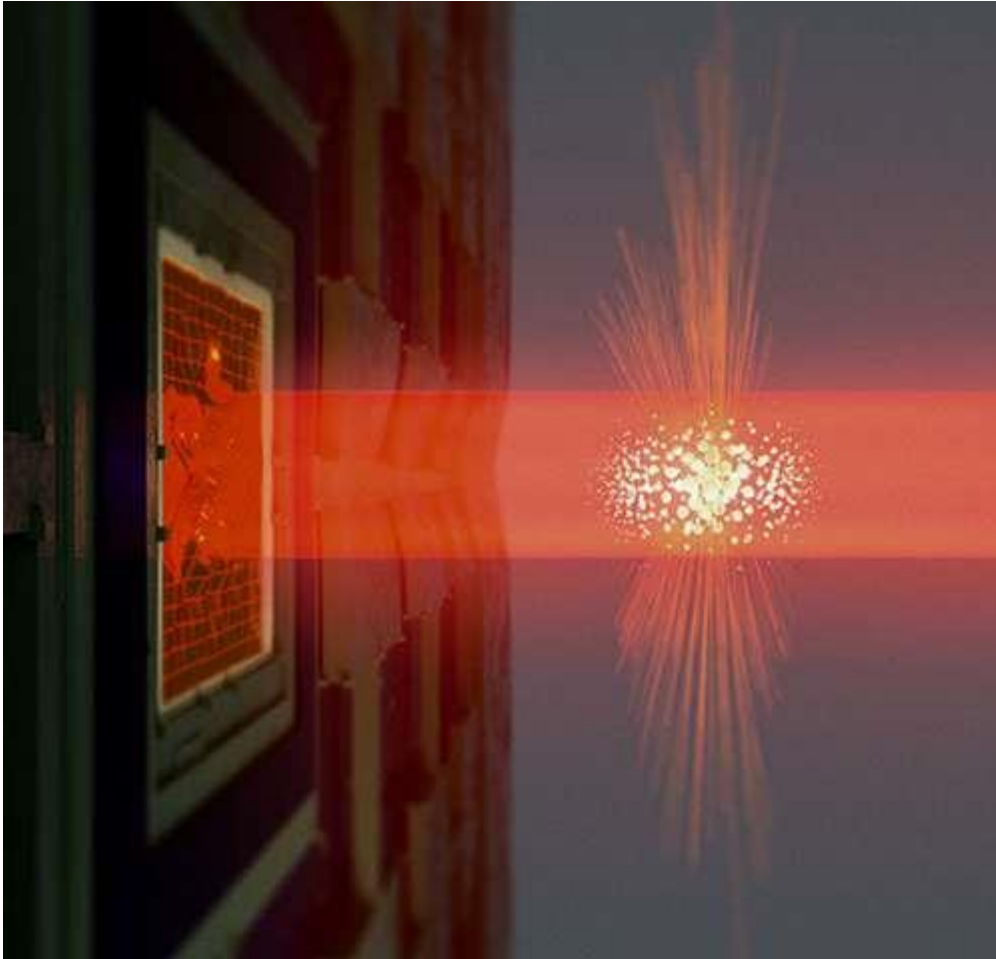
News media all over the world shifted into overdrive in October of 2017 when it was confirmed that a large international team of scientists had indeed measured the collision of two neutron stars; an event which took place 140 million [light](#) years from Earth and resulted in the formation of a kilonova.

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

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

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

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



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

A small glass cell

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

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

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

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

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

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

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

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

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

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

Gravitational wave detectors could shed light on dark matter

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Synopsis: Dark Photon Conjecture Fizzles

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

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

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

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

Exchanges of identity in deep space

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

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

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

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

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

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

Astronomers may have detected the first direct evidence of dark matter

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

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

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

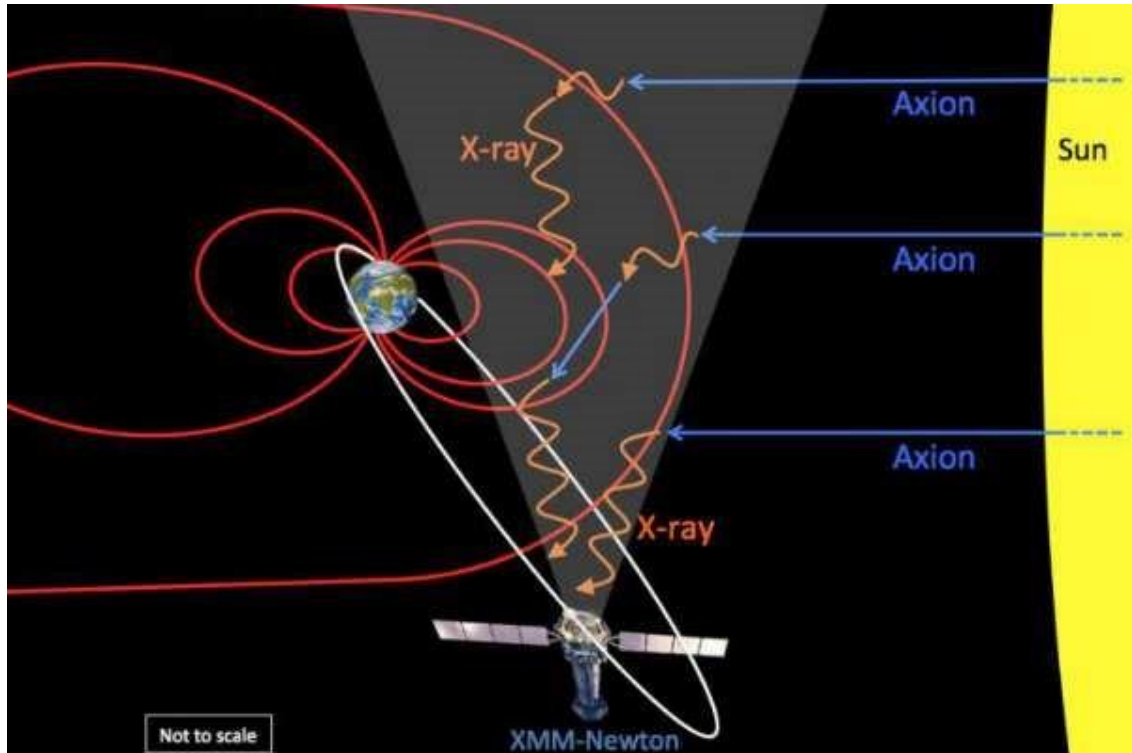
The researchers first detected the signal while searching through 15 years of measurements taking by the European Space Agency's orbiting XMM-Newton space observatory.

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

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

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

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



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

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

Hidden photons

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

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

Ideal mirror at hand

Fortunately for the team, an ideal mirror is at hand: a 13 m² 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/c². Another obvious choice is a receiver for gigahertz radiation, which corresponds to masses less than 0.001 eV/c²; however, this latter set-up would require more shielding.

Dark matter composition research - WIMP

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

Weakly interacting massive particles

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

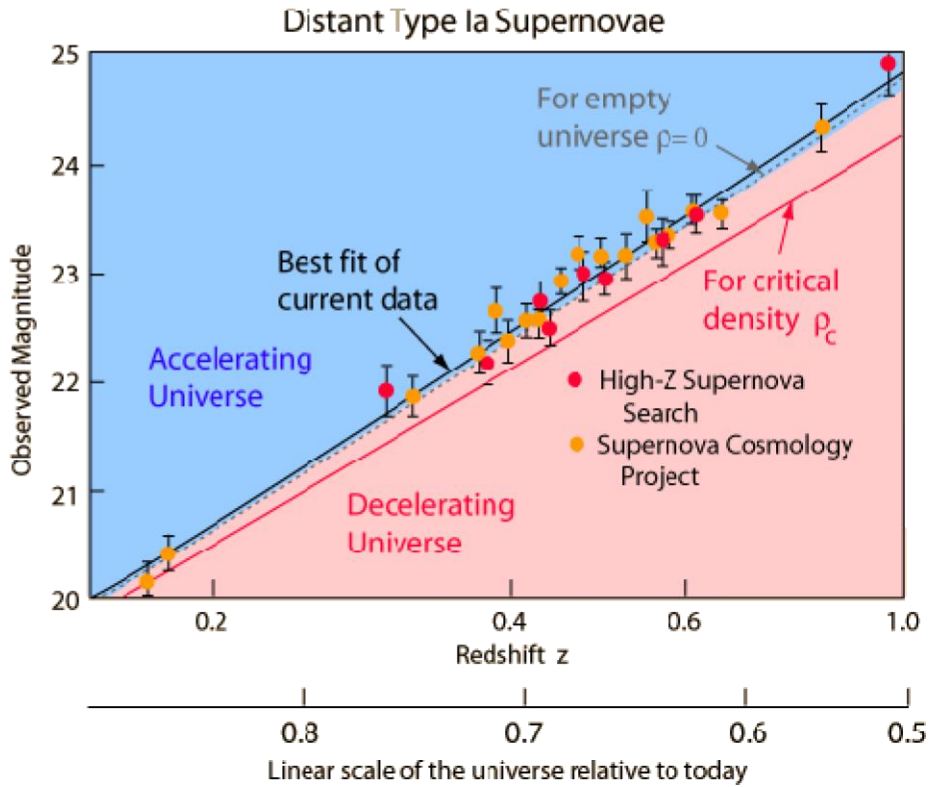
dark matter particle that was produced by falling out of thermal equilibrium with the hot dense plasma of the early universe, although it is often used to refer to any dark matter candidate that interacts with standard particles via a force similar in strength to the weak nuclear force. Its name comes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

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

Evidence for an accelerating universe

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

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



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

Equation

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

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

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

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

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

Explanatory models

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

Dark Matter and Energy

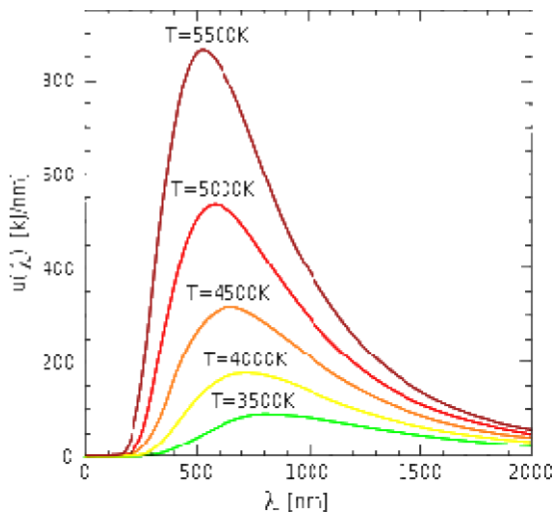
Dark matter is a type of matter hypothesized in astronomy and cosmology to account for a large part of the mass that appears to be missing from the universe. Dark matter cannot be seen directly with telescopes; evidently it neither emits nor absorbs light or other electromagnetic radiation at any significant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

Cosmic microwave background

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

Thermal radiation

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



Electromagnetic Field and Quantum Theory

Needless to say that the accelerating electrons of the steady stationary current are a simple demystification of the magnetic field, by creating a decreasing charge distribution along the wire, maintaining the decreasing U potential and creating the \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 ν frequency. It means that the mass of the proton and electron are electromagnetic and the result of the electromagnetic induction, caused by the changing acceleration of the spinning and moving charge! It could be that the m_0 inertial mass is the result of the spin, since this is the only accelerating motion of the electric charge. Since the accelerating motion has different frequency for the electron in the atom and the proton, they masses are different, also as the wavelengths on both sides of the diffraction pattern, giving equal intensity of radiation.

Electron – Proton mass rate

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

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

Gravity from the point of view of quantum physics

The Gravitational force

The gravitational attractive force is basically a magnetic force.

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

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

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

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

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

The Graviton

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

Conclusions

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

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

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

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

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

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

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