Rarest Radioactive Decay

Why is there more matter than antimatter in the universe? The reason might be hidden in the neutrino nature: one of the preferred theoretical models assumes, that these elementary particles were identical with their own anti-particles. [12]

Results from a new scientific study may shed light on a mismatch between predictions and recent measurements of ghostly particles streaming from nuclear reactors—the so-called "reactor antineutrino anomaly," which has puzzled physicists since 2011. [11]

Physicists have hypothesized the existence of fundamental particles called sterile neutrinos for decades and a couple of experiments have even caught possible hints of them. However, according to new results from two major international consortia, the chances that these indications were right and that these particles actually exist are now much slimmer. [10]

The MIT team studied the distribution of neutrino flavors generated in Illinois, versus those detected in Minnesota, and found that these distributions can be explained most readily by quantum phenomena: As neutrinos sped between the reactor and detector, they were statistically most likely to be in a state of superposition, with no definite flavor or identity. [9]

A new study reveals that neutrinos produced in the core of a supernova are highly localised compared to neutrinos from all other known sources. This result stems from a fresh estimate for an entity characterising these neutrinos, known as wave packets, which provide information on both their position and their momentum. [8]

It could all have been so different. When matter first formed in the universe, our current theories suggest that it should have been accompanied by an equal amount of antimatter – a conclusion we know must be wrong, because we wouldn't be here if it were true. Now the latest results from a pair of experiments designed to study the behaviour of neutrinos – particles that barely interact with the rest of the universe – could mean we're starting to understand why. [7]

In 2012, a tiny flash of light was detected deep beneath the Antarctic ice. A burst of neutrinos was responsible, and the flash of light was their calling card. It might not sound momentous, but the flash could give us tantalising insights into one of the most energetic objects in the distant universe.

The light was triggered by the universe's most elusive particles when they made contact with a remarkable detector, appropriately called IceCube, which was built for the very purpose of capturing rare events such as this. [6]

Neutrinos and their weird subatomic ways could help us understand high-energy particles, exploding stars and the origins of matter itself. [5]

PHYSICS may be shifting to the right. Tantalizing signals at CERN's Large Hadron Collider near Geneva, Switzerland, hint at a new particle that could end 50 years of thinking that nature discriminates between left and right-handed particles. [4]

The Weak Interaction transforms an electric charge in the diffraction pattern from one side to the other side, causing an electric dipole momentum change, which violates the CP and Time reversal symmetry.

The Neutrino Oscillation of the Weak Interaction shows that it is a General electric dipole change and it is possible to any other temperature dependent entropy and information changing diffraction pattern of atoms, molecules and even complicated biological living structures.

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GERDA experiment ready to discover rarest radioactive decay

Why is there more matter than antimatter in the universe? The reason might be hidden in the neutrino nature: one of the preferred theoretical models assumes, that these elementary particles were identical with their own anti-particles. This in turn would lead to an extremely rare nuclear decay process, the neutrinoless double-beta decay (0νββ). The experiment GERDA now has reached a most important improvement in the search for 0νββ decay by reducing the disturbances (background) to an unprecedented low level making it the first "background-free" experiment in the field. This achievement is reported in the recent Nature article appearing April 6th, 2017.

Neutrinos are ghostly particles which are extremely hard to detect. They play a central role in how the sun burns, how supernovae explode and how elements are formed during the big bang. Determining their properties has advanced our understanding of elementary particles considerably, best documented by the fact that so far four Nobel prizes have been awarded to neutrino related research. One fundamental property is still unknown: are neutrinos Majorana particles, i.e. identical to their own anti-particles? In that case 0νββ decay will exist. Strong theoretical arguments favor this possibility and the above mentioned absence of anti-matter in our universe is likely connected to the Majorana character of neutrinos.

"Normal" double beta decay is an allowed rare process where two neutrons in a nucleus decay simultaneously into two protons, two electrons and two anti-neutrinos. It has been observed for some nuclei like 76Ge, where single beta decay is not possible. The electrons and anti-neutrinos leave the nucleus, only the electrons can be detected. In 0νββ decay, no neutrinos leave the nucleus and the sum of the energies of the electrons is identical to the well known energy release of the decay. Measurement of exactly this energy is the prime signature for 0νββ decay.

GERDA experiment ready to discover rarest radioactive decay

Preparation of the GERDA experiment: Lowering the germanium detector array into the liquid argon tank - view from top.

Because of the importance of 0νββ decay in revealing the character of neutrinos and new physics, there are about a dozen experiments worldwide using different techniques and isotopes. The GERDA experiment is one of the leading experiments in the field, conducted by a European Collaboration. It is located in the underground Laboratori Nazionali del Gran Sasso of the Italian research organization INFN.

GERDA uses high-purity germanium detectors enriched in the isotope 76Ge. Since the germanium is source and detector at the same time, a compact setup with minimum additional materials can be realized leading to low backgrounds and high detection efficiency. The excellent energy resolution of germanium detectors and the novel experimental techniques developed by the GERDA collaboration provide unprecedented suppression of disturbing events from other radioactive decays (background events). Since 0νββ decay has a half-live many orders of magnitude longer than the age of the universe, the reduction of background events is most crucial for the sensitivity.

The bare germanium detectors are operated in 64 m3 of liquid argon at a temperature of -190 degree Celsius. The argon container itself is inside a 590 m3 tank filled with pure water which in turn is shielded by the Gran Sasso mountain against cosmic rays. The used argon and water are extremely pure in uranium and thorium; the liquids act as further shield for natural radioactivity from the surrounding. Their instrumentation provides additional means of background identification.

The novel techniques employed by GERDA reduced the number of background events in such a way, that now it is the first "background-free" experiment in the field. No 0νββ decays have been observed during the first five months of data taking and a lower half-life limit of 5x1025 yr was derived. Until the end of data taking in 2019 no background event should be left in the energy region where the 0νββ signal is expected and a sensitivity of 1026 yr will be reached. This makes GERDA best suited to discover a signal, which would manifest itself by a small number of events at the signal energy. [12]

New measurements suggest 'antineutrino anomaly' fueled by modeling error

Results from a new scientific study may shed light on a mismatch between predictions and recent measurements of ghostly particles streaming from nuclear reactors—the so-called "reactor antineutrino anomaly," which has puzzled physicists since 2011.

The anomaly refers to the fact that scientists tracking the production of antineutrinos—emitted as a byproduct of the nuclear reactions that generate electric power—have routinely detected fewer antineutrinos than they expected. One theory is that some neutrinos are morphing into an undetectable form known as "sterile" neutrinos.

But the latest results from the Daya Bay reactor neutrino experiment, located at a nuclear power complex in China, suggest a simpler explanation—a miscalculation in the predicted rate of antineutrino production for one particular component of nuclear reactor fuel.

Antineutrinos carry away about 5 percent of the energy released as the uranium and plutonium atoms that fuel the reactor split, or "fission." The composition of the fuel changes as the reactor operates, with the decays of different forms of uranium and plutonium (called "isotopes") producing different numbers of antineutrinos with different energy ranges over time, even as the reactor steadily produces electrical power.

The new results from Daya Bay—where scientists have measured more than 2 million antineutrinos produced by six reactors during almost four years of operation—have led scientists to reconsider how the composition of the fuel changes over time and how many neutrinos come from each of the decay chains.

The scientists found that antineutrinos produced by nuclear reactions that result from the fission of uranium-235, a fissile isotope of uranium common in nuclear fuel, were inconsistent with predictions. A popular model for uranium-235 predicts about 8 percent more antineutrinos coming from decays of uranium-235 than what was actually measured.

In contrast, the number of antineutrinos from plutonium-239, the second most common fuel ingredient, was found to agree with predictions, although this measurement is less precise than that for uraninum-235.

If sterile neutrinos—theoretical particles that are a possible source of the universe's vast unseen or "dark" matter—were the source of the anomaly, then the experimenters would observe an equal depletion in the number of antineutrinos for each of the fuel ingredients, but the experimental results disfavor this hypothesis.

The latest analysis suggests that a miscalculation of the rate of antineutrinos produced by the fission of uranium-235 over time, rather than the presence of sterile neutrinos, may be the explanation for the anomaly. These results can be confirmed by new experiments that will measure antineutrinos from reactors fueled almost entirely by uranium-235.

The work could help scientists at Daya Bay and similar experiments understand the fluctuating rates and energies of those antineutrinos produced by specific ingredients in the nuclear fission process throughout the nuclear fuel cycle. An improved understanding of the fuel evolution inside a nuclear reactor may also be helpful for other nuclear science applications. [11]

As hunt for sterile neutrino continues, mystery deepens

Physicists have hypothesized the existence of fundamental particles called sterile neutrinos for decades and a couple of experiments have even caught possible hints of them. However, according to new results from two major international consortia, the chances that these indications were right and that these particles actually exist are now much slimmer.

In the 1990s, particle physicists at Los Alamos National Laboratory noticed something puzzling in one of their experiments. Their results disagreed with other experiments that discovered neutrino oscillations—the surprising ability of neutrinos to morph from one flavor to another—and ultimately led to last year's Nobel Prize for physics. An experiment at Fermi National Accelerator Laboratory (Fermilab) that was designed to confirm or refute the results from Los Alamos only added to the mystery by producing mixed results.

To resolve the disagreement, theorists proposed the existence of an as-yet-undiscovered fundamental particle—a sterile neutrino. Physicists speculated that the hypothesized particles might hold a key to better understanding of the evolution of the universe and why it is mostly made of matter and not antimatter.

Based on the Los Alamos and Fermilab results, scientists predicted a range of possible physical properties, such as mass, that sterile neutrinos could have.

Several large research projects have been hunting for the elusive particles within that range.

Now in this latest study, by combining results from a different experiment at Fermilab, called the Main Injector Neutrino Oscillation Search (MINOS), and another in China, called the Daya Bay Reactor Neutrino Experiment, scientists have ruled out a large portion of the range of possible properties the hypothesized particles were predicted to be hiding in.

"So the plot thickens," says Karol Lang, a professor of physics at The University of Texas at Austin and co-spokesperson for the MINOS experiment. "But it's still possible that new experiments being developed at Fermilab might reveal some exciting new physics to explain these very different results."

The results are being published this week as three separate letters in the journal Physical Review Letters (see links below).

A team of researchers from UT Austin played many roles in producing the MINOS results, including graduate students Dung Phan, Simon De Rijck and Tom Carroll, and postdoctoral fellows Adam Schreckenberger, Will Flanagan and Paul Sail.

"It is very exciting to work on one of the pioneering experiments and have such a big impact on the field," says De Rijck.

Neither the MINOS nor Daya Bay results alone could be directly compared to the Los Alamos measurements, but combined, they could.

"It's not common for two major neutrino experiments to work together this closely," says Adam Aurisano of the University of Cincinnati, one of the MINOS scientists.

A resolution to the mystery of sterile neutrinos might come soon. Researchers in Fermilab's Short-Baseline Neutrino Program have already begun collecting data specifically targeting particles in the narrow mass range where sterile neutrinos might yet be hiding. Meanwhile, Lang and his colleagues in MINOS and Daya Bay have more data that they plan to analyze in the coming year, which might narrow the possible range of physical properties even further.

"A sterile neutrino, if found, would be a game changer for particle physics," says Phan. [10]

Weird quantum effects stretch across hundreds of miles

In the world of quantum, infinitesimally small particles, weird and often logic-defying behaviors abound. Perhaps the strangest of these is the idea of superposition, in which objects can exist simultaneously in two or more seemingly counterintuitive states. For example, according to the laws of quantum mechanics, electrons may spin both clockwise and counter-clockwise, or be both at rest and excited, at the same time.

The physicist Erwin Schrödinger highlighted some strange consequences of the idea of superposition more than 80 years ago, with a thought experiment that posed that a cat trapped in a box with a radioactive source could be in a superposition state, considered both alive and dead, according to the laws of quantum mechanics. Since then, scientists have proven that particles can indeed be in superposition, at quantum, subatomic scales. But whether such weird phenomena can be observed in our larger, everyday world is an open, actively pursued question.

Now, MIT physicists have found that subatomic particles called neutrinos can be in superposition, without individual identities, when traveling hundreds of miles. Their results, to be published later this month in Physical Review Letters, represent the longest distance over which quantum mechanics has been tested to date.

A subatomic journey across state lines

The team analyzed data on the oscillations of neutrinos—subatomic particles that interact extremely weakly with matter, passing through our bodies by the billions per second without any effect. Neutrinos can oscillate, or change between several distinct "flavors," as they travel through the universe at close to the speed of light.

The researchers obtained data from Fermilab's Main Injector Neutrino Oscillation Search, or MINOS, an experiment in which neutrinos are produced from the scattering of other accelerated, high-energy particles in a facility near Chicago and beamed to a detector in Soudan, Minnesota, 735 kilometers (456 miles) away. Although the neutrinos leave Illinois as one flavor, they may oscillate along their journey, arriving in Minnesota as a completely different flavor.

The MIT team studied the distribution of neutrino flavors generated in Illinois, versus those detected in Minnesota, and found that these distributions can be explained most readily by quantum phenomena: As neutrinos sped between the reactor and detector, they were statistically most likely to be in a state of superposition, with no definite flavor or identity.

What's more, the researchers found that the data was "in high tension" with more classical descriptions of how matter should behave. In particular, it was statistically unlikely that the data could be explained by any model of the sort that Einstein sought, in which objects would always embody definite properties rather than exist in superpositions.

"What's fascinating is, many of us tend to think of quantum mechanics applying on small scales," says David Kaiser, the Germeshausen Professor of the History of Science and professor of physics at MIT. "But it turns out that we can't escape quantum mechanics, even when we describe processes that happen over large distances. We can't stop our quantum mechanical description even when these things leave one state and enter another, traveling hundreds of miles. I think that's breathtaking."

Kaiser is a co-author on the paper, which includes MIT physics professor Joseph Formaggio, junior Talia Weiss, and former graduate student Mykola Murskyj.

A flipped inequality

The team analyzed the MINOS data by applying a slightly altered version of the Leggett-Garg inequality, a mathematical expression named after physicists Anthony Leggett and Anupam Garg, who derived the expression to test whether a system with two or more distinct states acts in a quantum or classical fashion.

Leggett and Garg realized that the measurements of such a system, and the statistical correlations between those measurements, should be different if the system behaves according to classical versus quantum mechanical laws.

"They realized you get different predictions for correlations of measurements of a single system over time, if you assume superposition versus realism," Kaiser explains, where "realism" refers to models of the Einstein type, in which particles should always exist in some definite state.

Formaggio had the idea to flip the expression slightly, to apply not to repeated measurements over time but to measurements at a range of neutrino energies. In the MINOS experiment, huge numbers of neutrinos are created at various energies, where Kaiser says they then "careen through the Earth, through solid rock, and a tiny drizzle of them will be detected" 735 kilometers away.

According to Formaggio's reworking of the Leggett-Garg inequality, the distribution of neutrino flavors—the type of neutrino that finally arrives at the detector—should depend on the energies at which the neutrinos were created. Furthermore, those flavor distributions should look very different if the neutrinos assumed a definite identity throughout their journey, versus if they were in superposition, with no distinct flavor.

"The big world we live in"

Applying their modified version of the Leggett-Garg expression to neutrino oscillations, the group predicted the distribution of neutrino flavors arriving at the detector, both if the neutrinos were behaving classically, according to an Einstein-like theory, and if they were acting in a quantum state, in superposition. When they compared both predicted distributions, they found there was virtually no overlap.

More importantly, when they compared these predictions with the actual distribution of neutrino flavors observed from the MINOS experiment, they found that the data fit squarely within the predicted distribution for a quantum system, meaning that the neutrinos very likely did not have individual identities while traveling over hundreds of miles between detectors.

But what if these particles truly embodied distinct flavors at each moment in time, rather than being some ghostly, neither-here-nor-there phantoms of quantum physics? What if these neutrinos behaved according to Einstein's realism-based view of the world? After all, there could be statistical flukes due to defects in instrumentation, that might still generate a distribution of neutrinos that the researchers observed. Kaiser says if that were the case and "the world truly obeyed Einstein's intuitions," the chances of such a model accounting for the observed data would be "something like one in a billion."

"What gives people pause is, quantum mechanics is quantitatively precise and yet it comes with all this conceptual baggage," Kaiser says. "That's why I like tests like this: Let's let these things travel further than most people will drive on a family road trip, and watch them zoom through the big world we live in, not just the strange world of quantum mechanics, for hundreds of miles. And even then, we can't stop using quantum mechanics. We really see quantum effects persist across macroscopic distances." [9]

Surprising neutrino decoherence inside supernovae

Neutrinos are elementary particles known for displaying weak interactions. As a result, neutrinos passing each other in the same place hardly notice one another. Yet, neutrinos inside a supernova collectively behave differently because of their extremely high density. A new study reveals that neutrinos produced in the core of a supernova are highly localised compared to neutrinos from all other known sources. This result stems from a fresh estimate for an entity characterising these neutrinos, known as wave packets, which provide information on both their position and their momentum.

These findings have just been published in EPJ C by Jörn Kersten from the University of Bergen, Norway, and his colleague Alexei Yu. Smirnov from the Max Planck Institute for Nuclear Physics in Heidelberg, Germany. The study suggests that the wave packet size is irrelevant in simpler cases. This means that the standard theory for explaining neutrino behaviour, which does not rely on wavepackets, now enjoys a more sound theoretical foundation.

One of the laws governing particles at the quantum scale - called the uncertainty principle - tells us that we cannot simultaneously know a particle's position and momentum (which is the product of their mass times their velocity) with arbitrary precision. Particles like neutrinos are therefore described by a mathematical entity, called wave packets, the size of which determines the uncertainty in the neutrino's position and momentum.

The authors find that neutrino wave packets in supernovae are unusually small in size. This implies that each individual neutrino displays decoherence. Kersten and Smirnov, however, show that this decoherence effect does not have any impact on the experimental measurement of the oscillation probability for each neutrino flavour; they only demonstrate this result in cases that are similar to, albeit simpler, than what happens in a supernova, where collective effects occur.

In this study, the authors thus provide a theoretical motivation to the use of the standard description of supernova neutrinos, which does not rely on wave packets.

Indeed, their findings suggest that collective effects are also unaffected by the neutrino wave packet size, a premise that has yet to be proven. [8]

Neutrinos hint at why antimatter didn’t blow up the universe

It could all have been so different. When matter first formed in the universe, our current theories suggest that it should have been accompanied by an equal amount of antimatter – a conclusion we know must be wrong, because we wouldn’t be here if it were true. Now the latest results from a pair of experiments designed to study the behaviour of neutrinos – particles that barely interact with the rest of the universe – could mean we’re starting to understand why.

Neutrinos and their antimatter counterparts, antineutrinos, each come in three types, or flavours: electron, muon and tau. Several experiments have found that neutrinos can spontaneously switch between these flavours, a phenomenon called oscillating.

The T2K experiment in Japan watches for these oscillations as neutrinos travel between the J-PARC accelerator in Tokai and the Super-Kamiokande neutrino detector in Kamioka, 295 kilometres away. It began operating in February 2010, but had to shut down for several years after Japan was rocked by a magnitude-9 earthquake in 2011.

Puff of radiation

In 2013, the team announced that 28 of the muon neutrinos that took off from J-PARC had become electron neutrinos by the time they reached Super-Kamiokande, the first true confirmation that the metamorphosis was happening.

They then ran the experiment with muon antineutrinos, to see if there was a difference between how the ordinary particles and their antimatter counterparts oscillate.

An idea called charge-parity (CP) symmetry holds that these rates should be the same.

CP symmetry is the notion that physics would remain basically unchanged if you replaced all particles with their respective antiparticles. It appears to hold true for nearly all particle interactions, and implies that the universe should have produced the same amount of matter and antimatter in the big bang.Matter and antimatter destroy one another, so if CP symmetry holds, both should have mostly vanished in a puff of radiation early on in the universe's history, well before matter was able to congeal into solid stuff. That's clearly not what happened, but we don't know why. Any deviation from CP symmetry we observe could help explain this discrepancy.

"We know in order to create more matter than antimatter in the universe, you need a process that violates CP symmetry," says Patricia Vahle, who works on NoVA, a similar experiment to T2K that sends neutrinos between Illinois and Minnesota. "So we're going out and looking for any process that can violate this CP symmetry."

Flavour changers

We already know of one: the interactions of different kinds of quarks, the constituents of protons and neutrons in atoms. But their difference is not great enough to explain why matter dominated so completely in the modern universe. Neutrino oscillations are another promising place to look for deviations.

This morning at the Neutrino conference in London, UK, we got our first signs of such deviations. Hirohisa Tanaka of the University of Toronto, Canada, reported the latest results from T2K. They have now seen 32 muon neutrinos morphing into the electron flavour, compared to just 4 muon antineutrinos becoming the anti-electron variety.

This is more matter and less antimatter than they expected to see, assuming CP symmetry holds. Although the number of detections in each experiment is small, the difference is enough to rule out CP symmetry holding at the 2 sigma level – in other words, there is only around a 5 per cent chance that T2K would see such differences if CP symmetry is preserved in this process.

Particle physicists normally wait until things reach the 3 sigma level before getting excited, and won't consider it a discovery until 5 sigma, so it's early days for neutrinos breaking CP symmetry. But at the same conference, Vahle presented the latest results from NoVA that revealed the two experiments were in broad agreement about the possibility.

The extent of CP violation rests on a key parameter called delta-CP, which ranges from 0 to 2π. Both teams found that their results were best explained by setting the value equal to 1.5π. “Their data really does prefer the same value that T2K does,” says Asher Kaboth, who works on T2K. “All of the preferences for the delta-CP stuff are pointing in the same direction.”

NoVA plans to run its own antineutrino experiments next year, which will help firm up the results, and both teams are continuing to gather more data. It’s too soon to say definitively, but one of the mysteries of why we are here could be on the road to getting solved. [7]

What the universe's most elusive particles can tell us about the universe's most energetic objects

In 2012, a tiny flash of light was detected deep beneath the Antarctic ice. A burst of neutrinos was responsible, and the flash of light was their calling card.

It might not sound momentous, but the flash could give us tantalising insights into one of the most energetic objects in the distant universe.

The light was triggered by the universe's most elusive particles when they made contact with a remarkable detector, appropriately called IceCube, which was built for the very purpose of capturing rare events such as this.

The team of international researchers now suspects the event may have originated from a quasar, which is the active nucleus of a galaxy billions of light-years away.

The flash also potentially opens up a new era of neutrino astrophysics and may help unravel the mystery of neutrino production in the universe.

The antisocial particle that came in from the cold

Neutrinos are elementary particles and one of the smallest building blocks of the universe. Despite being one of the most abundant and energetic particles, neutrinos have a reputation of being notoriously hard to detect.

This is because they very rarely interact with normal matter. In fact, billions of them pass through your body every minute without even causing a tickle.

What the universe's most elusive particles can tell us about the universe's most energetic objects

There’s a lot more of the IceCube neutrino detector below the ice. Credit: Erik Beiser, IceCube/NSF

So how do you find such an antisocial particle?

It might not look it from the frosty surface of Antarctica, but Ice Cube is one of the world's largest telescopes, and the largest for detecting neutrinos.

IceCube occupies a cubic kilometre of clear ice, which provides the best medium for thousands of sensors to capture that elusive burst of light created when a high energy neutrino collides with an ice particle.

Although the probability of a collision is minuscule, there are so many neutrinos that pass through the detector that eventually some will interact with the ice.

The trick then is to determine where the neutrinos originated. Neutrinos are produced by the nuclear reactions going on at the centre of stars and in other highly energetic cosmic processes.

So when trying to find origin of the 2012 neutrino burst, Professor Sergei Gulyaev, the director of Auckland University of Technology's Institute for Radio Astronomy and Space Research told The Conversation that there was no shortage of candidates. The sky was literally the limit.

"Out of millions of astronomical objects, which one was responsible?"

Nucleus of a galaxy

A network of New Zealand, Australian and African radio telescopes searched the skies for what might have triggered the 2012 flash.

But one candidate stood out. Radio astronomers were able to create an image of a distant object that appeared to change dramatically after the neutrino burst was registered in South Pole.

What the universe's most elusive particles can tell us about the universe's most energetic objects

The IceCube detector contains 5,160 individual sensors that go down to a depth of nearly 2.5 kilometres beneath the ice. Credit: IceCube Collaboration

From this, they decided that the most likely source of the neutrinos was a quasar, called PKS 1424-418, located 9.1 billion light years away – nearly at the edge of the visible universe.

A quasar is the active nucleus of a primordial galaxy with a supermassive black hole at its core.

"We knew before that huge fluxes of very energetic particles came from space. We call them 'cosmic rays'. Neutrinos are part of them. But we had no idea which astronomical objects are responsible for this."

Gulyaev emphasised that they had to be cautious before drawing any conclusions about the source of the neutrinos.

"We were very careful, but combining radio astronomical and gamma-ray observations made by NASA's Fermi gamma-ray space telescope, we now know where or what it is. Given the huge increase in energy, shape change and activity, we are 95% sure that a quasar was responsible for the event registered by IceCube."

Gulyaev added that this particular quasar was active while the universe was very young.

"Quasars are like dinosaurs. They became extinct a long time ago," said Gulyaev. "But because astronomy is like a time machine, we were able to study this quasar."

The study may also open a new window into the distant universe. Whereas most astronomy is conducted by studying electromagnetic radiation, such as light or radio waves, these can be obscured or distorted as they travel through space.

But because neutrinos pass through most matter, and aren't influenced by magnetic fields, they can pass through vast stretches of the cosmos uninterrupted. If we can detect them reliably, we might be able to observe things we can't normally see.

An exciting problem

Professor Ron Ekers, an astrophysicist from CSIRO, said the study presents tantalising possibilities of an extragalatic origin of the high energy neutrino burst.

However, the true test of time will be if the model can eventually predict future detections alongside more precise measurements of neutrino positions that would be possible in the future.

Ekers said that although the model presents a possible origin, a crucial step would be to increase the level of accuracy in neutrino detection instruments to more precisely pinpoint and narrow down possible sources.

"Current position errors for these neutrinos are quite large and there are many possible objects which could be the source."

Ekers added that both IceCube and the Mediterranean Neutrino Array (KM3NeT) have future plans to greatly improve positional accuracy to fulfil that need.

"Finding out where the high energy neutrinos come from is one of the most exciting problems in astrophysics today. Now we have a possible identification we desperately need to improve the directional accuracy of the neutrino detections. " [6]

Neutrinos: Ghosts of the Universe

Why, after millions of years of steadily lighting the cold darkness, does a supergiant star suddenly explode in a blinding blaze of glory brighter than 100 billion stars?
What exotic objects in deep space are firing out particles at by far the highest energies in the universe? And perhaps most mind-bending, why does the universe contain any matter at all? These mysteries have vexed astrophysicists and particle physicists for decades. The key to solving all three deep conundrums is itself one of the greatest enigmas of physics: the neutrino.

The universe is awash in these peculiar, nearly massless, subatomic particles. Created in tremendous numbers right after the Big Bang, and constantly churned out in stars and other places by radioactive decay and other reactions, trillions of these ghostly particles sail right through stars and planets, including our own.

Carrying no electrical charge, neutrinos are attracted neither to protons nor electrons, so they don’t interact with electromagnetic fields. They also don’t feel a powerful force that operates on tiny scales, known simply as the strong force, which binds protons and neutrons together in an atom’s nucleus.

Neutrinos are more aloof than supermodels, rarely interacting meaningfully with one another or with anything else in the universe. Paradoxically, it is their disengaged quality that earns them a crucial role both in the workings of the universe and in revealing some of its greatest secrets.

Neutrino physics is entering a golden age. As part of one experiment, neutrinos have recently opened a new window on high-energy sources in deep space, such as black holes spewing out particles in beams trillions of miles long.

Another astronomy experiment deep underground in a Japanese mine will use neutrinos to learn the average temperature and energy of ancient supernovae to better understand their typical behavior. And physicists are using computer modeling to close in on the neutrino's critical role in triggering the kind of supernovae that distribute essential elements like oxygen and nitrogen.

Beyond expanding the role of neutrinos in astronomy and uncovering their role in astrophysics, physicists are still trying to discover some of the neutrino's basic properties. Some researchers, for instance, are trying to pin down the particle's possible masses. That fundamental information would influence theories that explain the masses of other particles.

By determining yet another elusive fundamental property of neutrinos, researchers also hope to answer one of theoretical physics's great riddles: why all the matter and antimatter created by the Big Bang didn't cancel each other out and leave nothing but energy. At the dawn of the universe, for every particle of matter, such as an electron, there was an anti-electron; for every quark (a fundamental constituent of matter), there was an antiquark, explains physicist Chang Kee Jung of Stony Brook University. When these opposites meet, they should annihilate each other, creating pure energy.

So why is any matter left? The most plausible solution, leading physicists like Jung say, hinges on the theory that today's neutrinos, which have barely any mass, once had superheavy partners. These neutrino cousins, 100 trillion times more massive than a proton, formed in the tremendous heat that existed right after the Big Bang. They had the special androgynous ability to decay into either matter or antimatter counterparts. One such overweight particle might have decayed into a neutrino plus some other particle — like an electron, for instance — while another superheavy neutrino might have decayed into an antineutrino and another particle.

For this theory to explain why matter exists, those early superheavy neutrinos would have had to decay more frequently into particles than antiparticles. Physicists at neutrino detectors such as NOvA in Minnesota, in addition to trying to determine the masses of the neutrino, are studying whether today's lighter neutrinos switch from one type (or "flavor") to another at a different rate than antineutrinos. The same theory that could explain this behavior in today's light neutrinos could also explain the inclinations of superheavy neutrinos at the dawn of time. If the superheavy neutrino theory is correct, then these primordial particles are the "supreme ancestor" from which every particle in the cosmos descended.

Neutrino-related discoveries have already earned three Nobel prizes, and the path-breaking experiments underway could well earn more tickets to Stockholm. The seemingly superfluous neutrino couldn't be more essential to our understanding of the cosmos, or less concerned with its profound importance.

The Ice Telescope Cometh

Computers at the IceCube Laboratory at the Amundsen-Scott South Pole Station collect raw data and analyze results from the underground neutrino detector.

Scientists who want to detect neutrinos must build their detectors deep underground or underwater to filter out the cosmic rays that constantly bombard Earth.
(Neutrinos travel through matter, regardless of how dense.) Francis Halzen, a physicist at the University of Wisconsin-Madison, realized decades ago that Antarctica was an ideal spot because the ice was thick enough to bury thousands of light sensors more than a mile deep.

When a neutrino chances to slam into an atomic nucleus in the ice, an electron or muon (a heavier cousin of the electron) is created, releasing a trace of light. That trace of light can be picked up by IceCube, an underground telescope and particle detector at the South Pole. Halzen is one of nearly 250 people involved with the project.

In May 2012, IceCube physicists discovered the light footprints of two neutrinos with an incredible 1,000 times more energy than any neutrino ever detected before on Earth. Christened Bert and Ernie after the Sesame Street characters, they spurred IceCube scientists to re-examine the data at that energy level. Sure enough, they found 26 more high-energy neutrinos. When the scientists looked at more recent data through May 2013, they found nine more high-energy neutrinos, one of which had the energy of Bert and Ernie combined. “It’s named Big Bird, of course,” says Halzen.

Some neutrinos almost certainly hail from beyond our galaxy, and they could help solve a century-old mystery on the source of incredibly high-energy cosmic rays.
That source also is thought to produce high-energy neutrinos. Some possible scenarios: incredibly massive black holes erupting in jets of matter, galaxies colliding or star-producing factories known as starburst galaxies.

“IceCube is finally opening a new window on the universe,” says physicist John Beacom of Ohio State University. “All these years we have been doing astronomy with light (not just visible light), we have been missing a big part of the action.”

Neutrino Mysteries

Shape-Shifting

Neutrinos are notorious shape-shifters. Each one is born as one of three types, or flavors — electron, muon and tau — but they can change flavor in a few thousandths of a second as they travel, as if they can’t make up their mind what to be. Neutrinos, like other subatomic particles, sometimes behave like waves. But as the neutrino travels, the flavor waves combine in different ways. Sometimes the combination forms what is mostly an electron neutrino and sometimes mostly a muon neutrino.

Because neutrinos are quantum particles, and by definition weird, they are not one single flavor at a time, but rather always a mixture of flavors. On the very, very rare occasion that a neutrino interacts with another particle, if the reaction appears to produce an electron, then the neutrino was an electron flavor in its final moments; if it produces a muon, the neutrino was muon-flavored. It's as if the shy neutrino's identity crisis can only be resolved when it finally interacts with another particle.

Heavyweight Competition

Physicists hope to use neutrinos' strange shape-shifting behavior to unlock several mysteries. Scientists know the mass of every other fundamental particle, such as the electron, but the neutrino — at least a million times as light as the electron — is far more elusive because of its transformative ways.

The discovery of neutrino masses would influence the fundamental theory of how particles and forces interact, the so-called standard model of particle physics.
Physicists already know the theory is incomplete because it incorrectly predicts neutrinos have no mass. "It may help us to better understand the reasons behind the masses of all particles," says William Louis of Los Alamos National Laboratory. "A jigsaw puzzle is much easier to put together once all of the pieces are available."

The difficulty in pinning down neutrino masses lies in the Heisenberg uncertainty principle, a cornerstone of quantum physics. It states that certain properties of subatomic particles are linked such that the more precisely you know one, the less precisely you can know the other. For instance, if you know exactly where a particle is, then you can't know its momentum. And once you've pinned down the particle's momentum, you can't absolutely know its location. A neutrino's flavor and mass are linked in a similar way, says Indiana University physicist Mark Messier. You can't know both at the same time. For that reason, he says, "We always measure some combination of masses. … It does not even make sense to ask what the mass is for a single flavor of neutrino."

As far as scientists can tell, each neutrino is a combination of three masses, but they can't learn that combination without taking a measurement. Two of those masses are likely to identify as electron neutrinos a significant portion of the time, and one mass only infrequently comes up as electron neutrino, says Messier. Physicists are not sure if the greatest, or heaviest, of the three masses is most likely to be an electron neutrino or least likely to be an electron neutrino.

When Lefties Turn Right

All matter has a mirror image, called antimatter. For an electron, which has a negative charge, the antimatter twin — the positron — is identical except that it has a positive charge. If matter meets antimatter, they destroy each other in a burst of energy.

For each of the three flavors of neutrino, there is also a corresponding antineutrino called, sensibly enough, electron antineutrino, muon antineutrino and tau antineutrino.

Because neutrinos are neutral, their antiparticles cannot have opposite charges. Instead, their “spin” is reversed. (Neutrinos are too small to really spin like a planet; the term spin refers to a property that is in some ways equivalent to spin.) Neutrinos are “left-handed” — they always spin to the left, relative to their direction of motion. Antineutrinos are “right-handed.” The eccentric Sicilian theorist Ettore Marjorana suggested that since neutrinos are neutral, they may be their own antiparticle — meaning that under certain circumstances, a neutrino could act like an antineutrino. If that were true, it would satisfy one necessary condition for the supreme ancestor neutrino theory that explains why we and all matter in the universe exist.

Cracked Mirror?

If you apply the laws of physics to antimatter, everything works out the same, just reversed. A magnetic field would push on an electron and a positron with exactly the same force: For example, if the electron were pushed right, the positron would be pushed left. Physicists hope that neutrinos don’t necessarily follow this mirror effect, and that they may once again be the oddballs that lead to a new understanding of nature.

In experiments in the U.S. and Japan, researchers are trying to determine if the metamorphosis of neutrinos into different flavors happens at a different rate than the antineutrino transformations. So rather than, say, a 10 percent chance of an electron neutrino turning into a muon neutrino, for example, physicists wonder if the odds are lower that an electron antineutrino turns into a muon antineutrino. They’ve seen precedents for such “asymmetrical” behavior in a few other particles, and certain theories predict that behavior in neutrinos.

If neutrinos do indeed transform into other flavors at a different rate from antineutrinos, it’s likely that this matter/antimatter difference in neutrinos was present in their superheavy ancestors at the dawn of time, too.

Seeing Stars

Astrophysicist Hans-Thomas Janka and his team use a bank of supercomputers to create 3-D models of the heat that builds in a neutrino-driven explosion of a star.

Leonhard Scheck and H.-Thomas Janka (Max Planck Institute for Astrophysics)

Somewhere in the universe, at least once a second, a massive star goes supernova, blowing to smithereens with the intensity of an entire galaxy’s worth of shining stars. After 50 years of investigation, no one knows exactly why supernovae occur. But to astrophysicist Hans-Thomas Janka, it’s clear the neutrino is a major culprit in this mystery.

Working from the Max Planck Institute for Astrophysics in Munich, Janka has enlisted dozens of the world's most powerful computers on a decades-long quest to understand the incredibly complex mechanism of a supernova. Advances in computing power and physics have helped him build sophisticated models, spun from hundreds of thousands of lines of computer code, that capture the nuances of the stars' shape while taking into account everything from stars' rotation and nuclear reactions to Einstein's theory of gravity. Now, for the first time, Janka's latest models fully describe the behavior of neutrinos under the hellish conditions of a star's demise.

In 1982, James Wilson of Lawrence Livermore National Laboratory first showed how neutrinos might trigger the explosion. Wilson knew that when a massive star burns up the last of its fuel after some 10 million years, its core rapidly implodes, pulling all of the star's matter inward. The implosion begins to turn into an explosion, and a shock wave forms. But within a few thousandths of a second, it stops cold. Then something causes the shock wave to "revive" and trigger the explosion, leaving behind a dense neutron star.

Through rudimentary computer modeling, Wilson discovered that that something was neutrinos, generated in copious amounts — on the order of 1 followed by 58 zeroes — when the electrons and protons in the core turn into neutrons. Because those neutrons are packed so tightly — a teaspoon would weigh 100 million tons — the neutrinos would get trapped there, bouncing off and interacting with the other particles (mostly neutrons, but some protons and electrons) trillions of times.

The neutrinos would be delayed in the core only for a second, but Wilson suspected that enough heat would be generated to trigger the supernova explosion.

Limited by the era's computers and understanding of physics, Wilson's model relied on simplifications — such as the star being a perfect sphere — and incorrect assumptions about the behavior of very dense matter and how neutrinos move from the core's interior to the crucial outer parts where the heating of the shock wave occurs. The model did not work. Janka learned about Wilson's model four years later, as a graduate student at Technical University Munich. He thought the theory sounded plausible and developed a new way to describe neutrino physics in supernovae, working on newly available $25 million supercomputers at the Max Planck Institute, one of the few places in Europe where the computers were available for unclassified research. Janka seemed to work nonstop, his ferocious drive coexisting with a persistent fear: Because he was one of only a handful working in what was then a limited field of study, Janka worried that by the time he completed his doctorate, he'd be a 30-something with few job prospects.

But the heavens intervened. In 1987, the first supernova visible to the naked eye since 1604 appeared in the Large Magellanic Cloud, our closest neighboring galaxy. Of the trillions of neutrinos the blast emitted, detectors on Earth captured 24, suddenly inaugurating a new field of particle astrophysics. "It was an initial boost that affected all my career," says Janka. "That was the reason that a big neutrino astrophysics research program was started in Munich and that I got a permanent job there in 1995."

That 1987 supernova confirmed the basic picture of a collapsed core of a massive star spewing an enormous blast of neutrinos. Janka eagerly started building computer models, but like Wilson, he had to assume the star was spherical, an oversimplification dictated by the high costs of computing power. When Janka ran the models, the star did not explode. Over the next decade, he collaborated with Ewald Mueller of the Max Planck Institute for Astrophysics to create more complex models. They fleshed out how neutrinos interact and how they leak out of the core of a collapsed star. "He built up his expertise very systematically as he attacked different pieces of the puzzle," says physicist Thomas Baumgarte of Bowdoin College, who has known Janka for about 20 years.

By 2005, Janka had developed more sophisticated code for a model that more accurately represented the shape of the star, though it was still an approximation. In this model, called a two-dimensional type, Janka refined the physics of how neutrinos moved in connection with the flow of the other matter in the star. But he lacked computer power to test the model.

Then in 2006, fortune struck again. The managing director of the Max Planck Institute asked Janka if he could do anything with 700,000 euros, at the time equal to $875,000. Janka bought 96 1.282-gigahertz processors, the fastest available. "The computers worked on the problem continuously for the next three years to get one second of evolution — from supernova core collapse to 750 milliseconds after the neutron star at the center begins to form," Janka says. This work led to the first sophisticated 2-D model of a giant star in extremis — and this time, the model star exploded.

Janka's group had worked out highly complex physical equations to describe neutrino interactions and how the gas of the star flows and bubbles, turning Wilson's theoretical vision into a far more detailed and sophisticated simulation.

Since Janka simplified the star's shape, his model didn't completely solve the mystery. His group is now incorporating what's been learned about neutrino interactions into new, state-of-the-art models that don't idealize a star's shape. At Janka's disposal is a fair share of the processors of two huge supercomputers, one in Paris and one in Munich, with the power of 32,000 workstations: Together, they can calculate more than 100 trillion operations per second. But Janka finds himself once again at the outer limit of computing power. These 3-D models, he says, are in their infancy and don't yet explode. Janka's group recently won a five-year, $4 million grant to give the 3-D model higher resolution and to push the simulation "backward in time, and also forward, linking the model to observed supernova remnants," he says.

Janka "is doing the leading work" in this highly competitive field, says supernova pioneer Stanford Woosley of the University of California, Santa Cruz. Groups at Princeton University and Oak Ridge National Laboratory, he says, are also within reach. "Victory will go to the one who gets the 3-D model of a 15-solar-mass star [the size of 15 suns] to explode with the right energy," says Woosley, since that's the size of star that can synthesize elements important for life.

That's ultimately the allure of these fiery enigmas. "The oxygen we breathe, the iron in our blood, the carbon in plants, the silicon in the sand — all the matter that makes up you and the Earth is made and distributed by supernovae," Janka says. We are all star descendants, forged from matter created hundreds to thousands of light-years away in a titanic explosion where a reticent ghost particle finally, violently, made its presence felt.

Double Trouble

Several major experiments around the world are designed to catch the elusive neutrino in the act of not showing up. In a radioactive metamorphosis called single beta decay, a neutron (a neutral particle) in the nucleus of an unstable atom spontaneously turns into a proton (a positive particle) and emits an electron and an antineutrino — the antimatter twin of a neutrino.

In double beta decay, the interaction is doubled: Two neutrons simultaneously decay into two protons. However, instead of producing two electrons and two antineutrinos, as one might expect, physicists such as Giorgio Gratta of Stanford University suspect that in some instances, no antineutrinos are emitted. That can happen only if neutrinos are their own antiparticle, in which case an antineutrino would be emitted by a neutron and then — presto! — absorbed as a neutrino by a neutron.

The discovery of the neutrino's double anti-identity, although expected by many physicists, would contradict the standard model of particle physics, the current mainstream understanding of the way particles and fundamental forces behave, necessitating a paradigm-shifting extension. If the decay of an unstable atom produces two electrons but no antineutrinos, physicists will have found decisive evidence for this elusive, eccentric behavior.

Experiments in the United States, such as the Enriched Xenon Observatory 200 (EXO-200) in New Mexico, as well as ones in Japan and Europe, are trying to catch a glimpse of this fantastically rare interaction.

"People have been trying to find this critical decay for a long time," says Gratta, the lead scientist at EXO.

The Super-K's detector houses 13,000 photomultipliers that help detect the smallest trace of light from neutrino interactions.

Built in a zinc mine near Hida, Japan, the Super-Kamiokande (Super-K) experiment has been searching for telltale flashes of light in a 50,000-ton tank of the purest water on Earth since 1996.

When a low-energy neutrino or antineutrino from a supernova collides with a water molecule in the tank, the resulting light signal is recorded by about 100 of 13,000 photomultipliers, ultrasensitive light-detecting devices that turn a tiny flash of light into a larger recordable burst of electricity. But sometimes, false positives occur: Radioactive decays in the detector also create light, as do neutrinos produced in the atmosphere when they collide with the water.

Now, Super-K scientists plan to silence the false positives using a method suggested by physicists John Beacom and Mark Vagins that focuses on the antineutrinos that supernovae produce. They'll add 50 tons of the rare earth metal gadolinium to the water in Super-K, allowing them to tell the difference between encounters with antineutrinos and other light-emitting pretenders.

When an antineutrino knocks into a proton in the Super-K water, that proton turns into a neutron and instantly emits a positively charged particle that gives off blue light as it rapidly moves through the water. The gadolinium would capture the neutron about 20 microseconds after it's created, taking it into its own nucleus and leading to the immediate burst of gamma rays. The photomultipliers capture the whole sequence. No other particle interaction would lead to that one-two “heartbeat.” The light in each beat reveals two things: The first flash indicates the energy of the antineutrino; the second confirms that the particle was an antineutrino.

“Currently, Super-Kamiokande can detect neutrinos from supernova explosions anywhere in our own Milky Way galaxy,” says Vagins, of the Kavli Institute for the Physics and Mathematics of the Universe. “Adding gadolinium will make the detector vastly more sensitive, which will enable Super-K to begin collecting antineutrinos from supernova explosions anywhere within half the known universe.” That would include lower-energy, harder-to-detect antineutrinos created by massive stars that exploded billions of years ago. Adding gadolinium would “allow us to determine the total energy and temperature of an average supernova, two key inputs in all kinds of cosmological and stellar evolution models,” says Vagins.

Called GADZOOKS! — for Gadolinium Antineutrino Detector Zealously Outperforming Old Kamiokande, Super! — the enriched detector, expected to go online in 2017, will also have a better chance of catching the birth of a black hole in the remnants of an exploding star. Neutrinos can’t escape from black holes, and the supersensitive Super-K will be able to detect a telltale stream of neutrinos that suddenly shuts down. “Super-K would be able to see a black hole form minutes or even hours after the initial core collapse. … Without gadolinium, it will be limited to 10 seconds or so,” says Vagins.

Flying High

The balloon-borne experiment ANITA (Antarctic Impulsive Transient Antenna) heads to the heavens at the end of this year. It will try to detect the sources of the highest-energy neutrinos in the universe. These neutrinos are thought to result from ultrahigh-energy cosmic rays crashing into the low-energy invisible photons left over from the Big Bang that still suffuse all of space.

What sort of phenomenon creates and launches the cosmic ray sources of these neutrinos? Perhaps a hypernova — a “supernova on steroids” — or a rapidly spinning black hole or, more likely yet, a supermassive black hole, says physicist Peter Gorham of the University of Hawaii, the project’s lead investigator.

The NASA-funded balloon will be 35,000 meters over the Antarctic ice cap. Circling the South Pole, ANITA’s antennas will scan a million cubic kilometers of ice at a time, looking for the telltale radio waves emitted when an ultrahigh-energy neutrino hits a nucleus in ice. It will be ANITA’s third voyage.

Last year, physicists began shooting 150 trillion neutrinos per second from the Fermi National Accelerator Laboratory, west of Chicago, to a detector in Minnesota — a 503-mile underground trip that will take them just 2.7 milliseconds.

Called the NuMI Off-axis Electron Neutrino Appearance experiment, or NOvA, the project relies on a 15,400-ton detector containing 3 million gallons of a liquid solution with a material known as a scintillator. Scintillators absorb the energy of incoming particles and emit that energy in the form of light. Of the torrent of particles Fermilab sends, only about 10 neutrinos interact with the scintillator each week. But the result will be a light signature that reveals the neutrino's flavor and energy.

More than 200 scientists, engineers and technicians helped design and build Fermilab's flagship experiment over the past 12 years. Physicist Mark Messier of Indiana University, one of the experiment's co-leads, says NOvA "has the best shot at taking the next big step in uncovering new properties of neutrinos."

One of NOvA's goals, Messier says, is to help figure out which of the three mixes of neutrino flavors is heaviest and which is lightest — their so-called mass ordering. Mass is a fundamental but mysterious property of neutrinos that affects many physics theories because the origin of neutrino masses is still unknown.

The NOvA neutrinos will start off as muon flavor, but then do their typical transforming act into electron neutrinos. Electron-flavor neutrinos are special because they can interact with the Earth: They alone can meaningfully interact with electrons in atoms. The key for NOvA is that the greater the mass of the electron neutrino flavor, the more likely the beam of neutrinos will interact with the hundreds of miles of matter they cross on the way to the detector. "Because the electrons in the Earth 'drag' on the electron neutrinos, that effectively gives the electron neutrinos some additional mass," says Messier.

That effect determines the neutrino's transformation rate. If electron neutrinos tend to have the lightest mix of masses, the added heaviness from its earthly interactions would make it change to muon neutrinos at a higher rate because it would "mix" or "overlap more" with the muon masses, as Messier puts it, referring to the wavelike behavior of these particles. On the other hand, if the electron neutrinos contain the heaviest masses, then the additional Earth-induced mass would make them mix less with those of the other two neutrino flavors.

NOvA is also doing the experiment with antineutrinos, which offer a valuable comparison, Messier says. And it might give a hint of whether neutrinos and antineutrinos morph at different rates, yet another unusual neutrino property that would not be totally unexpected.

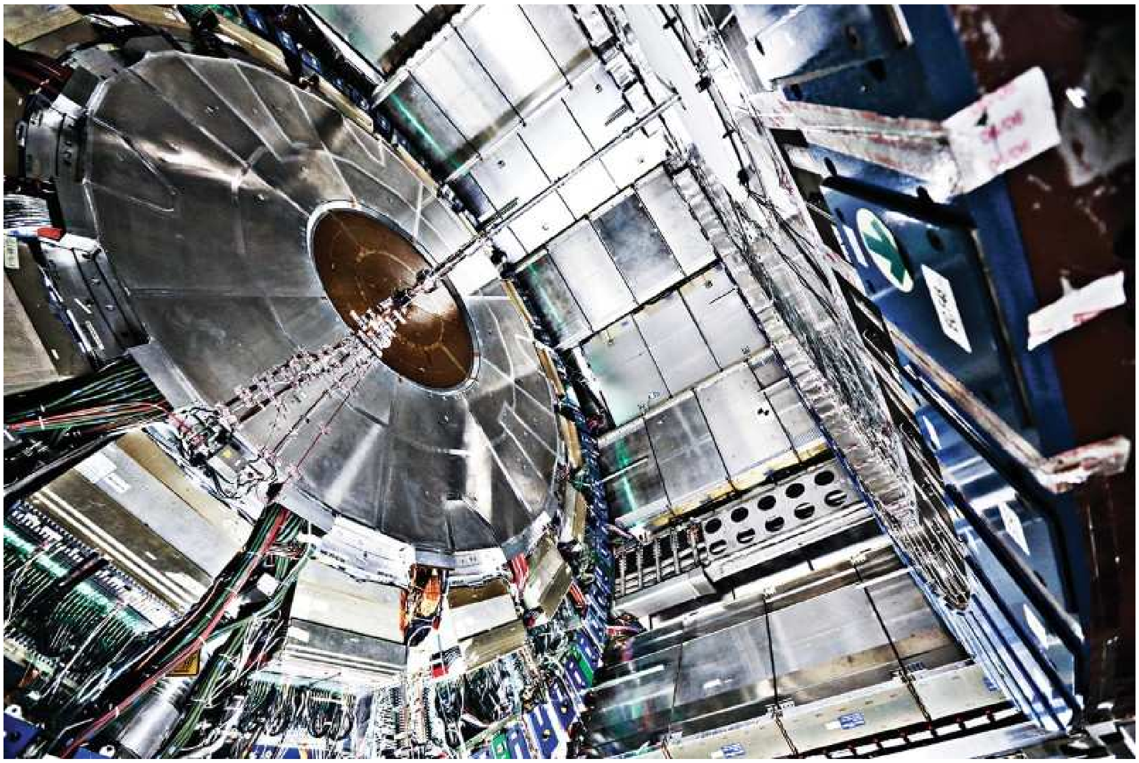
Neutrino Gold

1988: Leon Lederman, Melvin Schwartz and Jack Steinberger win the Nobel Prize in Physics for developing a way to generate beams of neutrinos in a particle collider and for discovering the muon neutrino.

1995: Frederick Reines wins a Nobel for detecting neutrinos for the first time in a 1953 experiment dubbed Project Poltergeist. Clyde Cowan, his collaborator, had died 21 years earlier.

2002: Ray Davis earns the prize for detecting neutrinos from the sun using 600 tons of dry-cleaning fluid in a giant underground tank in South Dakota. Davis shared the Nobel with Masatoshi Koshiba, who used the gigantic Kamiokande detector in Japan to confirm Davis' results and to capture neutrinos from a supernova that exploded in a neighboring galaxy. [5]

Possible new particle hints that universe may not be left-handed



Mirroring the universe (Image: Claudia Marcelloni/CERN)

Like your hands, some fundamental particles are different from their mirror images, and so have an intrinsic handedness or "chirality". But some particles only seem to come in one of the two handedness options, leading to what's called "left-right symmetry breaking".

In particular, W bosons, which carry the weak nuclear force, are supposed to come only in left-handed varieties. The debris from smashing protons at the LHC has revealed evidence of unexpected right-handed bosons.

After finding the Higgs boson in 2012, the collider shut down for upgrades, allowing collisions to resume at higher energies earlier this year. At two of the LHC's experiments, the latest results appear to contain four novel signals. Together, they could hint at a W-boson-like particle, the W', with a mass of about 2 teraelectronvolts. If confirmed, it would be the first boson discovered since the Higgs.

The find could reveal how to extend the successful but frustratingly incomplete standard model of particle physics, in ways that could explain the nature of dark matter and why there is so little antimatter in the universe.

The strongest signal is an excess of particles seen by the ATLAS experiment (arxiv.org/abs/1506.00962), at a statistical significance of 3.4 sigma. This falls short of the 5 sigma regarded as proof of existence (see "Particle-spotting at the LHC"), but physicists are intrigued because three other unexpected signals at the independent CMS experiment could point to the same thing.

“The big question is whether there might be some connection between these,” says Bogdan Dobrescu at Fermilab in Chicago. In a paper posted online last month, Dobrescu and Zhen Liu, also at Fermilab, showed how the signals could fit naturally into modified versions of left-right symmetric models (arxiv.org/abs/1507.01923). They restore left-right symmetry by introducing a suite of exotic particles, of which this possible W’ particle is one.

Another way to fit the right-handed W’ into a bigger theory was proposed last week by Bhupal Dev at the University of Manchester, UK, and Rabindra Mohapatra at the University of Maryland. They invoke just a few novel particles, then restore left-right symmetry by giving just one of them special properties (arxiv.org/abs/1508.02277).

Some theorists have proposed that these exotic particles instead hint that the Higgs boson is not fundamental particle. Instead, it could be a composite, and some of its constituents would account for the observed signals.

“In my opinion, the most plausible explanation is in the context of composite Higgs models,” says Adam Falkowski at CERN. “If this scenario is true, that would mean there are new symmetries and new forces just around the corner.”

“If the Higgs is really a composite particle, that would mean new forces just around the corner”

The next step is for the existence of the right-handed W’ boson to be confirmed or ruled out. Dobrescu says that should be possible by October this year. But testing the broader theories could take a couple of years.

Other LHC anomalies have disappeared once more data became available. That could happen again, but Raymond Volkas at the University of Melbourne, Australia, says this one is more interesting.

“The fact that the data hint at a very sensible and well-motivated standard model extension that has been studied for decades perhaps is reason to take this one a bit more seriously,” he says. [4]

Asymmetry in the interference occurrences of oscillators

The asymmetrical configurations are stable objects of the real physical world, because they cannot annihilate. One of the most obvious asymmetry is the proton – electron mass rate $M_p = 1840\ M_e$ while they have equal charge. We explain this fact by the strong interaction of the proton, but how remember it his strong interaction ability for example in the H – atom where are only electromagnetic interactions among proton and electron.

This gives us the idea to origin the mass of proton from the electromagnetic interactions by the way interference occurrences of oscillators. The uncertainty relation of Heisenberg makes sure that the particles are oscillating.

The resultant intensity due to n equally spaced oscillators, all of equal amplitude but different from one another in phase, either because they are driven differently in phase or because we are looking at them an angle such that there is a difference in time delay:

(1) $I = I_0 \sin^2 n\,\phi/2 \,/\, \sin^2 \phi/2$

If ϕ is infinitesimal so that $\sin\phi = \phi$, than

(2) $I = n^2 I_0$

This gives us the idea of

(3) $M_p = n^2 M_e$

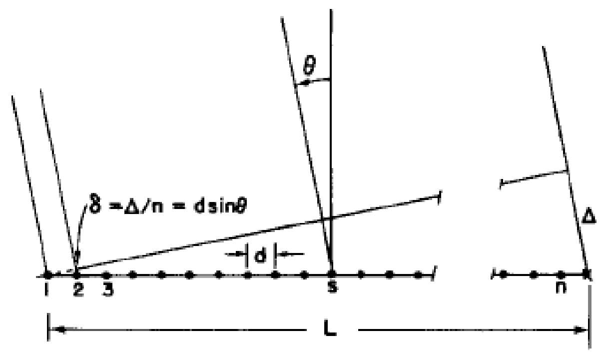


Fig. 30–3. **A linear array of *n* equal oscillators, driven with phases $\alpha_s = s\alpha$.**

Figure 1.) A linear array of n equal oscillators

There is an important feature about formula (1) which is that if the angle ϕ is increased by the multiple of 2π, it makes no difference to the formula.

So

(4) $d \sin \theta = m \lambda$

and we get m-order beam if λ less than d. [6]

If d less than λ we get only zero-order one centered at $\theta = 0$. Of course, there is also a beam in the opposite direction. The right chooses of d and λ we can ensure the conservation of charge.

For example

(5) $2(m+1) = n$

Where $2(m+1) = N_p$ number of protons and $n = N_e$ number of electrons.

In this way we can see the H_2 molecules so that 2n electrons of n radiate to 4(m+1) protons, because $d_e > \lambda_e$ for electrons, while the two protons of one H_2 molecule radiate to two electrons of them, because of $d_e < \lambda_e$ for this two protons.

To support this idea we can turn to the Planck distribution law, that is equal with the Bose – Einstein statistics.

Spontaneously broken symmetry in the Planck distribution law

The Planck distribution law is temperature dependent and it should be true locally and globally. I think that Einstein's energy-matter equivalence means some kind of existence of electromagnetic oscillations enabled by the temperature, creating the different matter formulas, atoms molecules, crystals, dark matter and energy.

Max Planck found for the black body radiation

As a function of wavelength (λ), Planck's law is written as:

$$B_\lambda(T) = \frac{2hc^2}{\lambda^5}\frac{1}{e^{\frac{hc}{\lambda k_B T}} - 1}.$$

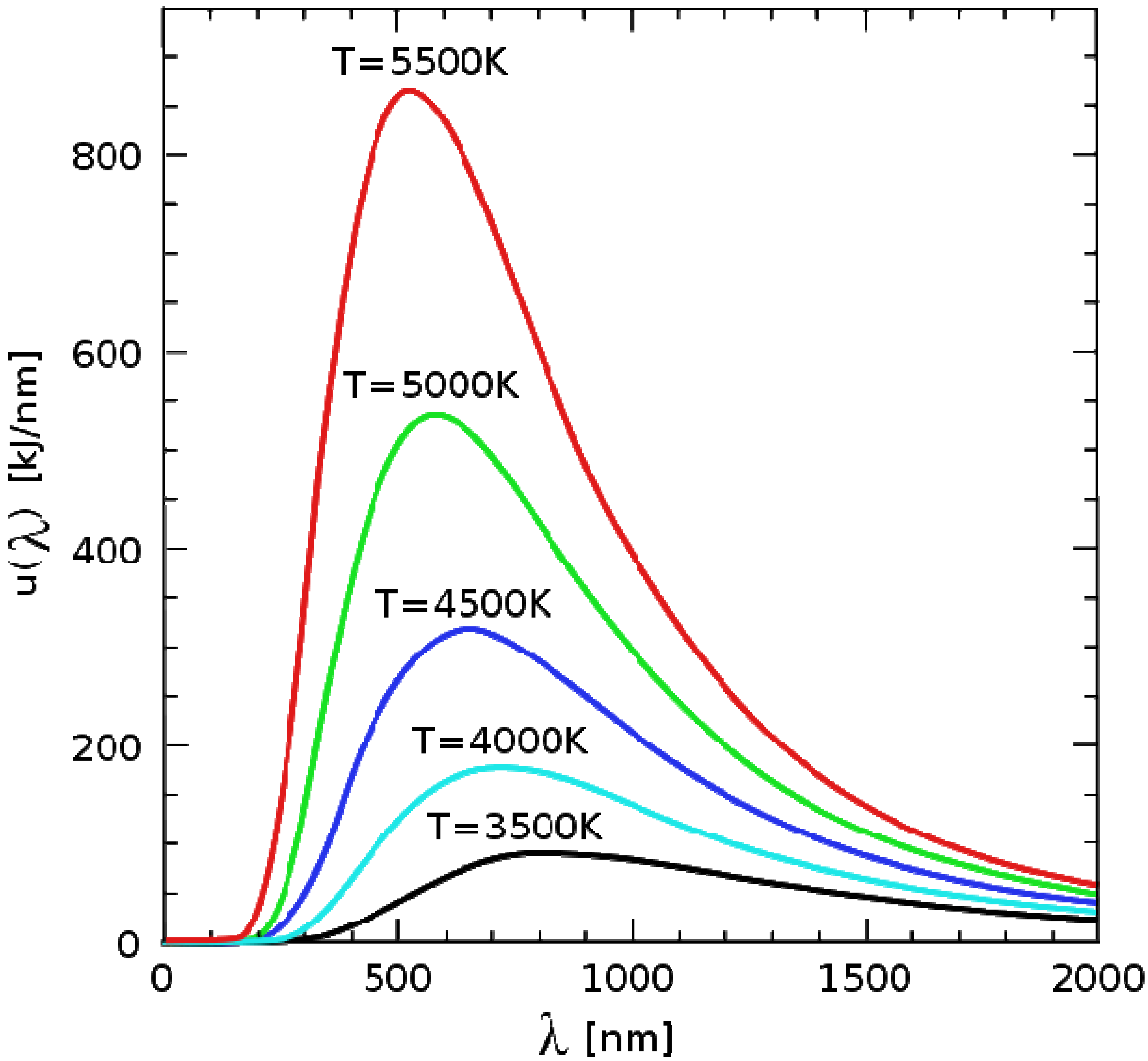


Figure 2. The distribution law for different T temperatures

We see there are two different λ_1 and λ_2 for each T and intensity, so we can find between them a d so that $\lambda_1 < d < \lambda_2$.

We have many possibilities for such asymmetrical reflections, so we have many stable oscillator configurations for any T temperature with equal exchange of intensity by radiation. All of these configurations can exist together. At the λ_{max} is the annihilation point where the configurations are symmetrical. The λ_{max} is changing by the Wien's displacement law in many textbooks.

(7) $$\lambda_{\max} = \frac{b}{T}$$

where λ_{max} is the peak wavelength, T is the absolute temperature of the black body, and b is a constant of proportionality called *Wien's displacement constant*, equal to $2.8977685(51)\times10^{-3}$ m·K (2002 CODATA recommended value).

By the changing of T the asymmetrical configurations are changing too.

The structure of the proton

We must move to the higher T temperature if we want look into the nucleus or nucleon arrive to $d<10^{-13}$ cm. If an electron with $\lambda_e < d$ move across the proton then by (5) 2 (m+1) = n with m = 0 we get n = 2 so we need two particles with negative and two particles with positive charges. If the proton can fraction to three parts, two with positive and one with negative charges, then the reflection of oscillators are right. Because this very strange reflection where one part of the proton with the electron together on the same side of the reflection, the all parts of the proton must be quasi lepton so $d > \lambda_q$. One way dividing the proton to three parts is, dividing his oscillation by the three direction of the space. We can order 1/3 e charge to each coordinates and 2/3 e charge to one plane oscillation, because the charge is scalar. In this way the proton has two +2/3 e plane oscillation and one linear oscillation with -1/3 e charge. The colors of quarks are coming from the three directions of coordinates and the proton is colorless. The flavors of quarks are the possible oscillations differently by energy and if they are plane or linear oscillations. We know there is no possible reflecting two oscillations to each other which are completely orthogonal, so the quarks never can be free, however there is an asymptotic freedom while their energy are increasing to turn them to the orthogonally. If they will be completely orthogonal then they lose this reflection and take new partners from the vacuum. Keeping the symmetry of the vacuum the new oscillations are keeping all the conservation laws, like charge, number of baryons and leptons. The all features of gluons are coming from this model. The mathematics of reflecting oscillators show Fermi statistics.

Important to mention that in the Deuteron there are 3 quarks of +2/3 and -1/3 charge, that is three u and d quarks making the complete symmetry and because this its high stability.

The Pauli Exclusion Principle says that the diffraction points are exclusive!

The Weak Interaction

The weak interaction transforms an electric charge in the diffraction pattern from one side to the other side, causing an electric dipole momentum change, which violates the CP and time reversal symmetry.

Another important issue of the quark model is when one quark changes its flavor such that a linear oscillation transforms into plane oscillation or vice versa, changing the charge value with 1 or -1. This kind of change in the oscillation mode requires not only parity change, but also charge and time changes (CPT symmetry) resulting a right handed anti-neutrino or a left handed neutrino.

The right handed anti-neutrino and the left handed neutrino exist only because changing back the quark flavor could happen only in reverse order, because they are different geometrical constructions, the u is 2 dimensional and positively charged and the d is 1 dimensional and negatively charged. It needs also a time reversal, because anti particle (anti neutrino) is involved.

The neutrino is a 1/2spin creator particle to make equal the spins of the weak interaction, for example neutron decay to 2 fermions, every particle is fermions with ½ spin. The weak interaction changes the entropy since more or less particles will give more or less freedom of movement. The entropy change is a result of temperature change and breaks the equality of oscillator diffraction intensity of the Maxwell–Boltzmann statistics. This way it changes the time coordinate measure and makes possible a different time dilation as of the special relativity.

The limit of the velocity of particles as the speed of light appropriate only for electrical charged particles, since the accelerated charges are self maintaining locally the accelerating electric force. The neutrinos are CP symmetry breaking particles compensated by time in the CPT symmetry, that is the time coordinate not works as in the electromagnetic interactions, consequently the speed of neutrinos is not limited by the speed of light.

The weak interaction T-asymmetry is in conjunction with the T-asymmetry of the second law of thermodynamics, meaning that locally lowering entropy (on extremely high temperature) causes the weak interaction, for example the Hydrogen fusion.

Probably because it is a spin creating movement changing linear oscillation to 2 dimensional oscillation by changing d to u quark and creating anti neutrino going back in time relative to the proton and electron created from the neutron, it seems that the anti neutrino fastest then the velocity of the photons created also in this weak interaction?

A quark flavor changing shows that it is a reflection changes movement and the CP- and T- symmetry breaking. This flavor changing oscillation could prove that it could be also on higher level such as atoms, molecules, probably big biological significant molecules and responsible on the aging of the life.

Important to mention that the weak interaction is always contains particles and antiparticles, where the neutrinos (antineutrinos) present the opposite side. It means by Feynman's interpretation that these particles present the backward time and probably because this they seem to move faster than the speed of light in the reference frame of the other side.

Finally since the weak interaction is an electric dipole change with ½ spin creating; it is limited by the velocity of the electromagnetic wave, so the neutrino's velocity cannot exceed the velocity of light.

The General Weak Interaction

The Weak Interactions T-asymmetry is in conjunction with the T-asymmetry of the Second Law of Thermodynamics, meaning that locally lowering entropy (on extremely high temperature) causes for example the Hydrogen fusion. The arrow of time by the Second Law of Thermodynamics shows the increasing entropy and decreasing information by the Weak Interaction, changing the temperature dependent diffraction patterns. A good example of this is the neutron decay, creating more particles with less known information about them.

The neutrino oscillation of the Weak Interaction shows that it is a general electric dipole change and it is possible to any other temperature dependent entropy and information changing diffraction pattern of atoms, molecules and even complicated biological living structures.

We can generalize the weak interaction on all of the decaying matter constructions, even on the biological too. This gives the limited lifetime for the biological constructions also by the arrow of time. There should be a new research space of the Quantum Information Science the 'general neutrino oscillation' for the greater then subatomic matter structures as an electric dipole change. There is also connection between statistical physics and evolutionary biology, since the arrow of time is working in the biological evolution also.

The Fluctuation Theorem says that there is a probability that entropy will flow in a direction opposite to that dictated by the Second Law of Thermodynamics. In this case the Information is growing that is the matter formulas are emerging from the chaos. So the Weak Interaction has two directions, samples for one direction is the Neutron decay, and Hydrogen fusion is the opposite direction.

Fermions and Bosons

The fermions are the diffraction patterns of the bosons such a way that they are both sides of the same thing.

The Higgs boson or Higgs particle is a proposed elementary particle in the Standard Model of particle physics. The Higgs boson's existence would have profound importance in particle physics because it would prove the existence of the hypothetical Higgs field - the simplest of several proposed explanations for the origin of the symmetry-breaking mechanism by which elementary particles gain mass. [3]

The fermions' spin

The moving charges are accelerating, since only this way can self maintain the electric field causing their acceleration. The electric charge is not point like! This constant acceleration possible if there is a rotating movement changing the direction of the velocity. This way it can accelerate forever without increasing the absolute value of the velocity in the dimension of the time and not reaching the velocity of the light.

The Heisenberg uncertainty relation says that the minimum uncertainty is the value of the spin: 1/2 h = d x d p or 1/2 h = d t d E, that is the value of the basic energy status.

What are the consequences of this in the weak interaction and how possible that the neutrinos' velocity greater than the speed of light?

The neutrino is the one and only particle doesn't participate in the electromagnetic interactions so we cannot expect that the velocity of the electromagnetic wave will give it any kind of limit.

The neutrino is a 1/2spin creator particle to make equal the spins of the weak interaction, for example neutron decay to 2 fermions, every particle is fermions with ½ spin. The weak interaction changes the entropy since more or less particles will give more or less freedom of movement. The entropy change is a result of temperature change and breaks the equality of oscillator diffraction intensity of the Maxwell–Boltzmann statistics. This way it changes the time coordinate measure and makes possible a different time dilation as of the special relativity.

The source of the Maxwell equations

The electrons are accelerating also in a static electric current because of the electric force, caused by the potential difference. The magnetic field is the result of this acceleration, as you can see in [2].

The mysterious property of the matter that the electric potential difference is self maintained by the accelerating electrons in the electric current gives a clear explanation to the basic sentence of the relativity that is the velocity of the light is the maximum velocity of the matter. If the charge could move faster than the electromagnetic field than this self maintaining electromagnetic property of the electric current would be failed.

Also an interesting question, how the changing magnetic field creates a negative electric field?
The answer also the accelerating electrons will give. When the magnetic field is increasing in time by increasing the electric current, then the acceleration of the electrons will increase, decreasing the charge density and creating a negative electric force. Decreasing the magnetic field by decreasing the electric current will decrease the acceleration of the electrons in the electric current and increases the charge density, creating an electric force also working against the change.
In this way we have explanation to all interactions between the electric and magnetic forces described in the Maxwell equations.
The second mystery of the matter is the mass. We have seen that the acceleration change of the electrons in the flowing current causing a negative electrostatic force. This is the cause of the relativistic effect - built-in in the Maxwell equations - that is the mass of the electron growing with its acceleration and its velocity never can reach the velocity of light, because of this growing negative electrostatic force. The velocity of light is depending only on 2 parameters: the magnetic permeability and the electric permittivity.
There is a possibility of the polarization effect created by electromagnetic forces creates the negative and positive charges. In case of equal mass as in the electron-positron pair it is simply, but on higher energies can be asymmetric as the electron-proton pair of neutron decay by week interaction and can be understood by the Feynman graphs.
Anyway the mass can be electromagnetic energy exceptionally and since the inertial and gravitational mass are equals, the gravitational force is electromagnetic force and since only the magnetic force is attractive between the same charges, is very important for understanding the gravitational force.

The Uncertainty Relations of Heisenberg gives the answer, since only this way can be sure that the particles are oscillating in some way by the electromagnetic field with constant energies in the atom indefinitely. Also not by chance that the uncertainty measure is equal to the fermions spin, which is one of the most important feature of the particles. There are no singularities, because the moving electron in the atom accelerating in the electric field of the proton, causing a charge distribution on delta x position difference and with a delta p momentum difference such a way that they product is about the half Planck reduced constant. For the proton this delta x much less in the nucleon, than in the orbit of the electron in the atom, the delta p is much higher because of the greatest proton mass.

The Special Relativity

The mysterious property of the matter that the electric potential difference is self maintained by the accelerating electrons in the electric current gives a clear explanation to the basic sentence of the relativity that is the velocity of the light is the maximum velocity of the matter. If the charge could move faster than the electromagnetic field than this self maintaining electromagnetic property of the electric current would be failed.

The Heisenberg Uncertainty Principle

Moving faster needs stronger acceleration reducing the dx and raising the dp. It means also mass increasing since the negative effect of the magnetic induction, also a relativistic effect!

The Uncertainty Principle also explains the proton – electron mass rate since the dx is much less requiring bigger dp in the case of the proton, which is partly the result of a bigger mass m_p because of the higher electromagnetic induction of the bigger frequency (impulse).

The Gravitational force

The changing magnetic field of the changing current causes electromagnetic mass change by the negative electric field caused by the changing acceleration of the electric charge.

The gravitational attractive force is basically a magnetic force.

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

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

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

The mass as seen before a result of the diffraction, for example the proton – electron mass rate 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. [1]

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.

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. [3]

What is the Spin?

So we know already that the new particle has spin zero or spin two and we could tell which one if we could detect the polarizations of the photons produced. Unfortunately this is difficult and neither ATLAS nor CMS are able to measure polarizations. The only direct and sure way to confirm that the particle is indeed a scalar is to plot the angular distribution of the photons in the rest frame of the centre of mass. A spin zero particles like the Higgs carries no directional information away from the original collision so the distribution will be even in all directions. This test will be possible when a much larger number of events have been observed. In the mean time we can settle for less certain indirect indicators.

The Casimir effect

The Casimir effect is related to the Zero-point energy, which is fundamentally related to the Heisenberg uncertainty relation. The Heisenberg uncertainty relation says that the minimum uncertainty is the value of the spin: 1/2 h = dx dp or 1/2 h = dt dE, that is the value of the basic energy status.
The moving charges are accelerating, since only this way can self maintain the electric field causing

their acceleration. The electric charge is not point like! This constant acceleration possible if there is a rotating movement changing the direction of the velocity. This way it can accelerate forever without increasing the absolute value of the velocity in the dimension of the time and not reaching the velocity of the light. In the atomic scale the Heisenberg uncertainty relation gives the same result, since the moving electron in the atom accelerating in the electric field of the proton, causing a charge distribution on delta x position difference and with a delta p momentum difference such a way that they product is about the half Planck reduced constant. For the proton this delta x much less in the nucleon, than in the orbit of the electron in the atom, the delta p is much higher because of the greater proton mass. This means that the electron is not a point like particle, but has a real charge distribution.
Electric charge and electromagnetic waves are two sides of the same thing; the electric charge is the diffraction center of the electromagnetic waves, quantified by the Planck constant h.

The Fine structure constant

The Planck constant was first described as the proportionality constant between the energy (*E*) of a photon and the frequency (*ν*) of its associated electromagnetic wave. This relation between the energy and frequency is called the **Planck relation** or the **Planck–Einstein equation**:

$$E = h\nu\,.$$

Since the frequency ν, wavelength *λ*, and speed of light *c* are related by *λν* = *c*, the Planck relation can also be expressed as

$$E = \frac{hc}{\lambda}.$$

Since this is the source of Planck constant, the e electric charge countable from the Fine structure constant. This also related to the Heisenberg uncertainty relation, saying that the mass of the proton should be bigger than the electron mass because of the difference between their wavelengths.

The expression of the fine-structure constant becomes the abbreviated

$$\alpha = \frac{e^2}{\hbar c}$$

This is a dimensionless constant expression, 1/137 commonly appearing in physics literature.

This means that the electric charge is a result of the electromagnetic waves diffractions, consequently the proton – electron mass rate is the result of the equal intensity of the corresponding electromagnetic frequencies in the Planck distribution law, described in my diffraction theory.

Conclusions

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. We can generalize the weak interaction on all of the decaying matter constructions, even on the biological too. This gives the limited lifetime for the biological constructions also by the arrow of time. The Fluctuation Theorem says that there is a probability that entropy will flow in a direction opposite to that dictated by the Second Law of Thermodynamics. In this case the Information is growing that is the matter formulas are emerging from the chaos. So the Weak Interaction has two directions, samples for one direction is the Neutron decay, and Hydrogen fusion is the opposite direction.

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