Playing Pool of Neutrinos

Hard to believe you can play pool with neutrinos, but certain neutrino interaction events are closer to the game than you think. [22]

If it turns out that neutrinos and antineutrinos oscillate in a different way from one another, this may partially account for the present-day matter–antimatter imbalance. [21]

Studying this really interesting particle that's all around us, and yet is so hard to measure, that could hold the key to understanding why we're here at all, is exciting—and I get to do this for a living," says Mauger. [20]

In the Standard Model of particle physics, elementary particles acquire their masses by interacting with the Higgs field. This process is governed by a delicate mechanism: electroweak symmetry breaking (EWSB). [19]

Nuclear physicists successfully measured the weak charge of the proton by shooting electrons at a cold liquid hydrogen target in an experiment carried out at the Department of Energy's Thomas Jefferson National Accelerator Facility. [18]

The IceCube Neutrino Observatory in Antarctica is about to get a significant upgrade. [17]

While these experiments seem miniature in comparison to others, they could reveal answers about neutrinos that have been hiding from physicists for decades. [16]

In a paper published today in the European Physical Journal C, the ATLAS Collaboration reports the first high-precision measurement at the Large Hadron Collider (LHC) of the mass of the W boson. [15]

A team of researchers at the University of Michigan has conducted a thought experiment regarding the nature of a universe that could support life without the weak force. [14]

The international T2K Collaboration announces a first indication that the dominance of matter over antimatter may originate from the fact that neutrinos and antineutrinos behave differently during those oscillations. [13]

Neutrinos are a challenge to study because their interactions with matter are so rare. Particularly elusive has been what's known as coherent elastic neutrino-nucleus scattering, which occurs when a neutrino bumps off the nucleus of an atom. [12]

Lately, neutrinos – the tiny, nearly massless particles that many scientists study to better understand the fundamental workings of the universe – have been posing a problem for physicists. [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 highenergy 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 righthanded 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.

Author: George Rajna

Playing pool with neutrinos: Certain interactions look similar to the game

Hard to believe you can play pool with neutrinos, but certain neutrino interaction events are closer to the game than you think.

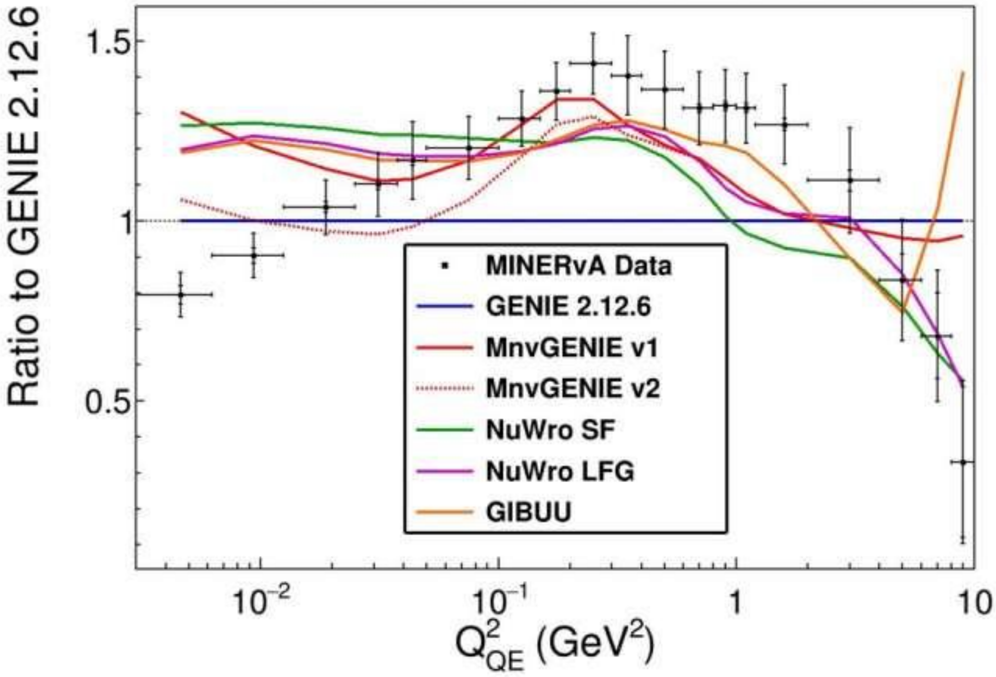
In these charged-current quasielastic interactions—CCQE interactions, for short—a neutrino strikes a particle in an atom's nucleus—a proton or a neutron. Two particles emerge from the collision. One is a muon, a heavier cousin of the electron. The other is either a proton (if the stationary particle is a neutron) or a neutron (if the stationary particle is a proton).

The neutrino interactions that result from these quasielastic reactions are like the collisions between balls in a game of pool: You can guess the energy of the incoming neutrino by measuring the direction and energy of only one of the outgoing particles, provided you know the types of all four particles that were in the interaction in the first place and the original direction of the neutrino.

CCQE interactions are an important interaction mode of neutrinos in current and future neutrino oscillation experiments, such as the international Deep Underground Neutrino Experiment, hosted by Fermilab.

They are similar to the elastic interactions every pool player knows except in one important way: The weak nuclear force allows the particles to change from one kind into another, hence the "quasielastic" name. In this subatomic pool game, the cue ball (neutrino) strikes a stationary red ball (proton), which emerges from the collision as an orange ball (neutron).

Since most modern neutrino experiments use targets made of heavy nuclei ranging from carbon to argon, nuclear effects and correlations between the neutrons and protons inside the nucleus can cause significant changes in the observed interaction rates and modifications to the estimated neutrino energy.



This plot shows the ratio of cross-section as a function of Q2 of data and various predictions with respect to one commonly used interaction model. Credit: MINERvA

At MINERvA, scientists identify the CCQE interactions by a long muon track left in the particle detector and potentially one or more proton tracks. However, this experimental signature can sometimes be produced by non-CCQE interactions due to nuclear effects inside the target nucleus. Similarly, nuclear effects can also modify the final-state particles to make a CCQE event look like a … event and vice versa.

Since nuclear effects can make it challenging to identify a true CCQE event, MINERvA reports measurements based on the properties of the final-state particles only and calls them CCQE-like events (since they will have contributions from both true CCQE and non-CCQE events). A CCQE-like event is one that has at least one outgoing muon, any number of protons or neutrons, and no mesons as final-state particles. (Mesons, like protons and neutrons, are made of quarks. Protons and neutrons have three quarks; mesons have two.)

MINERvA has measured the likelihood of CCQE-like neutrino interactions using Fermilab's medium-energy neutrino beam, with the neutrino flux peaking at 6 GeV. Compared to MINERvA's earlier measurements, which were conducted with a low-energy beam (3 GeV peak neutrino flux), this measurement has the advantage of a broader energy reach and much larger statistics: 1,318,540 CCQE-like events compared to 109,275 events in earlier low-energy runs.

MINERvA made these CCQE interaction probability measurements as a function of the square of the momentum transferred by the neutrino to the nucleus, which scientists denote as Q2. The plot shows discrepancies between the data and most predictions in low-Q2 and high-Q2 regions. By comparing MINERvA's measurement with various models, scientists can refine them and better explain the physics inside the nuclear environment.

MINERvA has also made more detailed measurements of the probability of neutrino interaction based on the outgoing muon's momentum. They take into account the muon's momentum both in the direction of the incoming neutrino's trajectory and in the direction perpendicular to its trajectory. This work helps current and future neutrino experiments understand their own data over a wide range of muon kinematics.

Mateus Carneiro, formerly of the Brazilian Center for Research in Physics and Oregon State University and now at Brookhaven National Laboratory, and Dan Ruterbories of the University of Rochester were the main drivers of this analysis. The results were published in *Physical Review Letters*. [22]

NA61/SHINE gives neutrino experiments a helping hand

Neutrinos are the lightest of all the known particles that have mass. Yet their behavior as they travel could help answer one of the greatest puzzles in physics: why the present-day universe is made mostly of matter when the Big Bang should have produced equal amounts of matter and antimatter. In two recent papers, the NA61/SHINE collaboration reports particle measurements that are crucial for accelerator-based experiments studying such neutrino behavior.

Neutrinos come in three types, or "flavors," and neutrino experiments are measuring with ever increasing detail how they and their antimatter counterparts, antineutrinos, "oscillate" from one flavor to another while they travel. If it turns out that neutrinos and antineutrinos oscillate in a different way from one another, this may partially account for the present-day matter–antimatter imbalance.

Accelerator-based neutrino experiments look for neutrino oscillations by producing a beam of neutrinos of one flavor and measuring the beam after it has traveled a long distance. The neutrino beams are typically produced by firing a beam of high-energy protons into long, thin carbon or beryllium targets. These proton–target interactions produce hadrons, such as pions and kaons, which are focused using magnetic aluminum horns and directed into long tunnels, in which they transform into neutrinos and other particles.

To get a reliable measurement of the neutrino oscillations, the researchers working on these experiments need to estimate the number of neutrinos in the beam before oscillation and how this number varies with the energy of the particles. Estimating this "neutrino flux" is hard, because neutrinos interact very weakly with other particles and cannot be measured easily. To get around this, researchers estimate instead the number of hadrons. But measuring the number of hadrons is also challenging, because there are too many of them to measure precisely.

This is where experiments such as NA61/SHINE at CERN's Super Proton Synchrotron come in. NA61/SHINE can reproduce the proton–target interactions that generate the hadrons that transform into neutrinos. It can also reproduce subsequent interactions that protons and hadrons undergo in the targets and focusing horns. These subsequent interactions can produce additional neutrino-yielding hadrons.

The NA61/SHINE collaboration has previously measured hadrons generated in experiments at 31 GeV/c proton energy (where c is the speed of light) to help predict the neutrino flux in the Tokai-to-Kamioka (T2K) neutrino-oscillation experiment in Japan. The collaboration has also been gathering data at 60 and 120 GeV/c energies to benefit the MINERvA, NOvA and DUNE experiments at Fermilab in the US. The analysis of these datasets is progressing well and has most recently led to two papers: one describing measurements of interactions of protons with carbon, beryllium and aluminum, and another reporting measurements of interactions of pions with carbon and beryllium.

"These results are crucial for Fermilab's neutrino experiments," says Laura Fields, an NA61/SHINE collaboration member and co-spokesperson for MINERvA. "To predict the neutrino fluxes for these experiments, researchers need an extremely detailed simulation of the entire beamline and all of the interactions that happen within it. For that simulation we need to know the probability that each type of interaction will happen, the particles that will be produced, and their properties. So interaction measurements such as the latest ones will be vital to make these simulations much more accurate," she explains.

"Looking into the future, NA61/SHINE will focus on measurements for the next generation of neutrino-oscillation experiments, including DUNE and T2HK in Japan, to enable these experiments to produce high-precision results in neutrino physics," Fields concludes. [21]

Can neutrinos help explain what's the matter with antimatter?

In physics, antimatter is simply the "opposite" of matter. Antimatter particles have the same mass as their counterparts but with other properties flipped; for example, protons in matter have a positive charge while antiprotons are negative. Antimatter can be made in a lab using high-energy particle collisions, but these events almost always create equal parts of both antimatter and matter and, when two opposing particles come in contact with one another, both are destroyed in a powerful wave of pure energy.

What puzzles physicists is that most everything in the universe, people included, is made of matter, not of equal parts matter and antimatter. While looking for insights that could explain what kept the universe from creating separate matter and antimatter galaxies, or exploding into nothingness, researchers found some evidence that the answer could be hiding in very common yet poorly understood particles known as neutrinos.

A team of researchers led by Christopher Mauger published results from the first set of experiments that can help answer these and other questions in fundamental physics. As part of the Cryogenic Apparatus for Precision Tests of Argon Interactions with Neutrino (CAPTAIN) program, their results, published in *Physical*

Review Letters, are an important first step towards building the Deep Underground Neutrino Experiment (DUNE), an experimental facility for neutrino science and particle physics research.

Particle colliders, such as the Large Hadron Collider at CERN, do experiments on quarks, one type of elementary particle. These experiments found some evidence that explains matter-antimatter symmetry, but only part of it. Experiments on another type of elementary particle, leptons, hints that these particles could more fully explain this universal asymmetry. Previous research on neutrinos, a type of lepton, found unexpected patterns in the three neutrino "flavors," results which physicists believe might also mean that their asymmetry might be larger than expected.

But the challenge with studying neutrinos is that they rarely interact with other particles; a single neutrino can pass through a light-year of lead without doing anything. Finding these rare interactions means that researchers need to study a large number of neutrinos for long periods of time. As an added challenge, the steady stream of muons produced by cosmic ray interactions in the upper atmosphere can make it difficult to spot the infrequent interactions that researchers are more interested in seeing.

The outer structures (red) for two prototype DUNE detectors that are currently being evaluated at CERN. (Image: CERN)

The solution? Go 5,000 feet underground, build four 10-kiloton detectors filled with liquid argon, and fire a beam of neutrinos made in a particle accelerator that's 800 miles away. This is the eventual goal of DUNE, an international neutrino research facility run by Fermilab, a particle physics and accelerator laboratory near Chicago. Excavations for the detector, which will be installed at the Sanford Underground Research Facility in South Dakota, are underway, and researchers are now busy with experiments before the first detector is installed in 2022.

As the first publication to come from CAPTAIN, researchers addressed a key technical challenge: How to handle measurements on other particle interactions. For example, when a neutrino interacts with argon, the neutrino picks up a charge and kicks out neutrons. A large fraction of the energy from the interaction will go into the neutron, but it has not been possible to determine the amount. "We must understand argon-neutron interactions if we want to properly do the experiment that's going to impact our understanding of matter and antimatter asymmetry," says Mauger.

He and his team built a 400-kilogram prototype of the DUNE detector, known as Mini-CAPTAIN, and collected data from a neutron beam at the Los Alamos National Laboratory. Former Penn postdoc Jorge Chaves, who worked as the analysis leader for this research, says that the bulk of the work involved reconstructing the signals from the detector into meaningful insights about the properties that they are interested in studying further.

As the first-ever dataset on neutron interactions in liquid argon at the energy ranges that will be used in DUNE, Chaves says that he is encouraged by the results obtained so far, even though they still need to get additional data. "Before, there was no measurement of this interaction cross-section, but now we have provided actual experimental results," he says. "With more data of the same quality, we would be able to make an even more precise measurement."

In the near-term, the CAPTAIN team will focus on refining the methods developed for this paper as well as on running other experiments before DUNE begins collecting data in 2026. Once the project officially kicks off, researchers hope to be able to use this facility to help answer questions from the fields of particle physics, nuclear physics, and even astrophysics.

Mauger considers the ongoing efforts of CAPTAIN and other projects as "Physics R&D," work that will help researchers collect important measurements and study phenomena in a way never done before. The many lofty goals of DUNE will take decades to complete, but Mauger says that what they are trying to achieve makes the effort worthwhile.

"Neutrinos are so hard to measure, sort of enigmatic, and there's some kind of allure in trying to understand how they work. Studying this really interesting particle that's all around us, and yet is so hard to measure, that could hold the key to understanding why we're here at all, is exciting—and I get to do this for a living," says Mauger. [20]

New milestone reached in the study of electroweak symmetry breaking

In the Standard Model of particle physics, elementary particles acquire their masses by interacting with the Higgs field. This process is governed by a delicate mechanism: electroweak symmetry breaking (EWSB). Although EWSB was first proposed in 1964, it remains among the least understood phenomena of the Standard Model as a large dataset of high-energy particle collisions is required to probe it.

After the discovery of the Higgs boson in 2012, the investigation of EWSB at the high-energy frontier began in earnest at the Large Hadron Collider (LHC) at CERN. Aside from precisely measuring the properties of the Higgs boson—in particular, its self-coupling—a key avenue to probing EWSB is the study of the high-energy behaviour of W and Z bosons as they scatter off one another. This process, which is governed by electroweak interactions, is known as massive vector boson scattering.

Vector boson scattering is one of several electroweak processes that contribute to the production of a pair of W or Z bosons in association with two "jets" of hadronic particles (each originating from a quark), which are produced preferentially opposite to each other in direction along the proton beams. Without the Higgs boson, the rate of this process would grow indefinitely with the collision energy. The EWSB mechanism should precisely cancel out this uncontrolled growth, according to the Standard Model. However, potential new physics processes could influence the rate of this process at high energy, making its precise measurement an important objective for the LHC experiments.

ATLAS physicists search LHC collisions for the electroweak production of two jets in association with a pair of massive vector bosons—either $W^{\pm}W^{\pm}$, $W^{\pm}Z$ or ZZ. These analyses are very challenging due to the scarceness of the signal in presence of a large, irreducible strong-interaction background. To improve the signal detection sensitivity, ATLAS physicists searched for events where the vector bosons had decayed to leptons, and they applied multivariate techniques to exploit subtle differences between signal and background events.

ATLAS successfully observed electroweak production of two jets in association with $W^{\pm}W^{\pm}$ and $W^{\pm}Z$ in 2018, using 36 fb^{-1} of 13 TeV proton–proton collision data. These results were achieved thanks to the large amount of data provided by the LHC, a carefully optimised search methodology, and the excellent calibration of the ATLAS detector to guarantee a precise measurement of leptons and jets. No significant deviation from Standard Model predictions was seen in these measurements.

Physicists then set out to observe the electroweak production of two jets in association with ZZ—the rarest of the three processes. The CMS collaboration searched for this process using 36 fb^{-1} of data, but found no clear evidence yet.

At the European Physical Society Conference on High-Energy Physics (EPS-HEP) in Ghent, Belgium, ATLAS presented a new search for this process using the full Run 2 dataset (139 fb^{-1}). The result combines two different channels originating from the decays of the Z-boson pair: four charged-leptons and two charged-leptons plus two neutrinos, respectively. Multivariate discriminants in form of Boosted Decision Trees (BDT) are trained to enhance the separation between the signal and background. The observed BDT distributions in both channels are examined together with a statistical method to determine the signal abundance.

The new ATLAS result provides the observation of the electroweak production of two jets in association with ZZ, with a statistical significance of 5.5 standard deviations. It is compatible with the Standard Model expectation of 4.3 standard deviations.

The observation of this process marks another milestone in the study of EWSB. Further scrutiny of EWSB will continue in other channels as well as with future datasets at the LHC. [19]

Considering the container to strengthen the weak force's signal

Nuclear physicists successfully measured the weak charge of the proton by shooting electrons at a cold liquid hydrogen target in an experiment carried out at the Department of Energy's Thomas Jefferson National Accelerator Facility. Dubbed Q-weak, the precision experiment featured many technical challenges for the physicists to solve for its successful conclusion.

One potentially confounding variable was the cold liquid hydrogen target itself. The target system was custom designed for Q-weak, with care being taken to build a system that could keep the hydrogen cold even while it was being bombarded by a merciless yet precise beam of spinning electrons.

The physicists even had to consider what impact the aluminum container that held the hydrogen would have on their result. For his part in solving this technical challenge and for the thesis he wrote about these efforts, Kurtis Bartlett was awarded the 2018 Jefferson Science Associates Thesis Prize.

The weak charge of the proton describes how much the weak force, one of the four fundamental forces of the universe, acts upon the proton.

"Probing the proton with an electron via the weak force, it allows you to actually measure the weak charge," Bartlett said.

But, as its name implies, the weak force is, well, weak. Electrons are far more likely to interact with protons via the electromagnetic force, another fundamental force.

Fortunately, the weak force has a unique marker: it violates a universal symmetry called parity. A process that conserves parity symmetry occurs with the same probability as its mirror image. The weak force exhibits asymmetry for parity transformations.

"Measuring this asymmetry gives access to the weak force," Bartlett said. "However, it's very difficult to actually do in the laboratory—it's a mathematical type of operation."

Instead, Q-weak used a stand-in for parity transformation. Before the electrons were accelerated, they were polarized so that they were all spinning either the same direction as the beam, or the opposite direction as the beam.

Because the electromagnetic force conserves parity symmetry, it interacts the same way with electrons spinning in either direction. But because the weak force violates parity symmetry, it interacts more with electrons spinning in one direction. Physicists are able to exploit this difference to get a measurement of the proton's weak charge.

Reaching that measurement, however, was not so simple. In the experiment, a small fraction of electrons that the physicists measure never actually hit the hydrogen target. Instead, some electrons scattered off the aluminum container that held the hydrogen, which contaminated the weak force signal the physicists were trying to measure.

That's where Bartlett came in. His task was to minimize this signal contamination by determining how much of the measured signal came from the aluminum target container.

"I went through the process of understanding how to correct our measured values," said Bartlett.

To do so, Q-weak removed the hydrogen target for some runs, replacing it with a piece of aluminum identical to the container. Then Q-weak again shot polarized electrons at the target, except instead of measuring parity asymmetry using a proton of hydrogen, Bartlett measured parity asymmetry using an aluminum nucleus.

"It's the first time that type of asymmetry has ever been measured, which is a pretty exciting thing," he said.

Bartlett worked on his thesis, "First Measurements of the Parity-Violating and Beam-Normal Single-Spin Asymmetries in Elastic Electron-Aluminum Scattering," at Jefferson Lab while pursuing his Ph.D. in experimental nuclear physics at William & Mary. His thesis advisor was Wouter Deconinck, an assistant professor of physics at William & Mary who also worked on the Q-weak experiment.

Bartlett presented his thesis work to the Jefferson Lab Users Organization Board of Directors, who oversee the JSA Thesis Prize award process. Users are scientists from across the U.S. and worldwide who conduct fundamental nuclear physics experiments with Jefferson Lab's research facilities and capabilities.

"I was excited to hear the news that I'd won, and I am very honored to receive it," Bartlett said. "Though I received this award for my dissertation, it is very much a group effort, and I want to highlight that Q-weak as a whole involved many scientists, engineers, technicians and administrative staff to get it all done."

The JSA Thesis Prize is awarded annually for the best Ph.D. student thesis on research related to Jefferson Lab science, and it includes a $2,500 cash award and a commemorative plaque. Nominations are judged on four criteria: the quality of the written work, the student's contribution to the research, the work's impact on the field of physics, and service (how the work benefits Jefferson Lab or other experiments).

The Southeastern Universities Research Association established the JSA Thesis Prize in 1999. It's now one of many projects supported by the JSA Initiatives Fund Program, which was established by Jefferson Science Associates to support programs, initiatives and activities that further the scientific outreach, and promote the science, education and technology missions of Jefferson Lab in ways that complement its basic and applied research focus.

"Graduate students are the driving force of any research enterprise, so the Jefferson Lab User Organization is proud to give out the thesis price this year again. We thank JSA for providing support for this prize," said Julie Roche, the 2018-2019 JLUO chair and professor at Ohio University. "As usual, the theses submitted were of very high quality and made deciding on a winner quite a challenge. I want to thank the selection committee lead by University of Virginia Professor Kent Paschke for its careful examination of the submissions. In the end, we are delighted to recognize Kurtis's work."

Bartlett is currently a postdoctoral research associate for the Space Science and Application Group at DOE's Los Alamos National Laboratory, where he develops space craft detectors that measure radiation to help determine the composition of planetary bodies.

"Although I'm developing hardware now, I'm still using the skill set developed in my dissertation research," Bartlett said. [18]

Upgrade of a research IceCube

The IceCube Neutrino Observatory in Antarctica is about to get a significant upgrade. This huge detector consists of 5,160 sensors embedded in a 1x1x1 km volume of glacial ice deep beneath the geographic South Pole. The purpose of this huge installation is to detect neutrinos, the "ghost particles" of the Universe. The IceCube Upgrade will add more than 700 new and enhanced optical sensors in the deepest, purest ice, greatly improving the observatory's ability to measure low-energy neutrinos produced in the Earth's atmosphere. The research in neutrinos at the Niels Bohr Institute, University of Copenhagen, is led by Associate Professor Jason Koskinen

The upgrade is necessary for the development of a new field of research

"The current IceCube detector is providing leading results in astrophysics and particle physics, specifically measurements of neutrino oscillations by researchers in Copenhagen, but can only take us so far. When neutrinos oscillate, they change 'flavour'—and actually change properties. Through a truly international effort, this new detector is going to be a huge leap forward in our ability to understand the fundamental properties of the neutrino in ways that no other project in the world can do now," says D. Jason Koskinen, Associate Professor and leader of the local IceCube research group at the Niels Bohr Institute.

Neutrino oscillations—creating a new neutrino vision

The principal goal of this first IceCube extension is to perform precision studies of the strange phenomenon known as 'neutrino oscillation,' where neutrinos produced as one type may 'oscillate' to another as they travel. The sensitivity of the upgraded detector will allow scientists at NBI and worldwide to test if neutrinos only oscillate between the three known types, or if there are also new and as yet undiscovered neutrino types participating. These new neutrino types are predicted by the leading theories seeking to explain the unimaginably tiny masses neutrinos possess.

Additionally, the upgrade will include an advanced suite of the calibration devices, designed to better characterise the properties of the glacier ice. This will allow scientists to more accurately pin-point the distant and violent sources of the high energy astrophysical neutrinos IceCube has discovered.

This upgrade will not only offer huge advances in fundamental neutrino physics and astrophysics, but will pave the way for a future expansion of the entire observatory to 10 times the size, opening a new era in neutrino astronomy. [17]

Neutrino experiments look to reveal big answers about how these fundamental particles interact with matter

Except in horror movies, most scientific experiments don't start with scientists snooping around narrow, deserted hallways. But a tucked-away location in the recesses of the Department of Energy's (DOE) Oak Ridge National Laboratory (ORNL) provided exactly what Yuri Efremenko was looking for.

Efremenko, an ORNL researcher and University of Tennessee at Knoxville professor, is the spokesperson for the COHERENT experiment, which is studying neutrinos. The team uses five particle detectors to identify a specific interaction between neutrinos and atomic nuclei. The most abundant particles in the universe, neutrinos are extremely light and have no electric charge. They interact very little with other particles. In fact, trillions pass through the Earth every second, leaving no impression. Needless to say, they're notoriously difficult to detect.

At first, the team surveyed a bustling area near the Spallation Neutron Source (SNS), a DOE Office of Science user facility at ORNL in Tennessee. The neutrons the SNS produces drive 18 different instruments that surround the SNS like spokes on a wheel. The SNS also produces neutrinos, which fly off in all directions from the particle accelerator's target. But putting the neutrino detectors on the same floor as the SNS would expose the devices to background particles that would increase uncertainties.

"We were really fortunate to go into the basement one day," said David Dean, ORNL's Physics Division Director. After moving some water barrels to the side and conducting background tests, they were in business. The basement location would protect the machines from exposure to background particles. Once scientists installed the experiment's detectors, they nicknamed the hallway "Neutrino Alley."

The experiment, called COHERENT, poses a stark contrast to most other neutrino experiments. To catch a glimpse of these miniscule particles, most experiments use incredibly large machines, often in remote locations. One is located at the South Pole, while another shoots neutrino beams hundreds of miles to a far detector. Besides its mundane location, COHERENT's main detector is barely bigger than a milk jug. In fact, it's the smallest working neutrino detector in the world.

But COHERENT and a sister experiment at ORNL, PROSPECT, are showing that neutrino experiments don't have to be enormous to make big discoveries. These two modest experiments supported by DOE's Office of Science are poised to fill some major gaps in our understanding of this strange particle.

The Mysteries of the Neutrino

While neutrinos are some of the smallest particles in the universe, investigating them may reveal massive insights.

"Neutrinos tell us a tremendous amount about how the universe is created and held together," said Nathaniel Bowden, a scientist at DOE's Lawrence Livermore National Laboratory and co-spokesperson for PROSPECT. "There's no other way to answer a lot of the questions that we find ourselves having." Understanding how neutrinos interact may even help us understand why matter—and everything made out of it—exists at all.

But neutrinos haven't made answering these questions easy. There are three different types of neutrinos, each of which behaves differently. In addition, they change type as they travel. Some scientists have proposed a not-yet-seen particle called the sterile neutrino. Physicists theorize that if sterile neutrinos exist, they would interact with other particles even less than regular ones do. That would make them nearly impossible to detect.

But that's a big "if." A sterile neutrino would be the first particle not predicted by the Standard Model, physicists' summary of how the universe functions.

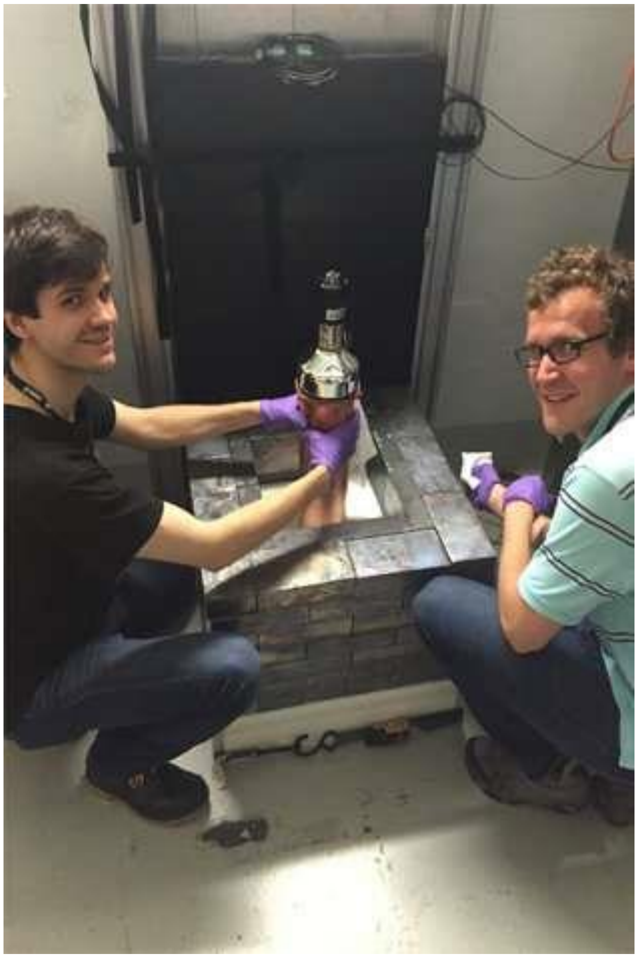
"Neutrinos may hold the clue to discovering particle physics beyond the Standard Model," said Karsten Heeger, a Yale University professor and co-spokesperson for PROSPECT.

Searching for a Coherent Answer with COHERENT

A team of scientists from ORNL, other DOE national laboratories, and universities designed the COHERENT experiment to identify a specific interaction between neutrinos and nuclei. While physicists had predicted this interaction more than 40 years ago, they had never detected it.

Most neutrinos only interact with individual protons and neutrons. But if a neutrino's energy is low enough, it should interact with an entire nucleus rather than its individual parts. Theorists proposed that when a low-energy neutrino approaches a nucleus, the two particles exchange an elementary particle called a Z boson. As the neutrino releases the Z boson, the neutrino bounces away. As the nucleus receives the Z boson, the nucleus recoils slightly. That interaction is called coherent elastic neutrino-nucleus scattering.

Because most nuclei are much bigger than individual protons or neutrons, scientists should see this type of interaction more frequently than interactions driven by higher energy neutrinos. By "seeing" the tiny recoil energy, COHERENT's gallon-sized detectors make it possible for scientists to study neutrino properties.



Bjorn Scholz (left) from the University of Chicago and Grayson Rich of the University of North Carolina at Chapel Hill and the Triangle Universities Nuclear Laboratory show off the world's smallest neutrino detector, which is part of the …more

"It's kind of cool that you could actually see an interaction of neutrinos with something you can hold in your hand," said Kate Scholberg, a Duke University professor and collaborator on COHERENT.

But none of this would be possible without ORNL's SNS. The neutrinos the SNS produces pass through concrete and gravel to reach ORNL's basement. They have just the right energy to induce this particular interaction. The SNS's pulsed beam also allows scientists to filter out background "noise" from other particles.

"There's quite a flux of neutrinos that was being wasted, at the SNS, so to speak. It is the perfect source for coherent scattering—the cat's pajamas," said Juan Collar, a University of Chicago professor and collaborator on COHERENT.

After running for 15 months, COHERENT caught neutrinos in the act of handing off Z bosons 134 times.

Looking over his graduate student's shoulder as he crunched the data, Collar was thrilled to see that the results came out exactly as expected. "When we finally looked at the processed, full dataset, we went 'wheeeeeee!'" he said.

Measuring this phenomenon – neutrino-nucleus elastic scattering – gives physicists a new and versatile tool to understand neutrinos.

"It's opened our window to look for the physics beyond the Standard Model," said Efremenko.

Using this interaction, scientists may be better able to understand how supernovae explode and produce neutrinos.

While these detectors are mainly used for fundamental research, their tiny size could also be useful for other applications. Nuclear reactors produce different types and amounts of neutrinos, depending on whether they produce energy or weapons-grade material. A detector as small as COHERENT's could make the effort to monitor nuclear facilities much easier.

Finding Precision with PROSPECT

While COHERENT looked for a specific phenomenon, the PROSPECT experiment will focus on making incredibly precise measurements of neutrinos from a nuclear reactor as they change type. Past nuclear reactor experiments have resulted in measurements that depart from theory. The PROSPECT team has designed an experiment that can explore any discrepancies, eliminate possible sources of error, or even discover the sterile neutrino.

Compared to previous neutrino reactor experiments, PROSPECT will be able to more accurately measure the number and type of neutrinos, the distance they travel from the reactor, and their energy. PROSPECT differs from other experiments in that its detector has multiple sections instead of one single chamber. This allows scientists to measure and compare various neutrino oscillation lengths – that is, how far from the reactor neutrinos are changing type.

If sterile neutrinos exist, this detector design may also enable scientists to observe regular neutrinos transitioning into sterile neutrinos. In theory, this new form of neutrinos should appear at a specific distance from the detector core.

The High Flux Isotope Reactor (HFIR), a DOE Office of Science user facility at ORNL, will provide PROSPECT with its neutrinos. Commercial nuclear reactors use a variety of uranium and plutonium fuels with different combinations of isotopes. This results in a broad spectrum of neutrino energies. That makes it difficult to pinpoint which isotopes are producing which neutrinos. As a research reactor, HFIR only uses one isotope of uranium: uranium-235. By measuring the antineutrinos from that single isotope, the PROSPECT team can better understand how all nuclear reactors produce neutrinos.

Scientists in the PROSPECT collaboration recently finished building a detector at Yale University's Wright Laboratory. While the active detector region is much bigger than COHERENT's milk-jug sized detector, it's still only four feet wide and weighs about five tons. Compared to detectors that weigh thousands of tons, this experiment too runs on the small side. Once PROSPECT is completed and in place, it will take data for three years.

While these experiments seem miniature in comparison to others, they could reveal answers about neutrinos that have been hiding from physicists for decades. It may just be a matter of scientists knowing where and how to look, even if that's down a seemingly ordinary storage hallway. [16]

First high-precision measurement of the mass of the W boson at the LHC

In a paper published today in the *European Physical Journal C*, the ATLAS Collaboration reports the first high-precision measurement at the Large Hadron Collider (LHC) of the mass of the W boson. This is one of two elementary particles that mediate the weak interaction – one of the forces that govern the behaviour of matter in our universe. The reported result gives a value of 80370±19 MeV for the W mass, which is consistent with the expectation from the Standard Model of Particle Physics, the theory that describes known particles and their interactions.

The measurement is based on around 14 million W bosons recorded in a single year (2011), when the LHC was running at the energy of 7 TeV. It matches previous measurements obtained at LEP, the ancestor of the LHC at CERN, and at the Tevatron, a former accelerator at Fermilab in the United States, whose data made it possible to continuously refine this measurement over the last 20 years.

The W boson is one of the heaviest known particles in the universe. Its discovery in 1983 crowned the success of CERN's Super proton-antiproton Synchrotron, leading to the Nobel Prize in physics in 1984. Although the properties of the W boson have been studied for more than 30 years, measuring its mass to high precision remains a major challenge.

"Achieving such a precise measurement despite the demanding conditions present in a hadron collider such as the LHC is a great challenge," said the physics coordinator of the ATLAS Collaboration, Tancredi Carli. "Reaching similar precision, as previously obtained at other colliders, with only one year of Run 1 data is remarkable. It is an extremely promising indication of our ability to improve our knowledge of the Standard Model and look for signs of new physics through highly accurate measurements."

The Standard Model is very powerful in predicting the behaviour and certain characteristics of the elementary particles and makes it possible to deduce certain parameters from other well-known quantities. The masses of the W boson, the top quark and the Higgs boson for example, are linked by quantum physics relations. It is therefore very important to improve the precision of the W boson mass measurements to better understand the Higgs boson, refine the Standard Model and test its overall consistency.

Remarkably, the mass of the W boson can be predicted today with a precision exceeding that of direct measurements. This is why it is a key ingredient in the search for new physics, as any deviation of the measured mass from the prediction could reveal new phenomena conflicting with the Standard Model.

The measurement relies on a thorough calibration of the detector and of the theoretical modelling of the W boson production. These were achieved through the study of Z boson events and several other ancillary measurements. The complexity of the analysis meant it took almost five years for the ATLAS team to achieve this new result. Further analysis with the huge sample of now-available LHC data, will allow even greater accuracy in the near future. [15]

Imagining the possibility of life in a universe without the weak force

A team of researchers at the University of Michigan has conducted a thought experiment regarding the nature of a universe that could support life without the weak force. In their paper uploaded to the *ArXiv* preprint server, the researchers suggest life could be possible in such an alternative universe, but it would definitely be different from what we observe in ours.

Physicists have debated the possibility of the existence of alternate universes for some time, though there is no evidence they exist. In this new thought experiment, the team at UM wondered if one or more of the laws of physics that we have discovered in this universe might not exist in others—if they do exist. Because it would be hard to imagine a universe that could exist without gravity and the strong and electromagnetic forces, the team instead focused on the weak force—the one behind such things as neutrons decaying into protons.

The team wondered what a universe without the weak force would look like. To visualize it, they created a simulation of such a universe starting from the Big Bang. In the simulation, matter was still created and condensed into stars, but from there on, things would be different, because in our universe, the weak force is responsible for the creation of the heavier elements. In a universe without the weak force, the existence of anything other than stars would require more free protons and fewer neutrons (because they could not decay). In such a universe, neutrons and protons could link up to make deuterium.

Stars fueled by deuterium instead of hydrogen, the researchers note, would still shine, they would just look different—likely redder and larger. But such stars could also serve as the source of all of the elements in the periodic table prior to iron, and the stellar winds could carry them out into space. If planets happened to form, they further note, they could hold water made from deuterium rather than hydrogen—and it is not impossible to imagine, they suggest, life forms made with deuterium water. [14]

Possible explanation for the dominance of matter over antimatter in the Universe

An electron-neutrino interaction observed by the T2K experiment. The neutrino interacts with a water molecule in the detector volume producing an electron which in turn emits Cherenkov light while travelling across the detector. This light is collected by special photo-sensors and converted into a measurable electric signal.

Credit: © Albert Einstein Center for Fundamental Physics (AEC), Laboratory for High Energy Physics

Neutrinos and antineutrinos, sometimes called ghost particles because difficult to detect, can transform from one type to another. The international T2K Collaboration announces a first indication that the dominance of matter over antimatter may originate from the fact that neutrinos and antineutrinos behave differently during those oscillations. This is an important milestone towards the understanding of our Universe. A team of particle physicists from the University of Bern provided important contributions to the experiment.

The Universe is primarily made of matter and the apparent lack of antimatter is one of the most intriguing questions of today's science. The T2K collaboration, with participation of the group of the University of Bern, announced today in a colloquium held at the High Energy Accelerator Research Organization (KEK) in Tsukuba, Japan, that it found indication that the symmetry between matter and antimatter (so called "CP-Symmetry") is violated for neutrinos with 95% probability.

Different Transformation of Neutrinos and Antineutrinos

Neutrinos are elementary particles which travel through matter almost without interaction. They appear in three different types: electron- muon- and tau-neutrinos and their respective antiparticle (antineutrinos). In 2013 T2K discovered a new type of transformation among neutrinos, showing that muon-neutrinos transform (oscillate) into electron-neutrinos while travelling in space and time. The outcome of the latest T2K study rejects with 95% probability the hypothesis that the analogous transformation from muon-antineutrinos to electron-antineutrinos takes place with identical chance. This is a first indication that the symmetry between matter and antimatter is violated in neutrino oscillations and therefore neutrinos also play a role in the creation of the matterantimatter asymmetry in the universe.

"This result is among the most important findings in neutrino physics over the last years," said Prof. Antonio Ereditato, director of the Laboratory of High Energy Physics of the University of Bern and leader of the Bern T2K group, "and it is opening the way to even more exciting achievements, pointing to the existence of a tiny but measurable effect." Ereditato added: "Nature seems to indicate that neutrinos can be responsible for the observed supremacy of matter over antimatter in the Universe. What we measured justifies our current efforts in preparing the next scientific enterprise, DUNE, the ultimate neutrino detector in USA, which should allow reaching a definitive discovery."

In the T2K experiment a muon-neutrino beam is produced at the Proton Accelerator Research Complex (J-PARC) in Tokai on the east coast of Japan and is detected 295 kilometres away by the gigantic Super-Kamiokande underground detector ("T2K" stands for "Tokai to Kamiokande"). The neutrino beam needs to be fully characterized immediately after production, that means before neutrinos start to oscillate. For this purpose, the ND280 detector was built and installed close to the neutrino departing point.

Researchers from the University of Bern, together with colleagues from Geneva and ETH Zurich, and other international institutions, contributed to the design, realization and operation of ND280. The group of Bern, in particular, took care of the large magnet surrounding the detector and built and operated the so-called muon monitor, a device needed to measure the intensity and the energy spectrum of the muon particles produced together with neutrinos. The Bern group is currently very active in determining the probability of interaction of neutrinos with the ND280 apparatus: an important ingredient to reach high-precision measurements such as the one reported here. [13]

World's smallest neutrino detector observes elusive interactions of particles

In 1974, a Fermilab physicist predicted a new way for ghostly particles called neutrinos to interact with matter. More than four decades later, a UChicago-led team of physicists built the world's smallest neutrino detector to observe the elusive interaction for the first time.

Neutrinos are a challenge to study because their interactions with matter are so rare. Particularly elusive has been what's known as coherent elastic neutrino-nucleus scattering, which occurs when a neutrino bumps off the nucleus of an atom.

The international COHERENT Collaboration, which includes physicists at UChicago, detected the scattering process by using a detector that's small and lightweight enough for a reseacher to carry. Their findings, which confirm the theory of Fermilab's Daniel Freedman, were reported Aug. 3 in the journal Science.

"Why did it take 43 years to observe this interaction?" asked co-author Juan Collar, UChicago professor in physics. "What takes place is very subtle." Freedman did not see much of a chance for experimental confirmation, writing at the time: "Our suggestion may be an act of hubris, because the inevitable constraints of interaction rate, resolution and background pose grave experimental difficulties."

When a neutrino bumps into the nucleus of an atom, it creates a tiny, barely measurable recoil. Making a detector out of heavy elements such as iodine, cesium or xenon dramatically increases the probability for this new mode of neutrino interaction, compared to other processes. But there's a trade-off, since the tiny nuclear recoils that result become more difficult to detect as the nucleus grows heavier.

"Imagine your neutrinos are ping-pong balls striking a bowling ball. They are going to impart only a tiny extra momentum to this bowling ball," Collar said.

To detect that bit of tiny recoil, Collar and colleagues figured out that a cesium iodide crystal doped with sodium was the perfect material. The discovery led the scientists to jettison the heavy, gigantic detectors common in neutrino research for one similar in size to a toaster.

No gigantic lab

The 4-inch-by-13-inch detector used to produce the Science results weighs only 32 pounds (14.5 kilograms). In comparison, the world's most famous neutrino observatories are equipped with thousands of tons of detector material.

"You don't have to build a gigantic laboratory around it," said UChicago doctoral student Bjorn Scholz, whose thesis will contain the result reported in the Science paper. "We can now think about building other small detectors that can then be used, for example to monitor the neutrino flux in nuclear power plants. You just put a nice little detector on the outside, and you can measure it in situ."

Neutrino physicists, meanwhile, are interested in using the technology to better understand the properties of the mysterious particle.

"Neutrinos are one of the most mysterious particles," Collar said. "We ignore many things about them. We know they have mass, but we don't know exactly how much."

Through measuring coherent elastic neutrino-nucleus scattering, physicists hope to answer such questions. The COHERENT Collaboration's Science paper, for example, imposes limits on new types of neutrino-quark interactions that have been proposed.

The results also have implications in the search for Weakly Interacting Massive Particles. WIMPs are candidate particles for dark matter, which is invisible material of unknown composition that accounts for 85 percent of the mass of the universe.

"What we have observed with neutrinos is the same process expected to be at play in all the WIMP detectors we have been building," Collar said.

Neutrino alley

The COHERENT Collaboration, which involves 90 scientists at 18 institutions, has been conducting its search for coherent neutrino scattering at the Spallation Neutron Source at Oak Ridge National Laboratory in Tennessee. The researchers installed their detectors in a basement corridor that became known as "neutrino alley." This corridor is heavily shielded by iron and concrete from the highly radioactive neutron beam target area, only 20 meters (less than 25 yards) away.

This neutrino alley solved a major problem for neutrino detection: It screens out almost all neutrons generated by the Spallation Neutron Source, but neutrinos can still reach the detectors. This allows researchers to more clearly see neutrino interactions in their data. Elsewhere they would be easily drowned out by the more prominent neutron detections.

The Spallation Neutron Source generates the most intense pulsed neutron beams in the world for scientific research and industrial development. In the process of generating neutrons, the SNS also produces neutrinos, though in smaller quantities.

"You could use a more sophisticated type of neutrino detector, but not the right kind of neutrino source, and you wouldn't see this process," Collar said. "It was the marriage of ideal source and ideal detector that made the experiment work."

Two of Collar's former graduate students are co-authors of the Science paper: Phillip Barbeau, AB'01, SB'01, PhD'09, now an assistant professor of physics at Duke University; and Nicole Fields, PhD'15, now a health physicist with the U.S. Nuclear Regulatory Commission in Chicago.

The development of a compact neutrino detector brings to fruition an idea that UChicago alumnus Leo Stodolsky, SM'58, PhD'64, proposed in 1984. Stodolsky and Andrzej Drukier, both of the Max Planck Institute for Physics and Astrophysics in Germany, noted that a coherent detector would be relatively small and compact, unlike the more common neutrino detectors containing thousands of gallons of water or liquid scintillator. In their work, they predicted the arrival of future neutrino technologies made possible by the miniaturization of the detectors.

Scholz, the UChicago graduate student, saluted the scientists who have worked for decades to create the technology that culminated in the detection of coherent neutrino scattering.

"I cannot fathom how they must feel now that it's finally been detected, and they've achieved one of their life goals," Scholz said. "I've come in at the end of the race. We definitely have to give credit to all the tremendous work that people have done before us." [12]

In search of 'sterile' neutrinos

Lately, neutrinos – the tiny, nearly massless particles that many scientists study to better understand the fundamental workings of the universe – have been posing a problem for physicists.

They know that these particles are produced in immense numbers by nuclear reactions such as those taking place within our sun. They also know that neutrinos don't interact very often with matter; billions of them passed through your hand in the time it took you to read this sentence.

But in a host of experiments around the world, researchers are finding a deficit in the number of neutrinos they see versus what they expect to see, based on theory. And this has nothing to do with the shifting back and forth between the three flavors of neutrino that physicists also already know about.

One possible explanation is that there is a fourth kind of neutrino that hasn't been detected. It's referred to as a sterile neutrino. And NIST scientists will begin looking for it next year as part of the Precision Oscillation and Spectrum Experiment (PROSPECT), a collaboration involving 68 scientists and engineers from 10 universities and four national laboratories.

"This is potentially a discovery experiment," says NIST's Pieter Mumm, who is a co-founder and cospokesperson for the project, along with Karsten Heeger at Yale University and Nathaniel Bowden at Lawrence Livermore National Laboratory. Discovering a new particle would be "super exciting," he continues, because a new type of neutrino is not part of the Standard Model of physics, the wellvetted explanation for the universe as we know it.

To find the new particle or definitively disprove its existence, the PROSPECT collaboration is preparing to build a first-of-its-kind detector for short-range neutrino experiments, using a nuclear reactor as the neutrino source.

The work could not only shed light on new physics, but it could also give researchers a new tool to monitor and safeguard nuclear reactors.

PROSPECTing for Neutrinos

Unlike other neutrino experiments, which typically look at the oscillations between the three known flavors over distances of kilometers or hundreds of kilometers, PROSPECT will look at neutrino oscillations over just a few meters, the space of a small room. The distance is too short to see oscillations between the known flavors. But it is exactly the right scale for the hypothesized sterile neutrino oscillations.

This setup "gives you a signature that's absolutely iron-clad," Mumm says. "If you see that variation, that characteristic oscillation, there is only one explanation for it. It has to be sterile neutrinos."

The detector itself will be about 4.5 meters cubed and will be composed of an 11-by-14 array of long skinny "cells" stacked on each other [see diagram], with an expected spatial resolution of about 10 cubic centimeters. As its source for neutrinos, PROSPECT will use the High Flux Isotope Reactor at Oak Ridge Laboratory in Tennessee. The experiment will be placed as close as possible to the reactor core itself – only 7 meters (about 20 feet) away.

PROSPECT will not see the sterile neutrinos directly. Rather, it will detect a particular kind of neutrino that is regularly produced in nuclear reactors: the electron-type antineutrino.

To identify an electron antineutrino, the researchers will look for a particular signal in light. Each cell in the detector is filled with a scintillating material. That means that energy is converted to light, which is amplified and picked up by a pair of photomultiplier tubes on each cell.

When a neutrino hits a proton in the liquid filling the cells, it creates new particles that deposit energy within the detector. These daughter particles form a signature that tells researchers that a neutrino was once there (see diagram above).

"What we're actually sensing is the light emitted by the liquid scintillator," Mumm says. The signal that they are looking for is "something that looks like a positron, followed at the appropriate time [tens of microseconds, or millionths of a second] by something that looks like a neutron capture."

Next Steps

So far, the collaboration has created a series of prototypes, including a pair of cells built to scale, and is running simulations to validate the models they are using to separate the signal from the high backgrounds they expect. Thanks to grants from the U.S. Department of Energy and the HeisingSimons Foundation this summer, they have begun to physically build the detector.

PROSPECT should answer the question of whether there are sterile neutrinos or not within three years, Mumm says. Meanwhile, the collaboration's work has some potentially game-changing spinoffs for reactor physics. For example, scientists could potentially use this technology to engineer a device to monitor reactor operations remotely.

"You can imagine, at least it seems to me, that this could be a pretty powerful tool in the right circumstances," Mumm says. "You can't shield neutrinos. There's no way to spoof it." [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 ShortBaseline 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, highenergy 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 1424418, 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 centuryold 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 twodimensional 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 1.282gigahertz 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 onetwo "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

SuperK 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.

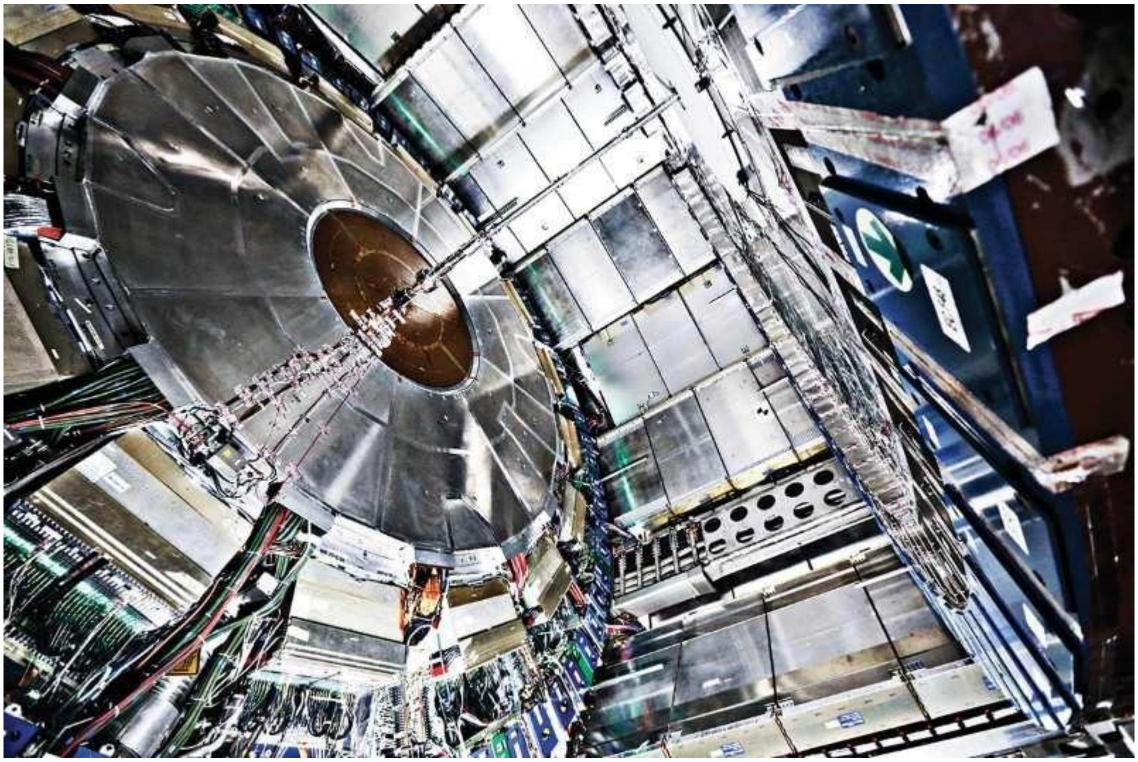
Neutrino Gold

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 lefthanded 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) $I = I_0 \sin^2 n\,\varphi/2 \,\mathbf{/}\, \sin^2 \varphi/2$

If φ is infinitesimal so that $\sin\varphi = \varphi$ than

(2) $\iota = n^2 \iota_0$

This gives us the idea of

(3) $M_p = n^2 M_e$

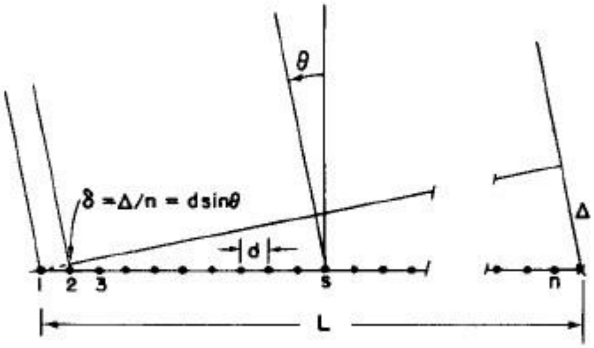


Fig. 30–3. A linear array of *n* equal oscillators, driven with phases $\alpha_s = s\alpha$.

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.

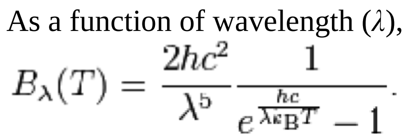
In this way we can see the H_2 molecules so that 2n electrons of n radiate to 4(m+1) protons, because $d_e > \lambda_e$ for electrons, while the two protons of one H_2 molecule radiate to two electrons of them, because of $d_e < \lambda_e$ for this two protons.

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:

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

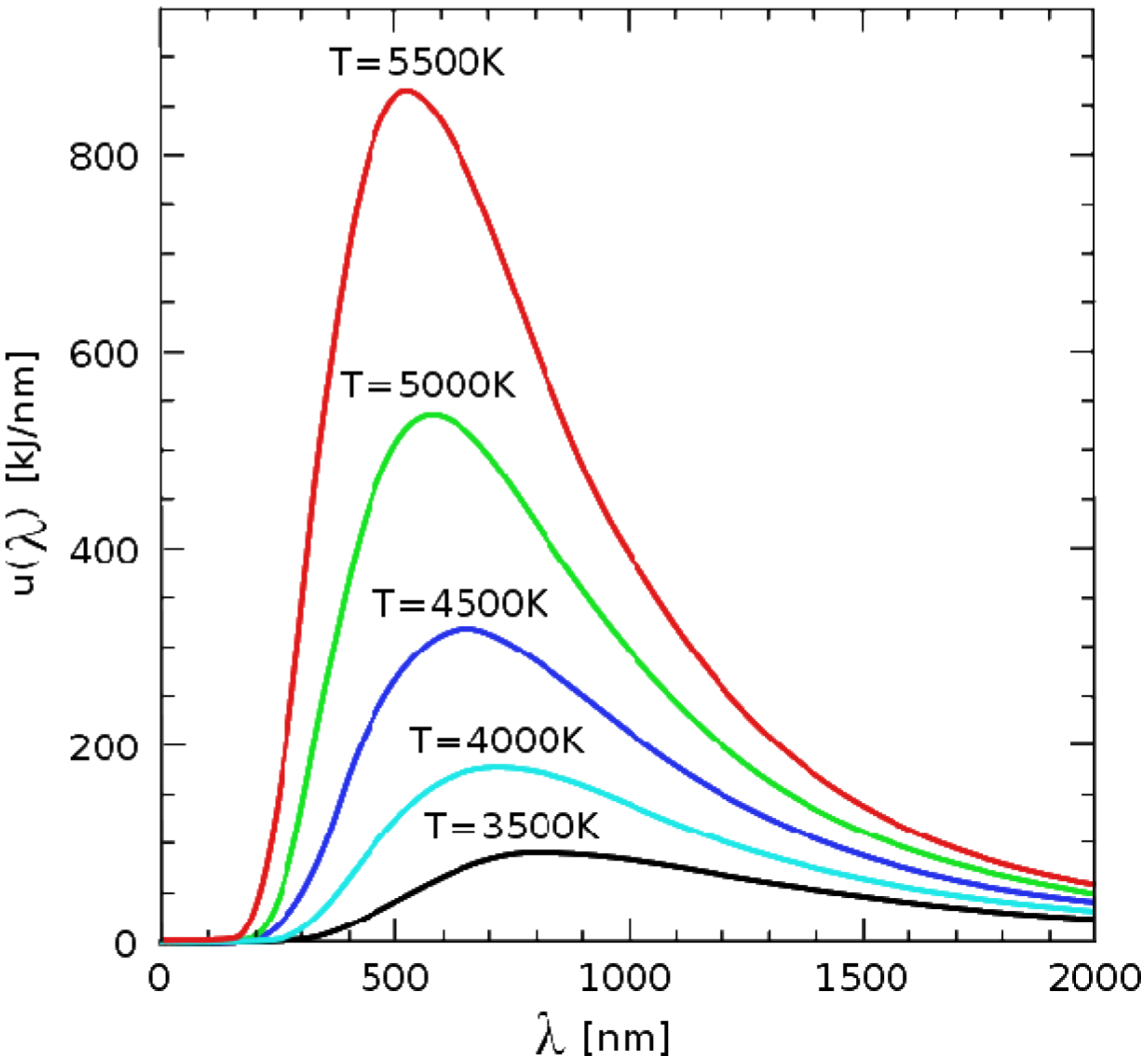


Figure 2. The distribution law for different T temperatures

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.

$$\lambda_{\max} = \frac{b}{T} \tag{7}$$

where $\lambda_{\max}$ 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.

References

[1] http://www.academia.edu/3834454/3_Dimensional_String_Theory

[2] http://www.academia.edu/3833335/The_Magnetic_field_of_the_Electric_current

[3] http://www.academia.edu/4158863/Higgs_Field_and_Quantum_Gravity

[4] https://www.newscientist.com/article/mg22730354-600-possible-new-particle-hints-thatuniverse-may-not-be-left-handed [5] Neutrinos: Ghosts of the Universe http://discovermagazine.com/2014/sept/9-ghosts-of-the-universe

[6] What the universe's most elusive particles can tell us about the universe's most energetic objects http://phys.org/news/2016-04-universe-elusive-particles-energetic.html [7] Neutrinos hint at why antimatter didn't blow up the universe

https://www.newscientist.com/article/2095968-neutrinos-hint-at-why-antimatter-didnt-blow-upthe-universe

[8] Surprising neutrino decoherence inside supernovae http://phys.org/news/2016-07-neutrino-decoherence-supernovae.html

[9] Weird quantum effects stretch across hundreds of miles http://phys.org/news/2016-07-weird-quantum-effects-hundreds-miles.html

[10] As hunt for sterile neutrino continues, mystery deepens http://phys.org/news/2016-10-sterile-neutrino-mystery-deepens.html

[11] In search of 'sterile' neutrinos http://phys.org/news/2016-12-sterile-neutrinos.html

[12] World's smallest neutrino detector observes elusive interactions of particles https://phys.org/news/2017-08-world-smallest-neutrino-detector-elusive.html

[13] Possible explanation for the dominance of matter over antimatter in the Universe https://www.sciencedaily.com/releases/2017/08/170804083109.htm

[14] Imagining the possibility of life in a universe without the weak force https://phys.org/news/2018-02-possibility-life-universe-weak.html

[15] First high-precision measurement of the mass of the W boson at the LHC https://phys.org/news/2018-02-high-precision-mass-boson-lhc.html

[16] Neutrino experiments look to reveal big answers about how these fundamental particles interact with matter https://phys.org/news/2018-02-neutrino-reveal-big-fundamental-particles.html

[17] Upgrade of a research IceCube https://phys.org/news/2019-07-icecube.html

[18] Considering the container to strengthen the weak force's signal https://phys.org/news/2019-07-weak.html

[19] New milestone reached in the study of electroweak symmetry breaking https://phys.org/news/2019-08-milestone-electroweak-symmetry.html

[20] Can neutrinos help explain what's the matter with antimatter? https://phys.org/news/2019-09-neutrinos-antimatter.html

[21] NA61/SHINE gives neutrino experiments a helping hand https://phys.org/news/2019-11-na61shine-neutrino.html

[22] Playing pool with neutrinos: Certain interactions look similar to the game

https://phys.org/news/2020-04-pool-neutrinos-interactions-similar-game.html