How the neutrino could solve great cosmic mysteries and win its next Nobel Prize

October 9 2015, by Simon Peeters

James Sinclair from the University of Sussex entering the SNO detector for upgrade work to transform this experiment into SNO+. Credit: The SNO+ collaboration, Author provided

The humble neutrino particle won its fourth Nobel Prize in physics this year (also in 2002, 1995 and 1988). Despite being millions of times smaller than other subatomic particles, it is of major importance in physics and could be the key to unravelling some of the universe's best-kept secrets. So where is neutrino research heading next – and what

could it discover?

Matter is made of fundamental particles. Most people will have heard of electrons, neutrons and protons – and perhaps even quarks, which make up the latter two. But to me, the neutrino is the most amazing fundamental particle. They are everywhere. About 65 billion neutrinos, produced by nuclear fusion in the Sun, pass through every square centimetre of area on Earth, every second (you could try and calculate that yourself), without doing anything.

Because neutrinos hardly interact with other matter, this year's Nobel prize winners for physics, Takaaki Kajita and Arthur B McDonald, had to build vast detectors, filled with thousands of tonnes of water, in order to study them. What they found out was that the neutrino is even more interesting than we thought.

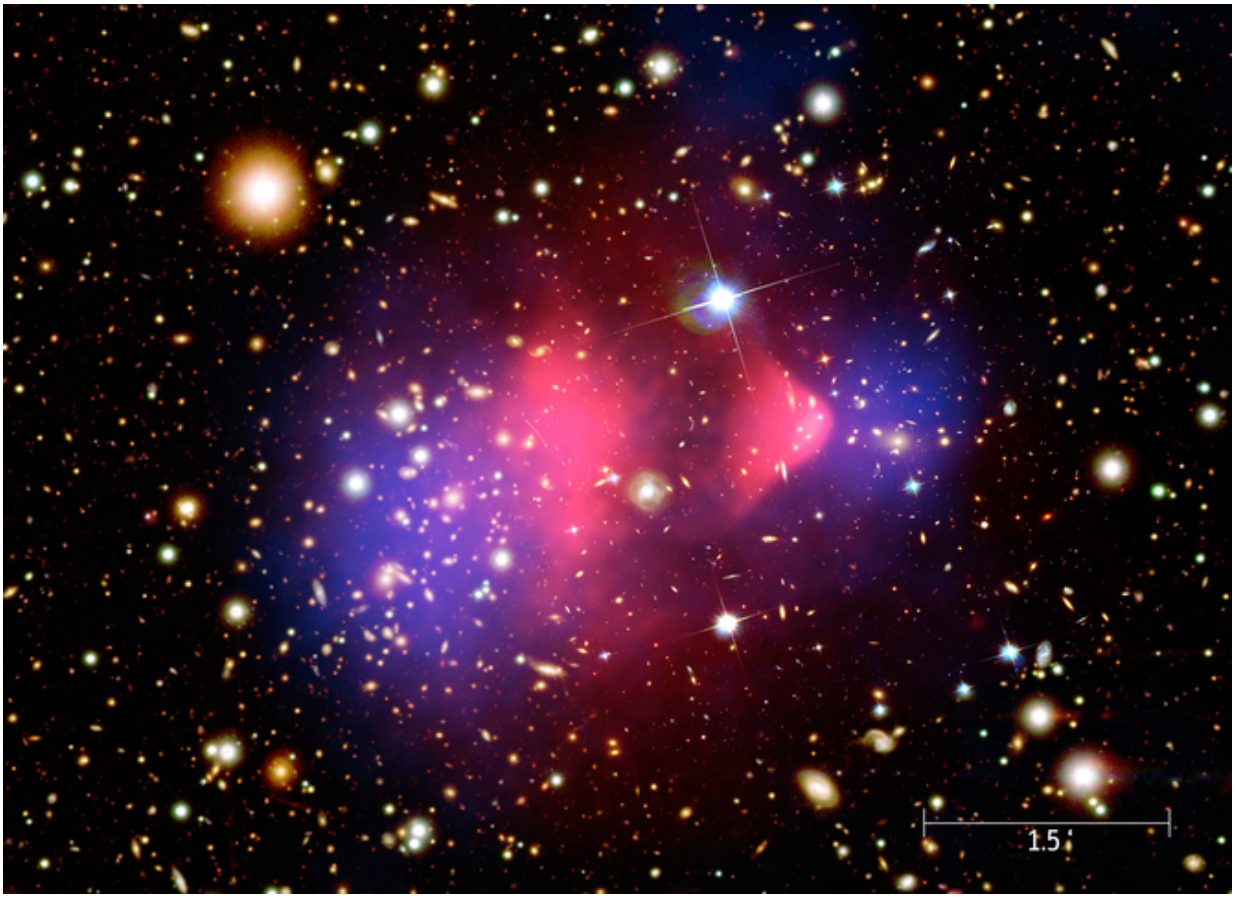
While travelling through space, a neutrino apparently continuously flips between different "types" of neutrino, changing the way they interact with matter. This is called neutrino oscillations. You might imagine this as a little fellow that, while running at nearly the speed of light, continuously changes the colour of its jacket by which you are trying to identify it. Neutrinos can only do this if they have mass. So until the results from these experiments were published, they were assumed to be massless. Clearly this was ground-breaking news.

Chasing new discoveries

Since these fascinating properties of neutrinos were revealed, around the year 2000, a large number of experiments have been successfully built to investigate this in more detail. However, as always, these new insights led to further questions. Today, we have studied neutrino oscillations in great detail and understand it pretty well.

But one very important question remains: does the neutrino oscillate the same as its polar opposite: the anti-neutrino? All particles have anti-particles. For example, the common electron, with a negative electric charge, has the positron as its anti-particle, which is virtually identical but has a positive charge and has to be produced in a nuclear reaction. But as the neutrino has no charge, it is difficult to know what its anti-particle would look like. In fact it could be virtually the same, but still behave differently.

The UK is taking a big part in two experiments that will study neutrino oscillations in the future in more detail to answer this question: HyperKamiokande in Japan, and the Deep Underground Neutrino Experiment in the US.



The distribution and movement of galaxies helped scientists figure out that dark matter could must be hiding in there. Credit: wikimedia

Solving the matter-antimatter mystery

Finding out that neutrinos interact differently to anti-neutrinos could have huge consequences as it could help solve one of the greatest mysteries in physics: why is our entire universe made out of just matter? We have strong reasons to believe that in the Big Bang, matter and anti-matter were created in equal measure. So where did all the anti-matter go? We know that anti-matter and matter destroy each other in a flash of light whenever they meet, so maybe this could explain that it's not around? Not really, all the matter would be gone as well.

One of the key components in the currently favoured explanation is that matter behaves differently to anti-matter. But the difference between how neutrinos and anti-neutrinos change the colour of their jacket isn't going to provide the entire solution. The answer comes with a possible solution to a second mystery relating to neutrinos: why is the mass of a neutrino so incredibly small?

The masses of other matter particles, generated by coupling to the famous Higgs particle, vary widely – from the electron, about 2,000 times smaller than the mass of a proton, to the top quark, which weighs nearly 200 times more than the mass of a proton. The neutrino mass, however, is at least 10,000,000,000 times smaller than the proton mass.

So why is the neutrino so much lighter than the other particles in the Standard Model? We believe their mass is generated differently. If this is correct, we could end up with two versions of neutrinos (on top of the

particle-anti-particle duality): one that has the tiny mass we observe today and an extremely heavy one, that was abundantly present when the universe was first born.

The mathematics of this theory states that, if these heavy neutrinos had anti-particles that behaved differently from them, they would subsequently decay into a number of smaller particles like electrons and positrons. However, this would have happened "asymmetrically", meaning that fewer anti-particles than particles would be created in the decay – which then, in the conditions of the early universe, could result in the (relatively) small amount of leftover matter that forms our universe today.

It's no wonder then, that scientists are investing so much effort into understanding the nature of the neutrino. The only way we currently know of to determine the exact nature of these neutrinos is to look for an extremely rare nuclear decay called "neutrinoless double-beta decay". This has never been observed and would only be possible if neutrinos are different than the other matter particles. A number of experiments is getting ready to study large quantities of isotopes for which it would be possible to observe this decay. The UK has leading roles in two of those: it is involved with the science and construction of the SuperNEMO experiment in France and SNO+, a modification of Art McDonald's Sudbury Neutrino Observatory (SNO) experiment in Canada.

Could dark matter be made up of neutrinos?

Neutrinos could possibly also explain puzzling observations made by astrophysicists. They have shown that there is much more matter in the universe than we can directly observe. We call the matter we don't see dark matter. There is about five times more of this unknown dark matter than all the matter that we do know about.

Until around 2000, it was thought that the ghost-like neutrinos could be this dark matter, but we now know that they are not heavy enough. We have observed three types of neutrinos – electron, muon and tau – and there seem to be three types of all the other matter particles. Since we don't know why there are only three, the obvious questions is: are there additional neutrinos that could explain the dark matter?

Many neutrino oscillation experiments are looking for cracks in our theory of neutrino oscillations that could be explained by additional neutrinos. Also astrophysicists are hunting for signs in cosmic rays for additional neutrinos.

What constitutes dark matter and why the universe has more matter than antimatter are two of the most important questions in physics today. If we could solve either of those or even just figure out why the neutrino is so light, it would be a major breakthrough. There is a world-wide race between many experiments going on to answer them: plenty of chances for the amazing neutrino to get (at least) one more Nobel!

Source: The Conversation

Citation: How the neutrino could solve great cosmic mysteries and win its next Nobel Prize (2015, October 9) retrieved 2 May 2024 from https://phys.org/news/2015-10-neutrino-great-cosmic-mysteries-nobel.html