ATMOSPHERIC NEUTRINO OSCILLATIONS
A LECTURE BY PROFESSOR TAKAAKI KAJITA
UNIVERSITY OF TOKYO

A couple of Fridays ago Marilyn announced that she had received an invitation for members to attend a talk to be given by Professor Takaaki Kajita about the discovery of Atmospheric Neutrino Oscillations and their link to neutrino mass, for which he jointly won the Nobel Prize in 2015.

I duly booked my ticket, and on Thursday 1st June set off for The Diamond, between Brook Hill and Leavygreave Road in Sheffield. The Diamond is a massive University Building containing amongst other things a library, a café, and a lecture theatre. On arrival we were all treated to refreshments before trouping into the lecture theatre.

Dr Matthew Malek was master of ceremonies, and he handed over to Professor Nigel Clarke, Vice President of the Faculty, who gave the introduction (The lecture was very well attended - a few late-comers had to clamber over the seats to find somewhere to sit). He briefly spoke about Professor Kajita, who in addition to neutrino research, was involved with the Japanese Gravitation Wave Detection project. He went on to explain that this lecture was one of a series of annual lectures called the Fred Combley Colloquia, named after a much respected professor who used to be Dean of the Faculty of Science.

Professor Kajita took the stand and delivered his talk. He started by explaining what neutrinos are; elementary particles that have no electric charge, and interact so weakly with normal matter that they can pass right through the Earth. Neutrinos come in three varieties, or “flavours”- electron neutrinos ($v^{e)}$, muon neutrinos (v^{μ}) and tau neutrinos (v^{τ}). In the very successful Standard Model of Particle Physics, neutrinos were considered <u>not</u> to have mass.

Atmospheric Neutrinos (ANs) are produced by the interaction between cosmic rays and the atmosphere, and were first observed in 1965 by two deep underground detectors, one in India and the other in South Africa.

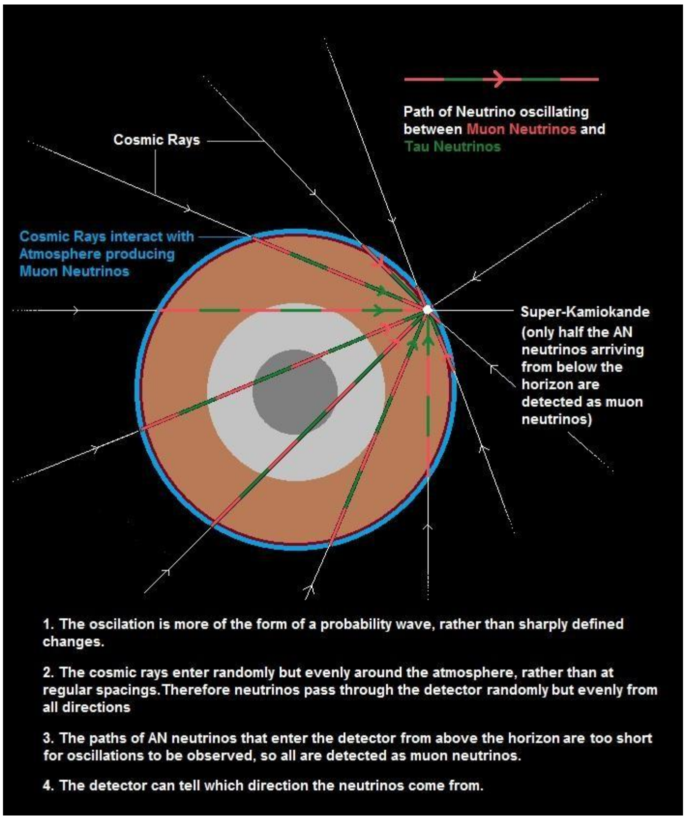
Professor Kajita helped build the first Kamiokande Detector, a 16m high tank of pure water deep underground, with photocells covering the inner surfaces of the tank to detect Cherenkov radiation (Cherenkov radiation is a cone of blue light produced when an electrically charged particle, accelerated by neutrino interaction, travels faster than the local speed of light, in this case in water. It’s analogous to a sonic boom from a supersonic aircraft. The cone is projected onto the surfaces of the detector as a ring pattern. Different particles can produce fuzzy rings or sharp rings and the direction of the neutrino and its energy can be determined).

The intention was to look for evidence of proton decay – the expected average half-life of protons according to the Grand Unified Theories of the 1970s is $10^{30\pm2}$ years (so a giant tank with that number of protons in might produce a decay once a year). During the experiments, a large amount of background noise in the form of cosmic neutrino detection was noted (I took this to mean Atmospheric Neutrinos).

Professor Kajita set out to investigate this noise with the intention of eliminating its effect from the results. His investigations did not fit the prediction – there were fewer v^{μ} neutrino events than expected. He was concerned that his team was mistaken about this deficit and spent a year checking their methods and results. There was no mistake, and the deficit was verified by a different experiment, the IMD experiment. He decided to research the deficit and he realised that one possibility was that the v^{μ} neutrinos were oscillating, or turning into the other varieties and therefore not being detected as v^{μ} neutrinos.

AN detection should be evenly spread from all directions for a detector like Kamiokande (there is a geometrical proof for this!). However it was noted that fewer upward passing neutrinos were being detected than downward passing neutrinos.

Downward passing ANs are created a short distance from the detector (in the atmosphere above) and do not have long enough to oscillate before entering the detector. Due to the mass (if any) of the neutrinos being small, the neutrino oscillation length was likely to be in the order of 1000km, therefore in order to turn into another variety at the point they pass through the detector, they would need to be travelling through the earth from below the horizon. In order to get enough data, a new detector, the Super-Kamiokande was built. This is 42m high and 39m across, and a kilometre deep under a mountain. The photocells were installed on the walls from rubber dinghies as the water levels were raised. Observations started in 1996.



In 1998 Super-Kamiokande obtained data that matched the predicted graph of oscillation probability against length of travel, which proved that the neutrinos were oscillating, and that therefore **neutrinos have mass** (the reasoning behind this link was not explained and is complex). Professor Kajita made the point that the observations can only be statistical, rather than directly watching individual neutrinos oscillating.

Neutrino masses are around 10^{10} times less than those of other fundamental particles.

Super-Kamiokande is still working and detecting ten times the number of events seen in 1998.

Professor Kajita briefly reported on independent experiments that had found neutrino deficits, and others that had detected neutrino oscillations that explain these deficits.

He commented on Future Neutrino Research:- Neutrinos with very small masses may be the key to understanding the imbalance of matter and anti-matter in the universe. Professor Kajita would like to look for CP violation (CP stands for charge-parity symmetry, which means that a charged particle should have exactly the same properties as the mirror image of its anti-particle). He acknowledged that this would be difficult.

Professor Kajita took questions after the lecture:-

Q: How would we be able to detect anti-neutrino oscillations?

A: We can generate our own!
Q: What causes neutrinos to oscillate?
A: If neutrinos have mass, they oscillate.

Q: Do other fundamental particles oscillate (this is the question I wanted to ask but was beaten to it)?
A: Not known!

Q: Did the neutrinos that were detected from Supernova 1987A appear to be any different to solar neutrinos?
A: No notable difference.

Q: Does the masses of neutrinos contribute to the mass of dark matter?
A: They might account for less than 1% of dark matter.

Q: Why not use lakes instead of purpose made water tanks?
A: They would need to be very deep!

Q: Why not install linked detectors on opposite sides of the earth?
A: That would be considered if the existing arrangements didn’t work well. As it is they work fine, so there would be no benefit.

Report by Rob McGregor