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Neutrino physicists get together down under

Christchurch in New Zealand provided an appropriate southern-hemisphere location for participants at Neutrino 2008 to hear the latest news from experiments that encompass the globe in more ways than one. Jenni Adams reports.

Résumé.

Des physiciens des neutrinos en Nouvelle-Zélande

La XXIIIe Conférence internationale sur la physique des neutrinos et l'astrophysique a fait le point sur les dernières évolutions dans le domaine. Elle s'est tenue à la fin mai à Christchurch (Nouvelle-Zélande) et a été organisée par l'Université de Canterbury et la collaboration IceCube, qui utilise Christchurch comme ville de transit pour l'Antarctique. Les résultats présentés ont montré que les expérimentateurs neutrino sont maintenant passés aux mesures de précision. Ils pensent que la masse et le mélange des neutrinos sont des manifestations de la physique au-delà du modèle standard. Il demeure cependant encore bien des zones d'ombre et des incertitudes.

In recent years neutrinos have moved onto centre stage in both astrophysics and particle physics, and the latest developments were on show at the XXIII International Conference on Neutrino Physics and Astrophysics on 26–31 May. Supported by the International Union of Pure and Applied Physics, Neutrino 2008 took place in Christchurch, New Zealand, where it was organized by the University of Canterbury and the IceCube collaboration, which uses Christ church as its staging area and gateway to Antarctica. Conference-goers celebrated the 100th anniversary of the award of the Nobel Prize to a former undergraduate of the University of Canterbury, Ernest Rutherford, whose life was the topic of the opening presentation by Cecilia Jarlskog from Lund.

IceCube

The question "Where are we?" is beloved of neutrino physicists. Alexei Smirnov of the Abdus Salam International Centre for Theoretical Physics in Trieste noted that a quarter of the papers found on the SPIRES high-energy physics database with this title are in neutrino physics. With the discoveries of neutrino masses and lepton-flavour mixing now established, there is a standard neutrino scenario in which neutrinos have masses in the sub-electron-volt range and there are two large mixings and one small or zero mixing between the three neutrino flavours. Neutrino experiments have moved into an era of precision measurements, motivated by the belief that neutrino mass and mixing are manifestations of physics beyond the Standard Model. However, as Smirnov noted, despite many years of effort and many trials, the physics underlying neutrino mass and mixing remains unidentified.

Roadmap of theoretical possibilities

Understanding neutrinos is a two-step process. The first step is to determine the values of the three mixing angles, the masses of the three mass eigenstates, and the value of the CP-violating phase. It is also necessary to find out whether the neutrino is its own antiparticle, that is whether it is as described by the physics of Paul Dirac or of Ettore Majorana. The second step is to try to understand why the neutrino matrix elements and the neutrino masses are what they are and what they tell us about physics well beyond the Standard Model. Stephen King from Southampton presented a roadmap of theoretical possibilities, including extra dimensions and possible grand unified theories, with each theoretical path linked to future experimental results.

Two of the mixing angles are now well determined: one through the solar-neutrino experiments and the other through the atmospheric- and accelerator-neutrino studies. The third angle, θ_{13}, is much less constrained but is no less important because it determines how close the mixing matrix is to the theoretically interesting, highly symmetric "tribimaximal" configuration. The best limits on θ_{13} are currently from the Double Chooz experiment. If θ_{13} is large enough, it may be possible to observe CP violation with neutrinos, and Yosef Nir from the Weizmann Institute explained how a large value for the CP-violating parameter, δ, could explain the observed baryon asymmetry in the universe via the process called leptogenesis.

Speakers from solar-neutrino experiments were the first to present their results, beginning with reports from the Borexino detector located at Gran Sasso National Laboratory in Italy, and from the third and final phase of the Sudbury Neutrino Observatory (SNO) in Canada. SNO's third phase included ^{3}He proportional counters to measure the rate of neutral-current interactions in the detector's heavy water. The Borexino experiment has results from 192 days of data taking and, as with earlier solar-neutrino measurements, these are best described by neutrino-flavour oscillation. The electron-neutrino flavour eigenstate, to a good approximation, is a linear combination of two mass eigenstates with masses m_1 and m_2. Neutrinos from the same energy range but at a much shorter baseline are detected by the KamLAND experiment in Japan, which observes antineutrinos from nuclear reactors. A combined analysis of the solar and KamLAND data now gives precise results for the mixing angle, Δ_{12}, and mass difference $\Delta m_{12}{}^2$, of the two mass eigenstates. The result of analysis with two flavours gives $\Delta_{12} = 33.8 + 1.4 -1.3\ °$ and $\Delta m_{12}{}^2 = 7.94 + 0.42 - 0.26 \times 10^{-5}\ \mathrm{eV}^2$.

The Super-Kamiokande experiment in Japan is now fully recovered from the accident in 2001, which destroyed around half of the original photomultiplier tubes. It has provided a high-precision measurement of neutrino oscillations by detecting atmospheric neutrinos in an energy range of hundreds of millions of electron-volts to a few tera-electron-volts. Jennifer Raaf from Boston gave the results from a combined analysis of the pre-accident and post-accident data taking. These include a mixing angle with $\sin^2 2\theta_{23} > 0.94$ at 90% confidence, which is the best constraint so far obtained for this parameter. The experiment also places limits on non-oscillation physics, such as neutrino decoherence, which is excluded at 5.0 σ, and neutrino decay, which is excluded at 4.1 σ.

Neutrino beams produced at particle accelerators offer the greatest control over the neutrino sources. They have been used to study the same neutrino oscillations that take place in atmospheric neutrino oscillation. The KEK-to-Kamioka (K2K) experiment was the first long-baseline neutrino experiment to operate, using neutrinos sent from the KEK laboratory to the Super-Kamiokande detector 250 km away. The K2K collaboration has previously reported results consistent with the Super-Kamiokande atmospheric neutrino results using data collected between 1999 and 2004. At the conference Hugh Gallagher from Tufts University presented new results from the Main Injector Neutron Oscillation Search (MINOS) experiment. This uses a muon–neutrino beam that is produced at Fermilab and observed at two sites: a near detector at Fermilab and a far detector 734 km away at the Soudan Underground Laboratory in Minnesota. MINOS now has the tightest constraint on the mass difference, finding $\Delta m_{23}{}^2 = 2.43 \pm 0.13 \times 10^{-3}\ \mathrm{eV}^{-2}$ and a result for the mixing angle that is consistent with that for Super-Kamiokande.

The conference also heard reports on future experiments that aim to measure θ_{13}. These include the reactor-neutrino experiments Double Chooz in France, Daya Bay in China and the Reactor Experiment for Neutrino Oscillation at Yonggwang in Korea, as well as the accelerator-neutrino experiments T2K, OPERA at the Gran Sasso National Laboratory, and NOvA at Fermilab.

Many efforts are under way to determine directly the absolute neutrino mass scale in laboratory experiments through nuclear beta-decay or neutrinoless double beta-decay, which is possible if the neutrino is Majorana. Beta-decay experiments can be categorized by the detector type and there were reviews of tracking, solid-state, calorimetric and scintillator detectors, with energy resolution being the crucial common ingredient. The neutrino mass scale can also be probed through cosmology; the relic neutrino density influences the evolution of large-scale structure in the universe. Richard Easther from Yale presented the latest results obtained by combining cosmic microwave background and supernova observations. The best fit constrains the mass sum from all neutrino flavours to be less than 1 eV, with better precision obtainable if the Hubble constant is known independently.

Neutrinos also probe a range of physical processes, from the heat source of the Earth to the location of high-energy cosmic accelerators. Bill McDonough of Maryland discussed how the detection of geoneutrinos can put limits on the amount of heat generated by uranium and thorium inside the Earth. KamLAND has already placed limits on this but is restricted by the background from reactor neutrinos. The next step may be the Hawaii Anti-Neutrino Observatory, HANOHANO – a proposed 10 kilotonne liquid scintillation detector designed to be transportable and deployable in the deep ocean. Its goal is to measure the neutrino flux from the Earth’s mantle for the first time.

Cosmic neutrinos may also unveil the very high-energy, cosmic-ray accelerators. Unlike photons or charged particles, neutrinos can emerge from deep inside their sources and travel across the universe uninterrupted. Julia Becker of Gothenberg University discussed some potential sources of cosmic neutrinos, including some of the most energetic objects in the universe, such as supernova remnants, microquasars and active galactic nuclei. To date, no experiment has observed extraterrestrial high-energy neutrinos, but cubic-kilometre telescopes (e.g. KM3Net, which is planned for the Mediterranean, and IceCube, under construction at the South Pole) are expected to be large enough to observe these cosmic neutrinos. Spencer Klein from the Lawrence Berkeley National Laboratory gave an update on the IceCube neutrino observatory, which uses the ice at the South Pole as a Cherenkov medium for the detection of high-energy neutrinos. The observatory comprises an in-ice, three-dimensional array of photomultiplier tubes and a surface air shower array. In February, half of the detector had been deployed, bringing the instrumented volume to roughly 0.5 km^3.

Although the field of neutrino physics has moved into a precision era, many puzzles remain and there is still much to be explained. A number of experiments are anticipating new results in the near future, so we can look forward to the next Neutrino conference, to be held in Athens in 2010.

About the author

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Further reading

For the Neutrino 2008 programme and presentations, see www.neutrino2008.co.nz (http://www.neutrino2008.co.nz)