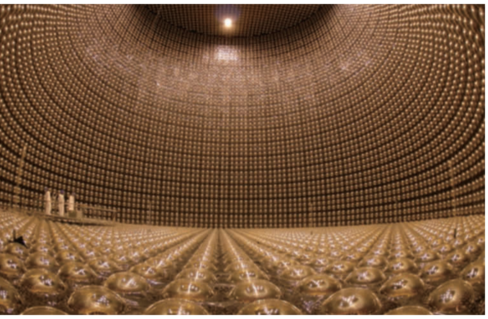


THE UNIVERSITY OF TOKYO

# Neutrinos and beyond — Opening a new era of cosmic-ray research

**Takaaki Kajita, a recipient of the 2015 Nobel Prize in Physics, and other researchers at the University of Tokyo's Institute for Cosmic Ray Research (ICRR) have been exploring new realms in particle physics research. Kajita's work on neutrinos and related research at ICRR is leading the world in this field.**

## The path to a Nobel prize

Particle physics and astrophysics are among the most active research fields at the University of Tokyo, and its Institute for Cosmic Ray Research (ICRR) is leading the world with explorations in these areas. ICRR is best known for its research on neutrinos using the world's largest underground neutrino detector, Super-Kamiokande. The detector is located in a mine in central Japan and is filled with 50,000 tons of pure water. Neutrinos, which are electrically neutral subatomic particles, exist in three different forms — electron, muon and tau. They are generated in various places, including the centre of the Sun and the Earth's atmosphere. Although neutrinos are the most abundant particle in space after photons, they are hard to observe because they rarely interact with matter. But they hold the key to many questions about how the Universe was formed.

Researchers at ICRR have discovered many important properties of these enigmatic particles, including the fact that neutrinos oscillate, or change from one type to another, as they travel through the Earth. One implication of this finding is that neutrinos have mass — a conclusion that has forced scientists to reassess the standard model of particle physics, which predicts that neutrinos are massless. These discoveries, which resulted in Kajita's 2015 Nobel Prize in Physics, were made a team led by him in 1998.

Kajita acknowledged his success owed a lot to the strong support he received from two mentors and former supervisors — Masatoshi Koshiba and Yoji Totsuka. Koshiba was awarded the 2002 Nobel Prize in Physics for detecting neutrinos produced in supernovae using Kamiokande, the predecessor of Super-Kamiokande. Totsuka led the Super-Kamiokande project as Koshiba's successor. Totsuka's contribution was so great that many believe he would have shared the Nobel Prize with Kajita if he were alive.

Kajita's award-winning work dates back to 1986 when he earned his PhD for researching proton decay. Soon after that, Kajita began to upgrade the software he was using to separate the proton-decay signal from the background noise produced by atmospheric neutrino interactions. He discovered that his data did not match theoretical calculations and began to search for the cause of this discrepancy. He was unable to find any problems with the data analysis or the simulation of atmospheric neutrino interactions. The Kamiokande collaboration reported this result in 1988, but the academic community was sceptical. "The result disagreed with those obtained by other researchers." Kajita recalls. "But Koshiba and Totsuka understood the importance of the Kamiokande data and gave me constant support."

The breakthrough came in 1996 when Super-Kamiokande began operating; within two years Kajita's team had definitively proved that neutrinos oscillated. They presented this finding at the International Conference on Neutrino Physics and Astrophysics. "To my surprise, the audience welcomed my presentation and gave me a standing ovation," Kajita says.

**More projects with Super-Kamiokande**

Since then, neutrino research has been steadily advancing. Some 120 researchers from seven countries take turns to analyse the data that is being continually generated by Super-Kamiokande. The facility is operated under the supervision of Masayuki Nakahata, head of Kamioka Observatory and solar neutrino specialist. Meanwhile, Yoichiro Suzuki, deputy director of the Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU) at the University of Tokyo, greatly contributed to explaining the discrepancy between data and theory for solar neutrinos, which had long puzzled researchers. Suzuki and Kajita were awarded the 2016 Breakthrough Prize in Fundamental Physics for their roles in the discovery and study of neutrino oscillation.

Neutrino research will be further accelerated in the next few years with the upgrade of Super-Kamiokande, which will allow it to detect supernova neutrinos more efficiently. There are also plans to build another detector, Hyper-Kaimokande, whose volume will be 20 times greater than that of Super-Kamiokande. This mega-detector is expected to begin operation in 2025 and the discovery of particle–antiparticle asymmetry in neutrinos is one of the major goals for it.

**Gamma rays and gravitational waves**

ICRR's exploration of new research fields goes beyond neutrinos. The institute is participating in the international project to build the Cherenkov Telescope Array (CTA), a next-generation observatory of very high-energy gamma rays. CTA will detect the highest-energy photons ever observed, which will lead to a deeper the understanding of star formation in the evolution of the Universe and many other events that cannot be observed using current technologies. In the CTA project, ICRR's Cherenkov Cosmic Gamma Ray Group is developing large-scale telescopes in collaboration with researchers in Japan, the USA and Europe.

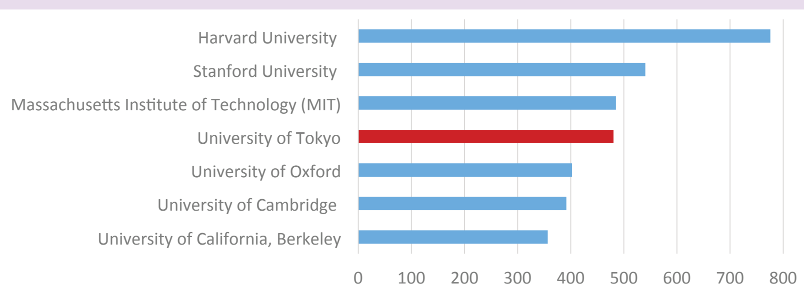
Another important project at ICRR is the Large-Scale Cryogenic Gravitational Wave Telescope (KAGRA). The first-stage facility was completed in October 2015. Gravitational waves are the curvature of space–time and they propagate at the speed of light according to Einstein's theory of relativity. On 11 February 2016, the Laser Interferometer Gravitational-Wave Observatory (LIGO) in the USA and its international collaborators made the momentous announcement that they had detected gravitational waves. "Detection of gravitational waves is very difficult, but the research — once thought impossible — is moving on thanks to the steady advance of science and technology and the endeavors of many researchers," says Shinji Miyoki, associate professor of ICRR and a member of the KAGRA project.

Researchers are now testing the laser interferometer and plan to commence its operation with cryogenic mirrors within the next year. Already, more than 200 researchers from around the world are participating in the KAGRA project.

Worldwide collaboration in this area is expected to accelerate. ICRR is poised to contribute to this new field of gravitational-wave astronomy by completing the construction of KAGRA and participating in international observation networks as soon as possible. Through collaborating with researchers around the world, ICRR aims to elucidate the mysteries of the Universe, by, for example, detecting the birth of black holes formed by the merger of binary neutron stars.

**Promoting cross-border cooperation**

All ICRR's projects are undergirded by the efforts of graduate students and young researchers, who perform vital activities ranging from the construction of equipment to data analysis. This is true for all the research done at the University of Tokyo. Young scientists are essential for research, and they sometimes create new research fields. As a world hub for knowledge collaboration, the University of Tokyo is supporting diverse research activities and developing an environment where young researchers can explore without constraints. To this end, the university makes proposals to the government as well as reviewing and reforming internal systems and publicizing its research activities. Support for young scientists, who will play a key role in next-generation research, is vital and should be made available by both universities and governments. As collaborative projects between researchers in different countries are becoming more prolific, it is crucial to create an environment in which researchers can flexibly and actively participate in global projects, interact with scientists around the world and create new values.




## Nature Index ranking

→ **The publication output of the University of Tokyo is ranked fourth in the world in terms of the weighted fractional count (data period: 1 December 2014–30 November 2015).**

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