Masatoshi Koshiba (1926–2020)
Innovative founder of neutrino astronomy

By Masayuki Nakahata1 and Atsuto Suzuki2

Masatoshi Koshiba, eminent experimental particle physicist, passed away on 12 November 2020. He was 94. By conducting electron–positron (e–e+) collider experiments, Koshiba used his creativity to advance the field of particle physics. He also adapted equipment to make ground-shifting discoveries, leading to the new fields of underground neutrino physics and neutrino astronomy.

Koshiba was born in Toyohashi, Japan, on 19 September 1926. He earned his B.S. in physics from the University of Tokyo in 1951 and completed his master’s thesis detecting cosmic rays with a nuclear emulsion technique. In 1953, he enrolled in the Graduate School of Physics at Rochester University in New York. After obtaining his Ph.D. in cosmic ray physics within 2 years, he was appointed as a research fellow at the University of Chicago in 1955. In 1958, he returned to the University of Tokyo, where he remained until his retirement in 1987.

After contributing to international cosmic ray collaborations, Koshiba began his exploration of accelerator particle physics in 1969, when he joined the construction of the e–e+ collider at Budker Institute of Nuclear Physics in Russia. Although the project was terminated in 1972, Koshiba pushed on with e–e+ collider experiments and later joined the Double Arm Spectrometer (DASP) experiment at Deutsches Elektronen-Synchrotron (DESY) in Germany. This project evolved into the JADE (Japan, Deutschland, and England) experiment at DESY. Through these experiments, Koshiba established the Standard Model of particle physics and discovered the gluon, which mediates strong interactions between quarks. In 1985, in recognition of these efforts, he received the Great Cross of Merit, the Order of Merit of the Federal Republic of Germany. Koshiba dreamed of constructing the next-generation e–e+ linear collider in Japan, a vision that will be realized with the completion of the e–e+ International Linear Collider (ILC).

In 1980, detecting evidence of a so-called Grand Unified Theory became a major challenge for experimentalists. This theory predicted that protons would decay, and Koshiba proposed a way to detect the process. We both joined Koshiba as he prepared to execute his experiment, known as the Kamioka Nucleon Decay Experiment (Kamiokande). He had constructed a 3000-ton water Cherenkov detector located 1000 m underground in the Kamioka mine. The distinguishing feature of this experiment was the use of 1000 photomultiplier tubes with a diameter of 51 cm, the largest in the world. Kamiokande started to collect data in 1983. Unfortunately, the lifetime of a proton was found to be much longer than the sensitivity of Kamiokande, and we could not find any positive signals. However, Koshiba—with characteristic ingenuity—noticed that the Kamiokande detector was sensitive to astrophysical neutrinos, including solar neutrinos (generated inside the Sun). He proposed an update to the detector to observe neutrinos instead.

The results of the first solar neutrino observation experiment, led by physicist Raymond Davis Jr. in 1968, had shown a deficit of neutrinos relative to the solar model prediction. Within 2 months of the start of Kamiokande’s solar neutrino data collection in 1987, billions of extragalactic messengers—the supernova (SN) 1987A neutrinos—swept through Earth. SN 1987A occurred in the Large Magellanic Cloud, 170,000 light-years away from the Solar System. On 23 February 1987, 11 neutrino events were observed in Kamiokande within 13 seconds. The energies and number of observed events in the Kamiokande data showed that the origin of a supernova was gravitational collapse and that 99% of the released gravitational energy is carried out by neutrinos, which confirmed the basic idea of the star core collapse. Davis and Koshiba shared the 2002 Nobel Prize in Physics “for pioneering contributions to astrophysics, in particular for the detection of cosmic neutrinos,” and the research field of neutrino astronomy was born.

Kamiokande succeeded in observing solar neutrinos, and the data—collected through 1990—clearly confirmed the solar neutrino deficit, the explanation for which remained a puzzle. In addition to the solar neutrino deficit, Kamiokande first observed the atmospheric neutrino anomaly that shows a deficit of muon neutrino to electron neutrino ratio of atmospheric neutrinos. Both the solar neutrino deficit and the atmospheric neutrino anomaly were predicted to be solved by neutrino oscillations induced by finite neutrino masses that had been predicted by the Grand Unified Theory. These anomalies were finally resolved in 1998 by the detection of evidence of neutrino oscillations in Super-Kamiokande, a 50,000-ton water Cherenkov detector originally proposed by Koshiba. For this work, physicist Takaaki Kajita, one of Koshiba’s Ph.D. students, was awarded the 2015 Nobel Prize in Physics.

Koshiba nurtured many talented physicists and educated them using his signature didactic messages. For example, Koshiba suggested that a researcher should always hold three or four new “eggs” (research ideas) at a time but should regularly ask whether each egg can still become a bird. If not, then the idea is no longer worth holding. He also recommended that experimental equipment incorporate as many distinctive devices as possible. That way, even if you fail to catch the prey you are aiming for, you will have a chance to catch other prey.

Koshiba’s incredible enthusiasm and outstanding ability to get things done were embodied by Kamiokande, which led to both neutrino astronomy and the discovery of finite neutrino masses. Koshiba always worked on his research with keen intuition, passion, foresight, and leadership. His innovative ideas inspired younger researchers, who built on his work to realize his dreams. Those young scientists will no doubt continue to advance the field of physics on the basis of the foundations that Koshiba put in place.

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