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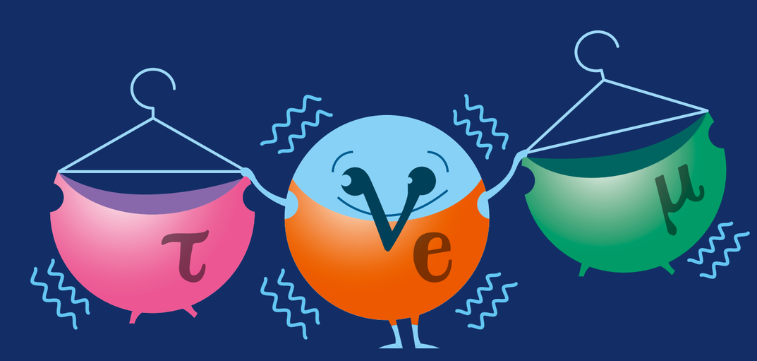
THE ROYAL SWEDISH ACADEMY OF SCIENCES

The Royal Swedish Academy of Sciences has decided to award the Nobel Prize in Physics 2015 to **Takaaki Kajita** and **Arthur B. McDonald** "for the discovery of neutrino oscillations, which shows that neutrinos have mass".

The Nobel Prize 2015 **in Physics**

Chameleons of space

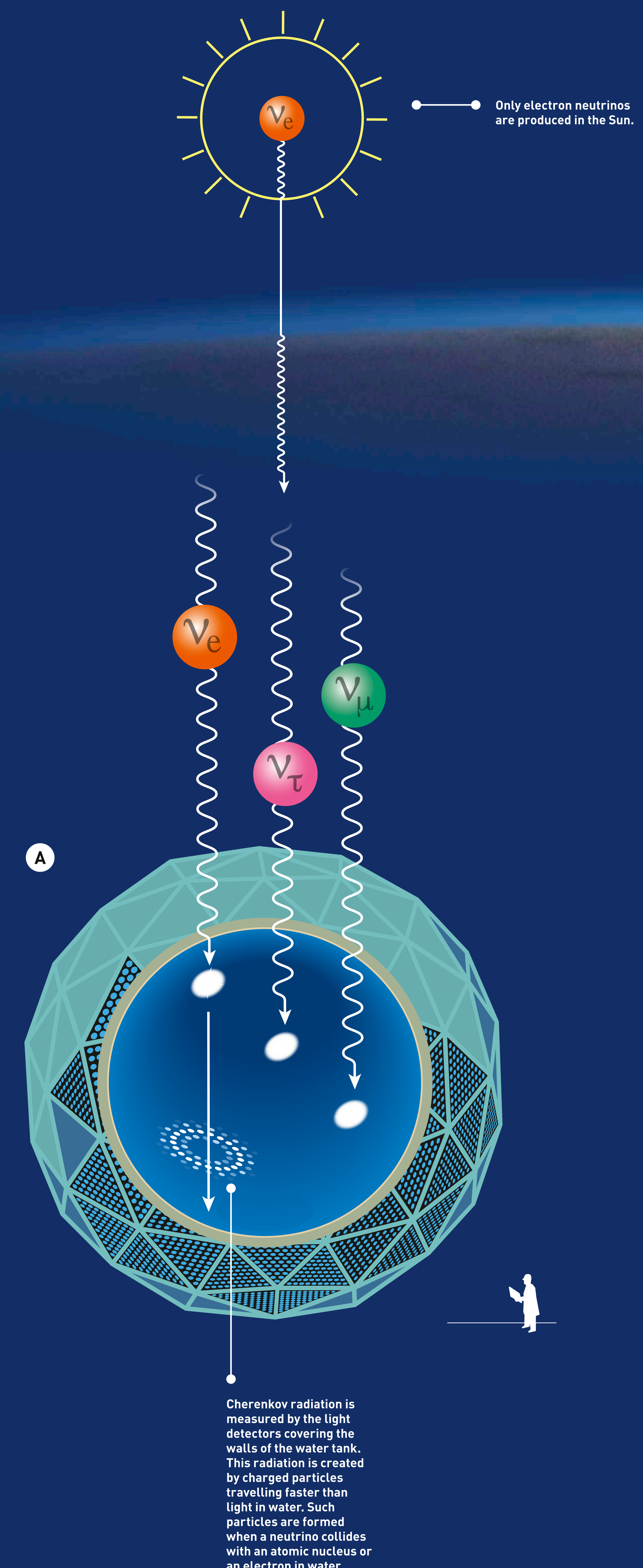


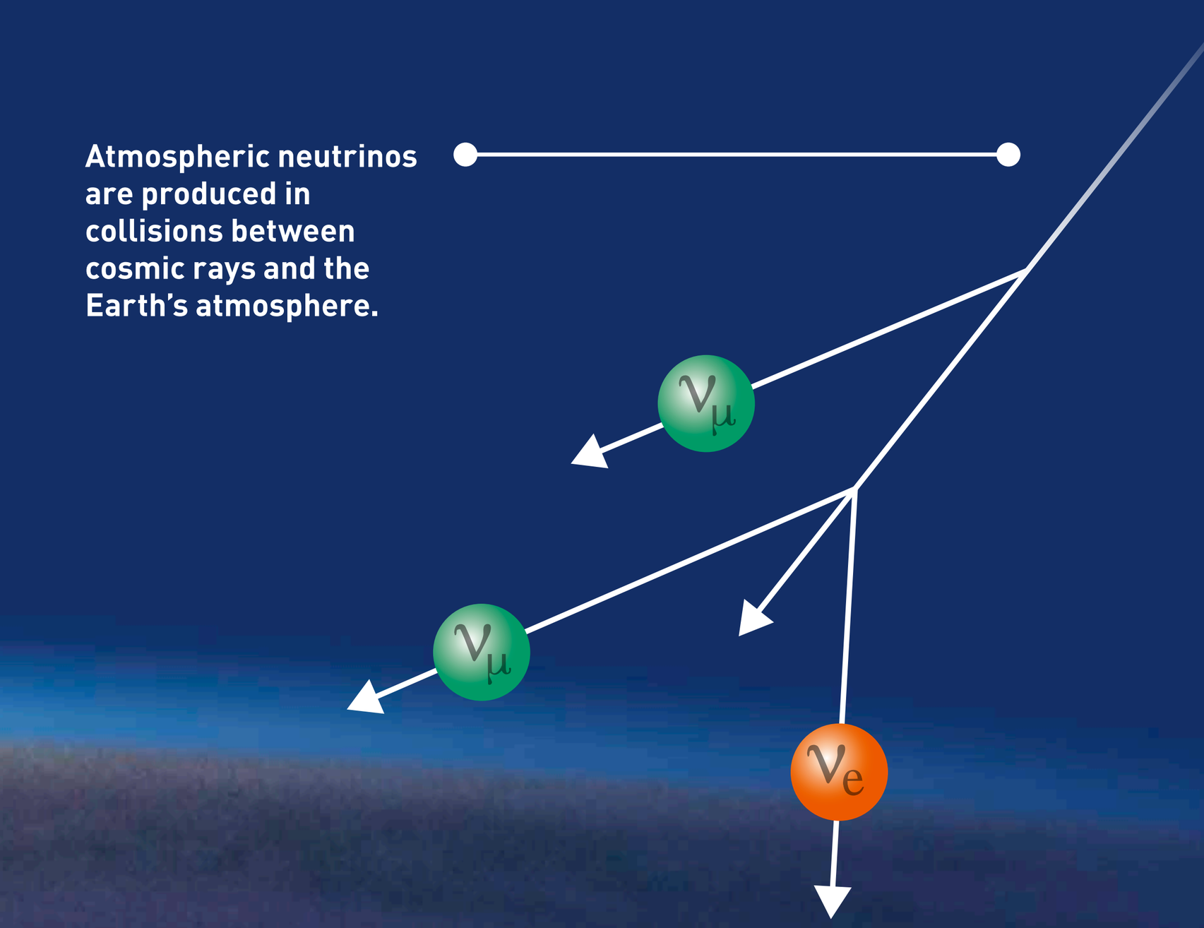
Takaaki Kajita in Japan and Arthur B. McDonald in Canada were key scientists in two large research groups that discovered that neutrinos change identities, which requires that neutrinos have mass. The discovery has changed our understanding of the innermost workings of matter and may prove crucial to our view of the universe.

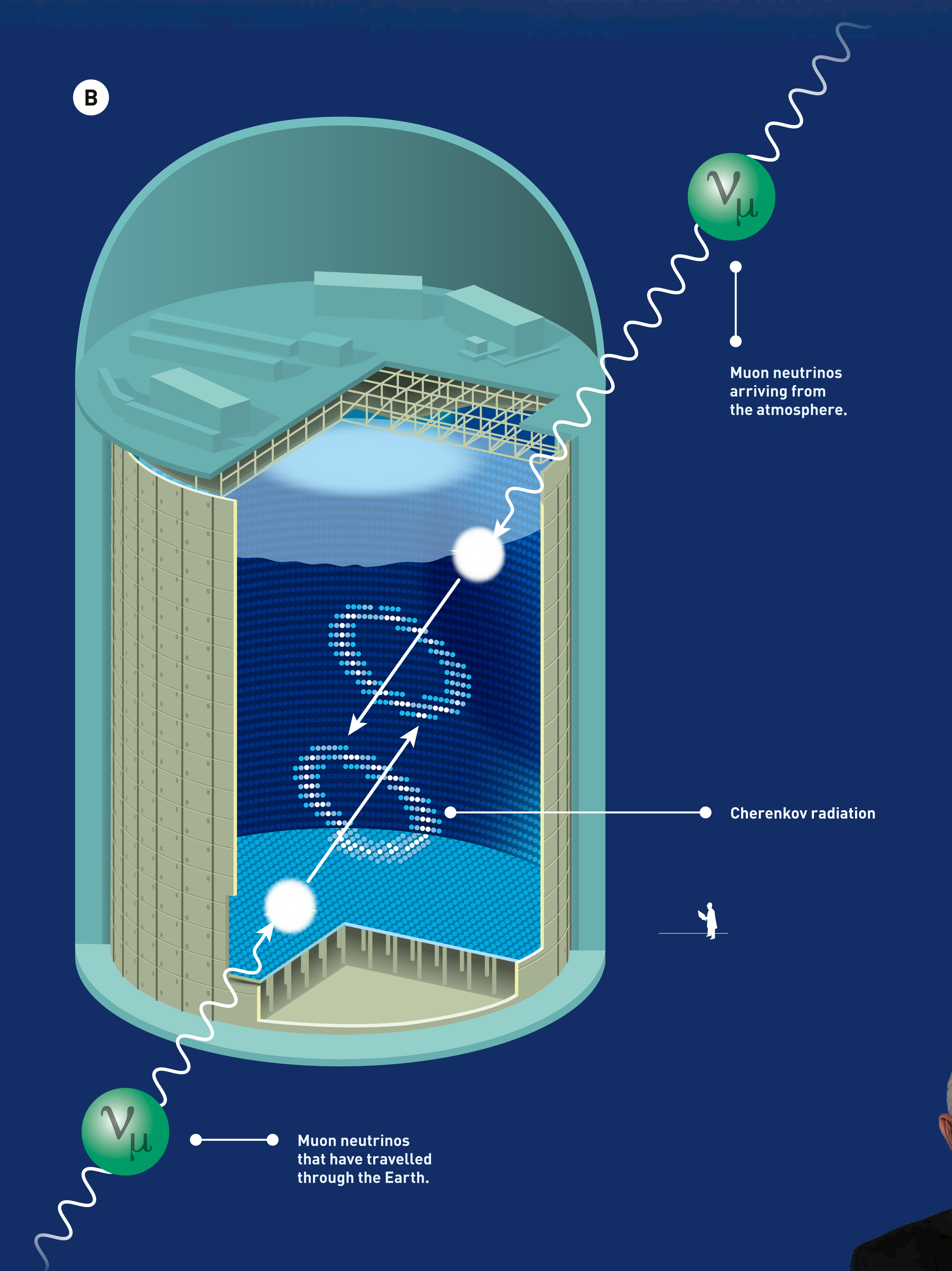
The discovery of neutrino identity changes has resolved a neutrino puzzle that physicists had wrestled with for decades. Compared to theoretical calculations of the number of neutrinos, up to two-thirds of them were missing in measurements performed on Earth. The two research groups discovered that the neutrinos had changed identities, which led to the conclusion that neutrinos must have some mass, however small. This discovery was historic for particle physics, as its Standard Model requires neutrinos to be massless. Thus new physics is now needed.

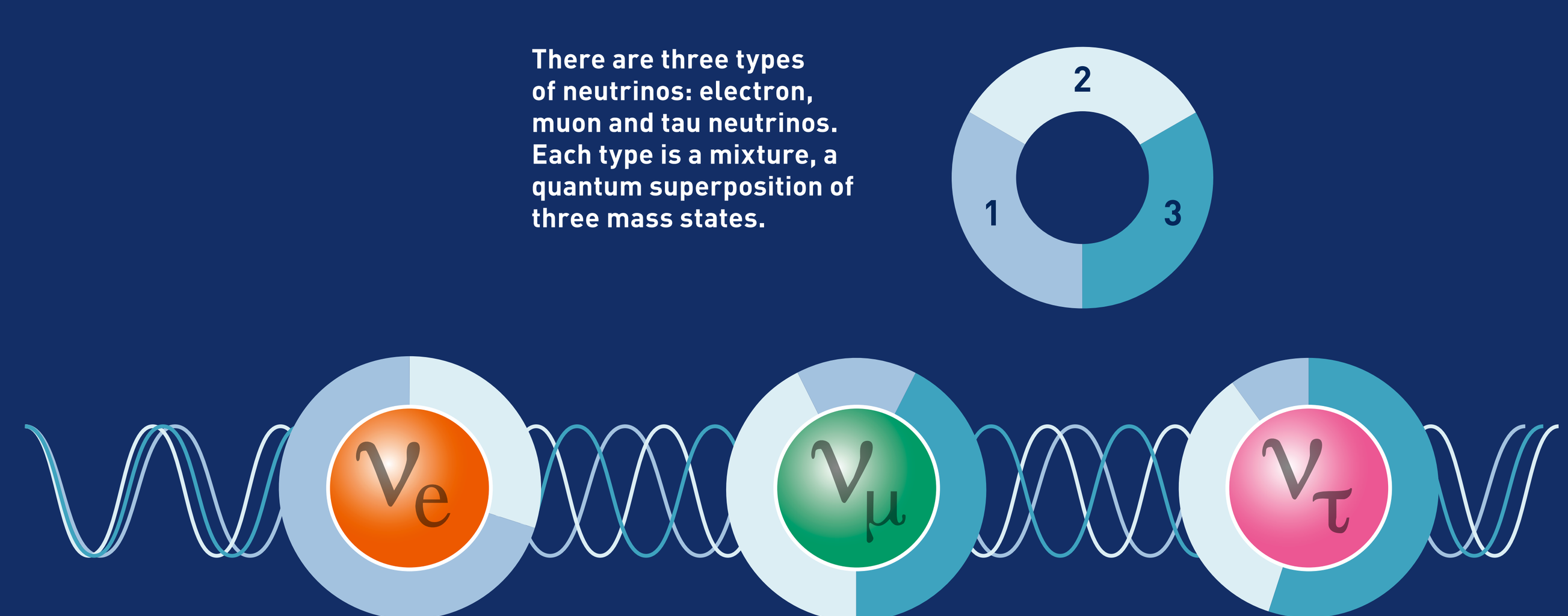
The Earth is constantly bombarded by neutrinos. Many are created in reactions between cosmic radiation and the Earth's atmosphere. Others are produced in nuclear reactions inside the Sun. Thousands of billions of neutrinos stream through our bodies every second. The combined weight of neutrinos is estimated to be roughly equal to that of all visible stars in the universe.

Hardly anything can stop the neutrinos; they are amongst nature's most elusive elementary particles. Experiments are continuing to uncover the all but hidden world of neutrinos. New discoveries about their deepest secrets are expected to change our current understanding of the history, structure and future of the universe.









Neutrino oscillations

Neutrinos change identities as they travel through space. Quantum physics is required to explain this magic, where the neutrinos are represented by superposed waves that correspond to neutrino states with different masses. When the neutrinos travel, these waves go out of phase and are superposed in different ways. The superposition in any given location yields the probability of which type of neutrino is most likely to be found there. These probabilities vary from one location to another – oscillate – and the neutrinos appear in their various identities. This is only possible if neutrinos have mass.

A Sudbury Neutrino Observatory

The detector measured neutrinos from the Sun. Its tank, filled with heavy water, was placed two kilometres under the surface of the Earth. Signals from all three types of neutrinos were registered in the tank. The sum of the neutrinos corresponded to what was expected, but there were not enough electron neutrinos – they must have changed identity.

B Super-Kamiokande

The detector measured atmospheric neutrinos. Its tank, filled with water, was placed one kilometre under the surface of the Earth. The muon neutrinos that arrived straight at Super-Kamiokande from the atmosphere were more numerous than those that arrived at the detector after passing through the Earth. The muon neutrinos that travelled further thus had time to change identity and become another type of neutrino.

Arthur B. McDonald
Canadian citizen. Born 1943 in Sydney, Canada. Professor Emeritus at Queen's University, Kingston, Canada.

Takaaki Kajita
Japanese citizen. Born 1959 in Higashimatsuyama, Japan. Director of Institute for Cosmic Ray Research and Professor at University of Tokyo, Kashiwa, Japan.

FURTHER READING More information on the Nobel Prize in Physics 2015: *http://kva.se/nobelphysics2015* and *http://nobelprize.org* **BOOKS:** ● **Jayawardhana, R.** (2013) *Neutrino Hunters: The Thrilling Chase for a Ghostly Particle to Unlock the Secrets of the Universe*, Scientific American/Farrar, Straus and Giroux ● **Close, F.** (2010) *Neutrino*, Oxford University Press **POPULAR SCIENCE ARTICLES:** ● **Hulth, P. O.** (2005) High Energy Neutrinos from the Cosmos, *http://nobelprize.org* ● **Bahcall, J. N.** (2004) Solving the Mystery of the Missing Neutrinos, *http://nobelprize.org* ● **McDonald, A. B., Klein, J. R.** and **Wark, D. L.** (2003) Solving the Solar Neutrino Problem, *Scientific American*, Vol. 288, no. 4, April ● **Kearns, E., Kajita, T.** and **Totsuka, Y.** (1999) Detecting Massive Neutrinos, *Scientific American*, Vol. 281, no. 2, August
LINKS: ● **Super-Kamiokande Homepage:** *www-sk.icrr.u-tokyo.ac.jp/sk/index-e.html* ● **Sudbury Neutrino Observatory Homepage:** *www.sno.phy.queensu.ca* ● **More references can be found in the Scientific Background:** *http://kva.se/nobelphysics2015*

Editors: Lars Bergström, Olga Botner, Gunnar Ingelman and Anne L'Huillier, The Nobel Committee for Physics, The Royal Swedish Academy of Sciences; Joanna Rose, Science Writer; Sara Gustavsson, Editor, and Laura Alexis, Nobel Assistant, The Royal Swedish Academy of Sciences. **Graphic design:** Ritator **Illustrations:** Johan Jarnestad/Infographics.se **Print:** Åtta45

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