From China to the South Pole: Joining forces to solve the neutrino mass puzzle

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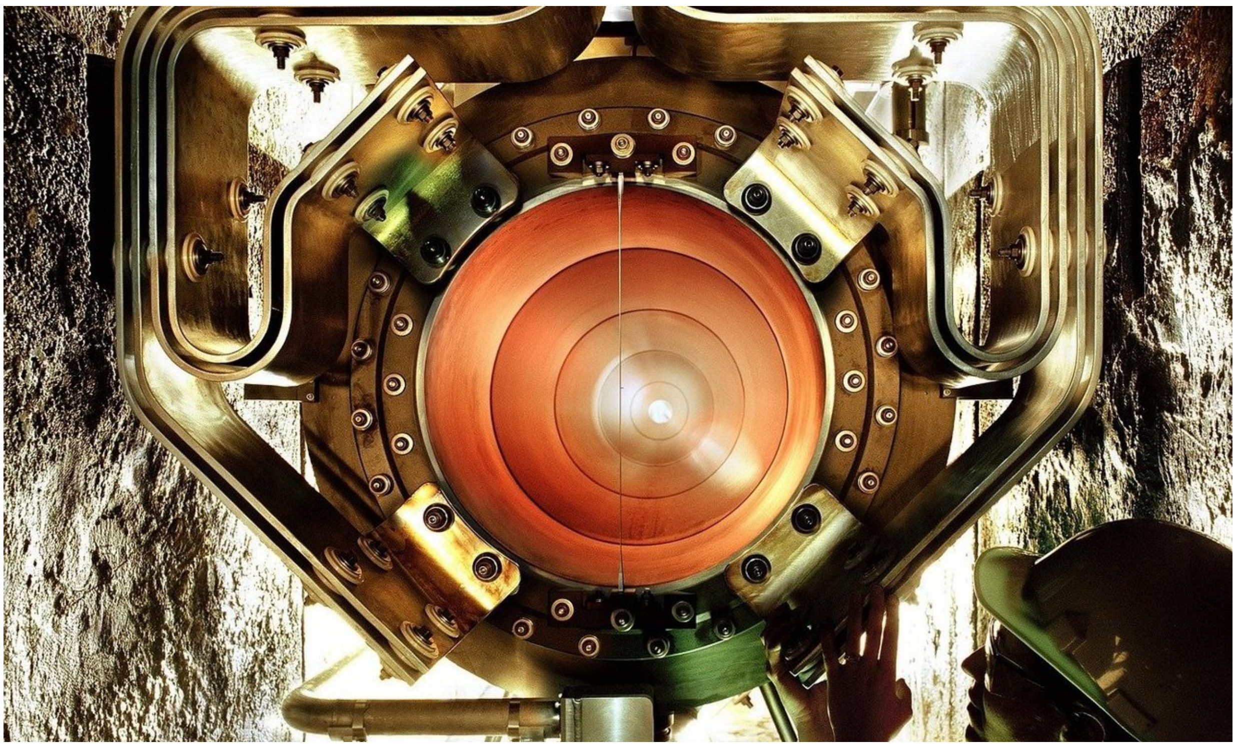

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Among the most exciting challenges in modern physics is the identification of the neutrino mass ordering. Physicists from the Cluster of Excellence PRISMA+ at Johannes Gutenberg University Mainz (JGU) play a leading role in a new study that indicates that the puzzle of neutrino mass ordering may finally be solved in the next few years. This will be thanks to the combined performance of two new neutrino experiments that are in the pipeline—the Upgrade of the IceCube experiment at the South Pole and the Jiangmen Underground Neutrino Observatory (JUNO) in China. They will soon give the physicists access to much more sensitive and complementary data on the neutrino mass ordering.

Neutrinos are the chameleons among elementary particles

Neutrinos are produced by natural sources—in the interior of the sun or other astronomical objects, for example—but also in vast quantities by nuclear power plants. However, they can pass through normal matter—such as the human body—practically unhindered without leaving a trace of their presence. This means that extremely complex methods requiring the use of massive detectors are needed to observe the occasional rare reactions in which these 'ghost particles' are involved.

Neutrinos come in three different types: electron, muon and tau neutrinos. They can change from one type to another, a phenomenon that scientists call 'neutrino oscillation'. It is possible to determine the mass of the particles from observations of the oscillation patterns. For years now, physicists have been trying to establish which of the three neutrinos is the lightest and which is the heaviest. Prof. Michael Wurm, a physicist at the PRISMA+ Cluster of Excellence and the Institute of Physics at JGU, who is playing an instrumental role in setting up the JUNO experiment in China, explains: "We believe that answering this question will contribute significantly towards enabling us to gather long-term data on the violation of matter-antimatter symmetry in the neutrino sector. Then, using this data, we hope to find out once and for all why matter and anti-matter did not completely annihilate each other after the Big Bang."

Global cooperation pays off

Both large-scale experiments use very different and complementary methods in order to solve the puzzle of the neutrino mass ordering. "An obvious approach is to combine the expected results of both experiments," points out Prof. Sebastian Böser, also from the PRISMA+ Cluster of Excellence and the Institute of Physics at JGU, who researches neutrinos and is a major contributor to the IceCube experiment.

No sooner said than done. In the current issue of the journal *Physical Review D*, researchers from the IceCube and the JUNO collaboration have published a combined analysis of their experiments. For this, the authors simulated the predicted experimental data as a function of the measuring time for each experiment. The results vary depending on whether the neutrino masses are in their normal or reversed (inverted) order. Next, the physicists carried out a statistical test, in which they applied a combined analysis to the simulated results of both experiments. This revealed the degree of sensitivity with which both experiments combined could predict the correct order, or rather rule out the wrong order. As the observed oscillation patterns in JUNO and IceCube depend on the actual neutrino mass ordering in a way specific to each experiment, the combined test has a discriminating power significantly higher than the individual experimental results. The combination will thus permit to definitively rule out the incorrect neutrino mass ordering within a measuring period of three to seven years.

"In this case, the whole really is more than the sum of its parts," concludes Sebastian Böser. "Here we have clear evidence of the effectiveness of a complementary experimental approach when it comes to solving the remaining neutrino puzzles." "No experiment could achieve this by itself, whether it's the IceCube Upgrade, JUNO or any of the others currently running," adds Michael Wurm. "Moreover it just shows what neutrino physicists here in Mainz can achieve by working together."

More information: M. G. Aartsen et al, Combined sensitivity to the neutrino mass ordering with JUNO, the IceCube Upgrade, and PINGU, *Physical Review D* (2020). DOI: 10.1103/PhysRevD.101.032006

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