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The slowest radioactive decay ever observed directly

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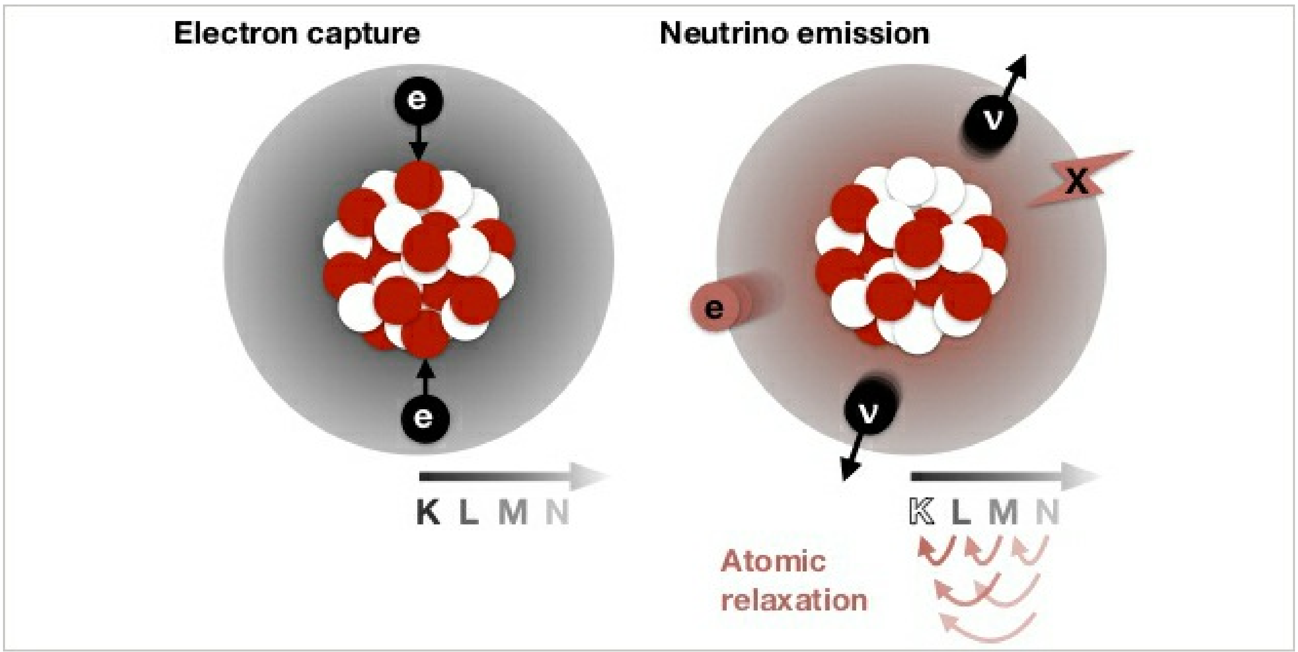

In double electron capture, two electrons and two protons simultaneously convert into two neutrons and two neutrinos. X-rays are emitted when the electron vacancies are subsequently filled.

The XENON1T detector was mainly built to detect interactions of dark matter particles, and has recently placed the world's most stringent limits on the coherent elastic scattering of weakly interacting massive particles with xenon nuclei. XENON1T, which was operated underground at the Laboratori Nazionali del Gran Sasso, used 3.2 tons of ultra-pure liquid xenon, of which 2 tons were within the sensitive region of the time projection chamber (TPC): a cylindrical volume that is observed by 248 photomultiplier tubes. The TPC, made out of materials selected for ultra-low radioactivity levels, allowed for the measurement of the scintillation and ionisation signals induced by a particle interaction - the latter by converting ionisation electrons into light by means of proportional scintillation. It provided a calorimetric energy measurement, a 3D position reconstruction, and the scatter multiplicity of events.

The data recorded between February 2, 2017 and February 8, 2018 as part of the dark matter search, were also analysed for the double electron capture (2νECEC) of 124-Xe with emission of two neutrinos. This is a very rare nuclear process that escaped detection for decades. Two protons in the 124-Xe nucleus simultaneously convert into neutrons by the absorption of two electrons, mostly from the K-shell, and the emission of two electron neutrinos. After the electron capture, the filling of the vacancies results in a detectable cascade of X-rays and Auger electrons at 64.3 keV. The nuclear binding energy Q = 2857 keV released in the process is carried away mostly by the two neutrinos, which are not seen within the detector.

During the analysis process, the XENON1T data in the energy region from 56 keV to 72 keV were blinded, thus inaccessible for analysis, and the energy scale around the expected signal at E_0 = (64.3 ± 0.6) keV was calibrated using mono-energetic lines from injected sources such as 83m-Kr, from neutron-activated xenon isotopes as well as γ-rays from radioactive decays in detector materials. Upon unblinding, 126 events from 2νECEC were observed, which - taking into account the isotopic abundance of 124-Xe, the fiducial volume containing 1.5 tons of natural xenon, and the measurement time - yields a half-life of 1.8 x 10^{22} years, the longest half-life ever measured directly. This measurement demonstrates the sensitivity of large xenon TPCs to ultra-rare decays, and sets the stage for 2νECEC searches that can complement double beta-decay experiments in the search for Majorana neutrinos.

Learn more about

Homepage image: Credits XENON1T.