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New direct bound on the local neutrino background overdensity with the first two KATRIN runs

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We present a direct search for cosmic relic neutrinos using data acquired during the first two science runs of the KATRIN experiment in 2019. Beta decay electrons originating from a high-purity molecular tritium gas source are analyzed by a high-resolution MAC-E filter near the endpoint at 18.57 keV. This measurement is sensitive to a local relic neutrino overdensity ratio of $\eta < 9.7 \cdot 10^{10}/\alpha$ $(1.1 \cdot 10^{11}/\alpha)$ at a confidence level of 90% (95%) with $\alpha = 1$ (0.5) for Majorana neutrinos (Dirac). A adjustment of the integrated electron tritium spectrum over a restricted area around the endpoint, taking into account the relic neutrino captures in the tritium source, yields no significant overdensity. This achievement is an improvement of the previous neutrino mass experiments at Los Alamos and Troitsk.

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1. Relic Neutrinos and their capture on radioactive nuclei

Neutrinos decoupled from other particles of the standard model when the universe was about one second old. The existence of a cosmic background (or relic) of neutrinos (CνB) is forecast with high confidence. Its mean density is expected to be 56 cm^{-3} per species in the whole universe. The relic neutrinos can be expected to aggregate around galaxies. Standard predictions of the local overdensity ratio of relic neutrinos η range from 1.2 to 20 for neutrino masses less than 0.6 electronvolt, rising with neutrino mass and depending on the putative density profile of the Milky Way [1]. A direct measurement of CνB continues to be one of the most challenging task in neutrino physics and would yield direct information about the ancient history of the universe. Relic neutrinos can interact with radioactive nuclei, such as tritium, via the neutrino capture reaction $\nu_e + N_Z^A \longrightarrow N_{Z+1}^A + e^-$ [2–4]. The Karlsruhe Tritium Neutrino Experiment (KATRIN) offers a high-precision measurement of the electronic spectrum of tritium β decay, $^3\mathrm{H} \rightarrow {}^3\mathrm{He}^+ + \mathrm{e}^- + \overline{\nu}_e$ (endpoint $E_0 = 18.57\,\mathrm{keV}$, half-life $t_{1/2} = 12.32\,\mathrm{yr}$). Used principally to measure the effective neutrino mass m_ν, KATRIN holds an upper limit of $m_\nu < 0.8\,\mathrm{eV}$ with a confidence level of 90% [5] as a result of the first two science campaigns of 2019. By employing the exact same dataset [5–7], KATRIN is placing new constraints on the local overdensity of η relic neutrinos.

2. First and Second KATRIN scientific runs in 2019

KATRIN [8–12] combines a windowless gaseous molecular tritium source (WGTS), with two spectrometers based on the principle of magnetic adiabatic collimation with electrostatic filtering (MAC-E-filter). High-purity tritium gas is continuously injected into the WGTS at 30 K. The gas diffuses from the center to the ends of the WGTS where it is pumped out by several turbomolecular pumps and a cryotrap in the pumping section. In the spectrometer section, using the MAC-E-filter technique, electrons (with charge $q = -e$) are guided by the magnetic field and precisely filtered by an electrostatic barrier (energy threshold qU). Only electrons whose energy is sufficient to overcome this barrier are transmitted to the focal plane detector. By varying the High Voltage (HV) setting U, the tritium β-decay spectrum is measured in an integral mode, with an energy resolution of $\Delta E = 2.8\,\mathrm{eV}$ at E_0. Transmitted electrons are subsequently counted, as a function of qU, by the focal plane silicon detector, segmented in 148 pixels.

The first science run (KNM1) was carried out from April 10 to May 13, 2019. All experimental details were already reported in [6]. In this search for relic neutrinos, we analyze the region from 37 eV below E_0 (22 HV set points) to 49 eV above. The resulting integral spectrum includes $1.48 \cdot 10^6$ β-decay electrons below E_0. The second measurement campaign (KNM2) was conducted from September 27 to November 19, 2019. The tritium source was operated at its nominal activity of $9.5 \cdot 10^{10}\,\mathrm{Bq}$ (13.0 µg of tritium). It yielded $3.68 \cdot 10^6$ β-decay electrons in the analysis range [E_0-40 eV , E_0], which is more than twice the number of KNM1.

3. KATRIN search for relic neutrinos

The neutrino capture differential spectrum can be approximated as a Gaussian model centered at $E_0 + m_\nu$, and with an intensity describing the overdensity ratio η. The main backgrounds arise from the irreducible β spectrum and the nominal KATRIN background. The relic neutrino capture rate on a single tritium nucleus is $R^\alpha_\mathrm{cap} = 4.2 \cdot 10^{-25} \cdot \alpha\ \mathrm{yr}^{-1}$ for $\eta = 1$ [13], with $\alpha = 0.5$ for non-relativistic Dirac neutrinos, and $\alpha = 1$ for Majorana neutrinos (our reference in what follows). We perform a global fit over the analysis range $[E_0 - 37\,\mathrm{eV},\ E_0 + 49\,\mathrm{eV}]$, treating $A_\mathrm{s},\ E_0,\ m^2_\nu,\ R_\mathrm{bg}$

and η as free fit parameters. A_s is the normalization of the tritium β-decay. R_{bg} the background, independently of the retarding potential. E_0 is the endpoint, and m_ν the effective β decay neutrino mass. Regarding the main observable η, we get for the KNM1 campaign a best fit value of $(3.7 \pm 1.4) \cdot 10^{11}$ with an uncertainty entirely dominated by the statistics. For the second campaign KNM2, we find a best fit value of $\eta = (-5.8 \pm 5.2) \cdot 10^{10}$ with an uncertainty on η still dominated by statistics. In both cases, the dominant systematic uncertainty is due to the background. We then proceed to combine these results into a final result with the full 2019 KATRIN dataset. No significant relic neutrino signal is observed and the parameter η is shown to be less than $9.7 \cdot 10^{10}/\alpha$ ($1.1 \cdot 10^{11}/\alpha$, $1.3 \cdot 10^{11}/\alpha$) at 90% (95%, 99%) for neutrino masses below 1 eV. This analysis comprises $5.16 \cdot 10^6$ β-decay electrons and $0.72 \cdot 10^6$ background events below E_0.

KATRIN is proceeding to meet the goal of 1000 days of data collected by 2024. The current high background metrics have triggered a re-evaluation of the final sensitivity on the η relic neutrino overdensity. We report an updated sensitivity prediction of $\eta < 1.0 \cdot 10^{10}/\alpha$ ($1.4 \cdot 10^{10}/\alpha$, $1.8 \cdot 10^{10}/\alpha$) at 90% (95%, 99%) for a background rate of 130 mcps on all detector pixels.

References

[1] Andreas Ringwald. How to detect big bang relic neutrinos? 2005.

[2] Steven Weinberg. Universal neutrino degeneracy. *Phys. Rev.*, 128:1457–1473, Nov 1962.

[3] Alfredo G. Cocco, Gianpiero Mangano, and Marcello Messina. Probing low energy neutrino backgrounds with neutrino capture on beta decaying nuclei. *JCAP*, 06:015, 2007.

[4] Amand Faessler et al. Can one measure the cosmic neutrino background? *International Journal of Modern Physics E*, 26(01n02):1740008, Jan 2017.

[5] M. Aker et al. Direct neutrino-mass measurement with sub-electronvolt sensitivity. *Nature Phys.*, 18(2):160–166, 2022.

[6] M. Aker et al. Improved upper limit on the neutrino mass from a direct kinematic method by katrin. *Phys. Rev. Lett.*, 123:221802, Nov 2019.

[7] M. Aker et al. Bound on 3+1 active-sterile neutrino mixing from the first four-week science run of katrin. *Physical Review Letters*, 126(9), Mar 2021.

[8] J. Angrik et al. Katrin design report. *FZKA scientific report*, (7090):1, 2005.

[9] M. Arenz et al. First transmission of electrons and ions through the KATRIN beamline. *JINST*, 13(04):P04020, 2018.

[10] Florian Priester, Michael Sturm, and Beate Bornschein. Commissioning and detailed results of KATRIN inner loop tritium processing system at Tritium Laboratory Karlsruhe. *Vacuum*, 116:42–47, 2015.

[11] M. Arenz et al. The KATRIN Superconducting Magnets: Overview and First Performance Results. *JINST*, 13(08):T08005, 2018.

[12] M. Arenz et al. Calibration of high voltages at the ppm level by the difference of ^{83m}Kr conversion electron lines at the KATRIN experiment. *Eur. Phys. J. C*, 78(5):368, 2018.

[13] Rastislav Hodak et al. Beta decaying nuclei as a probe of cosmic neutrino background. 2011.