Local density of relic neutrinos and its implications for PTOLEMY

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Based on [1], in collaboration with S. Gariazzo, J. Lesgourgues and S. Pastor

Introduction

Relic neutrinos are a prediction of the Standard Cosmological Model. Their **existence** is **indirectly probed** through the effective number of neutrinos, a parameter whose experimental determination, close to 3, is compatible with the presence of three active neutrino species in the early Universe. On the other hand, we know **from neutrino oscillations** that **at least two of them have** a **mass** large enough to be **non-relativistic today**, due to their energy dilution after decoupling because of cosmic expansion. Therefore they **can be trapped in the gravitational potential of our galaxy**. Here we present the calculation of the local overdensity of relic neutrinos due to gravitational clustering in the Milky Way (MW) and we discuss the implications for an experiment aiming at their direct detection.

N-one-body simulations

We use **N-one-body** simulations to follow the gravitational clustering of relic neutrinos in the MW. The entire phase-space of neutrinos is sampled running one single particle N times. This is possible as long as the following assumptions hold:

- the only interaction that matters is gravitational;
- DM and baryons evolve independently of neutrinos;
- neutrino evolution is also independent of other neutrinos.

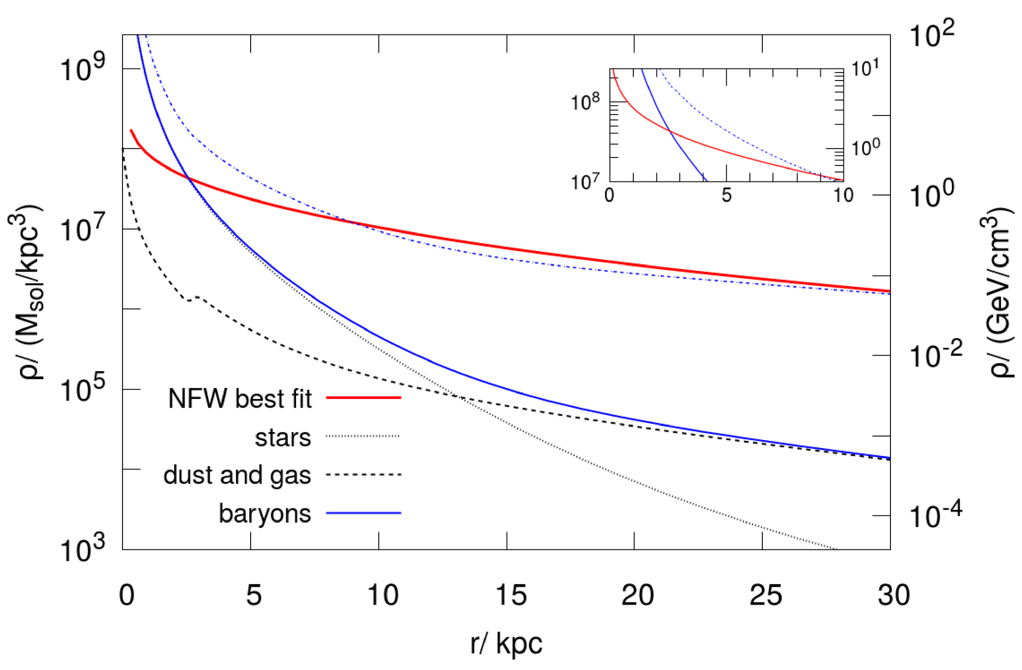
Adding baryons

The mass of baryons in the MW is expected to be much smaller than that of DM, but their gravitational attraction is important at the radial distance of the Solar System.

We add baryons from the observation-driven model in [4].

A **spherically symmetric profile** is assumed, which is adequate because:

- it reduces computational time,
- the height of the central region is comparable to its width,
- the **leading uncertainties come from the DM distribution**.



The redshift evolution is obtained from N-body simulations [5].

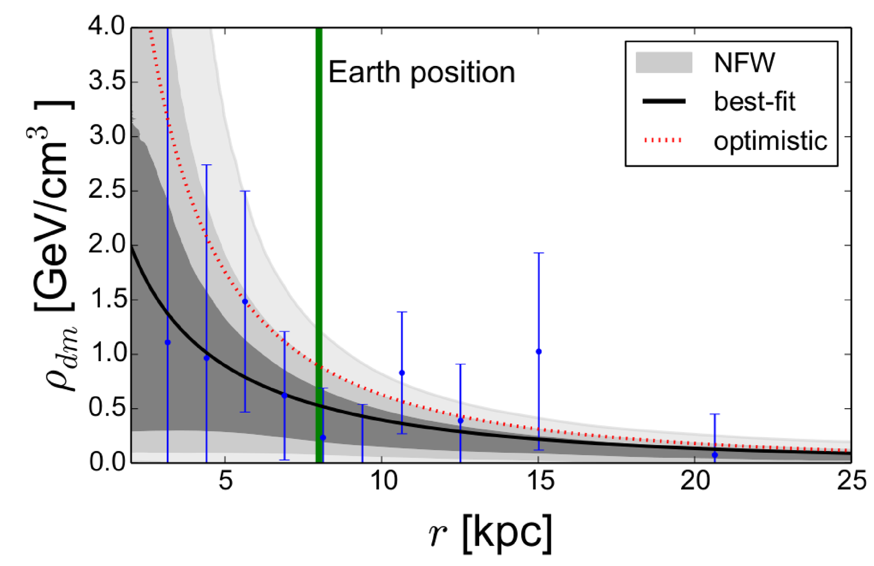
Modeling the dark matter halo in the Milky Way

We fit data of matter overdensities in the MW at different radii, obtained by comparing the rotational velocities of bound objects with respect to the luminous mass [2].

We use two distinct profile parameterizations:

- **NFW**, which includes an inner cusp;
- **Einasto**, which does not diverge.

The evolution of the dark matter (DM) profiles are obtained following the results of N-body simulations [3].



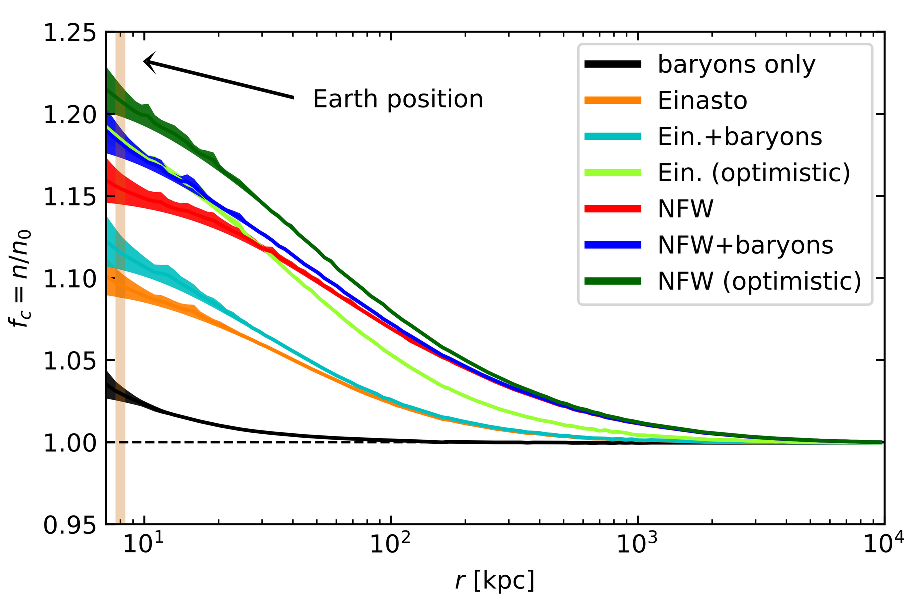
Relic neutrino clustering ($m_\nu = 60$ meV)

Results of the computation of the clustering in terms of the overdensity factor f_c for a neutrino species with a mass

close-to-minimal $m_\nu = 60$ meV.

Different models of matter density in our galaxy are compared.

Because of the presence of the central cusp, the overdensity is larger for a NFW parameterization.



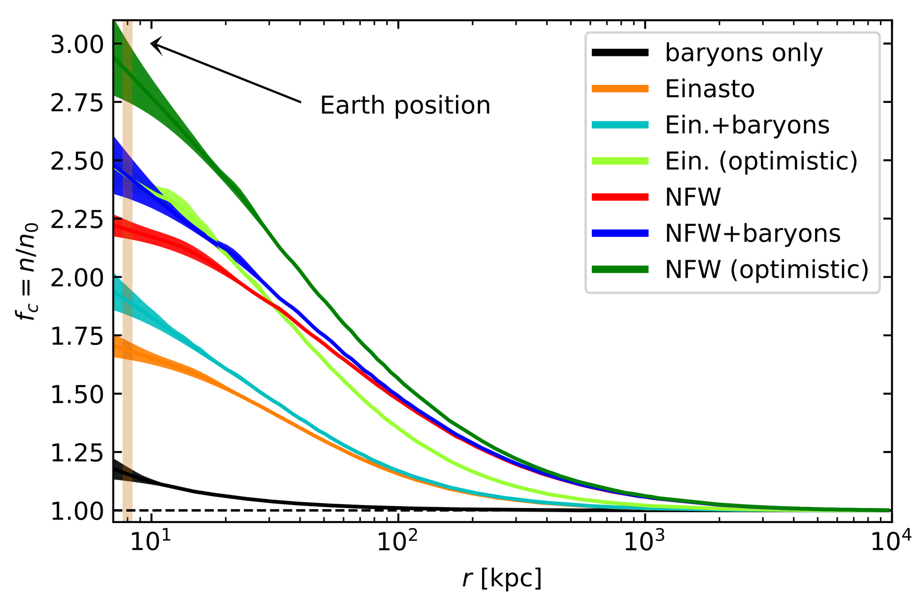
Relic neutrino clustering ($m_\nu = 150$ meV)

Results of the computation of the clustering in terms of the overdensity factor f_c for a neutrino species with a mass

degenerate $m_\nu = 150$ meV.

These masses are at the limit of allowed neutrino masses from cosmological measurements.

Different models of matter density in our galaxy are compared.



PTOLEMY

PonTecorvo Observatory for Light, Early-universe, Massive-neutrino Yield [6].

It is a proposed experiment aiming at relic neutrino detection with the following features:

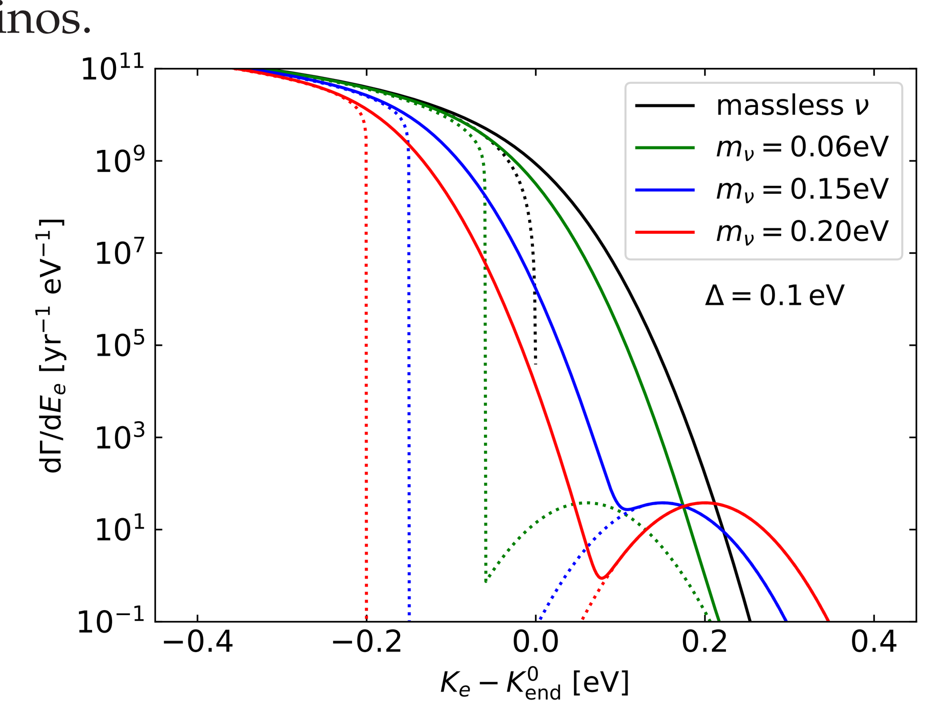
- Based on ν capture on tritium $\nu_e + {}^3\mathrm{H} \to {}^3\mathrm{He} + e^-$
- Total tritium mass of $\sim 100\,\mathrm{g}$
- Expected energy resolution of $\Delta \sim 100 - 150\,\mathrm{meV}$

The characteristic signature that is produced by the relic neutrino capture is a **peak in the energy** spectrum of the **released electron**, placed **$\sim 2m_\nu$ above the true β-decay endpoint**.

Implications for a PTOLEMY-like experiment

In the **table we show the relic neutrino overdensities** for different galactic halo models and neutrino masses, as well as the corresponding **expected number of neutrino capture events $\Gamma_{C\nu B}$**. We also distinguish between Dirac and Majorana nature of neutrinos.

masses (meV)	matter halo	overdensity f_c {best fit ǀ	$\Gamma^{D}_{C\nu B}$ (yr^{-1}) best fit + baryons ǀ	$\Gamma^{M}_{C\nu B}$ (yr^{-1}) optimistic}
any	any	no clustering	4.06	8.12
degenerate	NFW	2.18 ǀ 2.44 ǀ 2.88	8.8 ǀ 9.9 ǀ 11.7	17.7 ǀ 19.8 ǀ 23.4
$m_{\nu_{1,2,3}} = 150$	Einasto	1.68 ǀ 1.87 ǀ 2.43	6.8 ǀ 7.6 ǀ 9.9	13.6 ǀ 15.1 ǀ 19.7
minimal (IO)	NFW	1.15 ǀ 1.18 ǀ 1.21	4.07 ǀ 4.08 ǀ 4.08	8.15 ǀ 8.15 ǀ 8.16
$m_{\nu_3} = 60$	Einasto	1.09 ǀ 1.12 ǀ 1.18	4.07 ǀ 4.07 ǀ 4.08	8.14 ǀ 8.14 ǀ 8.15
minimal (NO)	NFW	1.15 ǀ 1.18 ǀ 1.21	4.66 ǀ 4.78 ǀ 4.89	9.31 ǀ 9.55 ǀ 9.77
$m_{\nu_{1,2}} = 60$	Einasto	1.09 ǀ 1.12 ǀ 1.18	4.42 ǀ 4.54 ǀ 4.78	8.84 ǀ 9.07 ǀ 9.55



However, if neutrino masses turn out to be close to minimal, the most important issue that a PTOLEMY-like experiment must address regards the energy resolution.

In order to distinguish a ν-capture event from the β-decay background, **an energy resolution of at least $\Delta \lesssim 0.7 m_\nu$ is required** [7].

Conclusions and acknowledgments

Gravitational clustering of relic neutrinos (non-relativistic nowadays) **leads to a local overdensity** from $10\% - 20\%$ for $m_\nu = 60\,\mathrm{meV}$ to a factor $2 - 3$ for larger masses allowed by cosmology. This **enhances the number of events expected in a PTOLEMY-like experiment**, which in summary depends on their mass scale and ordering, their nature (Dirac or Majorana) and, in particular, the true distribution of matter (especially that of DM) in the Milky Way.

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