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The clustering of cosmic neutrinos in the Milky Way

Rationale

Massive neutrinos of the cosmic background feel the gravitational attraction of dark matter halos and galaxies. We measure the clustering of these neutrinos in the Solar vicinity in view of future direct detection experiments, such as PTOLEMY. We extend previous works (Ringwald *et al.*, 2004, De Salas *et al.*, 2017, Zhang *et al.*, 2017) by:

- modelling the gravitational potential of the Milky Way (MW) in full 3D;
- considering the presence of nearby structures, like the Virgo cluster and the Andromeda galaxy, which may have an impact on the total amount of neutrinos at Earth's position.

Method

We use the **N-one-body approach** (Ringwald & Wong, 2004): one neutrino at a time is launched in the gravitational potential of the MW. Neutrinos are assumed not to interact with each other and not to affect the evolution of the dark matter halo of the MW.
We extend previous works, which have only explored the spherical symmetric case, with a full 3D treatment.
The clustering of neutrinos in the Solar neighborhood is computed as follows:

- particles are launched at $z = 0$ from the Sun's position;
- particles are traced back in time to obtain positions and momenta at $z = 4$;
- we construct a matrix that maps the initial momenta to the final ones;
- each particle is assigned a weight in order to reproduce a Fermi-Dirac distribution at $z = 4$;
- according to these weights, we reconstruct the neutrino density today at Earth.

Computation of the gravitational potential

We model the full 3D gravitational potential of the MW by solving the Poisson equation through Fourier transforms:

$$\Phi(\boldsymbol{r}) = -4\pi G \int \frac{\mathrm{d}^3\mathbf{k}}{(2\pi)^3} \frac{e^{i\mathbf{k}\cdot\mathbf{r}}}{|\mathbf{k}|^2} \int \mathrm{d}^3\mathbf{s}\ \rho(\mathbf{s})\ e^{i\mathbf{k}\cdot\mathbf{s}}.$$

We assume:

- a Navarro-Frenk-White (NFW) or an Einasto profile for the dark matter halo of the MW;
- a spherical stellar bulge with a De Vaucouleurs profile;
- an exponential profile in both radial and zenithal directions for all other baryonic components (i.e. gas, stars).

The density parameters and their time evolution are taken from Misiriotis *et al.* (2006), McMillan (2016), Marinacci *et al.* (2013) and Dutton *et al.* (2014).
We also include the Virgo cluster and the Andromeda galaxy, both modelled through a NFW profile. In fact, N-body simulations showed that neutrino halos are more extended than dark matter (Villaescusa-Navarro *et al.*, 2011) so that nearby massive structures may contribute to the total density of neutrinos at Earth's position. The geometry of the system we consider is sketched in Fig. 1.

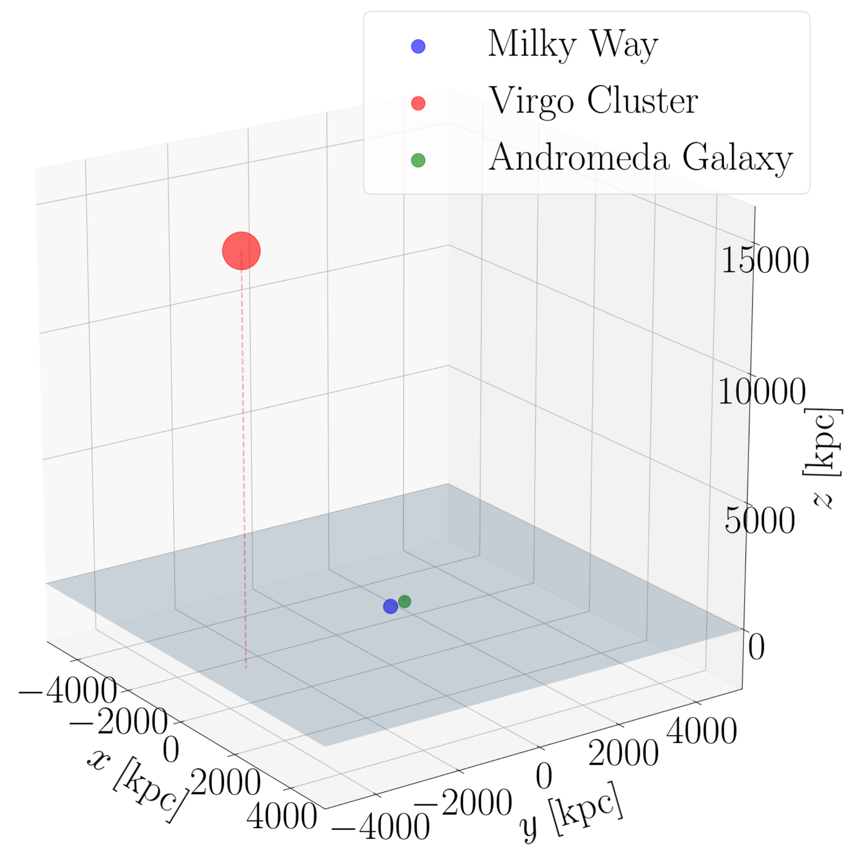

Figure 1: Relative position of the MW, the Andromeda galaxy and the Virgo Cluster relative to the former. The size of the dots corresponds the virial radius of the object.

Results

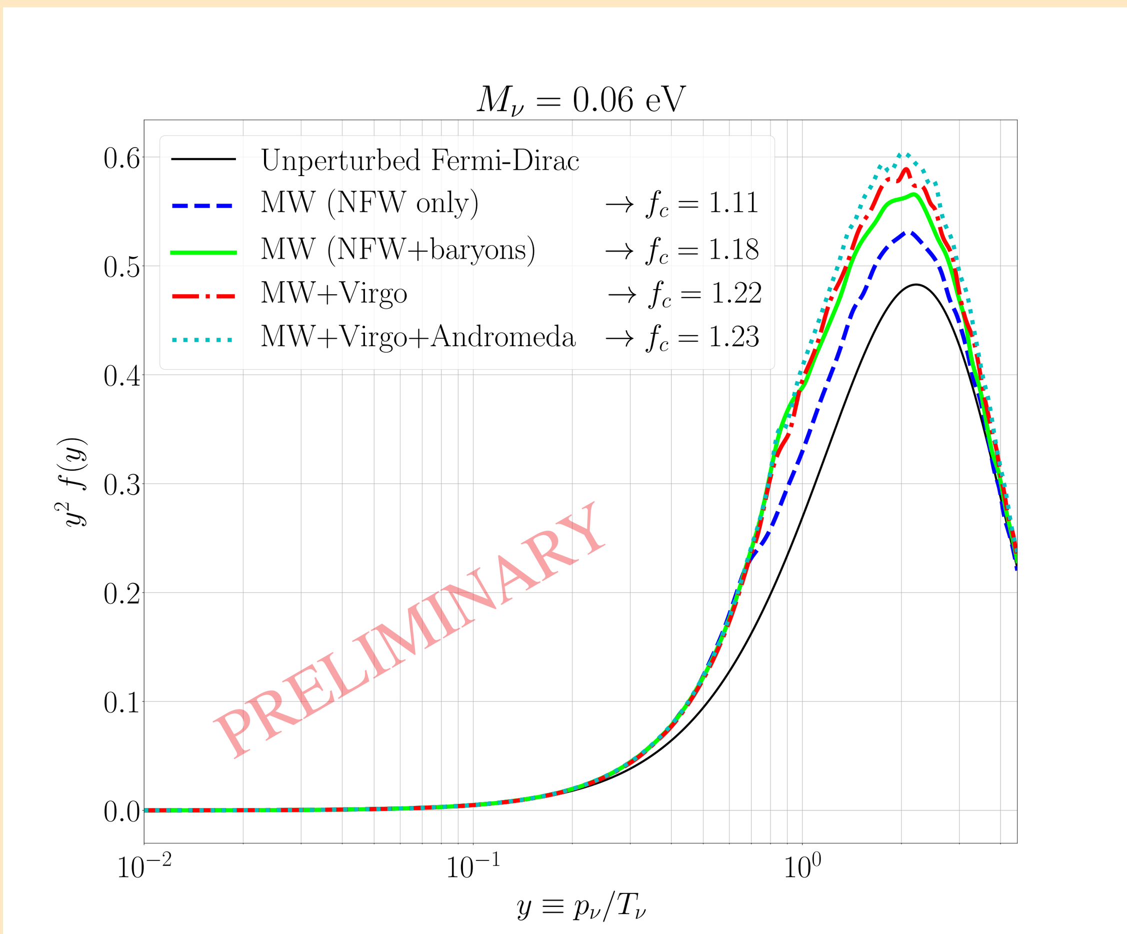

Figure 2: Present neutrino phase-space distribution at the Earth's position for different configurations of the system and $M_\nu = 0.06$ eV. For comparison, the unperturbed Fermi-Dirac distribution, which is taken as our initial distribution at $z = 4$, is plotted in black.

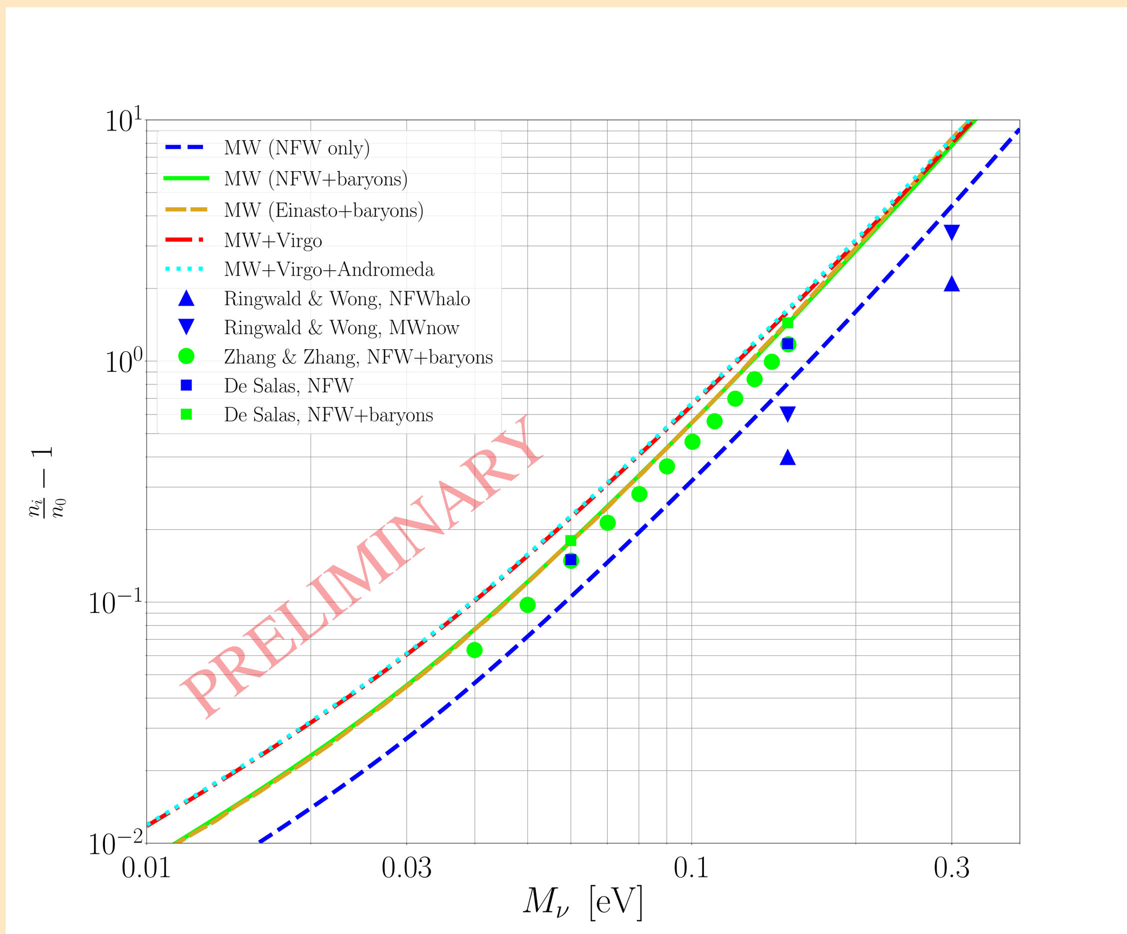

Figure 3: Neutrino overdensity at the Earth's position as function of neutrino mass for different configurations of our system, to which we add the case of Einasto profile instead of a NFW for the MW dark matter halo. Also reported are results from previous works.

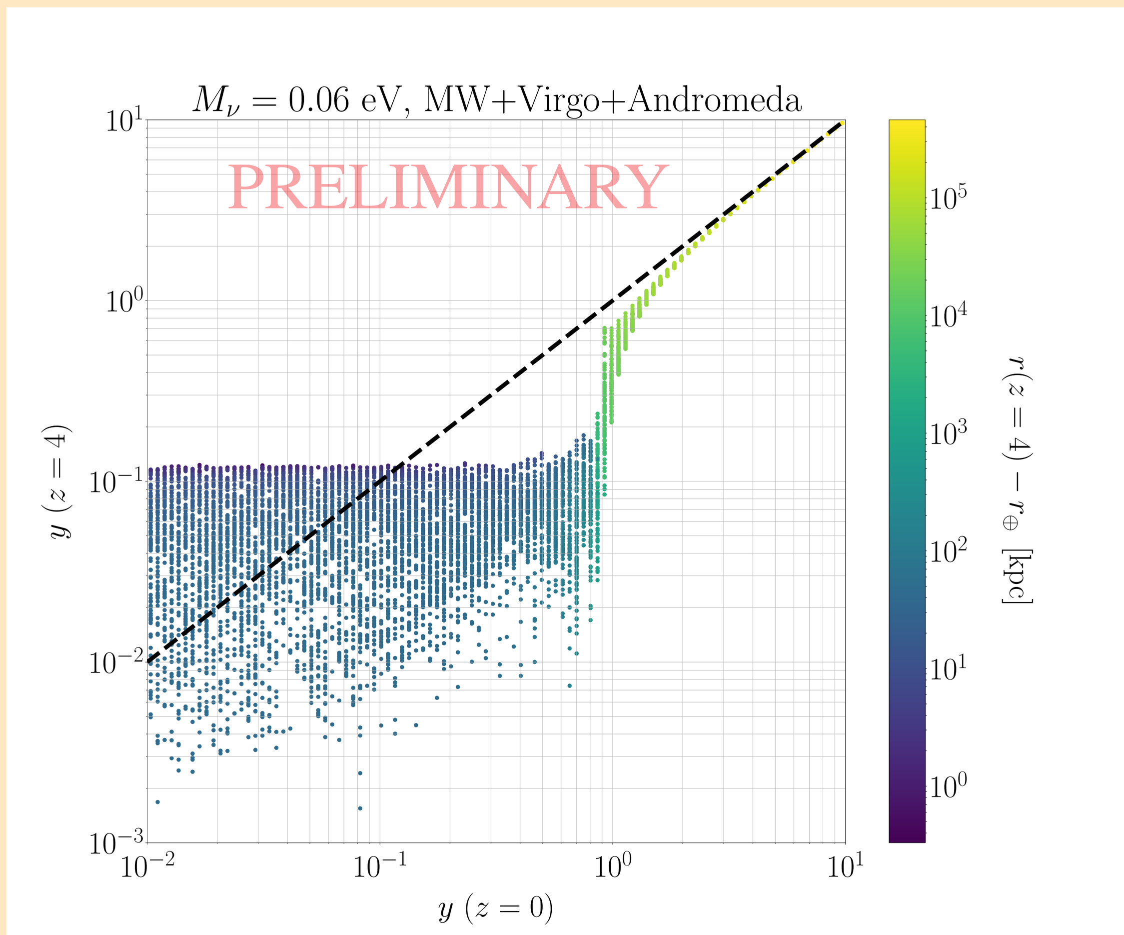

Figure 4: Mapping of initial ($z = 0$, x-axis) to final ($z = 4$, y-axis) momenta for $M_\nu = 0.06$ eV in the MW+Virgo+Andromeda configuration, color-coded by the distance these particles had from Earth at $z = 4$.

The present neutrino phase-space distribution in the Solar vicinity (shown in Fig. 2) depends on the gravity sources we consider: the more objects we add in our configuration, the higher the clustering factor. The MW dark matter halo contributes less than in De Salas *et al.* (2017), while the presence of baryons in the MW carries a larger contribution (see Fig. 3). Also, assuming an Einasto profile rather than a NFW for the MW does not have any relevant impact.

For $M_\nu = 0.06$ eV, the Virgo cluster enhances the clustering factor by $\sim 4\%$ with respect to the MW-only configuration; on the other hand the presence of Andromeda is almost negligible. Finally, Fig. 4 shows the mapping between initial and final momenta in our simulations: high energetic neutrinos pass undisturbed through the MW, while the turnaround point at $y \sim 1$ roughly corresponds to the escape velocity of the MW.

Conclusions

- 69, not 56, neutrinos per cm^3 per flavor in the Solar vicinity for $M_\nu = 0.06$ eV ($f_c = 1.23$);
- PTOLEMY: future direct detection experiment, exploits neutrino capture in tritium and measures recoil of electron on graphene sheet;
- Rate of interaction:

$$\Gamma_{C\nu B} = \sum_{i=1}^{N_\nu} |U_{ei}|^2\ f_c(M_{\nu,i})\ \left[n_{i,0}(\nu_{h_R}) + n_{i,0}(\nu_{h_L})\right]\ N_T\ \bar{\sigma} \sim 10\ \mathrm{yr}^{-1}$$

- Assuming Planck 2018 results ($M_\nu < 120$ meV at 95% C.L.), 2-σ detection possible only for energy resolution $\Delta \lesssim \left(0.86\ \frac{M_\nu}{\mathrm{meV}} - 14\right)$ meV, almost prohibitive to achieve.

References

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