Reconstruction of Cosmic Neutrino Background anisotropies

Willem Elbers, Carlos S. Frenk, Adrian Jenkins, Baojiu Li, Silvia Pascoli, Jens Jasche, Guilhem Lavaux and Volker Springel

willem.h.elbers@durham.ac.uk | www.willemelbers.com | arXiv:2307.03191

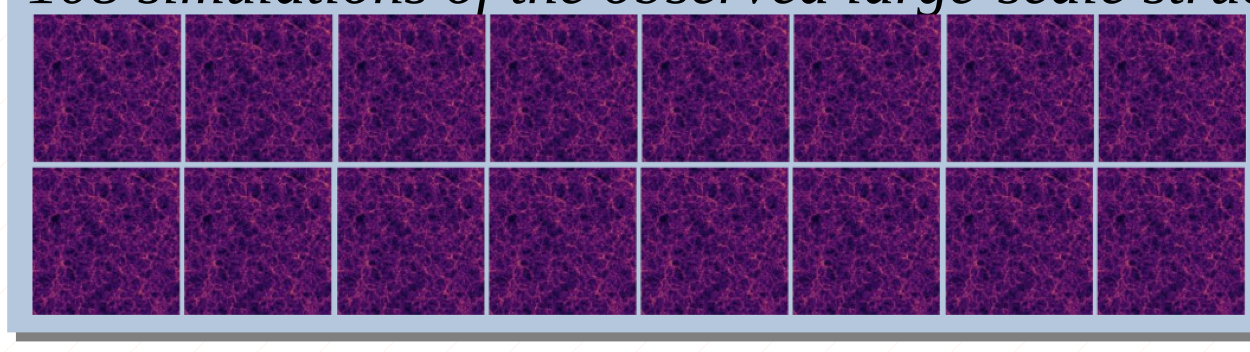
INTRODUCTION

- The Standard Model predicts the existence of a Cosmic Neutrino Background (CNB), consisting of neutrinos from the Early Universe that decoupled at $t = 1$ s. Despite strong indirect evidence, direct detection remains an elusive target.
- Gravitational clustering of neutrinos can boost the event rate of direct capture experiments like PTOLEMY. Previous studies have focussed on the clustering effect of the Milky Way, but not the observed large-scale distribution of galaxies.
- In addition to changing the event rate, the large-scale structure also imprints a strong anisotropy signal. We present a detailed analysis of this signal and explore its potential as a novel cosmological probe.

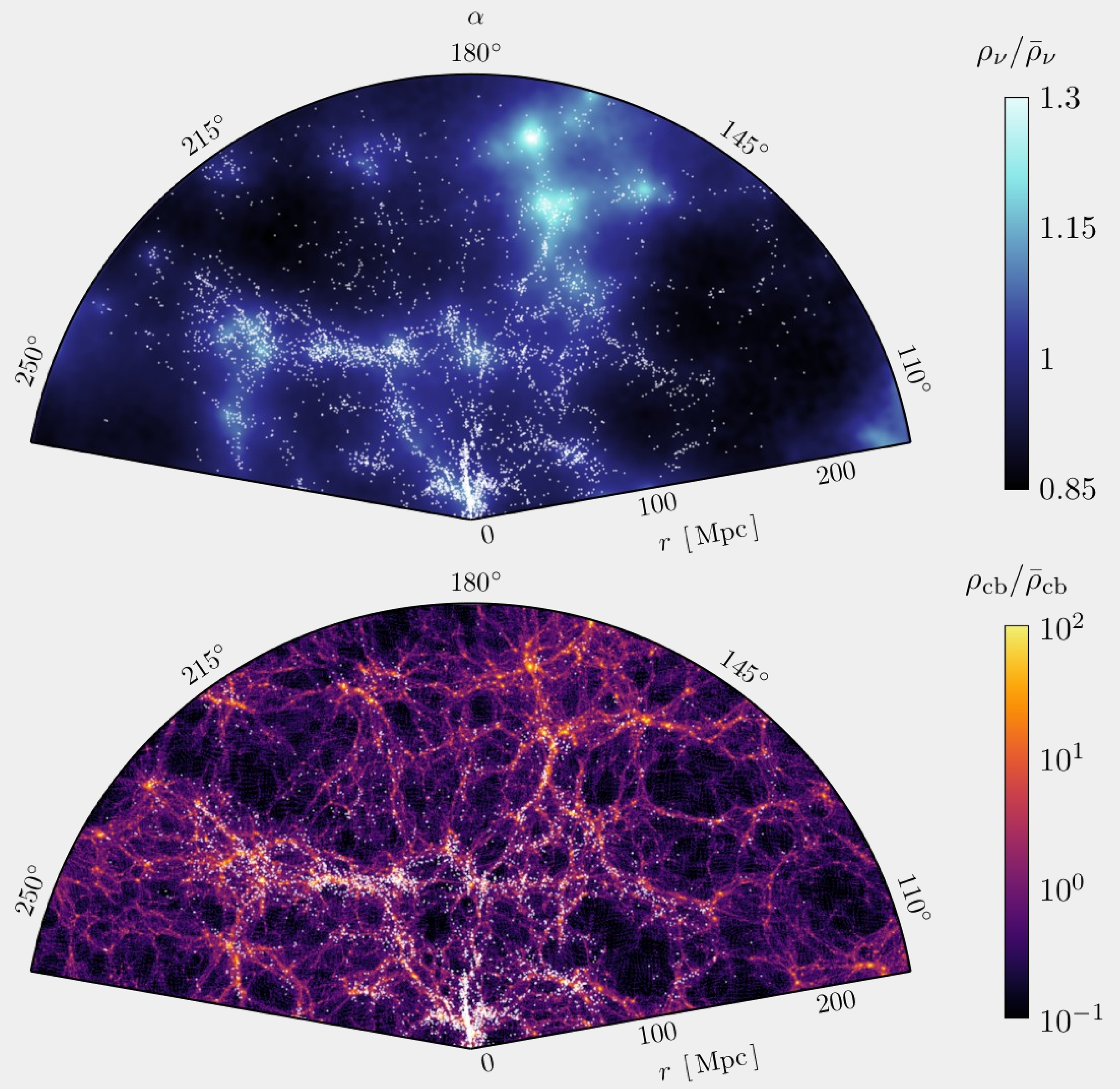
METHODS

We reconstruct the phase-space distribution of relic neutrinos from the 3D distribution of matter in the Local Universe. Our analysis relies on cosmological simulations and forward modelling of the 2M++ galaxy catalogue, which contains 69 160 galaxies within 200 Mpc/h of the Milky Way

108 simulations of the observed large-scale structure

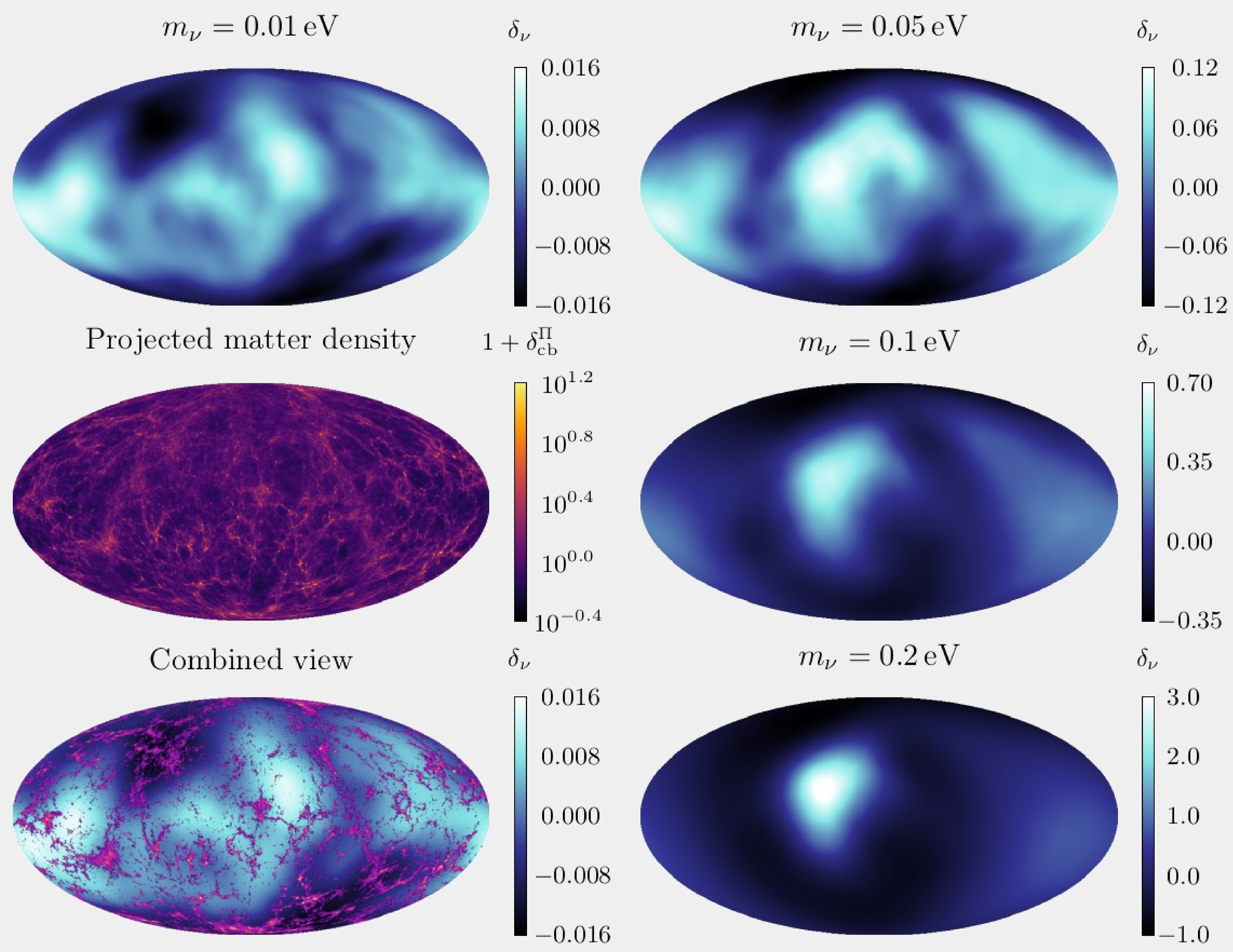


CONSTRAINED SIMULATIONS OF THE LOCAL UNIVERSE



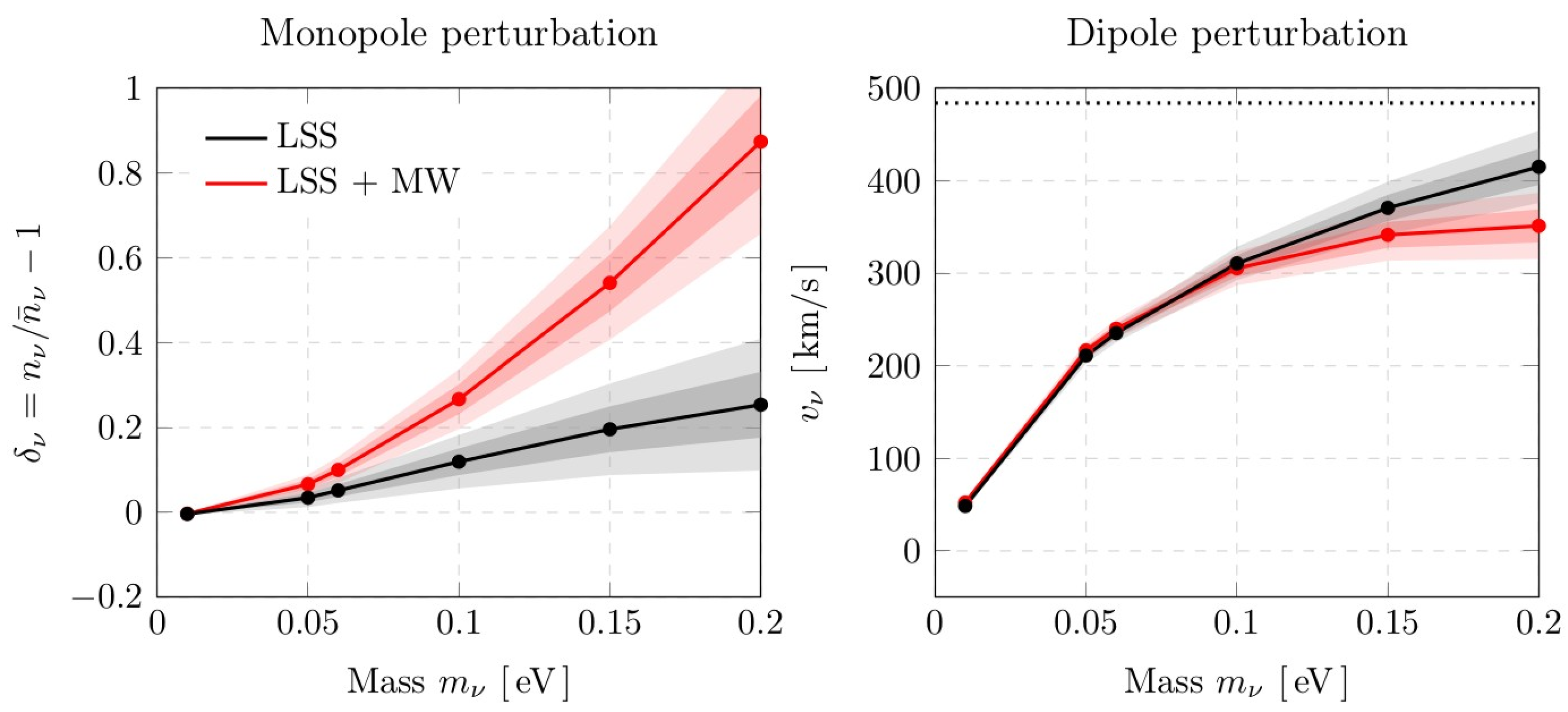
Slices of the expected neutrino (top) and dark matter (bottom) densities in a sector of the sky (right ascension $100^\circ \leq \alpha \leq 260^\circ$ within $r \leq 250$ Mpc), assuming a neutrino mass of $m_\nu = 0.06$ eV. The white dots are galaxies from the 2M++ catalogue. From Earth, one would see a deficit in neutrino flux along lines of sight that intersect massive structures, due to the trapping of neutrinos in the surrounding neutrino clouds.

RECONSTRUCTION OF LOCAL ANISOTROPIES



Angular anisotropies in the neutrino number density for $m_\nu = 0.01$ eV (top left) and for $m_\nu \in \{0.05, 0.1, 0.2\}$ eV (right). We also show the projected matter density within 200 Mpc of the observer, both separately (middle left) and overlaid on the top of the neutrino density for $m_\nu = 0.01$ eV (bottom left). We observe that the projected dark matter density and the local neutrino density are anti-correlated on the sky. The correlation depends on momentum, enabling a form of neutrino tomography.

CLUSTERING EFFECT ON THE MONOPOLE AND DIPOLE



(Left) The predicted enhancement of the local neutrino density as a result of the observed large-scale structure in the local Universe (LSS, black) and the combined effect of the LSS and the Milky Way (LSS + MW, red). (Right) The effect on the bulk neutrino velocity.

CONCLUSIONS

- Of relevance to direct capture experiments, we find that the gravitational clustering effect of the large-scale structure on the local number density of neutrinos is more important than that of the Milky Way for neutrino masses < 0.1 eV.
- Nevertheless, we predict that the density of relic neutrinos is close to the cosmic average, with a suppression or enhancement over the mean of (−0.3%, +7%, +27%) for masses of (0.01, 0.05, 0.1) eV. This implies no more than a marginal increase in the event rate.
- We also find that the angular distribution of neutrinos is anti-correlated with the projected matter density, due to the capture and deflection of neutrinos by massive structures along the line of sight. We demonstrate how this effect could be used as a cosmological probe.

Related papers:
Elbers et al. (2021), MNRAS, 507, 2614
Jasche & Lavaux (2019), A&A, 625, A64

DiRAC

Durham University