Clustering, lensing and ISW-RS from the neutrino DEMNUni simulations

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Outline

- DEMNUni: the “Dark Energy and Massive Neutrino Universe” project


- “DEMNUni: ISW, Rees-Sciama, and weak-lensing in the presence of massive neutrinos”, Carbone et al. in prep
DEMNUUni simulations (PI Carbone)

- 5x10^6 cpu-hours on BGQ/FERMI at CINECA
- 4 mixed dark matter cosmological simulations for CMB and LSS analysis in the presence of massive neutrinos
- Planck cosmology, \( M_\nu = 0, 0.17, 0.3, 0.53 \) eV (and \( w_0-w_a \) the next yr)
- Gadget-3 with \( \nu \)-particle component (Viel et al. 2010)
- box-side size: 2 Gpc/h
- particle number: 2 x 2048^3 (CDM+\( \nu \))
- CDM mass: 8 x 10^{10} M_\odot/h (neutrino particle mass depends on \( M_\nu \), 1% at \( k=1 \))
- softening length: 20 kpc/h
- starting redshift: \( z_{in} = 99 \)

\[
k_{nr} = 0.018(m_\nu/1\text{eV})^{1/2}\Omega_m^{1/2} h/\text{Mpc}
\]
Comparison between the DEMNUni runs and previous, recent simulations of massive neutrino cosmologies in terms of cold dark matter mass resolution and volume.
DEMNUUni matter power spectra for $M_\nu=0.3$ eV

The large volume and mass resolution of the DEMNUUni simulations allow to test different probes, and their combinations, in massive neutrino cosmologies, at the level of accuracy required by current and future galaxy surveys.
Total matter $P(k)$ ratios wrt LCDM

\[ k_{fs}(z) = 0.82H(z)/H_0/(1+z)^2(m_\nu/1\text{eV}) \ h\text{Mpc}^{-1} \]
Different contributions to the total matter $P(k)$

$P_m(k; z) = (1 - f_\nu)^2 P_{cb}(k; z) + 2 (1 - f_\nu) f_\nu P_{cb,\nu}(k; z) + f_\nu^2 P_\nu(k; z)$

$P_m(k)$ is described at the 1% level accuracy up to $k=1h$/Mpc, assuming the nonlinear evolution of CDM alone, and the linear prediction for the other components.
Perturbation theory vs Simulations

Here the neutrino induced scale-dependence is limited to the linear growth factor, $D(k,z)$, while the perturbation kernels are standard ones. PT works better with $M_{\nu}$

$$P_{mm}^{PT}(k) = (1 - f_\nu)^2 P_{cc}^{PT}(k) + 2 (1 - f_\nu) f_\nu P_{c\nu}^L(k) + f_\nu^2 P_{\nu\nu}^L(k)$$

(RegularizedPT: Bernardau et al 2008, Taruya et al 2012)
Modifications to Halofit

HALOFIT mapping only for CDM, other contributions are assumed to be linear. Shaded areas denote regions beyond the accuracy expected from Halofit.

$$P_{mm}^{HF}(k) = (1 - f_\nu)^2 P_{cc}^{HF}(k) + 2 f_\nu (1 - f_\nu) P_{cc}^{L}(k) + f_\nu^2 P_{\nu\nu}^{L}(k)$$

$$P_{cc}^{HF}(k) = \mathcal{F}_{HF}[P_{cc}^{L}(k)]$$
We recover the $\rho_{cc}$ and $\sigma_{cc}$ prescription from Ichiki & Takada (2012) and Castorina et al. (2014) for the MICE formula. Note the large halo-mass range.
Halo Mass Function: FoF (MICE) vs SO (Tinker)

Castorina, CC et al. 2015

The $\rho_{cc}$ and $\sigma_{cc}$ prescriptions allow to recover the theoretical MF for both FoF and SO halos.
The $\sigma_{cc}$ prescription mitigates the $\nu$-induced scale dependence of the bias at intermediate scales. The halo bias defined with respect to DM presents a spurious scale-dependence due to the difference between the cold and total matter power spectra.

\begin{align*}
    b_c &= \sqrt{\frac{P_{hh}}{P_{cc}}} \\
    b_m &= \sqrt{\frac{P_{hh}}{P_{mm}}}
\end{align*}

Same conclusions for the bias

Castorina, CC et al. 2015
Measurements in redshift space

Castorina, CC et al. 2015

\[ P_{h \cdot h, n}(k) = \frac{(1 + \beta \mu^2)^2}{P_{h \cdot h}(k)} = \sum_{l=0,2,4} P_{h \cdot h, \ell} L_{\ell}(\mu) \]

\[ P_{h \cdot h, 0}(k) = \left( 1 + \frac{2}{3} \beta + \frac{1}{5} \beta^2 \right) P_{h \cdot h}(k) \]
\[ P_{h \cdot h, 2}(k) = \left( \frac{4}{3} \beta + \frac{4}{7} \beta^2 \right) P_{h \cdot h}(k) \]
\[ P_{h \cdot h, 4}(k) = \frac{8}{35} \beta^2 P_{h \cdot h}(k), \]

\( f_c \) and \( \sigma_{cc} \) prescriptions work slightly better than \( f_m \) and \( \sigma_{mm} \) (velocity bias effects are neglected)
The scale dependent growth-rate

Using $b_m$ instead of $b_{cc}$ implies a systematic error on the determination of the growth rate at the level of 1-2\%.

$$\beta \equiv \frac{f}{b}$$

$$f(a) \equiv \frac{d \ln D(a)}{d \ln a}$$

$$f(k) = \sqrt{\frac{P_{hh}(k)}{P_{cc}(k)}} \frac{1}{3} \left[ \sqrt{45 \frac{P_{hh,0}(k)}{P_{hh}(k)}} - 20 - 5 \right]$$

Castorina, CC et al. 2015
Gradients in the grav. potential generated by LSS cause deviations in the CMB photon propagation from LS to us: points in a direction $n$ actually come from points on the last scattering surface in a displaced direction $n' = n + \nabla \psi$

### Lensing and ISW-RS quantities

Lensing potential in the small-angle scattering limit (Born approximation)

$$\Psi(\hat{n}) \equiv -2 \int_0^{r_*} \frac{r_* - r}{r_* r} \frac{\Phi(r\hat{n}; \eta_0 - r)}{c^2} dr$$

$r$ = comoving distance from the observer

Total ISW-RS effect

$$\Delta T(\hat{n}) = \frac{2}{c^3} T_0 \int_0^{r_L} \hat{\Phi}(r, \hat{n}) a dr$$

Gradients in the grav. potential generated by LSS cause deviations in the CMB photon propagation from LS to us:

$$\tilde{X}(\hat{n}) = X(\hat{n} + \nabla \psi(\hat{n}))$$

$X = T, Q, U$
Planck constraints on neutrinos (95% CL)

Planck-XIII (2015): the lensing reconstruction data, which directly probes the lensing power, prefers lensing amplitudes slightly below (but consistent with) the base LCDM prediction. The Planck+lensing constraint therefore pulls the constraints slightly away from zero towards higher neutrino masses. Extending the analysis up to L<900, Planck lensing gives non-zero best-fit value for the neutrino mass:

\[ \sum m_\nu = 0.16^{+0.08}_{-0.11} \text{ eV} \quad \text{(Planck TT+lowP+aggressive lensing+ BAO; 68\%)} \]
Deflection angle maps for $z_s=1$

CC et al. in prep
Weak-lensing angular power spectra at different redshifts

Lack of power on small scales due to grid resolution. The neutrino damping effect is correctly recovered up to $l=2000$
CMB-lensing angular power spectra

Power suppression is less than in the weak-lensing case since there is the contribution from higher $z$

CC et al. in prep
CMB-lensing vs ISW-RS

Planck-LCDM ISW/RS map

Planck-$M_\nu=0.53$ eV ISW/RS map

Planck-LCDM CMB-lensing potential map

Planck-$M_\nu=0.53$ eV CMB-lensing potential map

CC et al. in prep
At high redshift, the ISW effect would be null on all scales for $M_\nu=0$, while for $M_\nu>0$ it is still active on small scales because of free-streaming.

CC et al. in prep
ISWRS angular power spectra at different redshifts

At redshifts non DE-dominated there is an excess of power

\[ k_{fs}(z) = 0.82 \frac{H(z)}{H_0} / (1 + z)^2 \left( \frac{m_{\nu}}{1 \text{eV}} \right) h \text{Mpc}^{-1} \]
Sign inversion: the non-linear transition moves toward smaller scales with increasing neutrino mass
ISWRS-Weaklens cross correlation

Difference depends on the source redshift. Excess of power of the cross signal with respect to the auto-correlation signal.

(ISW-galaxy correlation predictions as function of the median redshift (Lesgourgues et al. 2008))

CC et al. in prep

FIG. 2: Ratio of the cross-correlation multipoles $C_{ij}^{\alpha\beta}$ and auto-correlation multipoles $C_{ii}^{\alpha\alpha}$ obtained for two cosmological models with neutrino density fractions equal to $\nu = 0.1$ or 0, and the same value of other cosmological parameters (see the text for details).
Conclusions

- Very large neutrino simulations for different probe combinations
- Previous results on bias and MF recovered and confirmed
- New Halofit prescription to account for massive neutrinos
- Good behaviour of exiting PT approximations if applied to CDM alone.
- Detection of the scale dependent growth-rate at linear scales
- Suppression of the CMB/weak-lensing signals, depending on the neutrino mass and source redshifts
- Enhancement of power at the ISW-RS transition of about 10% due to neutrino free-streaming
- Enhancement of the $\phi T$ cross-correlation in the case of the CMB lensing-potential, and for high redshift lensed sources, depending on the neutrino mass
- Suppression of $\phi T$ cross-correlation for low median redshift surveys, but anyway larger than $\phi \phi$ auto-correlation.