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DEMNUni: CMB - galaxy cross-correlation in the presence of massive neutrinos

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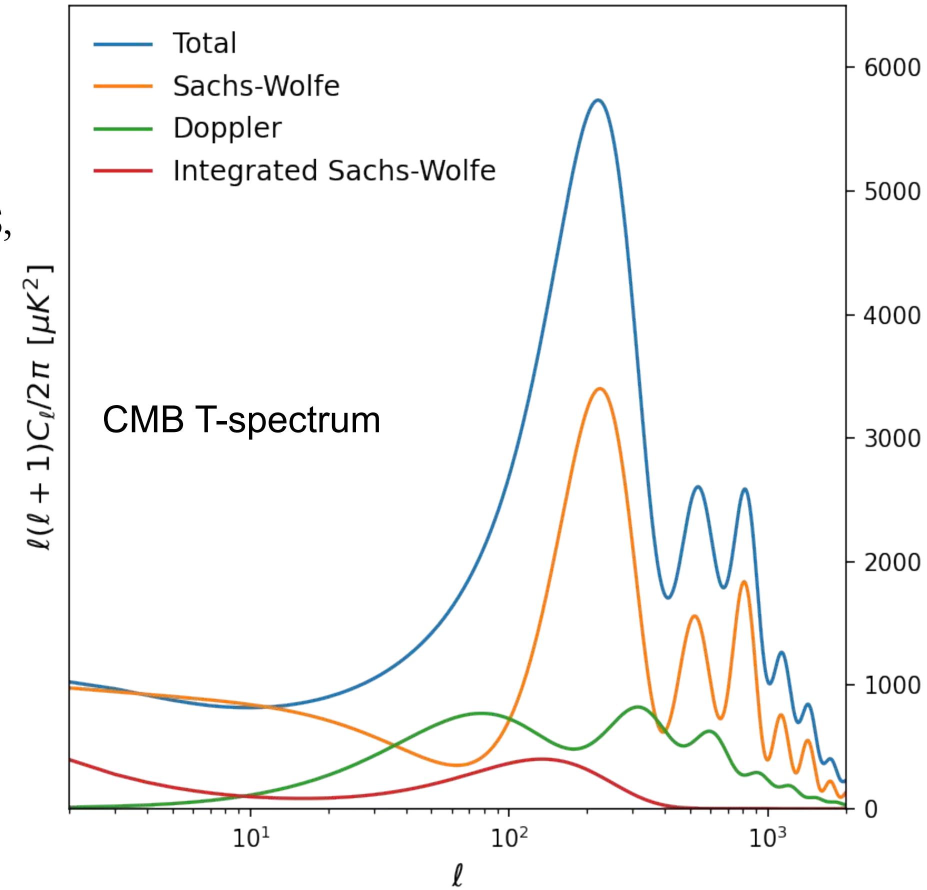
We need to study **CMB x Galaxy** to detect the late Integrated Sachs-Wolfe (ISW, R.K. Sachs and A.M. Wolfe,1967) effect and its **nonlinear** counterpart, the Rees Sciama (RS, R.K. Sachs and A.M. Wolfe,1967) effect:

$$\frac{\Delta T_{ISWRS}}{T_0}(\hat{\mathbf{n}}) = \frac{2}{c^2}\int_{t_{ls}}^{t_0} dt\, \dot{\Phi}(\hat{\mathbf{n}}, \chi, t)$$

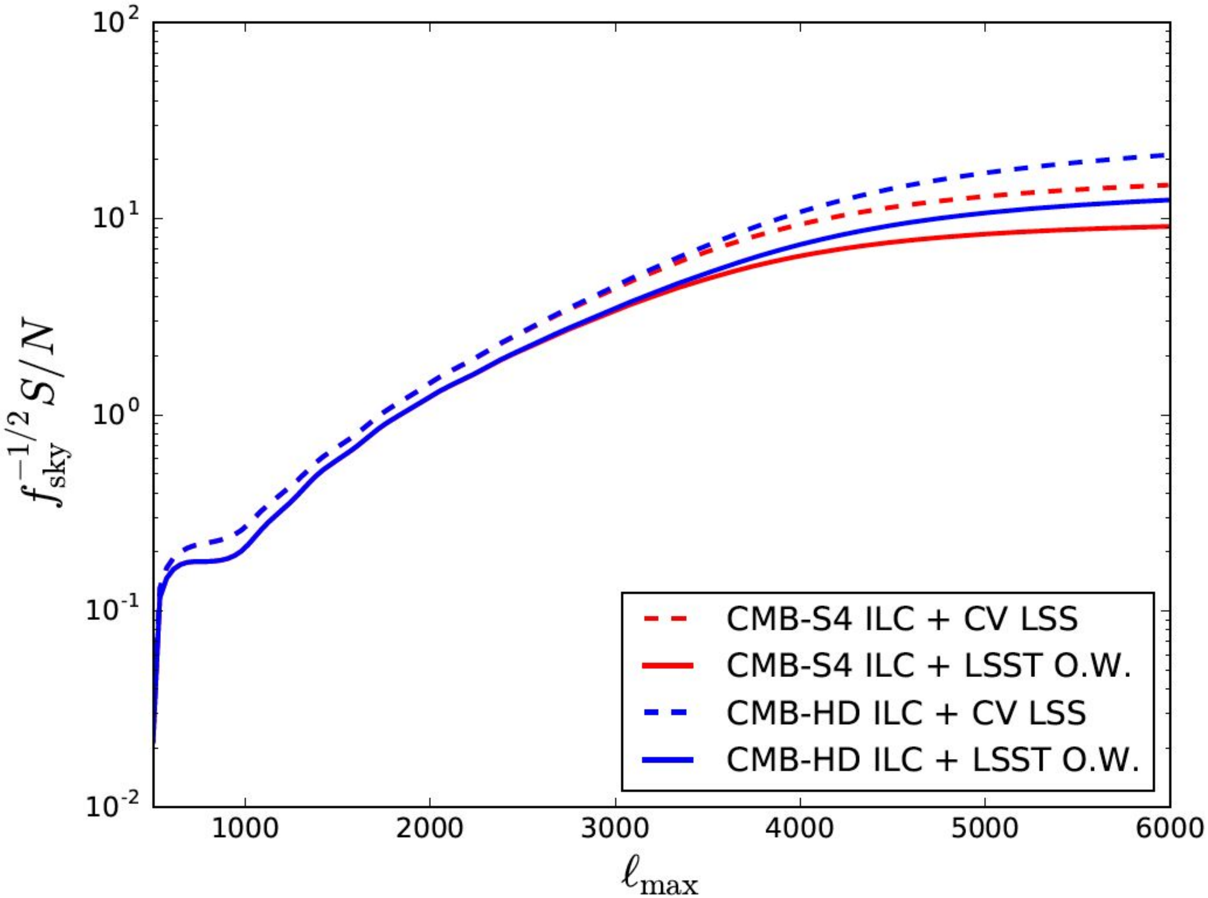
ISW is mainly due to the presence of **Dark Energy**.

RS is due to **structure formation**.

(R.G. Crittenden and N. Turok, 1996)



Is the RS effect detectable?



Credit: *Ferraro et al., 2022*

ILC : Internal Linear Combination
→ foreground + noise

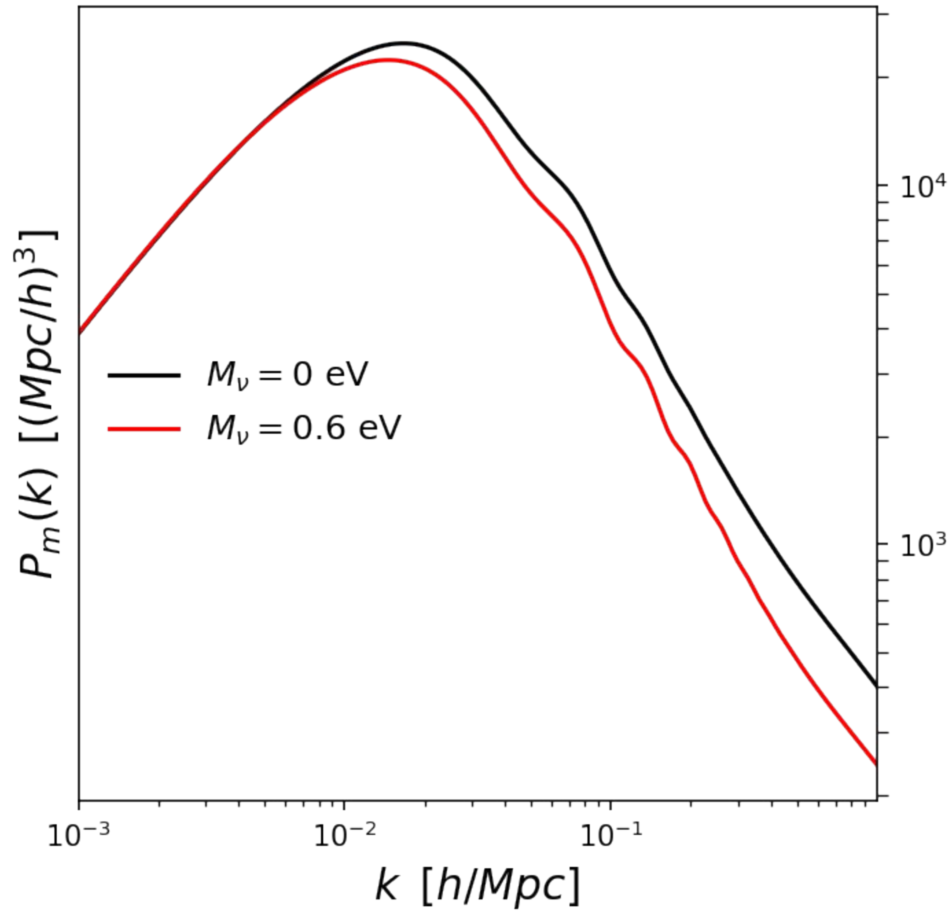
CV : Cosmic Variance

O.W. : Optimal redshift weight
→ w(z) estimated for every galaxy based on its photmetric redshift

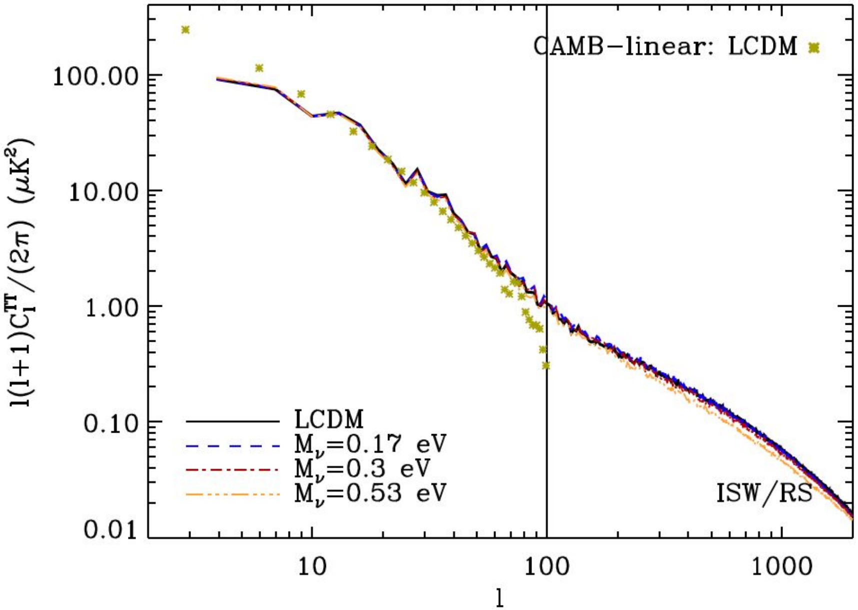
Why in the presence of massive neutrinos?

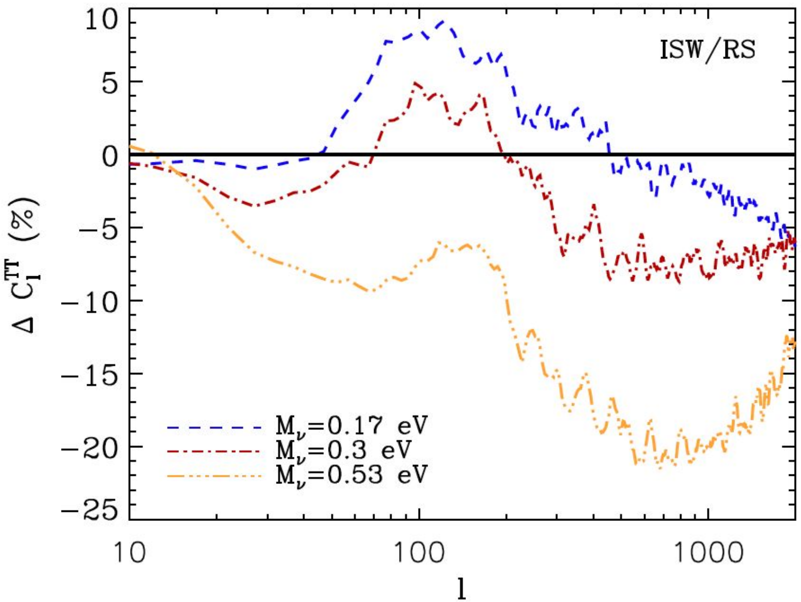
Massive neutrinos are responsible for the suppression of structure formation at small scales because of neutrino **free-streaming**.

The net consequence is a **suppression** of the matter power spectrum on small scales that directly **depends on** $\mathbf{M_\nu = \Sigma m_\nu}$ (Lesgourgues et al., 2008)



ISWRS in the presence of massive neutrinos





Credit: *Carbone et al.* ***2016***

[Simulated ISWRS induced temperature anisotropies for M_ν = 0, 0.17, 0.30, 0.53 eV at **z≃21**]

The presence of massive neutrinos induce a slow decay of the gravitational potential that generates the ISWRS effects even in absence of a background expansion.

On cosmological scales smaller than the characteristic neutrinos free-streaming length, neutrinos suppress the time derivative of the gravitational potential in a measure that **depends on $M_\nu = \Sigma m_\nu$**.

Analytical computation of the ISWRS - galaxy cross-spectrum with CAMB

WHAT:

develop an **analytical method** to compute the cross-correlations between ISWRS and the galaxy distribution

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HOW:

- using **Takahashi + Bird2014** and **Mead2020** **nonlinear** modelling of $P_m(k)$ in CAMB code

$$C_\ell^{\dot{\Phi} g} = \frac{3\Omega_m H_0^2}{2(\ell+1/2)^2} \cdot \int_{z_{\min}}^{z_{\max}} \mathrm{d}z\, n(z) b(z) H(z) a(z) \left[\partial_z \frac{P_{\delta\delta}(k,z)}{a(z)^2}\right]$$

- validating against the '**Dark Energy and Massive Neutrino Universe**' (**DEMNUni**) N-body simulations

WHY:

- produce accurate **modelling for future galaxy and CMB surveys**

- try to infer new constraints on $\mathbf{M}_{\nu}$

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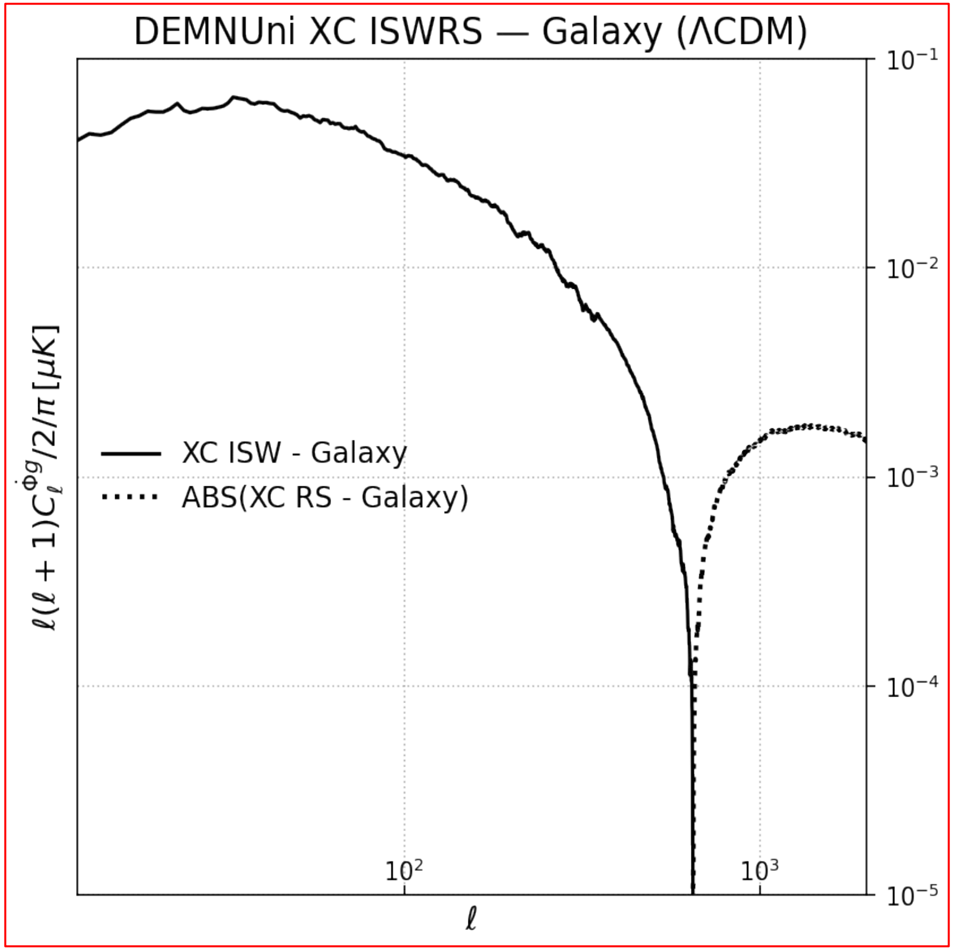
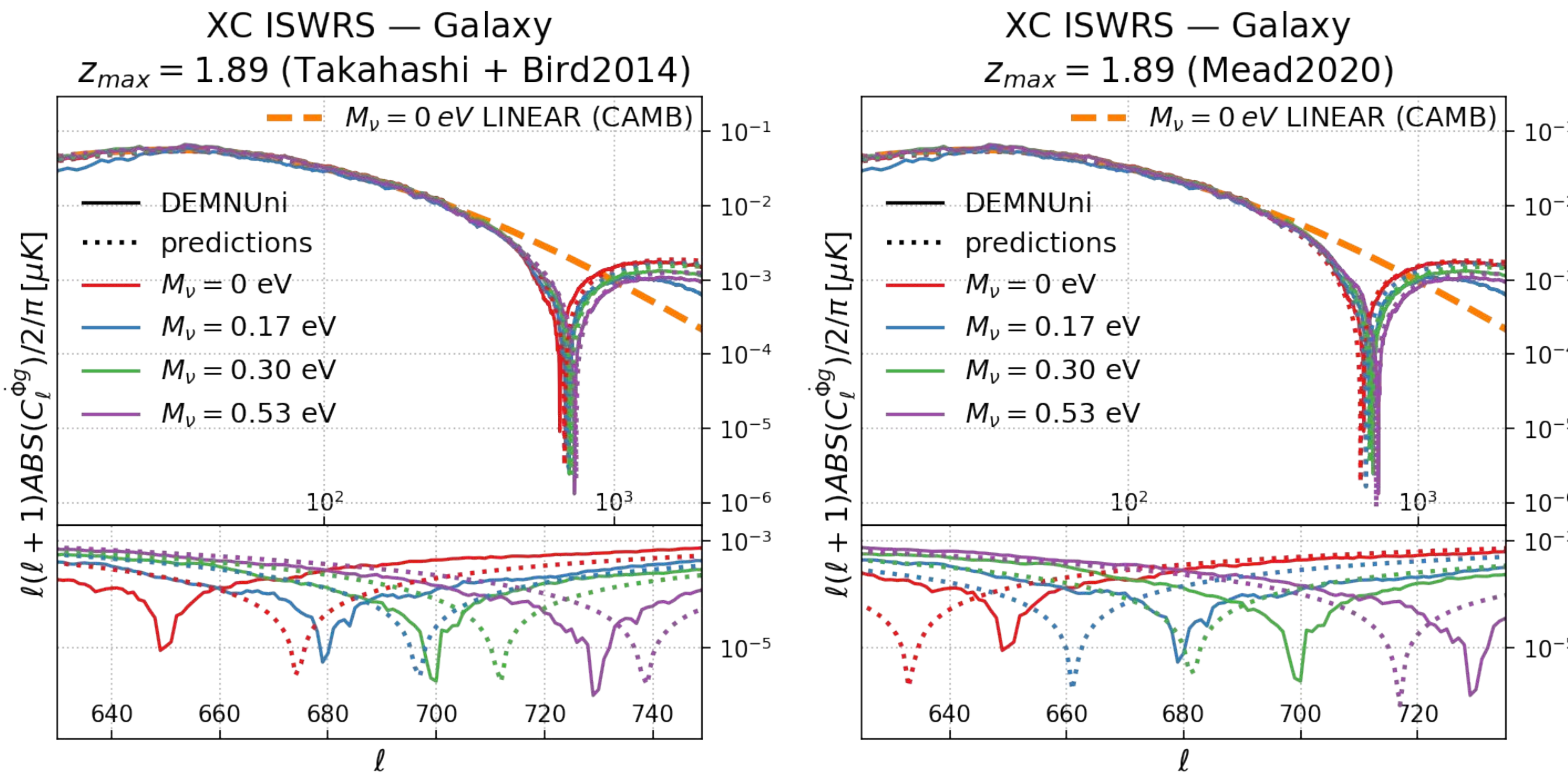
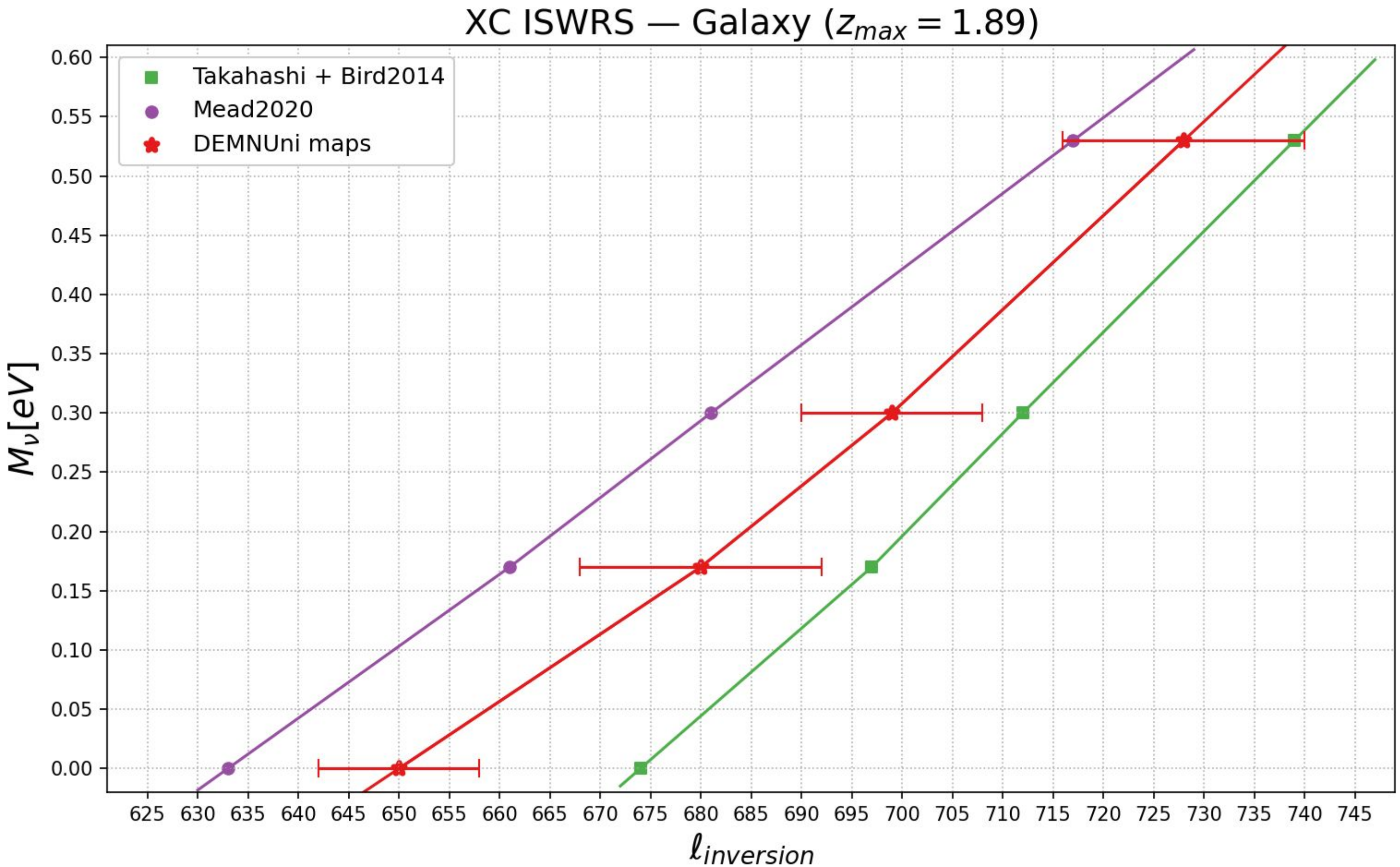




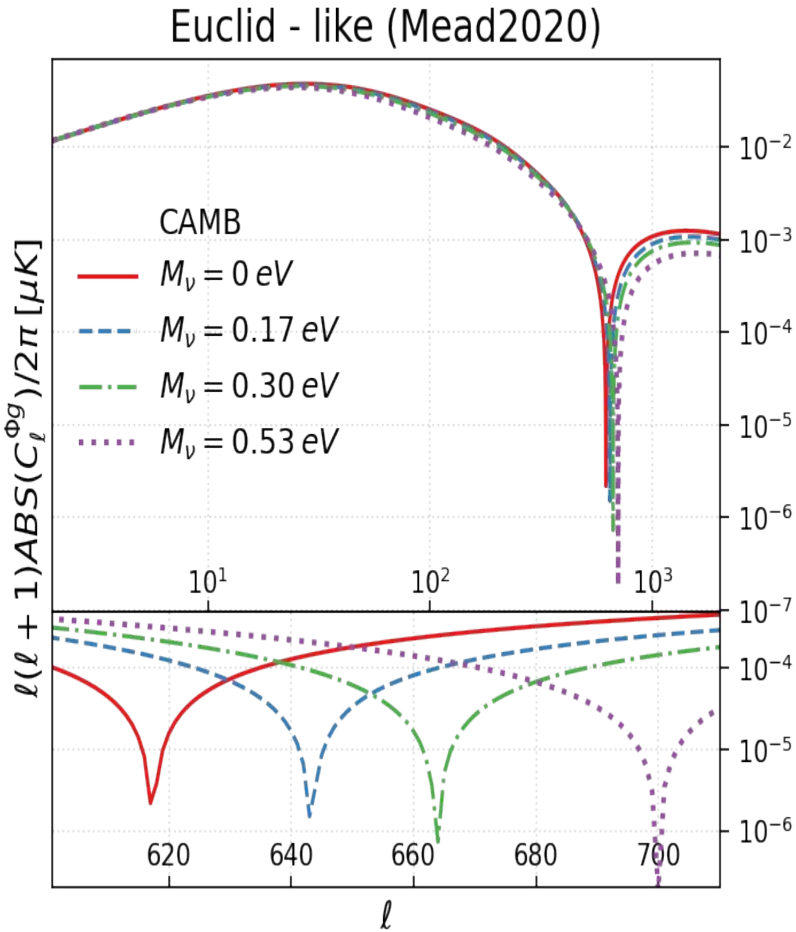
Credit: *Cuozzo et al. in prep*

Predictability of M_ν



Credit: *Cuozzo et al. in prep*

Nonlinear $P_m(k)$ modelling needs to be improved



Credit: *Cuozzo et al. in prep*

- The analytical method implemented allows us to model **future CMB and galaxy surveys**
- The results here presented will be soon submitted (**Cuozzo *et al.*, in prep.**)
- In the paper you will find the results even for the **ISWRS – CMB-Lensing cross-correlation**
- We are going to investigate the **S/N ratios** of this cross-spectra in the case of ***ν*ΛCDM cosmologies**
- Thanks to the availability of DEMNUni maps, it will be possible to investigate **Dynamical Dark Energy effects** on the cross-spectra

Thank you for your attention!

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References:

R.K. Sachs and A.M. Wolfe, *Perturbations of a Cosmological Model and Angular Variations of the Microwave Background*, ApJ 147 (1967) 73.

M.J. Rees and D.W. Sciama, *Large-scale Density Inhomogeneities in the Universe*, Nature 217 (1968) 511.

R.G. Crittenden and N. Turok, *Looking for a Cosmological Constant with the Rees-Sciama Effect*, Phys. Rev. Lett. 76 (1996) 575 [astro-ph/9510072]

J. Lesgourgues, W. Valkenburg and E. Gaztañaga,*Constraining neutrino masses with the integrated-Sachs-Wolfe-galaxy correlation function*, Phys. Rev. D77(2008) 063505 [0710.5525].

S. Ferraro, E. Schaan and E. Pierpaoli, *Is the Rees-Sciama effect detectable by the next generation of cosmological experiments?*, arXiv e-prints(2022) arXiv:2205.10332 [2205.10332].

C. Carbone, M. Petkova and K. Dolag, DEMNUni: ISW, Rees-Sciama, and weak-lensing in the presence of massive neutrinos, J. Cosmology Astropart. Phys. **2016** (2016) 034 [1605.02024].

A. Lewis and A. Challinor, *"CAMB: Code for Anisotropies in the Microwave Background."* Astrophysics Source Code Library, record ascl:1102.026, Feb., 2011.

R. Takahashi, M. Sato, T. Nishimichi, A. Taruya and M. Oguri, *Revising the Halofit Model for the Nonlinear Matter Power Spectrum*, ApJ **761** (2012) 152 [1208.2701].

S. Bird, M. Viel and M.G. Haehnelt, *Massive neutrinos and the non-linear matter power spectrum*, MNRAS 420 (2012) 2551 [1109.4416].

A.J. Mead, S. Brieden, T. Tröster and C. Heymans, HMCODE-2020: improved modelling of non-linear cosmological power spectra with baryonic feedback, MNRAS 502 (2021) 1401 [2009.01858].

DEMNUni N-body simulations

The **"Dark Energy and Massive Neutrino Universe"** (DEMNUni) simulations (*Carbone et al., 2016*) are a set of 16 high-resolution cosmological N-body simulations with $\boldsymbol{L = 2\, h^{-1}}$ **Gpc**, $\mathbf{N_p = 2048^3}$ **cold dark** matter particles and the **same number of neutrino particles**

The neutrino mass considered are: $\mathbf{M\nu = 0, 0.17, 0.30, 0.53}$ **eV**

For this work, three DEMNUni map sets have been used:

1. ISWRS maps produced via **ray-tracing** from $z_{min} = 0.02$ to $z_{max} = 1.89$ (*Carbone et al. 2008, Carbone et al. 2016*)

2. CMB-Lensing maps produced via **ray-tracing** from $z_{min} = 0.02$ to $z_{max} = 1.89$ (*Carbone et al. 2008, Carbone et al. 2016*)

3. Galaxy maps produced from the **projection of 3D lightcone shells**, that go from $z_{min} = 0.02$ to $z_{max} = 1.89$, onto 2D spherical maps (*Calabrese et al. 2015, Calabrese et al. in prep.*)

$$C_\ell^{\dot{\Phi}g} = \frac{3\Omega_m H_0^2}{2(\ell+1/2)^2} \cdot \int_{z_{\min}}^{z_{\max}} \mathrm{d}z\, n(z) b(z) H(z) a(z) \left[\partial_z \frac{P_{\delta\delta}(k,z)}{a(z)^2}\right]$$

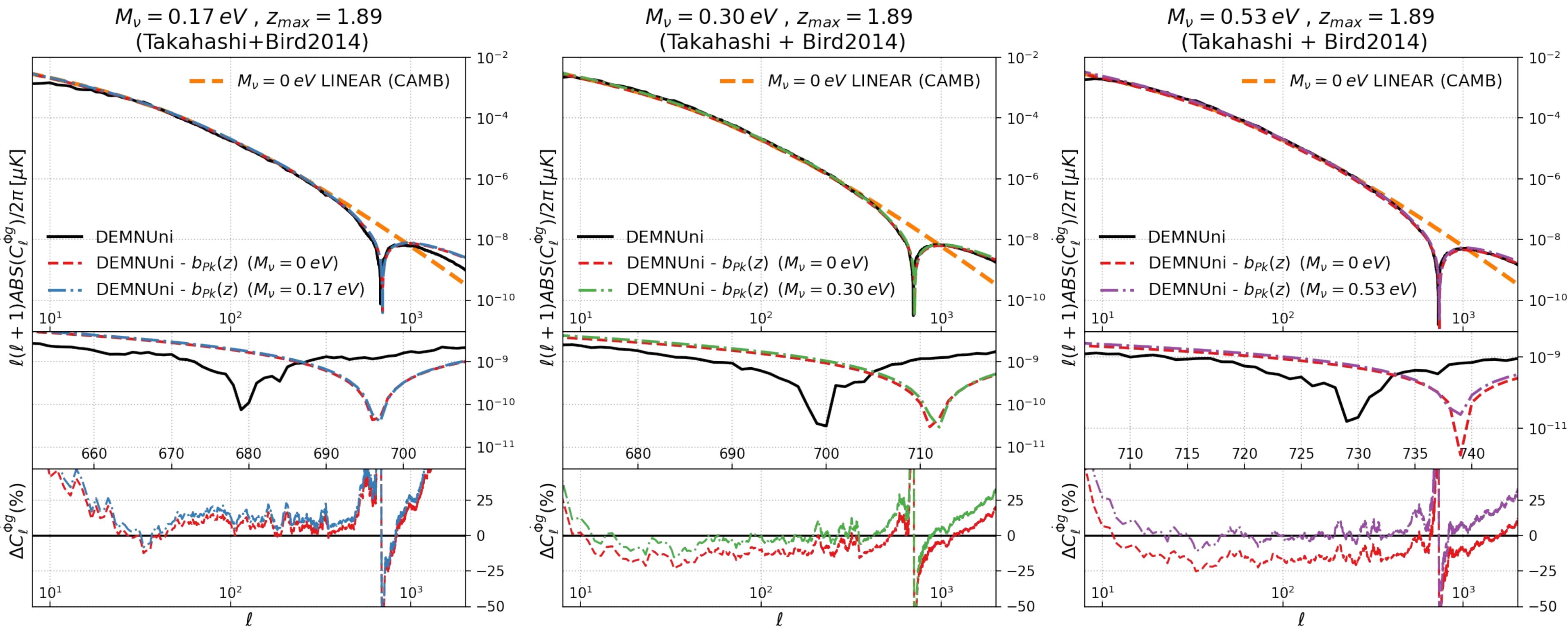
Galaxy selection function

Scale - independent bias function

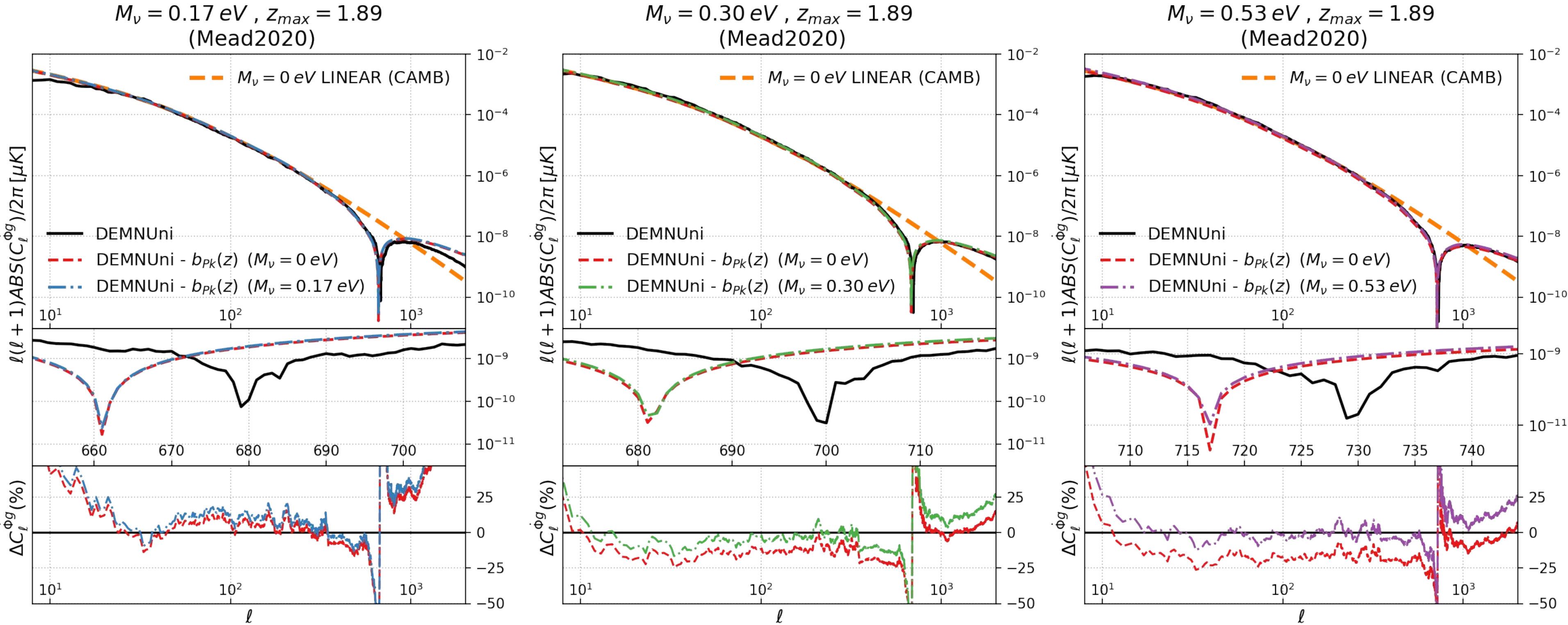
Time derivative of the
Dark Matter power spectrum

$$b_{gg}(z) = \left\langle \sqrt{\frac{P_{gg}(k)}{P_{mm}(k)}} \right\rangle$$

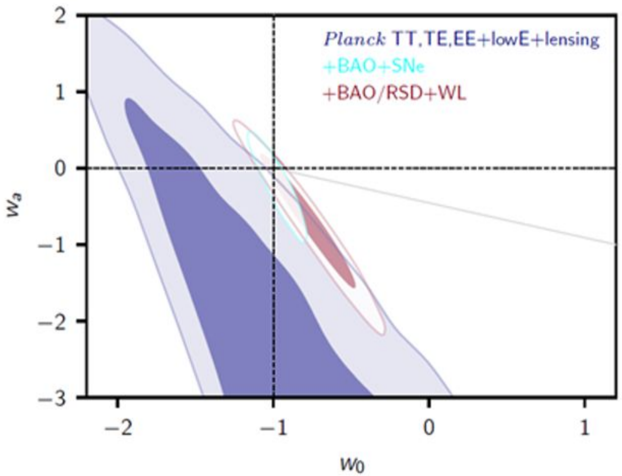
Testing different b(z) functions (Takahashi+Bird2014 modelling)

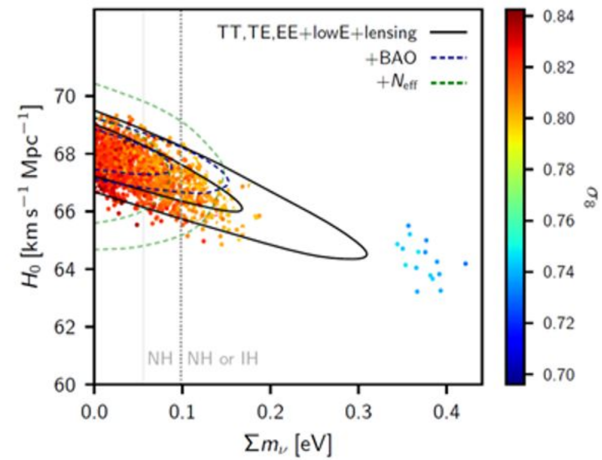


Testing different b(z) functions (Mead2020 modelling)



Planck2018 constraints on neutrino mass and w_0-w_a





Parameter	*Planck*+SNe+BAO	*Planck*+BAO/RSD+WL
w_0	-0.961 ± 0.077	-0.76 ± 0.20
w_a	$-0.28^{+0.31}_{-0.27}$	$-0.72^{+0.62}_{-0.54}$
H_0 [km s^{-1}Mpc^{-1}]	68.34 ± 0.83	66.3 ± 1.8
σ_8	0.821 ± 0.011	$0.800^{+0.015}_{-0.017}$
S_8	0.829 ± 0.011	0.832 ± 0.013

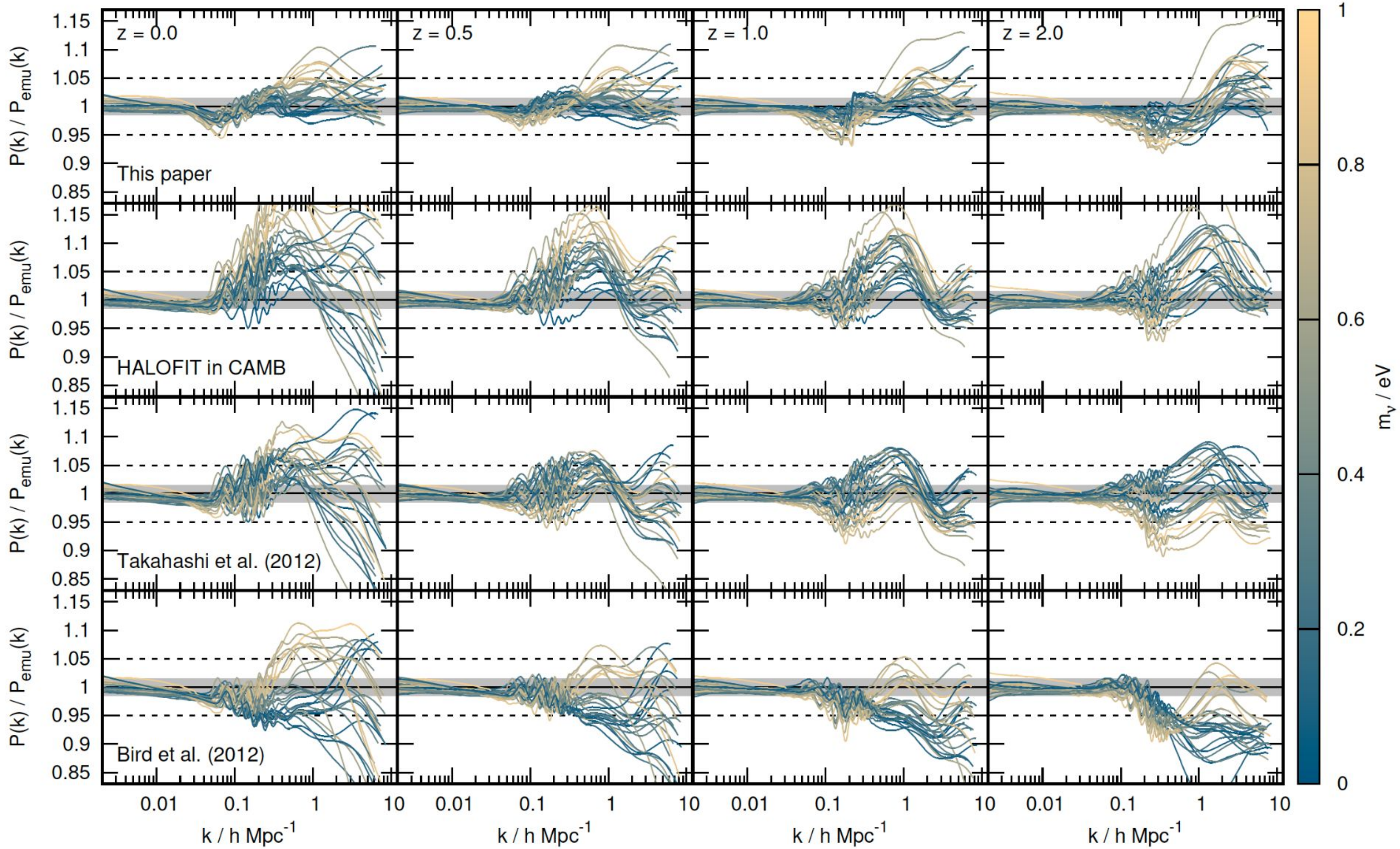
$\sum m_\nu < 0.16$ eV (95 %, *Planck* TT+lowE+BAO),

$\sum m_\nu < 0.13$ eV (95 %, *Planck* TT,TE,EE+lowE +BAO),

$\sum m_\nu < 0.13$ eV (95 %, *Planck* TT+lowE+lensing +BAO),

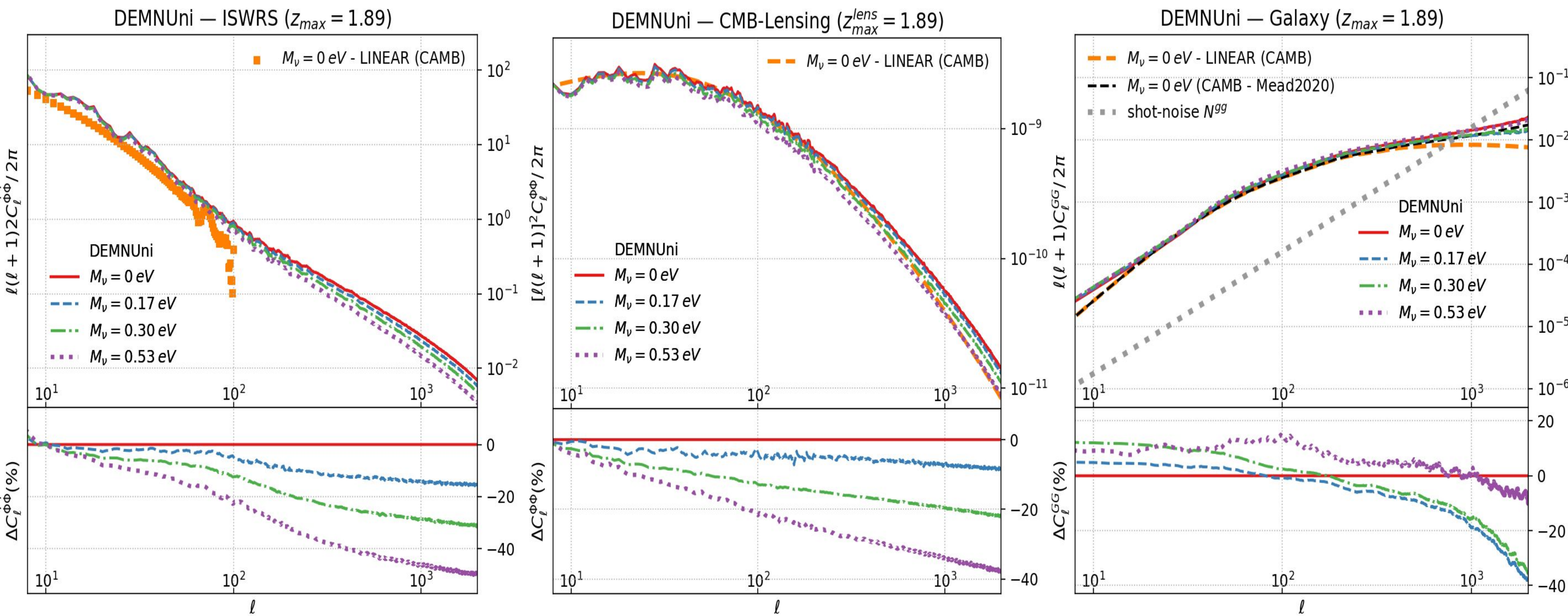
$\sum m_\nu < 0.12$ eV (95 %, *Planck* TT,TE,EE+lowE +lensing+BAO).

Takahashi+Bird2014 VS Mead2020

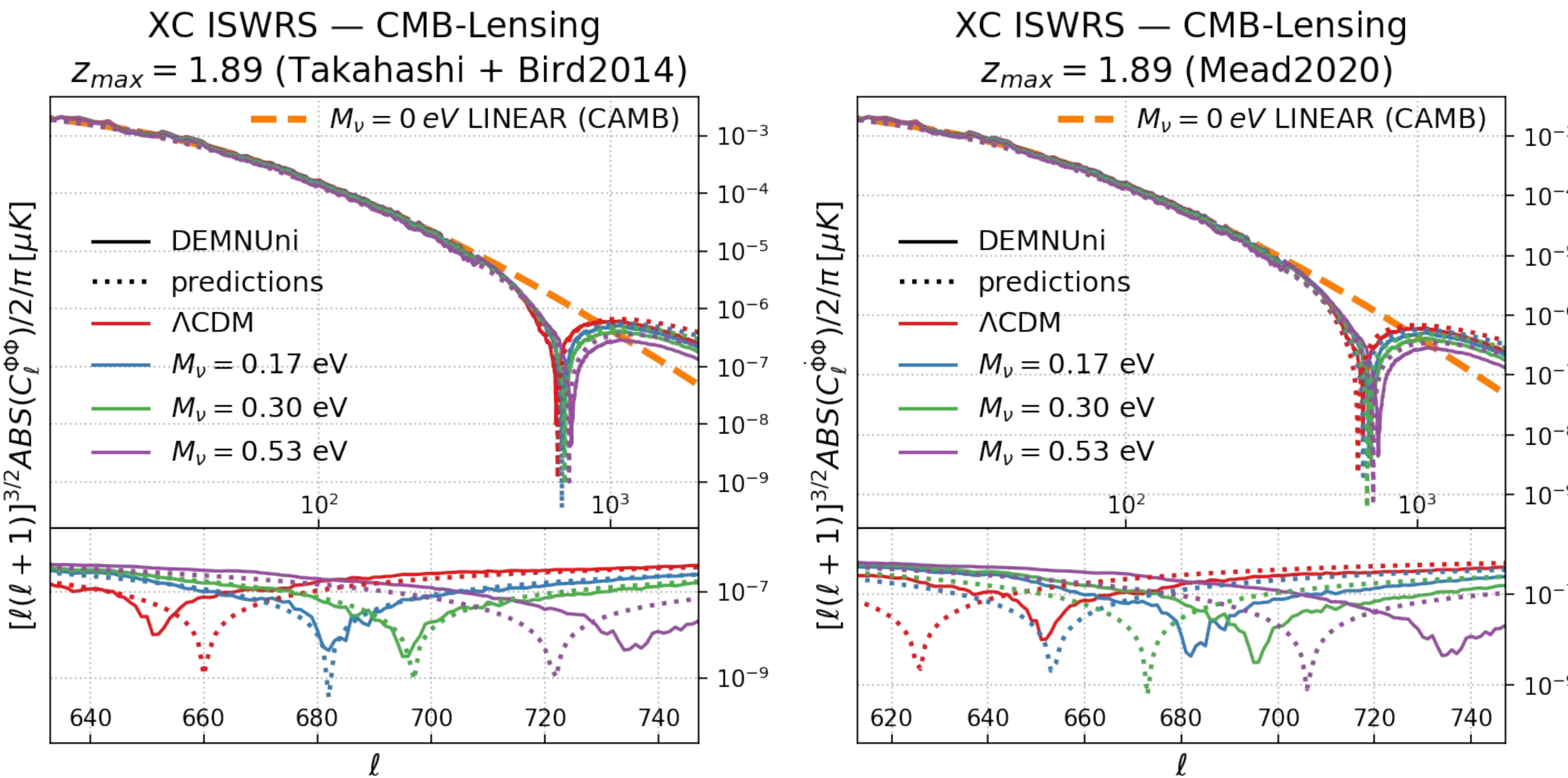


Credit: *Mead et al., 2020*

Spectra from DEMNUni maps

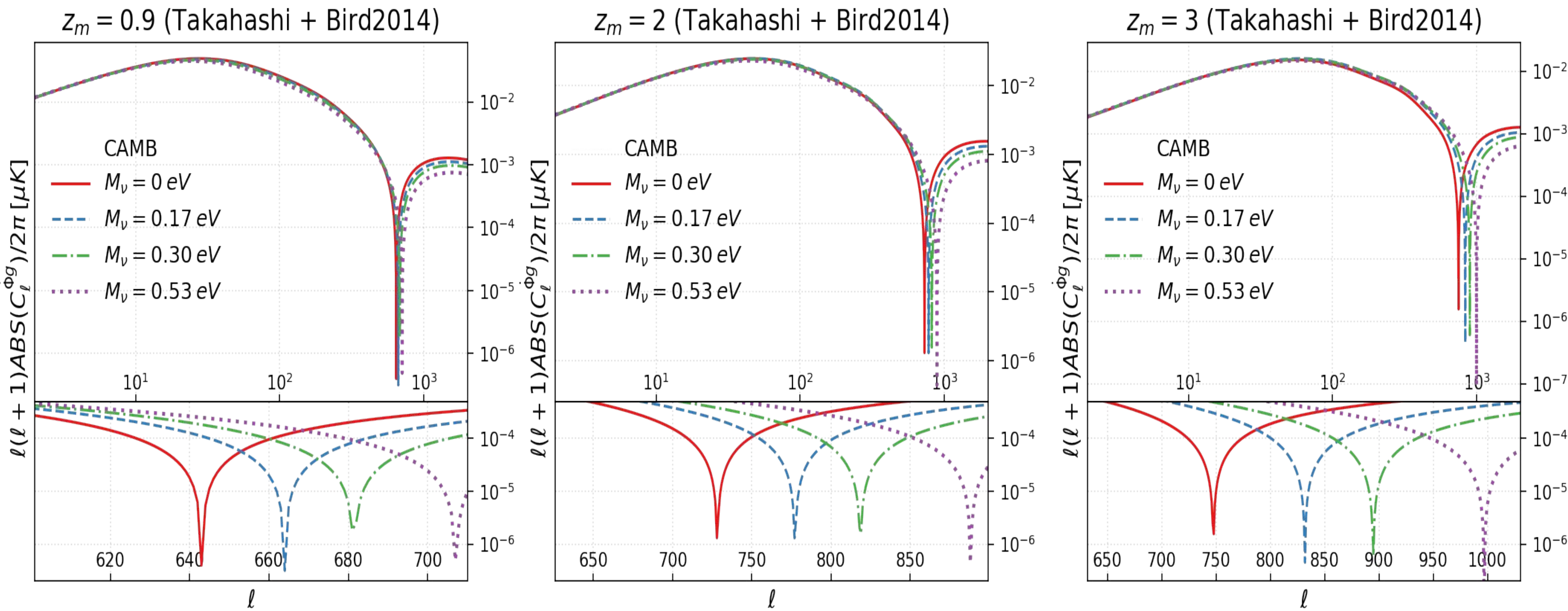


Analytical results: ISWRS - CMB Lensing cross-correlation

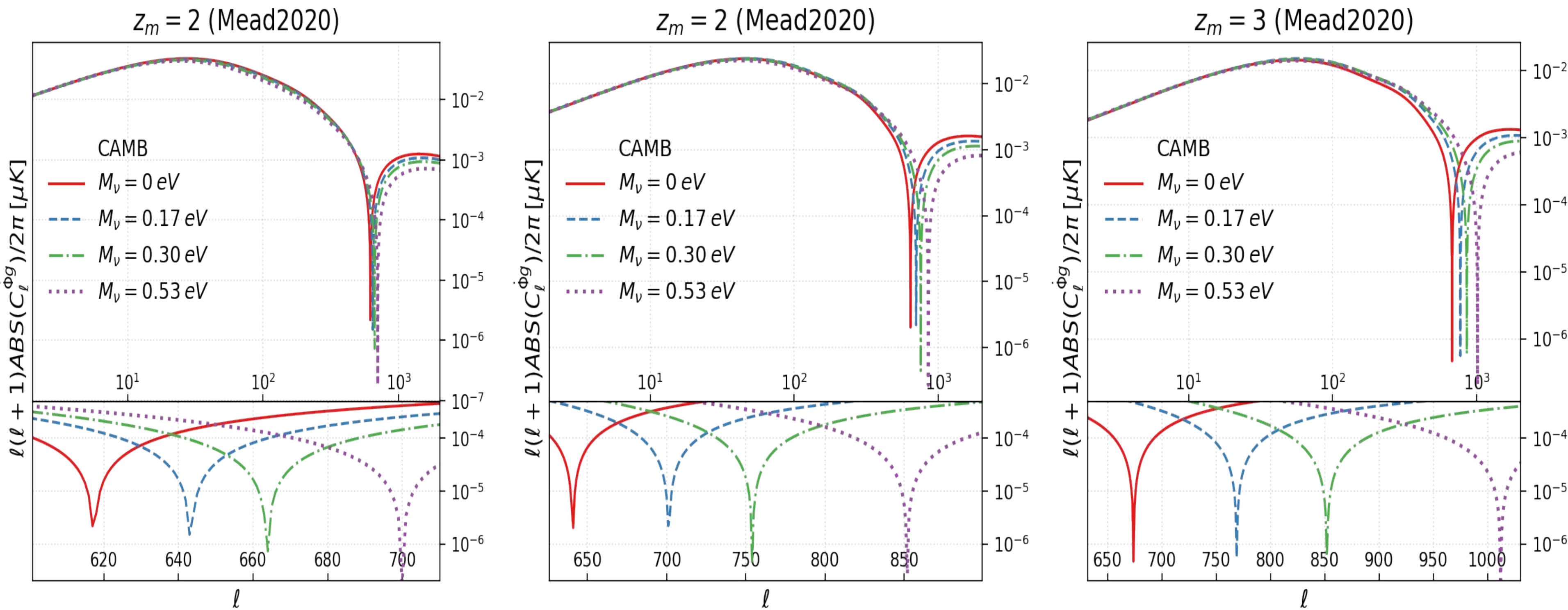


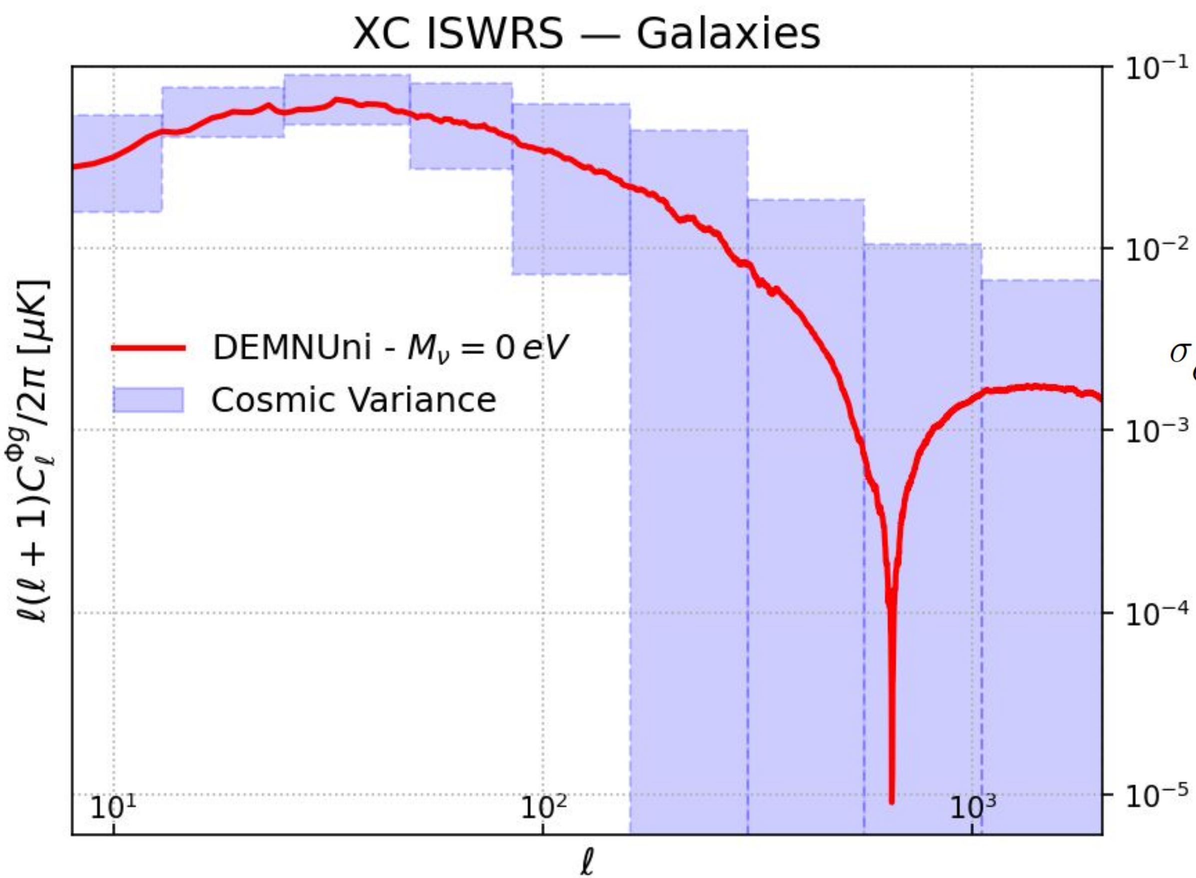
Credit: *Cuozzo et al. in prep*

Modelling for different n(z) with Takahashi+Bird2014



Modelling for different n(z) with Mead2020





$$\sigma_{C_\ell^{\dot{\Phi}g},\ bin_i} = \sqrt{\frac{(C_\ell^{\dot{\Phi}g})^2 + C_\ell^{TT}(C_\ell^{gg} + N^{gg})}{(2\ell+1)\Delta\ell_{bin_i}}}$$

Credit: *Cuozzo et al. in prep*