Euclid and the challange of neutrino mass detection

Maria Archidiacono

UNIVERSITÀ DEGLI STUDI DI MILANO

euclid

Euclid consortium

Timeline of neutrino cosmology

See talk by Steen Hannestad

	Inflation	Neutrinos decouple Formation of light elements (BBN)	Photons decouple and propagate (CMB)	Dark ages	Cosmic dawn	The present Universe
Temperature		1 MeV	1 eV			2.7 K
Redshifts (z)		10^8	1080			0

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$m_\nu \sim 3T$

$$\rho_{\rm radiation} = \rho_\gamma + \rho_\nu = \rho_\gamma \left(1 + \left(\frac{7}{8}\right)\left(\frac{4}{11}\right)^{4/3} N_{\rm eff}\right)$$

$$\rho_\nu \propto \rho_{\rm matter}$$

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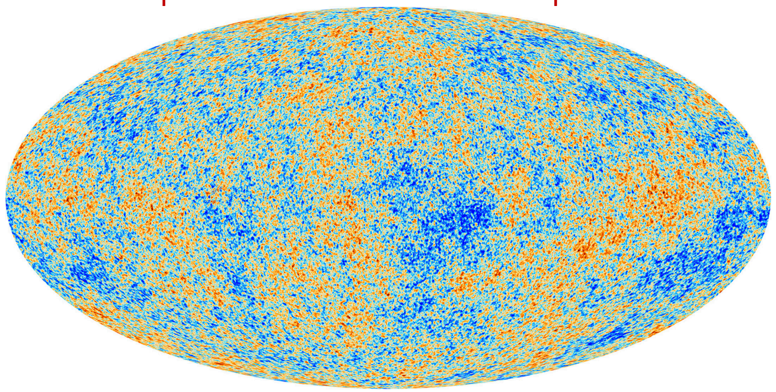
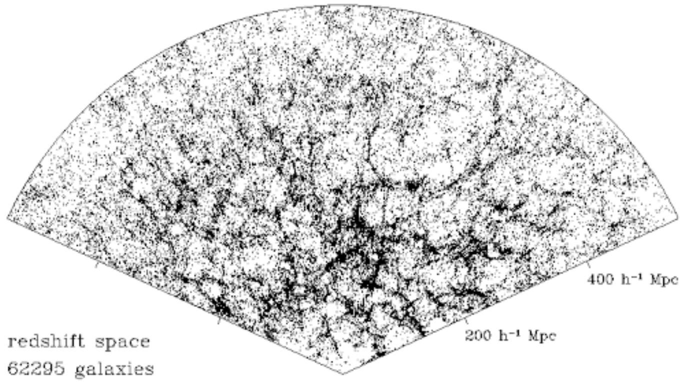
Inflation

Dark ages





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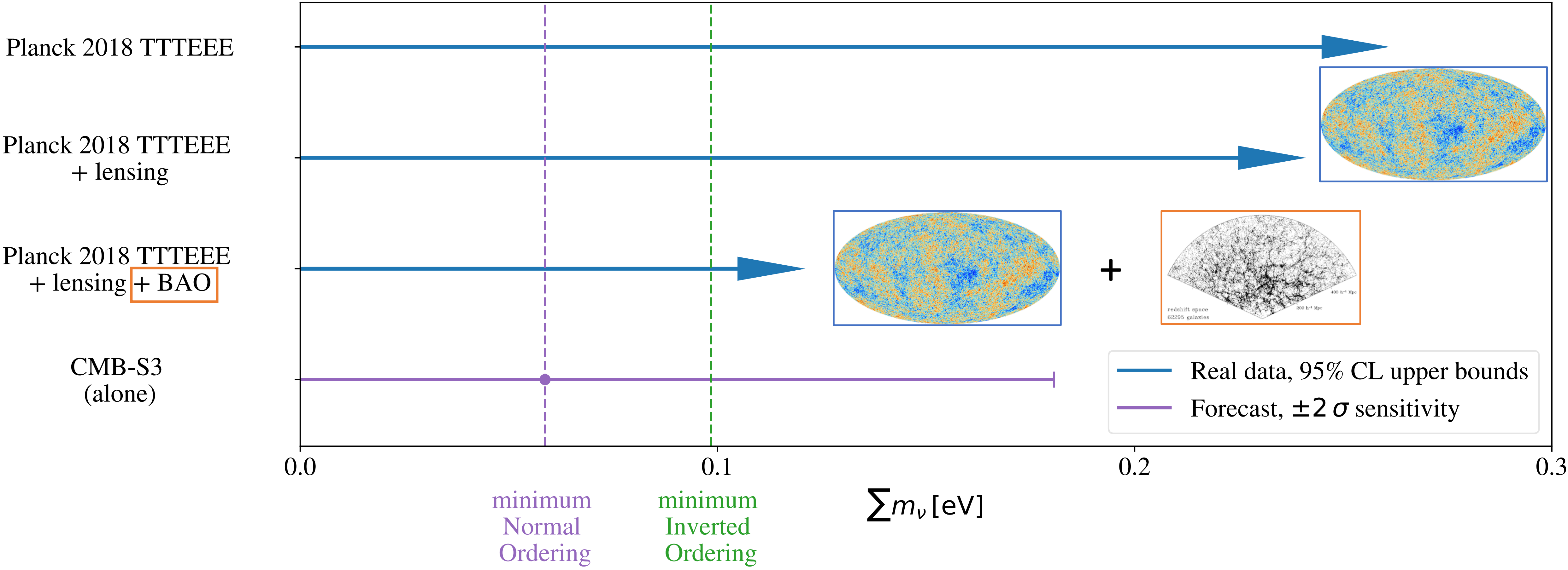
Neutrino mass constraints: recent history

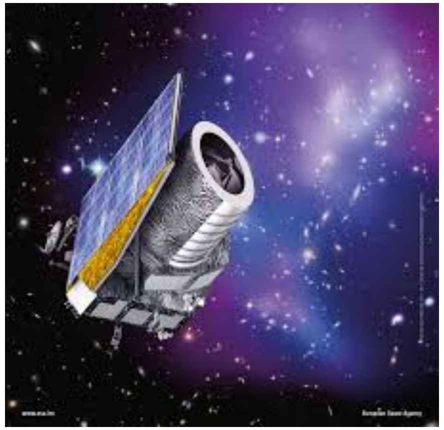


CMB alone will not be able to detect the neutrino mass.

→ Large scale structures

Euclid in a nutshell

Laureijs+ 2012

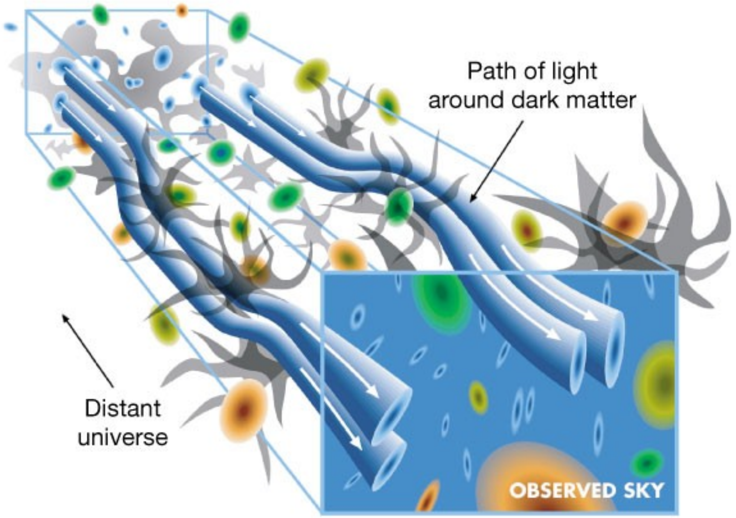


Main scientific objectives:

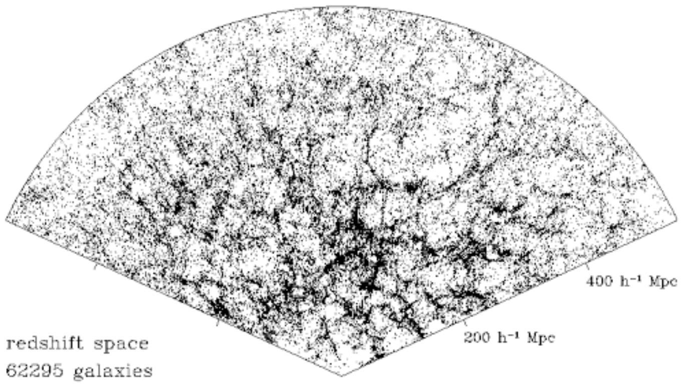
- Dark energy
- Modified gravity
- Initial conditions (inflation)
- <u>Massive neutrinos</u>

VIS+NISP: Shapes of > 1 bilion of galaxies and the redshifts of > 50 milions of galaxies aiming at 1% accuracy on the main observables:

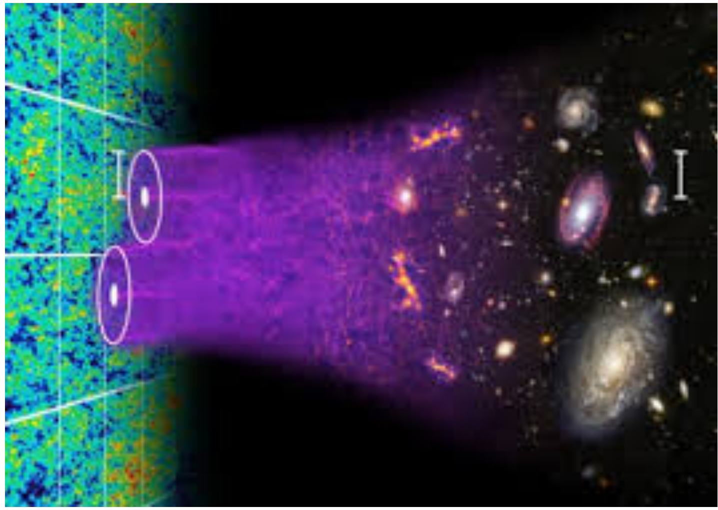
Weak gravitational lensing



Galaxy clustering



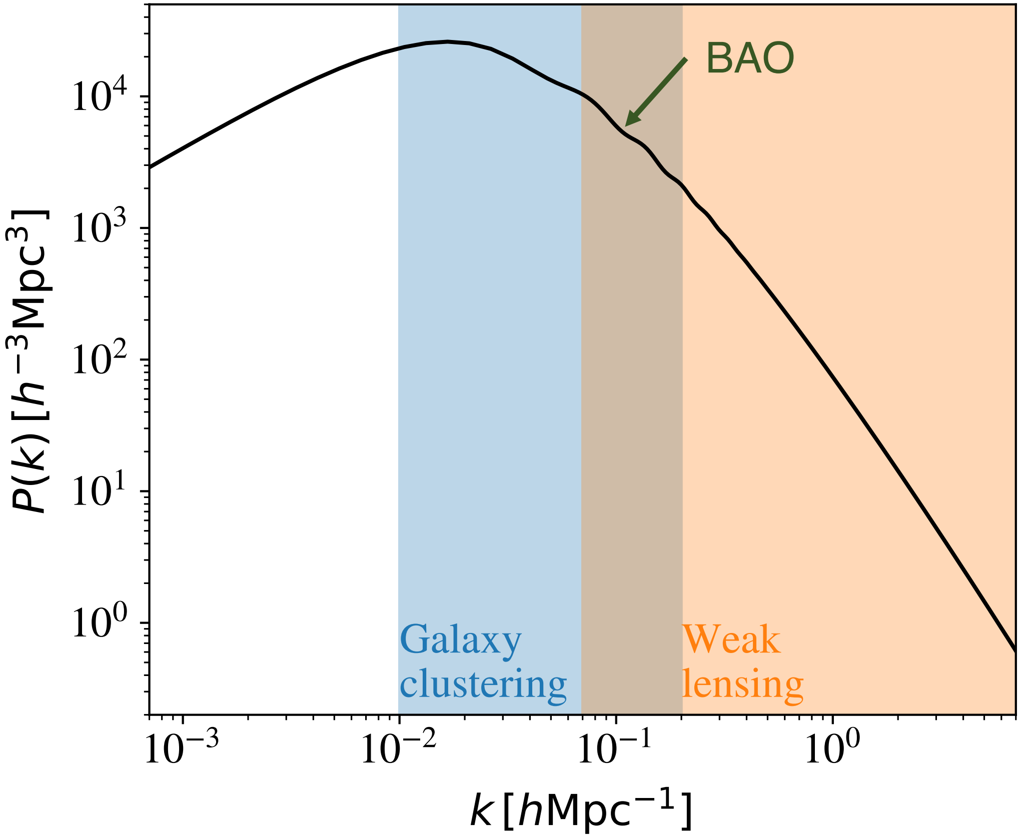
Baryonic Acoustic Oscillations



Matter power spectrum

$$P(k) = \int \xi(\mathbf{r}) e^{i\mathbf{k}\cdot\mathbf{r}} d^3x,$$

$$\xi(\mathbf{r}) = \langle \delta(\mathbf{x}) \delta(\mathbf{x}+\mathbf{r}) \rangle$$



Matter power spectrum with neutrinos

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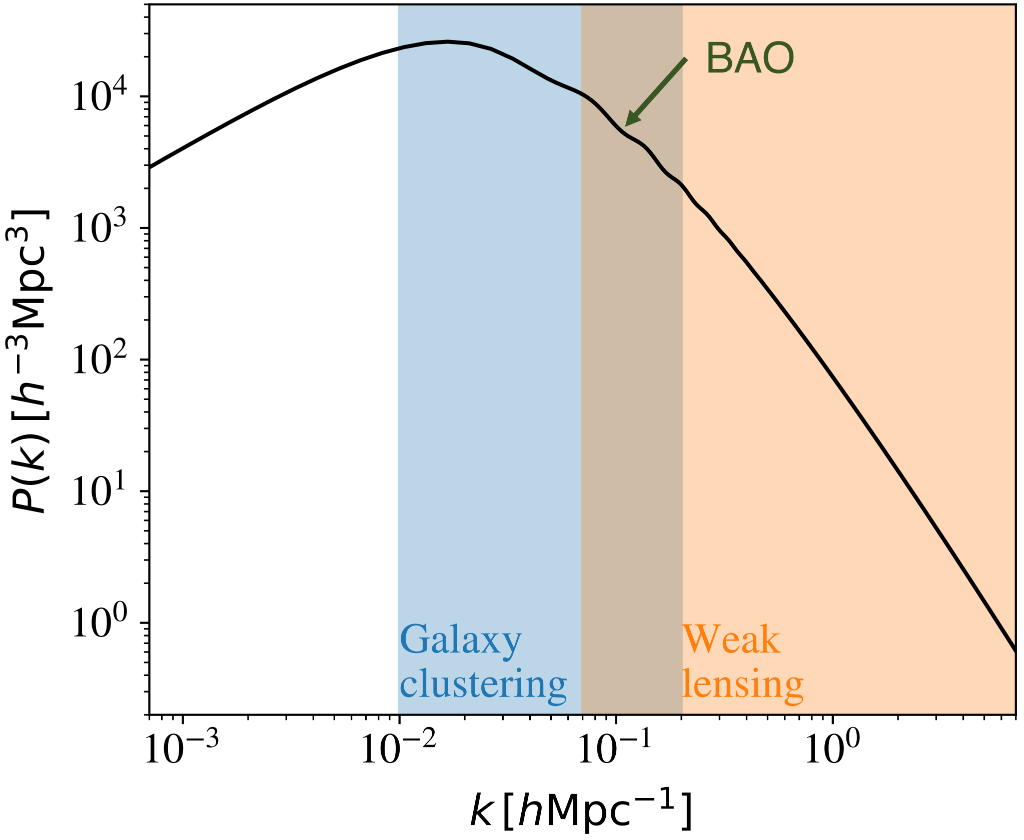
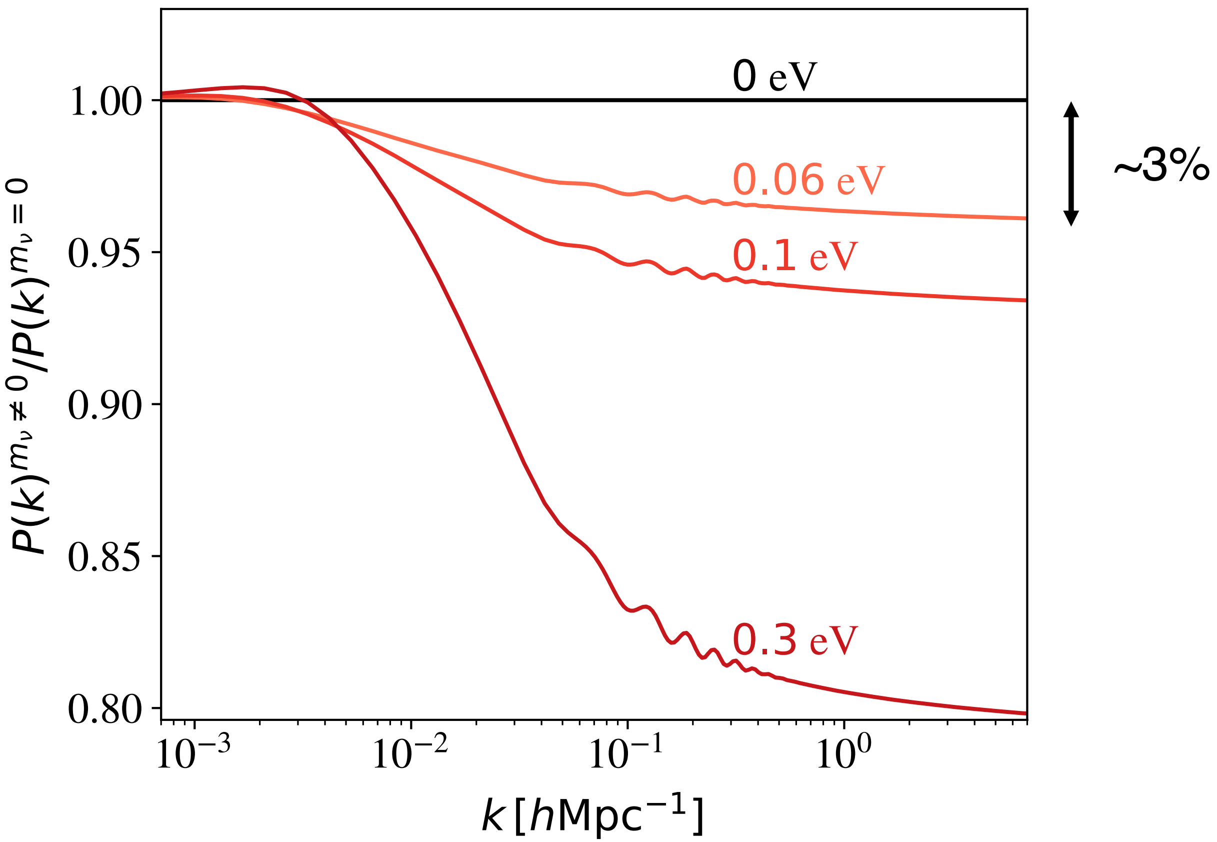
$$\xi(\mathbf{r}) = \langle \delta(\mathbf{x})\delta(\mathbf{x}+\mathbf{r})\rangle$$

In a massless neutrino Universe $\delta_{\rm cdm} \propto a$

In a massive neutrino Universe $\delta_{\rm cdm} \propto a^{1-\frac{3}{5}\frac{\Omega_\nu}{\Omega_m}}$





Matter power spectrum with neutrinos

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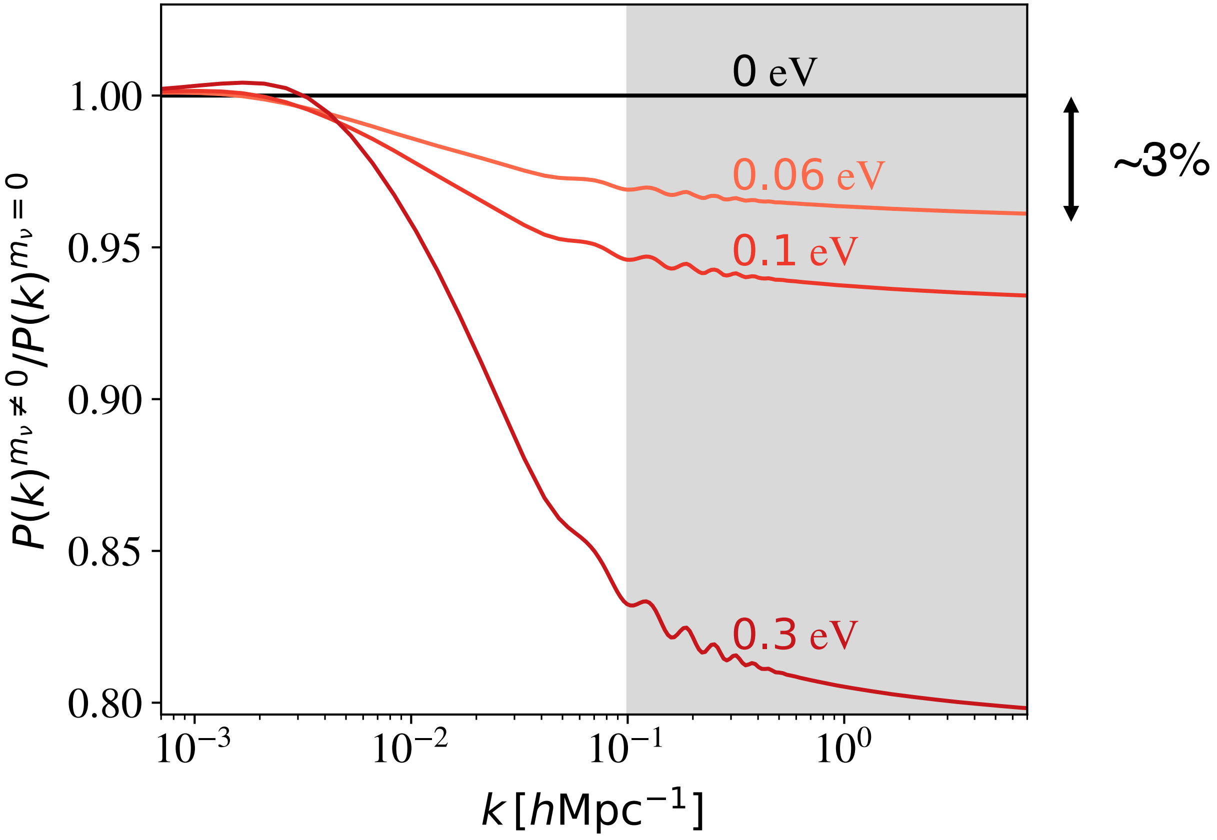
<u>Known unknowns</u>:

1. Galaxy bias $P_{galaxy} = b^2 P_{matter} + N$ *(see Castorina+ 2014)*
2. Non-linearities *(see Euclid Collaboration: Martinelli, Tutusaus, Archidiacono+ 2020; Euclid Collaboration: Knabenhans+ 2020)*
3. Baryonic feedback *(see Chisari+ 2019)*

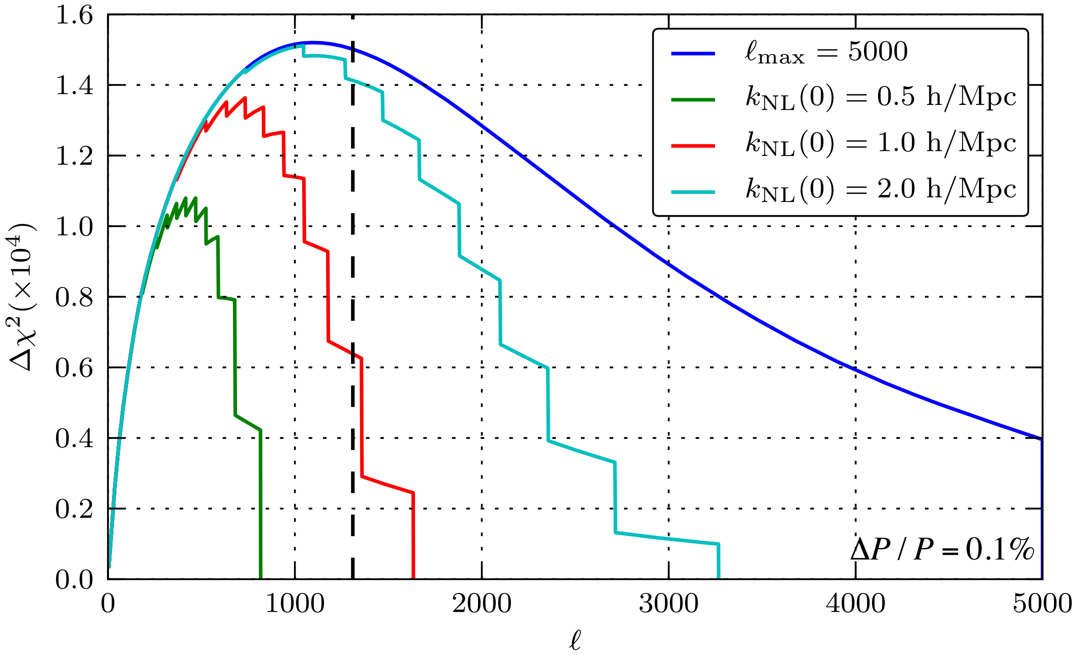


Exploiting the data …

without neglecting the uncertainties

Theoretical uncertainties: Weak Lensing

Sprenger, Archidiacono, Brinckmann, Clesse, Lesgourgues, JCAP 2019



$$k_{nl}(z) \propto k_{nl}(0)(1+z)^{2/(2+n_s)}$$

$$l_{max}^{zi} = k_{nl}(z) \times \bar{r}_{peak}^{zi}$$

k_{max}	$100\omega_b$	ω_{cdm}	θ_s	$\ln(10^{10}A_s)$	n_s	τ_{reio}	M_ν [eV]
0.5 h/Mpc	0.77	0.27	0.97	0.94	0.72	0.96	0.50
1.0 h/Mpc	0.76	0.27	0.94	0.95	0.70	0.98	0.41
2.0 h/Mpc	0.76	0.25	0.97	0.94	0.65	0.97	0.36
$l_{max} = 5000$	0.74	0.24	0.94	0.94	0.58	0.96	0.30
Planck only	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Conservative: $k_{nl}(0)$=0.5 h/Mpc

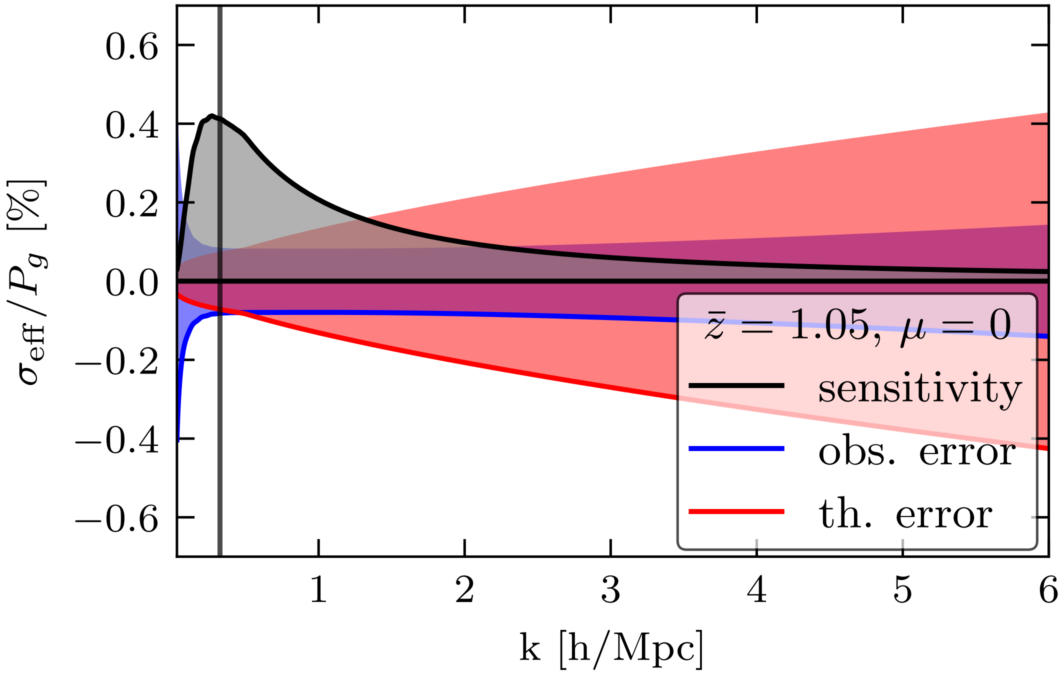
Optimistic: $k_{nl}(0)$=2.0 h/Mpc

Fiducial Σm_ν = 60 meV

	Planck+Euclid-WL
Conservative	43 meV
Optimistic	30 meV

Theoretical uncertainties: Galaxy Clustering

Sprenger, Archidiacono, Brinckmann, Clesse, Lesgourgues, JCAP 2019



$$\frac{d\chi^2}{dk\,d\mu} = \left[\frac{\Delta P_g(k,\mu,\bar{z})}{\sigma_{eff}(k,\mu,\bar{z})}\right]^2$$

$$\sigma_{eff}(k,\mu,\bar{z}) = \sigma_{obs}(k,\mu,\bar{z})\left[k^2\frac{V_r(\bar{z})}{2(2\pi)^2}\right]^{-1/2}$$

$$\sigma_{eff}(k,\mu,\bar{z}) \propto k^{-2}$$

Conservative: $k_{nl}(0)$=0.2 h/Mpc

Optimistic: th. err. & $k_{max}(0)$=10 h/Mpc

$$\alpha = \frac{\delta P_g}{P_g}$$

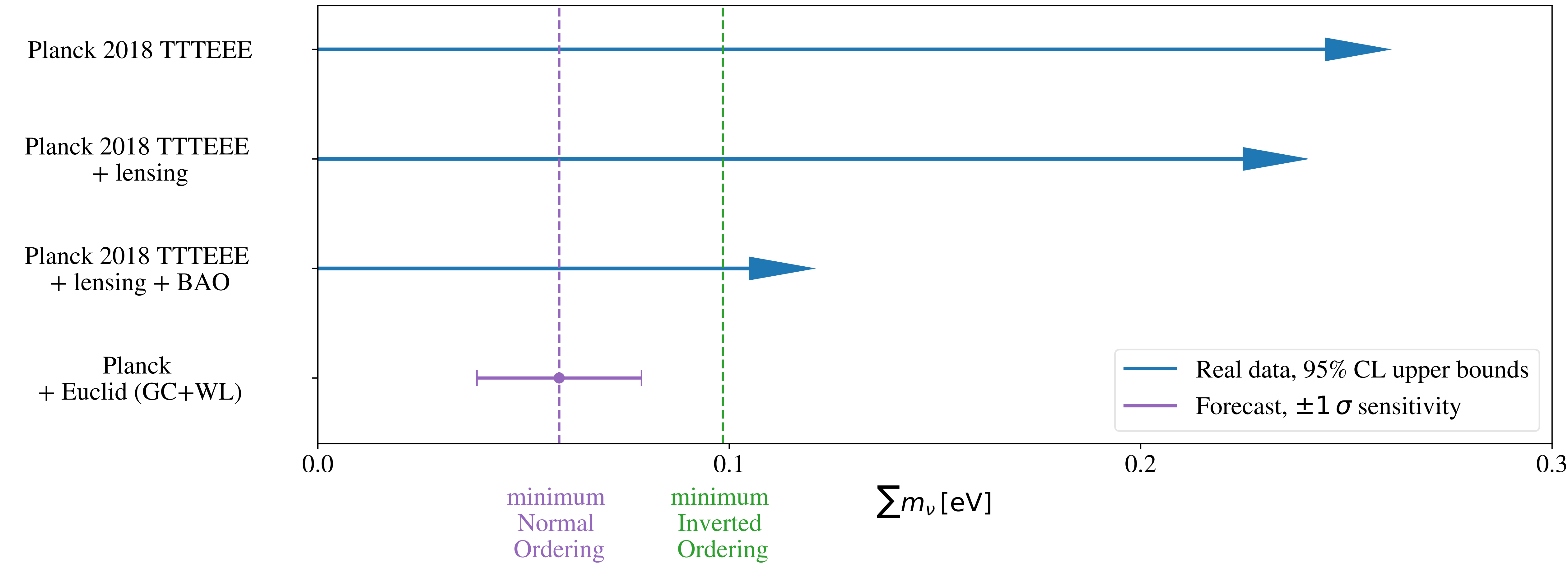
- 0.33% at k=0.01 h/Mpc
- 1% at k=0.3 h/Mpc
- 10% at k=10 h/Mpc

Fiducial Σm_ν = 60 meV

	Planck+Euclid-GC
Conservative	26 meV
Optimistic	20 meV

See also Baldauf+ 2016

Neutrino mass constraints: the future



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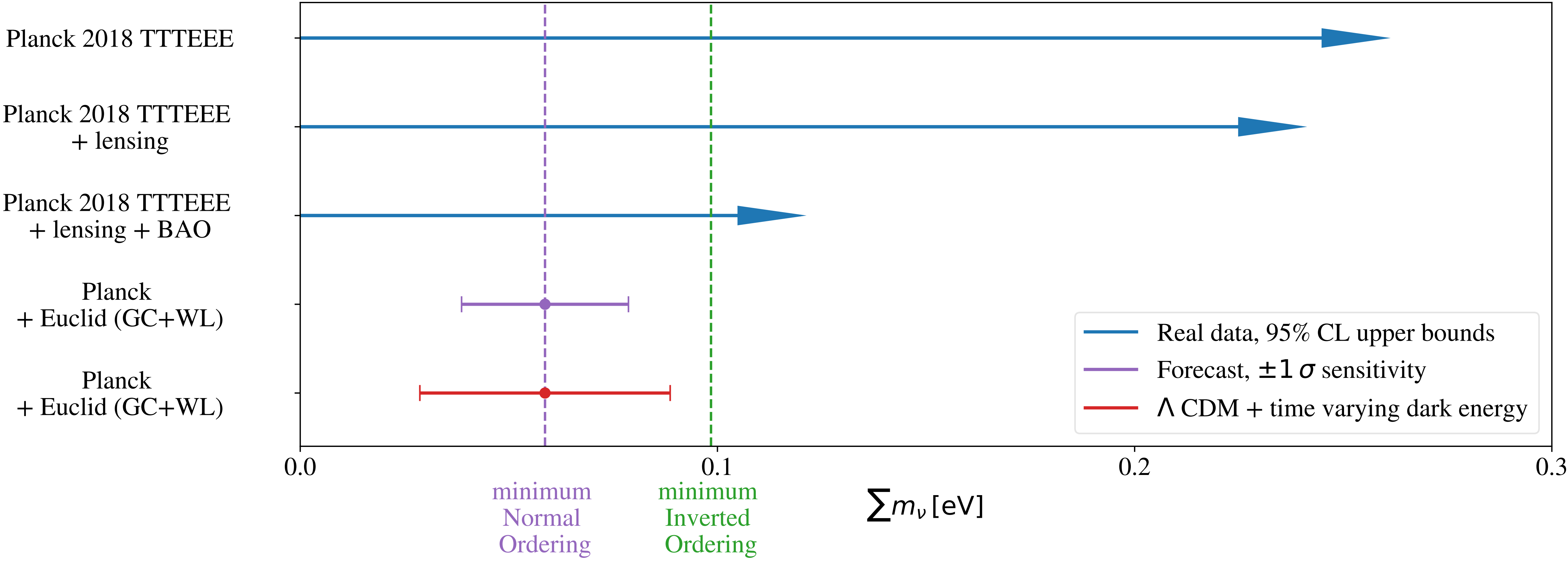
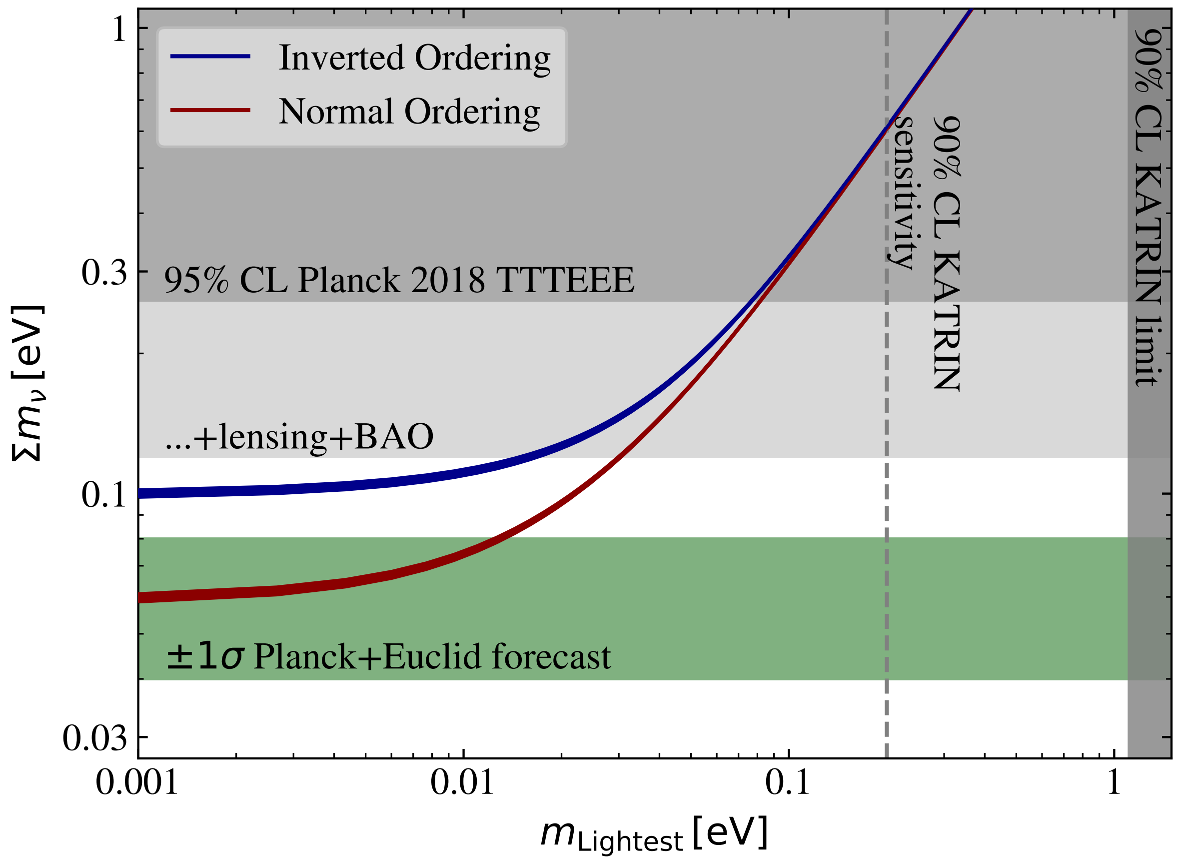
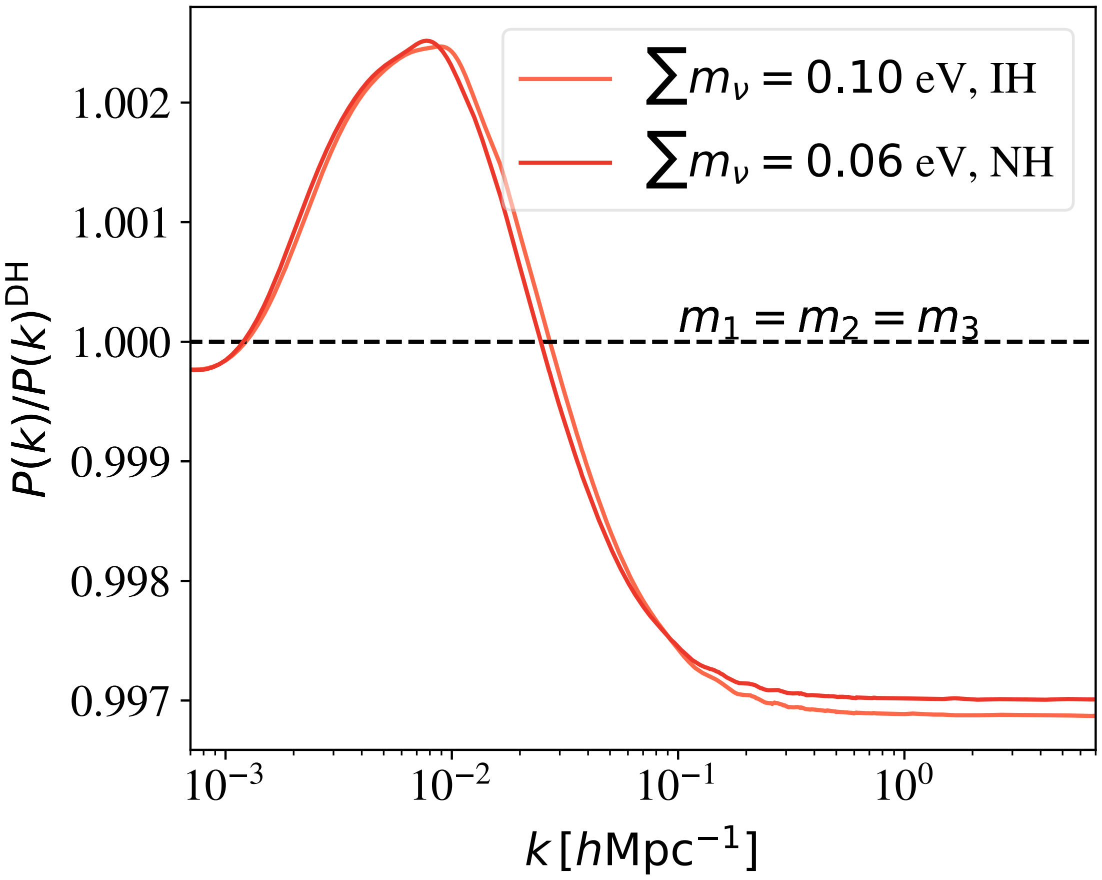


Higher order statistics can break degeneracies in extended models *(Chudaykin+ 2019, Hahn+ 2020, Ajani+ 2020)*

Neutrino mass ordering

Archidiacono, Hannestad, Lesgourgues, JCAP 2020





Conclusions

- Euclid can provide a *3σ evidence* for a non-zero neutrino mass sum in the minimal ΛCDM model
- If Σm_ν is about 0.06 eV, then the sensitivity to Σm_ν will *indirectly* favour Normal Ordering
- Theoretical challenges: get ready for Euclid!

Backup

Reconstructing the matter power spectrum

$$P(k) = \int \xi(\mathbf{r}) e^{i\mathbf{k}\cdot\mathbf{r}} d^3x,$$

$$\xi(\mathbf{r}) = \langle \delta(\mathbf{x})\delta(\mathbf{x}+\mathbf{r}) \rangle$$

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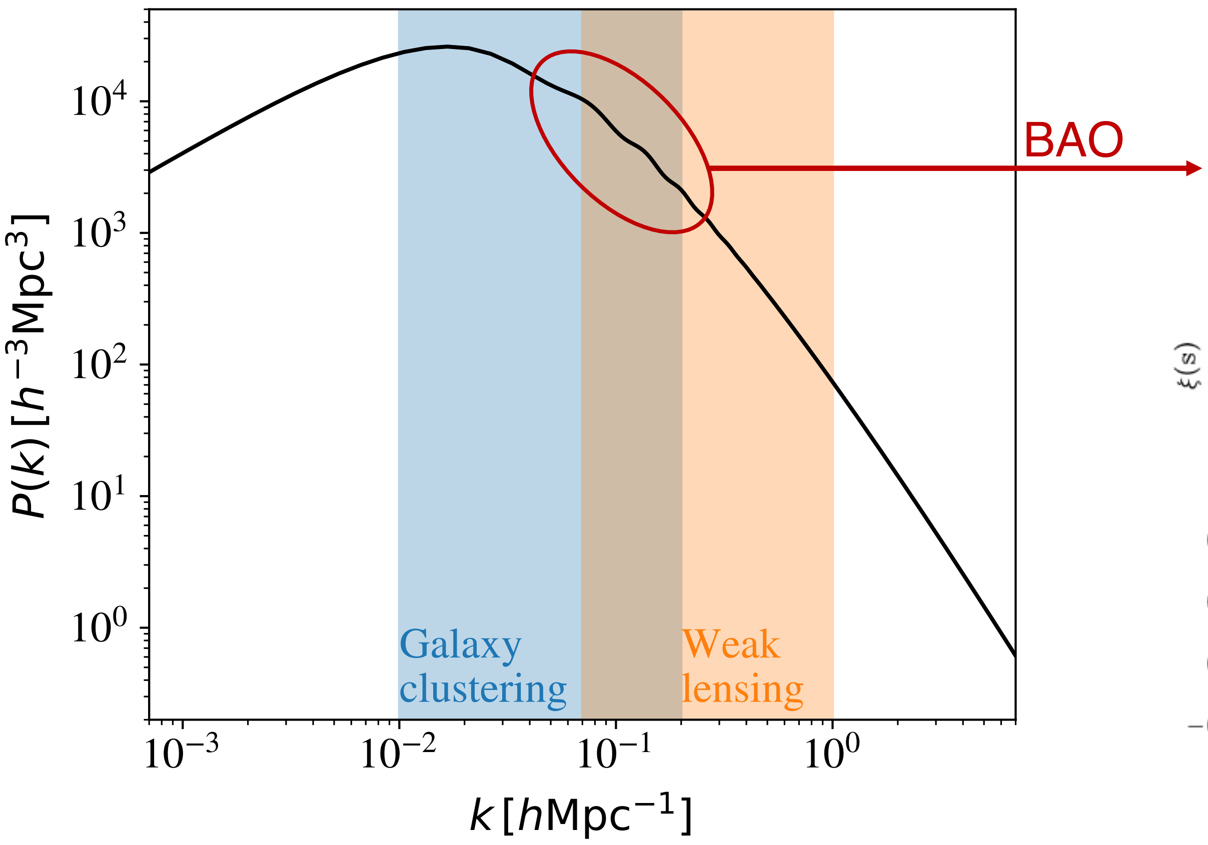

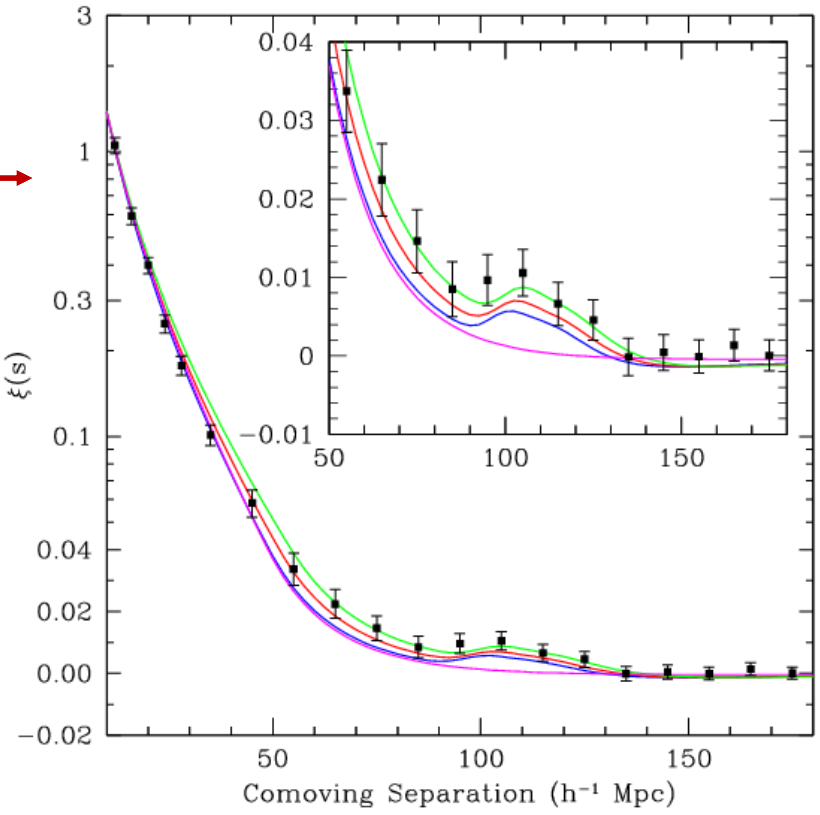

The neutrino mass challange

In a massless neutrino Universe $\delta_{\rm cdm} \propto a$

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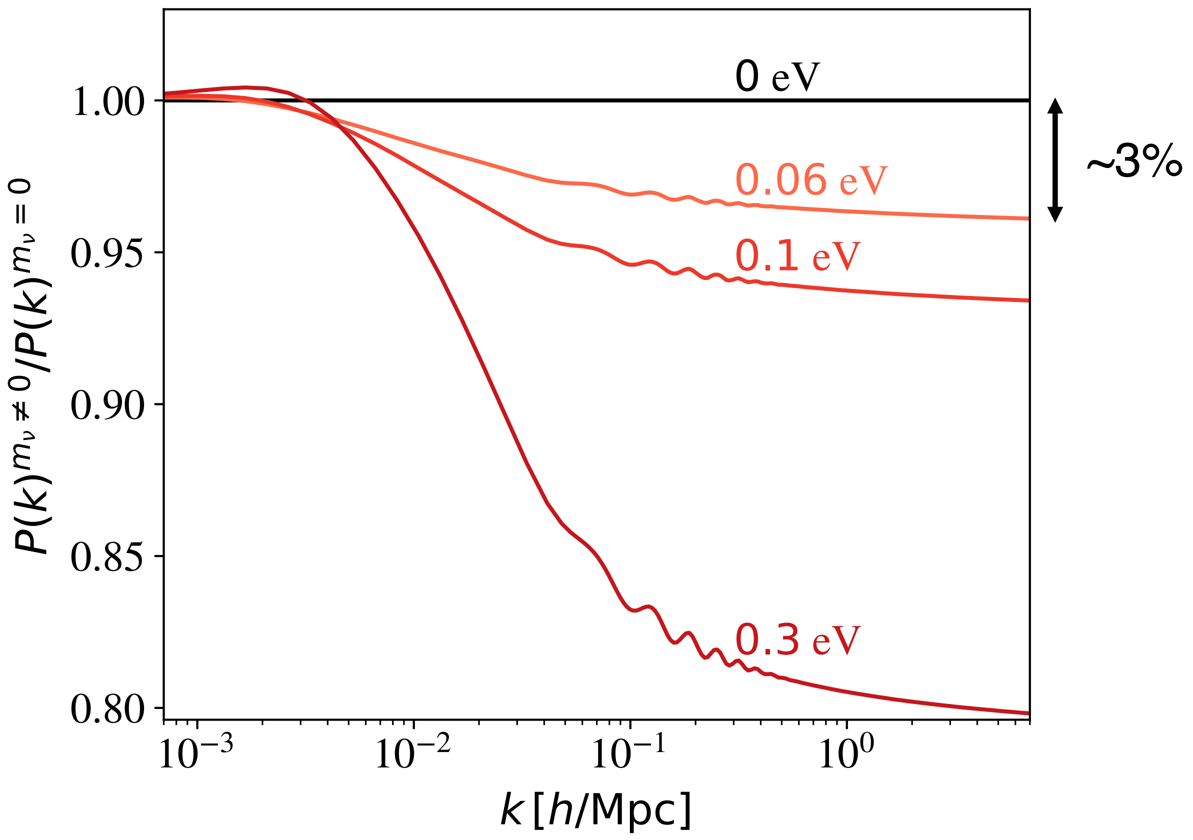
$$\Omega_\nu = \frac{\sum m_\nu}{93.14}$$



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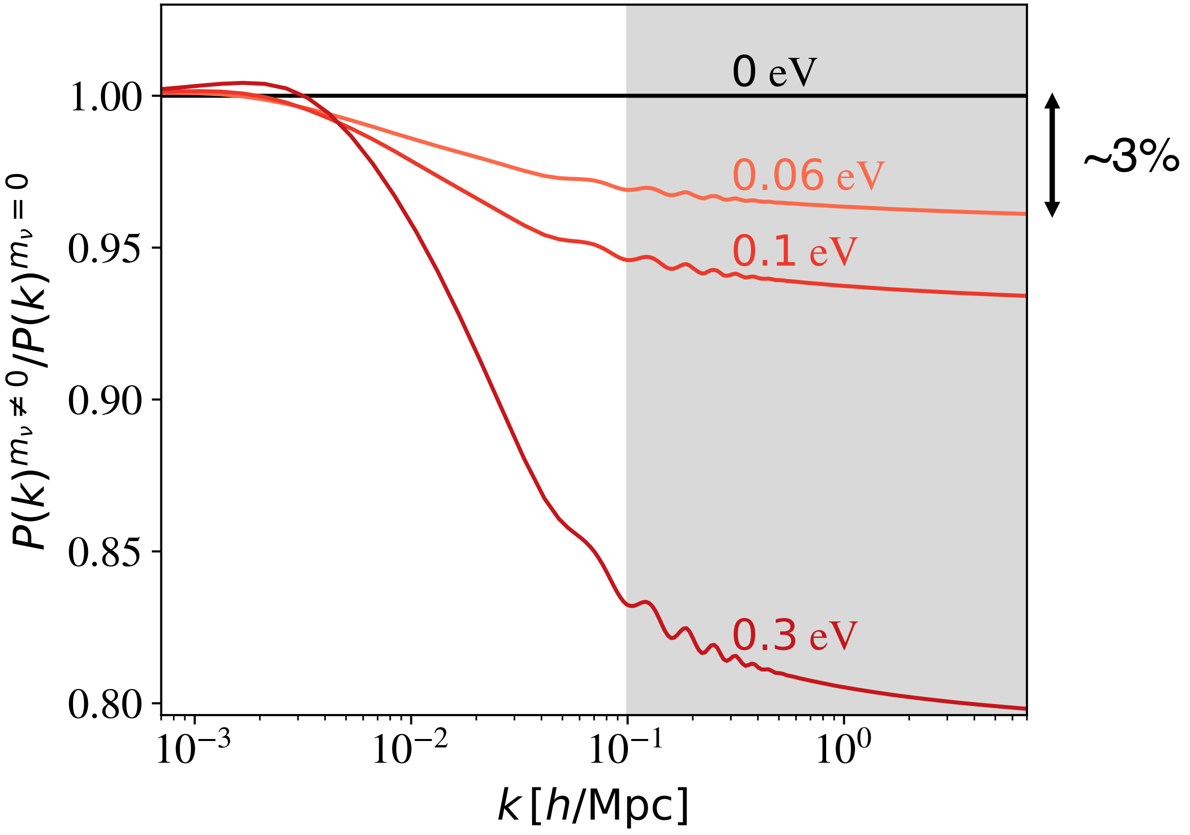

Challanges:

1. Galaxy bias $P_{galaxy} = b^2 P_{matter} + N$ *(see Castorina+ 2014)*
2. Non-linearities *(see Euclid Collaboration: Martinelli, Tutusaus, Archidiacono+ 2020; Euclid Collaboration: Knebnhans+ 2020)*
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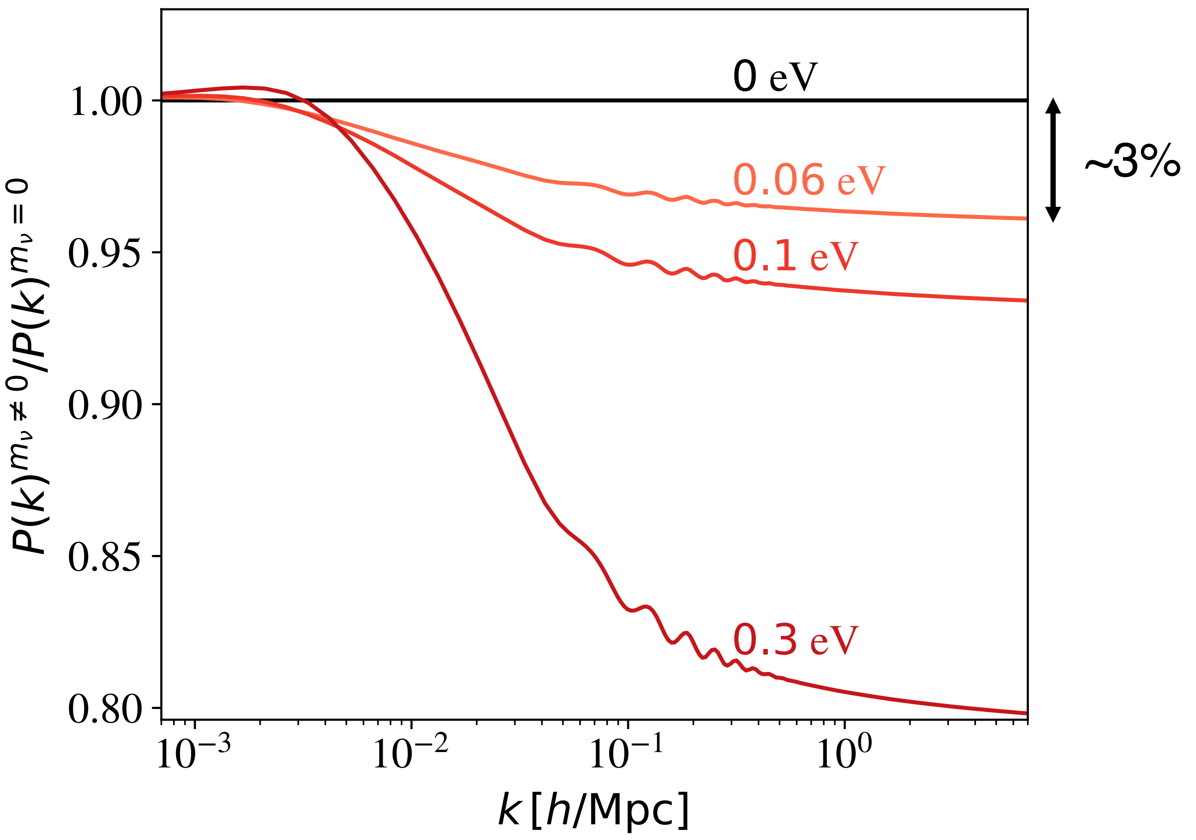

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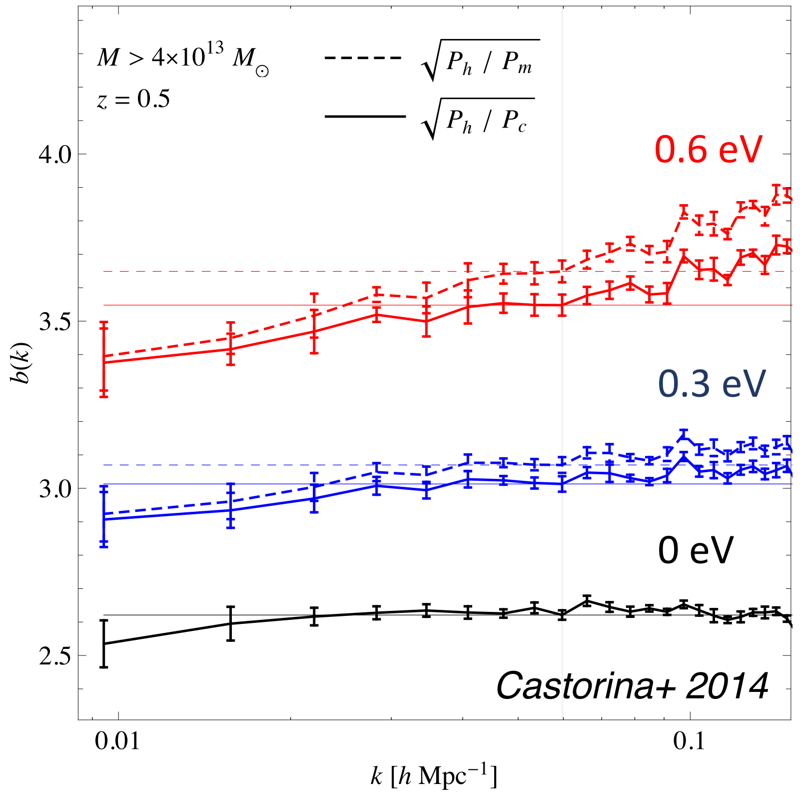

See also Vagnozzi+ 2018

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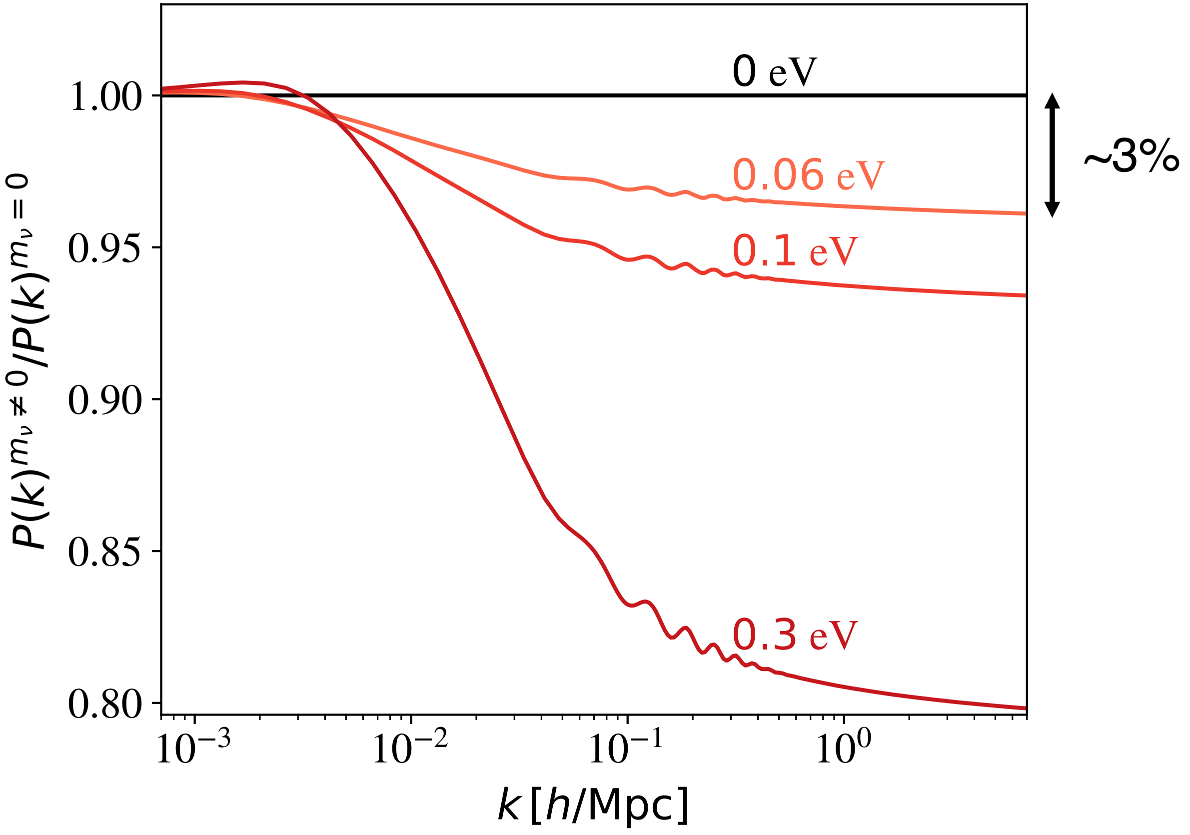
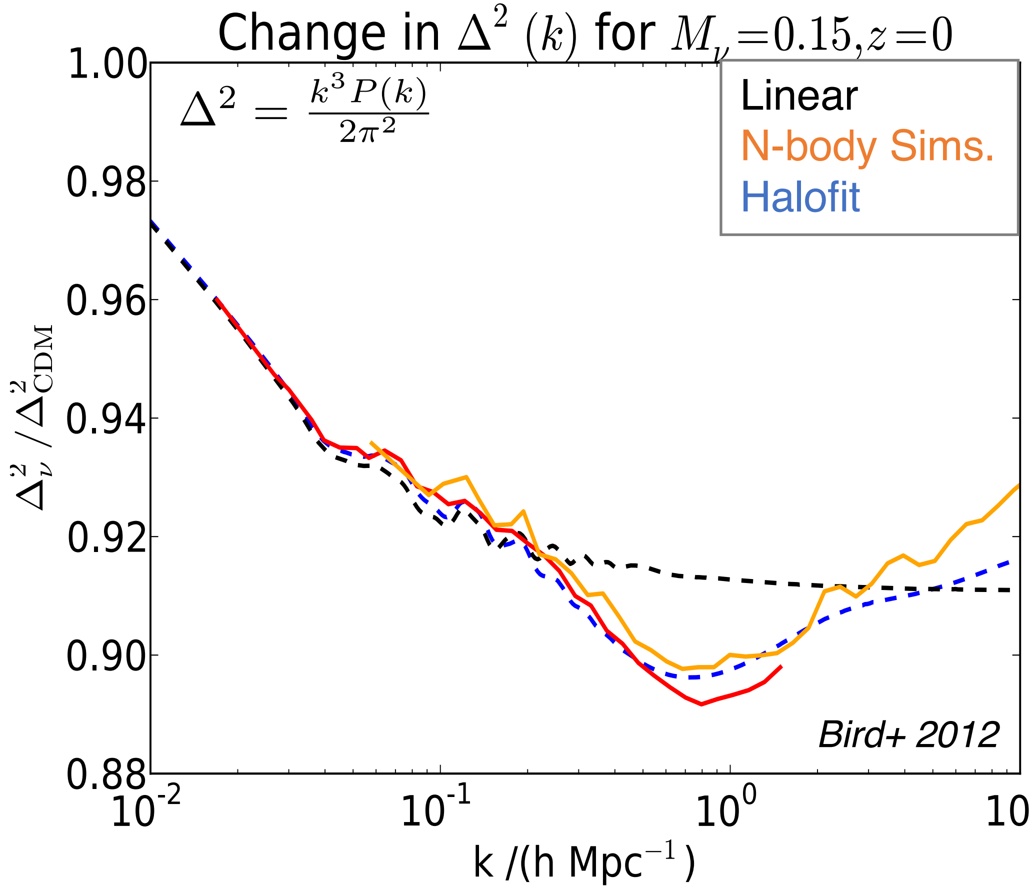


Challanges:

2. Non-linearities: δ ~ 1



See also Euclid Collaboration: Martinelli+ 2020

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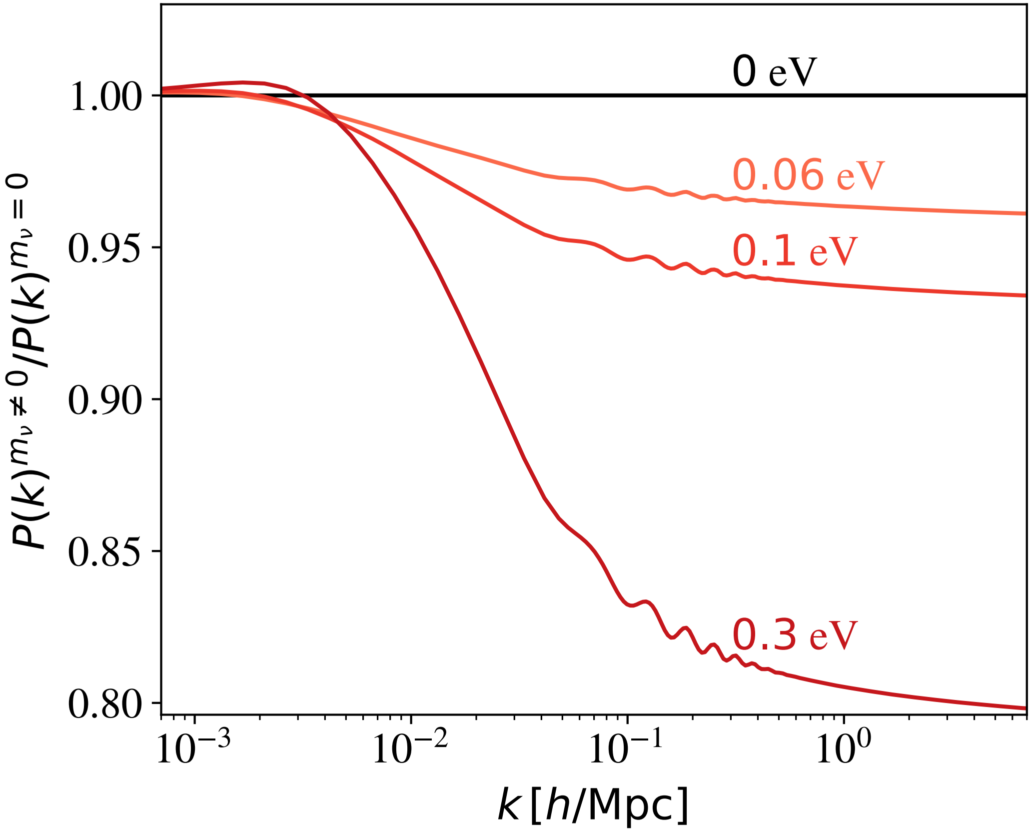


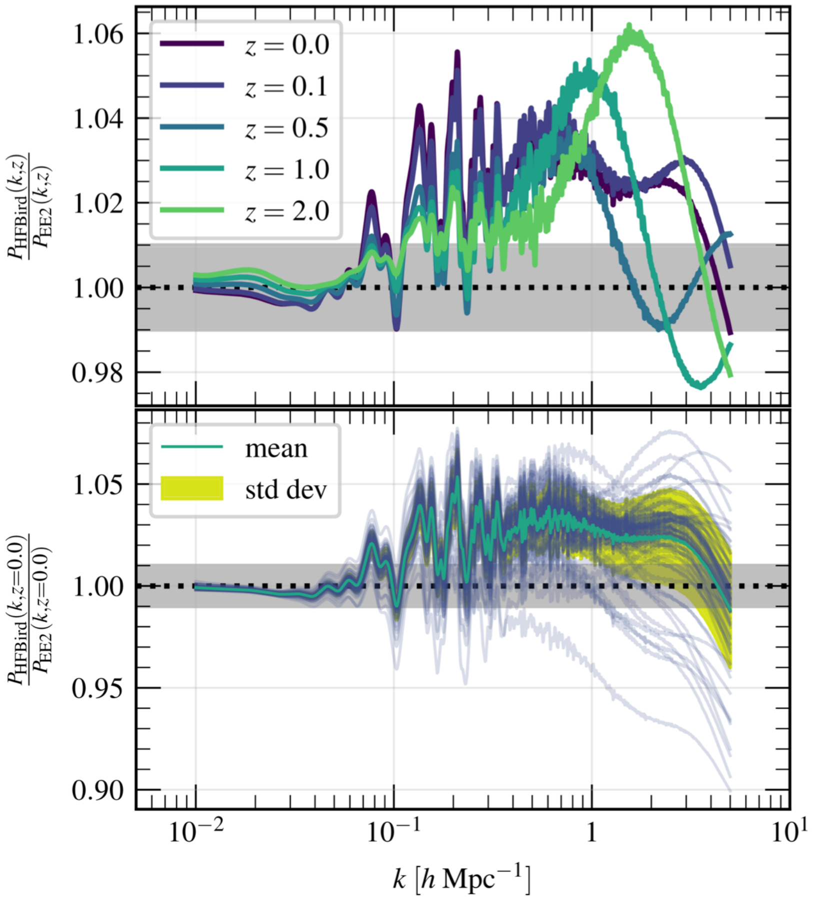
~3%

'Ideally' detectable with 1% accuracy

Challanges:

2. Non-linearities: δ ~ 1

Euclid Collaboration. Knabenhans+ 2020



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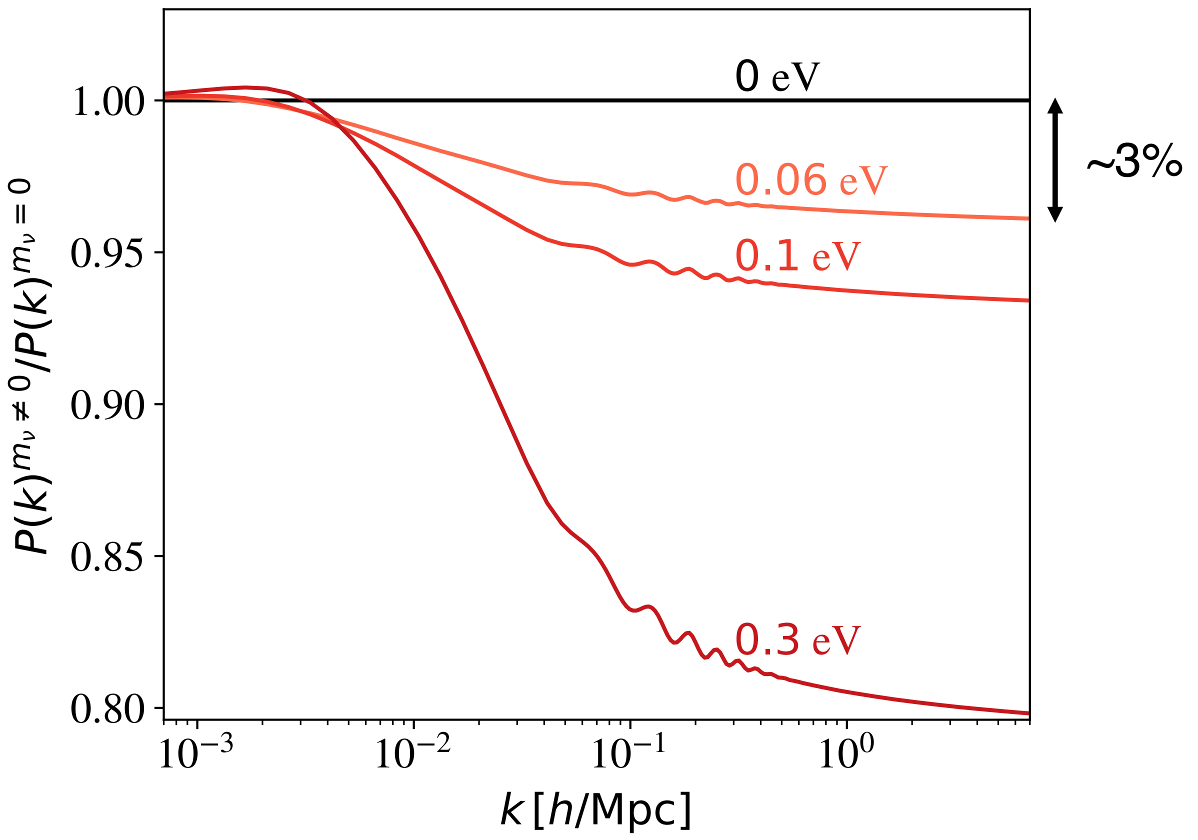

Challanges:

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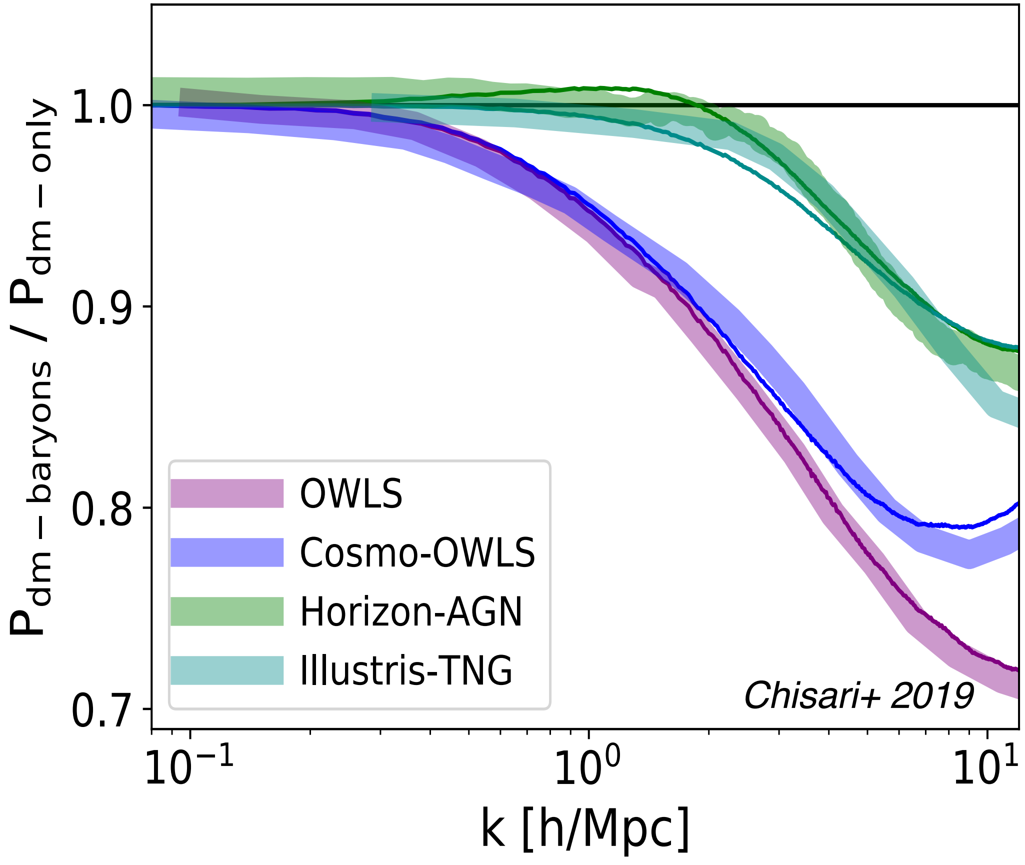

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