Something from nothing: Cosmic voids and their sensitivity to neutrinos : More in particular in their imprint in the CMB lensing map

Pauline Vielzeuf
EDSU, la Réunion, Nov 2023

CENTRE DE PHYSIQUE DES PARTICULES DE MARSEILLE
CPPM


Large Scale Structure
The cosmic web
filaments
clusters
~tens of Mpc/h
voids

Dark Energy and Massive Neutrino Universe : DEMNUni simulations (Gadget-3)

14 cosmological simulations with volume: $(2\ \mathrm{Gpc}/h)^3$, N_{part}: 2×2048^3 (CDM+)
baseline Planck-13 cosmology
+
M=0, 0.17, 0.3, 0.53 eV (DEMNUni-I)
&
$(M, w_0, w_a) = (0 \div 0.16, -0.9, \pm 0.3), (0 \div 0.16, -1.1, \pm 0.3)$ + M=0.32 (DEMNUni-II)

DEMNUni-Covariances

300 cosmological simulations with $V=1\ (\mathrm{Gpc}/h)^3$ and $N_{part}=2 \times 1024^3$ (CDM+):
140 TB of stored data at project completion

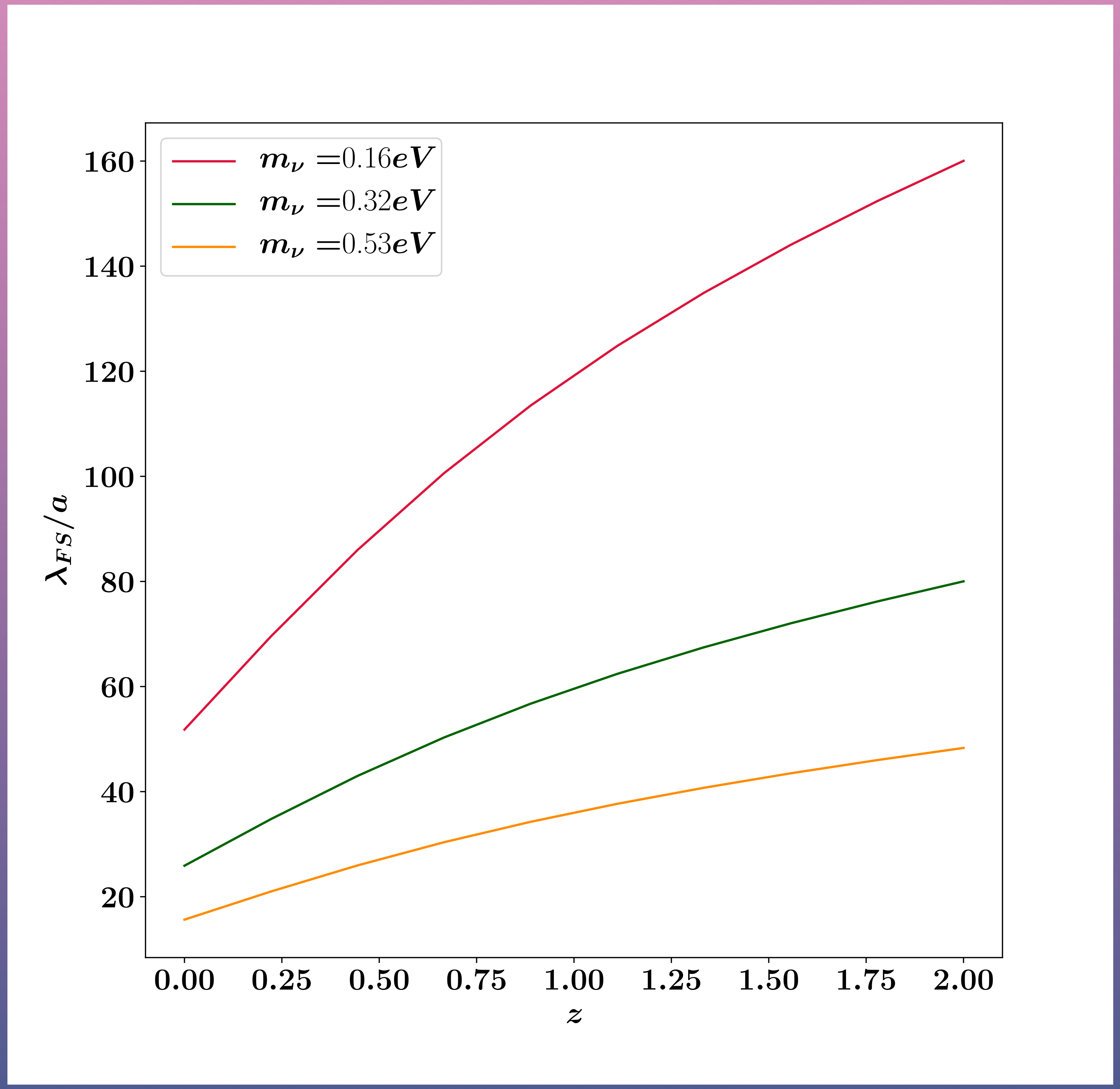
5 snaps per sim stored between z=0-2, all the halo/subhalo catalogs stored from z<2

300 TB of stored data @CINECA/CNAF/IA2-TS

- CMB lensing map for each catalog,
- CMB lensing separate effect from DM and Mnu for 0.53
- diluted DM particles catalog

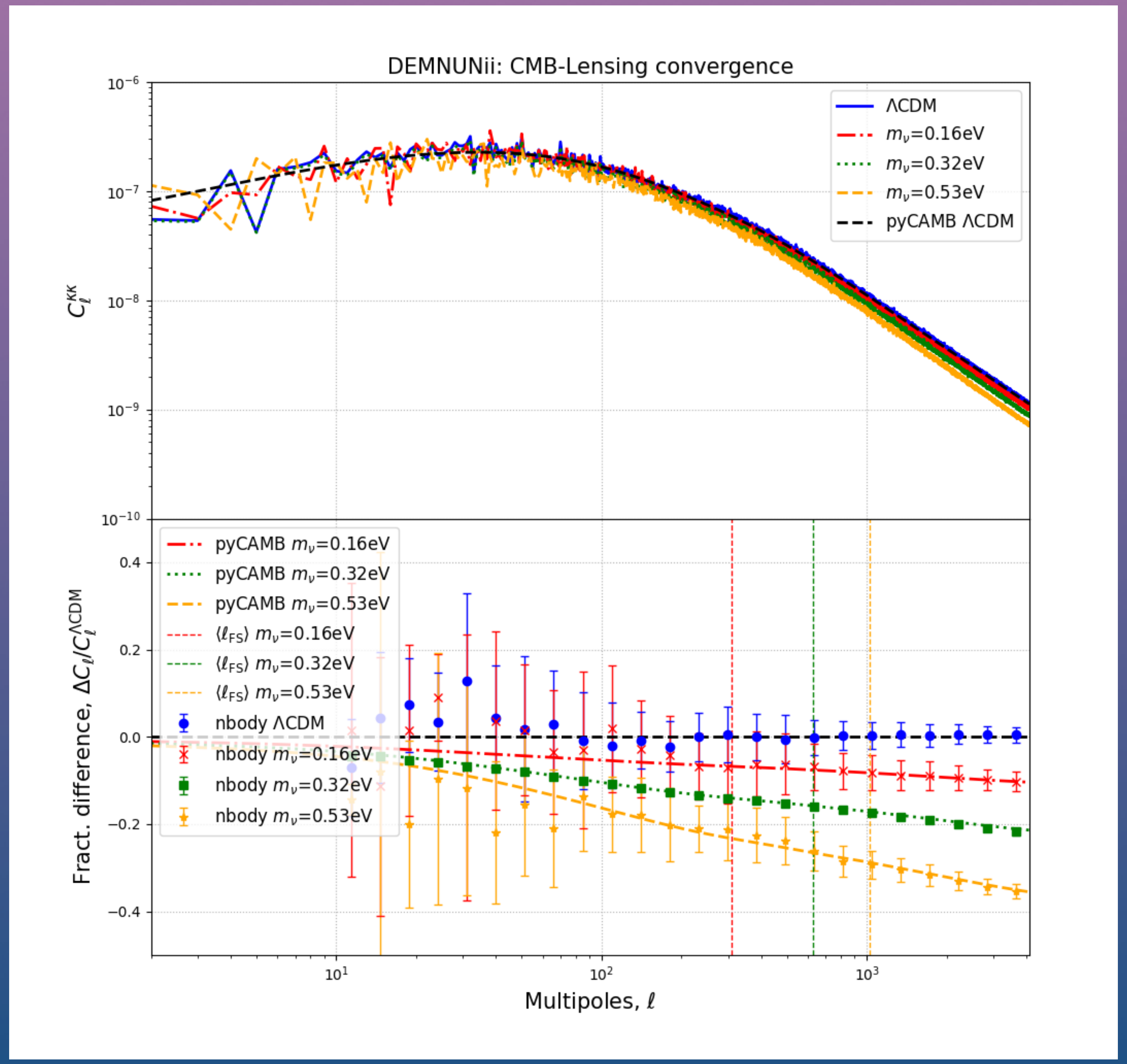
Neutrino free-streaming

At small scales, due to their non-zero velocity, massive neutrinos will travel across density fluctuations and thus smooth them, at scales comparable to cosmic voids, massive neutrinos will fall in the potential wells.



cosmic voids might be particularly affected by the presence of massive neutrino, due to the fact that the typical size of voids (10 to 100s of h^{-1}Mpc)

$$\lambda_{\rm FS}(m_\nu, z) \sim 8.1 \frac{H_0(1+z)}{H(z)} \left(\frac{1eV}{m_\nu}\right) h^{-1}{\rm Mpc},$$




Large Scale Structure
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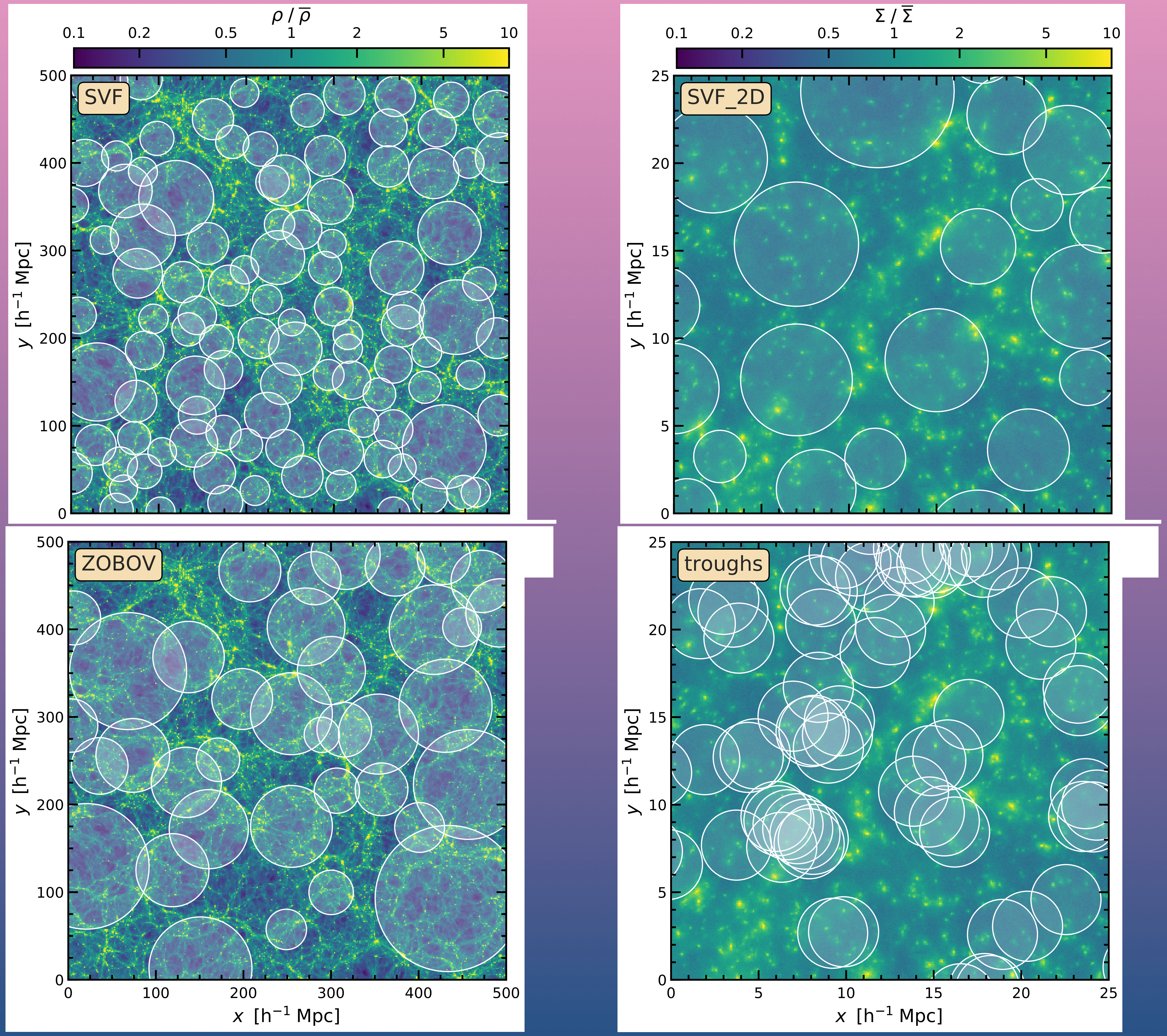
In the literature, a variety of void finder exists, and void finder can be run in different density tracers

Different methodology will identify different void populations, depending on the science case, some methodology will be more efficient than others.

Cautun et al. (2018) :

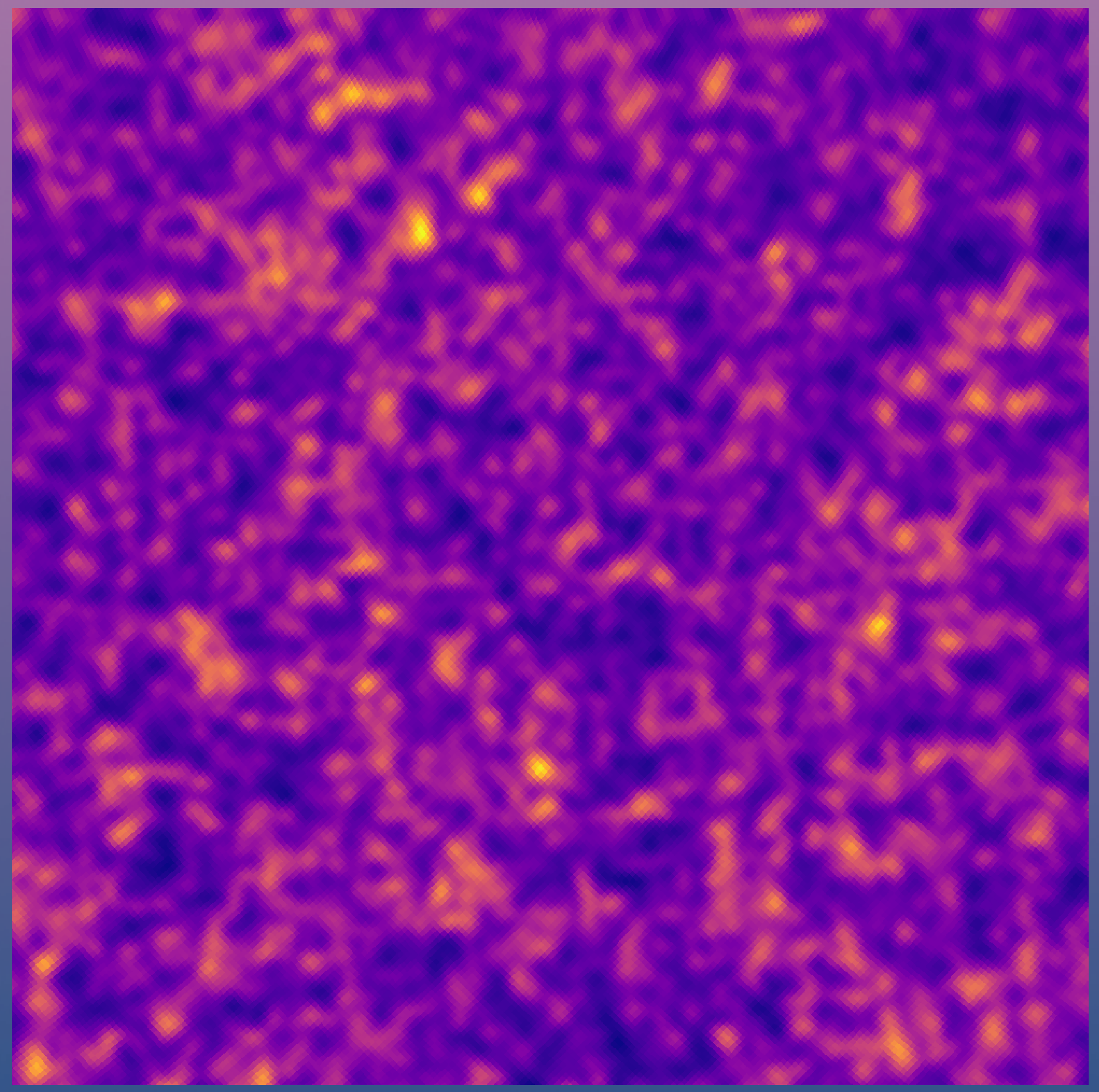
Void lensing observables are better indicators for tests of gravity if defined in 2D projection such as “tunnels" or “troughs".



Void identification : 2D void finder

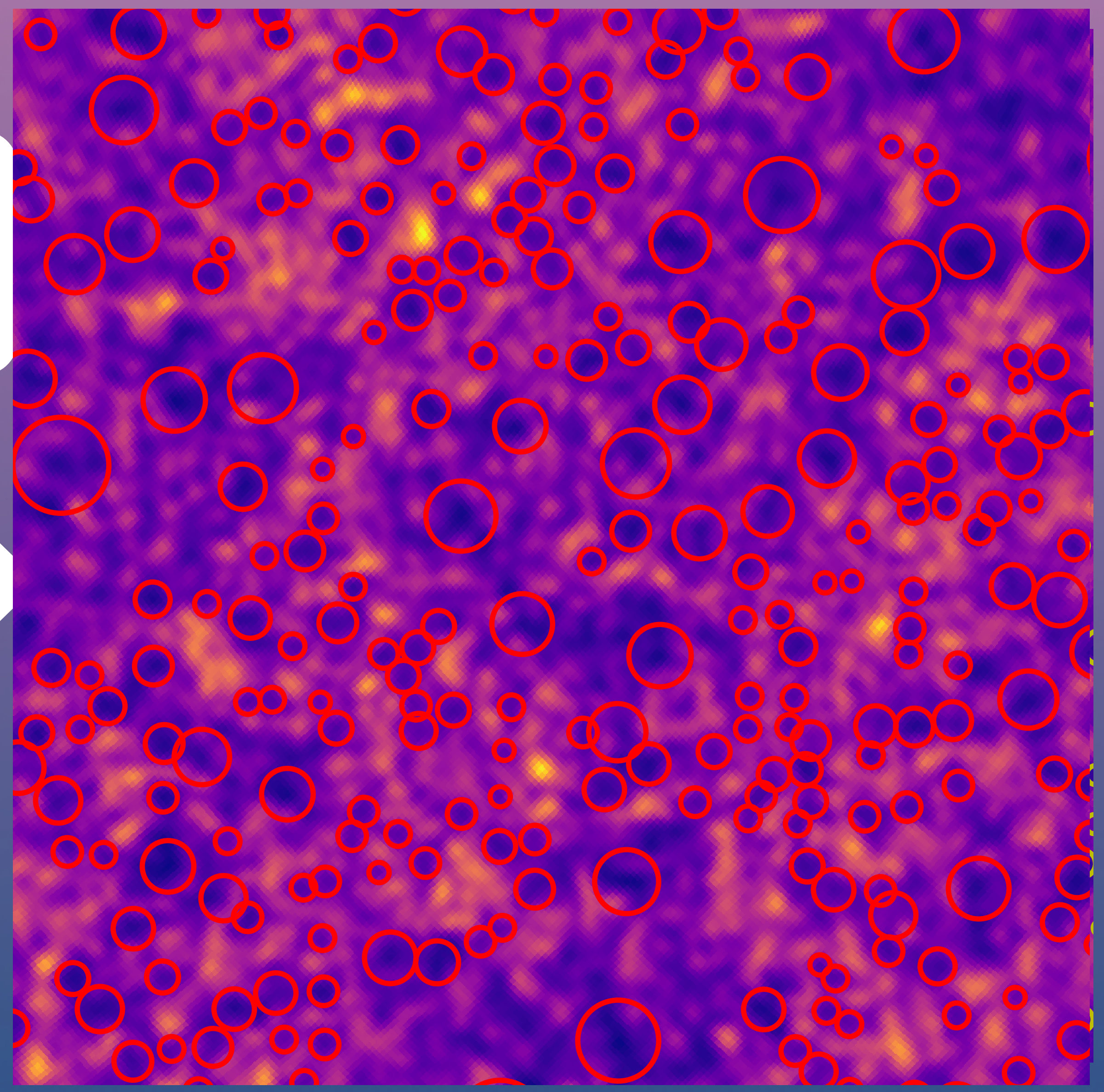
Sánchez et al. (DES Collaboration), MNRAS 465, 746, 2017.

Compute the density field as the number of galaxies in each pixel of an healpix map in a given redshift slide



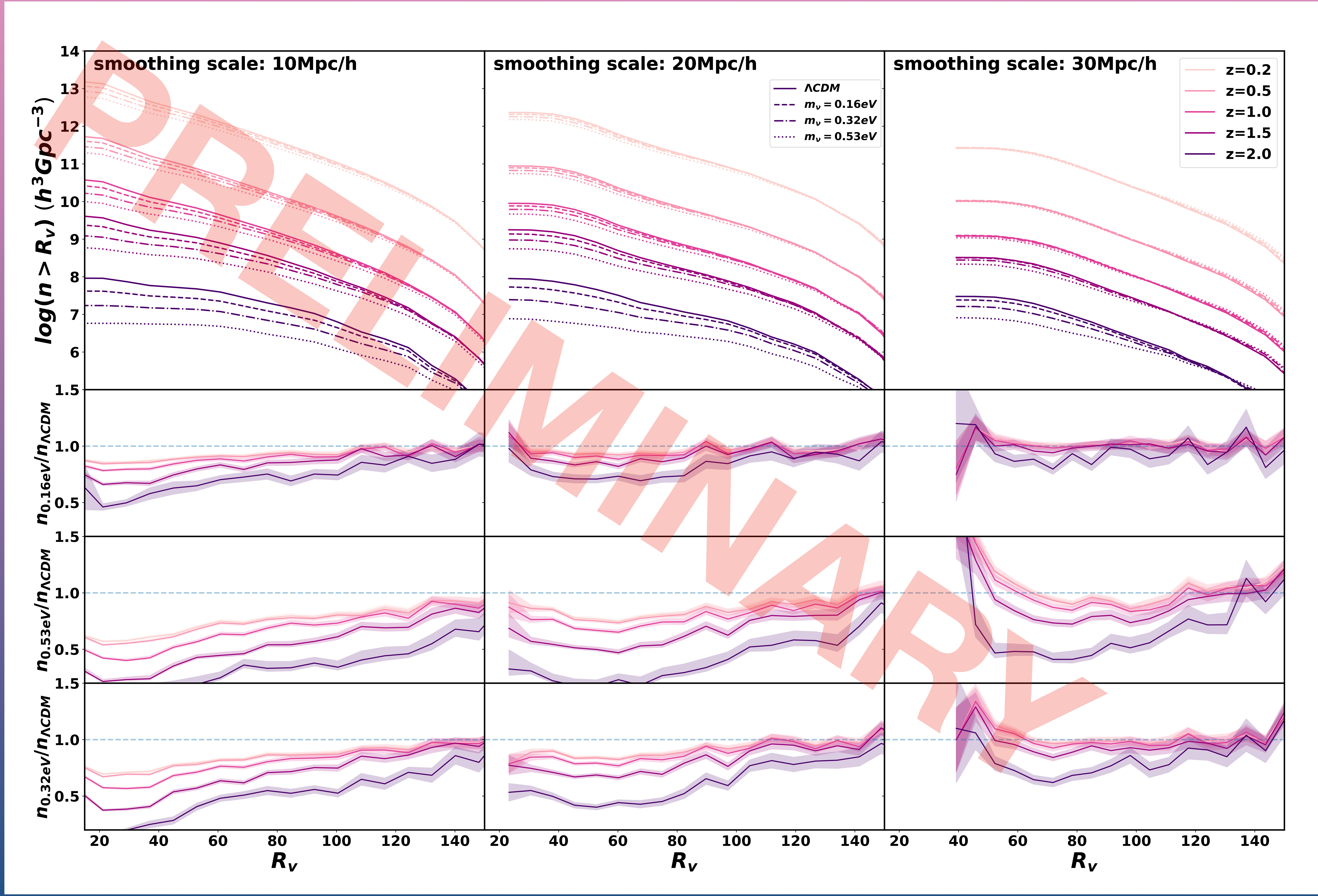
Gaussian Smoothing

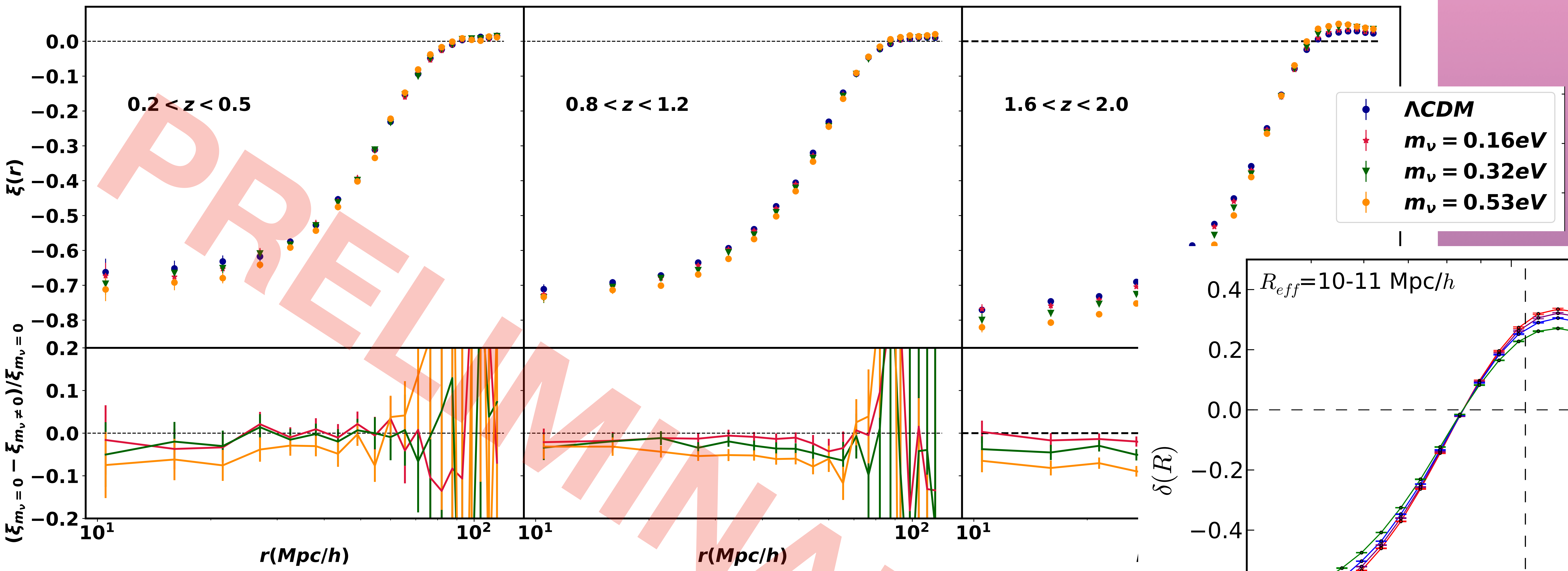
Grow circles around underdensed pixel until reaching the mean density of the map

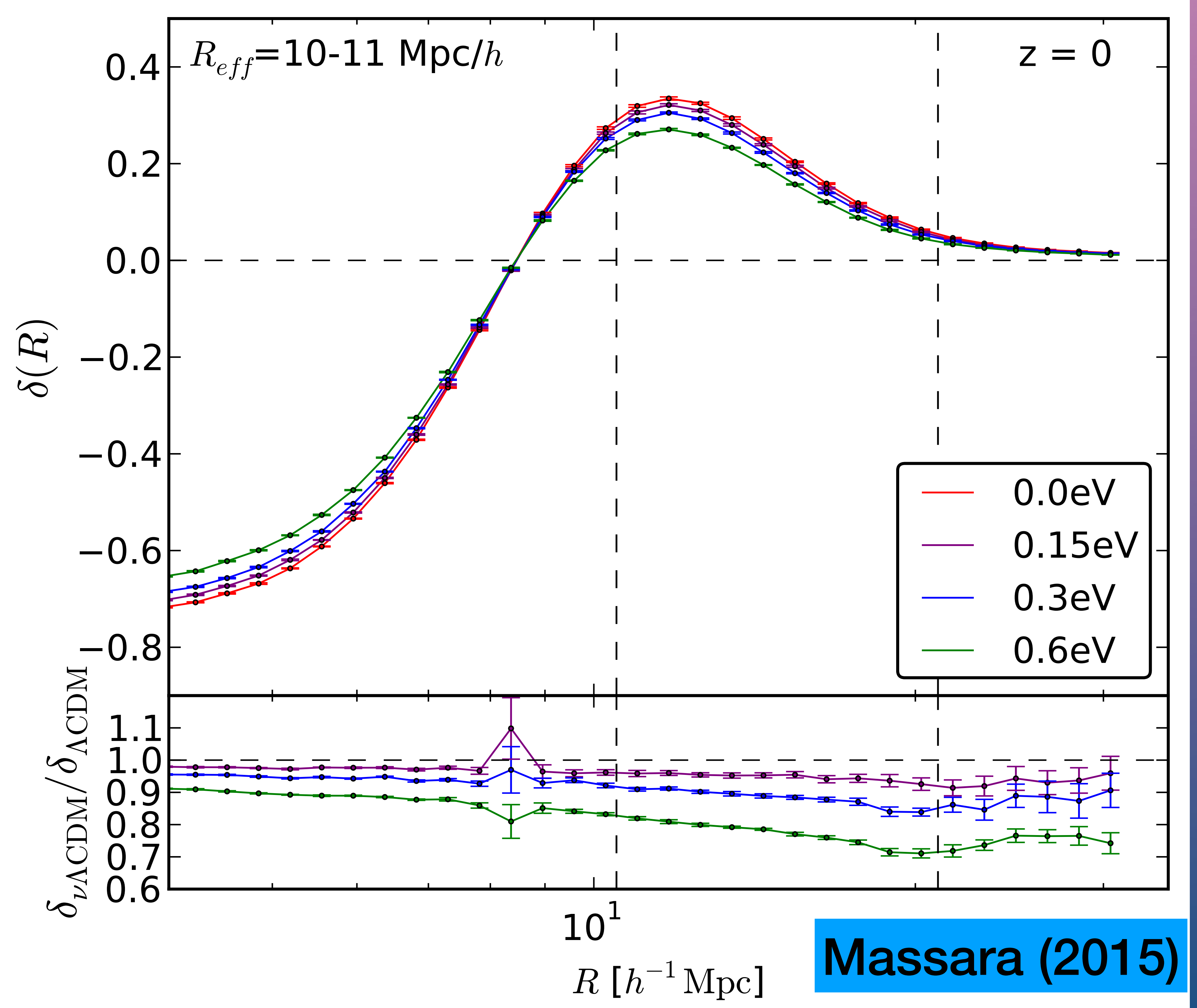


Neutrinos effect on the matter tracer

- Due to the overall **decrease in the tracer density**, the presence of massive neutrinos tends to decrease the total number of voids. We note that the **number of small voids tends to be more reduced** than the large ones. Such behaviour in the void size function can be directly explained by the decrease in the tracer density which in turn induces a **merge of the smaller structures** in the void identification procedure. As one increases the Gaussian smoothing in our void finder - and thus tracks larger structures - we can reduce this effect.



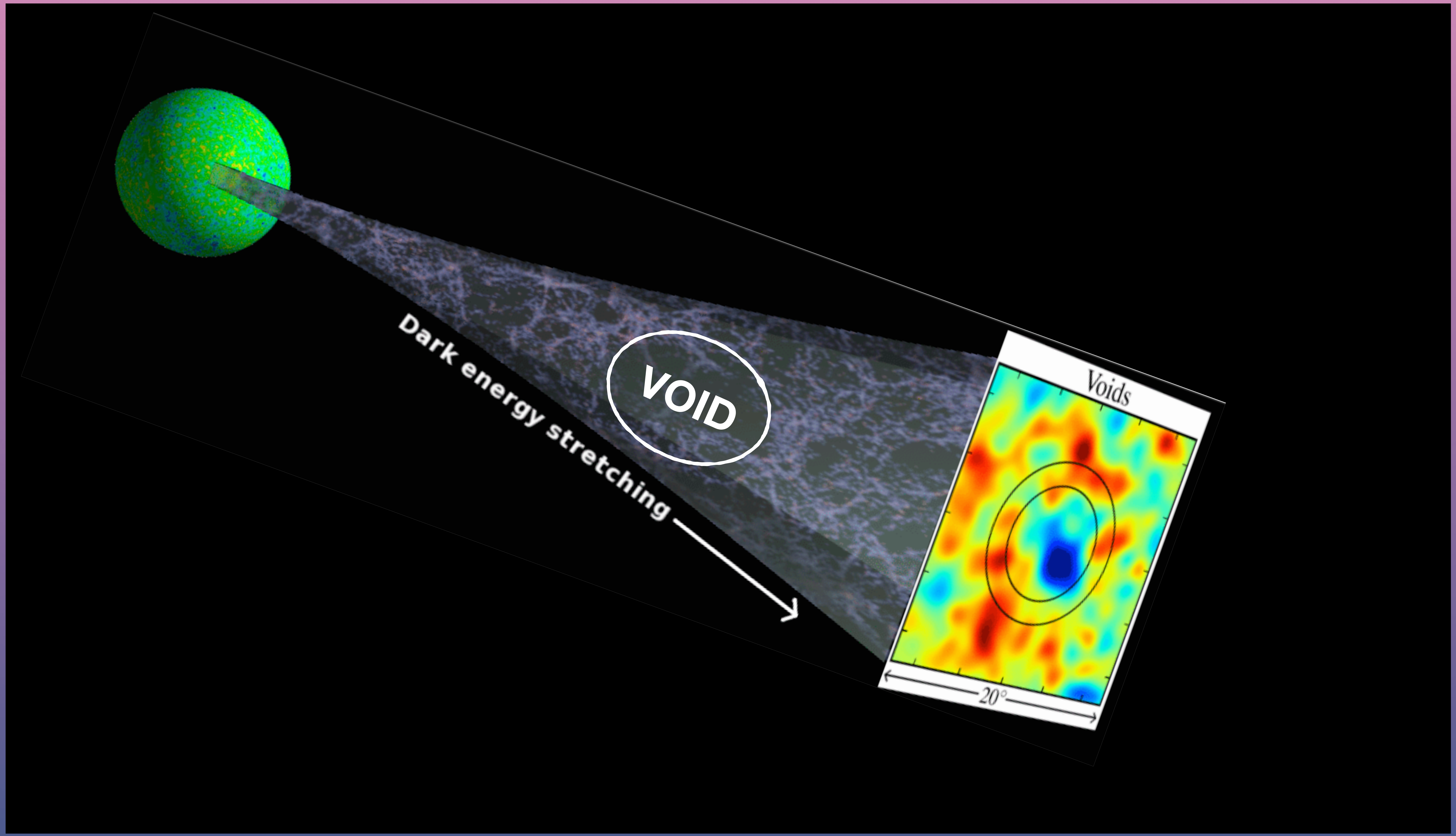




Massara (2015)

$$\xi_{ij}(r) = D_iD_j(r)/D_iR(r) - 1,$$

- Once we consider larger smoothing scales, the identified voids tend to be smoother
- Voids in massive neutrino cosmologies seem to be slightly deeper than in the massless case



Similarly to the deflection effects induced by the large structures that we observe on the sky on the photons coming from background galaxies, we should have lensing effects by the foreground matter field on the photons that come from the CMB

Void identification : 2D void finder

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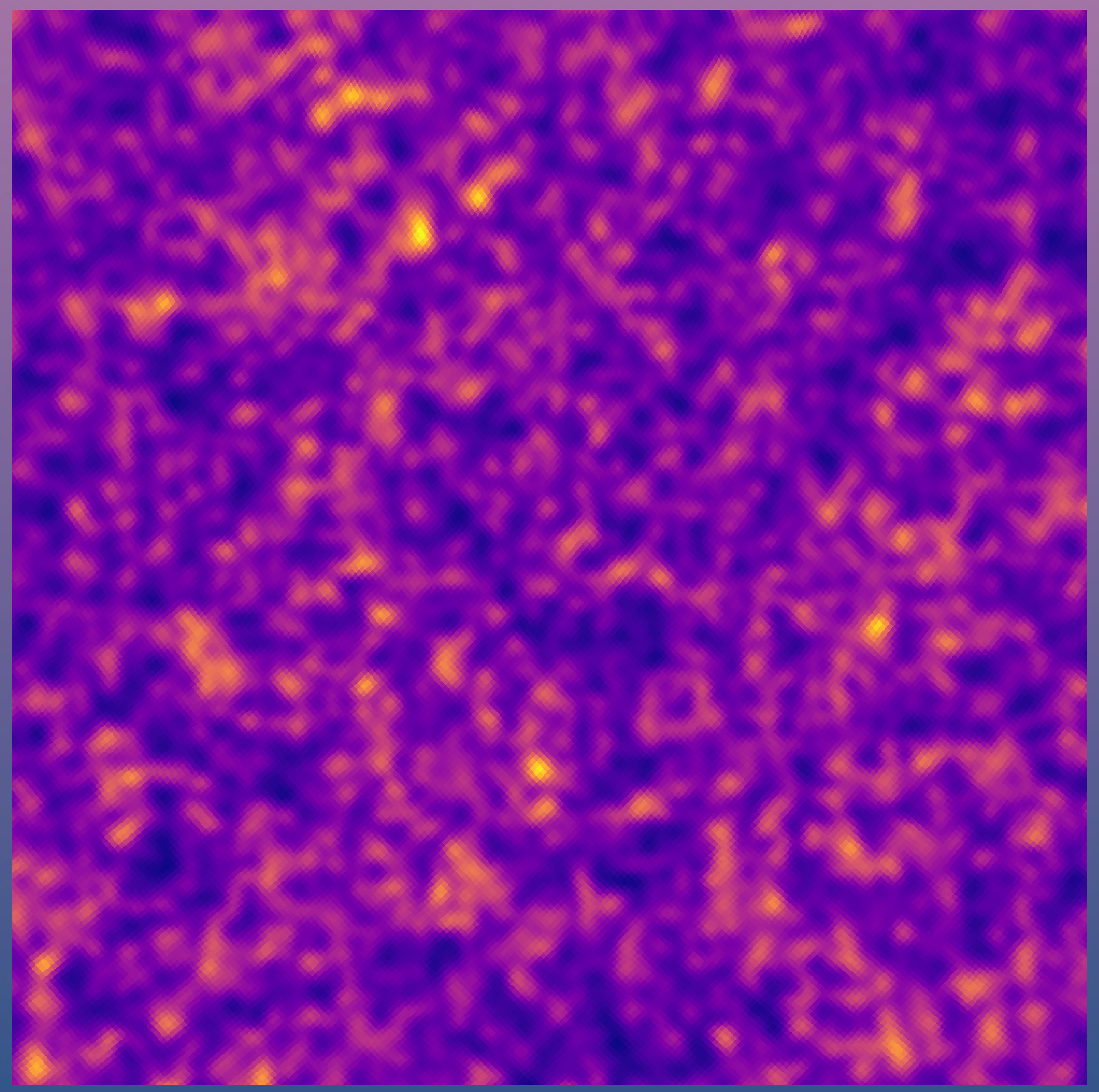

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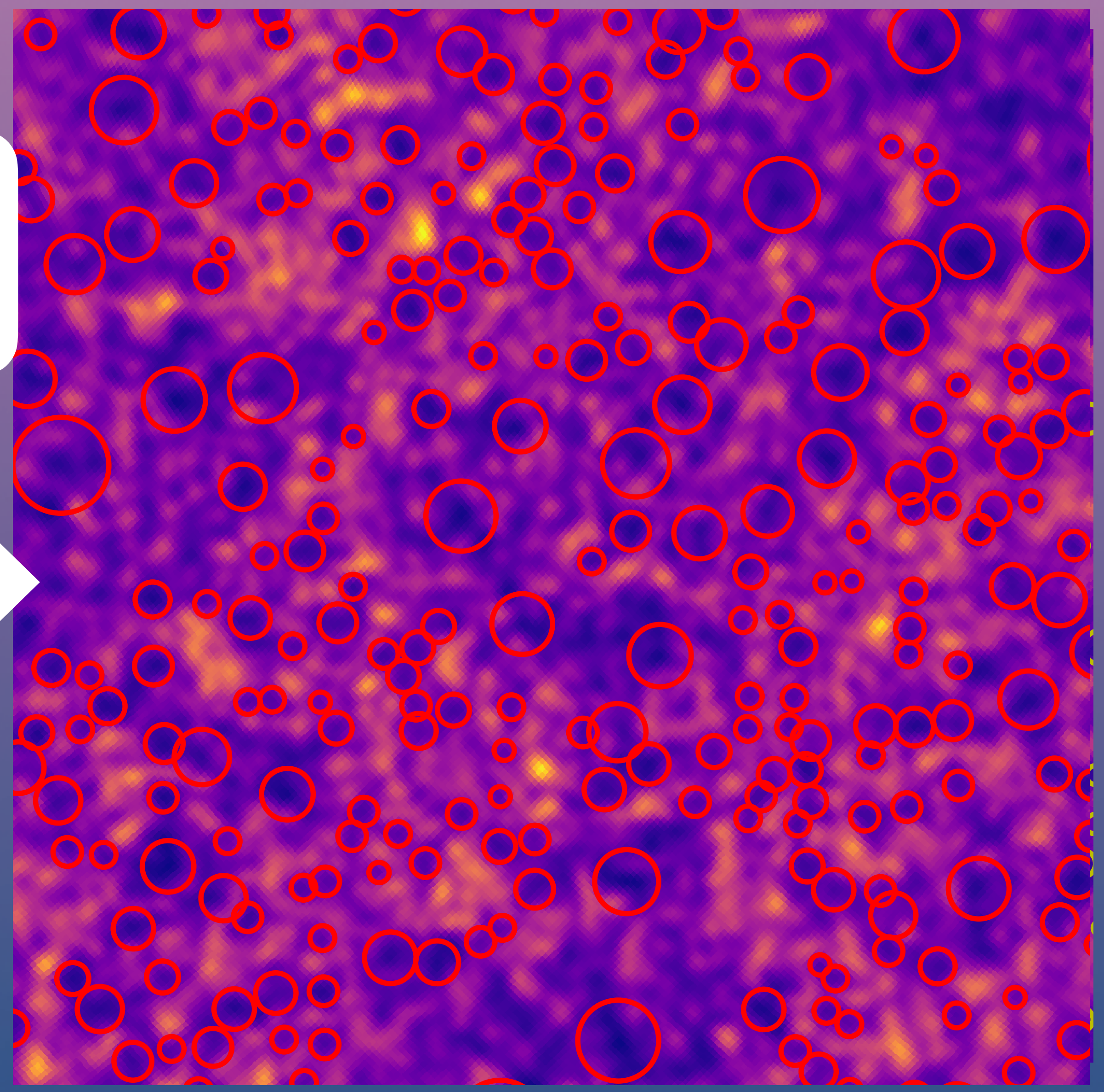
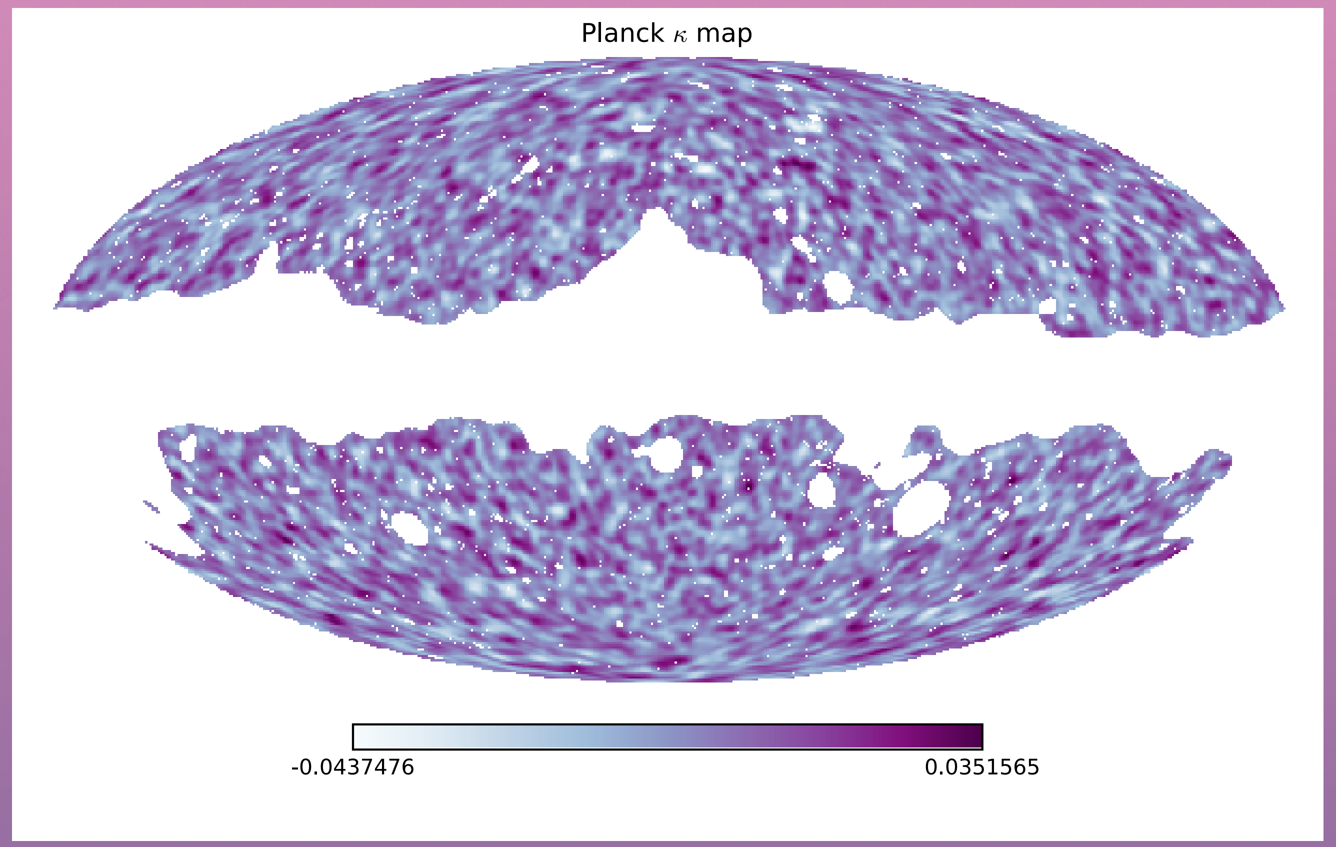
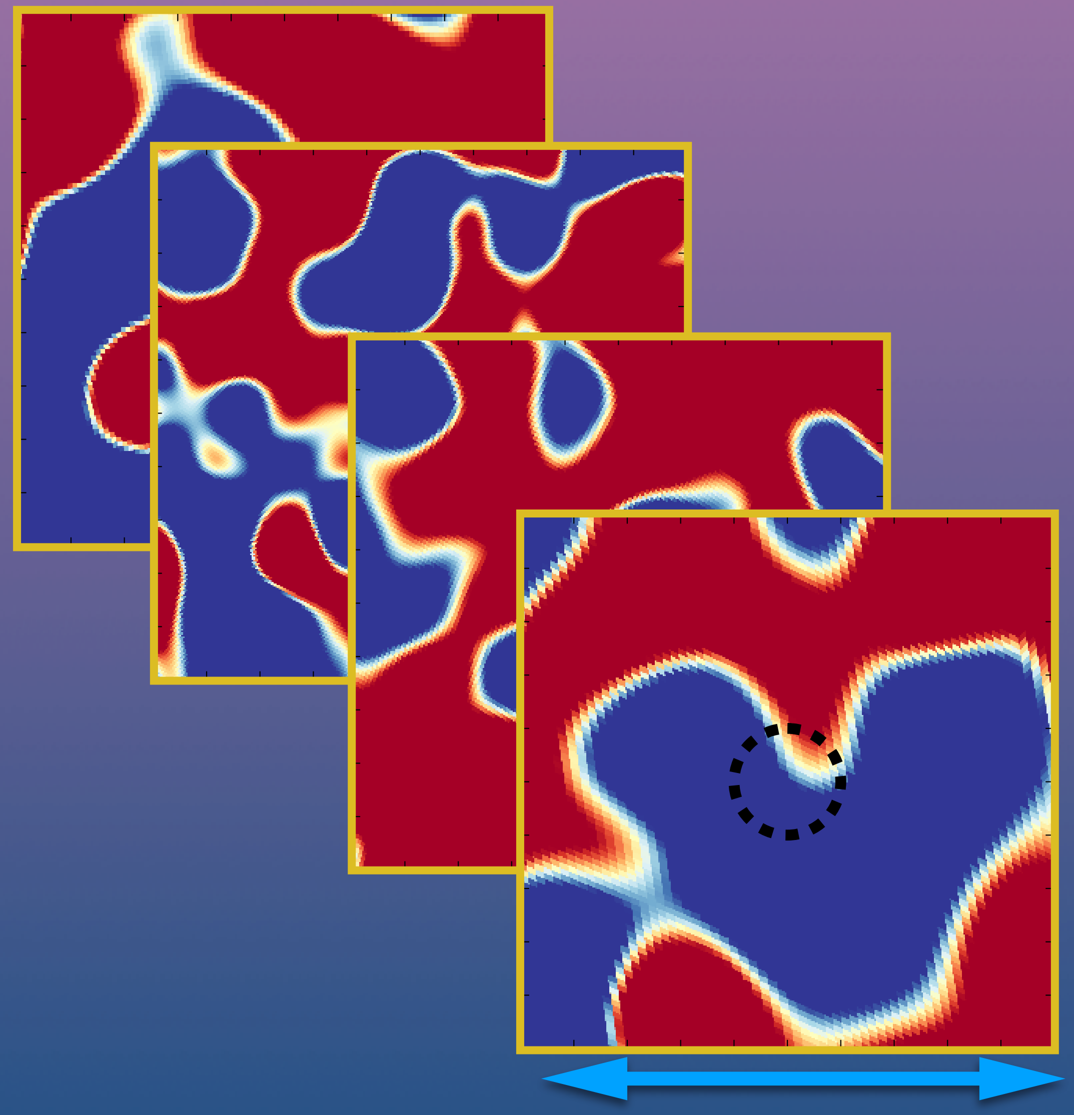


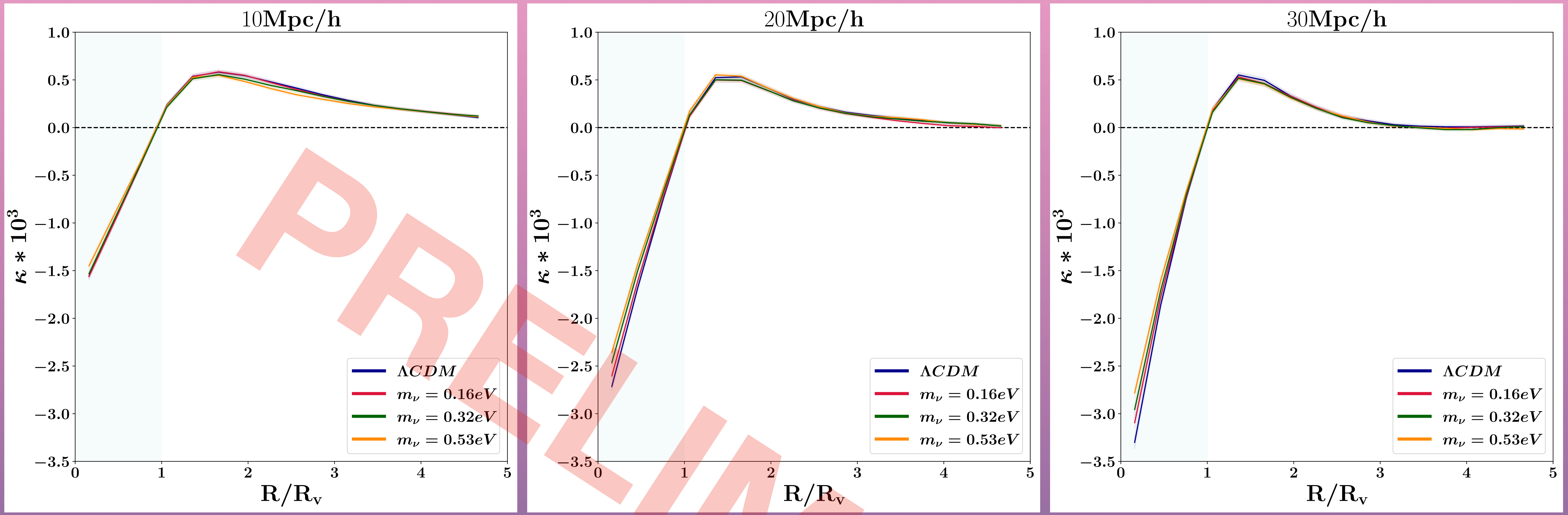
Stacking methodology





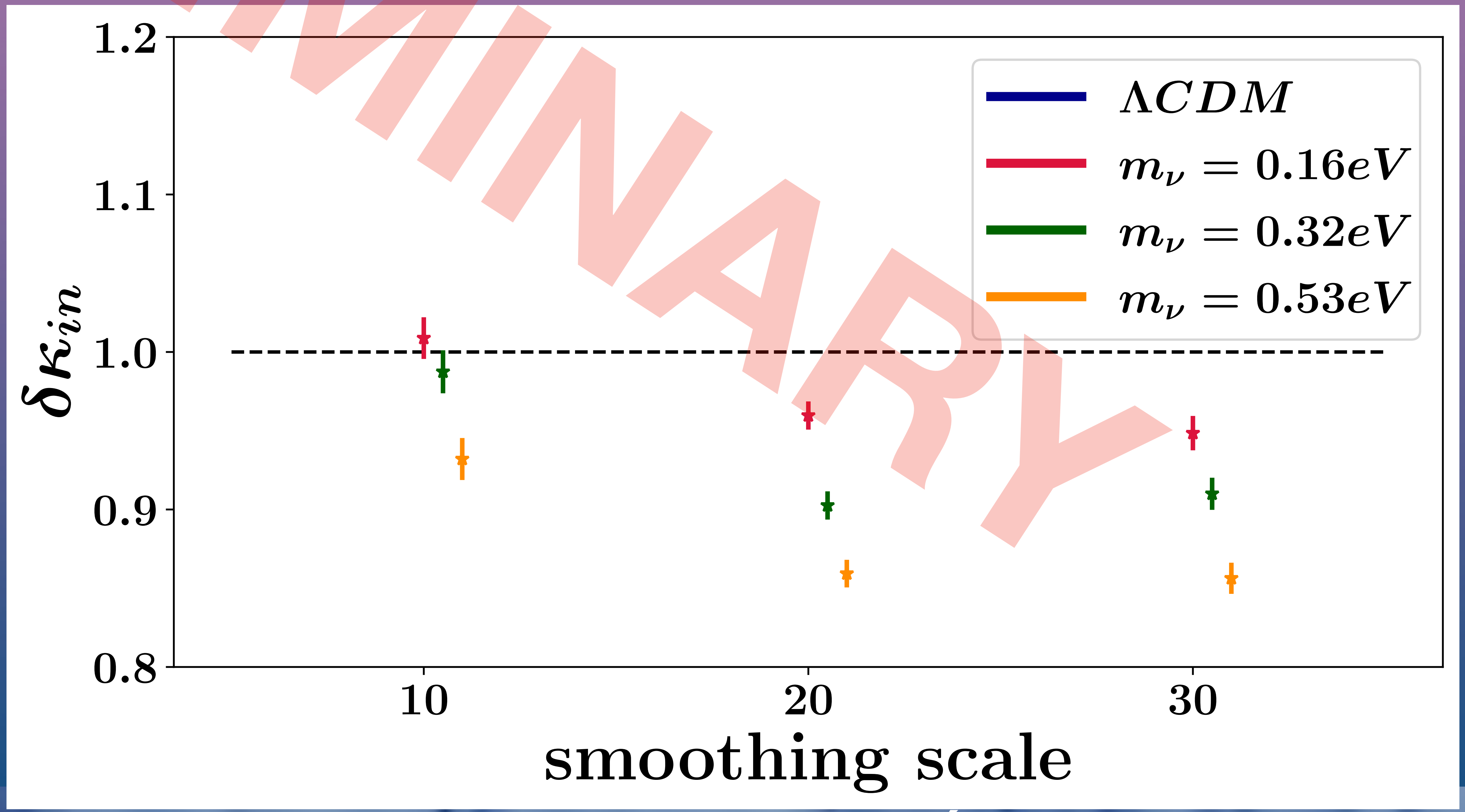
Correlation signal

The increase in the smoothing scale in the void finder results in a boost of the intensity of the correlation signal amplitude, and this boost seems to be dependent on the mass of the neutrinos present in the simulations



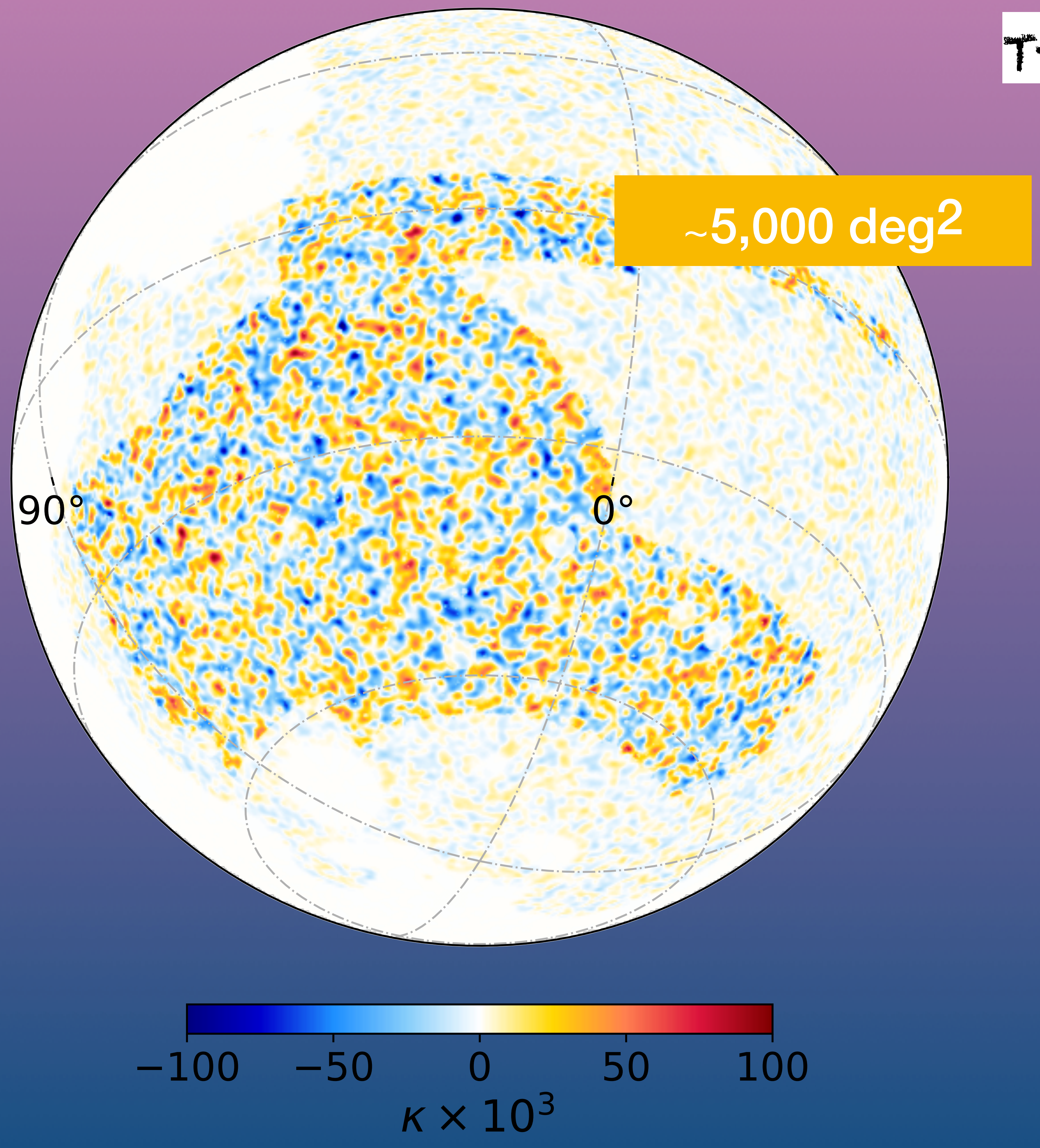
sensitivity parameter

$$\delta\kappa_{in} = \frac{\sum_0^{r<R_v/2} \kappa_{m_\nu = 0.16\text{eV}, 0.32\text{eV}, 0.53\text{eV}}}{\sum_0^{r<R_v/2} \kappa_{m_\nu = 0}},$$



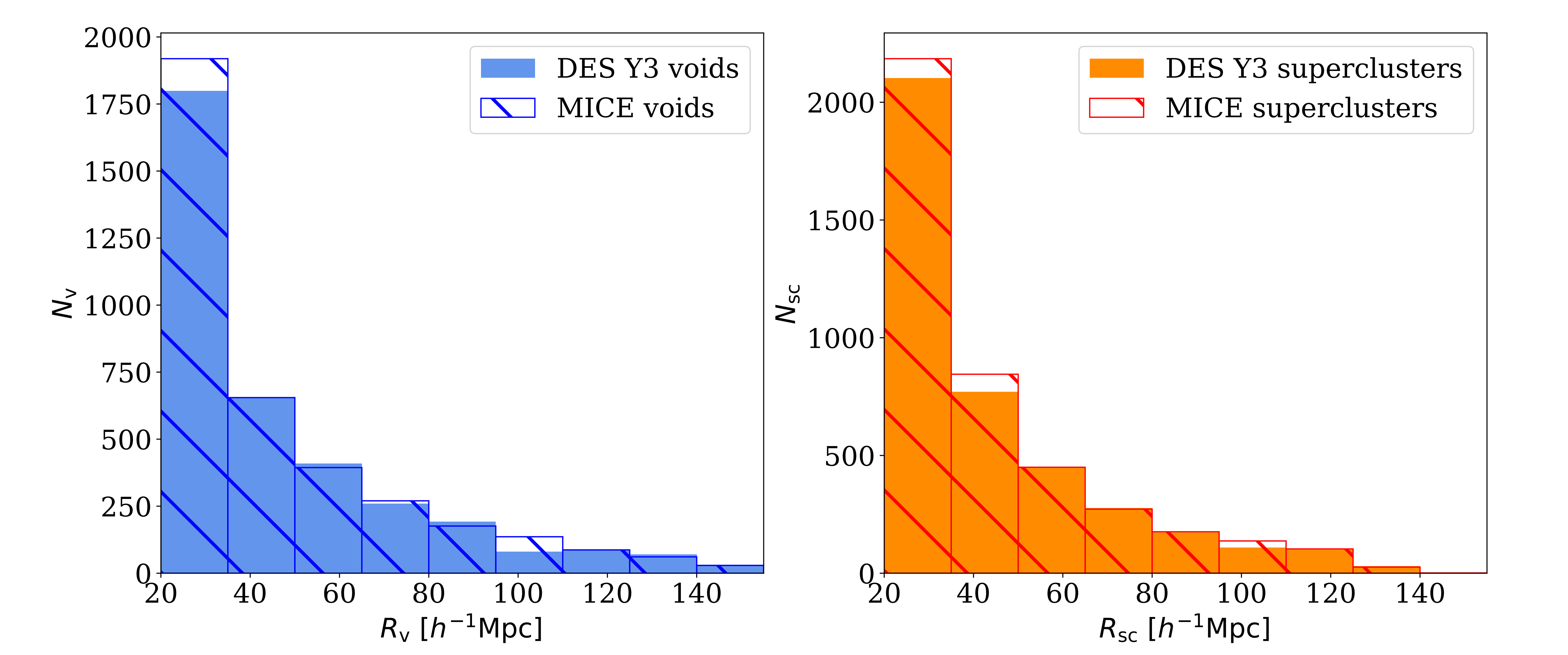
- *Dark Energy Survey Year 3 results: imprints of cosmic voids and superclusters in the Planck CMB lensing map*
  Kovács, A. ; **Vielzeuf, P.** ; Ferrero, I. ; Fosalba, P. ; et al. , **submitted to Mon. Not. R. Astron**, ADS | arXiv:2203.11306

Planck CMB κ map in the DES Y3 footprint



Tracer -> Selection of high-resoltution photometric redshift LRGs

Catalogue validation



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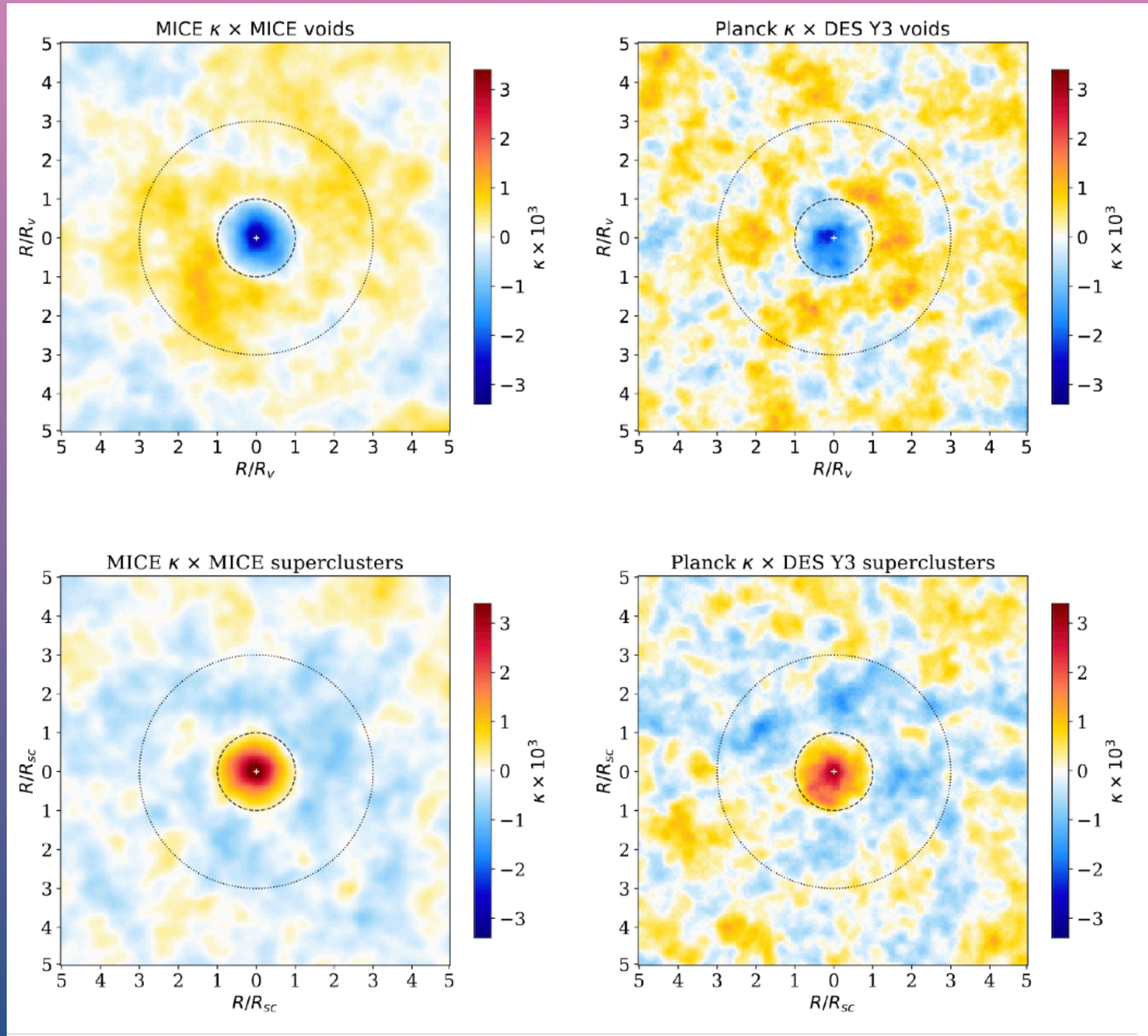
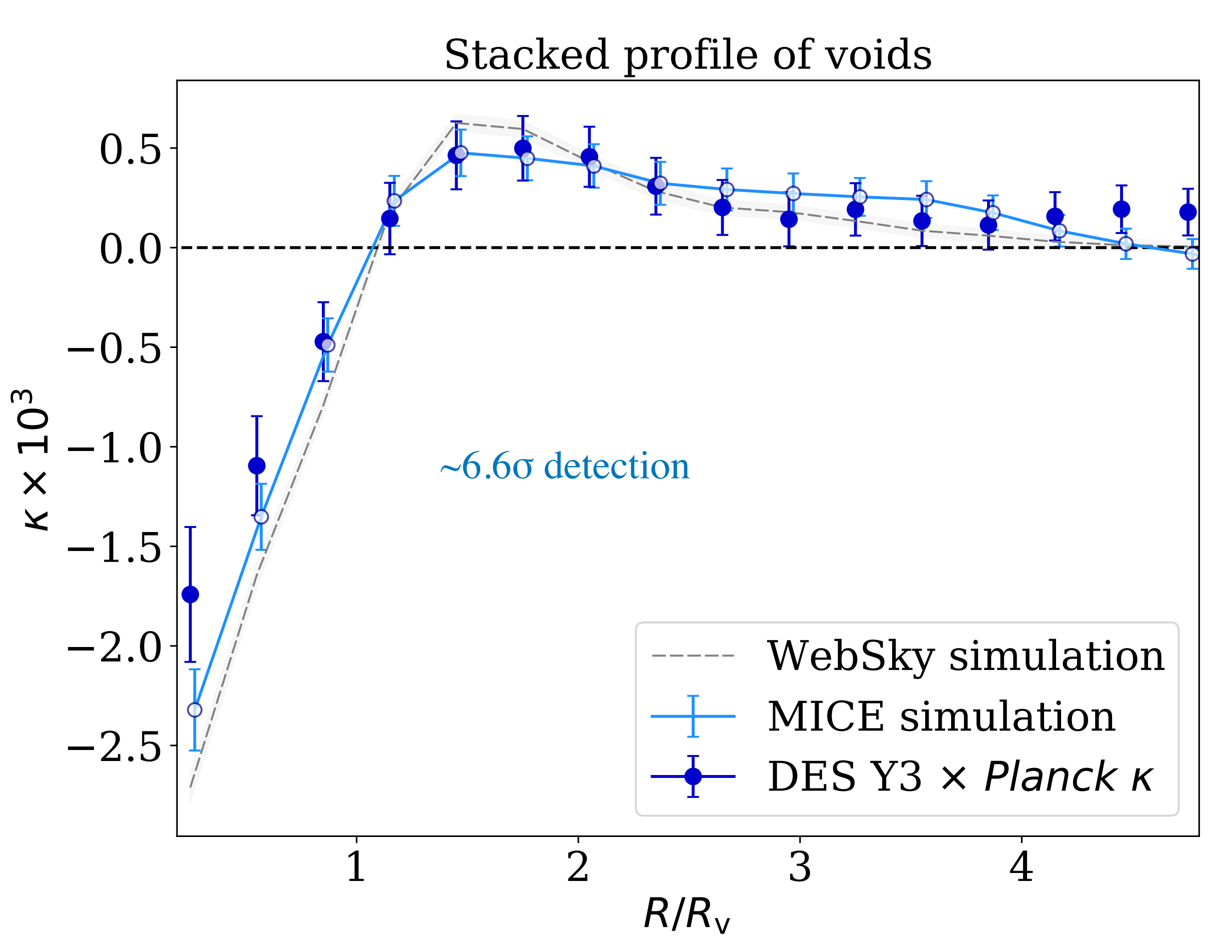
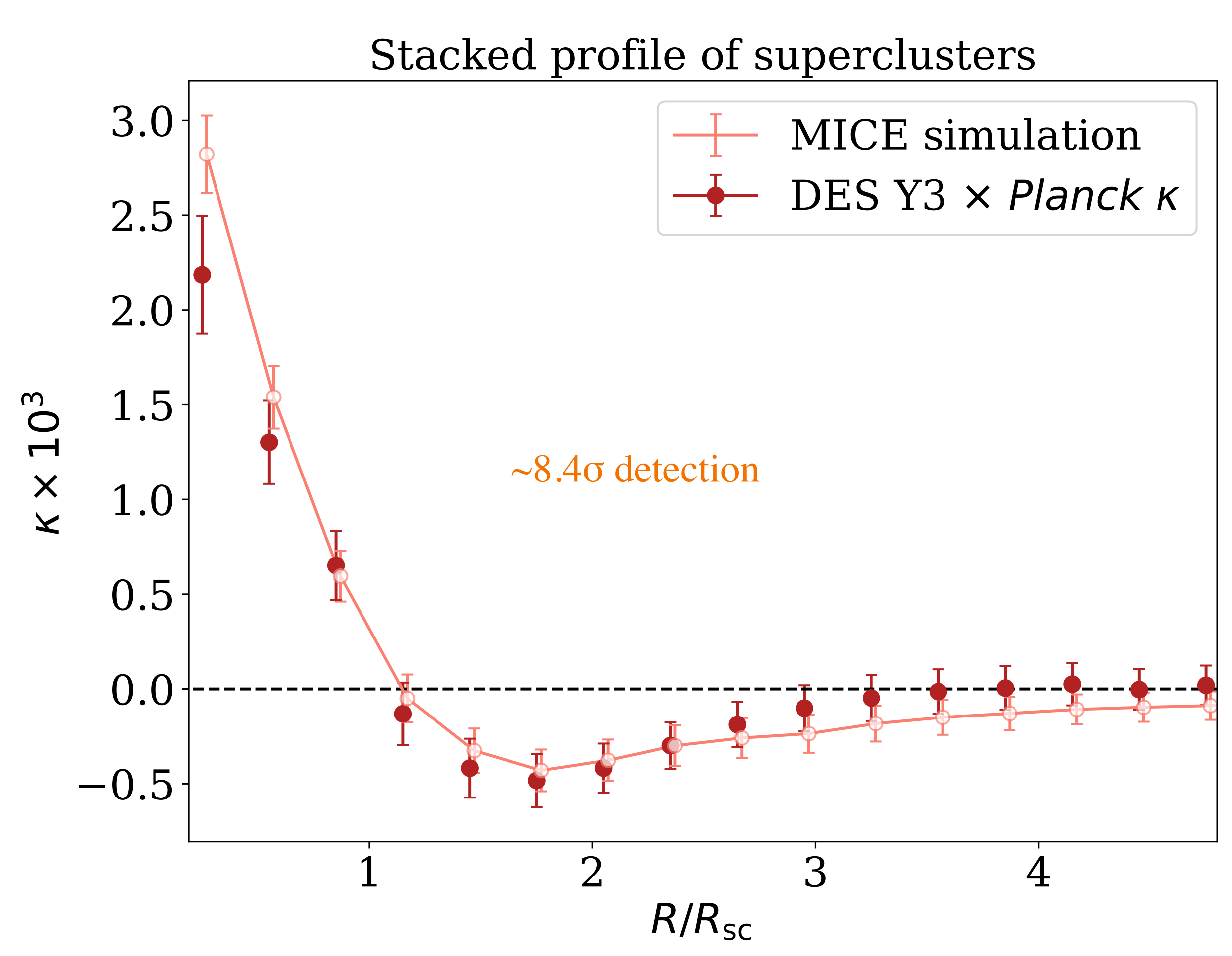


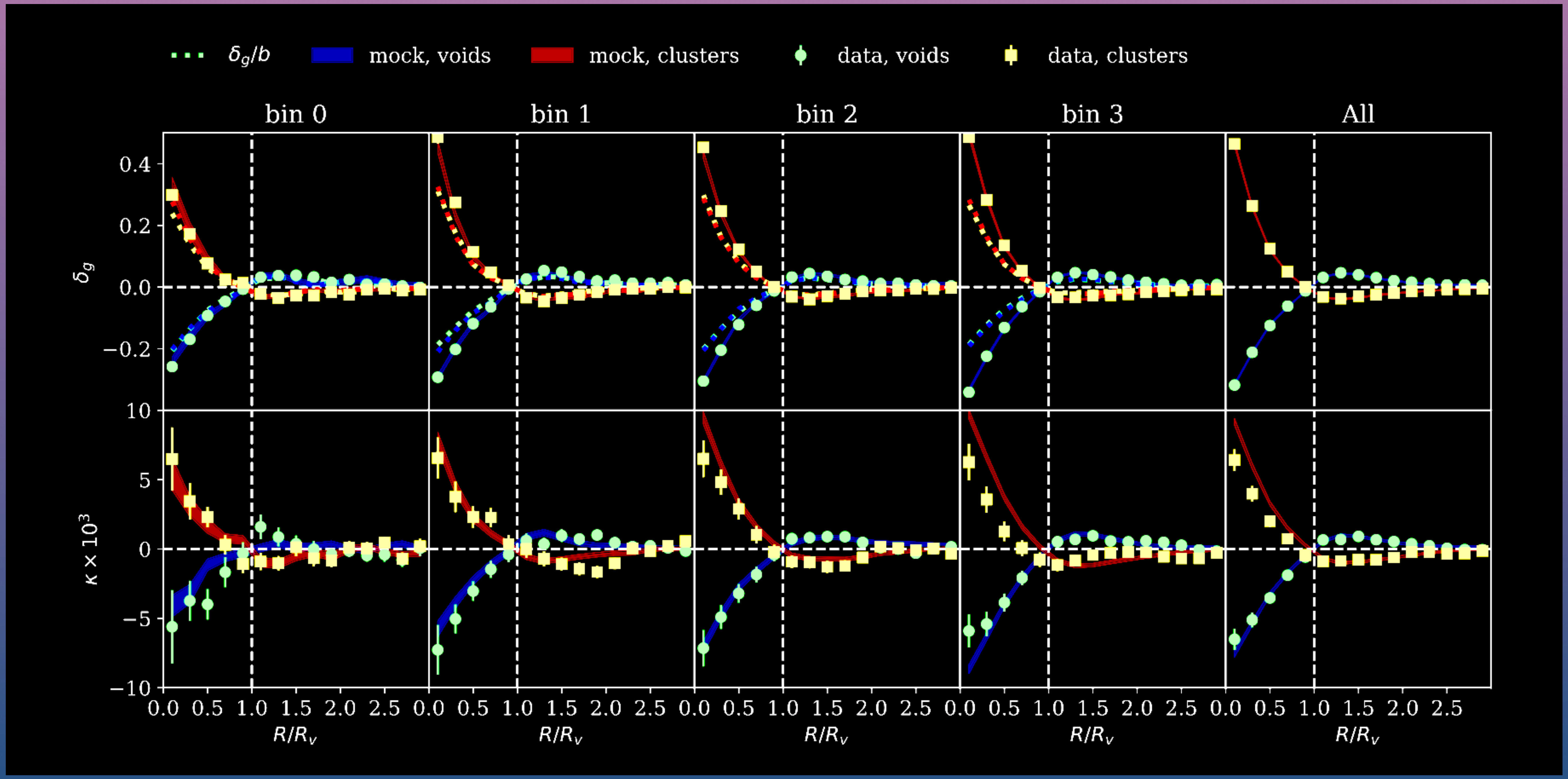
Simulations **Observations**





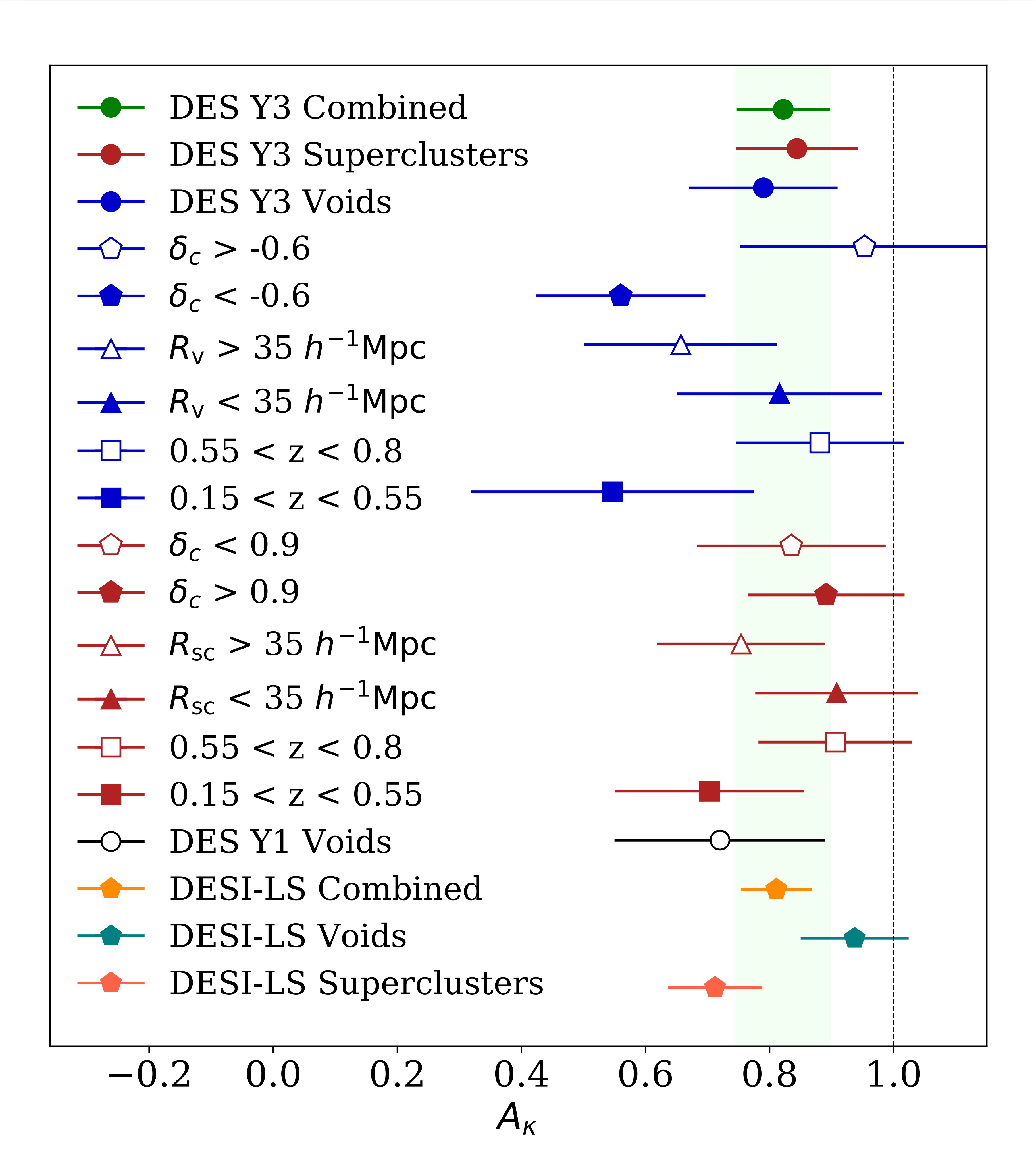
DESI Legacy

DESI Legacy Survey analysis
https://arxiv.org/abs/2105.11936



Summary : consistency parameter

$A_\kappa = \kappa_{DES} / \kappa_{sim}$ ~2.3σ tension



Cosmic voids are promising tool for cosmology and massive neutrino cosmology, in particular using their correlation signal with CMB maps

We note that the presence of massive neutrinos in our simulation tends to decrease the void-CMB lensing signal, and this effect is more enhanced as one increases neutrino mass, and for larger smoothing scales in the void identification process. This suggest that more the neutrinos are massive, less empty will be the voids (lower de-lensing signal implying more matter inside the voids).

The measure of the reduction in the lensing signal inside cosmic voids due to the presence of massive neutrinos is in particular interesting as it is consistent with the tensions in the same lensing signal with massless neutrinos and ΛCDM simulation

Data are coming lets develop voids cosmology!

2D void finder

identify voids in redshift slices, smoothing the density field of each slices with the smoothing scale as a free parameter