ON THE OPTIMAL EXTRACTION OF ALCOCK-PACZINSKY SIGNAL FROM VOIDS

GIULIA DEGNI

Active Network

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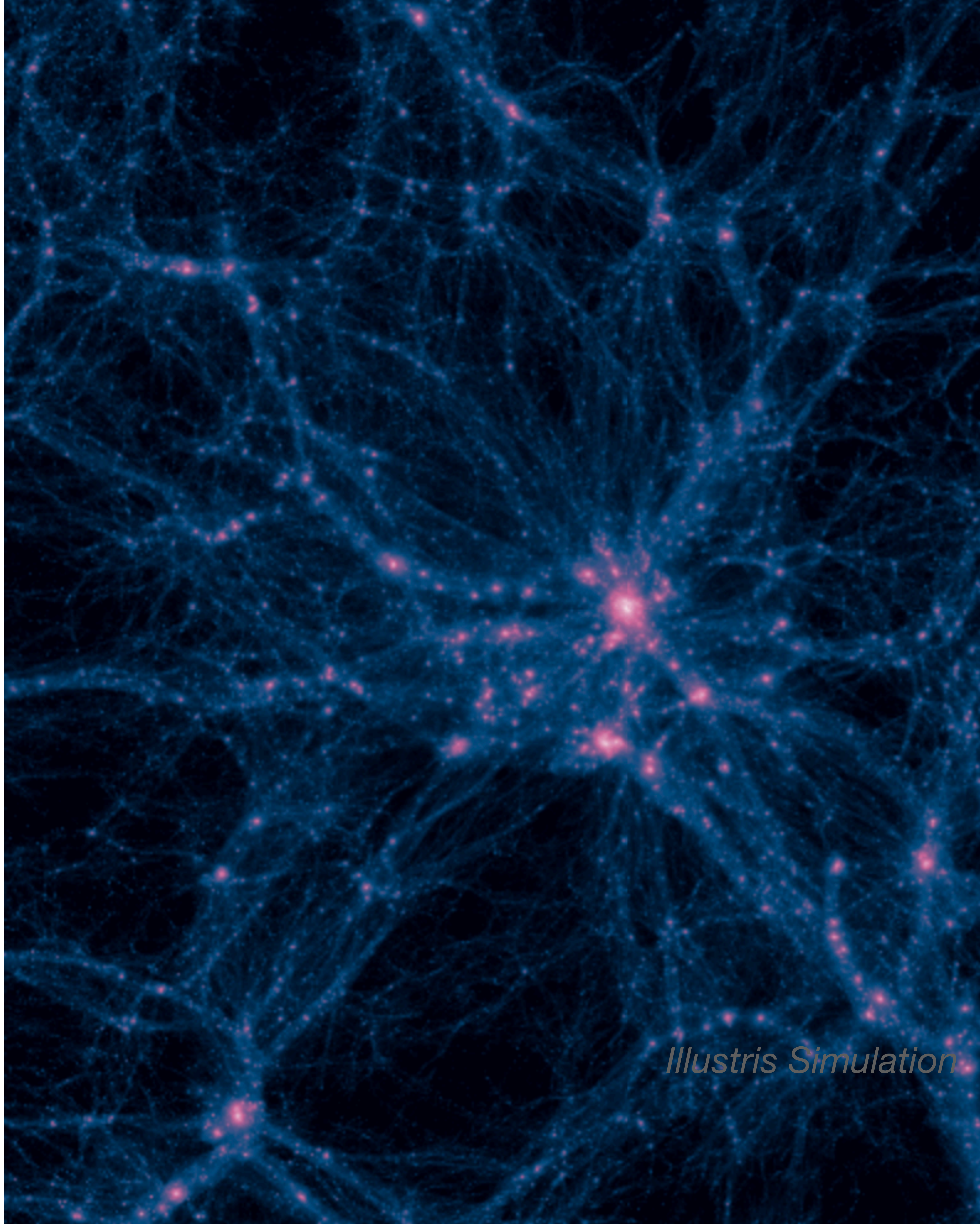
Understanding the Galaxy/Matter Connection in the Era of Large Surveys - Sestri Levante 17/09/2024

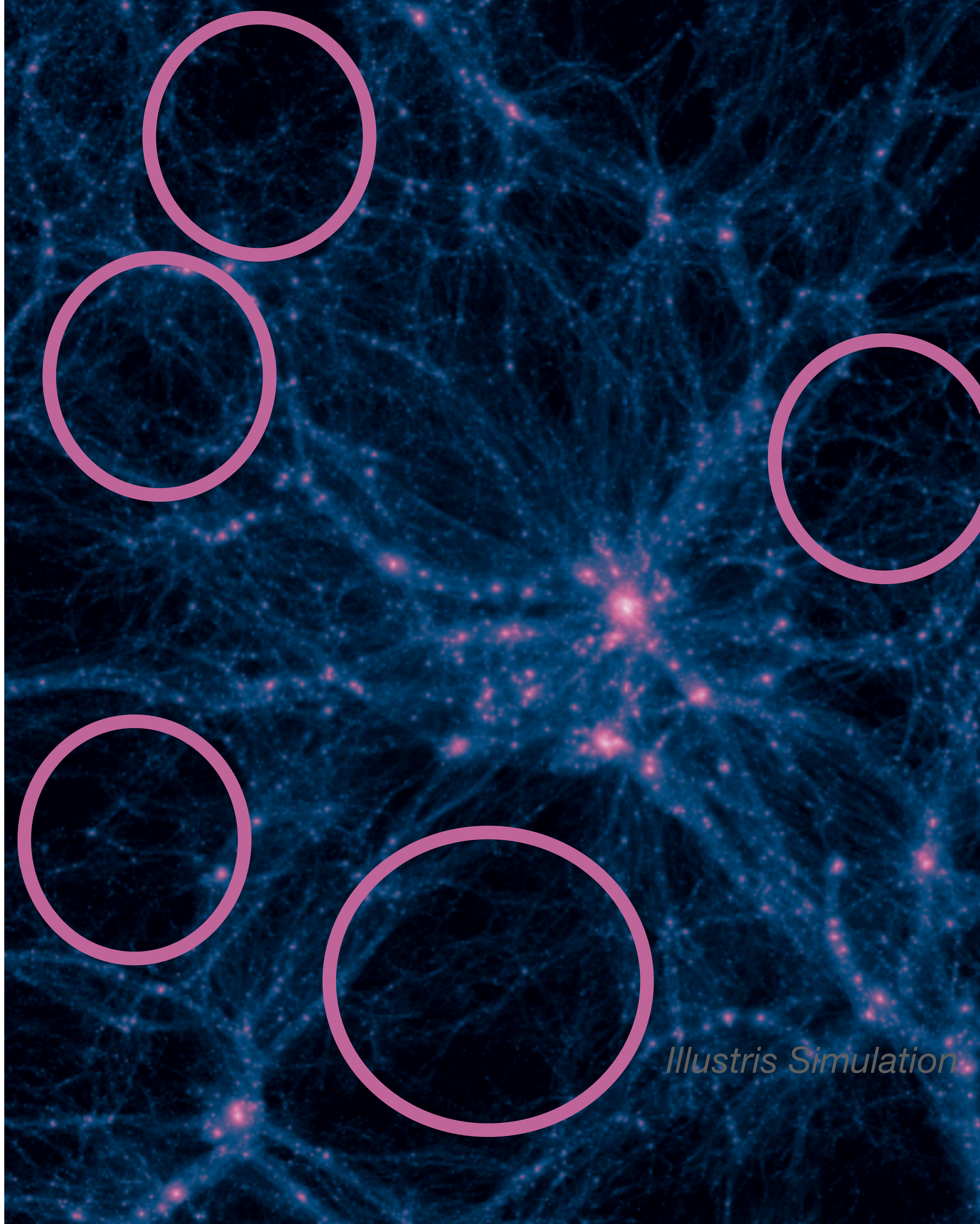
ROMA TRE UNIVERSITÀ DEGLI STUDI

INFN


Illustris Simulation

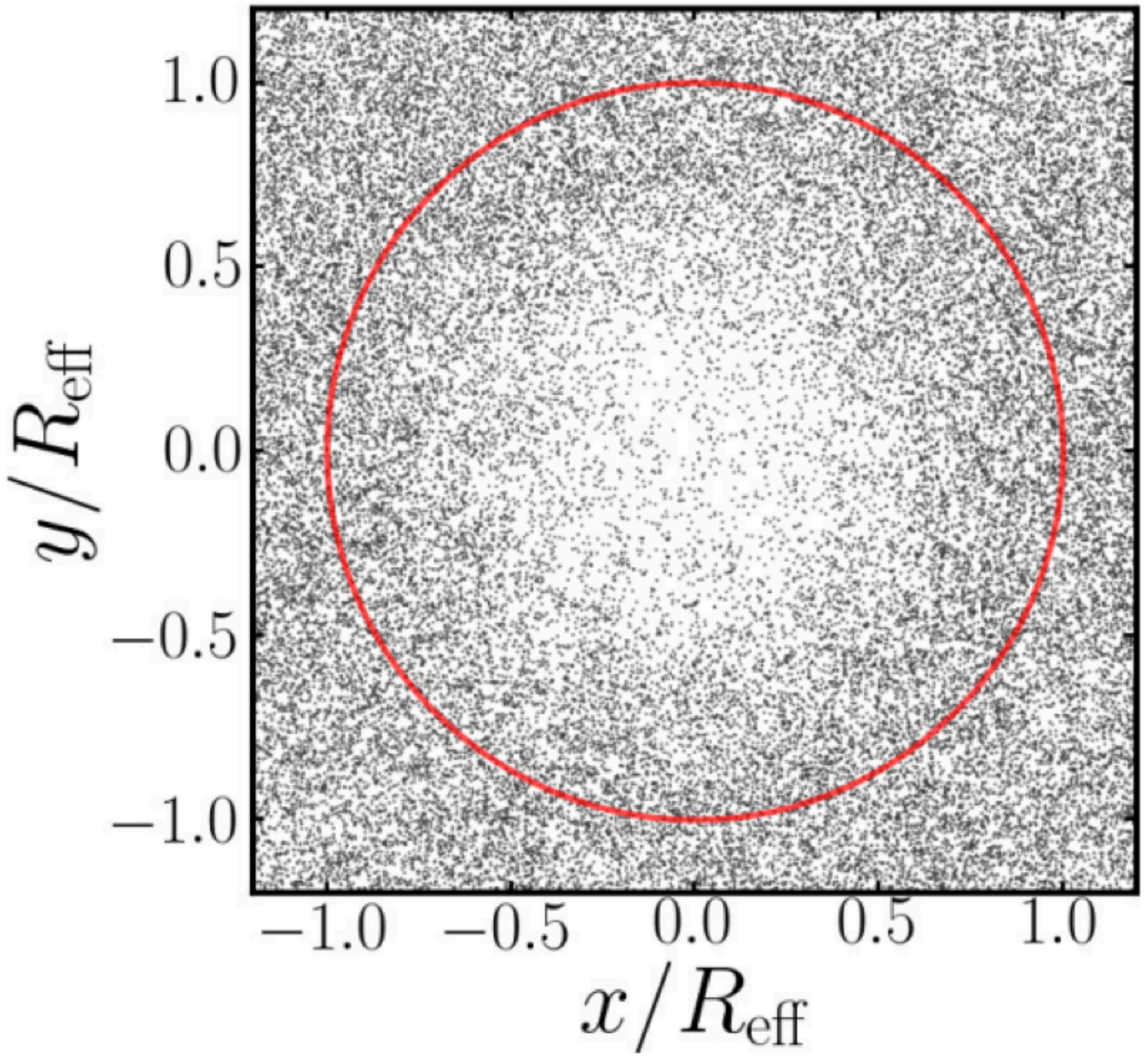
COSMIC VOIDS

- Large empty structures in the Universe
- Multiscale sensitivity (from 10 to 100 $Mpc\ h^{-1}$)
- Voids' studies require accessing large volumes **and** highly detailed maps of galaxy distribution
- **New generation surveys** will provide us with this data (Euclid, Roman,…)
- Nature of **dark energy**, $\sum m_\nu$, **test general relativity**



COSMIC VOID PROPERTIES

- Spherically symmetric once **stacked**



Mao et al. 2017

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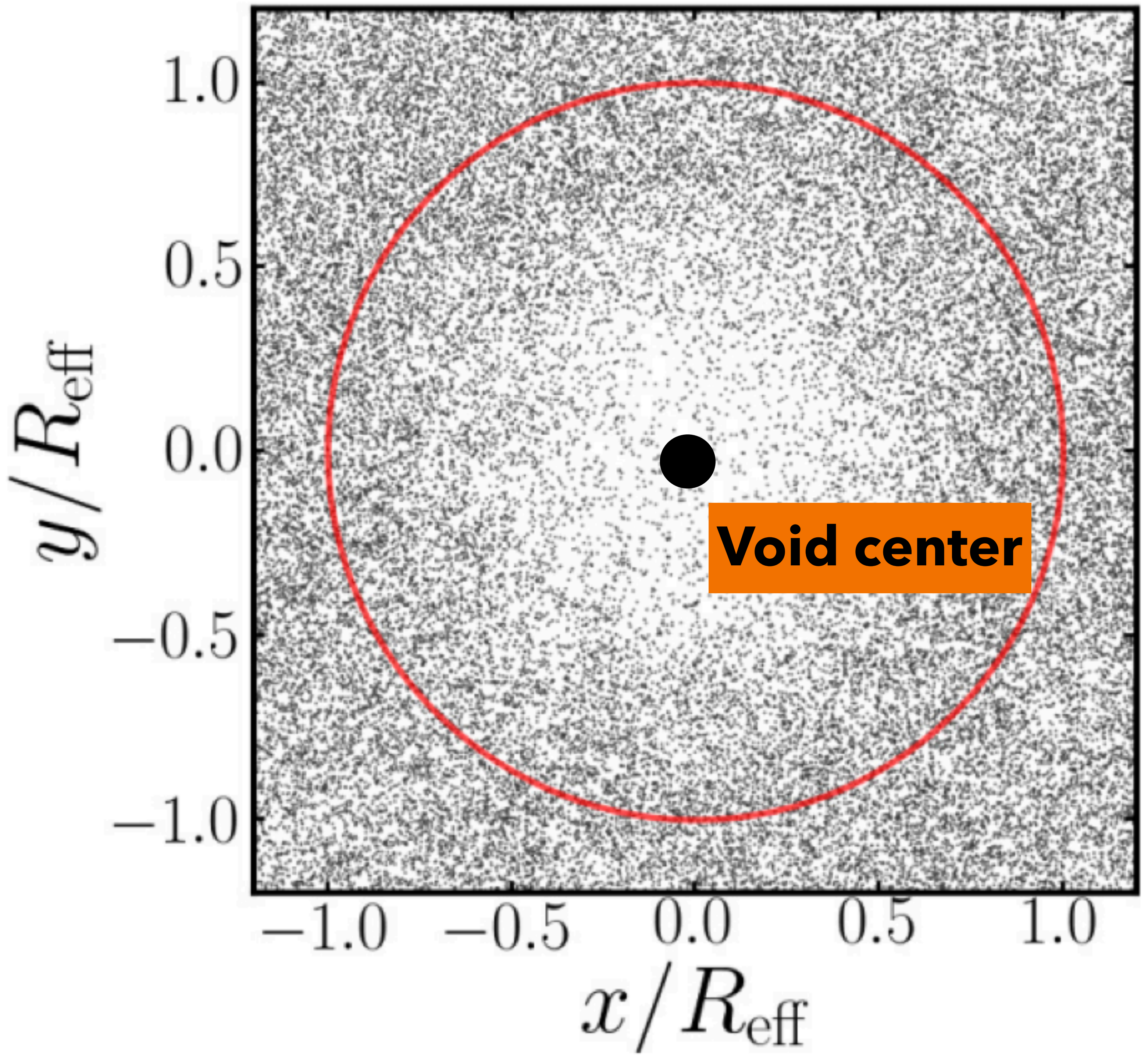

Mao et al. 2017

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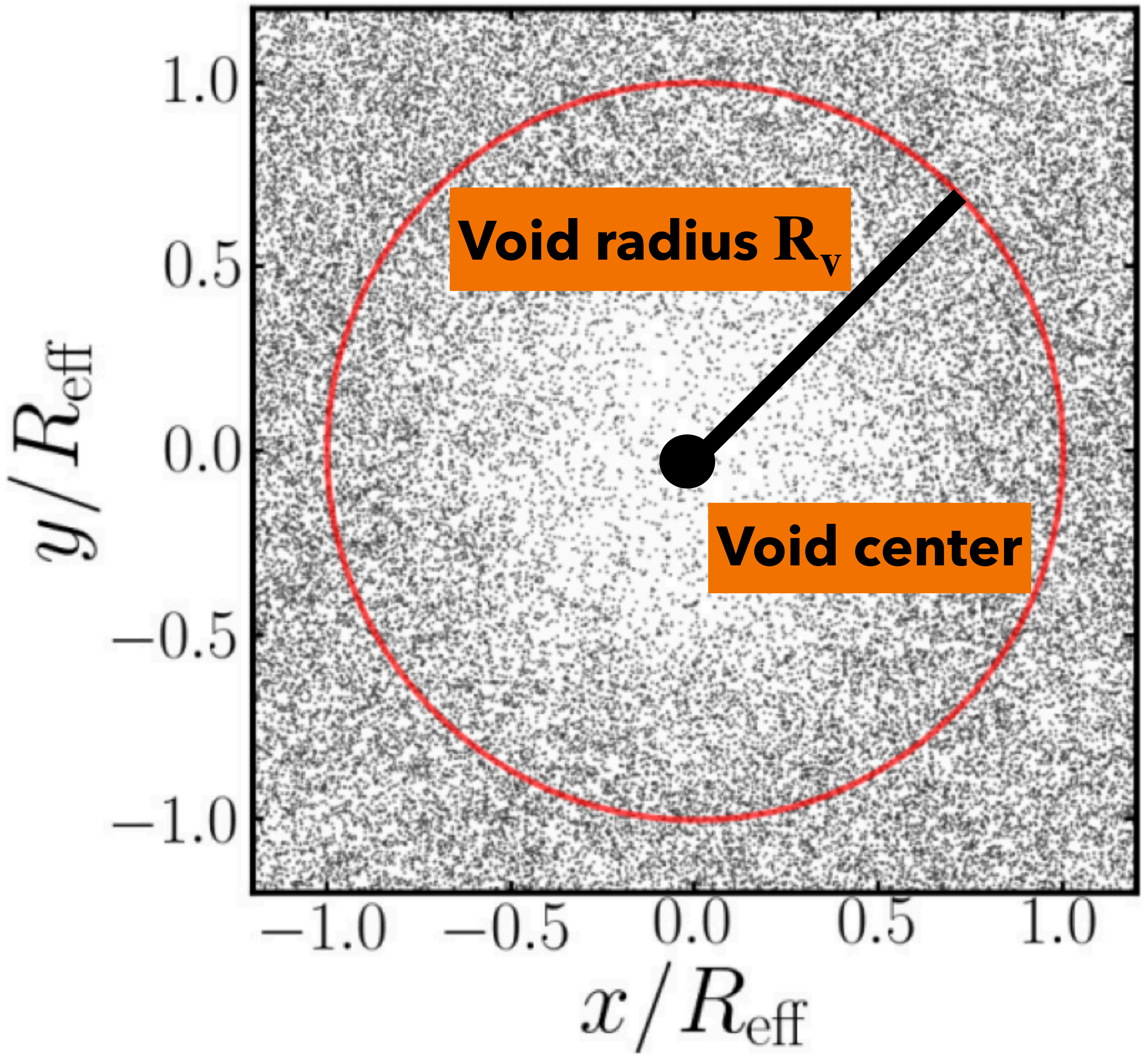

Mao et al. 2017

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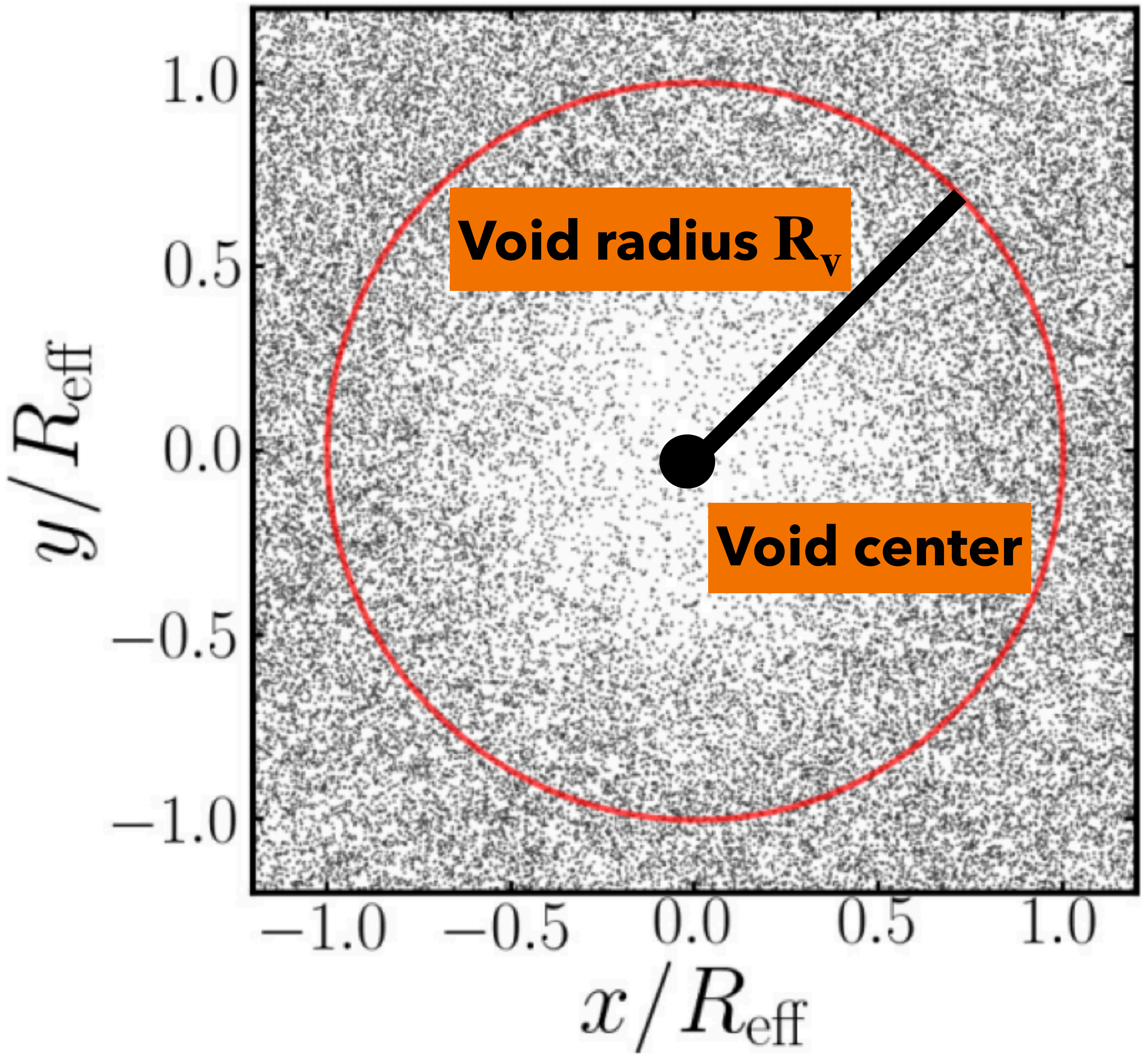
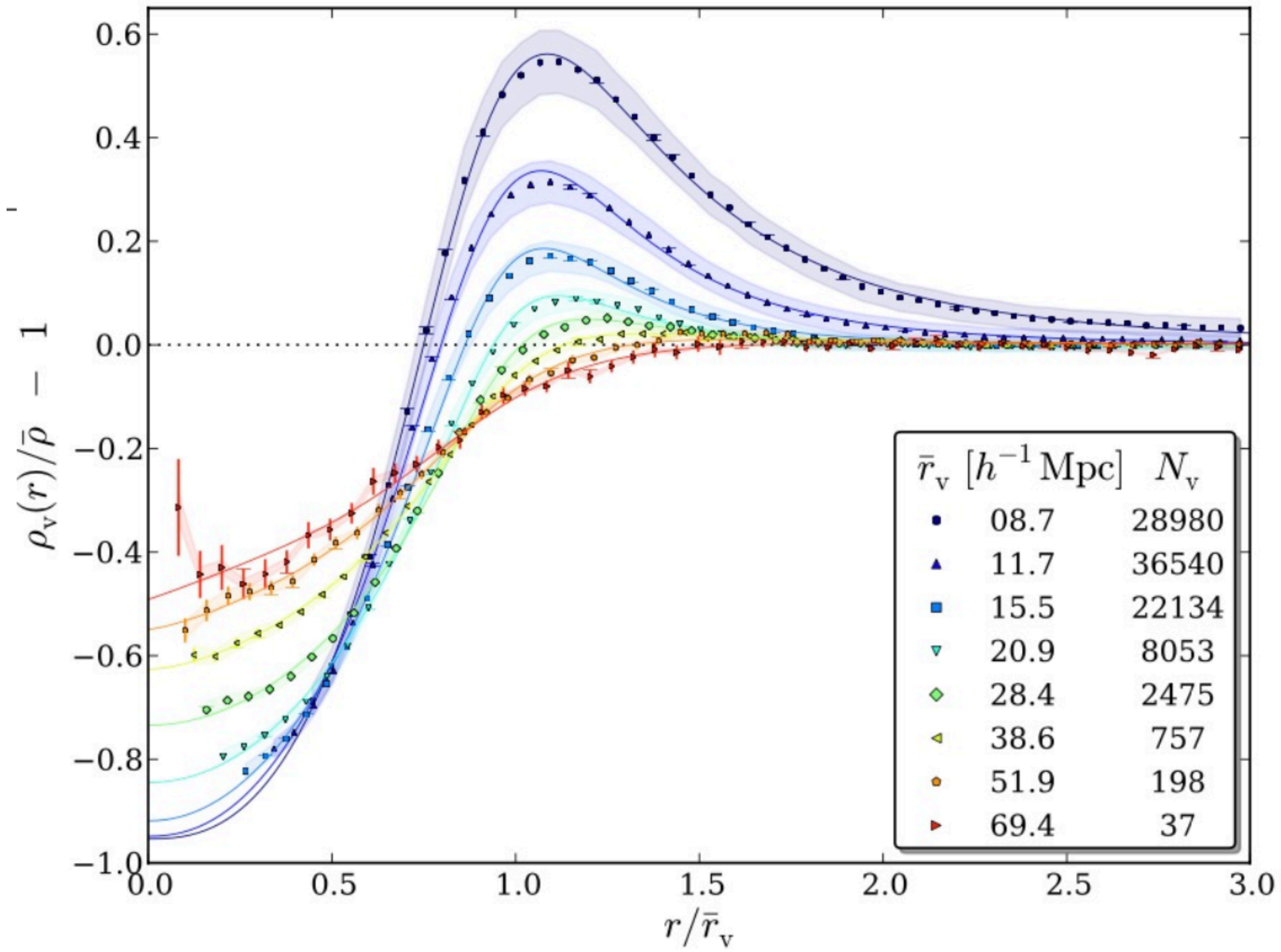


Mao et al. 2017

- Universal density profile



Hamaus et al. 2014

DISTORTIONS

Geometric distortions

Alcock-Paczynski (AP) effect from assuming an incorrect cosmological model

$$d(z) = \int_0^{z_\mathrm{h}} \frac{c}{H(z')} dz'$$

$$\epsilon = \frac{H_t(z) D_{A_t}(z)}{H_f(z) D_{A_f}(z)}$$

Dynamic distortions

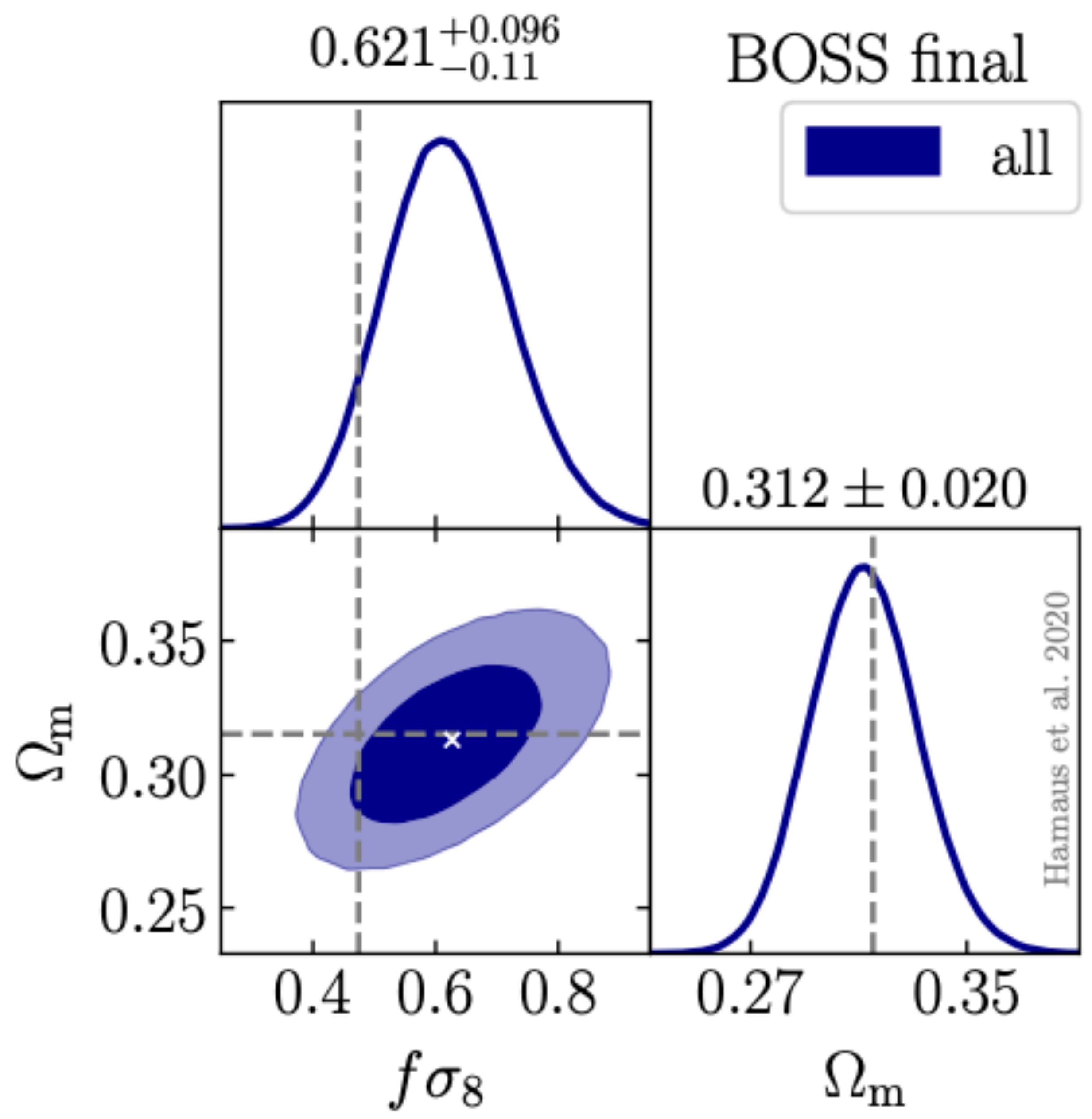
Redshift Space Distortions (RSD) from galaxy peculiar velocities

$$z_\mathrm{obs} = \left(\frac{v_\mathrm{pec}}{c} + 1 \right) (1 + z_\mathrm{h}) - 1$$

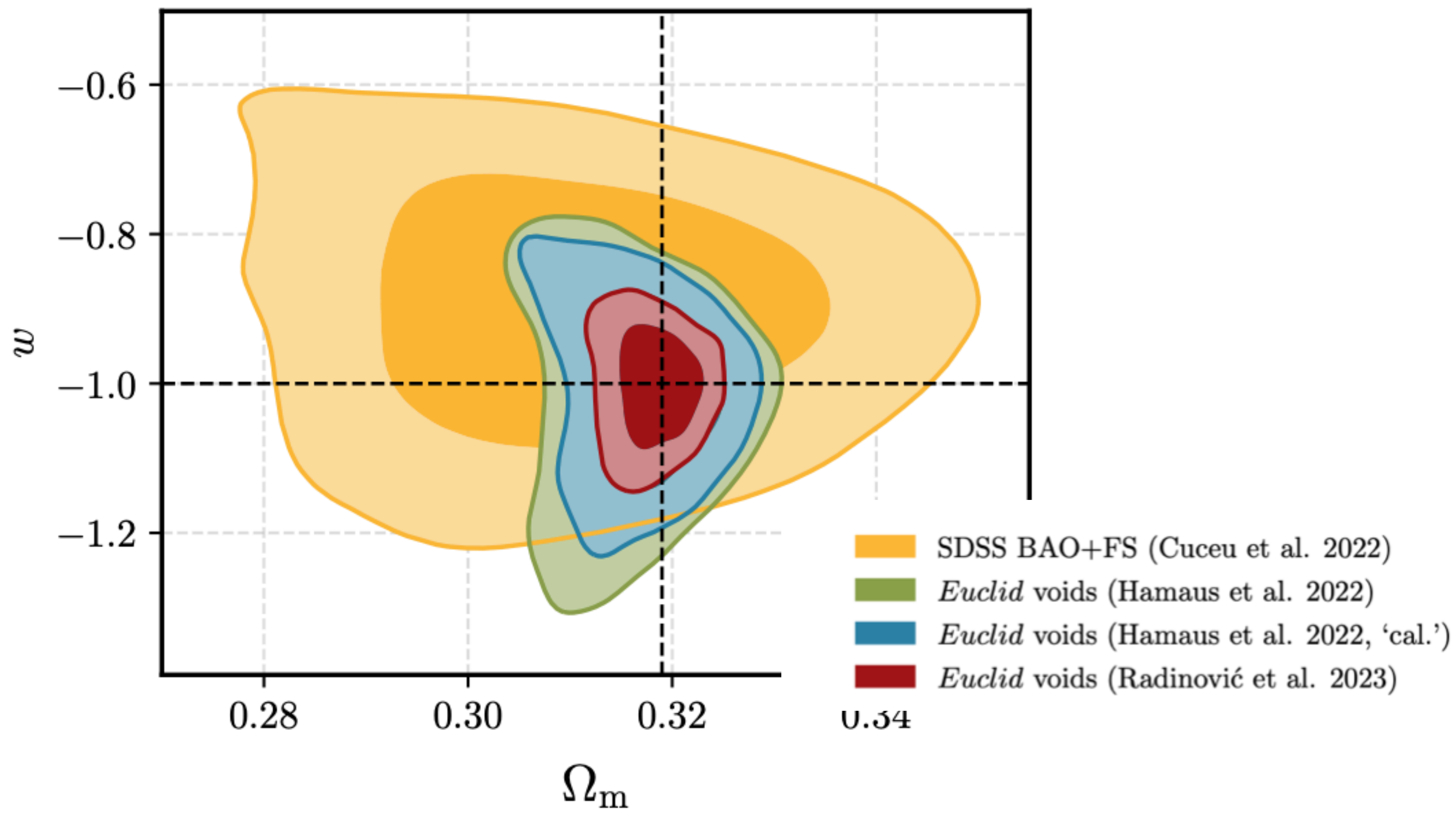
$$\beta = \frac{f}{b}$$

STATE OF THE ART

ΛCDM: **measurements with BOSS data**
Hamaus et al. 2020



$wCDM$: **Forecast with Euclid Flagship**
Radinovic et al. 2023



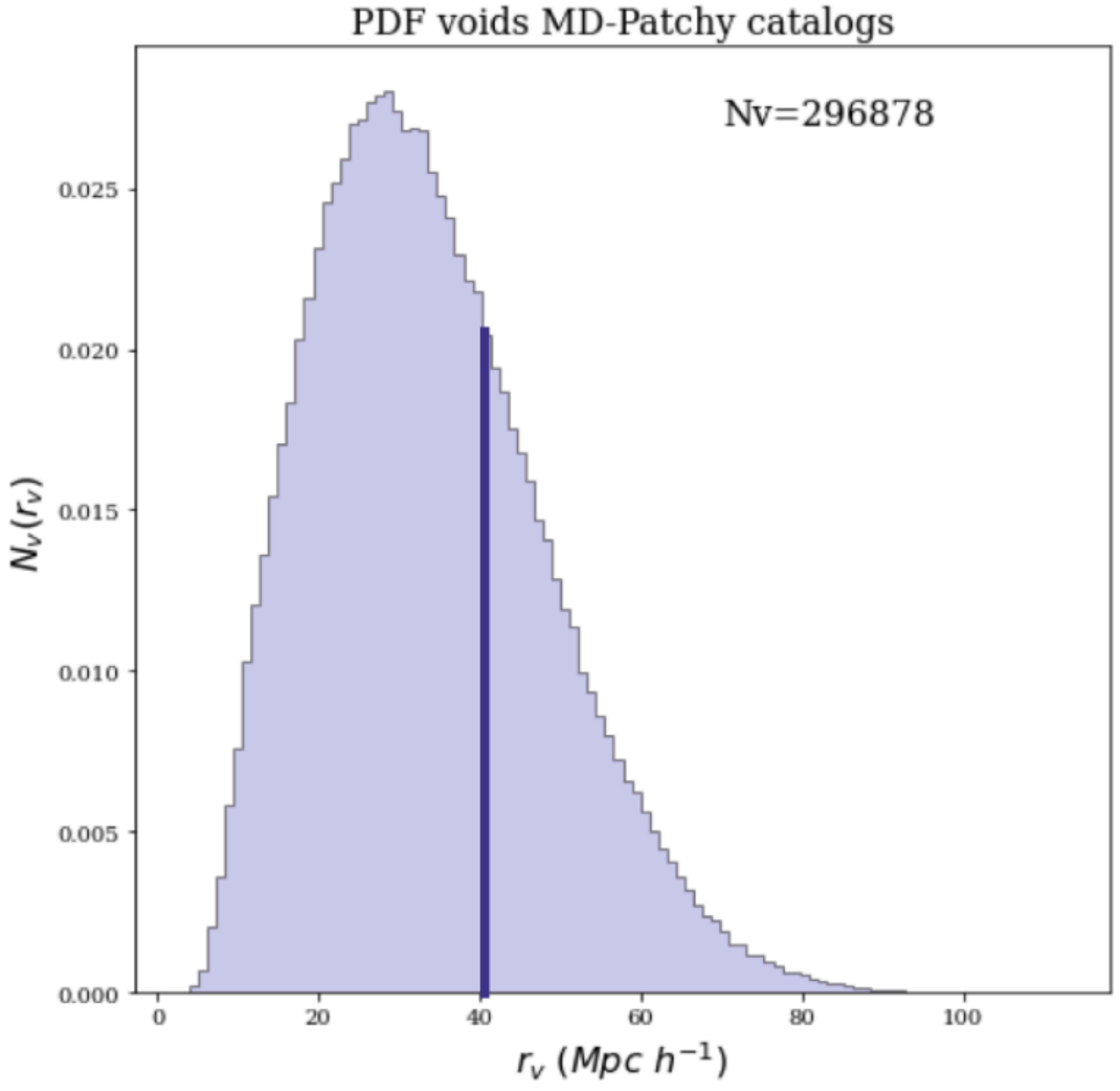
DEALING WITH REDSHIFT SPACE DISTORTIONS

- **Resdhift-space analysis :**

Void analysis with linear models use only large voids ($R_v \gtrsim 3$mps [Hamaus et al. 2020](#)): issues with the modeling for small voids

Selection effect ([Correa et al. 2023](#))

Eliminate redshift space distortions (RSD) using a Zel'dovich reconstruction (implemented by E. Sarpa) to gain statistical improvement.



Voids radii distribution in BOSS Patchy mocks

DEALING WITH REDSHIFT SPACE DISTORTIONS

- **Resdhift-space analysis :**

Void analysis with linear models use only large voids ($R_v \gtrsim 3\mathrm{mps}$ Hamaus et al. 2020): issues with the modeling for small voids

Selection effect (Correa et al. 2023)

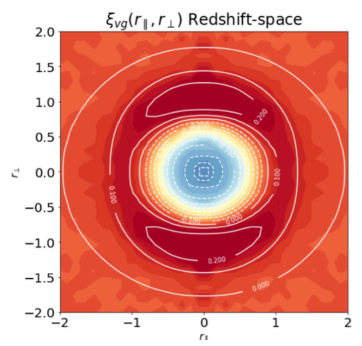
Eliminate redshift space distortions (RSD) using a Zel'dovich reconstruction (implemented by E. Sarpa) to gain statistical improvement.

- Use reconstruction technique to model galaxy peculiar velocities (numerical modeling of RSD)
- Identify voids in Reconstructed-space
- Constrain AP from residual distortions

NEW !

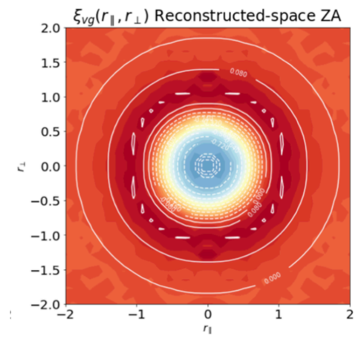
STRATEGY

Density field in z-space* — **Void Finder** → **Void Catalog in z-space** — **Cross-Correlation** + **Likelihood Analysis** → **Extract ϵ and β**



↓ **Linear velocity Reconstruction**

Density field in r-space* — **Void Finder** → **Void Catalog in r-space** — **Cross-Correlation** + **Likelihood Analysis** → **Extract ϵ and β**



*z-space = redshift-space
*r-space = reconstructed-(real)-space

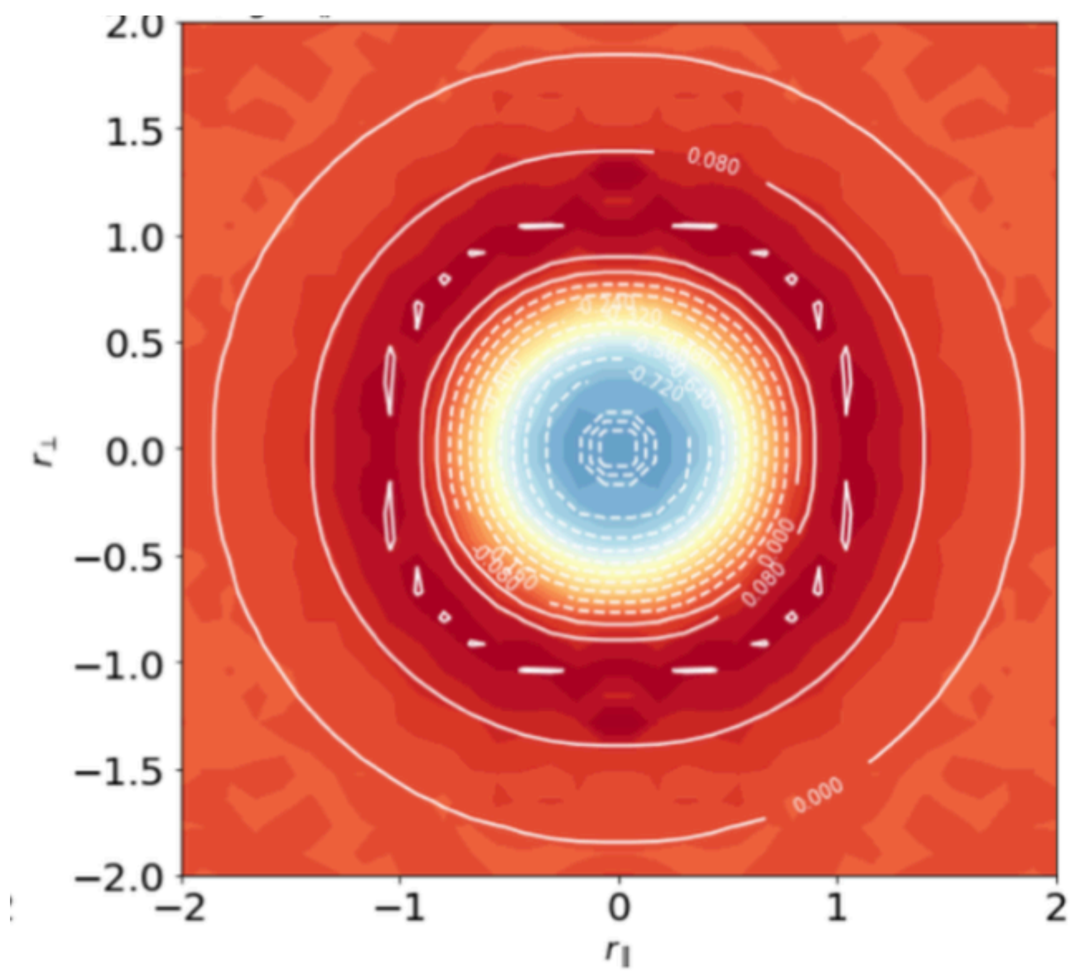
VOID-GALAXY CROSS-CORRELATION FUNCTION

Probability to find a galaxy g at distance r and angle θ from the void center v.

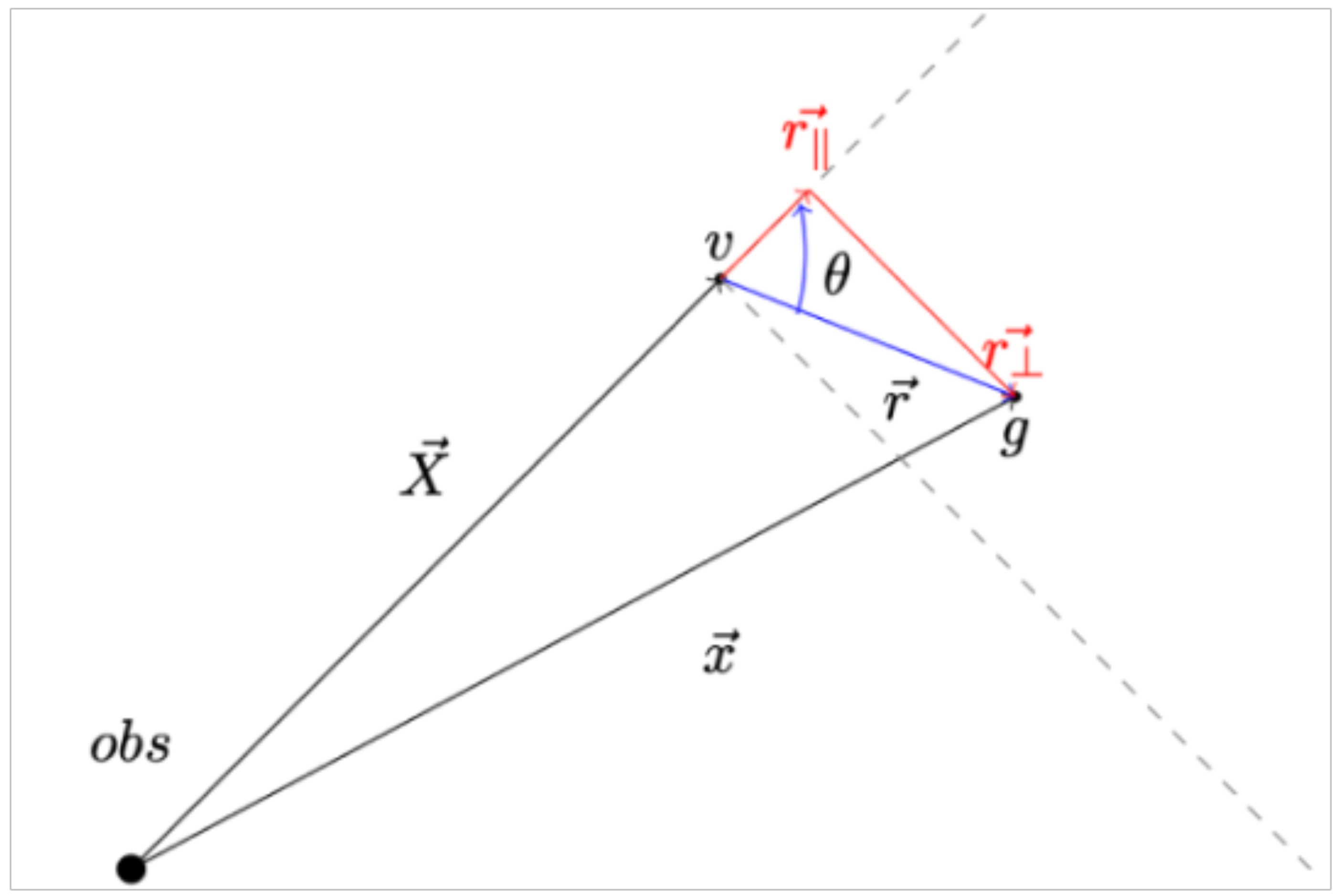
New estimator:

Davis-Peebles estimator:

$$\xi_{vg}^{DP}(r,\mu) = \frac{n_R}{n} \frac{D_v D_g(r,\mu)}{D_v R_g(r,\mu)} - 1$$



Void-galaxy pair



MODELING DISTORTIONS

Modeling for the Void-galaxy cross-correlation function and its multipoles:

Model for Real-Space ccf
Real-space ccf monopole measured in mocks

\+

Add RSD
1. Linear model presented in *Cai et al. 2017*
2. Empirical modification (nuisance parameters M and Q)

\+

Add AP distortions
Following the method presented in *Kazin et al. 2013*

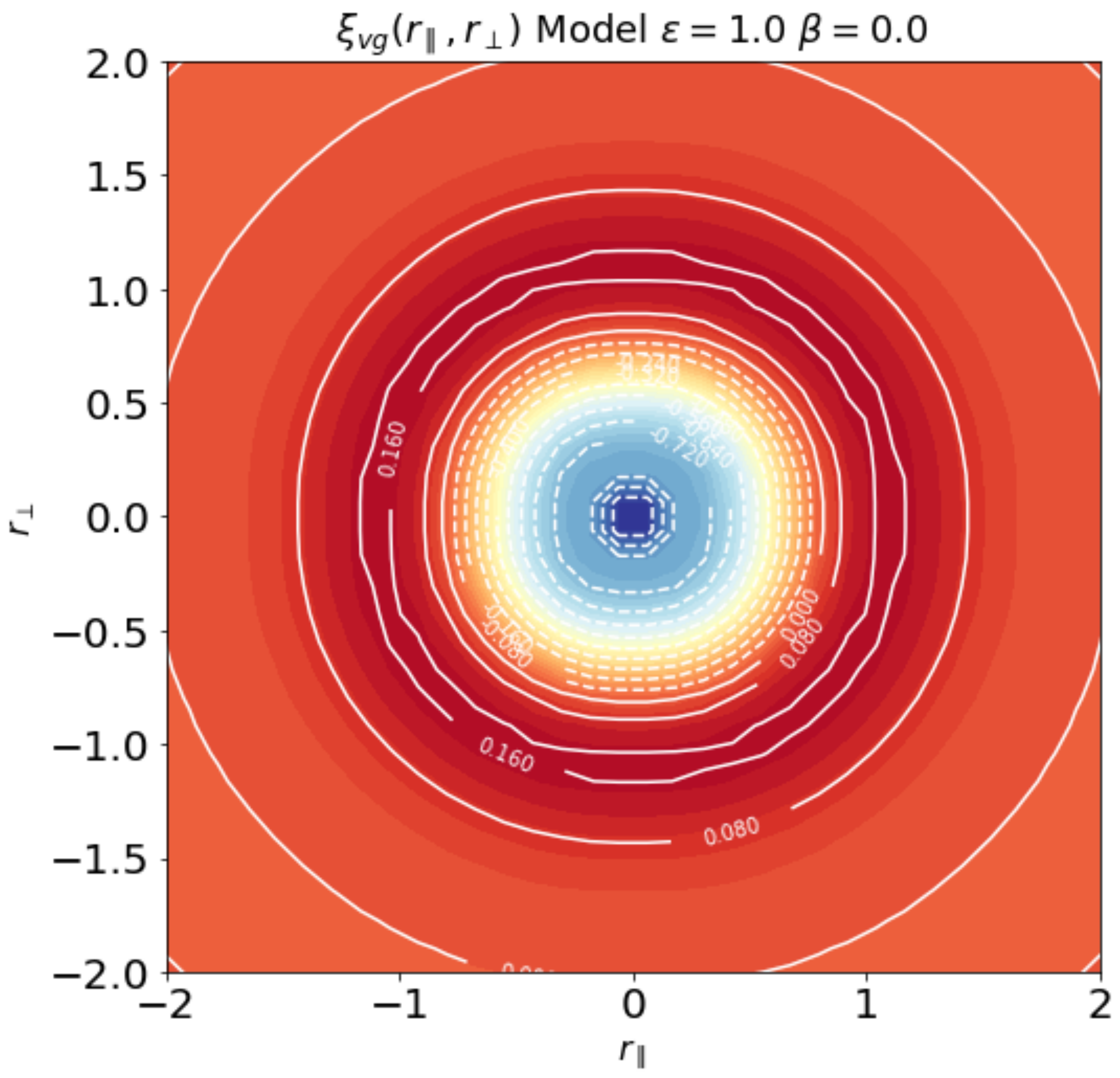
$$\xi^s(s,\mu) = \mathscr{M}\left\{\xi(r) + \frac{2}{3}\beta\bar{\xi}(r) + \mathscr{Q}\beta\mu^2[\xi(r) - \bar{\xi}(r)]\right\}$$

&

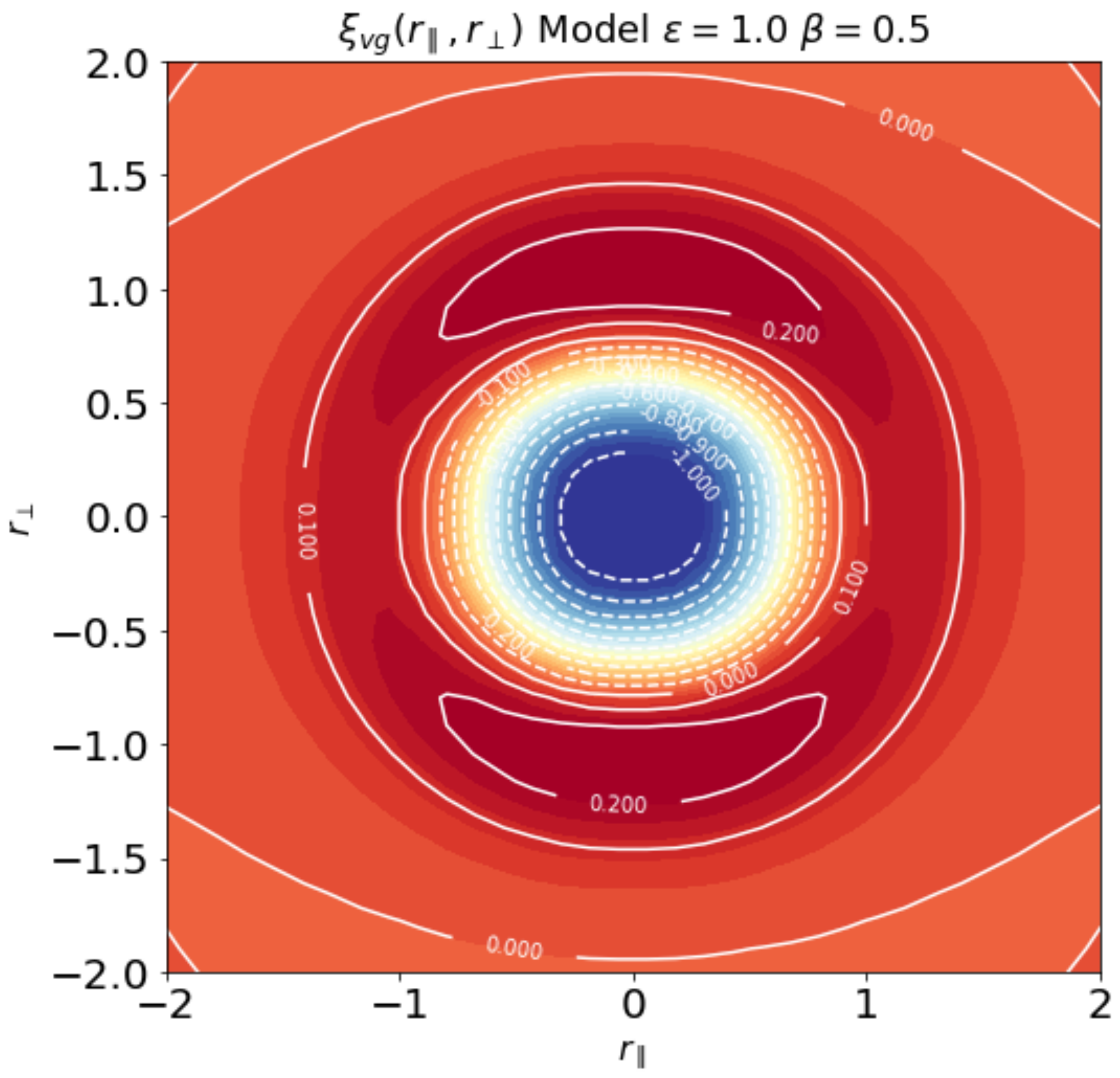
$$\frac{r_t(r_f,\mu_f)}{R_{vt}(r_f,\mu_f)} = \frac{s_f}{R_{vf}}\mu_f\epsilon^{-2/3}\sqrt{1+\epsilon^2(\mu_f^{-2}-1)}$$

MODELING DISTORTIONS

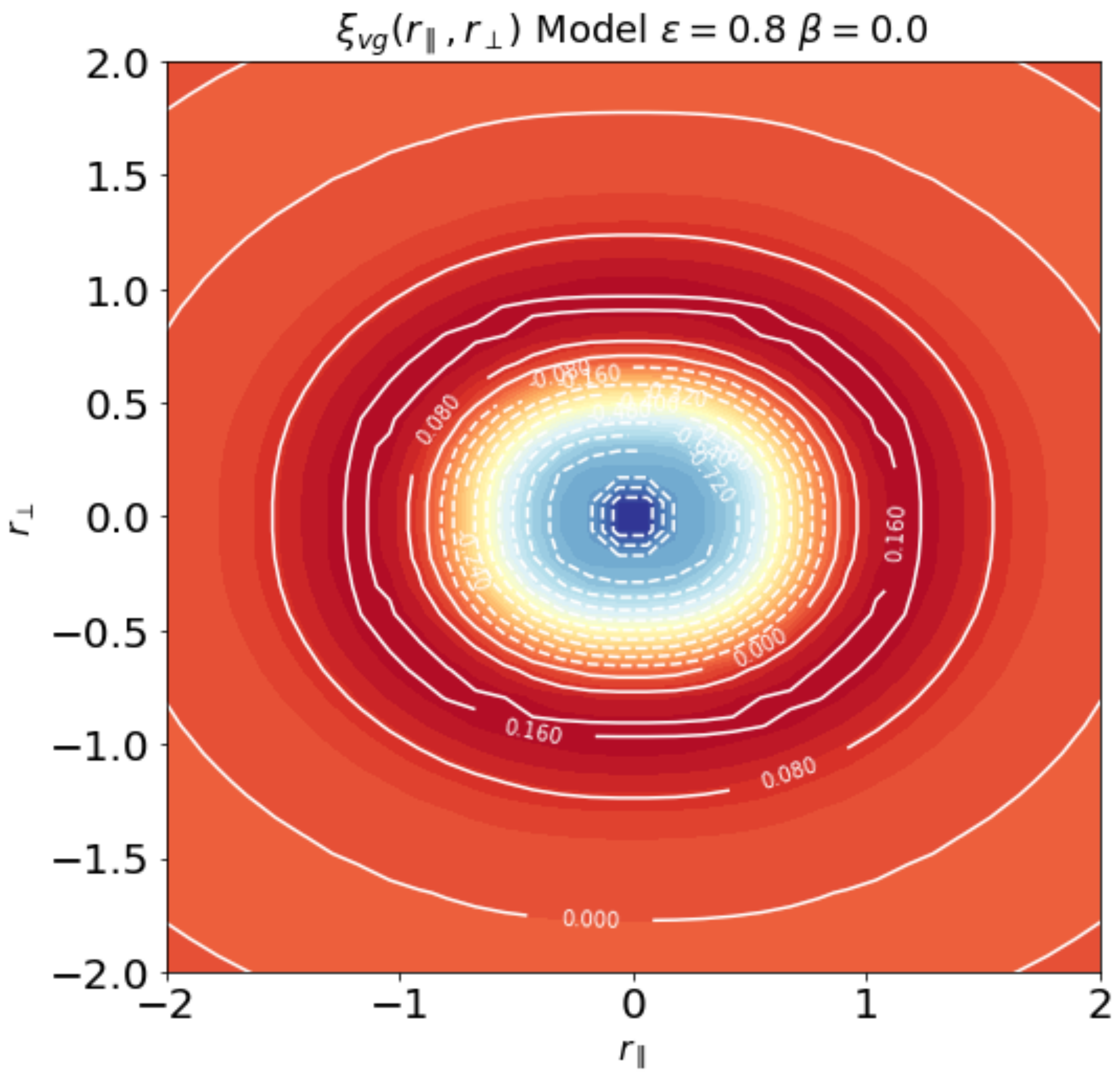
Real-Space



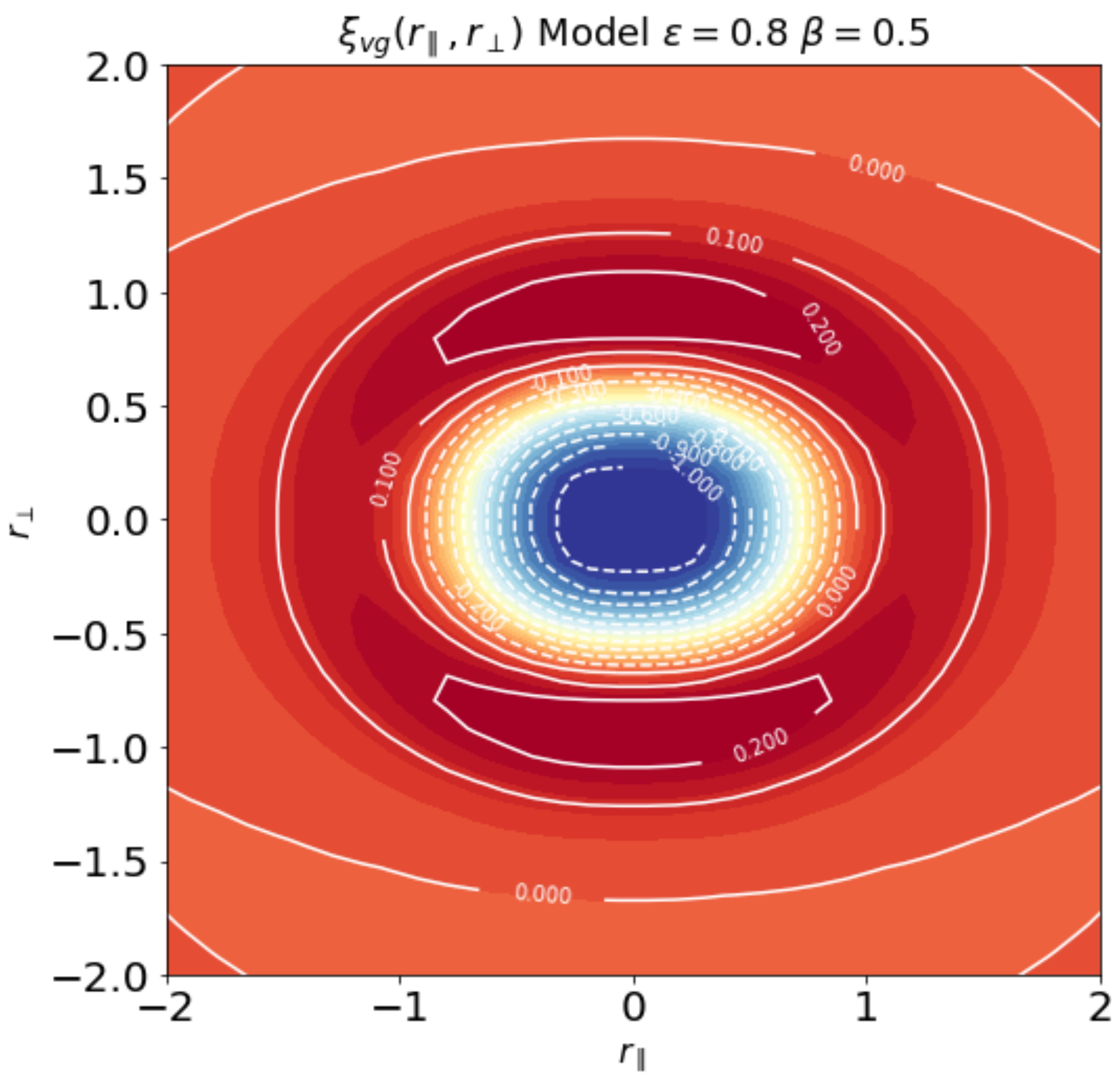
RSD



AP



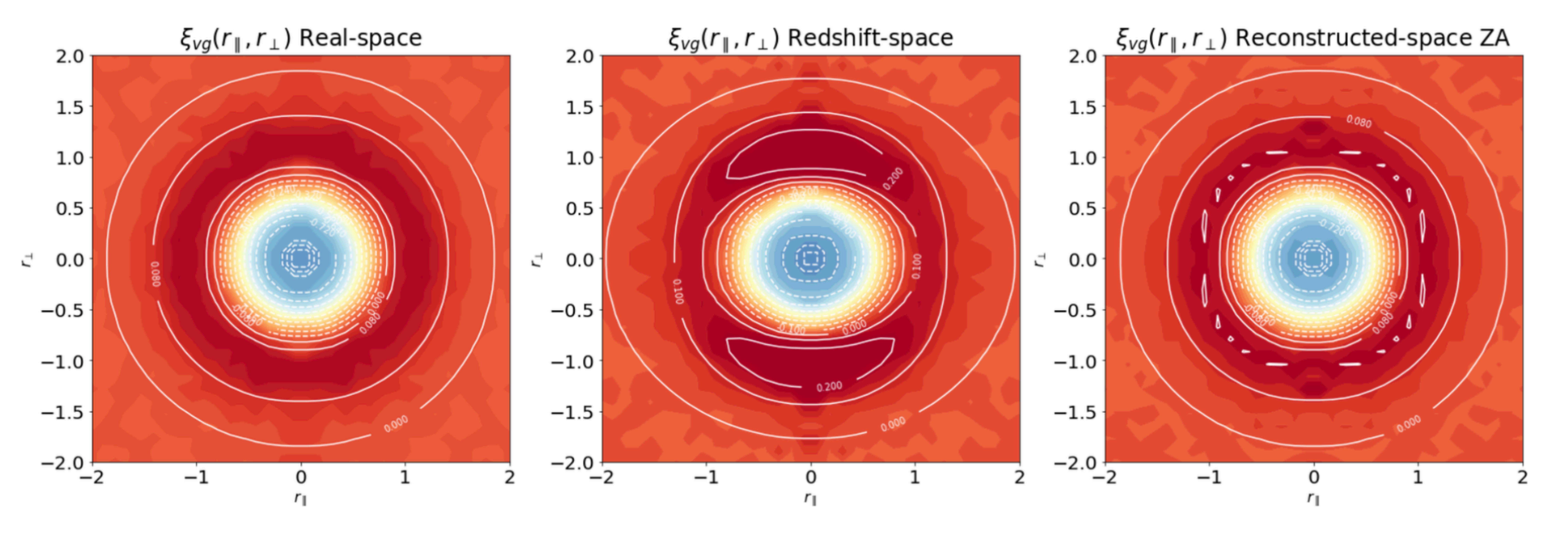
RSD + AP



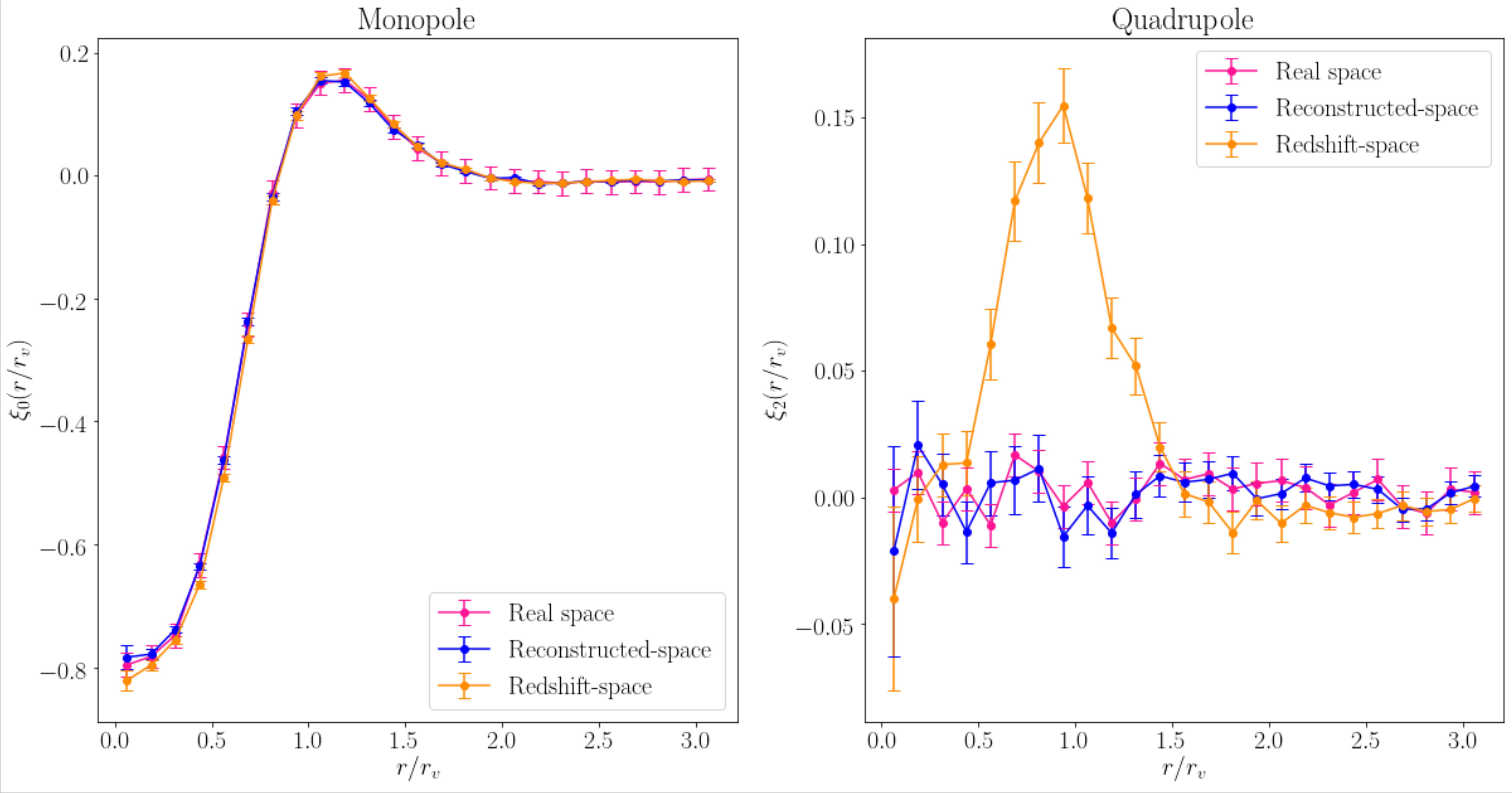
Data: Cubic Box, $L_{box} = 1000\ h^{-1}Mpc$, from Quijote Simulation High Resolution, $\bar{z} = 0.5$

Redshift-space: **anisotropies (only RSD)**

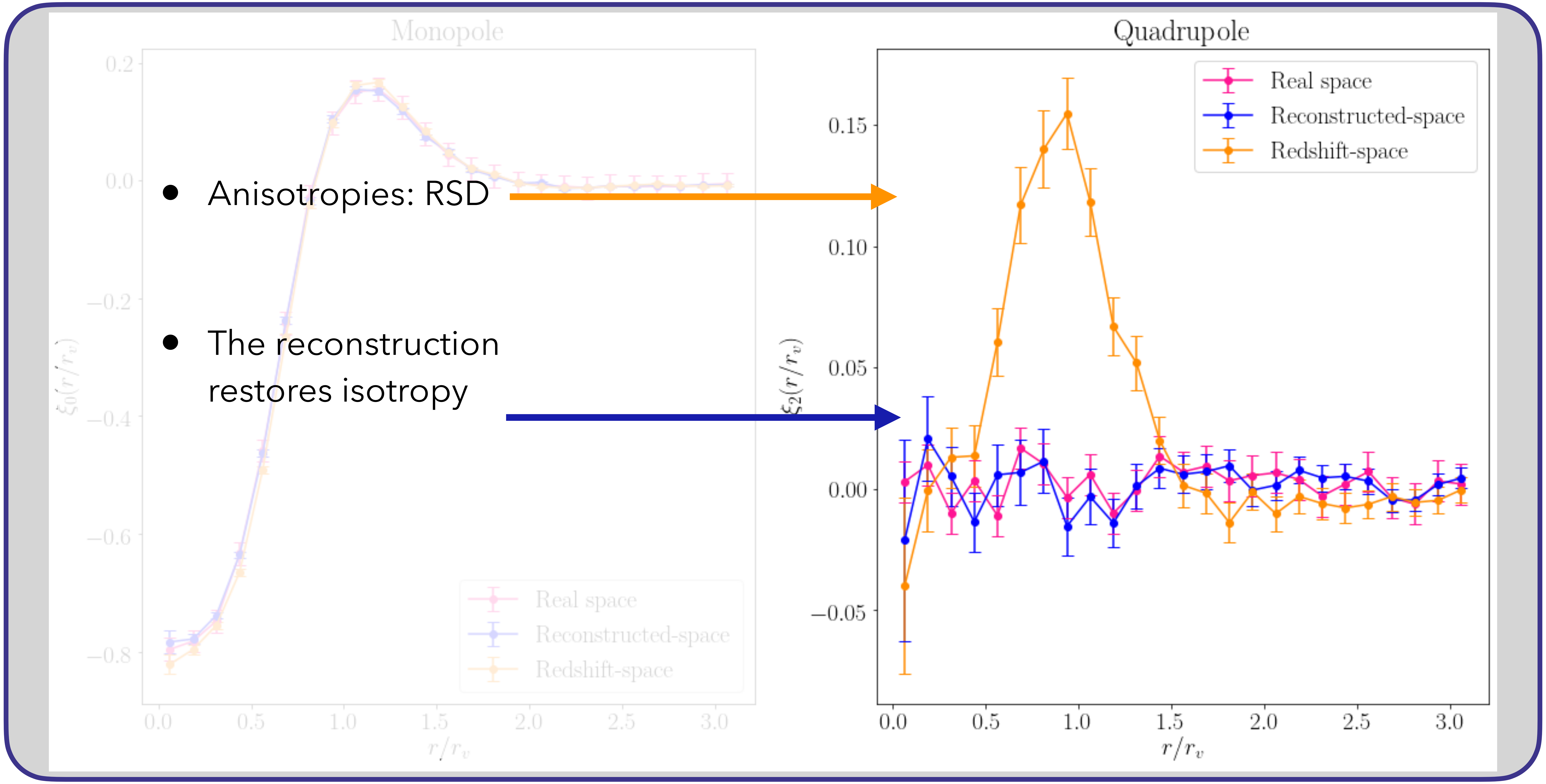
Reconstructed-space : **no anisotropies**



Void-galaxy cross-correlation function multipoles



Void-galaxy cross-correlation function multipoles



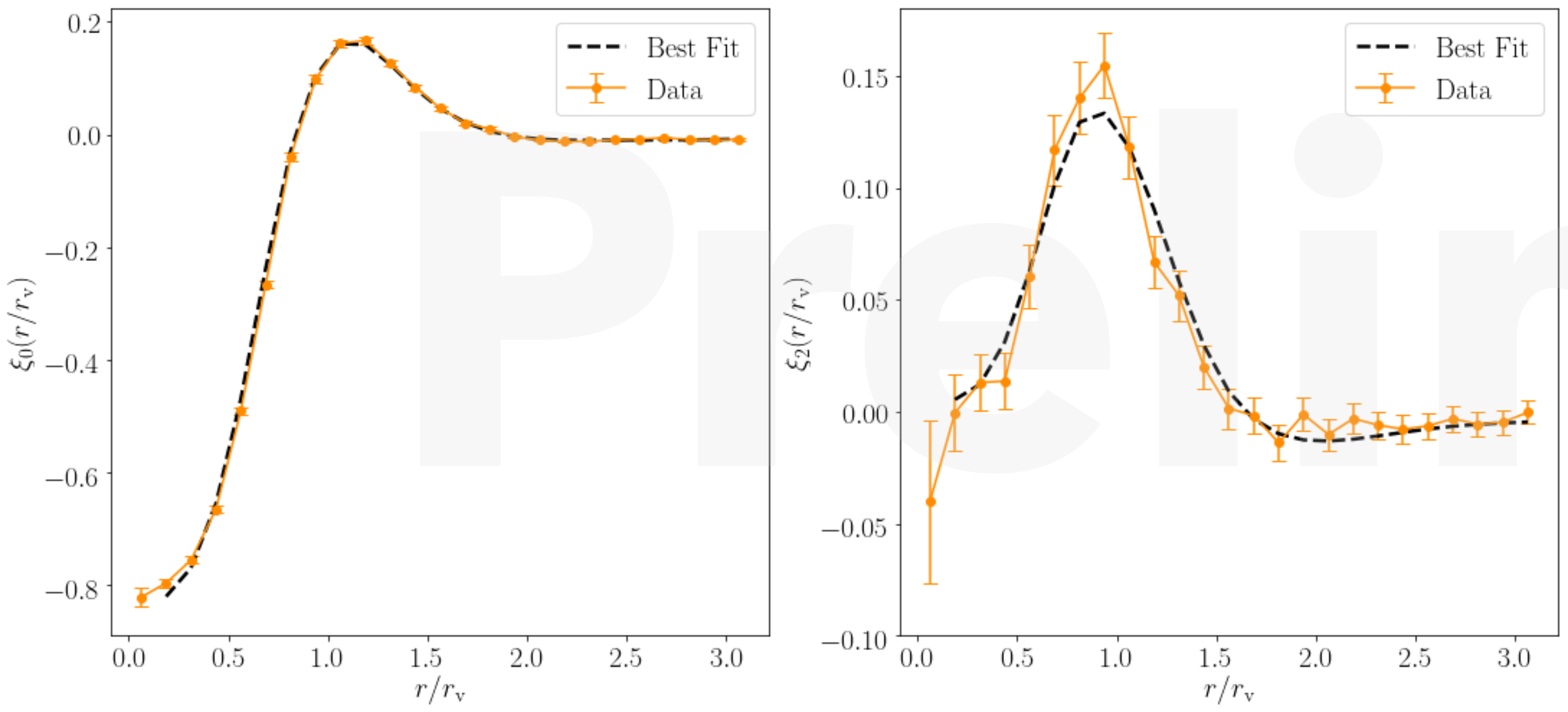
- Anisotropies: RSD
- The reconstruction restores isotropy

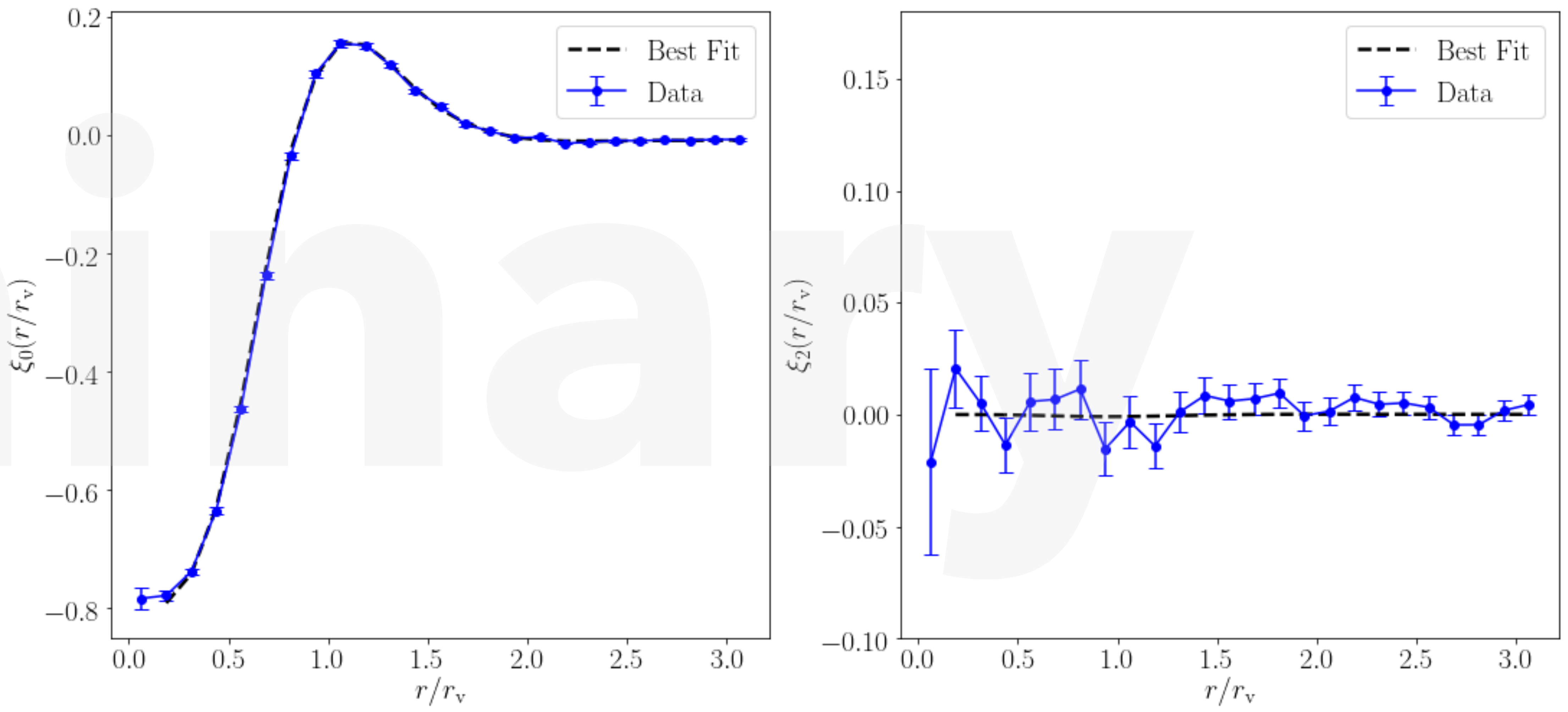
RESULTS

Redshift-Space

All the voids in the sample - no cut

Reconstructed-Space





$\epsilon = 1.026 \pm 0.017$
$\beta = 0.428 \pm 0.053$

Precision on ϵ :
1.7 %

$\epsilon = 1.004 \pm 0.012$
$\beta = 0.007 \pm 0.010$

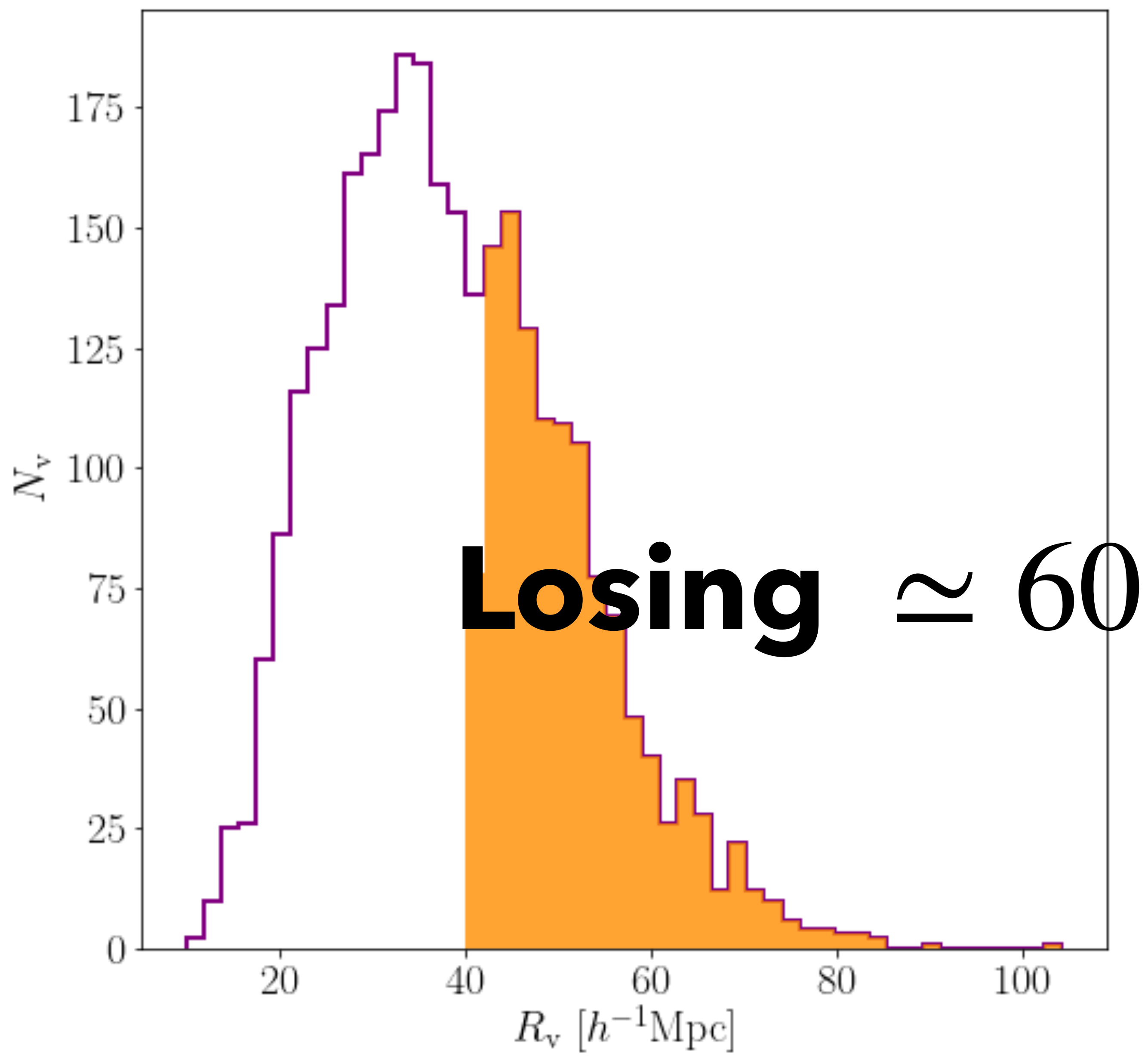
Precision on ϵ :
1.2 %

$1.5\sigma_\epsilon$ from the true value $\epsilon = 1$

$0.3\sigma_\epsilon$ from the true value $\epsilon = 1$

State of the art :

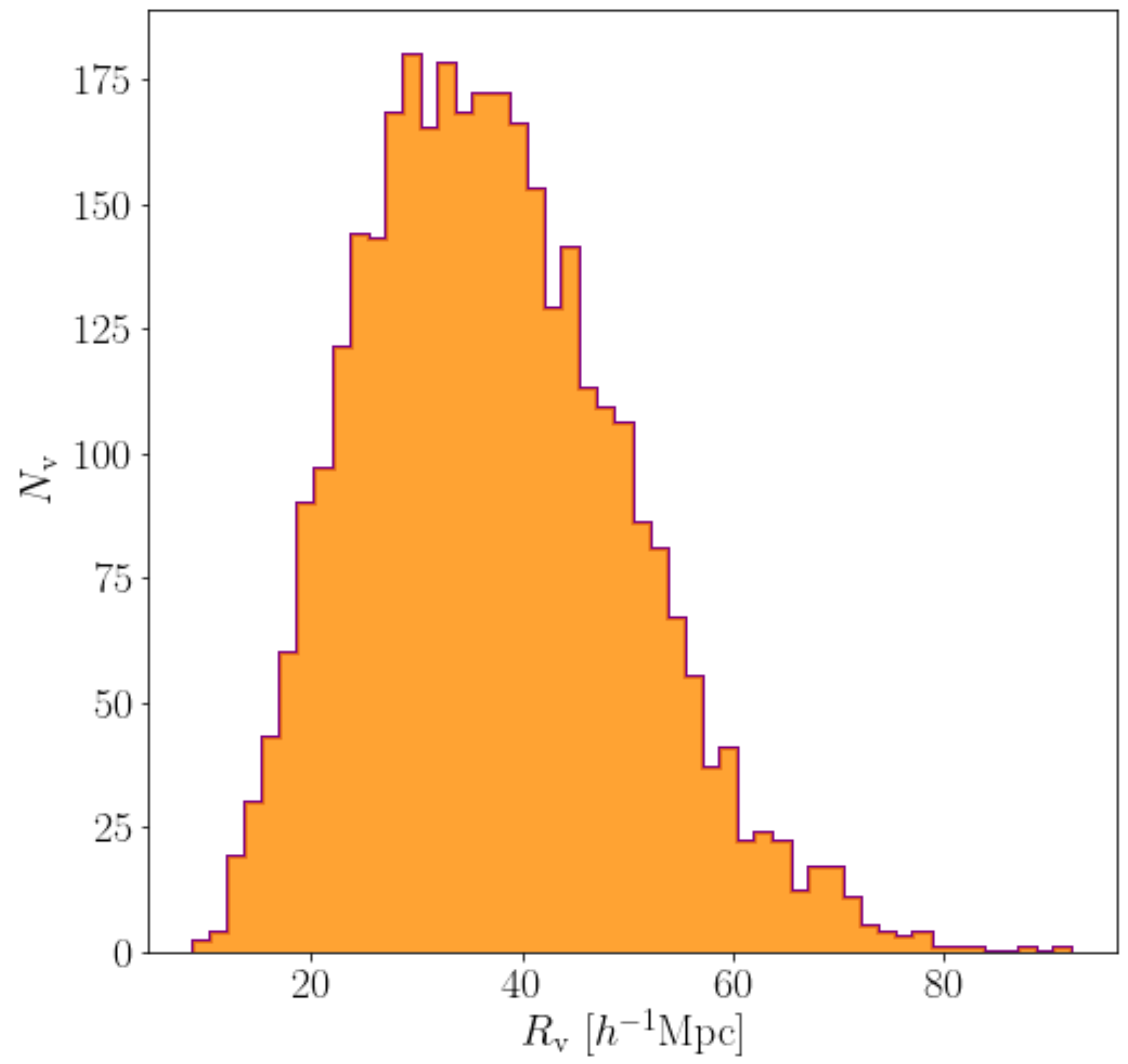
Redshift space analysis with larger voids $R_{\rm v} > 3{\rm mps}$



Losing $\simeq 60\,\%$ **of voids**

New method with analysis in reconstructed space:

All the voids in the sample



State of the art :

Redshift space analysis with larger voids $R_v > 3\text{mps}$

New method with analysis in reconstructed space:

All the voids in the sample

Precision on ϵ:
$2.1\,\%$

Precision on ϵ:
$1.2\,\%$

CONCLUSIONS

- Studied the impact of a linear reconstruction in cosmic voids
- First analysis correlating galaxies and voids in reconstructed space
- Differences between pure redshift-space and pure reconstructed-space analyses

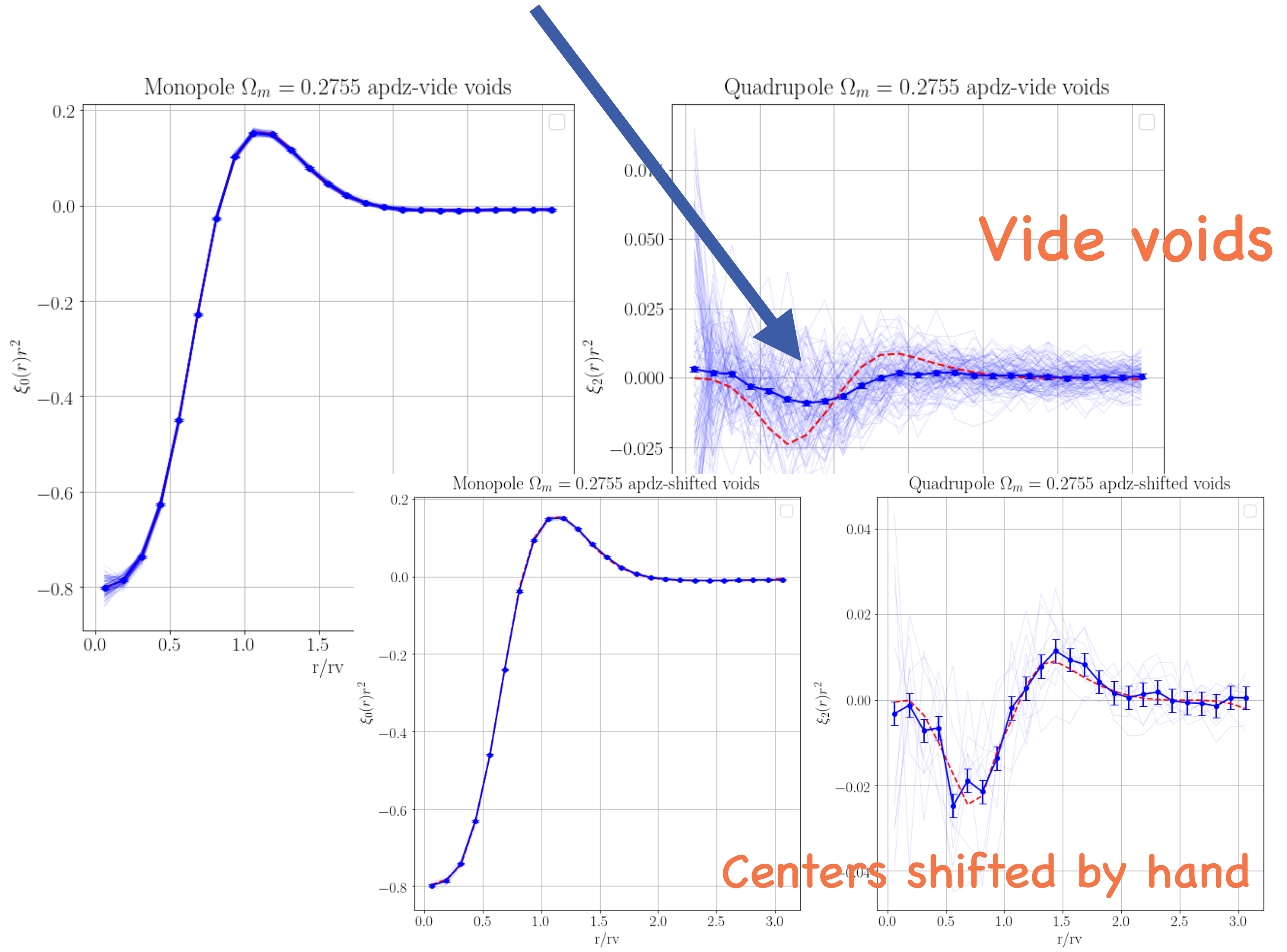
Take home message :

Reconstructed-space analysis : more accurate and more precise in recovering the AP parameter ϵ

FUTURE PERSPECTIVES

- Test the robustness of the method against an Alcock-Paczynski test *(in progress…)*

  ([Radinovic et al. 2024](#))



- Apply the method to data

Thank you for the attention

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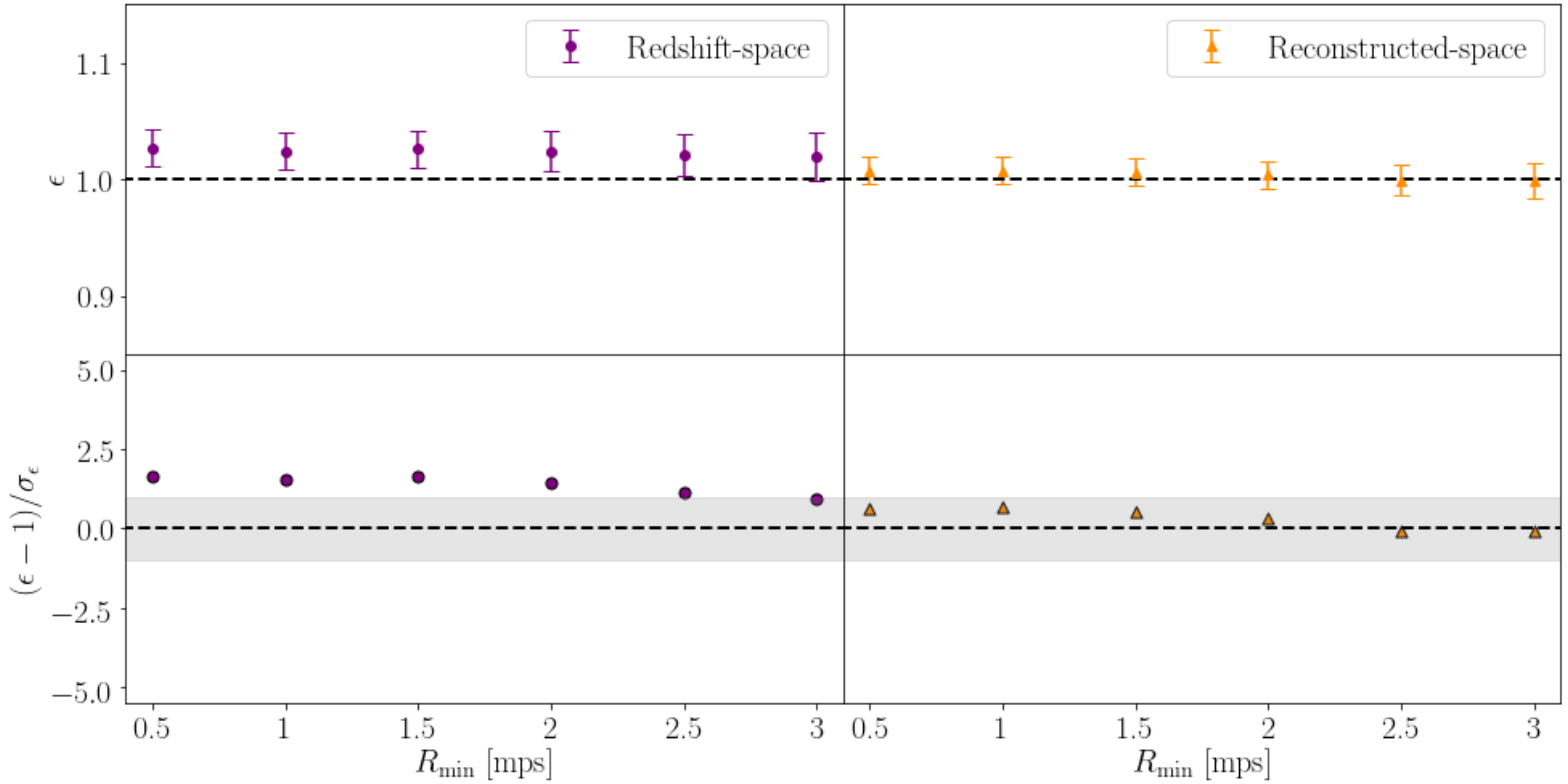
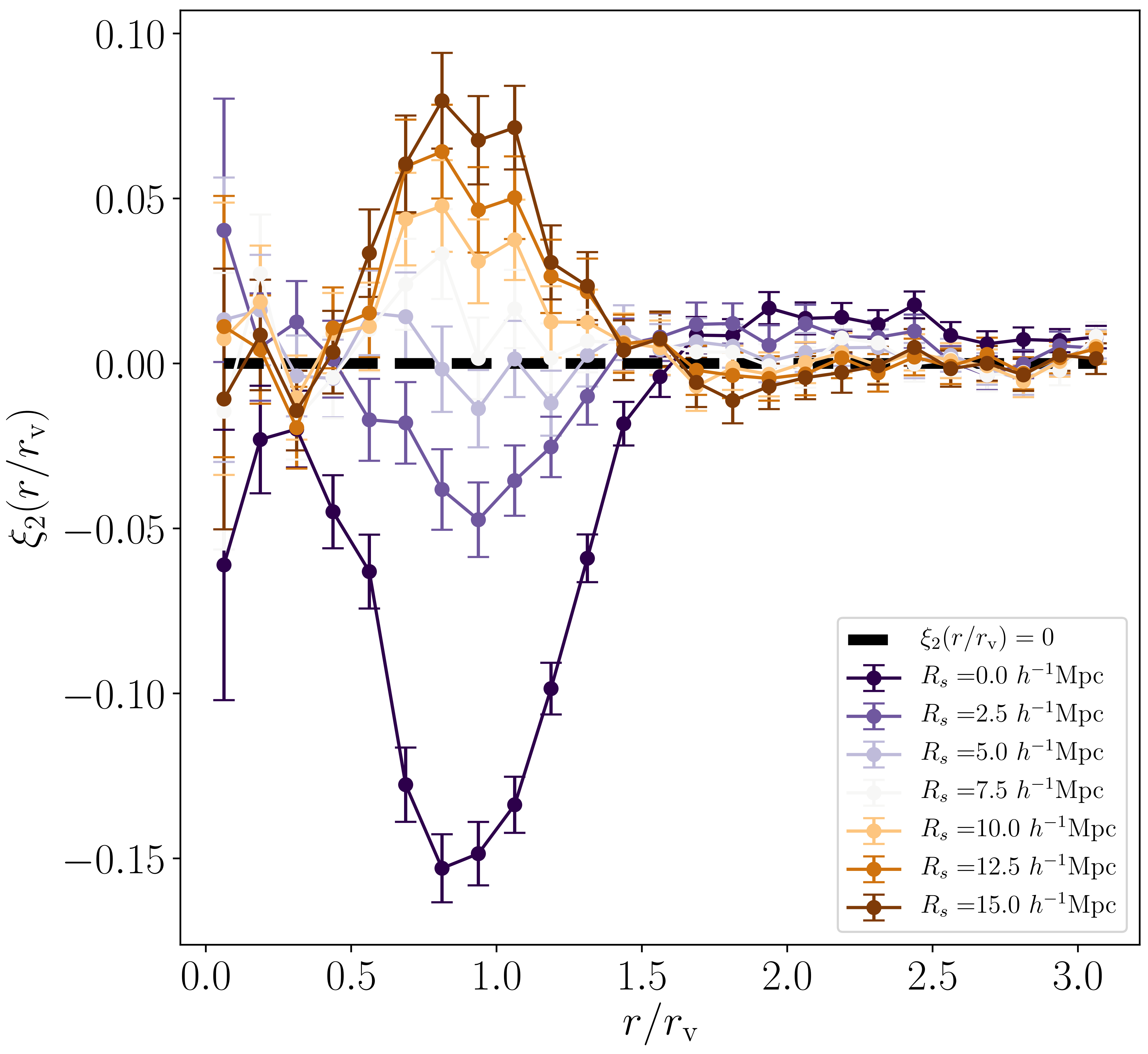


Redshift-space
Reconstructed-space
ϵ
1.1
1.0
0.9
$(\epsilon - 1)/\sigma_\epsilon$
5.0
2.5
0.0
−2.5
−5.0
0.5
1
1.5
2
2.5
3
$R_{\rm min}$ [mps]
$R_{\rm min}$ [mps]

Test robustness of the reconstruction: sensitivity to the smoothing scale R_S



Backup slide: Test robustness of the reconstruction 2