Image credit: J. Carretero (PIC), P. Tallada (PIC), S. Serrano (ICE) and the Euclid Consortium Cosmological Simulations SWG

The Void-Galaxy Cross-Correlation Function In Euclid

Slađana Radinović

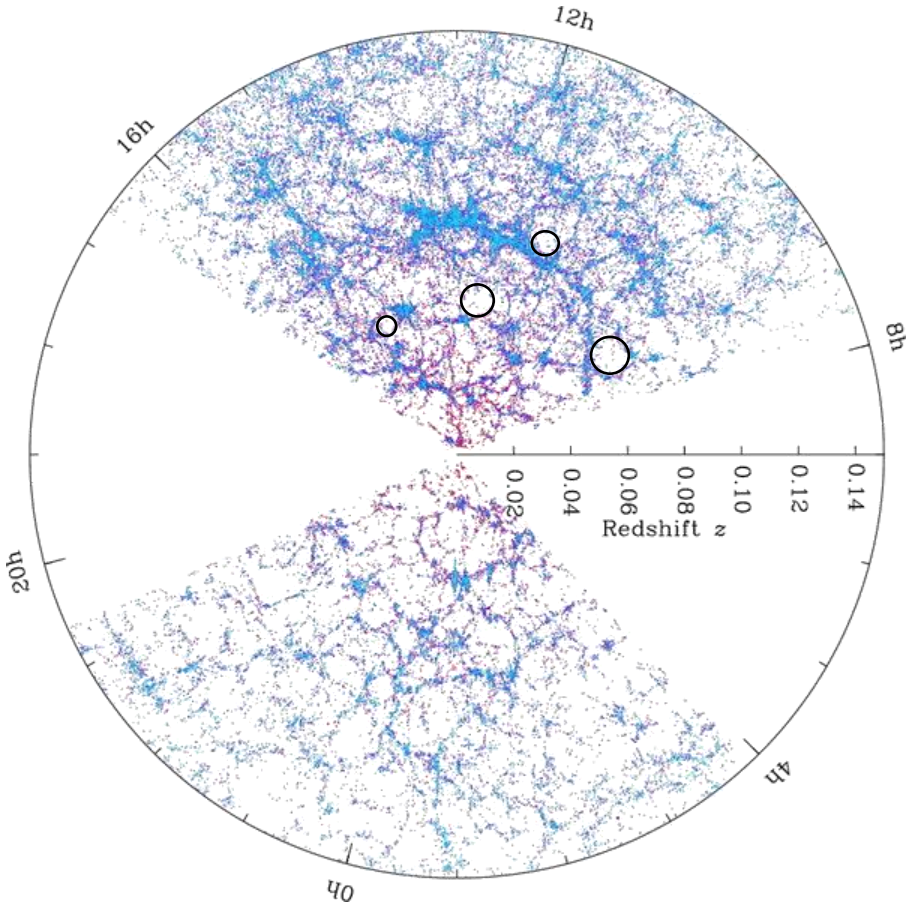
In collaboration with: S. Nadathur, H. Winther, W. Percival, A. Woodfinden, E. Massara, E. Paillas

Euclid Voids

Euclid consortium

UiO : Universitetet i Oslo

Cosmic voids



SDSS galaxies. Image Credit: M. Blanton and SDSS

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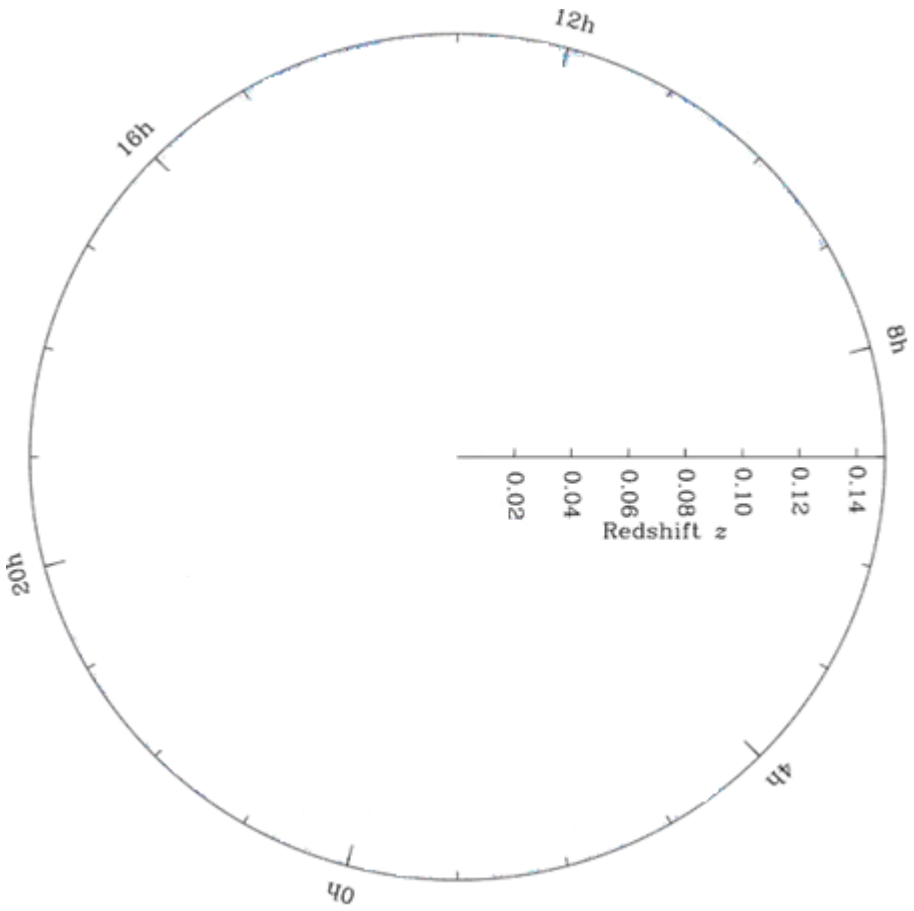

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Cosmic voids

- voids are underdense regions in the large-scale structure

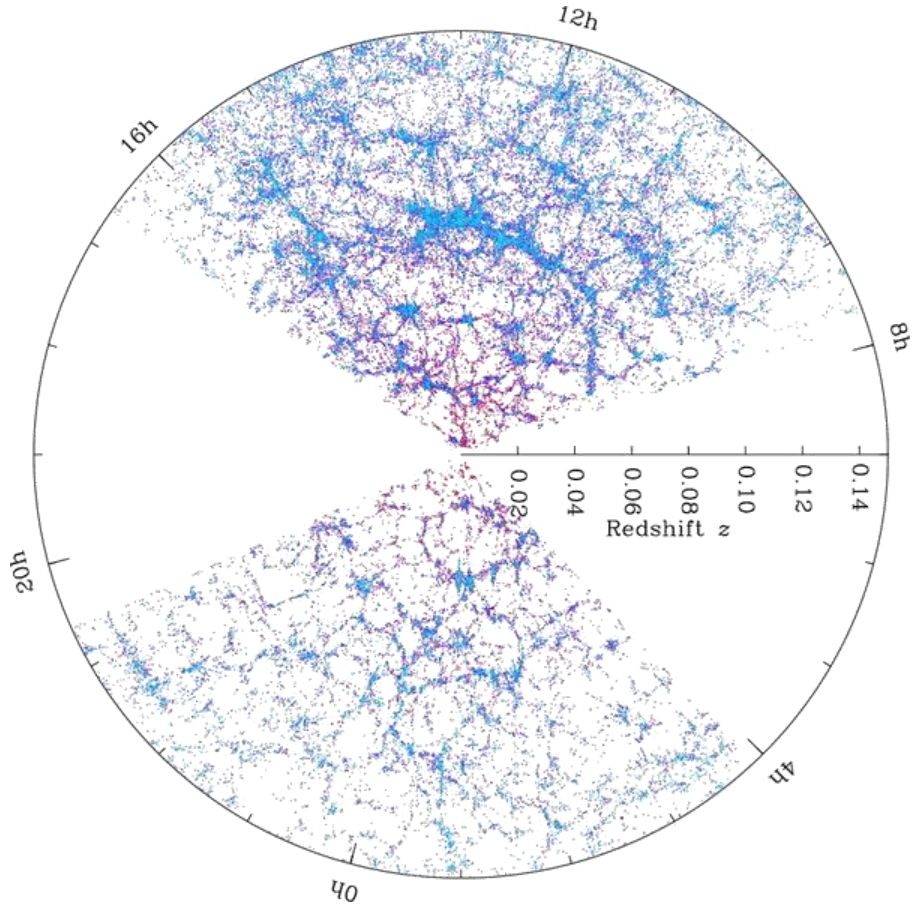
- different void-finding algorithms:
  - spherical
  - watershed (zobov and voxel)
- different:
  - voids
  - void properties
  - benefits

Pylians3

VIDE

Revolver

Revolver



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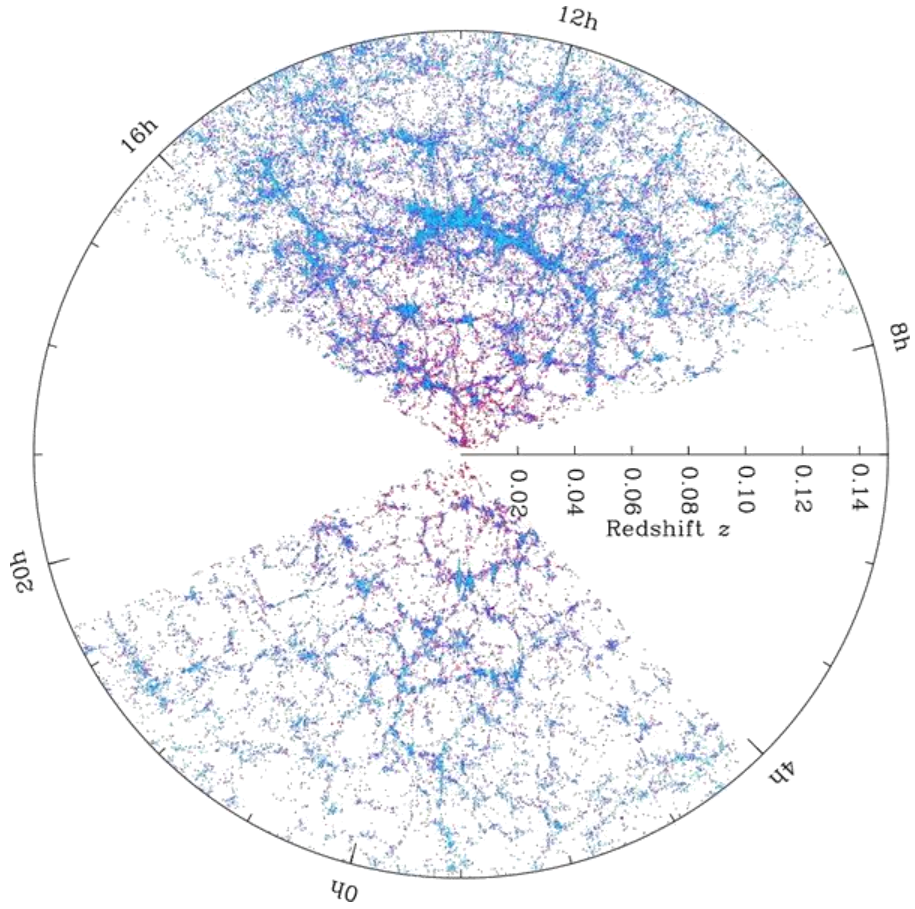

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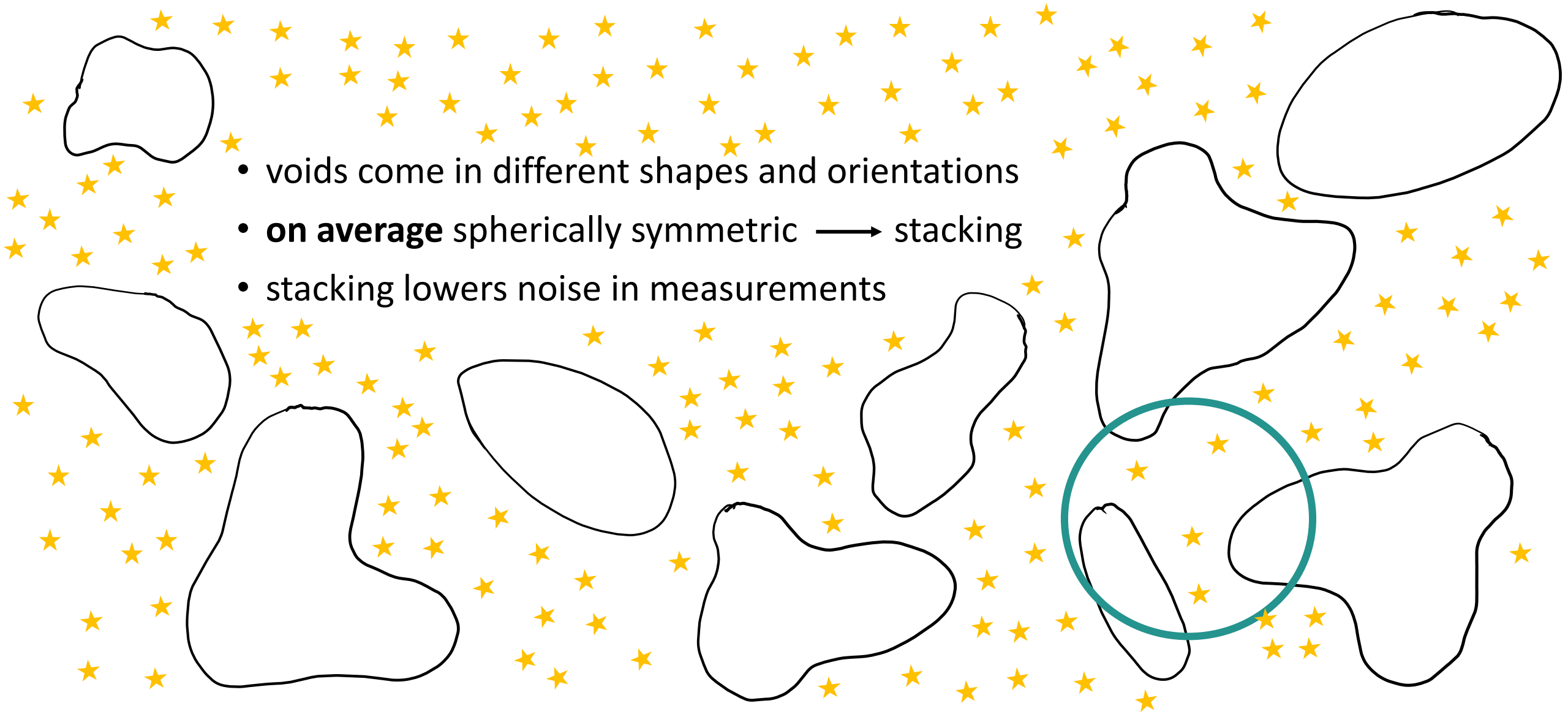
Cosmic voids

Great Lakes from space
Credit: SeaWiFS Project, NASA/Goddard Space Flight Center, ORBIMAGE

Cosmic voids



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- **on average** spherically symmetric ⟶ stacking
- stacking lowers noise in measurements

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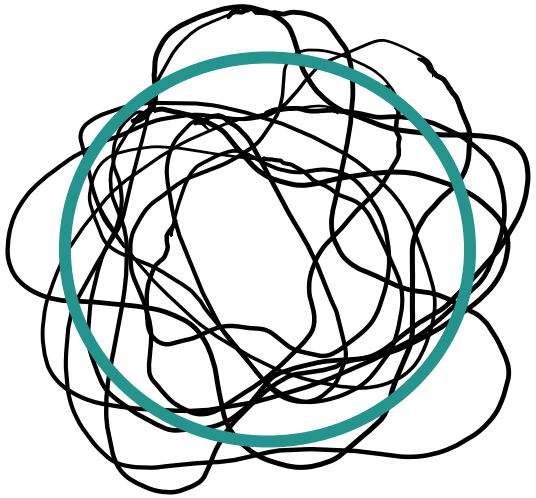

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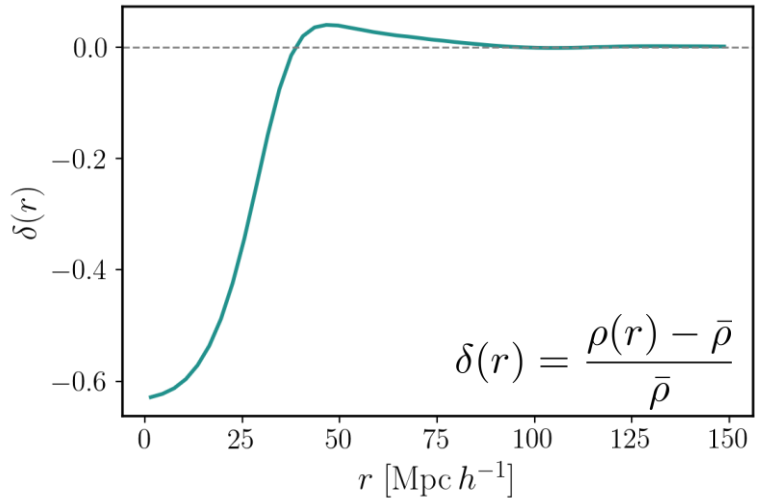
- Example: matter density



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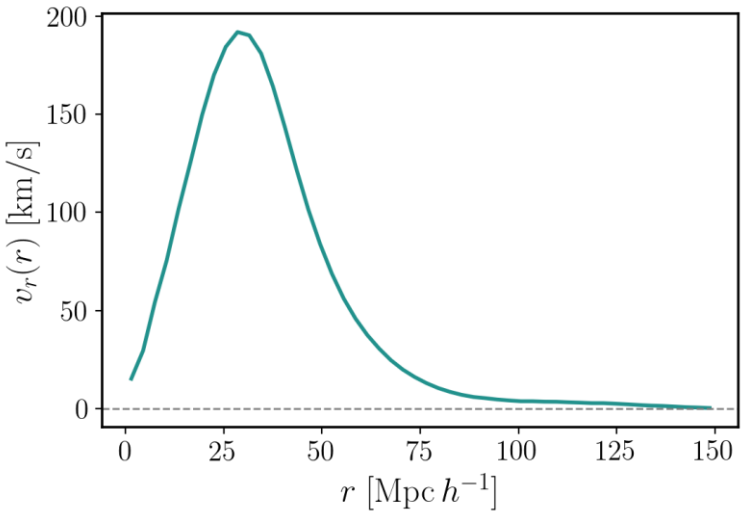


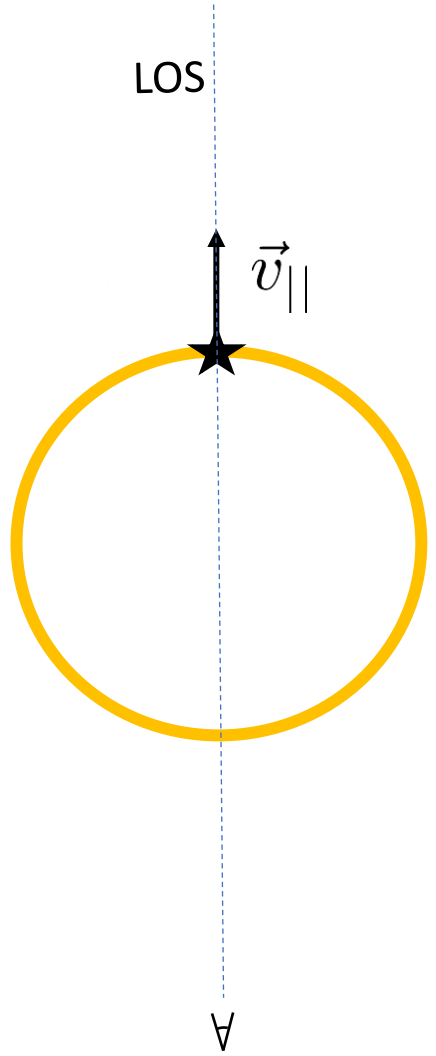
Cosmic voids

redshift-space distortions (RSD)

(constrains gravity through growth of structure)

Alcock-Paczynski effect (AP)

(constrains expansion history of the Universe)



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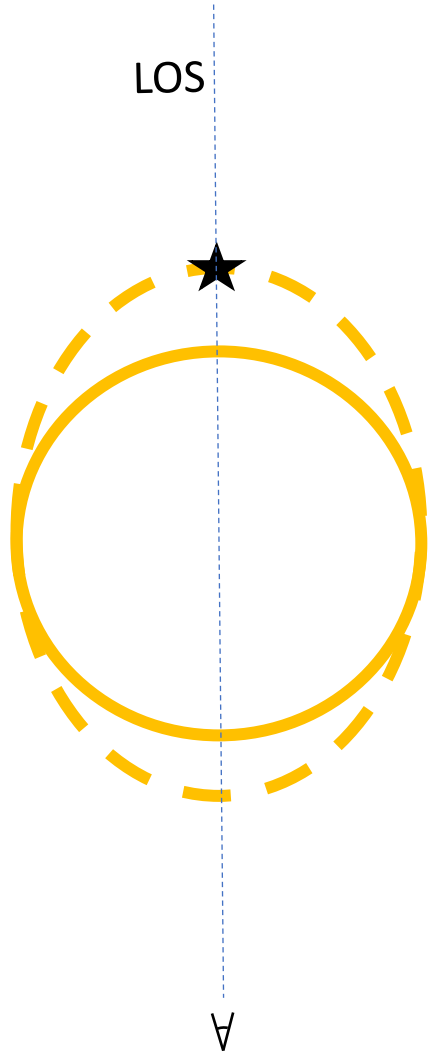

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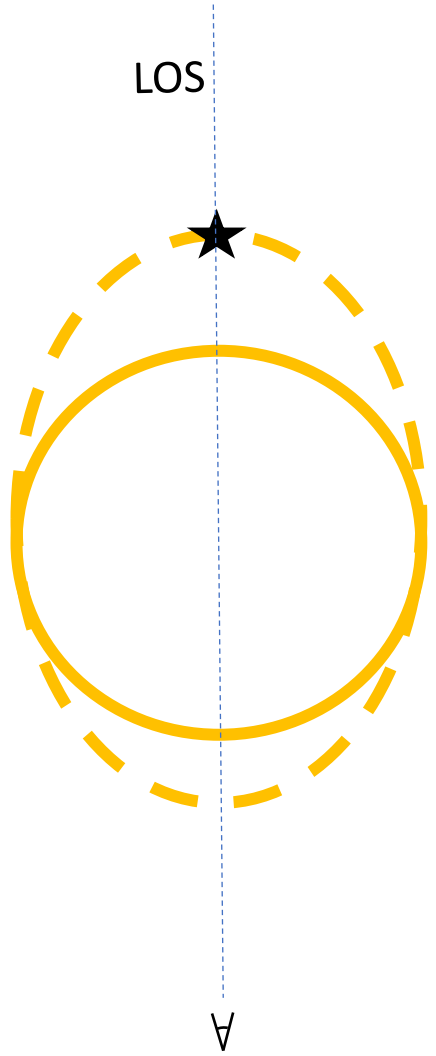

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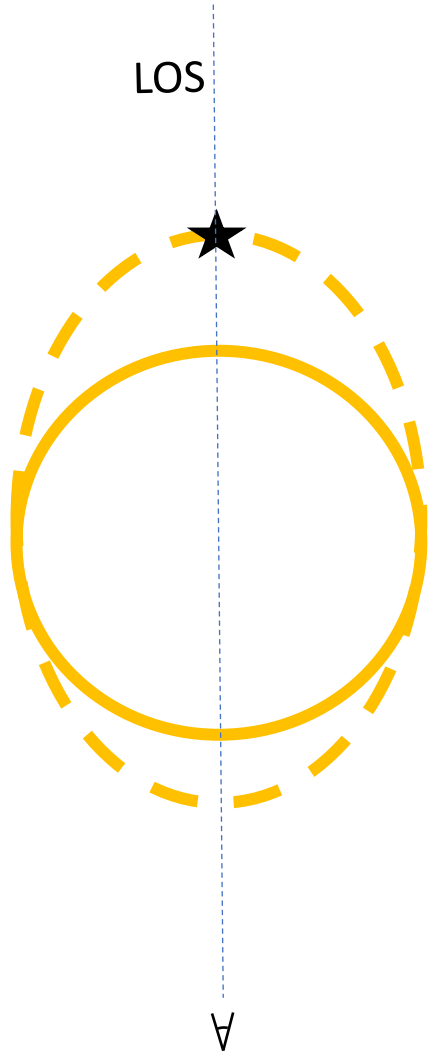
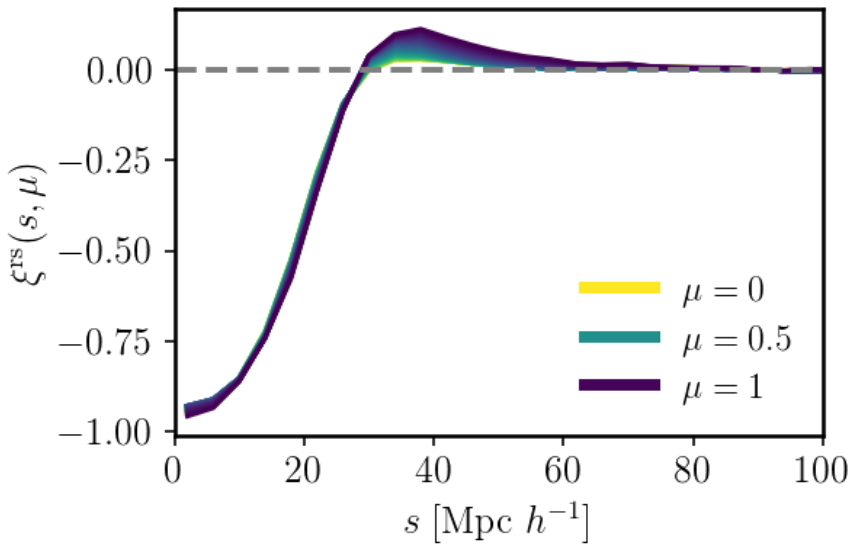
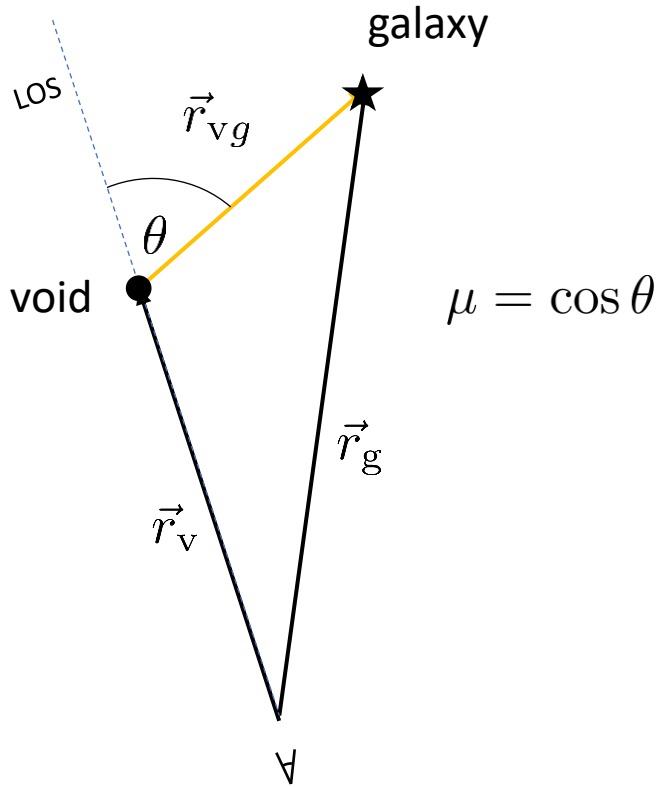


Void-galaxy cross-correlation function

- 3D cross-correlation function
- Landy-Szalay estimator:

$$\xi_{\rm LS}(r,\mu) = \frac{D_1D_2 - D_1R_2 - D_2R_1 + R_1R_2}{R_1R_2}$$





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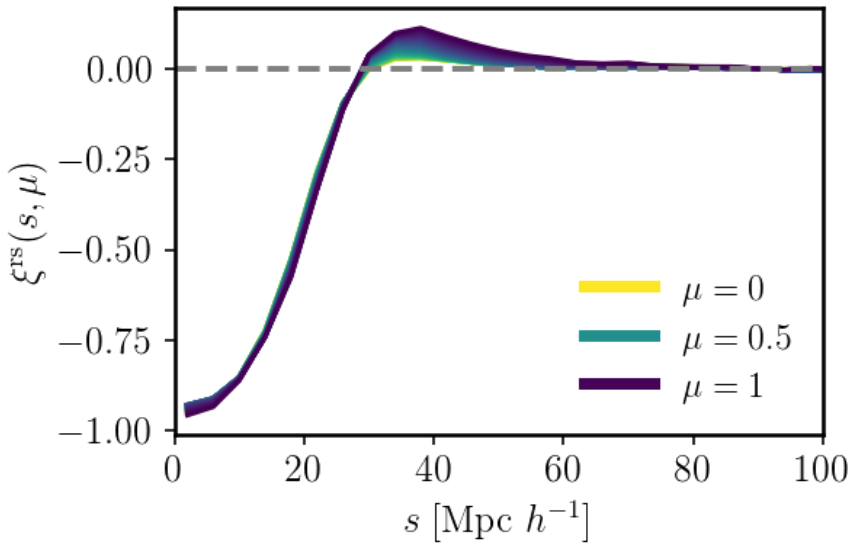

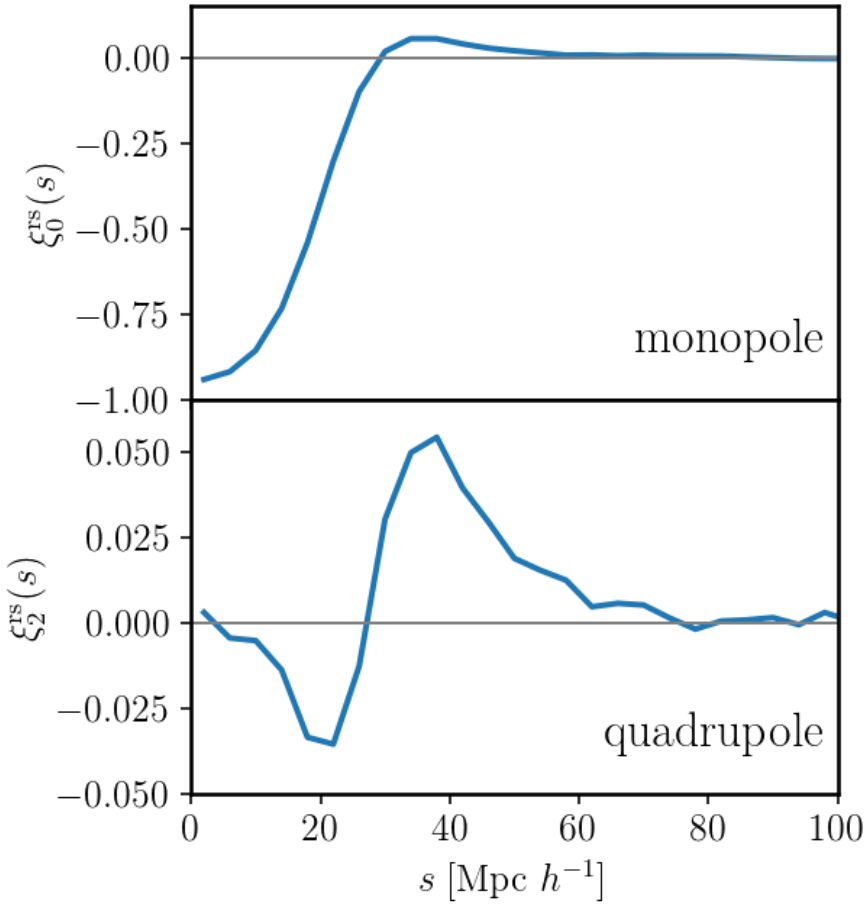

Void-galaxy cross-correlation function

- coordinate transformation: real-space → redshift-space
- general expression:

velocity distribution function

$$1 + \xi^{s,th}(\mathbf{s}) = \int (1 + \xi^{r}(\mathbf{r})) P(v_{||}, \mathbf{r}) dv_{||}$$

redshift space cross-correlation

real space cross-correlation

$$\frac{1}{\sqrt{2\pi}\sigma_{v_{||}}(r)} \exp\left[-\frac{(v_{||} - v_r\mu)^2}{2\sigma^2_{v_{||}}(r)}\right]$$

- assuming:
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  - Gaussian velocity distribution (Gaussian streaming model, e.g. Paz et al. 2013, Cai et al. 2016)

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Alcock-Paczyński effect

$$\left.\begin{aligned} \alpha_{\perp} &= \frac{D_{\mathrm{M}}(z)}{D_{\mathrm{M}}^{\mathrm{fid}}(z)} \\ \alpha_{||} &= \frac{D_{\mathrm{H}}(z)}{D_{\mathrm{H}}^{\mathrm{fid}}(z)} \end{aligned}\right\} \quad \epsilon = \frac{\alpha_{\perp}}{\alpha_{||}}$$

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- assuming:
  - void-galaxy pairs conserved
  - Gaussian velocity distribution (Gaussian streaming model, e.g. Paz et al. 2013, Cai et al. 2016)
  - templates + linear continuity equation

$$v_r(r) = -\frac{1}{3} f a H r \Delta(r) \propto f\sigma_8$$

Elena Massara et al. 2022

Reconstruction

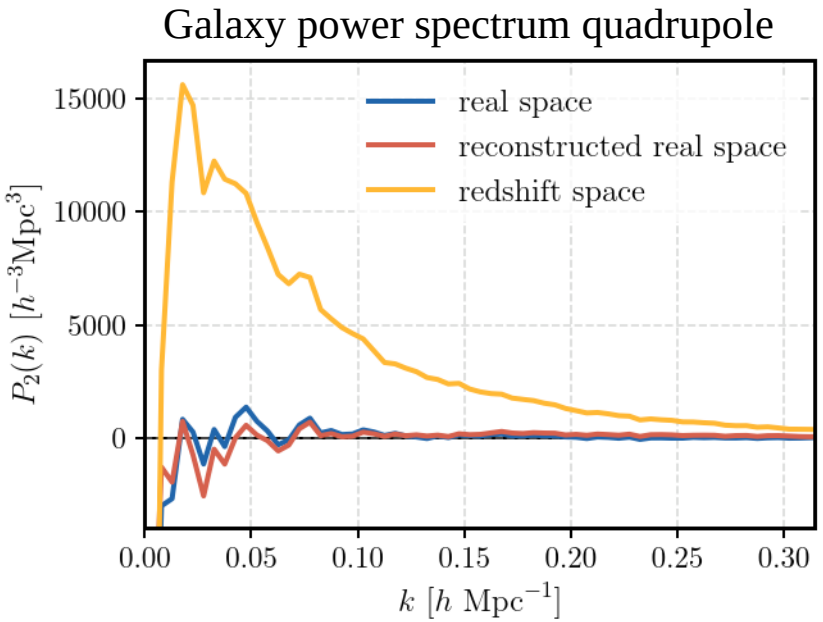
- selection effects when finding voids in redshift space
- reconstruction recovers real-space positions
  - (unlike in BAO analysis, only RSD removed)

- solve Zeldovich equation to get displacement field

$$\nabla \cdot \mathbf{\Psi} + \frac{f}{b} \nabla \cdot (\mathbf{\Psi} \cdot \hat{\mathbf{r}}) \hat{\mathbf{r}} = -\frac{\delta_g}{b}$$

$$\mathbf{\Psi}_{\mathrm{RSD}} = -f \left(\mathbf{\Psi} \cdot \hat{\mathbf{r}} \right) \hat{\mathbf{r}}$$

- shift galaxies to approximate real-space positions (Nadathur & Percival 2018)



Pipeline

- Run velocity field reconstruction on observed galaxy positions
- Find voids in the real-space galaxy field
- Calculate vgCCF with:
  1. real-space galaxies
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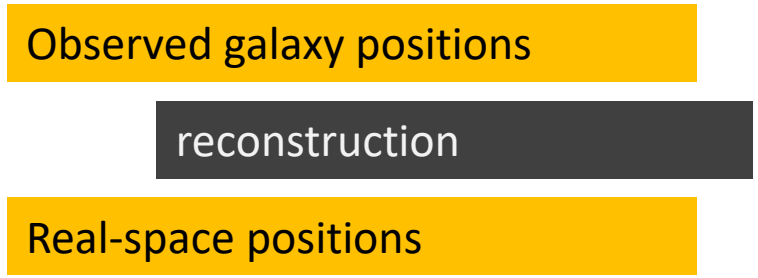
- parameter estimation using MCMC



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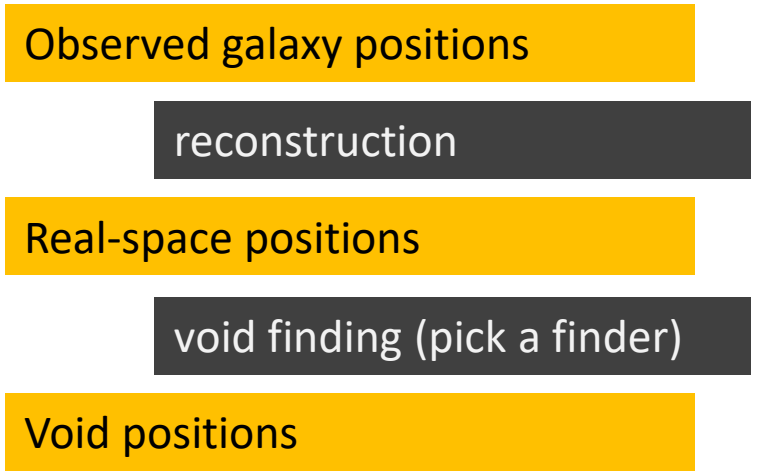

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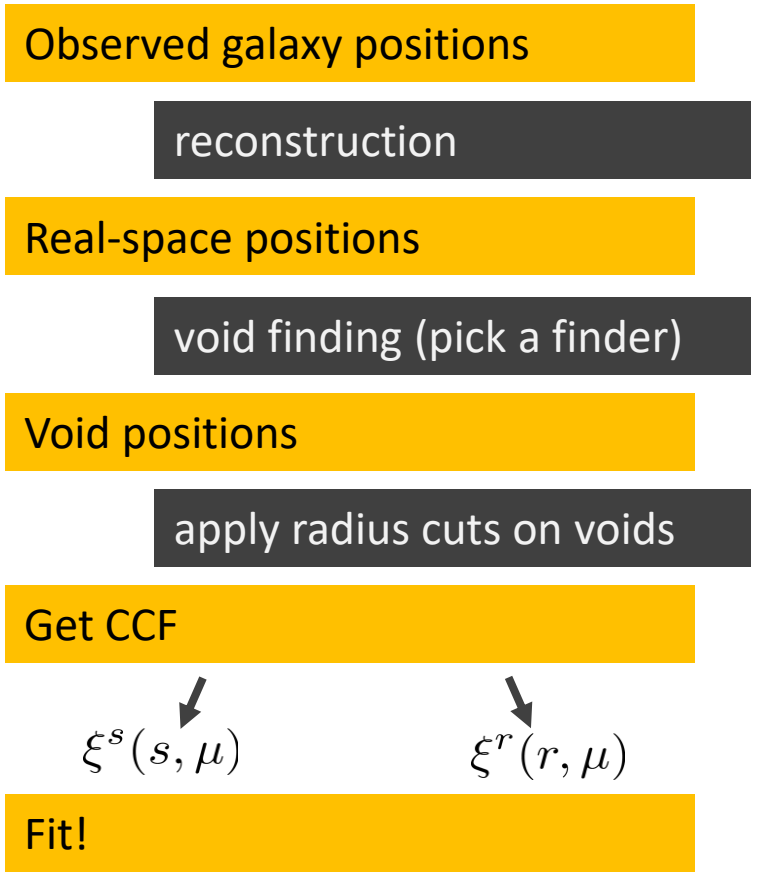


Euclid

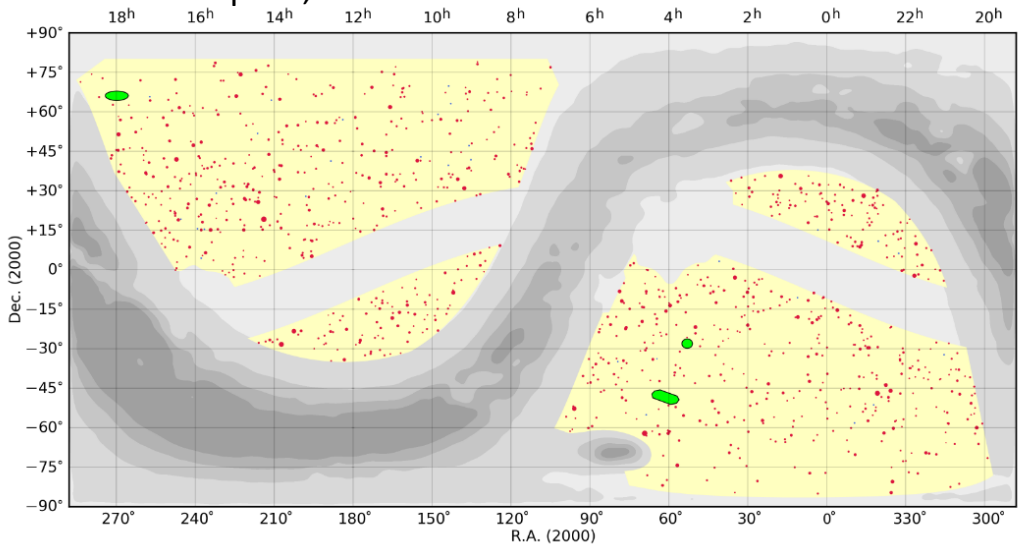
- launch: **July 2023**
- galaxy clustering and weak lensing

- spectroscopic redshifts for $\sim 10^7$ galaxies
- $0.9 < z < 1.8$
- covering almost third of the sky

- Flagship simulation
  - only one octant
  - down-sampled to 60%

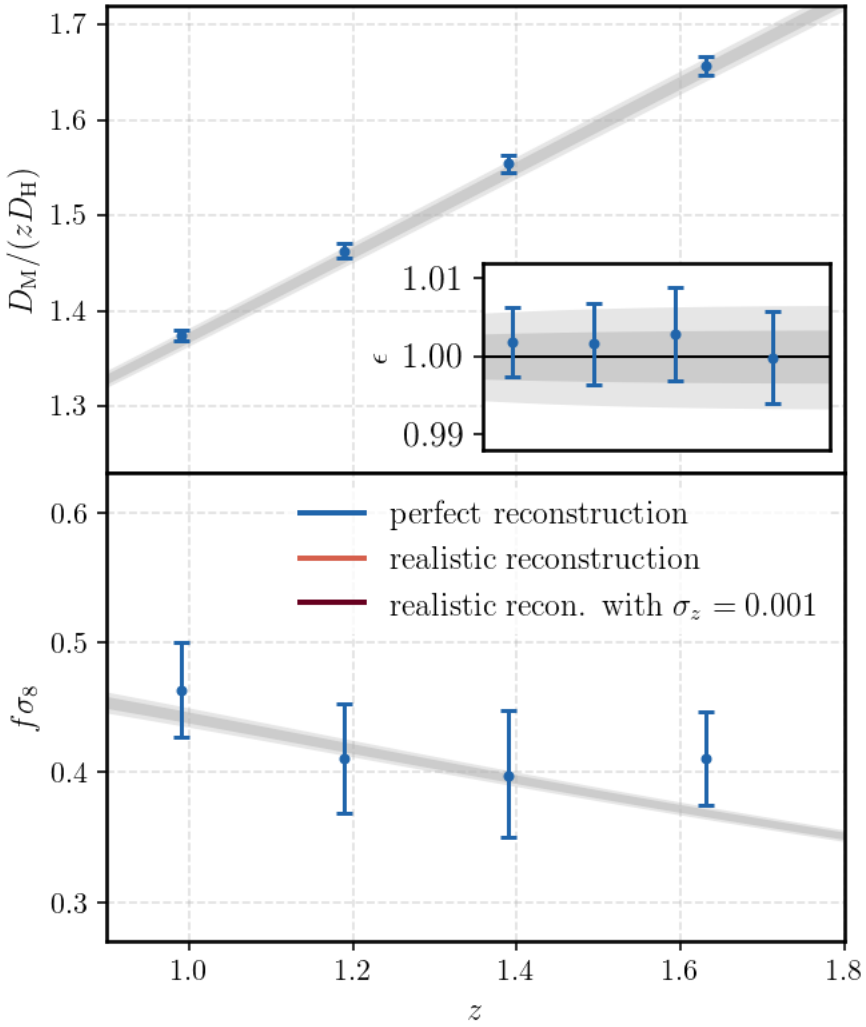
Copyright: ESA/C. Carreau

Euclid footprint, Scaramella et al. 2022



Results

1. analysis on Flagship
   - **perfect reconstruction (using true real space positions)**
   - realistic reconstruction
   - realistic reconstruction with redshift errors



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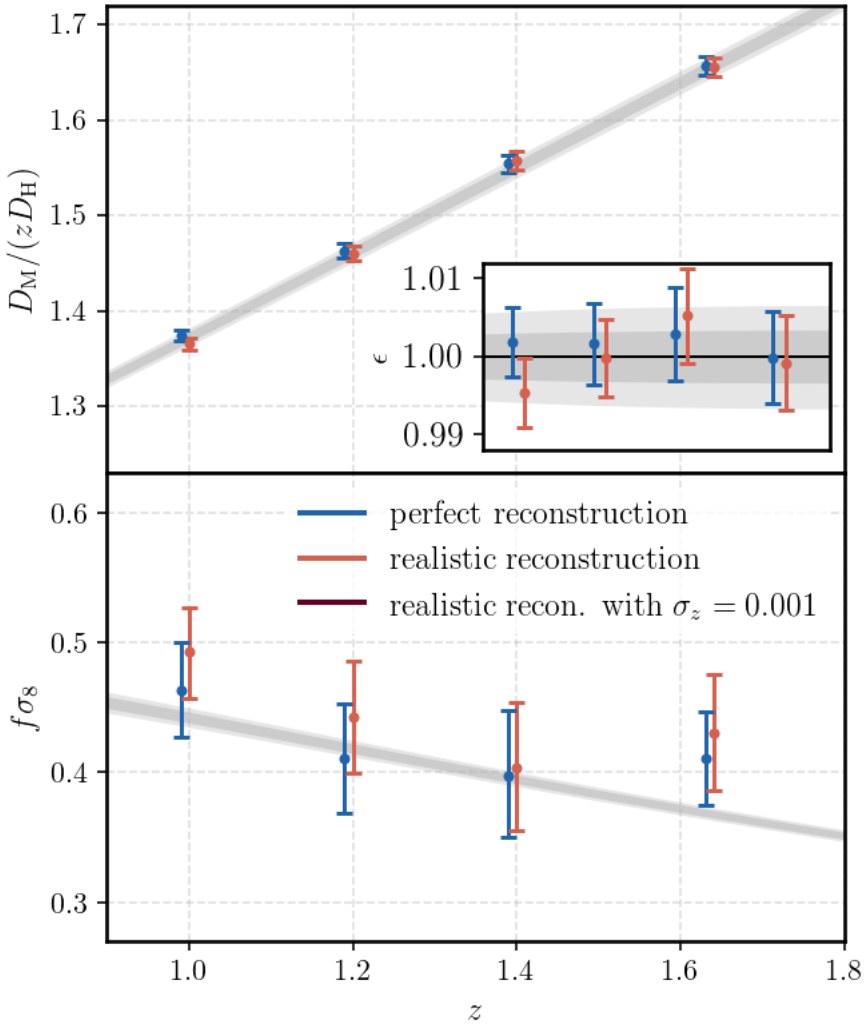

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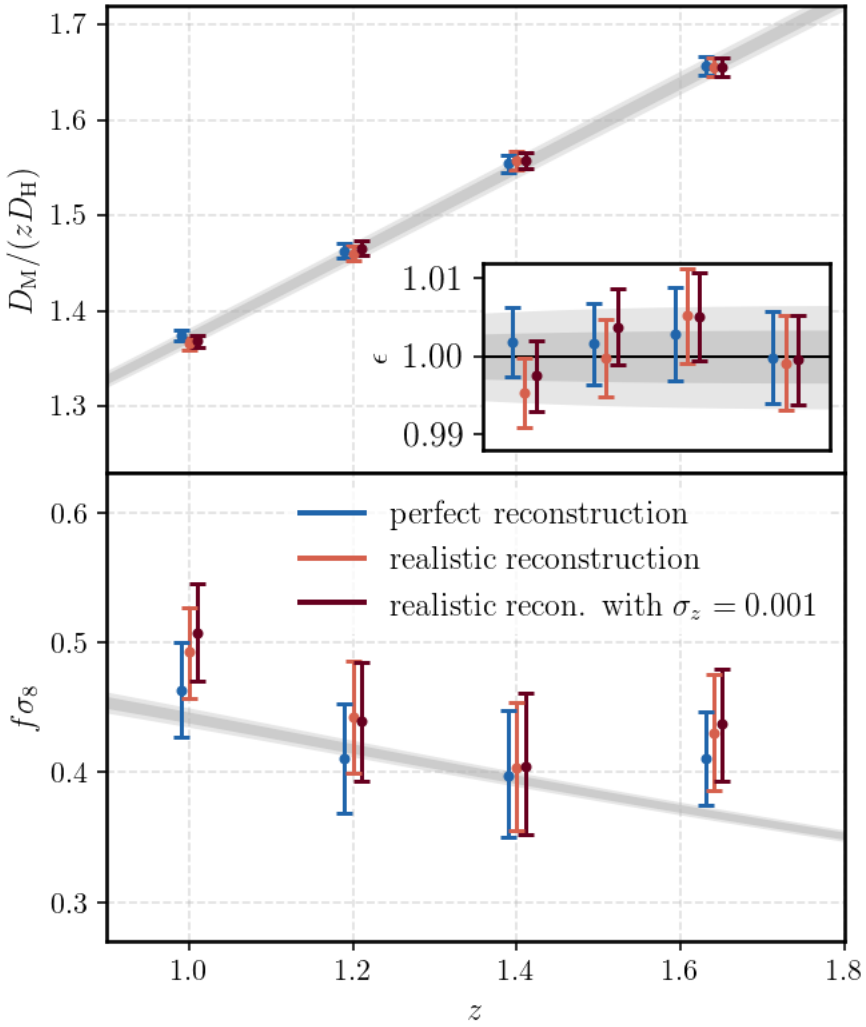

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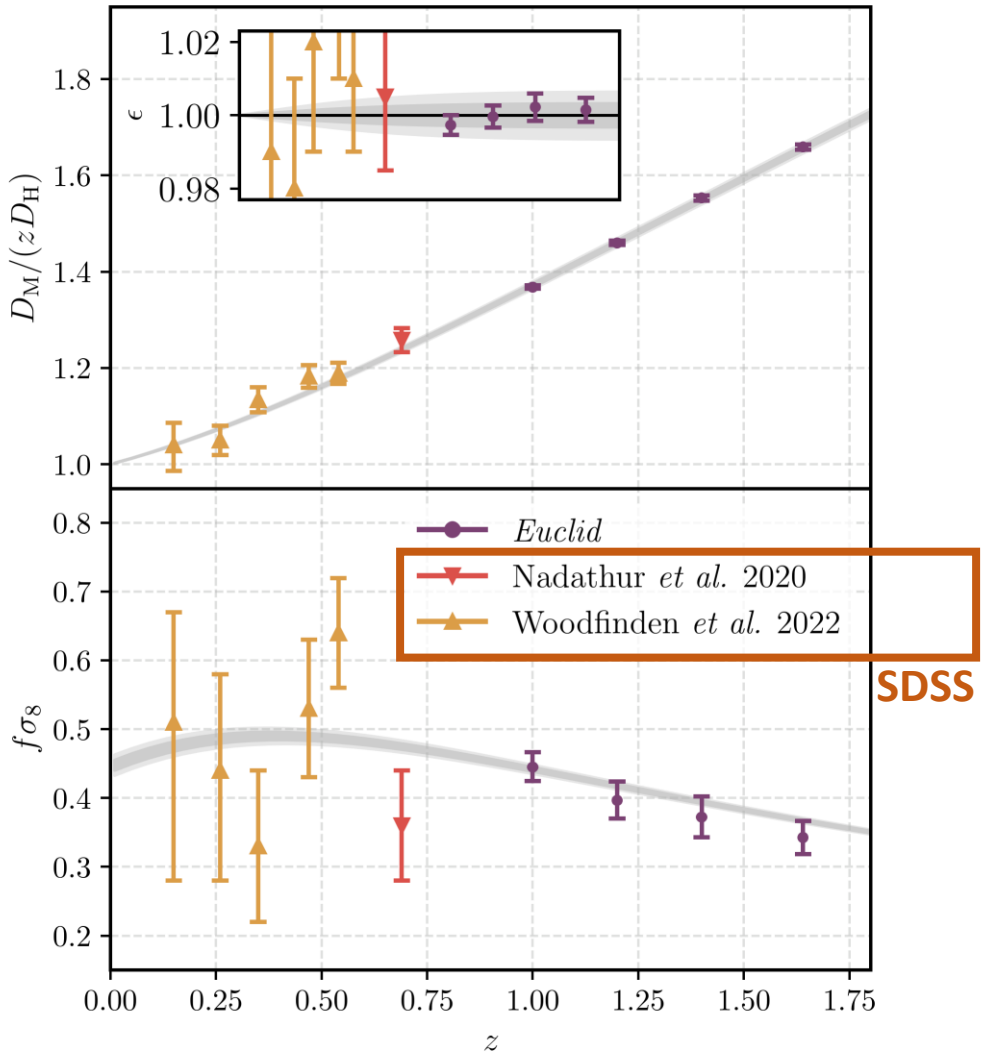
Radinovic et al. 2023



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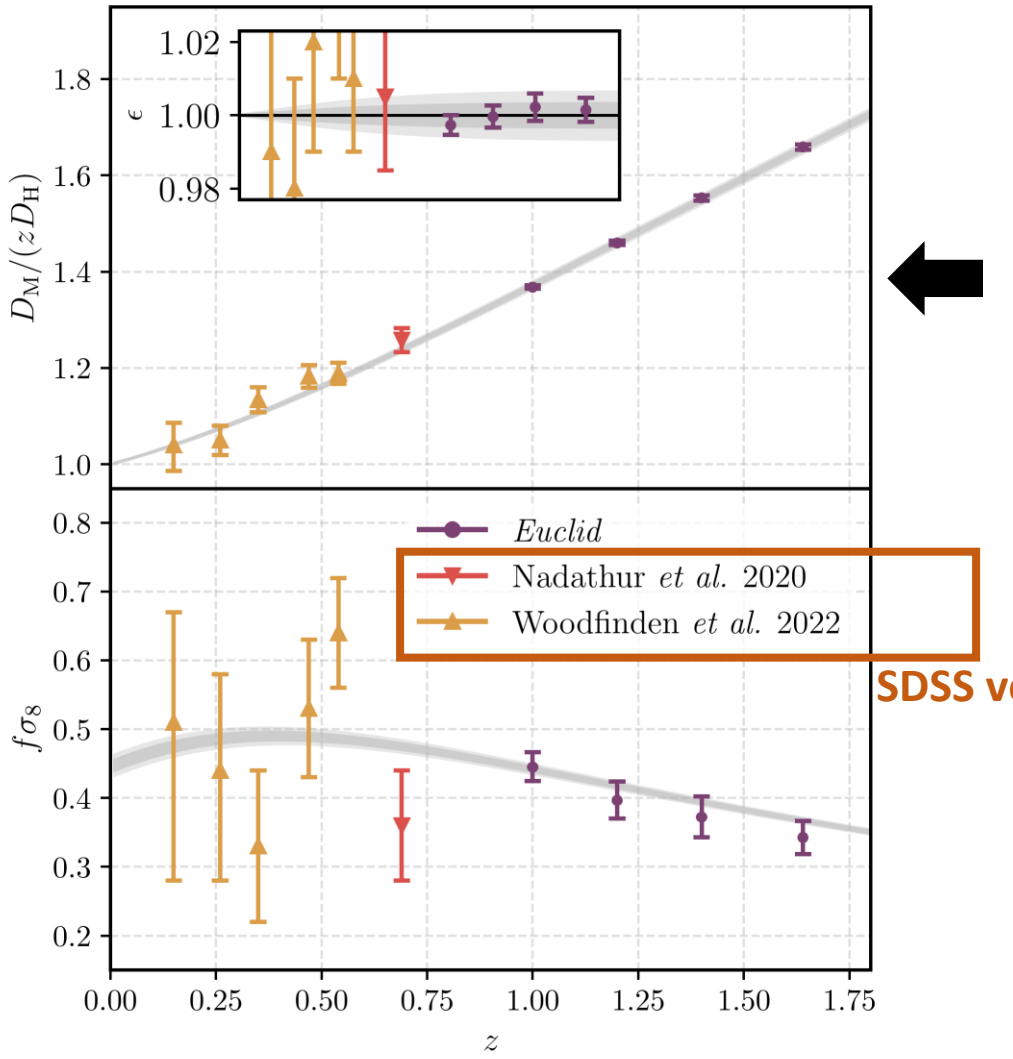
Radinovic et al. 2023



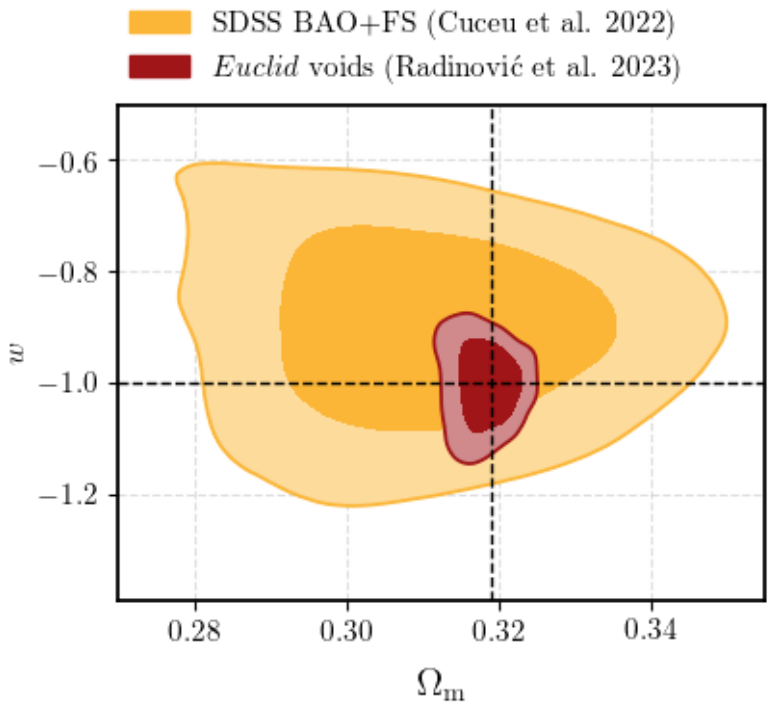
SDSS voids

Results

Flat wCDM cosmology

$$w = -1.00^{+0.06}_{-0.05}$$

$$\Omega_{\rm m} = 0.3183 \pm 0.0028$$



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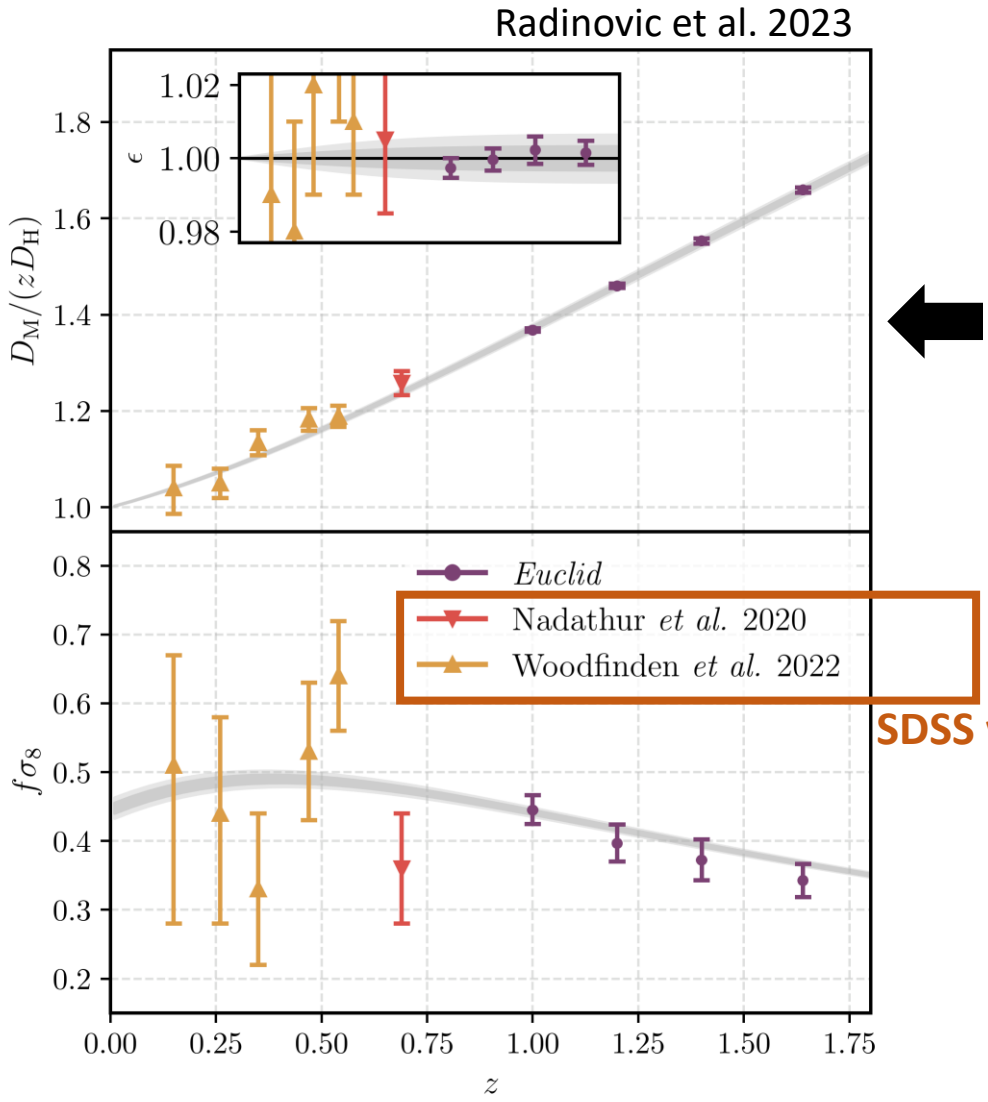

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Thank you

Questions?