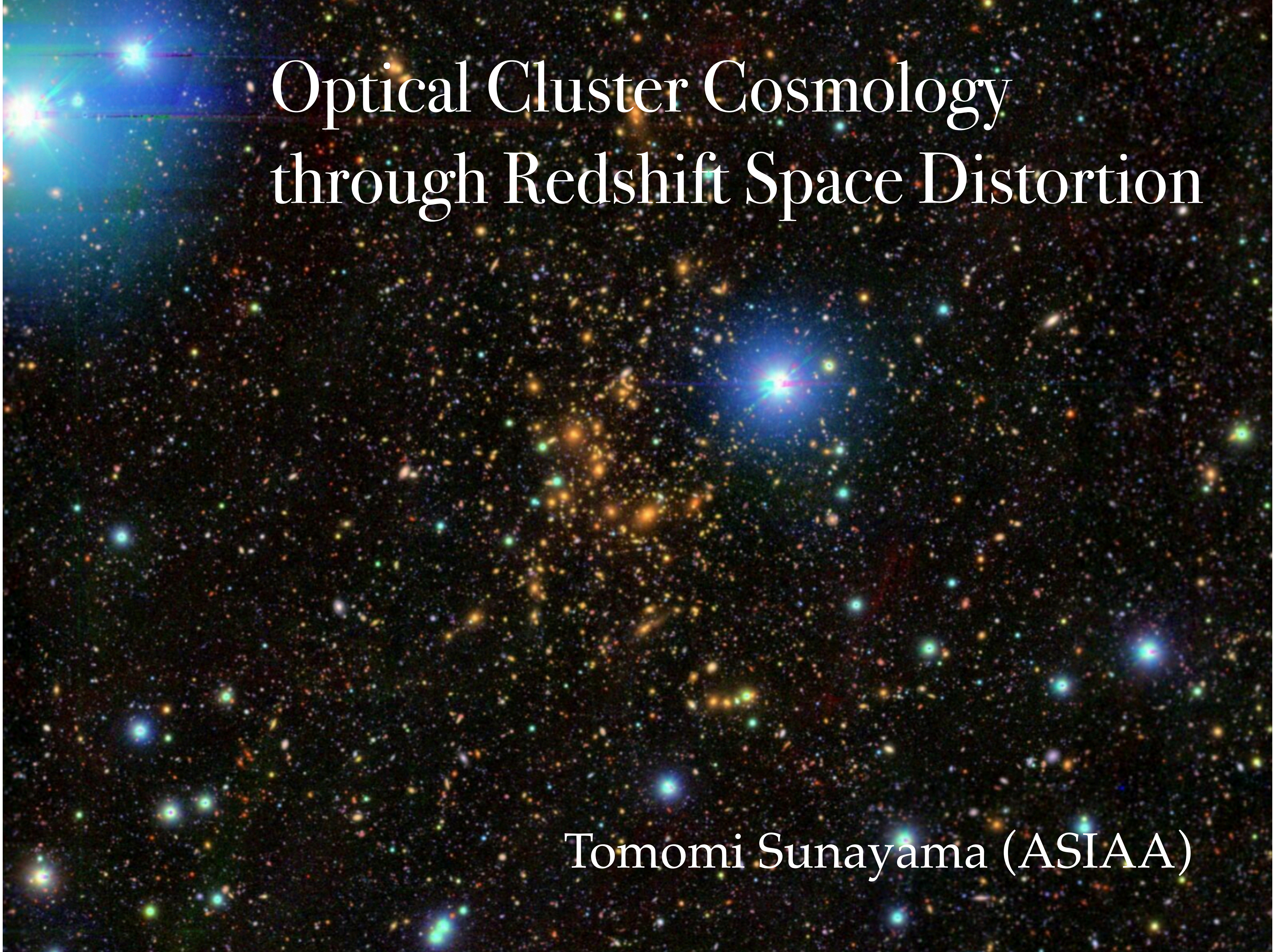
Optical Cluster Cosmology through Redshift Space Distortion

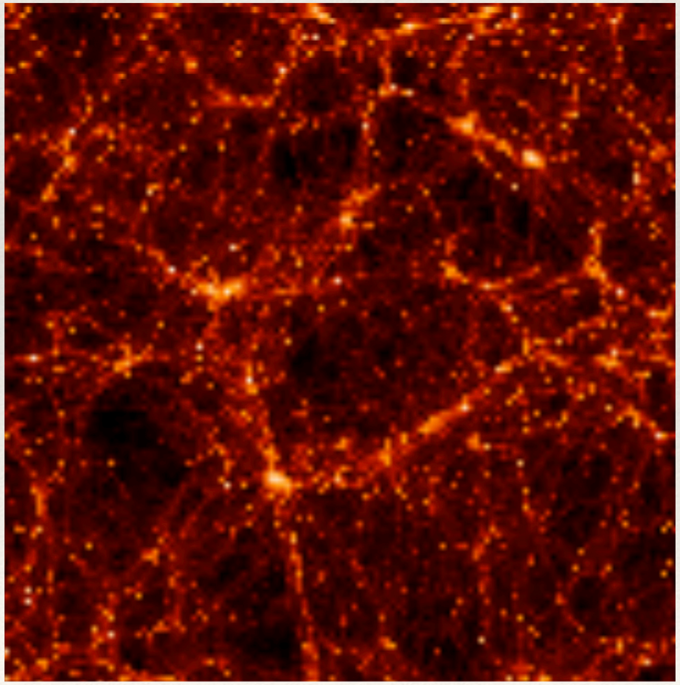


Tomomi Sunayama (ASIAA)

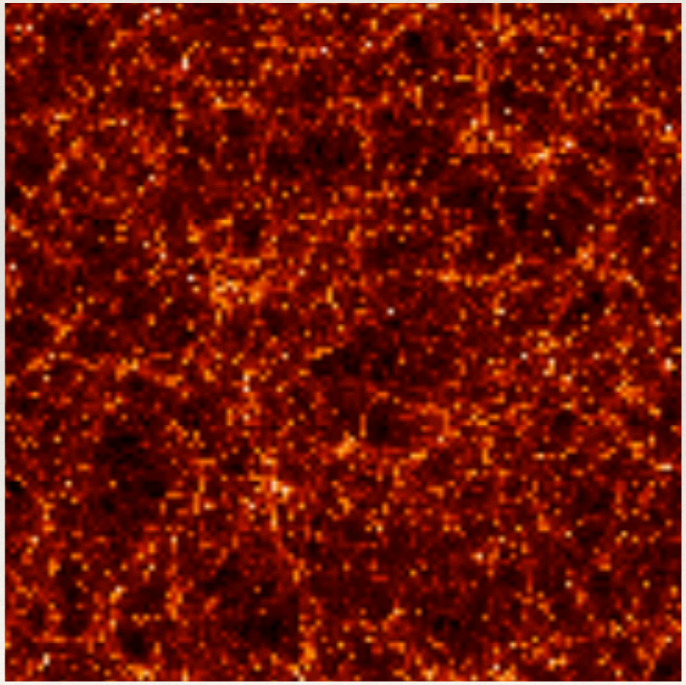
Clusters as a cosmological probe

- Count the number of clusters (as a function of halo mass)
- Tail of halo mass function (i.e., number of clusters) is sensitive to cosmological parameters

With Dark Energy



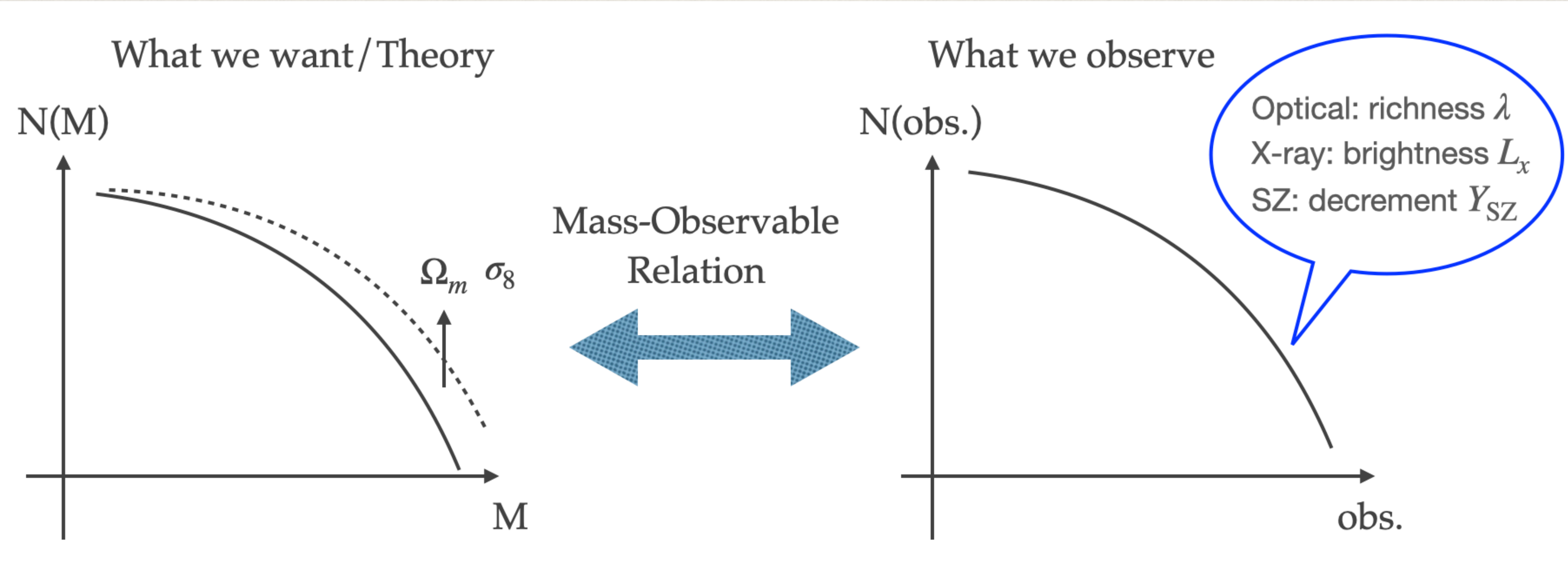
Without Dark Energy



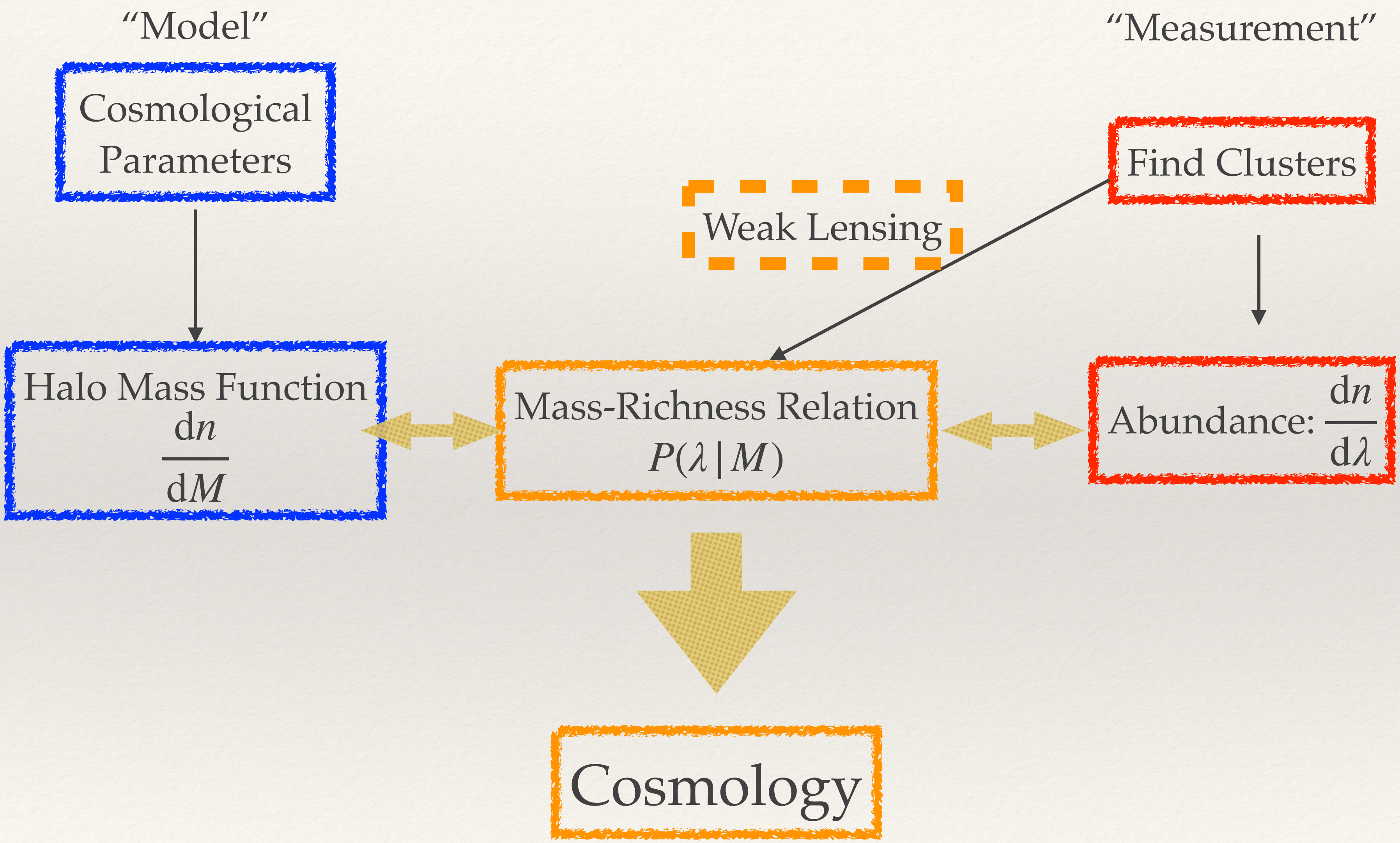
Virgo consortium

Challenge in Cluster Cosmology

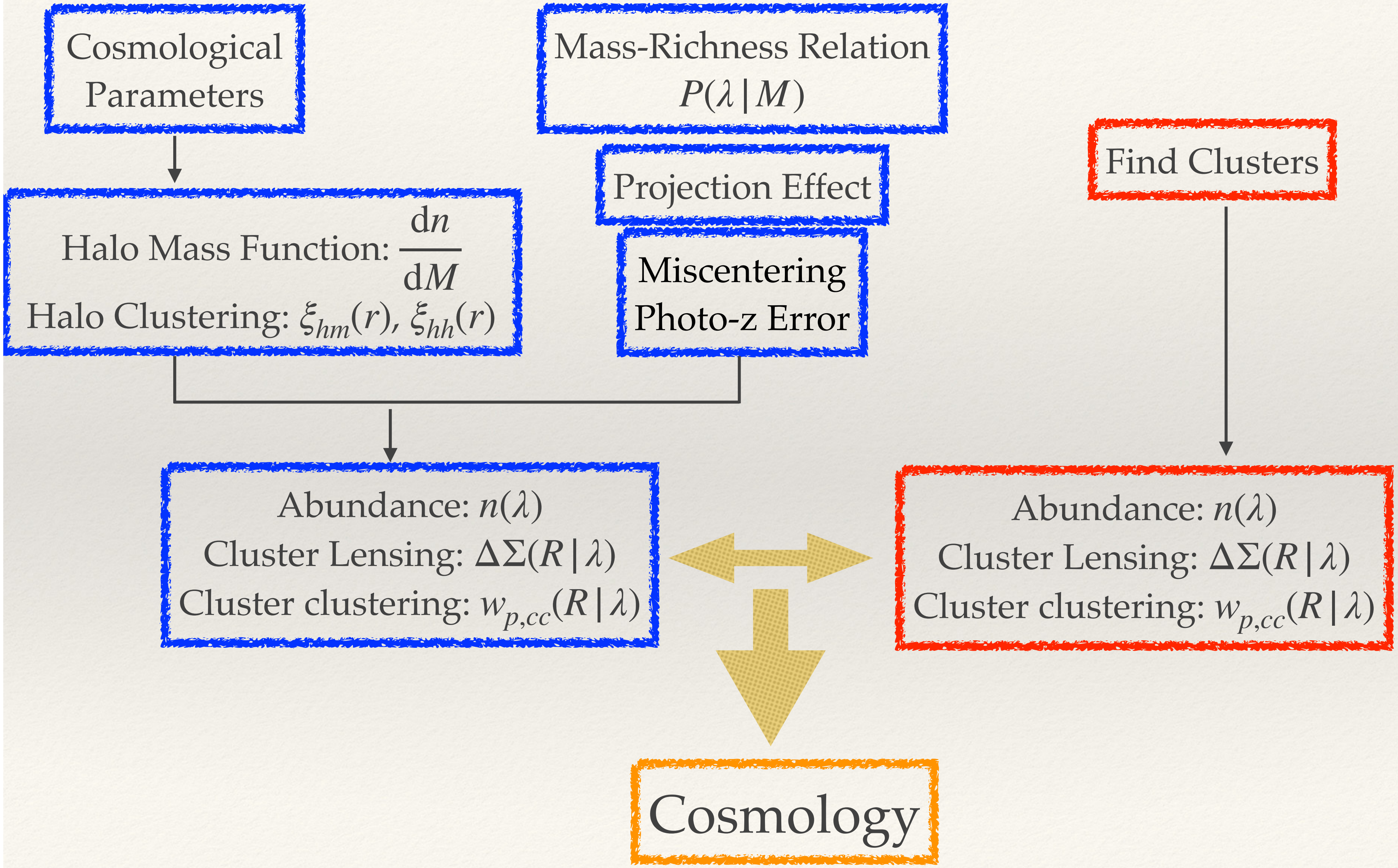
- Cosmic Visions Report (2016): " The number of massive galaxy clusters could emerge as the most powerful cosmological probe if the masses of the clusters can be accurately measured."
- Cluster mass is not a direct observable
- Optical clusters are known to be susceptible to many systematics



Recipe for Optical Cluster Cosmology



One -Step Full-Forward Modeling



One -Step Full-Forward Modeling

Cosmological Parameters

Halo Mass Function: $\frac{\mathrm{d}n}{\mathrm{d}M}$

Halo Clustering: $\xi_{hm}(r)$, $\xi_{hh}(r)$

Mass-Richness Relation $P(\lambda | M)$

Projection Effect

Miscentering

Photo-z Error

Abundance: $n(\lambda)$

Cluster Lensing: $\Delta\Sigma(R | \lambda)$

Cluster clustering: $w_{p,cc}(R | \lambda)$

Find Clusters

Abundance: $n(\lambda)$

Cluster Lensing: $\Delta\Sigma(R | \lambda)$

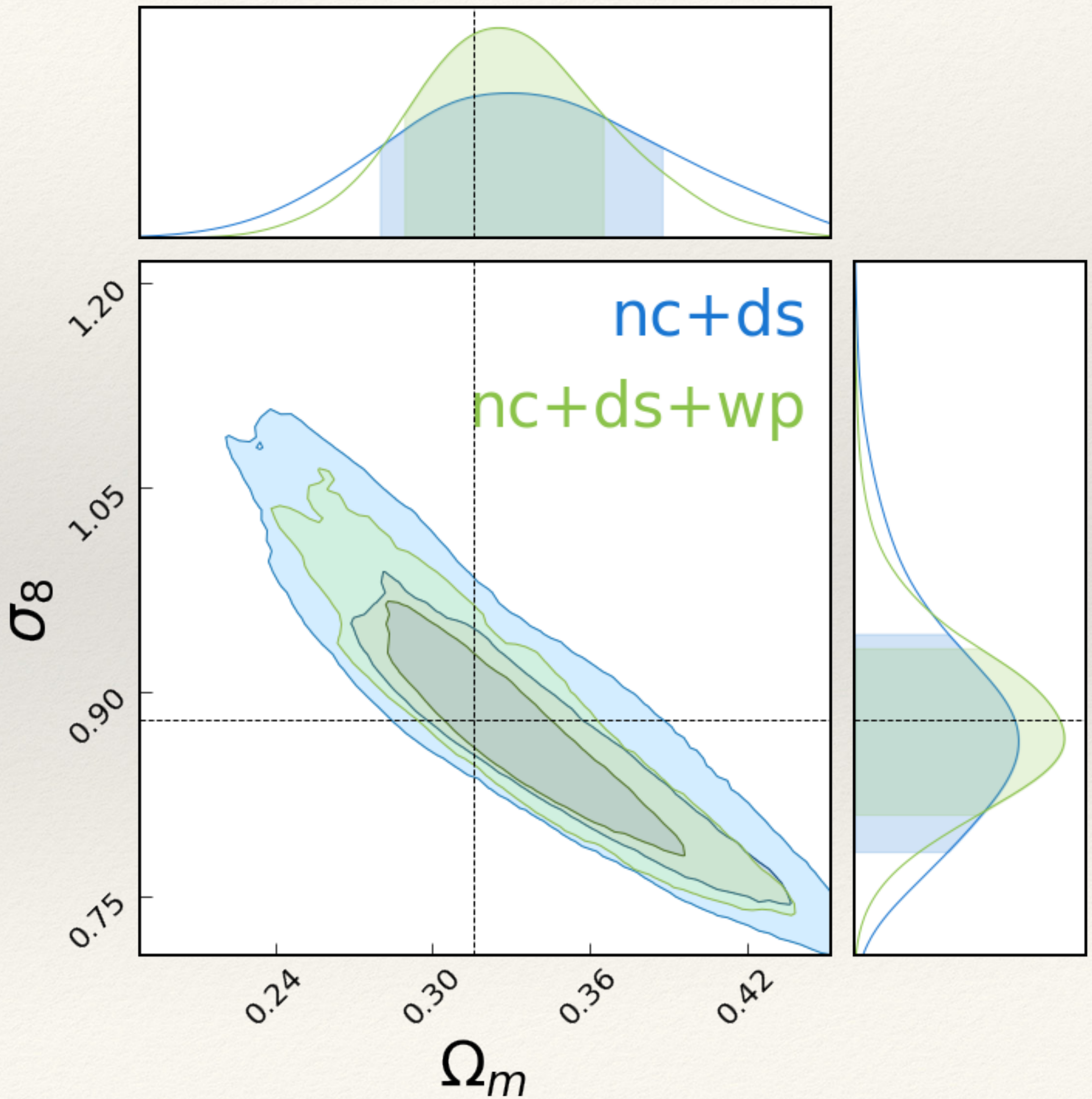
- Small scale / 1-halo $\rightarrow P(M | \lambda)$
- Large scale / 2-halo $\propto b_c(M)$

Cluster clustering: $w_{p,cc}(R | \lambda) \propto b_c^2(M)$

Cosmology

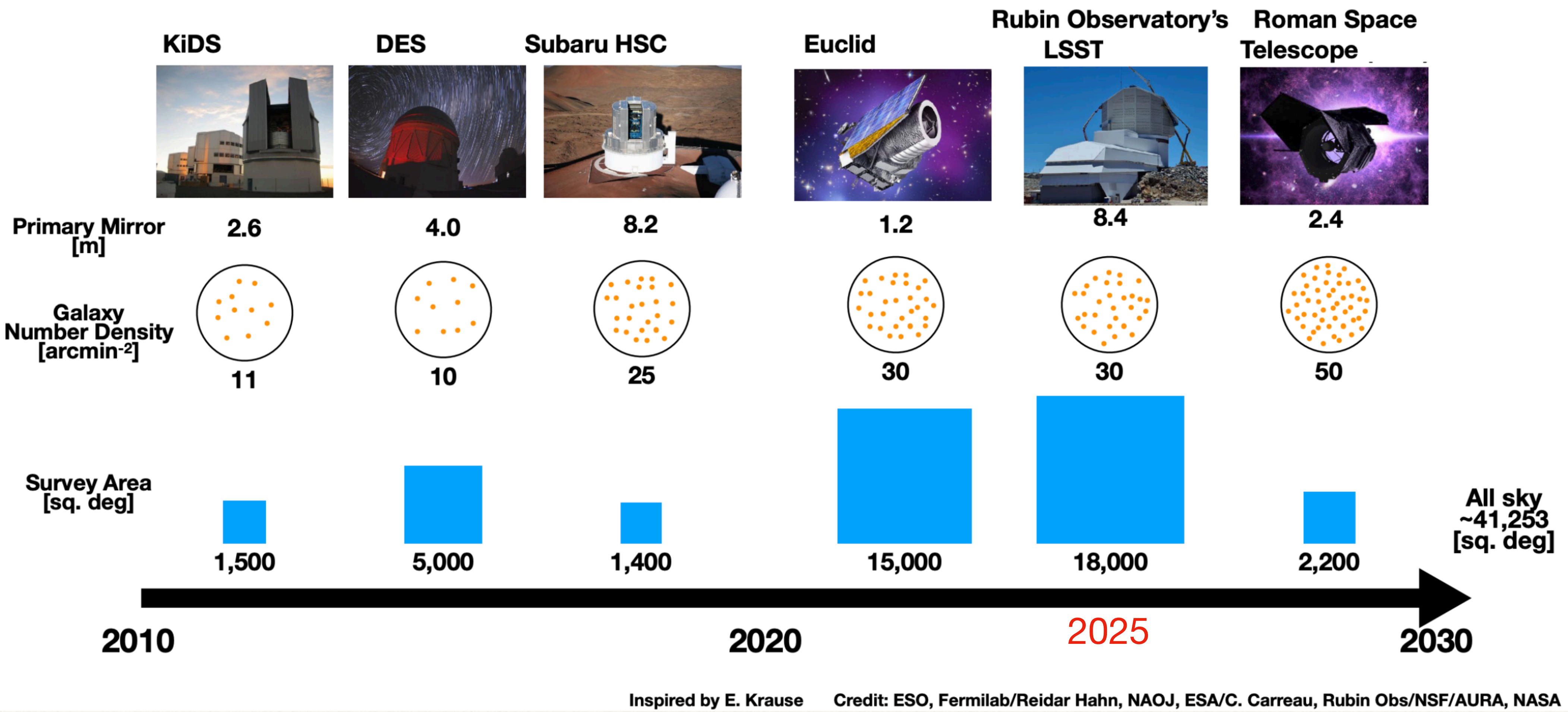
How much information does cluster clustering provide?

- Constraints on Ω_m and σ_8 are improved by 45% and 23%, respectively.



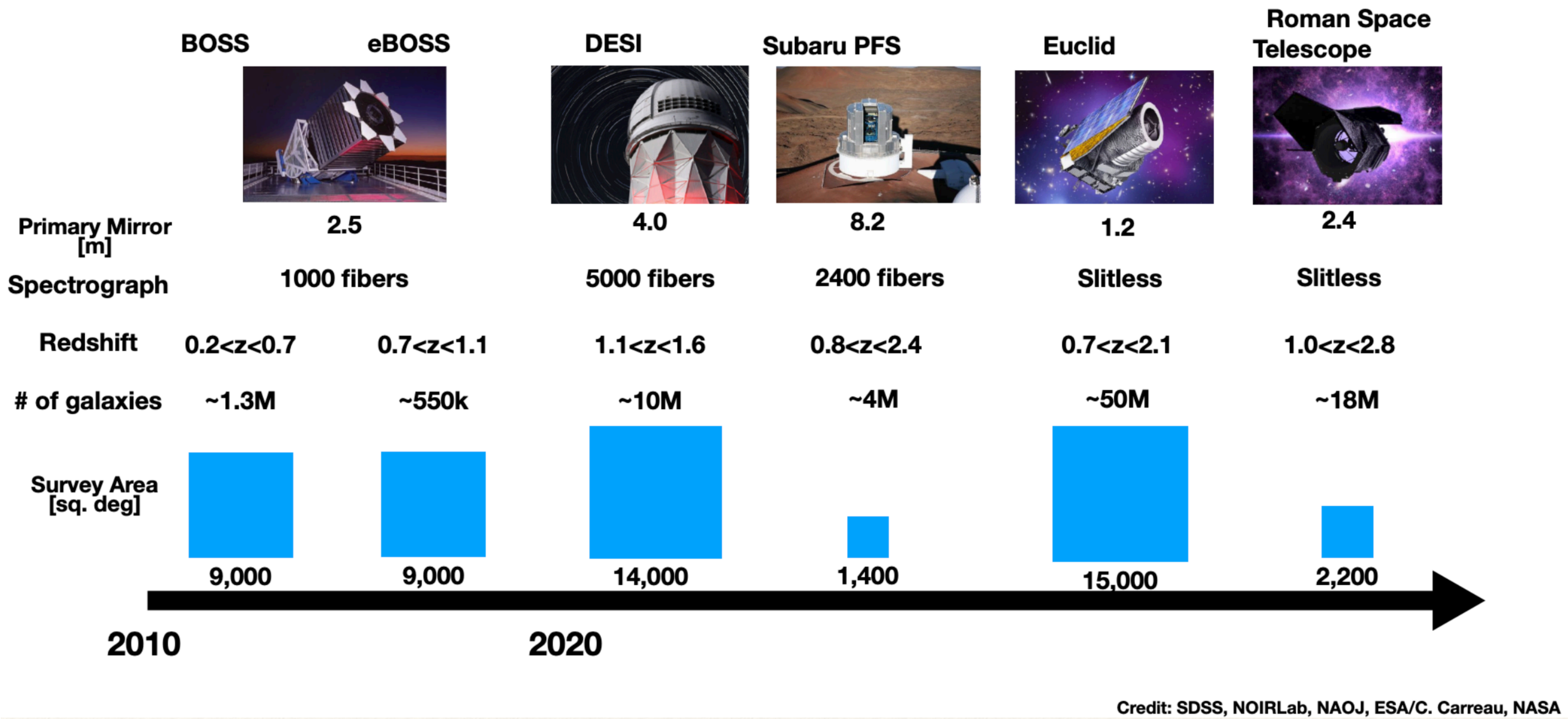
Photometric Surveys: Now and Future

10-100 million galaxies ⟷ 1-20 billion galaxies



Arai et al (incl. TS),2023

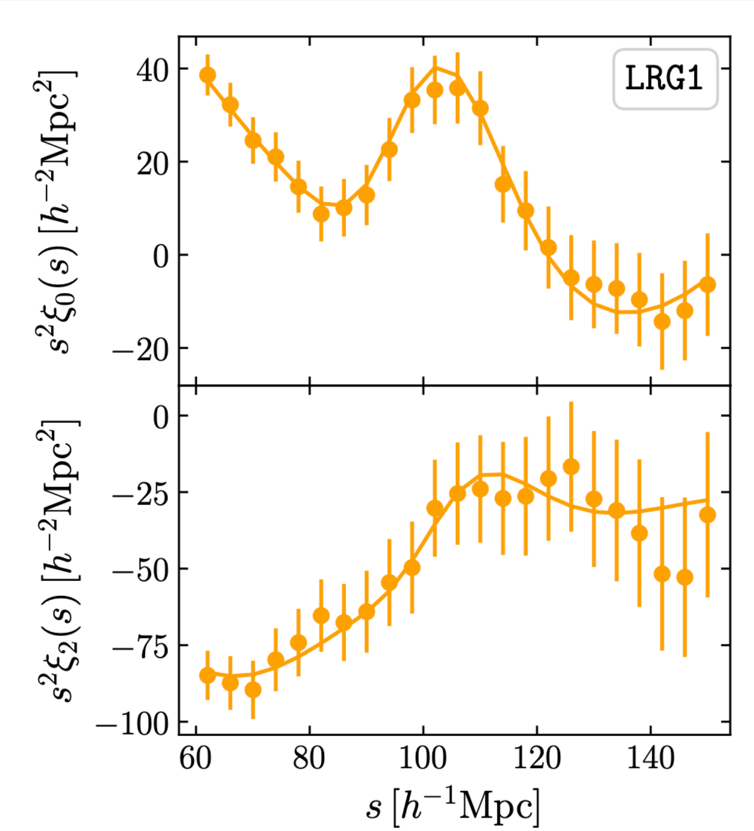
Roadmap of Spectroscopic Galaxy Surveys



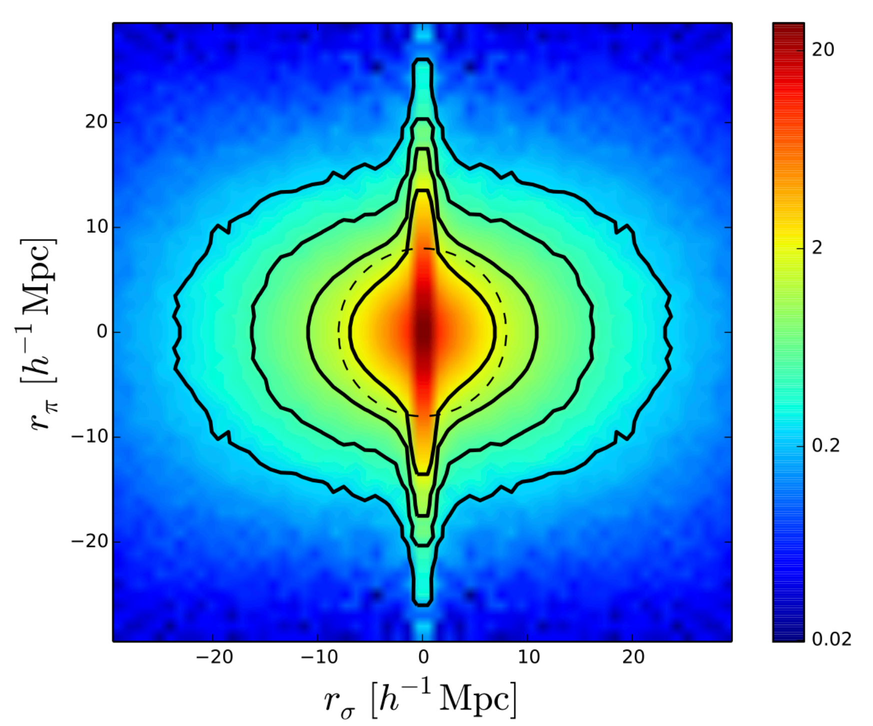
Arai et al (incl. TS),2023

What information can 3D clustering provide?

- Baryon Acoustic Oscillations (BAOs)
- Redshift-Space Distortion (RSD)



DESI Collaboration 2025



Reid+2014

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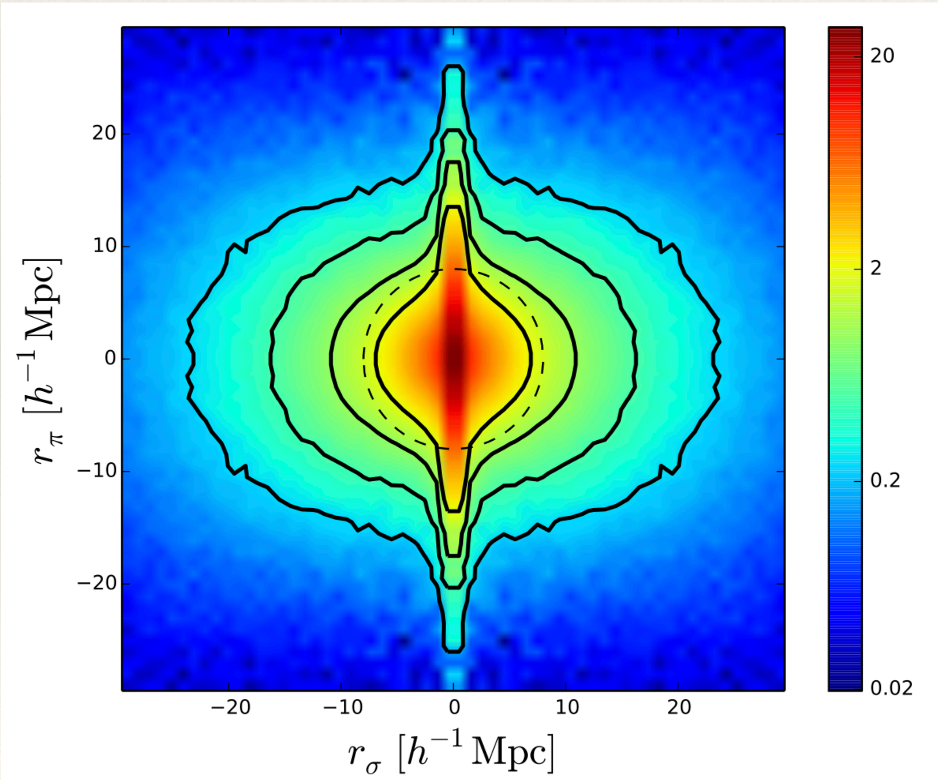


Reid+2014

$$cz = H_0 r + v_{\rm pec}$$

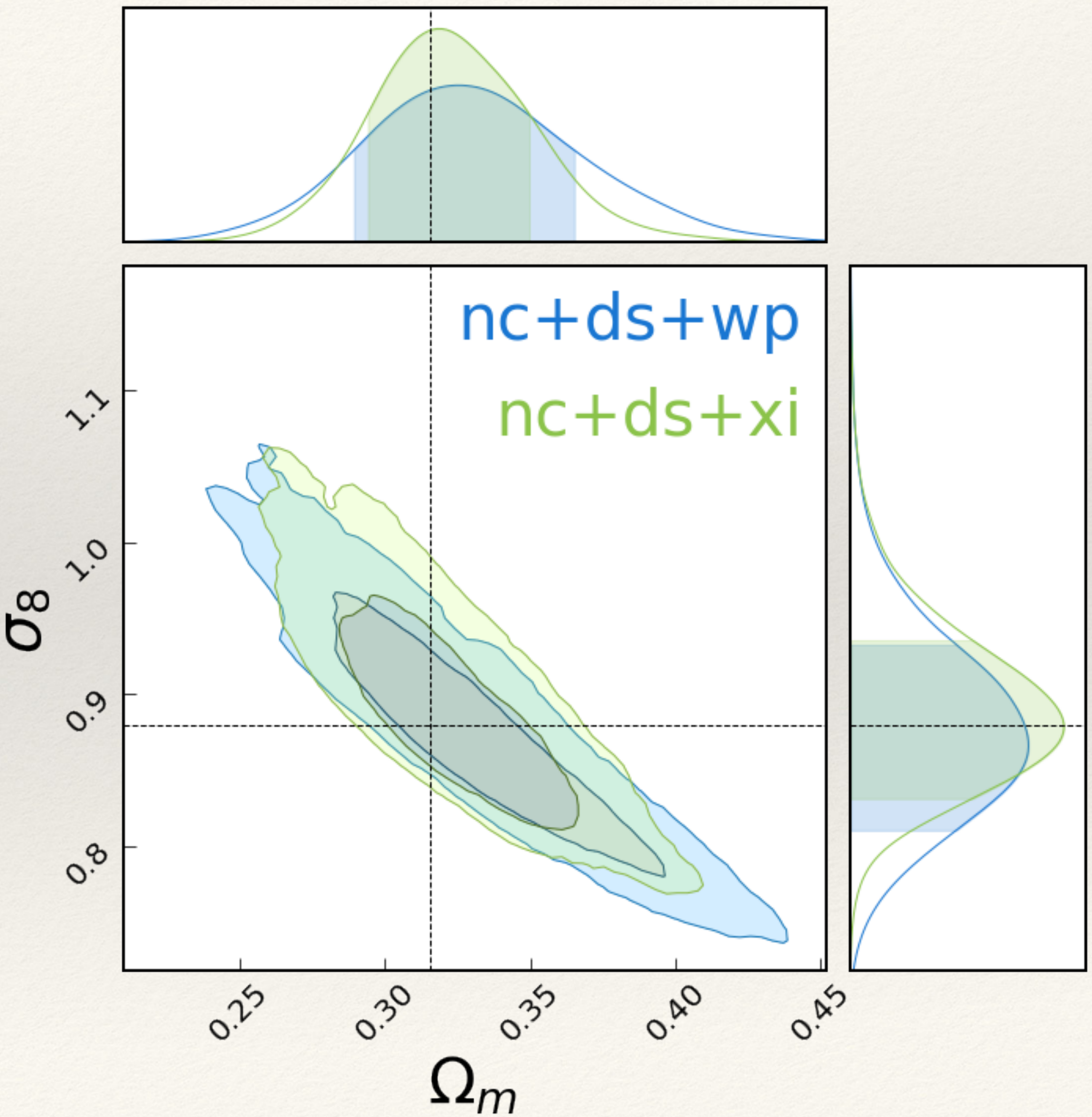
Redshift "What we measure" | Expansion of the Universe | Motion of Galaxies

$$|v_{\rm pec}| \sim \frac{d\sigma_8}{d\ln a} = f\sigma_8 \approx \Omega_m^\gamma \sigma_8$$

$$\delta_g^{(s)}(k,\mu) = (b + f\mu^2)\delta_m^{(r)}(k)$$

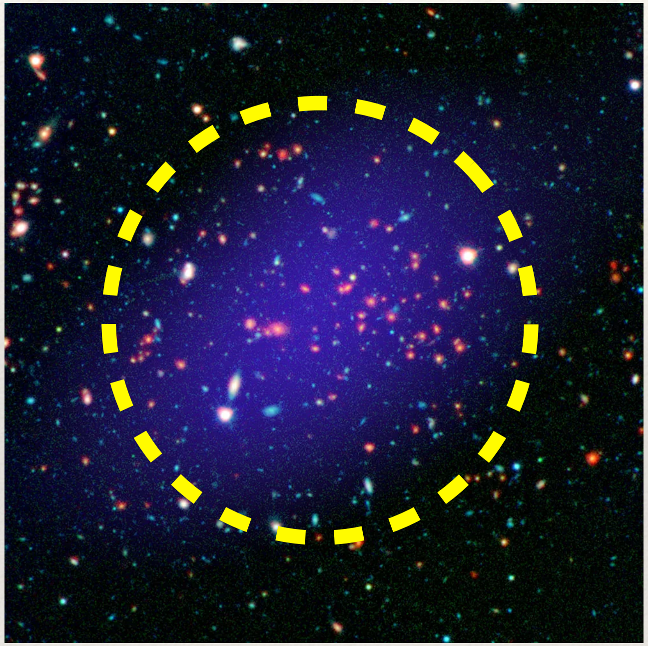
RSD can further improve cosmological constraints

- Constraints on Ω_m and σ_8 are improved by 33% and 15% respectively.
- RSD alone can improve the precisions of Ω_m and σ_8 by 60% and 40% respectively.

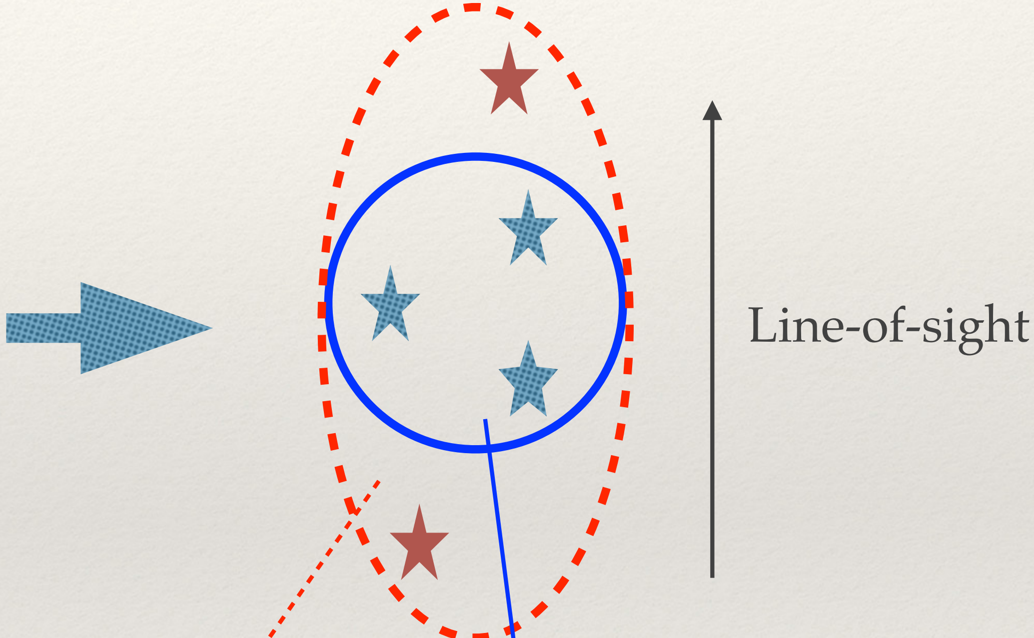


How does projection effects bias the result?

- Misidentification of member galaxies along the line-of-sight



WISE/Spitzer

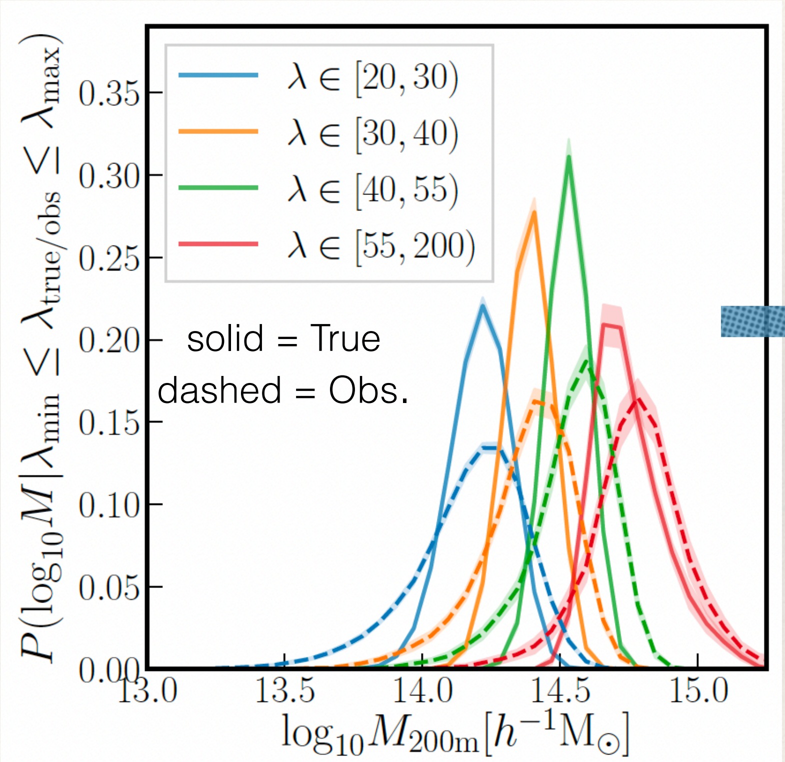


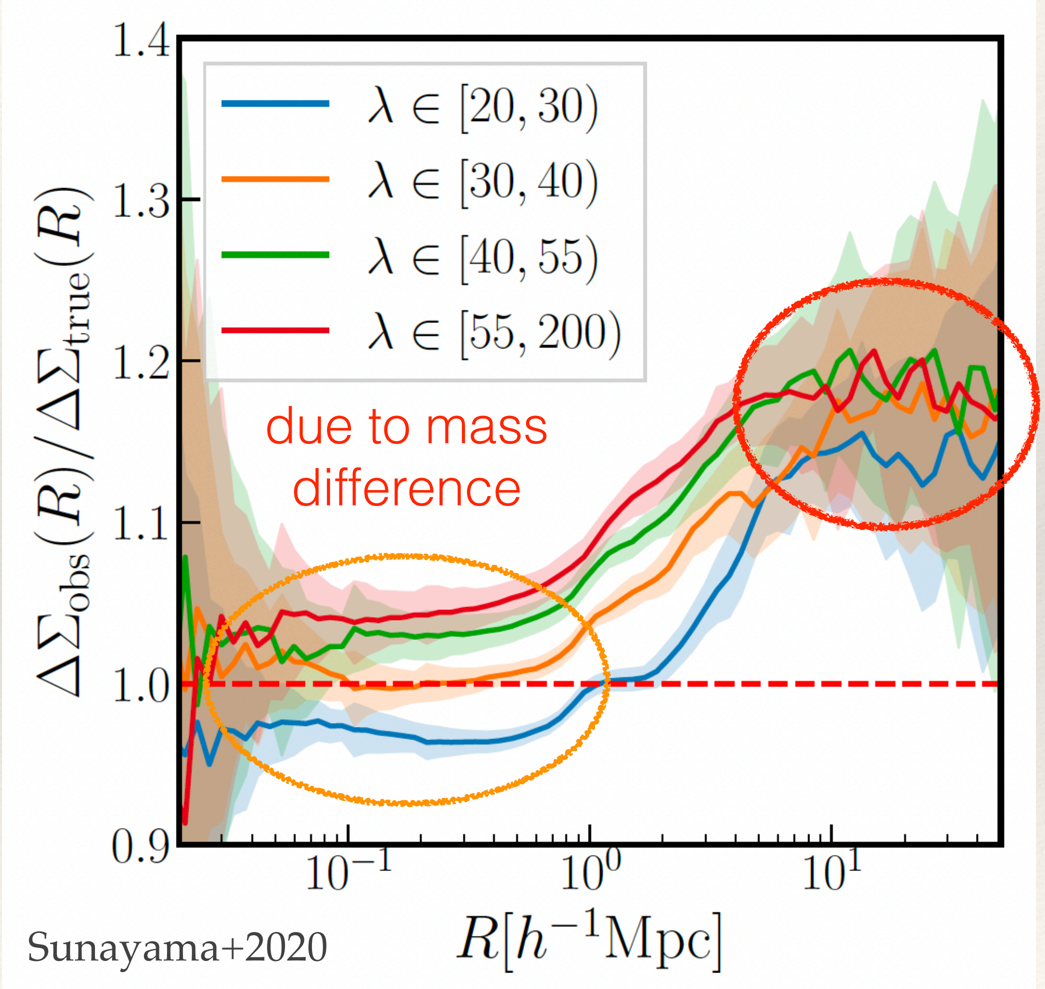
$$P(\lambda^{\rm ob}|M,z) = \int_0^\infty {\rm d}\lambda^{\rm true}\ P(\lambda^{\rm ob}|\lambda^{\rm true},z)P(\lambda^{\rm true}|M,z)\,,$$

The projection effect alters the mass-richness relation!

Projection effects beyond Mass-Richness Relation

- The boost on two-halo term cannot be explained by mass difference!

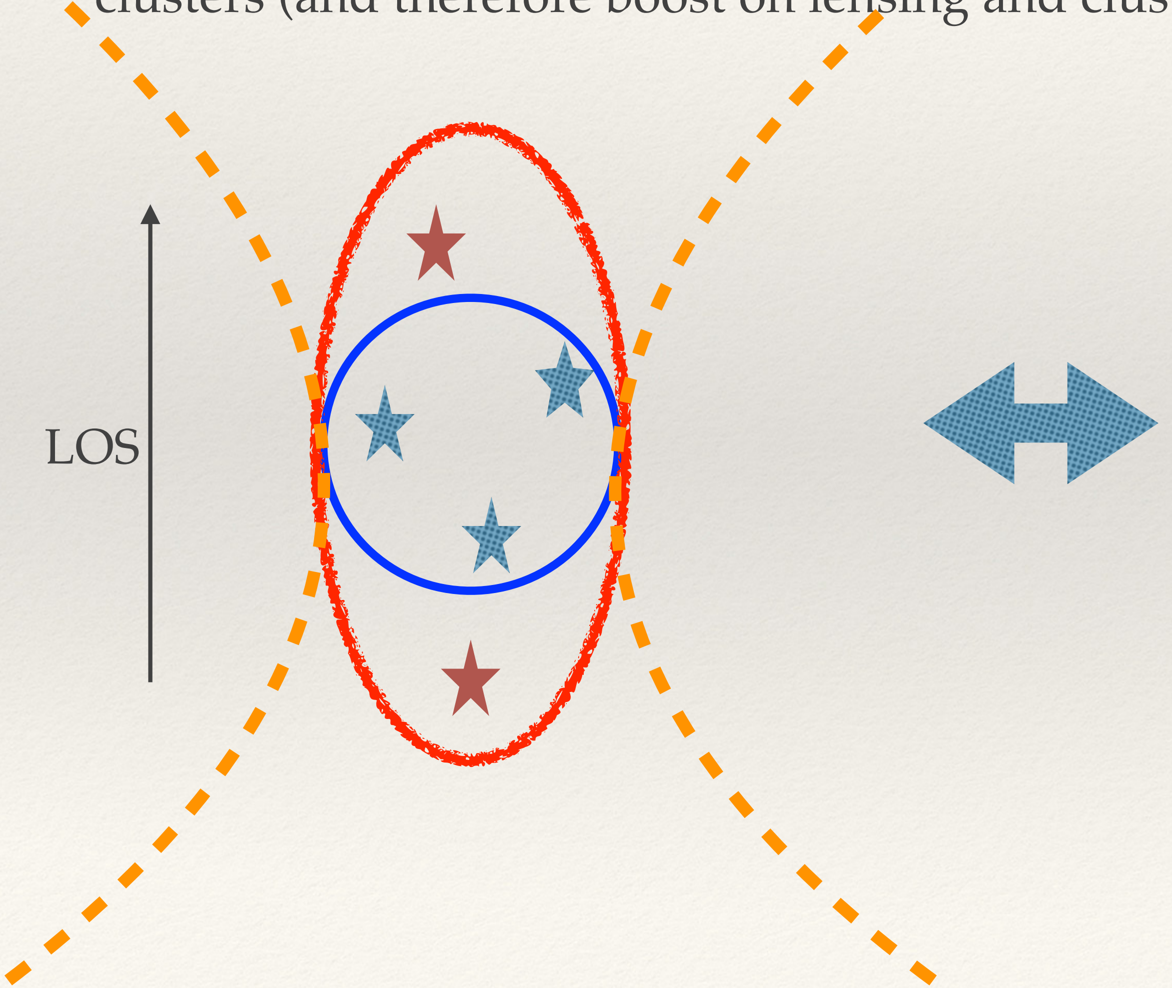


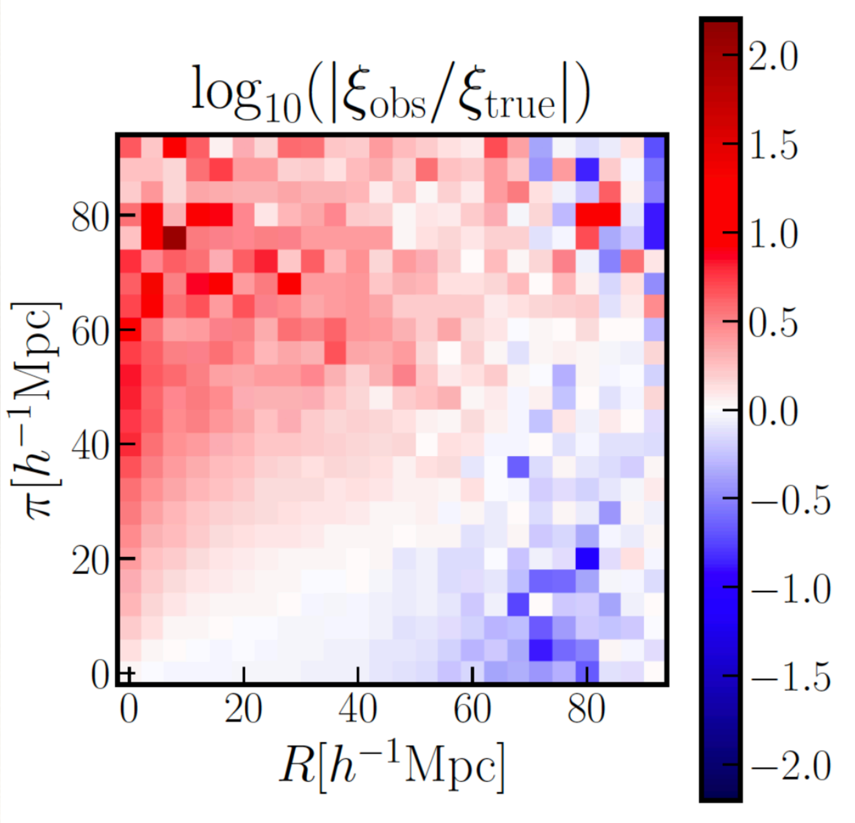


What is the cause of this boost on large scales?

Distribution of clusters is anisotropic

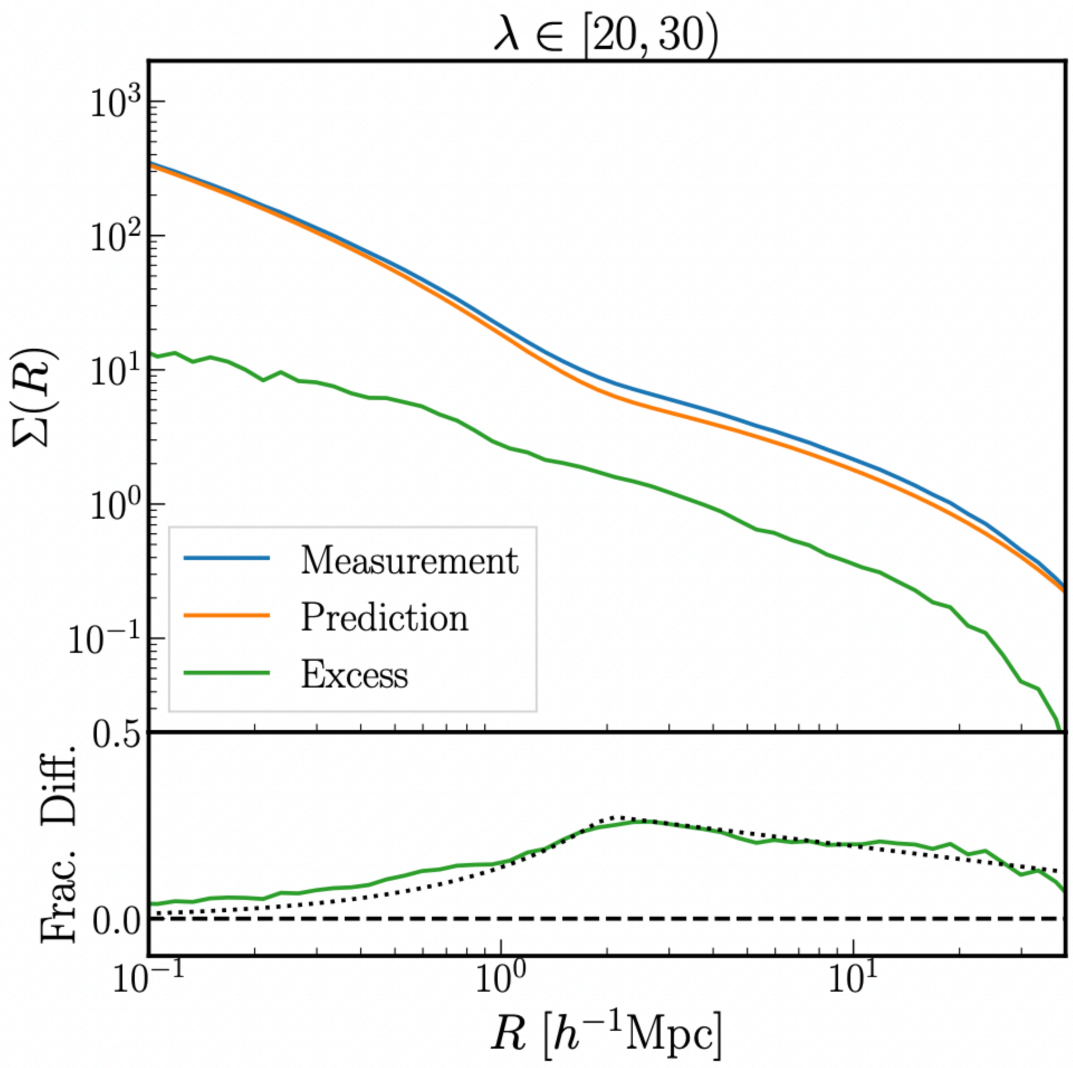
- Cluster finder preferentially identify clusters on aligned filaments along LOS as clusters
- Preferential selection of aligned structure is the cause of the anisotropic distribution of clusters (and therefore boost on lensing and clustering amplitudes)





Sunayama+2020

Modeling Projection Effects



Model the excess mass as a multiplicative factor

$$\Pi(R) = \begin{cases} \Pi_0 (R/R_0) & \text{for } R \le R_0, \\ \Pi_0 + c \ln(R/R_0) & \text{for } R > R_0. \end{cases}$$

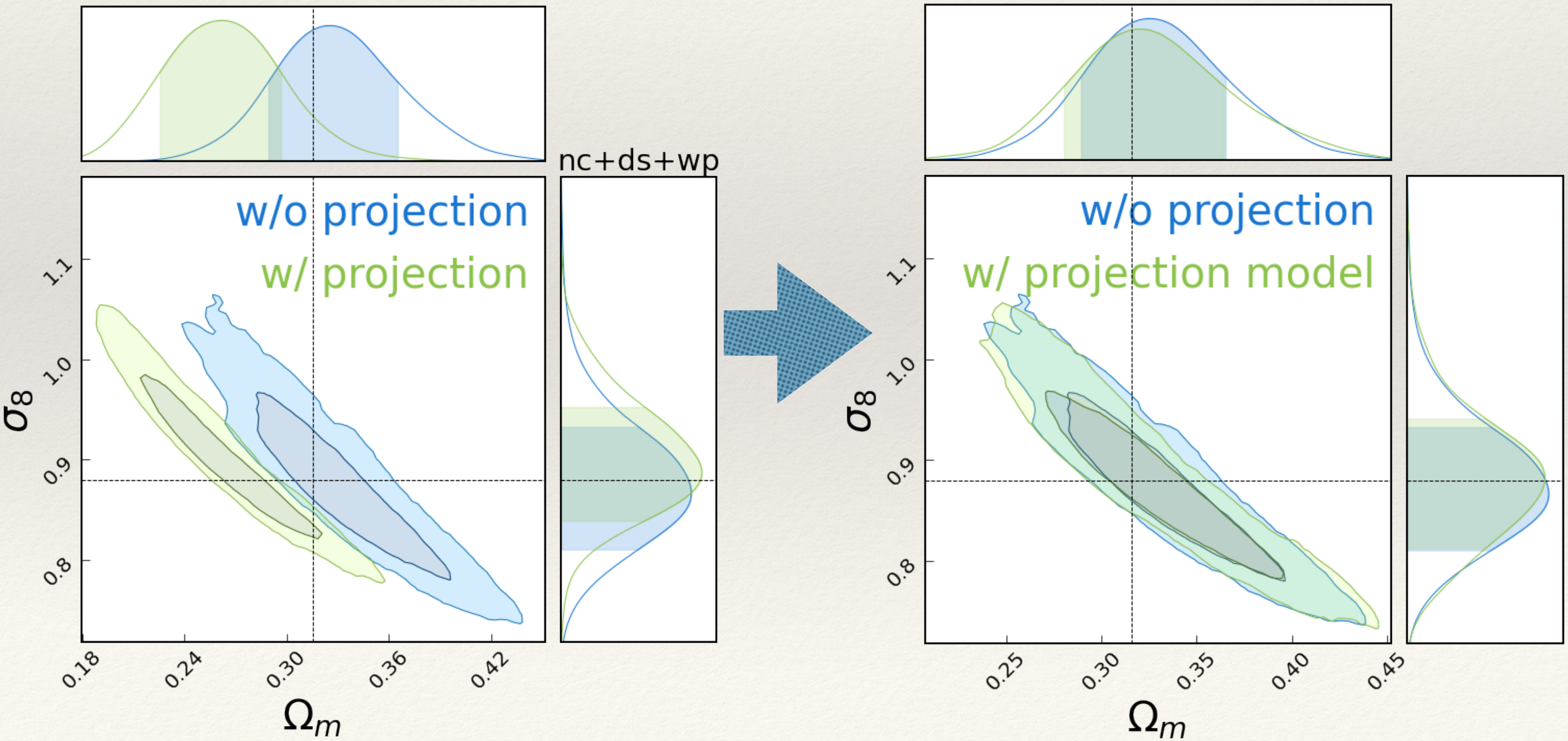
And treat it as effective biases

$$\Sigma(R) = \Pi(R)\Sigma^{\mathrm{iso}}(R),$$
$$w_{\mathrm{p}}(R) = \Pi^2(R) w_{\mathrm{p}}^{\mathrm{iso}}(R).$$

Park,TS+2022

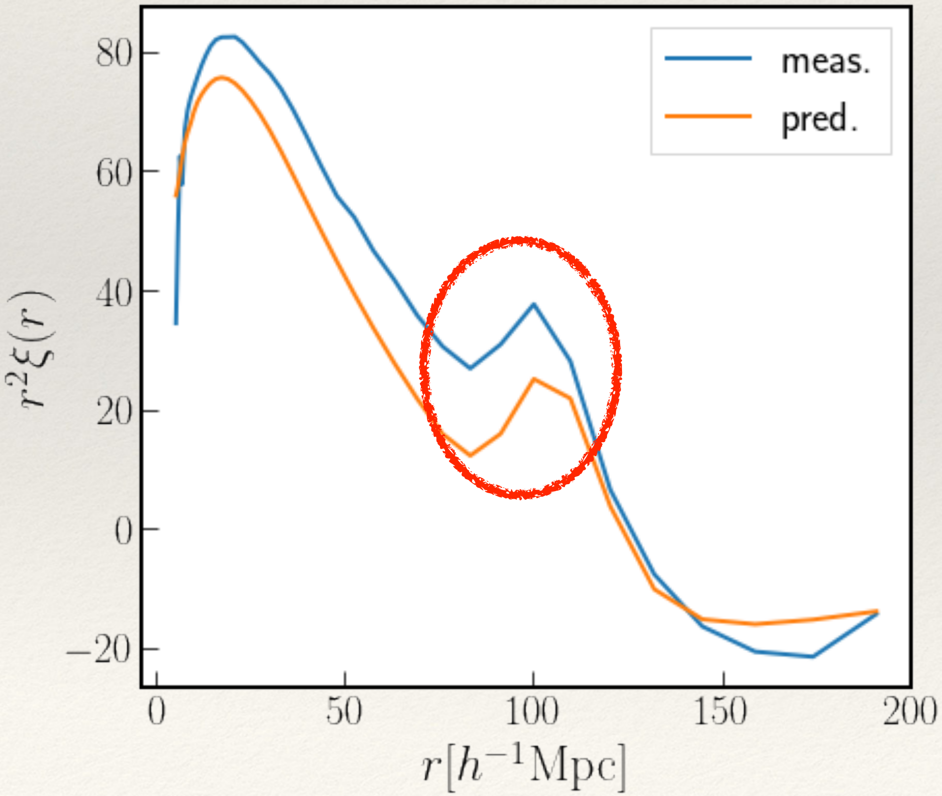
Projection effects can be modeled

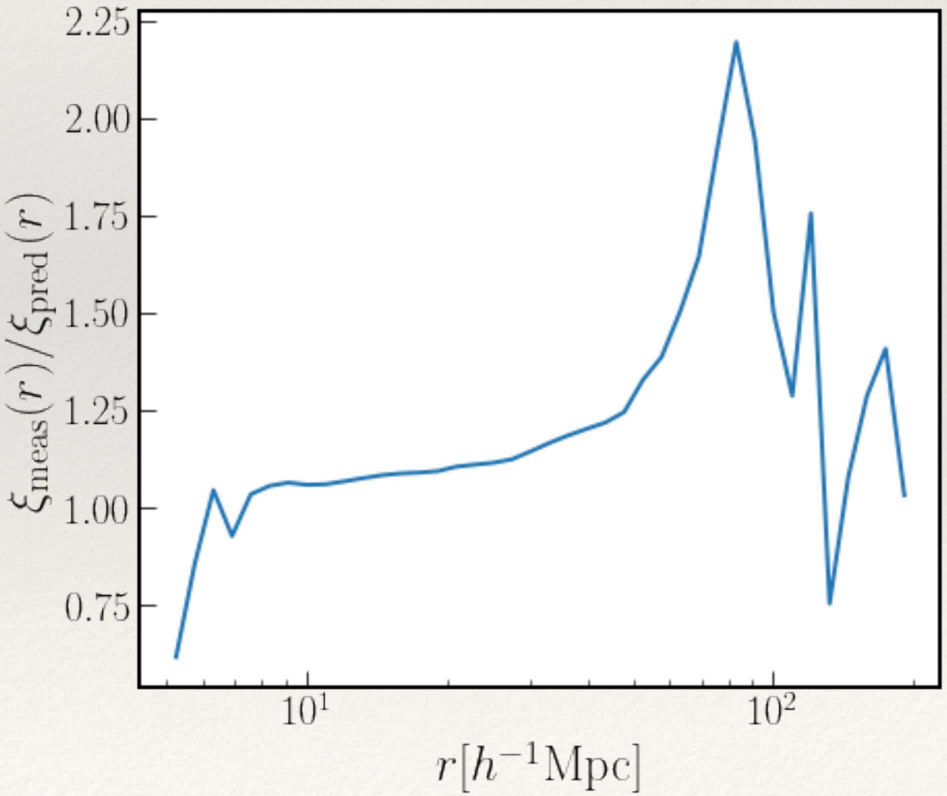
- The projection effect model can correct the cosmology constraints for the case of lensing and projected correlation functions.



Projection effects on 3D clustering

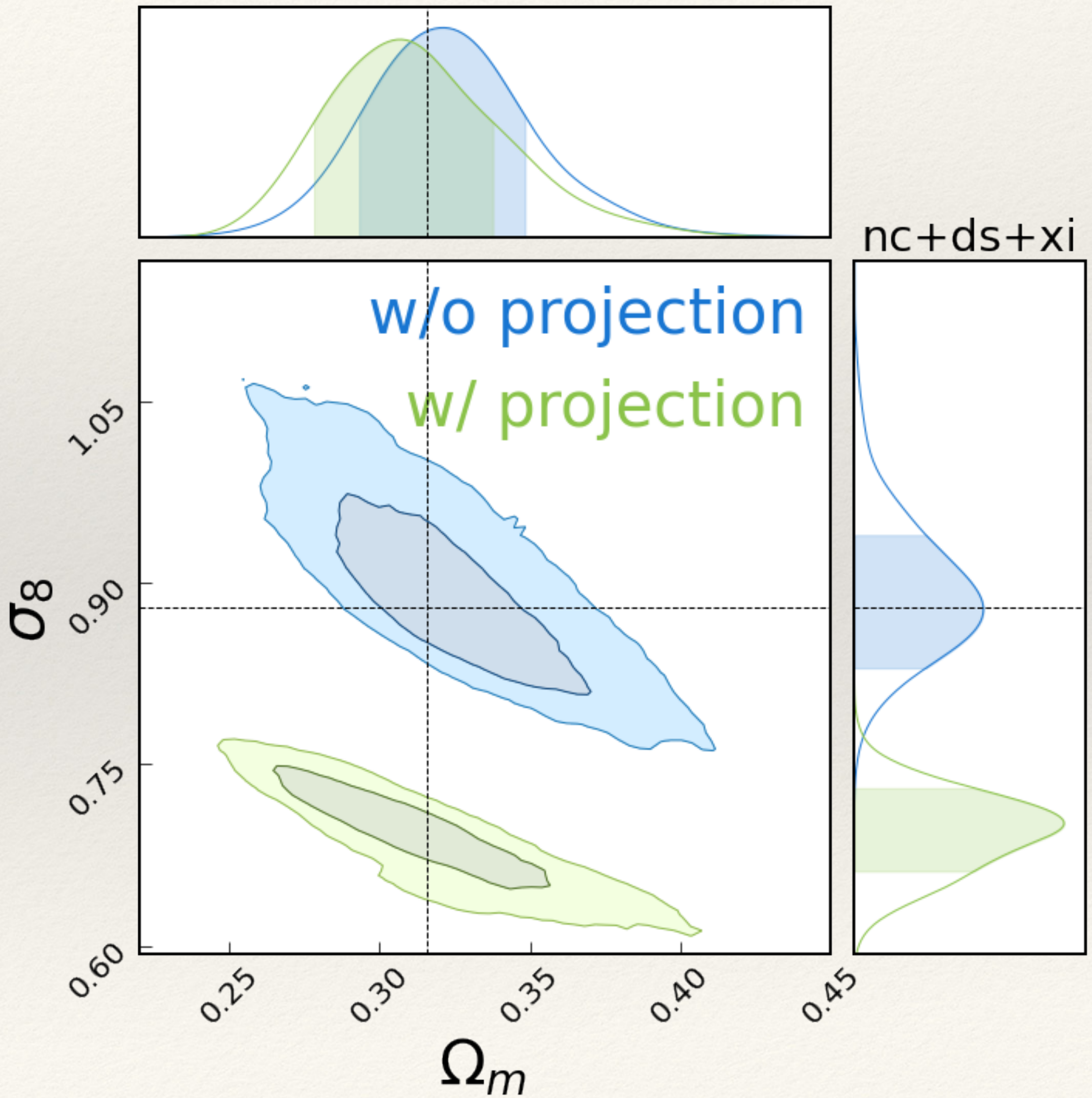
- Projection effects will alter the 3D correlation functions in a more complicated manner…





Projection effects can bias the constraints in a different way

- Using 3D clustering in the presence of projection effects can bias cosmological constraints, in particular σ_8!



Summary/Future Work

- Combining cluster clustering to cluster abundance and lensing can improve the constraints on Ω_m and σ_8 by 45% and 23%
- Additional information from RSD can improve Ω_m and σ_8 by 33% and 15% respectively
- Projection effects can bias the constraints on Ω_m and σ_8