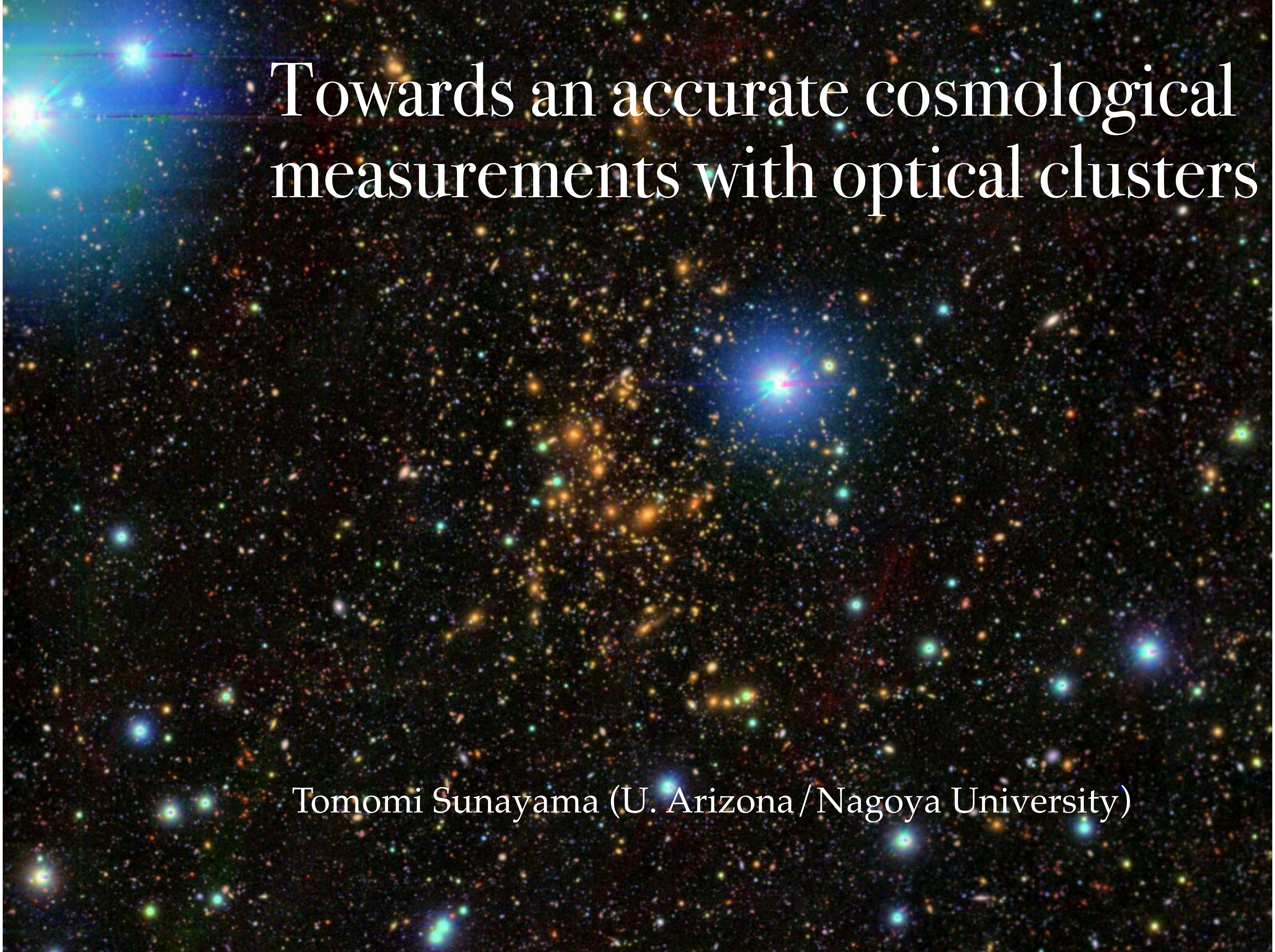
Towards an accurate cosmological measurements with optical clusters

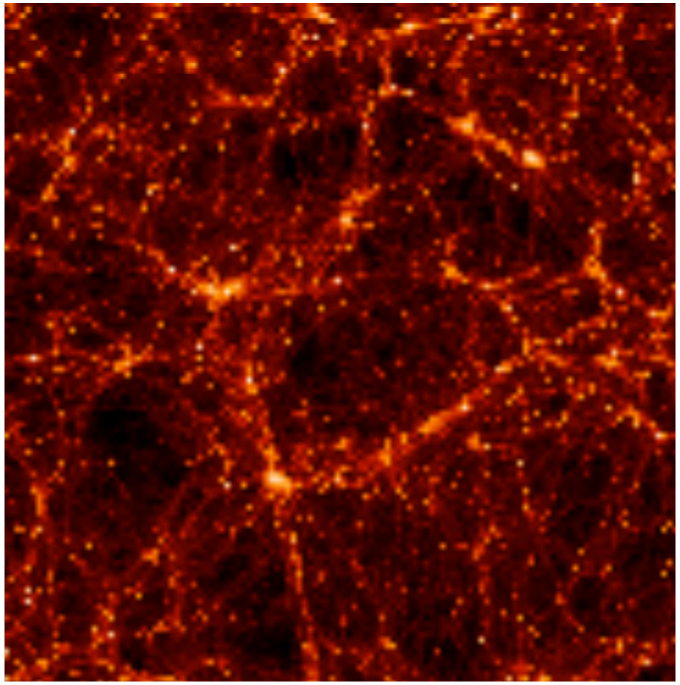


Tomomi Sunayama (U. Arizona/Nagoya University)

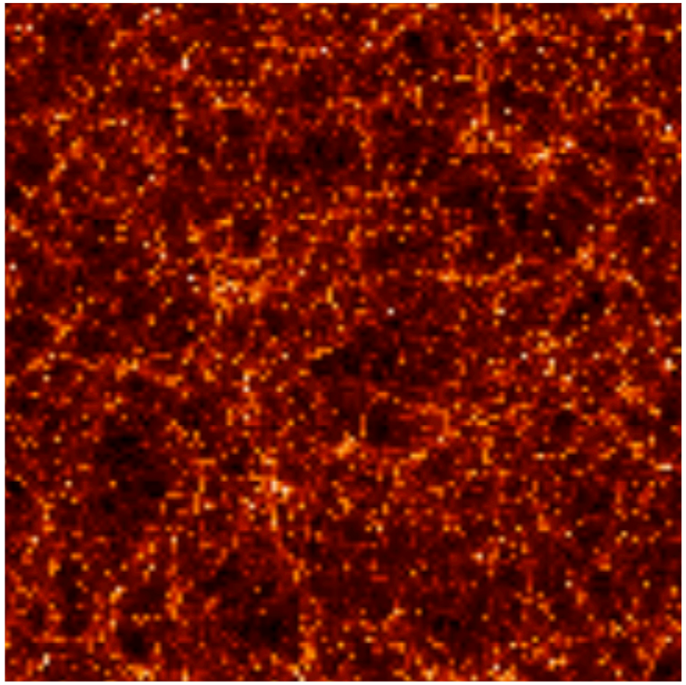
Clusters as a cosmological probe

- 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



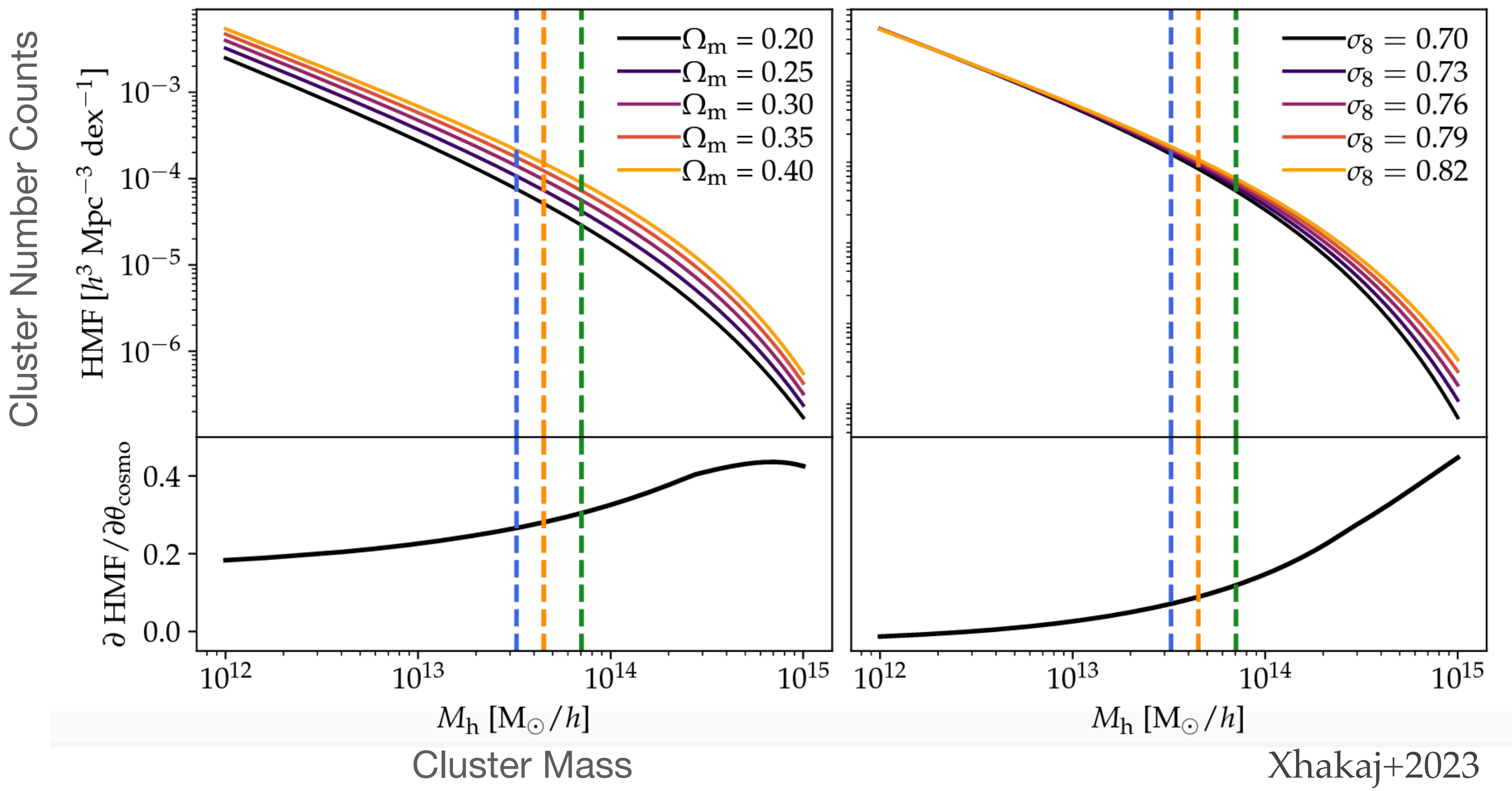
Without Dark Energy



Virgo consortium

Clusters as a cosmological probe

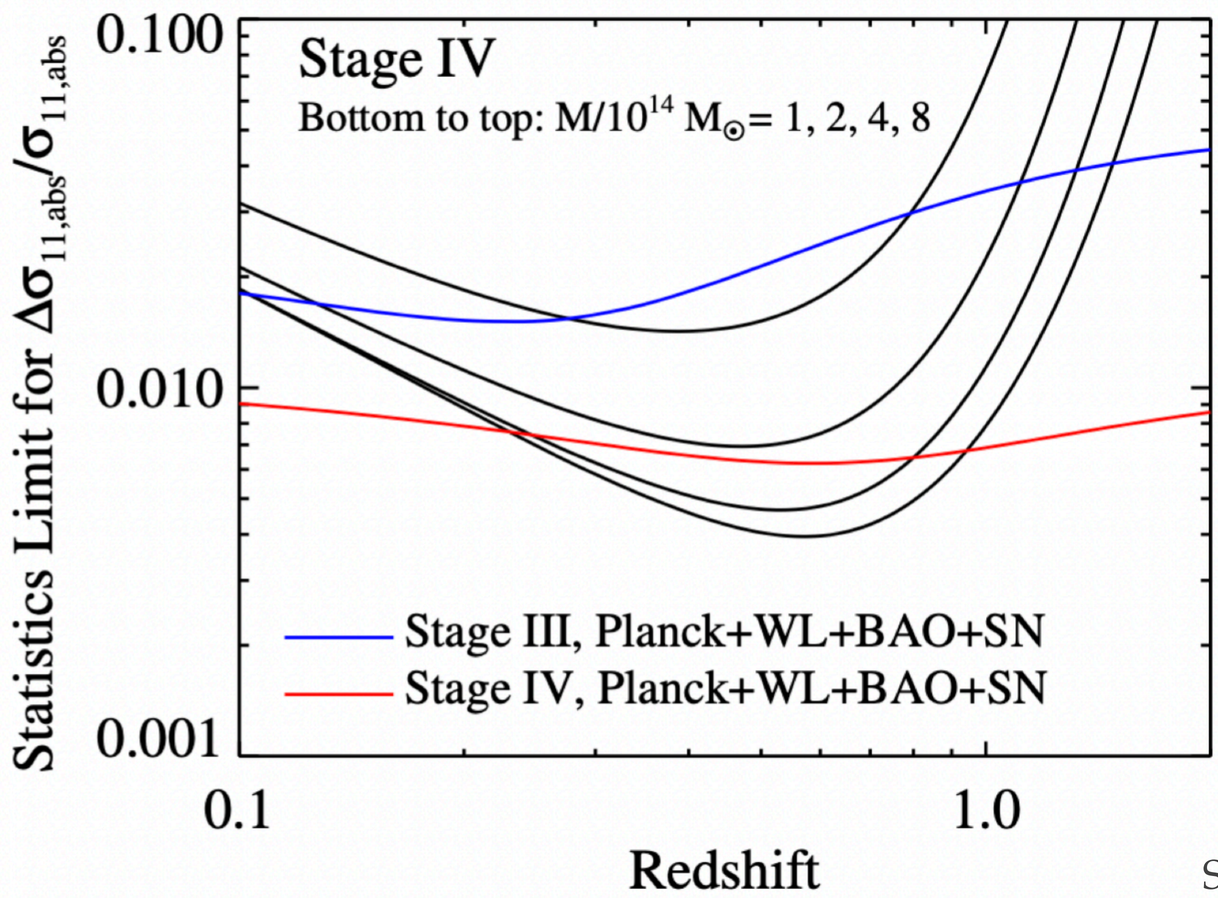
- Background cosmology (i.e., Ω_m) impacts the number density
- Clusters form from the highest density peaks in the initial density field
- σ_8 (="clumpiness"): higher σ_8 → more high-density peaks → more massive clusters



Xhakaj+2023

Clusters can be powerful…

- Cosmic Visions Report (2016): " The number of massive galaxy clusters could emerge as the most powerful cosmological probe…"

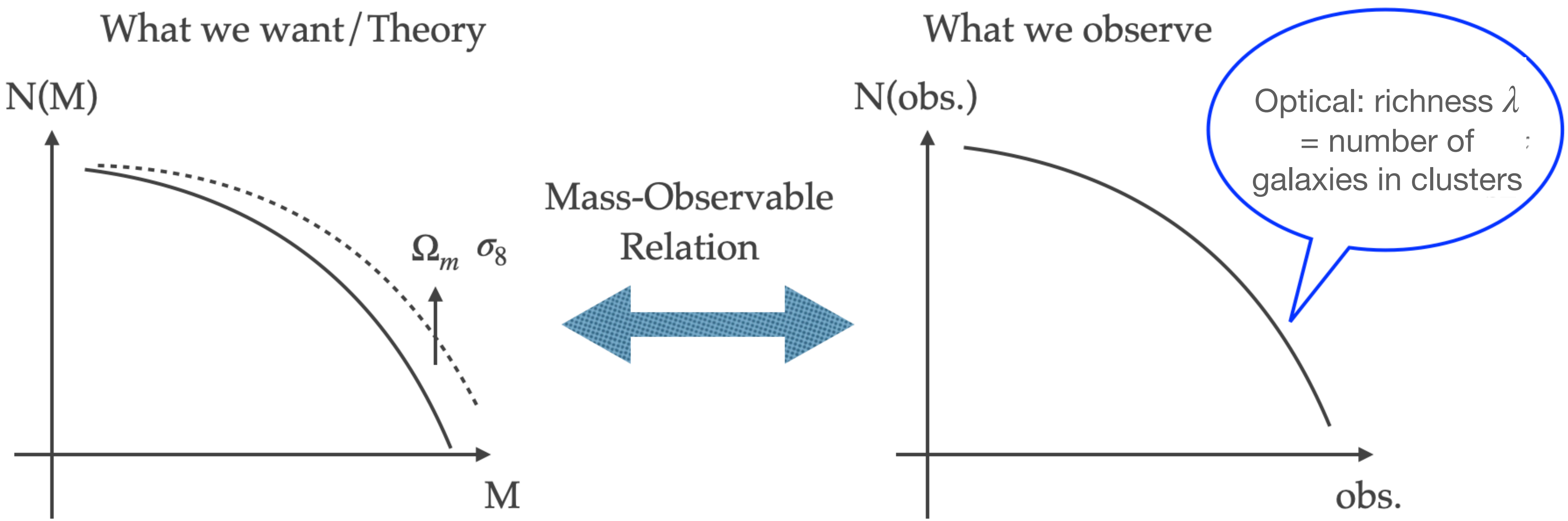


Optical clusters can be identified up to z~1 with the minimum mass of $10^{14}M_\odot/h$

Snowmass2013; Huterer et al.

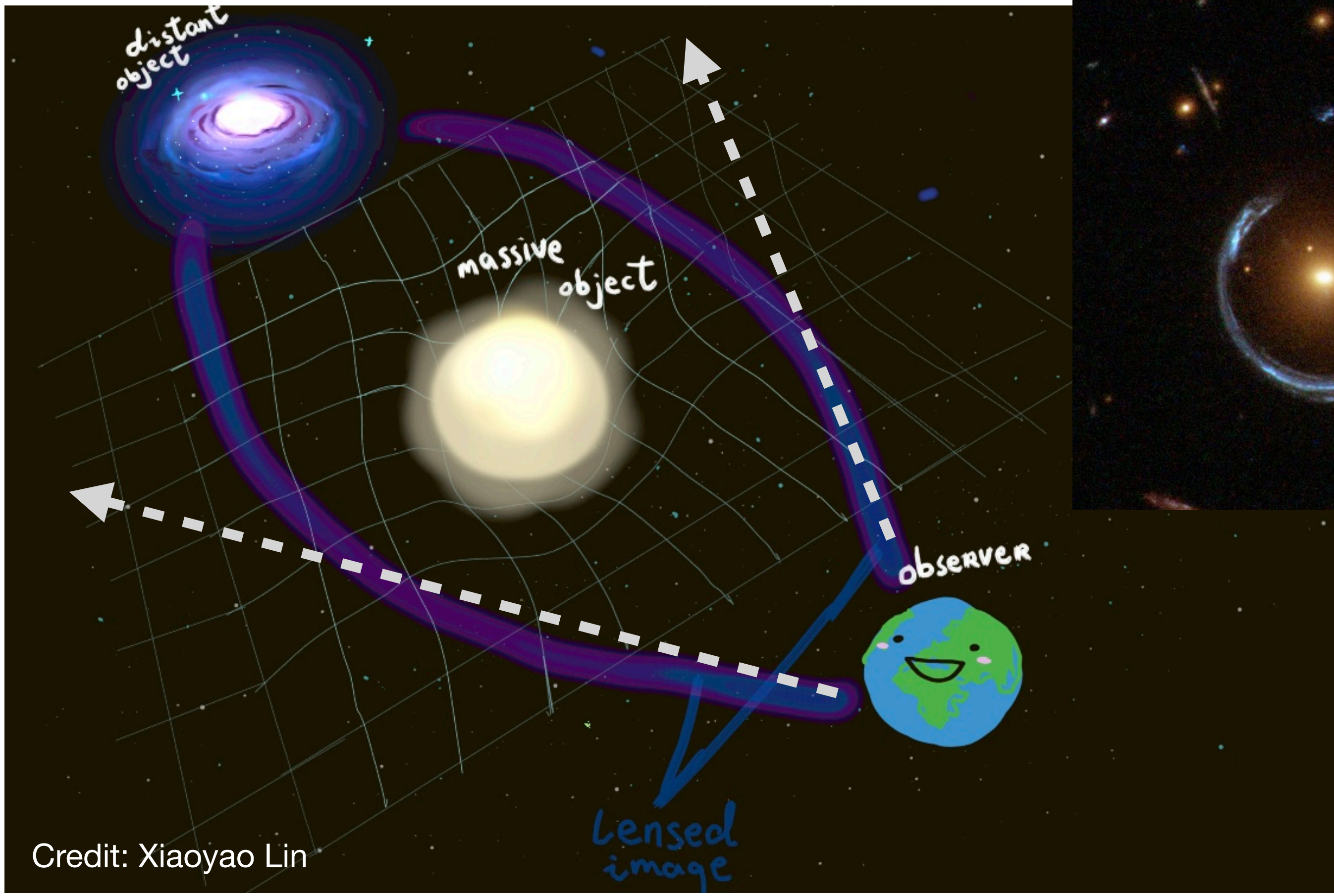
Challenge in Cluster Cosmology

- 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

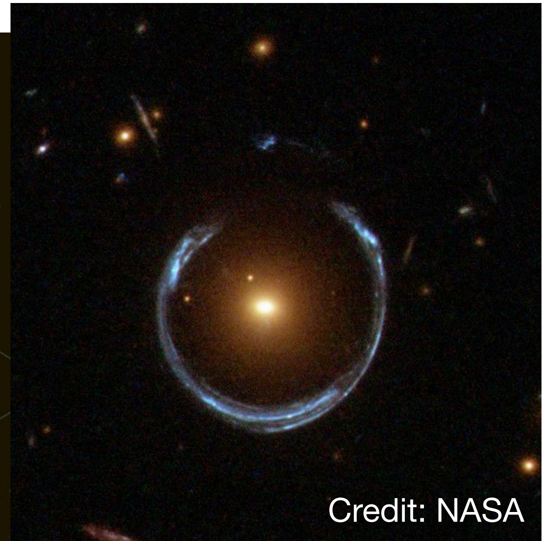


Gravitational Lensing

- When massive objects in the Universe distort spacetime, the path of light around it is bent, as if by a lens.
- Create multiple images of the same objects or distort the image of galaxies (strong lensing)



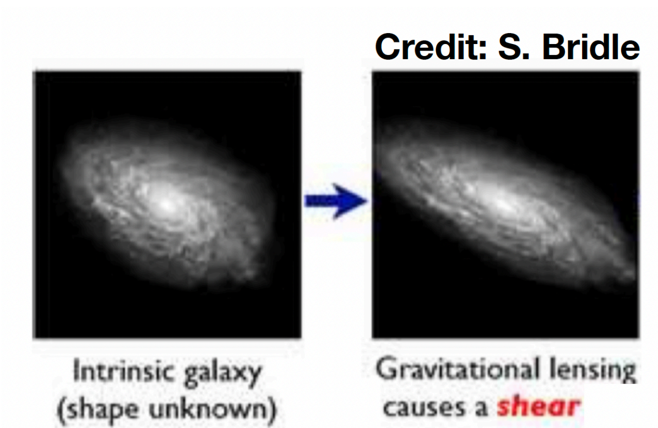
Credit: Xiaoyao Lin

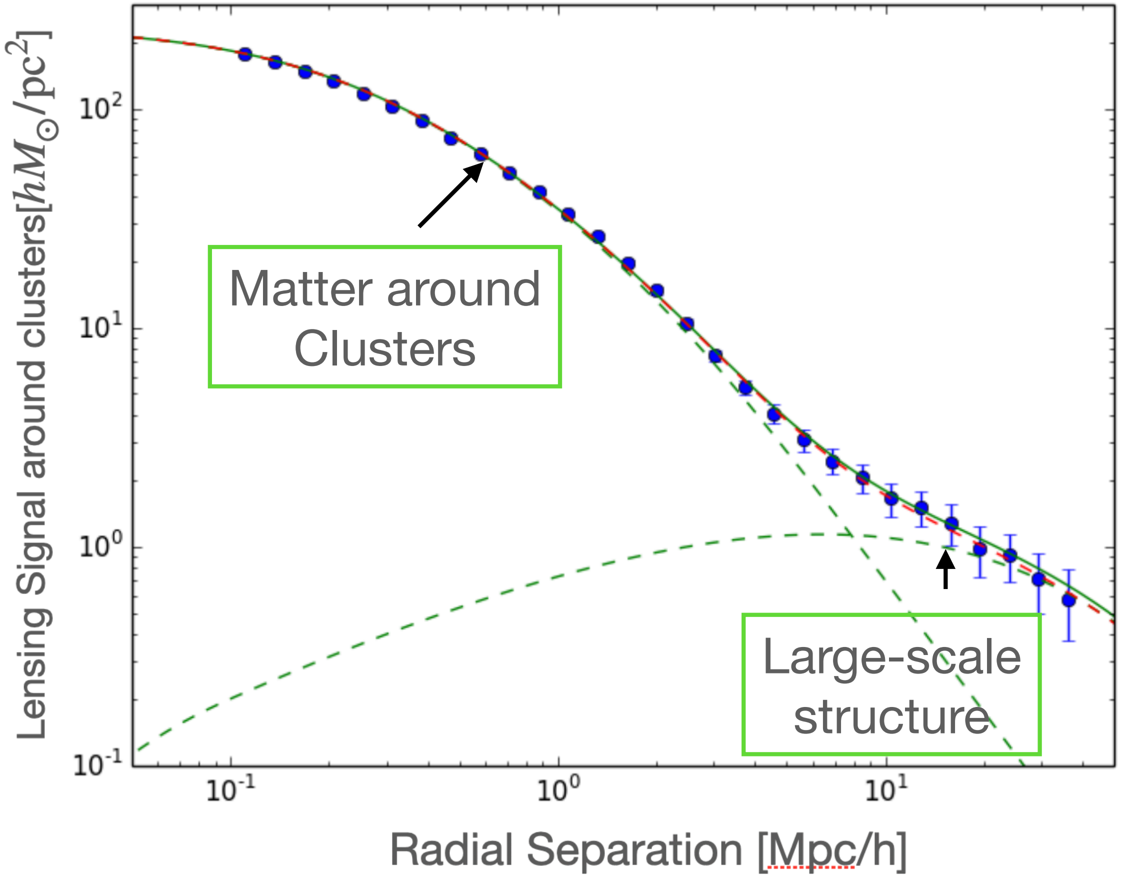

Credit: NASA

Weak Gravitational Lensing

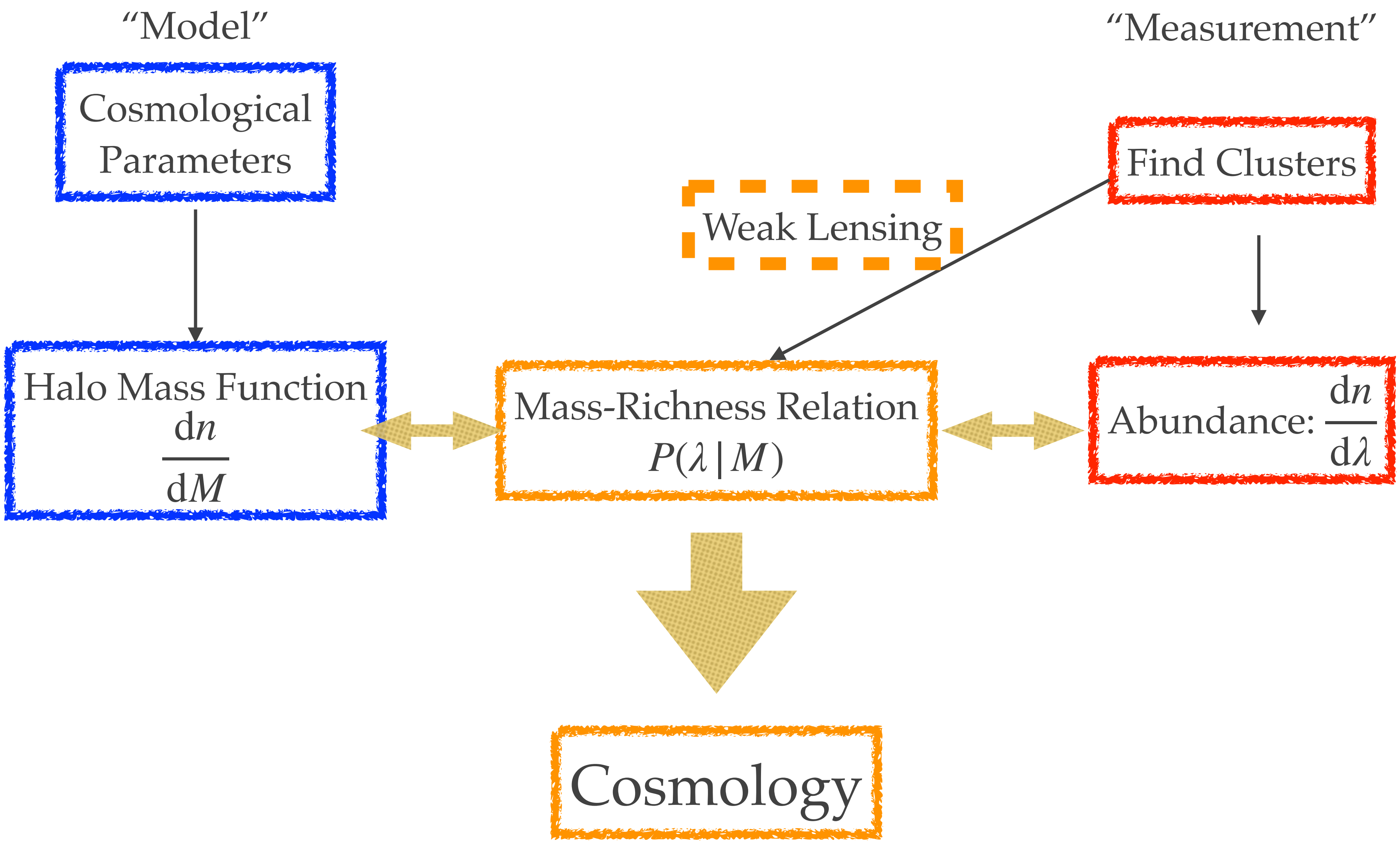
Can measure halo mass of clusters

- Coherent distortion of galaxy shapes (“shear”) is ~1% effect
- Required many galaxy images!

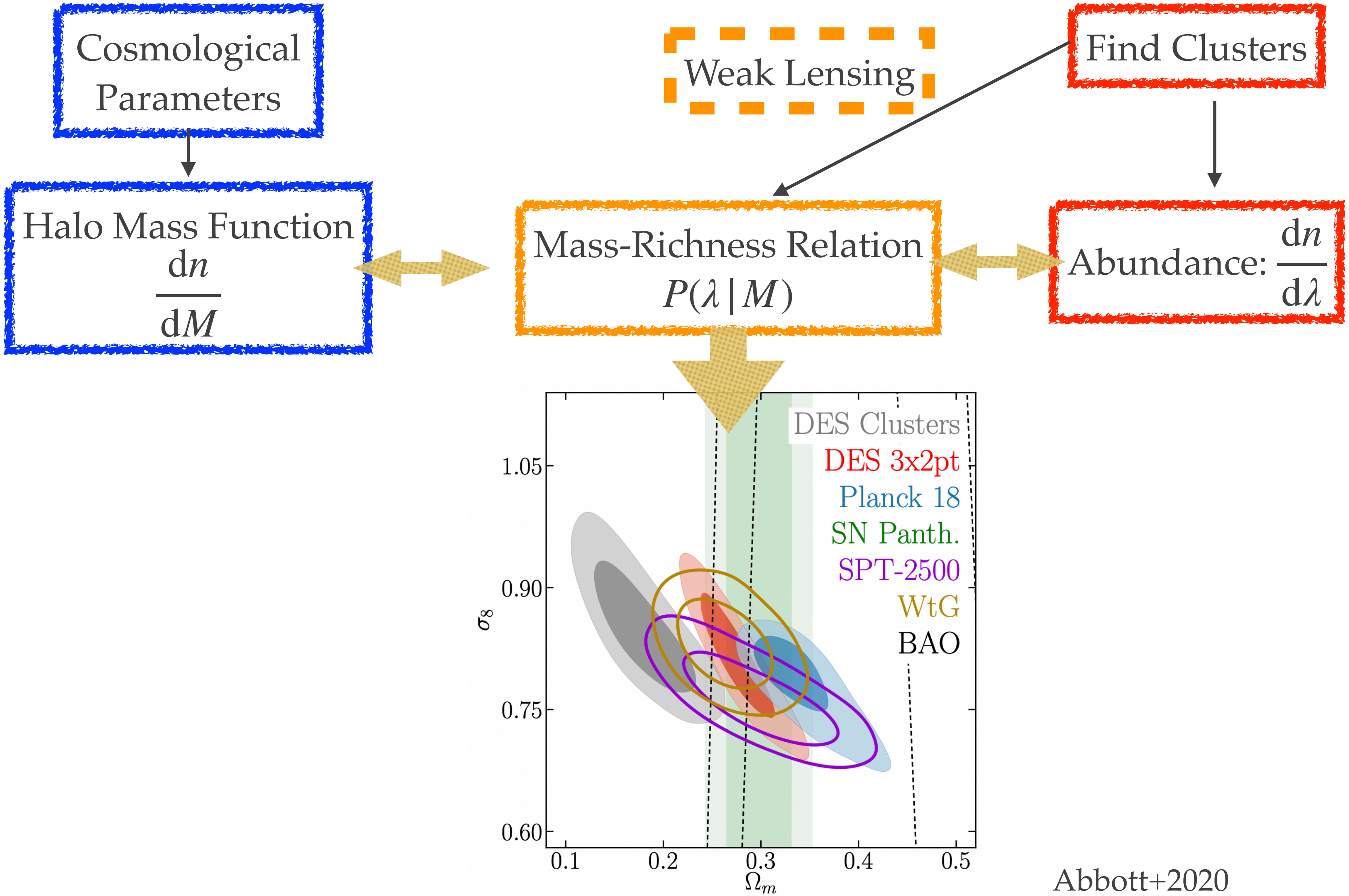




Recipe for Optical Cluster Cosmology



Current Status of Optical Cluster Cosmology



Abbott+2020

Current Status for Optical Cluster Cosmology

Cosmological Parameters

Halo Mass Function $\frac{dn}{dM}$

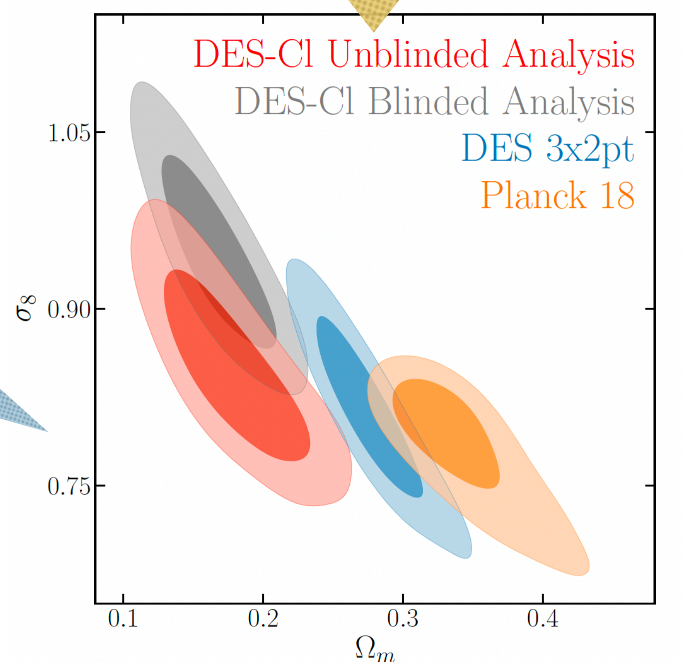
Weak Lensing

Find Clusters

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

Abundance: $\frac{dn}{d\lambda}$

Possible Systematics:
Membership dilutions
Miscentering
Halo Triaxiality
…



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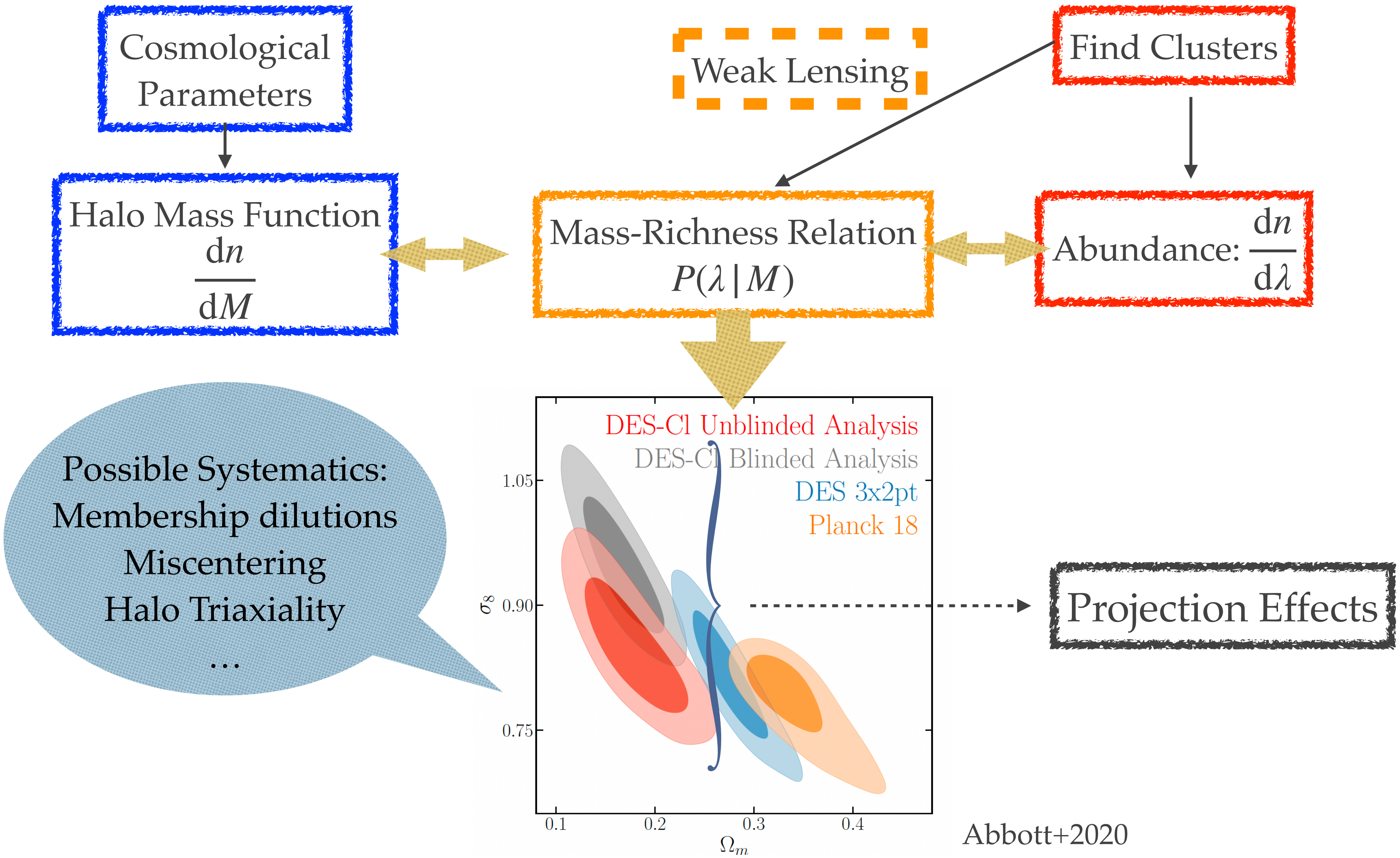
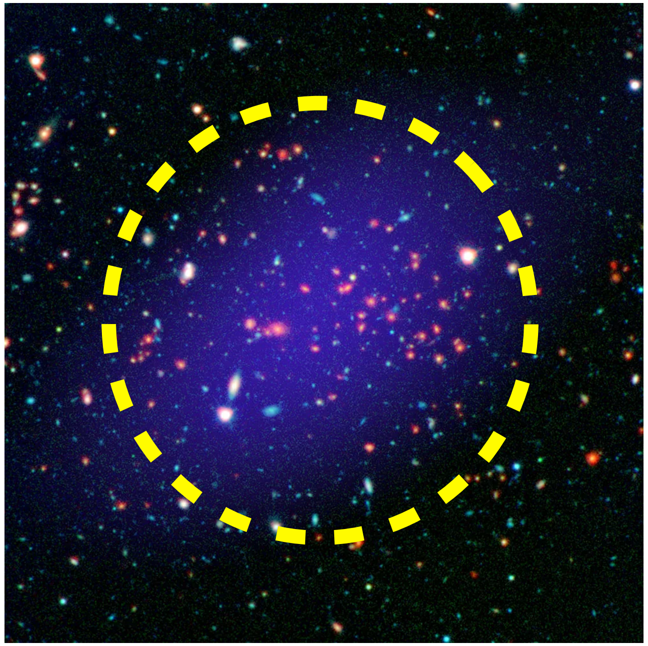
Current Status for Optical Cluster Cosmology

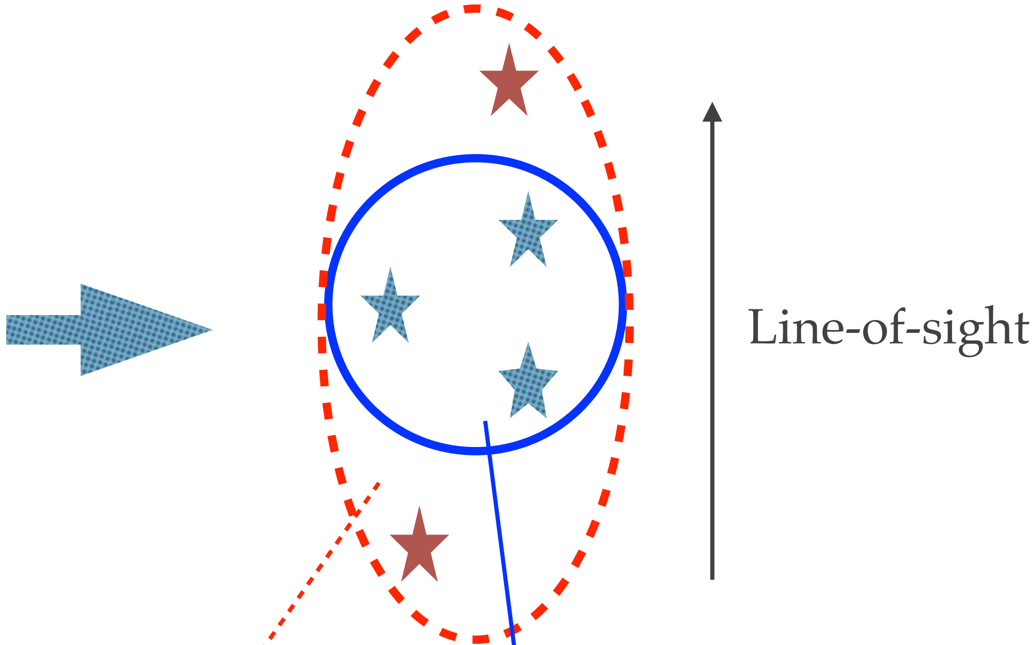


Projection Effects

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



WISE/Spitzer



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

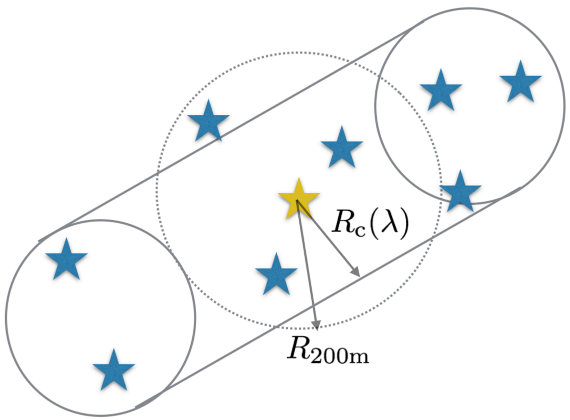
The projection effect alters the mass-richness relation!

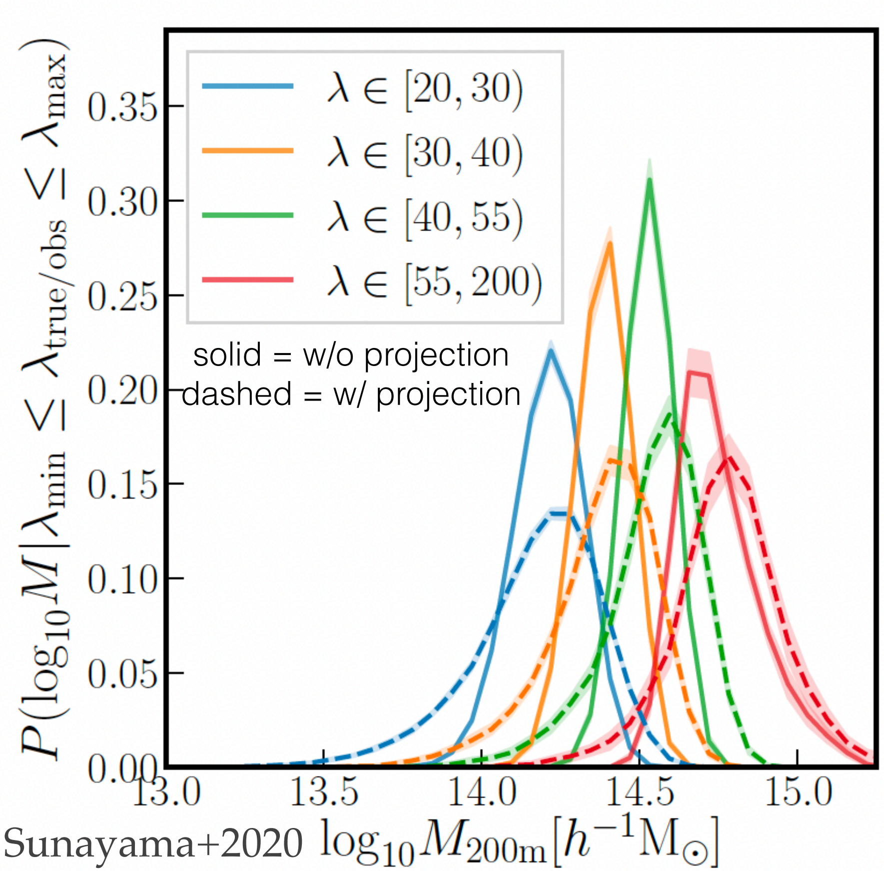
Mass-Richness Relation with Projection Effects

- Due to projection effects, there are more number of lower-mass halos in “observed” cluster samples
- The aperture size is smaller than the actual halo size for massive halos

$$\lambda_{\rm true} = N_{\rm cen} + N_{\rm sat}$$

$$\lambda_{\rm obs} = \sum_{R_j < R_c(\lambda)} p_{\rm mem,j}$$





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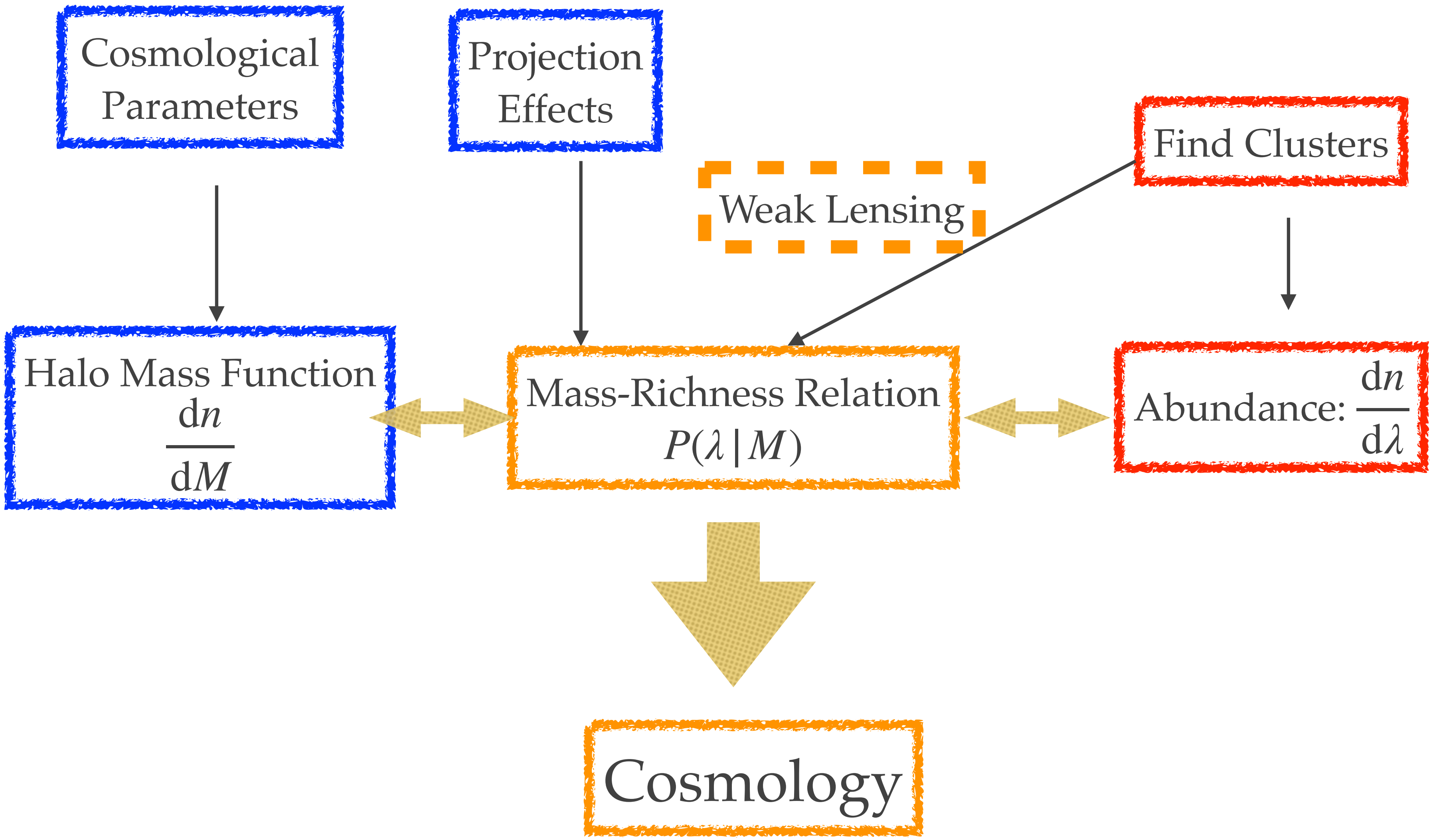
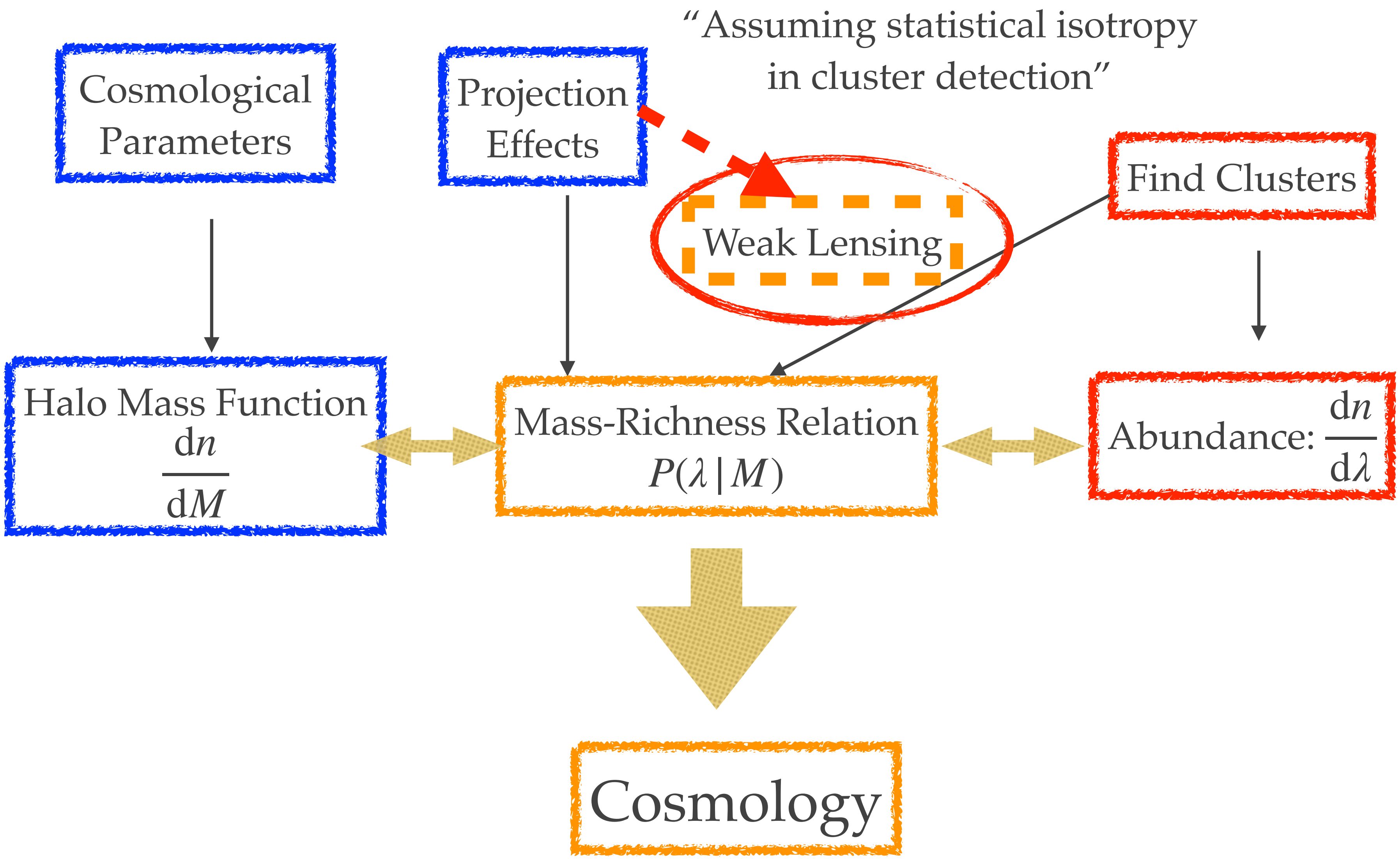
Recipe for Optical Cluster Cosmology

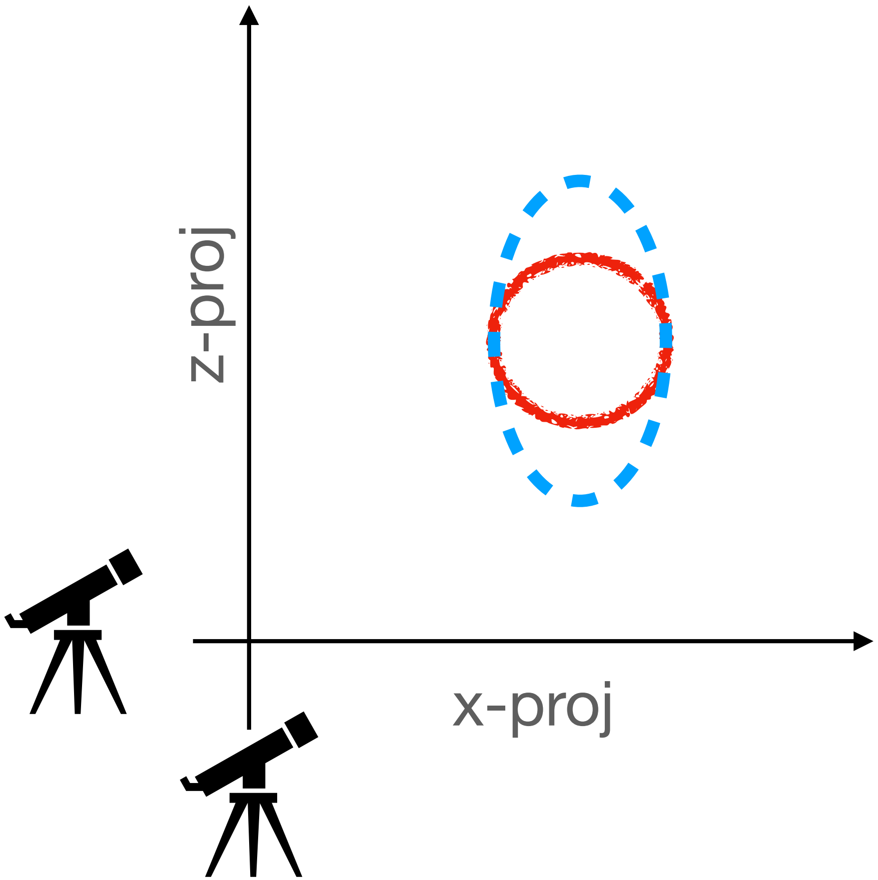


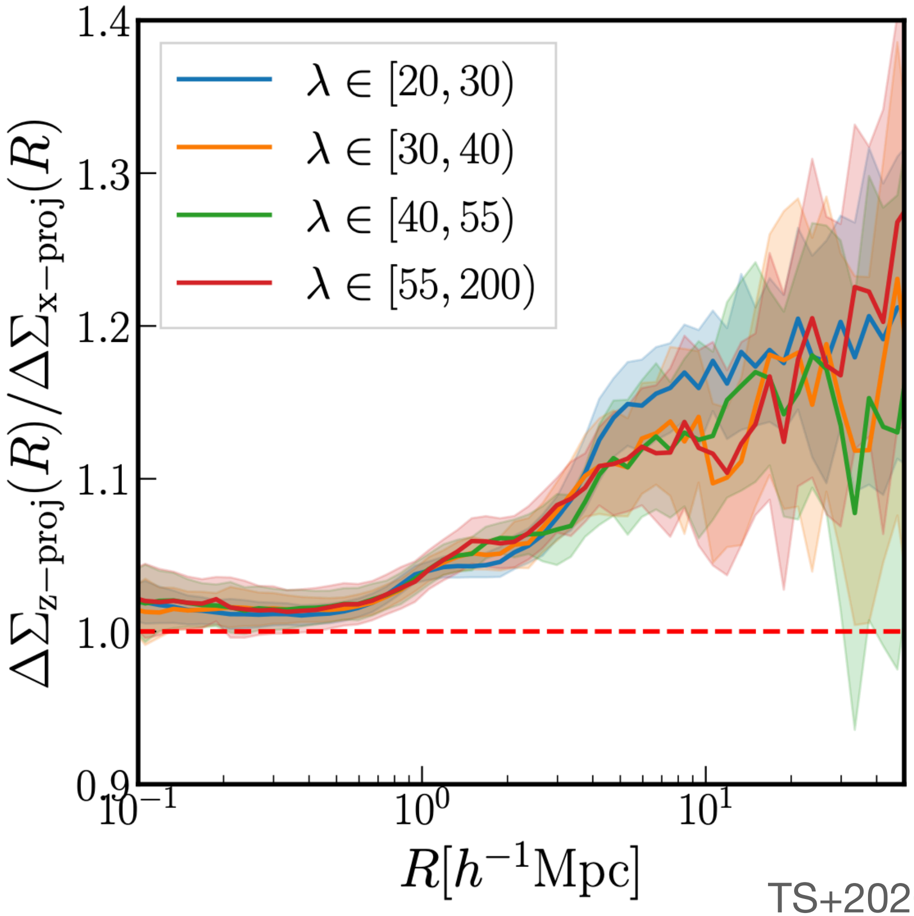
Recipe for Optical Cluster Cosmology



Projection effects correlate with large-scale structure

- We can measure lensing signals around clusters from two different directions





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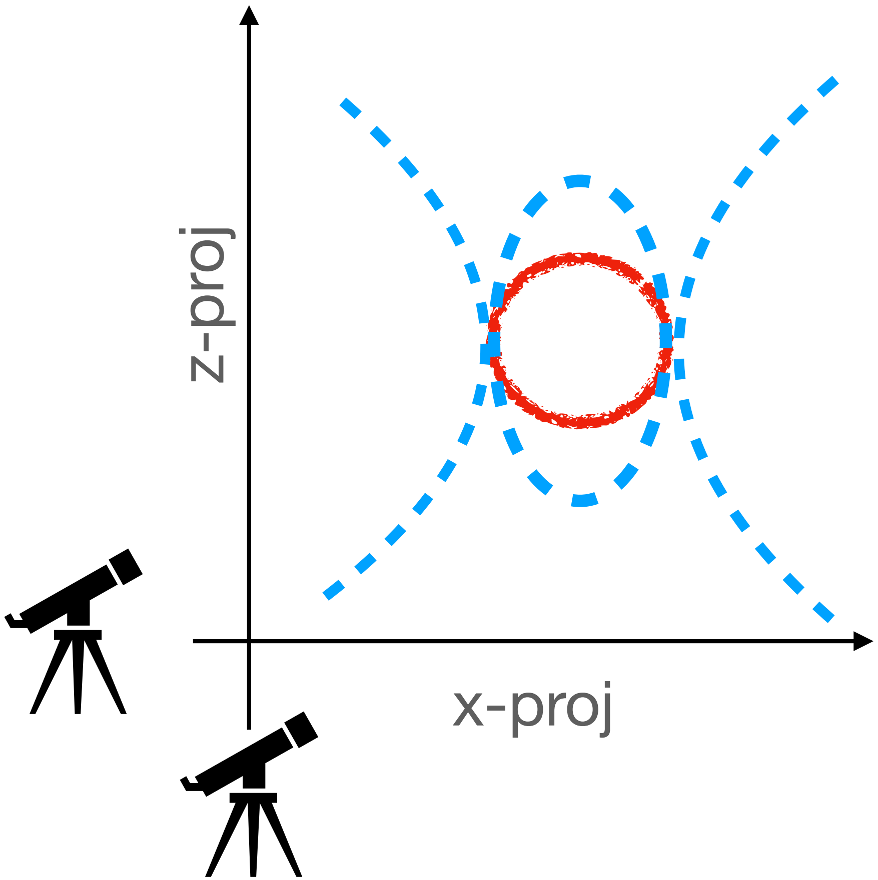
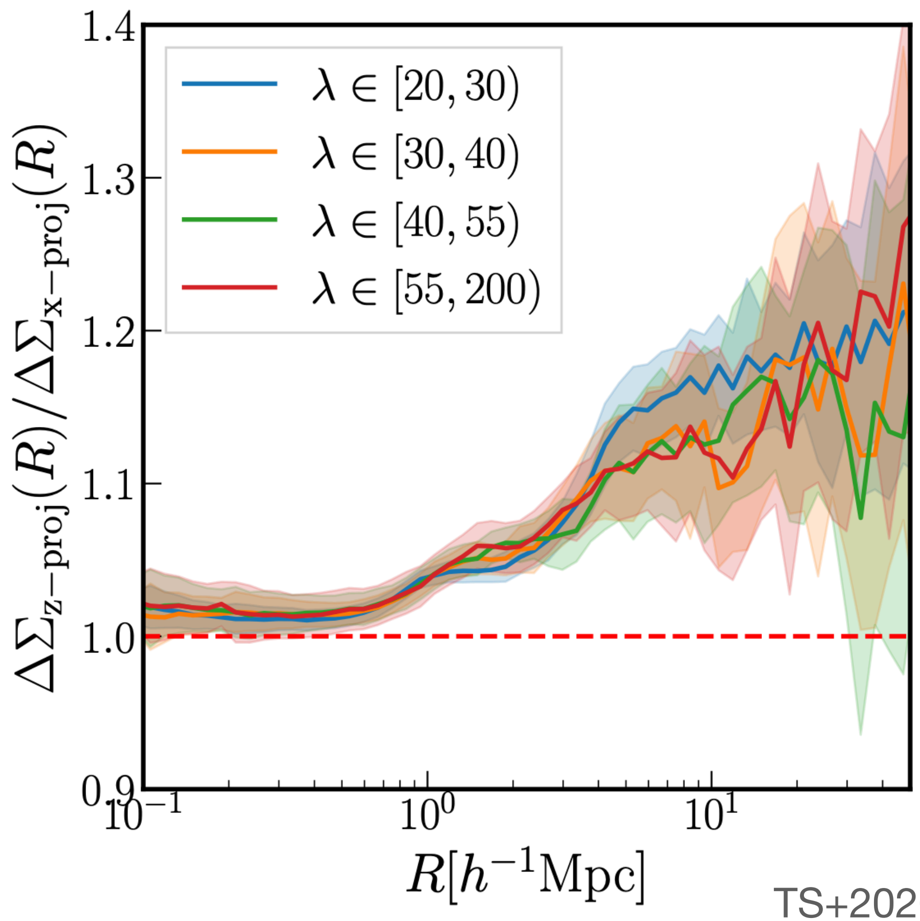
Measure lensing signals from different direction

- We can measure lensing signals around clusters from two different directions





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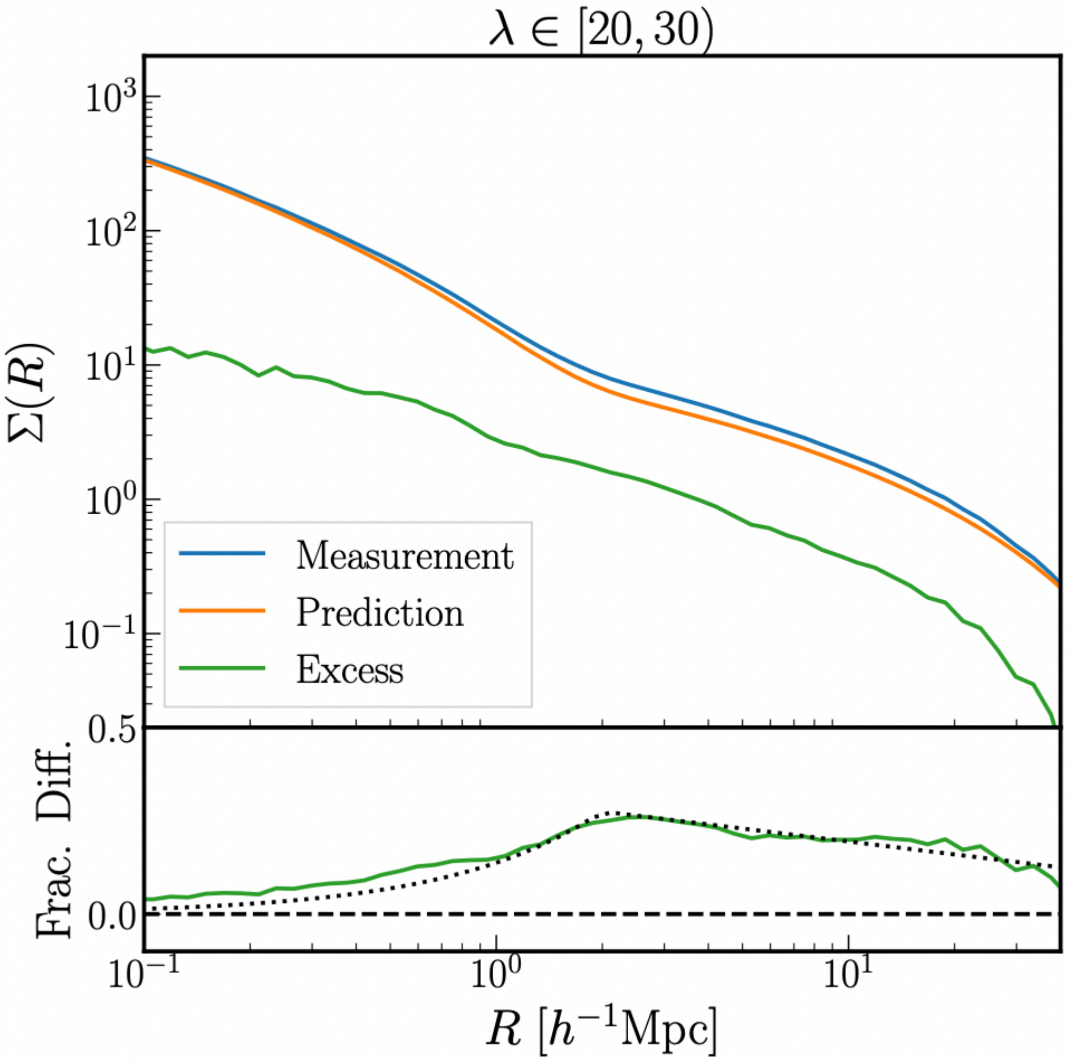
Distribution of optical clusters is anisotropic!

→cluster mass measurement is biased

Modeling Projection Effects



Model the excess mass as a multiplicative factor

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

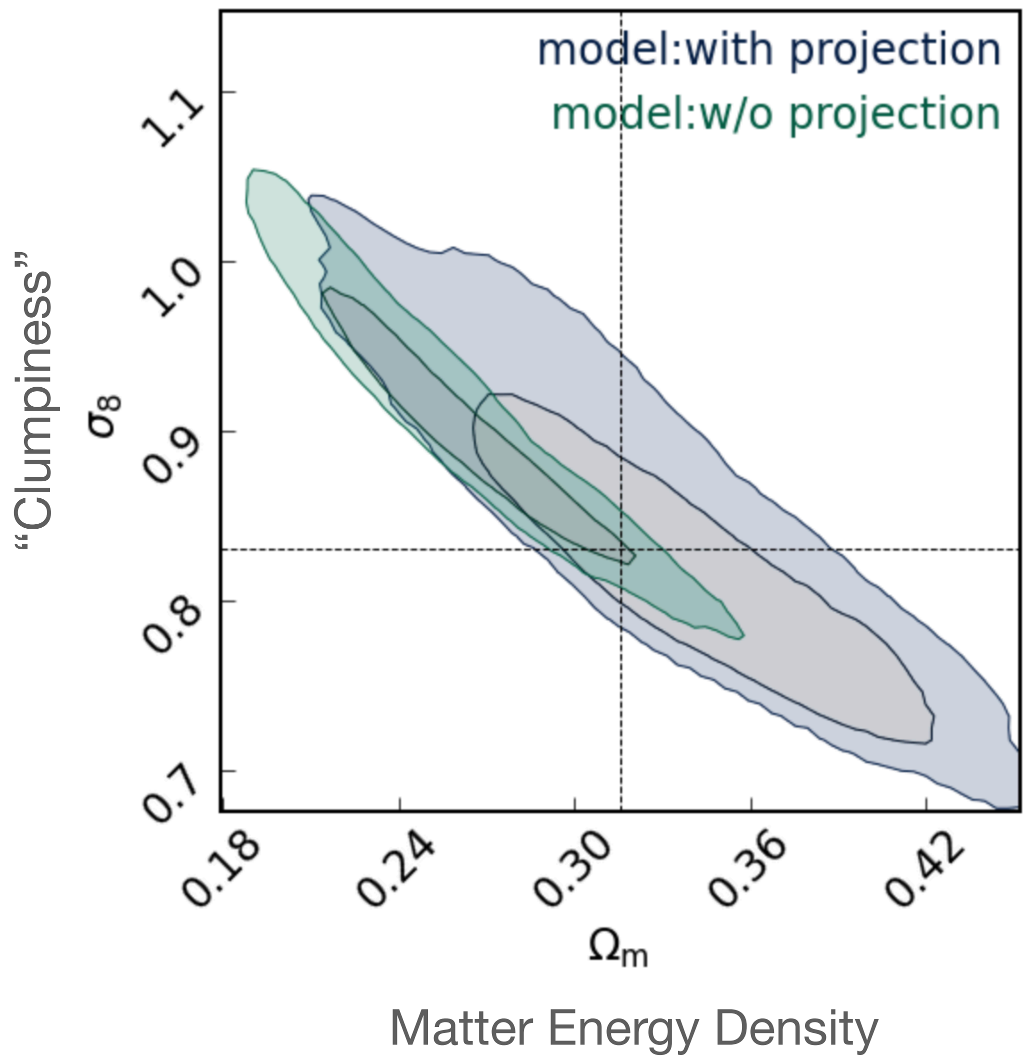
And treat it as effective biases

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

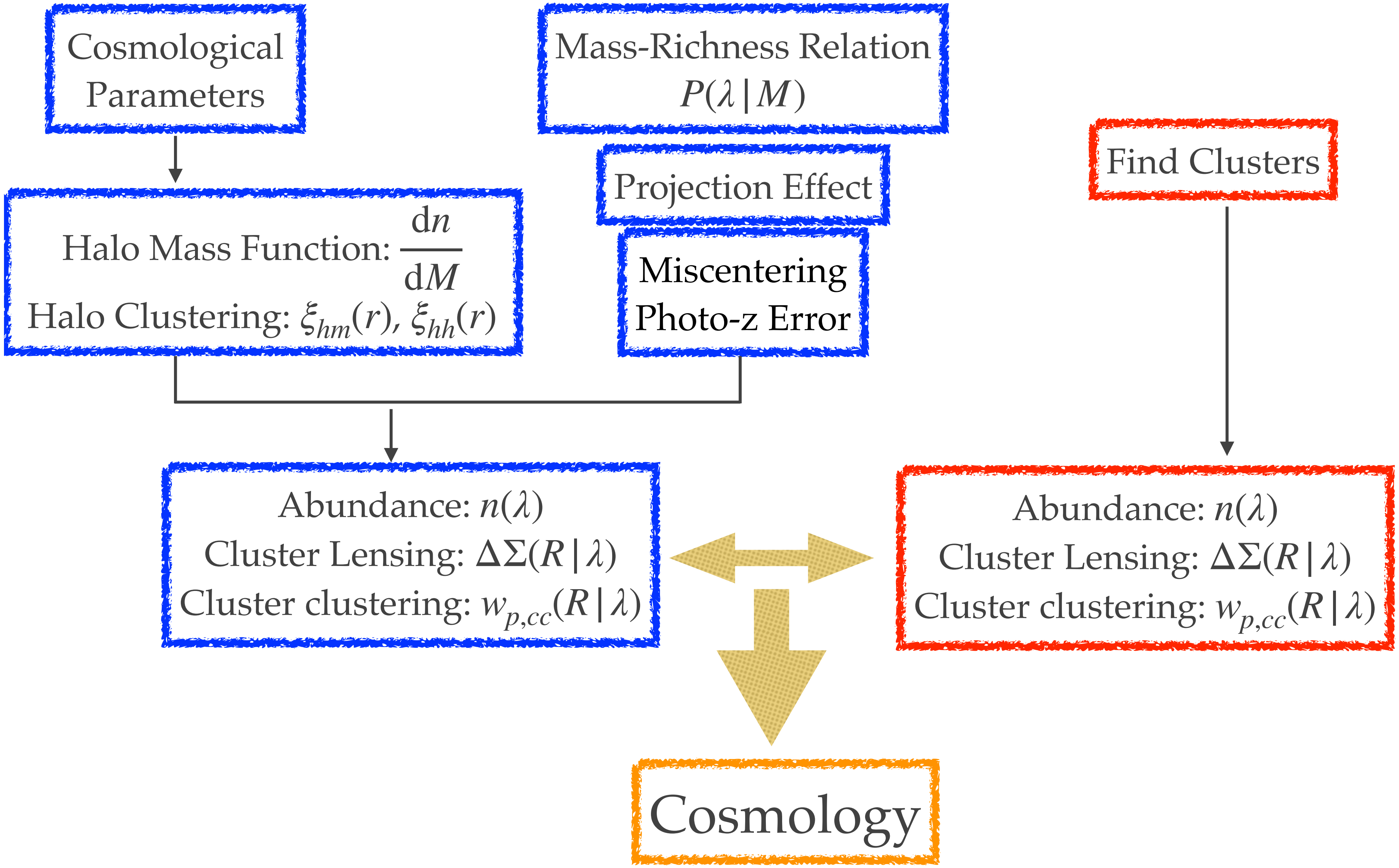
Park,TS+2022

Including projection effects fixes the problem!

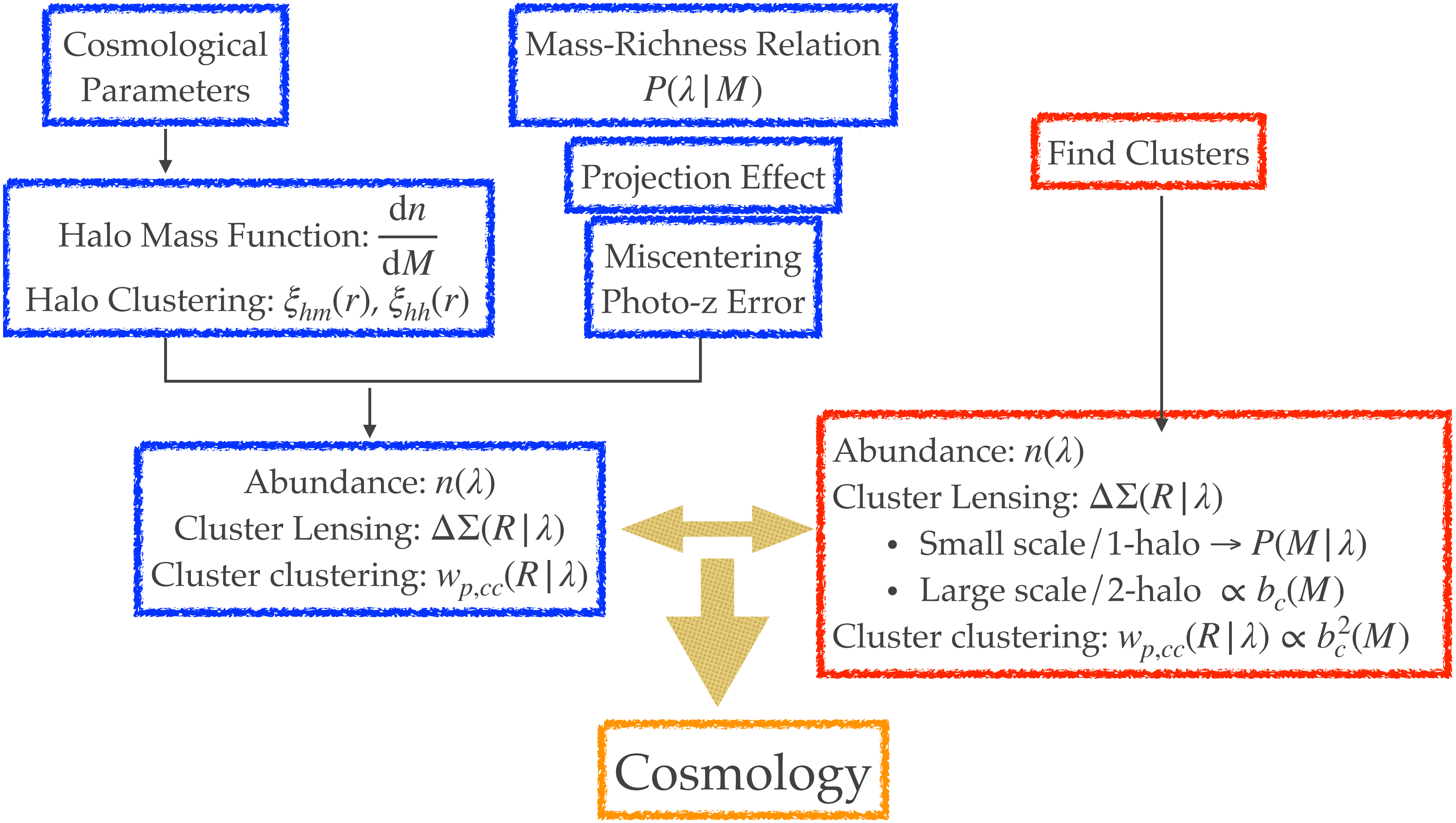
Ignoring the projection effects can bias the constraints on cosmological parameters



Full-Forward Modeling for cluster cosmology



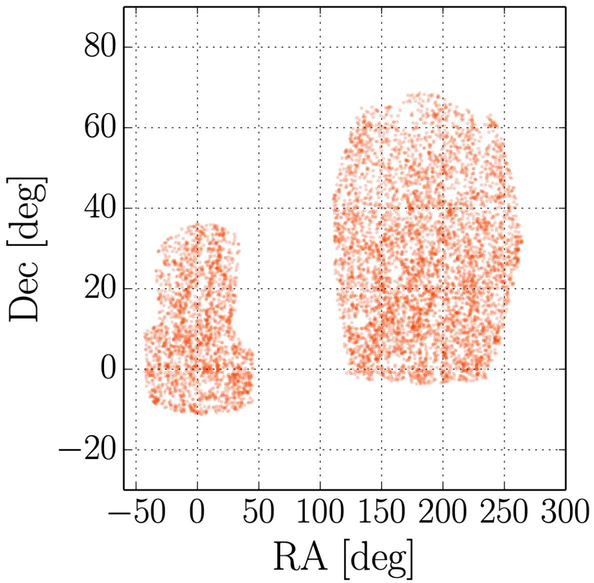
Full-Forward Modeling for cluster cosmology



SDSS redMaPPer clusters x HSC WL Measurement

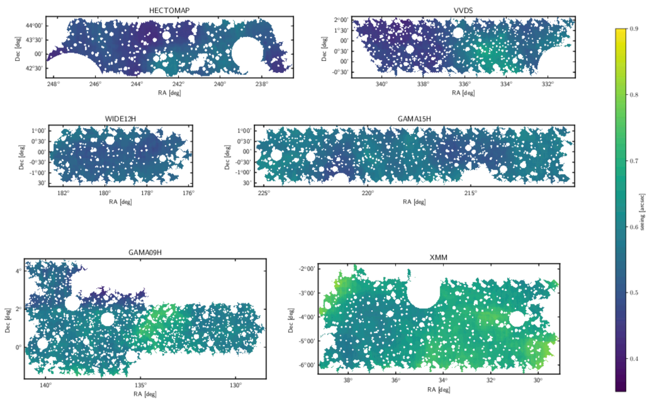
SDSS redMaPPer cluster sample

- Area ~ 8300 deg²
- z = [0.1, 0.33]
- λ = [20,30],[30,40],[40,55],[55,200]
- In total, ~8000 clusters
- Based on SDSS DR8 photometry



HSC-Y3 shape catalog

- Area ~ 433 deg² in total
- <z>~1.2.
- $n_s \sim 16 \mathrm{arcmin}^{-2}$



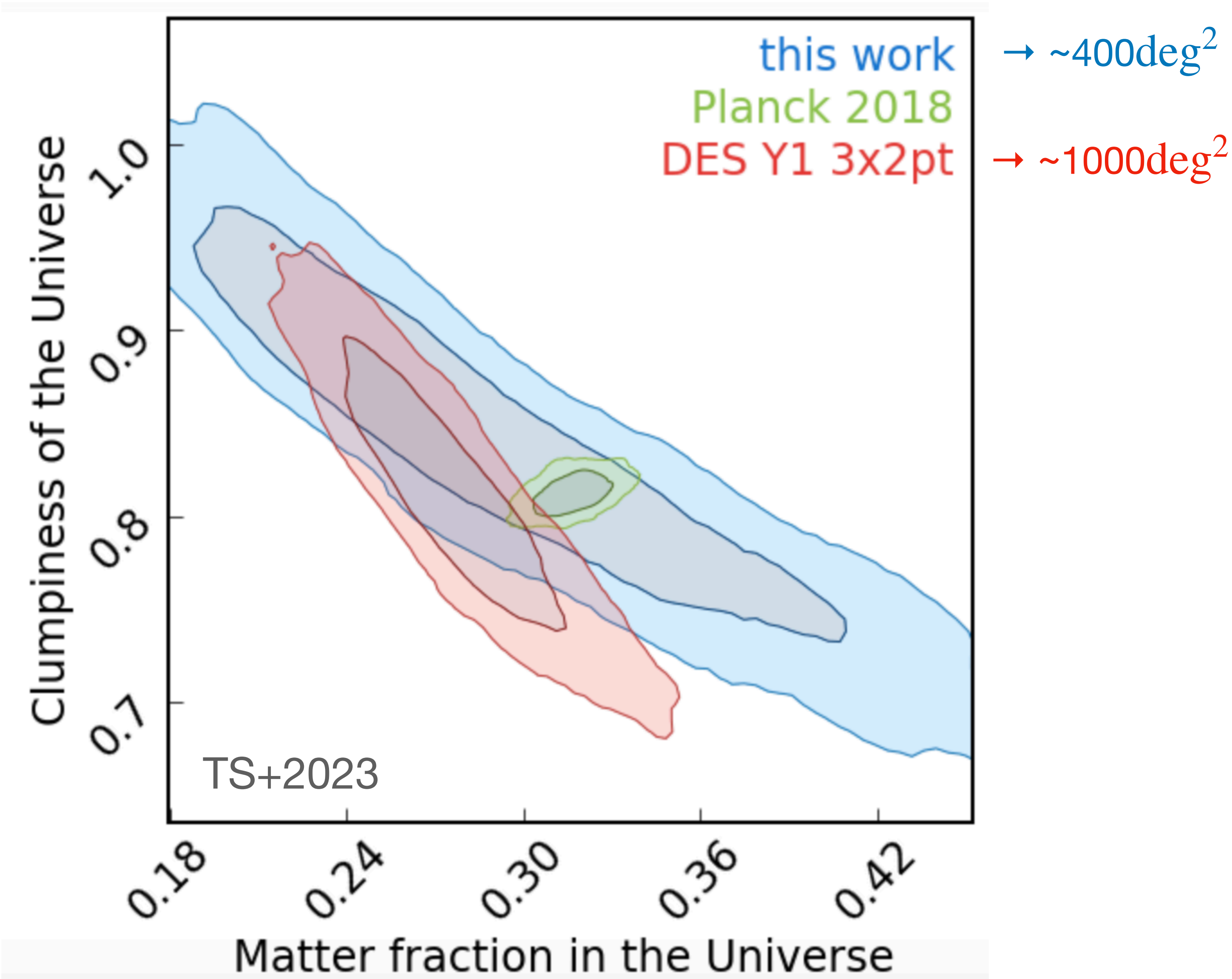
Cluster lensing signal

Cluster abundance

Cluster clustering signal

Optical Cluster Cosmology Constraints from HSC-Y3

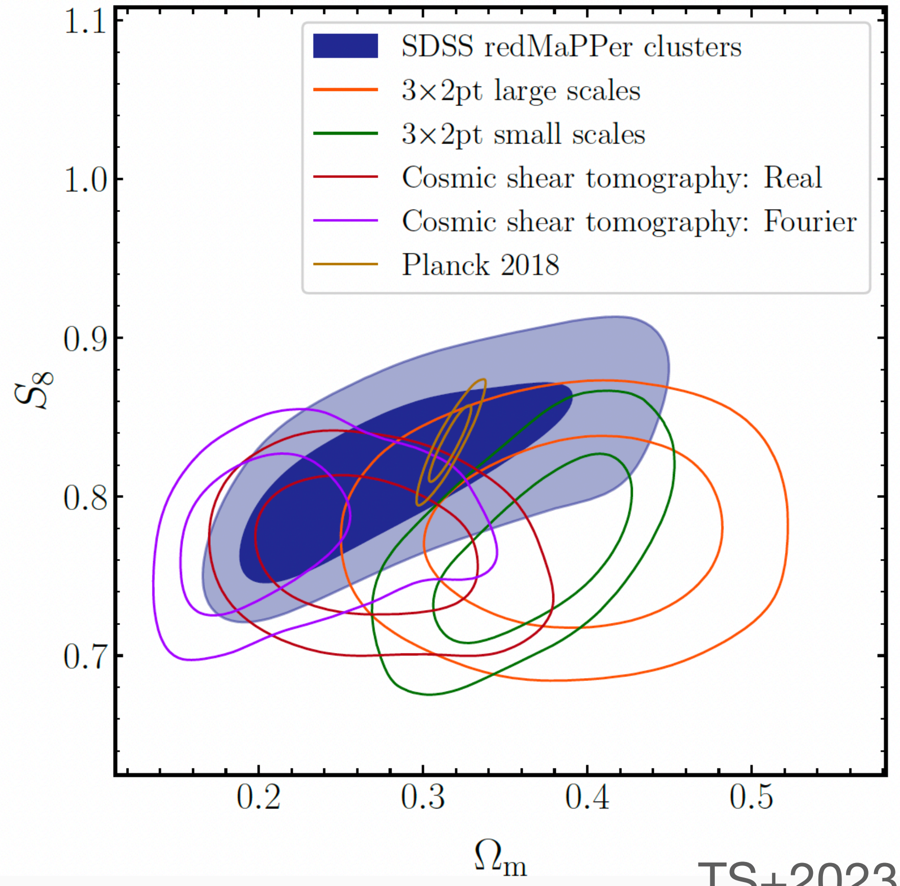
My result is consistent with other cosmology analyses from DES Y1 lensing (3x2pt) and Planck CMB measurements



Comparing to other HSC-Y3 lensing constraints…

My result is consistent with other HSC-Y3 lensing analyses at the level of 1-sigma on S_8

HSC Y3 lensing measurements



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Summary

- Projection effects make the distribution of optical cluster anisotropic
- Anisotropic distribution of optical clusters affect lensing signals around clusters—bias the cluster mass measurements from lensing
- Modeling projection effects fixed the problem of DES Y1 cluster cosmology analysis!