Galaxy cluster cosmology in the LSST Era

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Galaxy cluster abundance cosmology in the LSST Era

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Galaxy clusters

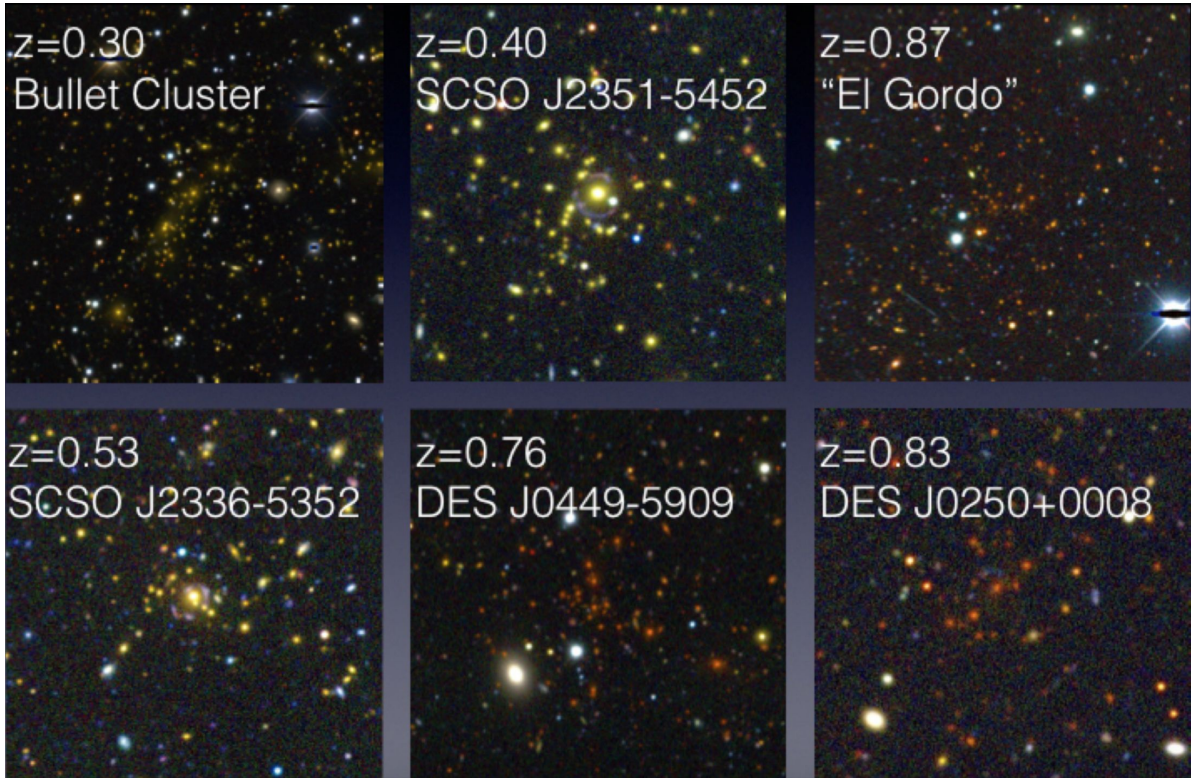
LSST:

Will find ~100k massive clusters

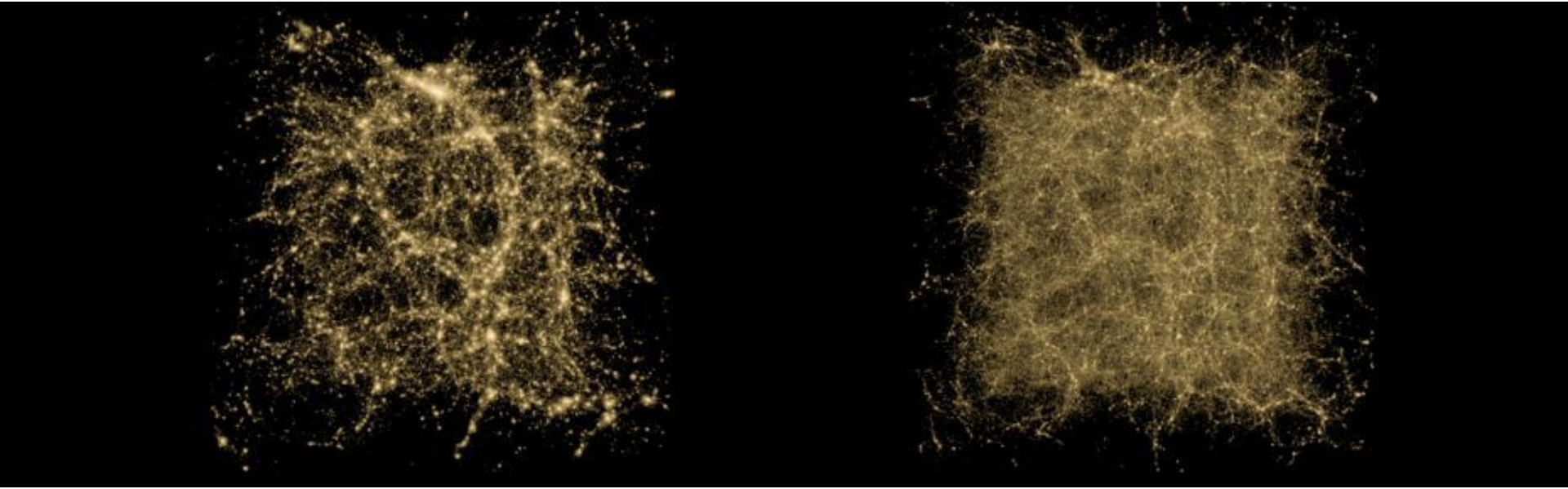
Up to ~1M galaxy groups

Complete up to z~1.2 (ish)

All clusters are identified by their **photometric properties**



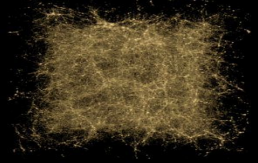
Structure probes cosmology!



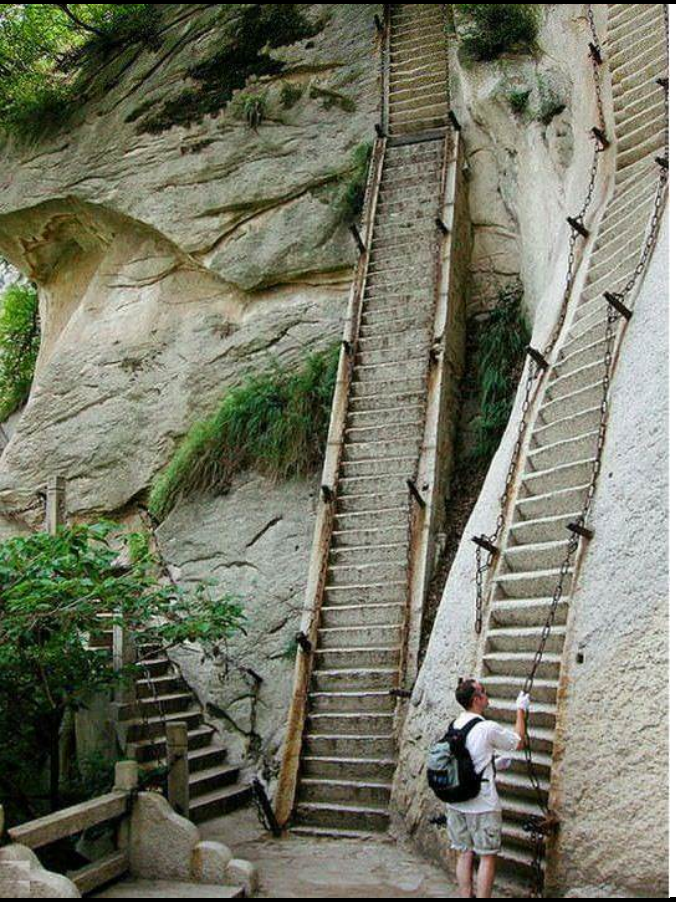
Lots of matter + little dark energy
= more structure

Lots of dark energy + little matter
= less structure

More clusters = more structure



Galaxy cluster cosmology in 3 easy steps

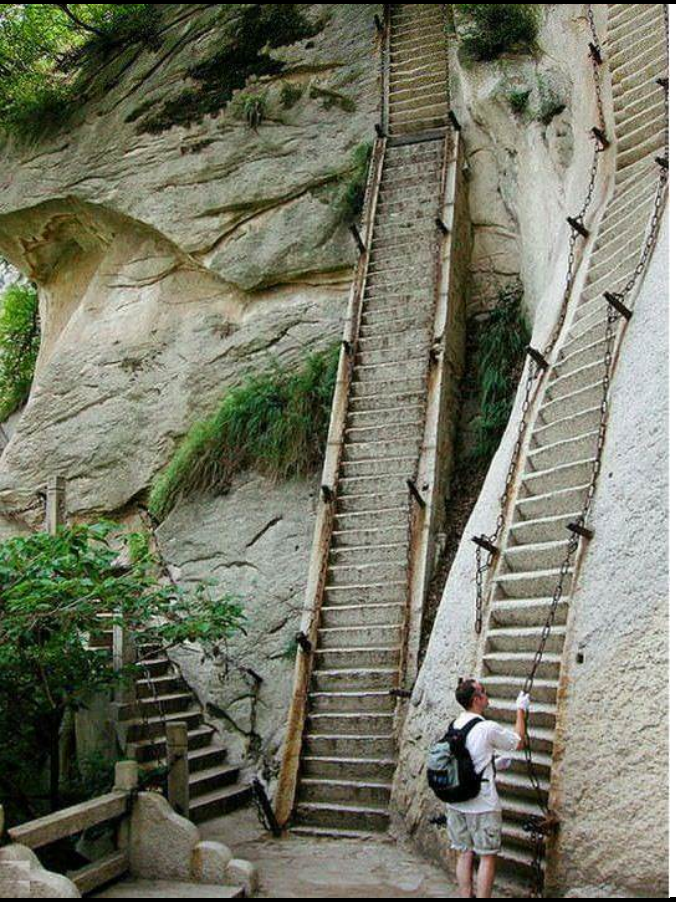


1. Find galaxy clusters

2. Measure cluster masses

3. Model cluster abundance

Galaxy cluster cosmology in 3 easy steps



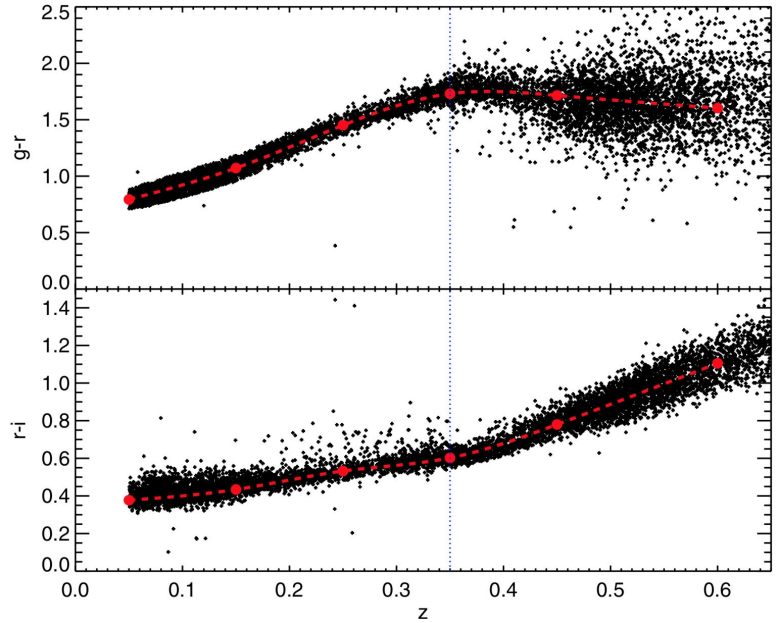
1. Find galaxy clusters

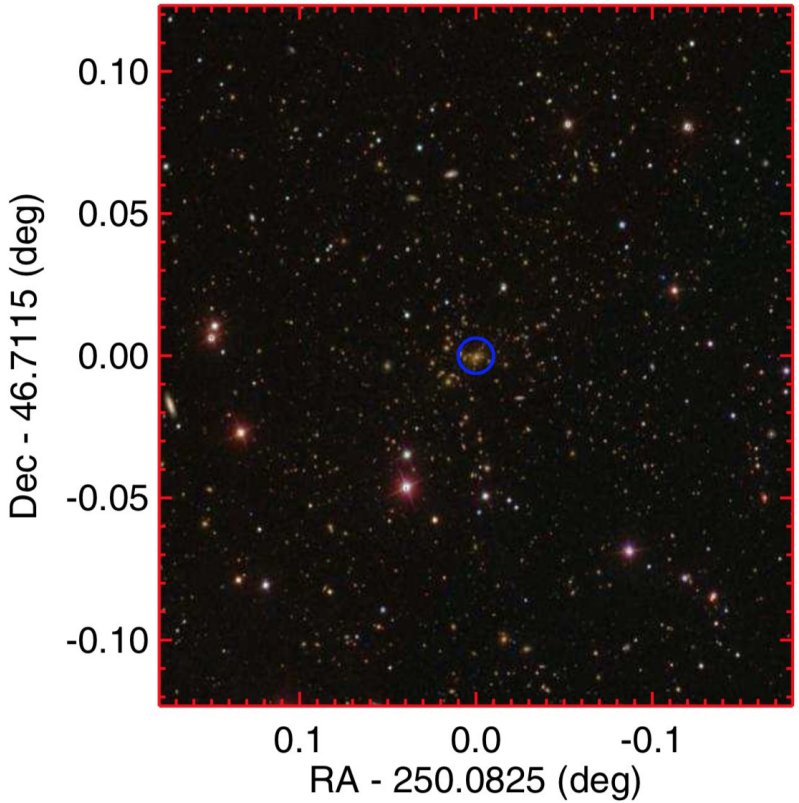
   (see Ricardo's talk)

2. Measure cluster masses

3. Model cluster abundance

Finding clusters photometrically - redMaPPer





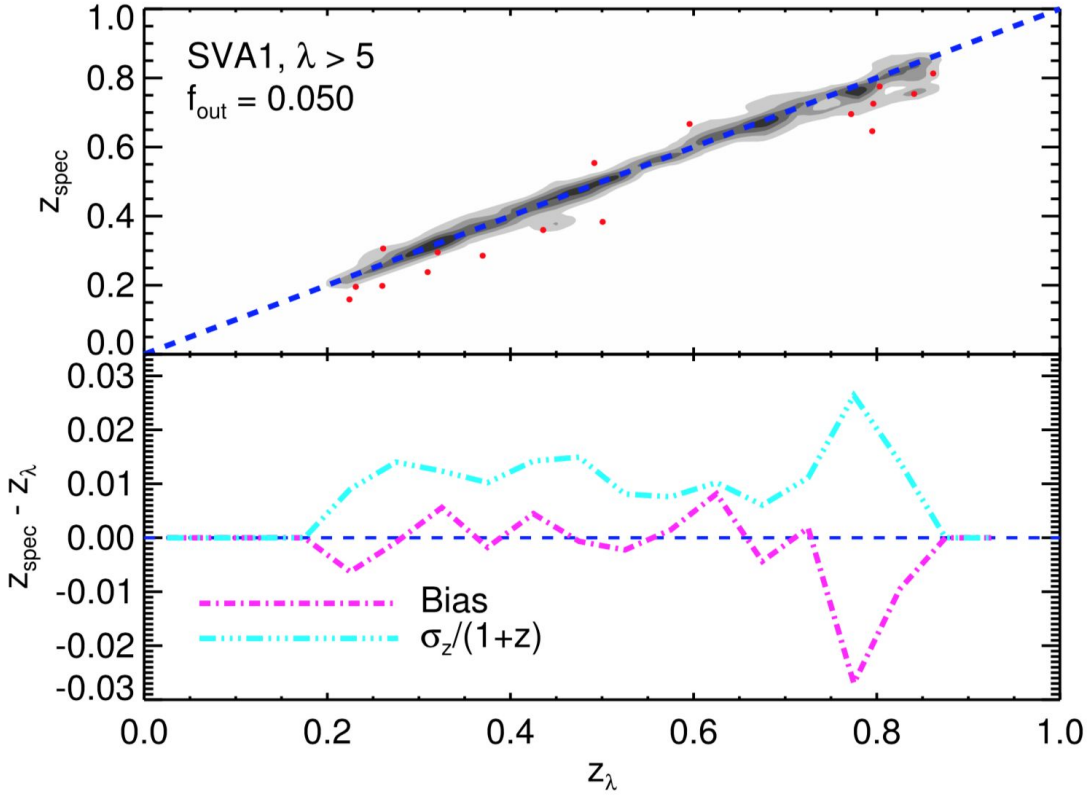
Clusters identified via the red sequence

redMaPPer redshifts

Obtain unbiased, precise redshifts.

Don’t require a vast spectroscopic catalog!

Rykoff+ (2014, 2016)



See also
Bellagamba+ (2017), Oguri+ (2017)

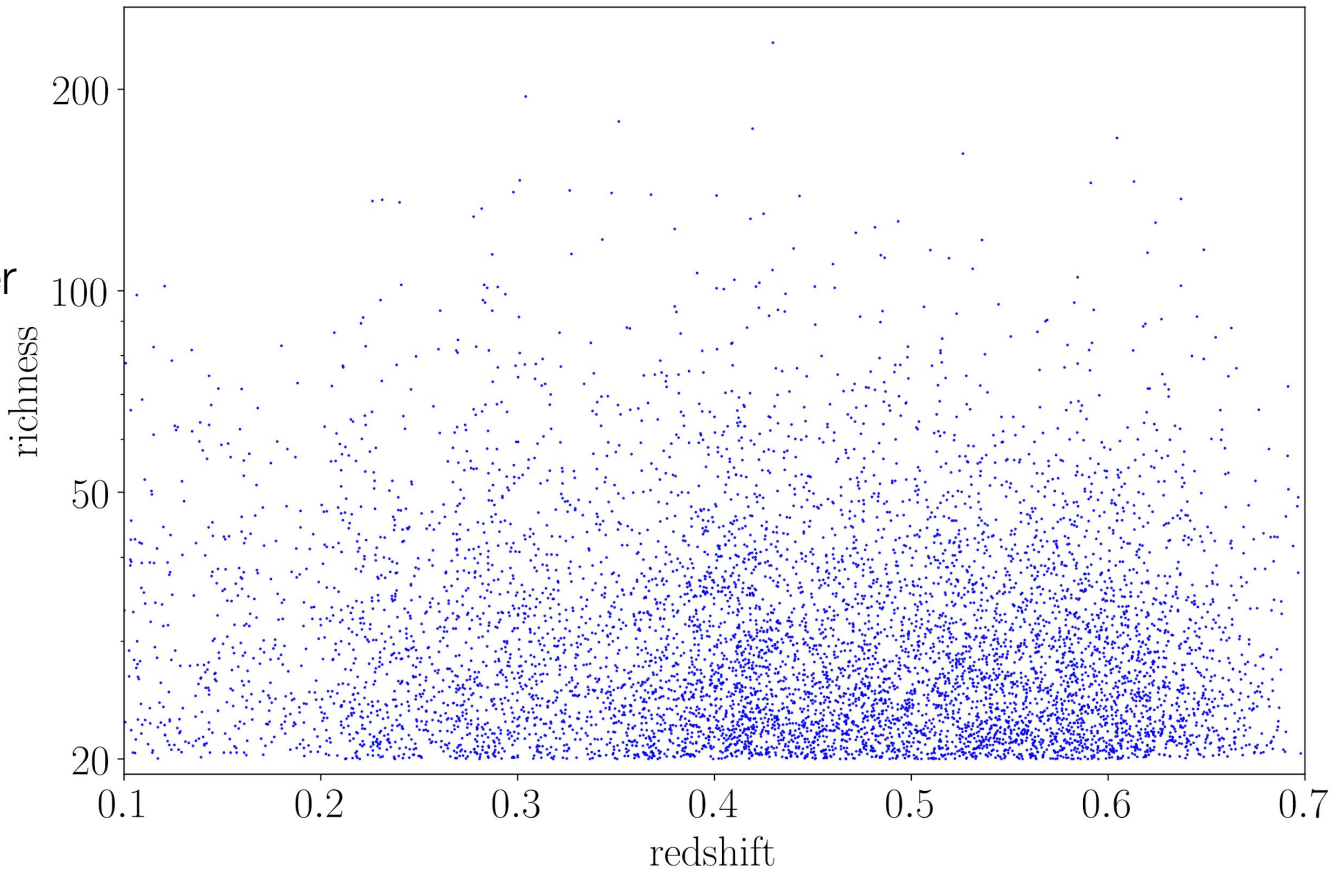
Example cluster catalog

DES: 5000 sq. deg.
(LSST: 18k sq. deg.)

redMaPPer cluster finder

7066 clusters
(76k at the group scale,
with >=5 galaxies)

DES Year 1 catalog
complete up to z=0.65

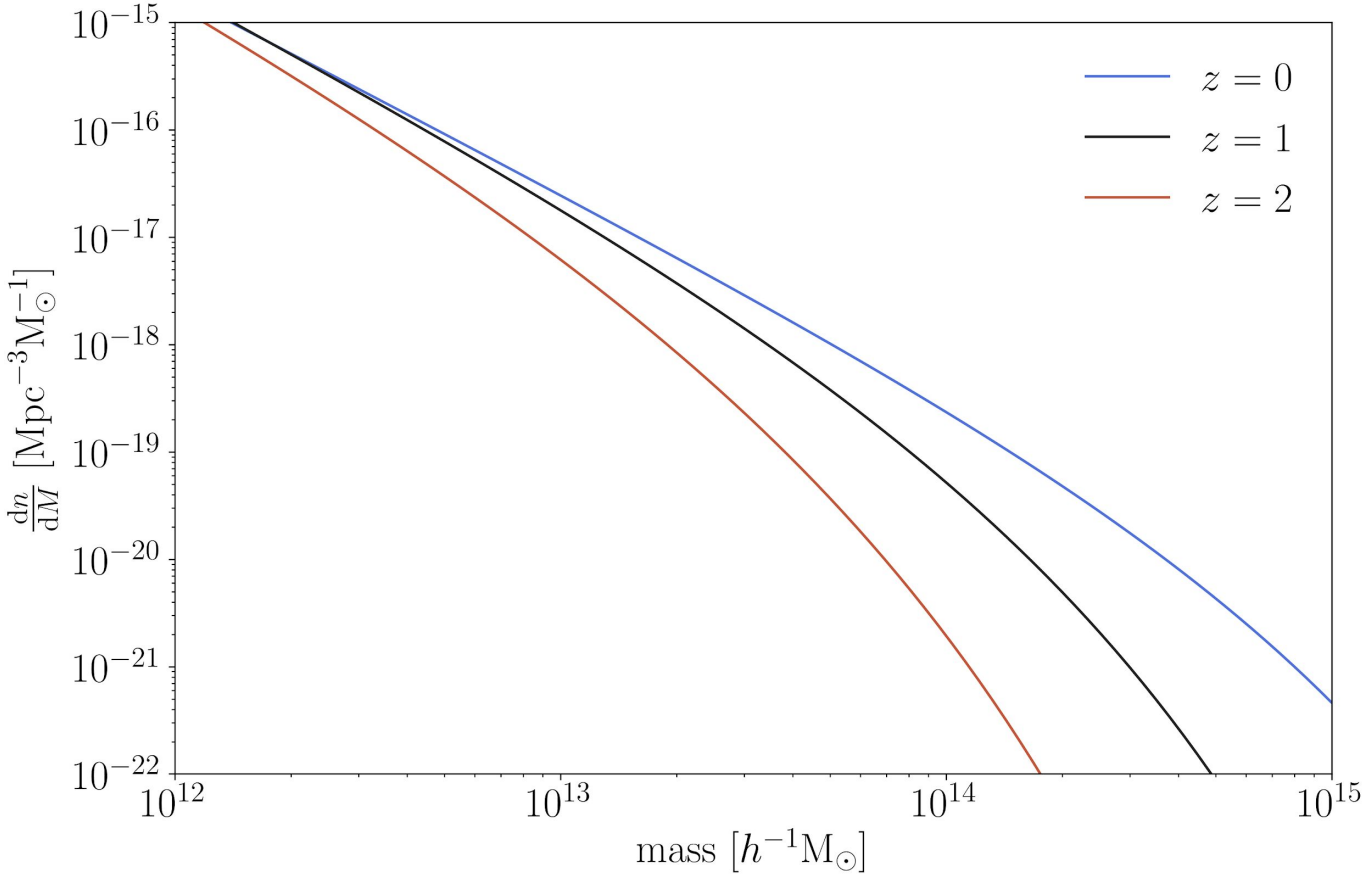


Halo mass function

From spherical collapse (you learned this in grad school, remember?)

Models e.g.:
Sheth & Tormen (2001),
Tinker+ (2008),
McClintock+ (2018)

HMF has one or more power law and an exponential



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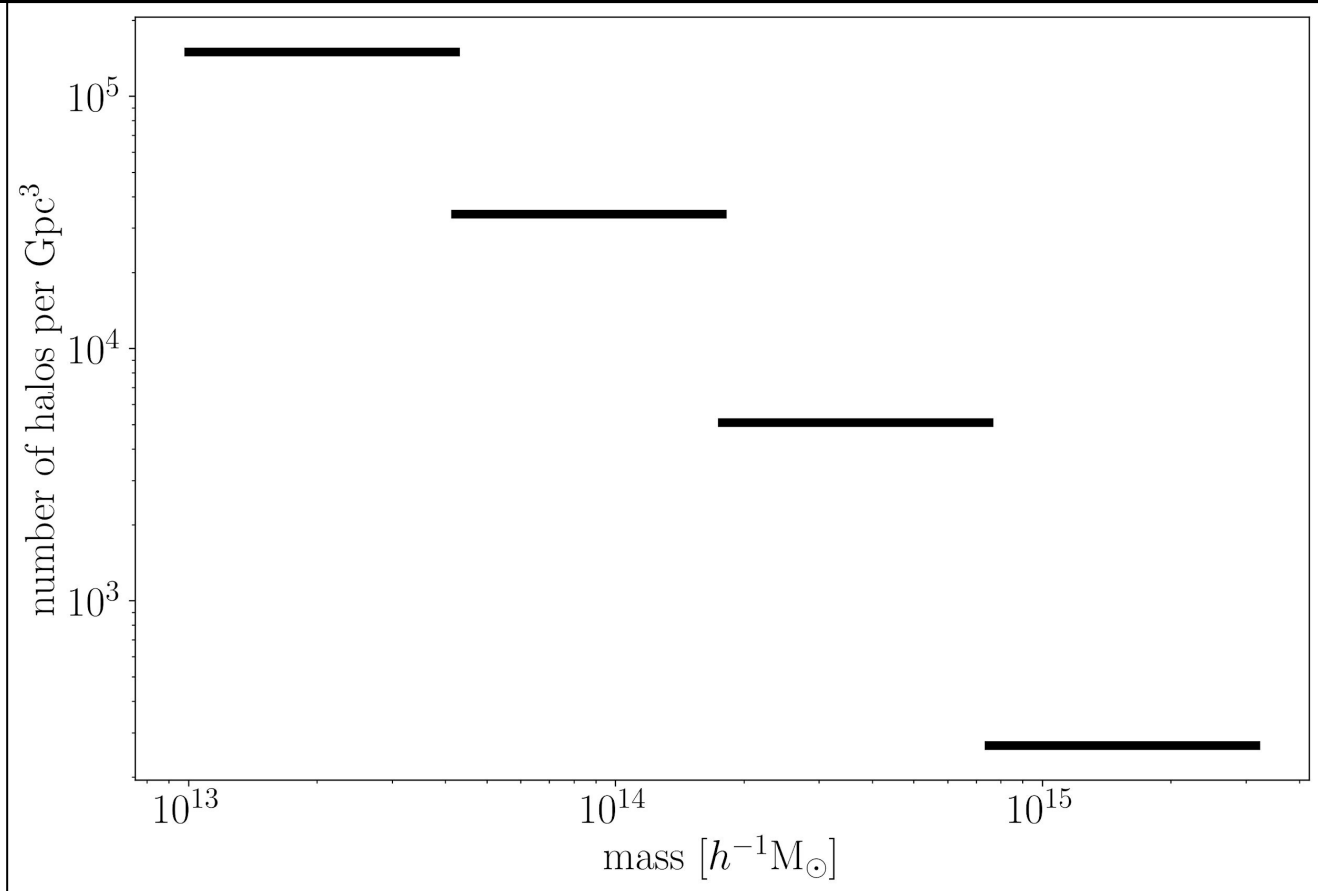
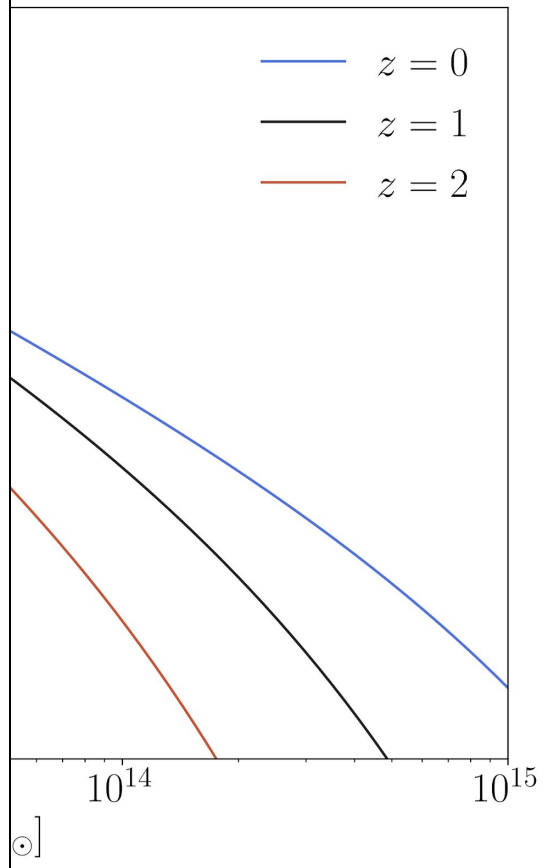
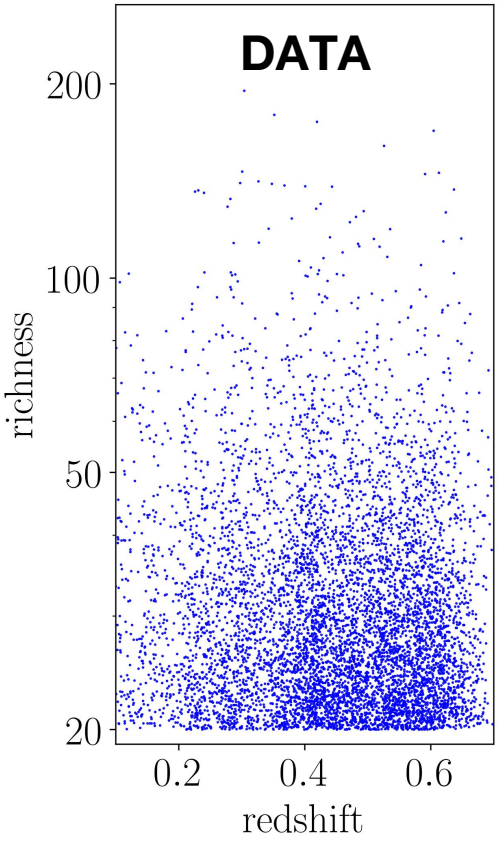
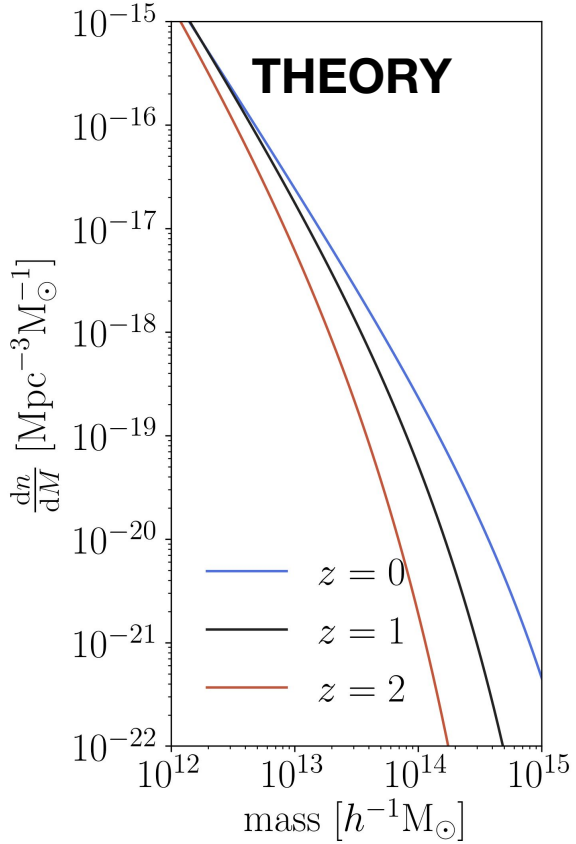




Cluster cosmology 101





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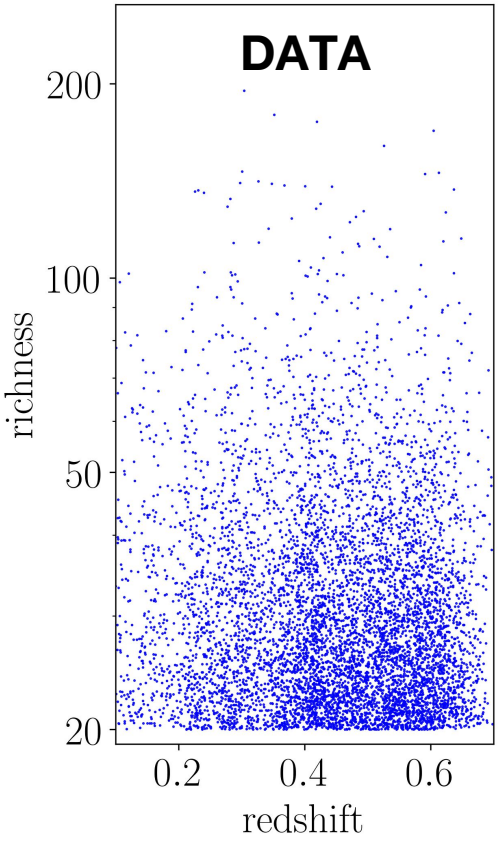

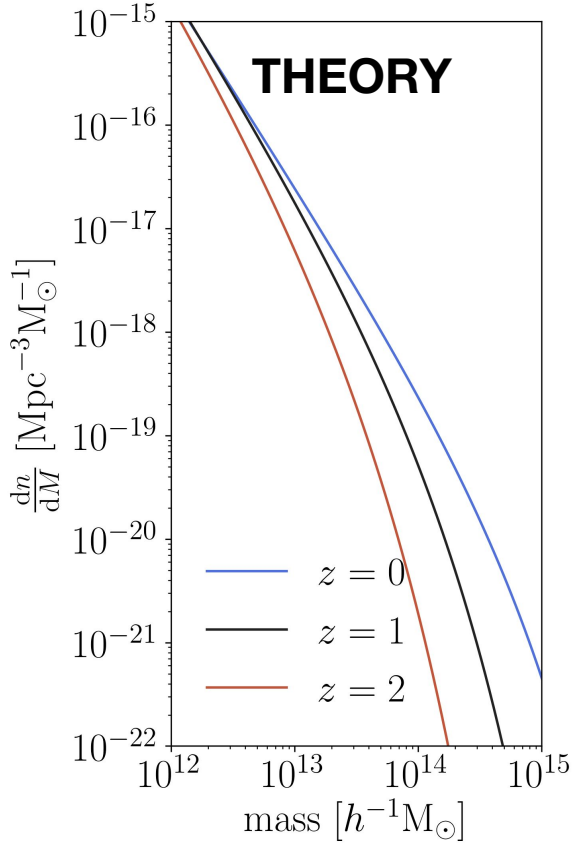

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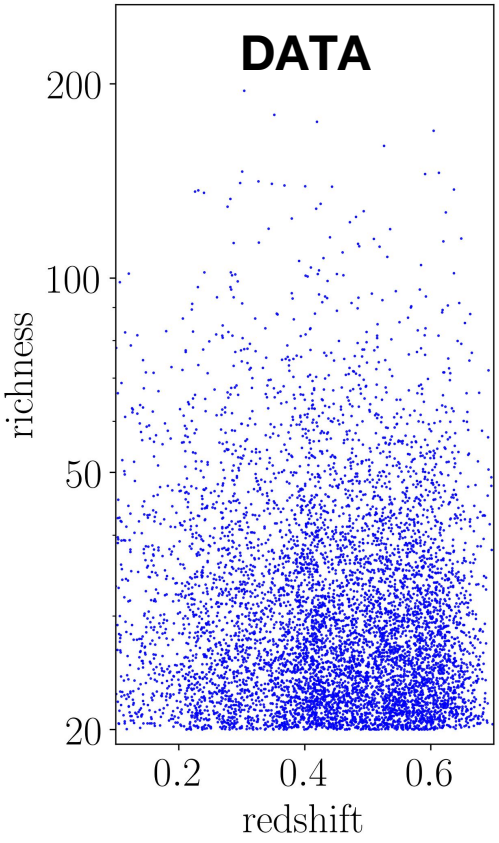

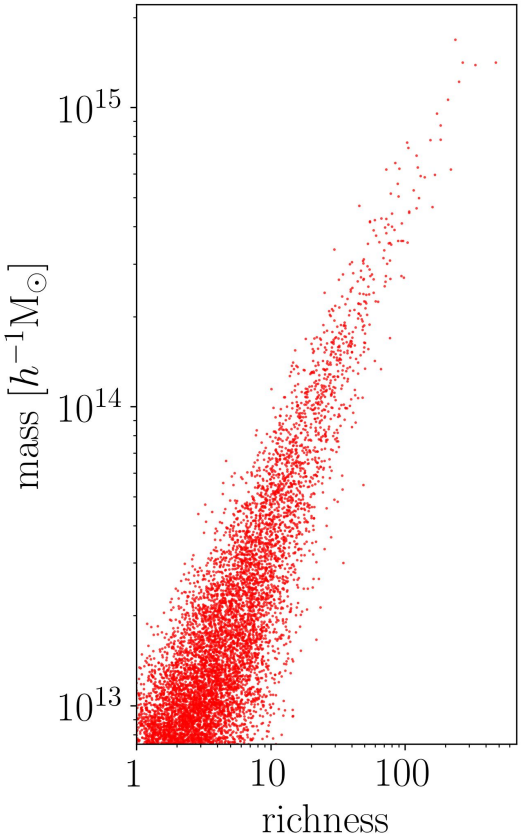

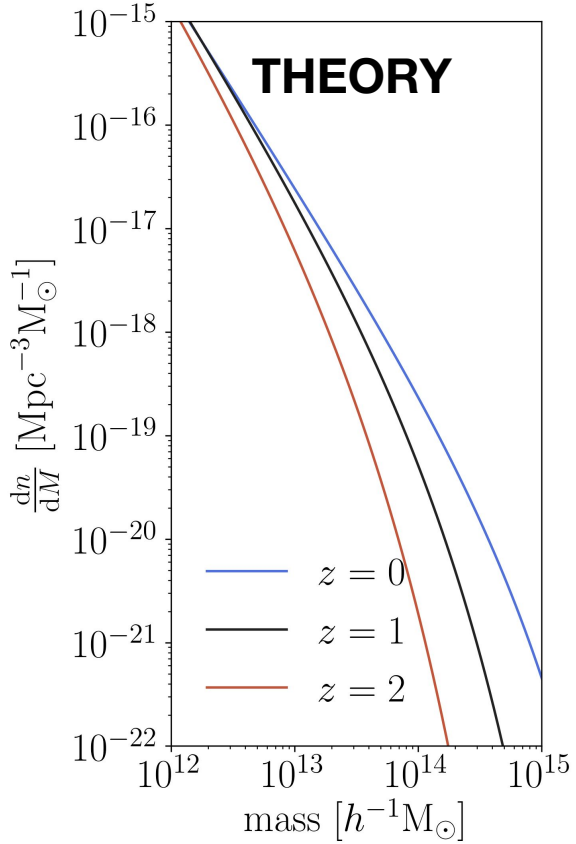

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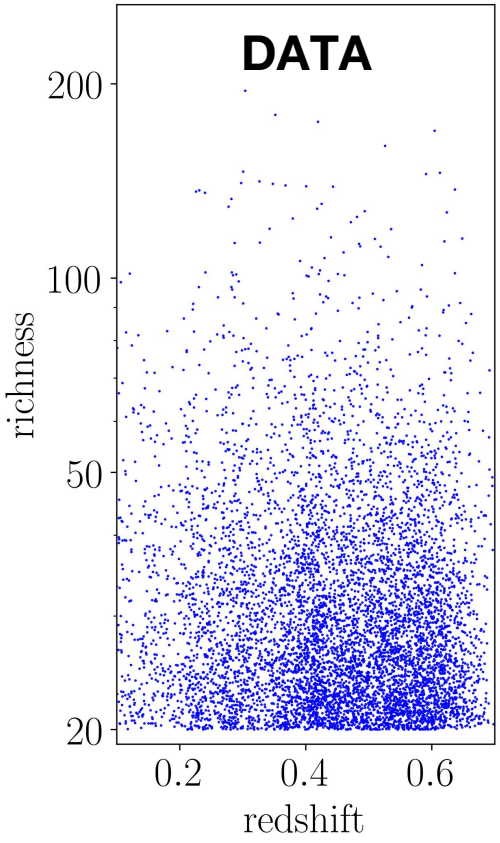
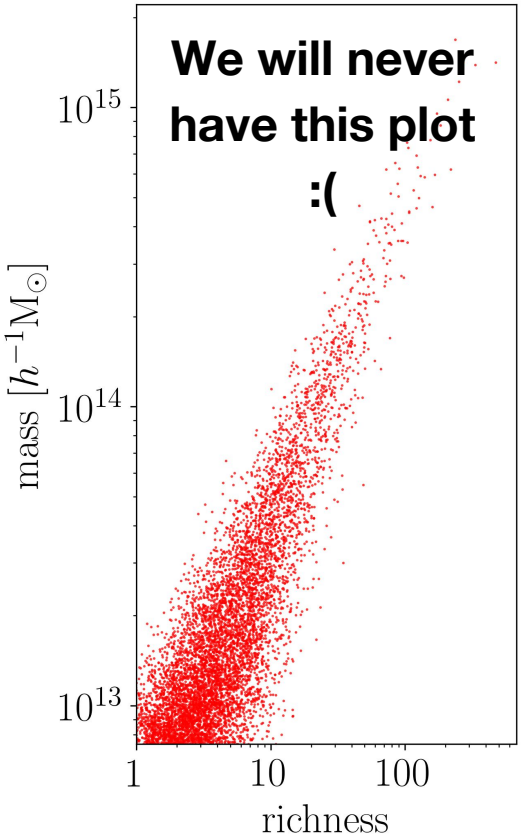
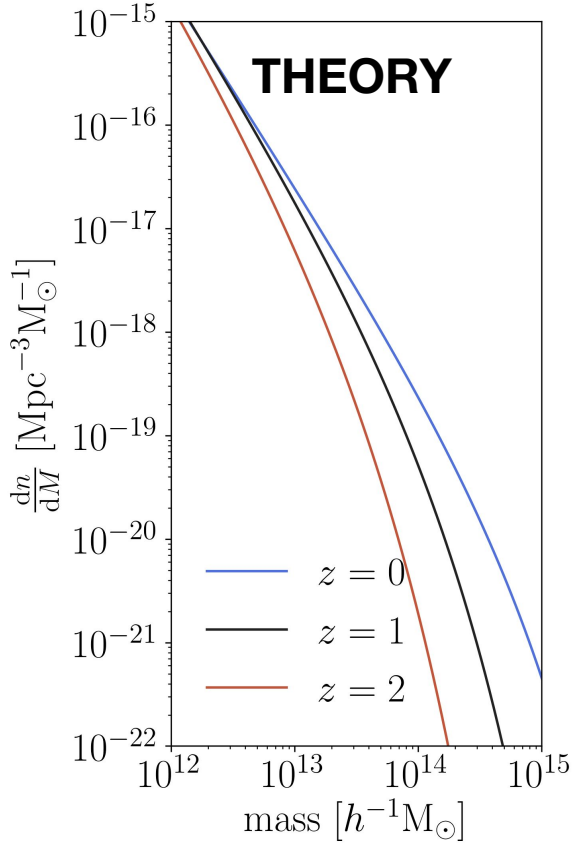
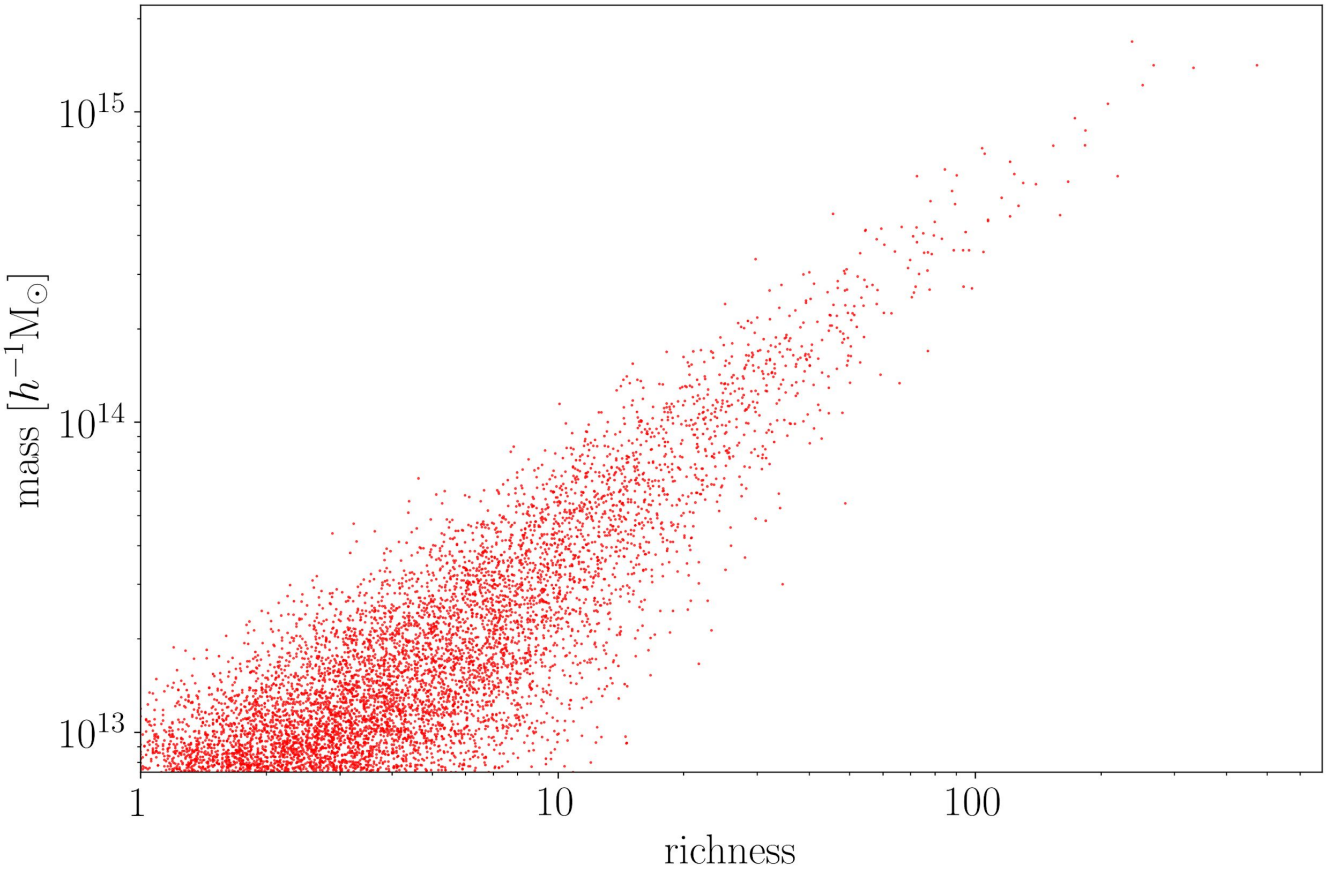






Cluster catalog vs. mass-richness relation



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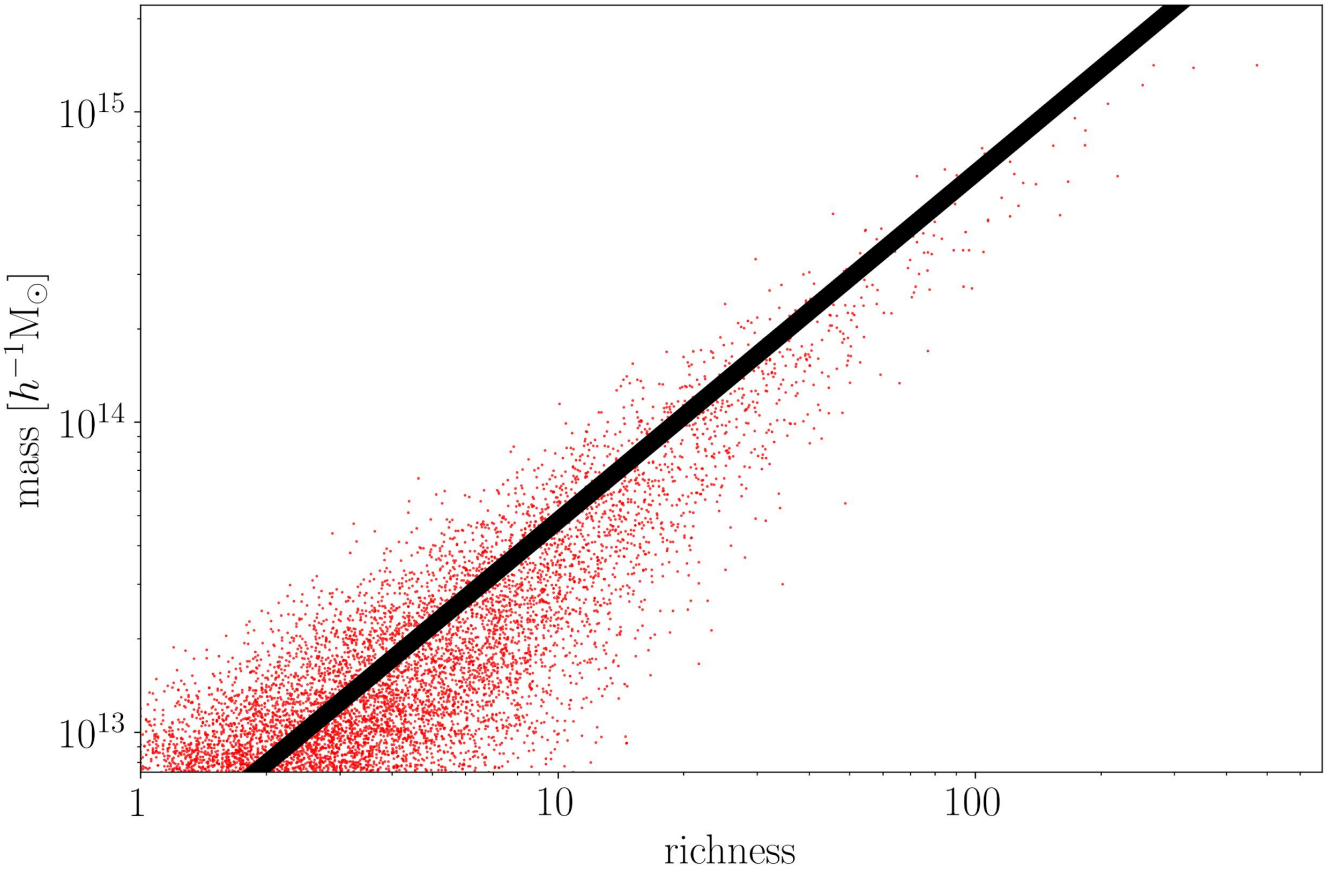
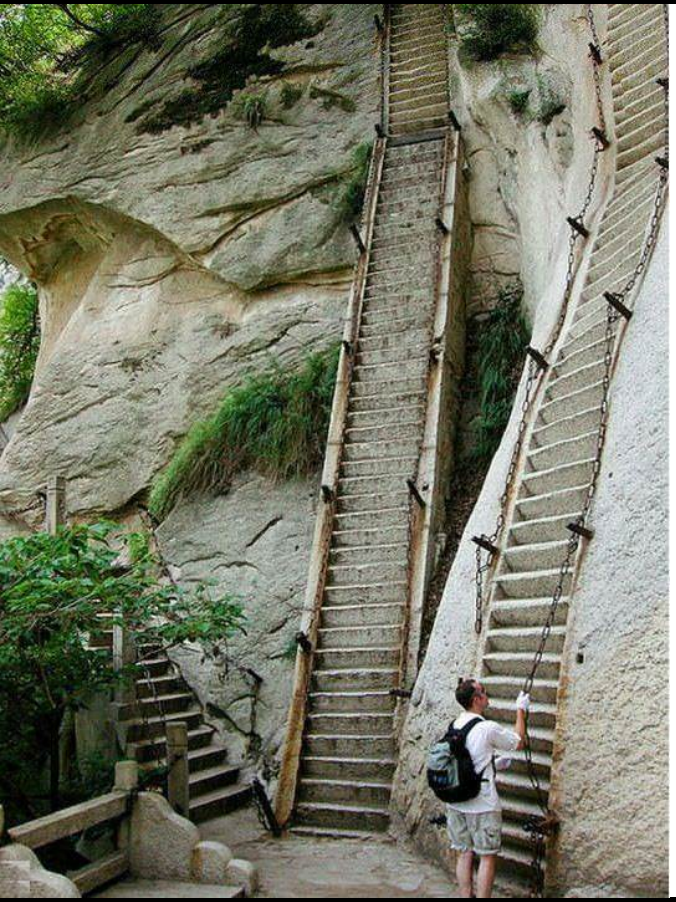


Galaxy cluster cosmology in 3 easy steps

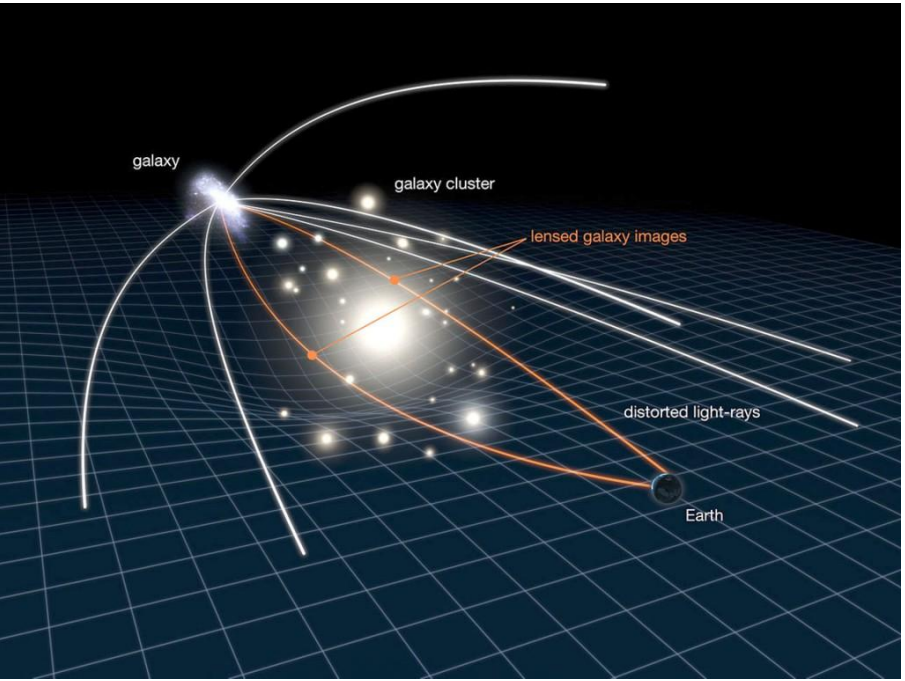


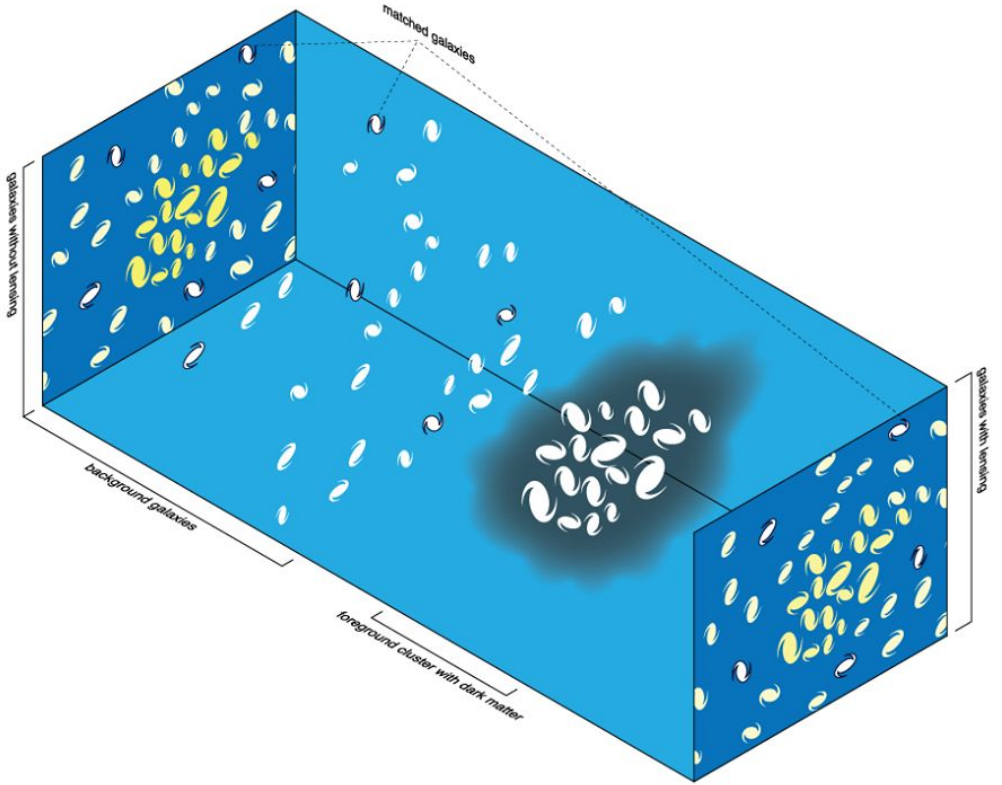
1. Find galaxy clusters

2. Measure cluster masses
   (see Mariana's talk)

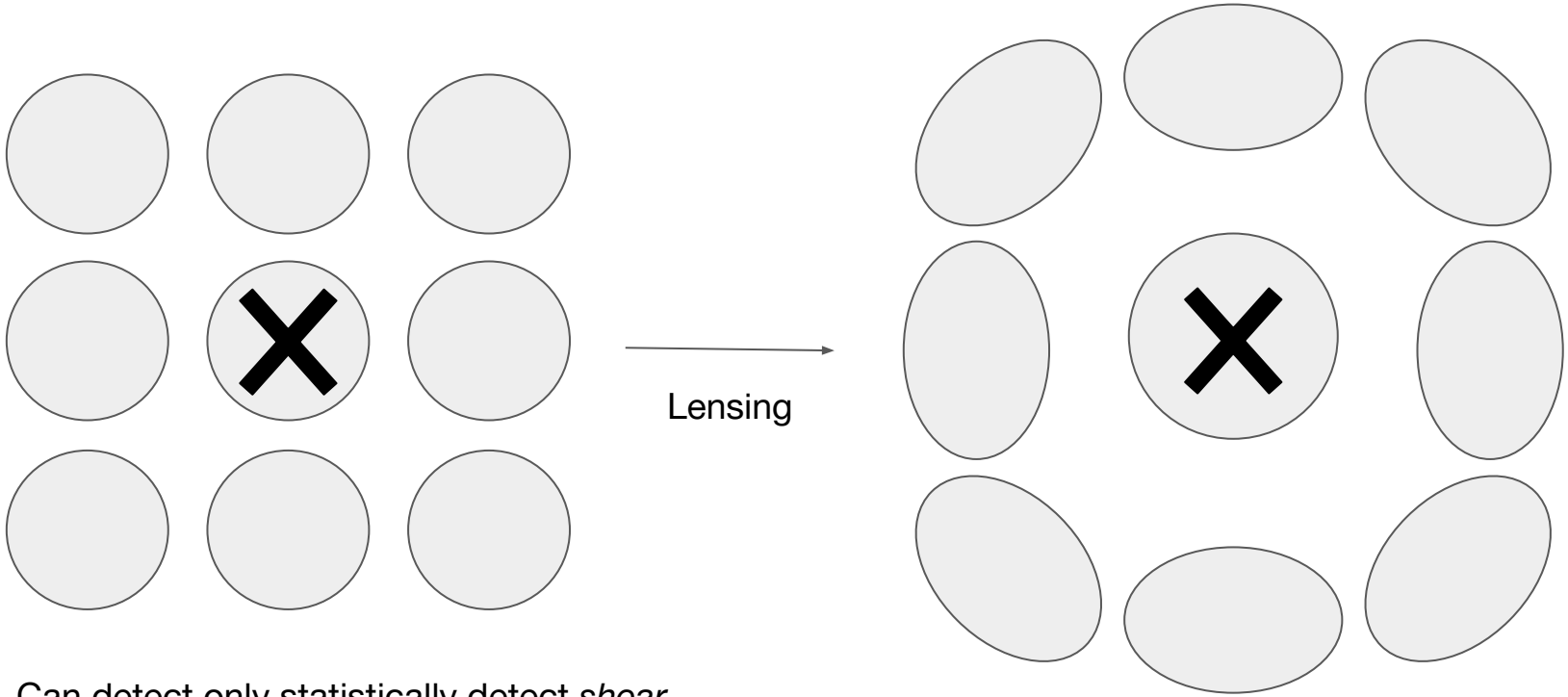
3. Model cluster abundance

Cluster masses from gravitational lensing



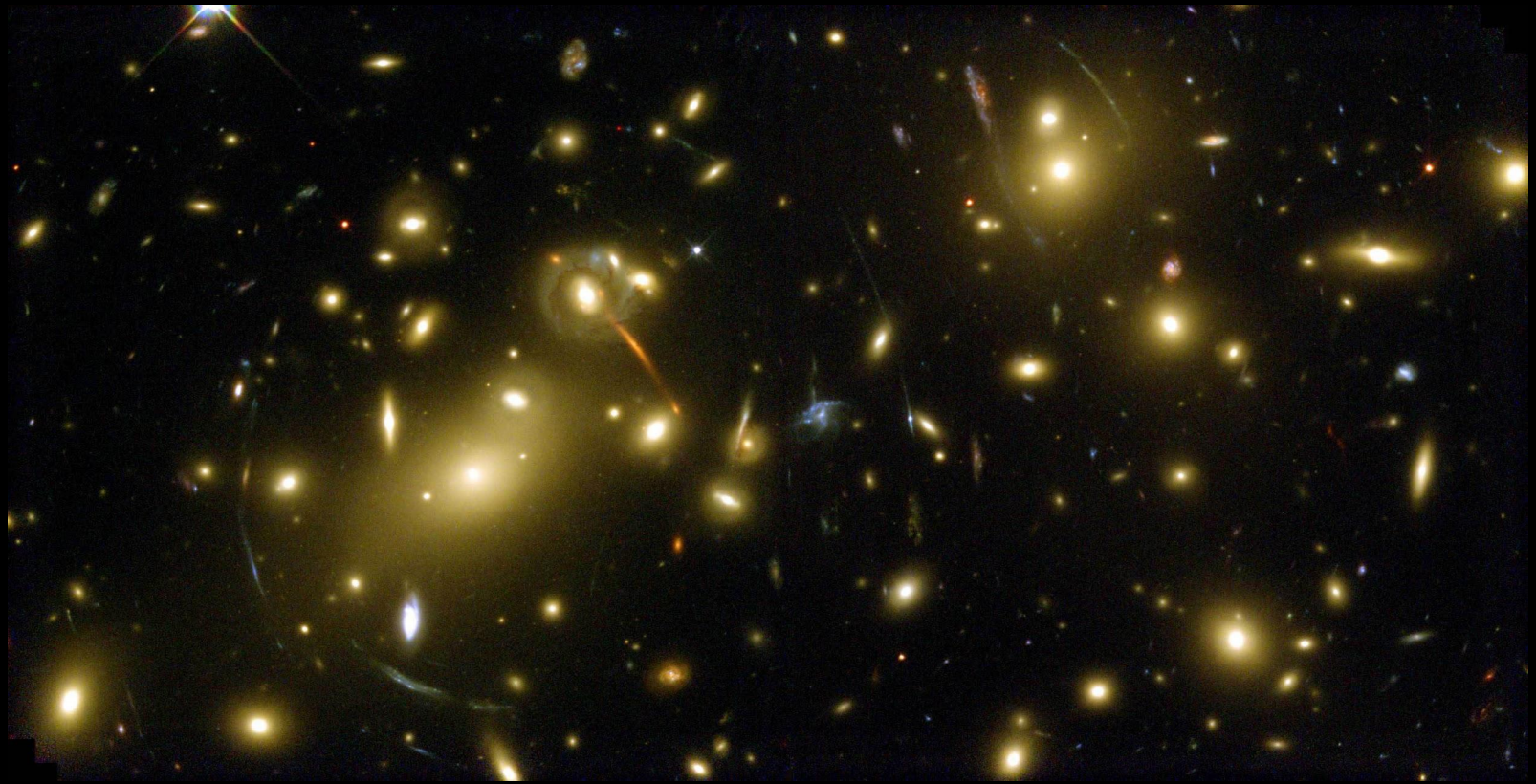


Weak gravitational lensing



Can detect only statistically detect *shear*.
Mean tangential ellipticity of *background galaxies* is sensitive to *cluster mass*.

Abell 2218 - gravitational lensing

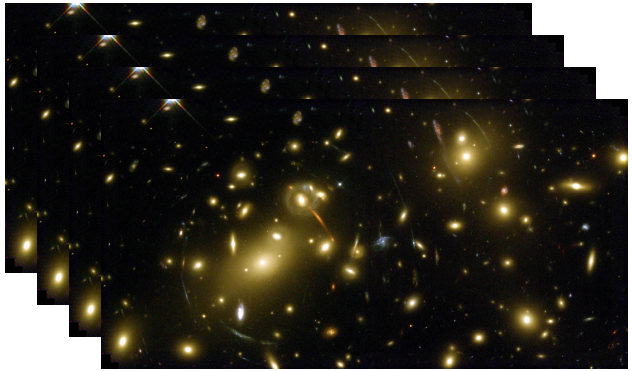


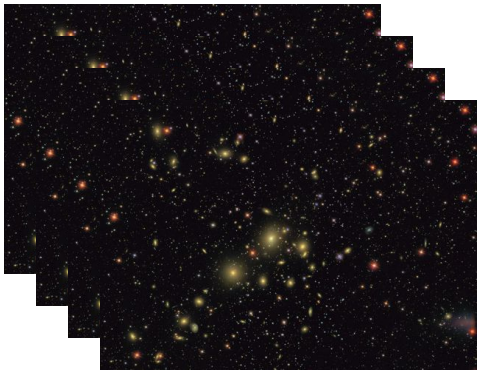
Cluster weak lensing in DES - stacking

Lensing signal is **noise dominated** for individual clusters.

With its large area, DES is great for a **stacked lensing analysis**.

Define groups of galaxy clusters grouped by **richness** and **redshift**, and stack their images.





Cluster weak lensing profiles

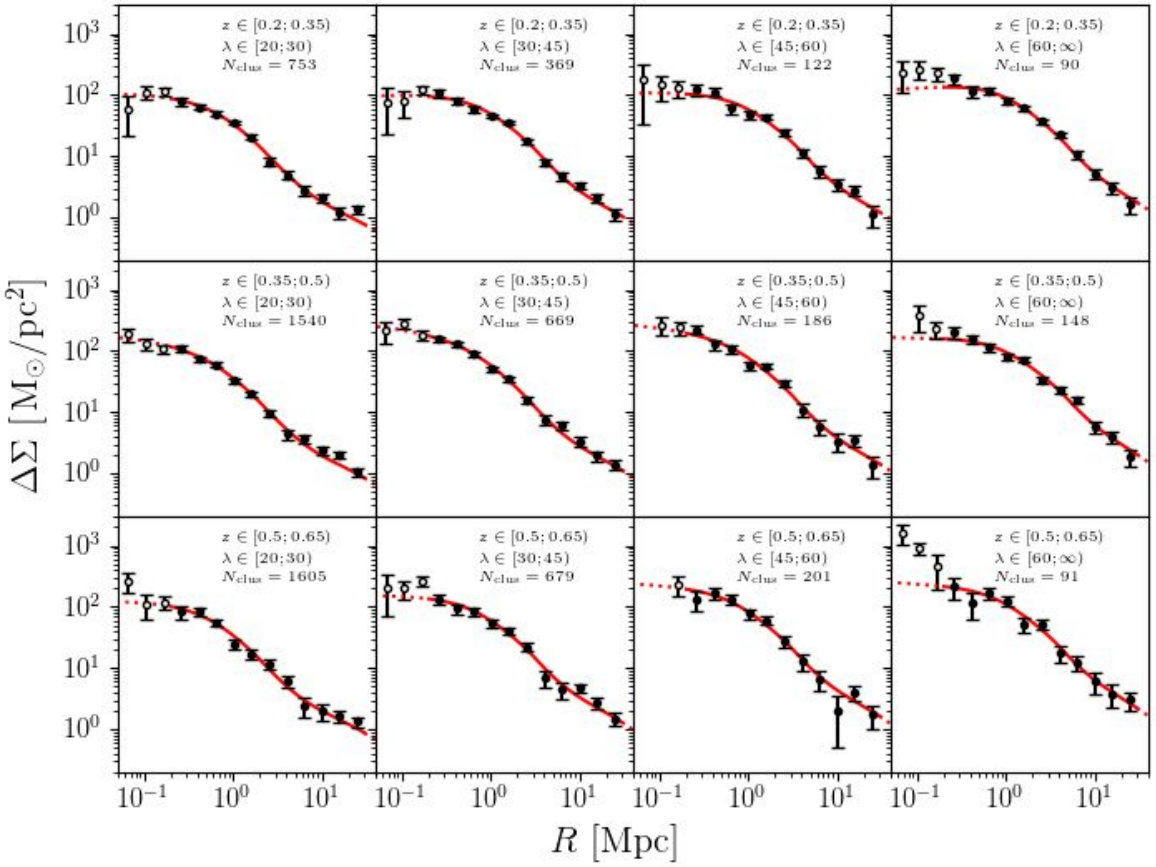
Cluster sample split by **redshift** (top to bottom) **richness** (left to right)

Black points:

- (differential) **surface mass density profile**
- Proportional to tangential shear

Red line:

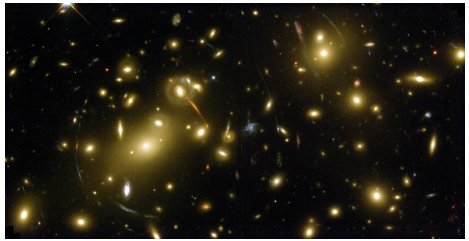
- best fit model



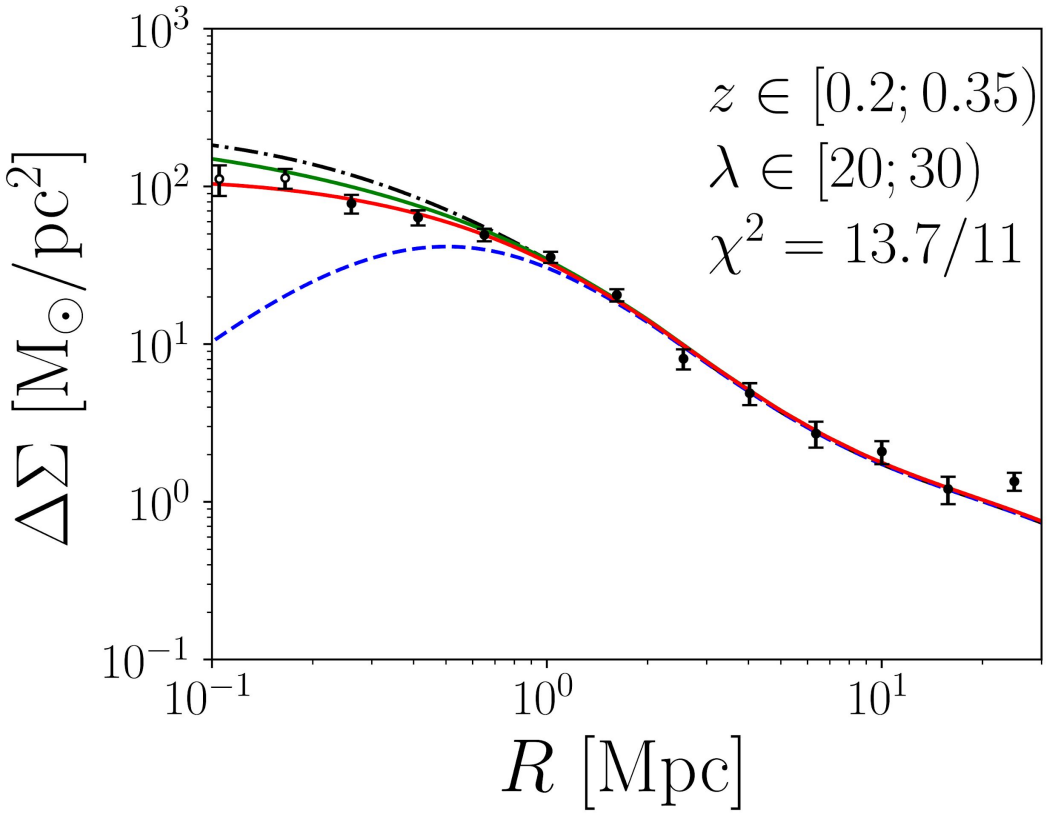
See: 1805.00039

Lensing model + systematics

Lensing model:
- centered (black .-)
- miscentered (blue -)
- boost factor, shear+pz (red)
- triaxiality+proj. (not shown)



Boost factor model (not shown):
- NFW 2-parameter model
- *De-boosted* the model lensing profile (See: 1812.05116)

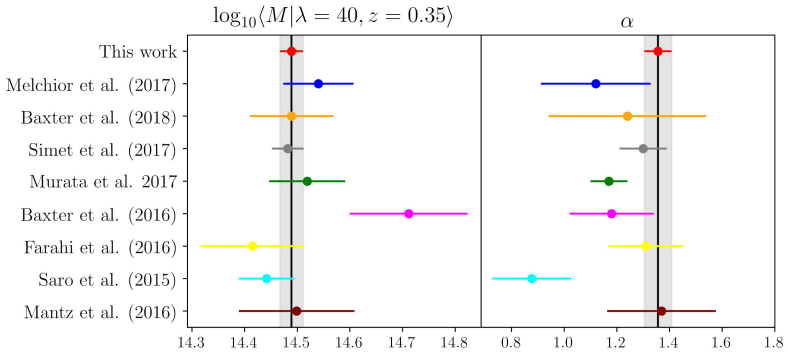


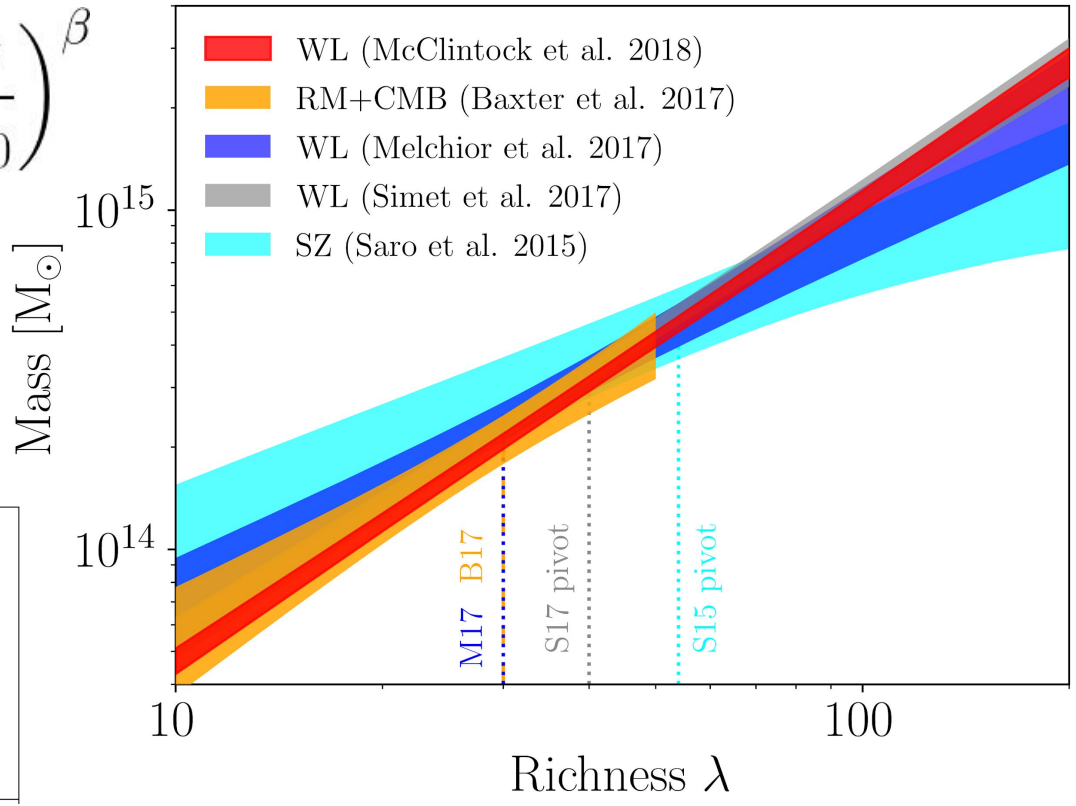
Mass--richness relation

$$\langle M|\lambda, z\rangle = M_0 \left(\frac{\lambda}{\lambda_0}\right)^{\alpha} \left(\frac{1+z}{1+z_0}\right)^{\beta}$$

Stacked masses measured at the 8% level.

Normalization constrained at the 5% level.





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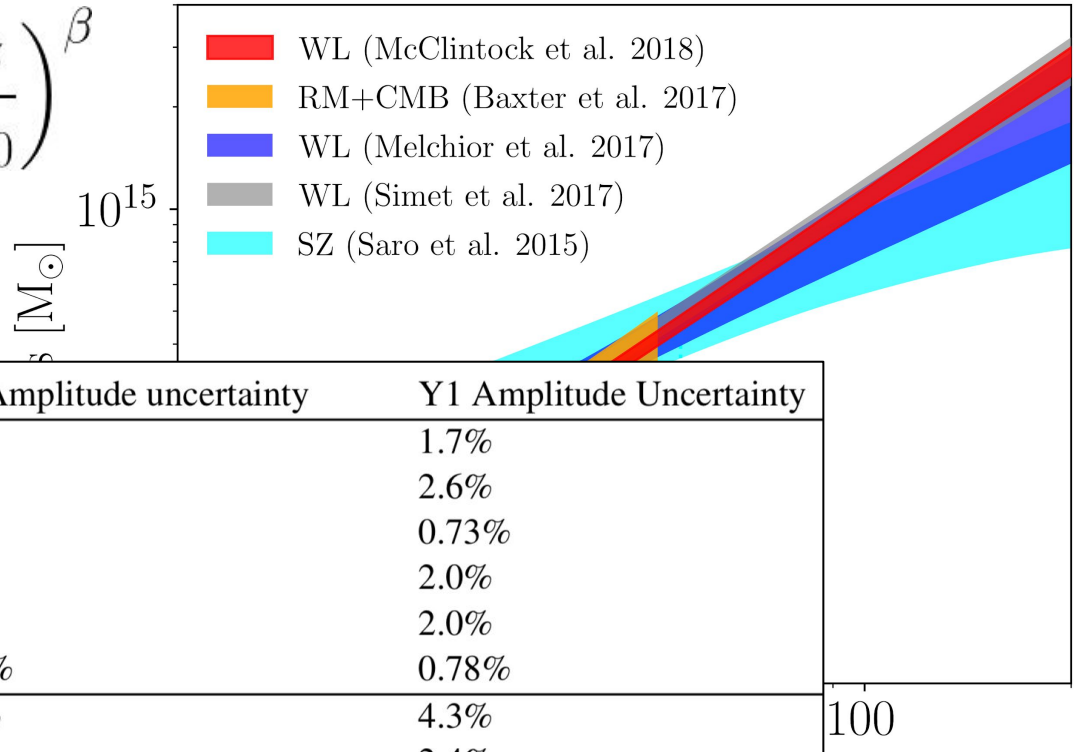

Source of systematic	SV Amplitude uncertainty	Y1 Amplitude Uncertainty
Shear measurement	4%	1.7%
Photometric redshifts	3%	2.6%
Modeling systematics	2%	0.73%
Cluster triaxiality	2%	2.0%
Line-of-sight projections	2%	2.0%
Membership dilution + miscentering	$\leqslant$ 1%	0.78%
Total Systematics	6.1%	4.3%
Total Statistical	9.4%	2.4%
Total	11.2%	5.0%

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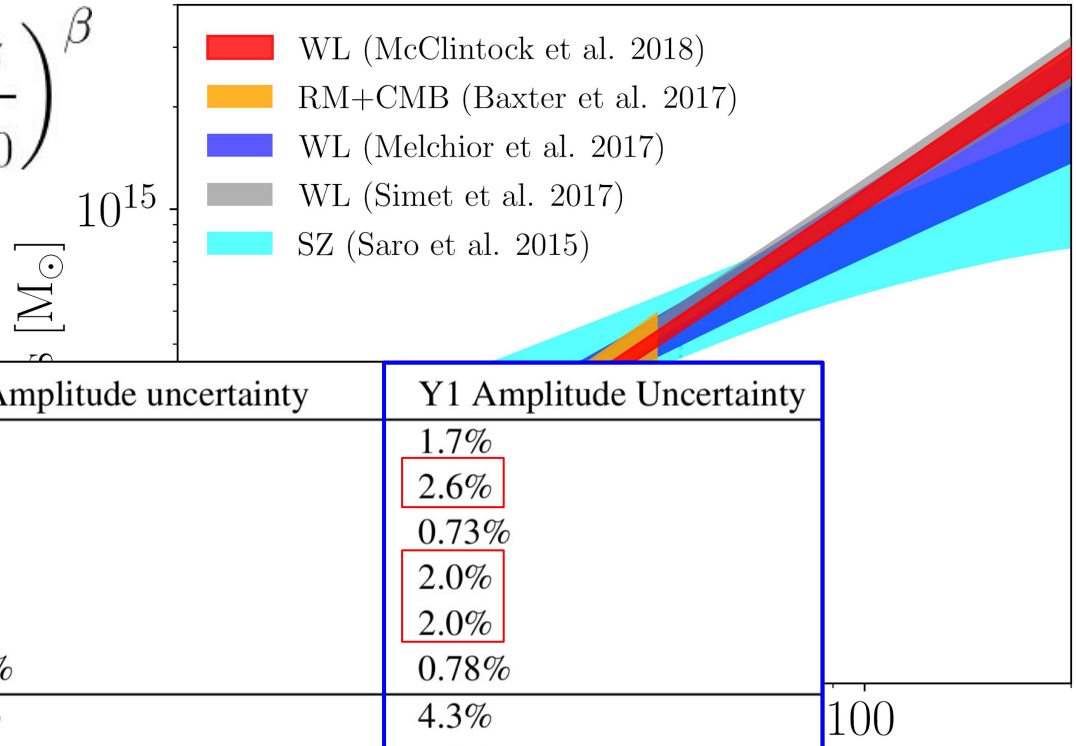

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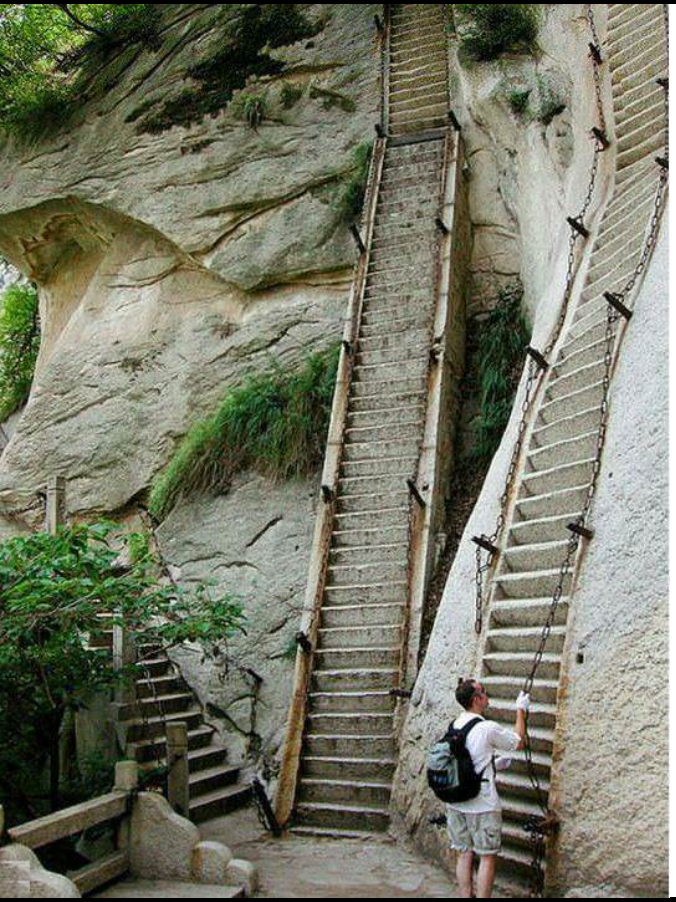

1. Find galaxy clusters

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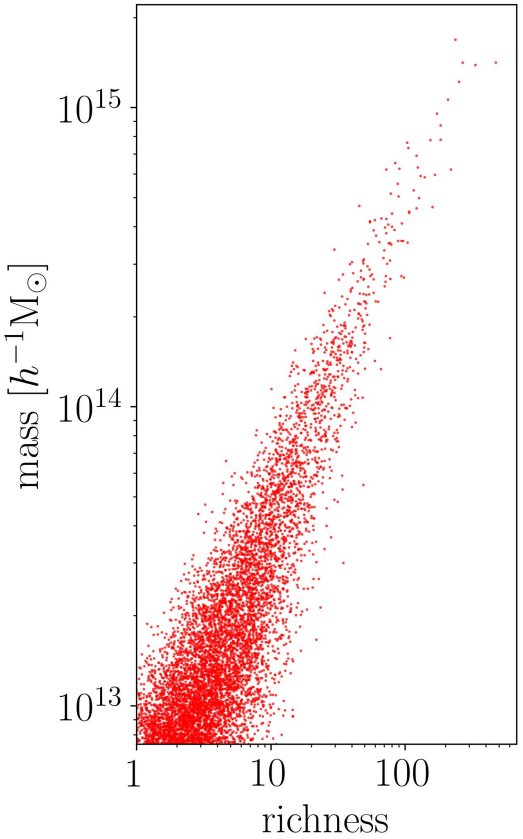
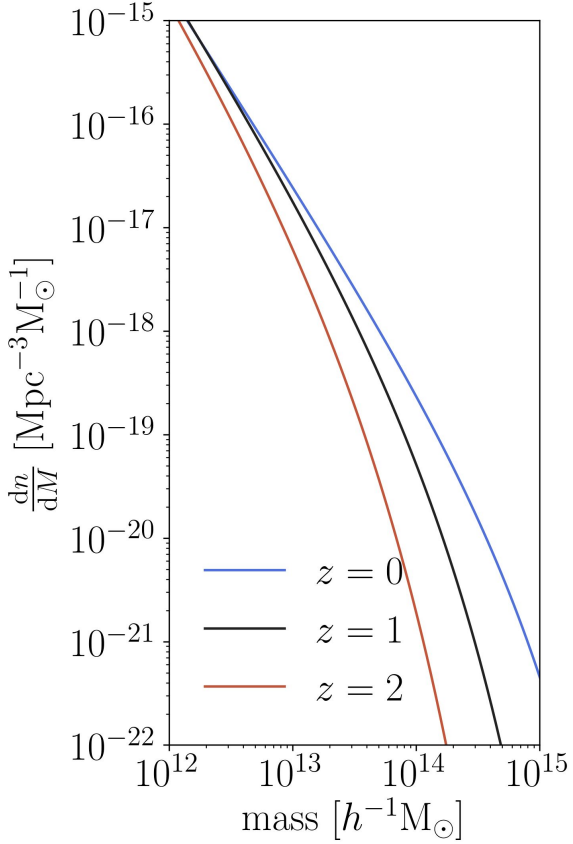
Cluster abundance

1) Projection effects cause scatter in cluster richnesses

2) S-T or Tinker mass functions are accurate at the 5% level or worse!





Cluster abundance - Problems!

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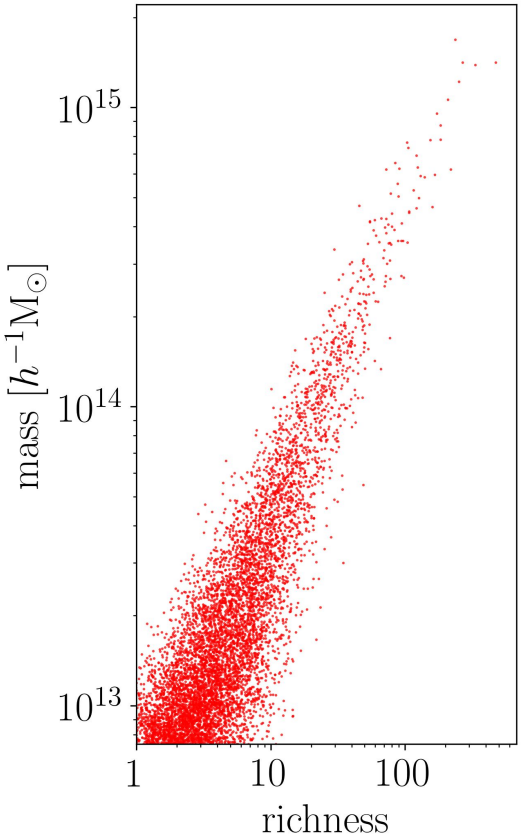
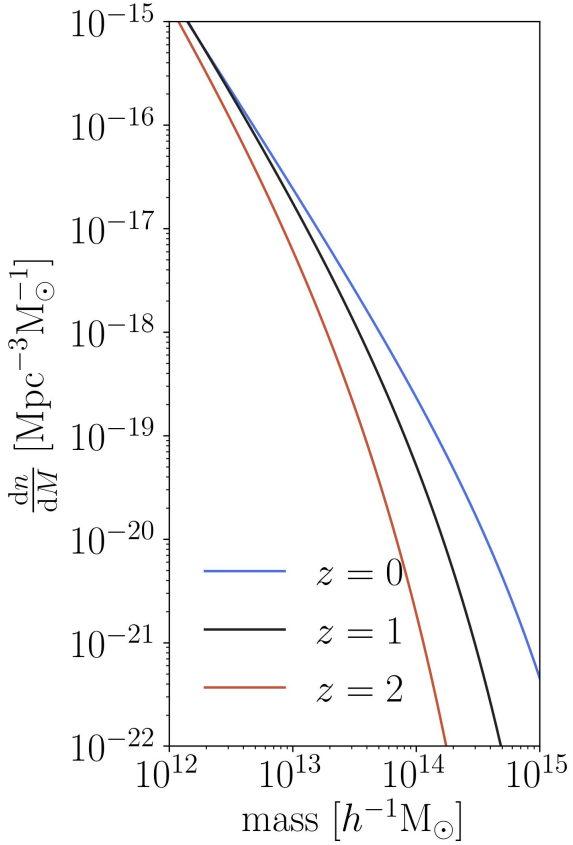
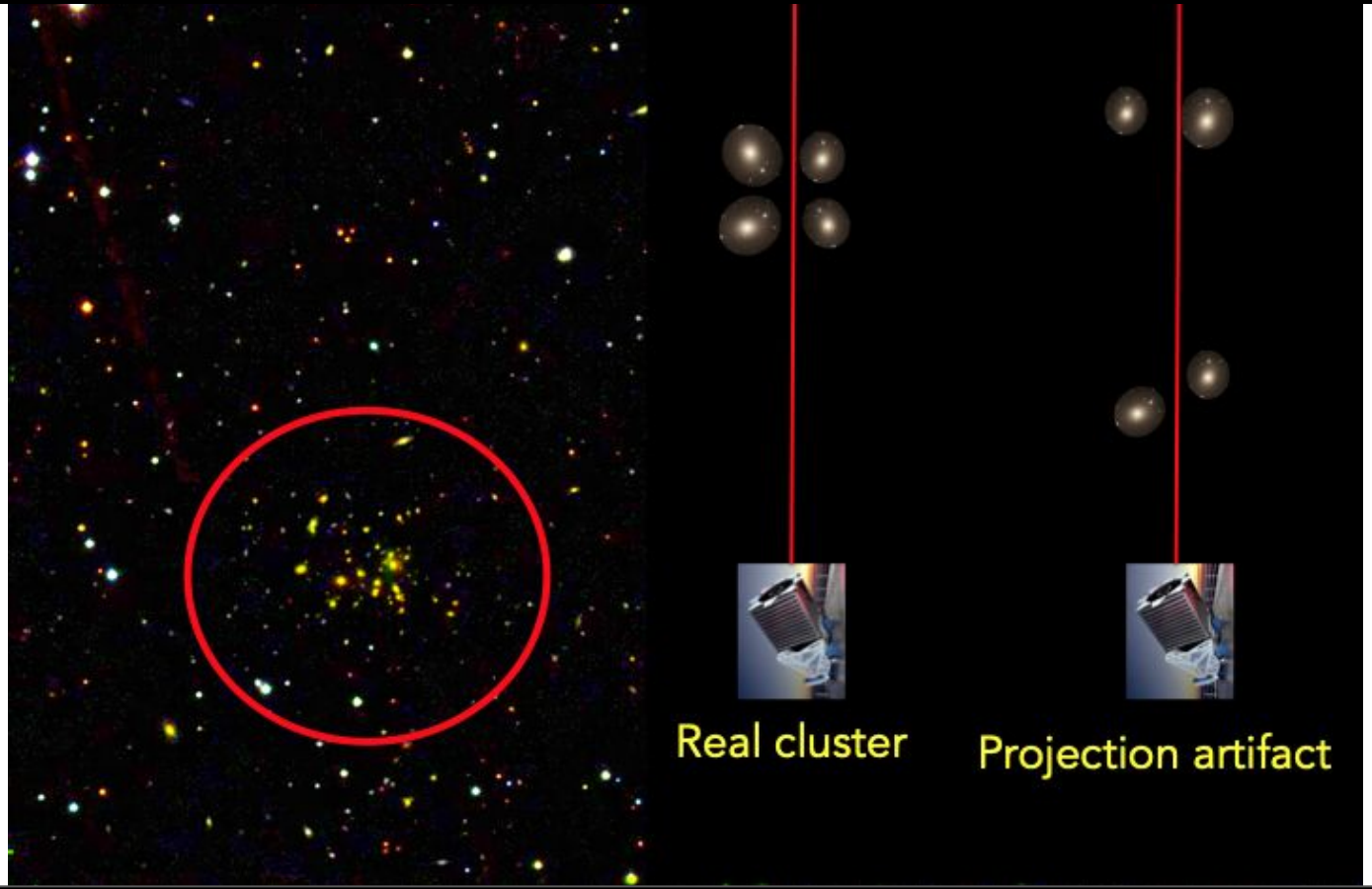
2) S-T or Tinker mass functions are accurate at the 5% level or worse!





Projection effects



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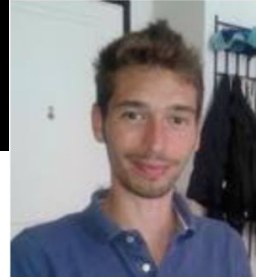
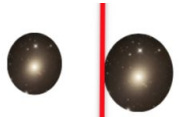


Need to know how many of these galaxies

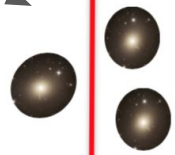
Bleed into these clusters

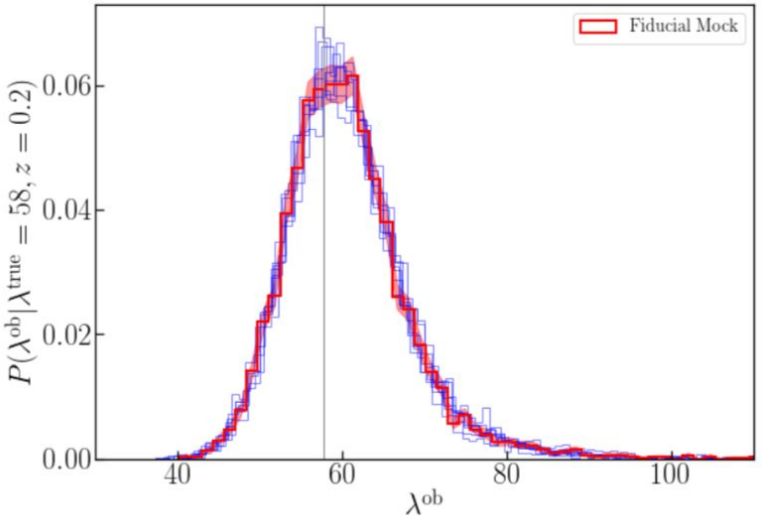
$$\lambda_{\rm total} = \lambda_1 + f\lambda_2$$

- Successfully reproduced in mocks
- Calibrated *using* the data, meaning this effect introduces *no extra free parameters*



2





Costanzi et al.: 1807.07072

Cluster abundance

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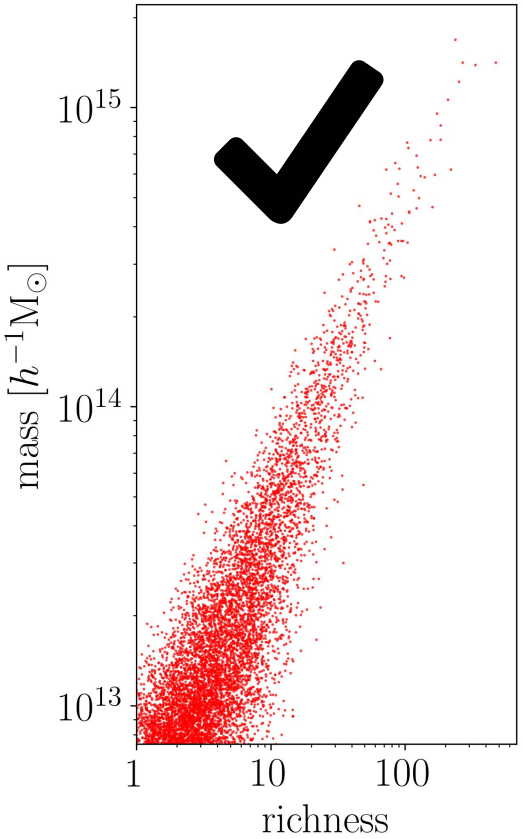

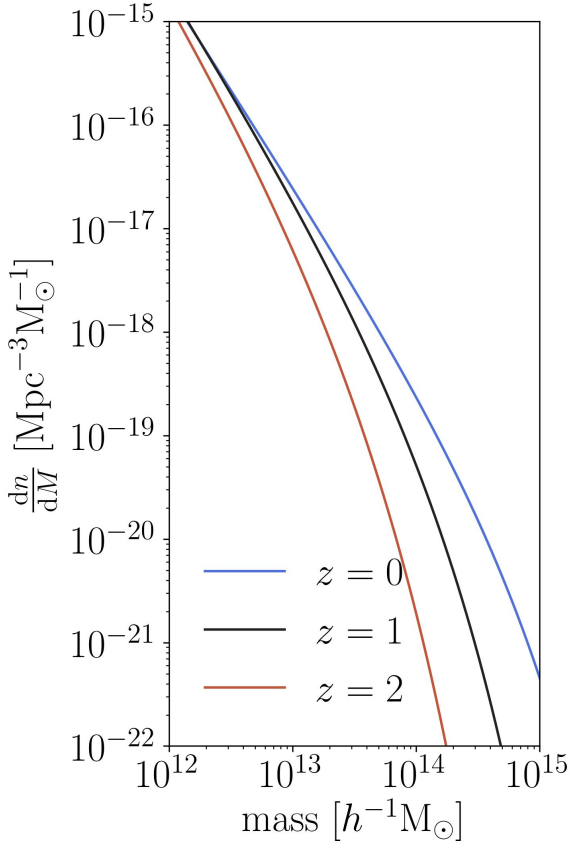

Cluster abundance - Problems!

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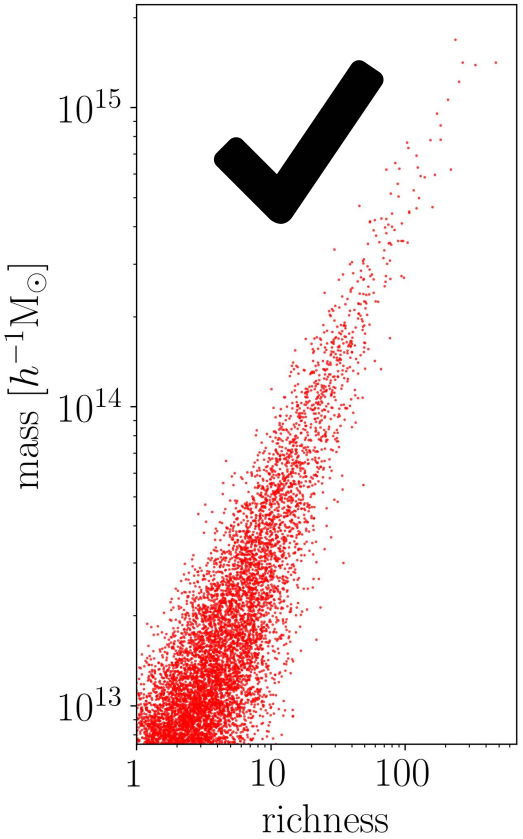
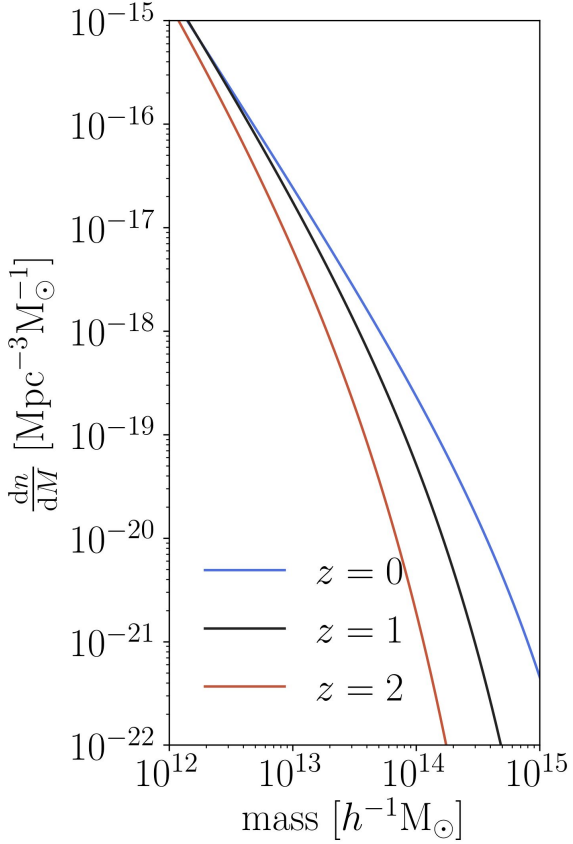
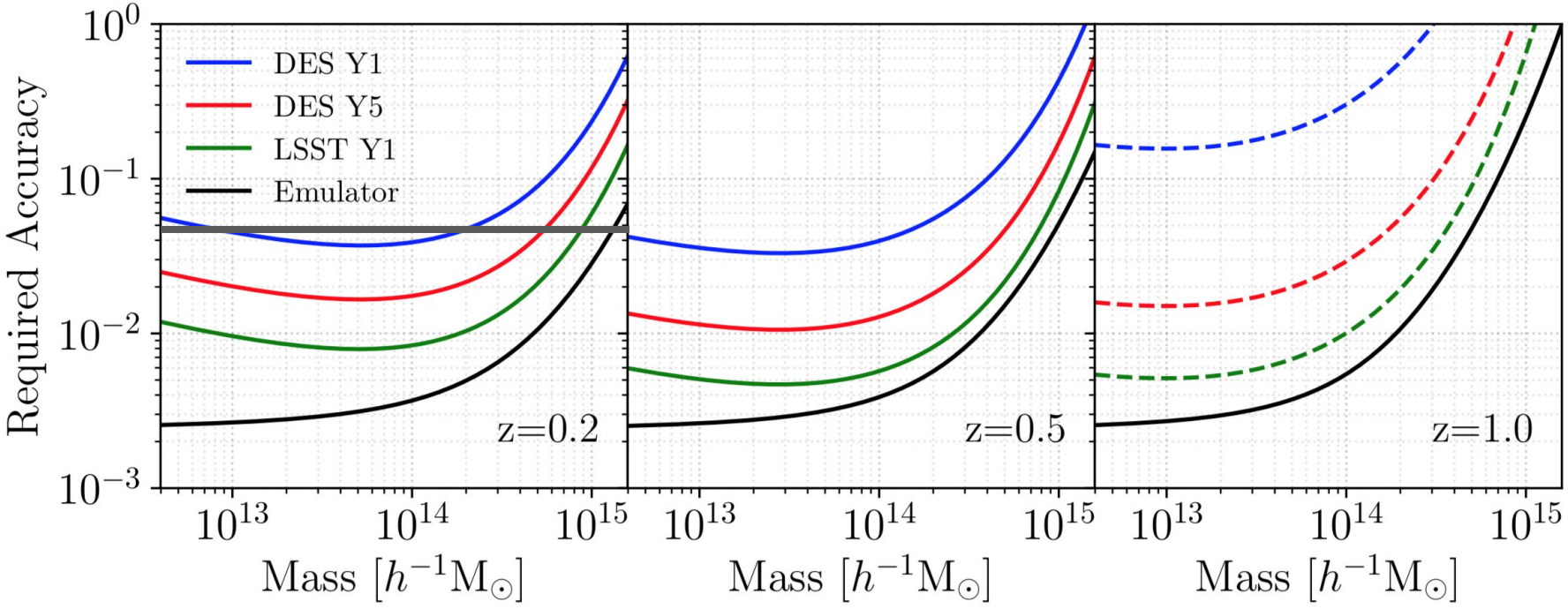
2) S-T or Tinker mass functions are accurate at the 5% level or worse!

This would **dominate** the error budget in LSST!



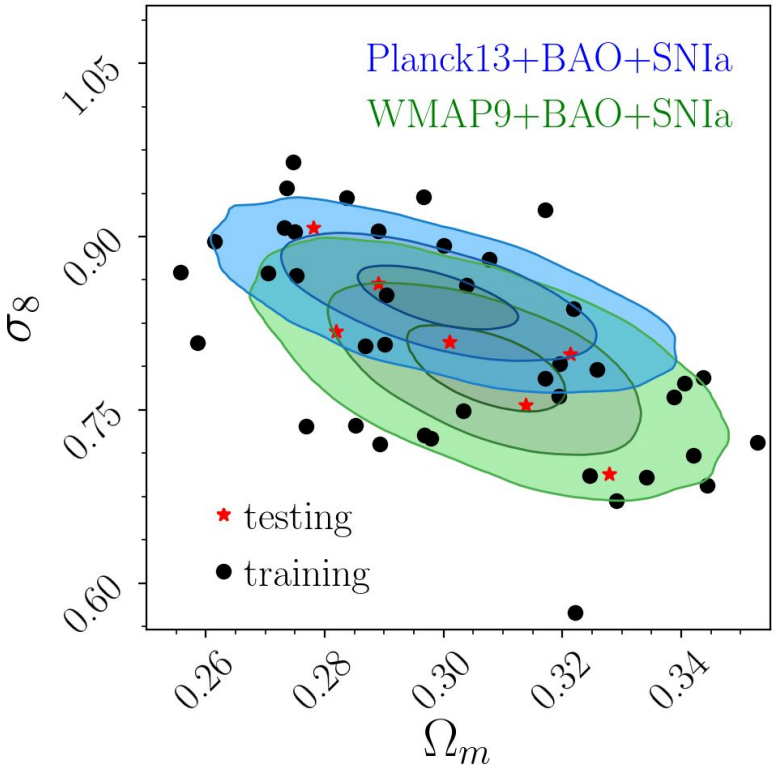


Mass function model needed for LSST!



Cluster cosmology would be **systematics limited**

Solution - interpolate between simulations



Suite of **simulations** (40 training, 35 testing)

Spread out in a 7 dimensional cosmological parameter space

- 2 dimensions shown here

Measure cluster abundance in sims

Use **machine learning** techniques to **interpolate** between simulations.

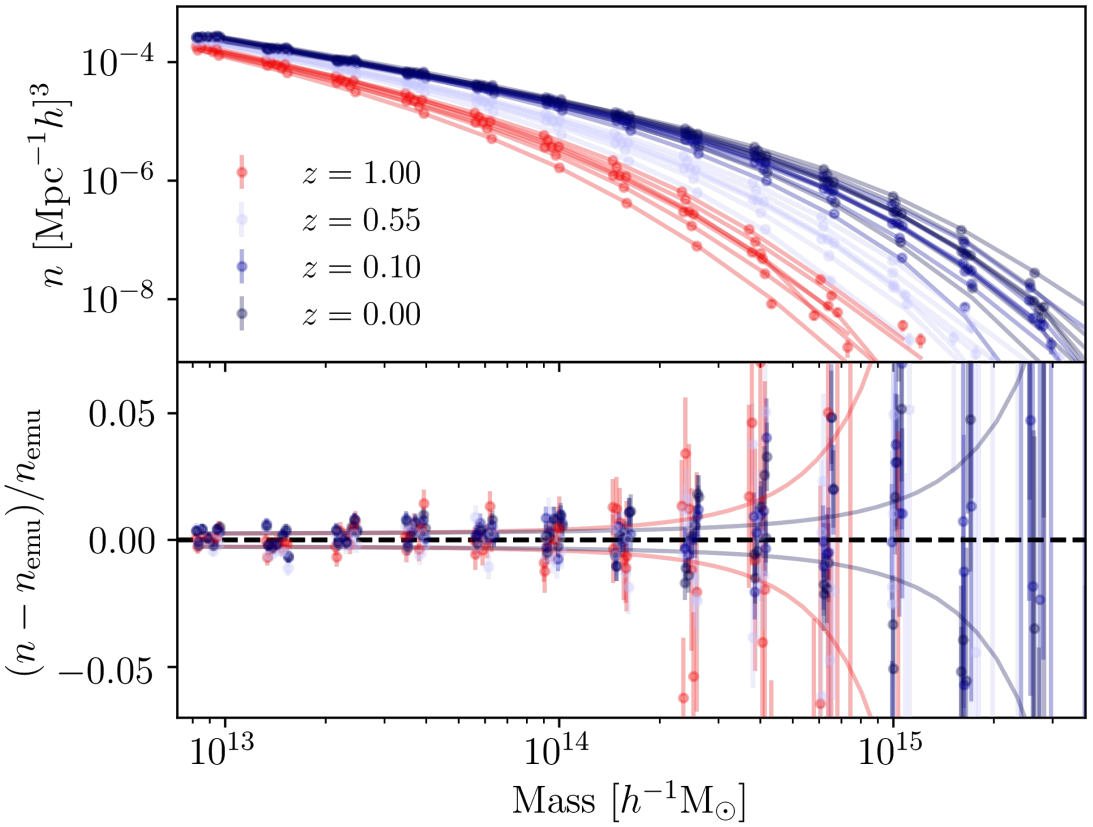
Test simulations

Predicting abundance at arbitrary cosmology is crucial!

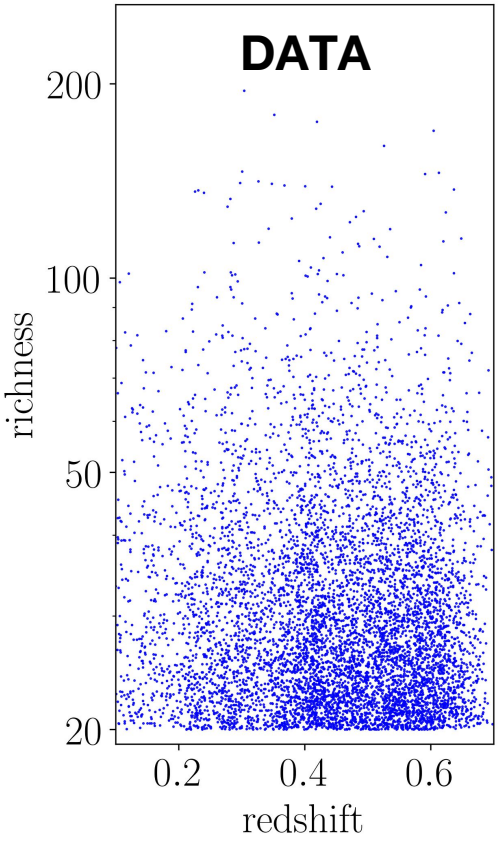
Training simulations were less accurate than the testing simulations.

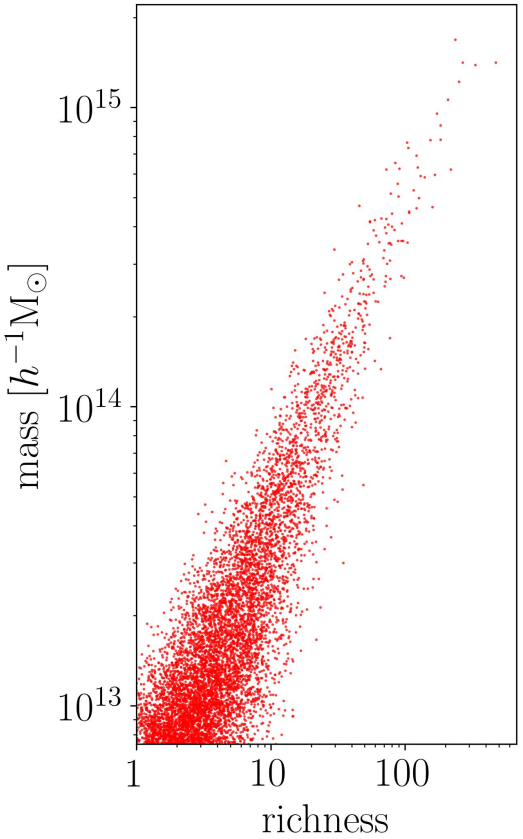
Achieved ~1% accuracy for interesting mass scales.

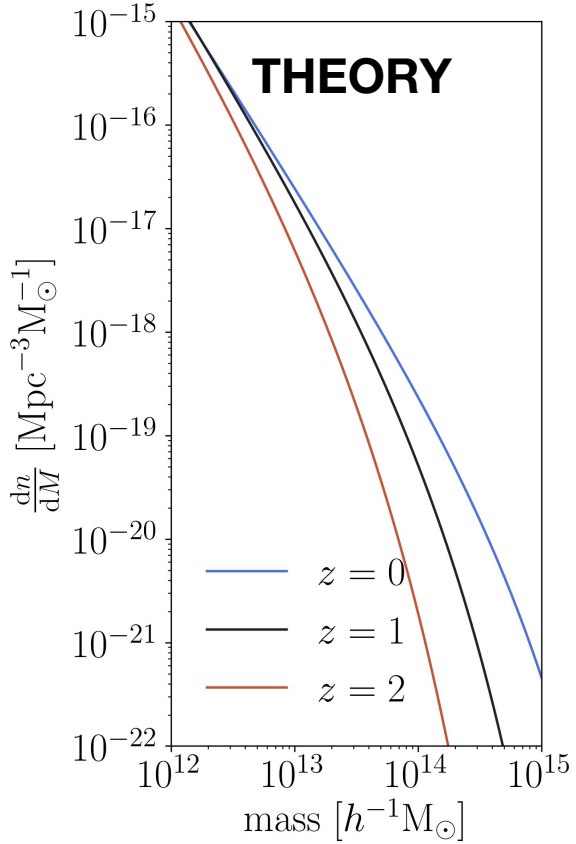
See: 1804.05866



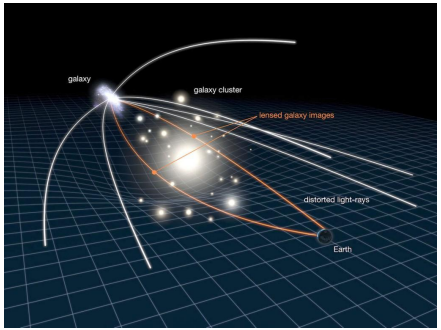
Cluster cosmology 101

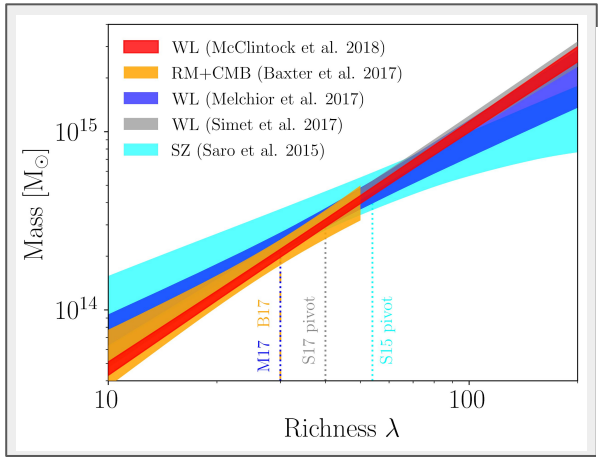


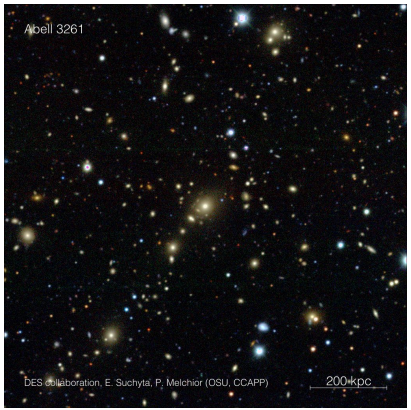


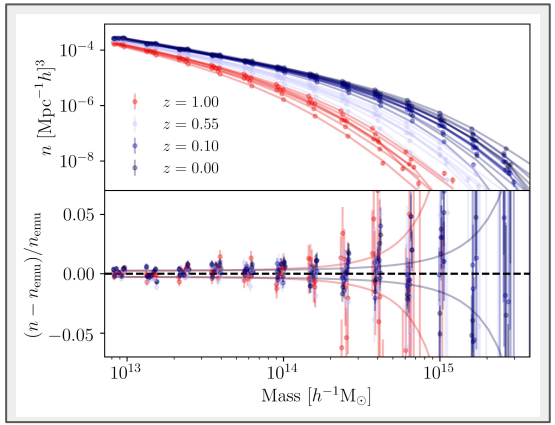


Enabling galaxy cluster cosmology in DES









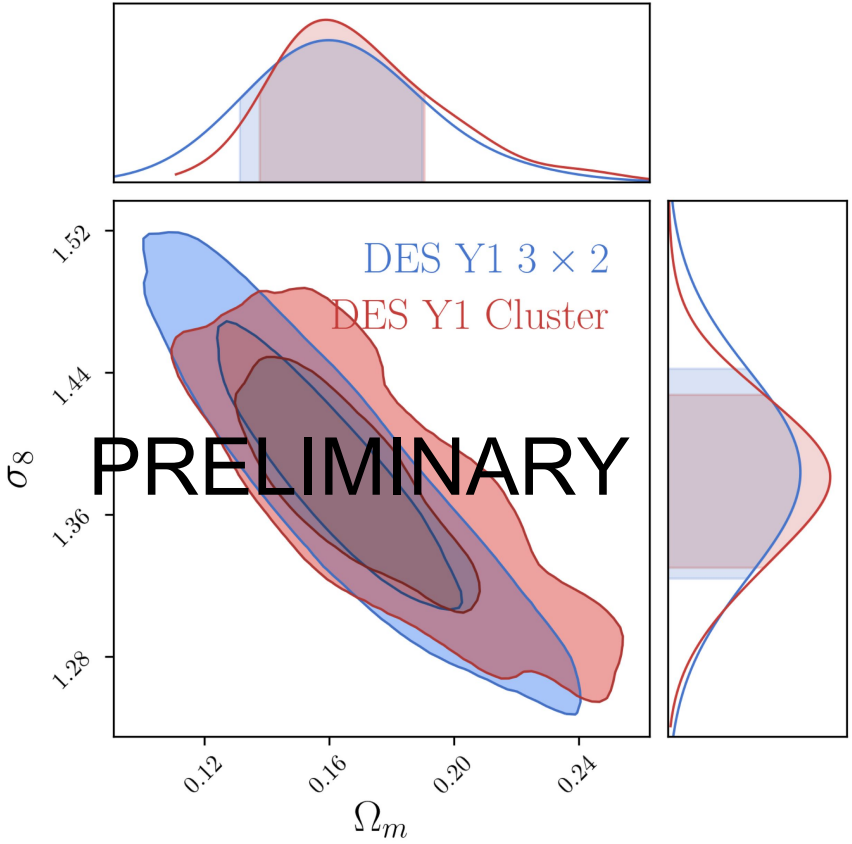


Image courtesy of M. Costanzi

Thank you!

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