

*mm Universe 2025, Chicago, June 24, 2025*

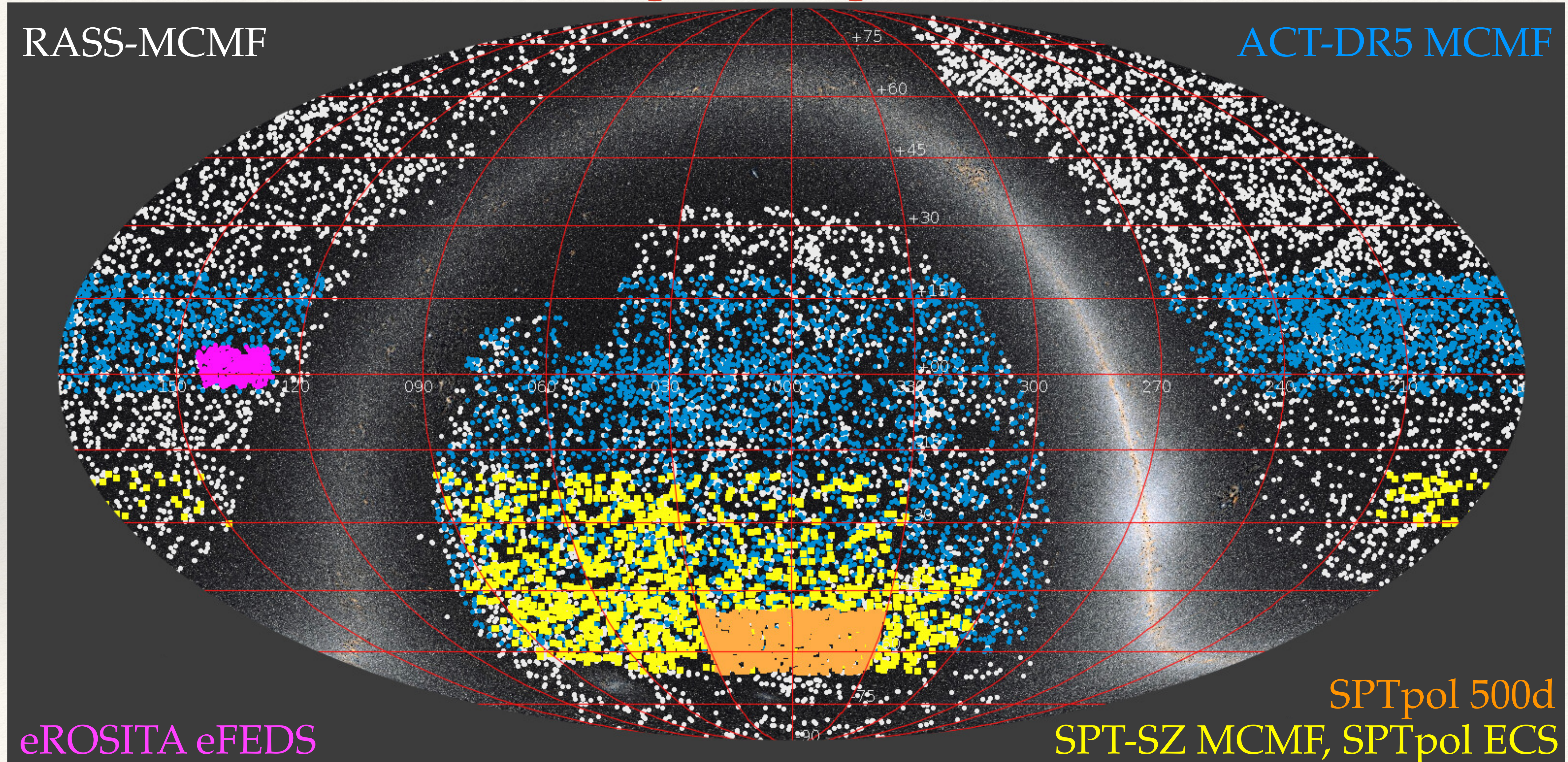
# Well-understood SZ and X-ray cluster catalogs for cosmology

by Matthias Klein, LMU Munich

In collaboration with: J. Mohr, S. Bocquet, L. Bleem, I. Chiu, C. Davies, D. Hernandez-Lang, A. Singh and S. Vogt  
and the SPT, DES and Euclid collaborations



# Some cluster catalogs using MCMF confirmation





# Cluster catalogs using MCMF confirmation

## SZ surveys

### SPT:

- ❖ SPT-SZ MCMF (813 clusters, DES+WISE, Klein+24a)
- ❖ SPTpol 500d (544 clusters, DES+WISE, Bleem+24)
- ❖ SPT-3G EDFS (188 confirmed clusters, DESI LSDR10, Archipley+25)

### Planck:

- ❖ PSZ-MCMF (853 clusters, DES, Hernandez-Lang+23)

### ACT

- ❖ ACT-DR5 MCMF (6,237 clusters, LS DR10+ WISE, Klein+24b)

## X-ray surveys

### ROSAT:

- ❖ 2RXS x DES-SV (88 clusters, Klein+18)
- ❖ MARD-Y3 (2,953 clusters, DES, Klein+19)
- ❖ RASS-MCMF (8,449 clusters, DESI LSDR10, Klein+24)

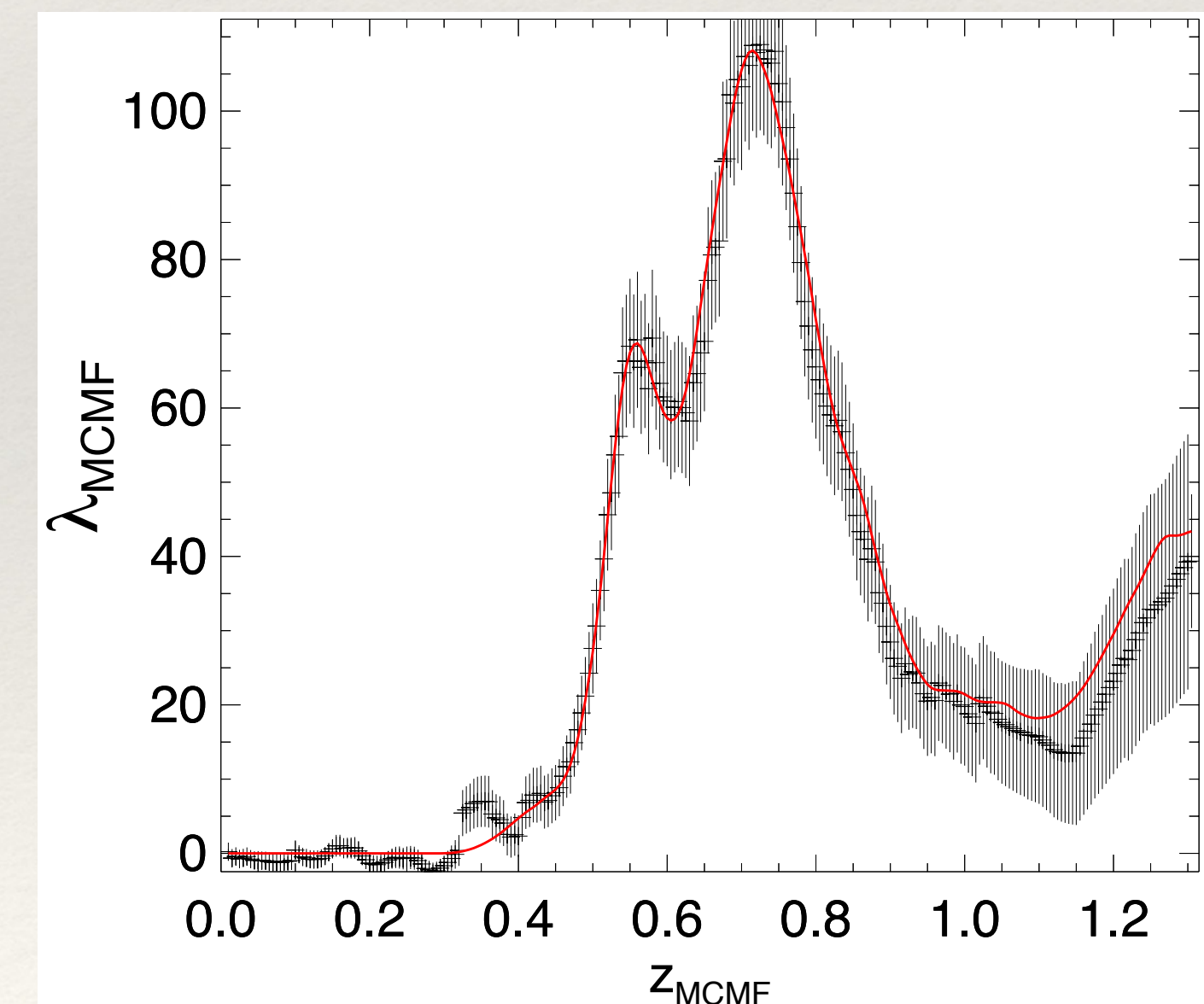
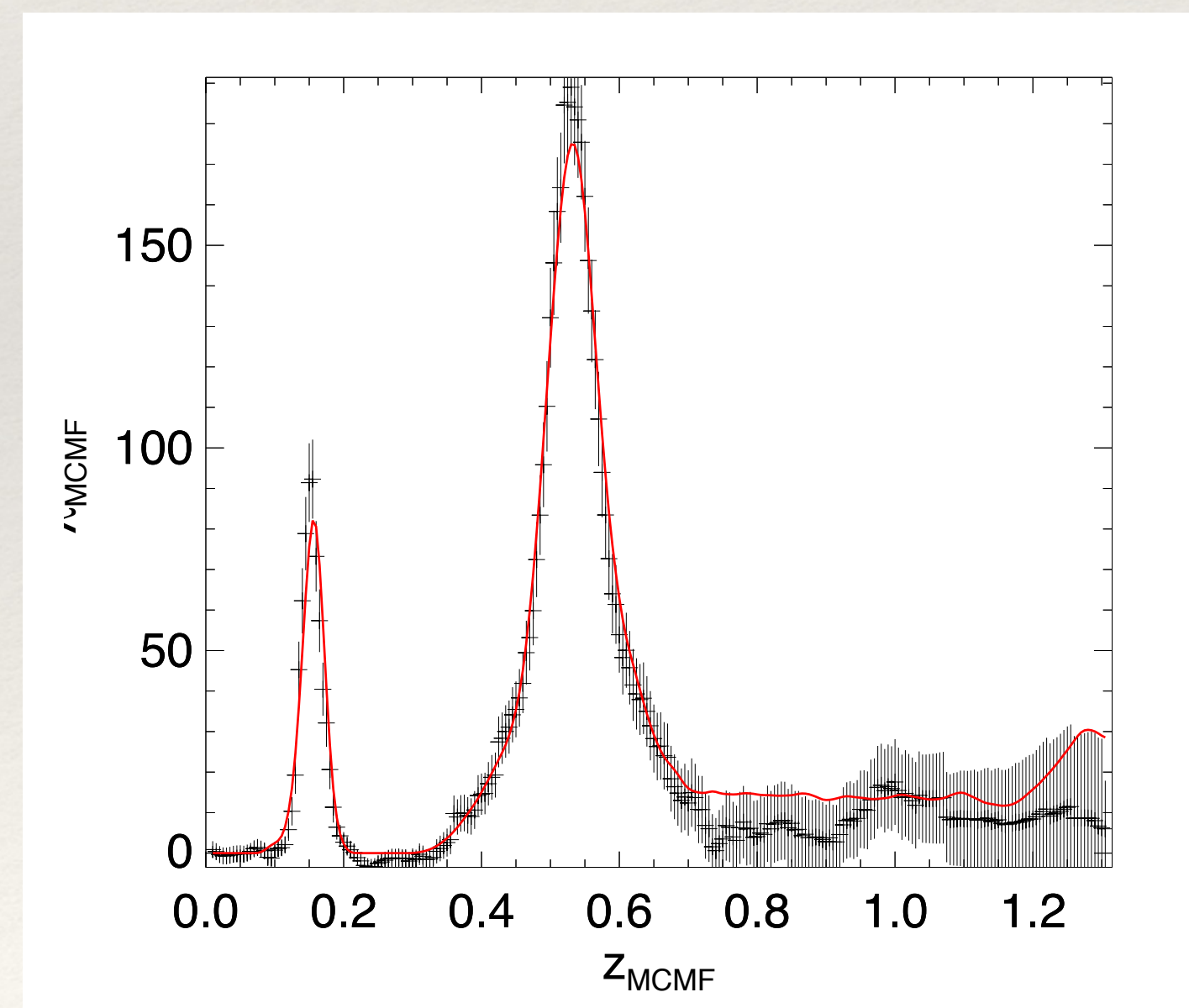
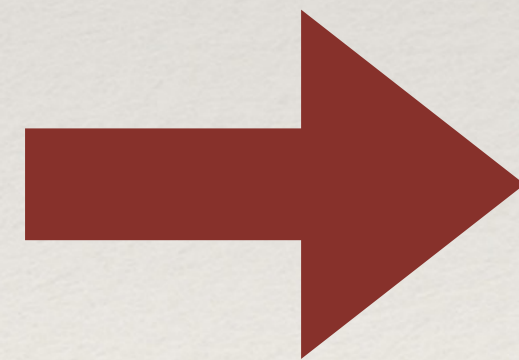
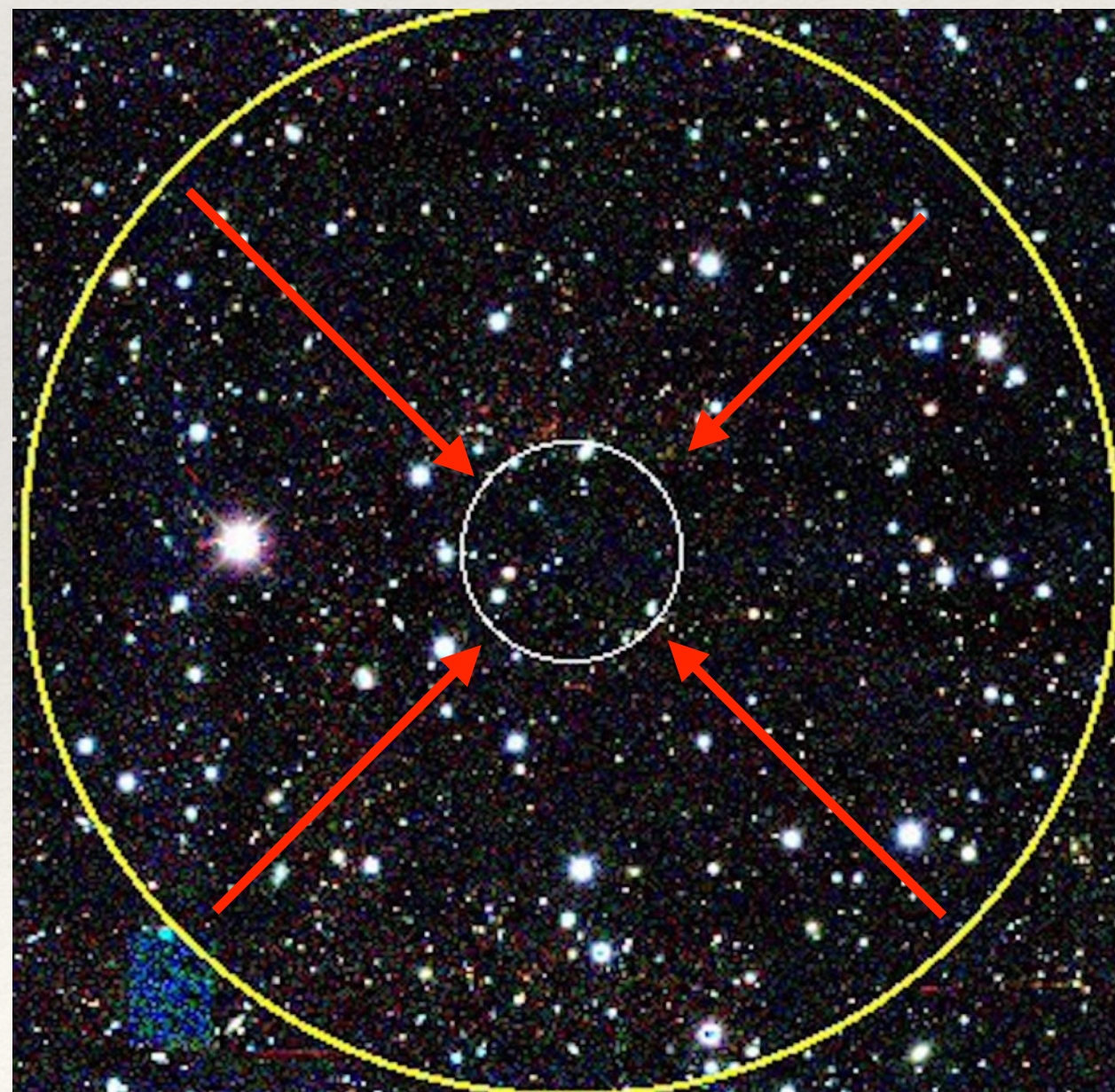
### eROSITA:

- ❖ eFEDS group and cluster catalog (477 clusters, Liu+22, Klein+22)
- ❖ eFEDS clusters in PS sample (Bulbul+22)



# Multi-Component Matched Filter (MCMF) confirmation tool

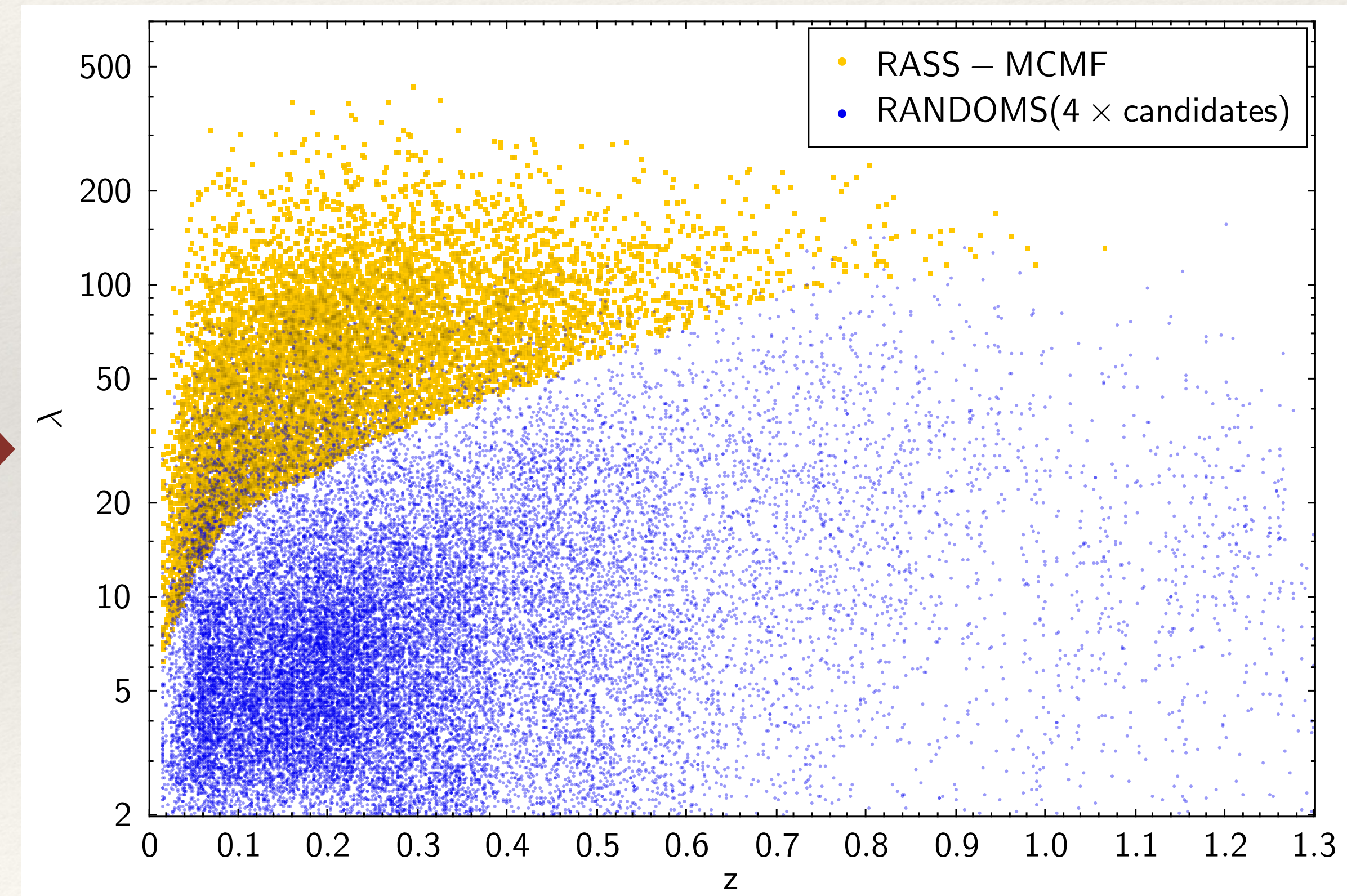
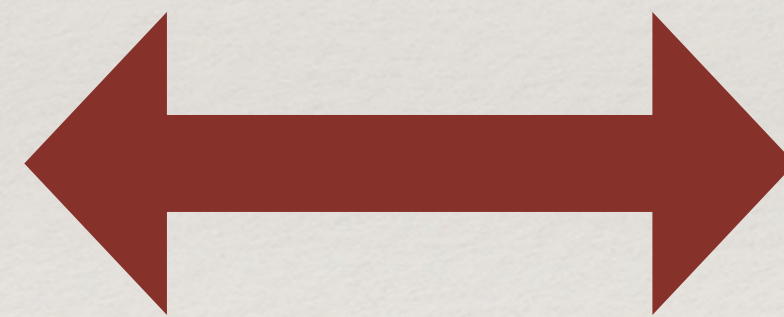
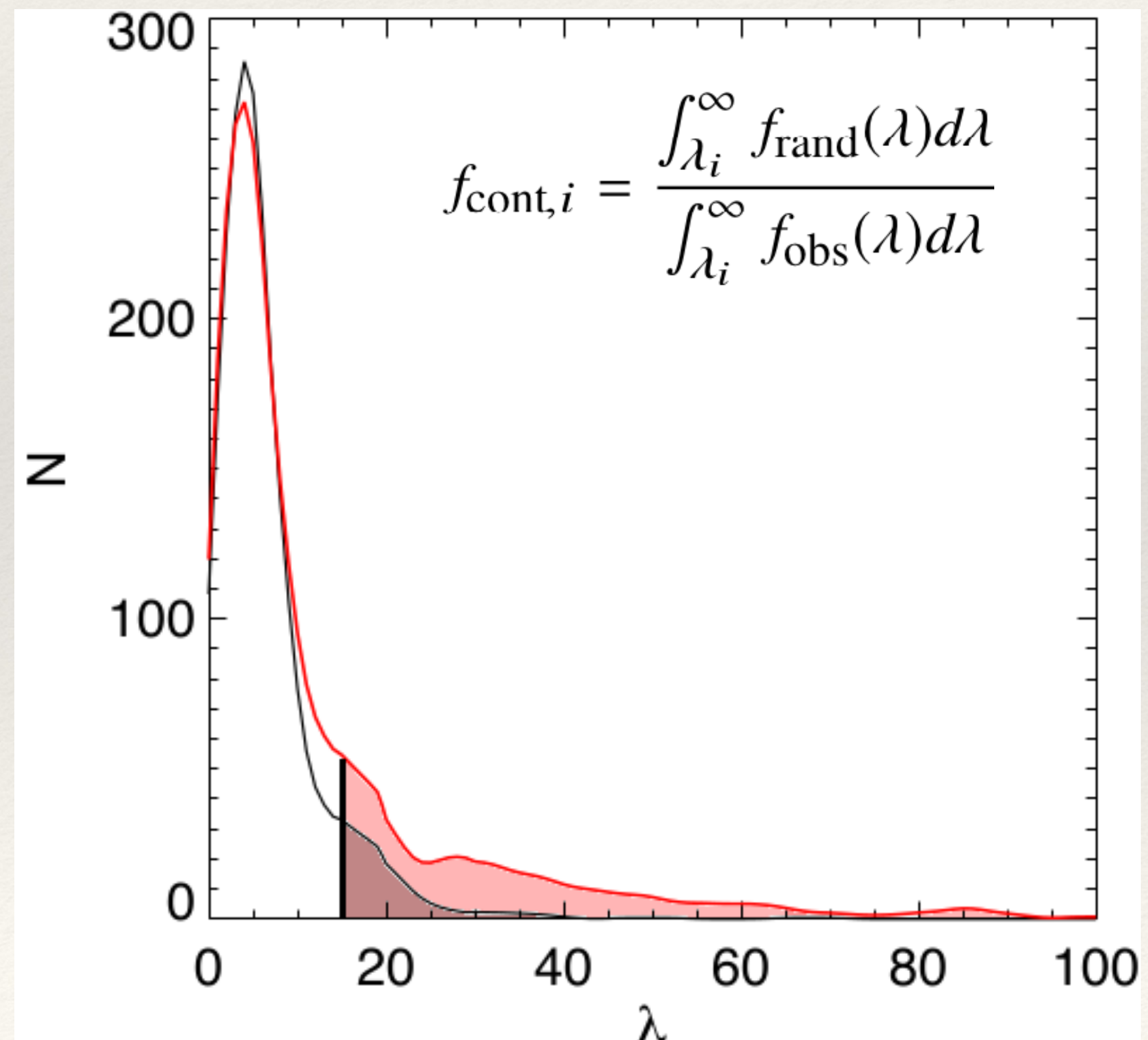
- ❖ search for optical clusters along the line of sight towards ICM candidates and record richness ( $\lambda$ ) &  $z$ 
  - > uses ICM prior on mass and position (Ra, Dec,  $M_{500}(z)$ )
  - > red sequence technique (multi-colour filter, radial filter, luminosity filter)
  - > allows to identify and de-blend multiple structures along the line of sight





# Multi-Component Matched Filter (MCMF) confirmation tool

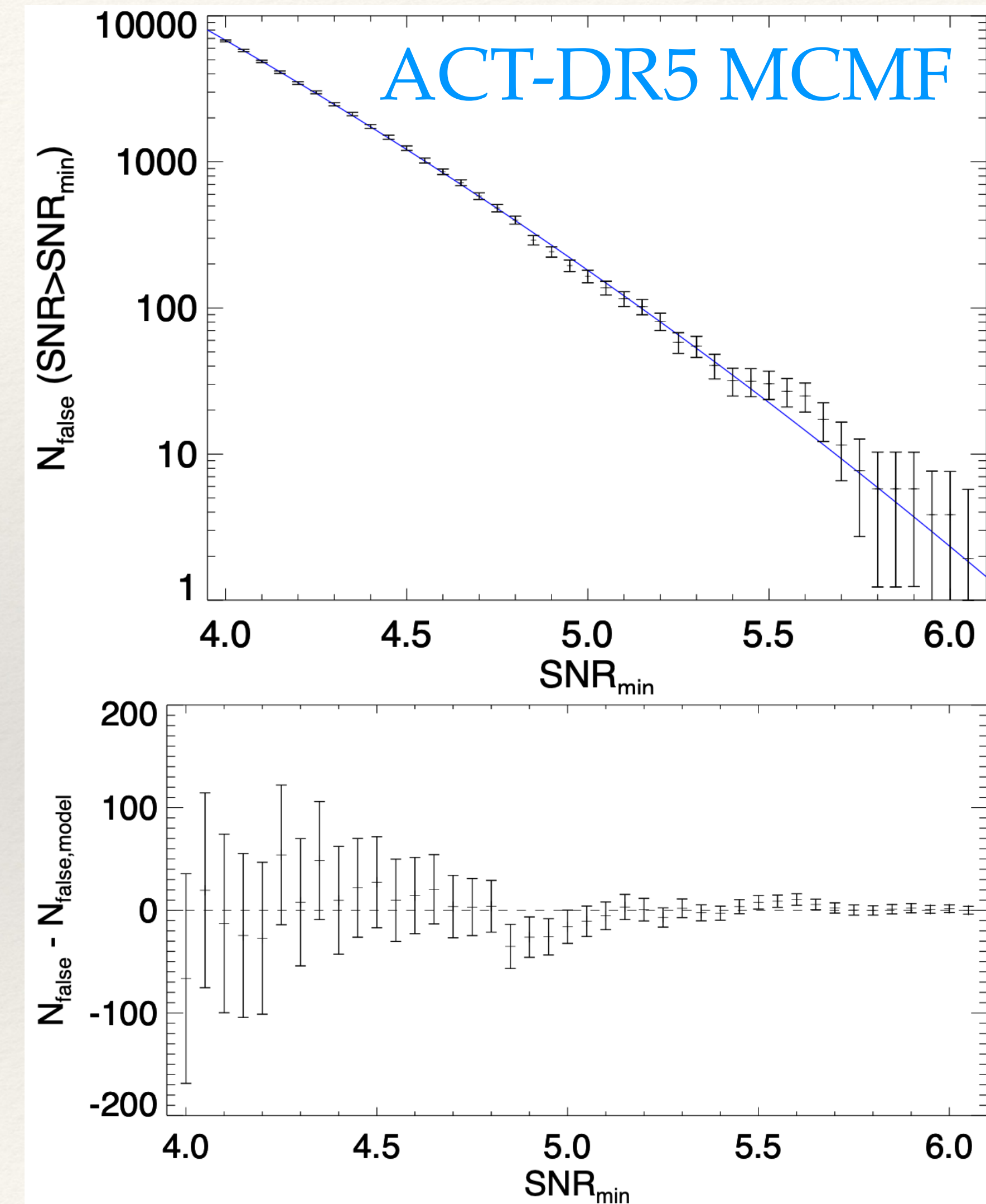
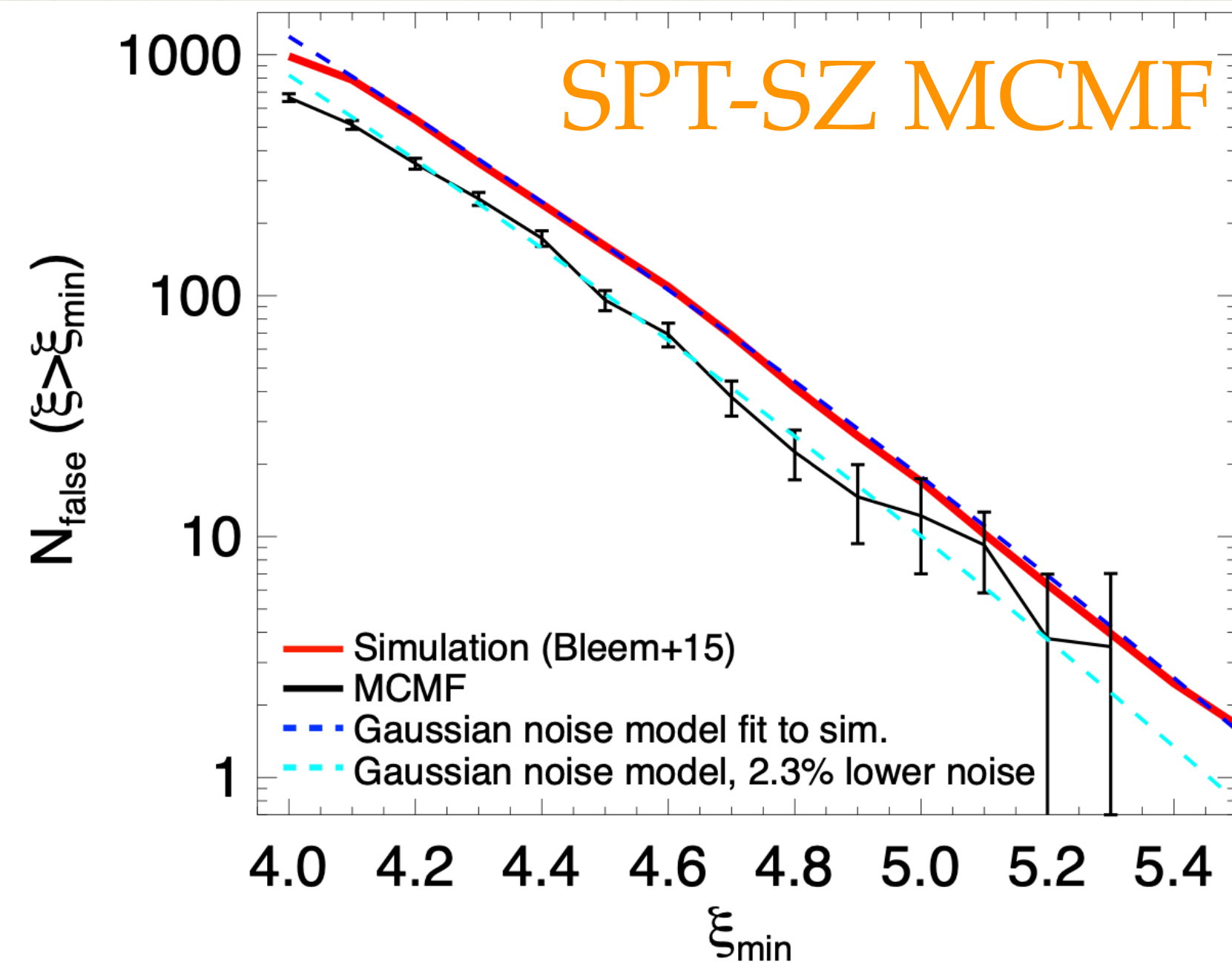
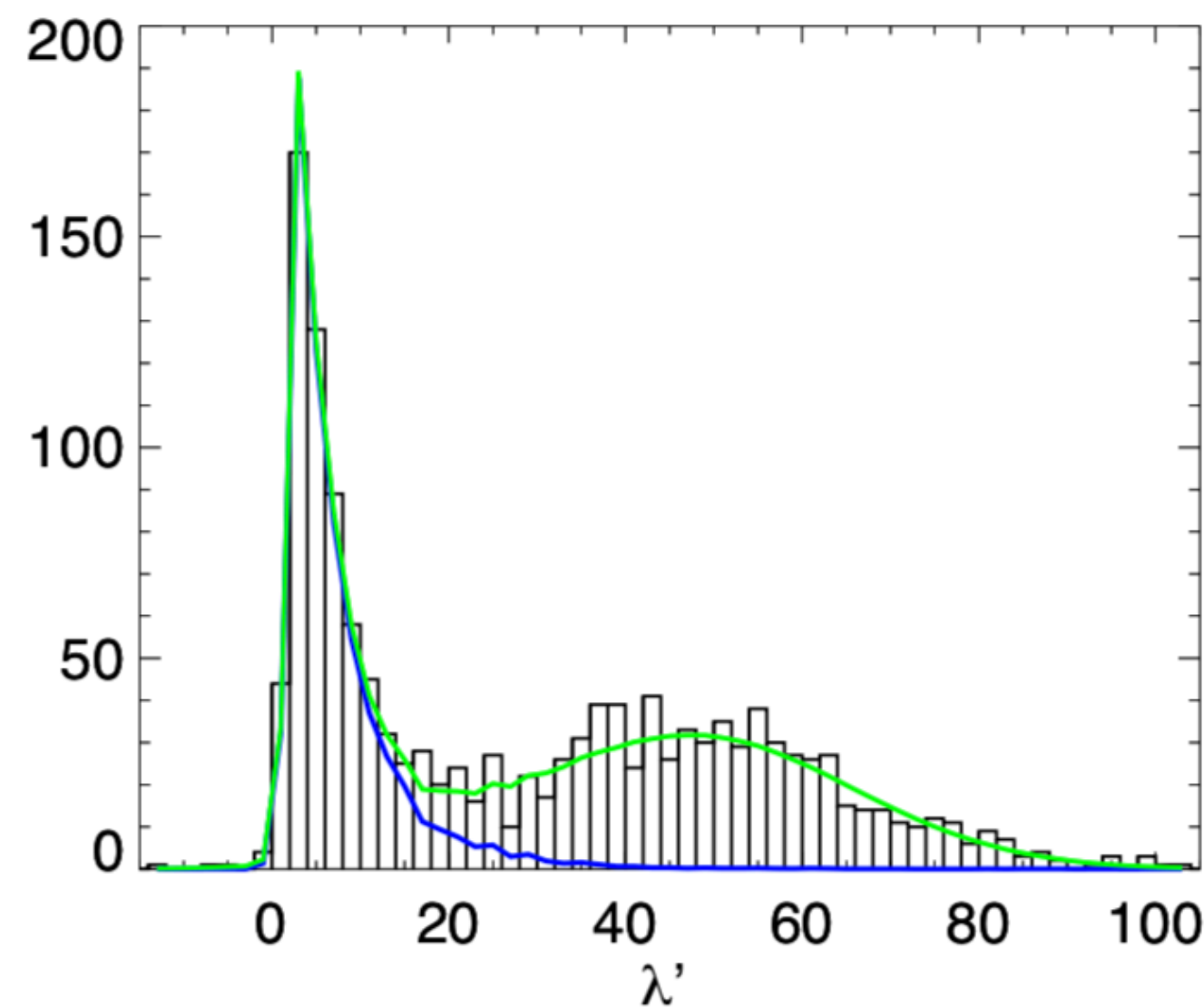
- ❖ search for optical clusters along the line of sight towards ICM candidates and record richness ( $\lambda$ ) &  $z$
- ❖ repeat along random line of sights (reject regions of true candidates & follow survey characteristics)
- ❖ look at  $\lambda$  -distribution at given  $z$  and calculate contamination suppression factor ( $f_{\text{cont}}$ )
- ❖  $f_{\text{cont}}$  selection ensures constant contamination as function of redshift





# Estimating contamination & purity

- ❖ Estimating number of false detection using richness distribution of randoms and true sources (mixture model)
  - > gives total number true clusters
  - > initial purity / contamination of the cluster candidate list
- ❖ contamination of MCMF catalogs: initial contamination x  $f_{\text{cont}}$  cut
- ❖ with number of selected clusters & contamination
  - > number of true clusters in MCMF catalog —> completeness w.r.t. SZ selection

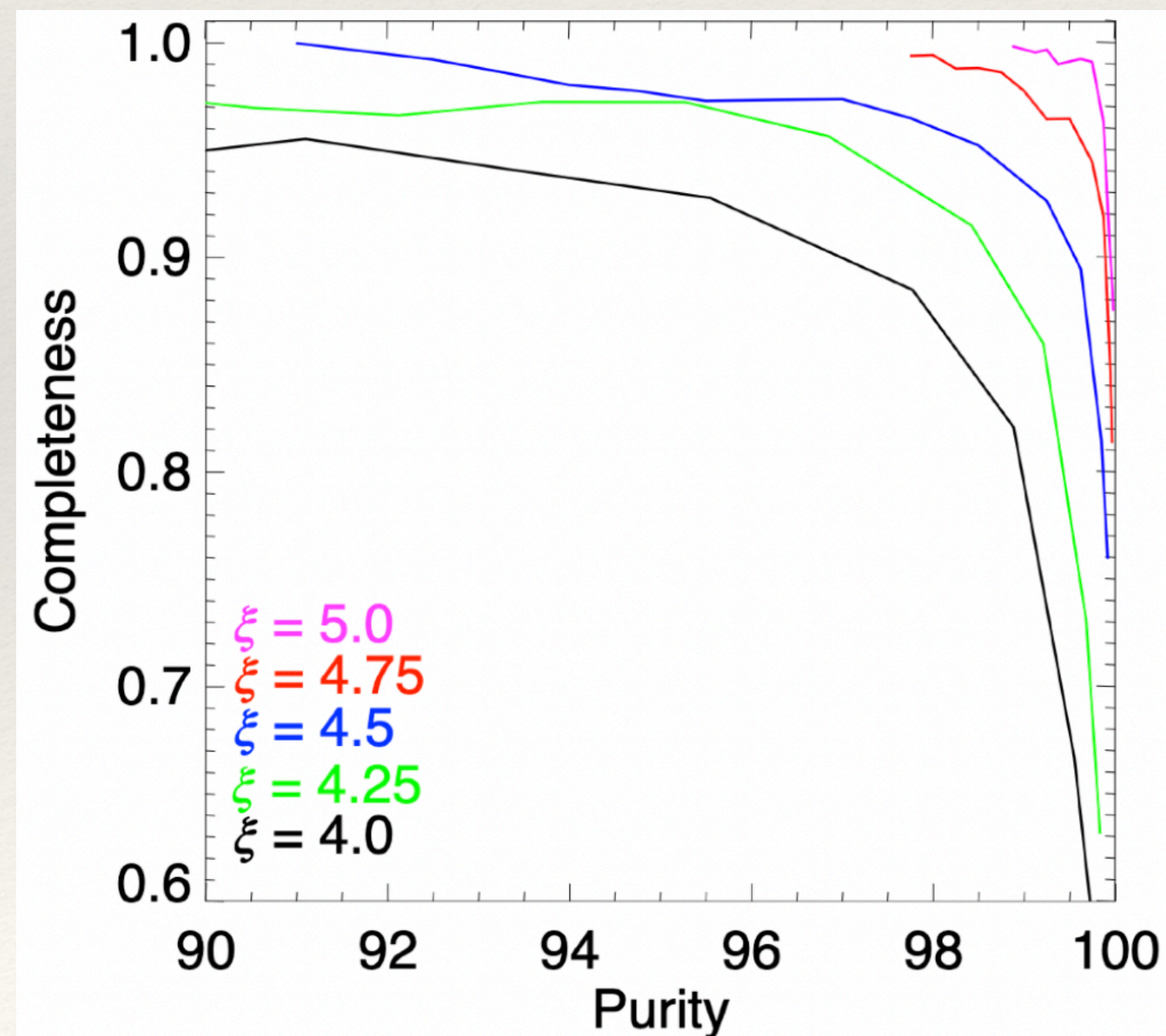


**Figure 5.** Modeling the richness distribution of SPT candidates as mixture of contaminants and clusters. The composite model (contaminant + gaussian) is shown in green, the contaminant population is shown in blue.

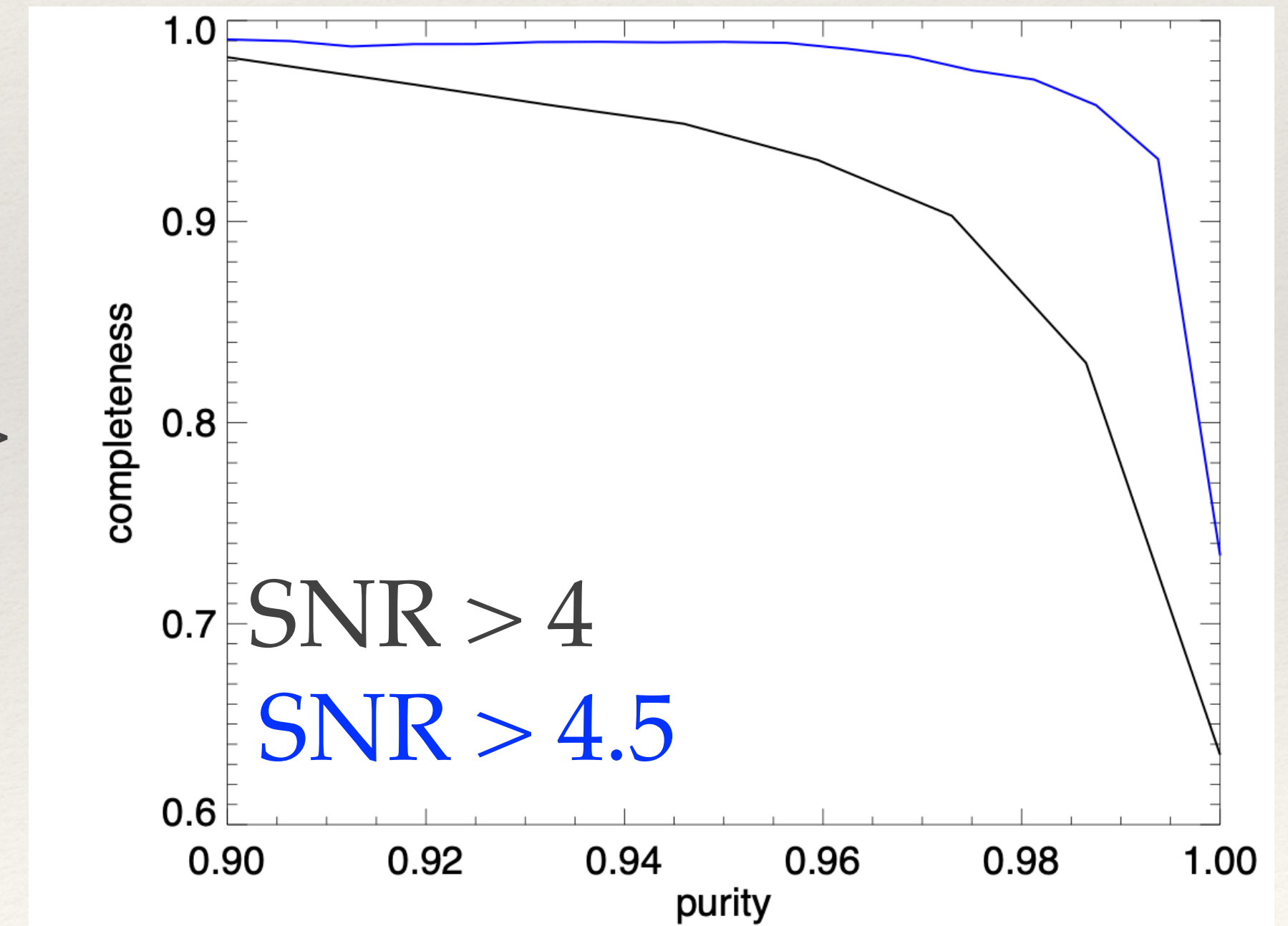


# Tuning sample to your needs:

- ❖ sample purity & completeness can be tuned to specific science case
- ❖ changing SZ selection (increasing S/N threshold) impacts initial purity
  - > reduces impact of MCMF confirmation on completeness
- ❖ Incompleteness due to MCMF confirmation can be (easily) traced / modelled
- ❖ if contamination is < Poisson noise, contamination might be ignored



← SPT-SZ MCMF  
ACT-DR5 MCMF →





# SPT cosmology

- ❖ MCMF follow-up on all three SPT surveys in the DES overlap region using DES & WISE
- ❖ expected impact on number of SZ-selected clusters 2-3%

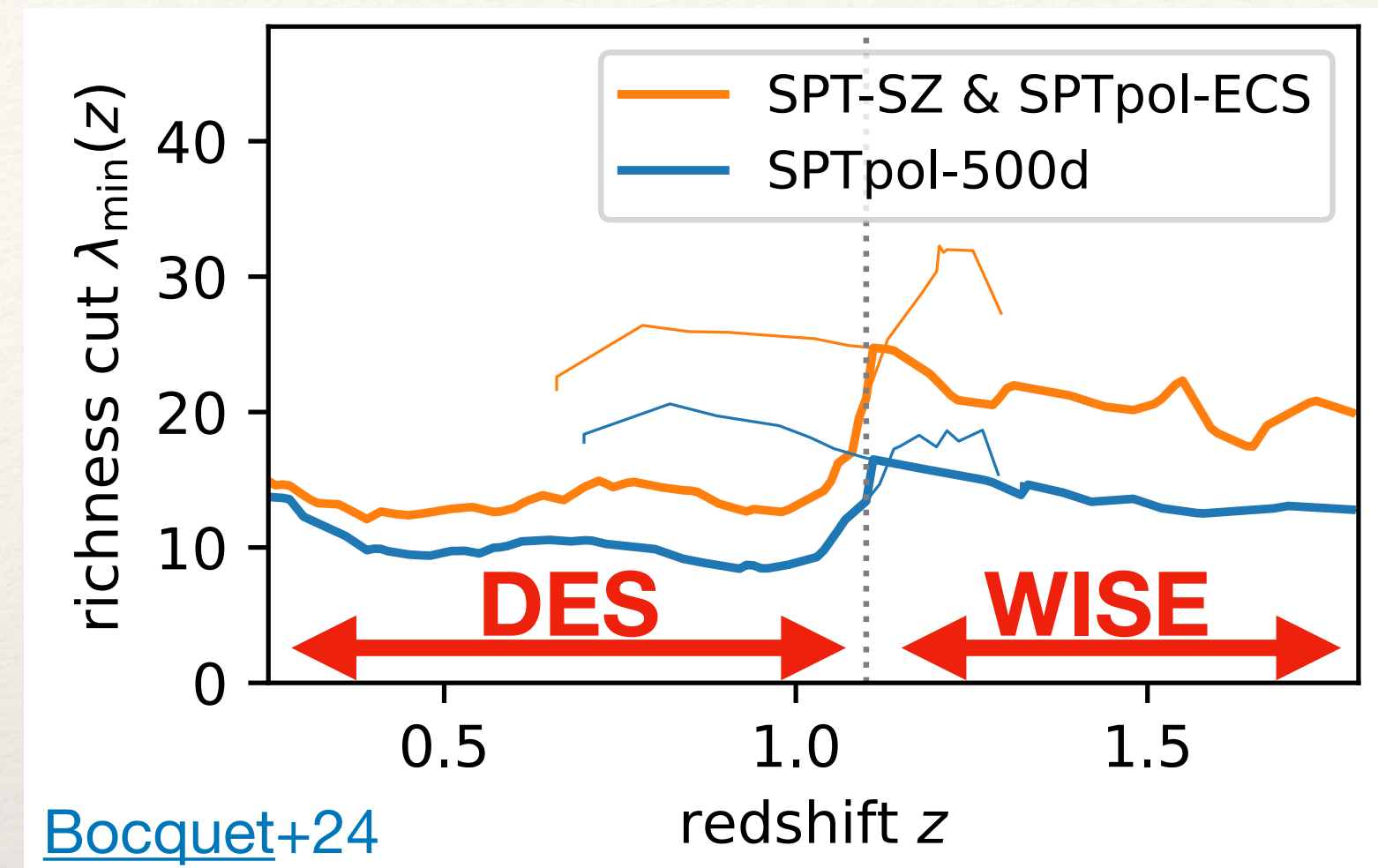
## $\Lambda$ CDM & WCDM cosmology (Bocquet+24):

- ❖ Competitive constraints, especially on  $S_8^{\text{opt}} \equiv \sigma_8 (\Omega_m/0.3)^{0.25}$
- ❖ No evidence for “ $S_8$  tension” with Planck ( $1.1 \sigma$ )
- ❖ consistent with most previous cluster studies
- ❖ Clusters-only and Clusters+Planck constraints favor dark energy equation of state parameter  $w < -1$  at  $\sim 2\sigma$

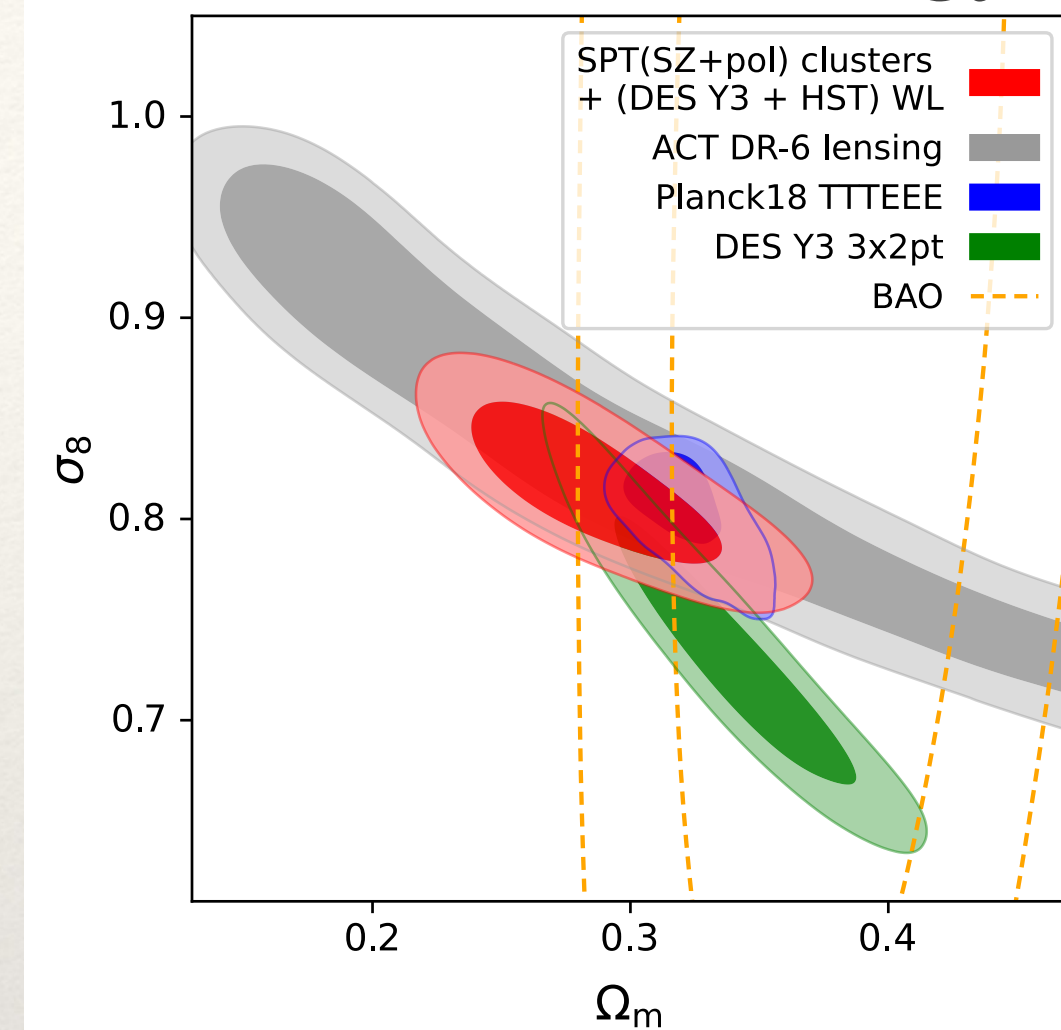
## Follow-on cosmological studies on non-standard models:

- ❖  $f(R)$  cosmology (Vogt+24)
- ❖ interacting dark sector (Mazoun+25)

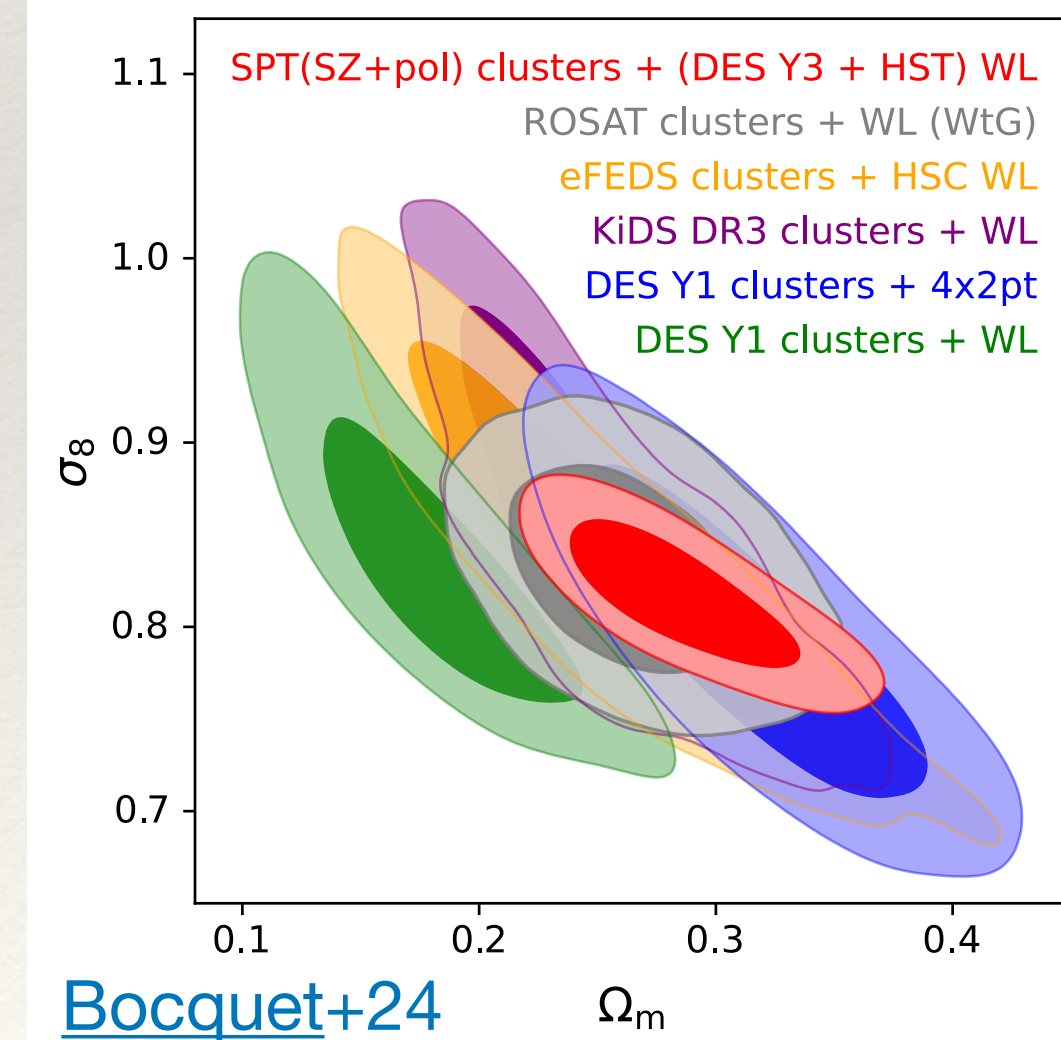
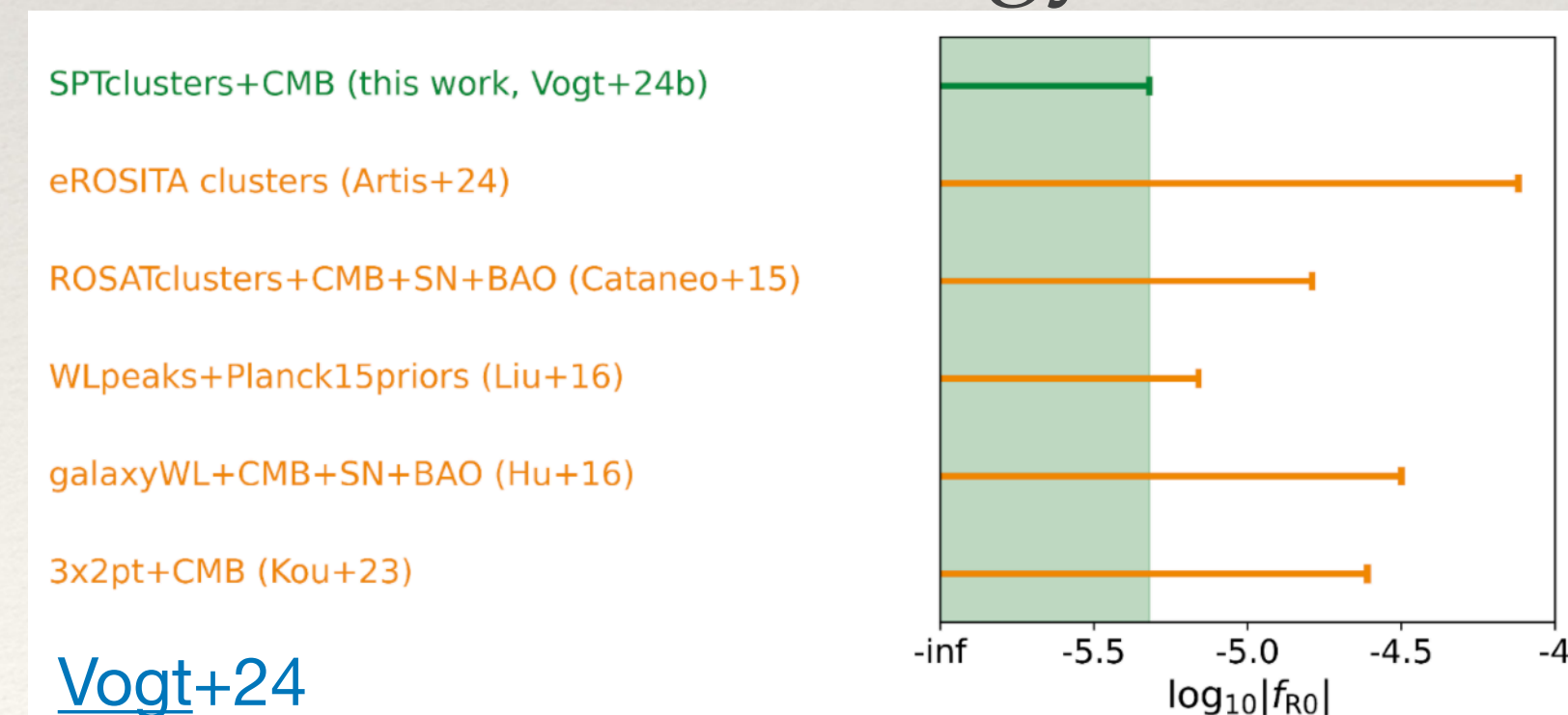
## MCMF confirmation



## $\Lambda$ CDM cosmology



## $f(R)$ cosmology





# eFEDS Cosmology (Chiu+23)

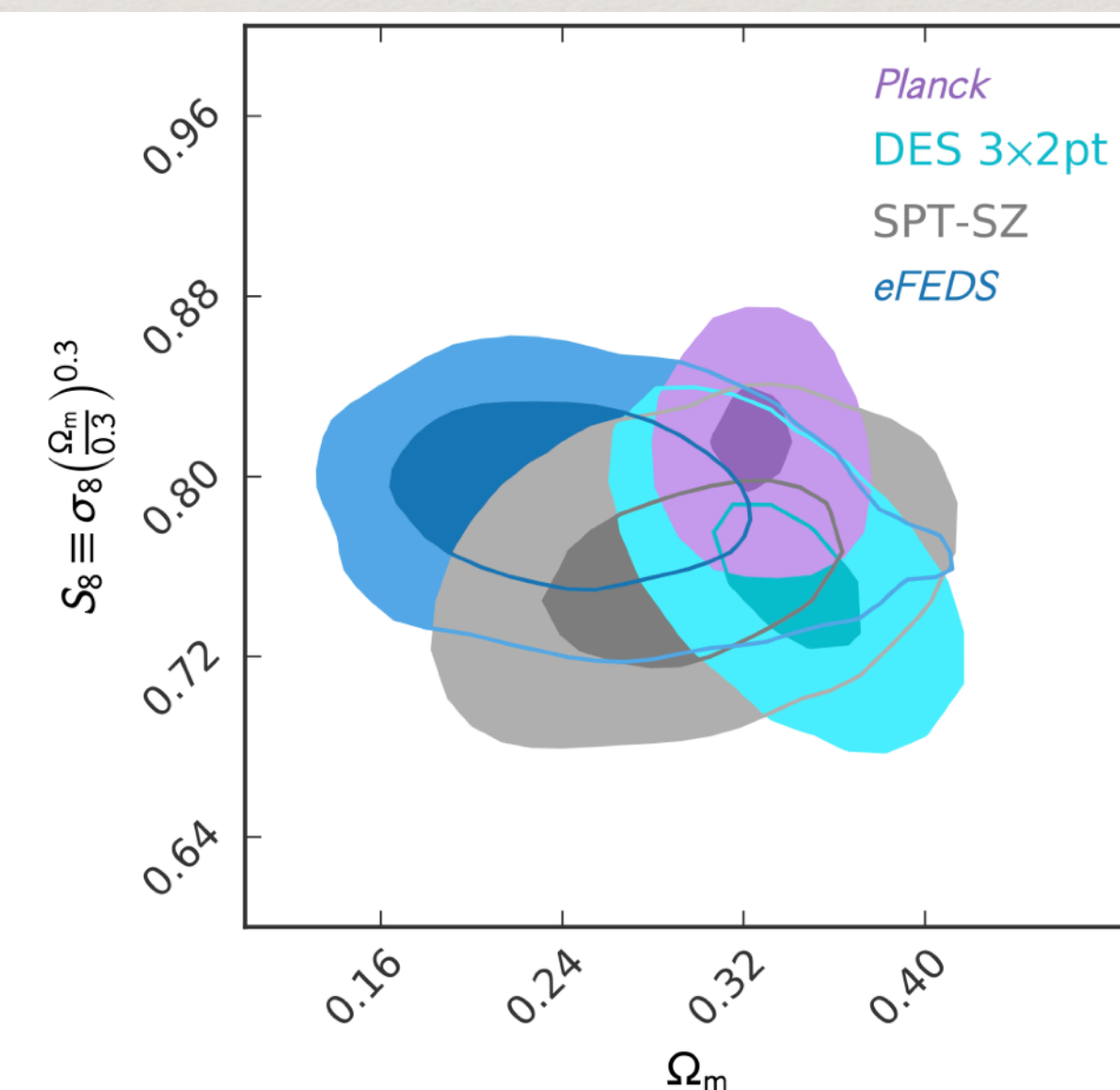
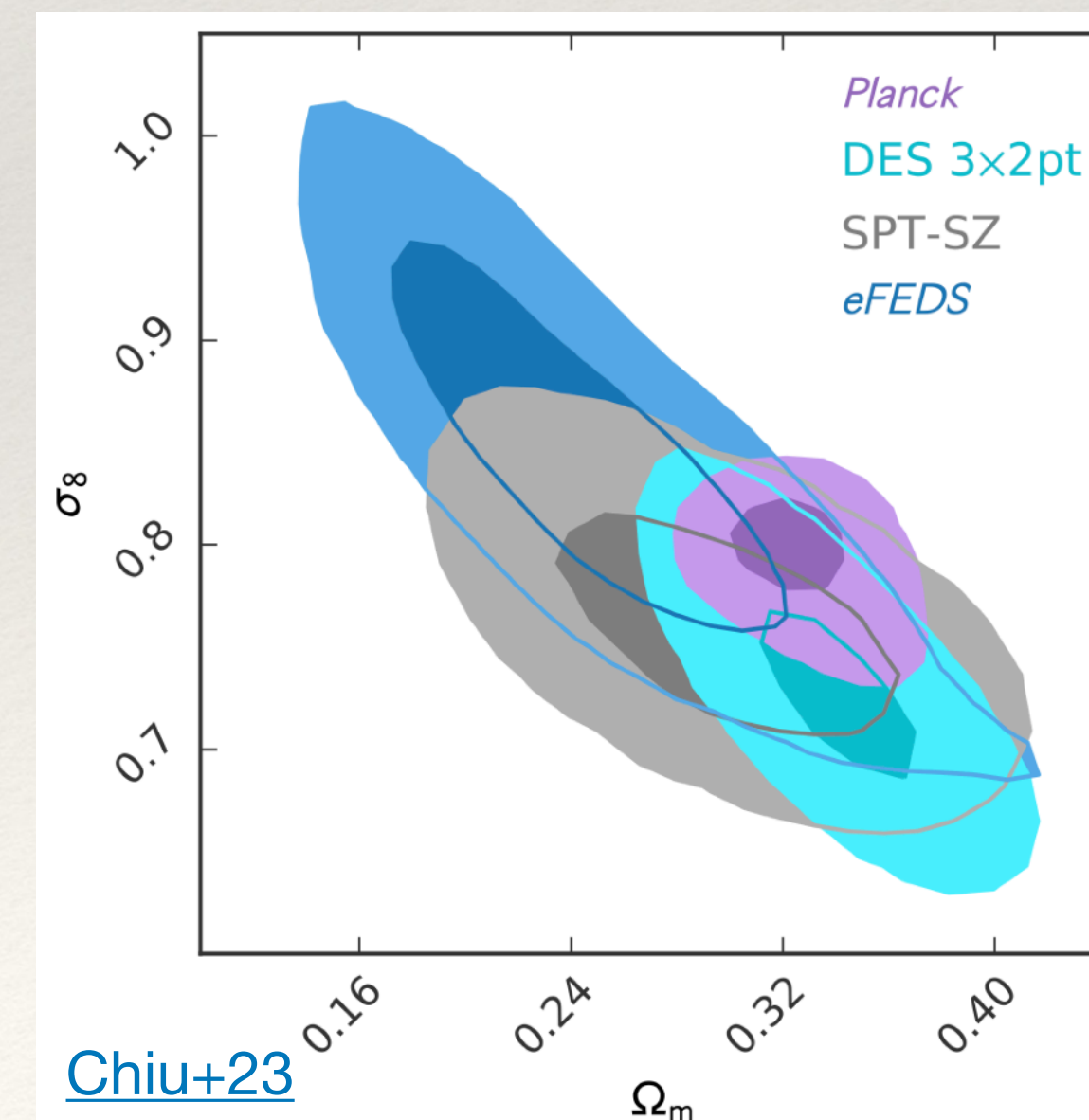
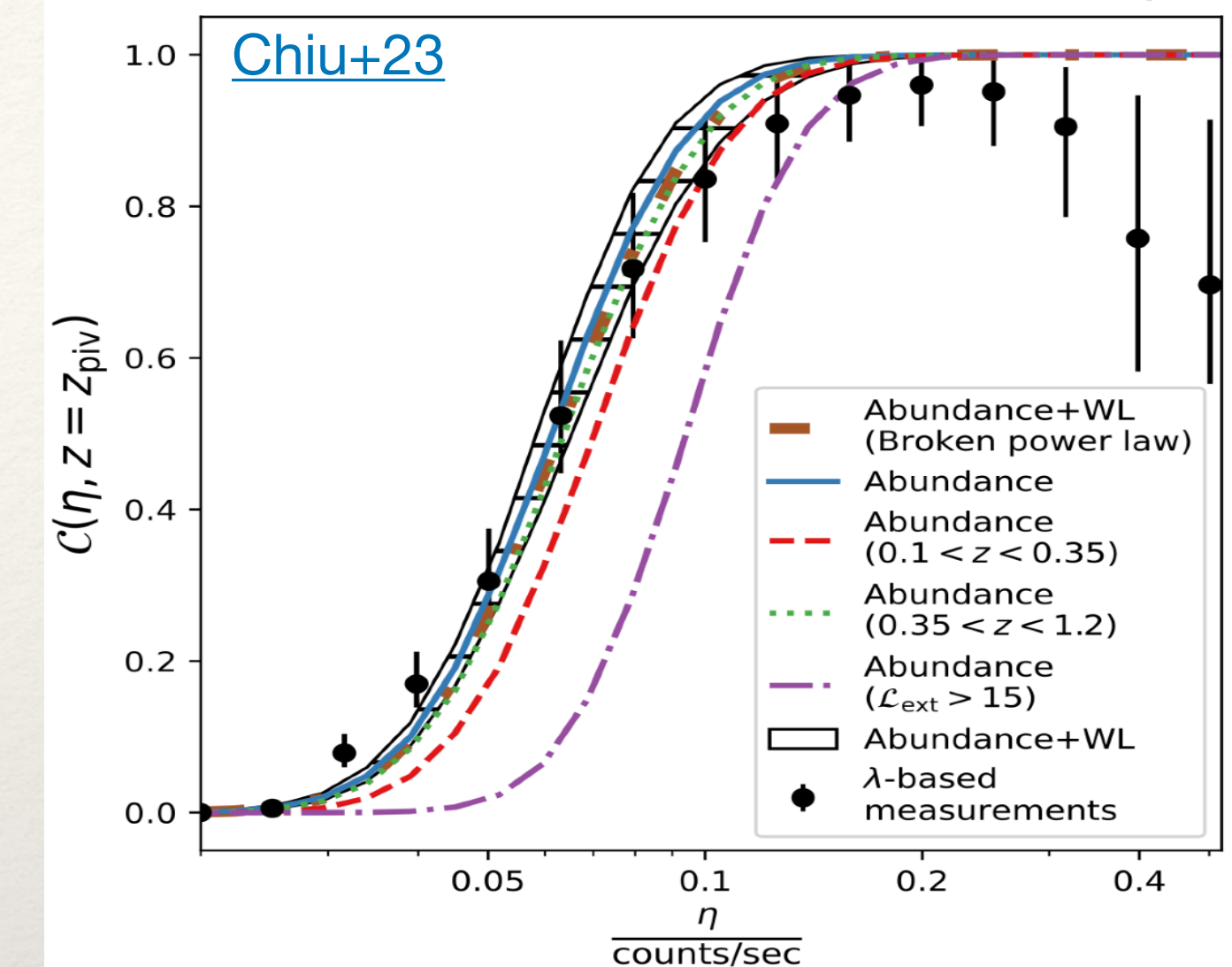
## Data:

- ❖ Catalog: eROSITA final equatorial depth survey
- ❖ 455 clusters, 177 with HSC weak meaning, 120 deg<sup>2</sup>
- ❖ detection & extend likelihood selected sample

## Method

- ❖ same kind of modelling approach as for SPT analysis (including optical selection)
- ❖ modelling of “lost” clusters that went into point source sample
  - > add completeness function to the abundance likelihood
  - > apply MCMF statistics to point source list & empirically estimate number of lost systems

## clusters lost to PS catalog





# RASS-MCMF cosmology (forecast)

## RASS-MCMF: (Klein+23)

❖  $\sim 25,000 \text{ deg}^2$ ,  $\sim 8,400$  clusters

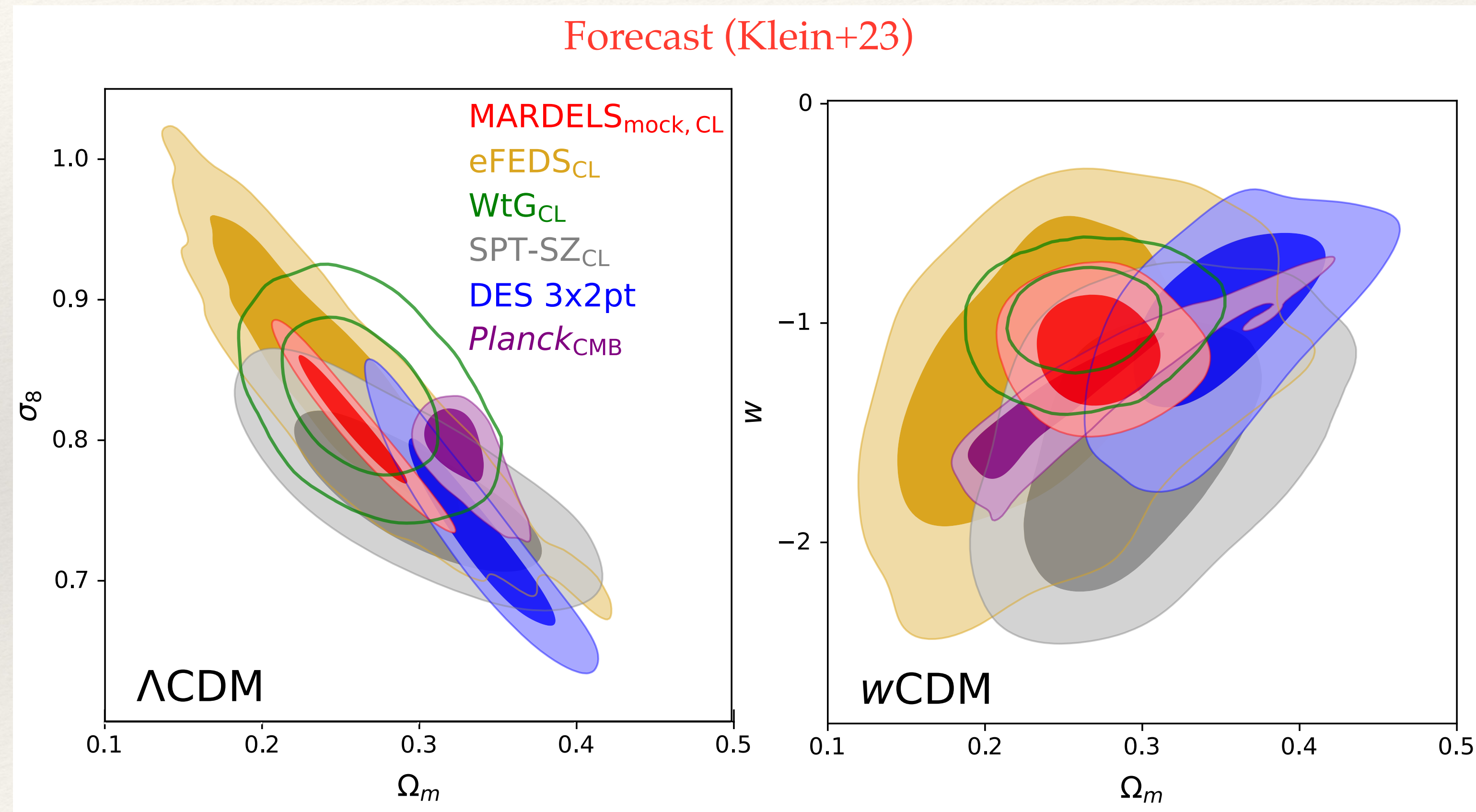
cosmology: (Hernandes-Lang+, in prep.)

❖ similar analysis method as Bocquet+24, Chiu+23

❖  $\sim 5000$  clusters + DES WL

❖ no extent selection

—> approx. similar constraining power as eRASS1





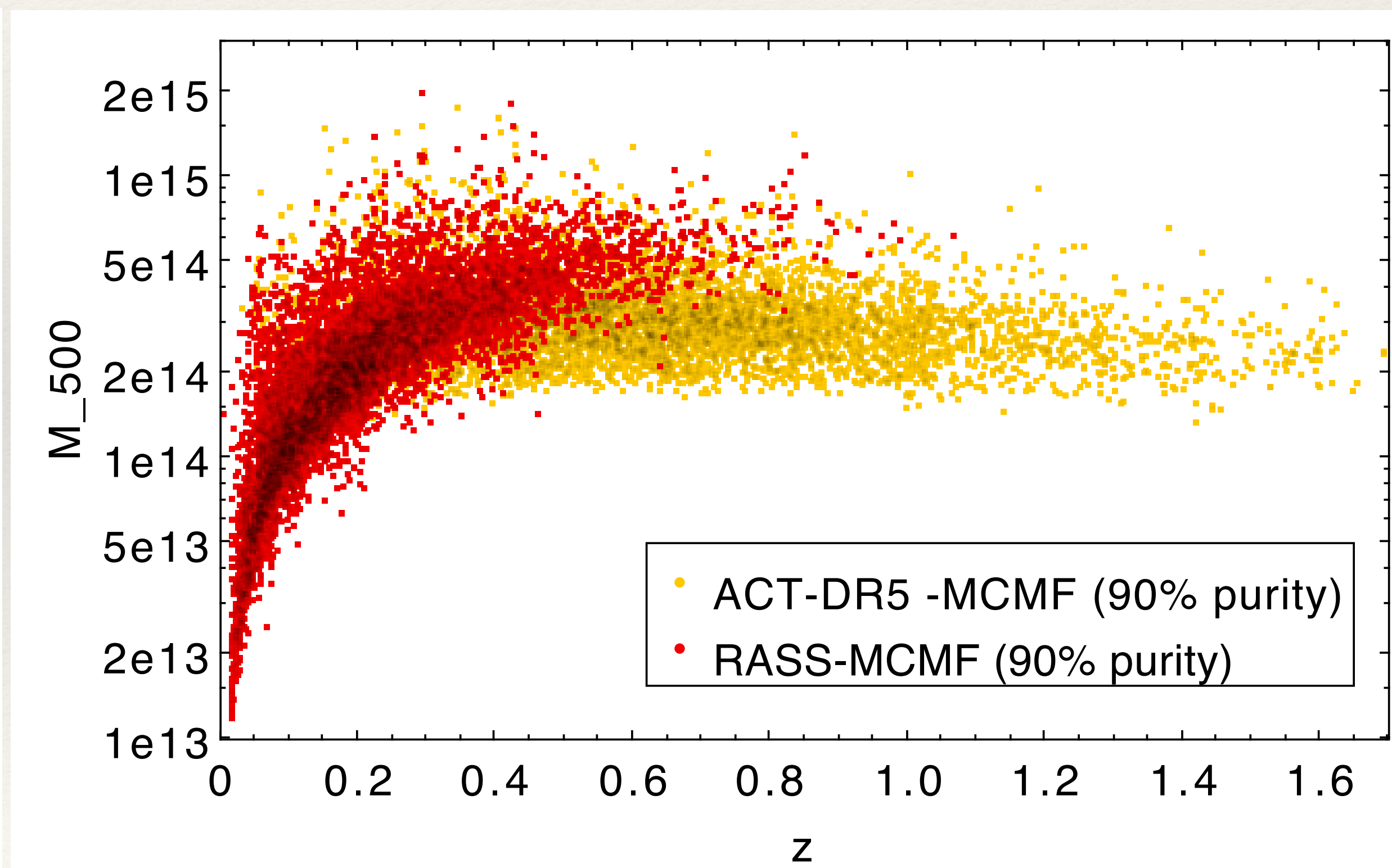
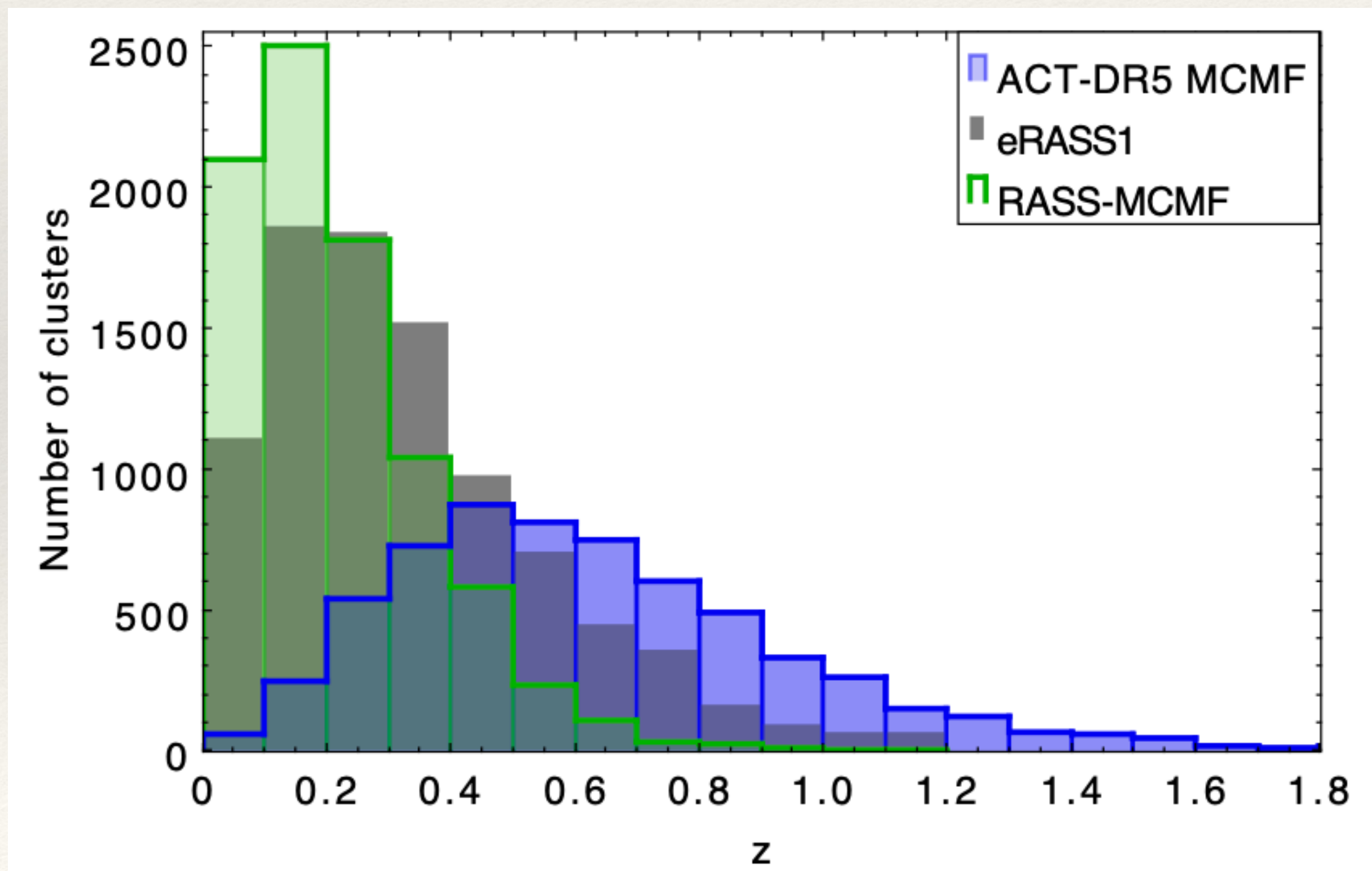
# ACT-DR5 & RASS MCMF

## ACT-DR5 MCMF: (Klein+24)

- ❖ 13,000 deg<sup>2</sup>
- ❖ ~6,100 clusters (~700 clusters at  $z > 1$ )

## RASS-MCMF: (Klein+23)

- ❖ ~25,000 deg<sup>2</sup>
- ❖ ~8,400 clusters

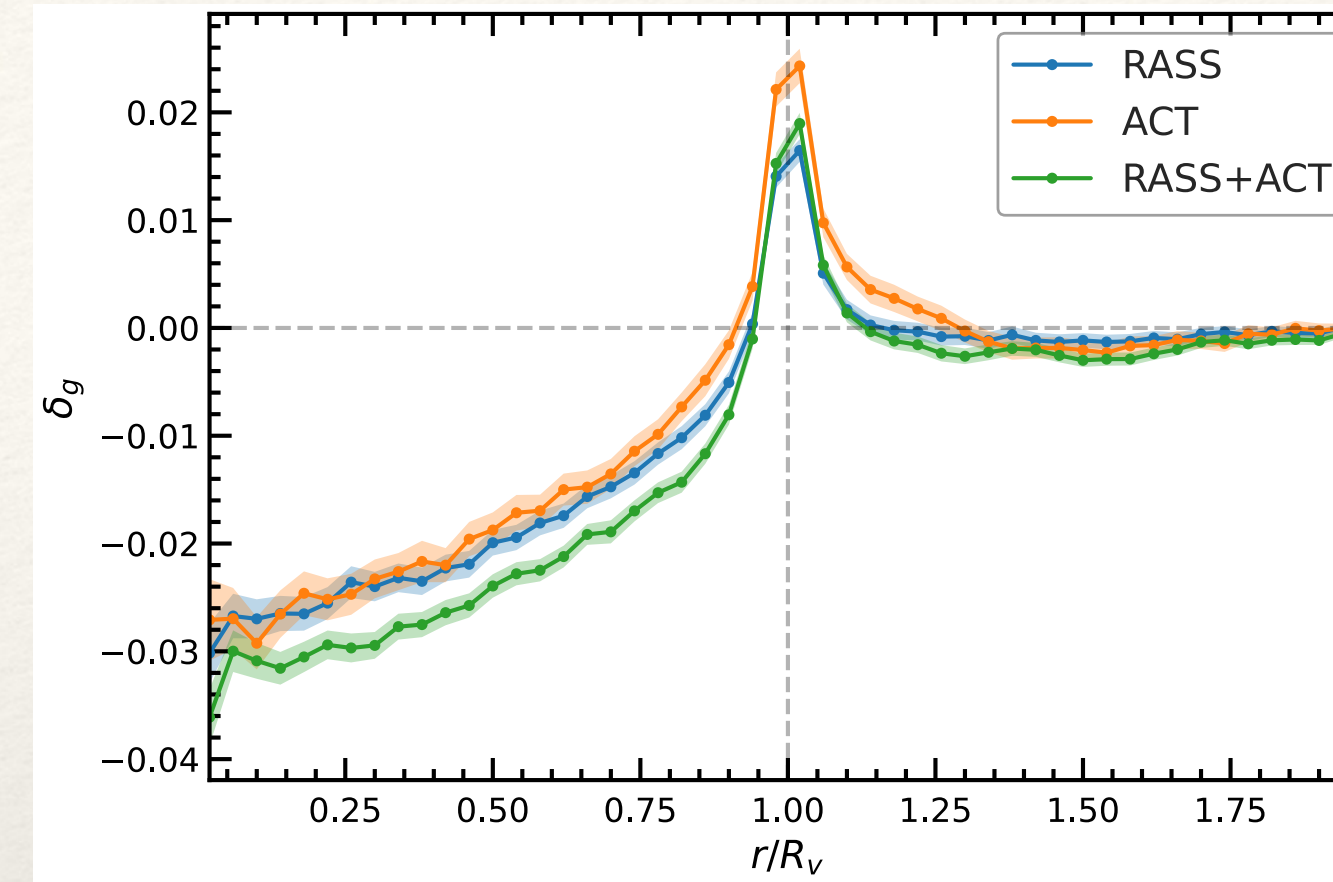




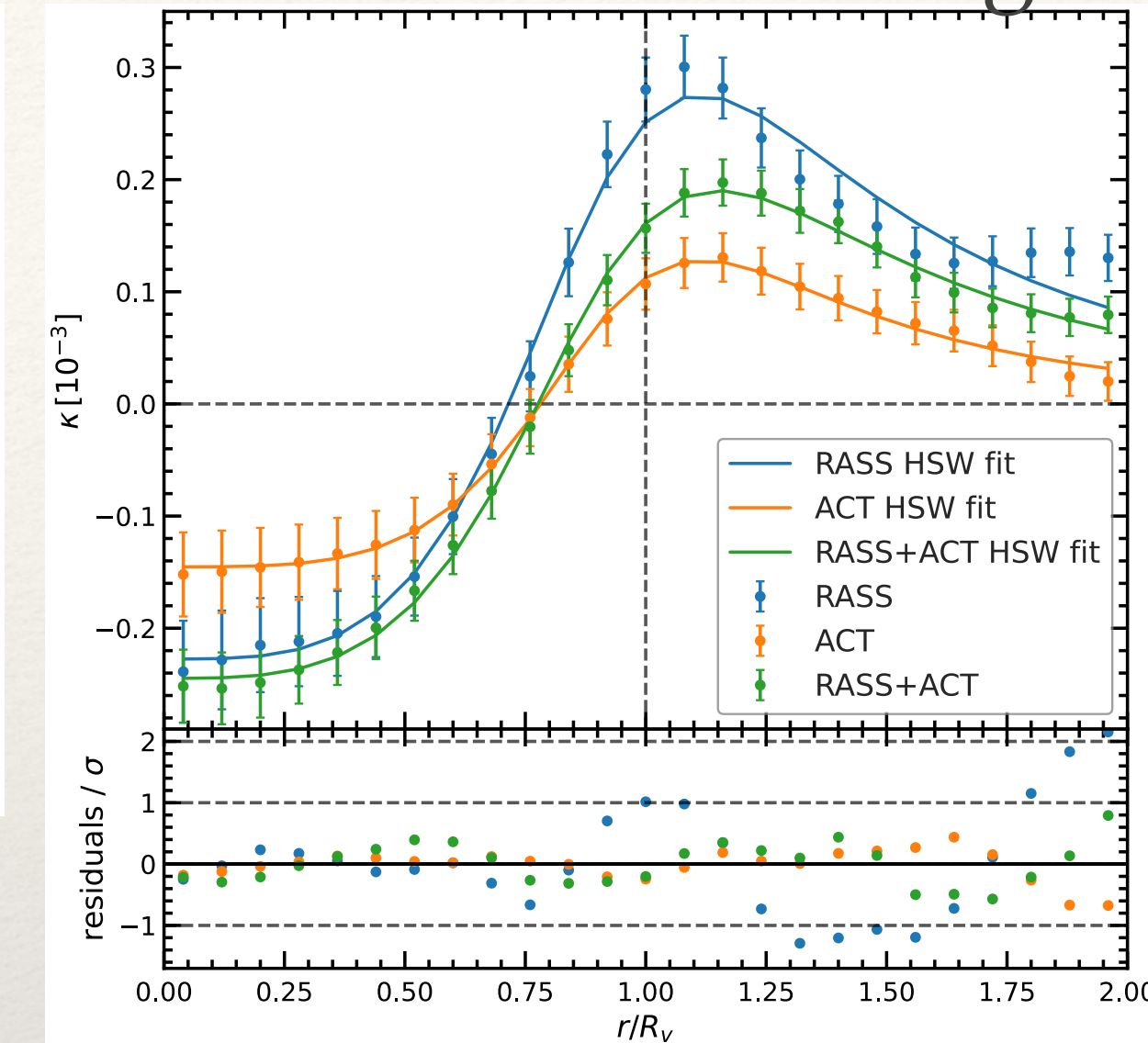
# Cosmic tunnels from ACT-DR5 & RASS-MCMF (Davies+25, in prep)

- ❖ use clusters to trace edges of voids/tunnels
- ❖ largest under dense regions on the sky
- ❖ 3.x sigma detection of integrated Sachs-Wolfe effect

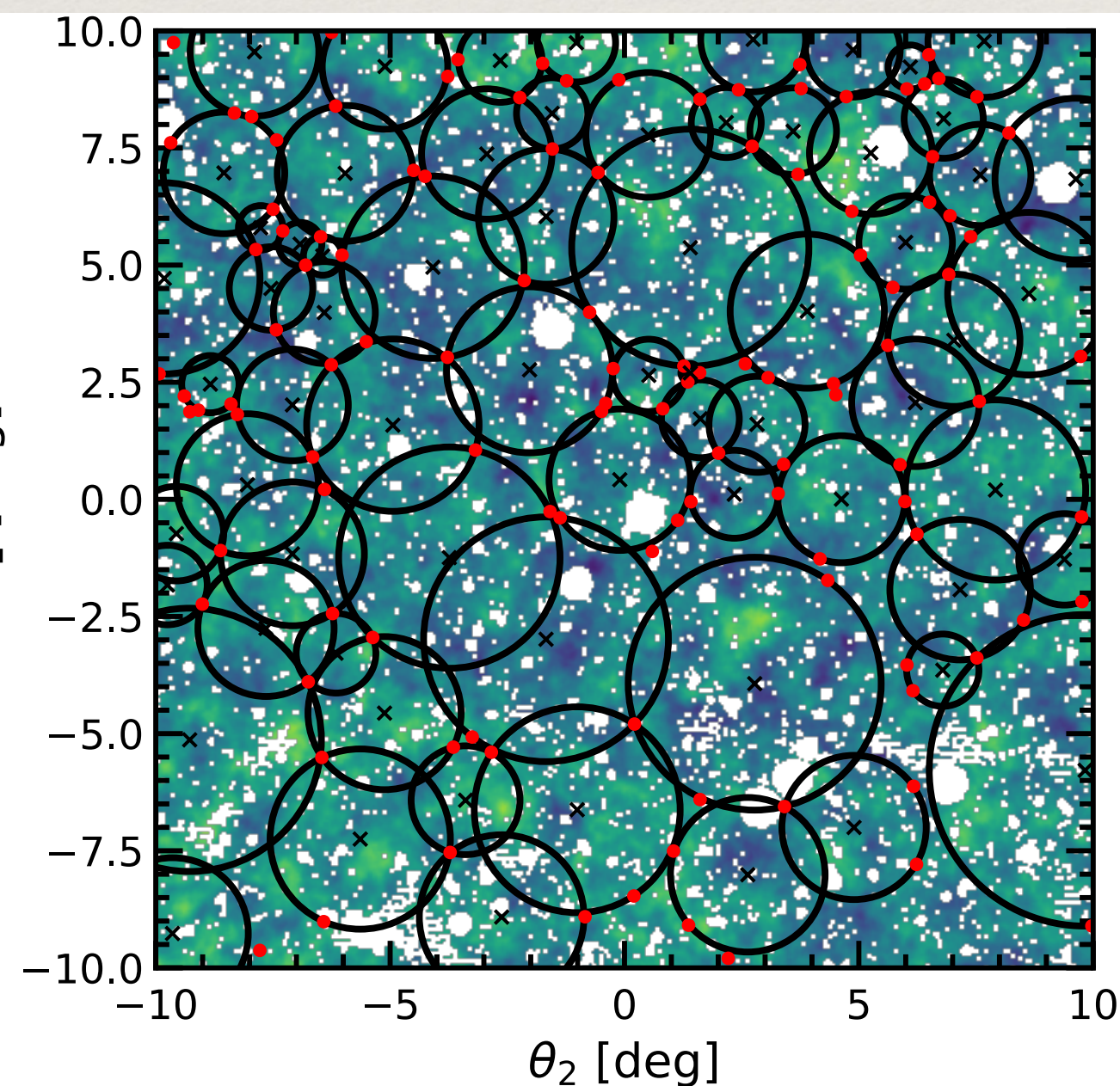
Galaxies



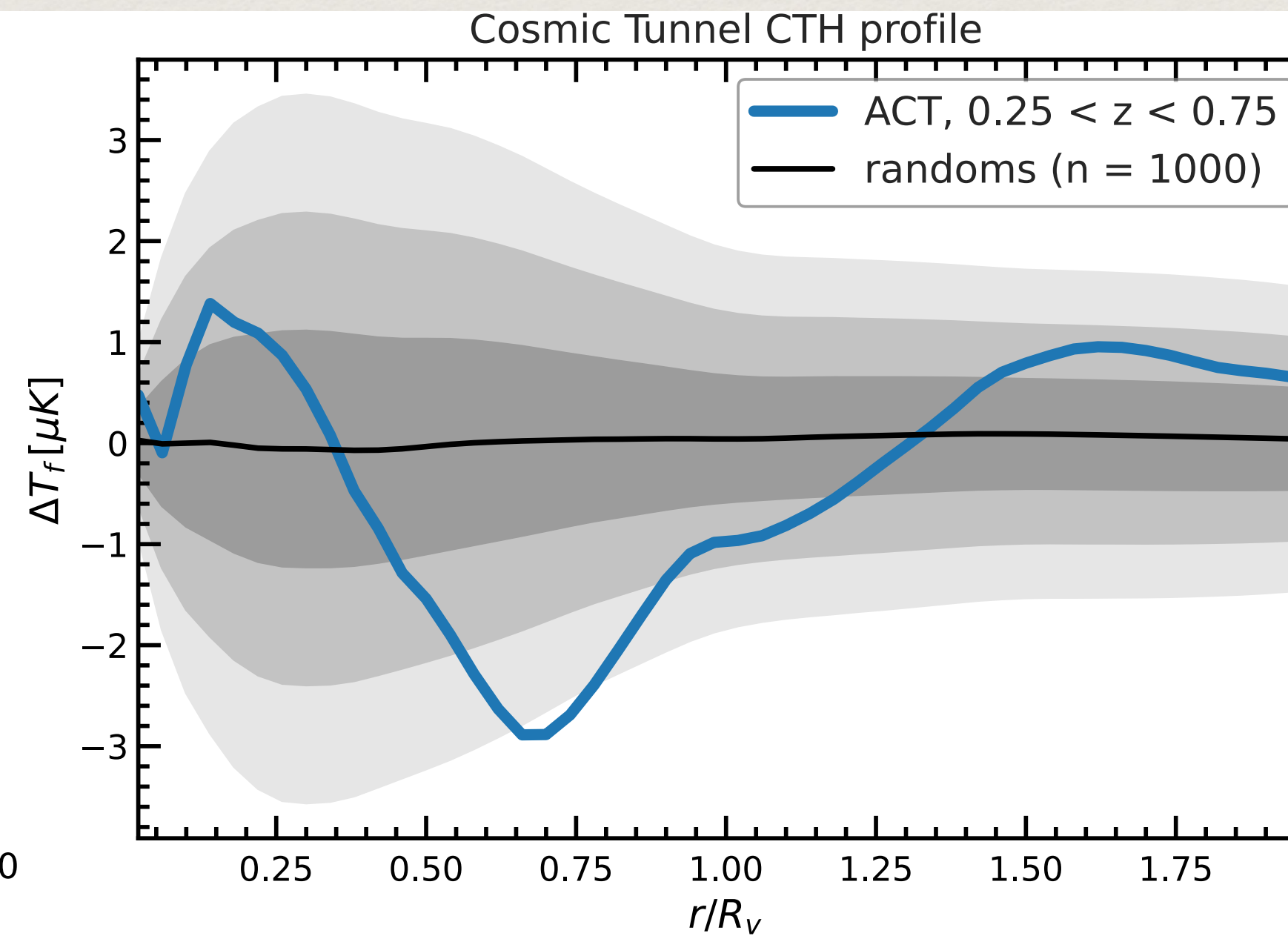
DES weak lensing



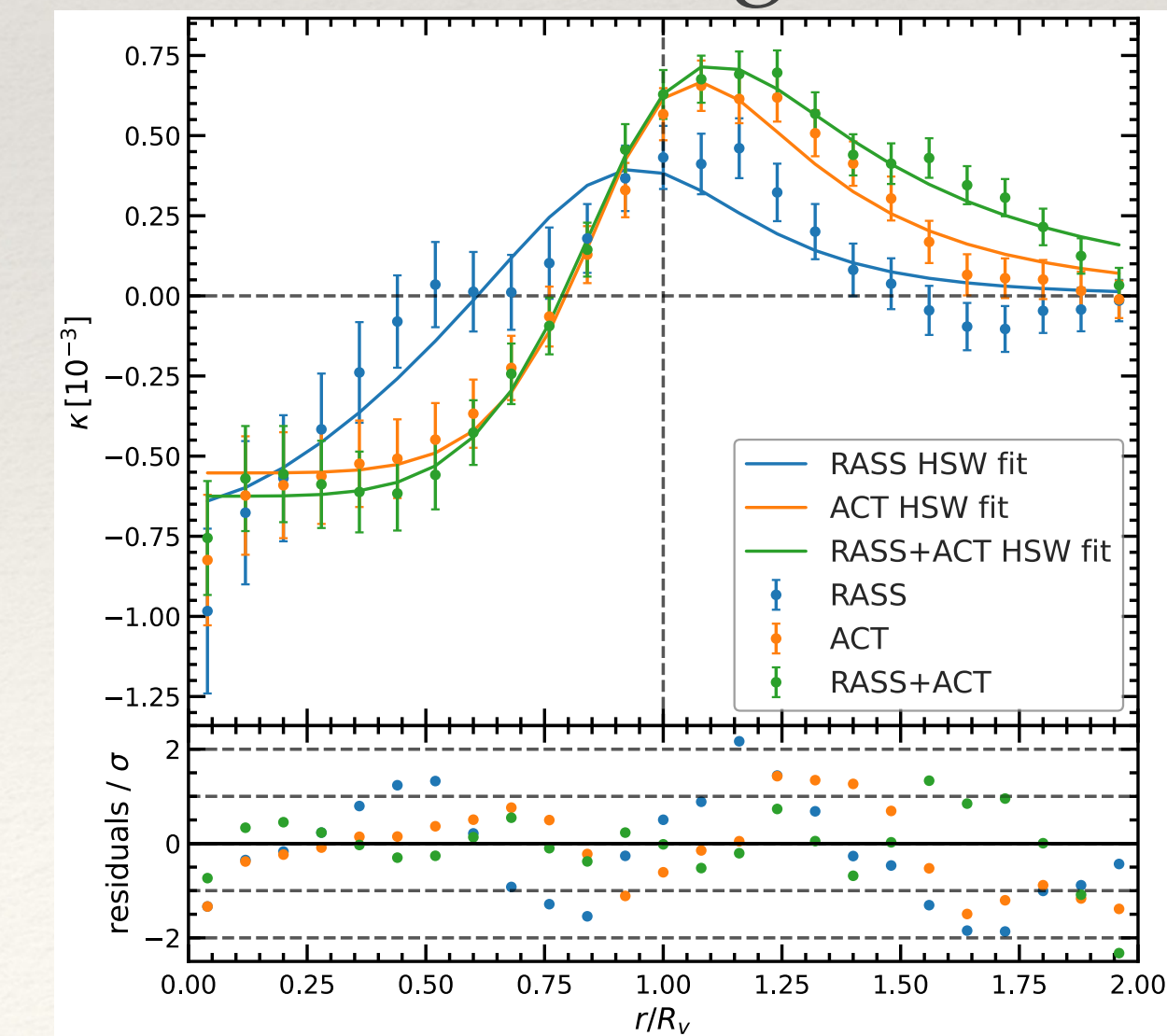
Method



ISW



CMB lensing (ACT)





# Outlook

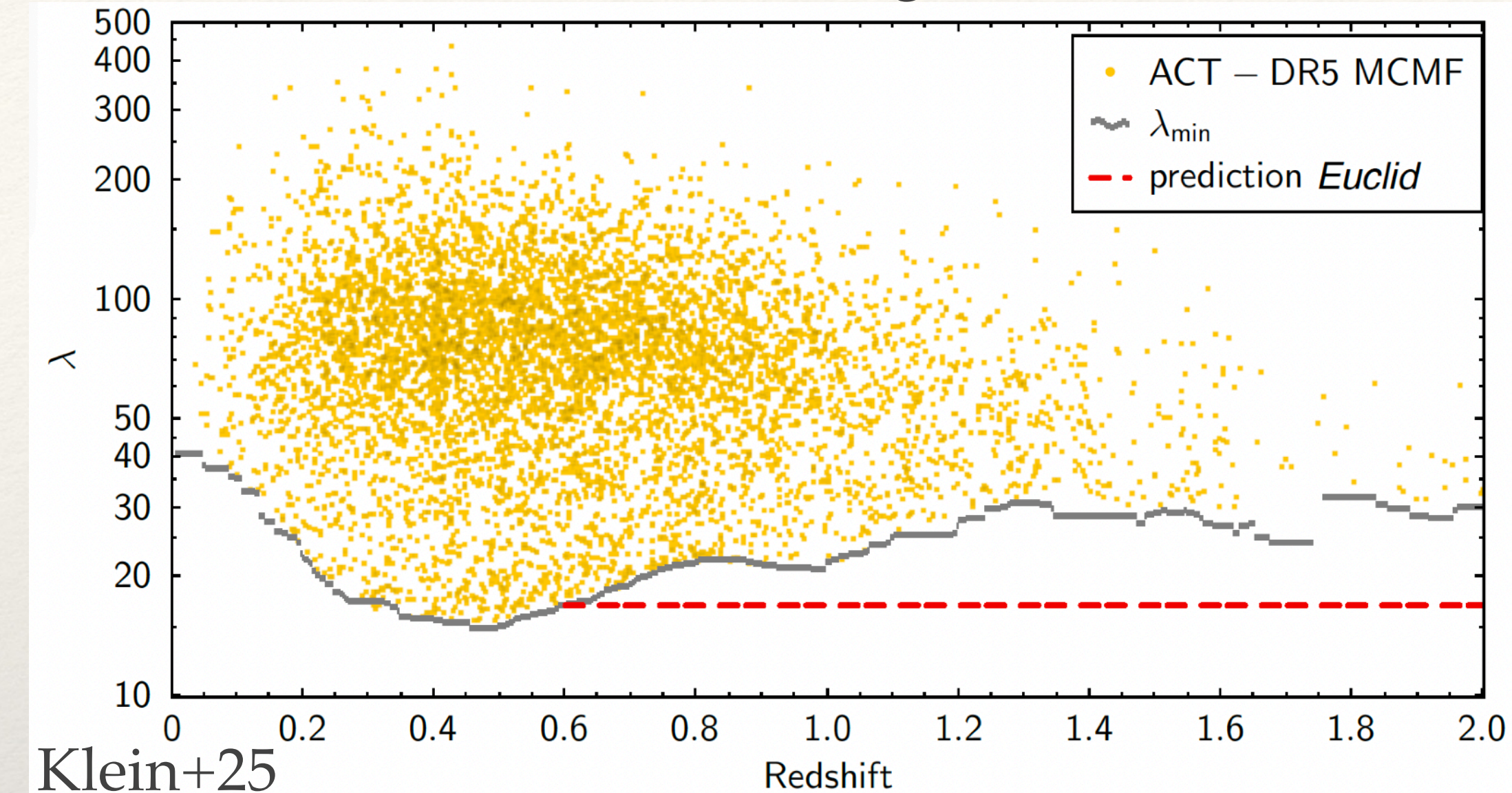
## New catalogs with MCMF contribution:

- ❖ SPT-3G 1500d (Bleem+, in prep)
- ❖ ACT-DR6 MCMF (Klein+, in prep)
- ❖ samples with Euclid-based confirmation
- ❖ + X

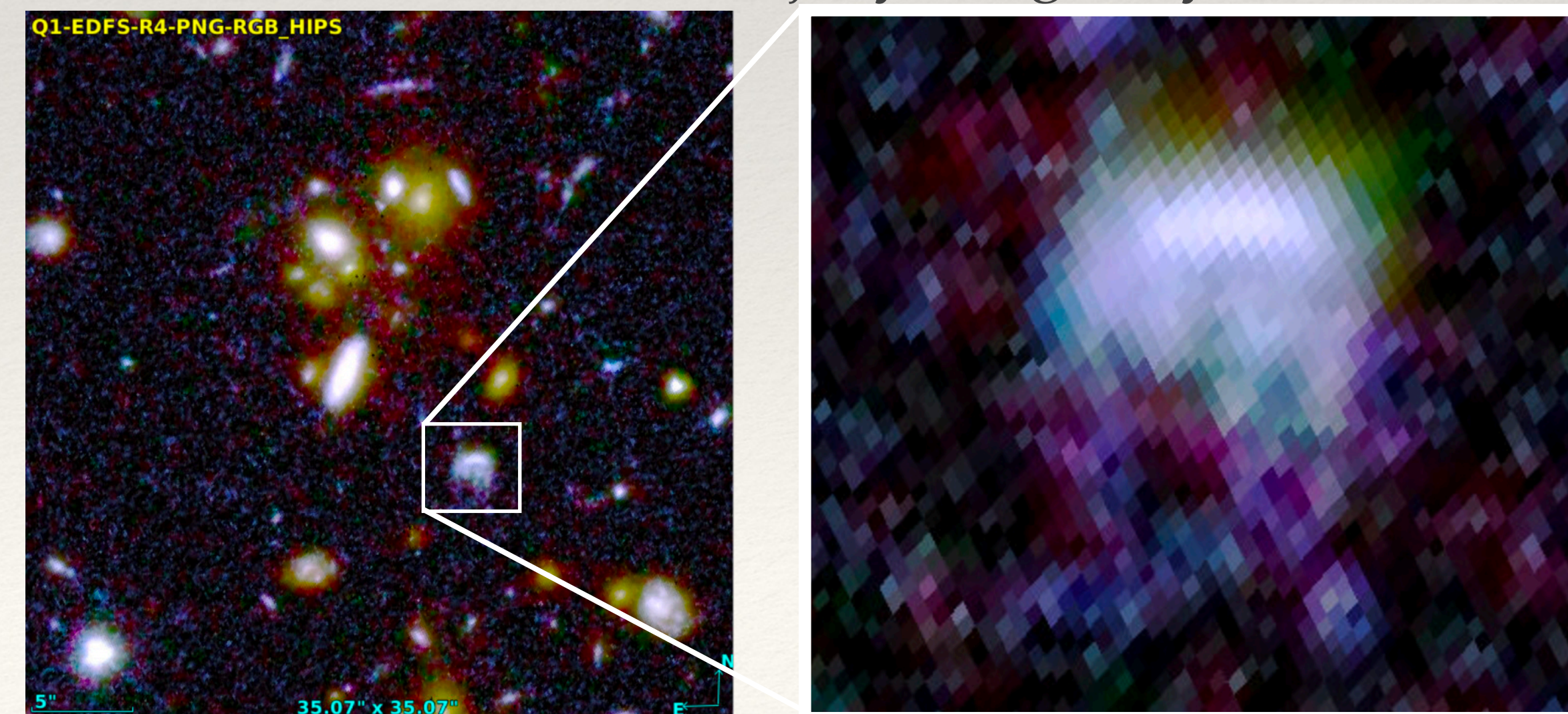
## Science projects:

- ❖ Cosmic tunnels from RASS-MCMF and ACT-DR5 MCMF (Davies+, in prep.)
- ❖ RASS-MCMF cluster clustering (Fumagalli+, in prep.)
- ❖ RASS-MCMF cosmology (Hernandez-Lang+, in prep.)
- ❖ Baryon feedback in SPT & MARD-Y3 clusters (Singh+, in prep.)
- ❖ ACT-DR6 MCMF (+ RASS-MCMF) cosmology (Klein+, in prep.)

Euclid confirmation at  $z > 1$  as good as DES at  $z = 0.6$



New discoveries: A jellyfish galaxy at  $z = 1.32$





# Summary

RASS-MCMF

ACT-DR5 MCMF

- ❖ ICM-selected samples + MCMF confirmation powerful combination
- ❖ MCMF approach proven to work in eFEDS and SPT cluster cosmology studies
- ❖ new cluster cosmology studies upcoming using  $\sim 5,000$  clusters ( $\sim 5\times$  SPT,  $\sim$  eRASS1)
- ❖ most catalogs available online (e.g. Vizier)
- ❖ Interested in using our cluster catalogs for your study? ...come and talk to me

eROSITA eFEDS

SPTpol 500d  
SPT-SZ MCMF, SPTpol ECS