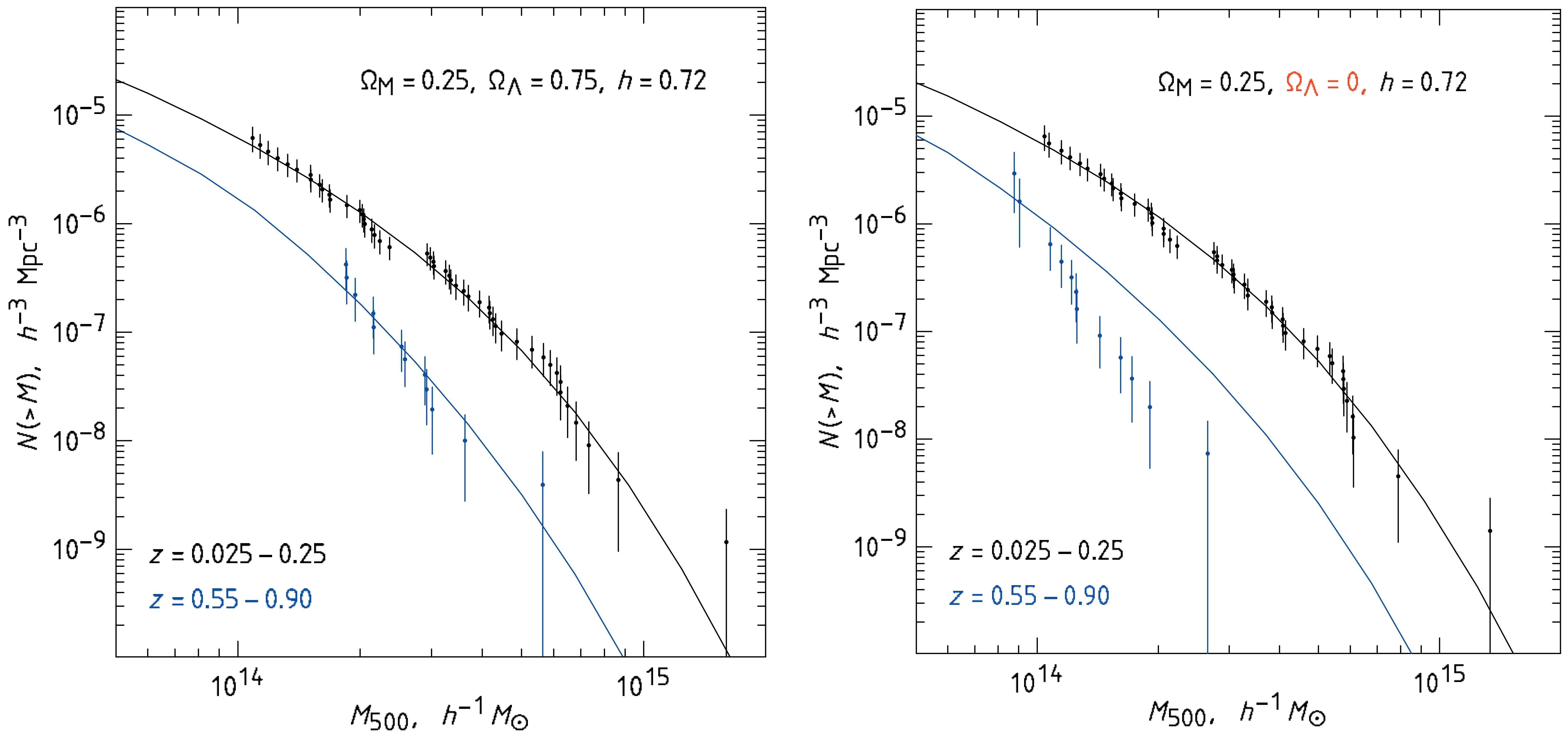
Galaxy Cluster Cosmology with the South Pole Telescope and the Dark Energy Survey

with Sebastian Grandis, Matthias Klein, Maria Paulus, Joe Mohr (LMU Munich)
and further members of the South Pole Telescope and Dark Energy Survey collaborations

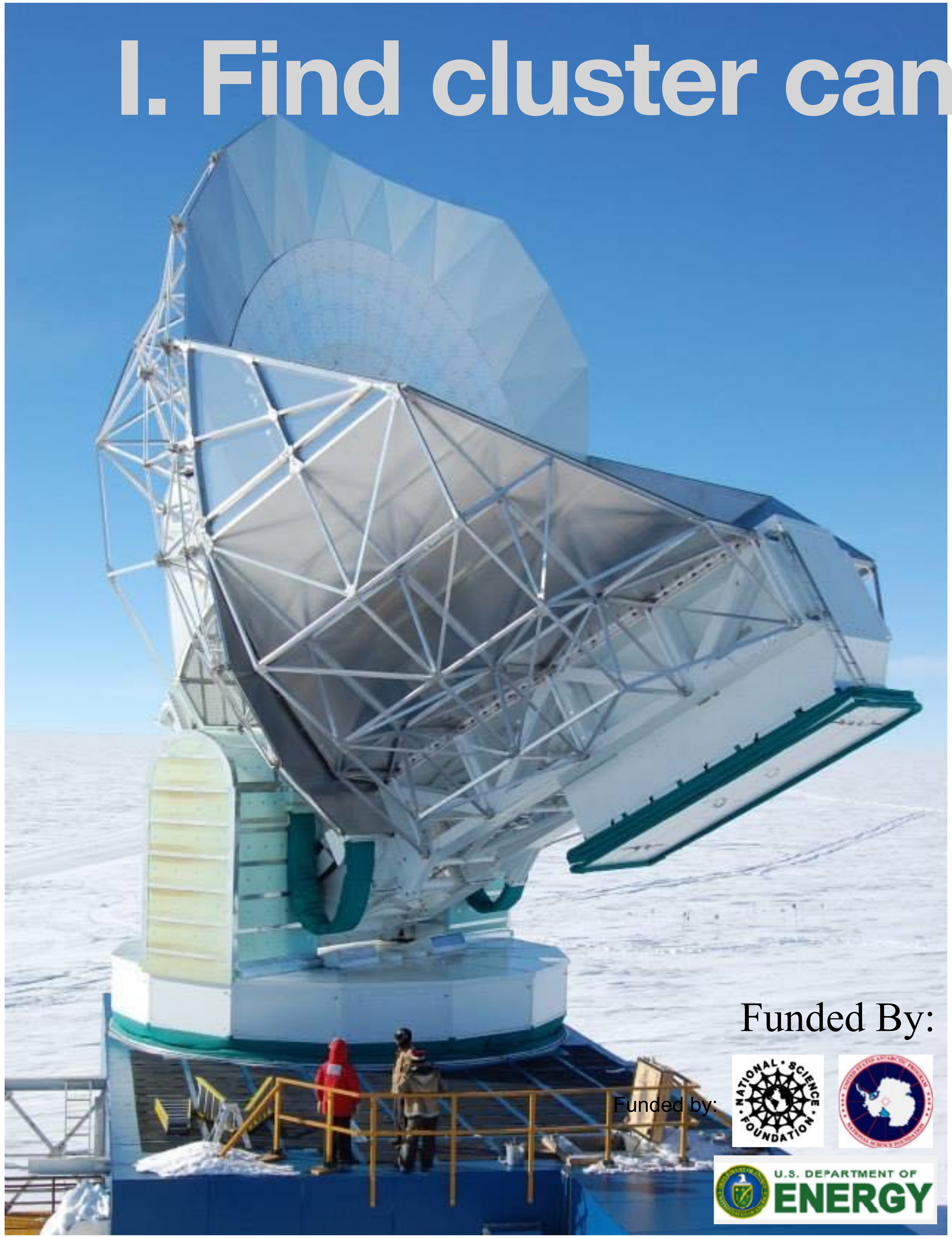
Sebastian Bocquet — CMB-S4 Summer 2021 Meeting

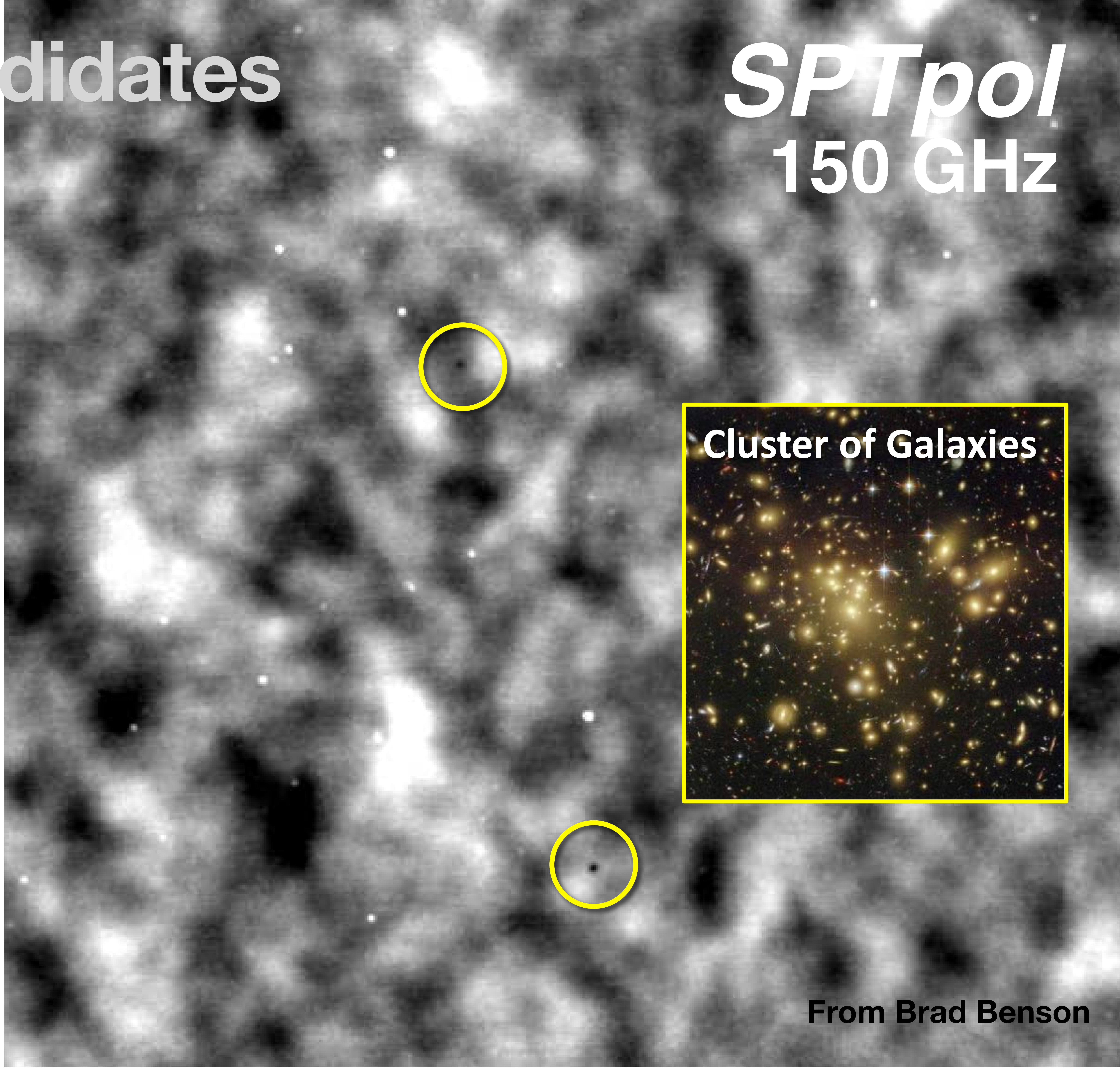
Introduction to cluster abundance cosmology



- Halo abundance prediction from the halo mass function
- Compare observed with predicted number (see figure from Vikhlinin+09)
- Main limitation: how to convert from “mass” to the actual observable(s)? → mass calibration

I. Find cluster candidates

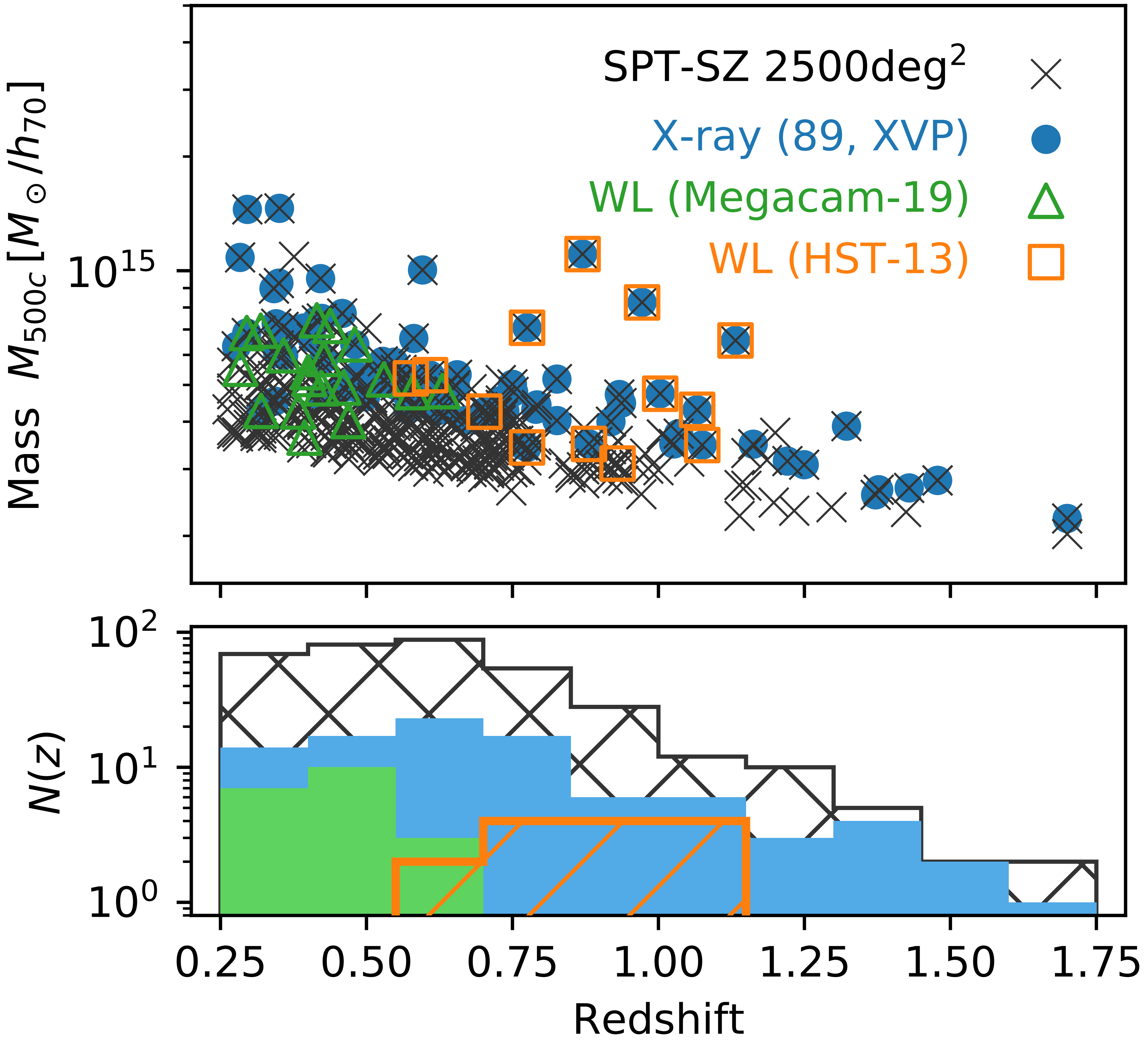




From Brad Benson

II. Get multi-wavelength follow-up data (including redshifts)

SPT-SZ cluster sample as of 2019, more recent work in a few slides



Precursor analyses based on X-ray mass calibration: Benson+13, Reichardt+13, Bocquet+15, de Haan+16

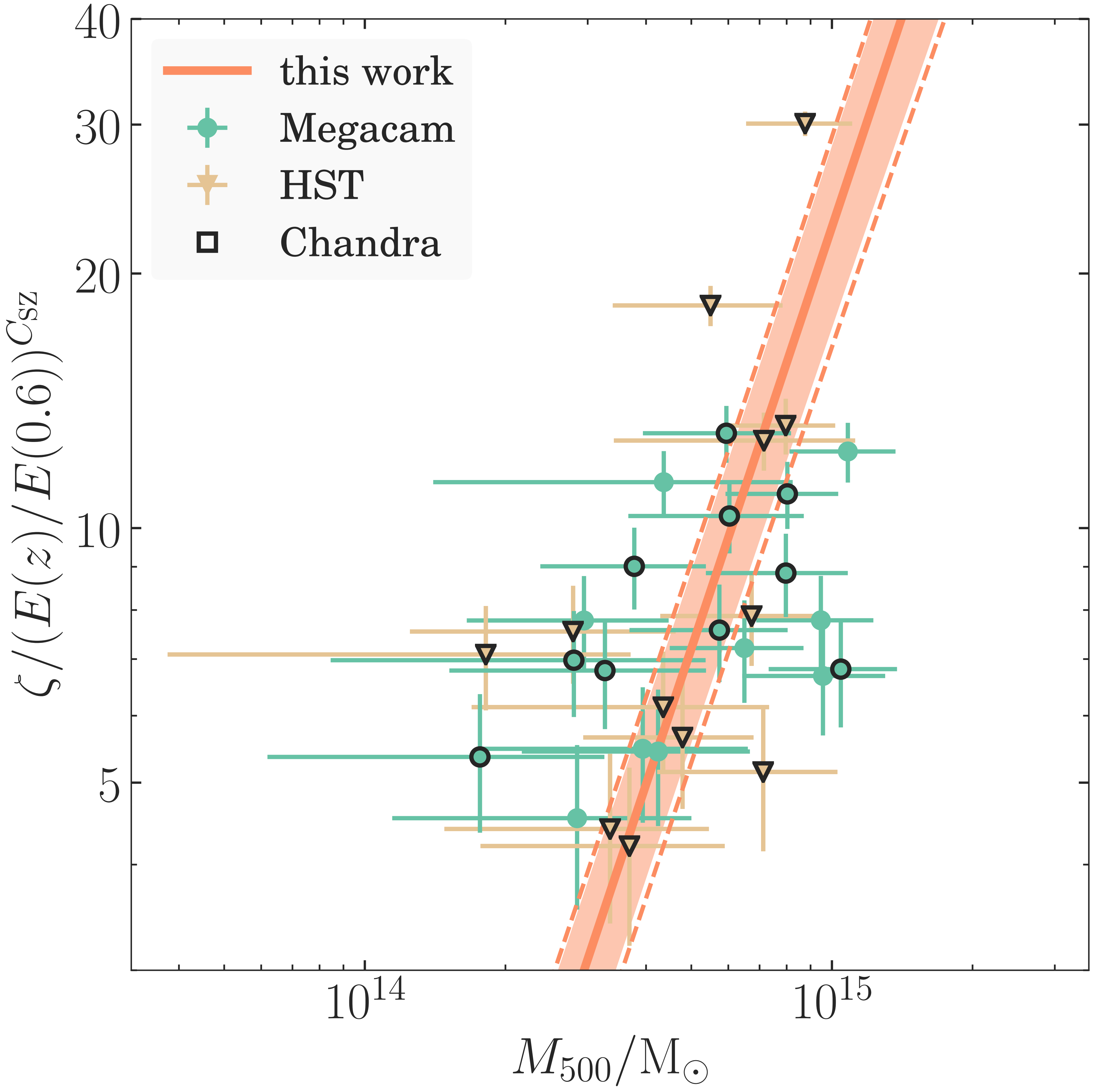
SPT-SZ cluster sample: 343 SZ-selected clusters above detection SNR 5 and $z > 0.25$

X-ray follow-up data: McDonald+13,17

Weak-lensing follow-up data:
HST-13 (Schrabback+18)
Megacam-19 (Dietrich,Bocquet+19)

III. Weak-lensing mass calibration

Megacam & Hubble data for SPT clusters (Schrabback et al. 2018; Dietrich,Bocquet et al. 2019)



SZ signal

Weak-lensing inferred mass

Use known Mwl—Mhalo relation to calibrate SZ—mass relation

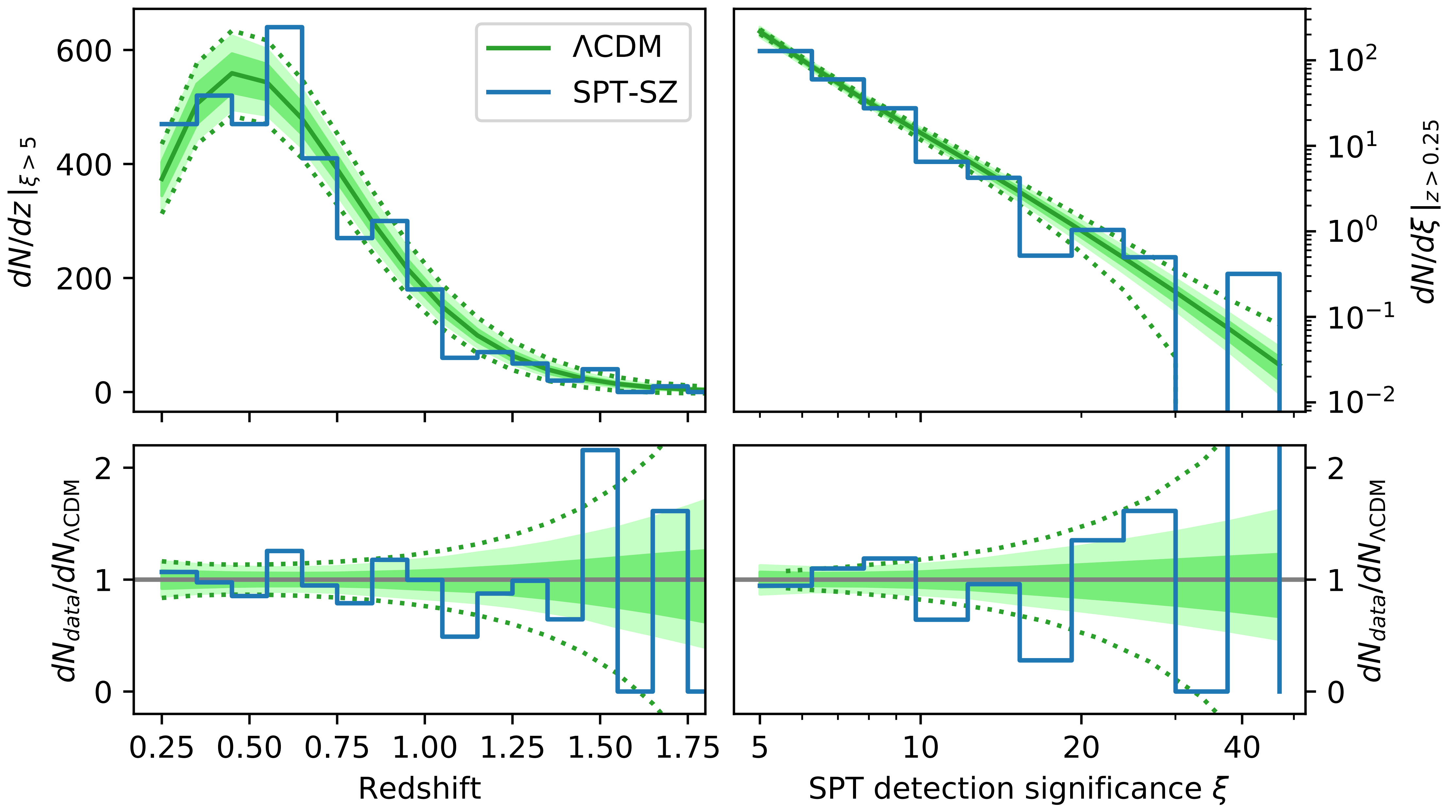
IV. SPTcl Cosmological constraints

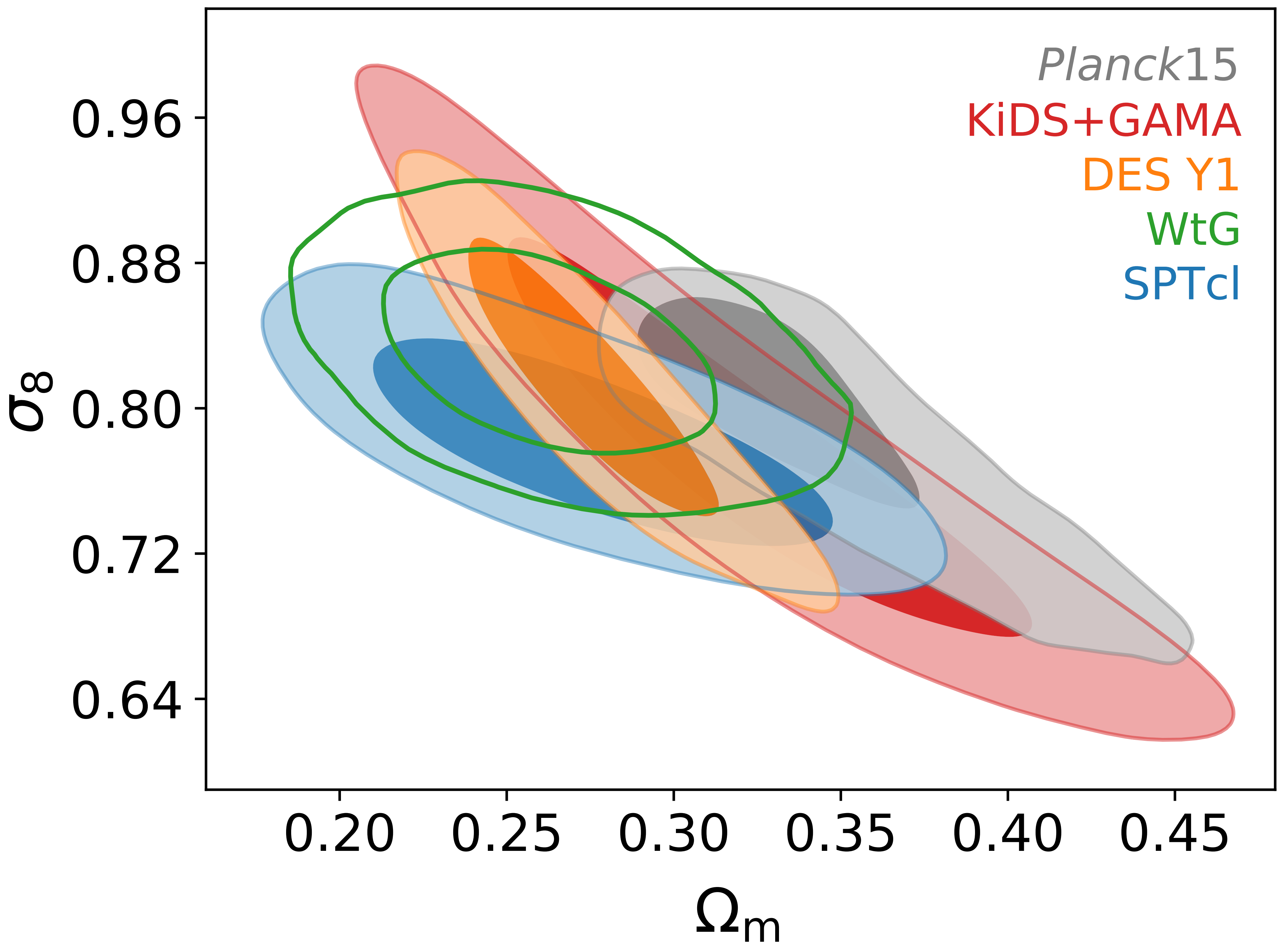
LCDM constraints (w/ massive neutrinos) Bocquet+19

- Wide flat priors on SZ scaling relation parameters fully encompass posterior

- Cluster constraint statistically limited by mass calibration: need more (weak lensing) data! (currently 32 clusters)

- 1.5 σ agreement with *Planck*15 TT+lowTEB

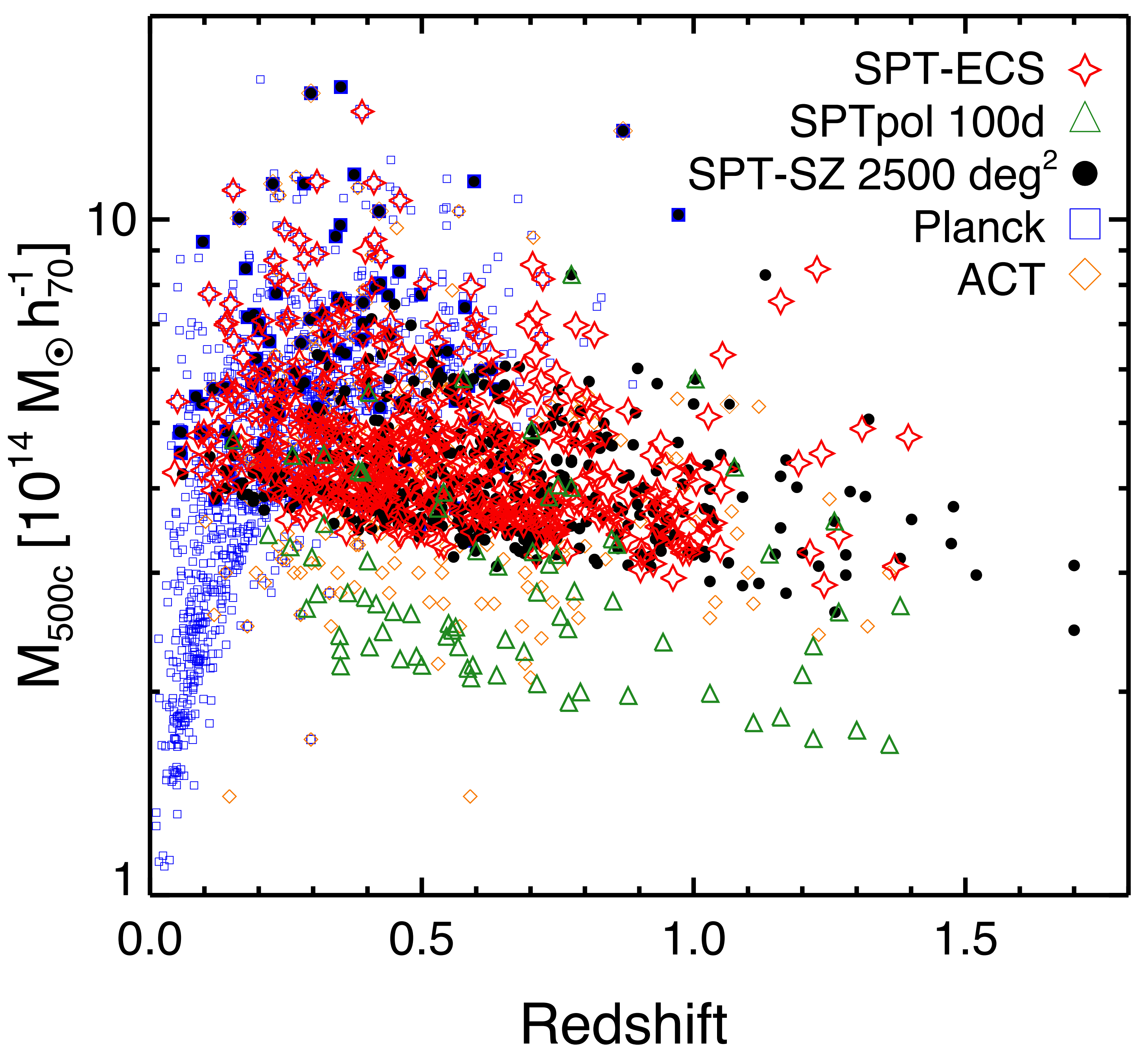


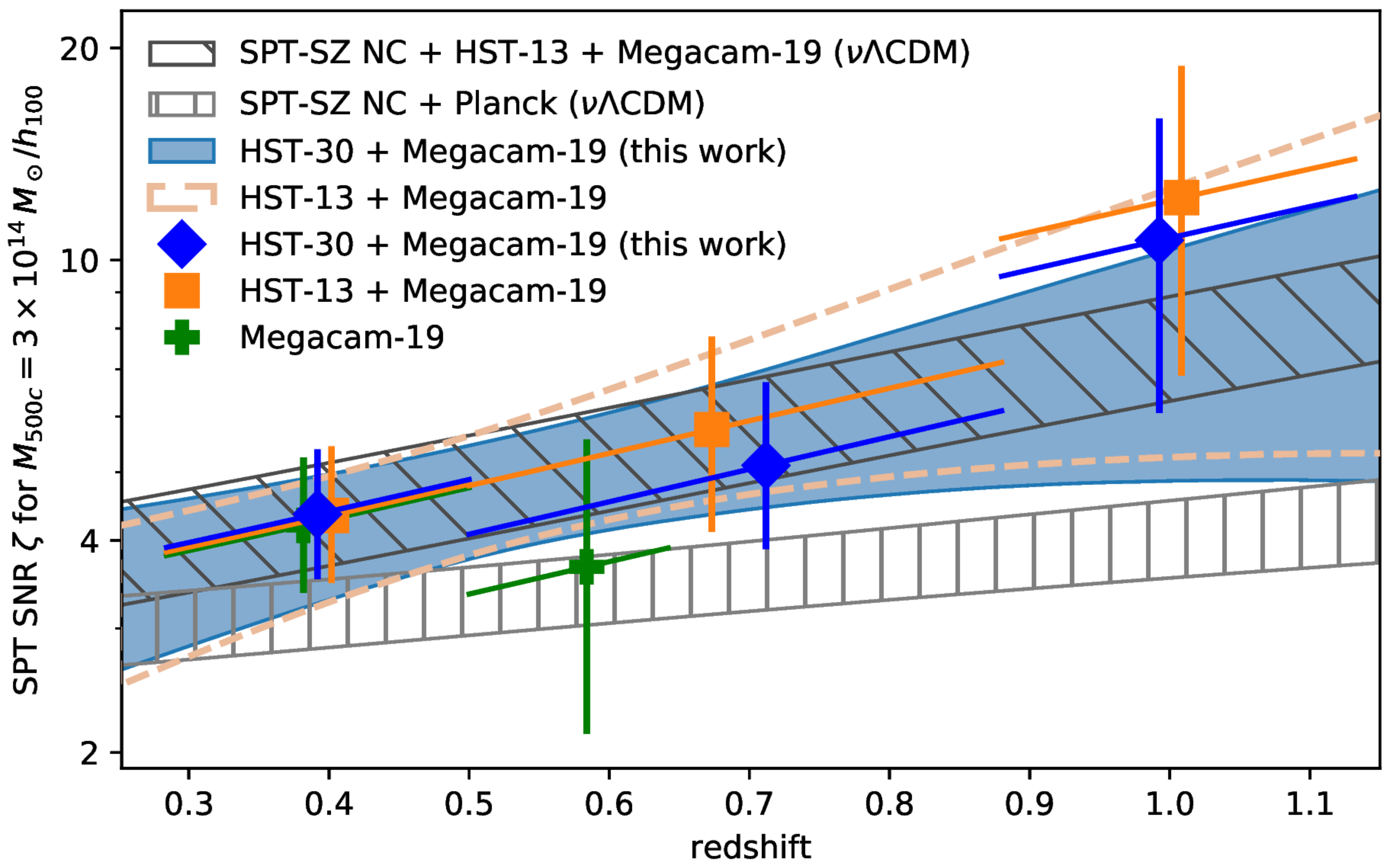


How to improve?

— Larger cluster sample
— More weak-lensing data with small systematic uncertainties

Recent progress





New cluster catalogs:

- Deep 100 square-degree SPTpol-100d survey (Huang+20)
- Wide 2700 square-degree SPTpol-ECS survey (Bleem,Bocquet+20)

~1000 clusters above detection SNR 4.5

Redshifts/optical confirmation mainly from Dark Energy Survey

High-redshift cluster weak-lensing using Hubble Space Telescope

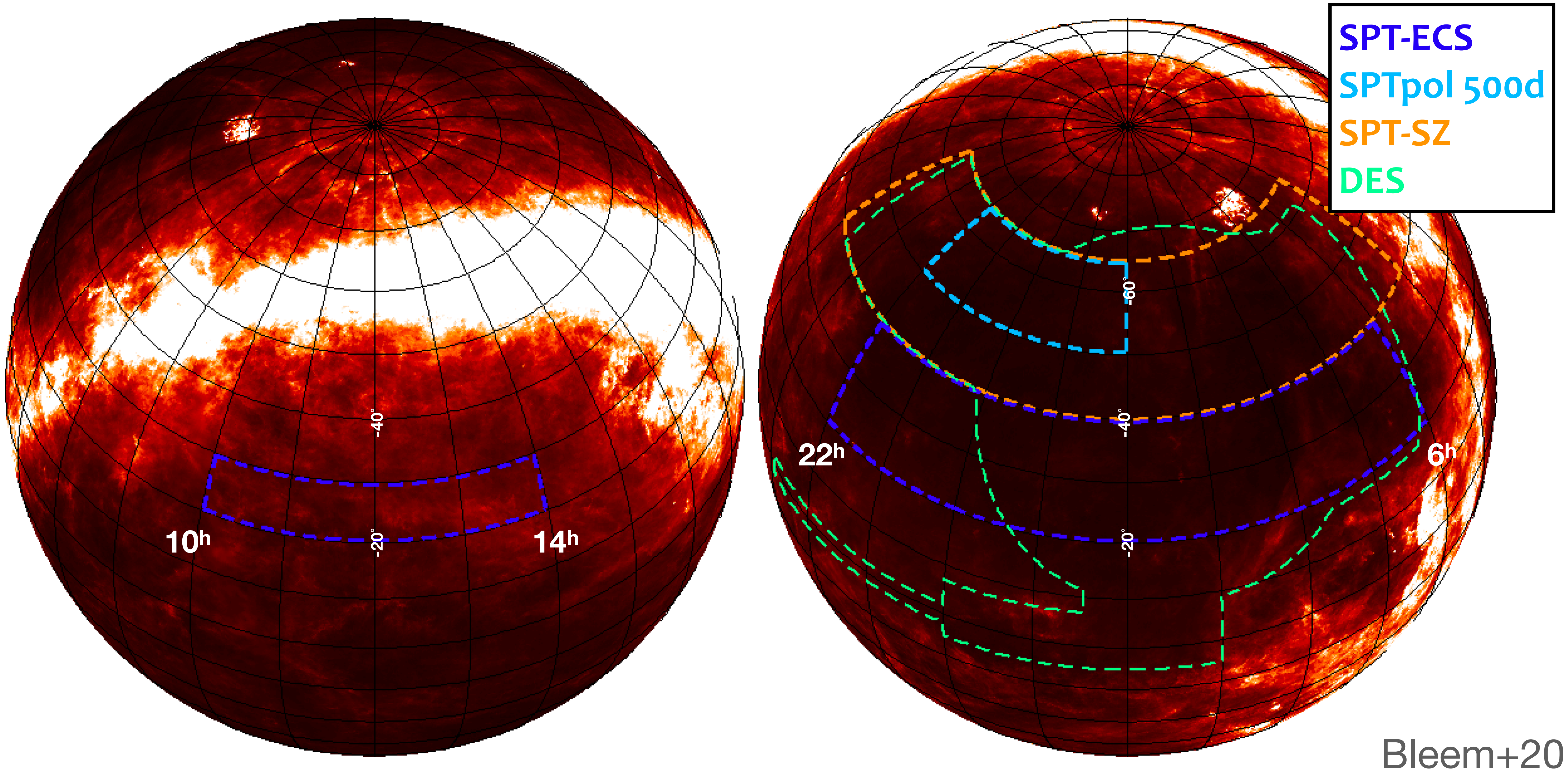
High-z dataset now comprises 30 HST clusters (Schrabback,Bocquet+21)

Analysis of 9 additional z>1.1 cluster ongoing (Zohren+ in prep.)

The Dark Energy Survey

- CTIO Blanco Telescope
- 5000 square degrees in *grizy*
- Survey is complete — analysis of Y3 data ongoing
- Strategically overlaps the SPT survey

SPT and DES surveys



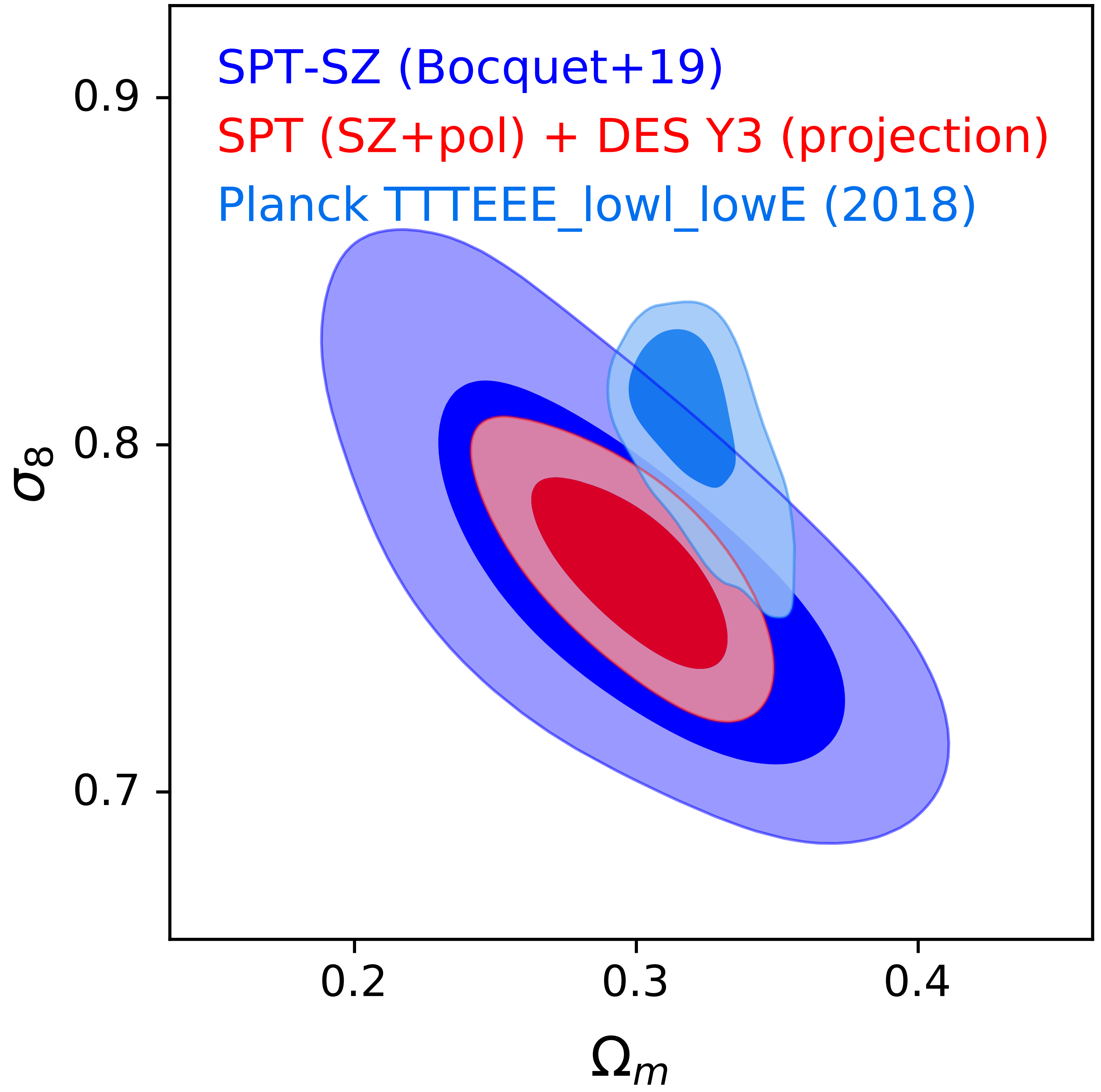
Dark Energy Survey Year 3: *griz*, 4143 deg2, > 300e6 objects

SPT-SZ + SPTpol-ECS + SPTpol-500d: 5200 deg2
(deeper pol-100d and pol-500d are within SPT-SZ)

SPT-SZ + SPTpol + DES Year 3 weak-lensing

Bocquet et al. in prep.

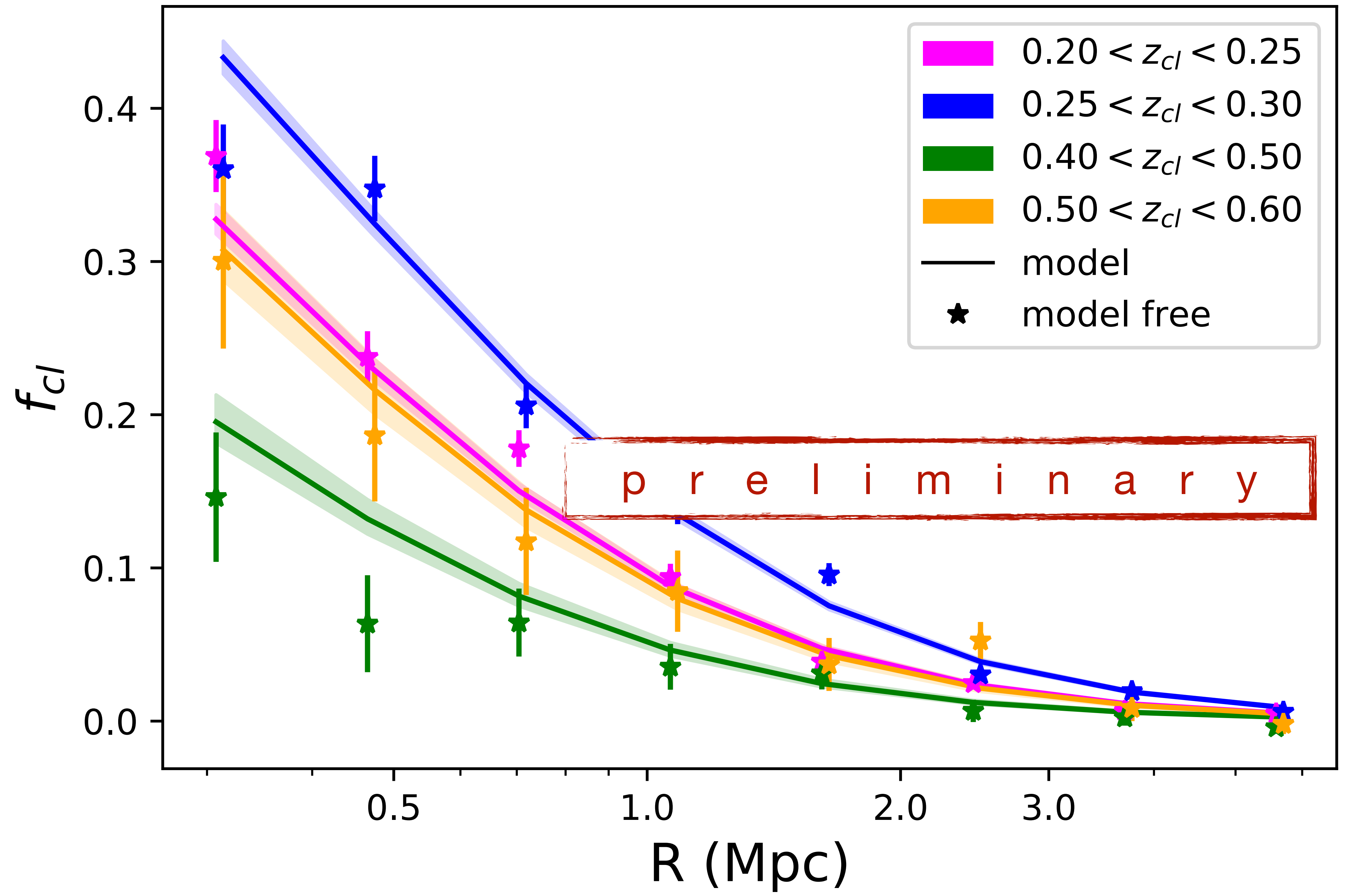
- O(1000) SPT selected clusters
  - Optical confirmation (Lindsey Bleem, Matthias Klein)
- DES weak-lensing mass calibration up to z~0.85
- Code validation using mocks
- Blind analysis



Cluster member contamination

a.k.a. boost factors (cluster members in lensing source sample)

- P(z) decomposition (e.g., Gruen+14, Varga+19) applied to non-stacked weak-lensing data
- Application to DES Year 1 data (see Figure; Paulus+ to be submitted)
- Following same approach for DES Year 3

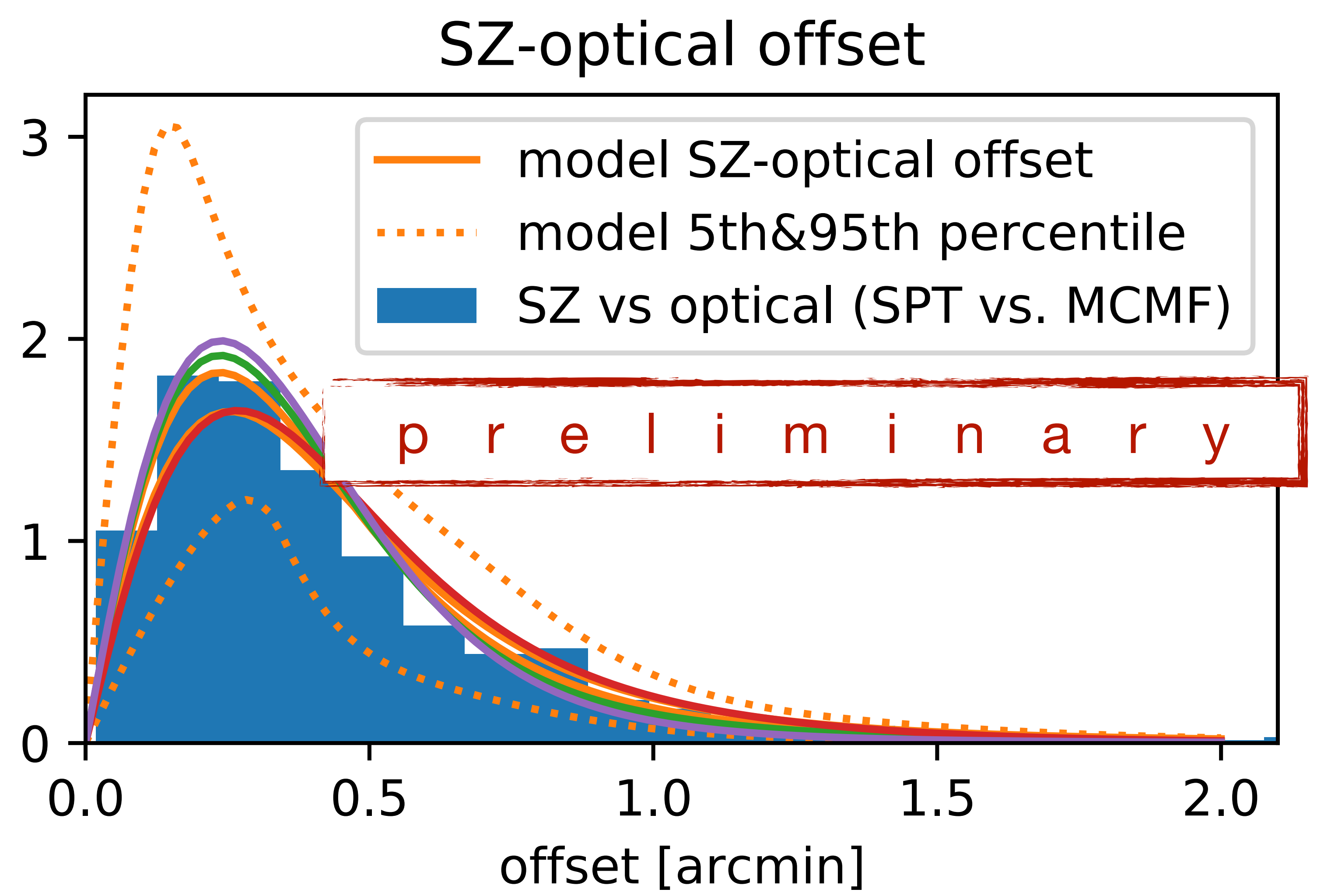


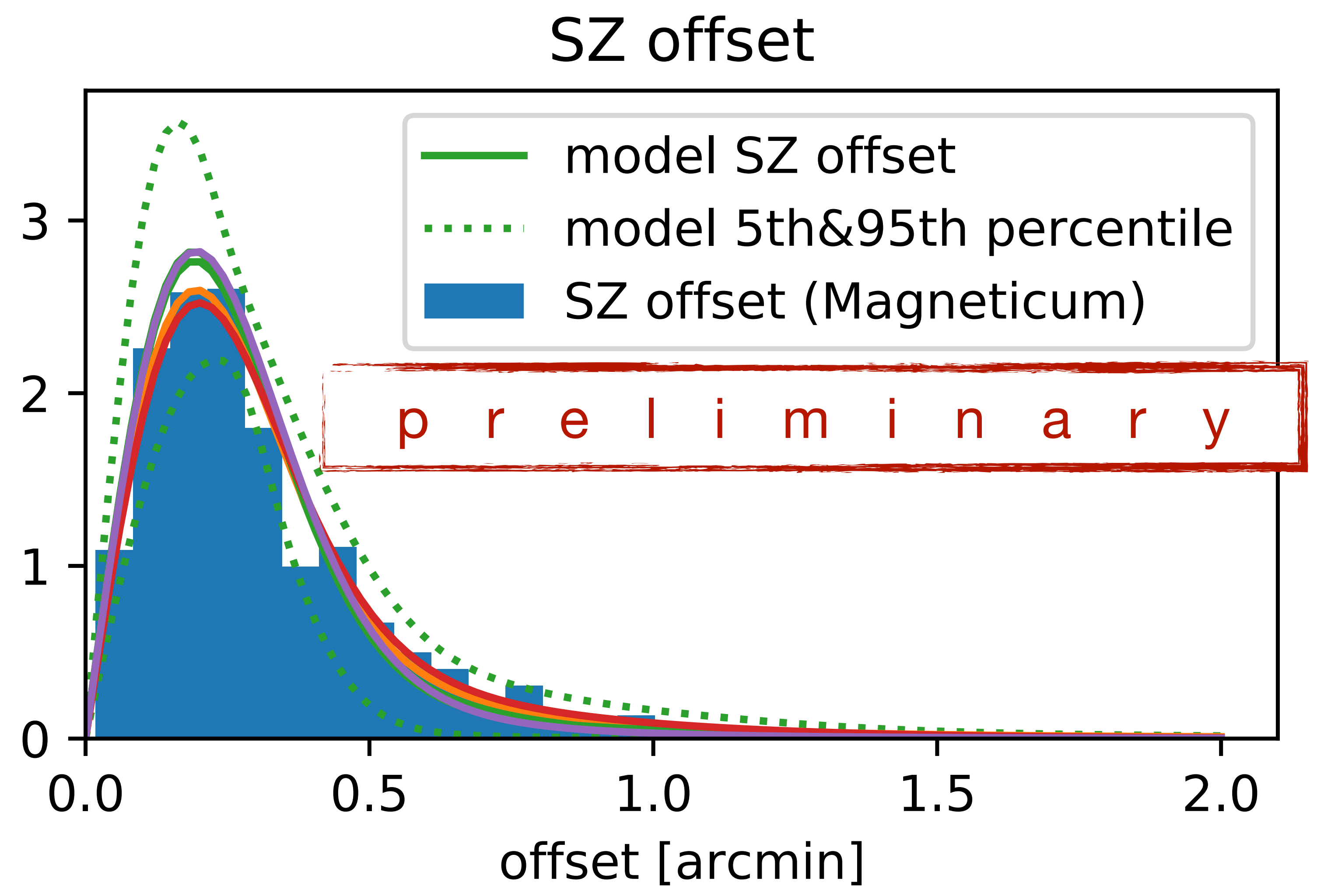
Miscentering

Offset between true halo center and observational center

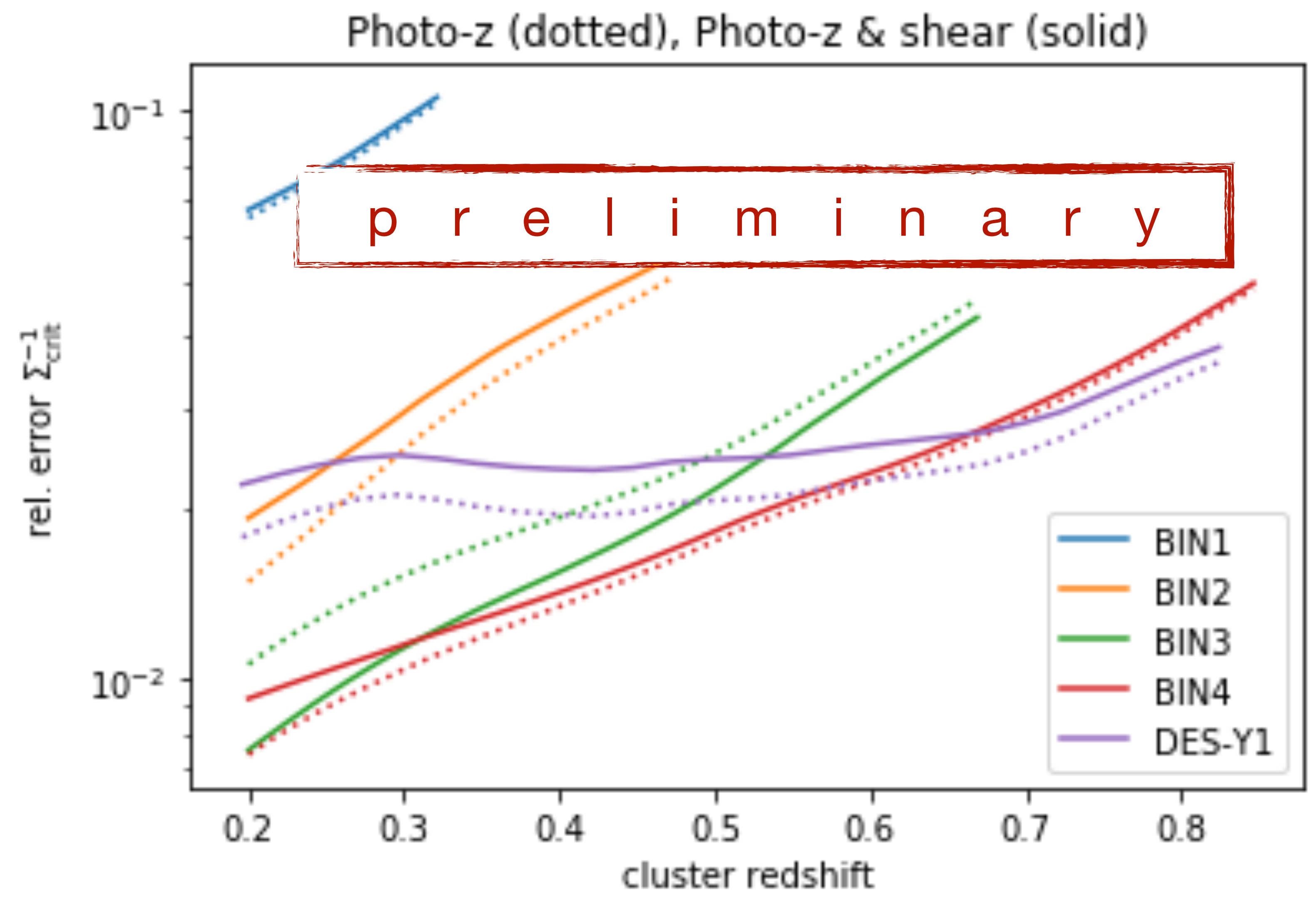
- Joint SZ & optical miscentering model
  - Fits the data
  - Reproduces SZ miscentering in Magneticum hydrodynamical simulation

- See also Saro+15, Gupta+16, Zhang+19





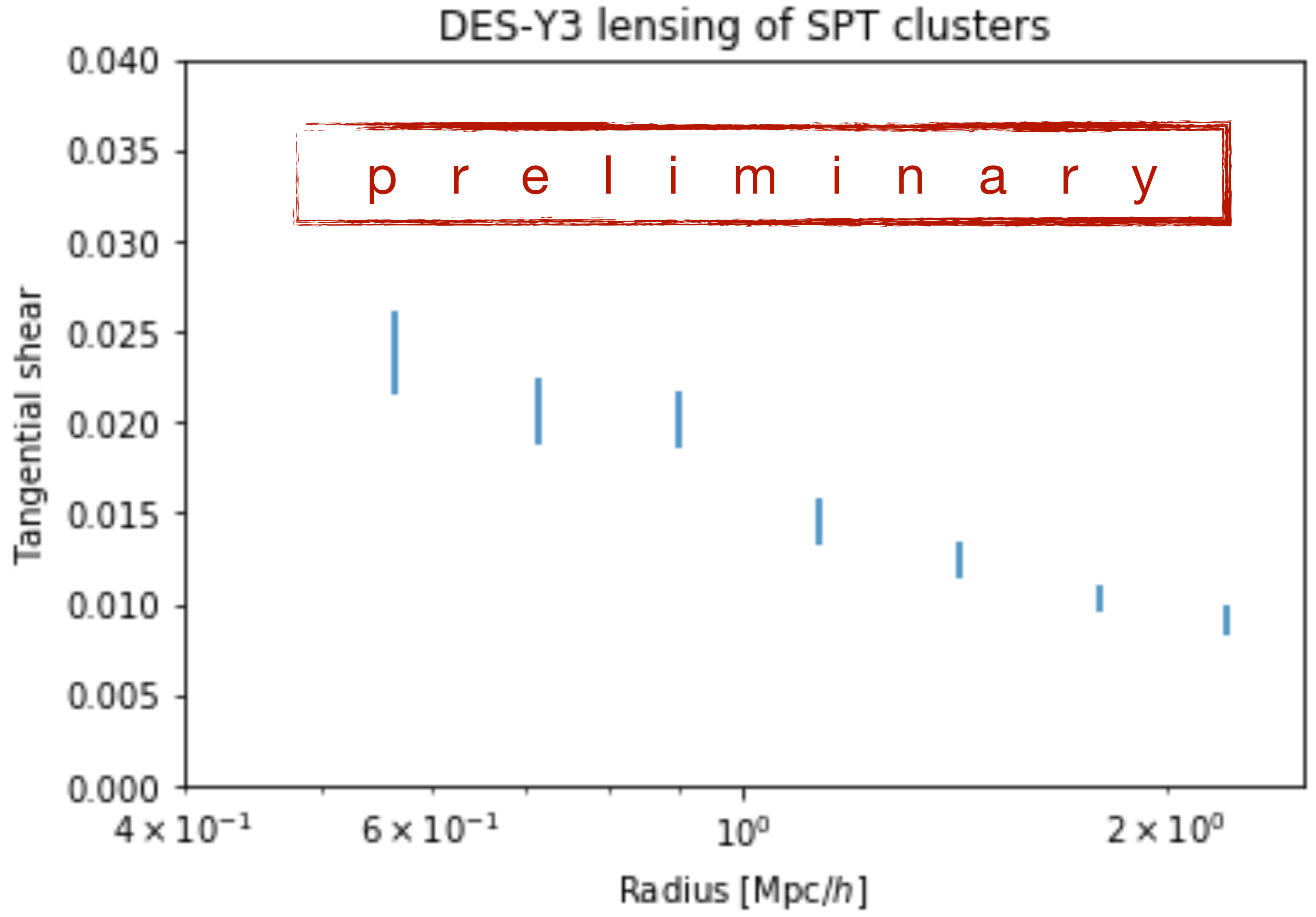
DES Y3 Weak-lensing shear and photo-z



Systematic uncertainty in inv(Sigma_crit)

Significant improvement over DES Year 1

Shout-out to the DES weak-lensing folks!



SPT SNR > 4.5 clusters

0.5 Mpc/h < r < 3.2 / (1+z) Mpc/h

Shear SNR ~ 80

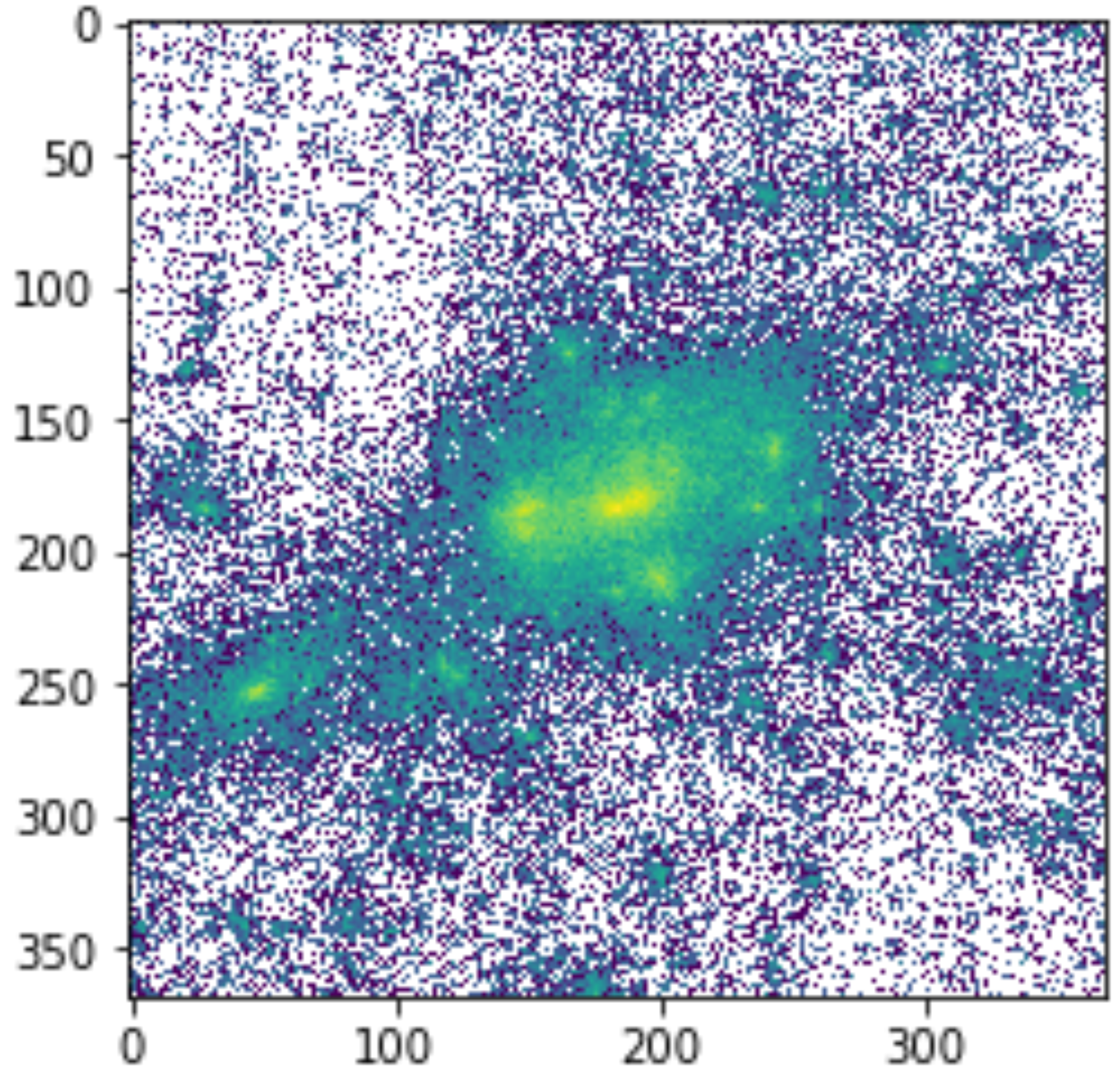
Full weak-lensing model

Following Grandis,Bocquet+21

- Mass modeling (halo profiles, miscentering, uncorrelated LSS)
- Shear modeling (shear and photo-z calibration, cluster member contamination)
- Impact of baryonic effects on halo profiles by comparing Magneticum and Illustris TNG hydrodynamical simulations: 2% difference in mass

‣ Total systematic weak-lensing uncertainty: 3 — 6 % as function of cluster z

Halo projection in Magneticum



Outlook

- Not yet saturating systematic floor
- Weak-lensing mass calibration beyond z ~ 0.9 remains poorly constrained (but HST lensing up to z ~ 1.7)
- Looking forward to high-SNR CMB lensing!

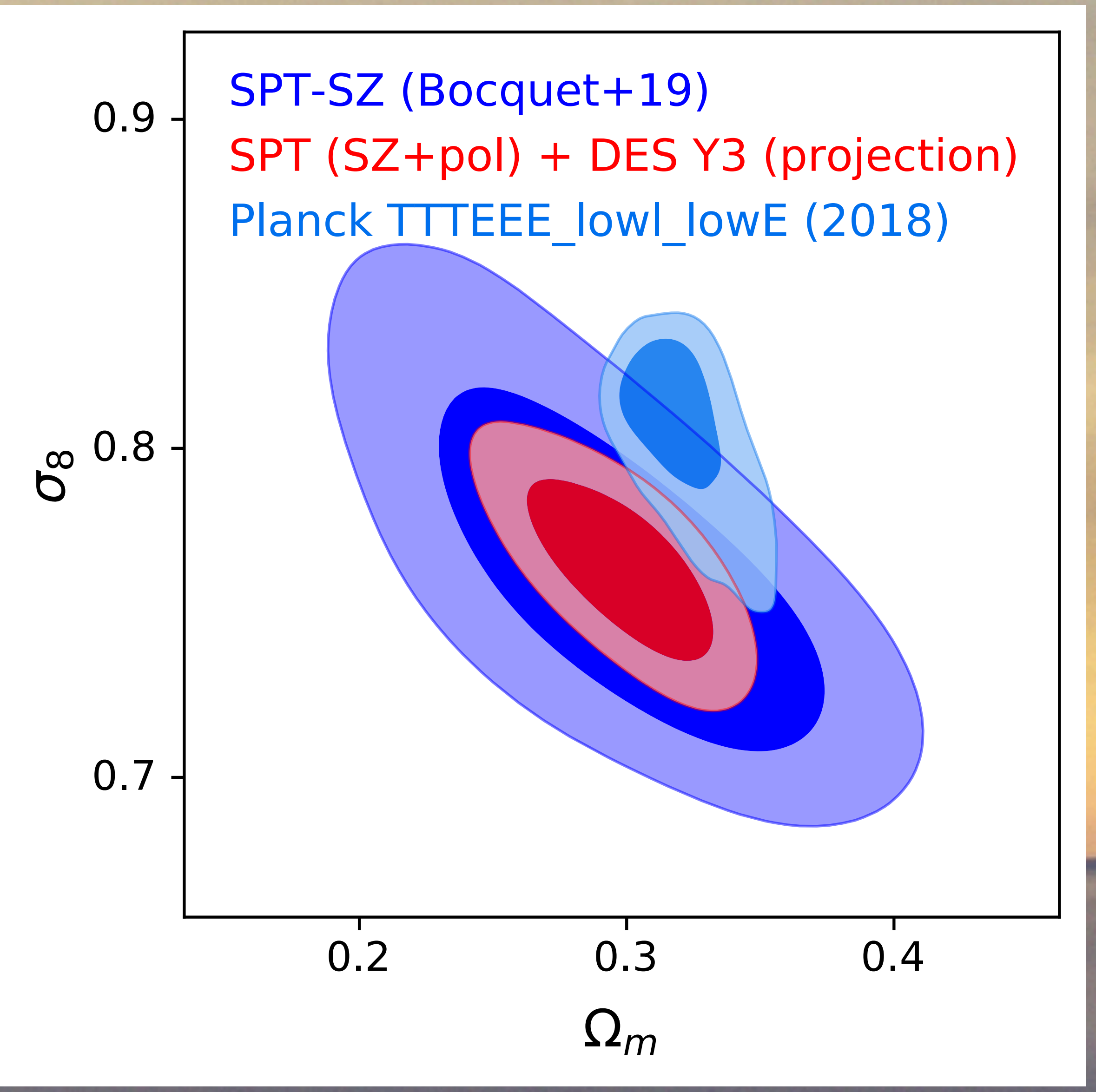


Image credit: SPT 2018 winter-overs Adam & Joshua