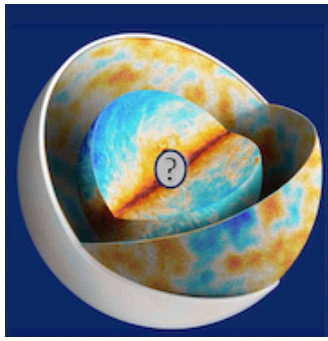

Colloque national CMB-France #4

Galaxy clusters in mm wavelengths:
combine Planck and SPT

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IAS Orsay

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CNRS

ClustersXCosmo – erc European Research Council

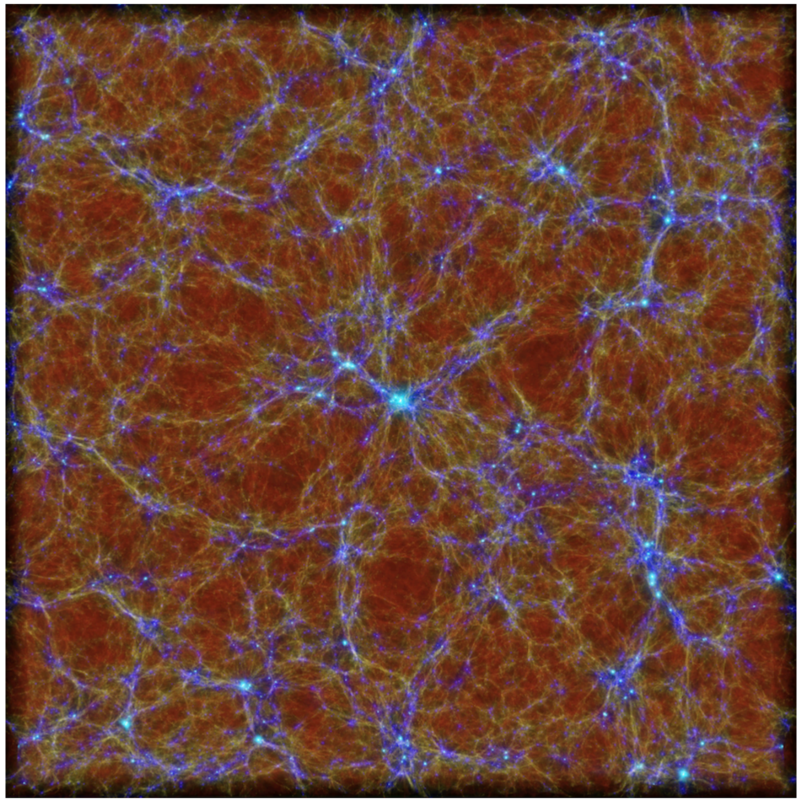
Outline

- Cosmology with galaxy clusters
  - Impact of mass calibration
- Combine observation from different experiments
  - Planck + SPT → in collaboration with A. Saro and SPT
  - Step 1:
    - independent calibration of Planck cluster masses
    - cosmological analysis

ApJ 934, no.2, 129 (2022)

Galaxy Clusters

Credit: E. Siegel



Credit: Hirschmann et al. 2014

- Largest gravitationally bound structures in the Universe
- Peaks in the cosmic web
- Multi-component systems:
    - Observables at different wavelengths

Dependence on cosmological parameters: $\sigma_8, \ \Omega_m$

$$\sigma^2 = \frac{1}{2\pi^2} \int \mathrm{d}k\, k^2 P(k,z)\, |W(kR)|^2$$

Cluster cosmology

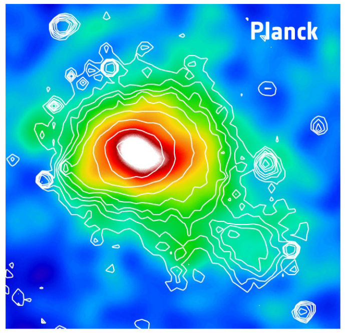
Cluster cosmology: *mass* and *redshift* of clusters

Cluster number counts:

***NC(z,obs)* = Mass Function x Scaling Relations x Selection Function**

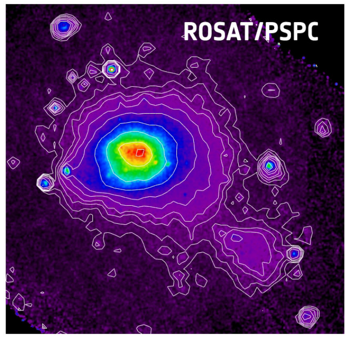
Cosmology/theory
Theoretical NC(z,M)

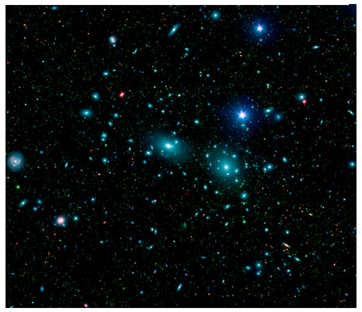
Astrophysics
Survey observable - cluster mass



mm-wavelengths
Hot gas

Xray-wavelengths
Hot gas





Optical wavelengths
Galaxies

COMA cluster

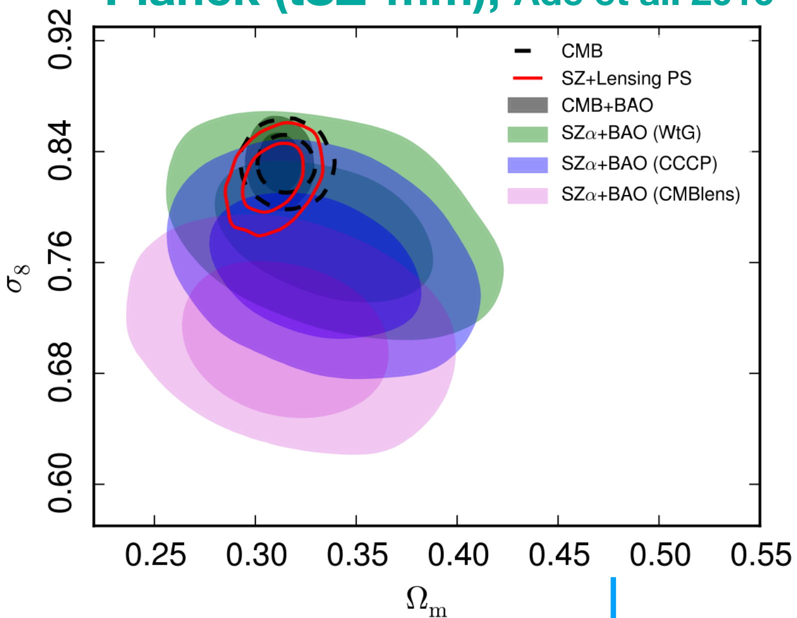
Multi-wavelengths analysis:
Unique way to calibrate cluster mass

Observations
Survey and detection strategy

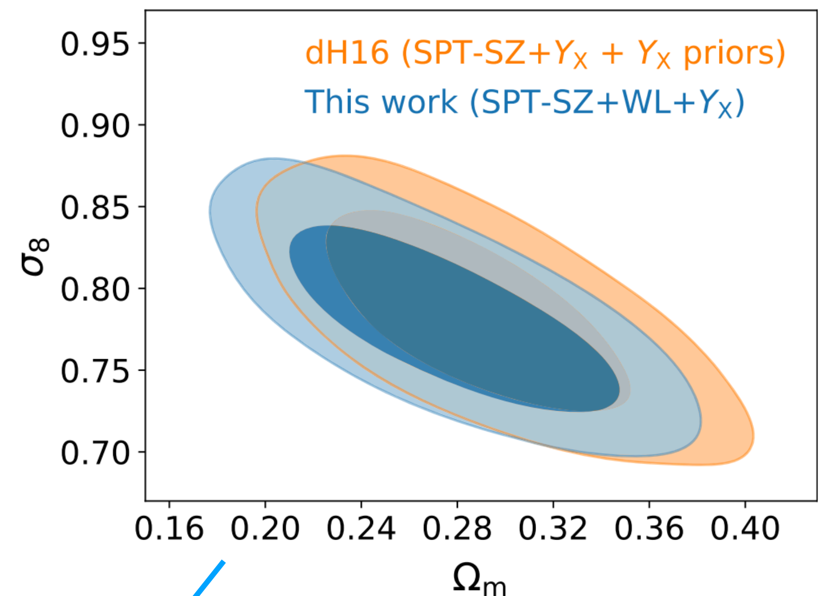
Constraints on cosmological parameters:
precise characterisation of the building blocks

Cluster cosmology

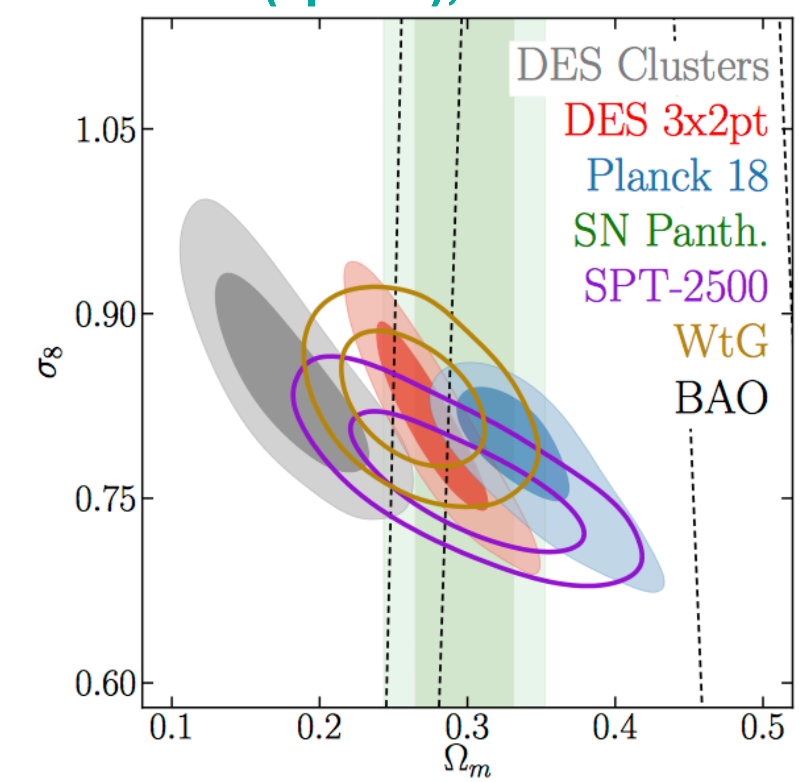
Planck (tSZ-mm), Ade et al. 2016



SPT (tSZ-mm), Bocquet et al. 2019



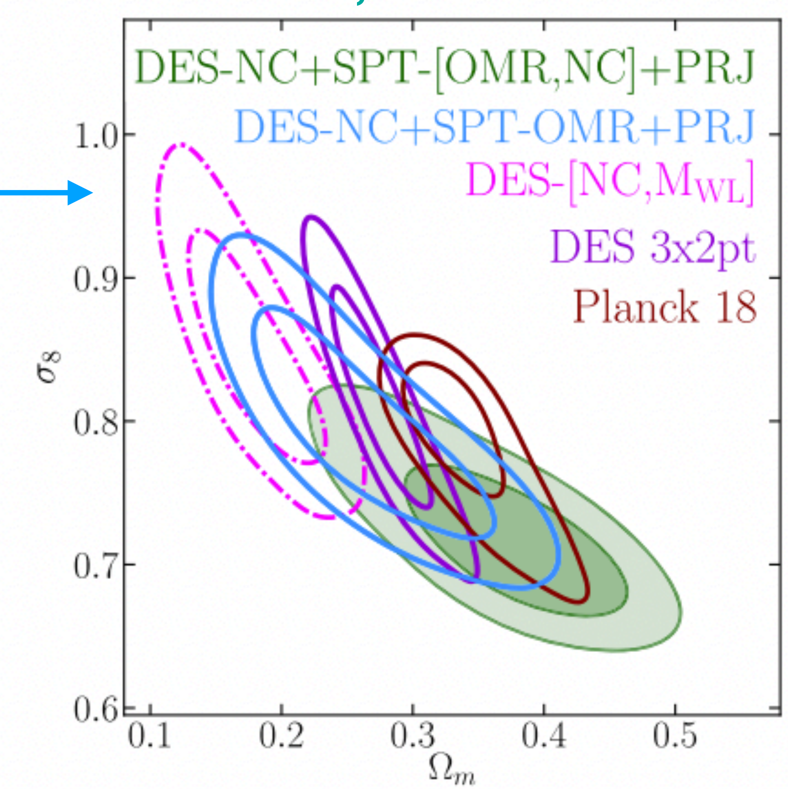
DES (optical), Abbott et al. 2020



- PSZSPT catalogue (Melin et al. 2021)
- Planck+SPT cluster cosmological analysis (Salvati et al. 2022)
- Not mentioning: Combinations at the map level

See talks of Boris Bolliet (ACT) and Corentin Hanser (NIKA2) on Tuesday

SPT+DES, Costanzi et al. 2021



tSZ clusters: Planck

Mass calibration

Cluster number counts:

***NC(z,obs)* = Mass Function x Scaling Relations x Selection Function**

- Self-similarity: gravity is the only acting force
- Spherical symmetry
- Hydrostatic equilibrium

→ $Y_{\rm SZ} D_A^2 \propto M_{\rm tot}^{5/3} E(z)^{2/3}$

Planck Scaling Relations

$$E^{-\beta}(z)\left[\frac{D_A^2(z)\,Y_{500}}{10^{-4}\,{\rm Mpc}^2}\right] = Y_*\left[\frac{h}{0.7}\right]^{-2+\alpha}\left[\frac{(1-b)\,M_{500}}{6\cdot 10^{14} M_\odot}\right]^{\alpha}$$

$\alpha,\ Y_*$ → from X-ray observations

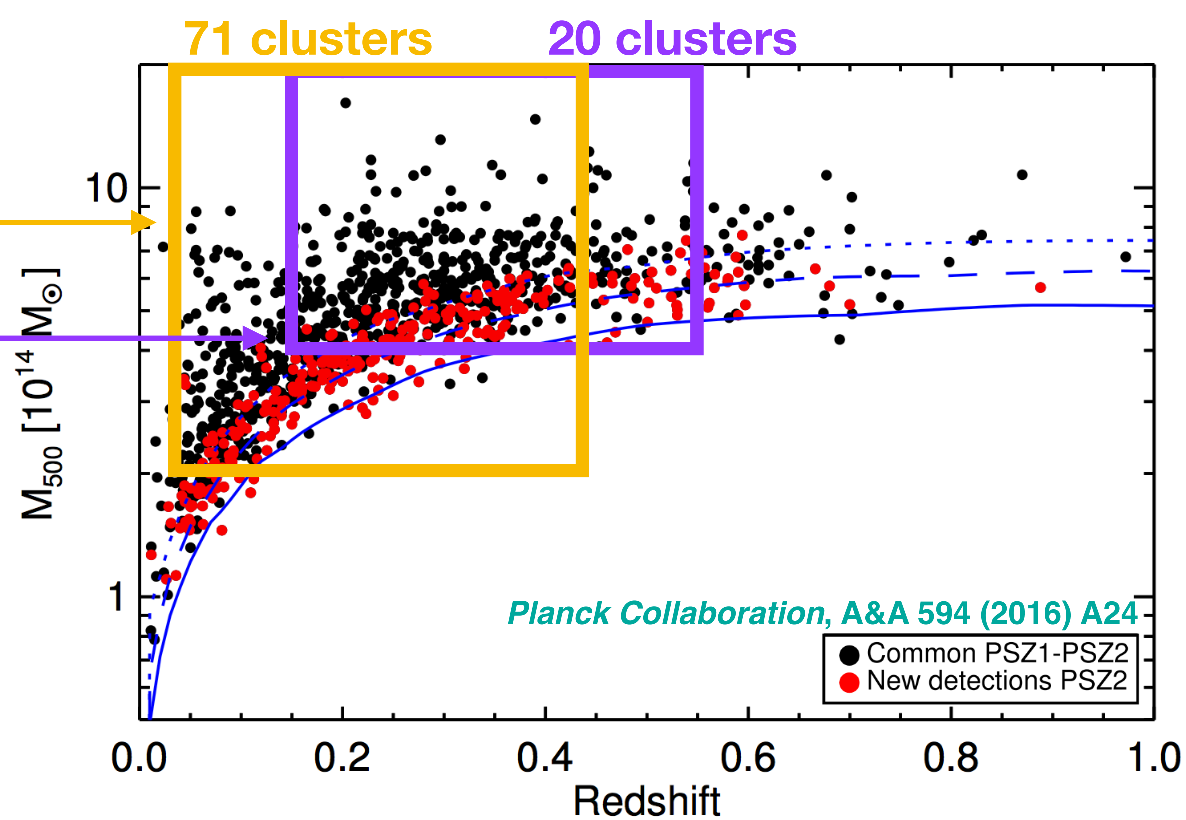
$(1-b)$ → from WL mass evaluations

$\beta = 2/3$ → from self-similarity

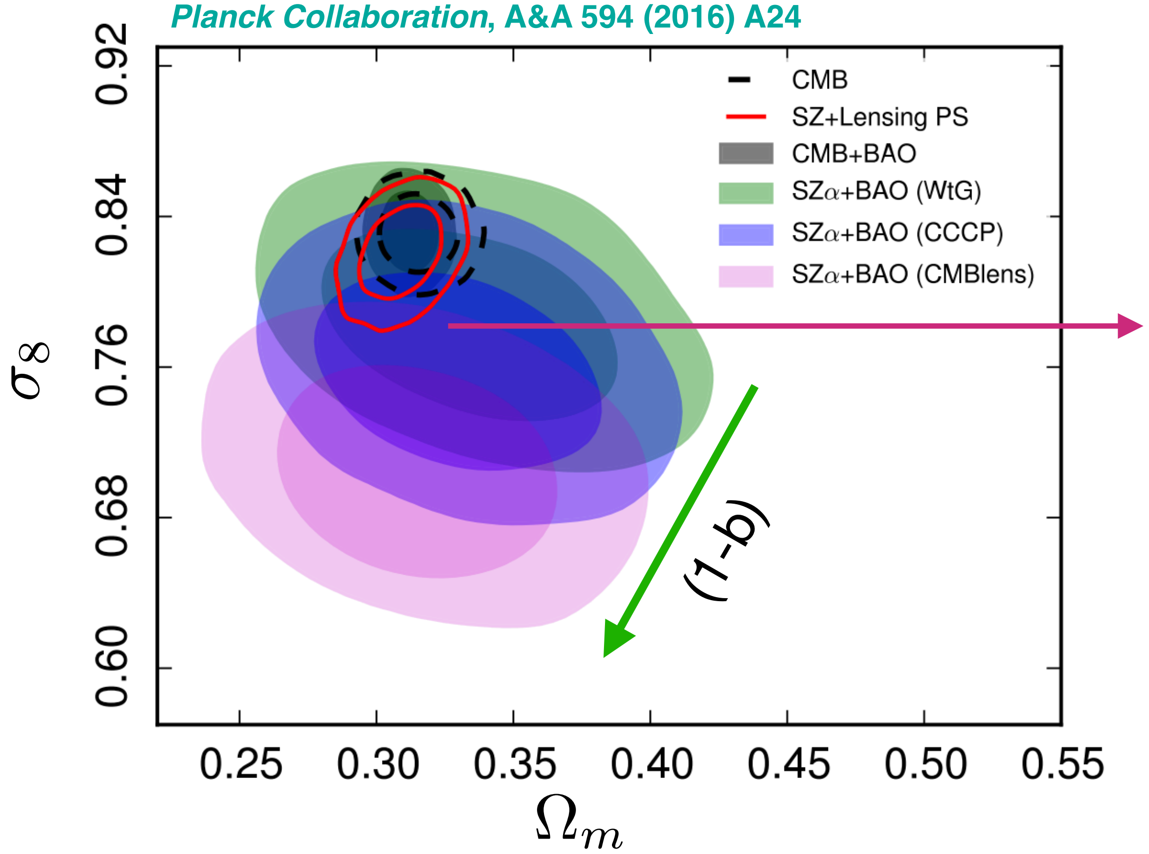
Planck Collaboration, A&A 594 (2016) A24

$$(1-b) = \frac{M_{\rm SZ}}{M_{500}}$$

Planck cosmological cluster sample: 439 clusters



Planck Collaboration, A&A 594 (2016) A24



tension between CMB primary anisotropies and Galaxy Clusters: $\simeq 2.4\,\sigma$ on σ_8

$$(1-b) = \frac{M_{\rm SZ}}{M_{500}}$$

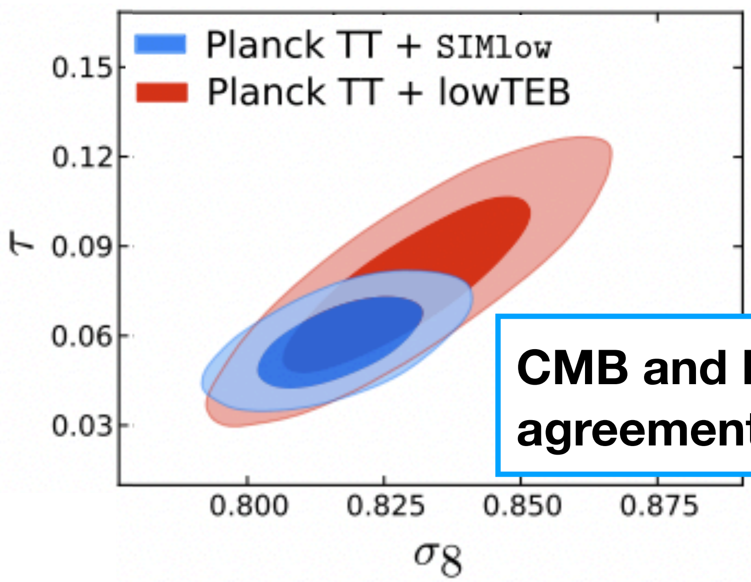
$$\mathrm{CMB} + \mathrm{NC}^{\rm tSZ} : (1-b) = 0.58 \pm 0.04$$

$$\mathrm{CCCP:}\ (1-b) = 0.780 \pm 0.092$$

Hoekstra et al., MNRAS 449 (2015) no.1, 685

- **Tight correlation between cosmological and scaling relation parameters**
- **Mass calibration: largest source of uncertainty in current cluster cosmology**

Planck Collaboration, A&A 596, A107 (2016)



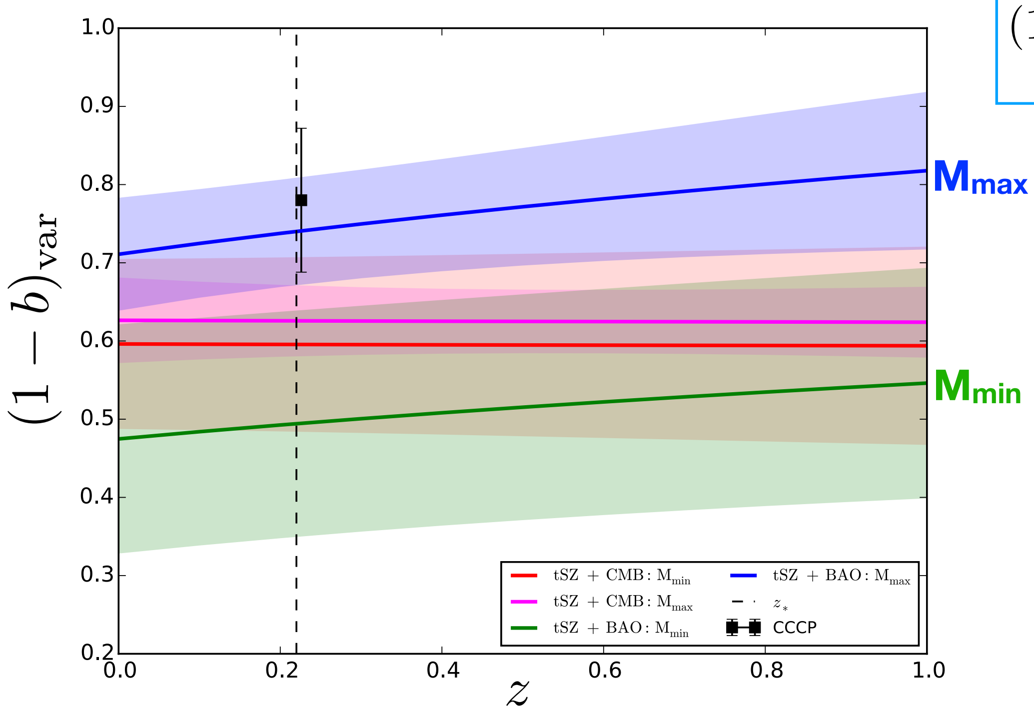
CMB and NCtSZ:
agreement at $1.5\,\sigma$ on σ_8

CMB + NCtSZ

$(1-b) = 0.58 \pm 0.04$	P15
$(1-b) = 0.65 \pm 0.04$	LCDM
$(1-b) = 0.67 \pm 0.04$	Neutrinos
$(1-b) = 0.63 \pm 0.04$	DE
$(1-b) = 0.62 \pm 0.03$	P18

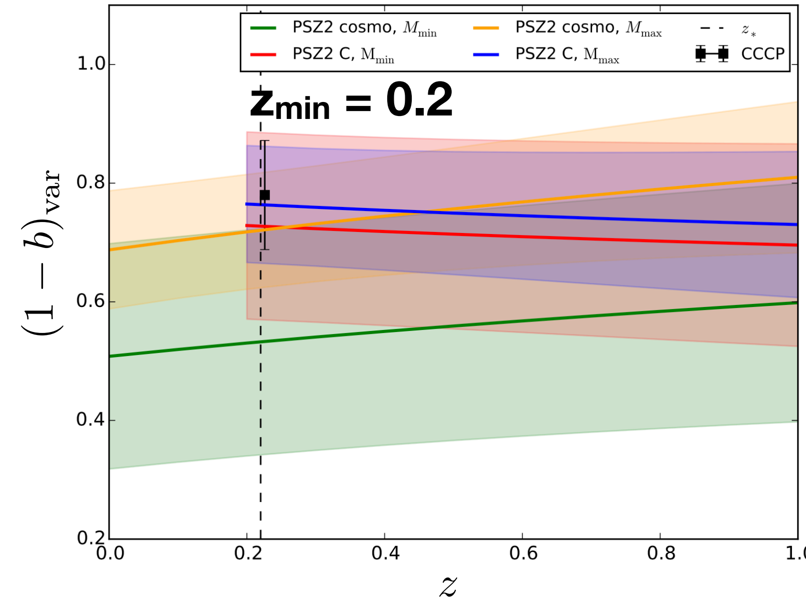
Salvati et al., A&A 614, A13 (2018)

Salvati et al., A&A 626, A27 (2019)



(1-b) increasing with redshift

$$(1-b)_{\rm var} = (1-\mathcal{B}) \cdot \left(\frac{M}{M_*}\right)^{\alpha_b} \cdot \left(\frac{1+z}{1+z_*}\right)^{\beta_b}$$



Selection effects:
results change for different cluster samples

Planck+SPT

Mass calibration might be affected by selection choices

- Multi-wavelengths observations for the full cluster sample
- Independent constraints on mass calibration parameters

Combine Planck and SPT cluster catalogs

Planck

Planck 2015. A&A 594, A24 (2016)
Planck 2015. A&A 594, A27 (2016)

- Survey characteristics:
  - 65% of the sky (~26815 deg2)
  - Frequencies: 100, 143, 217, 353, 545, and 857 GHz (HFI instrument)
  - Resolution: [5',10']
- Cosmological Catalog
  - 439 clusters
  - z = [0,1]
- Cluster extraction: Matched Multi-filters approach
  - Arnaud profile
- EXTERNAL Mass calibration
  - X-ray and WL observations

SPT-SZ

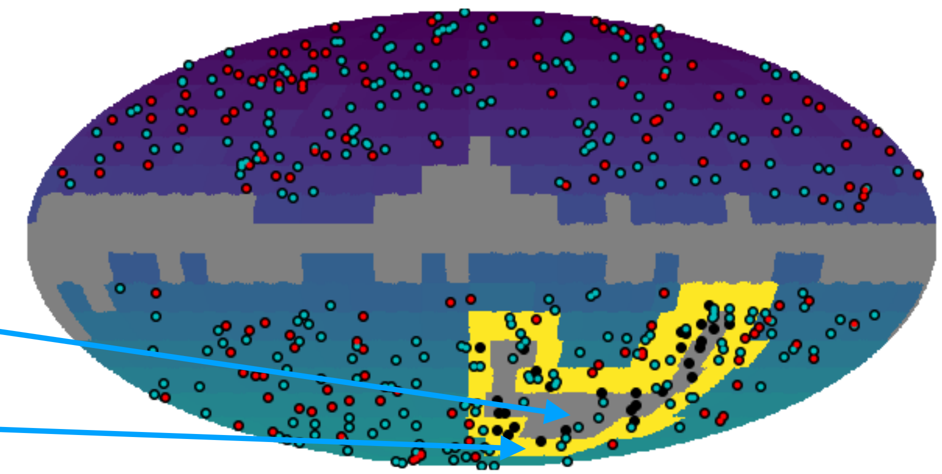
SPT. Bleem at al., APJ Suppl. 216 (2015) no.2, 27
SPT. Bocquet et al., APJ 878 (2019) no.1, 55

- Survey characteristics:
  - 2500 deg2 area
  - Frequencies: 95, 150 GHz
  - Resolution: ~ 1'
- Cosmological catalog
  - 365 clusters
  - z = [0.25,1.7]
- Cluster extraction: Matched Multi-filters approach
  - Beta profile
- INTERNAL Mass calibration
  - X-ray and WL observations
  - empirical, multi-observable approach

Combine Planck and SPT-SZ cluster likelihood

Pre-processing of Planck map

- Starting from original Planck sky
- 417 patches, after applying galactic mask
- Removing 16 sky patches completely overlapping with SPT sky
- Reducing sky fraction of 35 patches partly overlapping with SPT sky



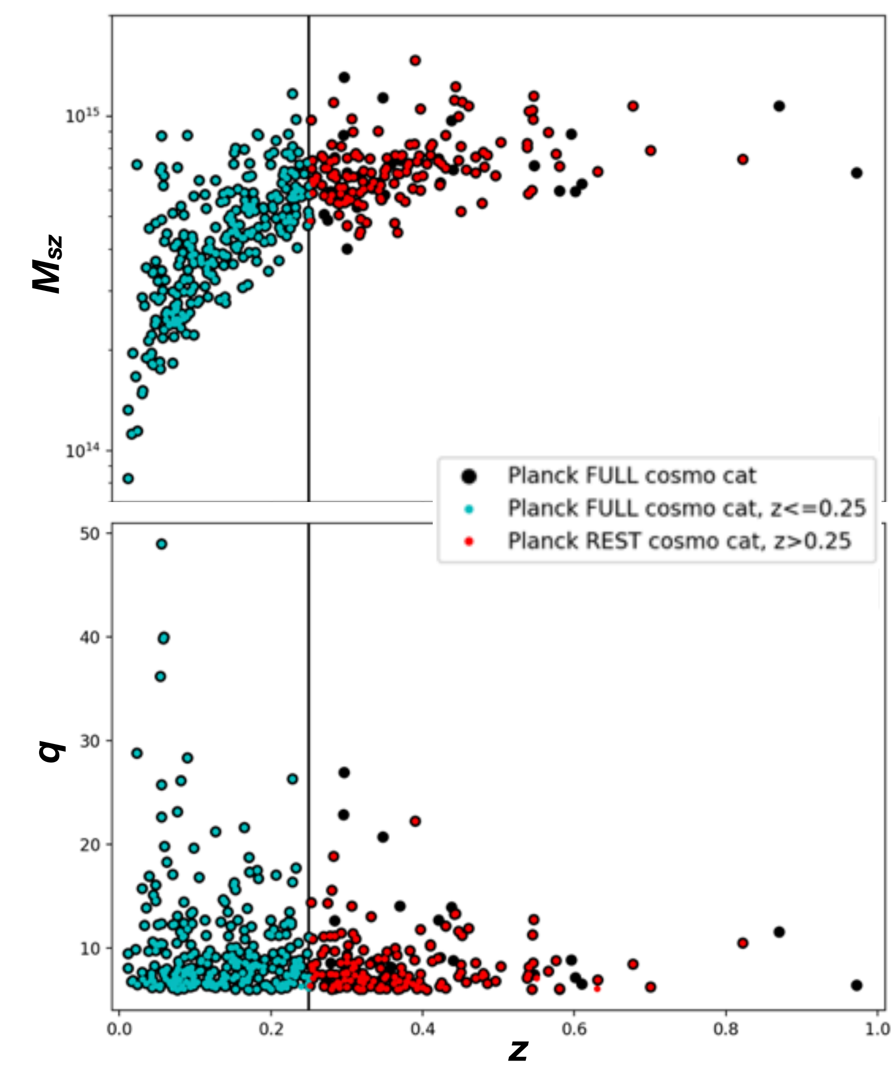
Pre-processing of Planck cluster catalog

- Removing 27 Planck clusters overlapping with SPT catalog + 2 clusters in removed patches

Planck vSPLIT cluster counts likelihood

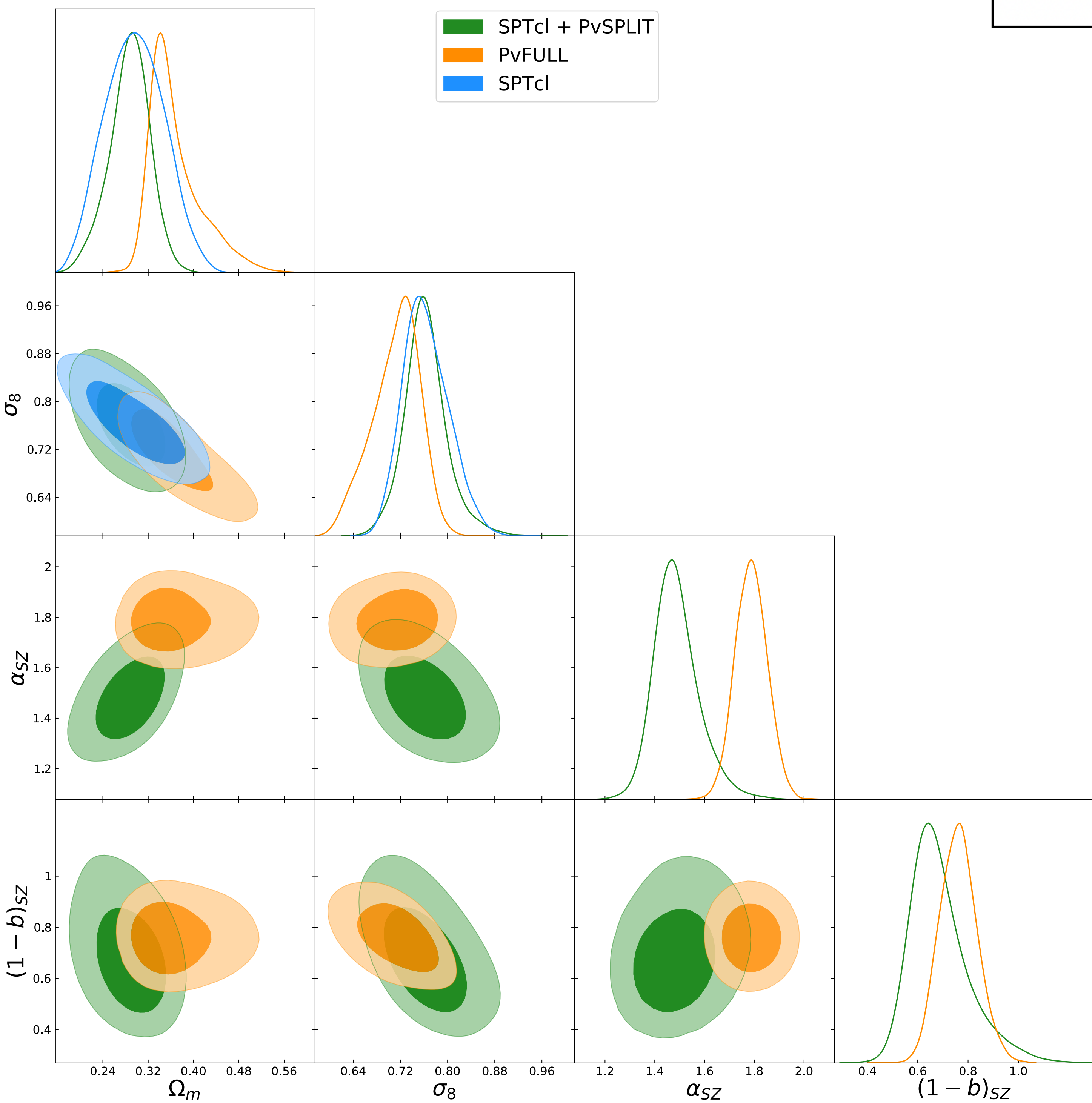
- z <= 0.25
  - 271 clusters, 417 patches
- z > 0.25
  - 139 clusters, 401 patches

$$\ln \mathscr{L}_{\rm TOT} = \ln \mathscr{L}_{\rm SPT} + \ln \mathscr{L}_{\rm P1} + \ln \mathscr{L}_{\rm P2}$$



Planck+SPT

$$E^{-\beta_{SZ}}(z)\left[\frac{D_A^2(z)\bar{Y}_{500}}{10^{-4}\mathrm{Mpc}^2}\right] = Y_{*,SZ}\left[\frac{h}{0.7}\right]^{-2+\alpha_{SZ}}\left[\frac{(1-b)_{SZ}M_{500}}{6\times10^{14}M_\odot}\right]^{\alpha_{SZ}}$$



Paramater	$\nu\Lambda$CDM		
	SPTcl + PvSPLIT	PvFULL	SPTcl
Ω_m	$0.29^{+0.04}_{-0.03}$	$0.37^{+0.02}_{-0.06}$	0.30 ± 0.03
σ_8	$0.76^{+0.03}_{-0.04}$	$0.71^{+0.05}_{-0.03}$	$0.76^{+0.03}_{-0.04}$
α_{SZ}	$1.49^{+0.07}_{-0.10}$	1.79 ± 0.06	–
$(1-b)_{SZ}$	$0.69^{+0.07}_{-0.14}$	$0.76^{+0.07}_{-0.08}$	–

Parameter	Value
$\log Y_{*,SZ}$	-0.19 ± 0.02
α_{SZ}	1.79 ± 0.08
β_{SZ}	0.66
$\sigma^a_{\ln Y_{SZ}}$	0.173 ± 0.023
$(1-b)_{SZ}$	0.780 ± 0.092

Parameter	Value
$\log Y_{*,SZ}$	-0.19 ± 0.02
β_{SZ}	0.66
$\sigma^a_{\ln Y_{SZ}}$	0.173 ± 0.023

Salvati, Saro + SPT collab.
ApJ 934, no.2, 129 (2022)

$$E^{-\beta_{SZ}}(z)\left[\frac{D_A^2(z)\bar{Y}_{500}}{10^{-4}\mathrm{Mpc}^2}\right] = Y_{*,SZ}\left[\frac{h}{0.7}\right]^{-2+\alpha_{SZ}}\left[\frac{(1-b)_{SZ}M_{500}}{6\times10^{14}M_\odot}\right]^{\alpha_{SZ}}$$

Paramater	$\nu\Lambda$CDM		
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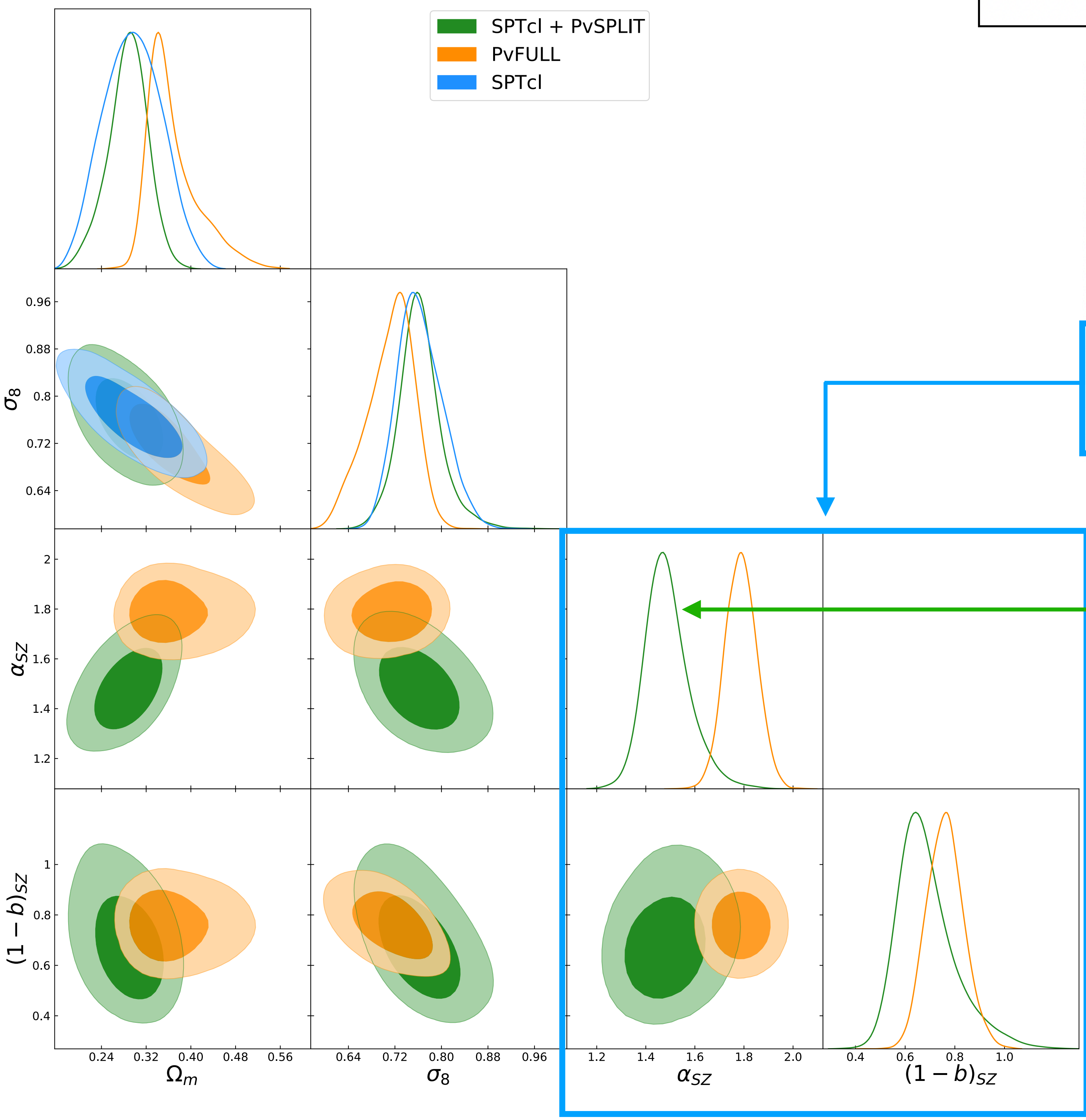
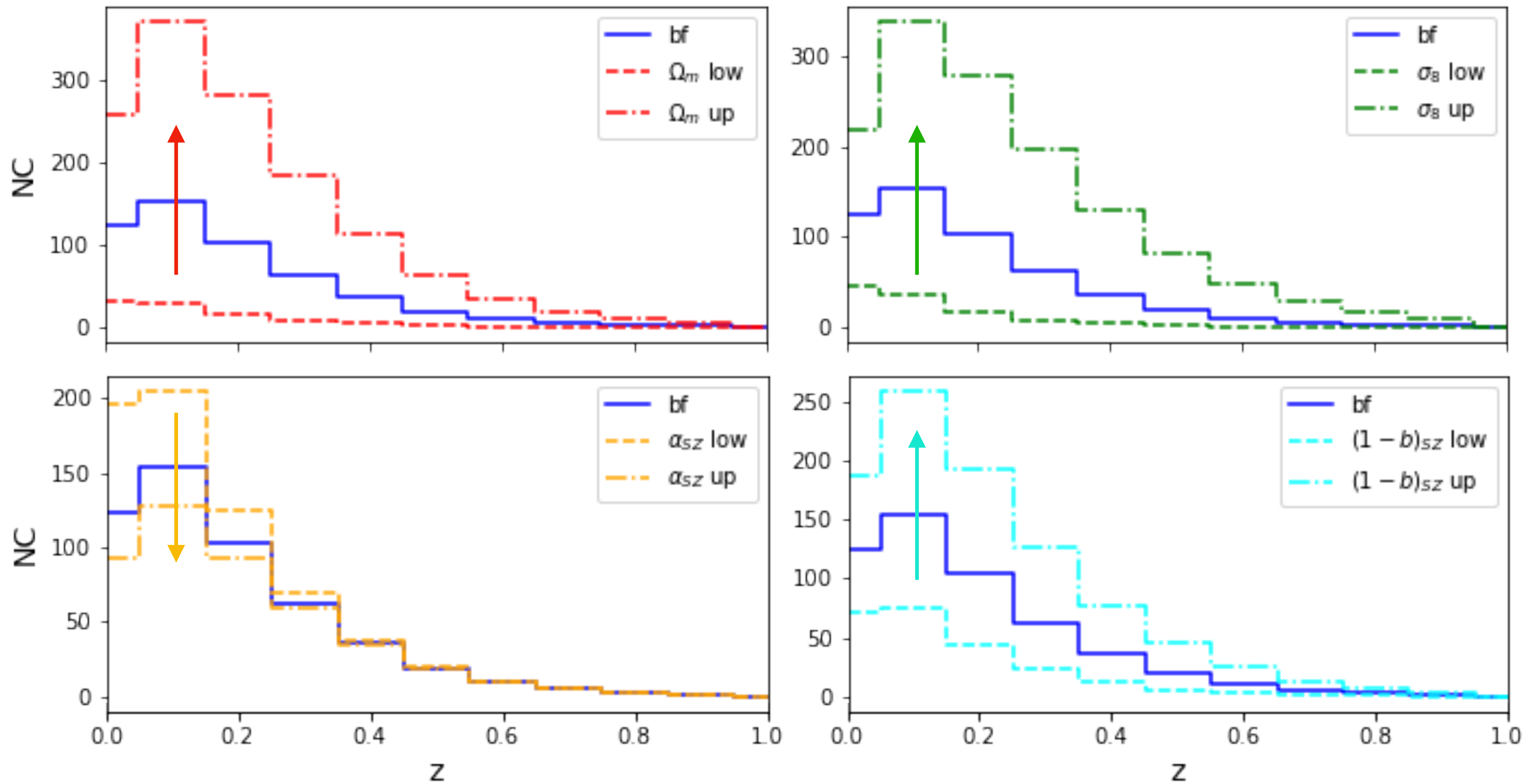


$\sim 4\sigma$ lower than self-similar value: lower value of Ω_m

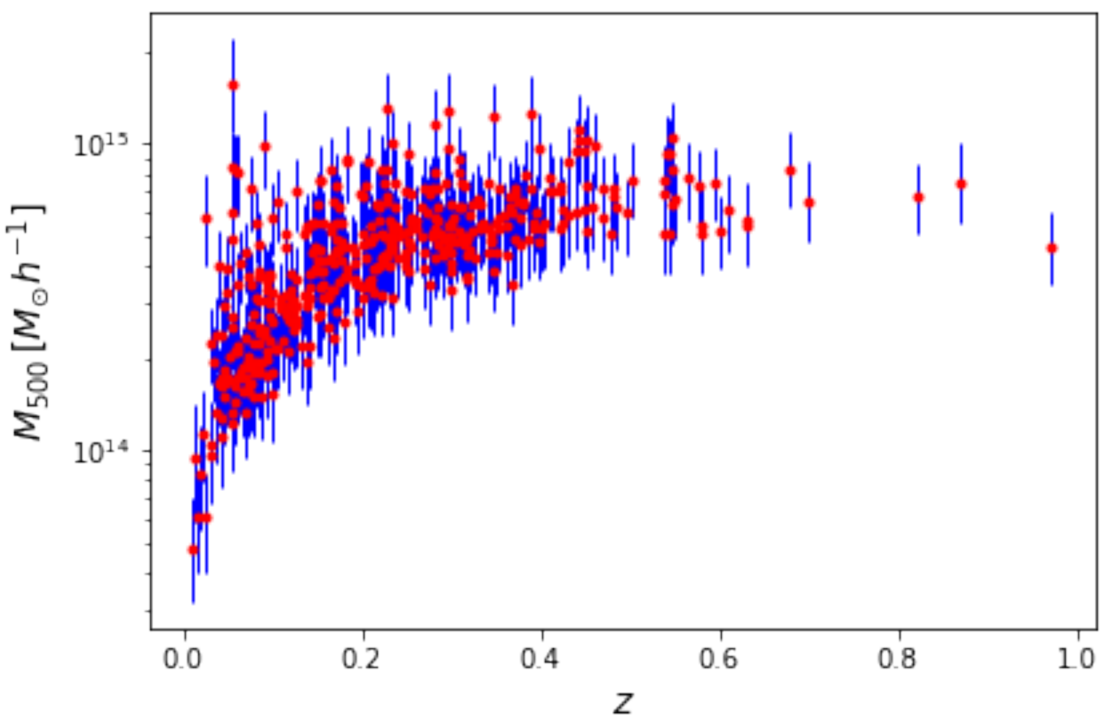
- tilt in the HMF (accounting for less objects at lowM)
- accomodate for this tilt (balancing highM - lowM)

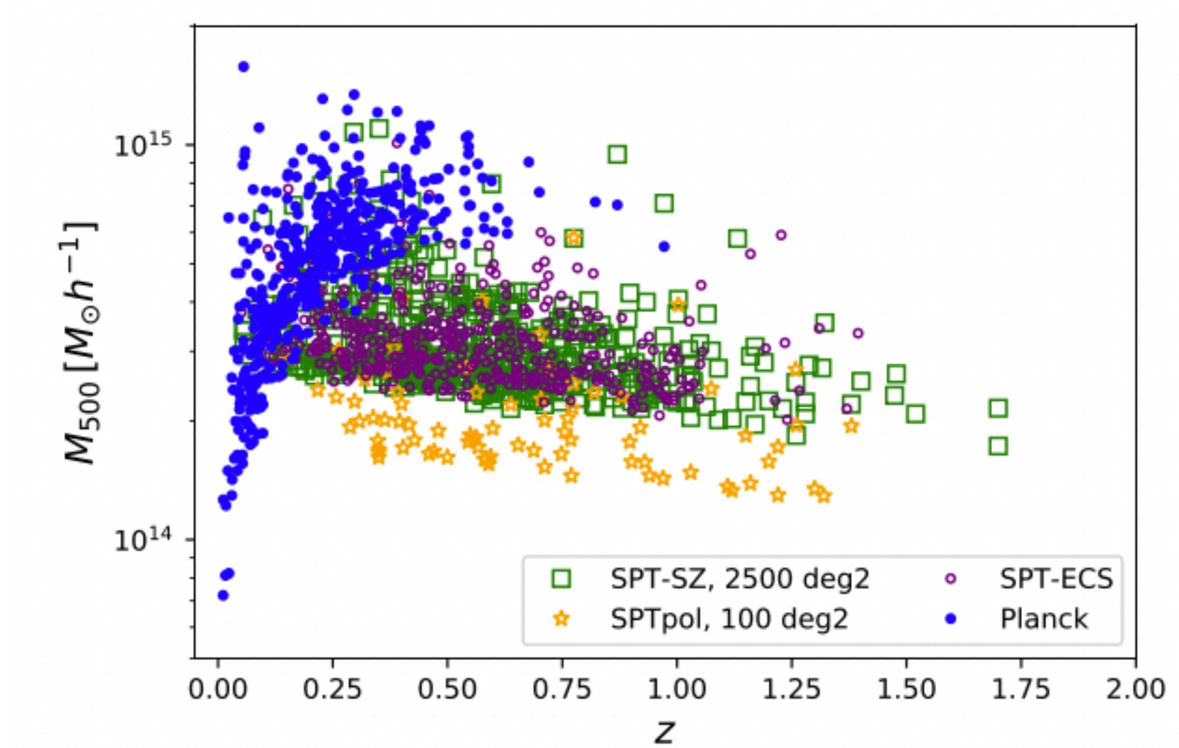
Cosmology and mass calibration



Mass catalogues

Released Catalogs
https://pole.uchicago.edu/public/data/sptplanck_cluster/





Cluster masses M_{500}
- marginalising over cosmological and scaling relation parameters

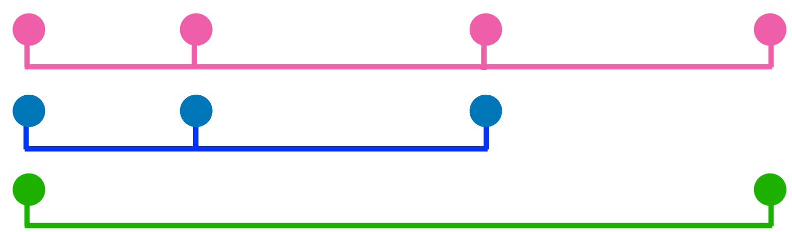
Cluster masses M_{500}
- fixed values of cosmological and scaling relation parameters

Mass bias

Salvati, Saro + SPT collab.
ApJ 934, no.2, 129 (2022)

$$(1-b)_M = \frac{M_{SZ}}{M_{500}}$$

$$(1-b)_M = \mathrm{Amp} \cdot \left(\frac{M_{500}}{M_*}\right)^{\gamma_M} \cdot \left(\frac{1+z}{1+z_*}\right)^{\gamma_z} \cdot \left(\frac{\sigma_f(\theta)}{\bar{\sigma_f}(\theta)}\right)^{\gamma_n}$$



	bias(M,z)	bias(noise)	bias(M,z,noise)
Amp	$0.69^{+0.05}_{-0.10}$	$0.60^{+0.06}_{-0.14}$	$0.69^{+0.04}_{-0.09}$
γ_M	$-0.40^{+0.04}_{-0.06}$	-	$-0.41^{+0.04}_{-0.06}$
γ_z	0.74 ± 0.13	-	0.81 ± 0.13
γ_n	-	$-0.37^{+0.14}_{-0.12}$	$0.05^{+0.06}_{-0.08}$

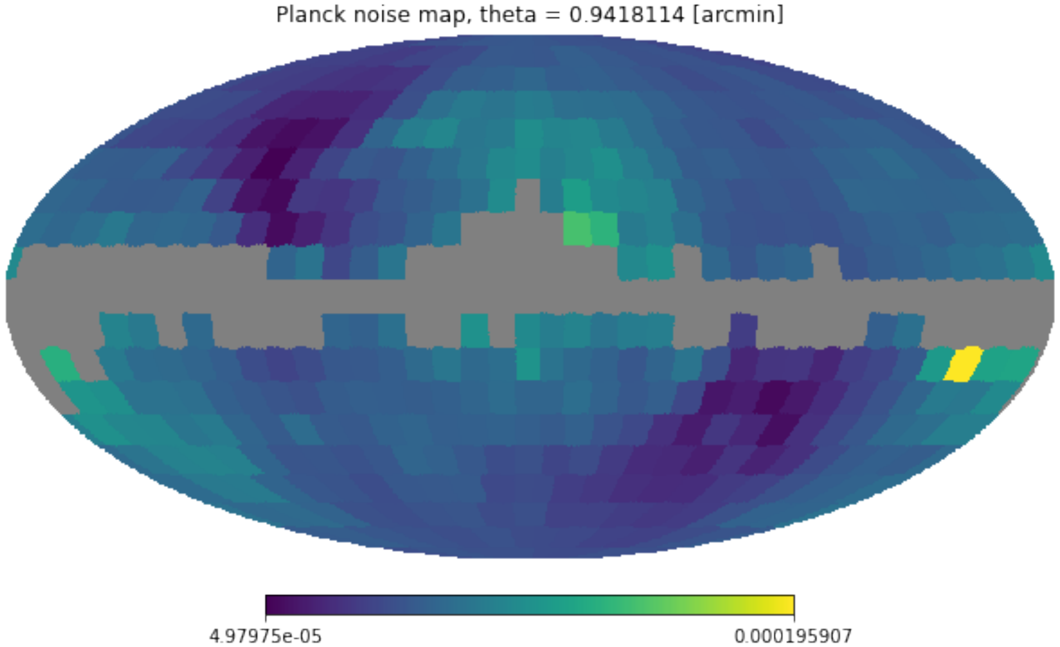
Increasing trend for high-z and low-M

Increasing trend for high-z and low-M

Mass estimation in patches with higher noise are more biased (possibly due to a loss in tSZ signal)

Systematic related to cluster detection

Planck noise map, theta = 0.9418114 [arcmin]



Upcoming SPT cluster results

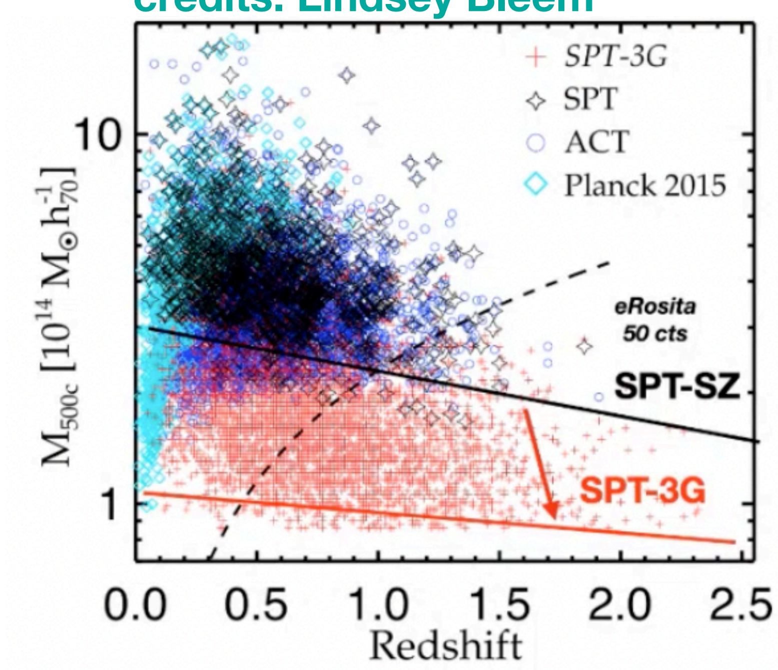
- SPT-SZ + SPTpol + DES-Y3 coming up!
- Future: SPT-3G cluster analysis

Expected Number of $S/N \geqslant 5$ Clusters from SZ Surveys

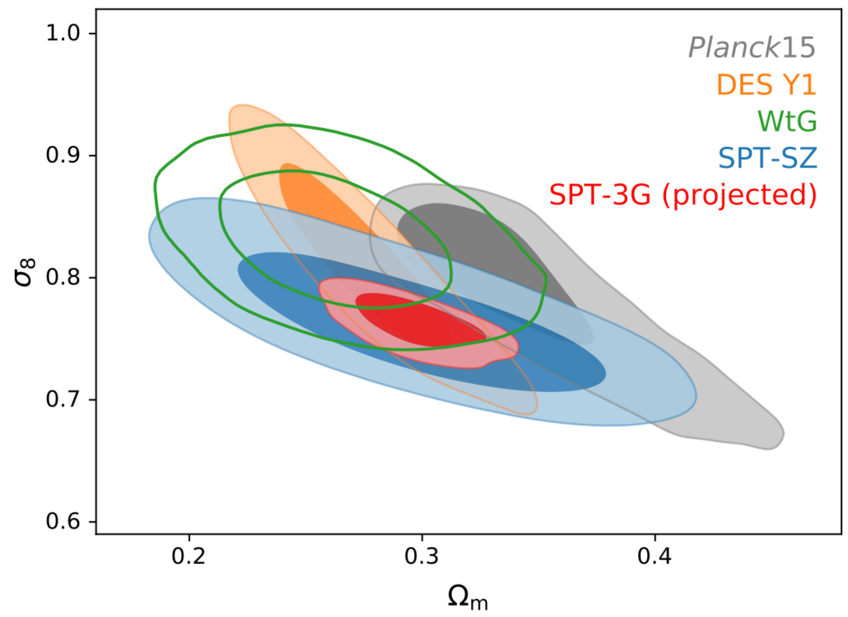
Experiment	Total Clusters			z^{med}	M_{500c}^{med} $[10^{14} M_\odot]$
	Total	$z \geqslant 1.5$	$z \geqslant 2$		
SPT-SZ	410	7	...	0.6	3.6
SPTpol	600	24	3	0.7	2.5
SPT-3G	6935	477	80	0.7	1.3

S. Raghunathan, 2022 ApJ 928 16

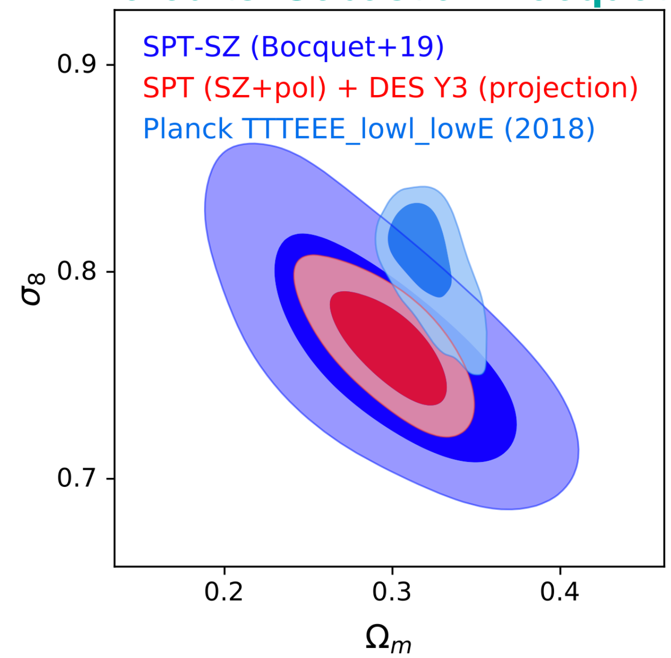
credits: Lindsey Bleem



credits: Prakut Chaubal



credits: Sebastian Bocquet



Conclusions and Future developments

Mass calibration: open issue in current cluster cosmology

- Use of external calibrations: necessary starting point
- Need for improvement
  - Larger samples for the calibration
  - Combination with other observations
- NEED TO IMPROVE OUR UNDERSTANDING OF CLUSTER PHYSICS BEFORE TALKING ABOUT TENSIONS!!!

Planck+SPT combination

- Independent calibration of Planck cluster masses
- Next step:
  - Implement same "internal calibration" for Planck cluster analysis
- Ultimate goal: Full coherent analysis
  - Large cluster catalog ($z<1.7$)
  - Characterise impact of astrophysics on cosmological evolution of clusters