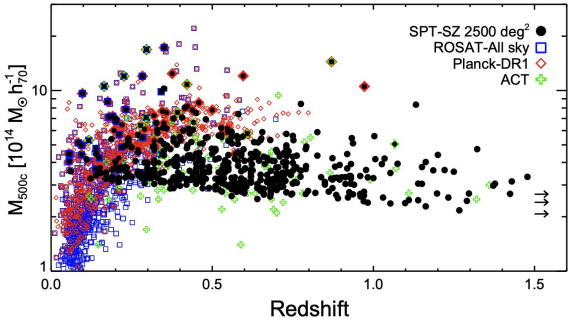
Sunyaev-Zel'dovich Cluster Pressure Profiles Measured using SPT-SZ and Planck Survey Data

mmUniverse 2025

Matthew Young, Lindsey Bleem, SPT Collaboration

SZ-derived pressure profiles

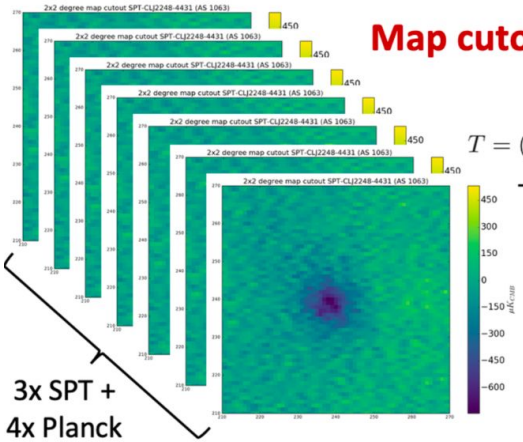
- Pipeline development for constraining cluster pressure profiles from multi-frequency CMB maps
- SZ cluster catalogues are mass-limited, large mass/redshift parameter space
  - SPT-SZ cluster catalogue
    - N=516
    - $2.5 \times 10^{14} M_{\odot} < M_{500} < 15.7 \times 10^{14} M_{\odot}$
    - $z \lesssim 1.7$
- Subsample populations derived from Chandra X-ray observations
    - Cool-Core / Non-cool Core (McDonald+13)
    - Relaxed /Disturbed (Nurgaliev+13)
- Fit for profile mass/redshift trends



Bleem+ 2015
2310.00059

Subsample	z Range	α Range	$A_{\rm phot}$ Range	$N_{\rm cluster}$	$\langle z \rangle$	$\langle M_{500} \rangle^{\dagger}$
X-ray observed subsets						
Low-z	$z < 0.6$	...	...	40	0.46	5.5 ± 0.3
Low-z, CC	$z < 0.6$	$\alpha > 0.39$	...	19	0.48	5.3 ± 0.5
Low-z, NCC	$z < 0.6$	$\alpha < 0.39$	...	21	0.45	5.7 ± 0.4
High-z	$z > 0.6$	...	...	40	0.82	4.2 ± 0.2
High-z, CC	$z > 0.6$	$\alpha > 0.39$	...	20	0.80	3.9 ± 0.3
High-z, NCC	$z > 0.6$	$\alpha < 0.39$	...	20	0.84	4.4 ± 0.3
Relaxed	...	...	$A_{\rm phot} < 0.1$	31	0.66	5.9
Disturbed	...	...	$A_{\rm phot} > 0.5$	19	0.62	6.5
Full SPT-SZ sample ($z > 0.25$)						
All	...	...	...	454	0.63	4.5
Low-z	$z < 0.6$	...	...	238	0.44	4.9
High-z	$z > 0.6$	...	...	216	0.84	4.1

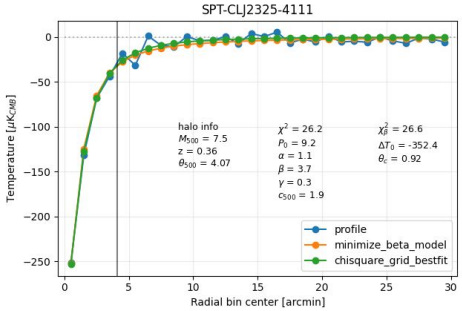
Pipeline overview



Map cutouts

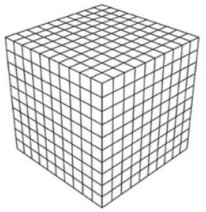
$$T = (\tilde{B}^T \tilde{W} \tilde{B})^{-1} \tilde{B}^T \tilde{W} \tilde{M}$$

Temperature Profile



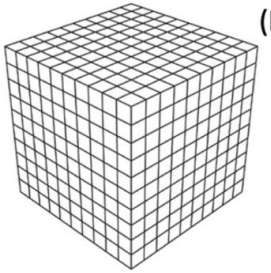
GNFW lookup table

$$P/P_{500} = P_0(c_{500}x)^{-\gamma}[1 + (c_{500}x)^{\alpha}]^{-(\beta-\gamma)/\alpha}$$

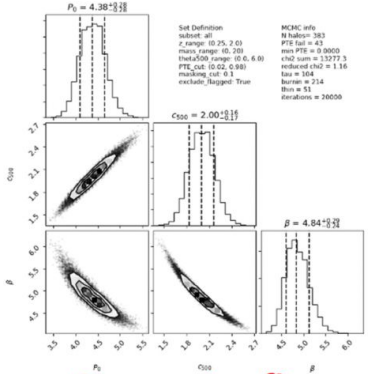


χ^2 grid

(P_0, c_{500}, α, β)



MCMC grid set



Parameter fits

Computing temperature profiles

Multi-band *Plagge et al.*

m: # fourier modes (nxn pixel map)

b: # ring bins

f: # bands

observed map: $M =$ (f × 1 matrix, m rows)

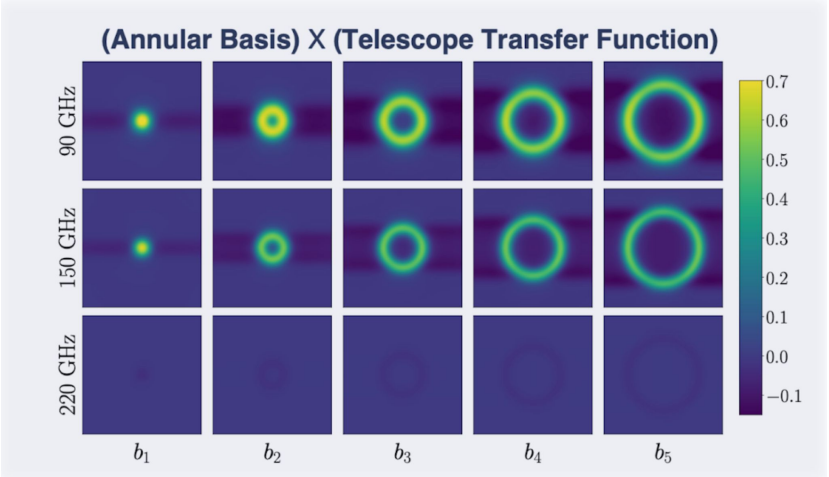
annular basis xfer func: $B =$ (f × b matrix, m rows)

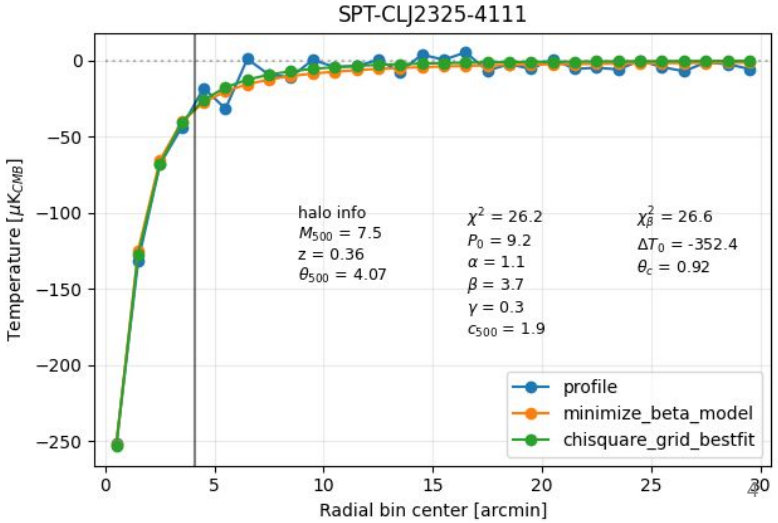
map covariance: $C =$ (m × m block-diagonal matrix, f × f blocks)

temperature profile: $T =$ (1 × b matrix)

Least-square solution (to M=BT)

$$T = (B^T W B)^{-1} B^T W M$$

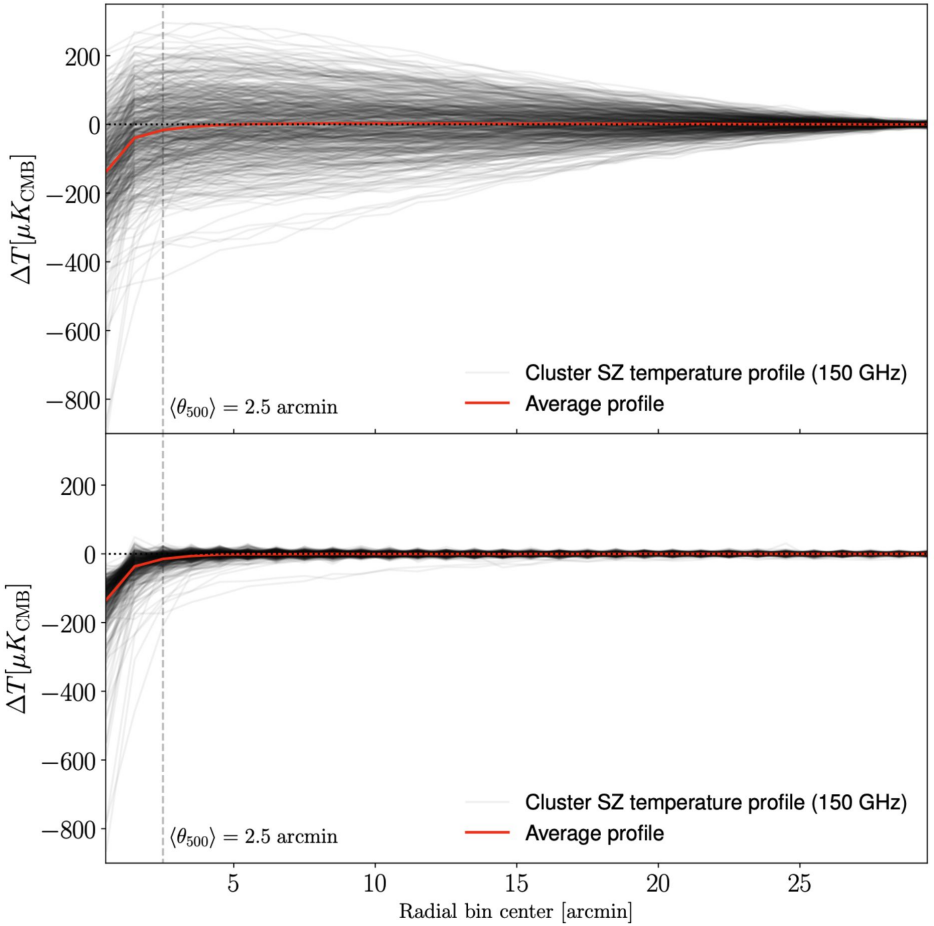




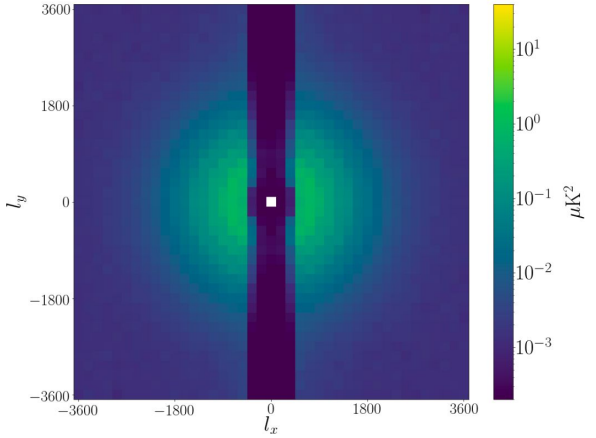
Temperature profiles (+ map covariances)

SPT-SZ

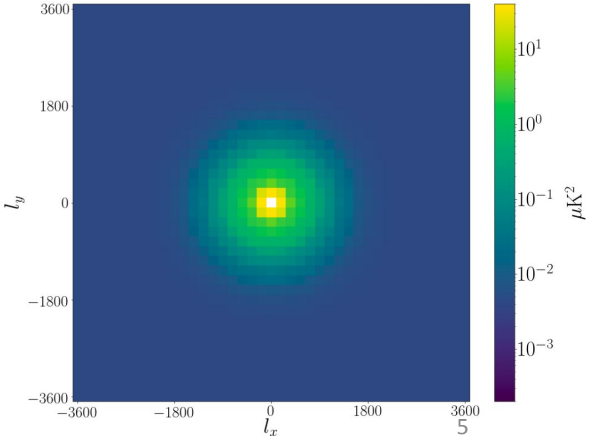
SPT-SZ + Planck



SPT-SZ



Planck



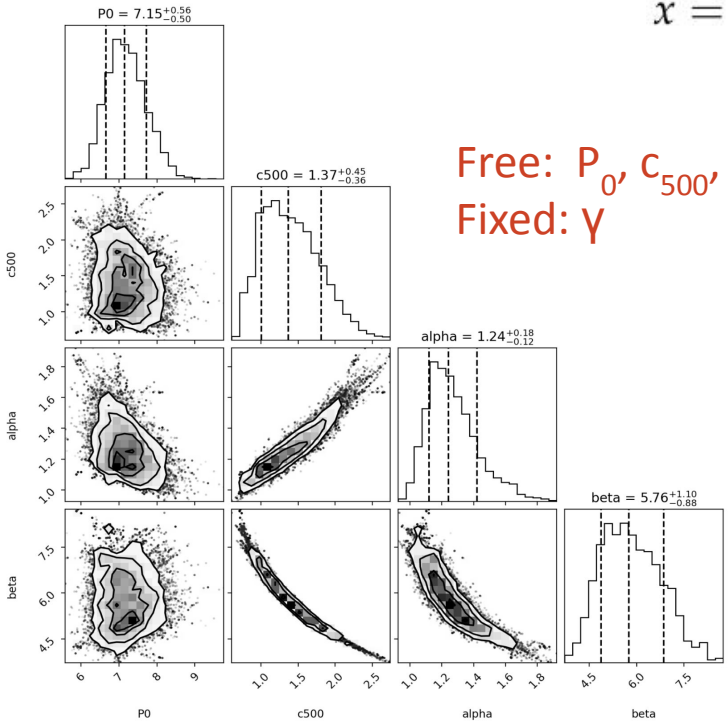
GNFW pressure model fitting

$$\frac{P}{P_{500}}\frac{1}{f(M)} = \frac{P_0}{(c_{500}x)^{\gamma}[1+(c_{500}x)^{\alpha}]^{(\beta-\gamma)/\alpha}}$$

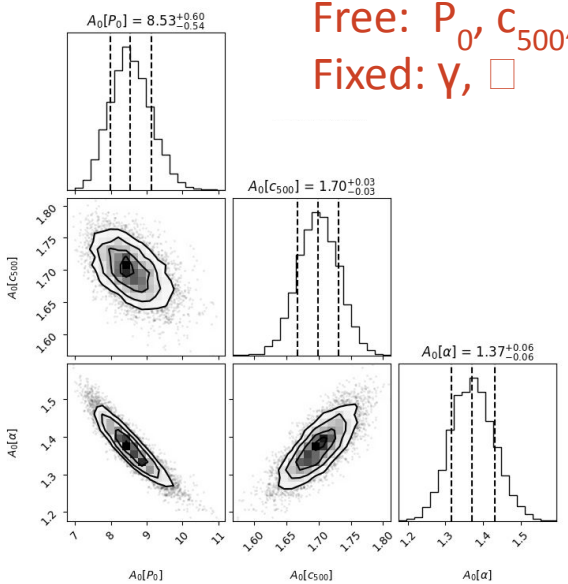
$$x = r/R_{500}$$

5 free parameters

- P_0 : pressure normalization
- c_{500} : gas concentration $(r_s = R_{500}/c_{500})$
- γ : slope at small radii ($r \ll R_{500}$)
- α : slope at intermediate radii ($r \sim R_{500}$)
- β : slope at large radii ($r \gg R_{500}$)

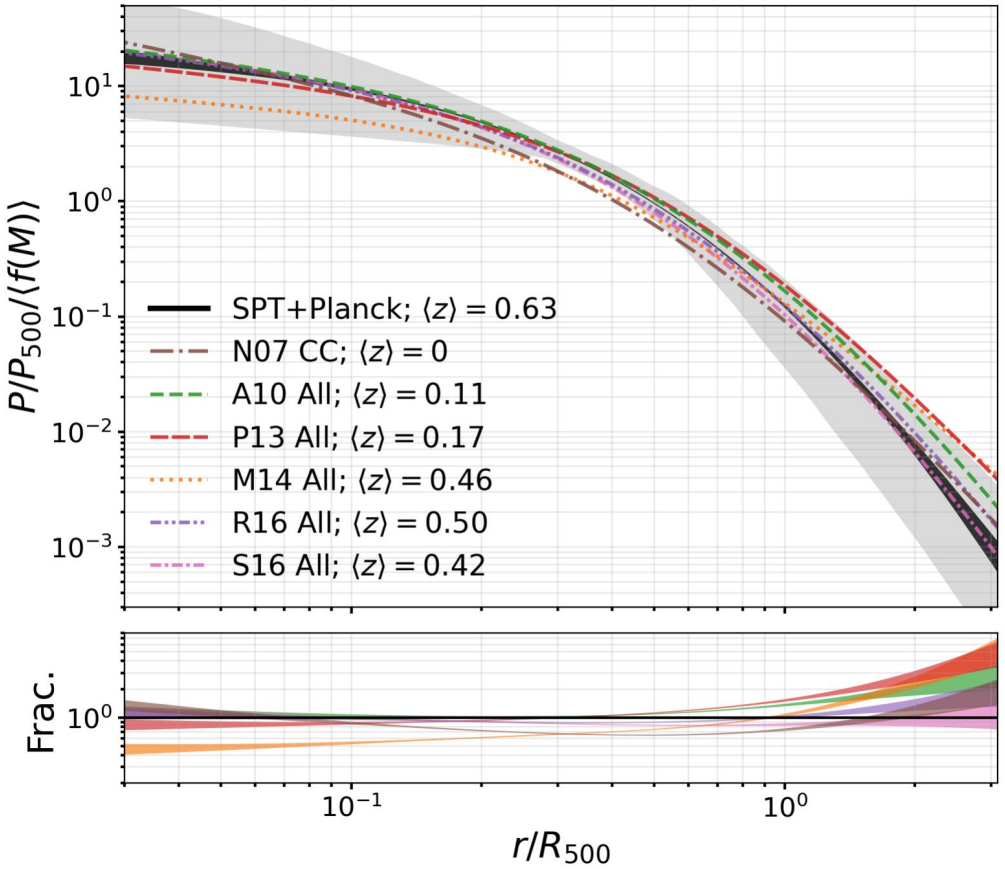


Free: P_0, c_{500}, α, □
Fixed: γ

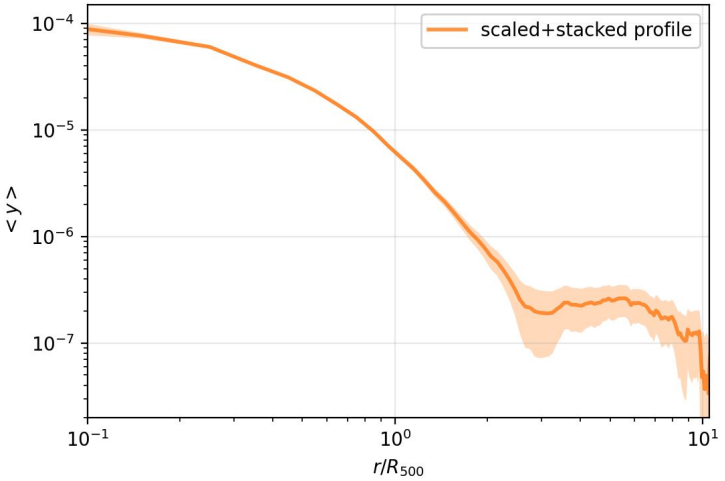


Free: P_0, c_{500}, α
Fixed: γ, □

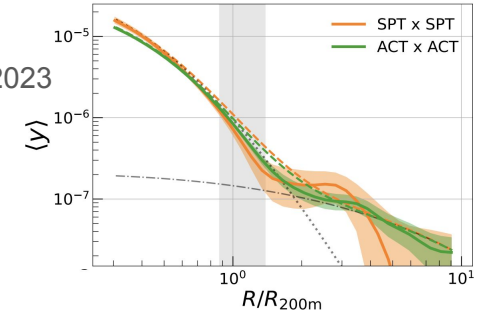
Universal GNFW pressure profile fit - all clusters, N=516



Scaled+stacked compton-y profile



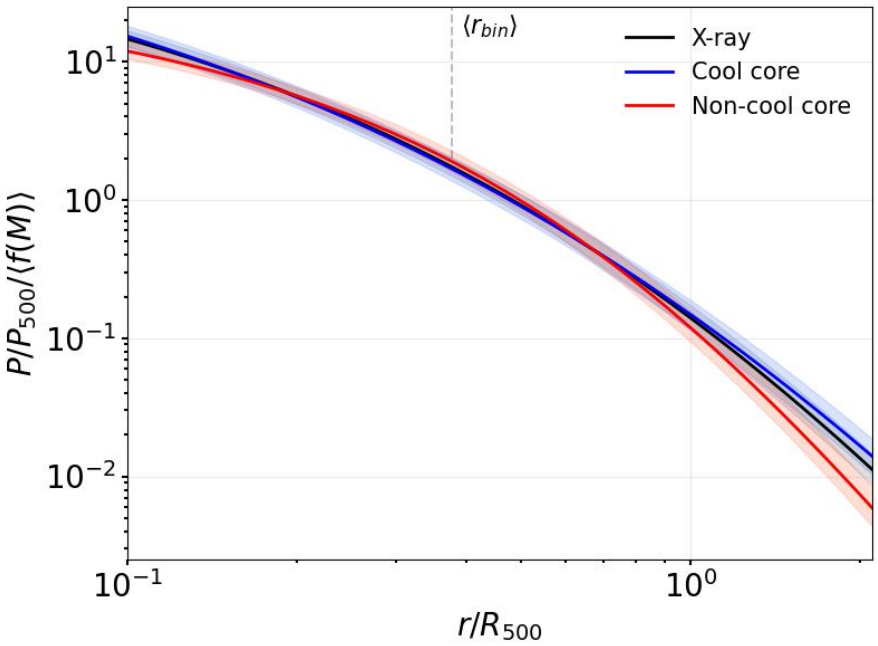
Anbajagane+ 2023
2310.00059



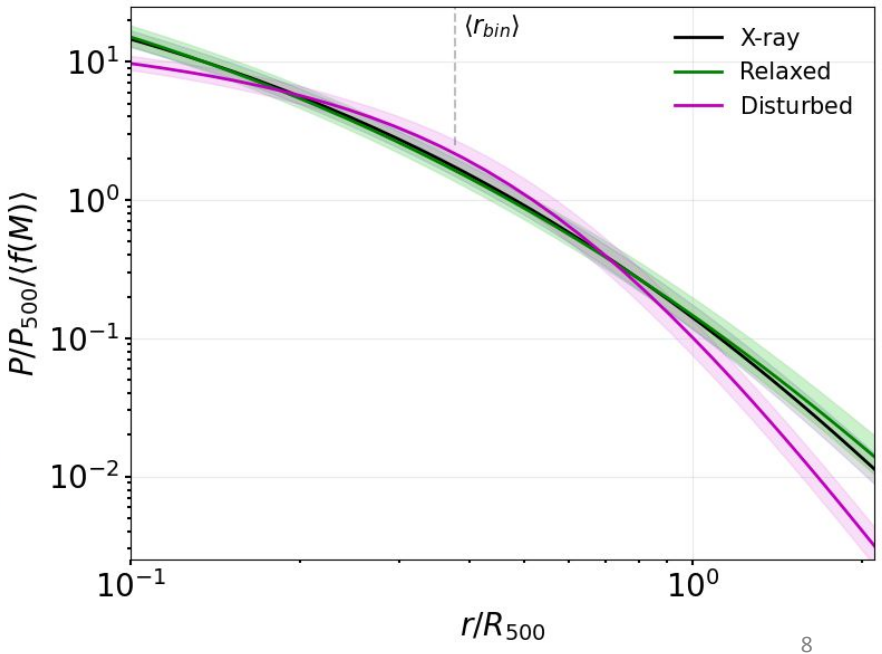
X-ray observed subsample fits

- 83 clusters (0.3 < z < 1.2) observed using *Chandra* X-ray Observatory
- X-ray data used to define subsamples (McDonald+2013, Nurgaliev+2013)

Cool Core vs. Non-Cool Core



Relaxed vs. Disturbed



Summary

- Universal profile fit shows a lower average pressure at high radii compared to Arnaud+2010/Planck+2013, consistent with Sayers+2016
- Significant disparity in pressure profile fits between the relaxed and disturbed subsamples
- SPT-3G cluster catalogue will increase the sample size x10, with improved SN on SPT-SZ sample

P_0, c_{500} fit distribution