The Atacama Cosmology Telescope: A census of bridges between galaxy clusters

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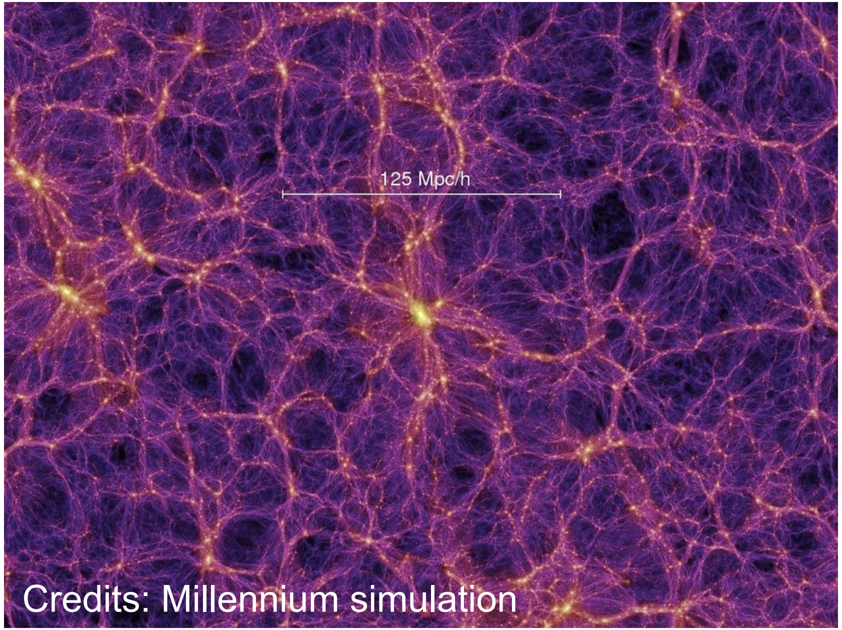
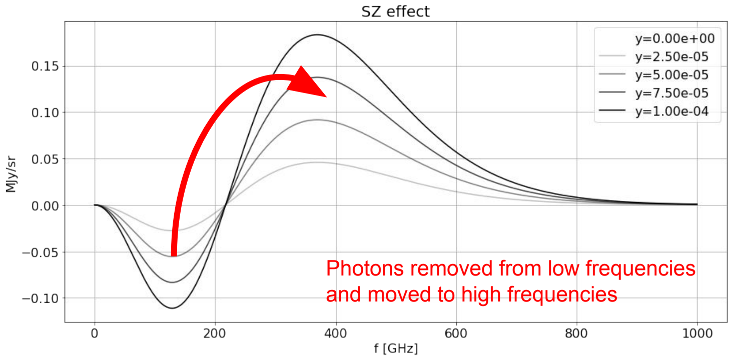
Who let the baryons out?

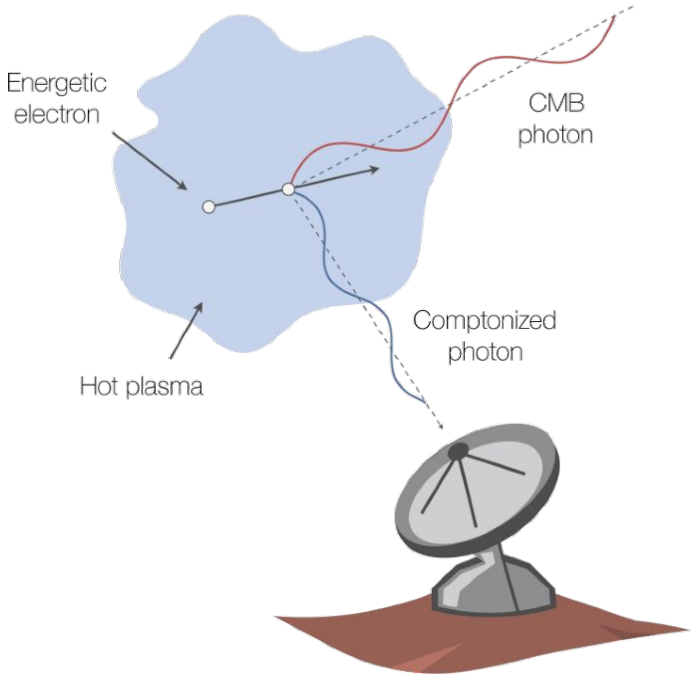
- Discrepancy between the amount of baryons derived from early and late-universe observations.
- Well accepted solution: Warm-Hot Intergalactic Medium (WHIM) in cosmic filaments
- **Supported by hydrodynamical simulations and observations**
- Low density and temperature, thus low emission. Difficult to observe!
- Can be detected via Sunyaev-Zel'Dovich effect
- **Current experiments are getting sensitive enough to detect and characterize them.**



Sunyaev-Zel'Dovich effect

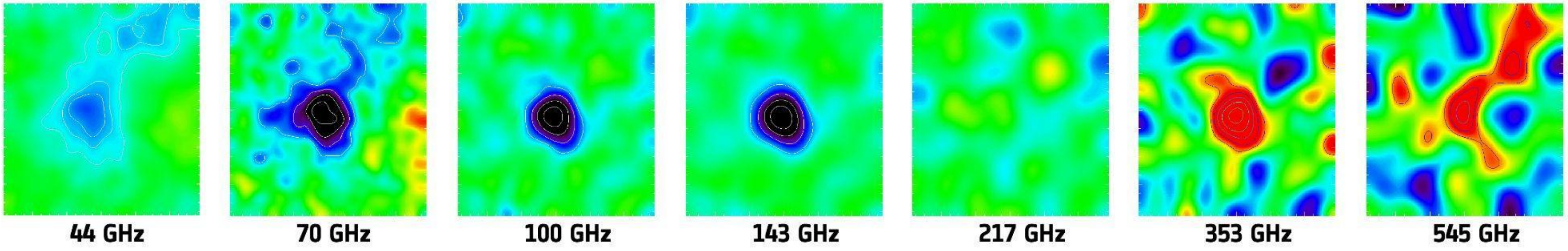
- Anisotropic spectral distortion of the CMB
- Low energy CMB photons are up-scattered at higher frequencies by scattering with hot electrons in clusters (Intra-Cluster Medium)
- This produces an **unique spectral distortion**





Mroczkowski (2019)

Sunyaev-Zel'Dovich effect



credit: ESA / HFI & LFI Consortia

- The amplitude is proportional to the integrated electron pressure along the line of sight
- Higher signal compared to X at lower densities
- Easy to disentangle from other astrophysical processes
- Wide field of view millimeter cameras are optimal instruments for this kind of observations

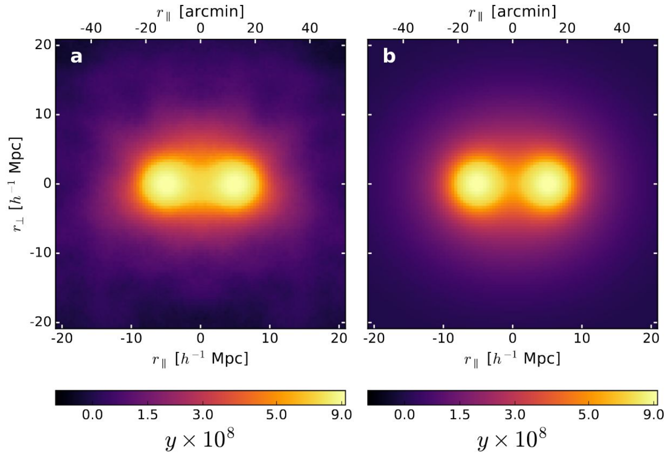
$$y = \frac{\sigma_T}{m_e c^2} \int P_e(r) dr = \frac{\sigma_T}{m_e c^2} \int n_e(r) k_B T_e(r) dr$$

$$\updownarrow$$

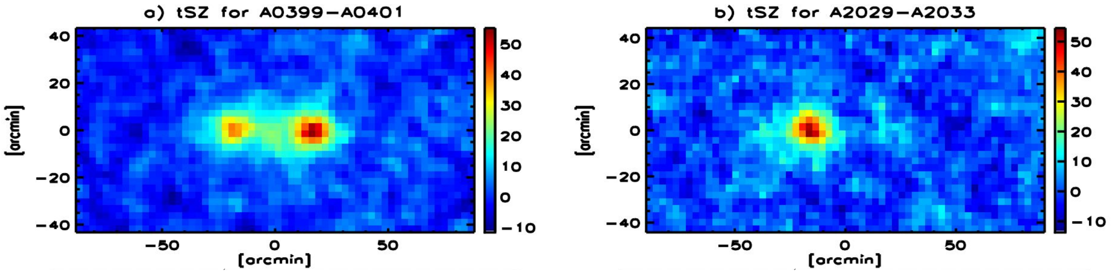
$$L_X \propto \int n_e(r)^2 T^{1/2} dr$$

Bridges between clusters

- WHIM between interacting clusters ("Bridges") are compressed, thus easier to observe
- Pre-merger clusters are interesting, because a primordial filament is being compressed.
- First tentative observations with Planck
  - Average bridge signal detected by stacking thousands of clusters
  - Only 2 bridges observable because of resolution (10') and Compton-y sensitivity



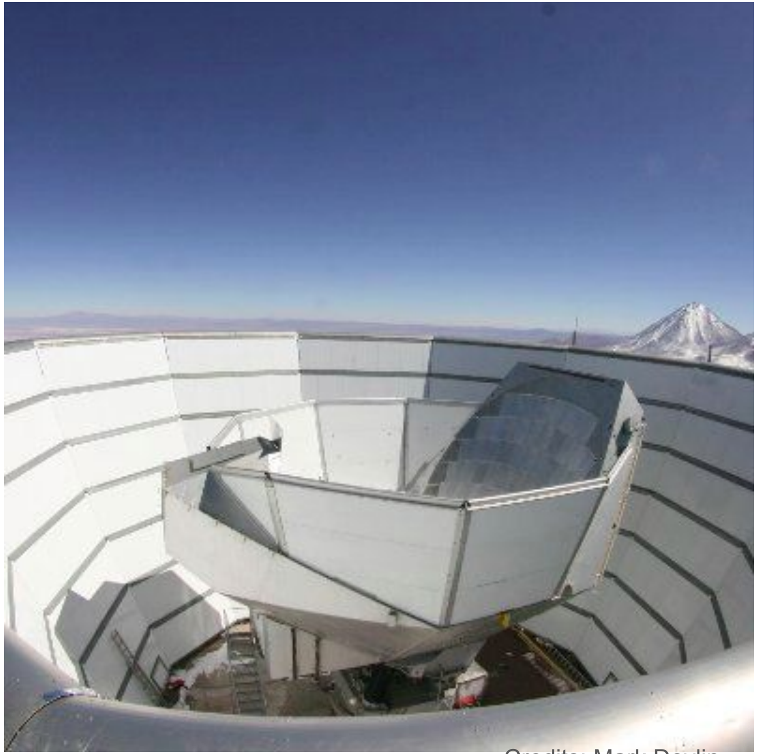
De Graaff et al. (2019)



Ade et al. (2012)

Cosmic web at arcmin resolution: ACT

- The new generation of CMB telescopes offers an increase in both angular resolution and Compton-y sensitivity.
- Atacama Cosmology Telescope was a 6m off-axis gregorian telescope in Chile
- Three generations of receivers. The latest receiver, ACTPol, observed at 30, 40, 98, 150, 220 and 270 GHz with TES detectors
- Produced high resolution (1.6’), high sensitivity (y~1e-6) Compton-y maps of ~40% of the sky.
- Example: bridge between Abell 399 and Abell 401, first tentatively detected by Planck, confirmed at 5 sigma by ACT.



Credits: Mark Devlin

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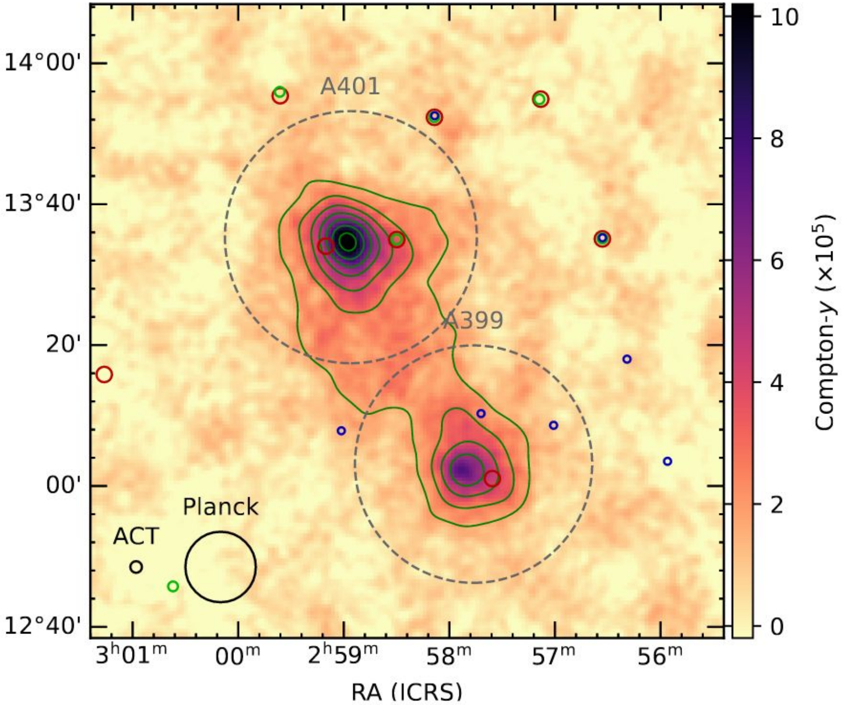
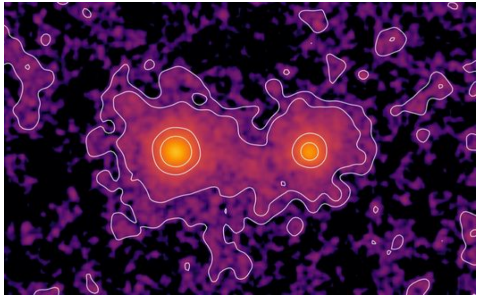


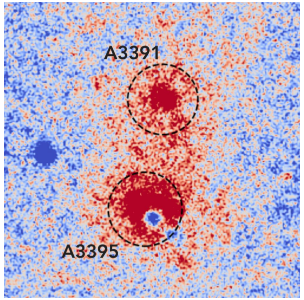
More bridges?

We know few bridges between local clusters
Can we use the latest ACT data to find new ones?

The ACT Bridge Census
(Isopi et al., submitted to JCAP, arXiv:2410.14404)



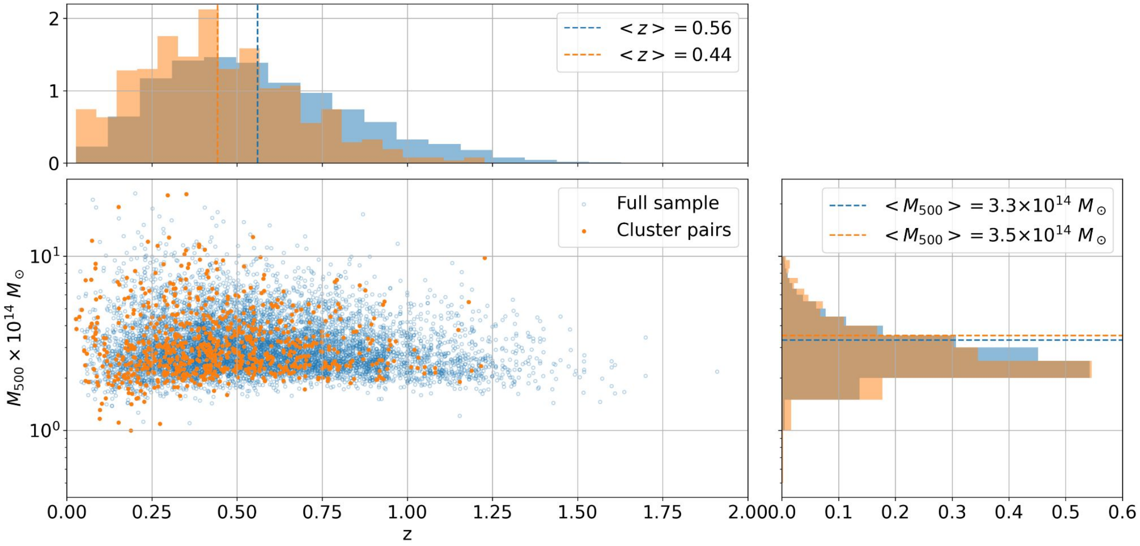
A3395/A3391
(Capalbo et al. in prep)



System too cool to not deserve its own paper

The ACT Bridge Census

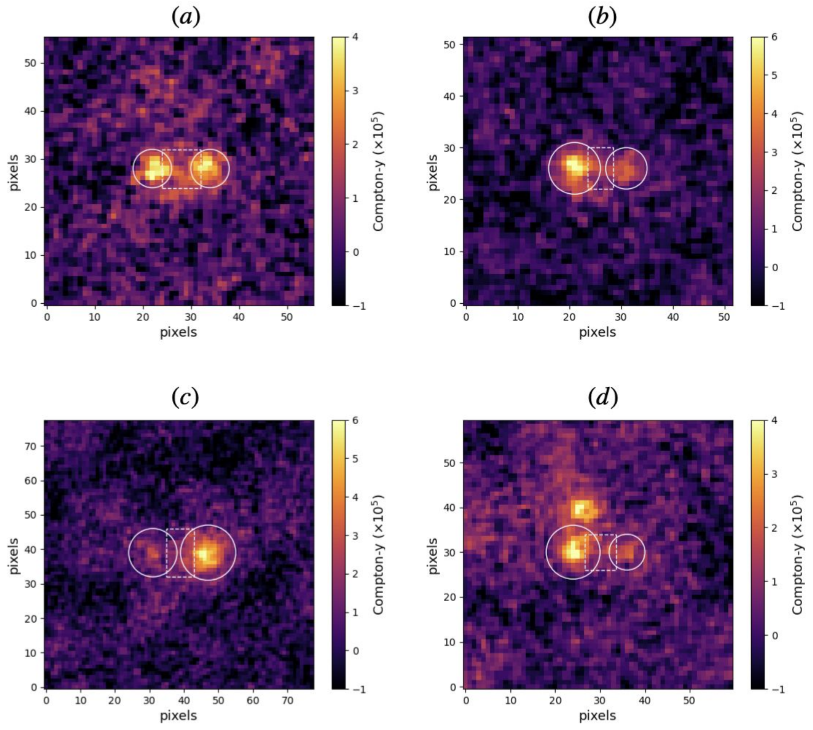
- ACT detected thousands of clusters with the SZ effect
  - **~7000 clusters** (DR6, preliminary)
  - **~300 multiple systems** (DR6, preliminary)
- **The census aims to study the cluster systems more in detail.**
- Two approaches:
  - Single pair fit
  - Stack



Adapted from Hilton et al. (in prep)

Single pairs

- We selected single pairs to be fitted using a “rough” SNR estimate in the inter-cluster region (Bonjean et al.)
- 4 clusters with S/N > 2
- Fit a 2D model like in Hincks et al. 2022
- Two of them show a *tentative* bridge detection at ~2.5 sigma with ACT + Planck data only
- Targeted observations needed to confirm these tentative detections.
- **Observing single bridges is hard!**



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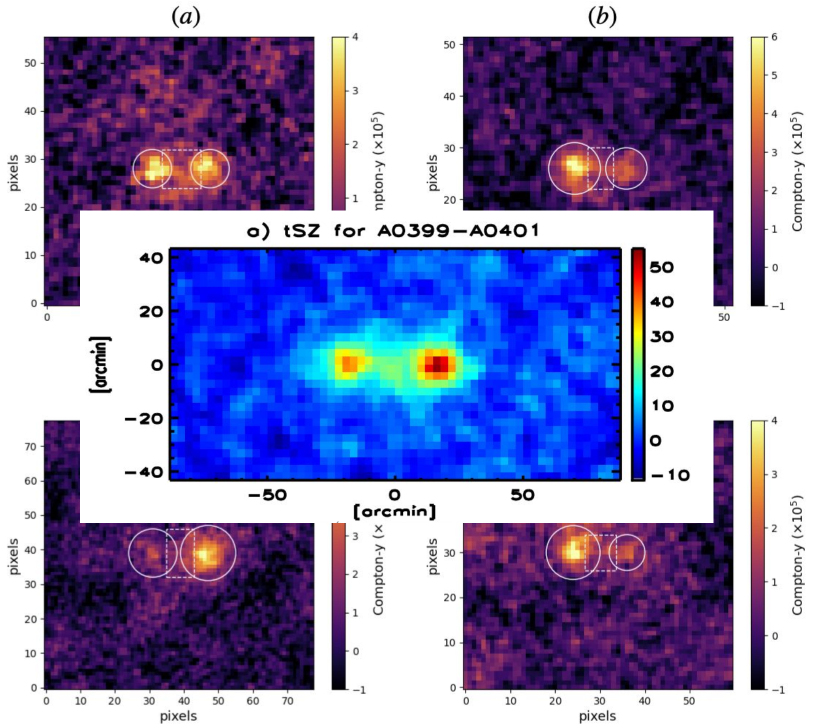

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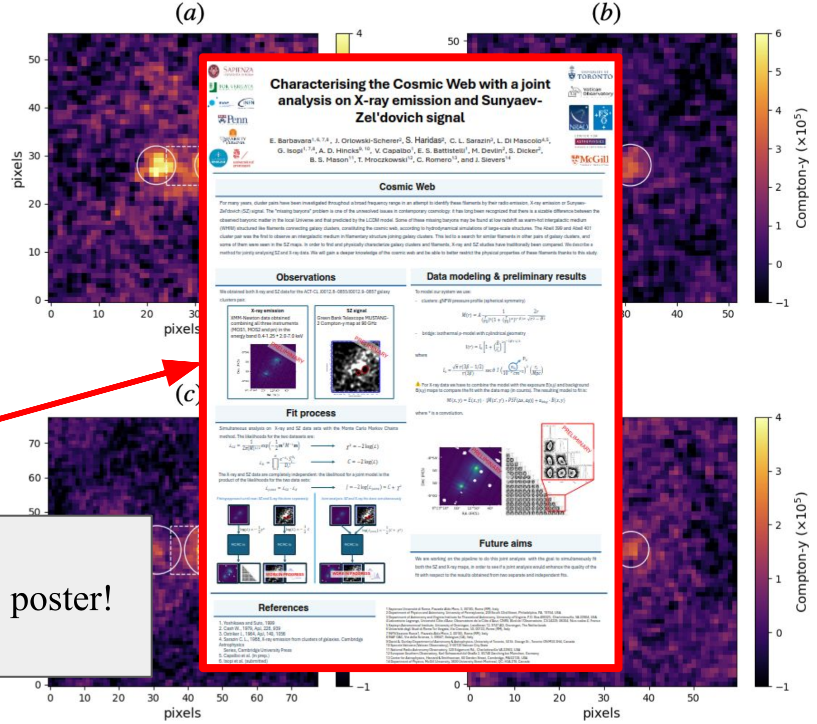
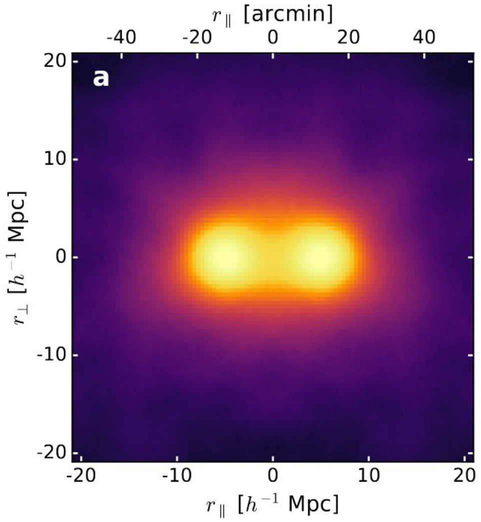
Check Eleonora’s poster!

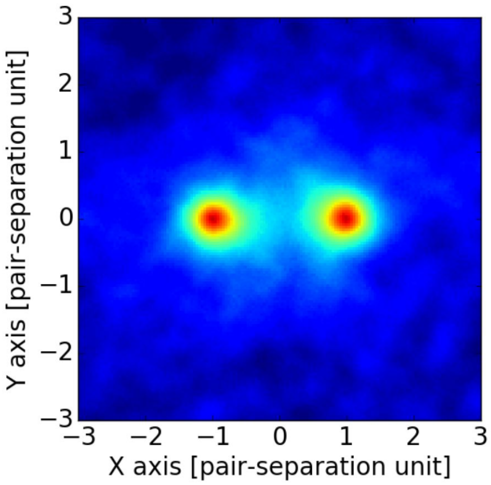


Stacking clusters

- Stacking was applied to Planck data to increase SNR and have a statistical detection of WHIM
- Stack on selected pairs of LRGs or CMASS galaxies used as proxy
- Galaxies usually associated with halos with mass ~1e13 M_sun
- We applied this approach on ACT, but directly stacking on clusters



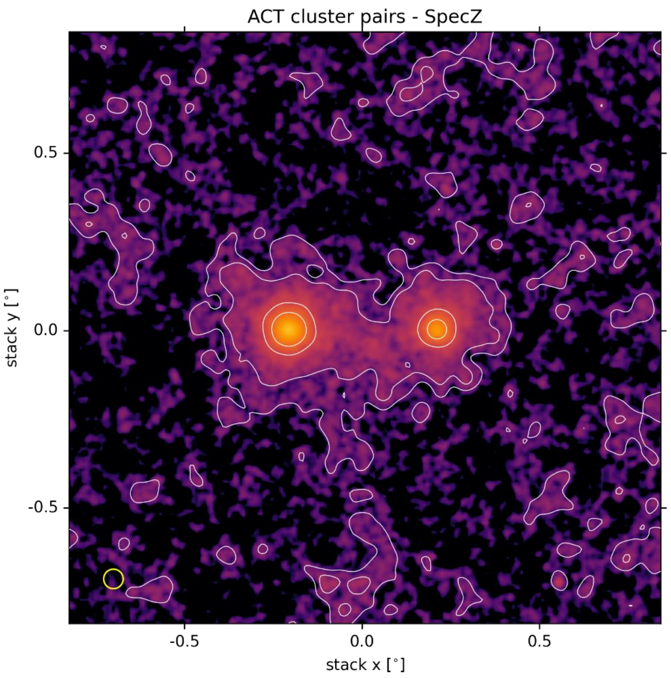
De Graaff (2019)



Tanimura (2019)

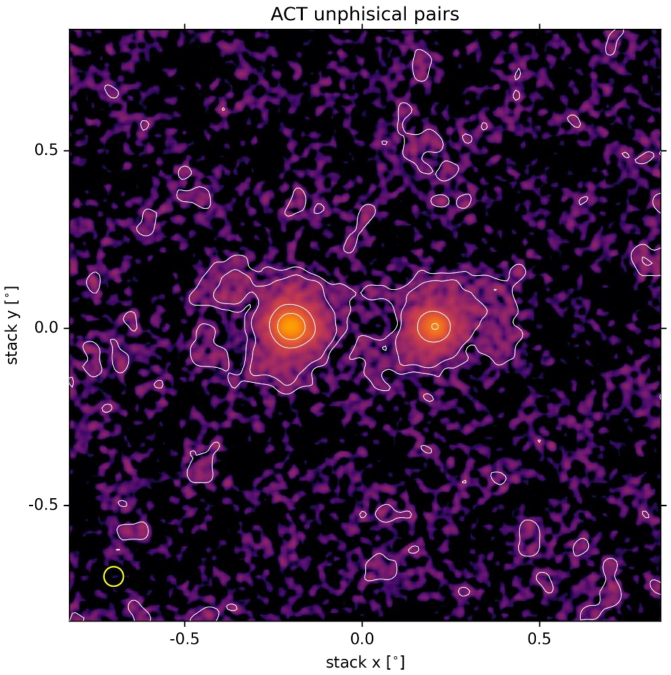
Stacking clusters

- We stack 86 cluster pairs to enhance the SNR and detect fainter structures between them.
- Only using systems with spectroscopic redshift measurements



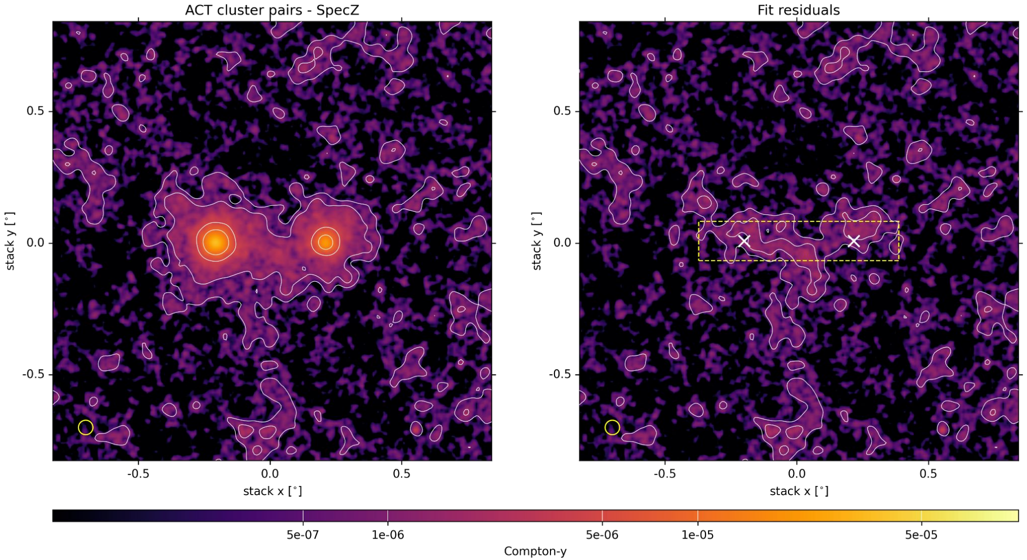
Stacking clusters

- We stack 86 cluster pairs to enhance the SNR and detect fainter structures between them.
- Only using systems with spectroscopic redshift measurements
- If compared to a stack on non physical pairs (i.e. close in the sky, but separated along the line of sight), there is a clear excess



Stacking clusters

- We fit the map with a 2D model (same approach as Hincks et al. 2022) in order to model and subtract cluster profiles
- We find a 3.3 sigma evidence for an excess signal



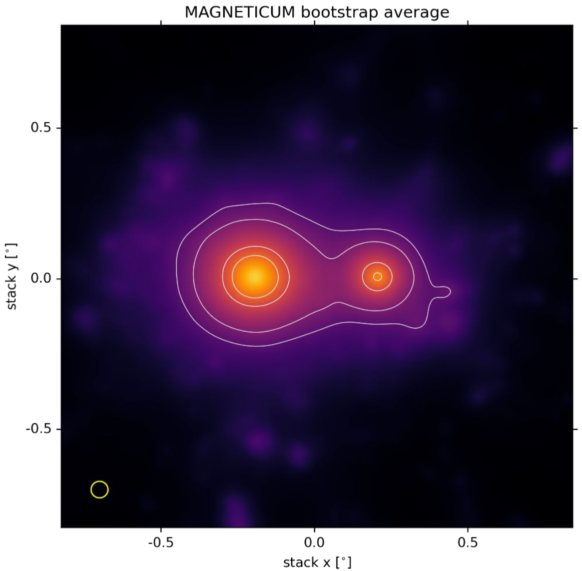
Model	# free parameters	Likelihood ratio			ΔAIC
		W	p-value	σ	
$2gNFW_{sph}$	10	–	–	–	10.29
$2gNFW_{sph}$+cyl-β	13	16.29	9.9×10^{-4}	3.29	0

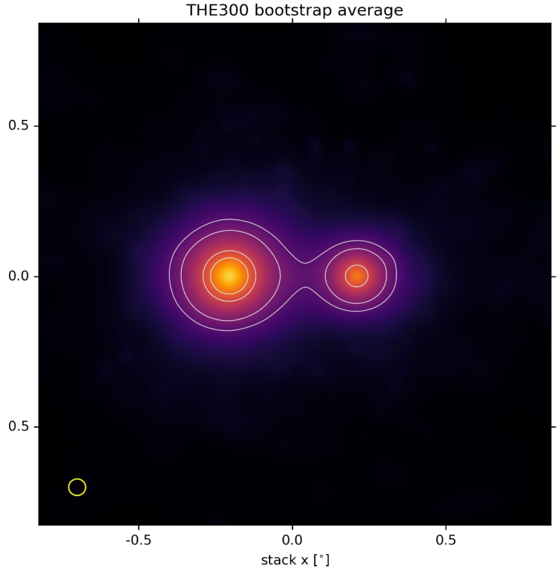
$$A_{fil} = 7.2^{+2.3}_{-2.5} \times 10^{-7}$$

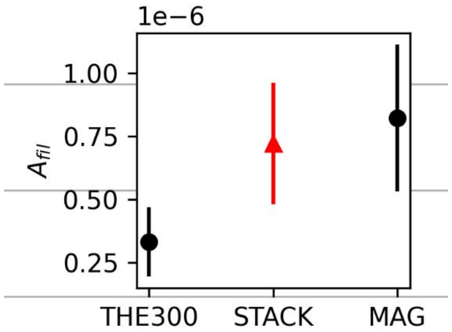
~10 times larger than Planck stacking results

Comparison with simulations

- We compare our result with THE300 and Magneticum-Pathfinder simulations
- We reproduced the ACT observation by selecting a similar cluster sample and fitted it as the stack with real data.
- Good agreement between simulations and data

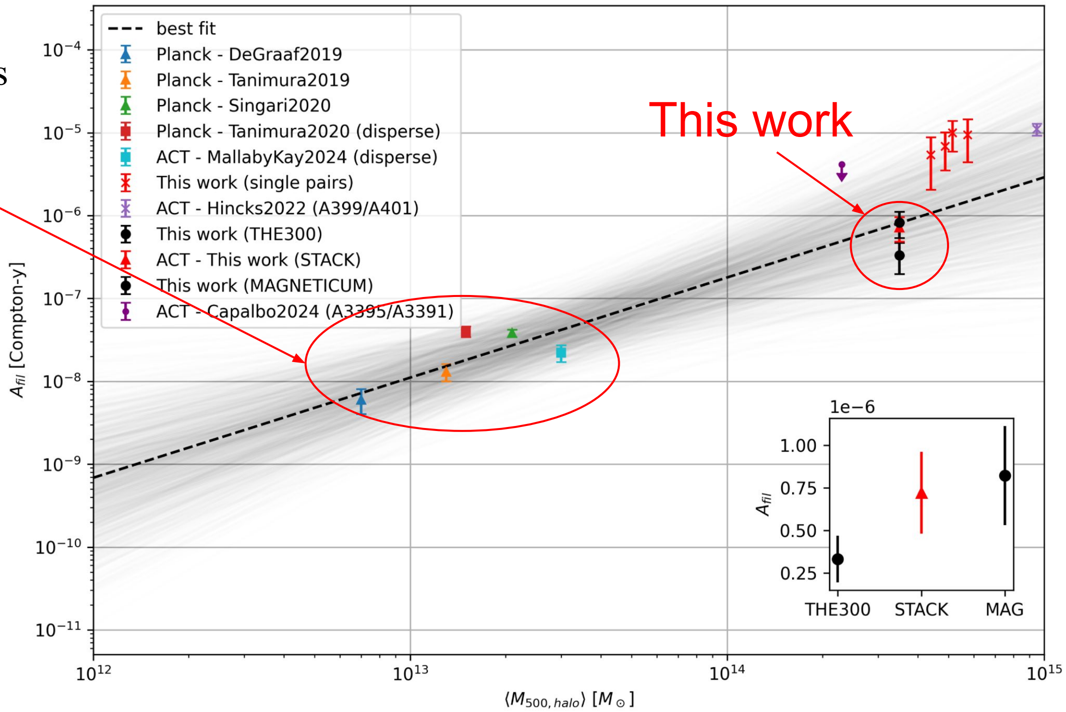






Evidence for a scaling relation

- The signal we observe in the stacking is ~10 times larger than what has been observed with galaxy stacking or DisPerSE papers.
- **We are probing the 10^14 m_sun mass range for the first time**
- A mass - pressure/density scaling relation is predicted by theory, and we are starting to observe it for the first time with the SZ effect.

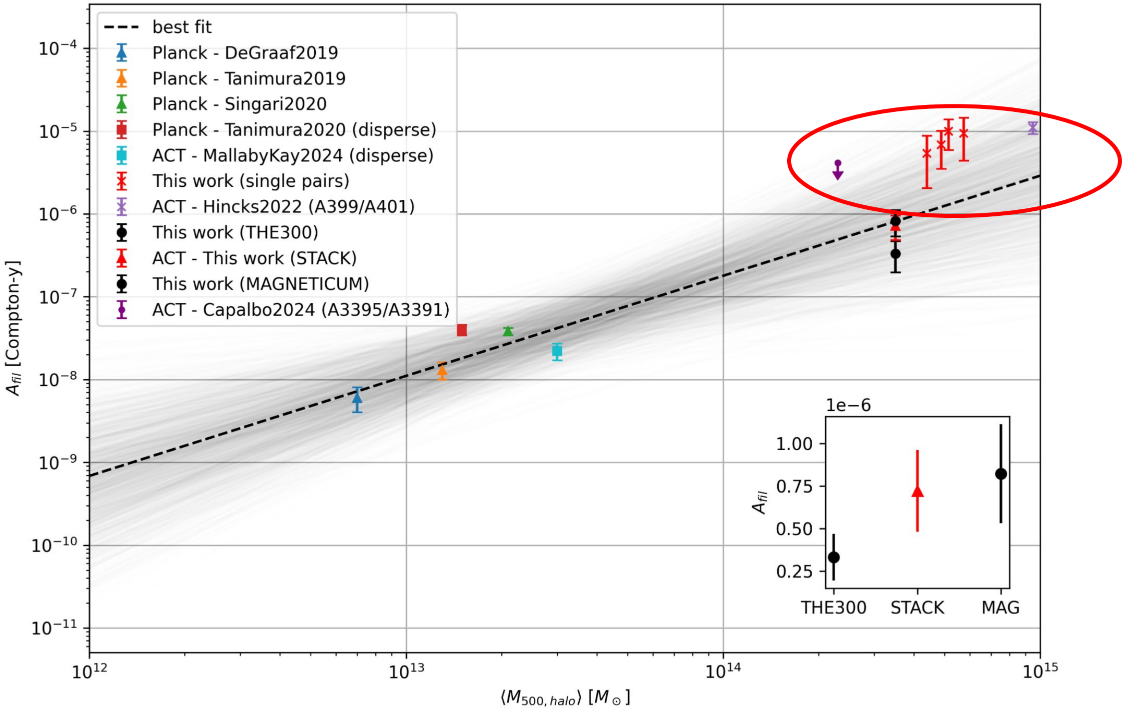


Evidence for a scaling relation

- Best fit slope:

$$1.21^{+0.34}_{-0.35}$$

- Empirical relation for estimating the bridge signal between two clusters of a given mass.
- Detections on single pairs of clusters appear to be above the best fit line.
- Expected, we observe the brightest filaments.



Conclusions

- We surveyed the ACT DR6 cluster catalog in search for new bridges
  - Tentatively detected two new bridges with ACT+Planck data alone
  - Interesting targets for X-ray or high resolution SZ observations
- We stacked 86 cluster systems in search for a filamentary structure
  - Observed an excess at the 7.2e-7 level with a 3.3 sigma significance
  - First detection by directly stacking on pairs of SZ-selected clusters
  - First detection in the ~10^14 mass range
- By combining this work with past results, we find observational evidence for a scaling relation in filaments.
  - Useful for proposing observations
  - Could be a hint for a sub-virial self-similarity in filaments?

Thanks for your attention!