Emmanuel Schaan Chamberlain fellow

Halo gas thermodynamics from the CMB

Implications for large-scale structure & galaxy formation

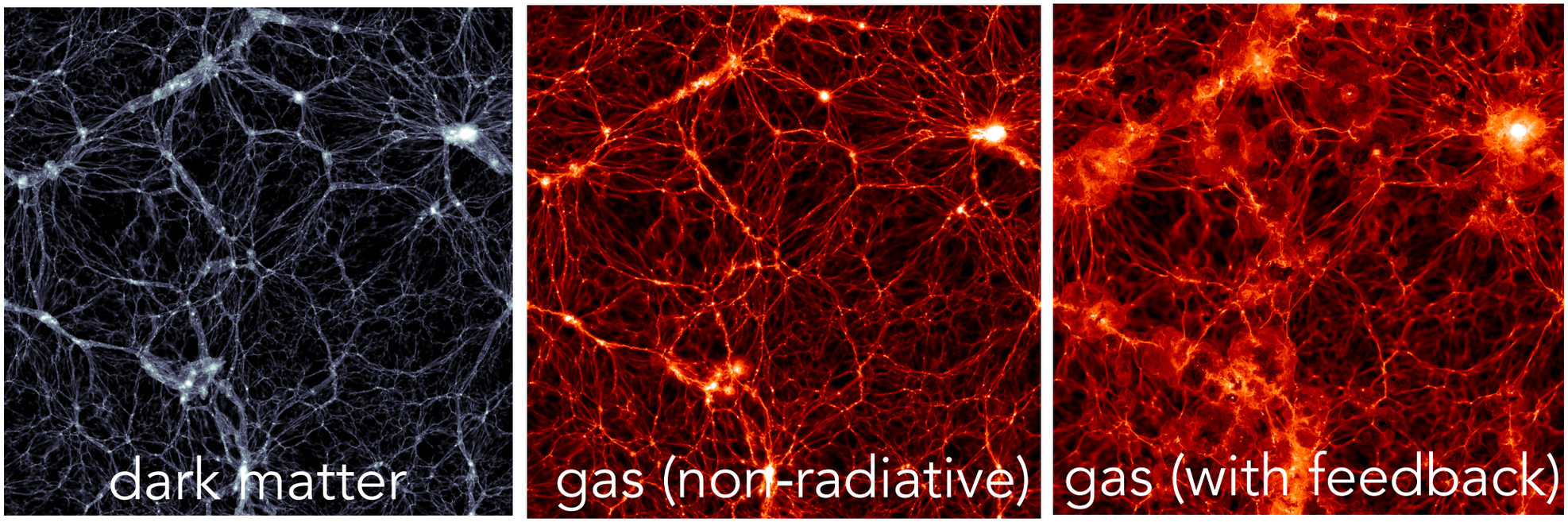
arxiv:2009.05557, arxiv:2009.05558

with Stefania Amodeo, Simone Ferraro, Nick Battaglia, ACT, Kendrick Smith, Mariana Vargas-Magaña





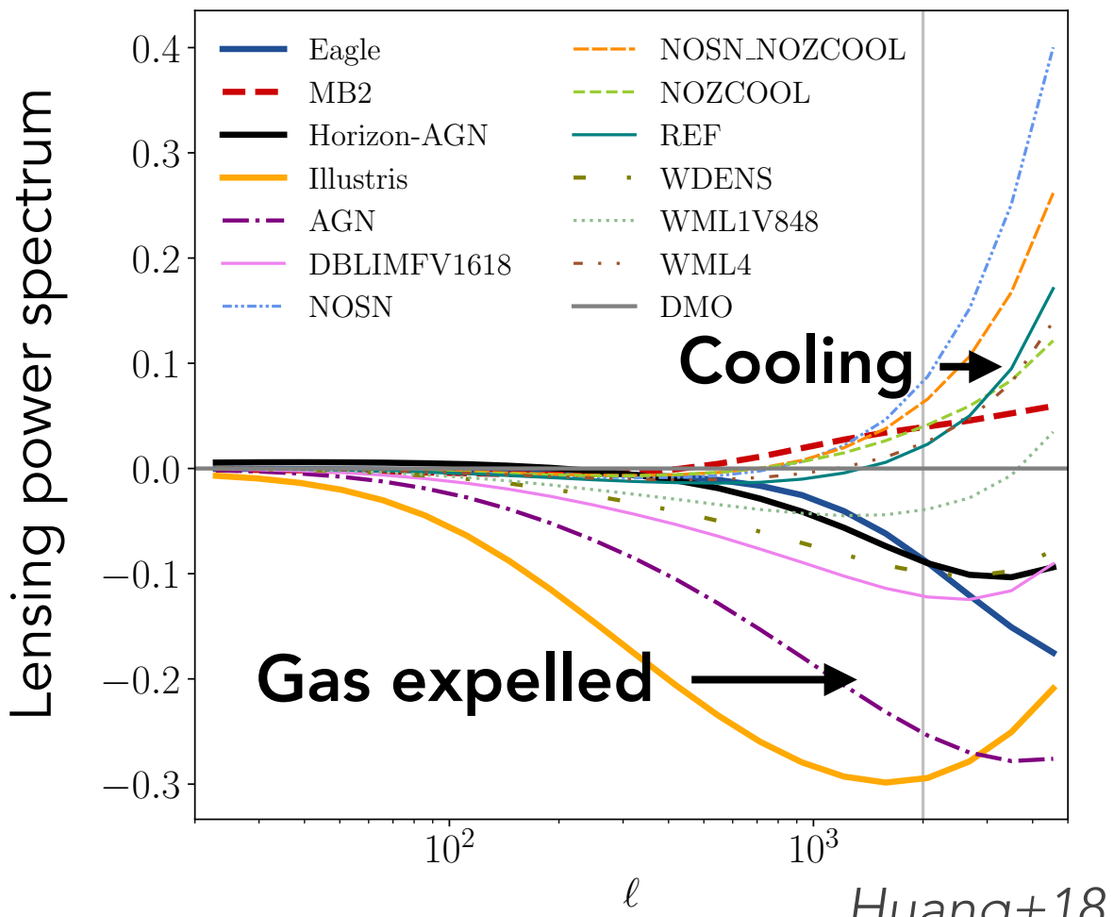

Missing baryon “opportunity”: Galaxy formation & Cosmology



Haider+16, Illustris simulation

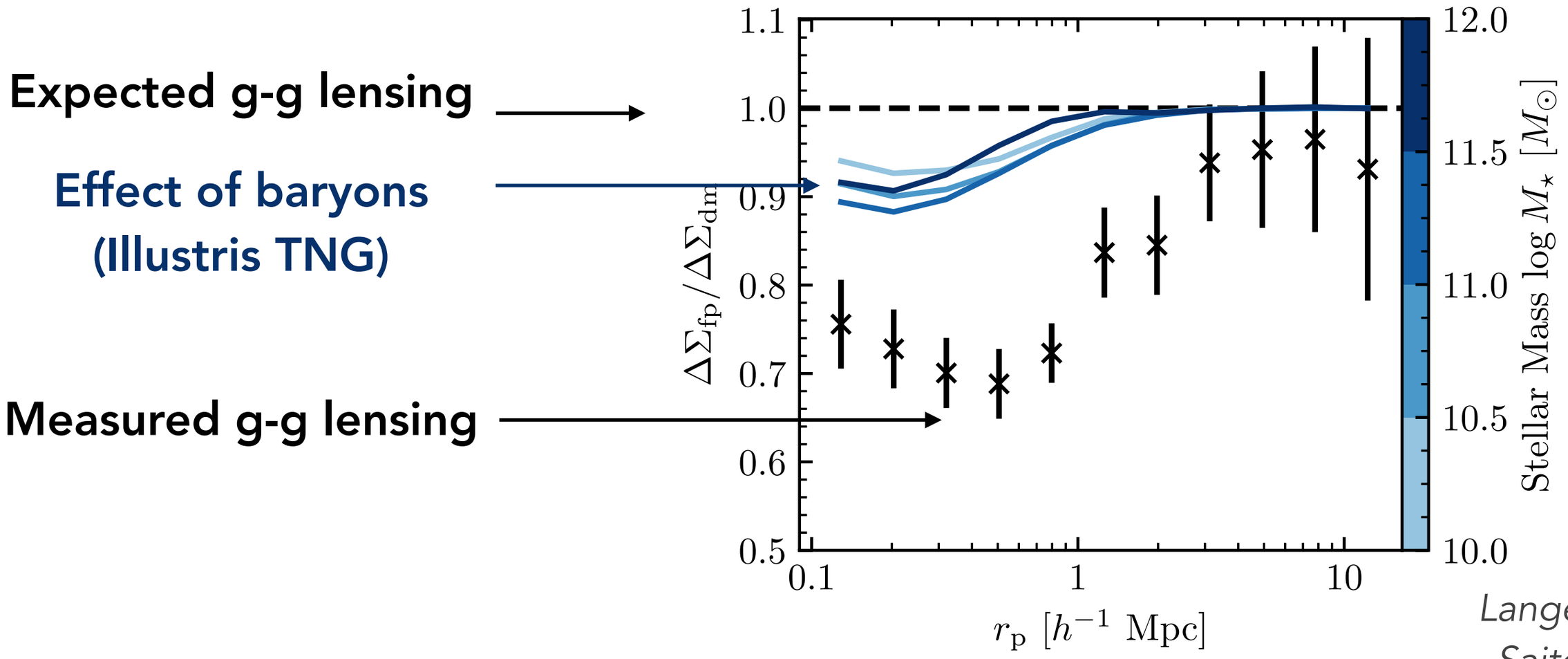
Feedback pushes gas outside virial radius
Too faint to detect around low mass halos, at high z
→ **Localization is uncertain**

Baryons ~15% total matter
→ **Largest (30%) uncertainty on the small-scale matter power spectrum**



Huang+18

“Galaxy-galaxy lensing is low” tension



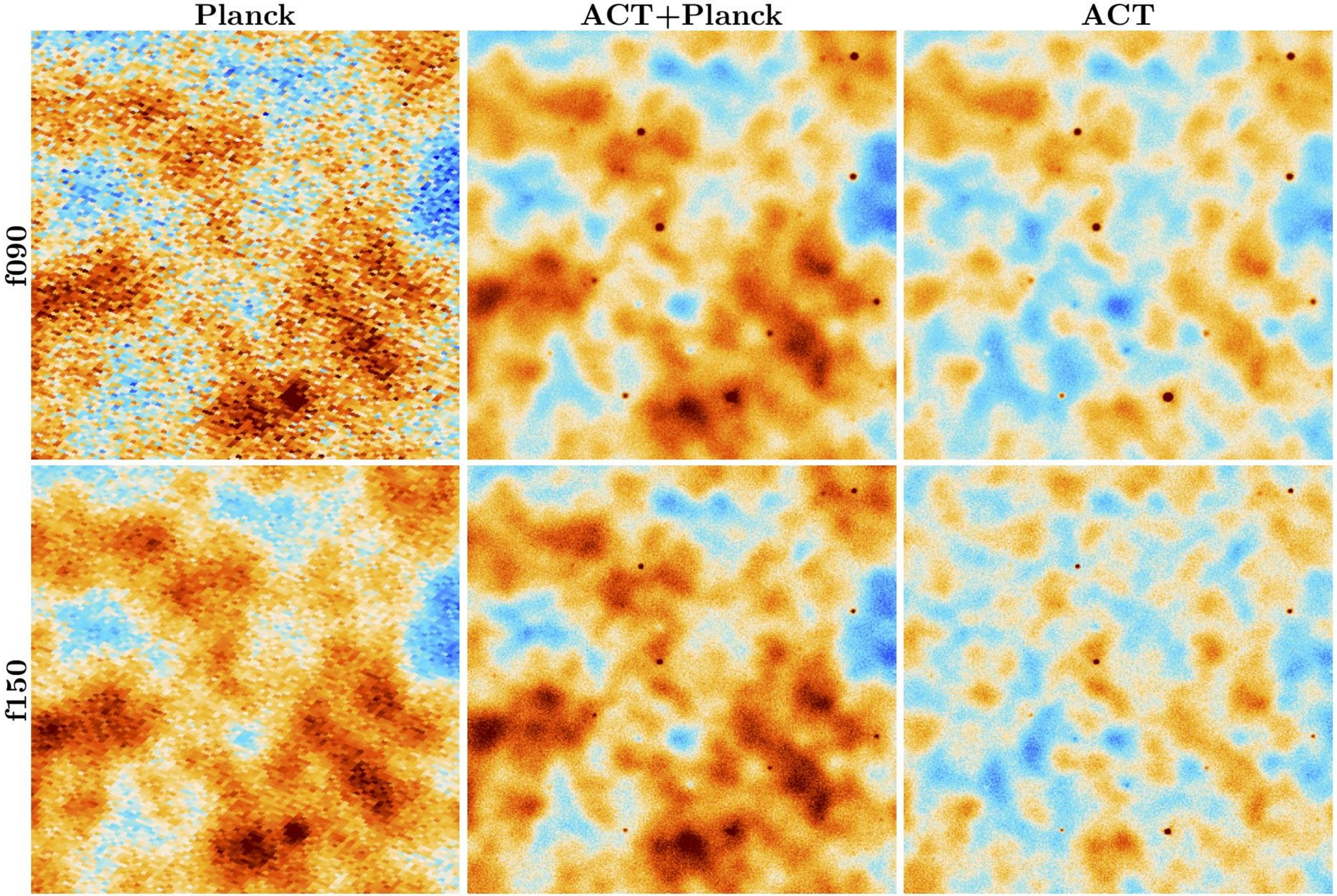
Lange+19
Saito+16
Leauthaud+16
Zu+20

Prediction from clustering overestimates lensing

Baryons, photo-z, shear calibration, HOD, assembly bias, new physics?

→ Directly measure gas profiles for the same exact halos?

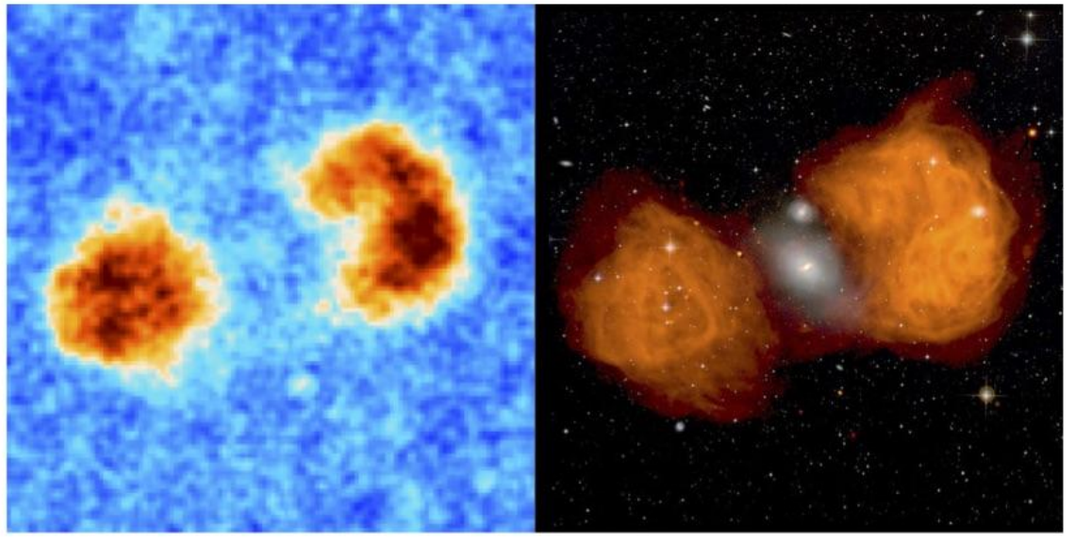
CMB can help!



Naess+20

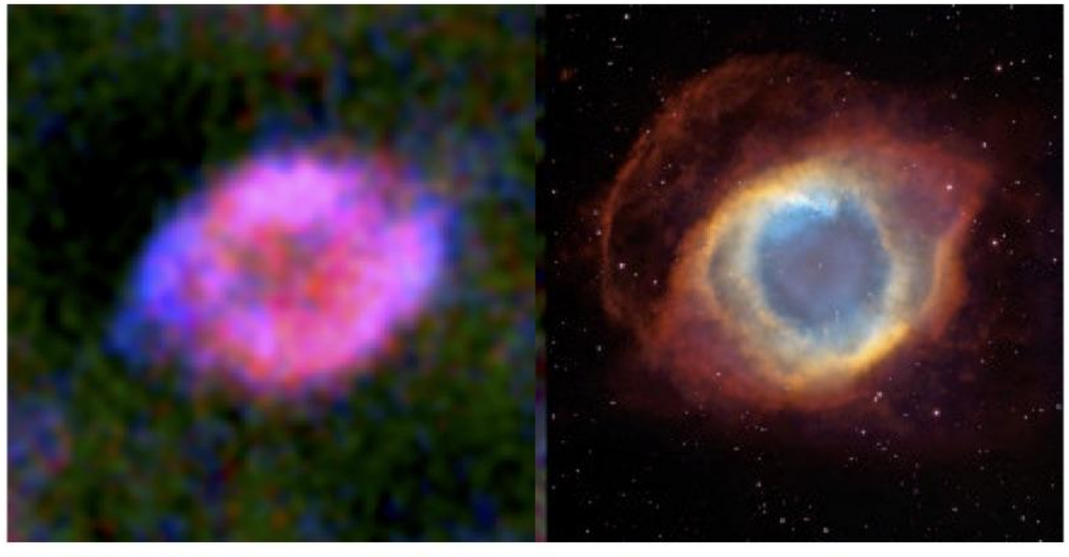
(High-res CMB digression :))

Fornax A



ACT+Planck f090 - f150 Radio+Optical

Helix Nebula

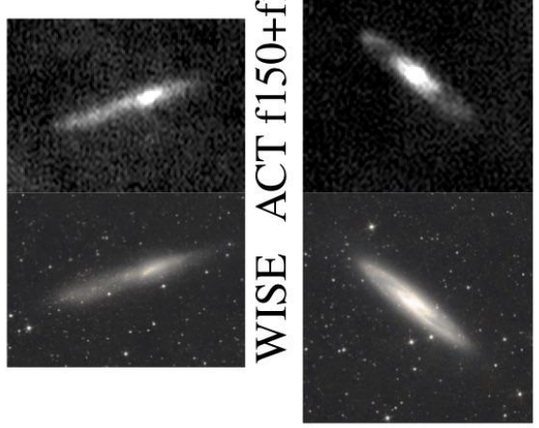


ACT+Planck multifreq Hubble

Leo Triplet

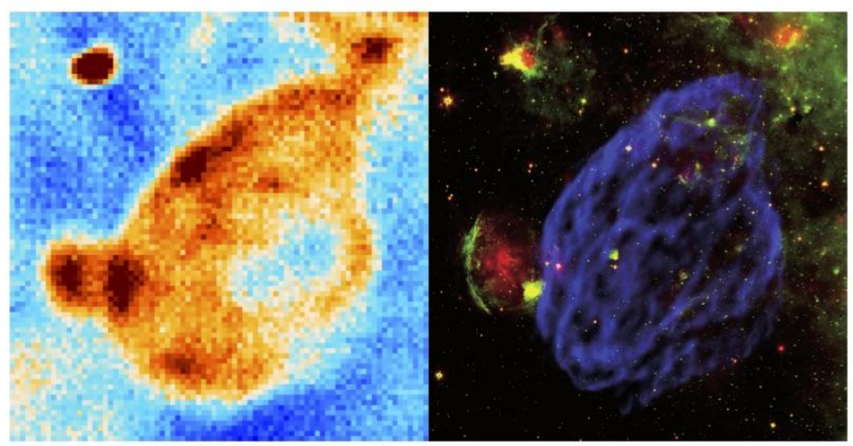
ACT+Planck f150+f220 WISE

NGC 55 NGC 253



WISE ACT f150+f220

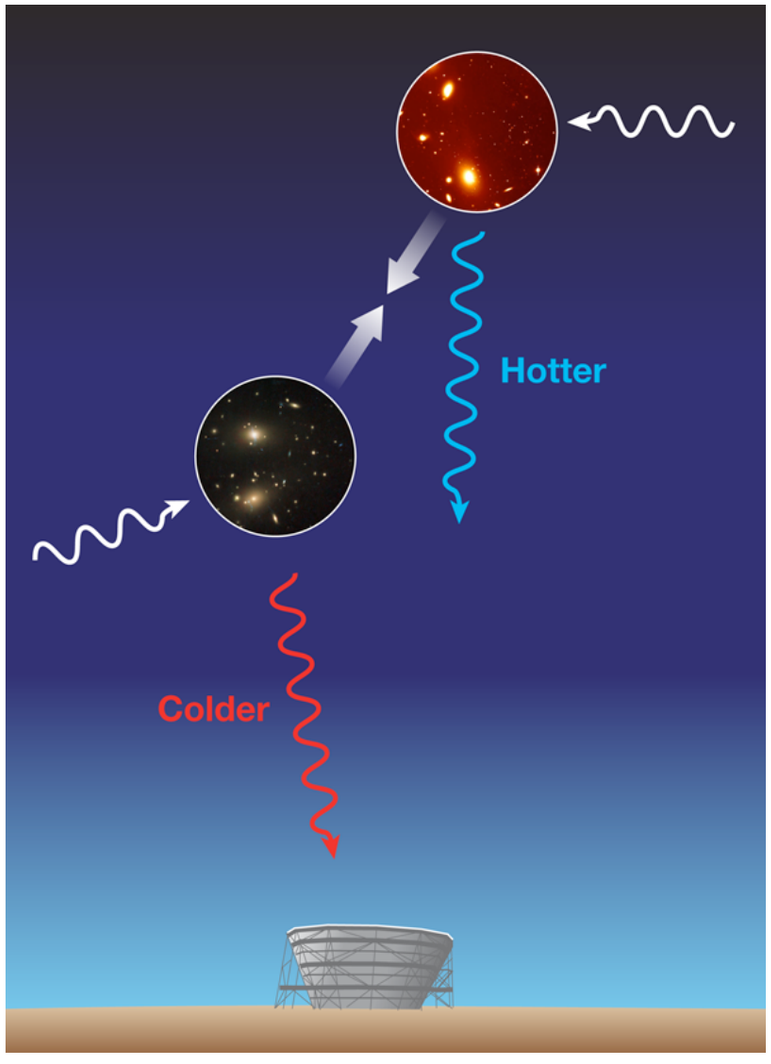
Supernova remnant W44



ACT+Planck f090 - f220 VLA+Spitzer

Naess+20

Kinematic & thermal Sunyaev-Zel'dovich effects



Hand et al 2012

$$\frac{\delta T_{\rm kSZ}}{T_{\rm CMB}} = \tau \frac{v_{\rm bulk}}{c} \quad \propto \; n_e$$

→ gas density

$$\frac{\delta T_{\rm tSZ}}{T_{\rm CMB}} = f(\nu)\; \tau \left(\frac{v_{\rm thermal}}{c}\right)^2 \quad \propto \; n_e \, T_e$$

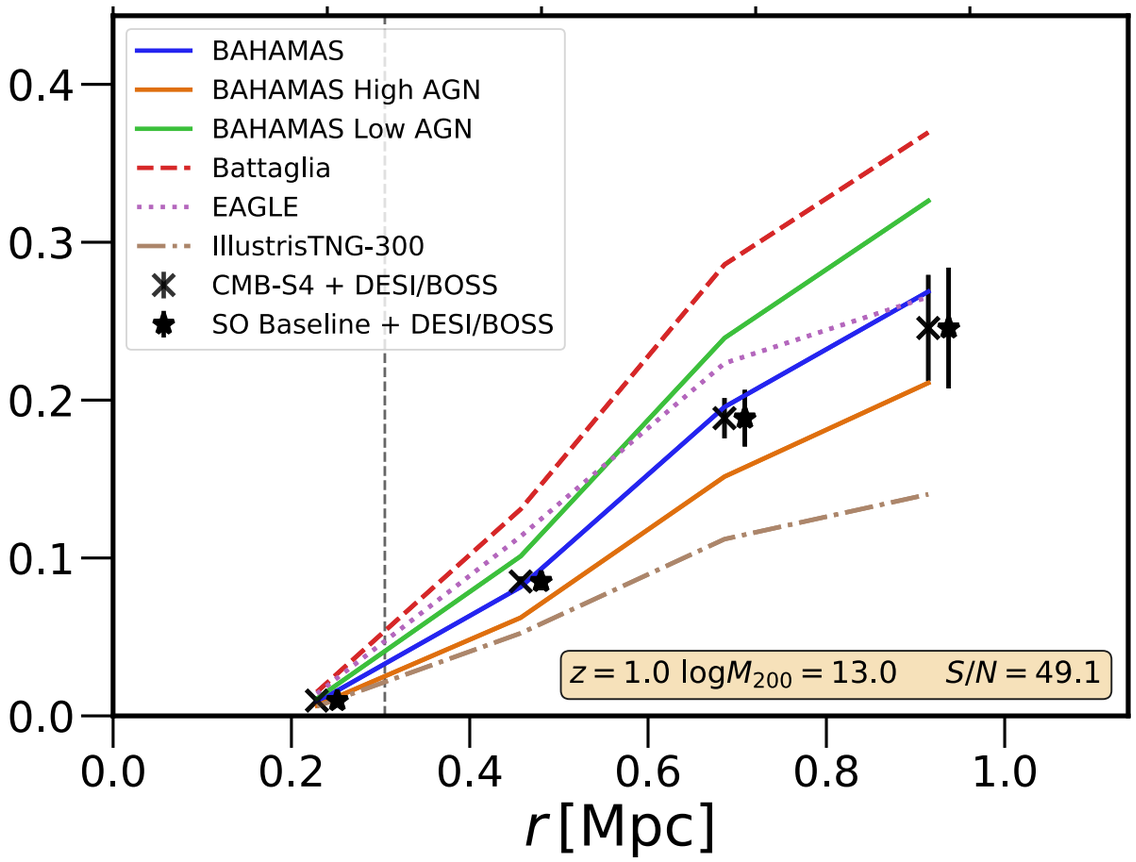
→ gas thermal energy / pressure

→ **Unexplored territory:**

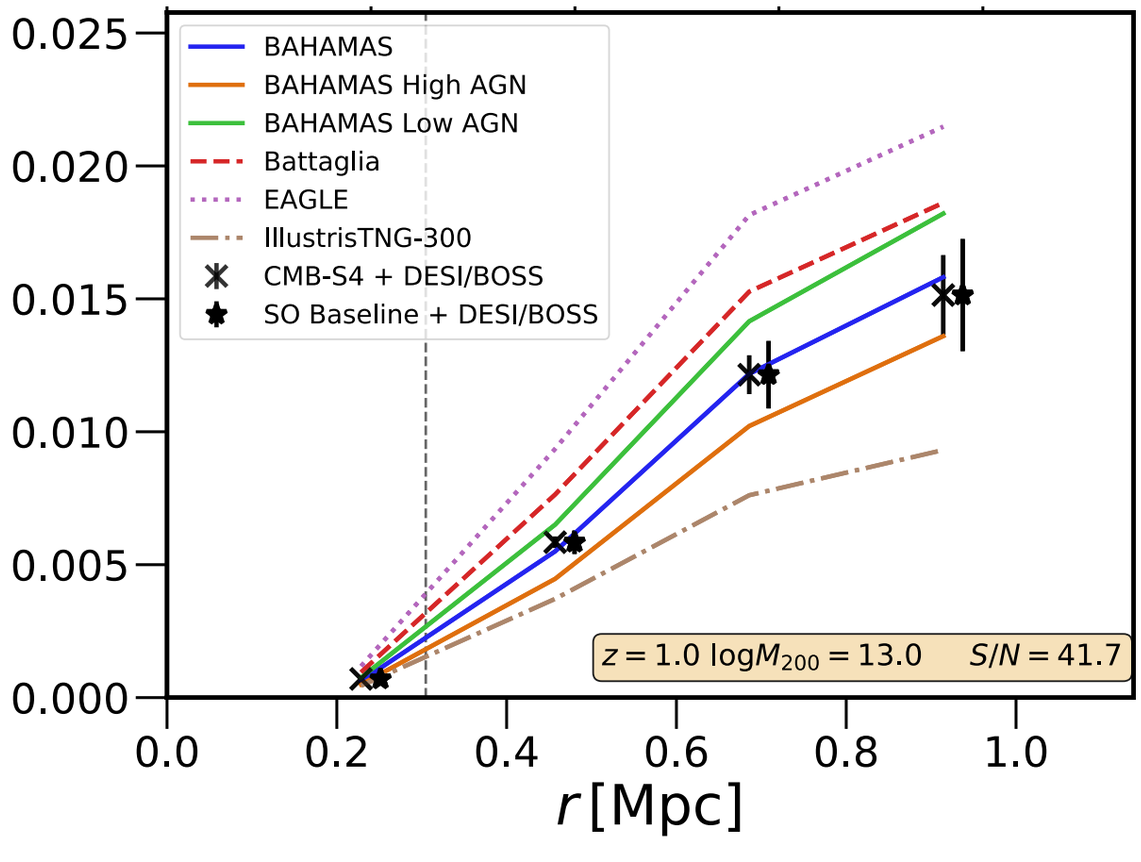
Low mass halos, high z, far outside the virial radius

High S/N with CMB S4 & DESI

kSZ cumulative profile



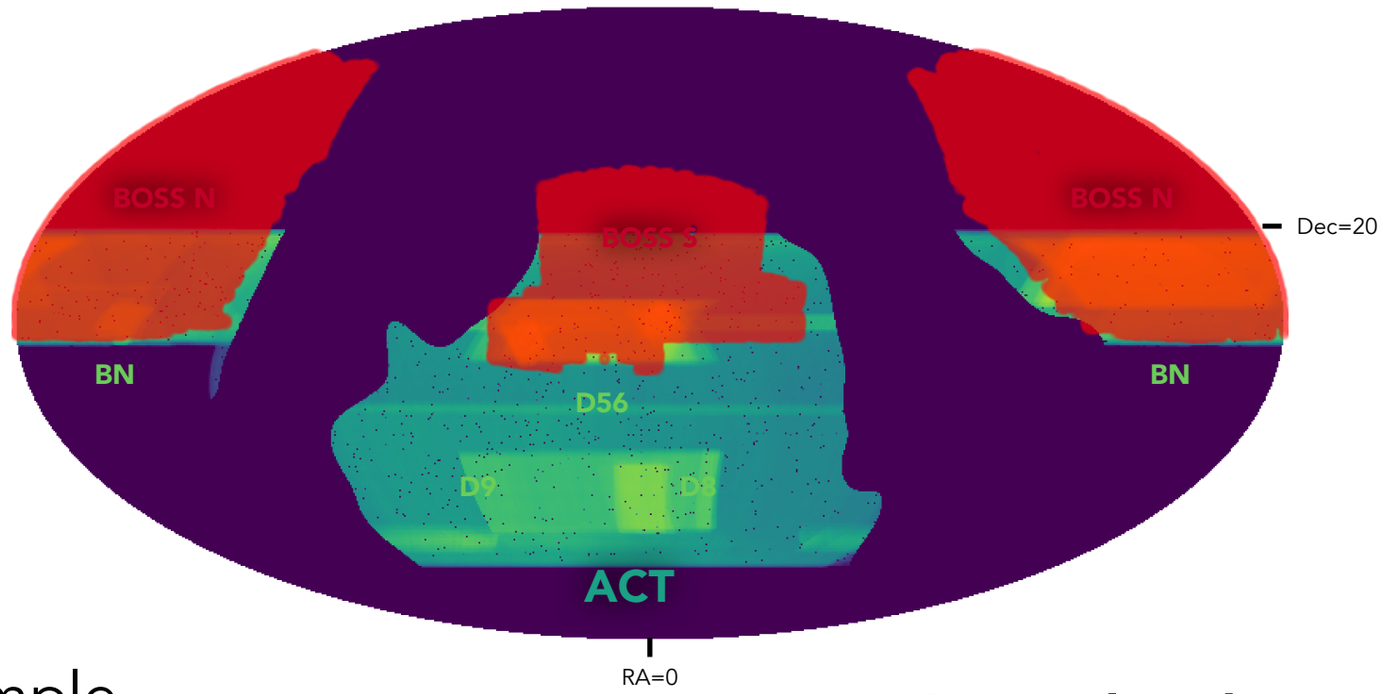
tSZ cumulative profile



CMB S4 DSR, Battaglia+17

and lensing profiles for the same halos!

Combining BOSS & ACT+Planck



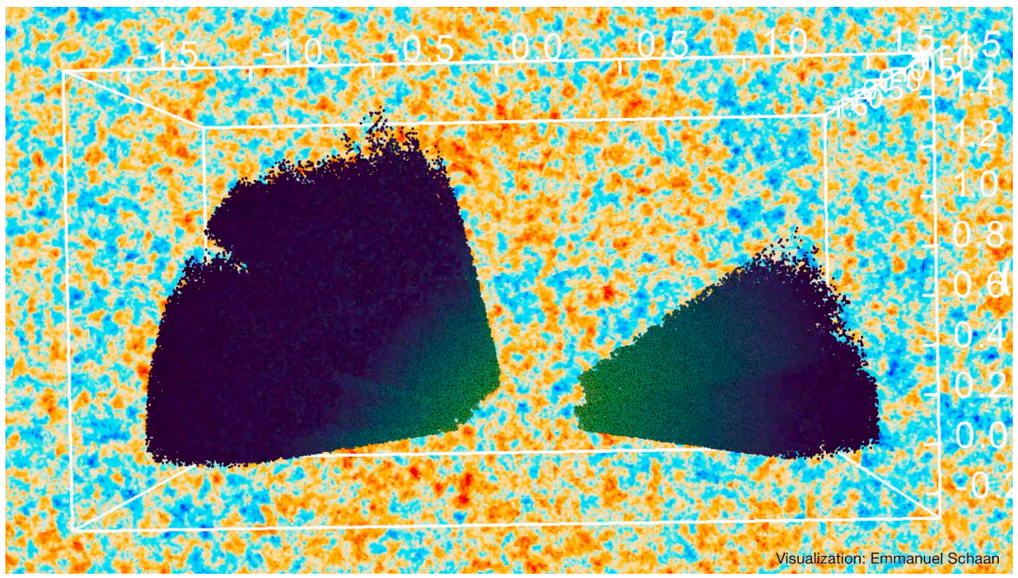
BOSS CMASS

Spectroscopic sample

~400k galaxy groups, $10^{13} M_{\odot}$

z = 0.4 - 0.7

BAO, Clustering, galaxy-galaxy lensing, CMB lensing



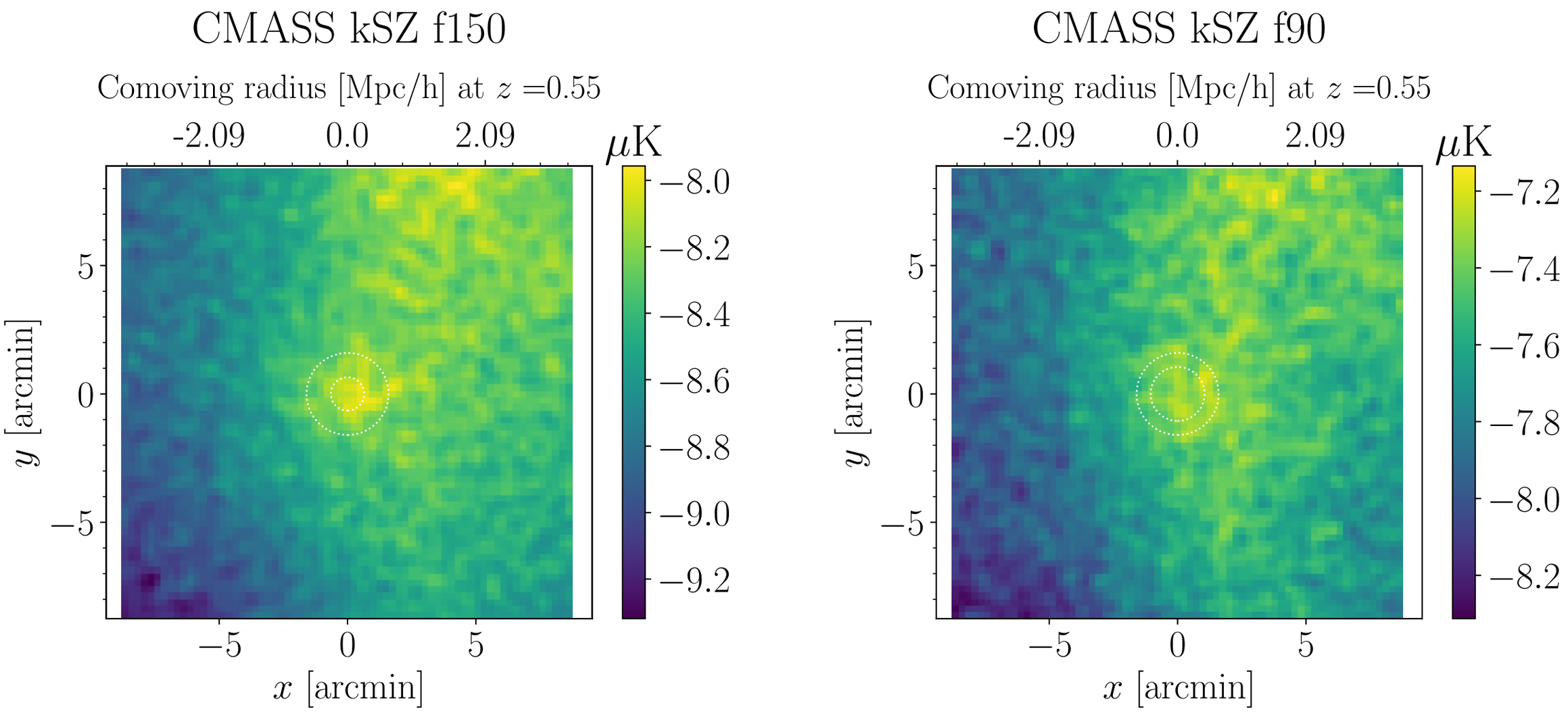
ACT + Planck

ACT DR5 + Planck,150GHz and 98GHz *Naess+20*

ACT DR4 ILC maps *Madhavacheril+20, Choi+20, Aiola+20*

Image: Debra Kellner

CMASS kSZ

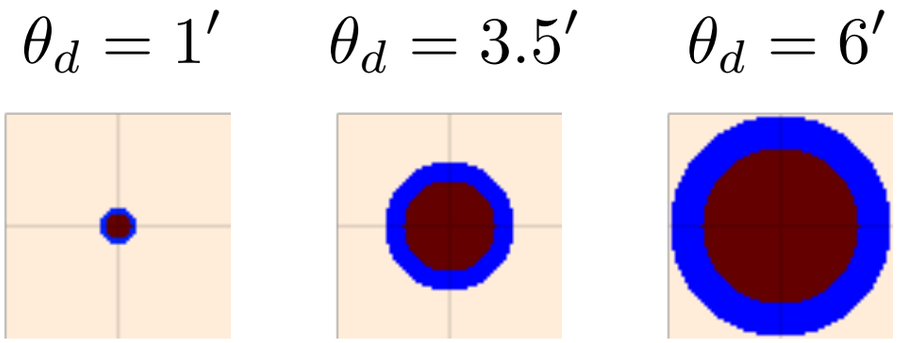


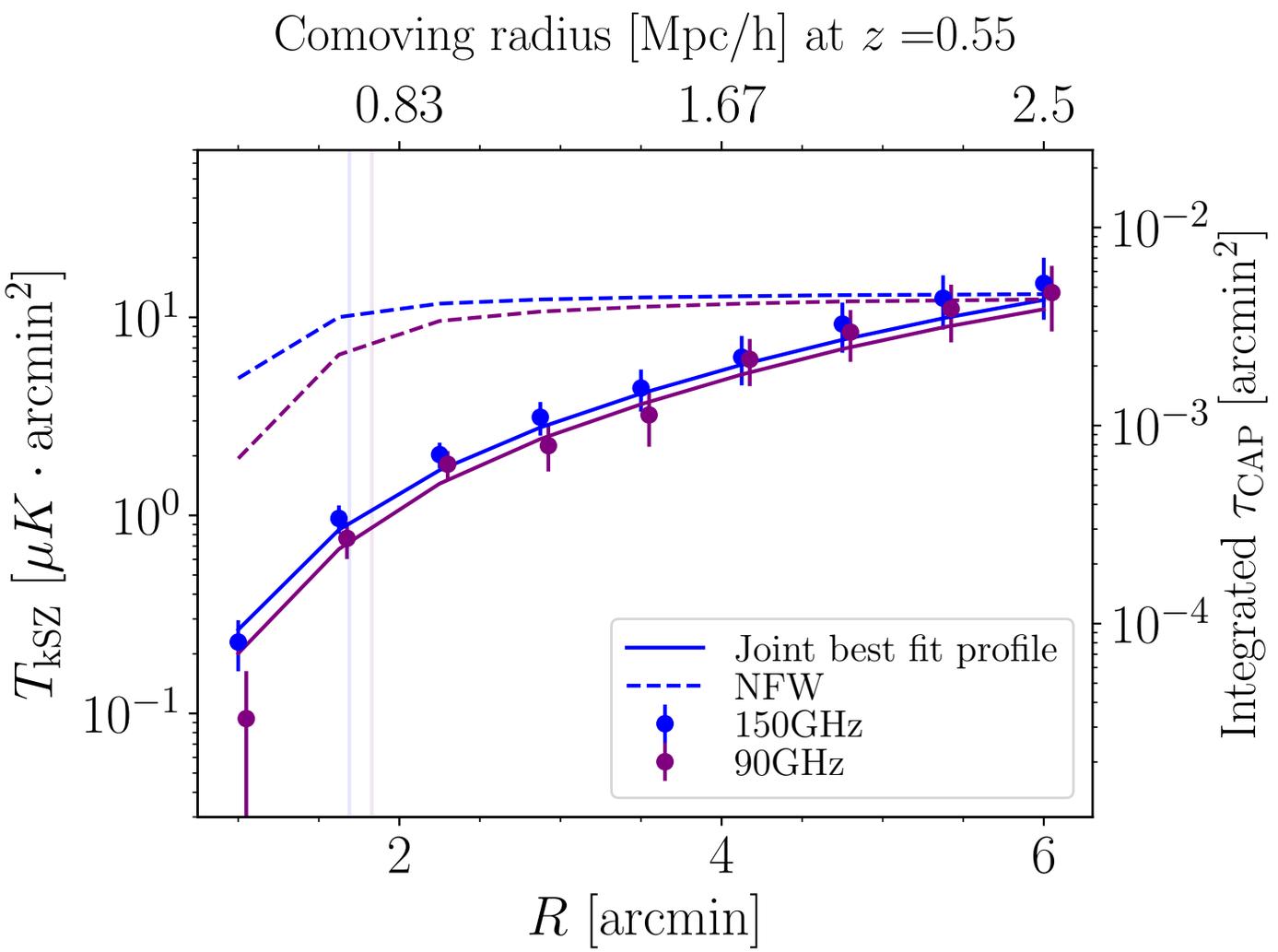
Imaging the gas! (no filtering applied)

Highest significance kSZ measurement: 6-8σ

Large-scale CMB noise in common, small-scale detector noise independent

Gas does not follow DM



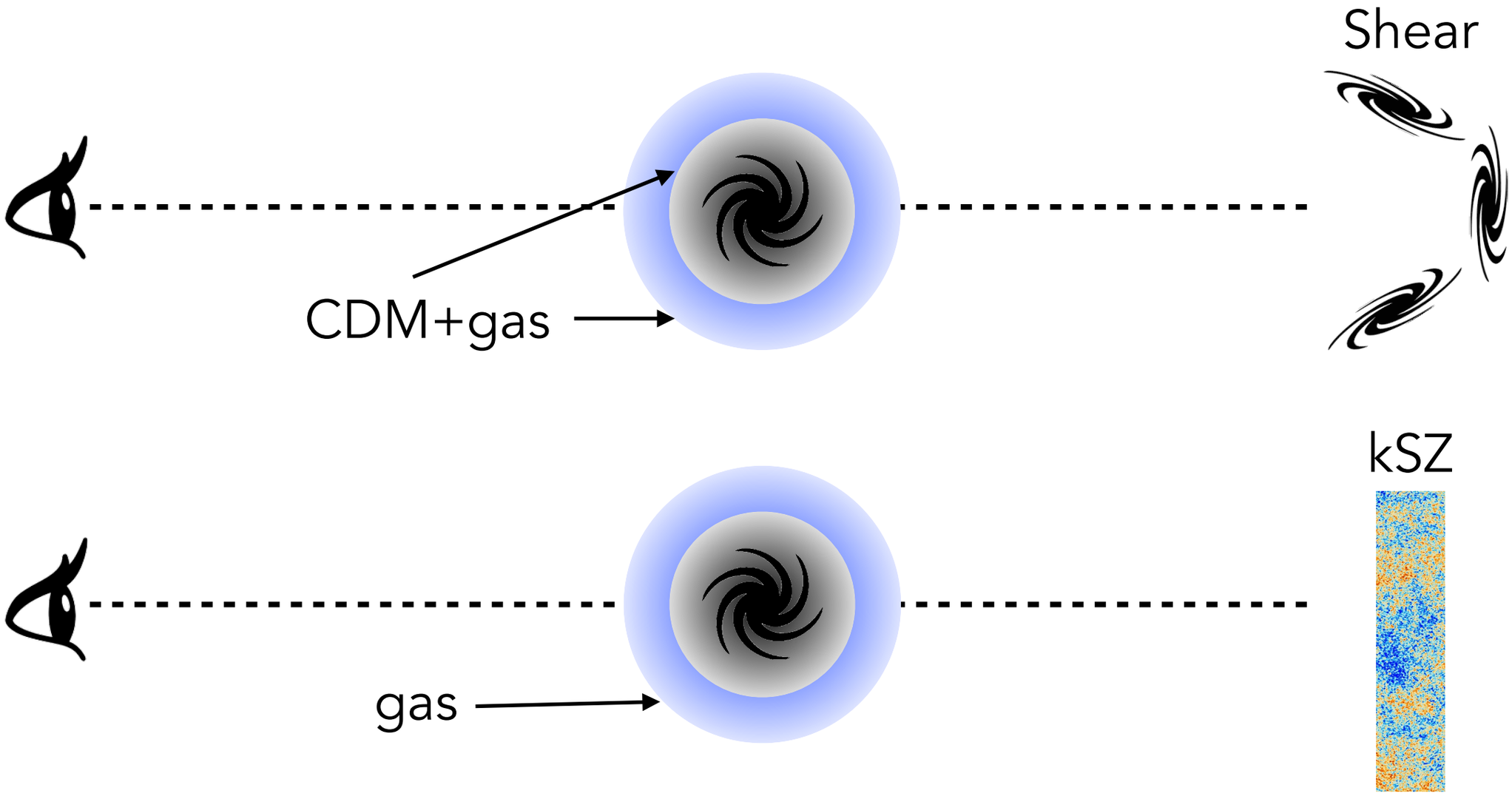


Schaan Ferraro Amodeo Battaglia & ACT 20

The gas profile is more extended than the dark matter profile

No-kSZ rejected at 6-8σ, but NFW rejected at >90σ!

kSZ & galaxy - galaxy lensing

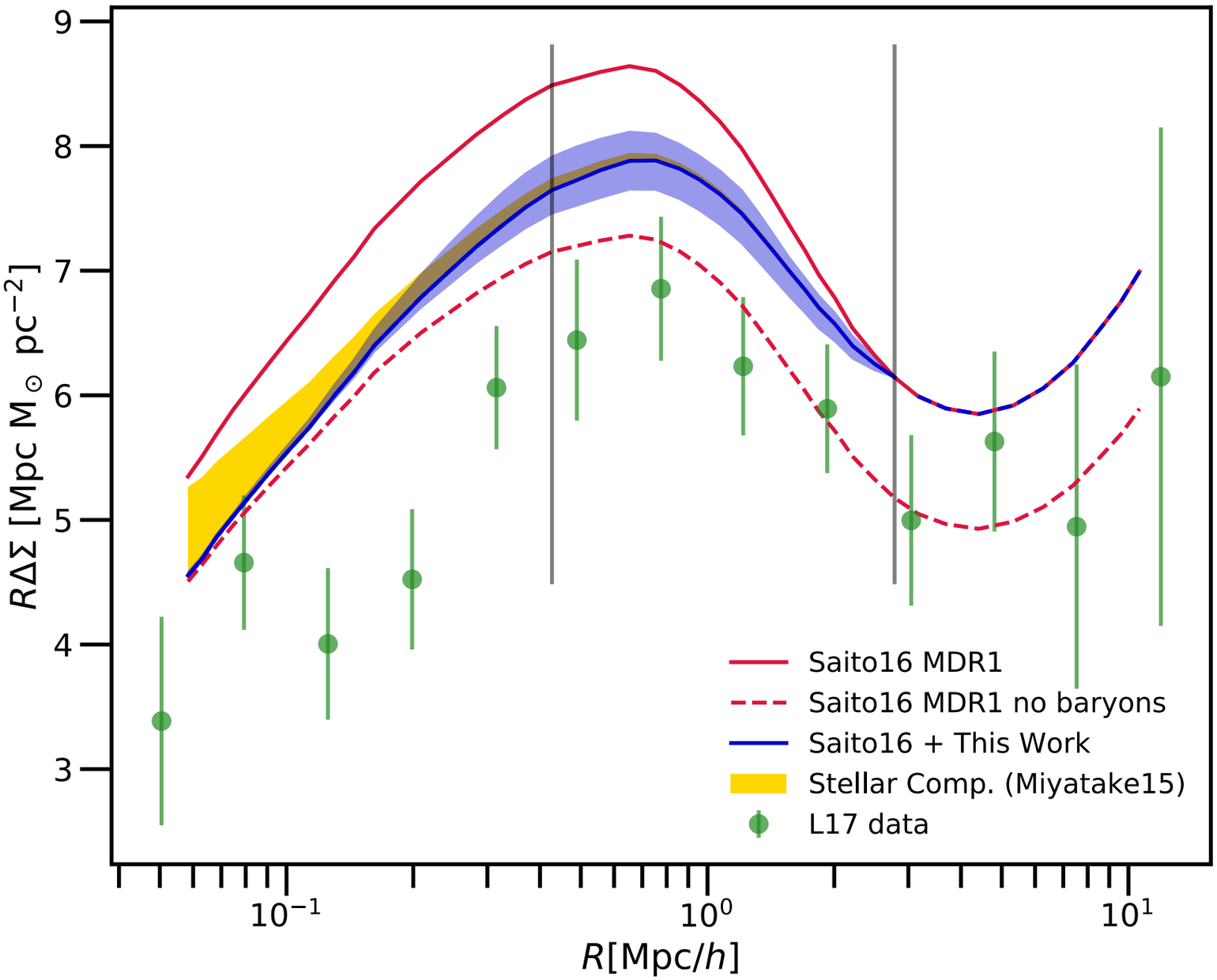


Total mass profile and gas profile

Same halos, HOD, weighting (linear in mass, VS tSZ or Xray), angular scales

→ no modeling needed

"Lensing is low" tension



Amodeo Battaglia Schaan Ferraro & ACT 20

kSZ determines the baryonic contribution!

Baryons only partially alleviate the tension

Subtleties

Reaction of the DM to the expelled baryons

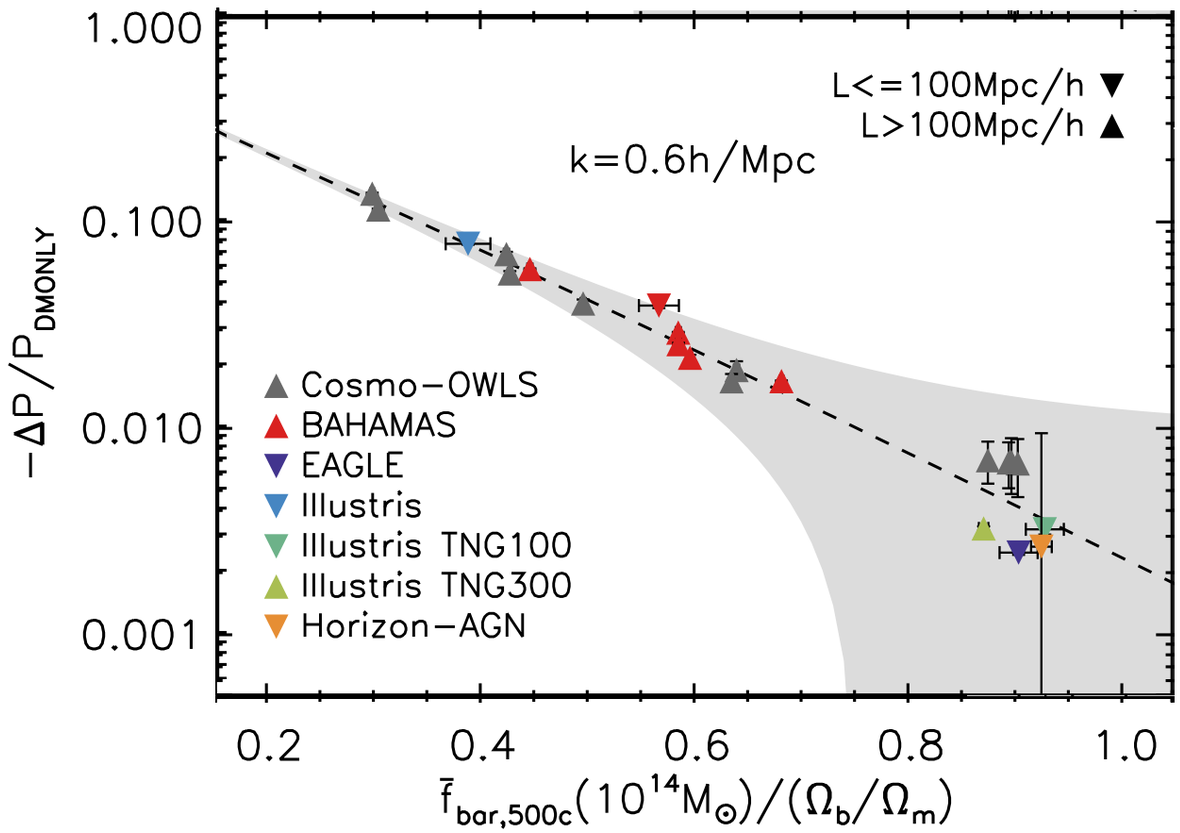
Schneider+19: "adiabatic relaxation" of the DM when the baryons are pushed out by feedback

$$\frac{r_f}{r_i} - 1 = a\left[\left(\frac{M_i}{M_f}\right)^n - 1\right], \qquad M_i \equiv M_{\rm nfw}(r_i),$$
$$M_f \equiv f_{\rm clm} M_{\rm nfw}(r_i) + M_{\rm cga}(r_f) + M_{\rm gas}(r_f)$$

Schneider+19

Baryonic effect on cosmic shear without measuring all halos

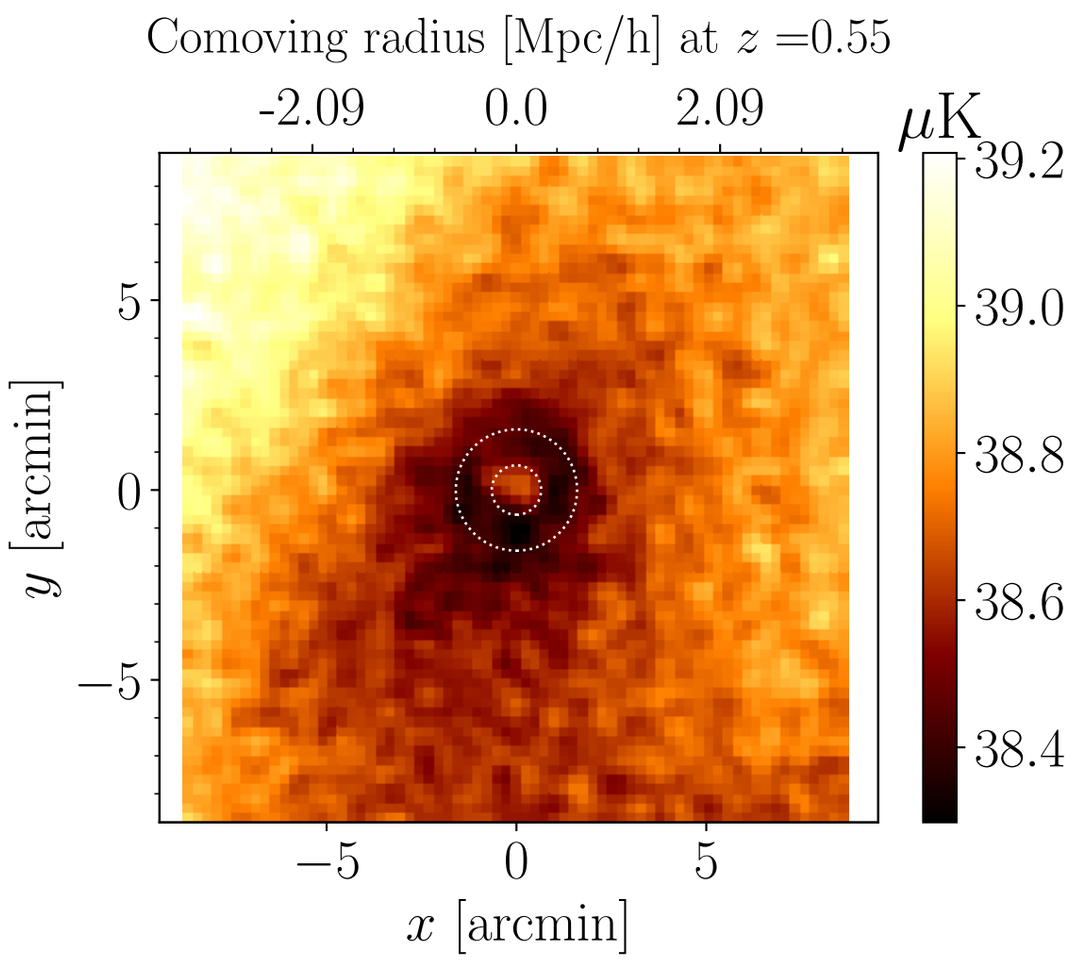
van Daalen+19:



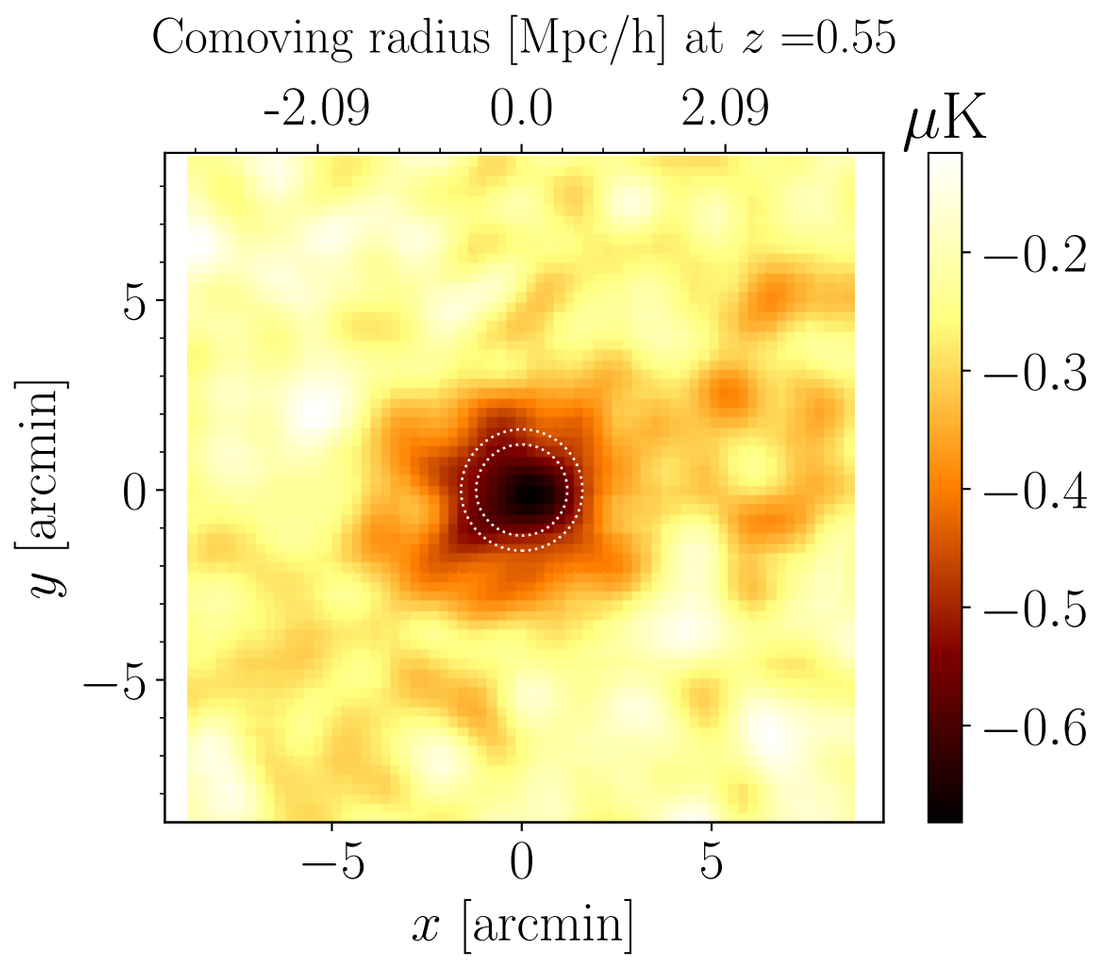
van Daalen+19

CMASS tSZ + dust

150 GHz



tSZ ILC no CIB



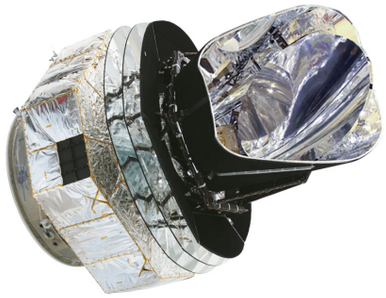
Extended tSZ profile is well resolved!

Point-like dust emission at 150 GHz,

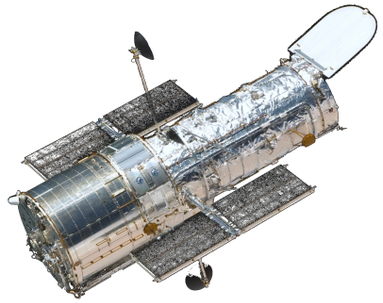
modeled with Herschel data / nulled with constrained ILC

Measurement summary

ACT + Planck (microwave)



Hubble *(optical)*



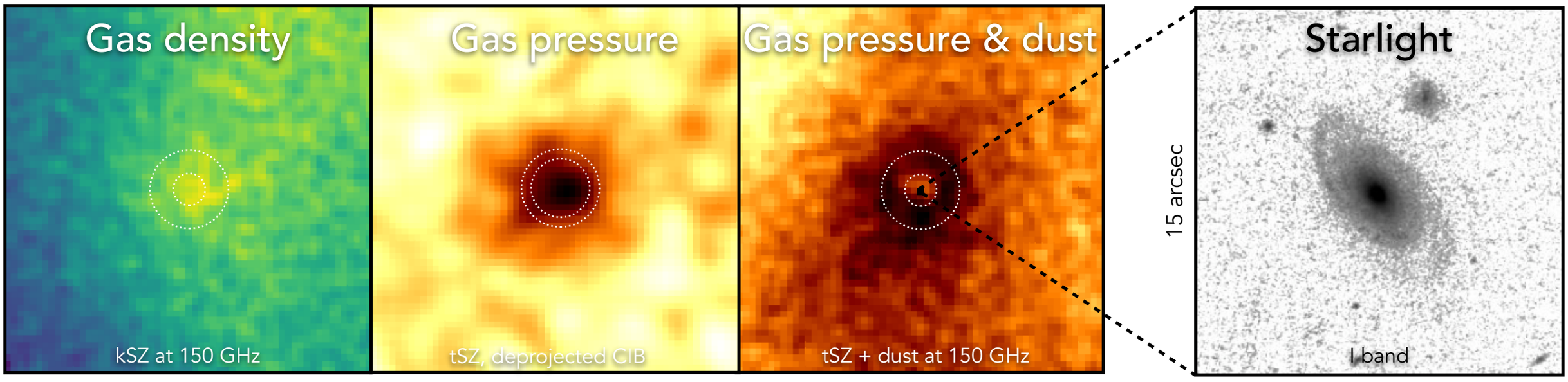


Figure: Emmanuel Schaan. ACT+Planck microwave images: Schaan et al 2020. HST ACS I band image: Masters et al 2011. ACT photo: John Ward. Planck photo: ESA/AOES Medialab. HST photo: NASA.

Gas density, gas pressure, dust emission far outside the virial radius from low mass galaxy groups

Emmanuel Schaan

tSZ / kSZ = gas temperature

$$\frac{\delta T_{\rm kSZ}}{T_{\rm CMB}} = \tau \frac{v_{\rm bulk}}{c} \quad \propto \; n_e$$

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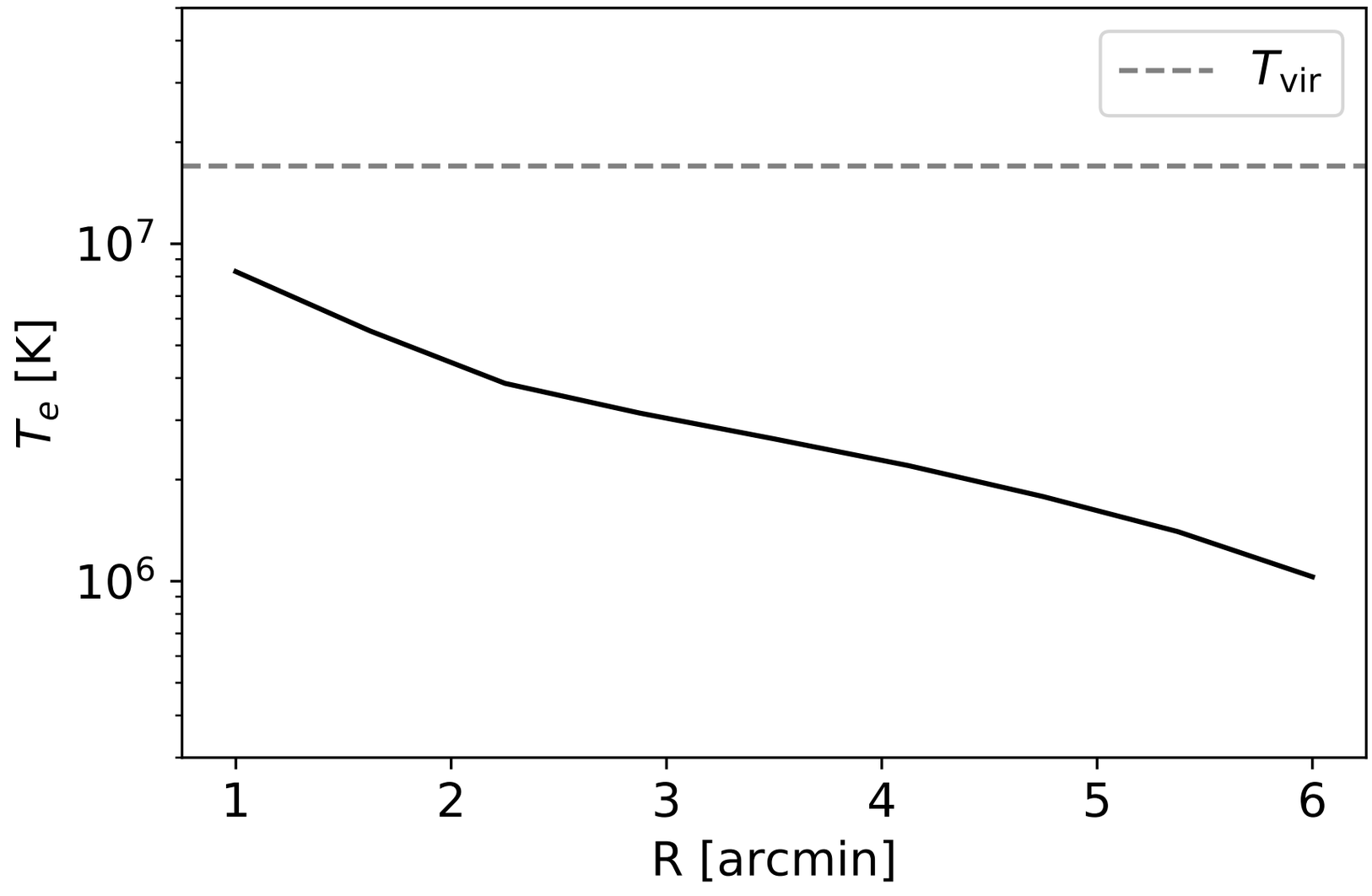


Amodeo Battaglia Schaan Ferraro & ACT 20

Energy injection & non-thermal pressure

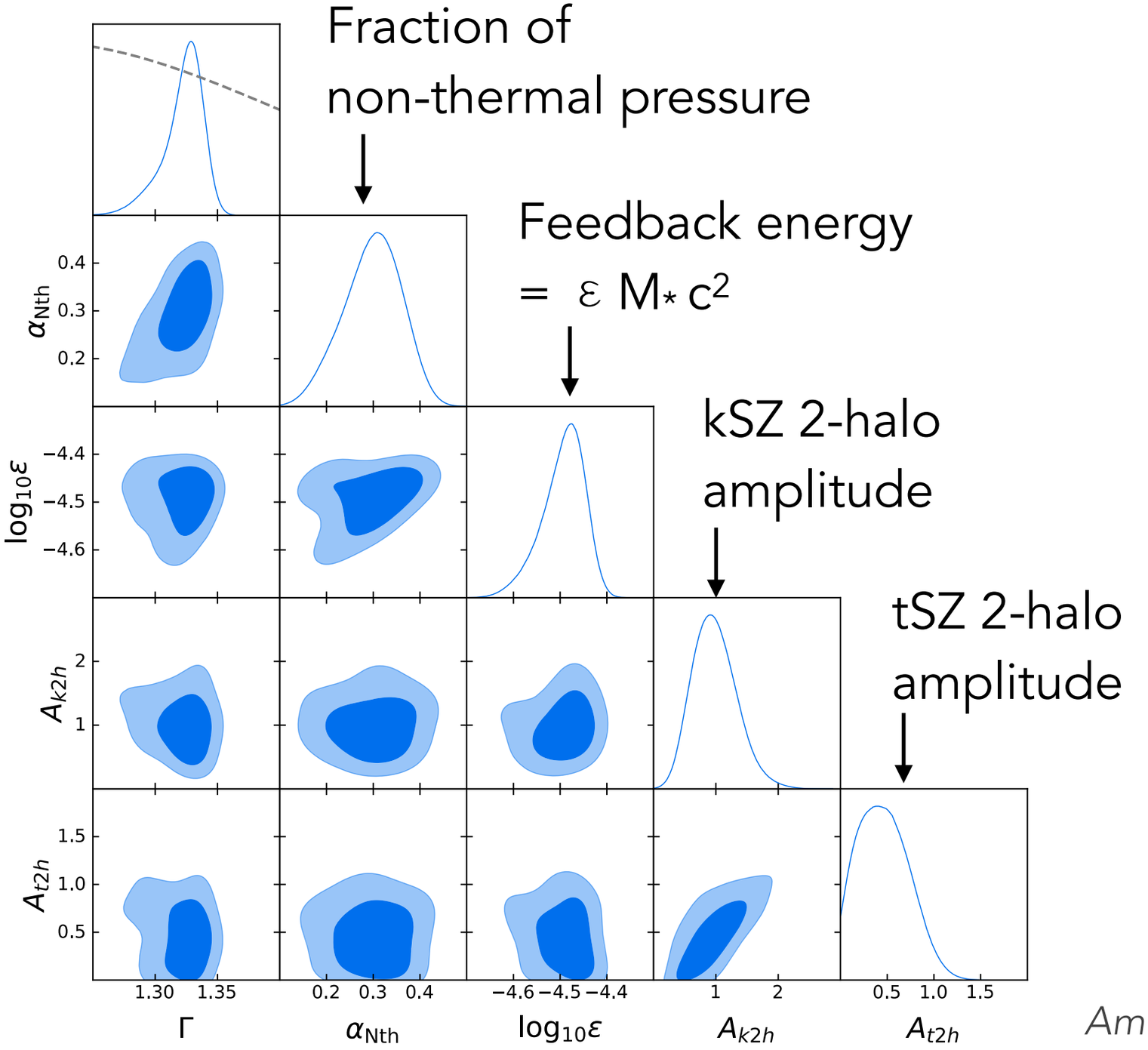
Polytropic index

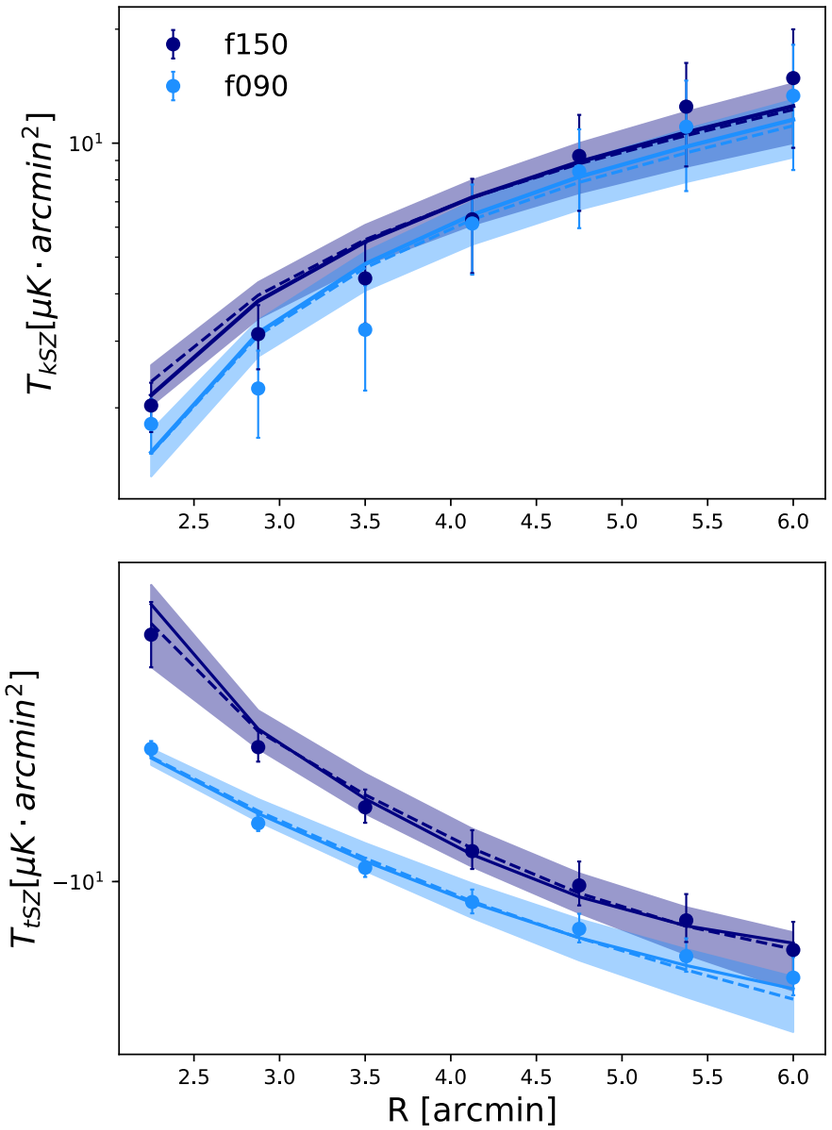
Fraction of non-thermal pressure

Feedback energy = $\varepsilon M_* c^2$

kSZ 2-halo amplitude

tSZ 2-halo amplitude





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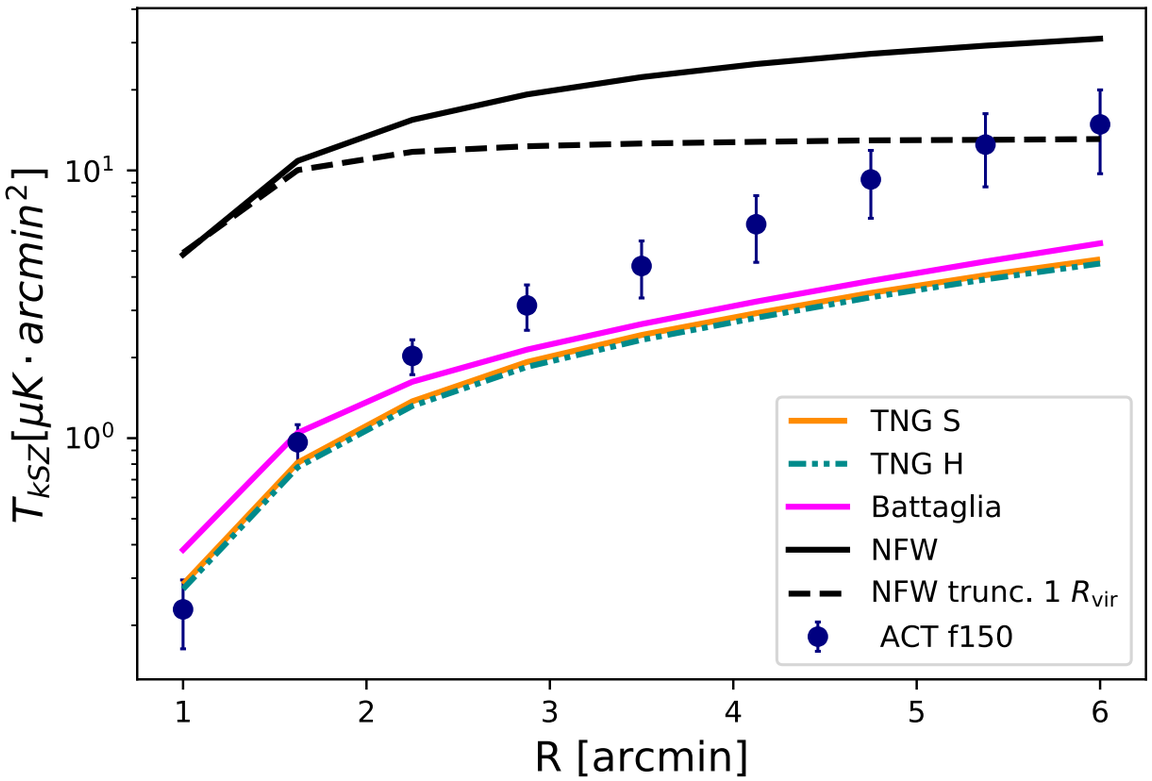
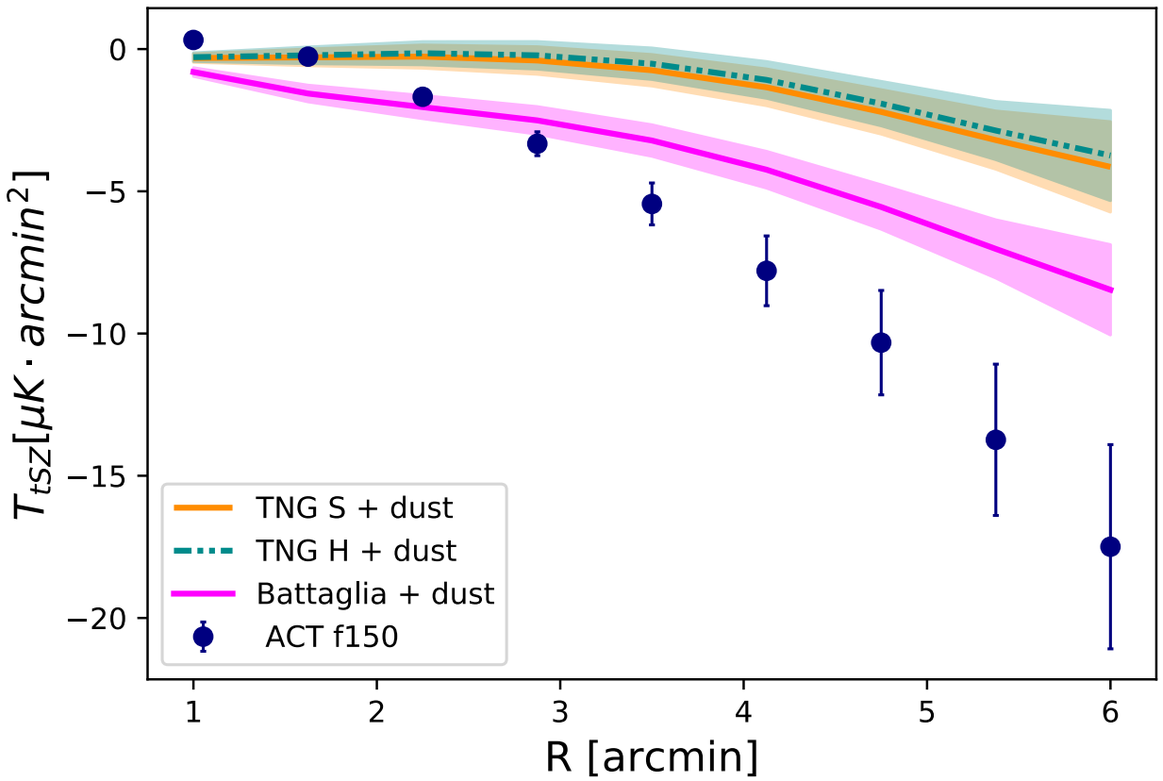
Ostriker Bode Babul 05

Hydro simulations





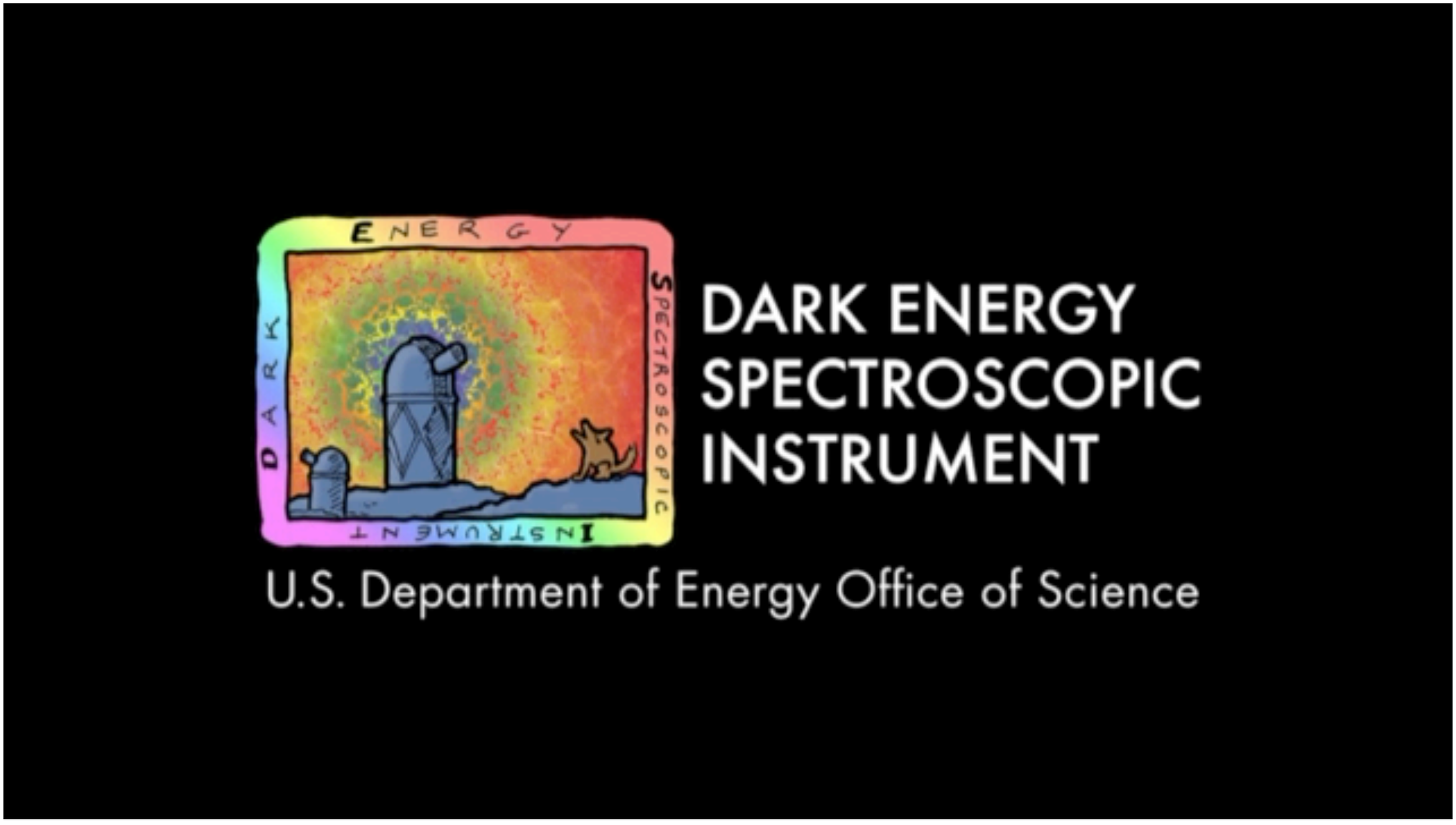
Amodeo Battaglia Schaan Ferraro & ACT 20

New territory: low halo masses, outside virial radius

Data suggests hotter gas in the outskirts

Informs subgrid feedback prescriptions in hydro sims

DESI has started!



5k fiber spectrograph on 4m Mayall telescope

→ **5% kSZ by Y1**

Conclusions

Highest kSZ signal-to-noise to date (6-8σ)

Gas more extended than dark matter (formally >90σ)

KSZ fixes the baryonic contribution to galaxy-galaxy lensing

KSZ & tSZ: gas temperature, feedback energy, non-thermal pressure
→ new input for hydro simulations

Measurement summary

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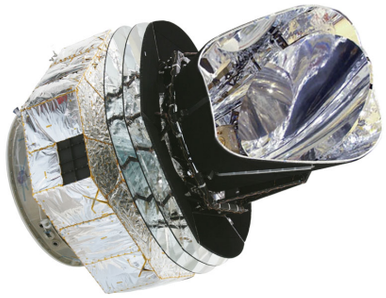

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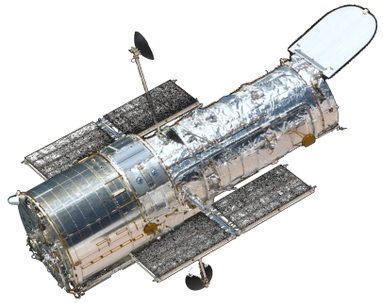

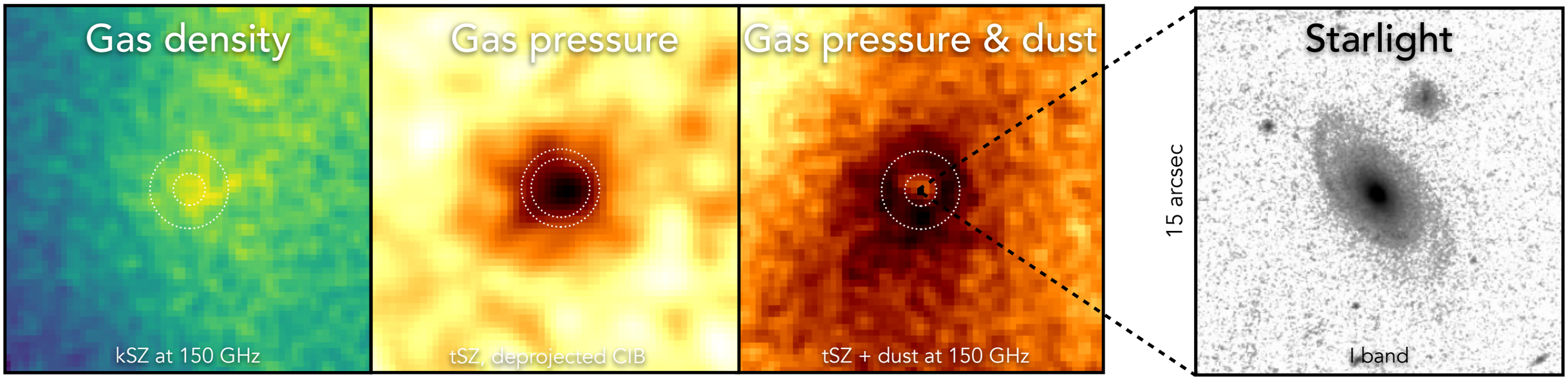

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