A roadmap to establishing the kSZ effect as a benchmark for AGN feedback models

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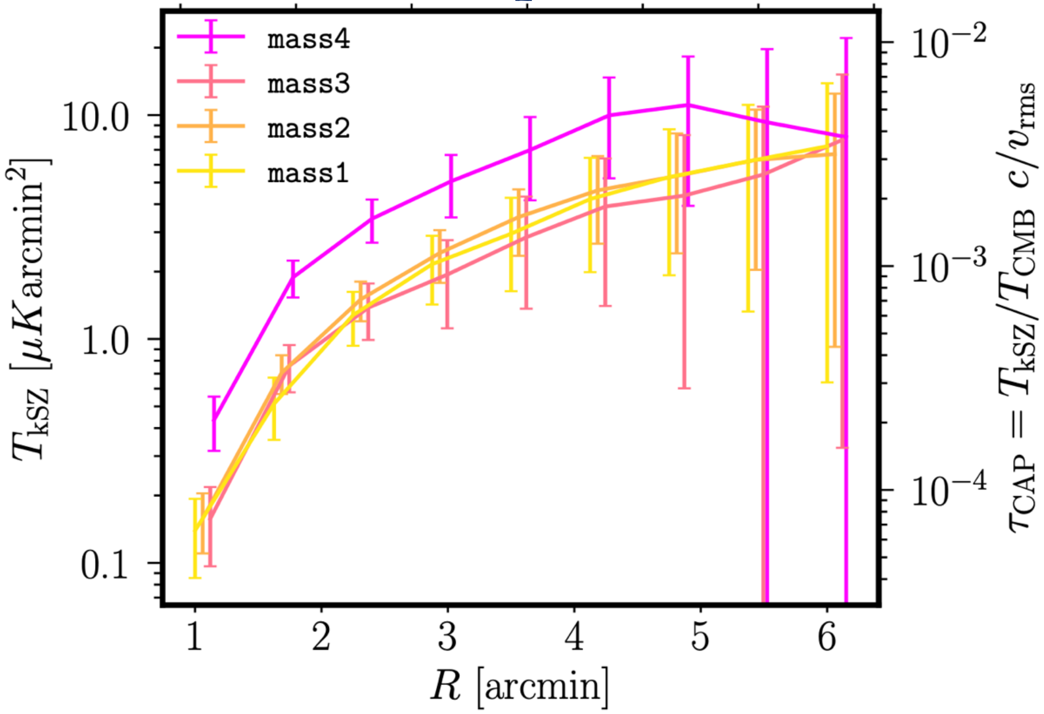
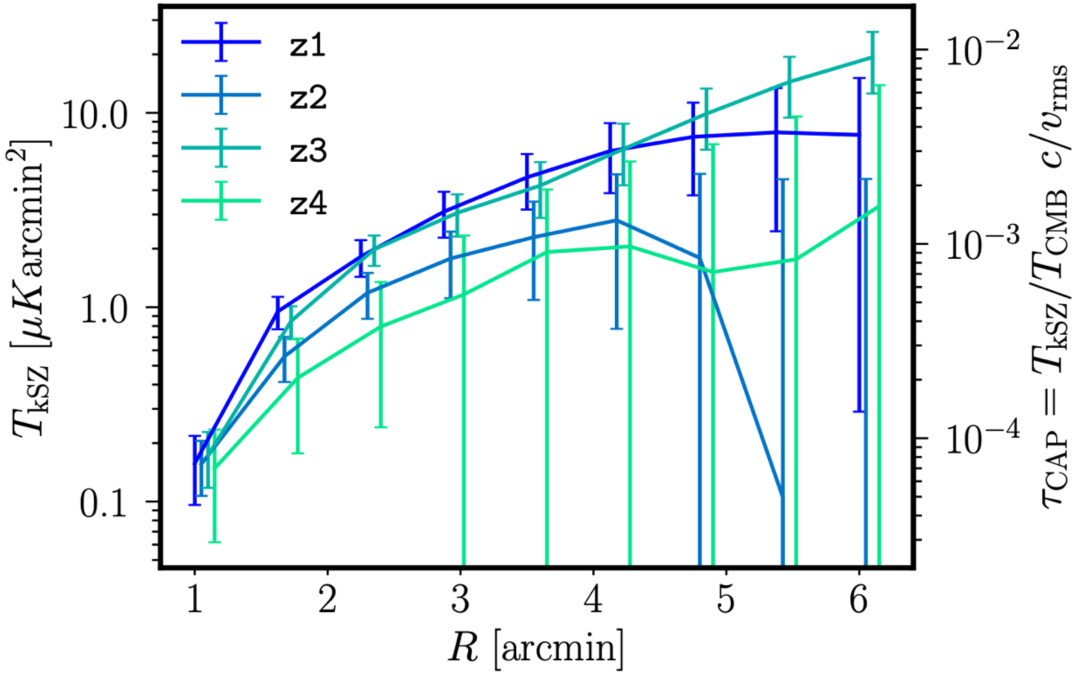
DESI Y1 x ACT kSZ and beyond…

kSZ measurements probe the mass and redshift dependence of feedback in the outskirts of groups & clusters

Stellar mass dependence



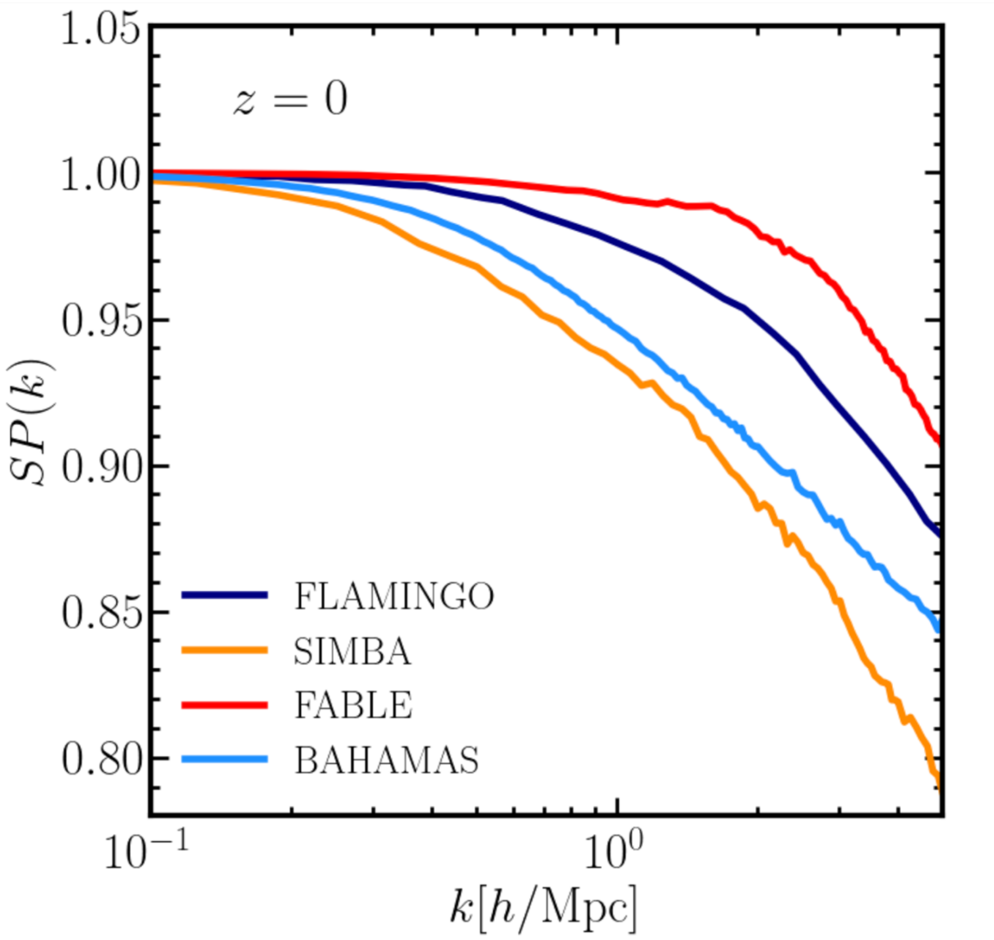
Redshift dependence



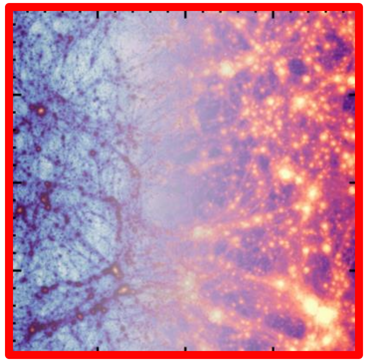
[Ried Guachalla+2025, Schaan+2020]

Extracting unbiased cosmology from weak lensing

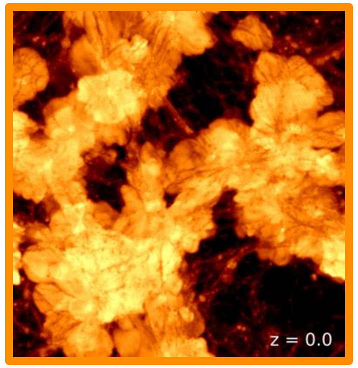
Weak lensing requires accurate predictions for the impact of baryonic feedback processes on the non-linear matter distribution



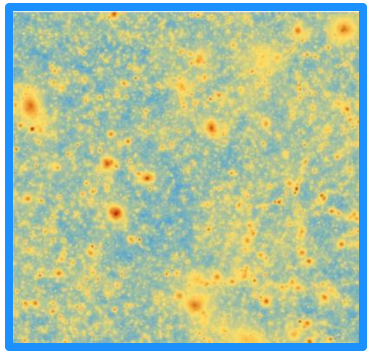
FABLE



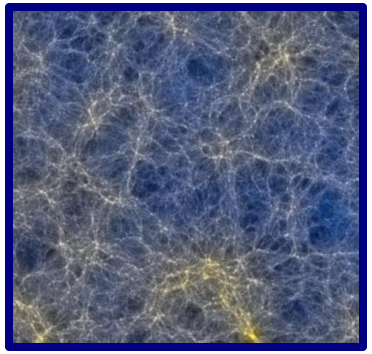
SIMBA



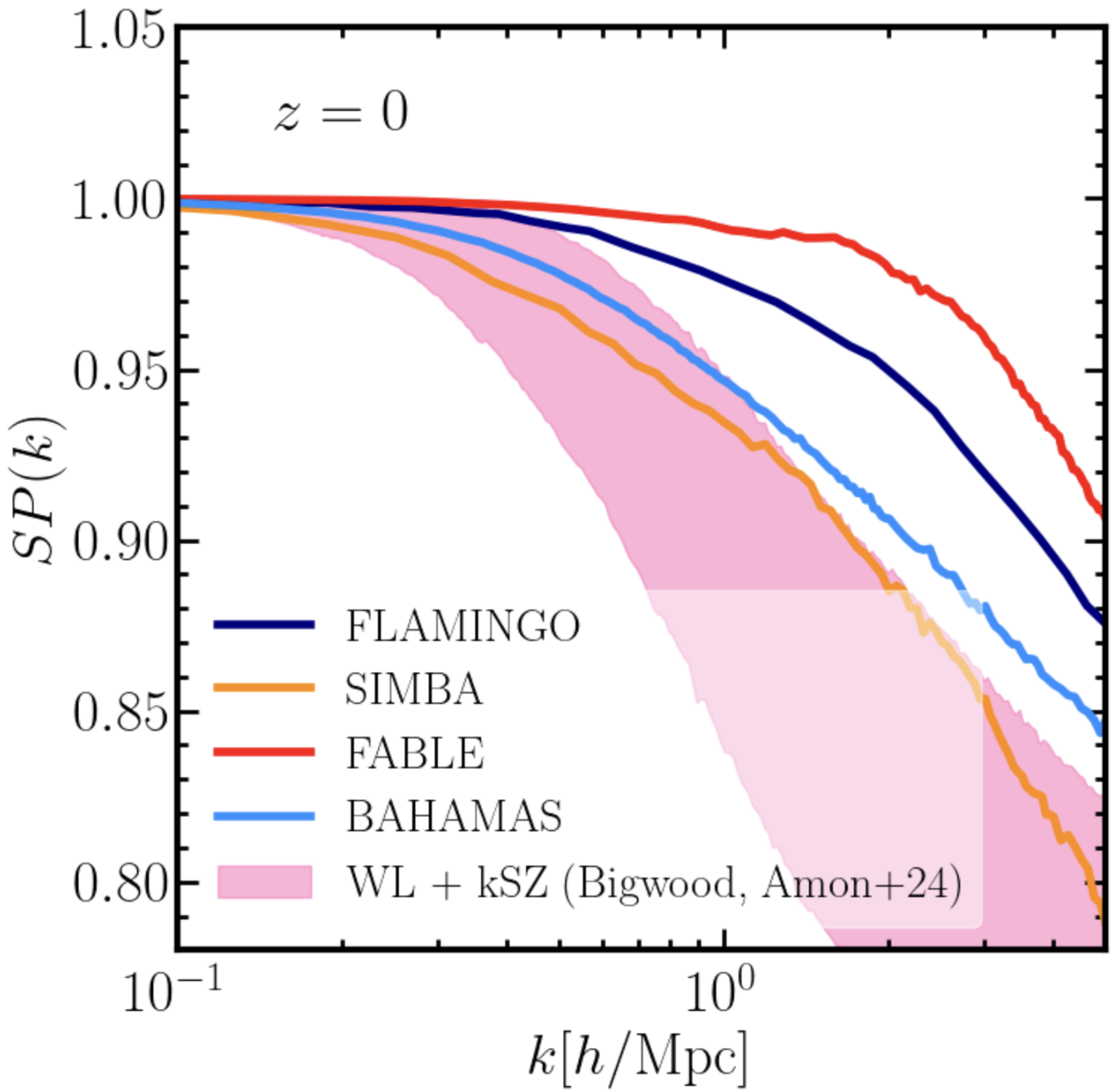
BAHAMAS



FLAMINGO



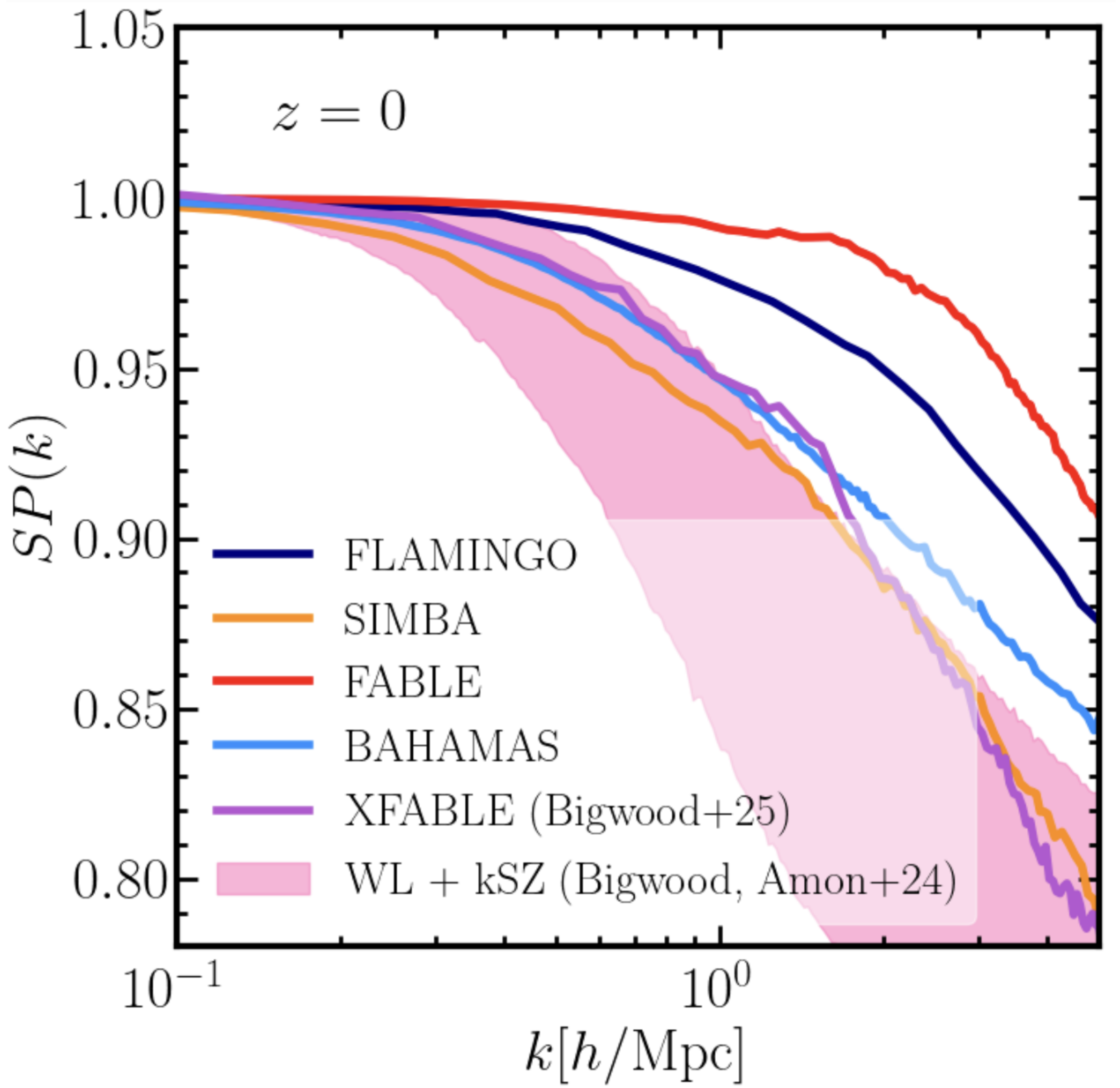
Lensing + kSZ: *A joint cosmological analysis*



kSZ pushes us to a more 'extreme' feedback scenario than the hydrodynamical simulations predict

[*Bigwood, Amon+2024*]

XFABLE: *the case for large-scale AGN feedback in hydrosimulations*



XFABLE demonstrates larger scale AGN feedback, whilst remaining consistent with all key group & cluster properties

FABLE

Fiducial AGN feedback model

XFABLE

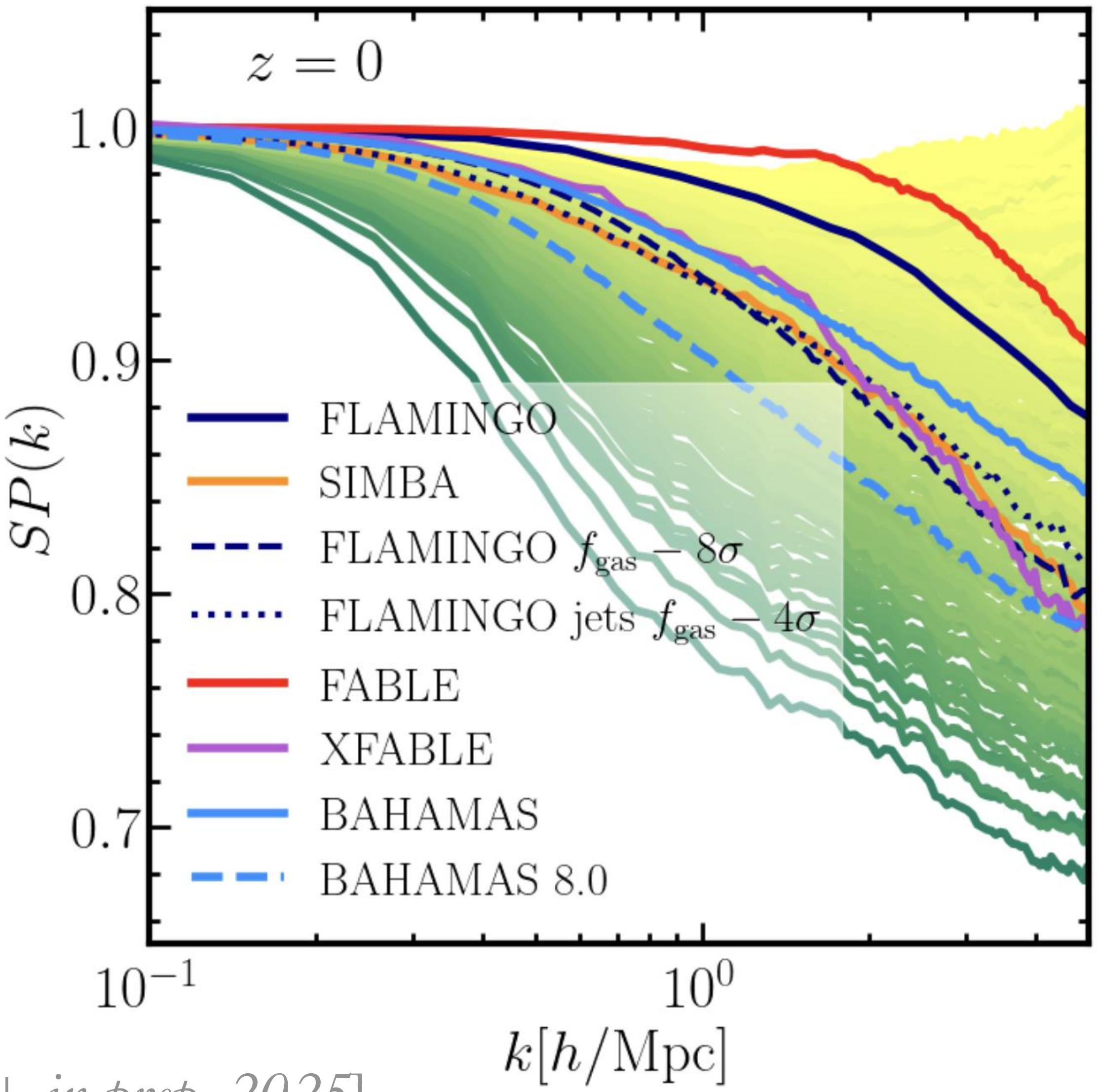
Radio mode acting in a larger population of black holes, with jets thermalizing at larger cluster-centric distances

[Bigwood+2025]

A simulation study of the kSZ effect

1. Do any of the hydrosimulations predict kSZ signals in agreement with observations?

2. How do we establish the kSZ effect as a benchmark for AGN feedback models in hydrodynamical simulations?



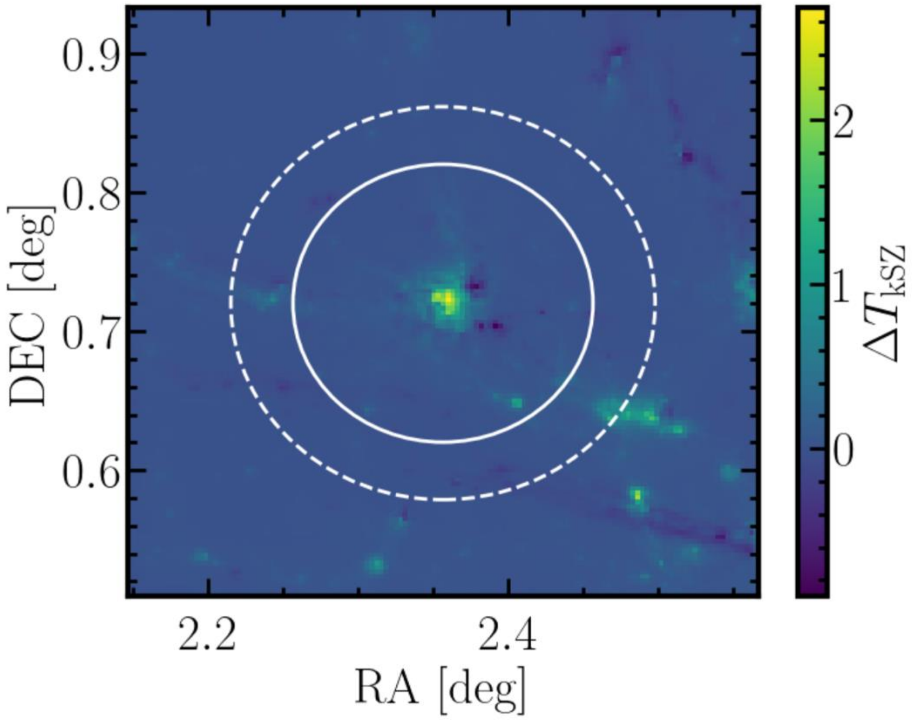
Masa Yamamoto

[Bigwood, Yamamoto, Siegel, Amon, McCarthy+ in prep. 2025]

Measuring stacked kSZ profiles in simulations

1. In the simulations we measure:

- *Gas mass*
- *Gas line of sight velocity*
- *Halo line of sight velocity*

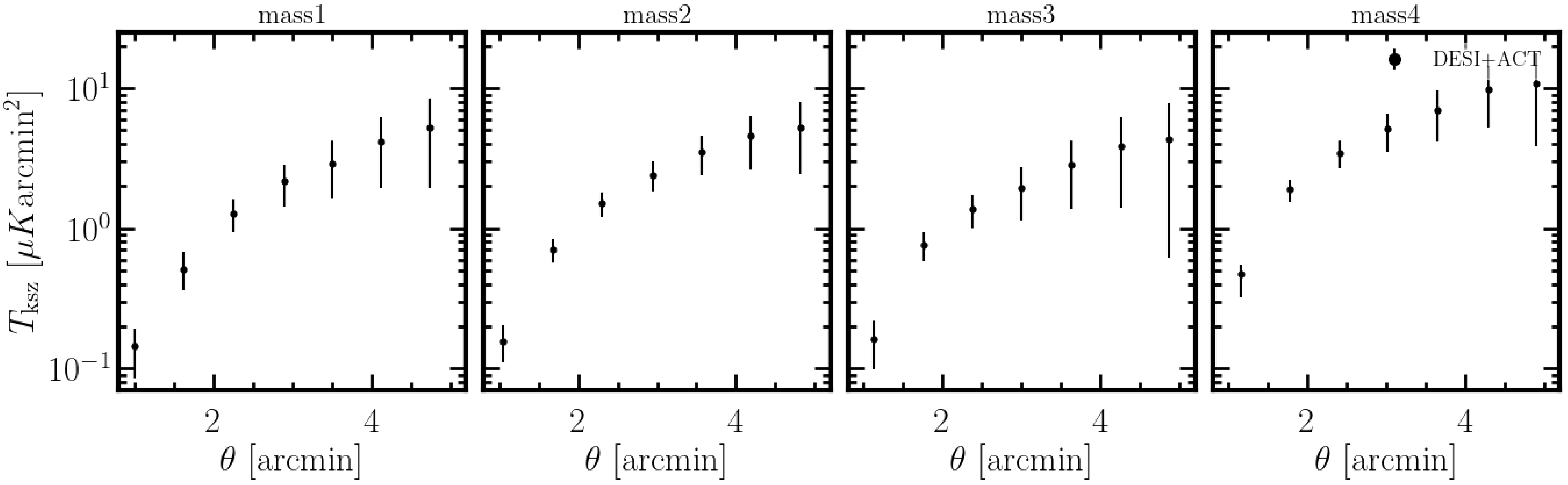


2. We follow the methodology used in the observations, *i.e. CAP filtering, modelling the beam.*

3. We measure a velocity-weighted stack over many galaxies: selecting the sample is key!

The stellar mass dependence of the kSZ: comparing to DESI x ACT

How do we select the right galaxy sample in the simulations?

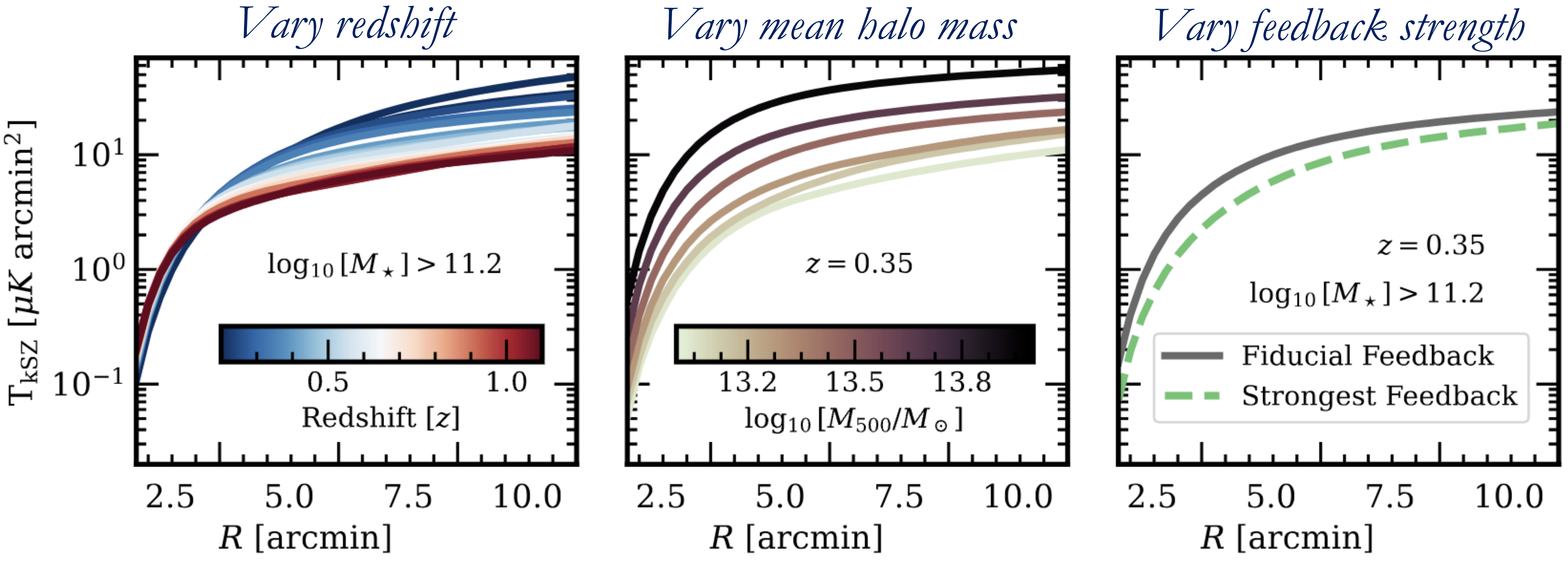


[*Ried Guachalla+2025*]

CHALLENGE

The stellar mass dependence of the kSZ: comparing to DESI x ACT

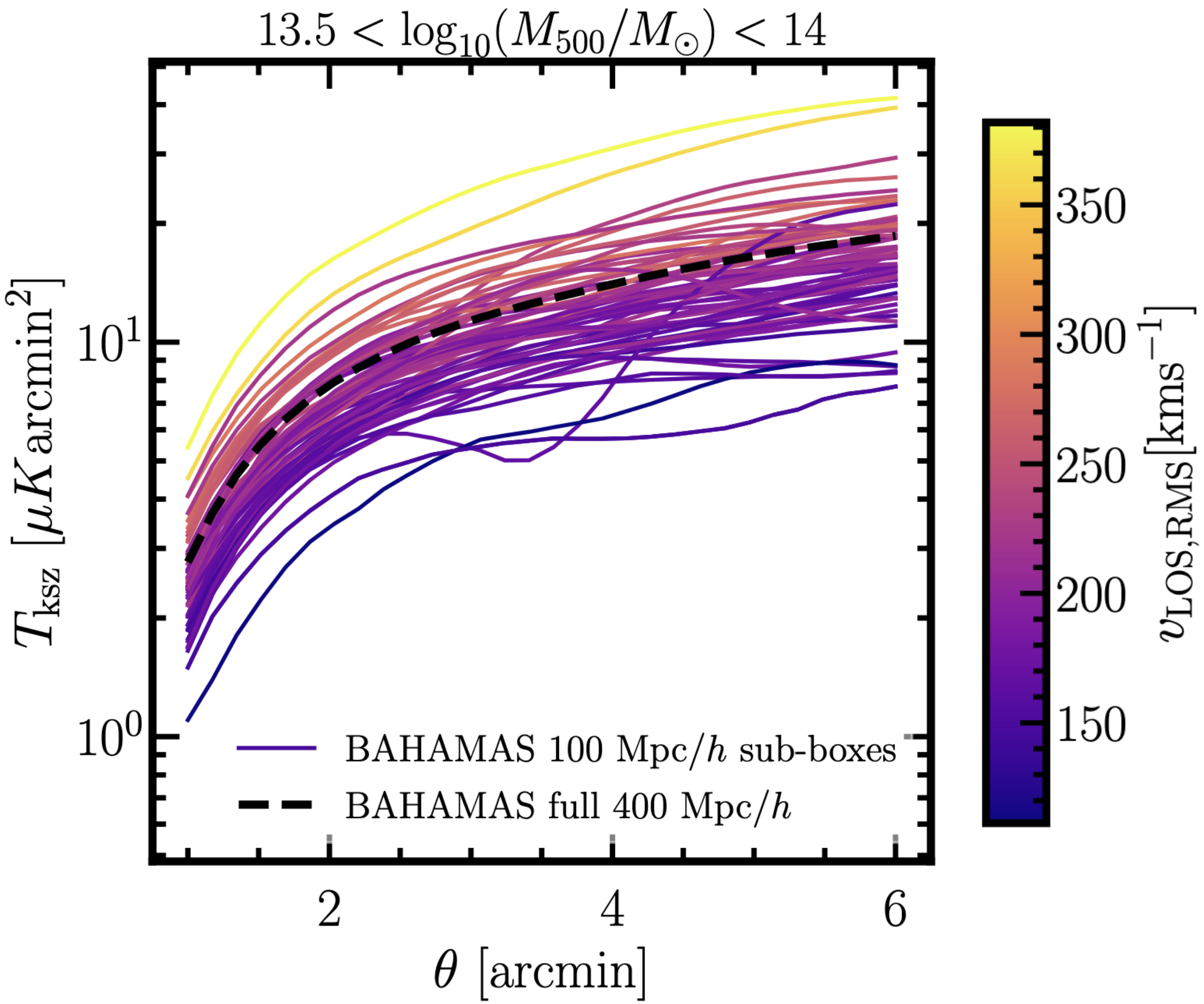
Selecting the wrong mean halo mass & redshift of your sample can appear as differences in feedback strength…



[*Siegel+ in prep.*]

Jared Siegel

Managing cosmic variance



$$\hat{T}_{\rm kSZ}(\theta_{\rm d}) = -\frac{1}{r_v}\frac{v_{\rm rms}^{\rm rec}}{c}\frac{\sum_i \mathcal{T}_i(\theta_{\rm d})(v_{{\rm rec},i}/c)/\sigma_i^2}{\sum_i (v_{{\rm rec},i}/c)^2/\sigma_i^2}$$

Poor statistics in 100Mpc/h boxes means scatter in $v_{\rm LOS,RMS}$ significantly impacts the kSZ amplitude

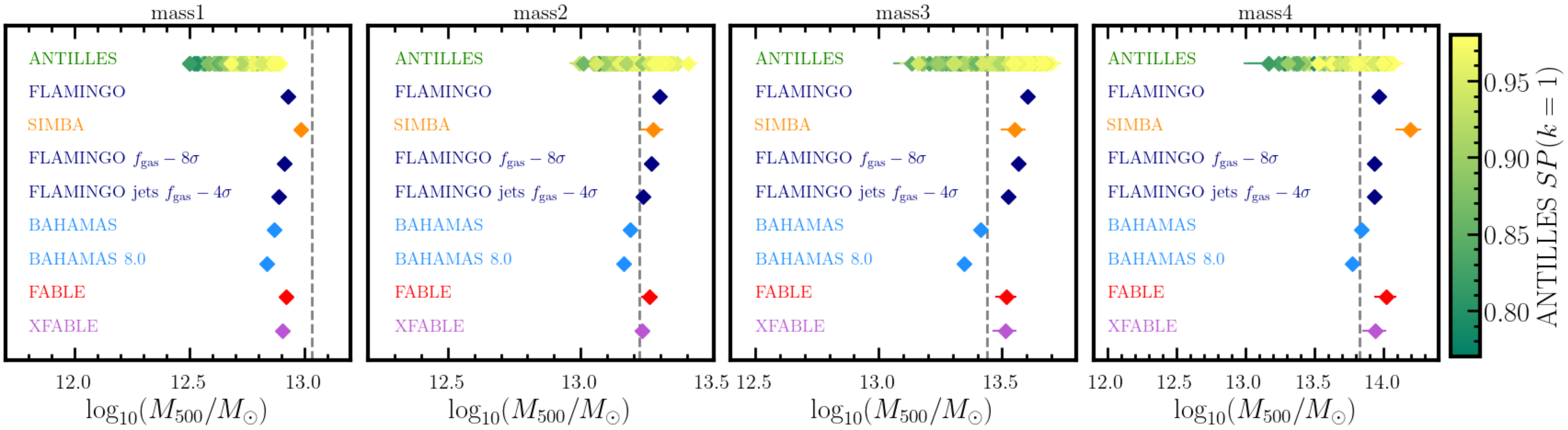
Bigwood, Yamamoto, Siegel, Amon, McCarthy+ in prep. 2025]

CHALLENGE

The stellar mass dependence of the kSZ signal: *abundance matching*

We don't trust the stellar masses reported in simulations, so we could abundance match to an observed GSMF

But this leaves us with huge differences in the mean halo mass of our stacked objects between simulations

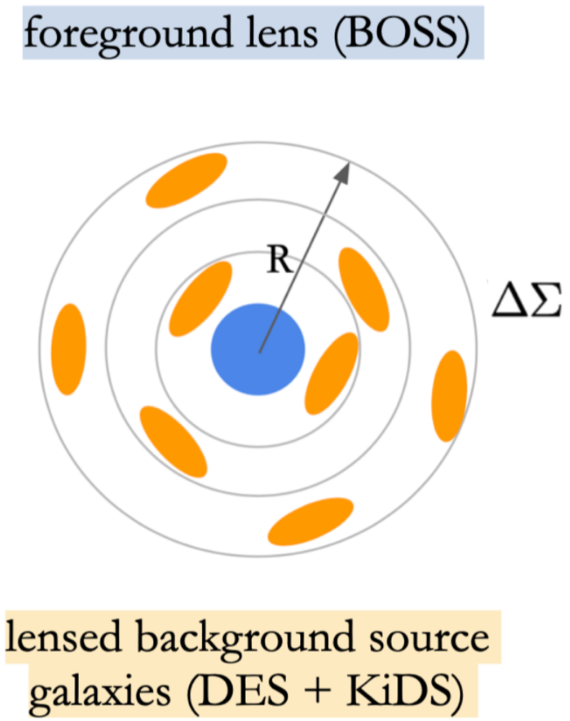


Bigwood, Yamamoto, Siegel, Amon, McCarthy+ in prep. 2025]

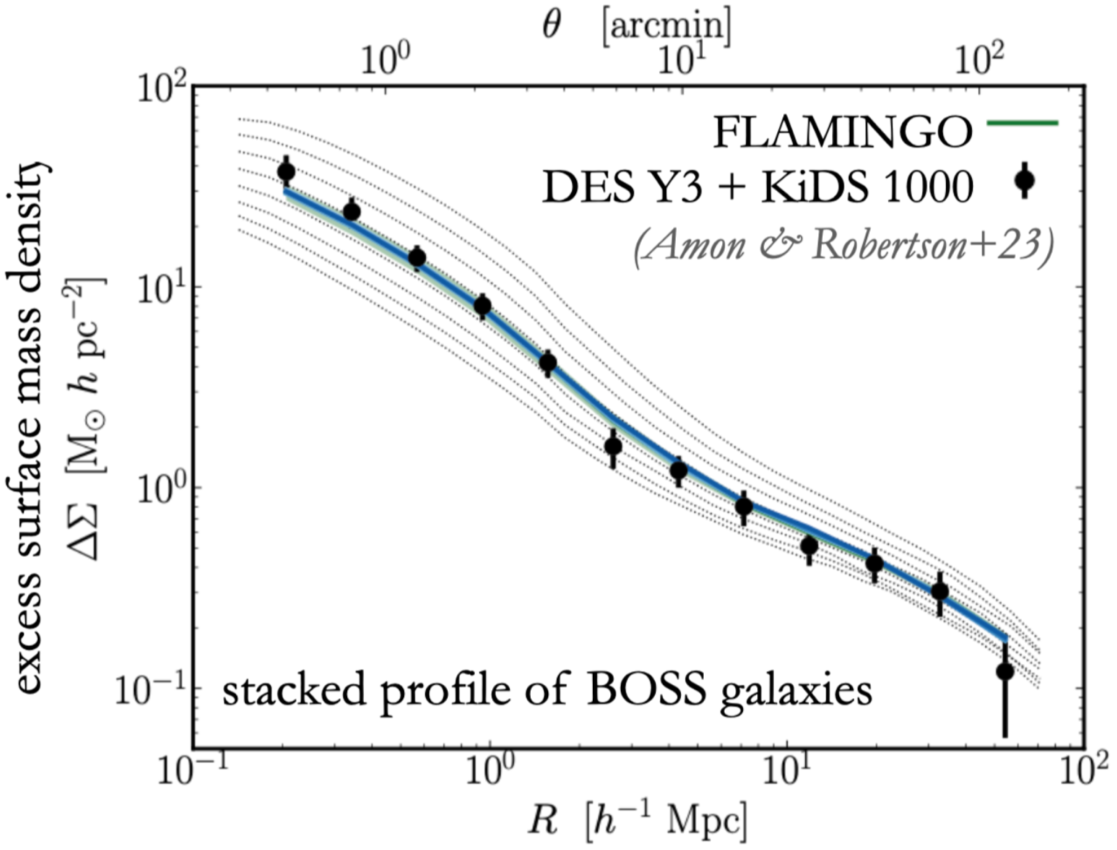
CHALLENGE

Galaxy-galaxy lensing can help…

Galaxy-galaxy lensing can tell us the mean halo mass!

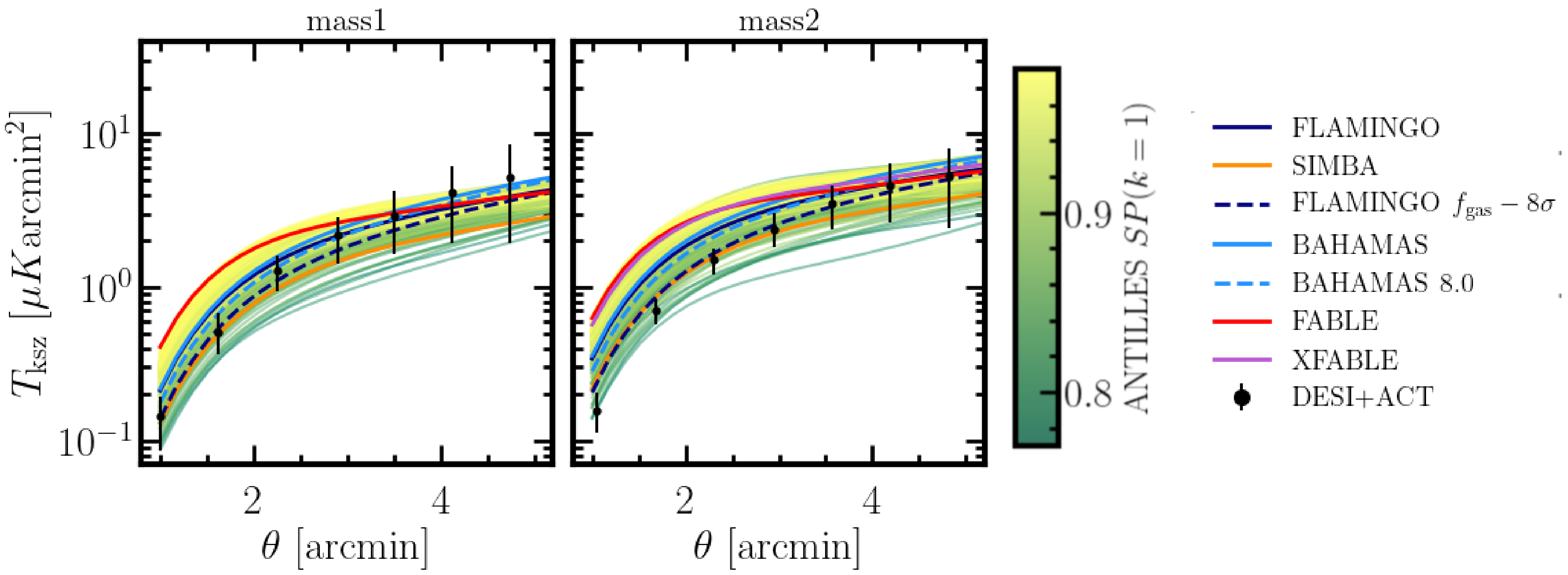


Jared Siegel



[McCarthy, Amon+24, Siegel+ in prep.]

The stellar mass dependence of the kSZ signal: *galaxy-galaxy lensing*



Bigwood, Yamamoto, Siegel, Amon, McCarthy+ in prep. 2025]

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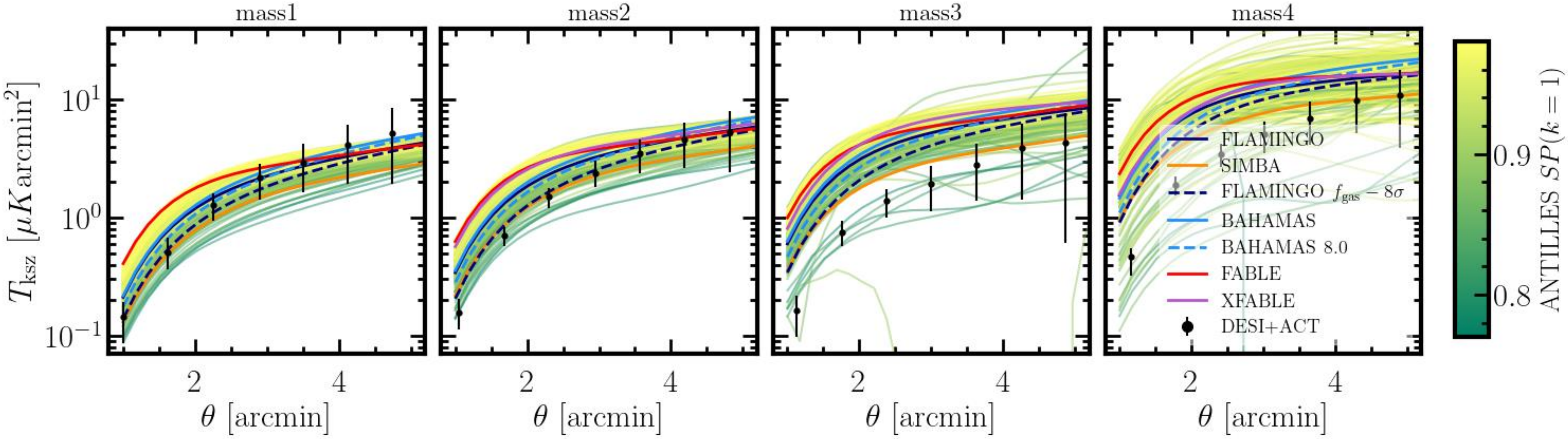
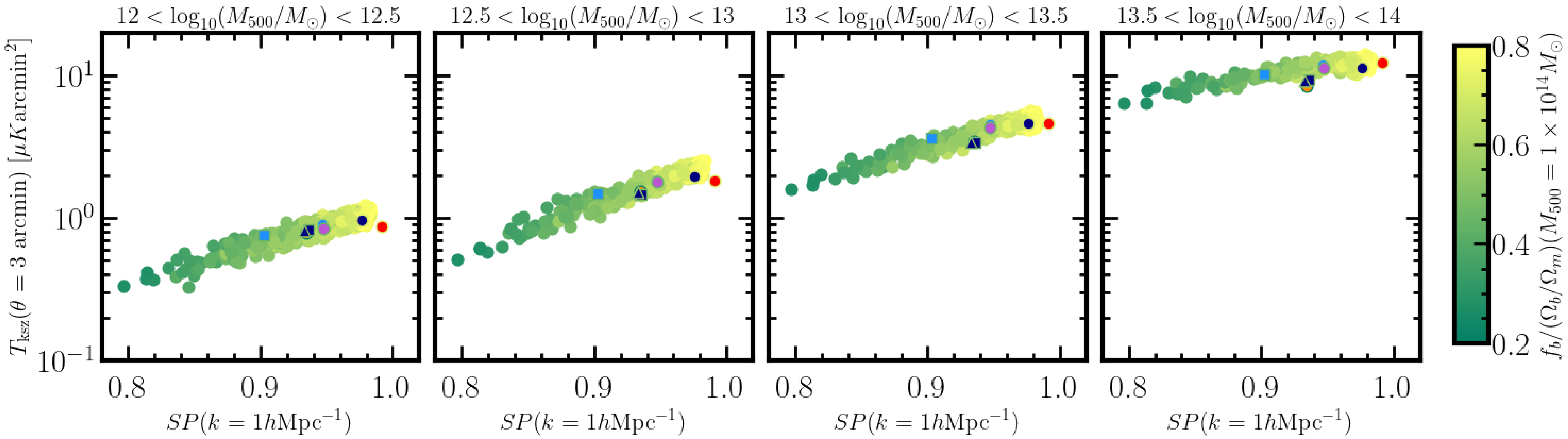


No single hydrosimulations can match the stellar mass dependence of the kSZ signal seen in the data

Bigwood, Yamamoto, Siegel, Amon, McCarthy+ in prep. 2025]

Looking ahead: *a simulated-based emulator for kSZ-SP(k)*

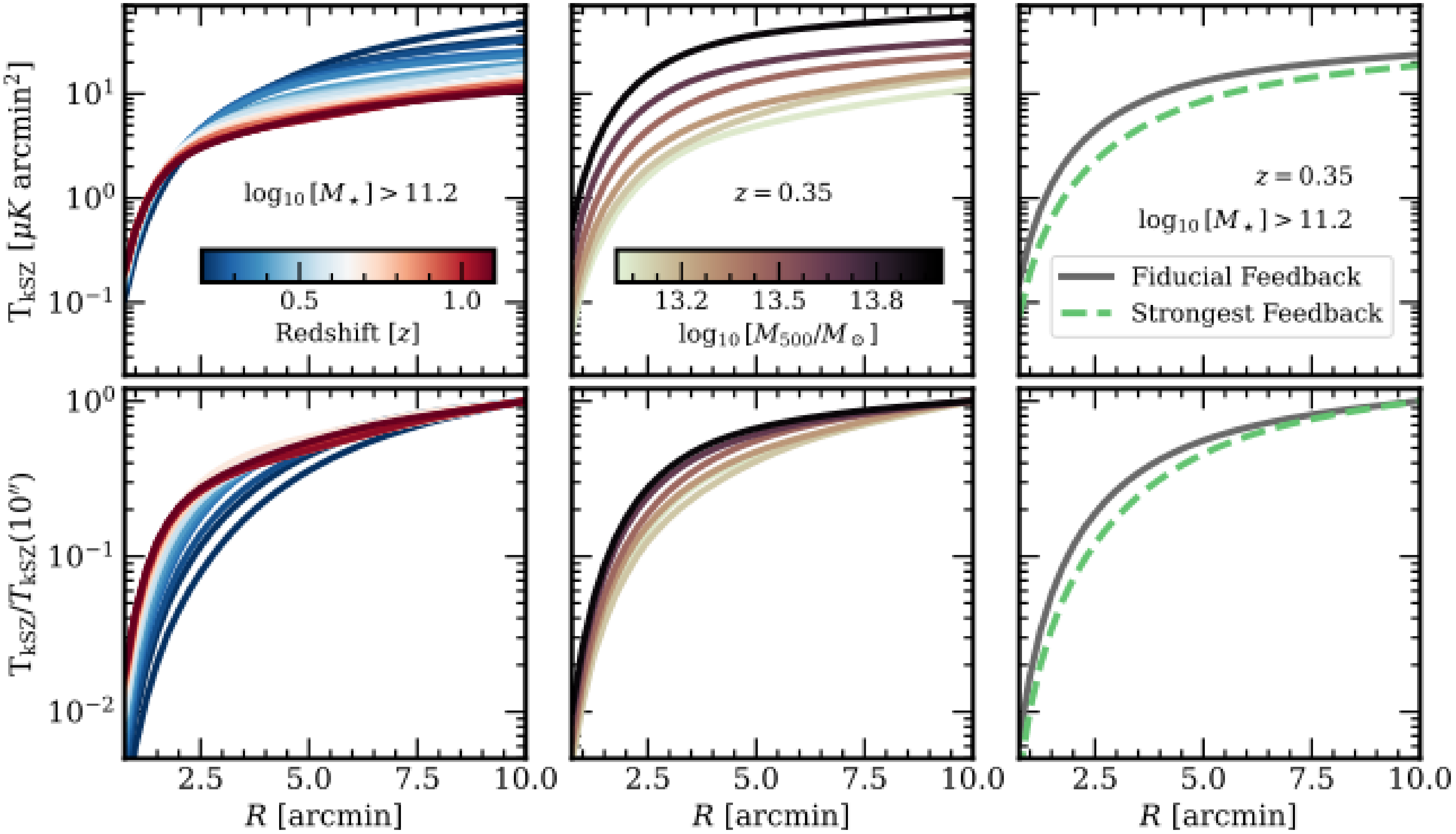


Summary

Lensing+kSZ prefers a more extreme feedback scenario than many hydrodynamical simulations (*Bigwood, Amon+2024*) & degeneracies exist in subgrid AGN feedback modelling (*Bigwood+2025*)

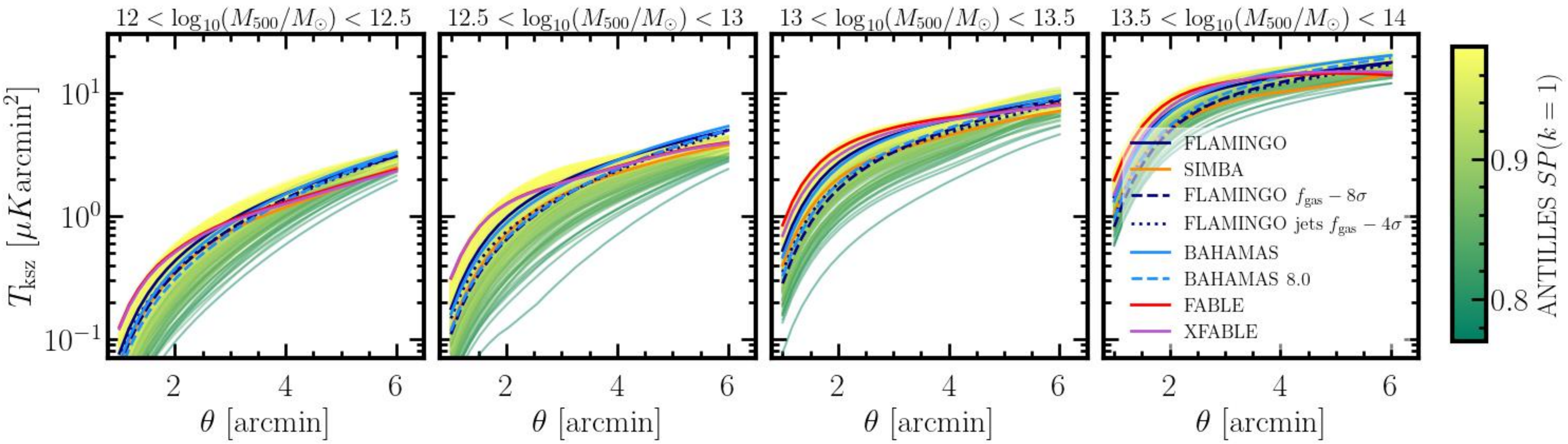
We have established a roadmap for using kSZ as a benchmark of feedback models

No simulation can reproduce the mass dependence of the DESI+ACT measurements; scrutinizing both the simulations and the data is required (*Bigwood, Yamamoto, Siegel, Amon, McCarthy+ in prep. 2025*)



$T_{\rm kSZ}$ [μK arcmin^2]
$\log_{10}[M_\star] > 11.2$
Redshift [z]
$z = 0.35$
$\log_{10}[M_{500}/M_\odot]$
Fiducial Feedback
Strongest Feedback
$T_{\rm kSZ}/T_{\rm kSZ}(10'')$
R [arcmin]

The halo mass dependence of the kSZ



Bigwood, Yamamoto, Siegel, Amon, McCarthy+ in prep. 2025]

Measuring kSZ profiles in simulations

Gas velocity *Gas mass*

1. $$b = \frac{v_r \sigma_T m_g}{\mu_e m_p \Omega_{\rm pixel} d_A^2 c}$$

Measuring kSZ profiles in simulations

Gas velocity　　*Gas mass*

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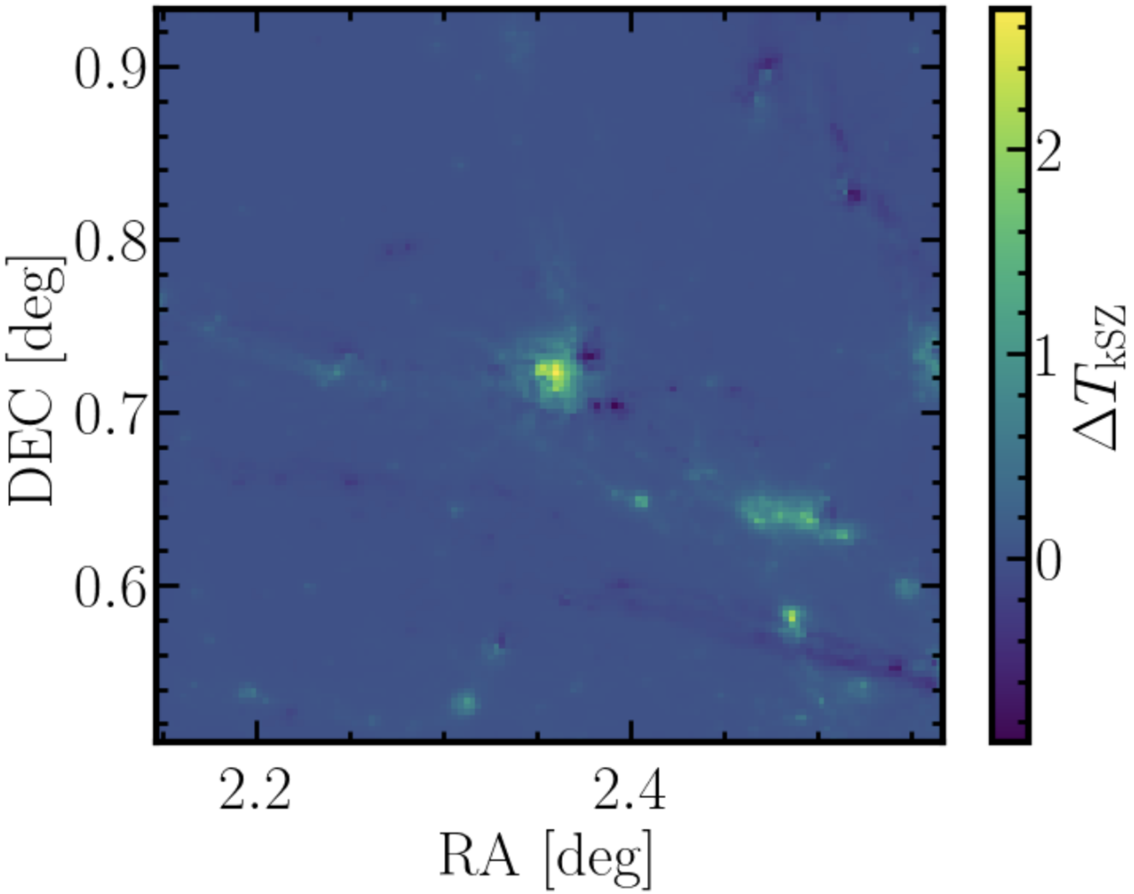

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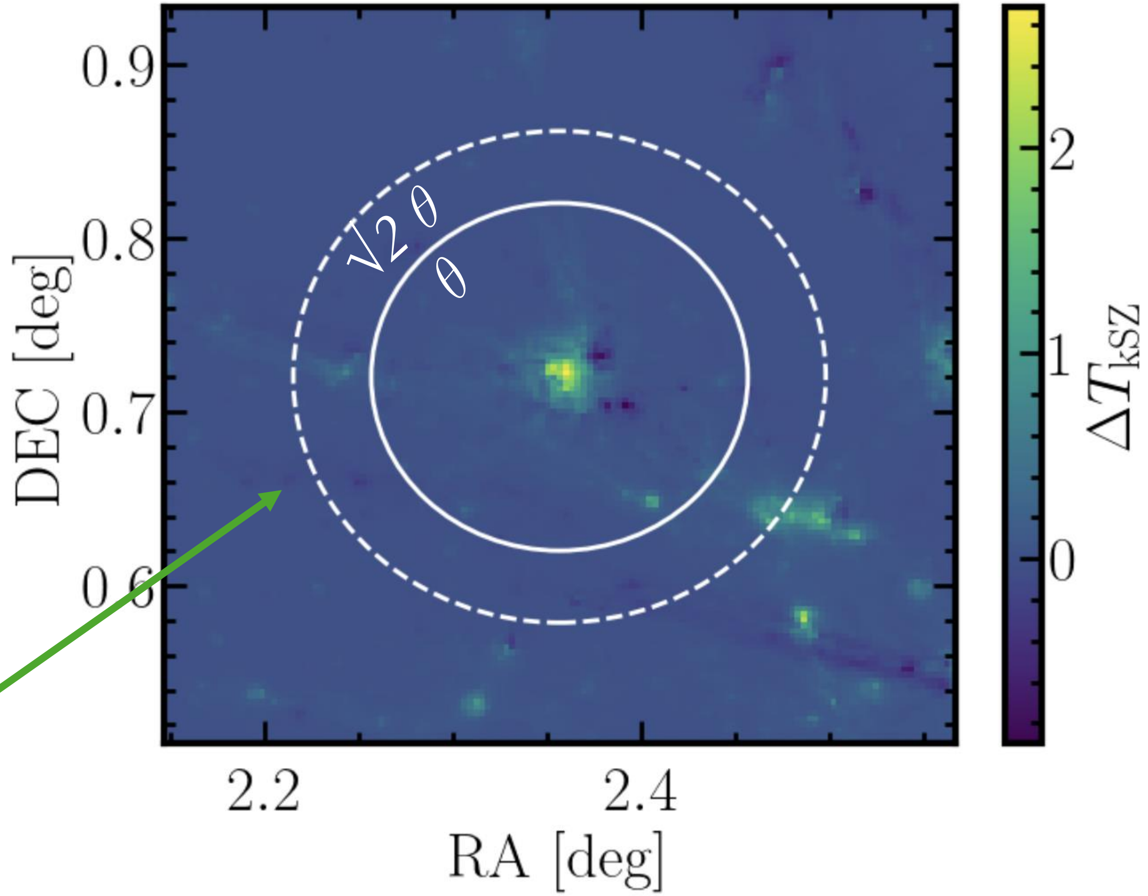
3. Measure signal within CAP filter centered on galaxies



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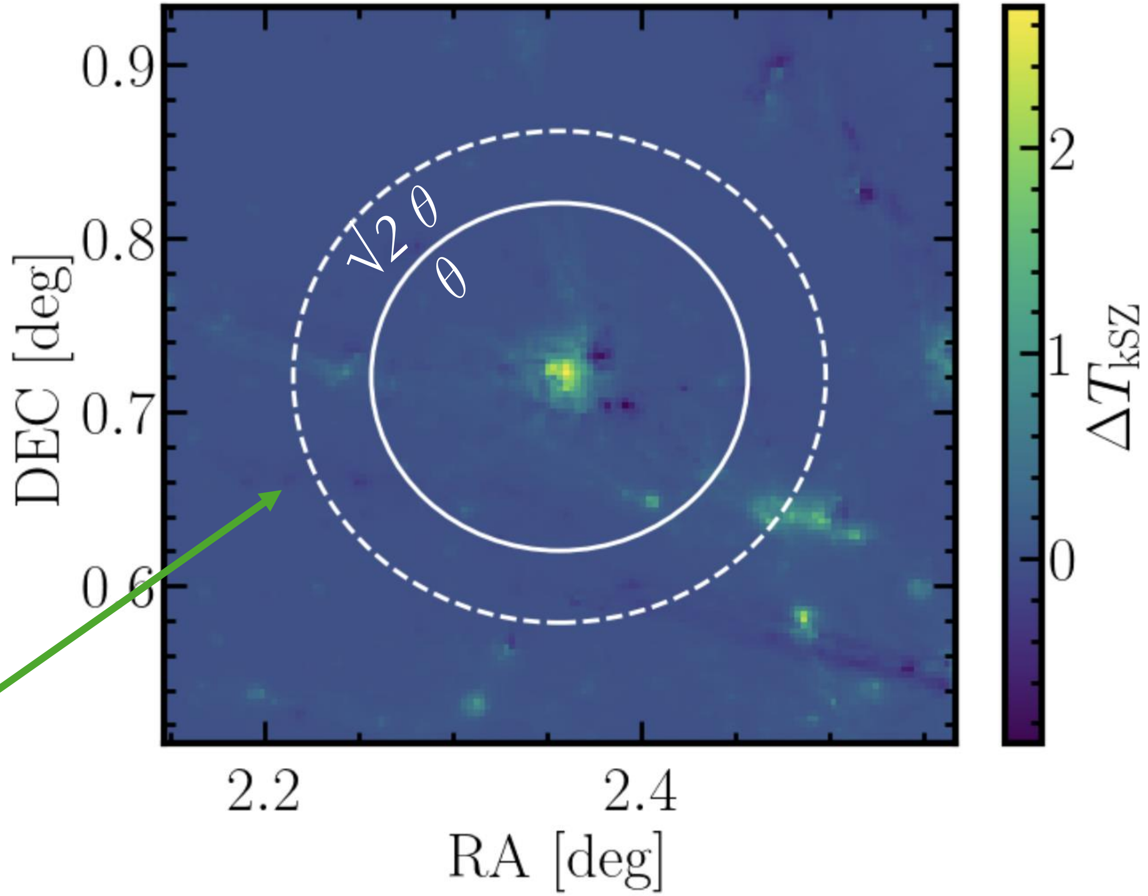
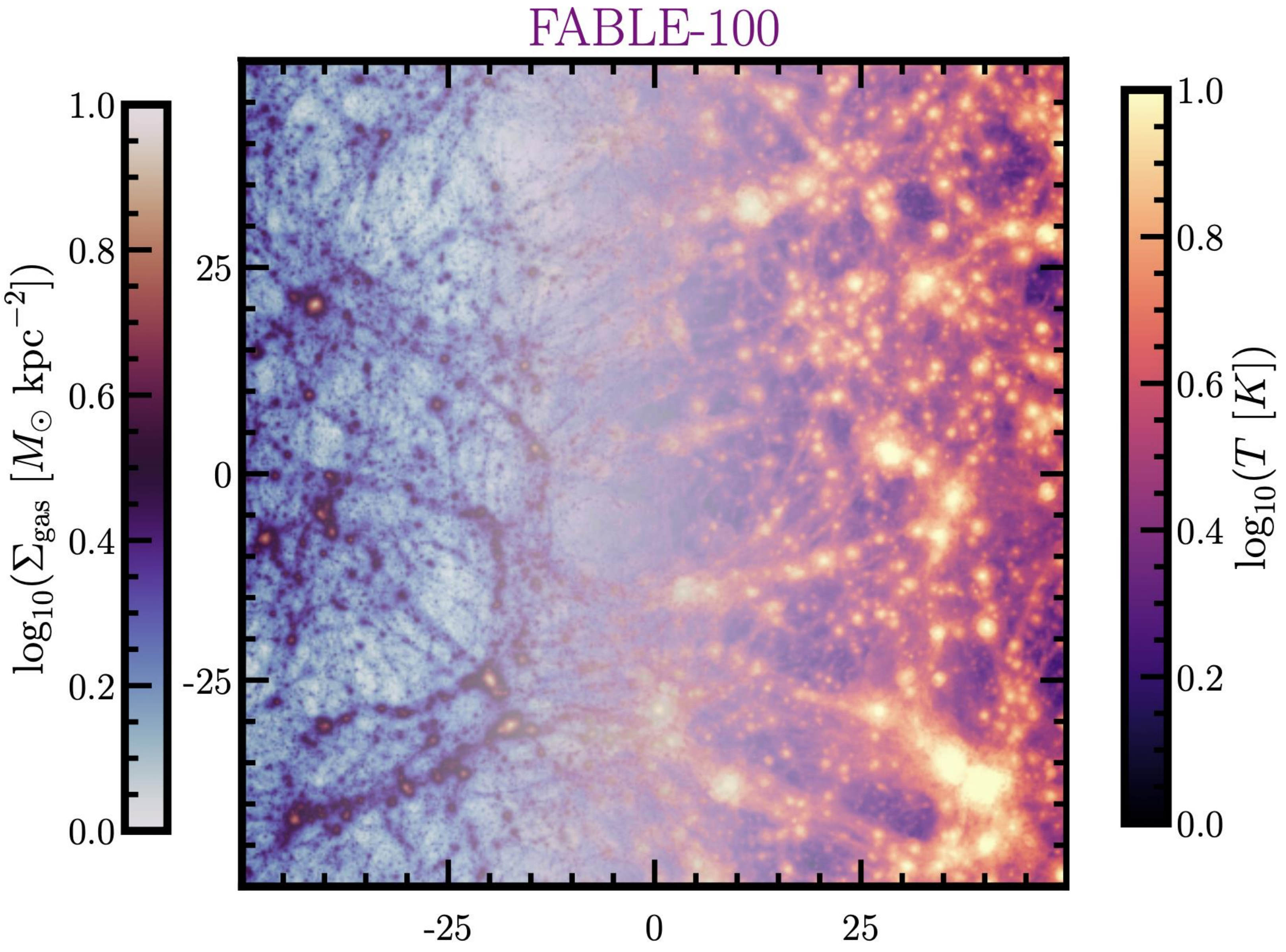


4. $$\hat{T}_{\rm kSZ}(\theta_{\rm d}) = -\frac{1}{r_v}\frac{v_{\rm rms}^{\rm rec}}{c}\frac{\sum_i \mathcal{T}_i(\theta_{\rm d})(v_{{\rm rec},i}/c)/\sigma_i^2}{\sum_i (v_{{\rm rec},i}/c)^2/\sigma_i^2}$$

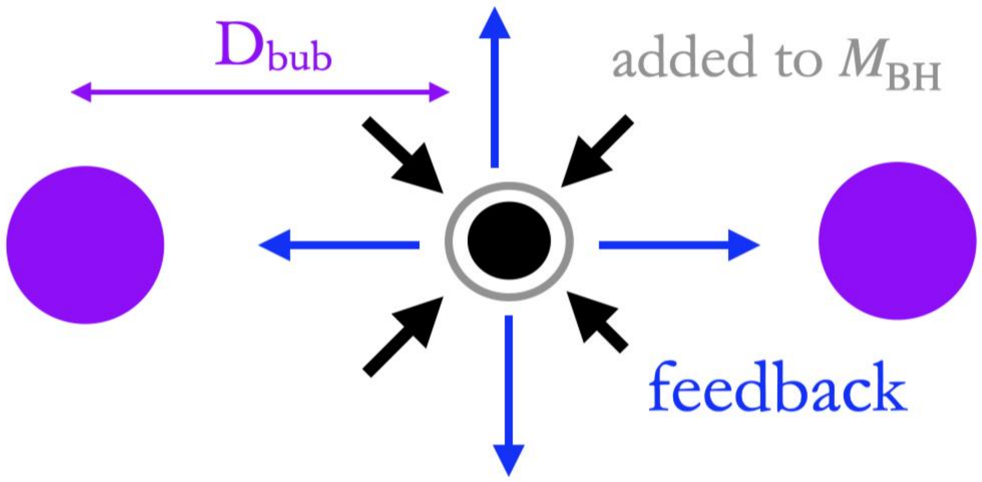
Velocity weighted galaxy stack

The FABLE simulation suite



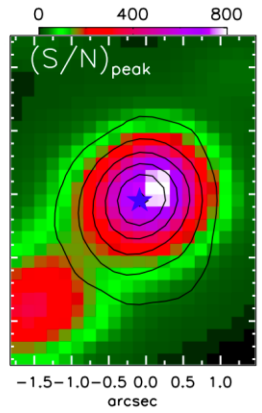
[Bigwood+2025]

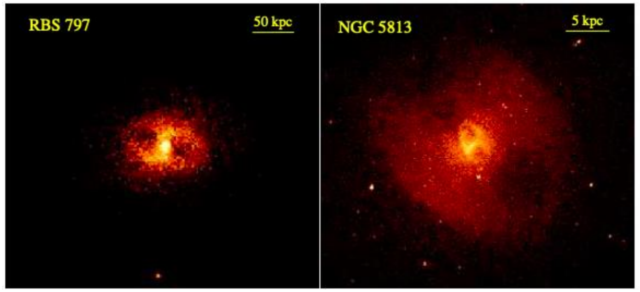
The FABLE simulation suite



Efficient BH accretion

Inefficient BH accretion

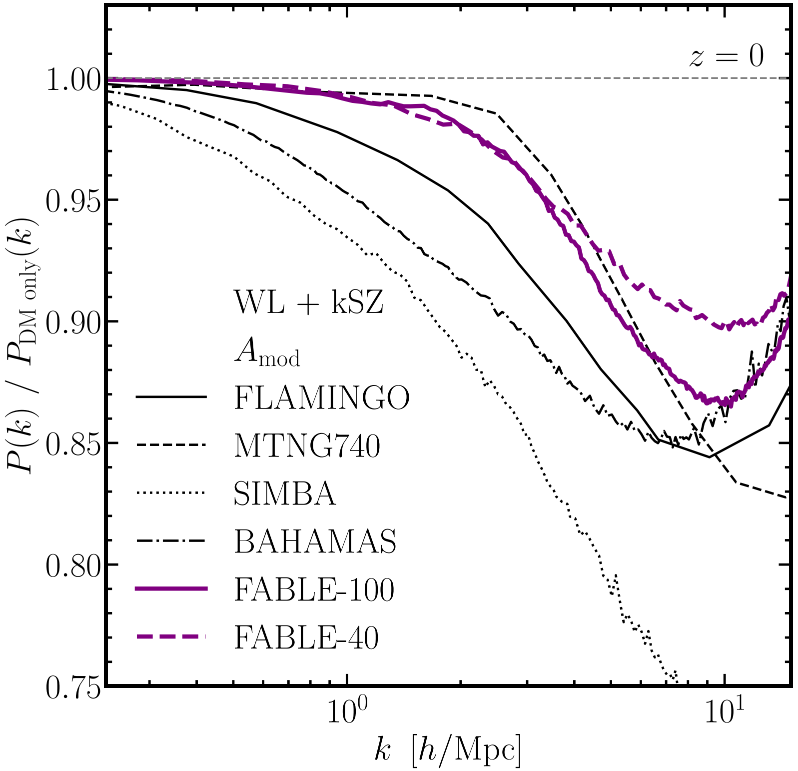




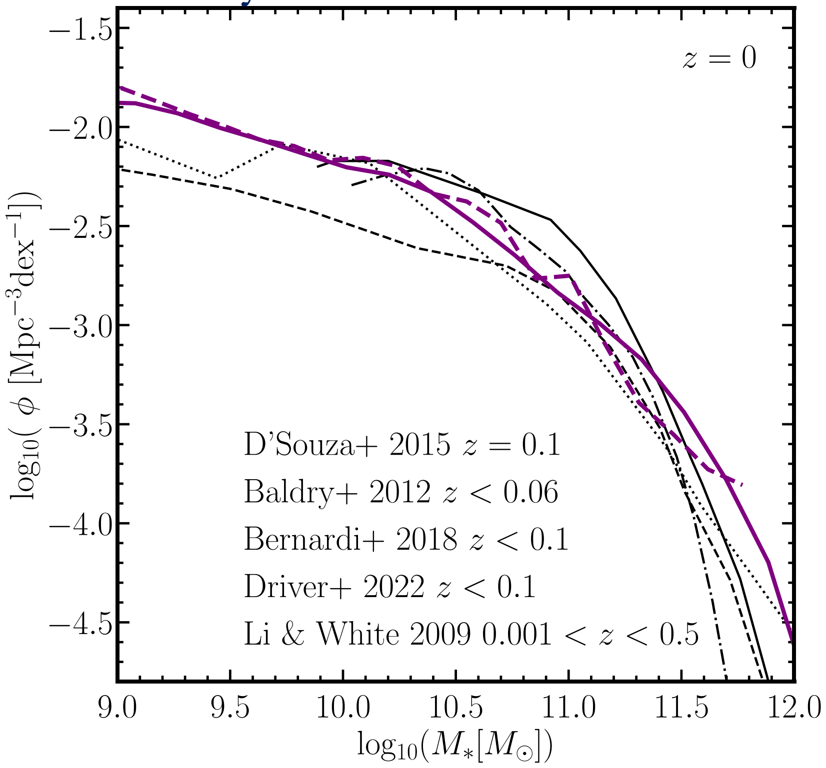
'*Quasar mode*':
a fraction of the available feedback energy is coupled thermally to the surrounding gas

'*Radio mode*':
*H*ot bubbles are inflated at a distance D_{bub} from the black hole, as if injected by an AGN jet

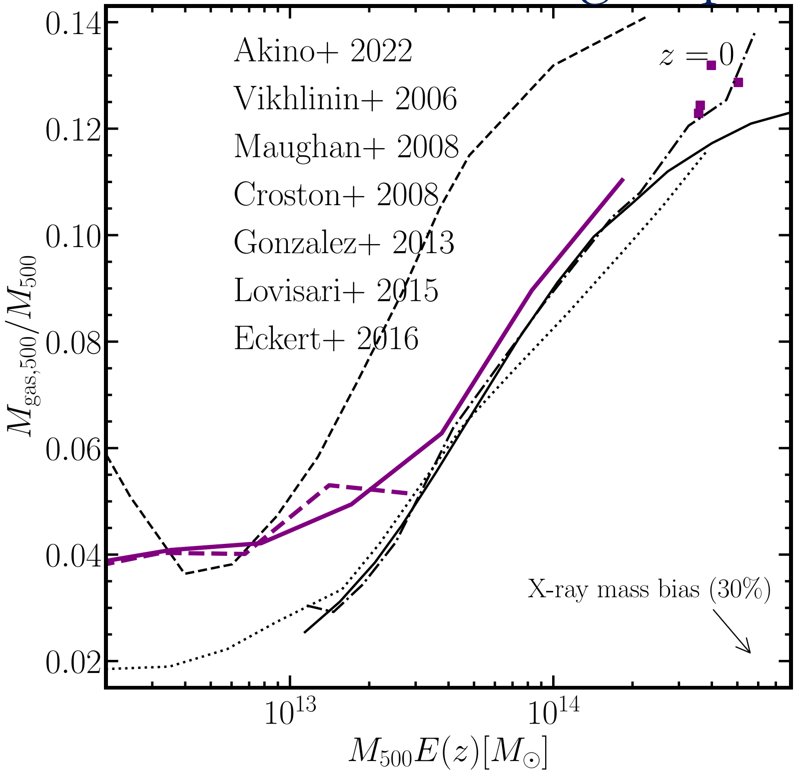
Baryonic feedback: how extreme is too extreme?



Galaxy stellar mass function

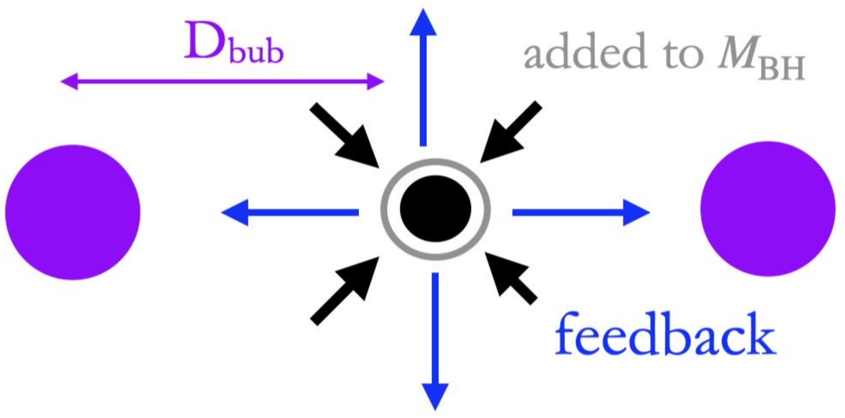


Gas fractions in groups



[Bigwood+2025]

FABLE vs XFABLE



FABLE

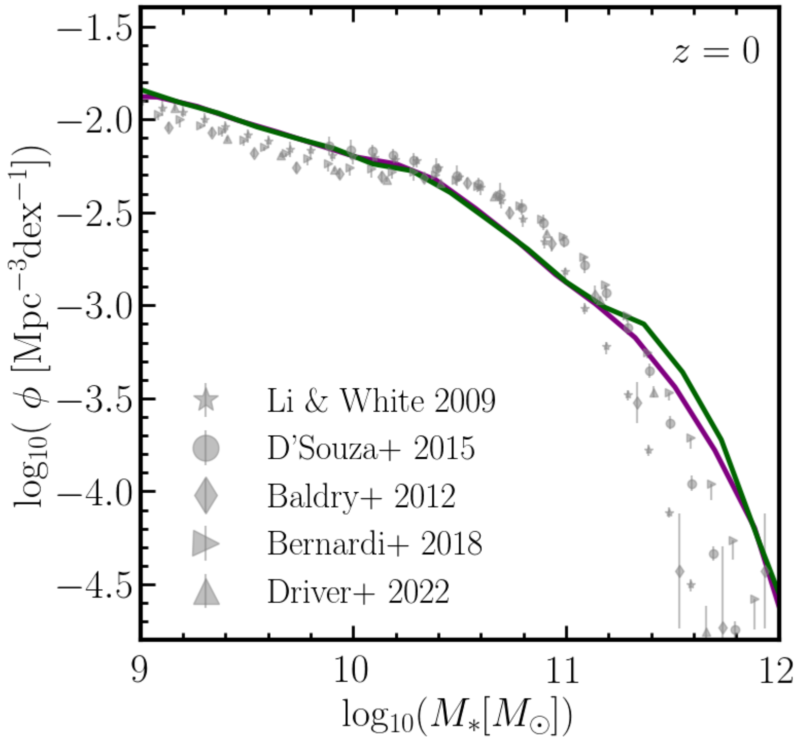
1. $D_{bub} \sim 30$ kpc
2. Lower accretion rate limit on entering the radio mode
3. No BH mass limit on radio mode
4. No pressure limit on AGN bubbles

XFABLE

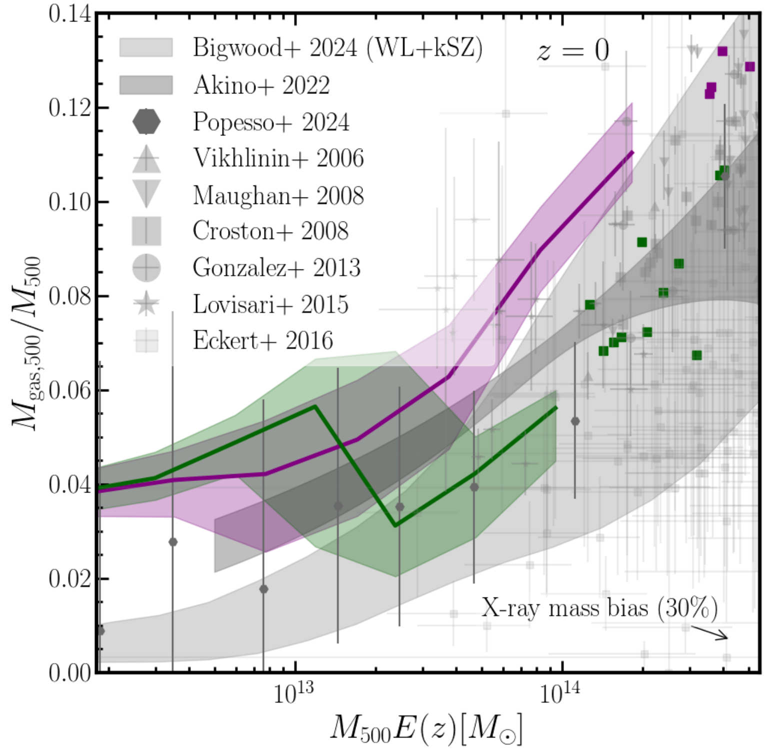
1. $D_{bub} = 100$ kpc
2. BHs with higher accretion rates enter radio mode
3. *But* only heaviest $M_{BH} > 10^9\, M_\odot$ enter radio mode
4. Pressure limit on AGN bubbles: $E_{bub}/E_{ICM} < 20$

FABLE vs XFABLE: other cluster properties

Galaxy stellar mass function



Group hot gas mass fractions



FABLE

Fiducial AGN feedback model

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Radio mode acting in a larger population of black holes, with jets thermalizing at larger cluster-centric distances

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