



**Emmanuel Schaan** Chamberlain fellow

# **Halo thermodynamics from kSZ with rec. vel.: Progress update**

with *S Amodeo, A Amon, F Ardila, H Aung, N Battaglia, J deRose, S Ferraro, C Hill, S Huang, J Lange, A Leauthaud, M Madhavacheril, D Nagai, A Roman, A Schneider, K Smith*  
& ACT

# Why care about the gas?



Galaxies surrounded by vast gaseous halos

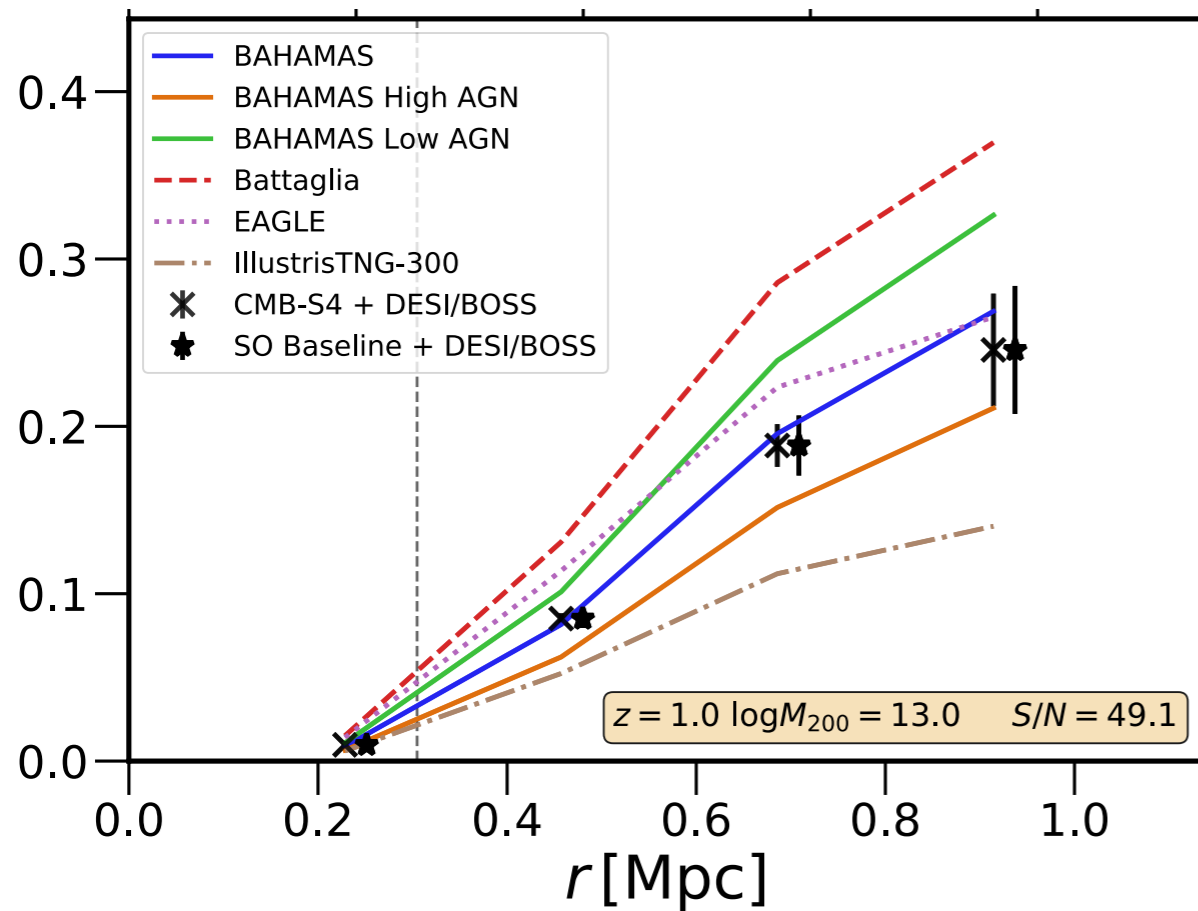
Gas is more extended than dark matter,  
due to feedback in galaxy formation

→ Key astrophysical unknown!

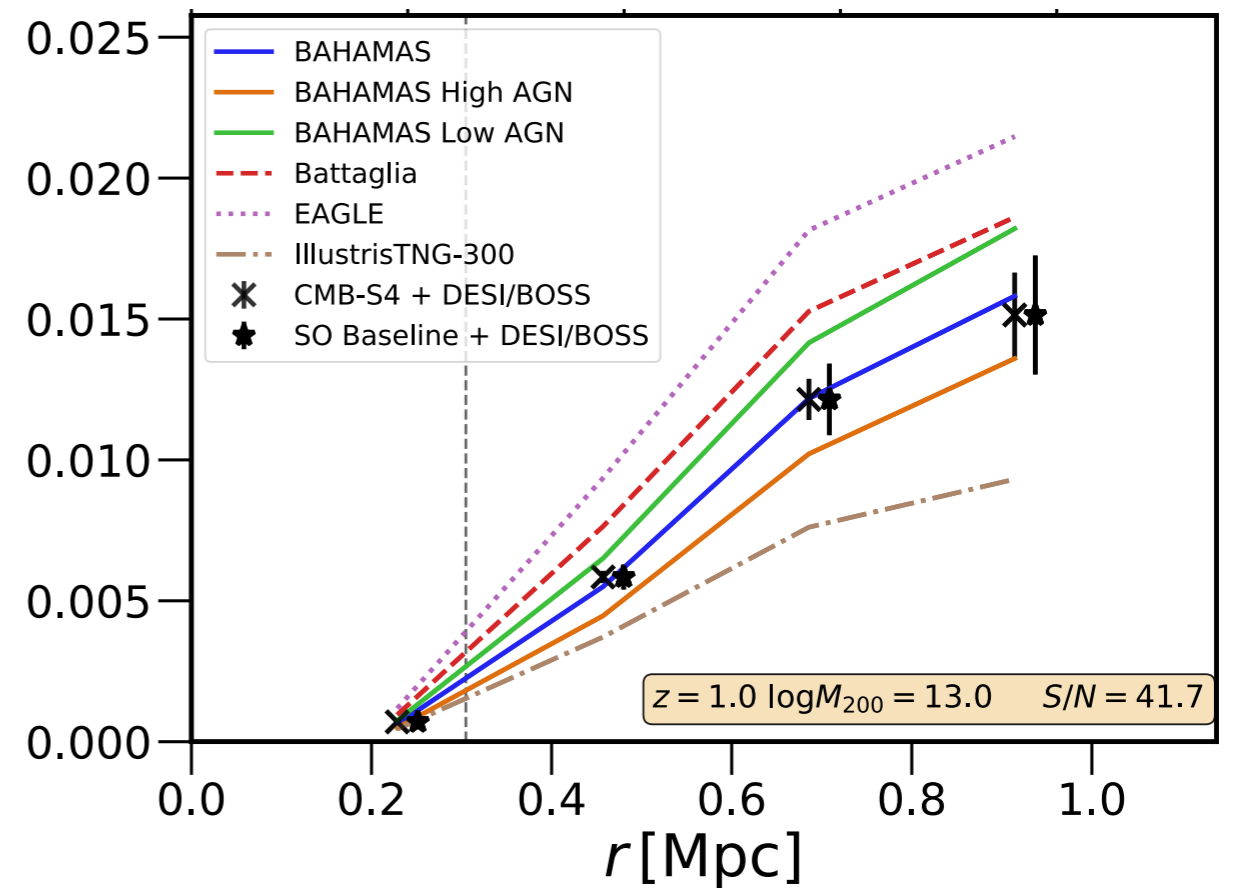
Main limiting theoretical systematic for galaxy lensing

# High S/N with CMB S4 & DESI

## kSZ cumulative profile



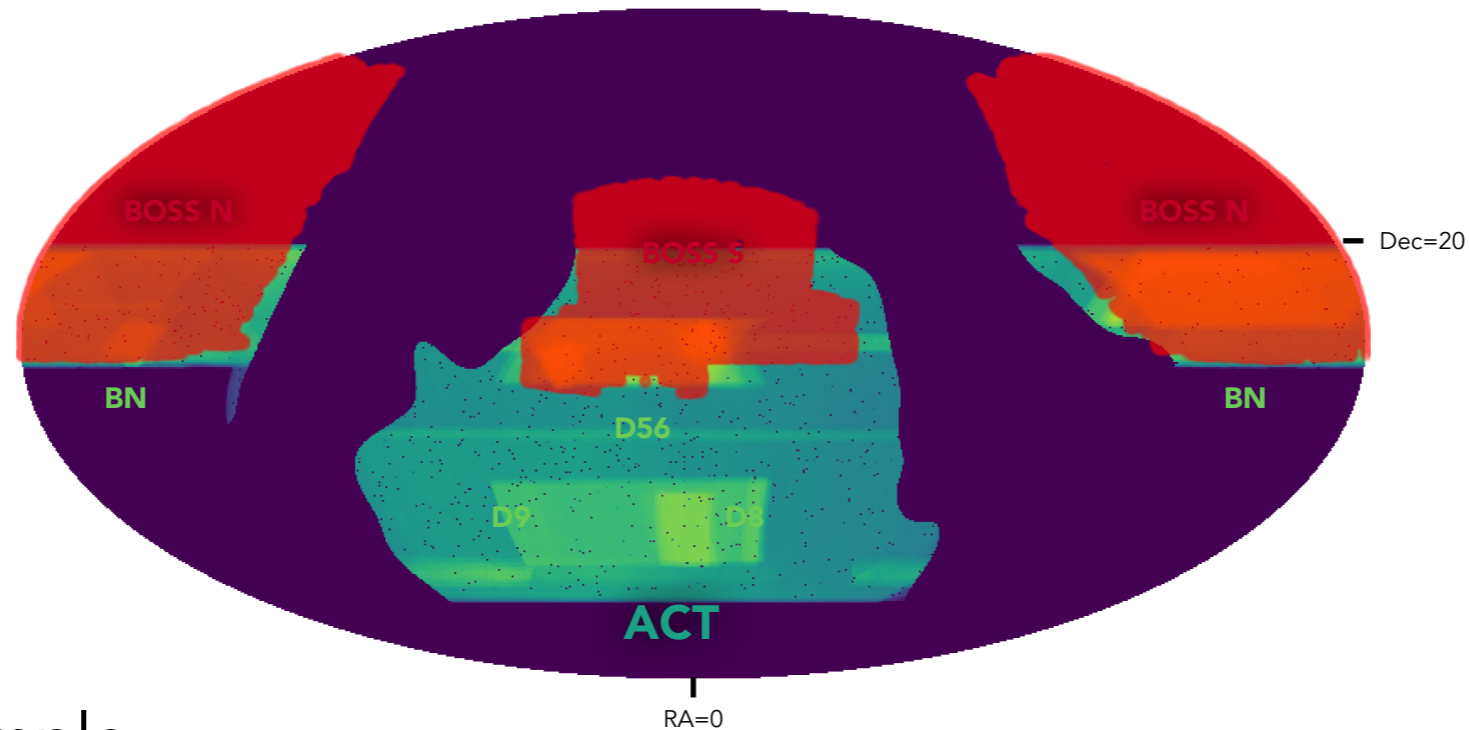
## tSZ cumulative profile



*CMB S4 DSR,  
Battaglia+17*

and lensing profiles for the same halos!

# Recent measurement: BOSS & ACT+Planck



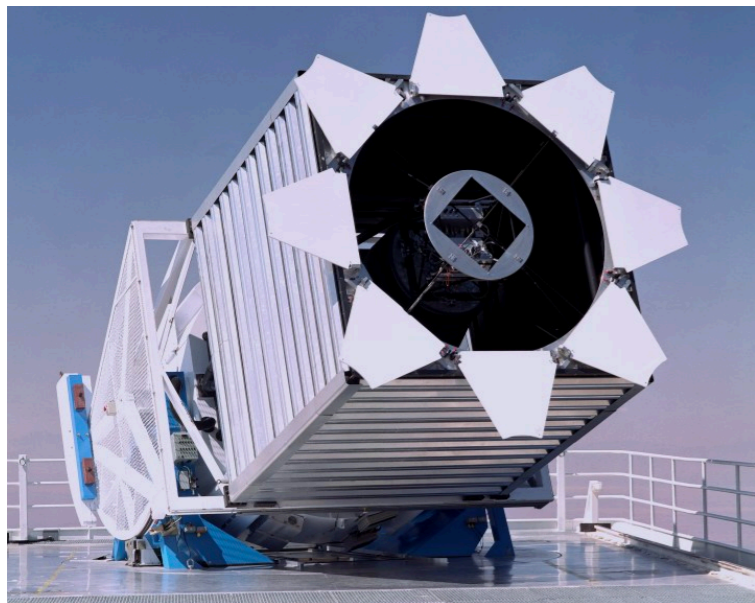
## BOSS CMASS

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

# Measurement: CMASS

ACT + Planck (microwave)

Hubble (optical)

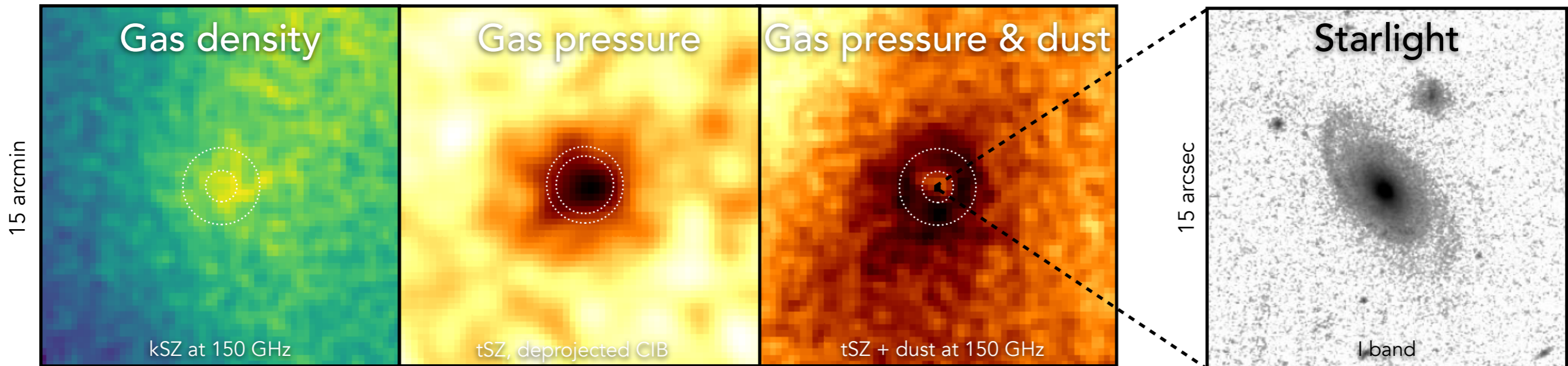
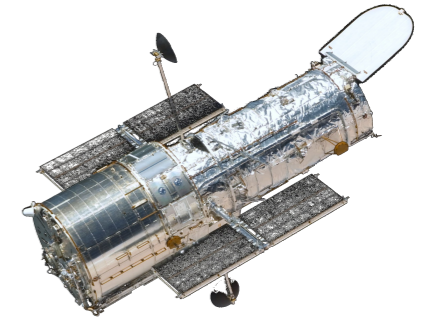
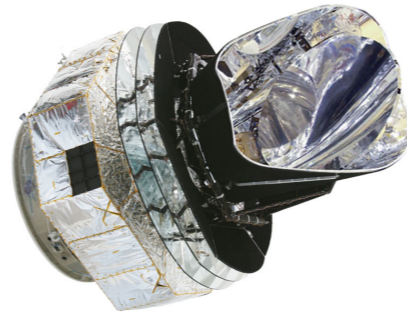


Figure: Emmanuel Schaan. ACT+Planck microwave images: Schaan et al 2020. HST ACS I band image: Masters et al 2011. ACT photo: John Ward. Planck photo: ESA/AOES Medialab. HST photo: NASA.

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

# Measurement: LOWZ

ACT + Planck (microwave)

Hubble (optical)

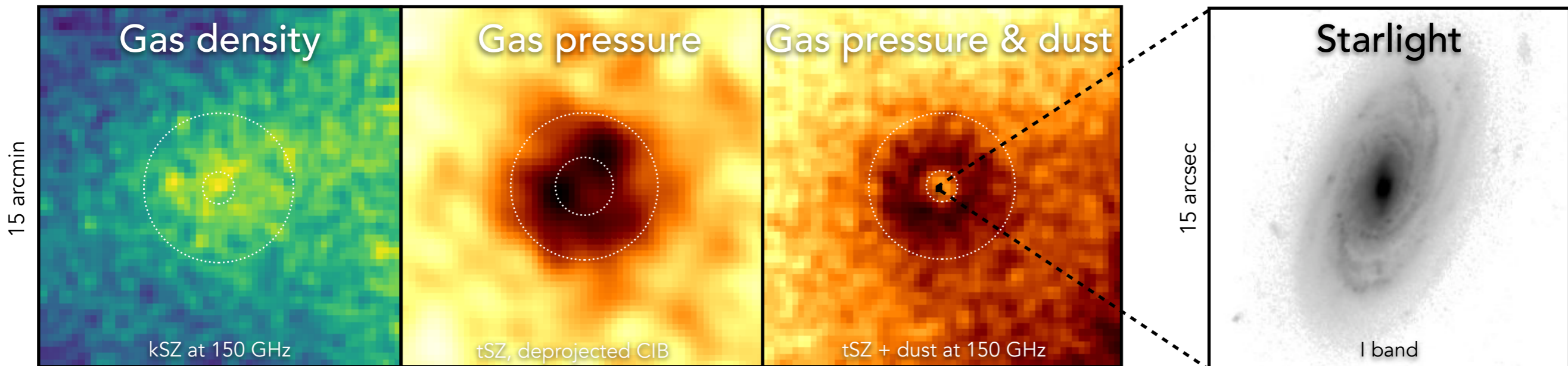
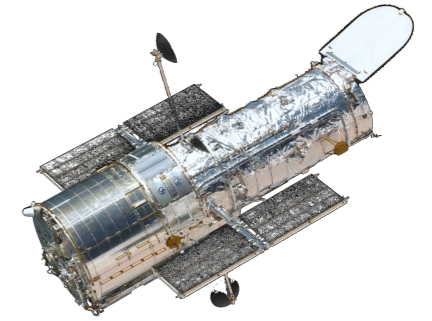
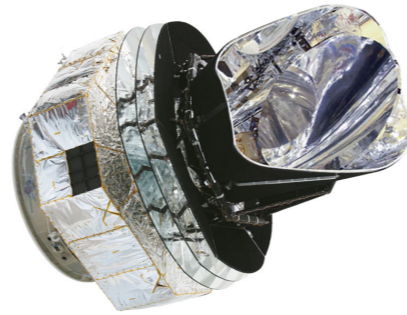


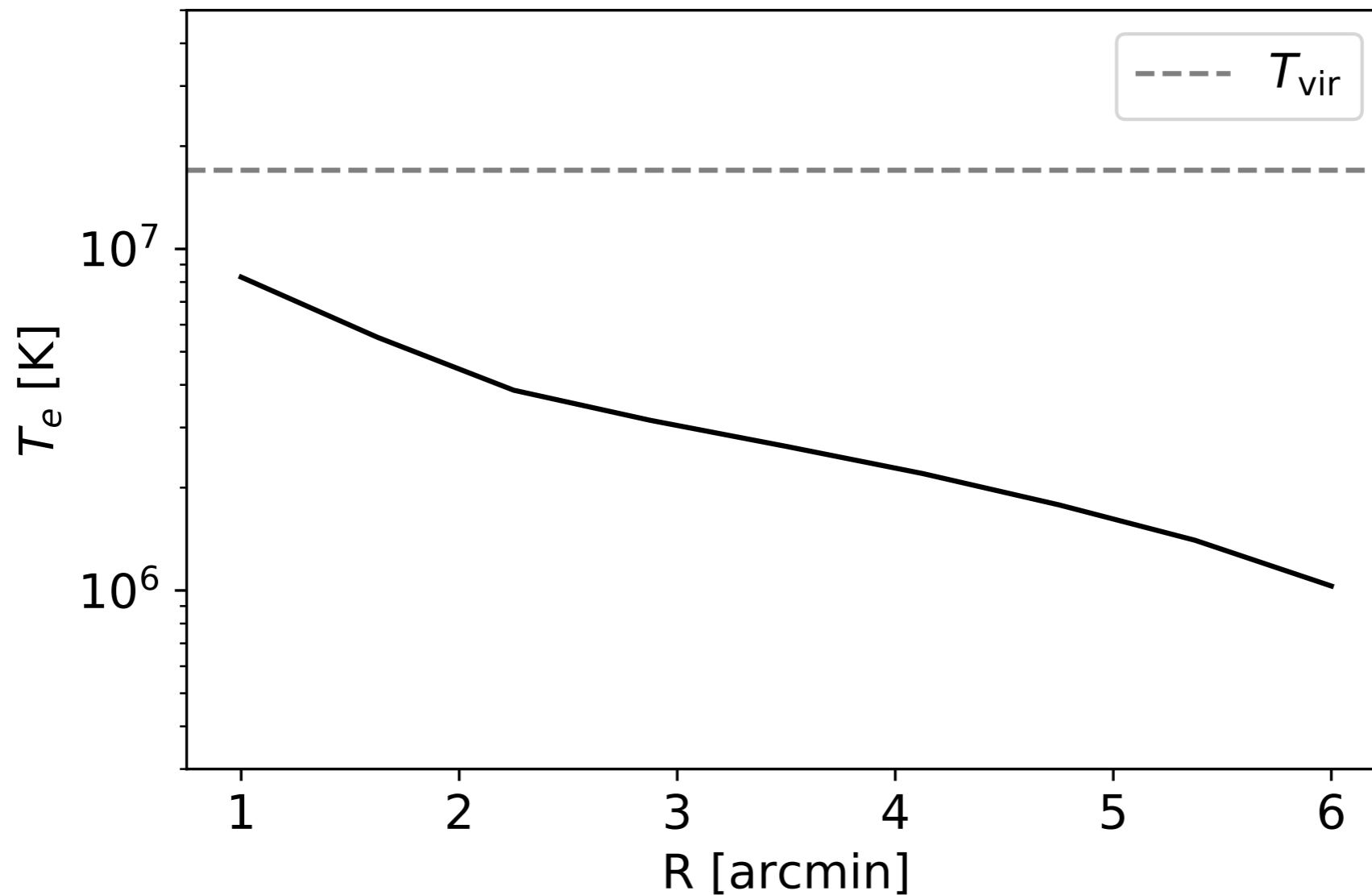
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Gas density, gas pressure, dust emission  
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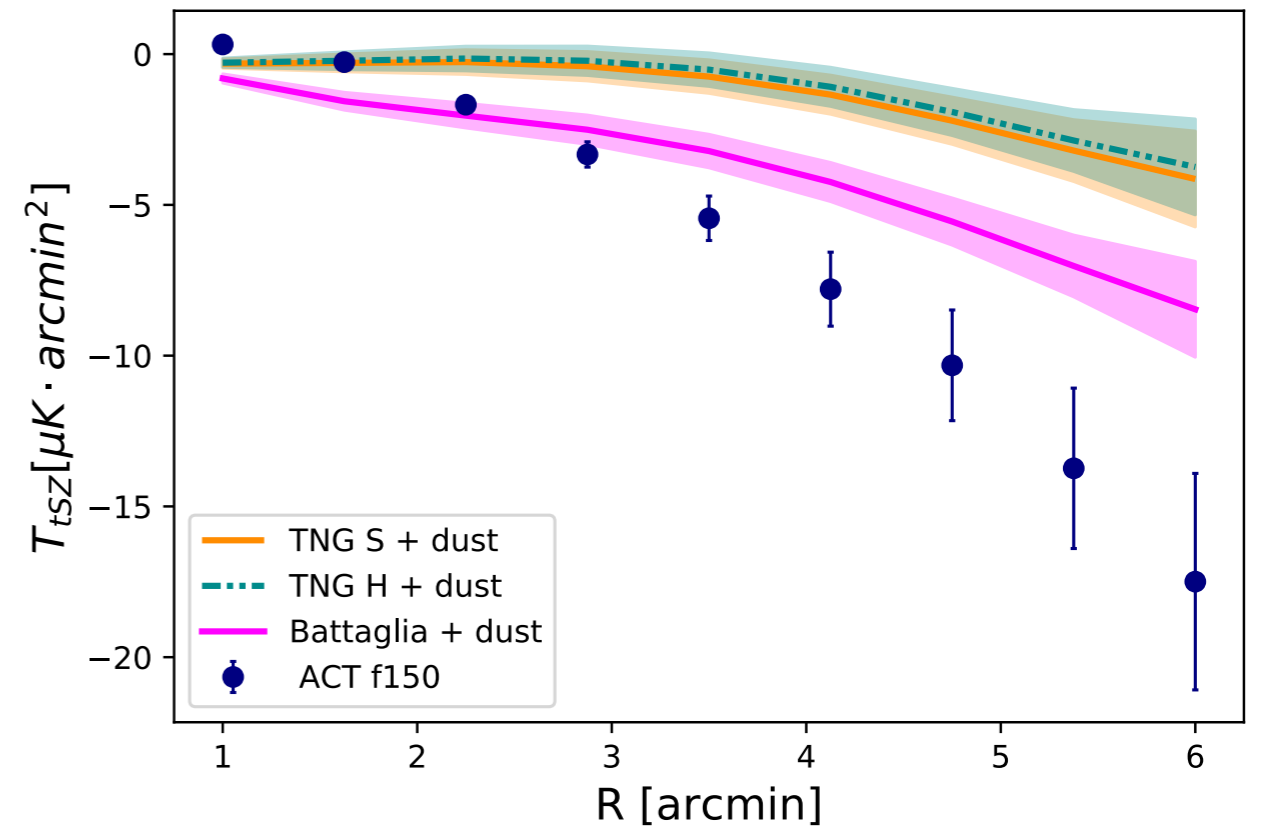
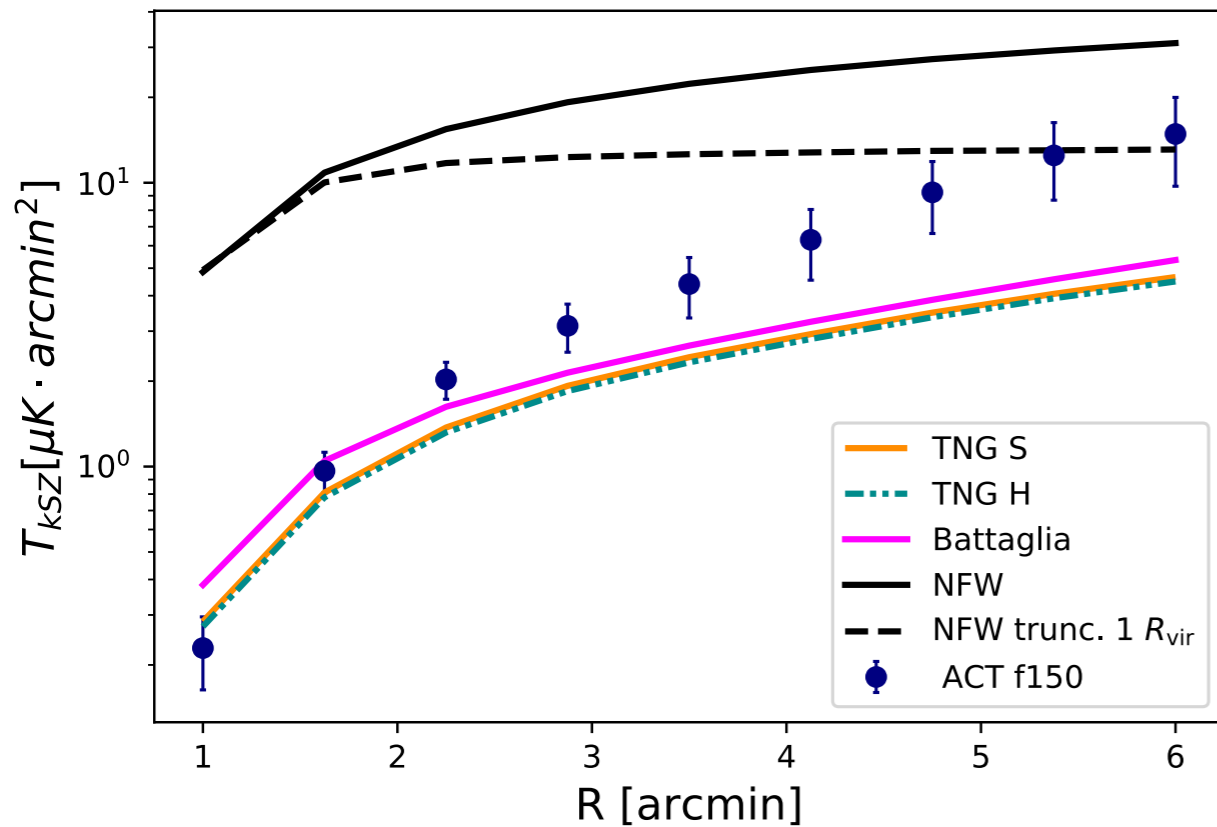
# tSZ / kSZ = gas temperature!

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

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



# Informing hydrodynamical simulations



*Amodeo Battaglia Schaan Ferraro & ACT 20*

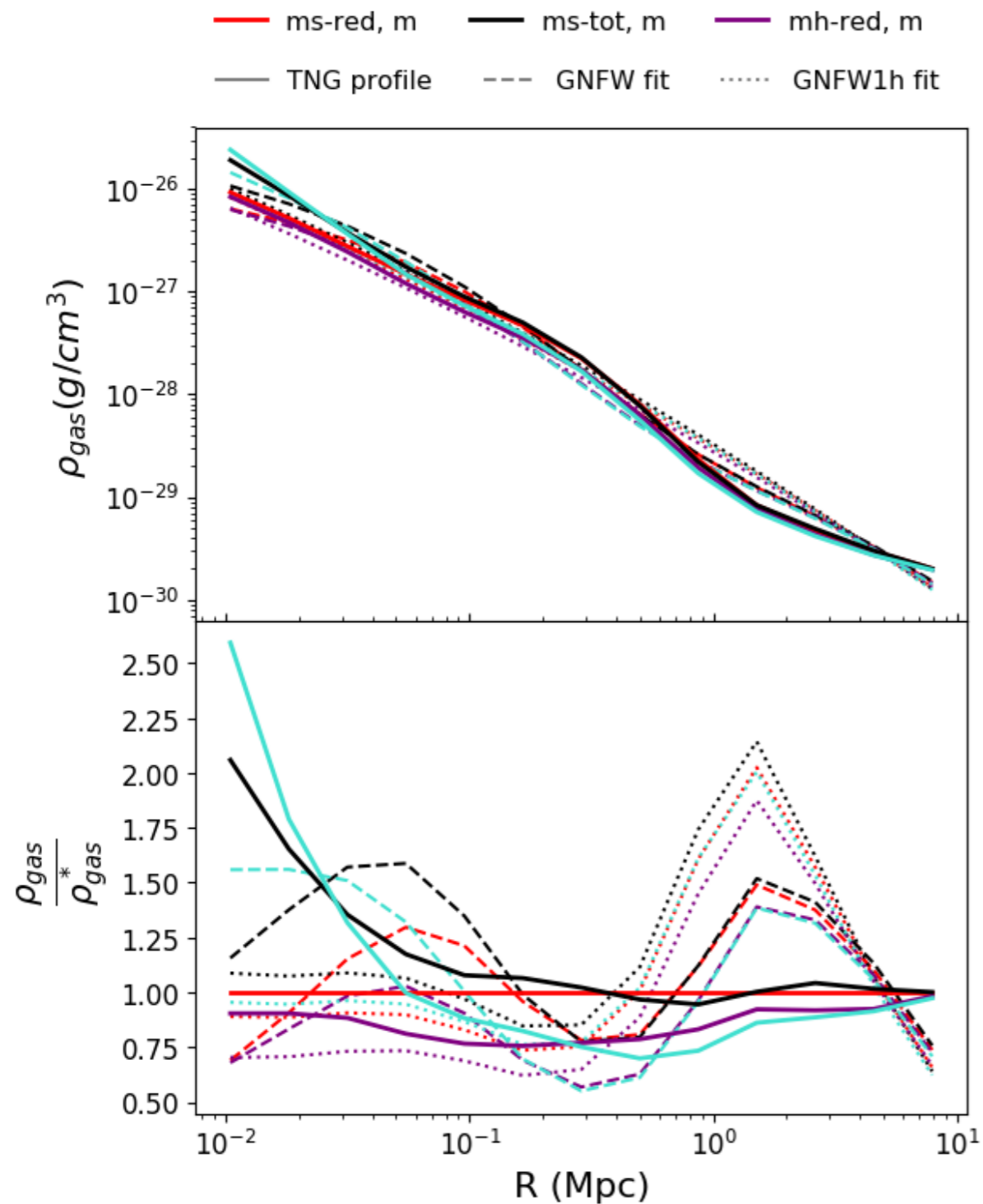
New territory: low halo masses, outside virial radius

Data suggests hotter gas in the outskirts

Informs subgrid feedback prescriptions in hydro sims



# Constraining galaxy formation: challenges



**Color selection matters**

red vs black

**Stellar/halo mass selection matters**

red vs purple

**GNFW not expressive enough**

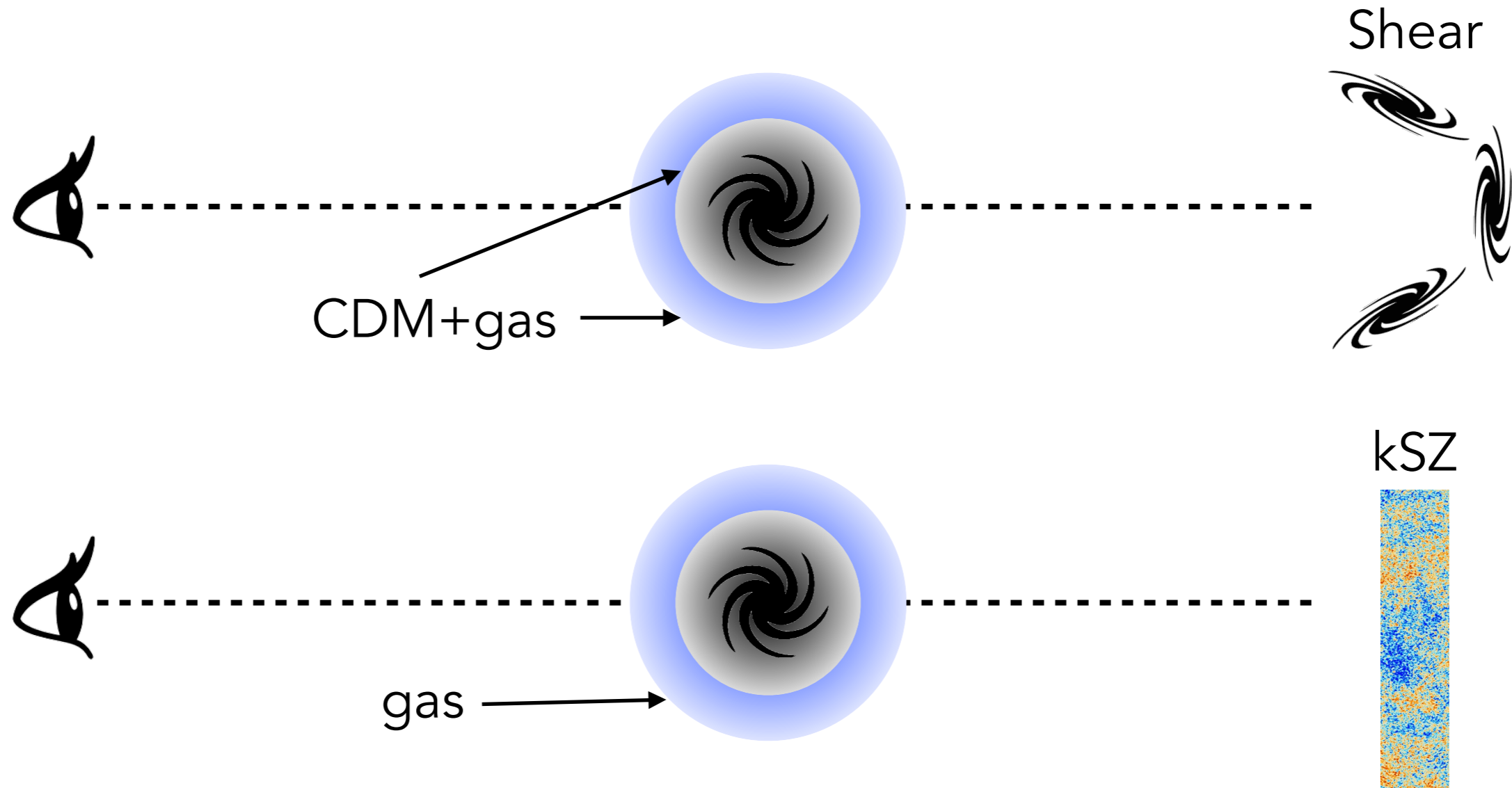
solid vs dashed

**2-halo term matters**

dashed vs dotted

*Moser Amodeo Battaglia Alvarez Ferraro Schaan+21*

# 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**

# Is BOSS lensing low?

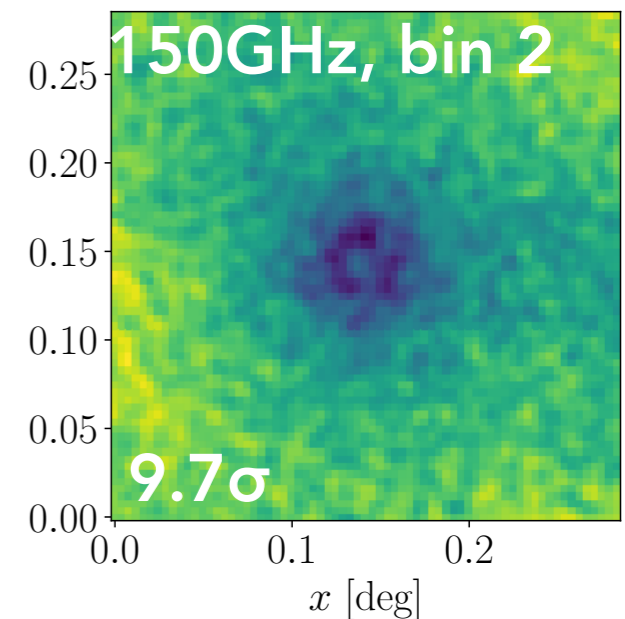
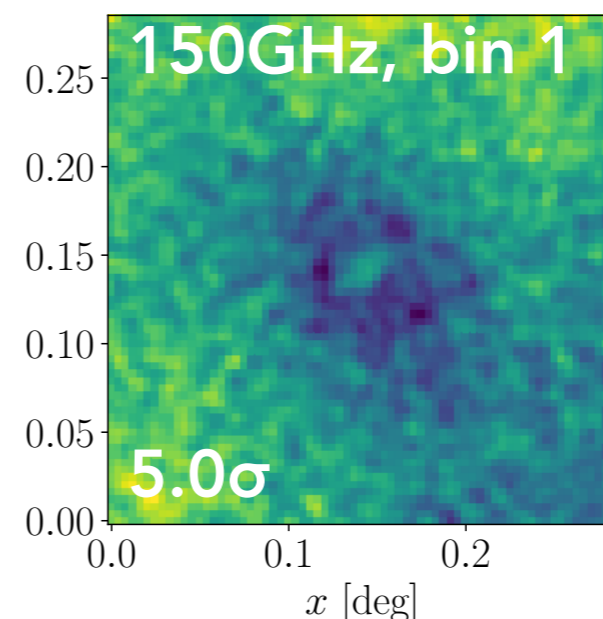
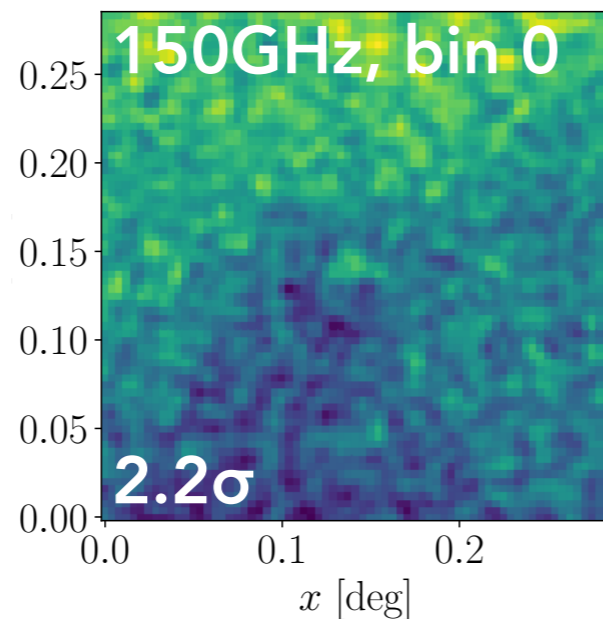
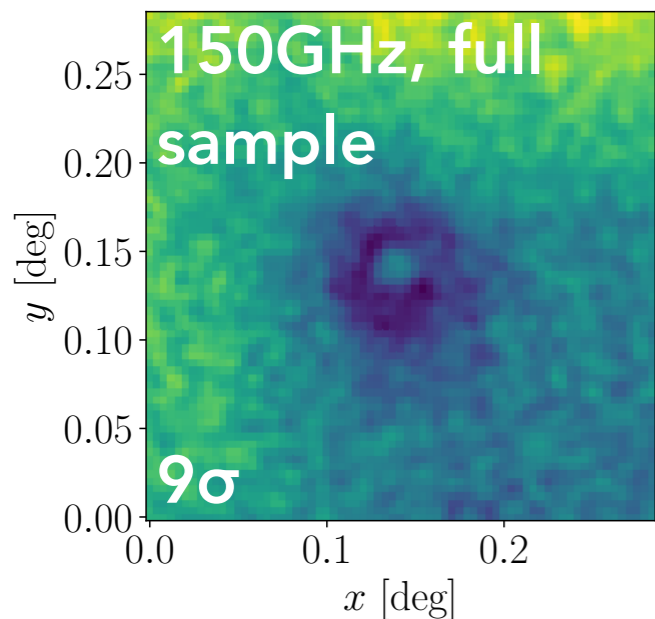
*S Amodeo, A Amon, F Ardila, H Aung, N Battaglia, J deRose, S Ferraro, S Huang, J Lange, A Leauthaud, D Nagai, A Roman, E Schaan, A Schneider*

Joint analysis of tSZ, gg lensing, RSD for BOSS galaxies

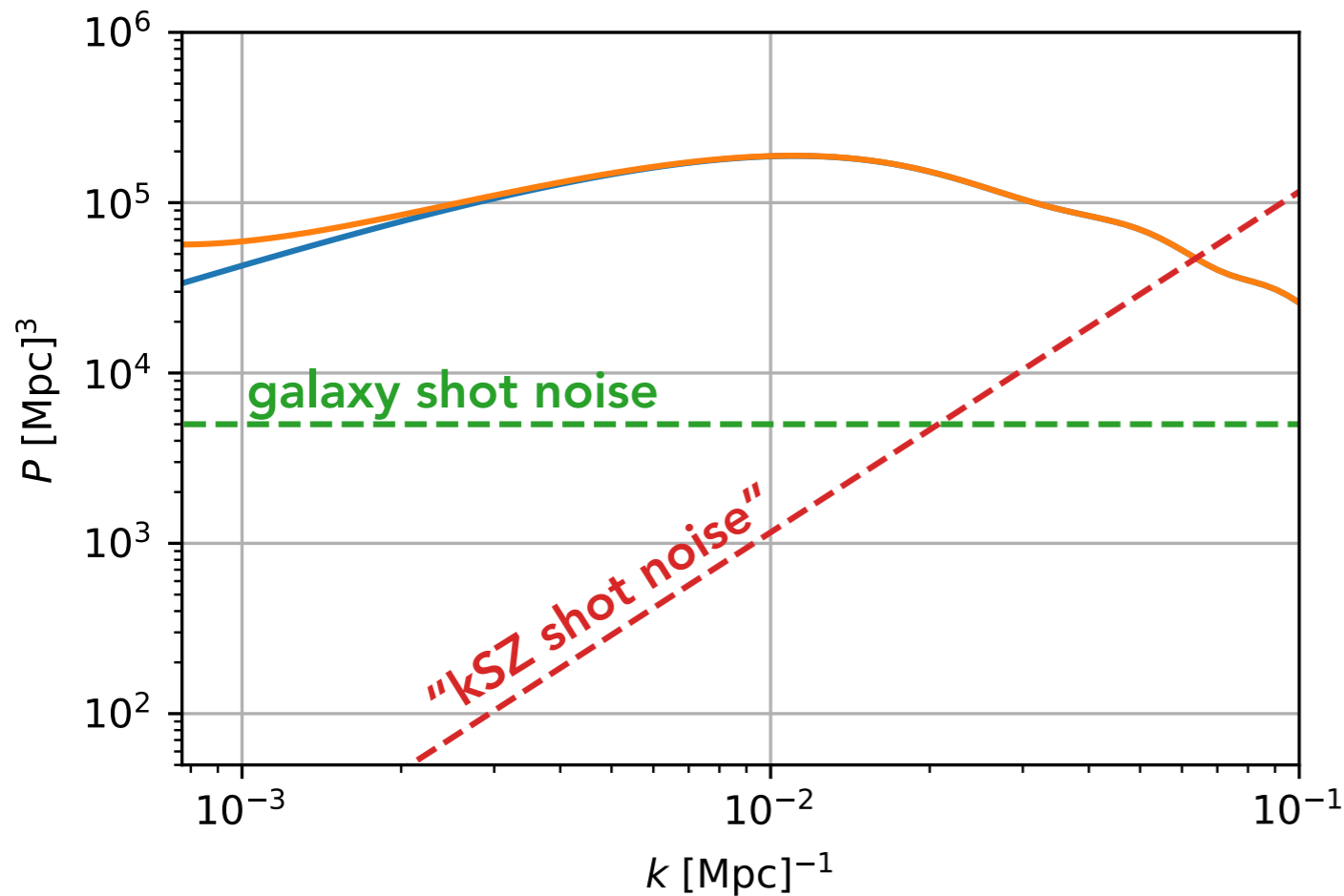
Investigate low lensing tension depending on host halo mass



3 Stellar mass bins =  $[10^{11.4} - 10^{11.57}[$ ,  
 $[10^{11.57} - 10^{11.75}[$ ,  
 $[10^{11.75} - 10^{13.0}]$



# kSZ quadratic estimator



	baseline 1	baseline 2
survey volume $V$	100 Gpc <sup>3</sup>	100 Gpc <sup>3</sup>
central redshift $z$	1.0	1.0
galaxy density $n_g$	$2 \times 10^{-4}$ Mpc <sup>-3</sup>	$10^{-2}$ Mpc <sup>-3</sup>
halo bias $b_h$	1.6	1.6
photo- $z$ error $\sigma_z$	-	0.06
CMB sensitivity	5 $\mu$ K-arcmin	1 $\mu$ K-arcmin
CMB resolution	1.5'	1.5'
$\sigma_{f_{NL}}^{\text{gal}}$	6.0	5.3
$\sigma_{f_{NL}}^{\text{kSZ+gal}}$	3.3	0.7
$\sigma_{f_{NL}}^{\text{gal}} / \sigma_{f_{NL}}^{\text{kSZ+gal}}$	1.8	7.8

*Munchmeyer+18*

kSZ yields lower noise than galaxy density!

Several groups implementing estimator: Johnson+, Munchmeyer+, Smith+

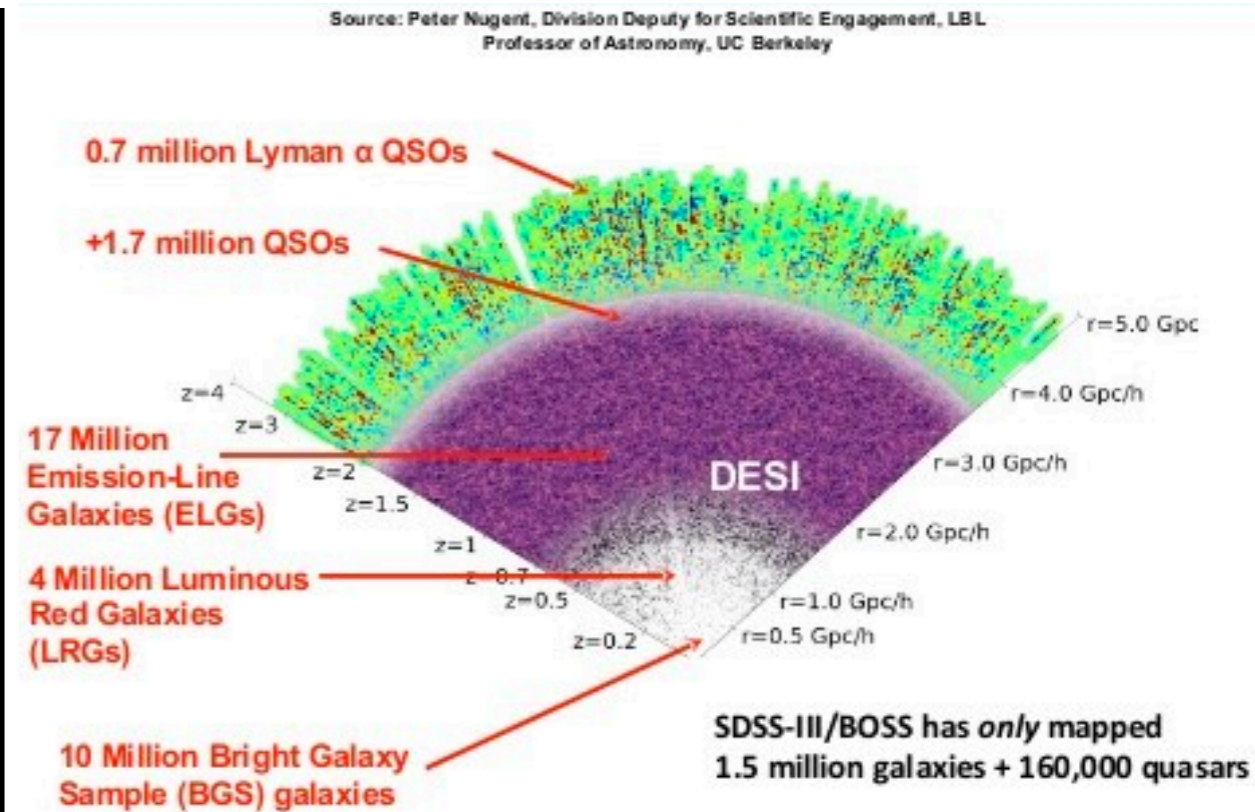
Alex Roman & Kendrick Smith working on BOSSxACT ( $5\sigma$  currently)

# DESI has started!



**DARK ENERGY  
SPECTROSCOPIC  
INSTRUMENT**

U.S. Department of Energy Office of Science



Commissioning complete, main survey ongoing until 2025

5k fiber spectrograph on 4m Mayall telescope

35M redshifts over 14k deg<sup>2</sup>

In 2.5 months, DESI gathered as many redshifts as BOSS+eBOSS in 10 years!

# Route towards S4: DESI x ACT

## Project idea 1: tSZ from ACT + Legacy Survey LRG, BGS, ELG, QSO

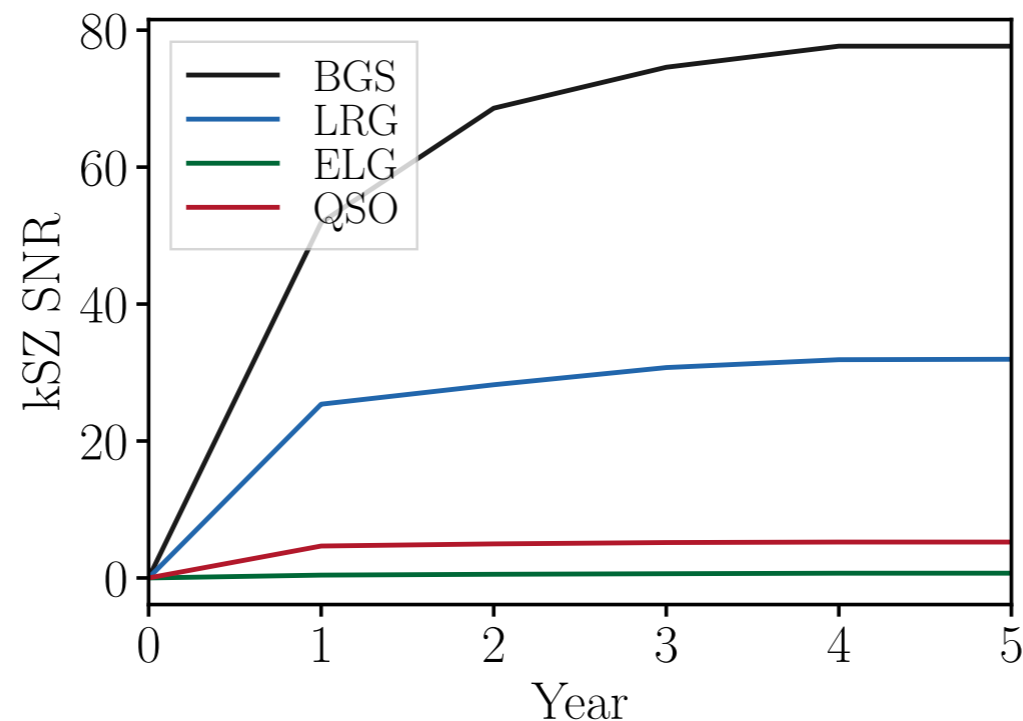
high precision tSZ profiles

## Project idea 2: tSZ & kSZ from ACT + DESI LRG, BGS, ELG, QSO

highest precision kSZ profiles

best constraints on galaxy formation and baryonic correction to lensing

Codes [Thumbstack](#), [MopC-GT](#), [Iskay](#) are ready to use!



## Project idea 3: large-scale velocities & $f_{nl}$ from kSZ

Smith+18, Münchmeyer+19