

A CMB view of DESI galaxies

Simone Ferraro

(Lawrence Berkeley National Lab / UC Berkeley)



mm Universe 2025
June 25, 2025

Five target classes

>50 million redshifts

(SDSS x20)

2.4 million QSOs

Lya $z > 2.1$

Tracers $1.0 < z < 2.1$

17 million ELGs

$0.6 < z < 1.6$

6 million LRGs

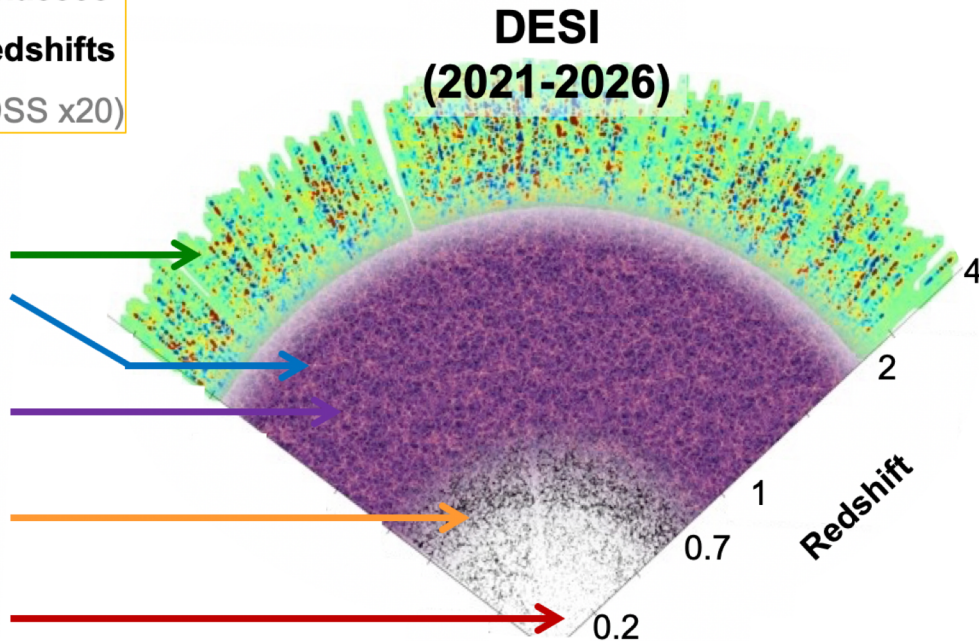
$0.4 < z < 1.0$

10 million

Brightest galaxies

$0.0 < z < 0.4$

DESI
(2021-2026)



Opportunities from DESI x ACT/Planck CMB

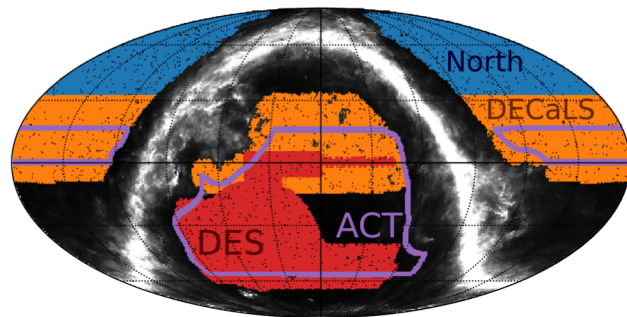
3

- DESI has large overlap with Planck (~17,000 sq deg) and ACT (9,000 sq deg with spectroscopy and 13,000 with imaging).
- ACT provides high resolution (~3.5x better), low noise (3x better than Planck).
- MoU with ACT leading to 20+ “papers” approved and in progress.

Opportunities:

- CMB is a “backlight” that reveals:
 - Dark matter
 - Gas density
 - Gas pressure
 - Thermal energy (temperature)
 - Dust emission

} >90% of galaxy's mass!
- Complementary to information in images & spectra
- Major limitation for current and future surveys

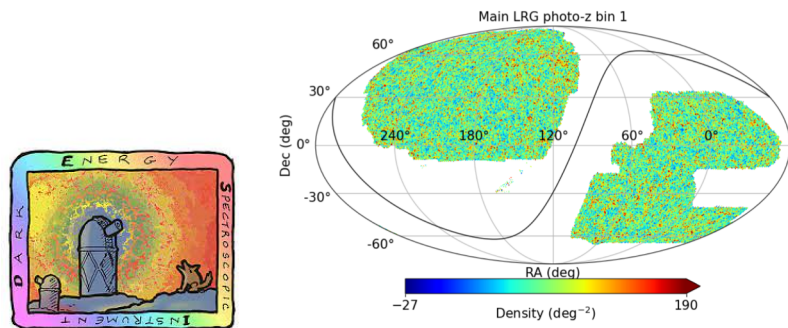
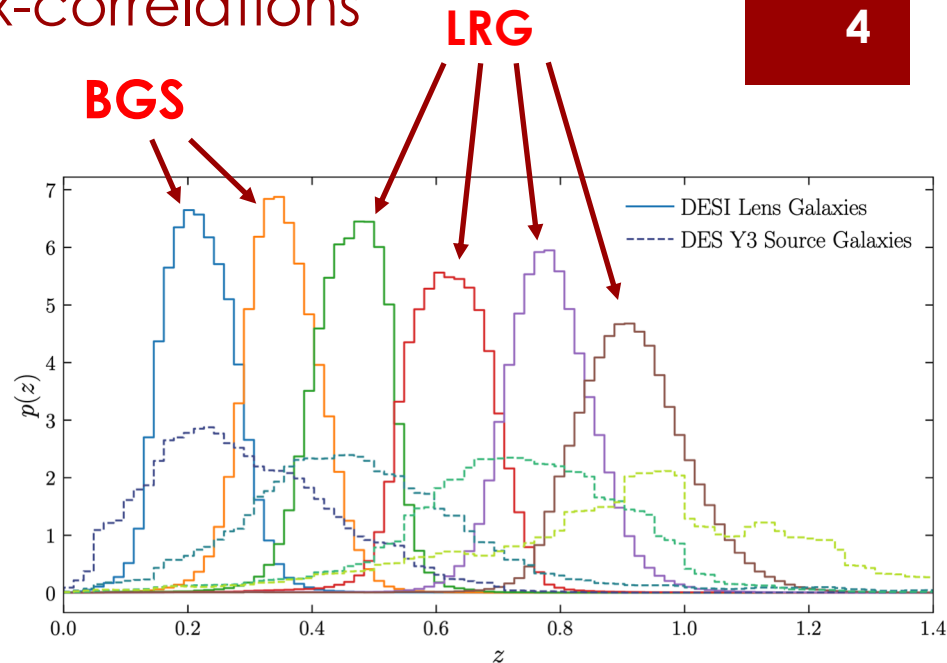


N. Sailer

DESI photometric samples for x-correlations

4

- About 20,000 sq deg.
- LRG: 10M galaxies for main sample. 27M for the “extended”
- BGS: 15M galaxies
- Spectroscopic calibration for all of them.
- Good photo-zs $\sigma_z/(1+z) \sim 0.02$
- Stellar contamination $< 0.3\%$.
- Magnification and systematic well-understood.



Rongpu Zhou

R. Zhou, SF ++ (DESI, 2023)
Chen, DeRose, Zhou, SF++ (2024)

DESI x CMB lensing (ACT and Planck)

5

- Immune from photo-z errors, shear calibration, blending, Intrinsic Alignments, ...
- Similar SNR to galaxy weak lensing
- Hybrid Effective Field Theory model
- CMB lensing norm correction (**G. Farren**)
- Break bias – cosmology degeneracy

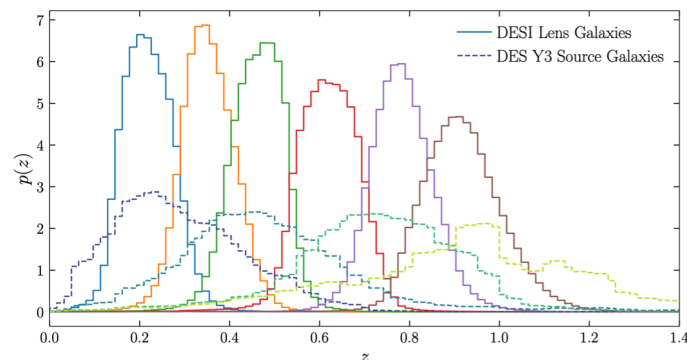
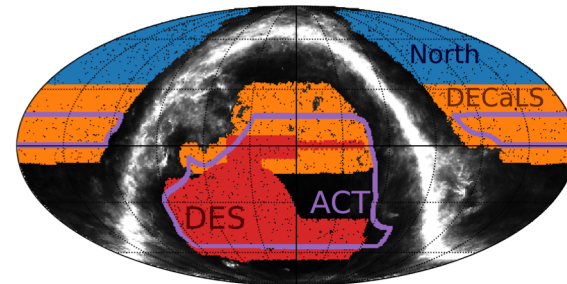
$$\frac{C^{\kappa g}}{\sqrt{C^{gg}}} \sim \frac{b\sigma_8^2}{\sqrt{b^2\sigma_8^2}} = \sigma_8$$

Sailer, Kim, SF++ (2024)
Kim, Madhavacheril++ inc SF (2024)
Sailer, DeRose, SF++ (2025)

→ See **Joshua Kim's** talk on Friday for more details!

ACT DR6 lensing maps: Madhavacheril++, Qu++
, MacCrann (ACT, 2023) + Planck: Carron++ (2022)

Simone Ferraro (LBNL)



Noah Sailer



Joshua Kim



Simone Ferraro



Mathew
Madhavacheril

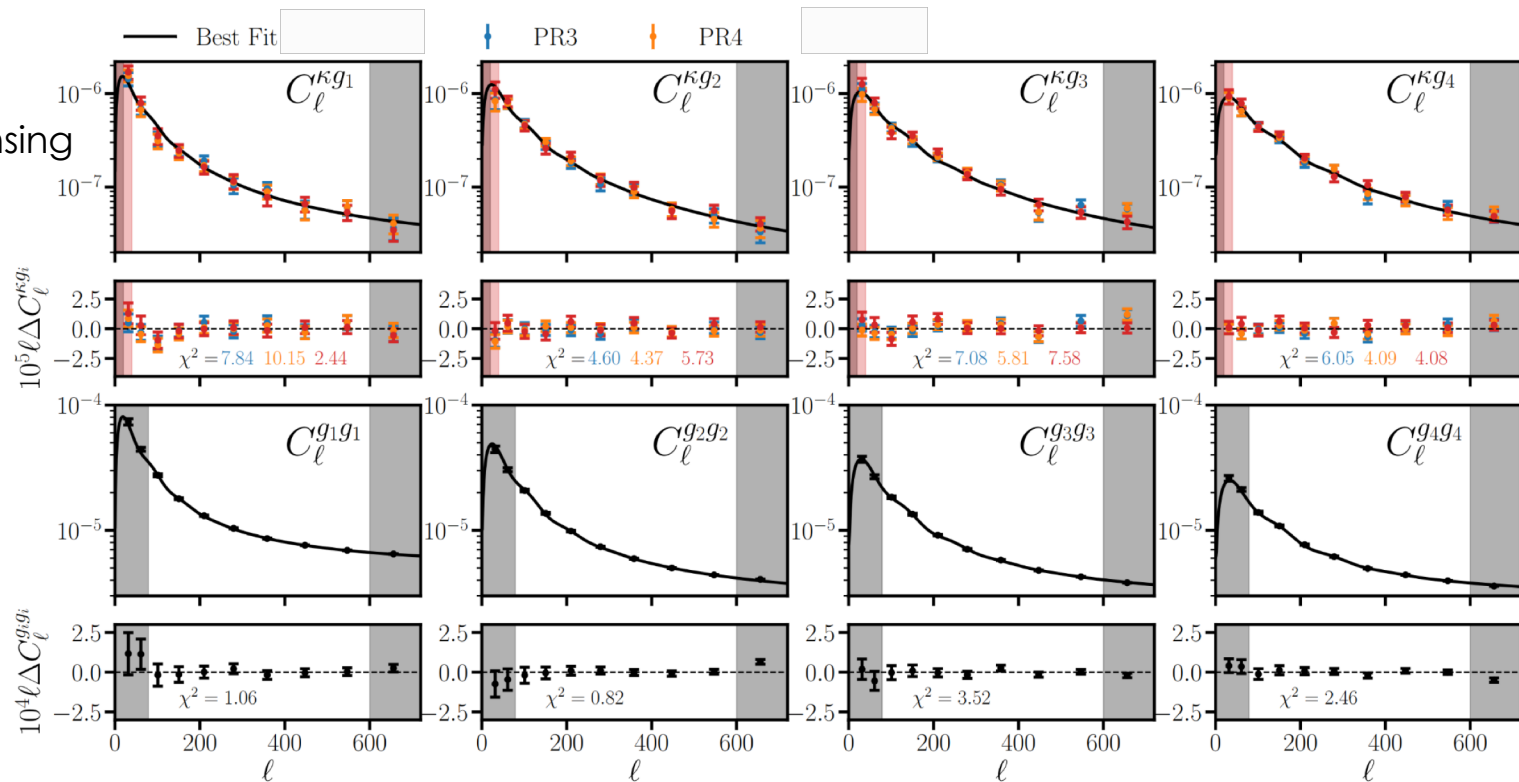


Martin White

Example: DESI LRG x CMB lensing

6

galaxies x CMB lensing



galaxies x galaxies

Data level

- null correlation with curl estimator
- null correlation with CMB deprojected reconstruction
- consistent C^{kg} when using CIB deprojected ILC
- consistency when adopting more conservative galactic, extinction and stellar density masks
 - negligible correlations between galaxies and their systematic weights
- consistency in both galactic hemispheres

Inference level

- variations in C^{kg} and C^{gg} across imaging footprints
- variations in C^{kg} and C^{gg} on footprints with/without direct spectroscopic calibration
- consistent C^{kg} when measured with different frequencies or temperature vs polarization
- consistency of galaxy-galaxy cross-spectra with that predicted from fits to C^{kg} and C^{gg} alone
- consistency between ACT and Planck
- robustness to different scale cuts
- robustness to different priors
- consistent results from all three fiducial models
- consistent cosmology from all four redshift bins
- consistent results when galaxy mask restricted to only overlap with CMB lensing mask

Simulation level

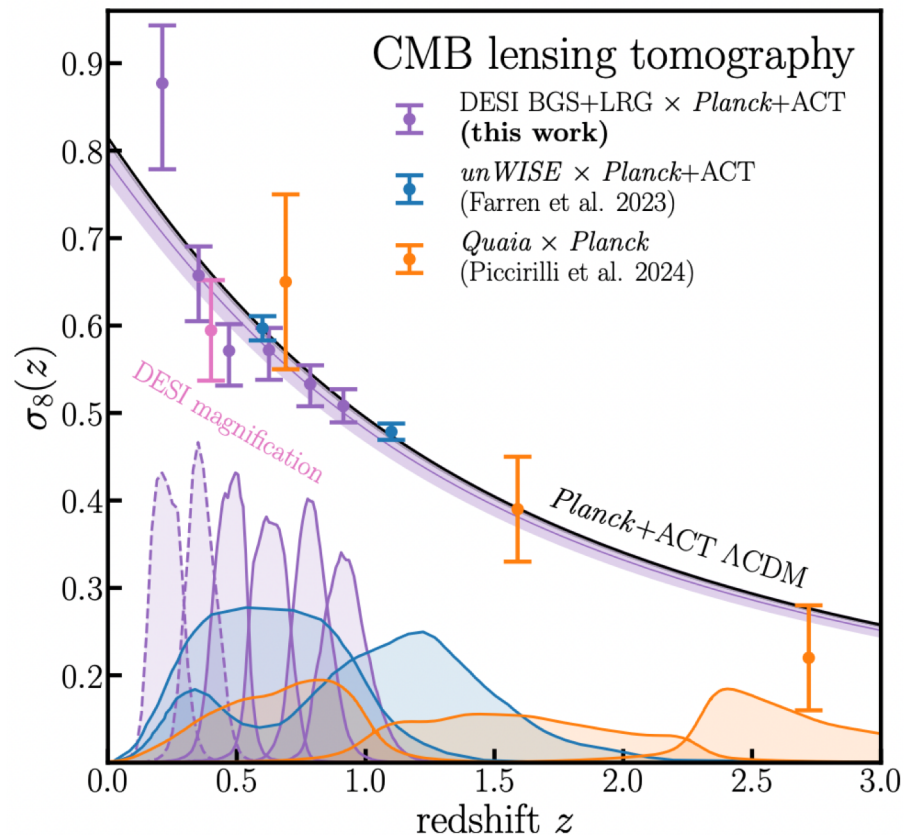
- expect negligible contamination from extragalactic foregrounds from Websky sims

+ foreground tests!!

No evidence for statistically significant systematic contamination at the parameter level

DESI x CMB lensing results

- Immune to photo-z, IA, shear calibration, blending, etc. Smaller (negligible?) baryon effects.
- Similar statistical power to galaxy lensing $\sim 2.5\%$.
- Bridge the gap between dark energy and matter domination.
- Cosmological use of “magnification”.
- Fully consistent with CMB (Planck cosmology) $\rightarrow$ no evidence of “low” lensing, at least on large and intermediate scales.



Sailer, Kim, SF et al (2024)
Kim, Madhavacheril et al – inc SF (2024)
Sailer, DeRose, SF et al (2025)

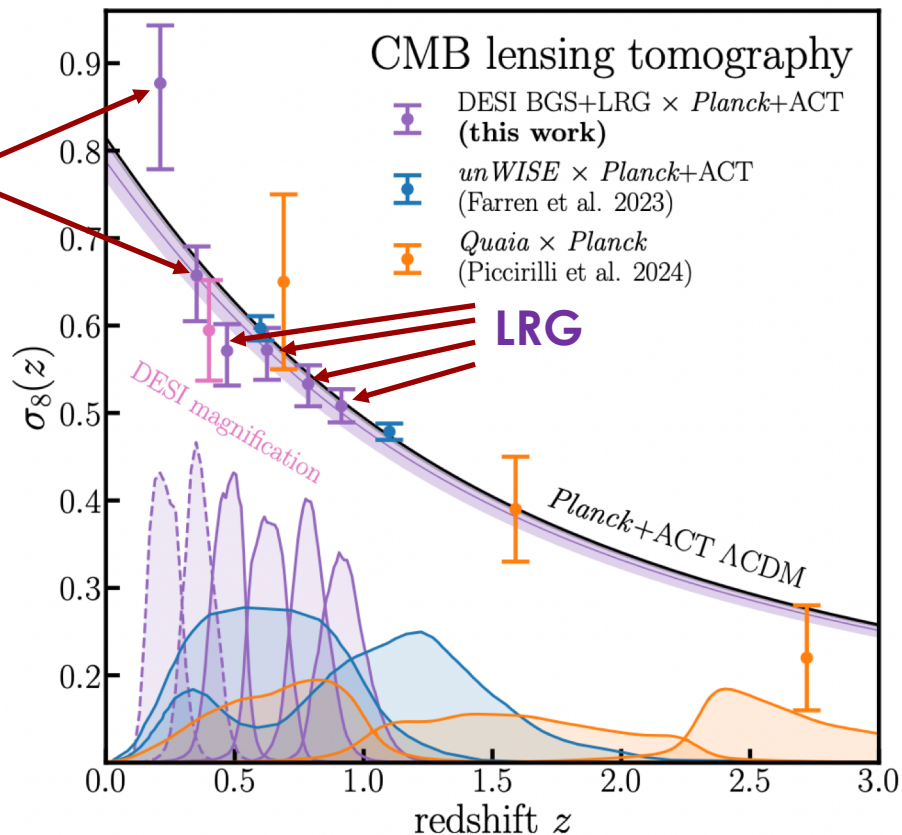
DESI x CMB lensing results

- Immune to photo-z, IA, shear calibration, blending, etc. Smaller (negligible?) baryon effects.
- Similar statistical power to galaxy lensing $\sim 2.5\%$.
- Bridge the gap between dark energy and matter domination.
- Cosmological use of “magnification”.
- Fully consistent with CMB (Planck cosmology) $\rightarrow$ no evidence of “low” lensing, at least on large and intermediate scales.

Also related work by F. Qu, Q. Hang, G. Farren et al for similar redshift range, T. Karim++ et al for the **ELG**, and de Belsunce et al (coming soon!) for the **QSO** and **Ly-alpha**.

BGS

LRG

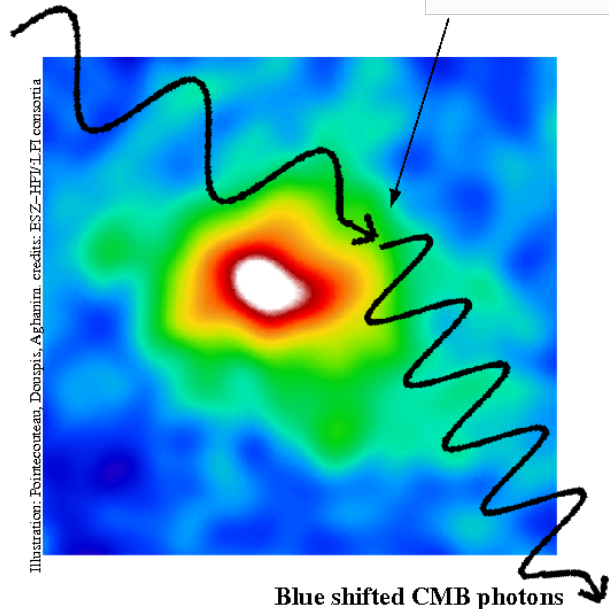


Sailer, Kim, SF et al (2024)
Kim, Madhavacheril et al – inc SF (2024)
Sailer, DeRose, SF et al (2025)

The Sunyaev-Zel'dovich effect(s)

10

CMB Photons I kinematic SZ



$$\left(\frac{\Delta T}{T}\right)_{\text{kSZ}} \propto \boxed{N_e(\theta)} \frac{v_r}{c}$$

column density radial
of electrons velocity

thermal SZ

$$\left(\frac{\Delta T}{T}\right)_{\text{tSZ}} \propto N_e(\theta) T_e(\theta)$$

patchy screening

$$\left(\frac{\Delta T}{T}\right)_{\text{bSZ}} \propto N_e(\theta) \left(\frac{\Delta T(\theta)}{T}\right)_{\text{primary}}$$

Baryons are **~16%** of the mass → **major systematic for weak lensing** and potentially **clustering**

our SZ team

Simone Ferraro (LBNL)



Ried Guachalla, Liu, Hadzhiyska, Schaan, Ferraro

Noah Sailer

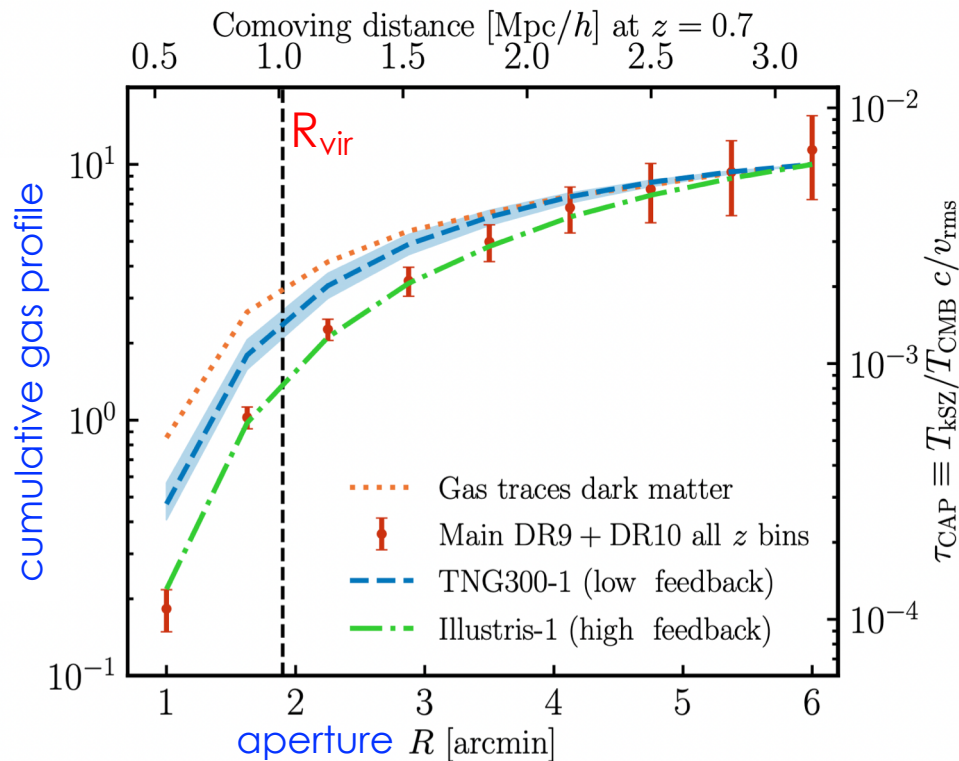
Evidence of large feedback from the DESI LRGs

11

Photometric LRG: highest SNR to date and “dry run for LSST”.

Measured as a function of mass & redshift.

Strong evidence of “excess feedback” → large effect on **weak lensing** and **matter power spectrum** (details in progress).



B. Hadzhiyska, S. Ferraro, B. Ried Guachalla, E. Schaen et al (ACT + DESI)

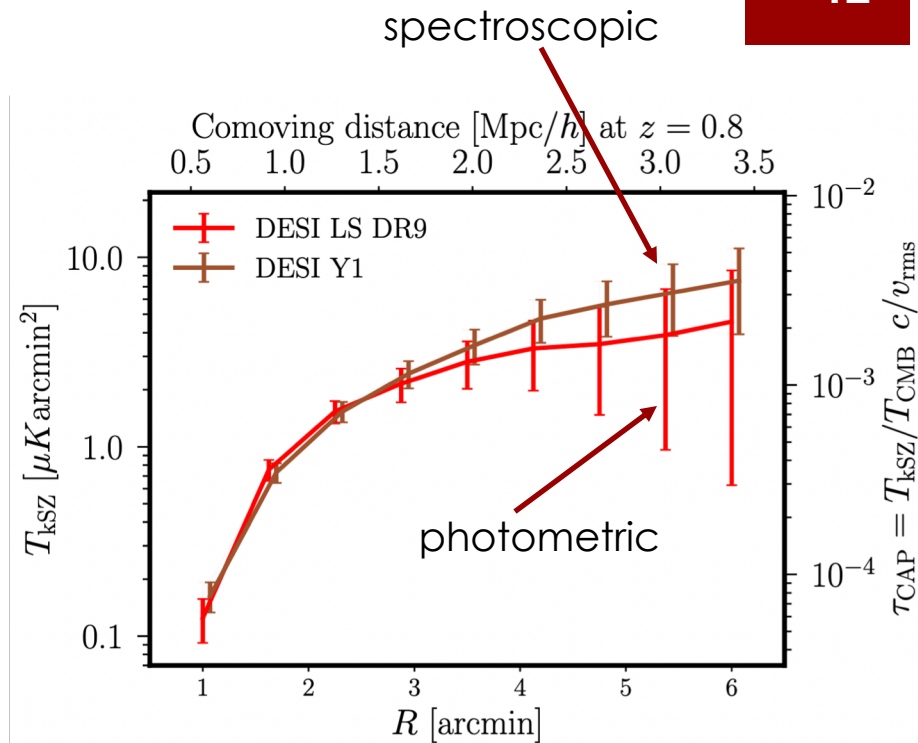
Spectroscopic Y1 kSZ

12

Photometric and spectroscopic measurements fully consistent, also showing excess feedback.

Detailed measurements for BGS and ELG.

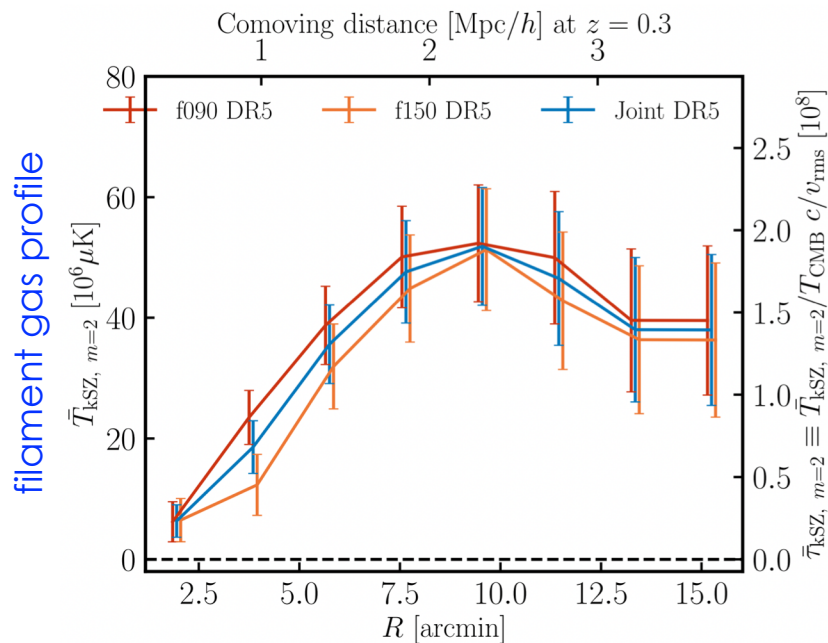
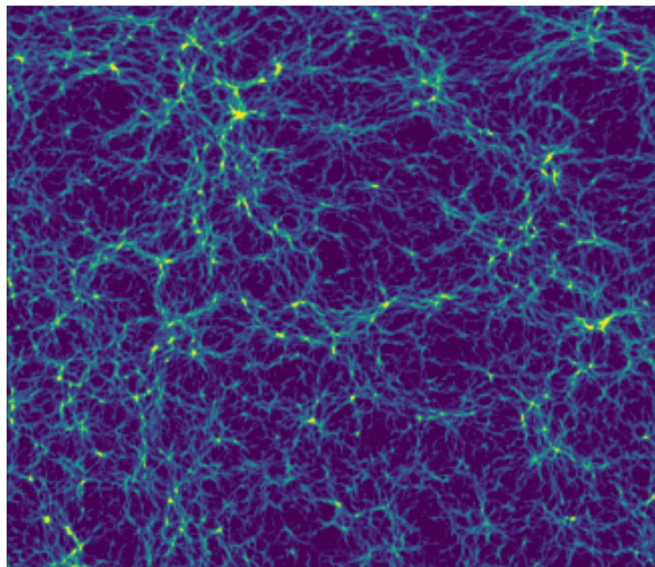
DESI Y3 will more than quadruple the overlap with ACT, and will take these measurements to a new level. Stay tuned!



B. Ried Guachalla, E. Schaan, B. Hadzhiyska, S. Ferraro et al (ACT + DESI)

Tracing Cosmic Gas in Filaments with BGS

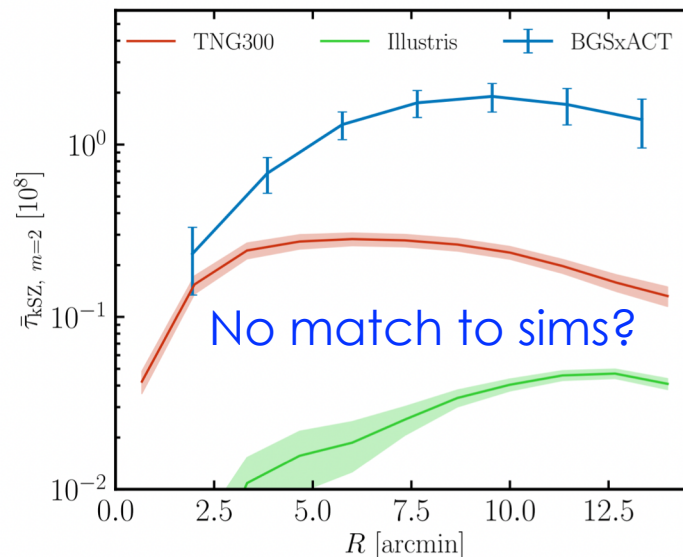
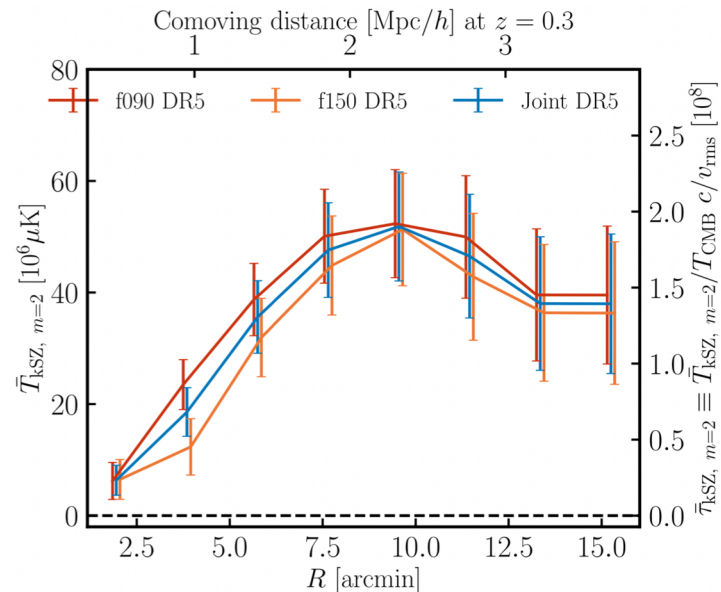
Orient stacking along filament and estimate quadrupole. First detection!



More to come from anisotropic kSZ + tSZ + lensing (DESI x ACT, M. Lokken++)

Do hydrodynamical simulation accurately capture the gas in the cosmic web?

14



Evidence of anisotropic feedback? Stay tuned for much more to come!

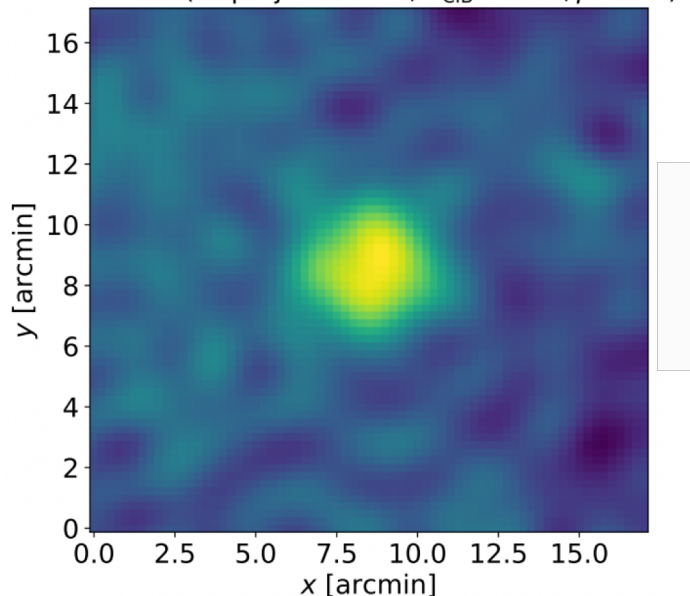
The thermal SZ effect (tSZ)

$$\left(\frac{\Delta T}{T}\right)_{\text{tSZ}} \propto N_e(\boldsymbol{\theta})T_e(\boldsymbol{\theta}) = \text{thermal pressure}$$



Henry Liu

ACT DR6 (Deprojected CIB, $T_{\text{CIB}} = 10.7$, $\beta = 1.6$)



Biggest challenge: model or deproject dust!

- Moment deprojection
- Multi-frequency fits to (90, 150, 220) GHz
- Consistent results
- No evidence for extended dust in the lowest redshift bins, strong evidence for the highest two

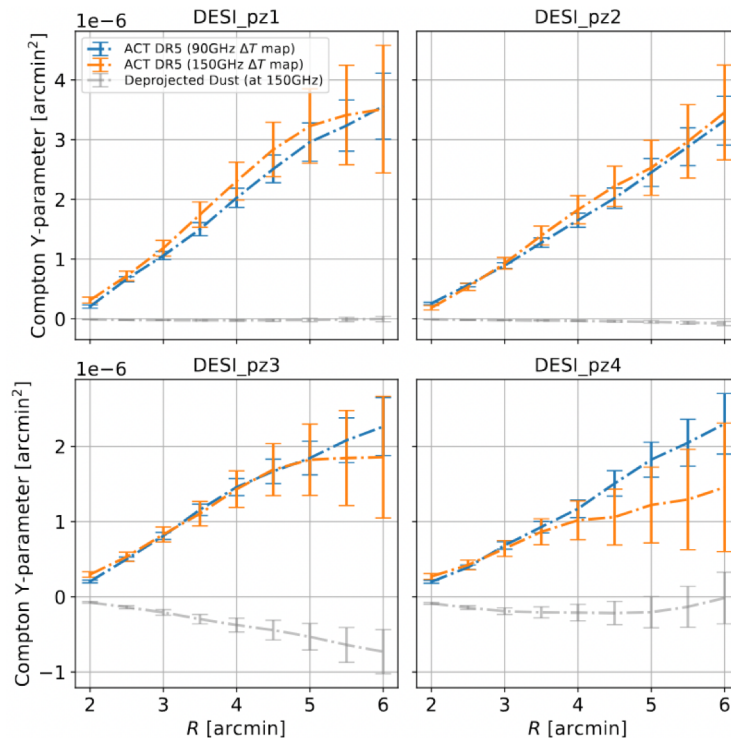
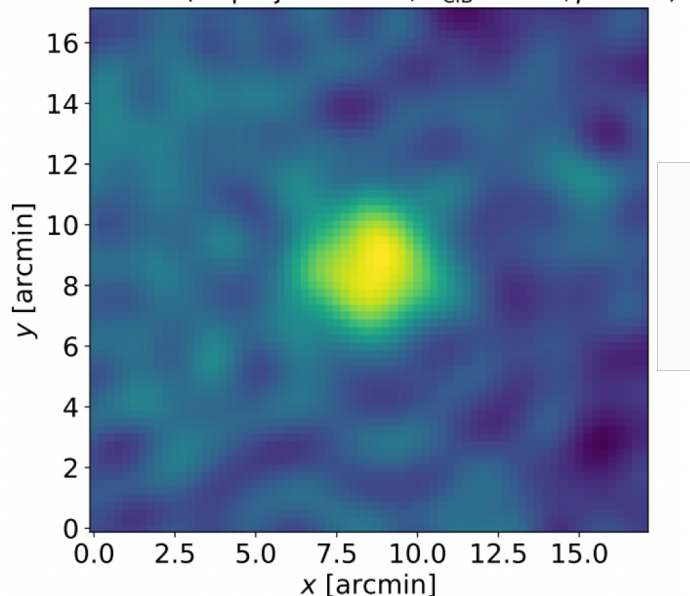
Liu, Ferraro, Schaen++ (2025, ACT + DESI)
Compton y maps from Coulton++ (2024, ACT)

The thermal SZ effect (tSZ)

16

$$\left(\frac{\Delta T}{T}\right)_{\text{tSZ}} \propto N_e(\boldsymbol{\theta})T_e(\boldsymbol{\theta}) = \text{thermal pressure}$$

ACT DR6 (Deprojected CIB, $T_{\text{CIB}} = 10.7, \beta = 1.6$)

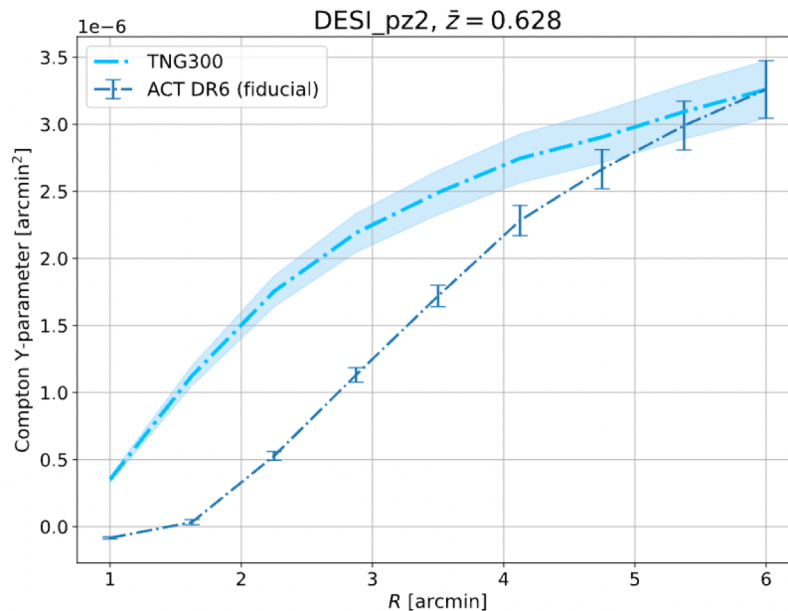
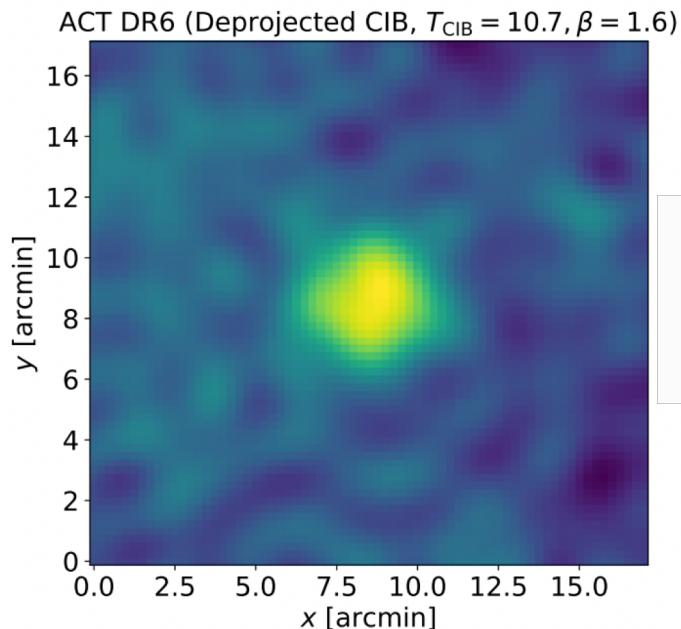


Liu, Ferraro, Schaan++ (2025, ACT + DESI)

The thermal SZ effect (tSZ)

17

$$\left(\frac{\Delta T}{T}\right)_{\text{tSZ}} \propto N_e(\boldsymbol{\theta})T_e(\boldsymbol{\theta}) = \text{thermal pressure}$$



Strong evidence for “large” feedback!

Liu, Ferraro, Schaen++ (2025, ACT + DESI)

(Patchy or anisotropic) screening

18

Two new papers
out this week!

$$\left(\frac{\Delta T}{T}\right)_{\text{bSZ}} \propto N_e(\boldsymbol{\theta}) \left(\frac{\Delta T(\boldsymbol{\theta})}{T}\right)_{\text{primary}}$$

- Measures N_e , similar to kSZ, but is a factor of ~ 24 smaller.
- Quadratic estimators: typically receive contribution from CMB lensing.
- Measurement with DESI photometric LRG: self consistent comparison to the kSZ signal.

Mapping the gas density with the kinematic Sunyaev-Zel'dovich and patchy screening effects: a self-consistent comparison

Boryana Hadzhiyska,^{1,2,3,*} Noah Sailer,^{3,2} and Simone Ferraro^{2,3}

Bias hardened estimators of patchy screening profiles

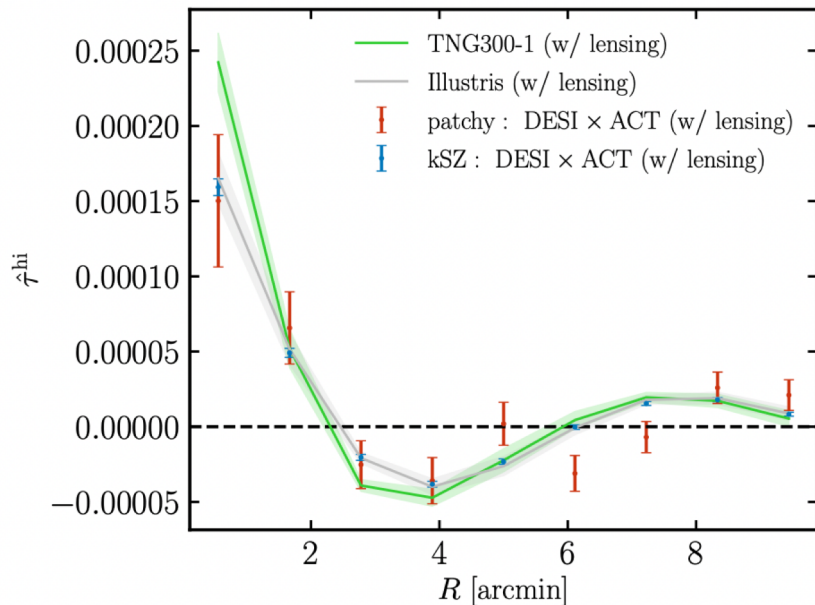
Noah Sailer,^{1,2,*} Boryana Hadzhiyska,^{3,2,1} and Simone Ferraro^{2,1}

(Patchy or anisotropic) screening

19

Two new papers
out this week!

$$\left(\frac{\Delta T}{T}\right)_{\text{bSZ}} \propto N_e(\boldsymbol{\theta}) \left(\frac{\Delta T(\boldsymbol{\theta})}{T}\right)_{\text{primary}}$$



- kSZ and screening fully consistent
- Lensing can be modeled or mitigated successfully
- Screening shows a preference for “large” feedback found with kSZ and tSZ!

Hadzhiyska, Sailer, Ferraro (2025)
Sailer, Hadzhiyska, Ferraro (2025)

See also [Schutt++ \(2024\)](#) for different estimators
and [Coulton++ \(2024\)](#) for a search with unWISE + ACT

Velocity reconstruction (kSZ tomography)

$$\left(\frac{\Delta T}{T}\right)_{\text{kSZ}} \approx \sigma_T \boxed{N_e(\boldsymbol{\theta})} \boxed{\frac{v_r}{c}}$$

column density of electrons
radial velocity

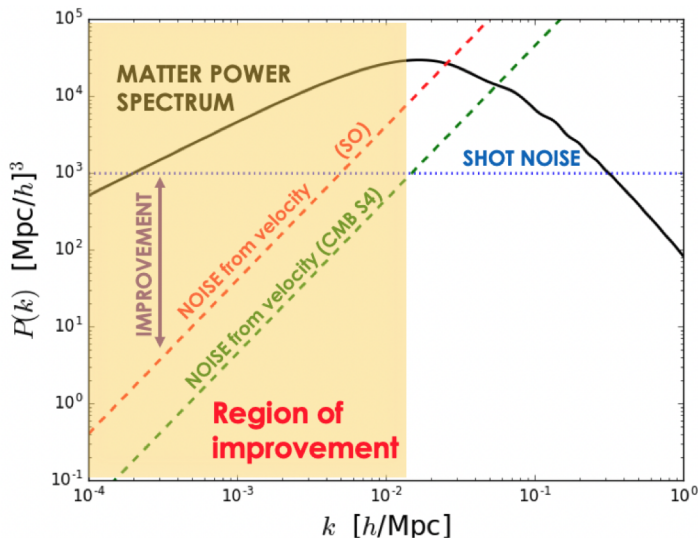
20

$$\hat{v}_r(\mathbf{k}_L) = N_{v_r}(k_L) \frac{K_*}{\chi_*^2} \int \frac{d^3 \mathbf{k}_S}{(2\pi)^3} \frac{d^2 l}{(2\pi)^2} \frac{P_{ge}(k_S)}{P_{gg}^{\text{tot}}(k_S) C_l^{TT, \text{tot}}} \left(\delta_g^*(\mathbf{k}_S) T^*(\mathbf{l}) \right) (2\pi)^3 \delta^3 \left(\mathbf{k}_L + \mathbf{k}_S + \frac{\mathbf{l}}{\chi_*} \right)$$

Cayuso et al 2018

Smith et al 2018

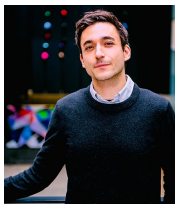
Münchmeyer et al 2018



Velocity Reconstruction from KSZ: Measuring f_{NL} with ACT and DESILS

Selim C. Hotinli,¹ Kendrick M. Smith,¹ and Simone Ferraro^{2,3}

to appear shortly + lots of work in progress on DESI x ACT!



Selim Hotinli

→ See Selim's talk for this work + other related talks (Fiona, Anderson, Avery, ...)

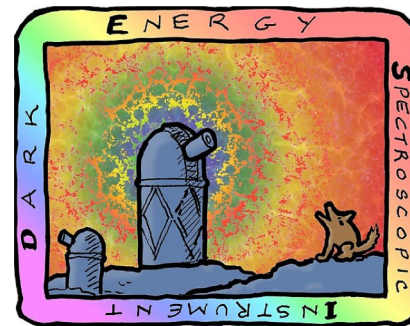
Conclusions

21

- (CMB) Lensing “is not low” at least on relatively large scales.
- All data consistent and pointing to the same conclusions.
- Strong evidence for very large feedback on galaxy & group scales. Not in contradiction with clusters results.
- Anisotropic results are puzzling.
- Studies of mass, redshift, environment dependence are essential.
- Much more to come soon!



Thanks!



A CMB view of DESI galaxies

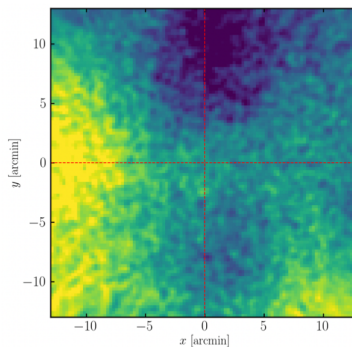
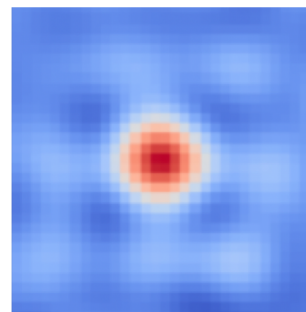
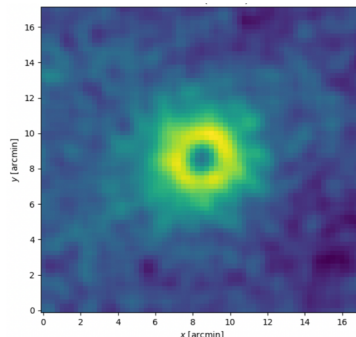
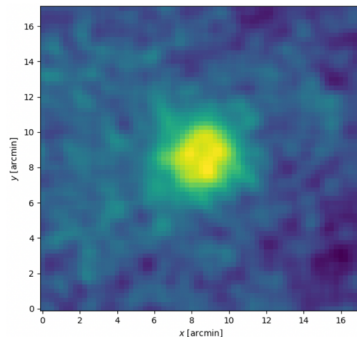
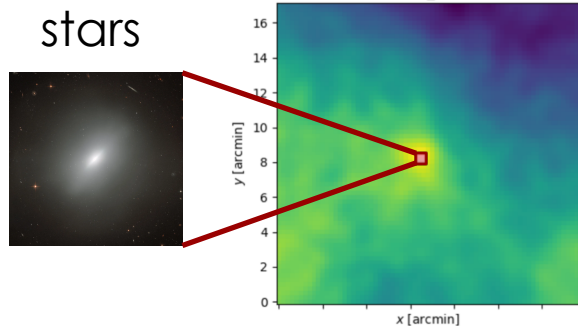
22

gas density
(kSZ and screening)

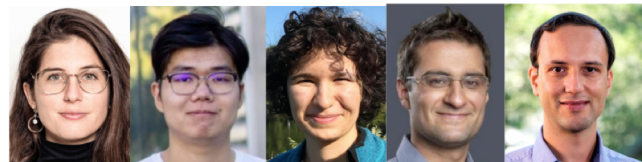
thermal pressure
(tSZ)

thermal pressure + dust
(tSZ + CIB)

mass
(CMB lensing)



filaments
(kSZ)



Ried Guachalla, Liu, Hadzhiyska, Schaan, Ferraro



Noah Sailer

+ DESI and ACT collaborators