Title: A CMB view of DESI galaxies

Speakers: Simone Ferraro

Collection/Series: Cosmic Ecosystems

Subject: Cosmology

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Abstract:

Information about the late-time Universe is imprinted on the small-scale CMB as photons travel to us from the surface of last scattering. Several processes are at play and small-scale fluctuations are very rich and non-Gaussian in nature. I will review some recent and exciting results that use the Sunyaev-Zel'dovich (SZ) effects and gravitational lensing to paint a full picture of the visible and dark matter in and around DESI galaxies. I will discuss how a combination of measurements can probe velocity fields at cosmological distances and inform us on galaxy energetics. I will also show recent measurements of weak lensing of the CMB and its cross-correlation with DESI, and how they can help us interpret intriguing discrepancies in cosmological parameters between the high and low redshift Universe.

A CMB view of DESI galaxies

Simone Ferraro
(Lawrence Berkeley National Lab / UC Berkeley)

Cosmic Ecosystems
July 29, 2025

DESI

Dark **E**nergy **S**pectroscopic **I**nstrument: Massively multiplexed spectroscopic survey with 5000 robotic fibers, over ~14,000 sq. deg

Five target classes

>50 **million redshifts**

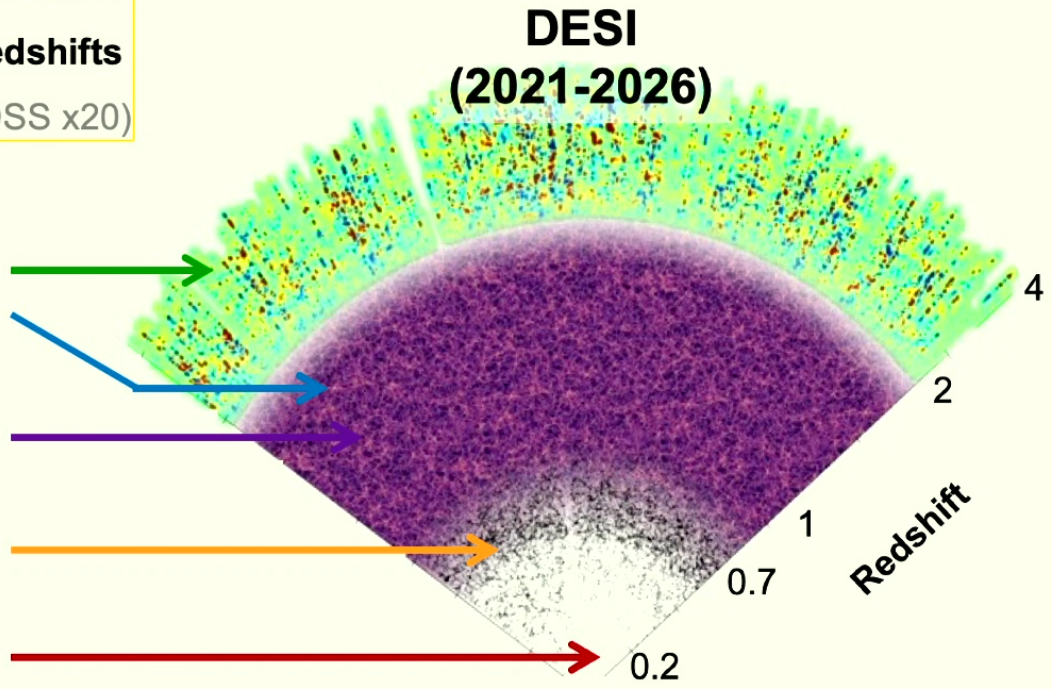
(SDSS x20)

2.4 million QSOs
Lyα $z > 2.1$
Tracers $1.0 < z < 2.1$

17 million ELGs
$0.6 < z < 1.6$

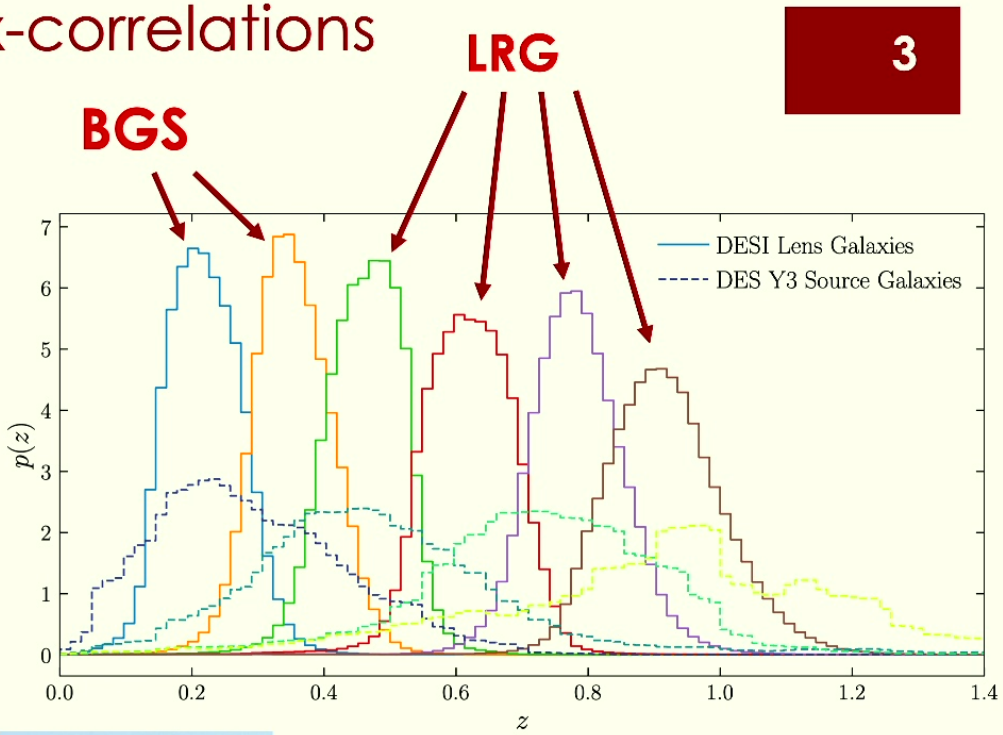
6 million LRGs
$0.4 < z < 1.0$

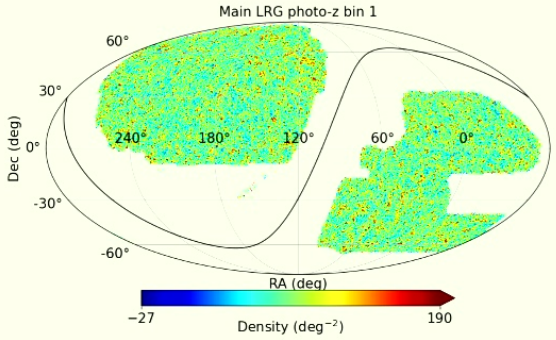
10 million Brightest galaxies
$0.0 < z < 0.4$



DESI photometric samples for x-correlations

- 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.





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

Rongpu Zhou

Photons interact with matter!

CMB lensing $$\left(\frac{\Delta T}{T}\right)_{\rm lensing} \propto \nabla\phi(\boldsymbol{\theta}) \cdot \nabla \left(\frac{\Delta T(\boldsymbol{\theta})}{T}\right)_{\rm primary}$$

kinematic SZ $$\left(\frac{\Delta T}{T}\right)_{\rm kSZ} \propto N_e(\boldsymbol{\theta}) \frac{v_r}{c}$$

column density of electrons

radial velocity

thermal SZ $$\left(\frac{\Delta T}{T}\right)_{\rm tSZ} \propto N_e(\boldsymbol{\theta}) T_e(\boldsymbol{\theta})$$

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

our team

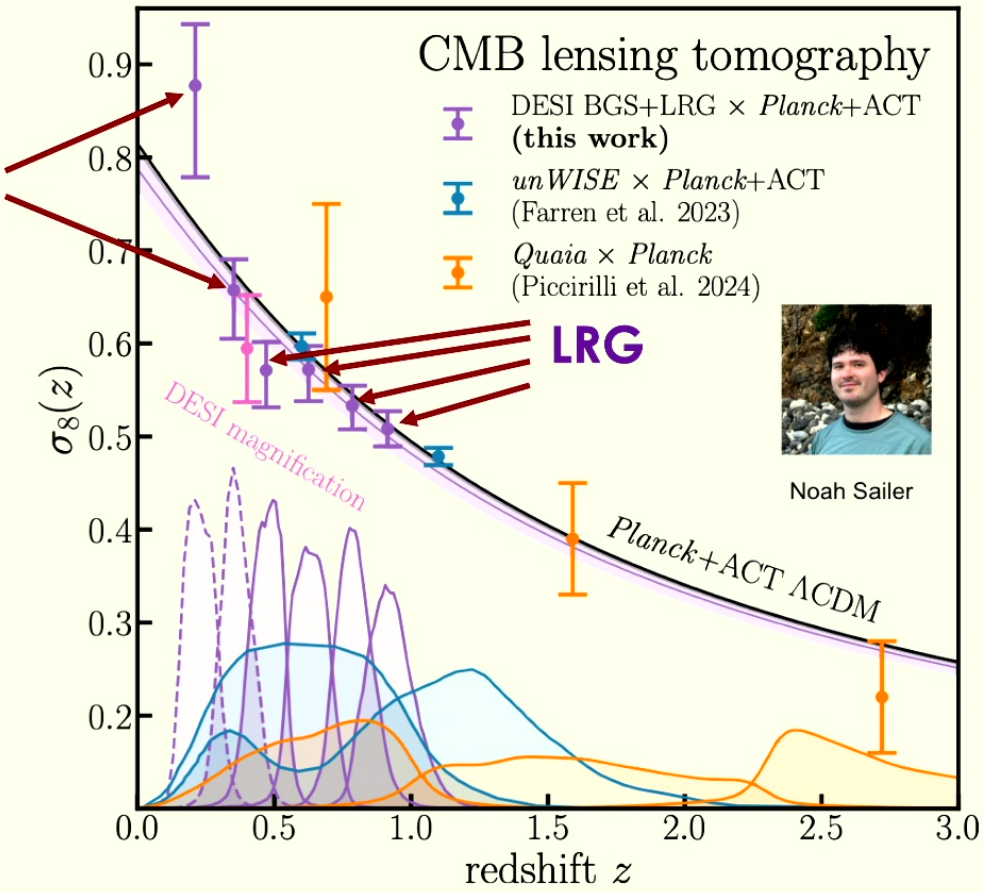
Ried Guachalla, Liu, Hadzhiyska, Schaan, Ferraro

Noah Sailer

Gerrit Farren

Growth of structure from DESI x CMB lensing (ACT + Planck)

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



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

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

kSZ from DESI LRGs

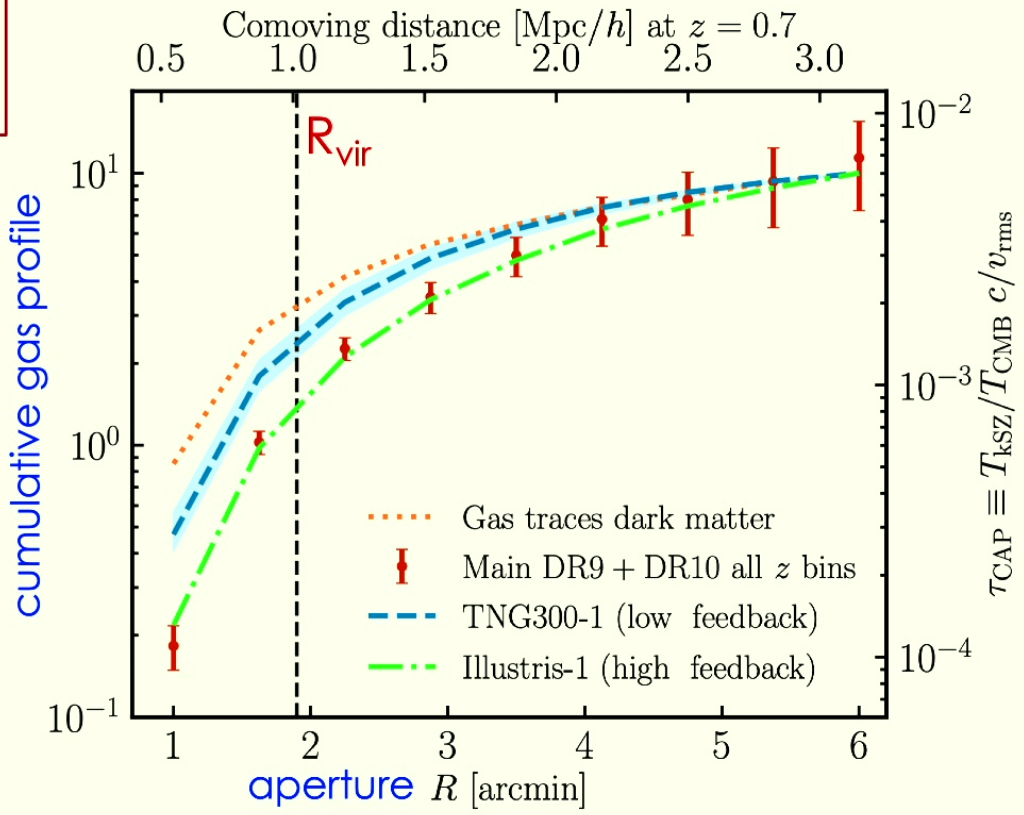
kinematic SZ $\left(\frac{\Delta T}{T}\right)_{\rm kSZ} \propto N_e(\boldsymbol{\theta})\ \frac{v_r}{c}$

Both photometric and spectroscopic analyses agree! Highest SNR to date and "dry run" for LSST.

Measured as a function of mass & redshift.

Some evidence of "large feedback" → Effect on weak lensing and matter power spectrum (details in progress). Subtleties in the interpretation (see Boryana's and Manu's talks)

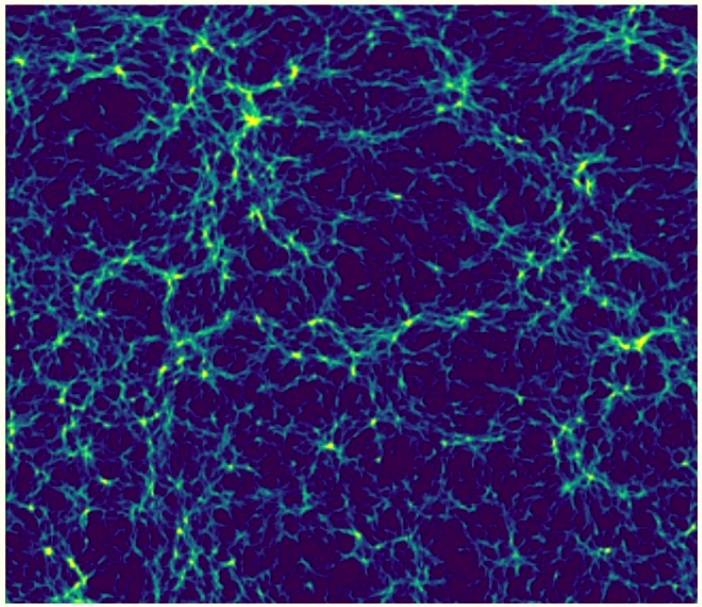
Much more to come with DESI Y3!



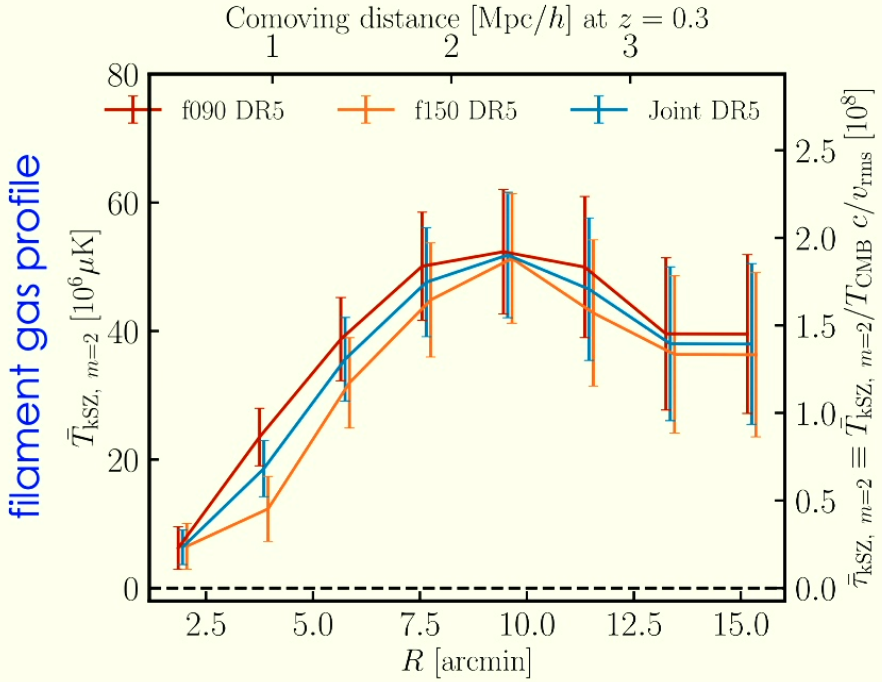
B. Hadzhiyska, S. Ferraro, B. Ried Guachalla, E. Schaan et al (photometric)
B. Ried Guachalla, E. Schaan, B. Hadzhiyska, S. Ferraro et al (spectroscopic)

Cosmic Gas in Filaments with BGS: kSZ

Orient stacking along filament and estimate quadrupole. First detection!



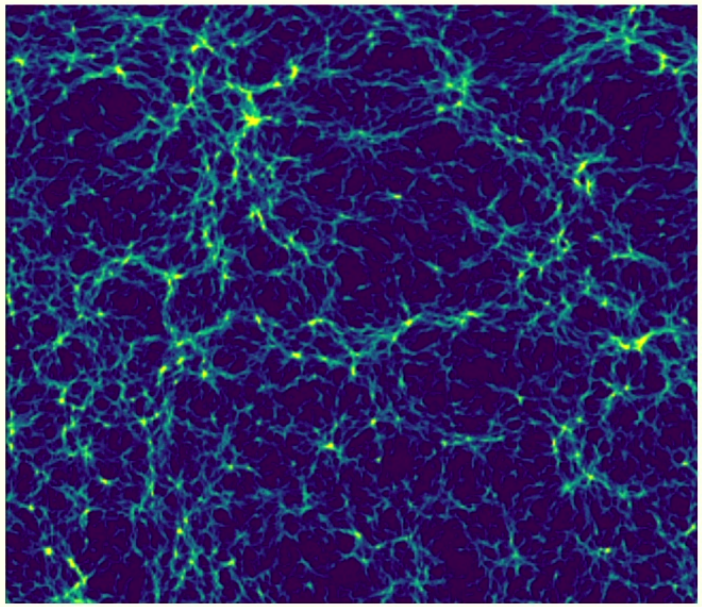
filament gas profile

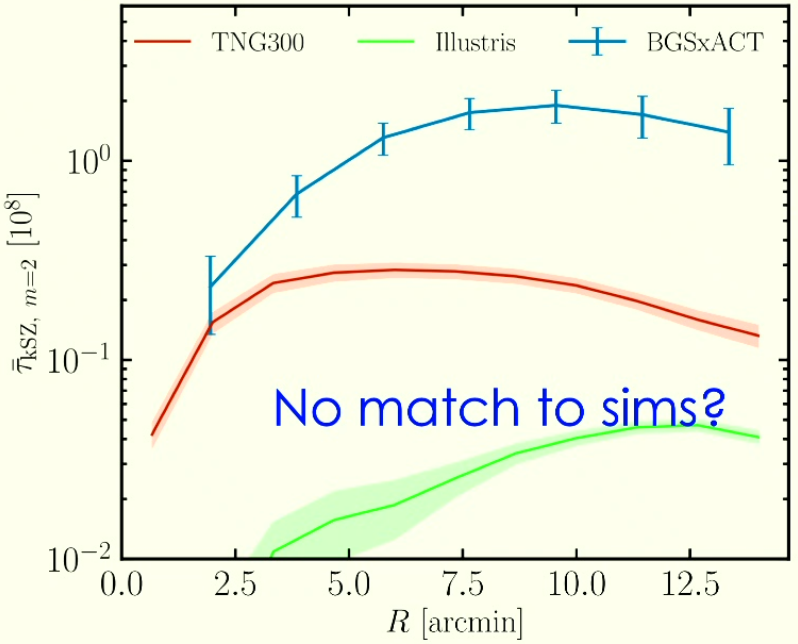


B. Hadzhiyska, S. Ferraro, R. Zhou (2024)

Cosmic Gas in Filaments with BGS: kSZ

Do hydro sims capture the anisotropy correctly?





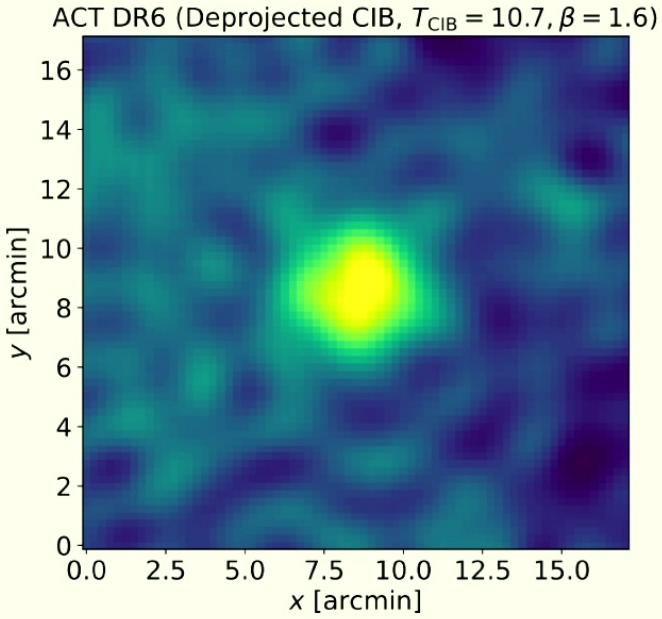
Evidence of anisotropic feedback? Stay tuned for much more to come!

B. Hadzhiyska, S. Ferraro, R. Zhou (2024)

The thermal SZ effect (tSZ)

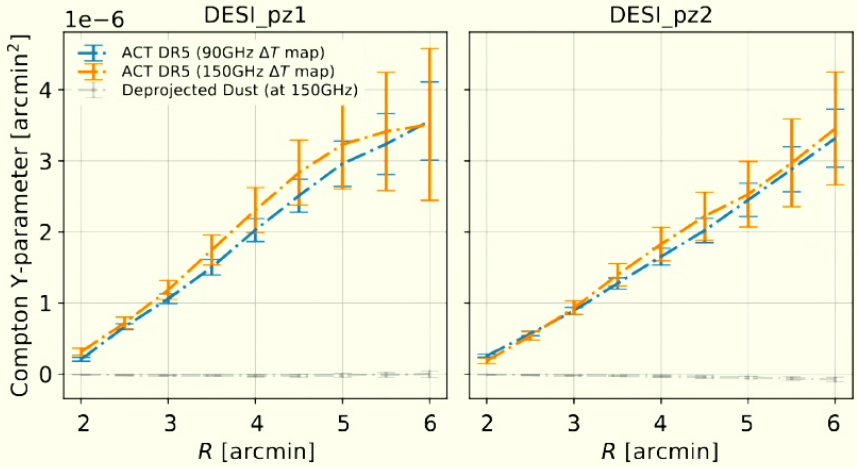
thermal SZ $\left(\frac{\Delta T}{T}\right)_{\rm tSZ} \propto N_e(\boldsymbol{\theta}) T_e(\boldsymbol{\theta})$ = thermal pressure

Henry Liu



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 at higher z



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

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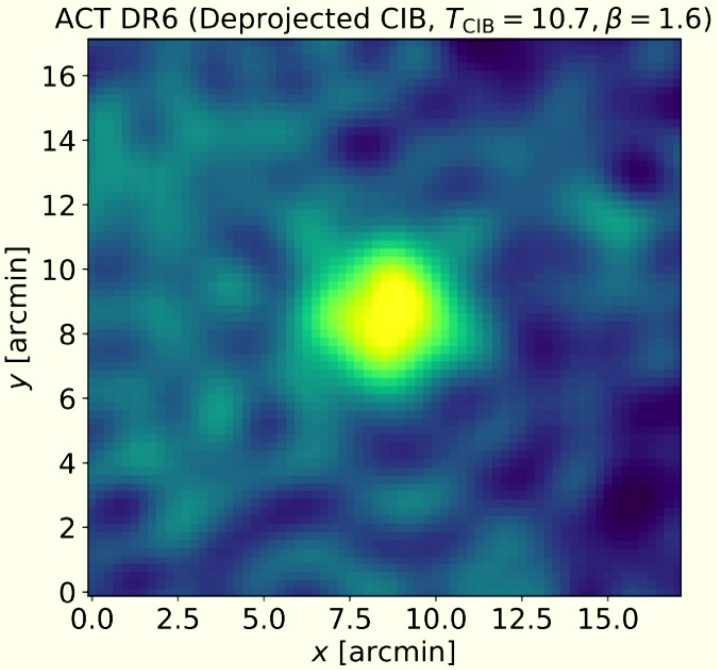

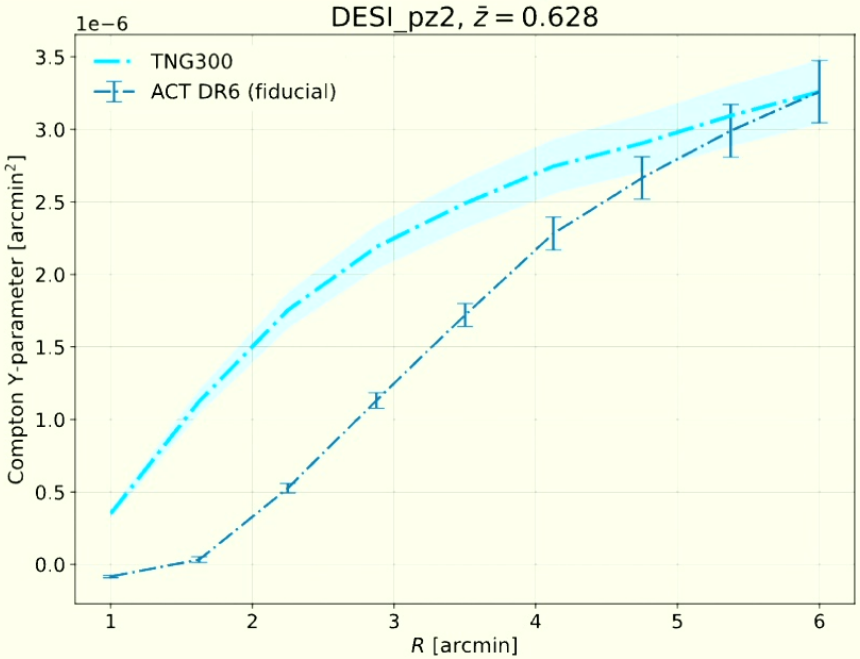

Evidence for "large" feedback?

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

Patchy (or anisotropic) screening

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

- 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 kSZ.

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]

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

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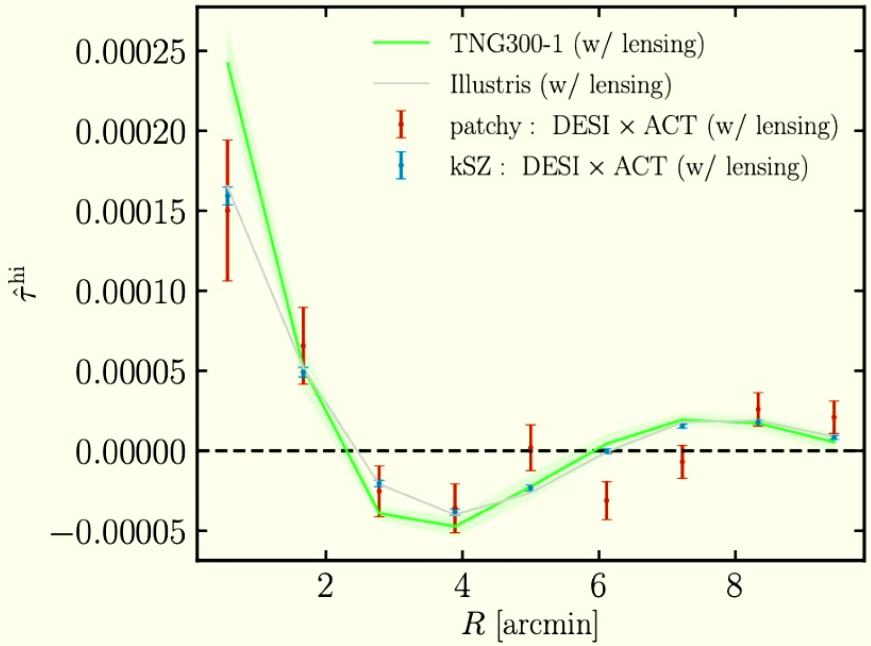
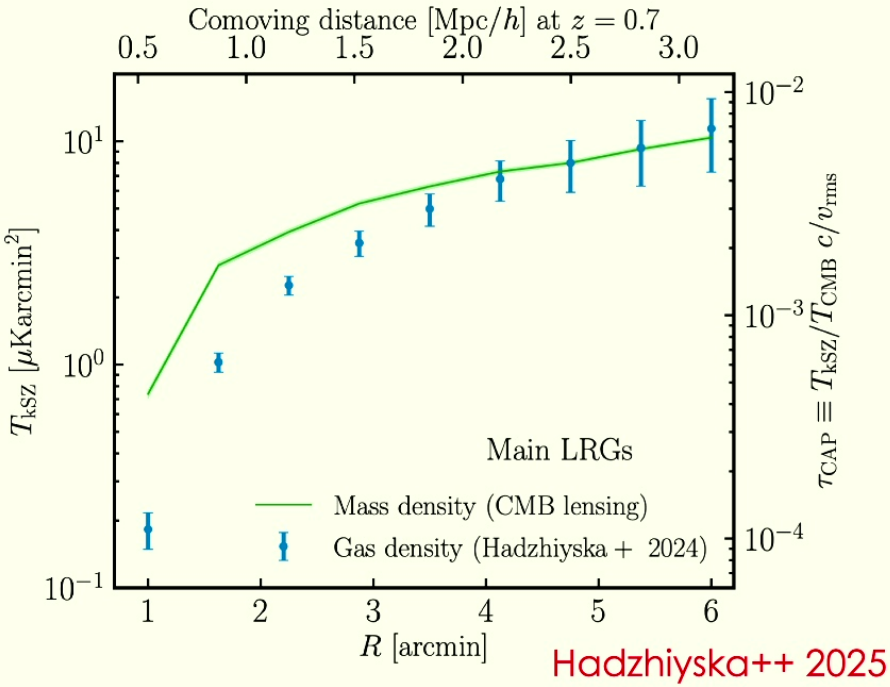


- kSZ and screening fully consistent
- Lensing can be modeled or mitigated successfully
- Screening also shows a preference for "large" feedback found with kSZ and tSZ

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

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

Interpreting it all…



Hadzhiyska++ 2025

Lensing measurement of the <u>same</u> sample
→ reduce model dependence
(miscentering, HOD, selection function etc).
See **Boryana's talk** this afternoon!

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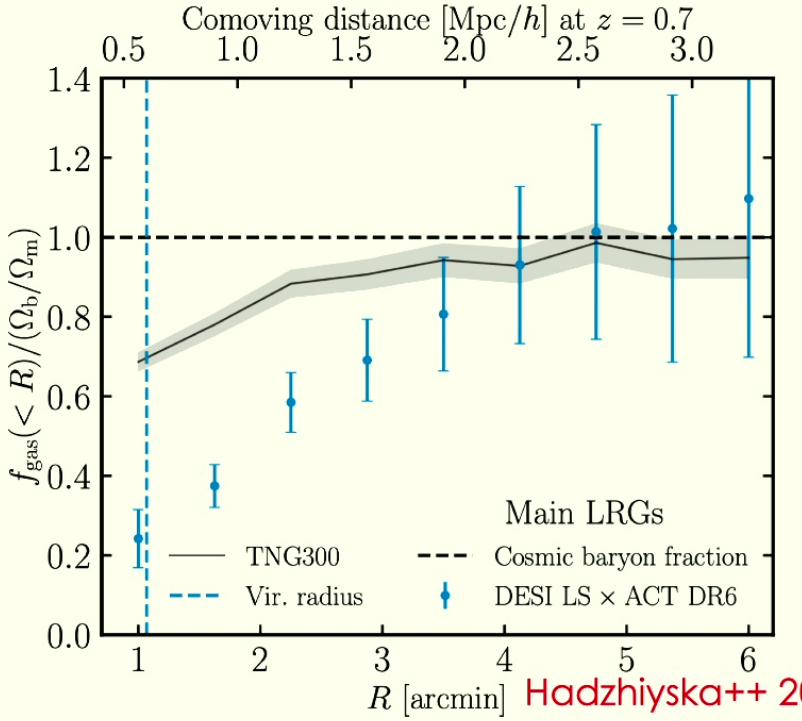

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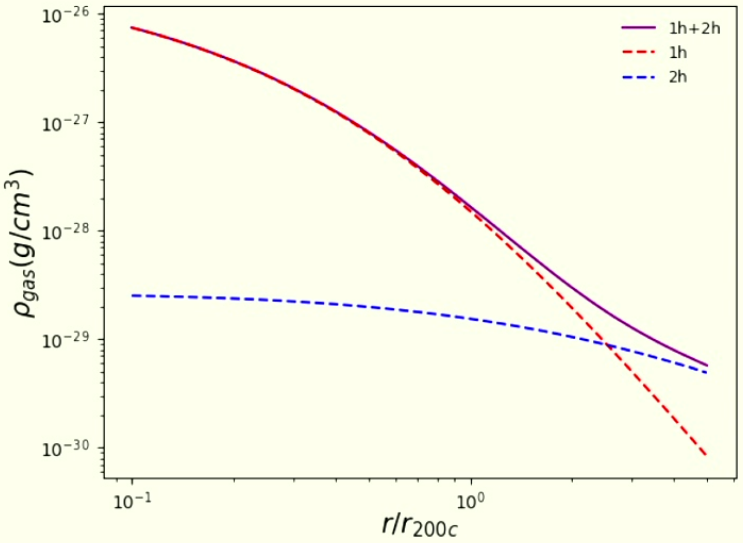


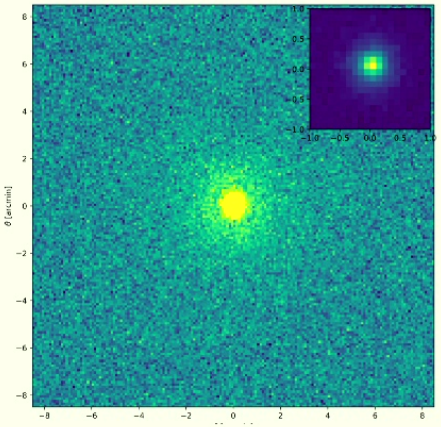
Amodeo+ 2020, Moser+ 2021, Sunseri+ 2024
+ lots of work by Ried Guachalla, Schaan, Hadzhiyska+

Need to model effects from galaxy-halo connection, 2h term, sample selection, HOD etc, when interpreting the results or comparing to simulations.
See **Manu's talk** next!

Complementary observations (only focusing on two for now)

X-ray

$$\mathrm{CR}(\boldsymbol{\theta}) \propto N_e^2(\boldsymbol{\theta})\; C(\boldsymbol{\theta})\; \Lambda_c(\epsilon, T_e(\boldsymbol{\theta}), Z(\boldsymbol{\theta})) + \mathrm{p.s.}$$



DESI LRGs with eROSITA

very high SNR!

Can a simple model explain all observations?

kSZ → N_e

tSZ / kSZ → T_e

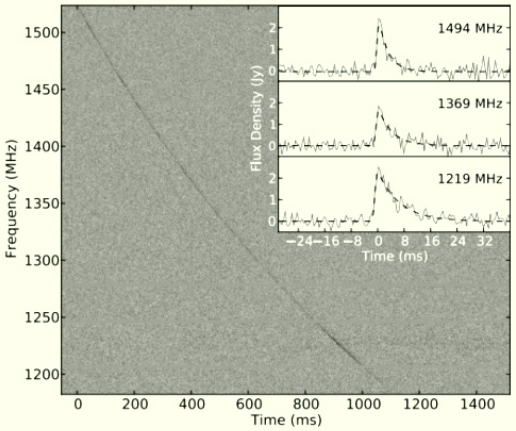
X-ray → $N_e^2\, F(T_e)$?

See **Gerrit's talk** for the answer!

Gerrit Farren

FRB

$$\mathrm{DM}(\boldsymbol{\theta}) \approx N_e(\boldsymbol{\theta})/(1+z) + \mathrm{DM}_{\mathrm{other}}$$



Highly complementary to kSZ, especially for large scales.

Need ~ 10^4 FRBs to improve over kSZ at ~ $2R_{vir}$. Excellent probe of the "2-halo" term.

Independent of velocity!

A CMB view of DESI galaxies

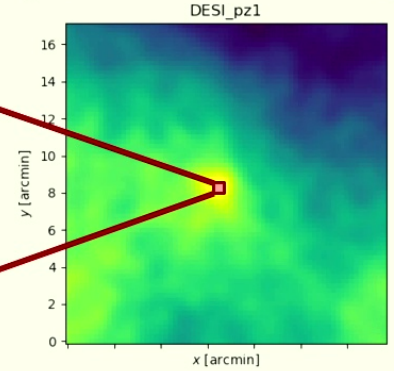
gas density
(kSZ and screening)

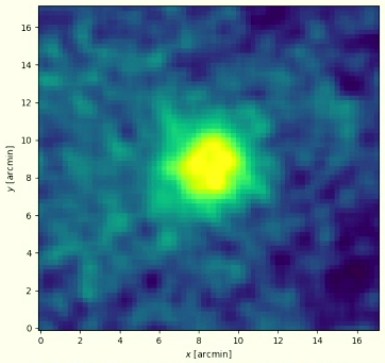
thermal pressure
(tSZ)

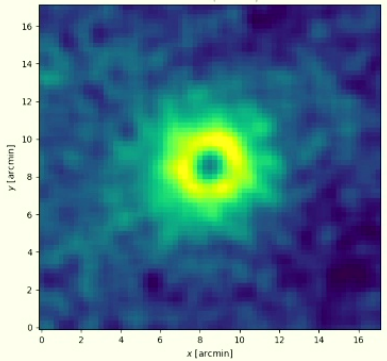
thermal pressure + dust
(tSZ + CIB)

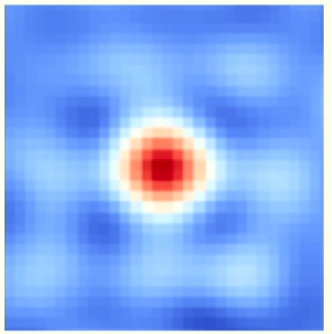
mass
(CMB lensing)

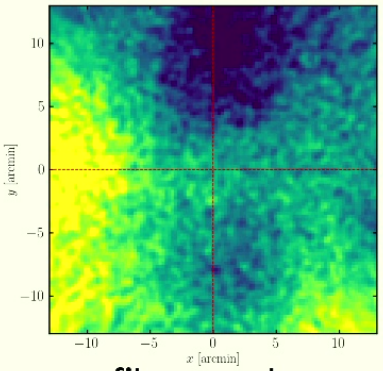
stars



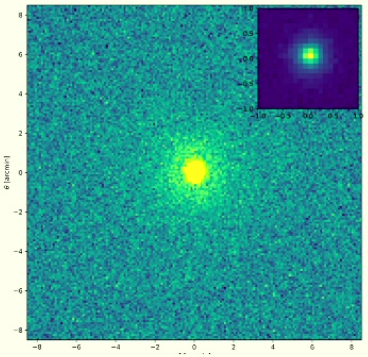








filaments
(kSZ)



hot gas
(X-ray)

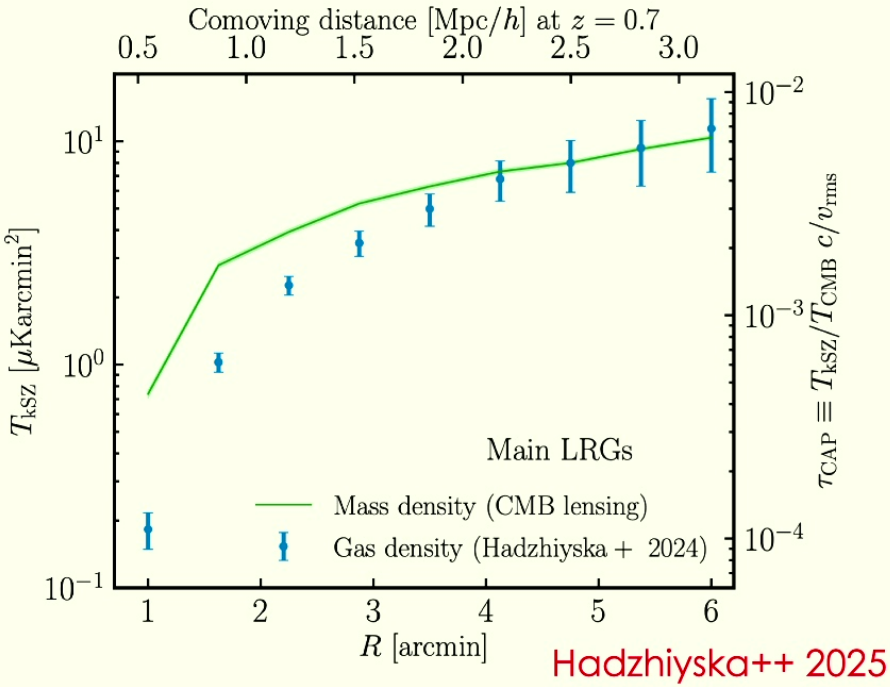
Ried Guachalla, Liu, Hadzhiyska, Schaan, Ferraro

Noah Sailer

Gerrit Farren

+ DESI and ACT collaborators

Interpreting it all…



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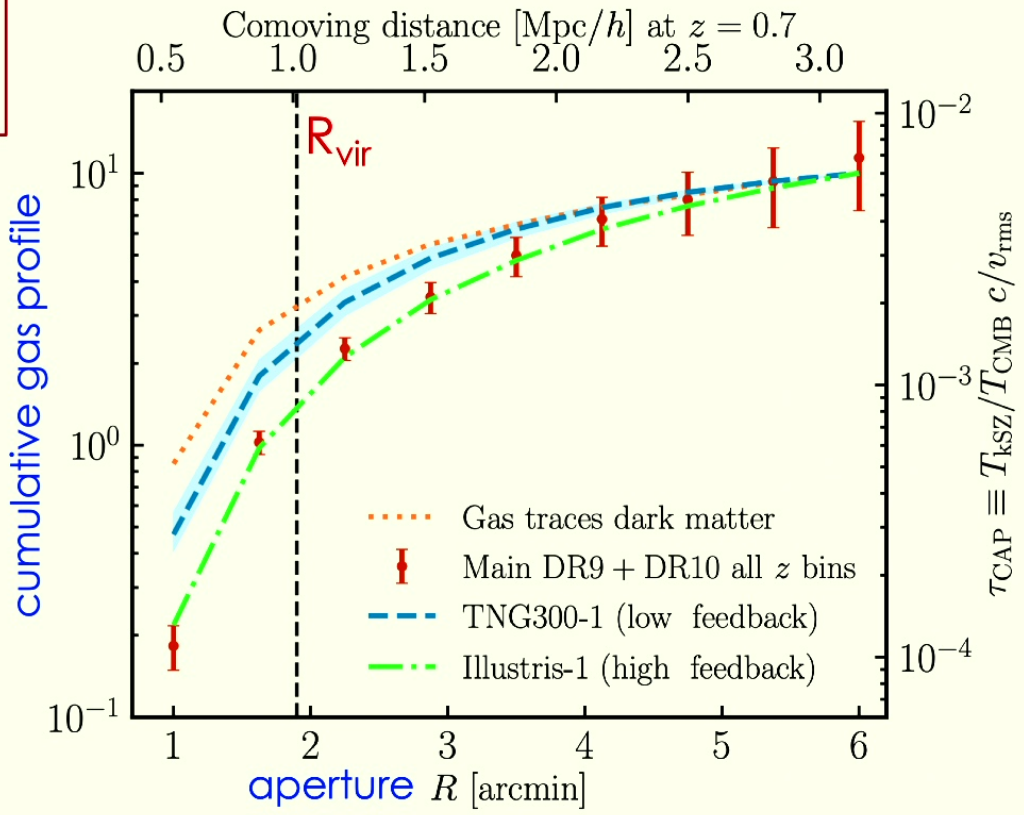
Much more to come with DESI Y3!



B. Hadzhiyska, S. Ferraro, B. Ried Guachalla, E. Schaan et al (photometric)
B. Ried Guachalla, E. Schaan, B. Hadzhiyska, S. Ferraro et al (spectroscopic)

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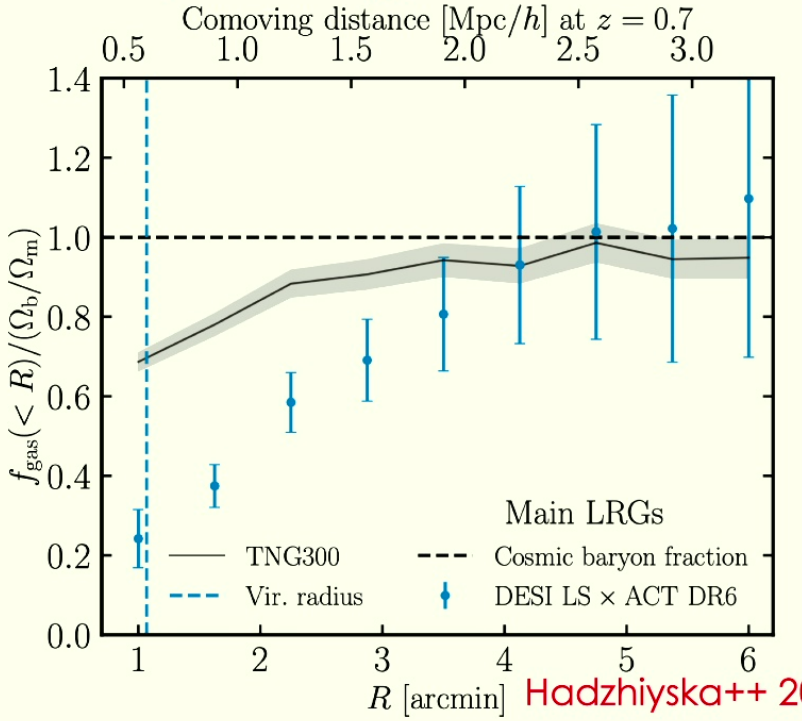

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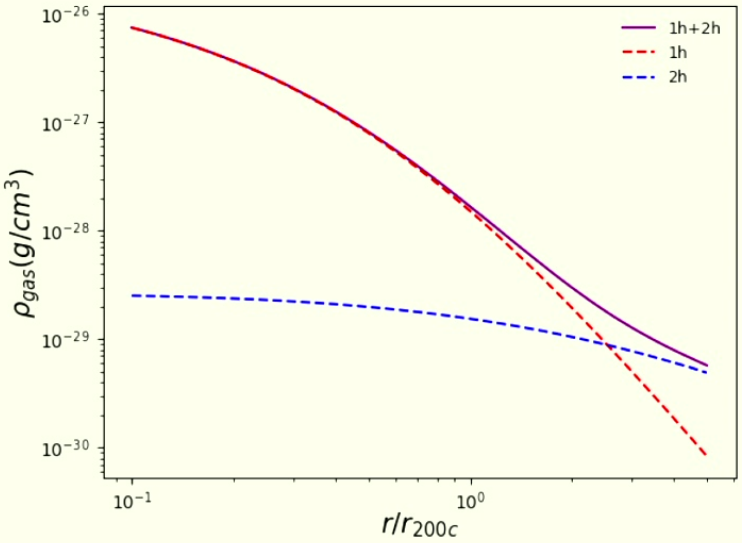

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