The Cosmic Microwave Background as a Backlight II

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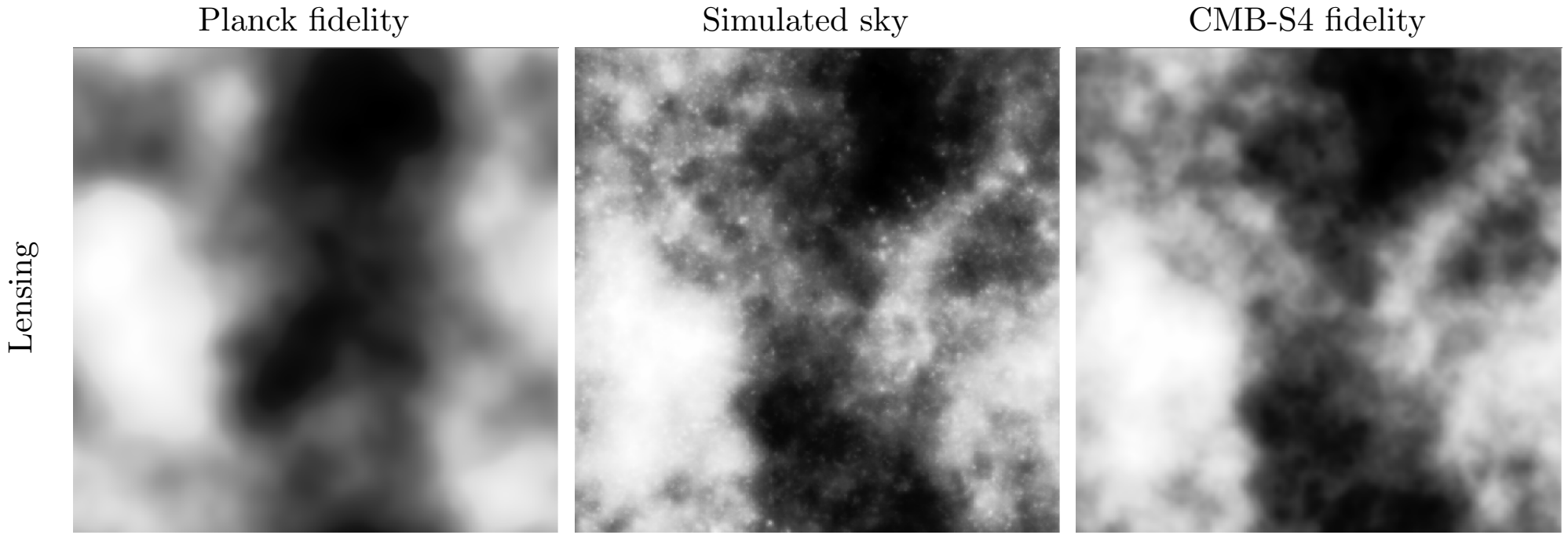
CMB Lensing

A map of all the matter in the Universe, in projection

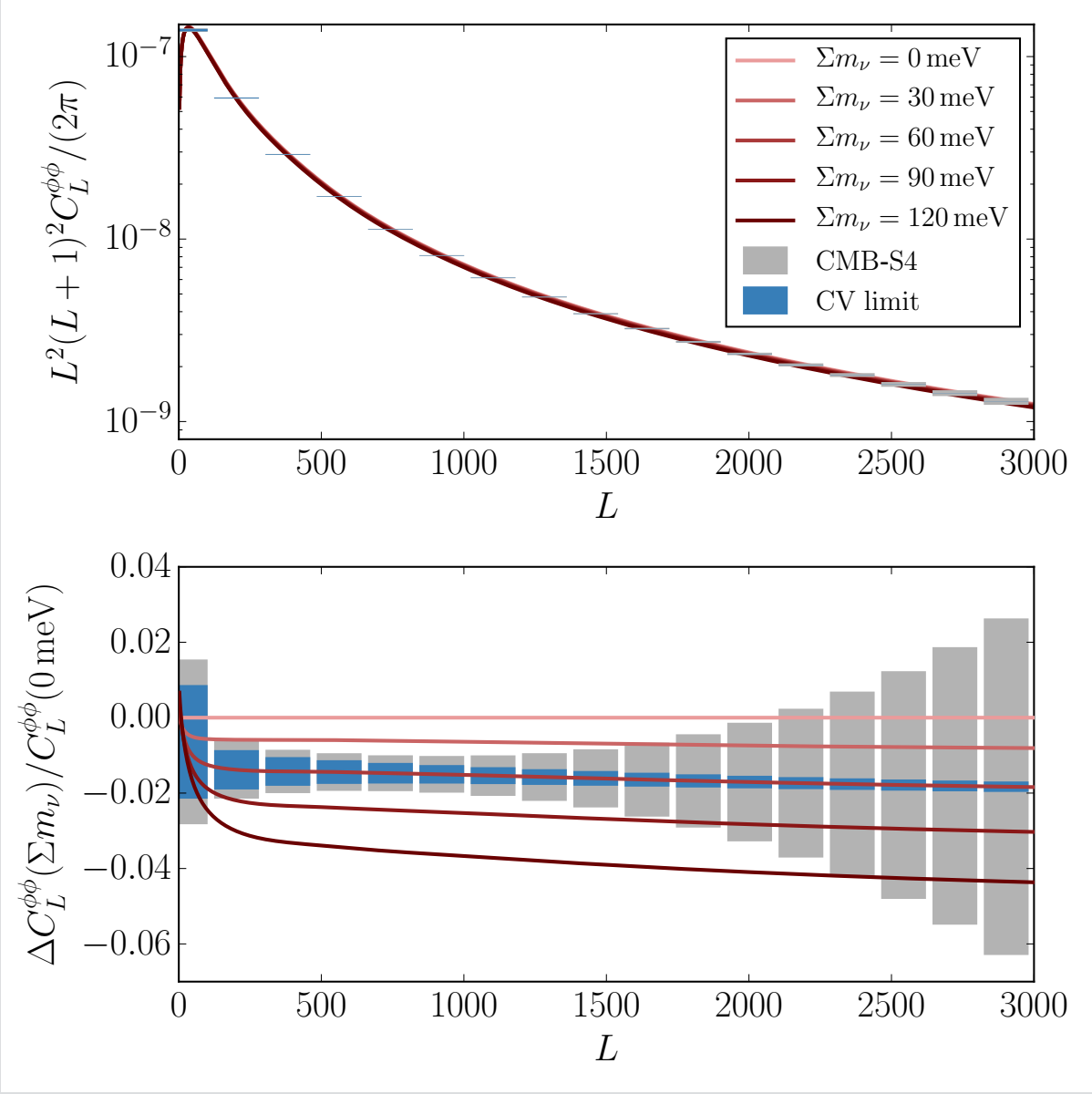


CMB-S4 DSR report (2019)

CMB Lensing

500σ
~0.2% precision

$\sigma(\Sigma m_\nu) \sim$ 15-30 meV
(minimal is 60 meV)



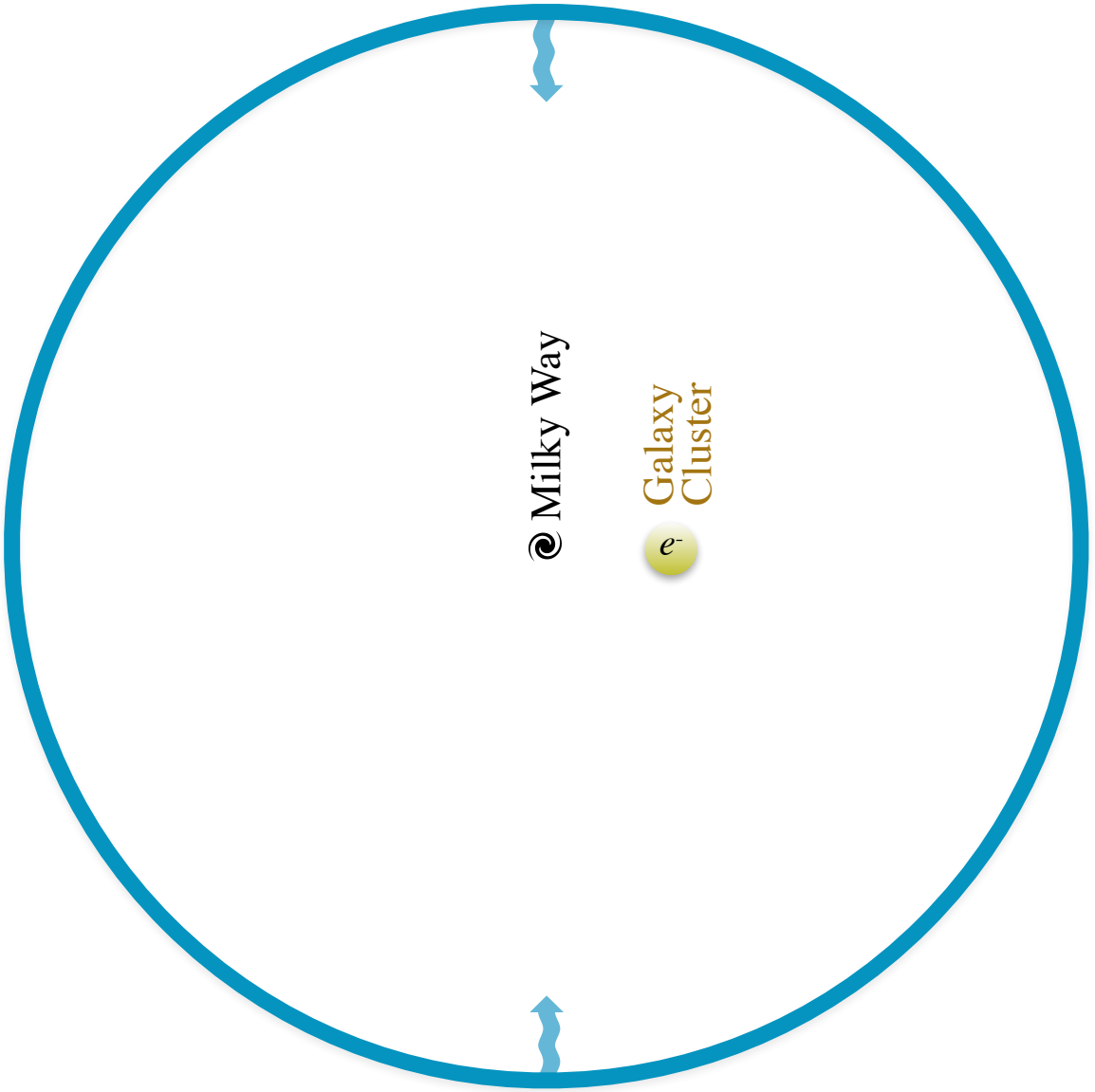
See talk by Boryana Hadzhiyska

CMB-S4 science book (2016)

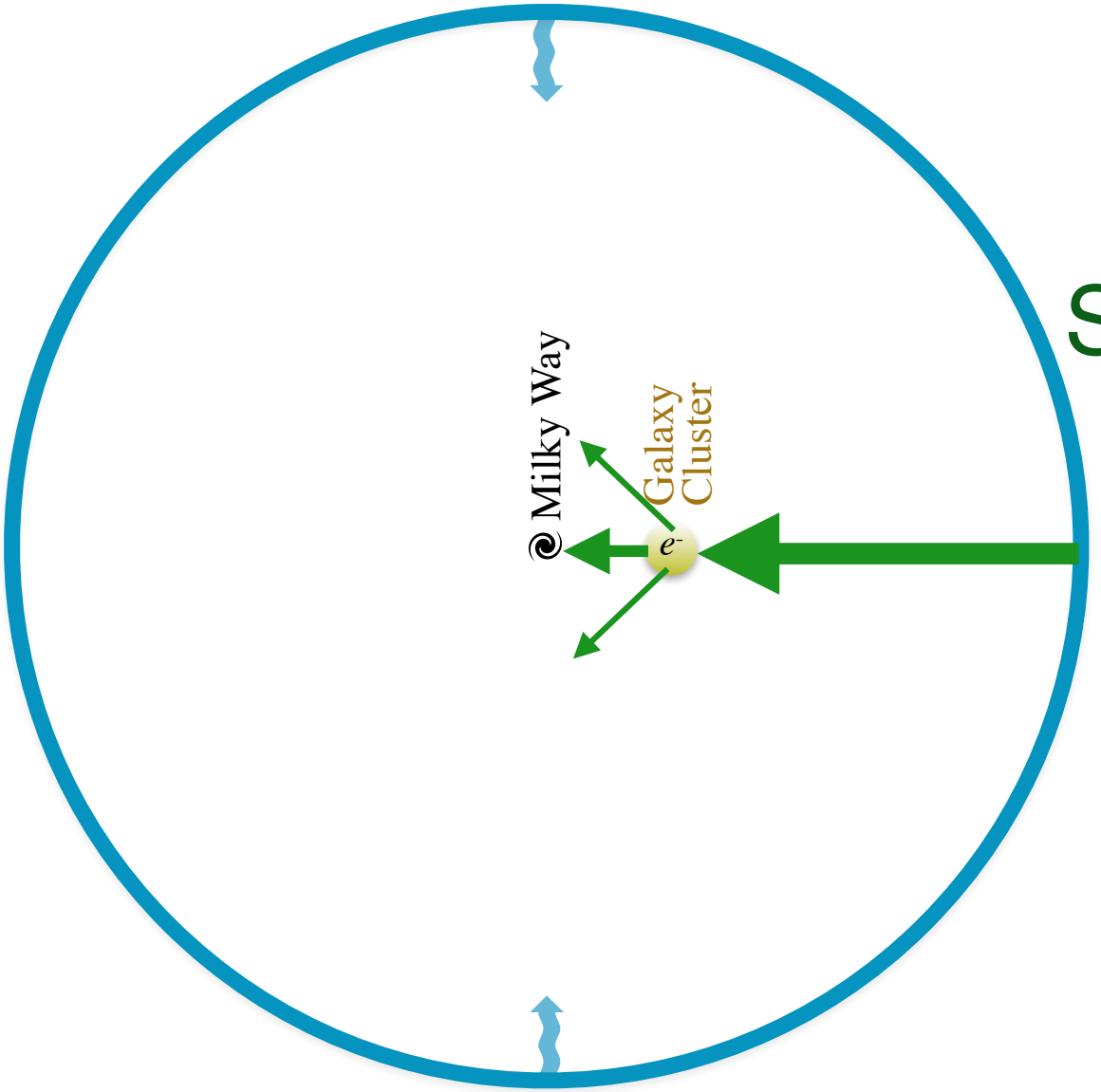
CMB Lensing Challenges

- ESTIMATORS
  The most broadly-used estimator (Hu and Okamoto 2002) is not optimal for CMB-S4's low noise!
  - Several next-gen approaches available (Carron & Lewis 2018, Millea, Anderes, Wandelt 2019, Millea+ 2021, Hadzhiyska+ 2019)
- BARYONIC FEEDBACK (AGN, SNe)
  is a concern (Chung, Foreman, AvE 2020) but can likely be mitigated (McCarthy, Foreman, AvE 2020)
- FOREGROUNDS
  Several mitigation methods available (Osborne+2013, Madhavacheril & Hill 2018, Schaan & Ferraro 2018, Sailer+2020)

Patchy τ



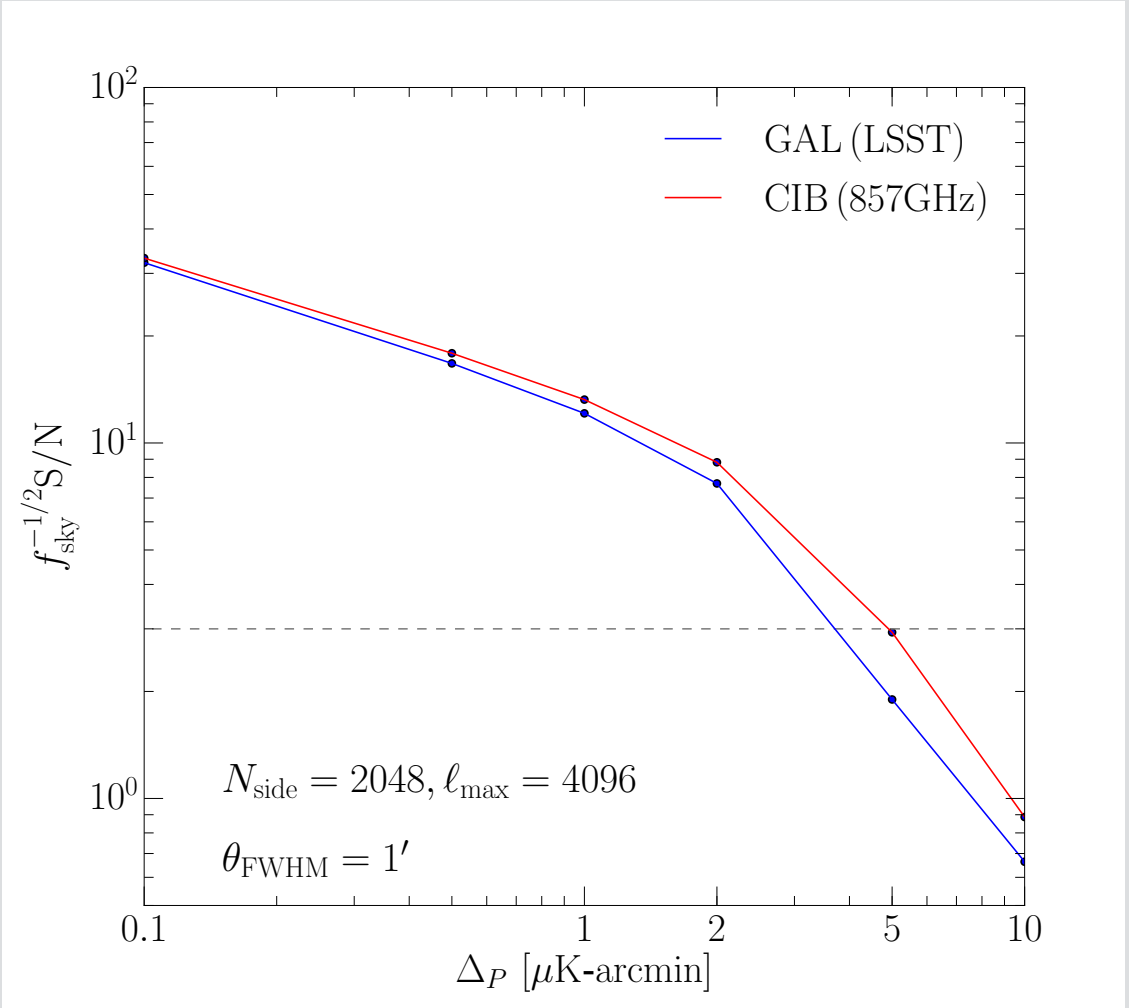
Patchy τ



Screening

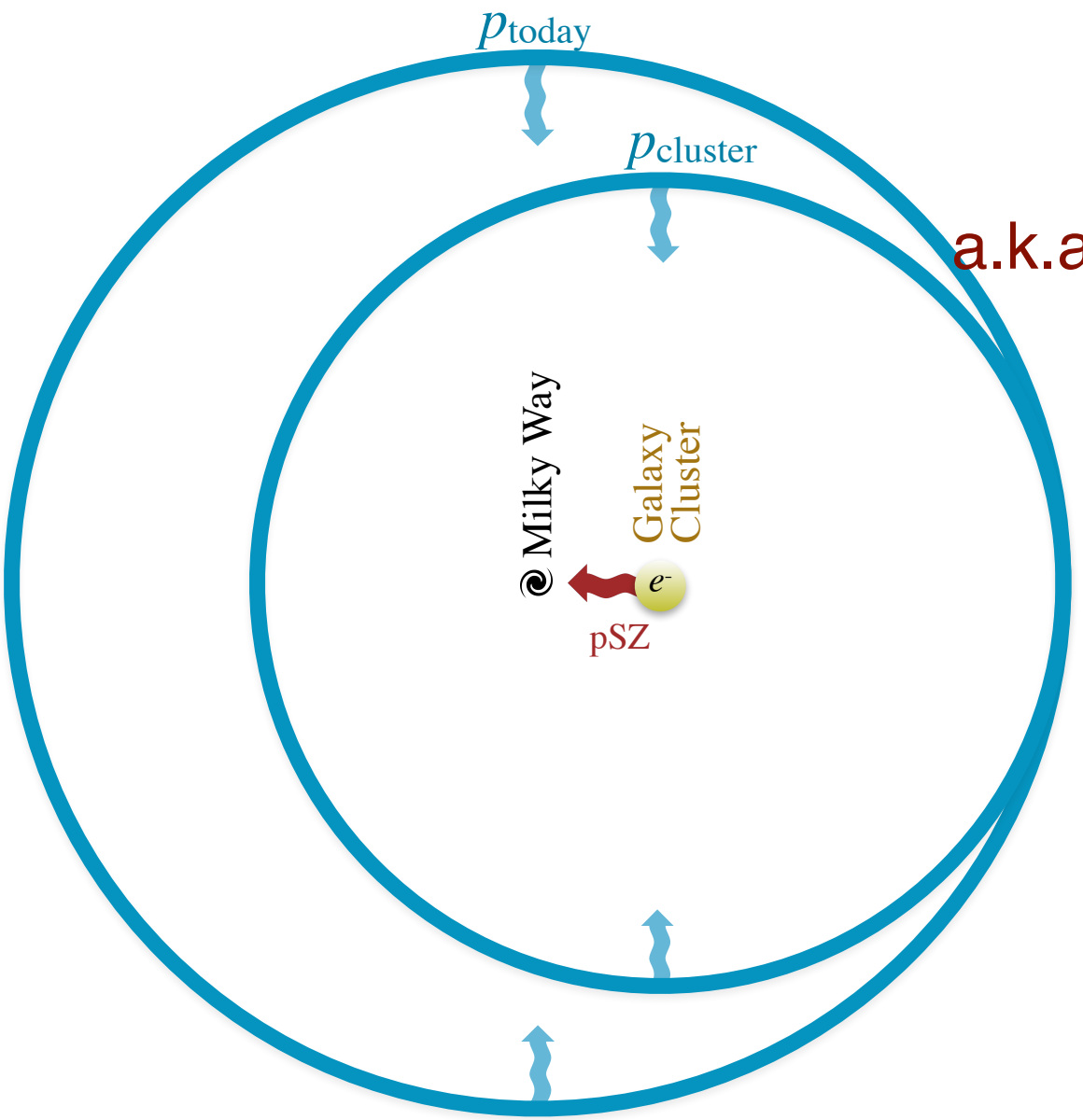
Patchy τ Screening

- Reconstructed τ maps from patchy screening (Dvorkin & Smith 2009)
- ~10σ correlation with Rubin galaxy sample at z<1 (Feng & Holder 2018)
- ~4-17σ correlation with 21cm from reionization (HERA,SKA) depending on foreground treatment / contamination (Roy+2020)
- Also correlated with Compton-y (Namikawa+2021)



Feng & Holder 2018

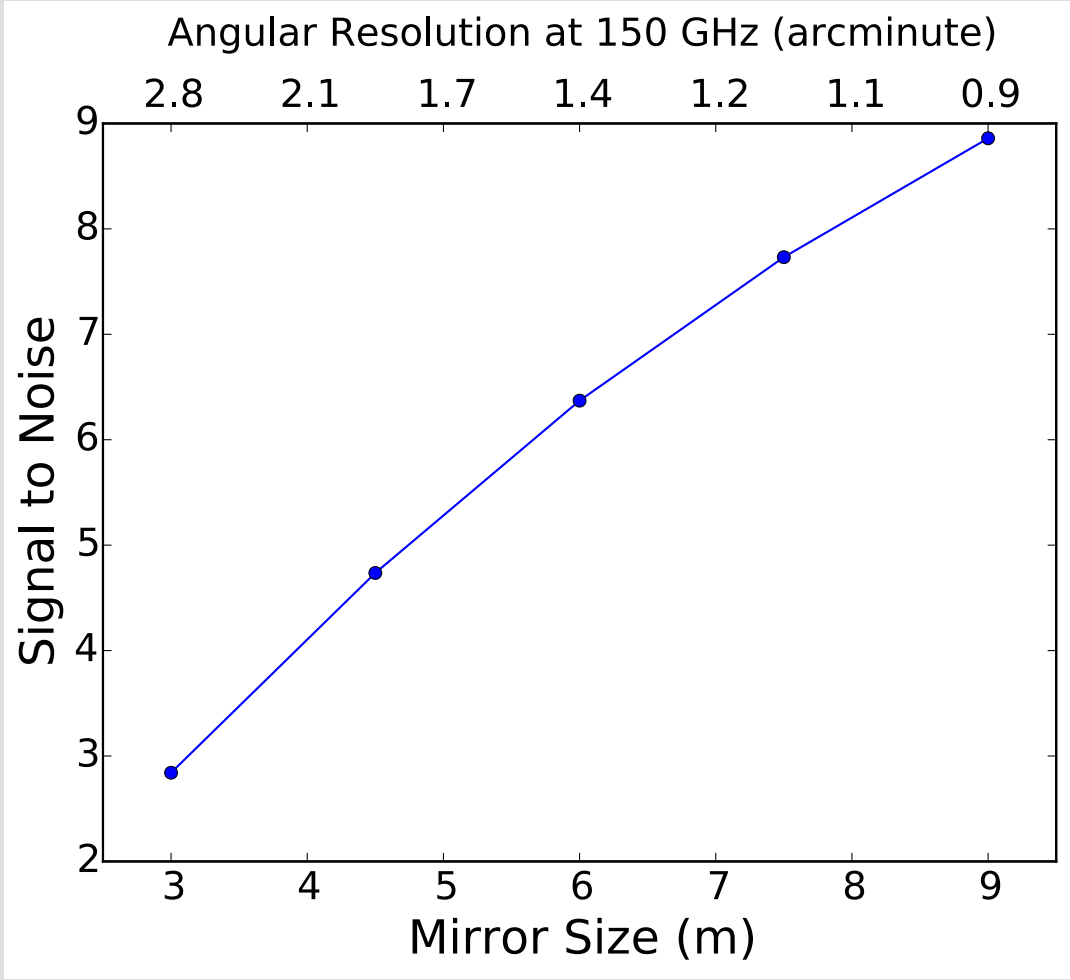
Patchy τ



Scattering
a.k.a. Polarized SZ

Patchy τ Scattering

- We will detect the polarized quadrupole scattering (pSZ) from the S4-selected clusters (Louis+2017)



Louis+2017
See also Hall & Challinor 2014

Non-Gaussianity

- Primordial scalar NG:
  still some improvement over *Planck* possible

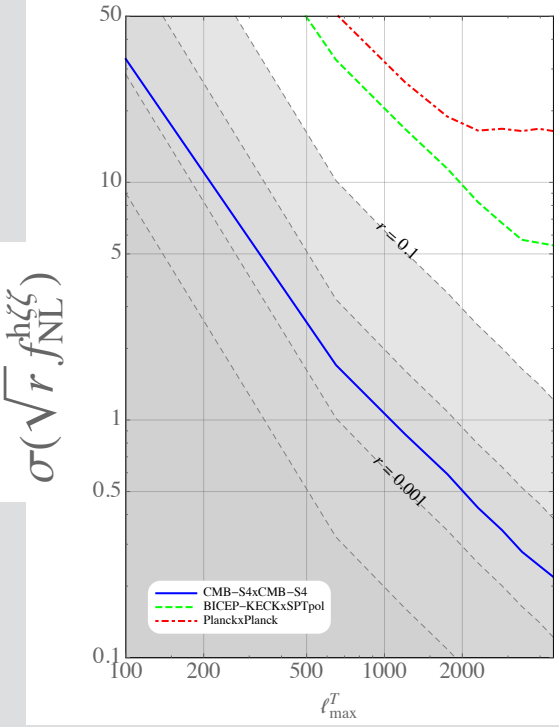
Type	*Planck* actual (forecast)	CMB-S4	CMB-S4 + low-ℓ *Planck*	Rel. improvement
Local	$\sigma(f_{\rm NL}) = 5\,(4.5)$	$\sigma(f_{\rm NL}) = 2.6$	$\sigma(f_{\rm NL}) = 1.8$	2.5
Equilateral	$\sigma(f_{\rm NL}) = 43\,(45.2)$	$\sigma(f_{\rm NL}) = 21.2$	$\sigma(f_{\rm NL}) = 21.2$	2.1
Orthogonal	$\sigma(f_{\rm NL}) = 21\,(21.9)$	$\sigma(f_{\rm NL}) = 9.2$	$\sigma(f_{\rm NL}) = 9.1$	2.4

CMB-S4 Science Book (2016)

- Primordial tensor NG:
  Low B-mode noise with S4 will allow for new constraints on e.g. <BTT> bispectra

See talk by Will Coulton

<BTT> bispectrum



Planck x Planck

BICEP x SPTpol

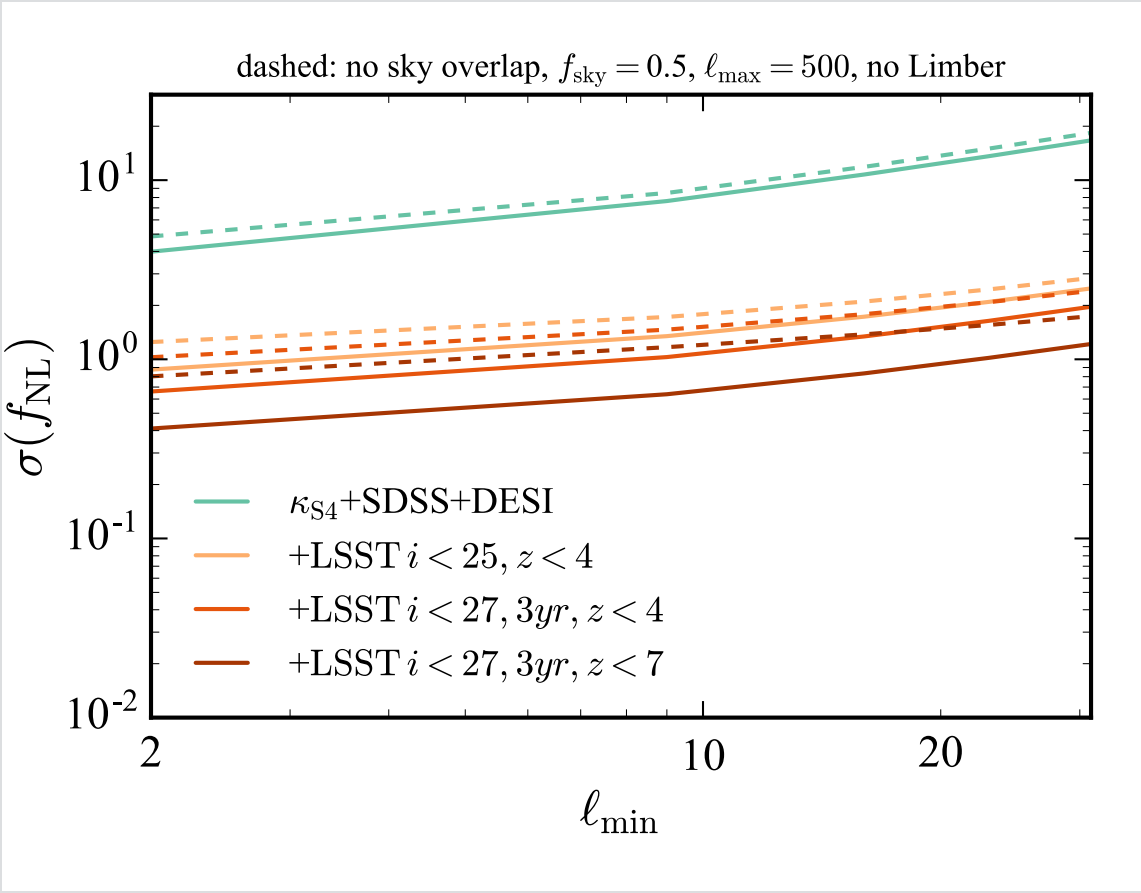
CMB-S4 x CMB-S4

Meerburg, Meyers, AvE, Ali-Haimoud 2016

See also Duivenvoorden+ 2020

Non-Gaussianity

- f_{NL} from scale-dependent halo bias (Dalal+ 2007)
- CMB-S4 lensing maps can be used with e.g. the Rubin Survey to achieve $\sigma(f_{NL})\sim1$

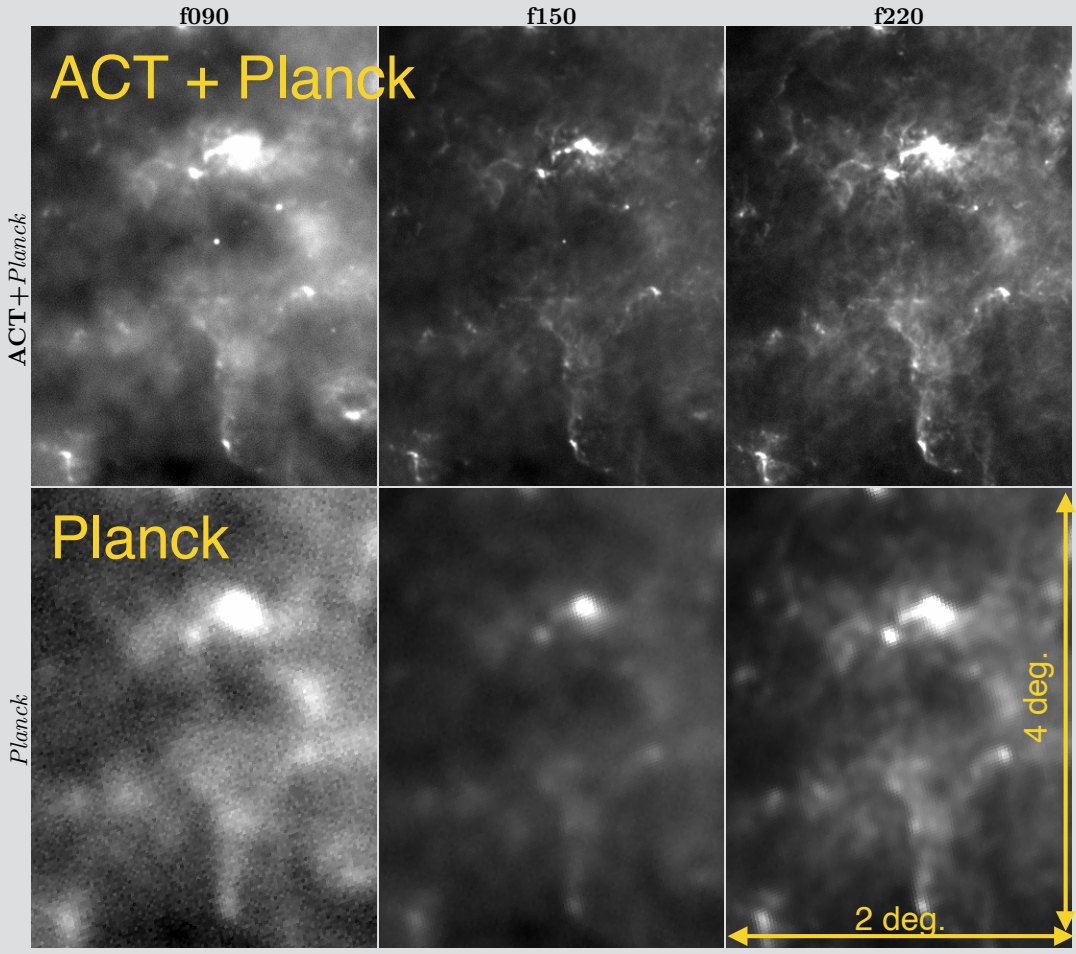


Schmittfull & Seljak 2018

Galactic Science

- High-resolution maps from the ground reveal detail not seen by *Planck*!
- Studying magnetic fields in star-forming regions
- Turbulence, coupling between gas and dust

See talk by Susan Clark



ACT DR5 maps
Naess+ (ACT) 2021

Dust in galaxies

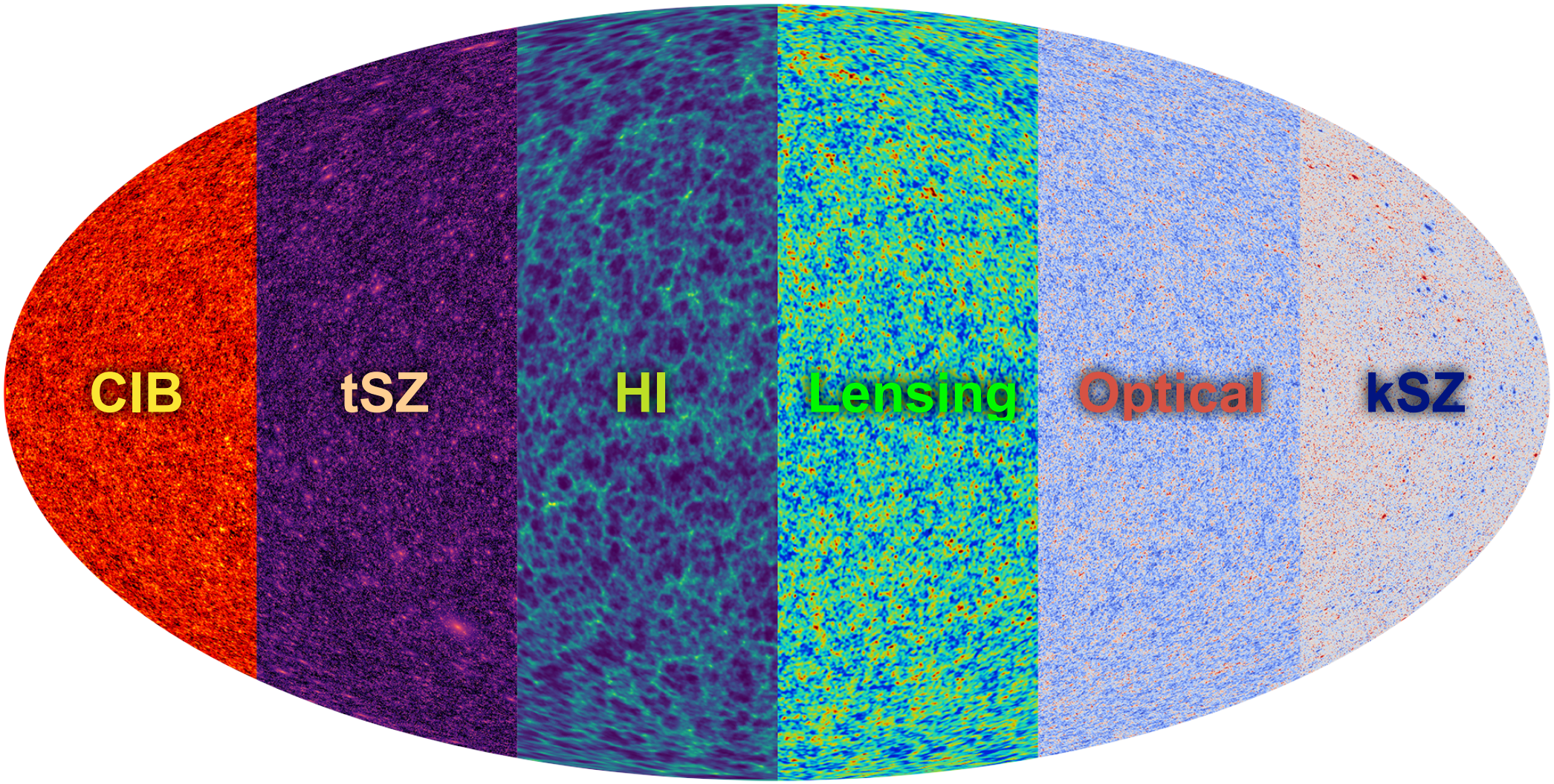
Hot electrons in galaxy clusters

Neutral hydrogen in galaxies

CMB lensing mass

Starlight from galaxies

Free electrons in galaxies



The CMB as a Backlight

Websky Sims from Stein, Alvarez, Bond, AvE, Battaglia 2020