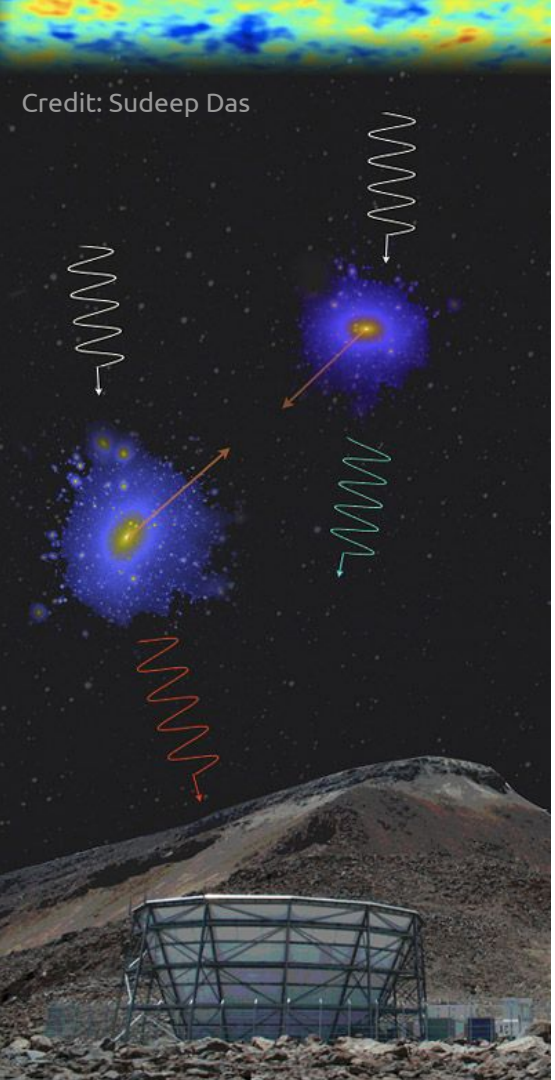
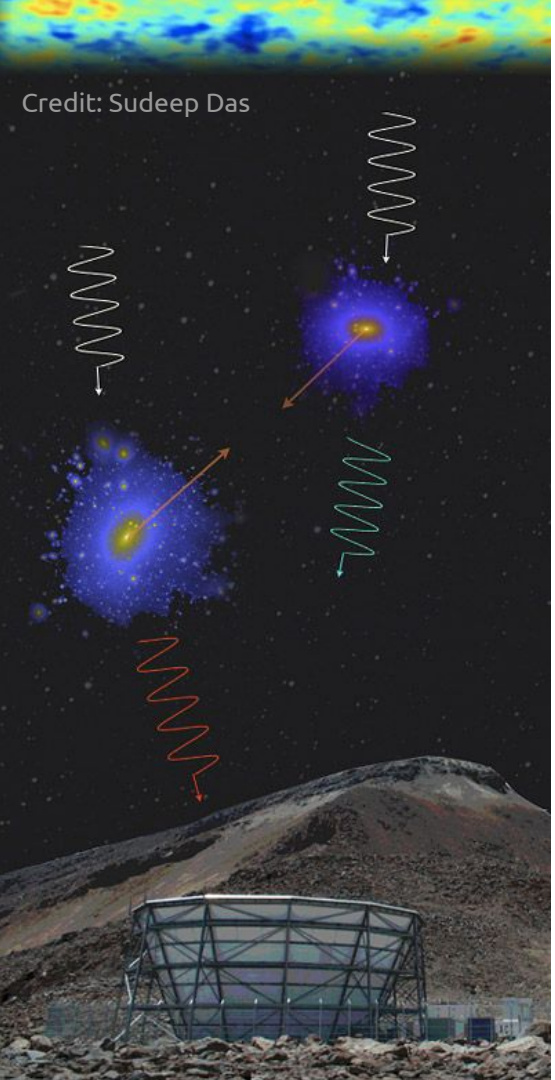


kSZ x Galaxies

Mathew Madhavacheril
Perimeter Institute



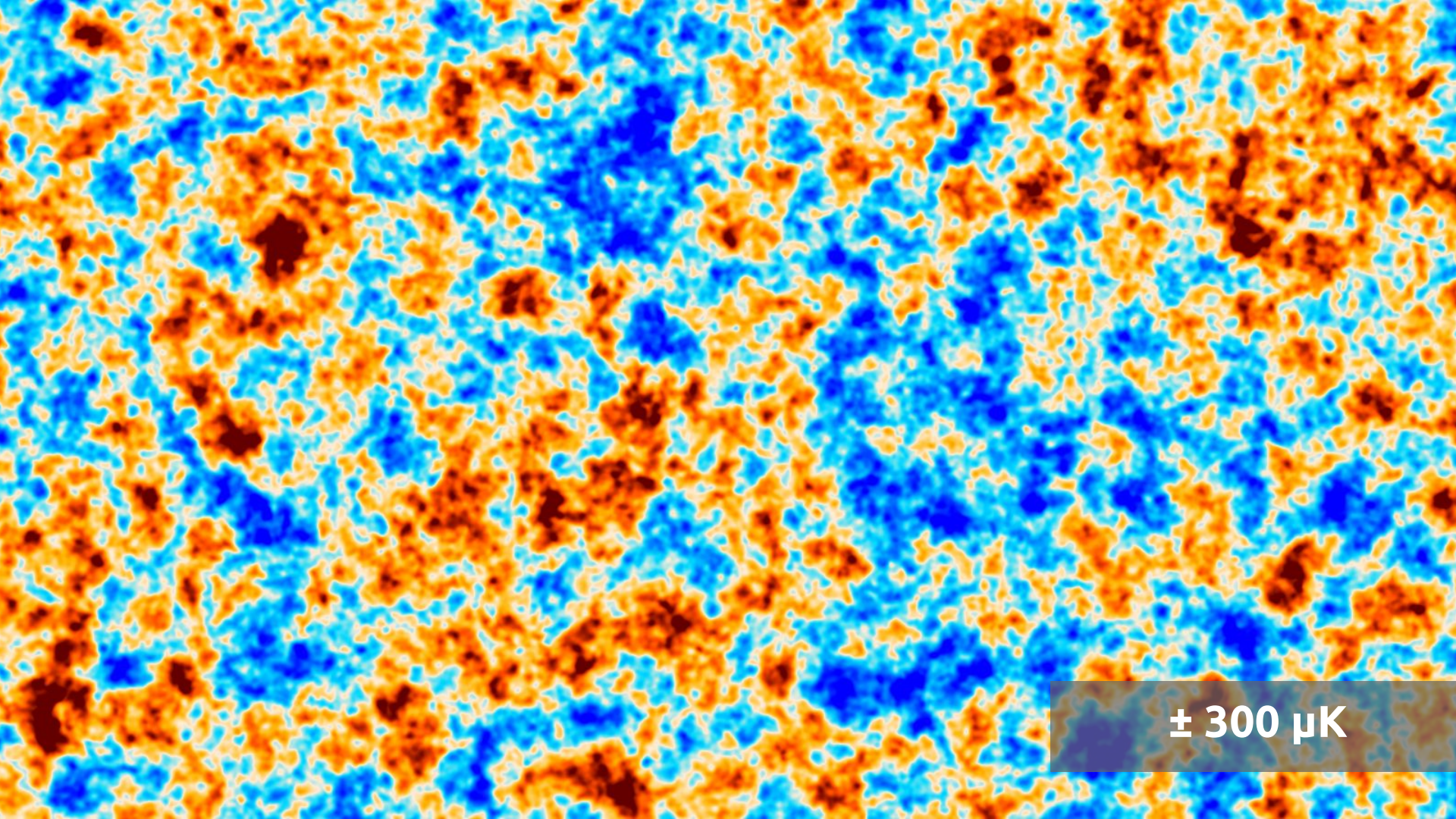
Moving electrons leave an imprint in the CMB

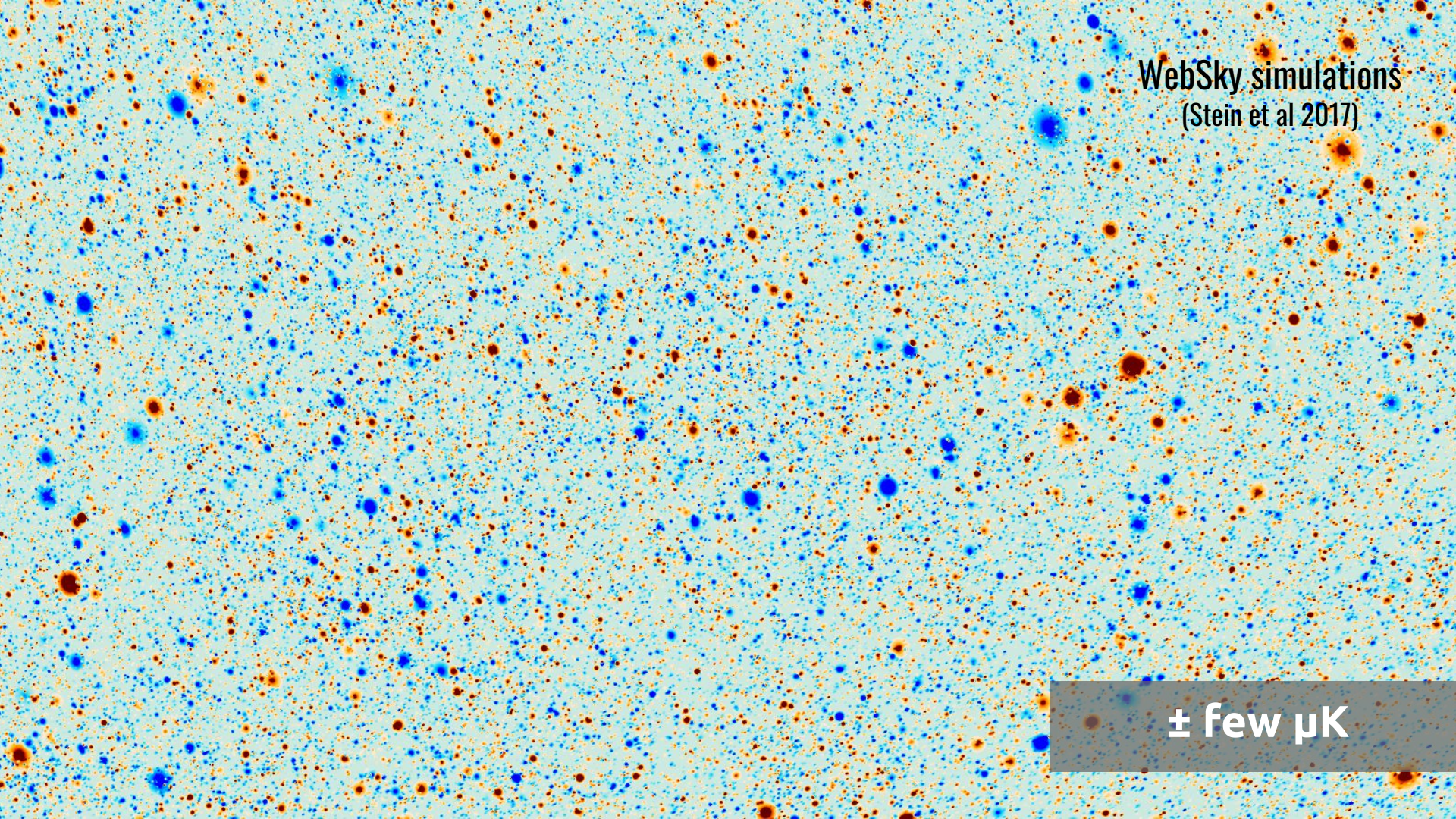
kinematic SZ: Doppler shift of CMB photons scattering off electrons with bulk velocity

$$\frac{\Delta T_{\rm kSZ}(\vec{\mathbf{n}})}{T_{\rm CMB}} \sim \int d\chi e^{-\tau(z)} v_r \delta_e(\vec{\mathbf{n}}, \chi)$$

Contributions from
ionized gas in and between clusters 0 < z < 6
(also from reionization, but not in this talk!)

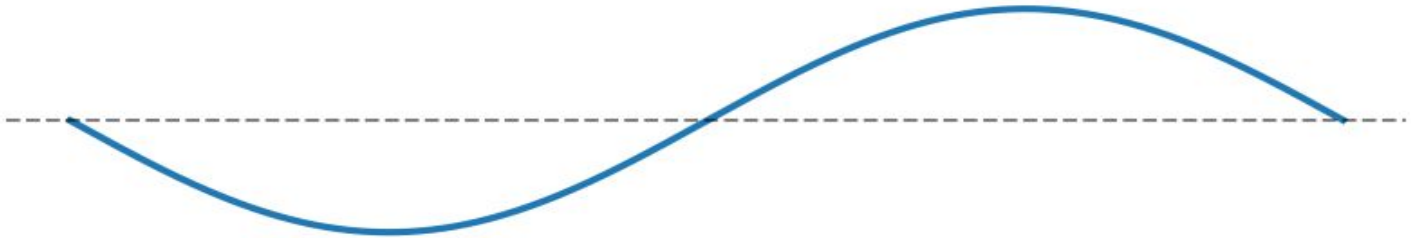
Currently detected only at the <**10 sigma** level
But expected to improve quickly with deeper CMB (S4!) and large volume galaxy surveys (e.g. VRO, DESI).
SNR O(100-1000) expected!


± 300 μK

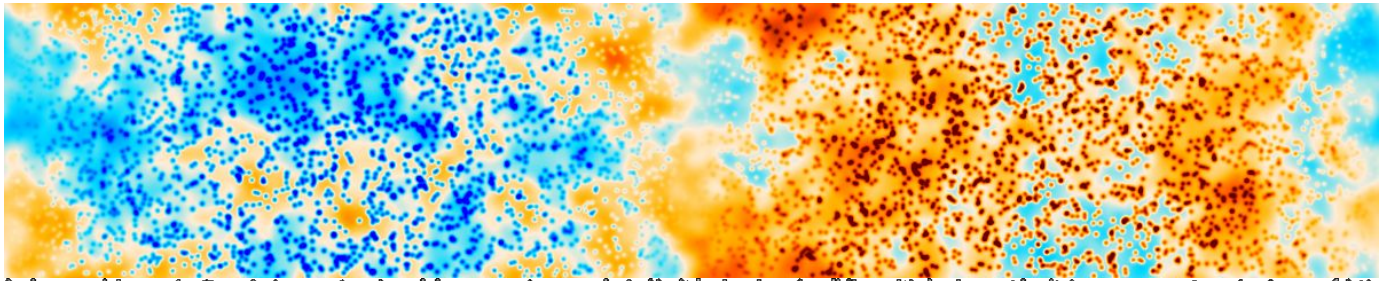

WebSky simulations
(Stein et al 2017)
± few μK

Why we need a galaxy survey

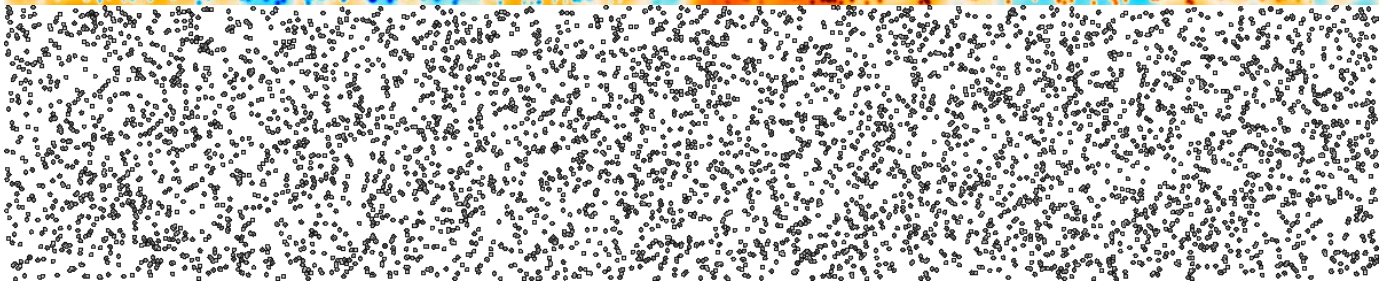
Cosmic velocity mode



CMB temperature

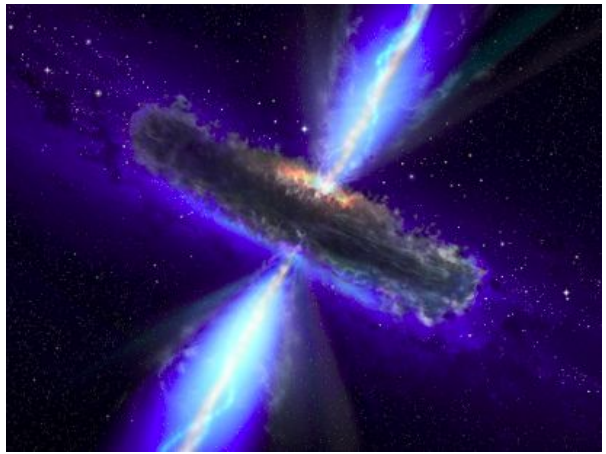


Galaxy positions



Cross-correlation <gT>=0

Astrophysical application
(and implications for cosmology)



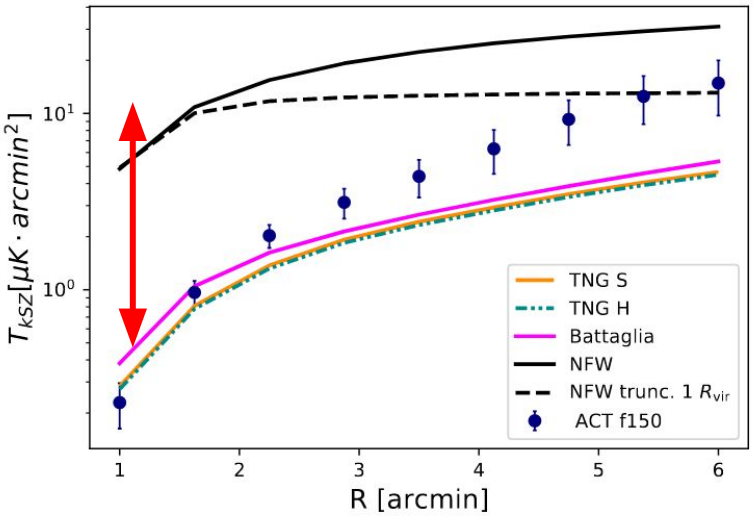
See Battaglia, Hill+ Astro 2020 White Paper for more

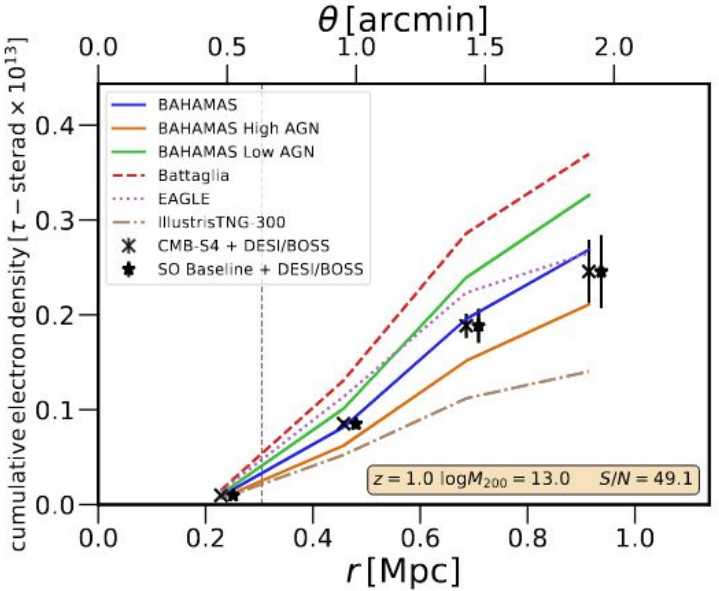
$$\frac{\Delta T_{\rm kSZ}(\boldsymbol{n})}{T_{\rm CMB}} \sim \int d\chi e^{-\tau(z)} \delta_e(\boldsymbol{n}, \chi) v_r$$

Astrophysical application: rule out galaxy formation models

$$\frac{\Delta T_{\rm kSZ}(\boldsymbol{n})}{T_{\rm CMB}} \sim \int d\chi e^{-\tau(z)} \delta_e(\boldsymbol{n}, \chi) v_r$$

Hill/Battaglia for CMB-S4 DSR





Current: ACT x BOSS

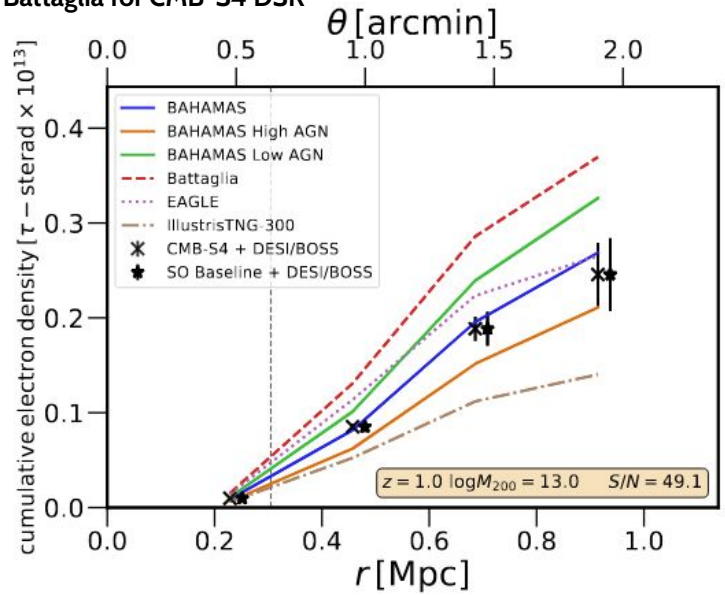
Amodeo, Battaglia et al ACT 2021
Schaan, Ferraro et al ACT 2021
Vavagiakis et al ACT 2021

Future: CMB S4 x DESI
(one redshift bin!)

Astrophysical application: rule out galaxy formation models

$$\frac{\Delta T_{\rm kSZ}(\boldsymbol{n})}{T_{\rm CMB}} \sim \int d\chi e^{-\tau(z)} \delta_e(\boldsymbol{n}, \chi) v_r$$

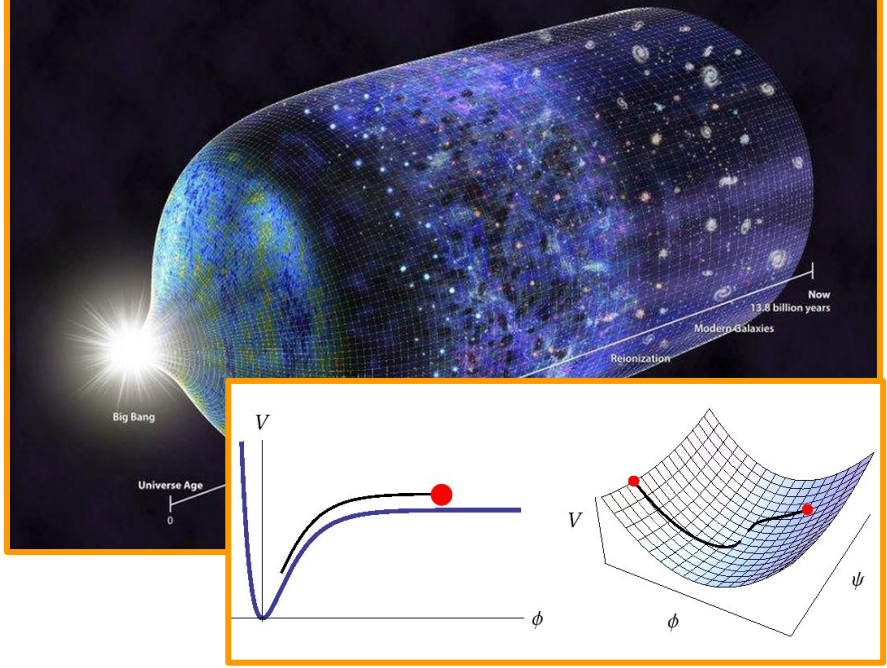
Hill/Battaglia for CMB-S4 DSR



Future: CMB S4 x DESI (one redshift bin!)

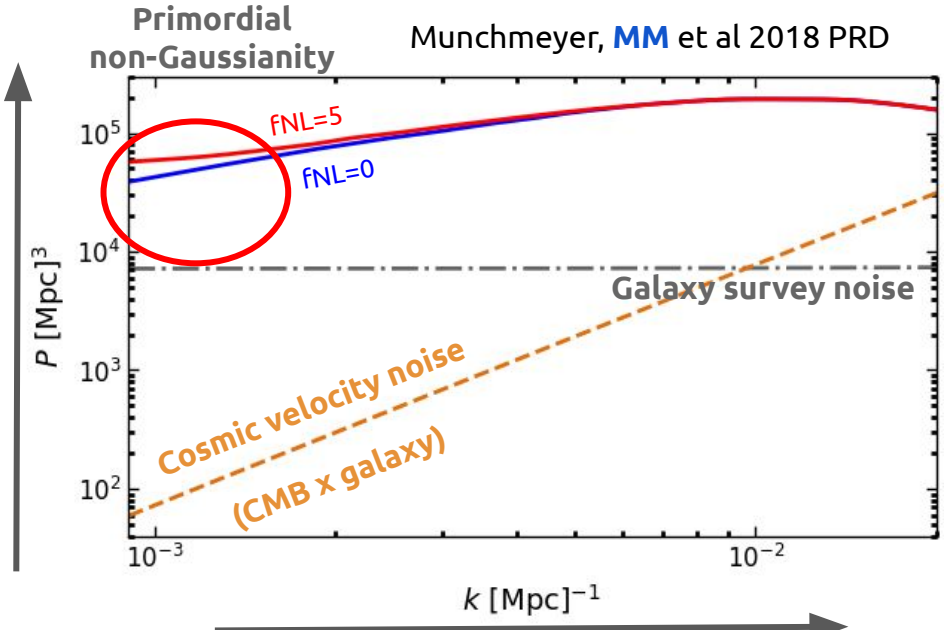
- Distinguish between models of feedback and galaxy formation
- Directly measure gas distribution and baryonic feedback in **galaxy-galaxy lensing**
- Inform baryonic feedback models in **cosmic shear**
- **kSZ measurements poised to provide data-driven control over baryonic feedback for galaxy surveys**
- **This translates to more robust and more precise cosmology from galaxy surveys (and from CMB lensing)**

New cosmological applications of kSZ



$$\frac{\Delta T_{\rm kSZ}(\boldsymbol{n})}{T_{\rm CMB}} \sim \int d\chi e^{-\tau(z)} \delta_e(\boldsymbol{n}, \chi) v_r$$

Multi-field inflation from the cosmic velocity field: 1.5-3x improvement



Y-axis: How much clustering

X-axis: (1/length) scale

Rule out or detect MFI that predicts fNL ~ 1

New application of the kinetic Sunyaev Zeldovich (kSZ) effect that probes cosmic velocities using **CMB x galaxy cross-correlation**

Use the kSZ derived velocity field to reduce sample variance in the galaxy field

- Can be done with **photometric** surveys just as well
- Unaffected by astrophysical uncertainty

Eventually:

VRO alone: $\sigma(f_{NL}) \sim 1.5$

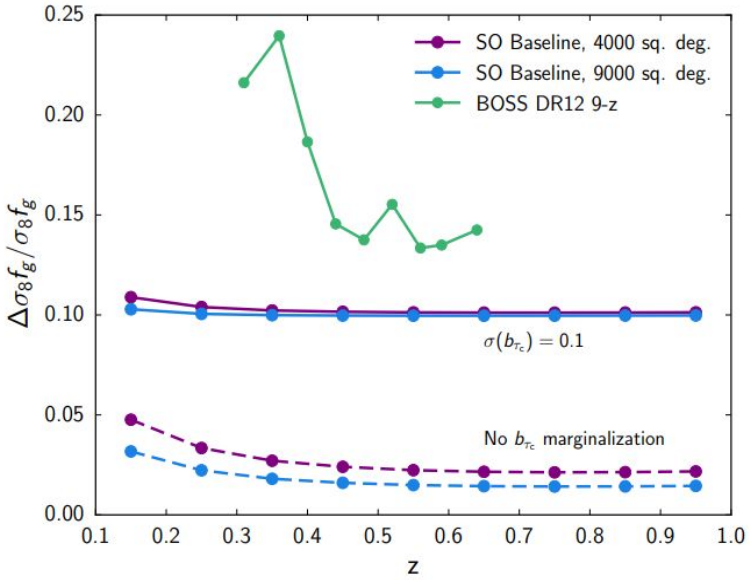
SO and VRO, **$\sigma(f_{NL}) \sim 1$**

S4 and VRO, **$\sigma(f_{NL}) \sim 0.5$**

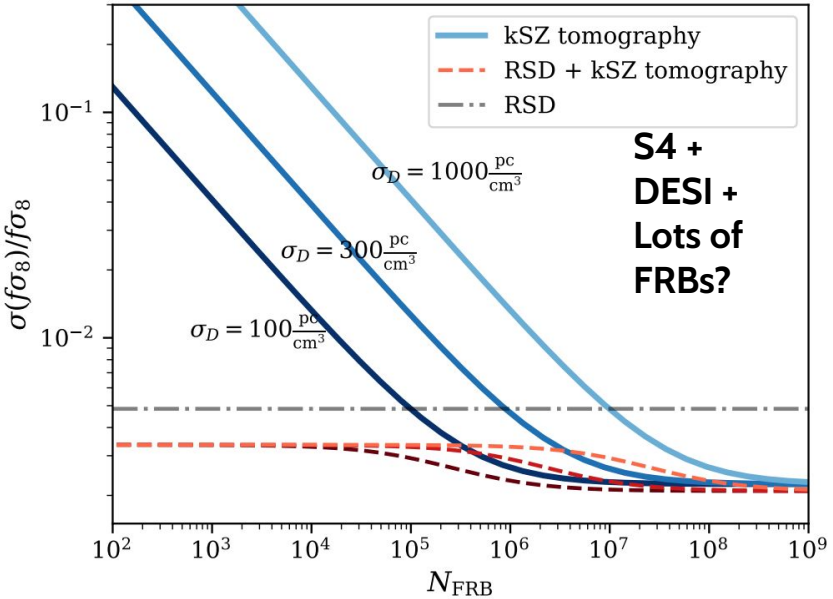
Growth rate: needs an external tau prior, e.g. from FRBs

$$\frac{\Delta T_{\rm kSZ}(\boldsymbol{n})}{T_{\rm CMB}} \sim \int d\chi e^{-\tau(z)} \delta_e(\boldsymbol{n}, \chi) v_r \qquad v \approx \frac{faH}{k}\delta_m$$

arXiv:1808.07445 SO Collab. produced by **Victoria Calafut**



Growth rate f constrains neutrino mass, dark energy equation of state, modified gravity...



MM, Battaglia, Smith, Sievers arxiv:1901.02418

Outlook

- Enormous potential in CMB-S4 x (DESI, SPHEREx, VRO, Euclid, Roman...) through kSZ effect for both astrophysics and cosmology
- S4 depth and resolution key to high SNR measurement
- Pan-experiment coordination essential for:
  - Joint simulations of CMB (with realistic secondaries) and LSS (with realistic HODs)
  - Software pipelines for cross-correlation and systematics assessment
- More theory exploration needed: kSZ tomography likely has many more cosmological applications (e.g. f(k)), and robust velocity field inference needs more investigation with simulations (see e.g. Giri, Smith 2021, Smith, MM+ 2018)