New views of cosmic gas from Atacama Cosmology Telescope observations of the millimetre sky

UNIVERSITY OF CAMBRIDGE

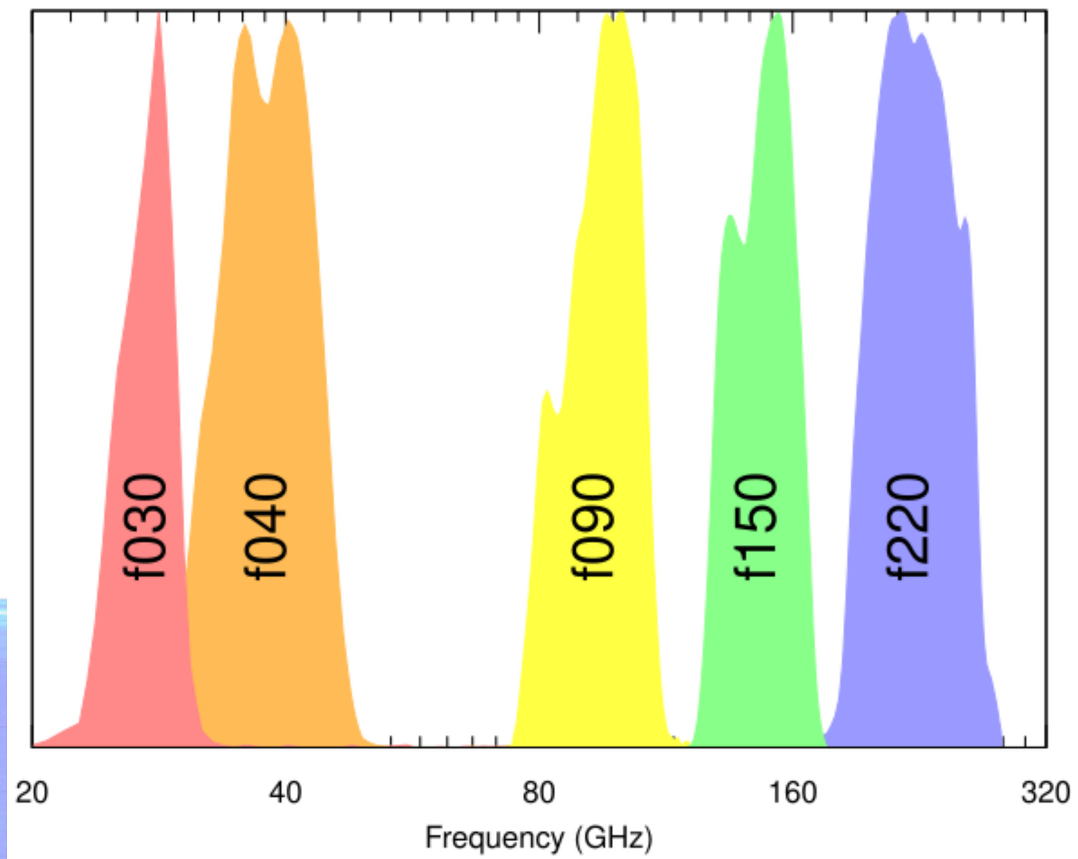
William Coulton with Adri Duivenvoorden, Lucas Kuhn, Zack Li and the ACT collaboration

KICC

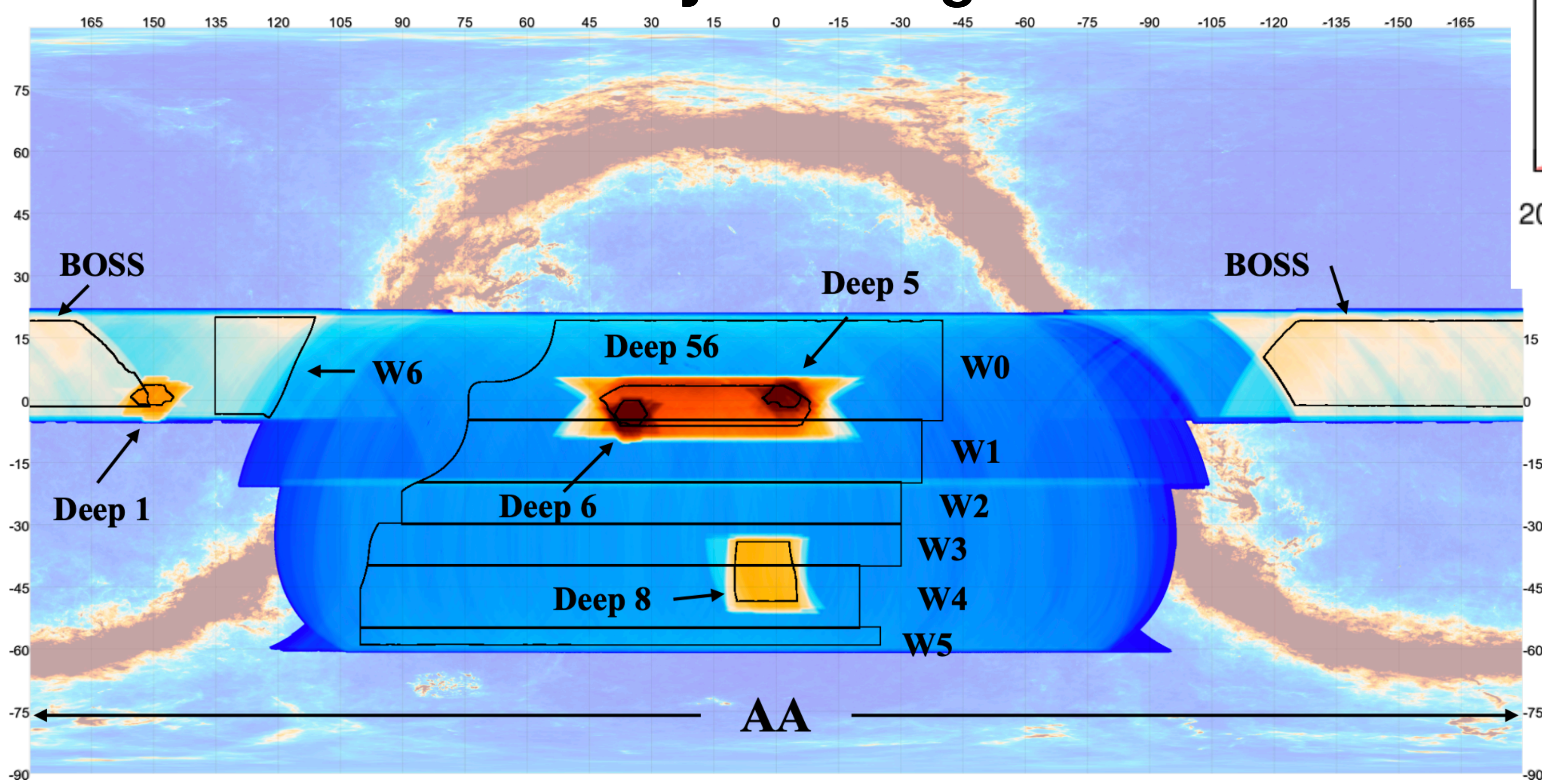
Atacama Cosmology Telescope (ACT)

2007 - 2022

Frequency Coverage



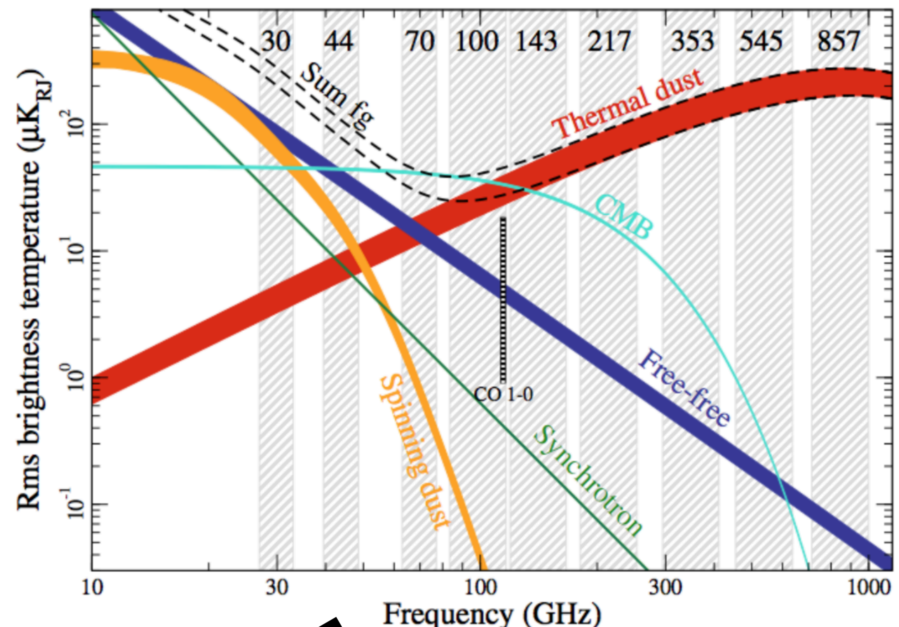
Sky Coverage



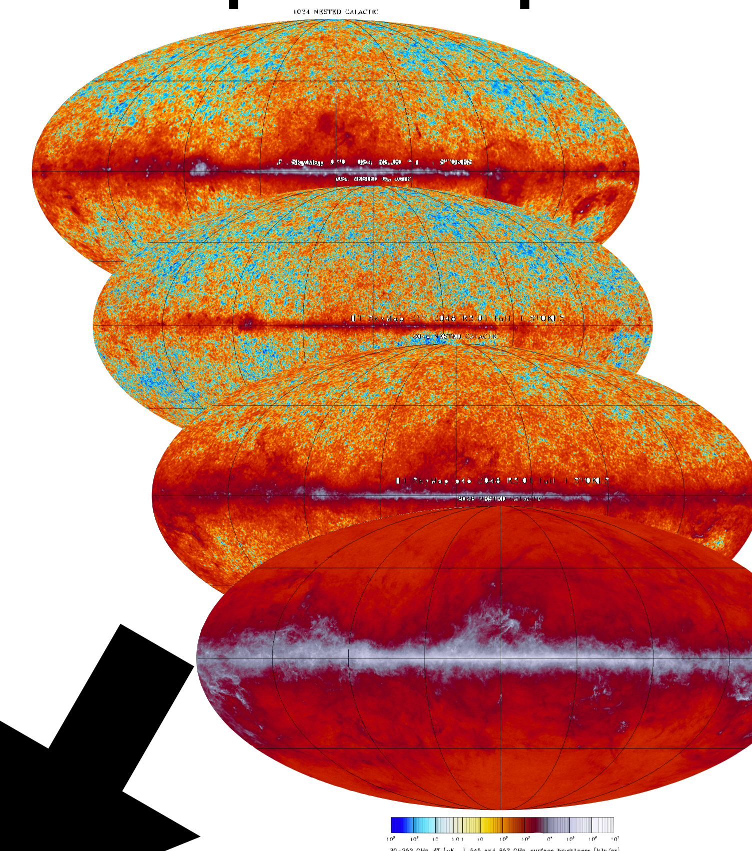
Component Separation

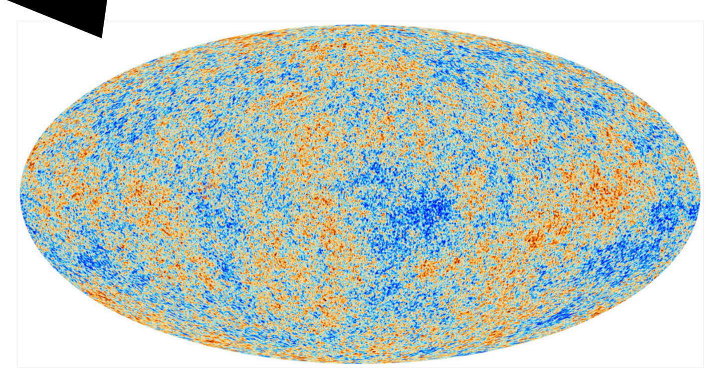
- The aim is to isolate signal of interest
- Utilize different spatial and frequency dependence of signals
- Combine different experiments with different noise/resolution etc
- Challenge:
  how to exploit different spatial properties of each component?

Frequency dependence of the sky components



Spatial Properties





Map of the signal of interest

Dickinson (2016), ESA

Thermal Sunyaev Zel'dovich effect

- Caused by inverse Compton scattering of CMB photons of hot electrons

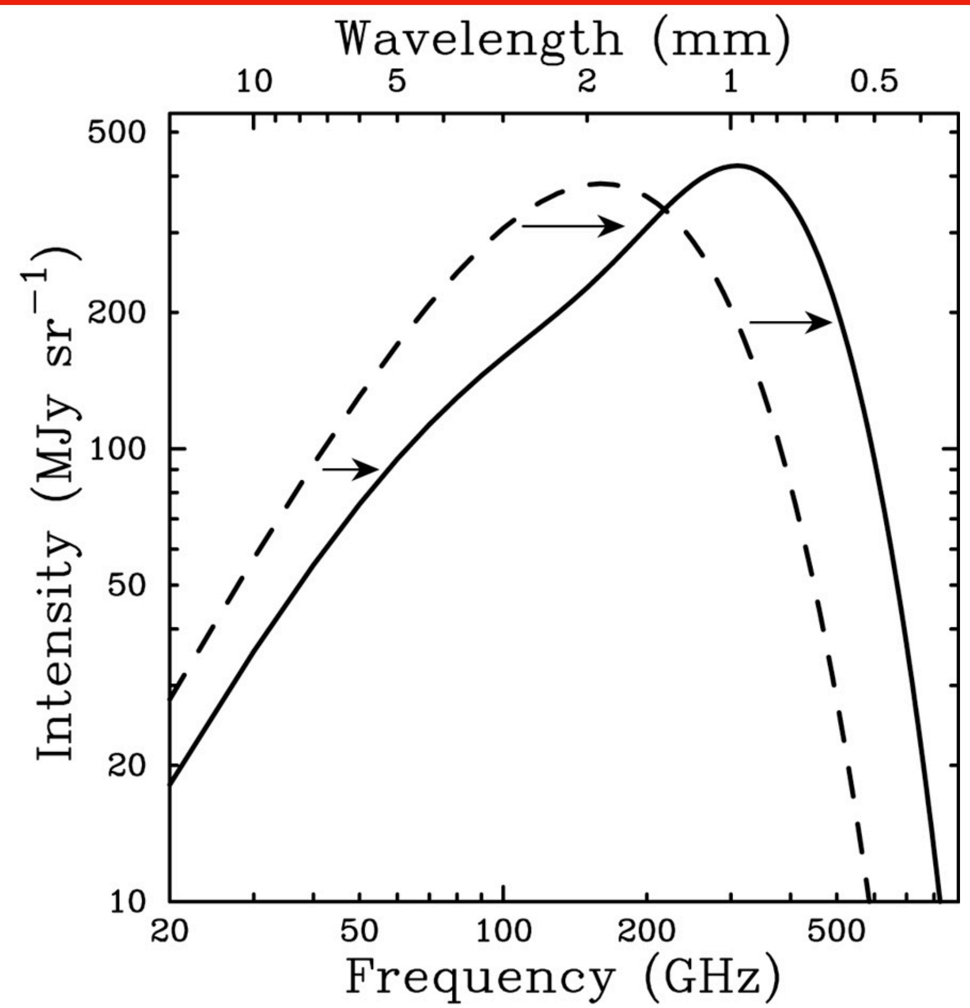
Frequency Response

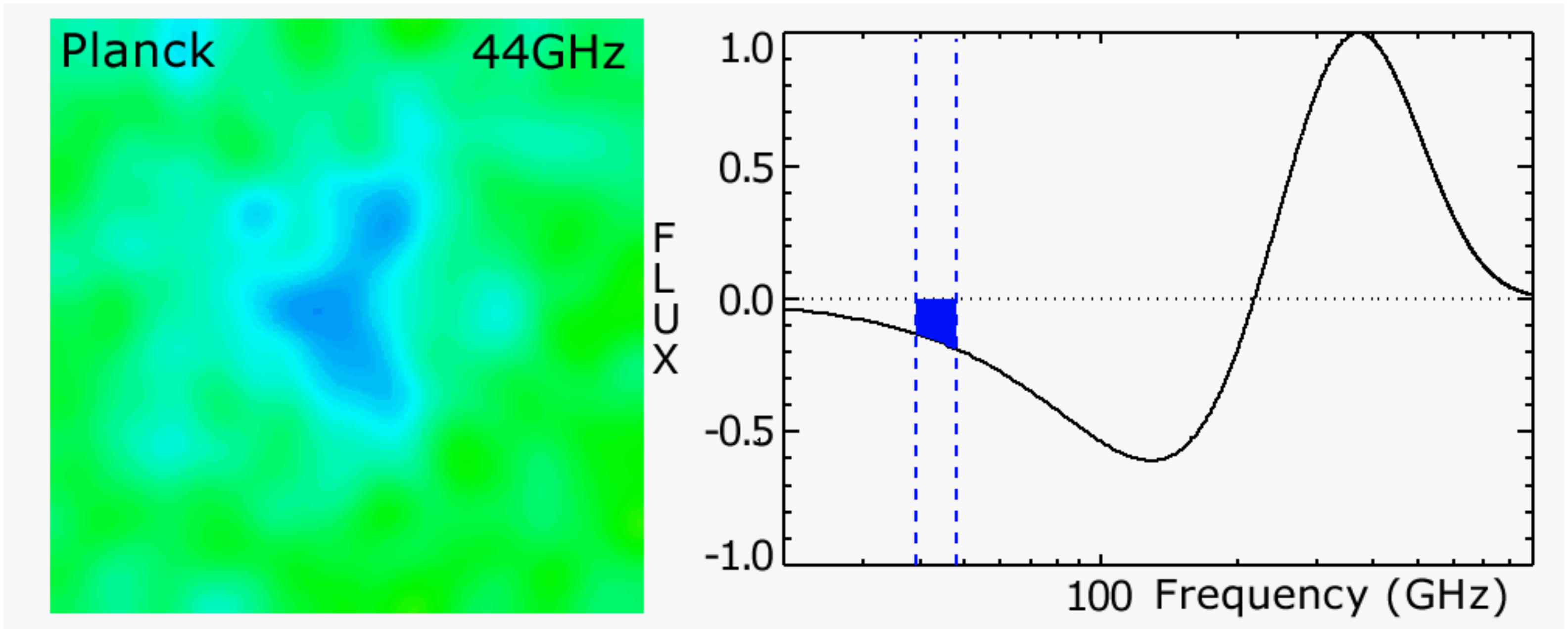
$$\delta I(\mathbf{n}, \nu) = g(\nu) y(\mathbf{n})$$

with:

$$y(\mathbf{n}) \propto \int \mathrm{d}l \, P_e(\mathbf{n}, l)$$

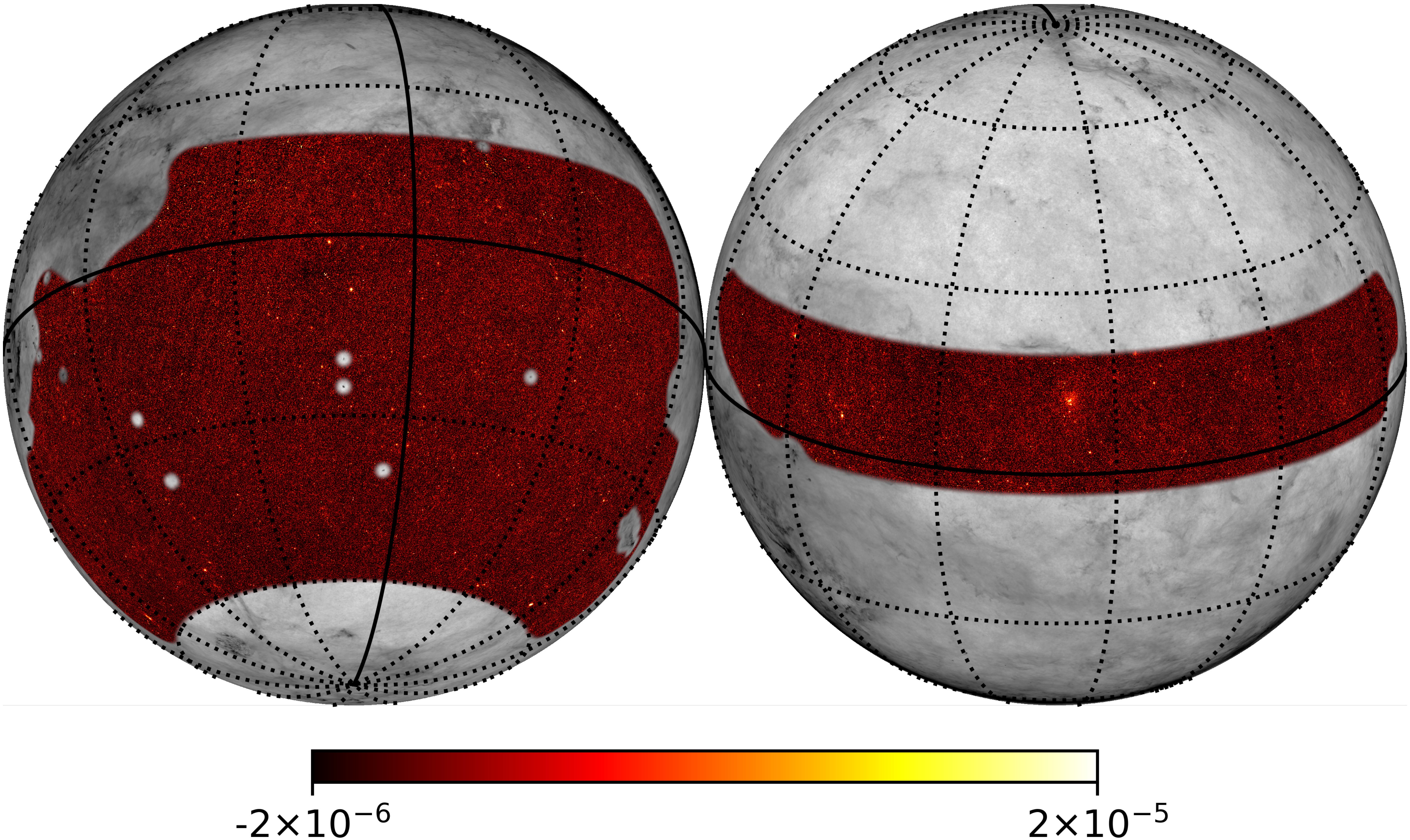
Electron Pressure





Source: Carlstrom et al (2002)

Our new Compton-y map



Coulton et al (2023)

What is the relativistic Sunyaev Zeldovich effect?

- The usual tSZ formula:

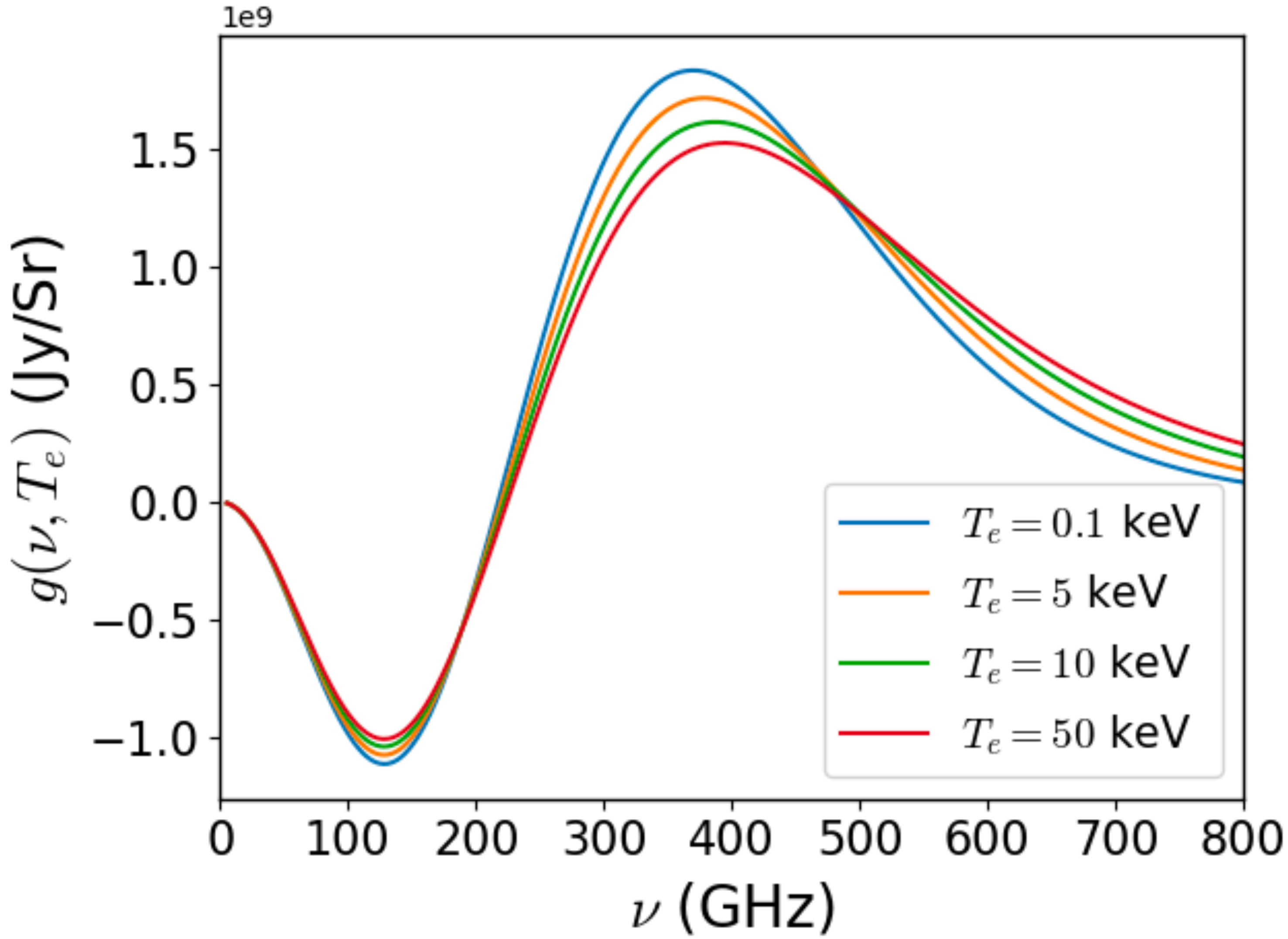
  $$\delta I(\mathbf{n}, \nu) = g(\nu) y(\mathbf{n})$$

  assumes non-relativistic electron ($T_e << m_e c^2 / k_B$)

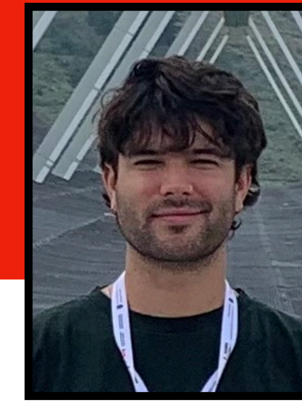
- X-ray measurements show that $T_e \gtrsim$ few keV !

- For relativistic electrons: $\delta I(\mathbf{n}, \nu, T_e) = g(\nu, T_e) y(\mathbf{n})$!

Relativistic SZ signature for electrons at different temperatures



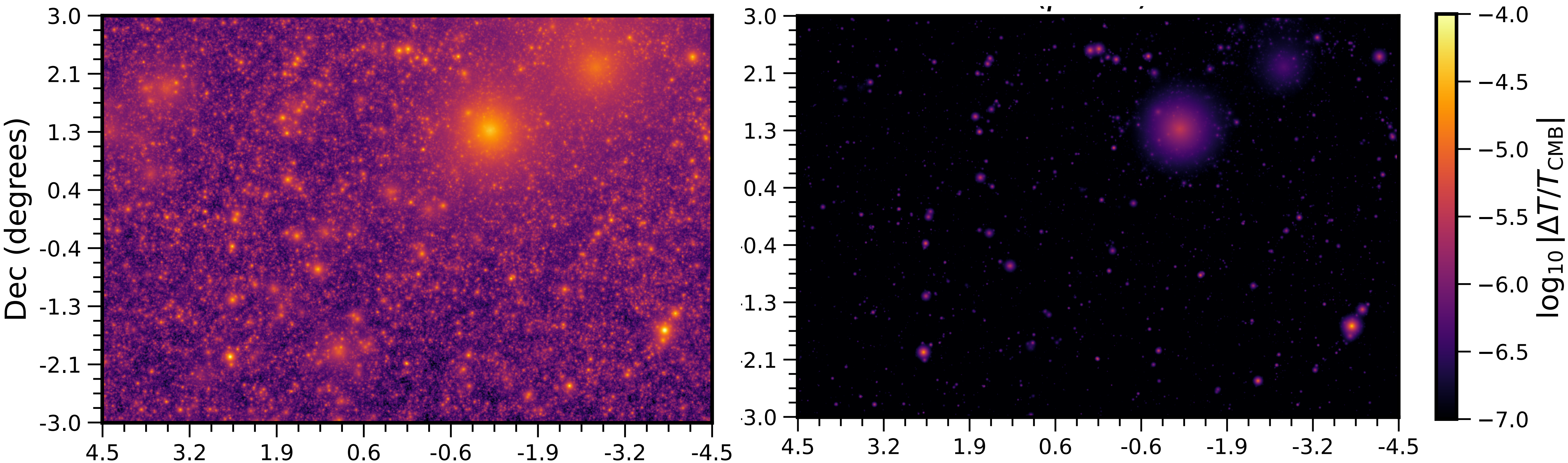
How does this appear on the sky?

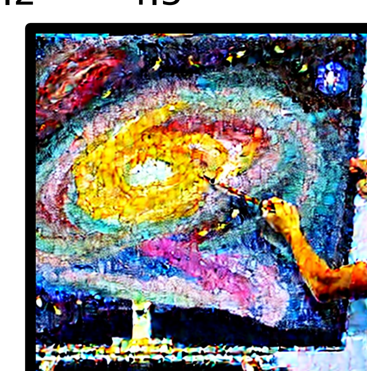


Done with Lucas Kuhn and Zack Li

A simulated ~40 degree² patch of the (web)-sky

Non-relativistic tSZ | **rSZ -(tSZ+kSZ)**





How do we measure it?

- Expand around a mean temperature, $\bar{T}$:

$$\Delta I(\mathbf{n}, \nu) = \sum_{i=0} \tilde{g}_{(i)}(\nu, \bar{T})\,(T_e - \bar{T})^i\, y(\mathrm{n})$$

- The zeroth order term is:

$$\Delta I(\mathbf{n}, \nu) = \tilde{g}_0(\nu, \bar{T}) y(\mathbf{n}) \quad \text{with} \qquad y(n) = \int n_e T_e \mathrm{d}l$$

- Whilst the first order term is now:

$$\Delta I^{(1)}(\mathbf{n}, \nu) = y(\mathbf{n}) \times (T_e(\mathbf{n}) - \bar{T}) g_{(1)}(\nu, \bar{T})$$

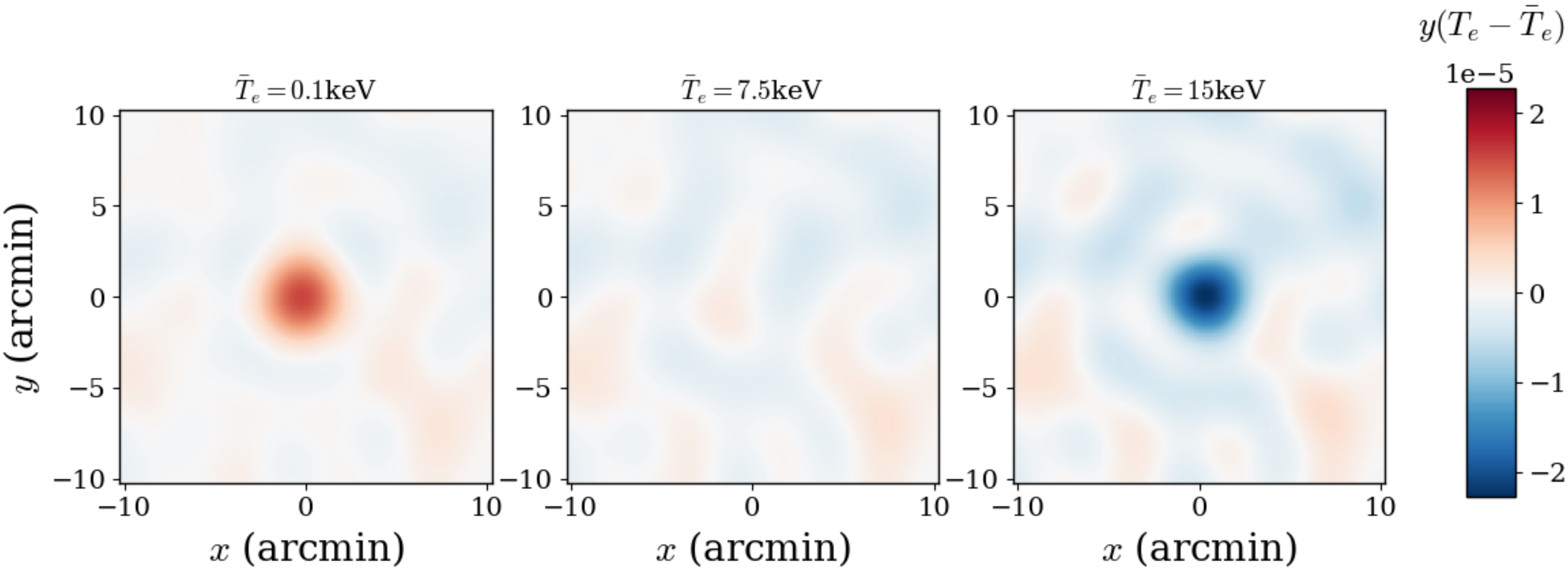
- Can use this to do “spectroscopy”!

- Current SNR per object is low, so we do this for a stack of clusters

Remazeilles and Chluba (2020)

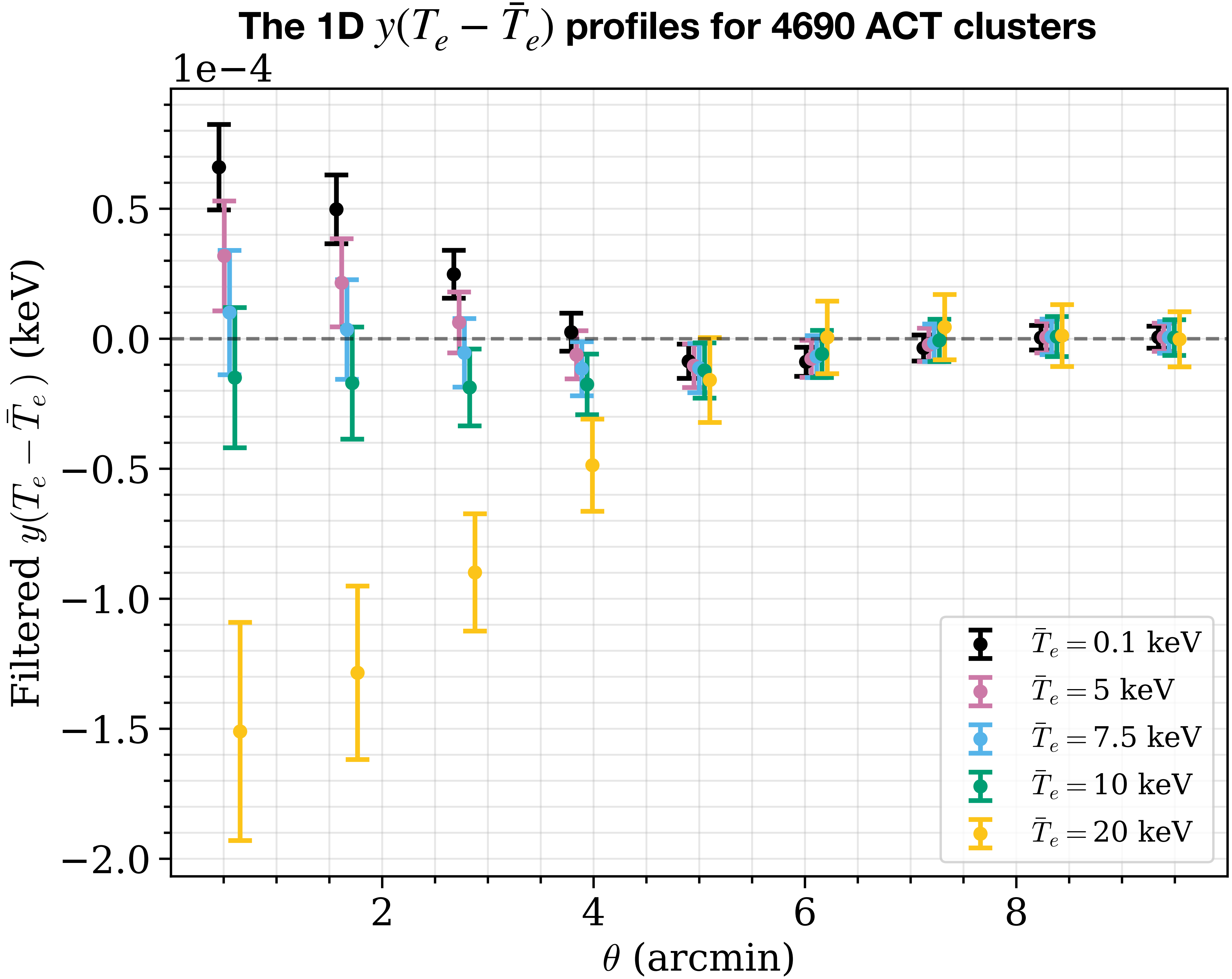
Analysis à la Mathieu and Jens

Measure: $y(\mathbf{n})\left(T_e(\mathbf{n}) - \bar{T}_e\right)$ where $\bar{T}_e$ is a trial temperature



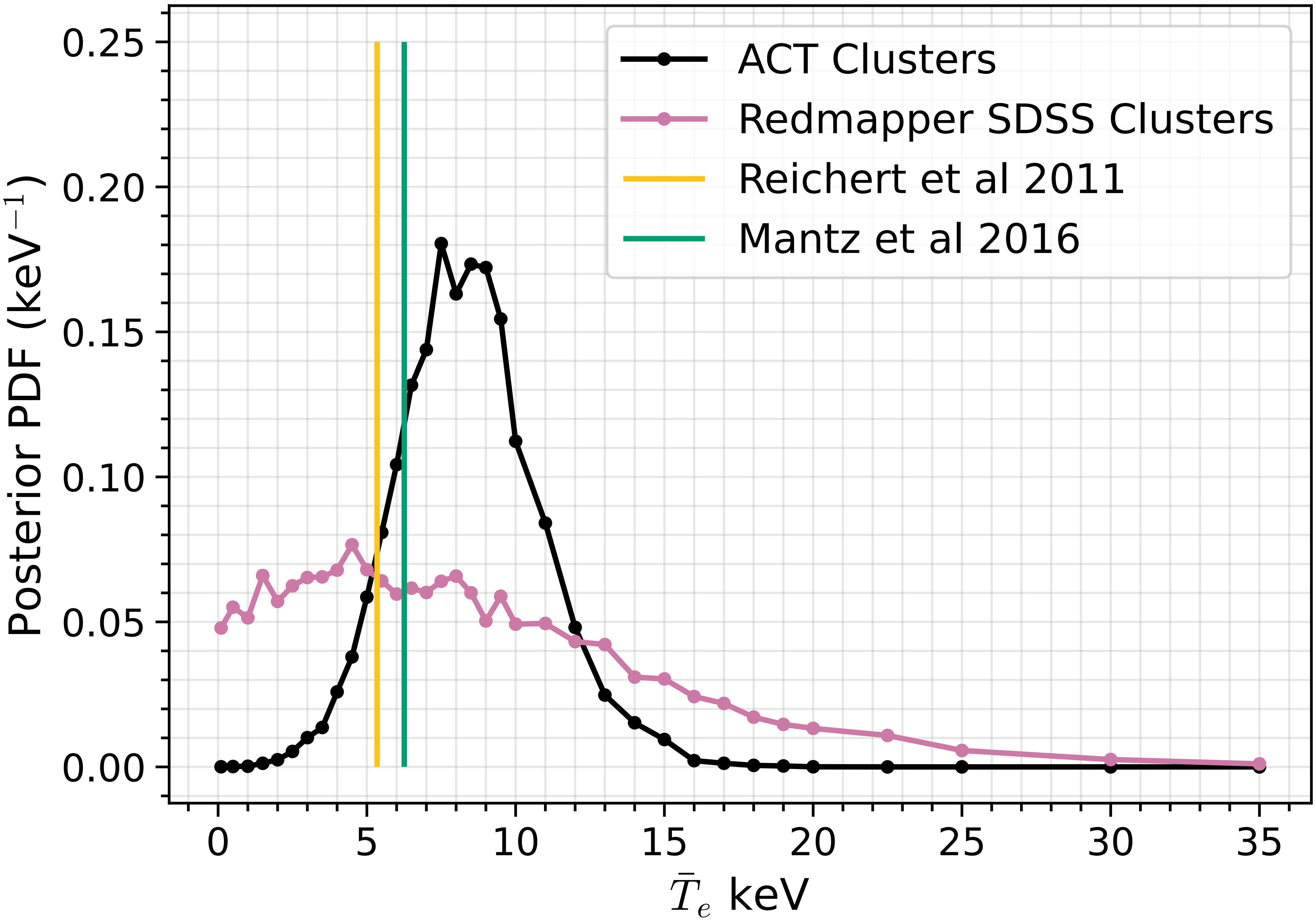
Remazeilles and Chluba (2020)

Our measurement



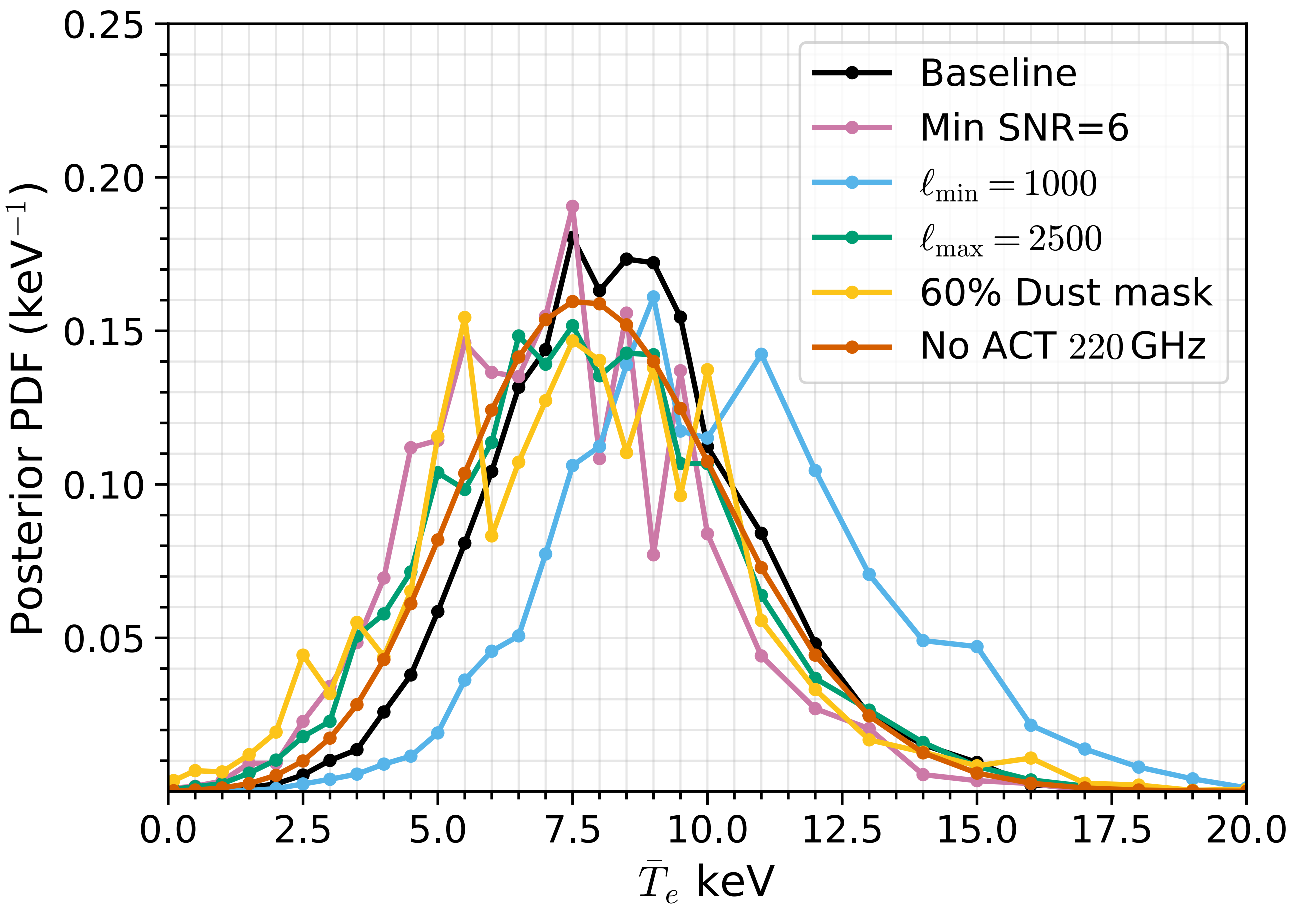
How well do we constrain the temperature?

The mean temperature of the 4690 ACT clusters compared to other measurements

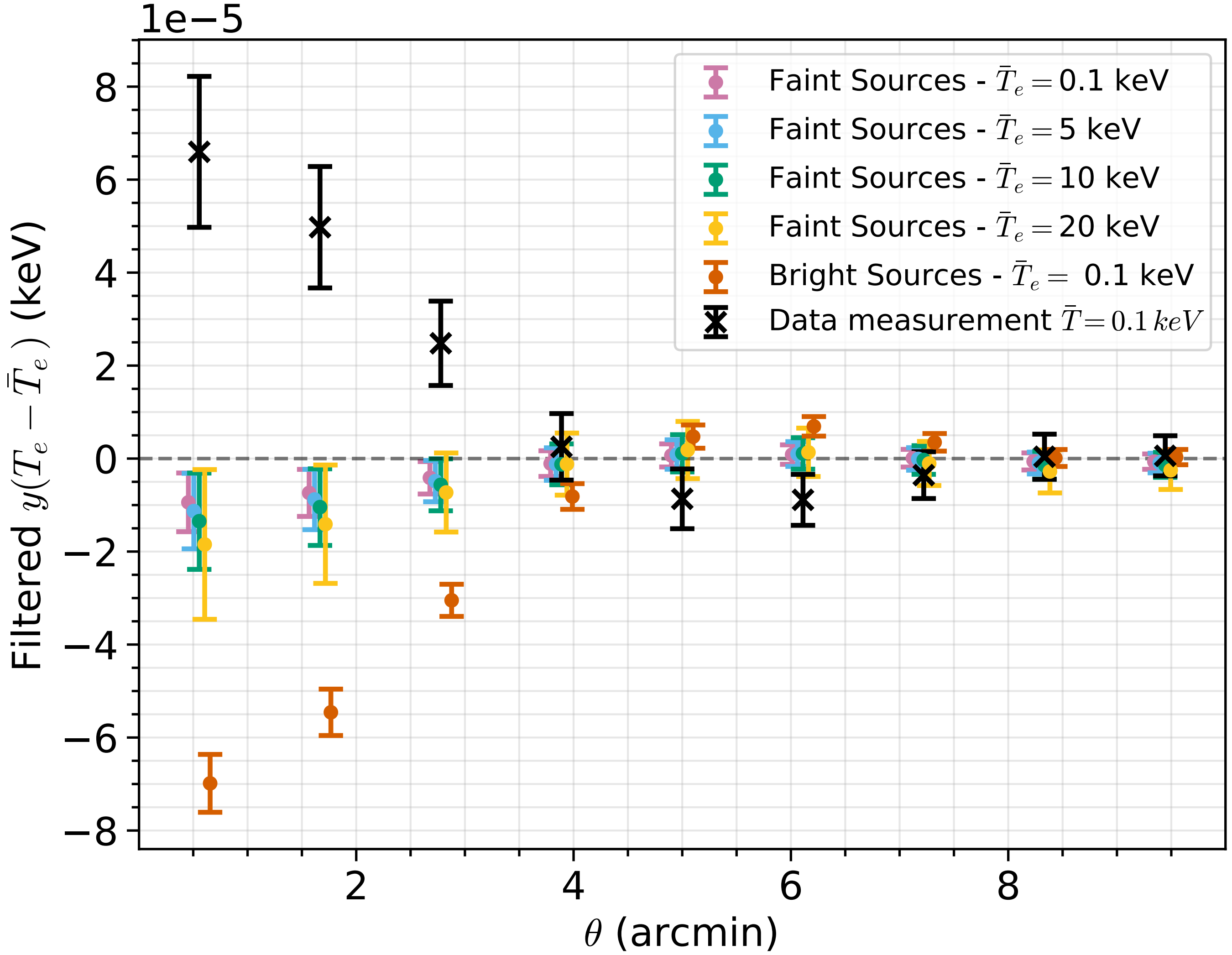


Consistency and robustness tests

Test of different analysis choices



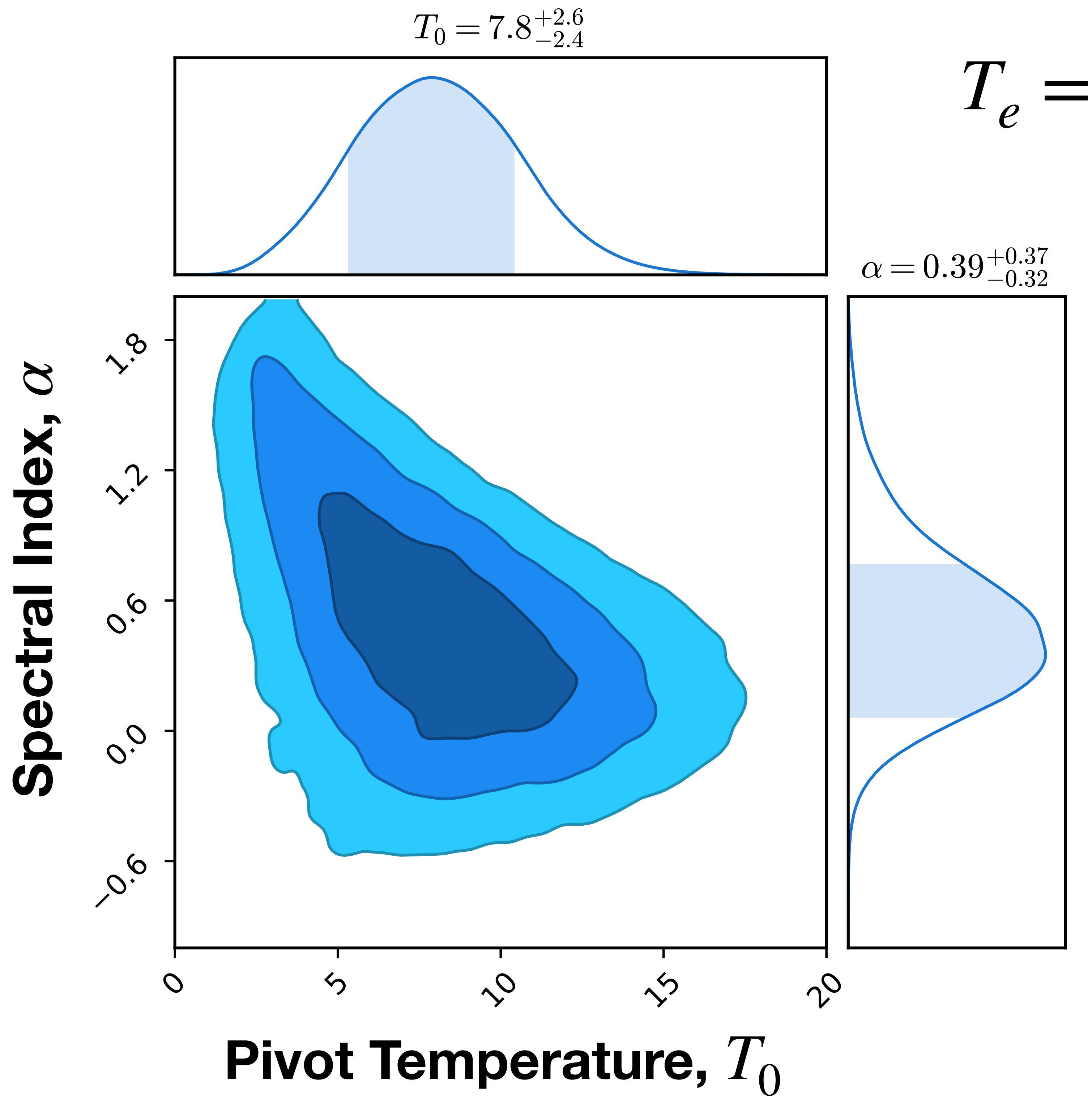
Test for biases from radio sources (similar test was done for CIB)



From profiles to physics

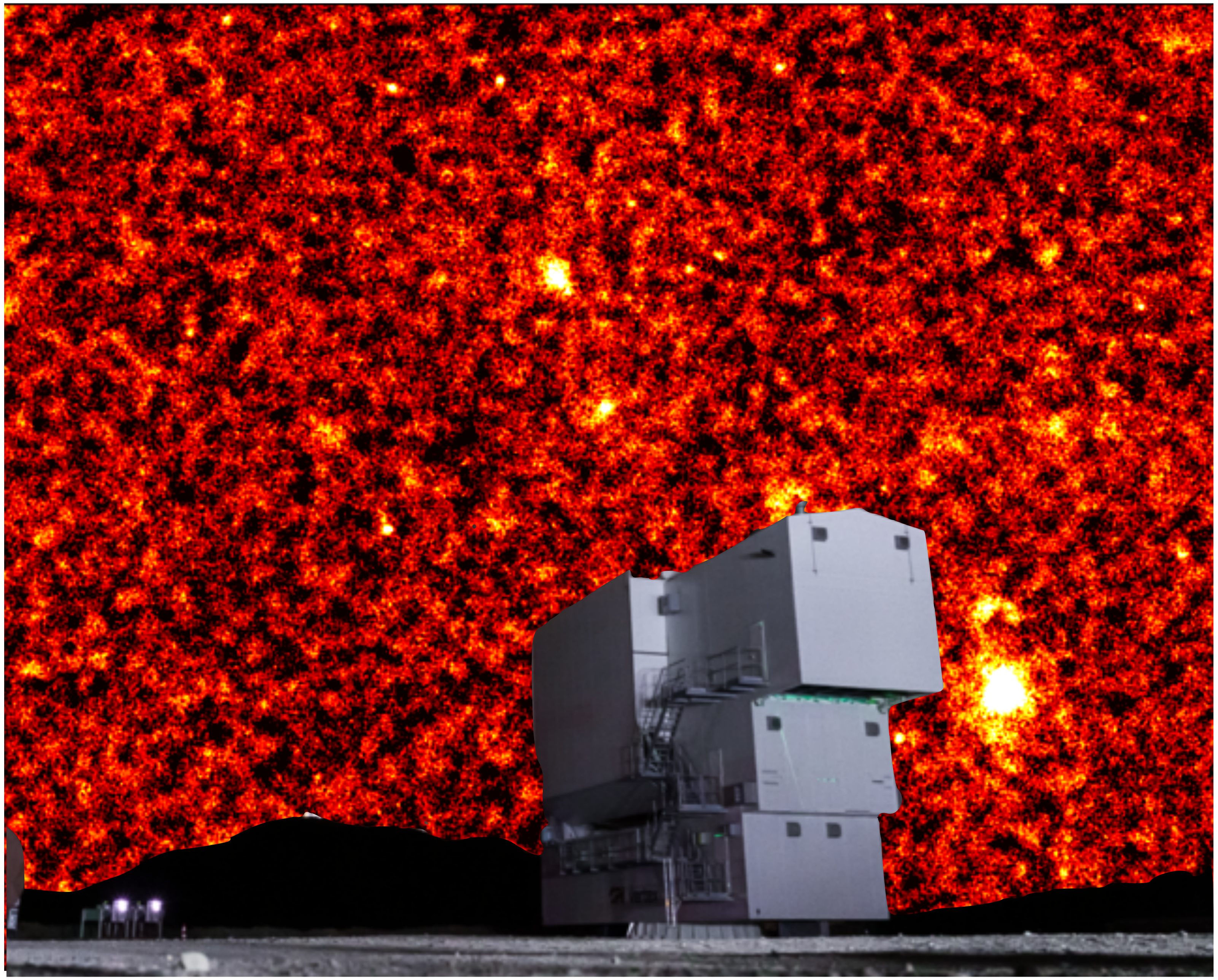
Instead of measuring the entire stack, we can subdivide and search for evolution

$$T_e = T_0 \left(\frac{y_{500}}{y^0} \right)^{\alpha}$$



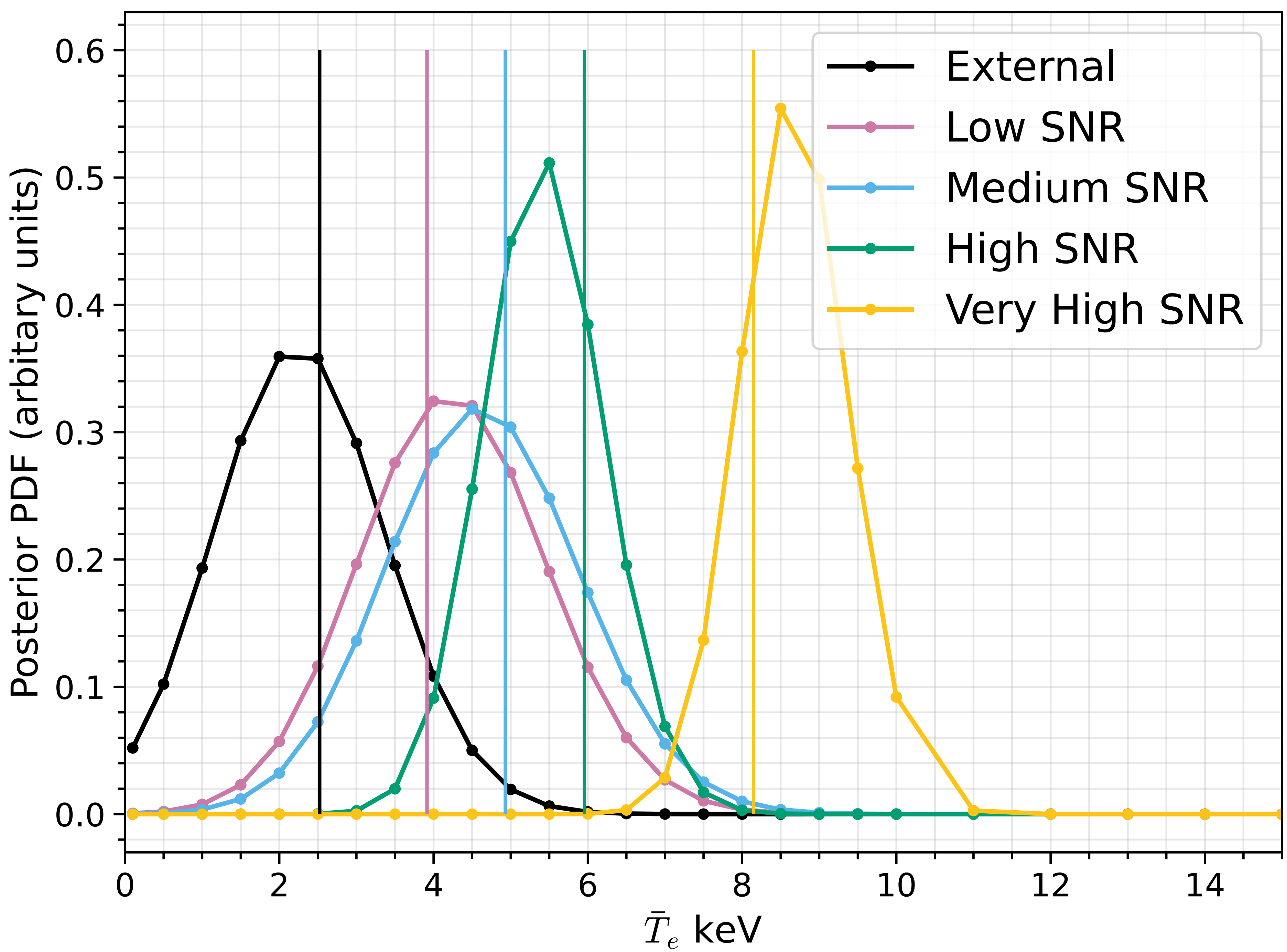
The Simons Observatory

The Simons Observatory



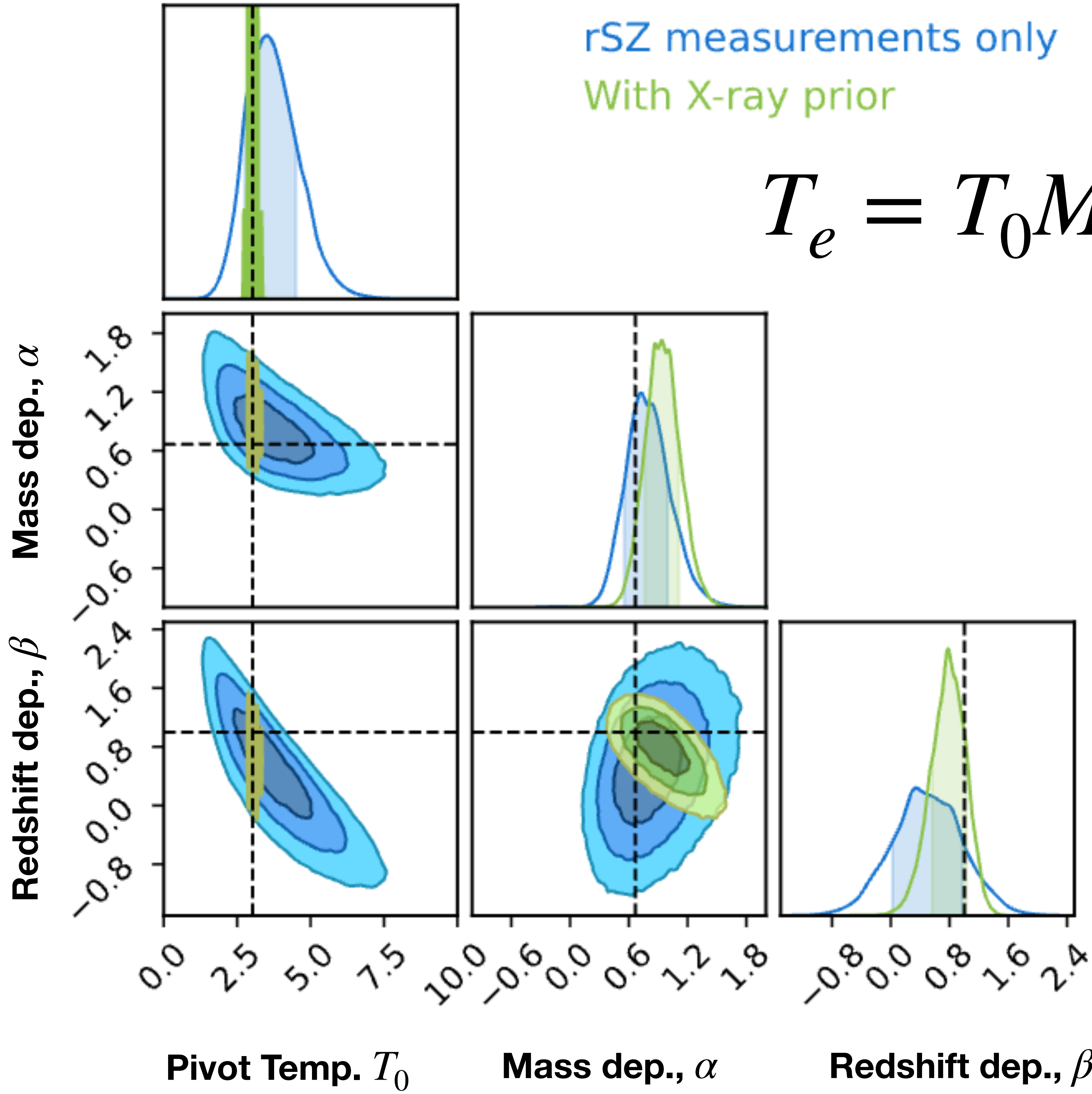
The future is relatively hot!

Forecast constraints for how well Simons Observatory can constrain the mean temperature for stacks of clusters



From cluster samples to physics

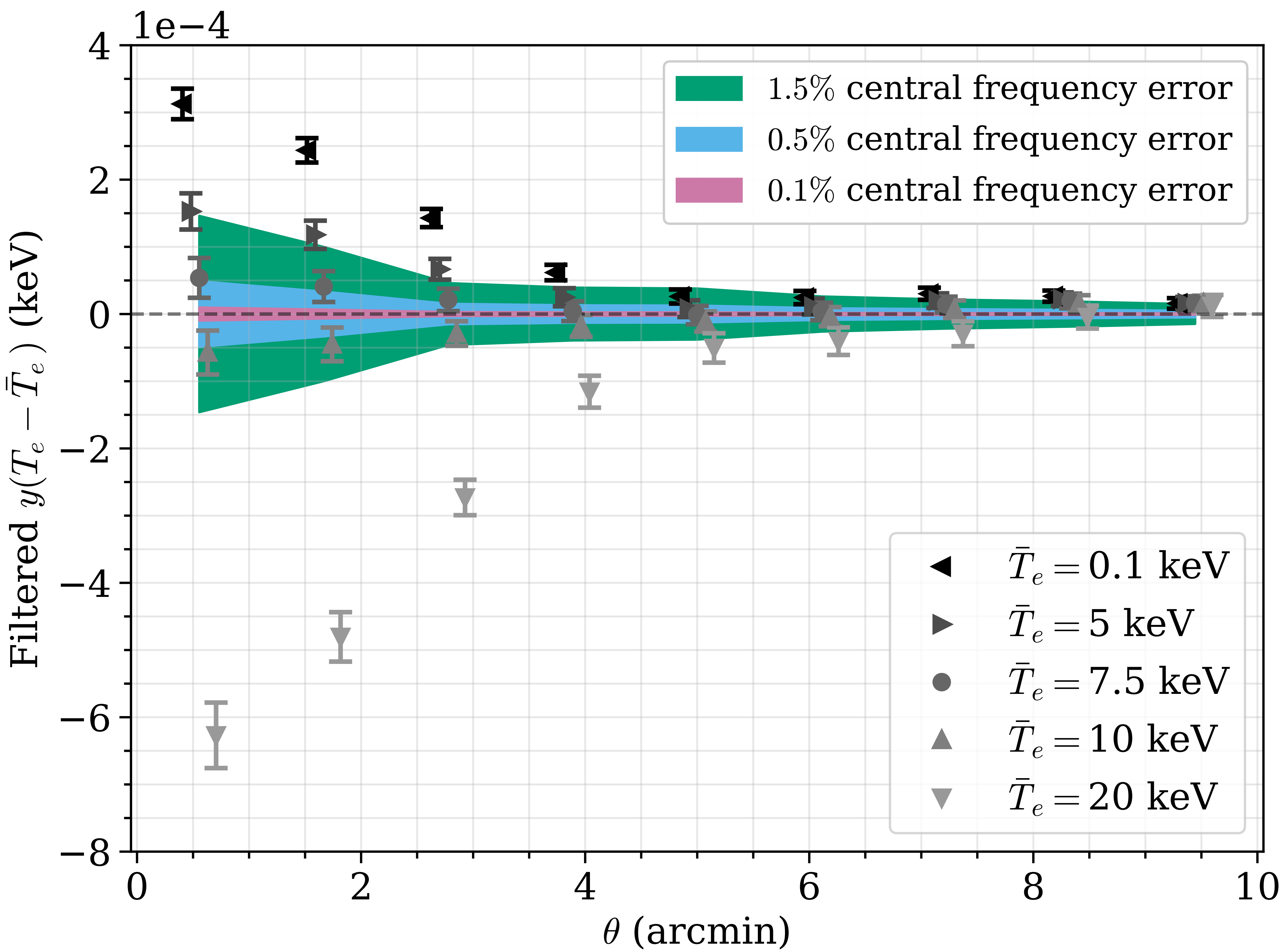
Forecast constraints on temperature-mass-redshift relations with Simons Observatory



$$T_e = T_0 M^{\alpha}(1+z)^{\beta}$$

The challenge of instrumental systematics

A comparison of forecast SO measurements vs instrumental systematics uncertainties



What is the patchy-screening effect?

A schematic of the patchy screening effect

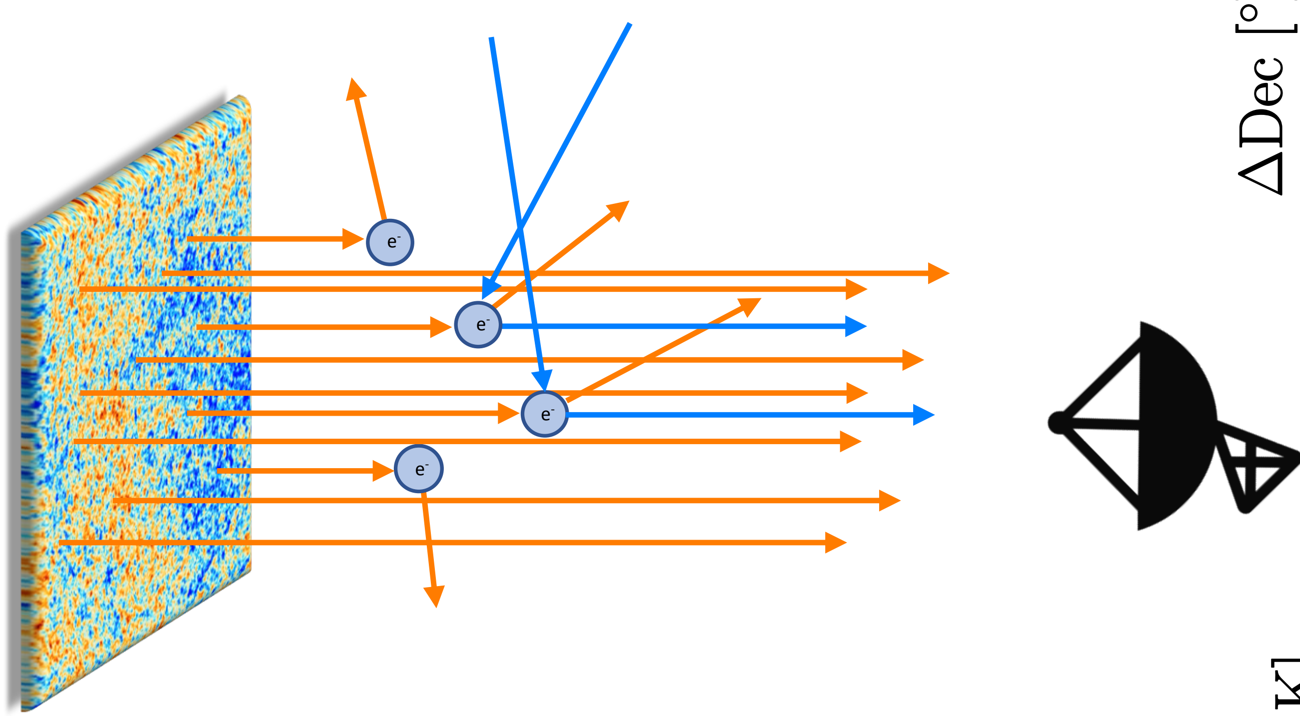
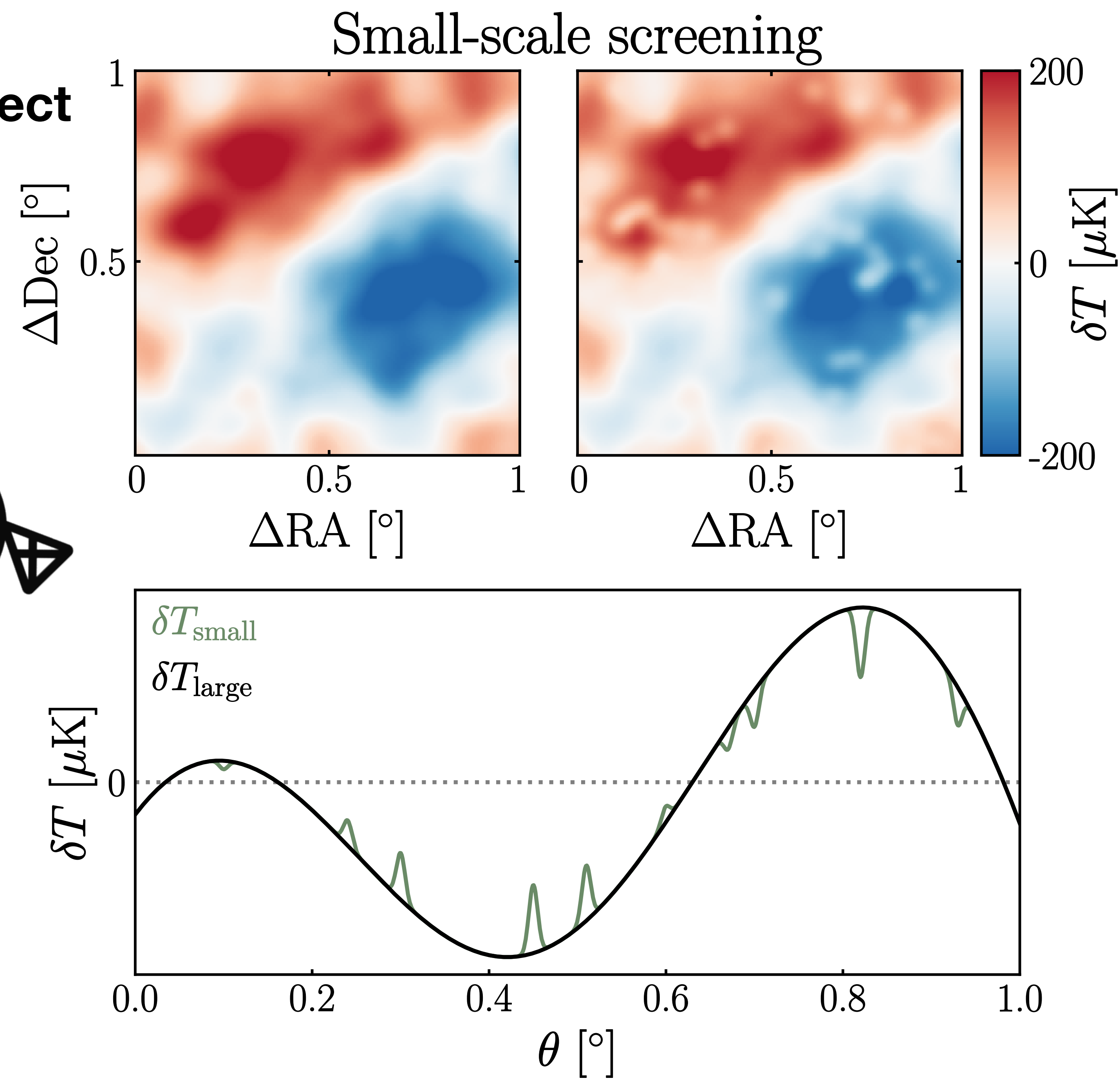


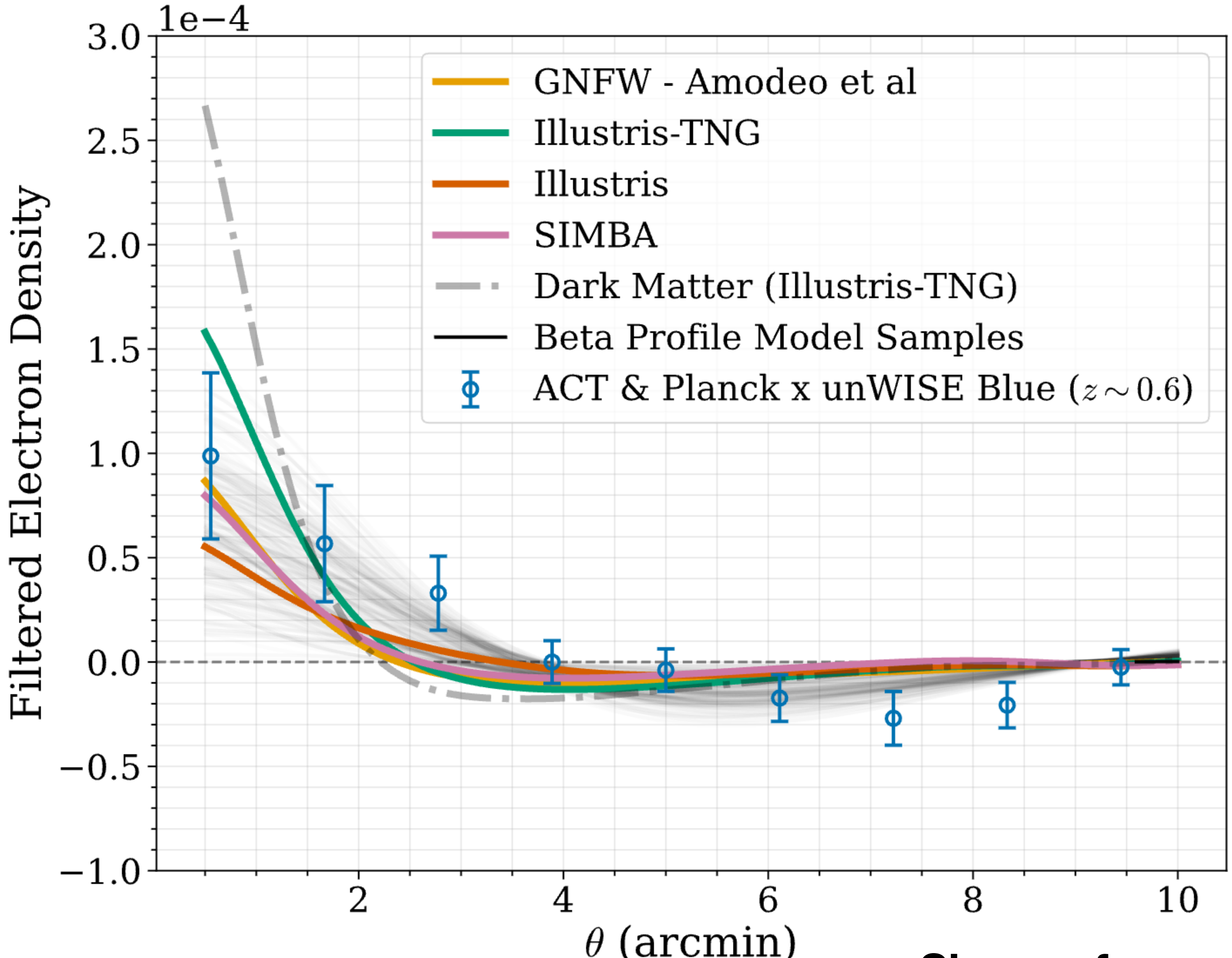
Image by Darby Kramer



Schutt et al including WRC (2024)

An upper limit on the gas density around unWISE galaxies from ACT

Comparison of measured 1D profile to a set of theoretical models



Shape of curve:
1) Profile of free electrons
2) Filtering applied to CMB data

Conclusions

- Publicly available ACT+Planck Compton-y map <u>here</u>
- Measuring the rSZ is hard!
    - Requires high resolution, low noise measurements
      … especially at high frequencies
    - A very precise characterisation of the instrument!
- We have made a $\sim 4\sigma$ measurement of the effect
- SO will dramatically improve this to $> 20\sigma$ and provide interesting constraints on temperature evolution!
    - Providing we can constrain the systematics
    - Can we be smarter about mitigating the CIB?