A “temperature inversion” estimator to detect the screening of the CMB by the large-scale structure

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Different imprints on the CMB due to the LSS

- Integrated Sachs-Wolfe & Rees-Sciama effect
  - Variation with time of the gravitational potential between us and the surface of last scattering
  - Dark energy, curvature of the Universe
- Lensing
  - Gravitational deflection of the CMB photons due to the LSS
  - Projected distribution of all the dark matter
- Scattering: Sunyaev–Zeldovich effect
  - Spectral distortion of the CMB through scattering by high-energy electrons in clusters
  - Distribution and properties of the gas in the Universe
  - Very important signal and foreground in cosmology and galaxy evolution
- Scattering: screening

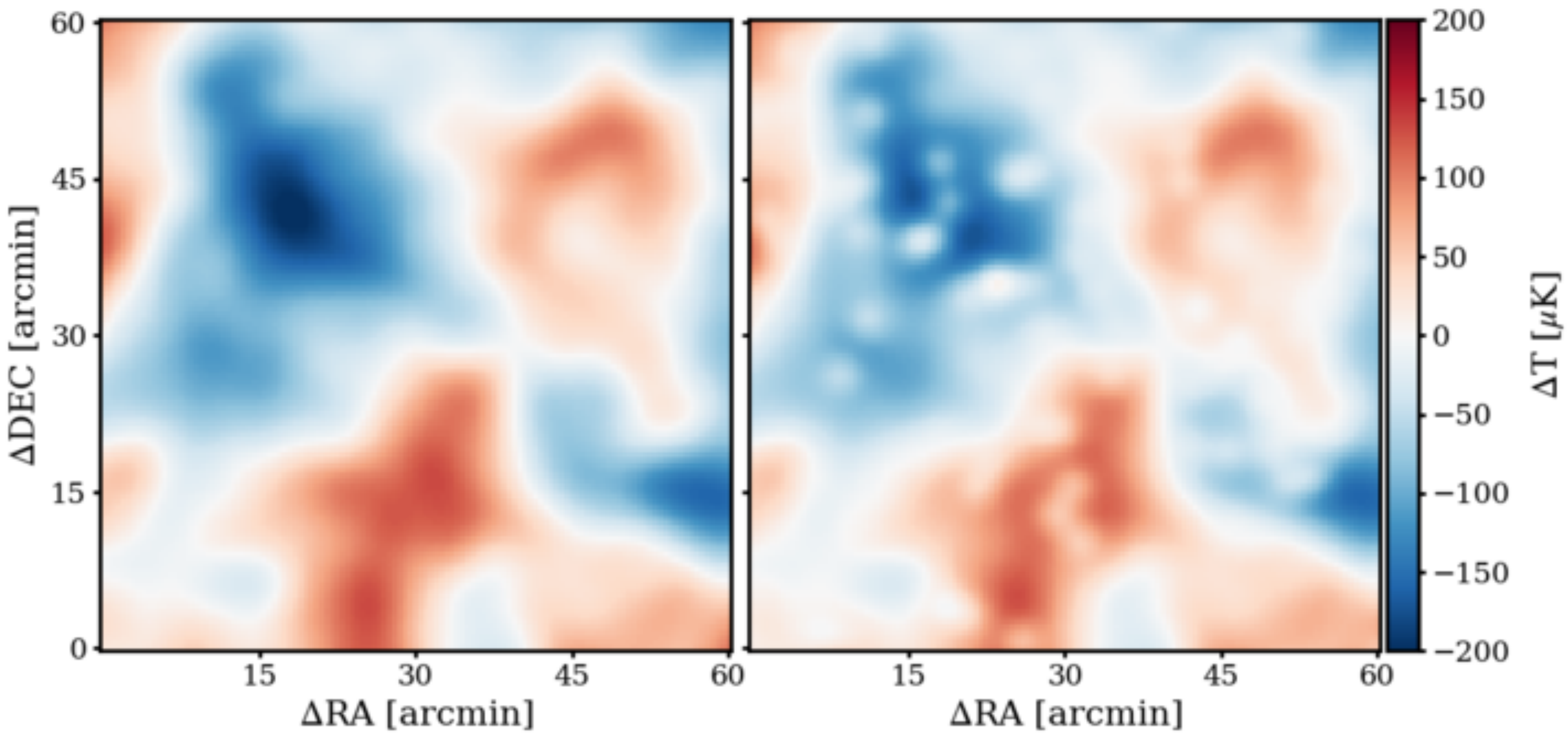
Screening of the CMB photons

- CMB photons scattered in and out of the line of sight by e^- in the gas in galaxies and clusters

- Damping of the CMB anisotropies

- LOS with more e^- more suppressed and vice-versa
  - Damping is anisotropic
  - New CMB-anisotropies

Screening of the CMB photons



Brings the CMB temperature in a given patch close to the mean

$$\frac{\delta T_{\rm obs}}{\bar{T}} = \frac{\delta T_{\rm true}}{\bar{T}} (1 - \tau)$$

Why study screening?

- Contributions from two epochs
  - Reionization (sometimes also called patchy screening)
    - Patchy screening is a probe of reionization
  - Late-time Universe

- Linear in gas profile
  - Very useful to study distribution of the gas in the Universe
  - Calibrating baryonic effects: halo-baryon connection

- Combining with kSZ will allow to measure velocity field amplitude
  - Cosmological parameters like growth rate, $f_{\rm NL}$ etc.

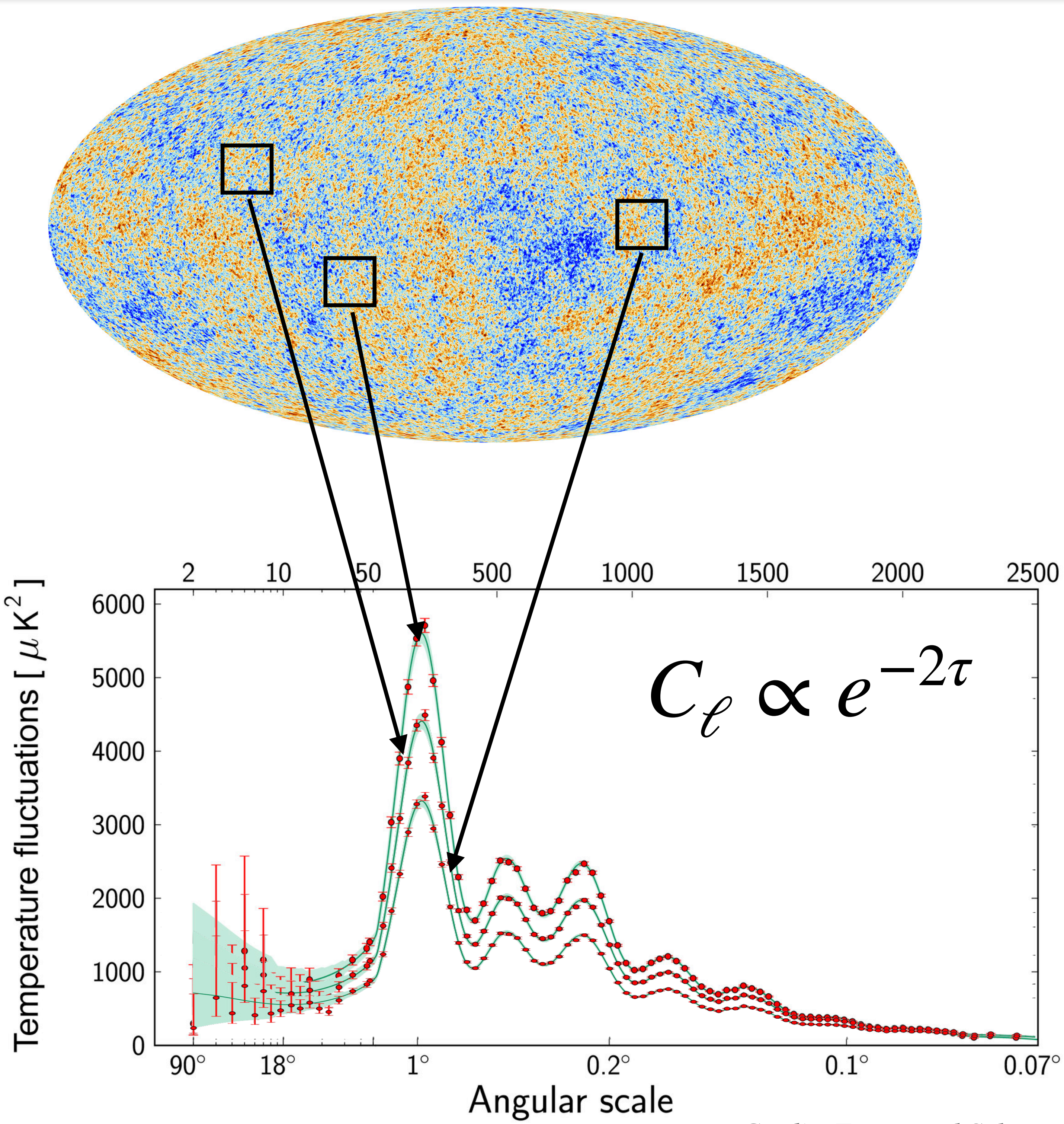
How to measure this effect?

$$\frac{\delta T_{\rm obs}}{\bar{T}} = \frac{\delta T_{\rm true}}{\bar{T}}(1-\tau)$$

$$\delta T_{\rm obs} = \delta T_{\rm true} - \nabla\phi \cdot \nabla \delta T_{\rm true} \longrightarrow \text{CMB lensing}$$

- Lensing causes mode coupling ➞ Quadratic estimator (QE) *(Hu, Okamoto 02)*
- Screening causes mode coupling, like lensing ➞ QE *(Dvorkin Smith 09)*

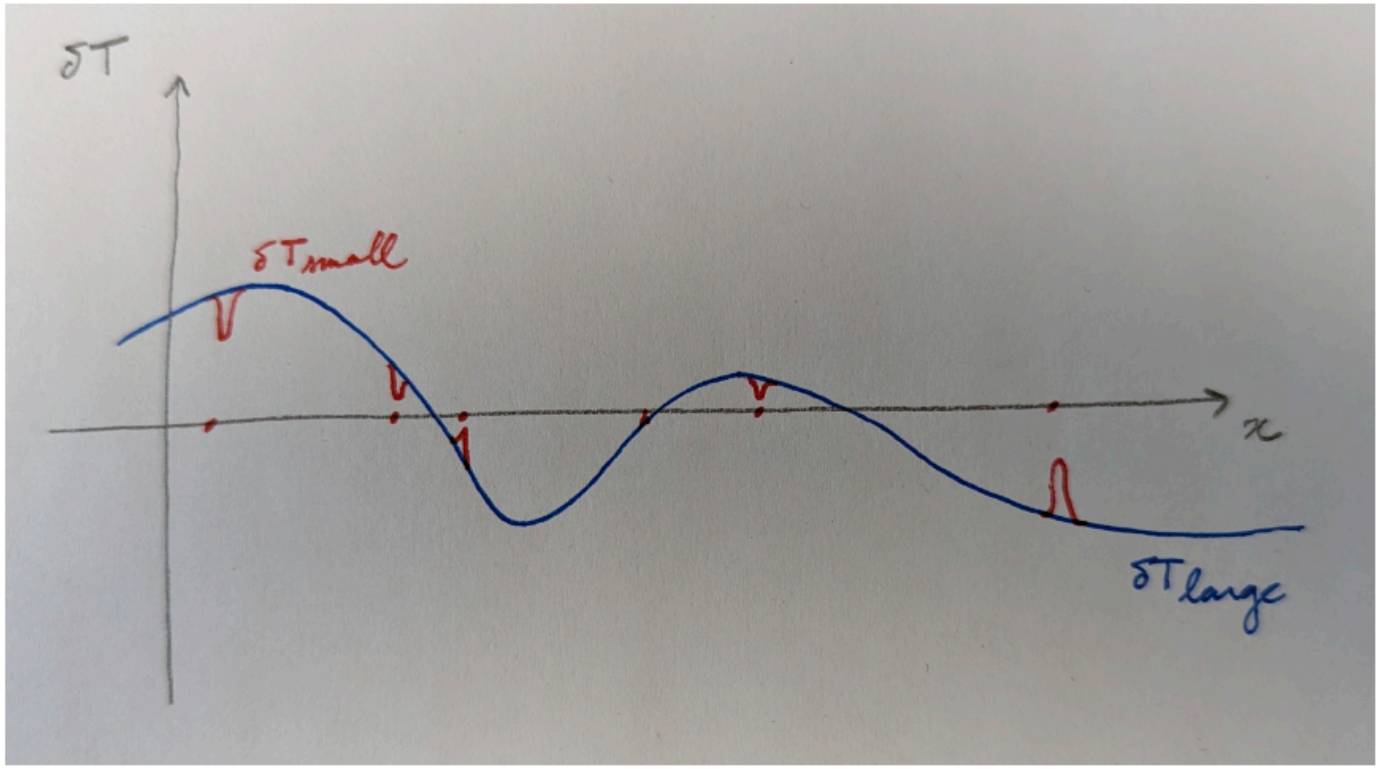
QE: large-scale τ limit



Credit: Emmanuel Schaan

- Local power spectrum amplitude gives large-scale τ
- Foregrounds & lensing also modify the local power spectrum
  → biases QE
  → lensing & foreground hardening
  (Namikawa, Roy, Sherwin, Battaglia, Spergel 21)
- Currently quantifying biases and noise costs from hardening

QE: small-scale τ limit



Small-scale screening limit:

- $1 - \hat{\tau}^{\mathrm{QE}}(x) \sim \delta T(x) \frac{T^{\mathrm{long\ WF}}(x)}{\langle T^{\mathrm{long\ WF\ 2}} \rangle}$
- "Temperature inversion" estimator analogous to "Gradient inversion" estimator *(Horowitz, Ferraro, Sherwin 19, Hadzhiyska, Sherwin, Madhavacheril, Ferraro 19)*
- $1 - \hat{\tau}^{\mathrm{TI}}(x) \sim \frac{\delta T(x)}{T^{\mathrm{long\ WF}}(x)}$

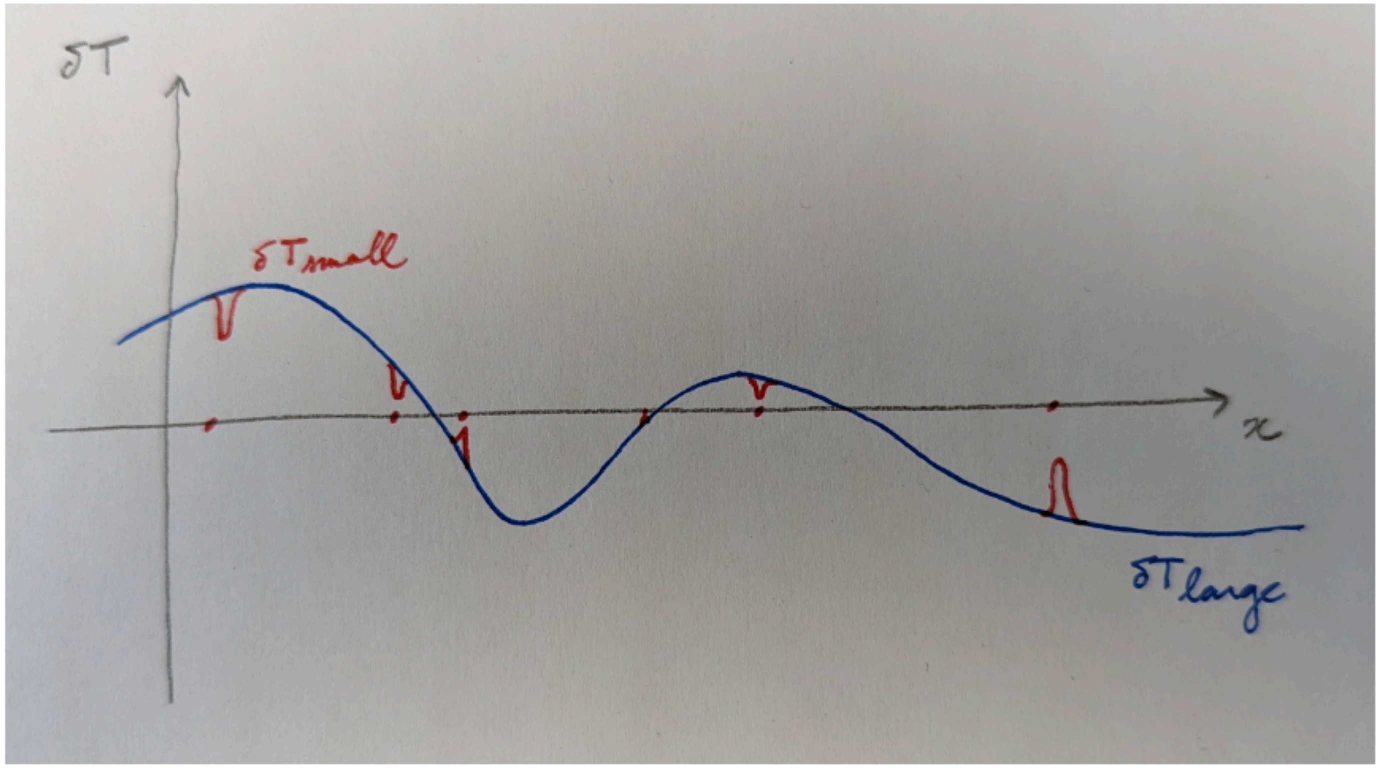
$$\frac{\delta T_{\mathrm{obs}}}{\bar{T}} = \frac{\delta T_{\mathrm{true}}}{\bar{T}} (1 - \tau)$$

Relationship between QE and TI

Small-scale screening limit:

- $1 - \hat{\tau}^{\rm QE}(x) \sim \delta T(x) \dfrac{T^{\rm long\ WF}(x)}{\langle T^{\rm long\ WF\ 2} \rangle}$
- $1 - \hat{\tau}^{\rm TI}(x) \sim \dfrac{\delta T(x)}{T^{\rm long\ WF}(x)}$
- $1 - \hat{\tau}^{\rm QE}(x) = \left[1 - \hat{\tau}^{\rm TI}(x)\right] \dfrac{T^{\rm long\ WF\ 2}(x)}{\langle T^{\rm long\ WF\ 2} \rangle}$
- Small scale QE is unbiased
- However, irreducible statistical error even with arbitrarily small experimental noise
- TI, on the other hand, can have arbitrarily small error

TI: lensing & foreground biases



"Temperature inversion"

$$1 - \hat{\tau}^{\rm TI}(x) \sim \frac{\delta T(x)}{T^{\rm long\ WF}(x)}$$

- In cross-correlation with tracers:
  - Both insensitive to foregrounds due to the sign change if $T^{\rm long}$ is clean
  - Lensing from the tracers does not add bias nor noise
  - Lensing from other objects adds noise
  - Same conclusions hold for small scale approximate QE as well

Current work and next steps

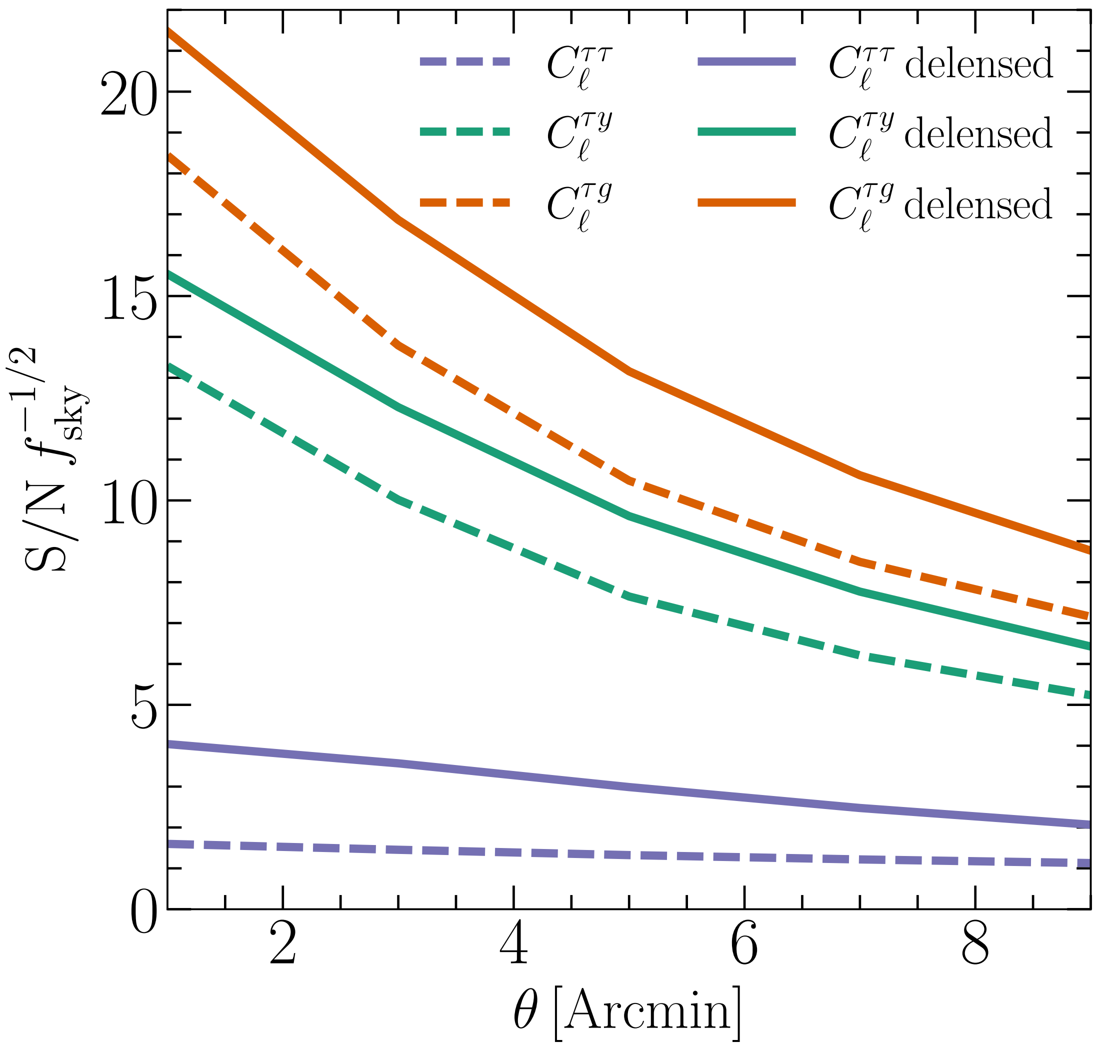
- Implementing all estimators
- Forecasting & comparing SNR
- Checking lensing & foreground biases in cross-correlation
- Clarifying the relation between all estimators
- First ever detection of this effect with the **current** data

Thank you!

Screening quadratic estimator

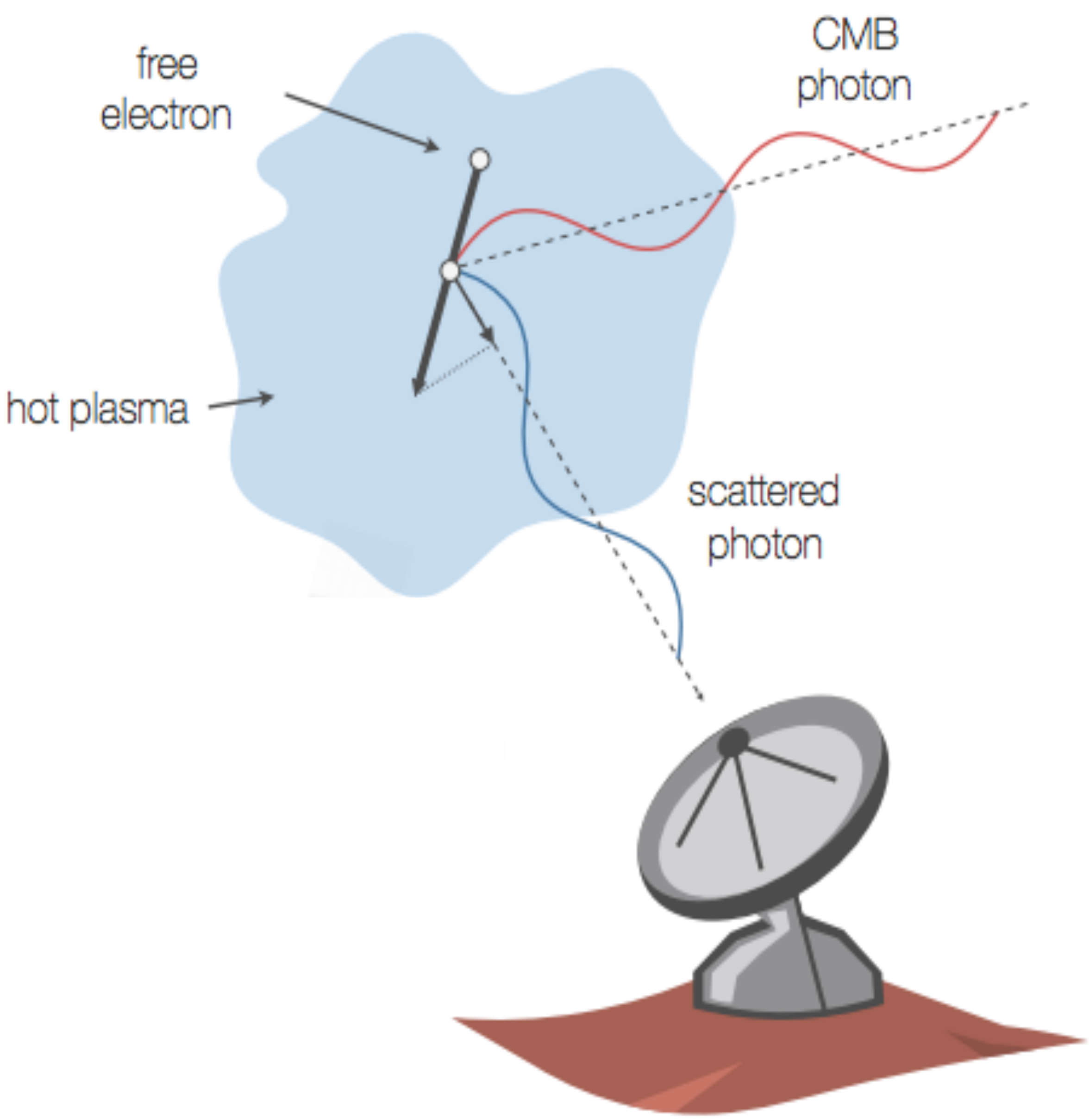
$$\frac{\delta T_{\rm obs}}{\bar{T}} = \frac{\delta T_{\rm true}}{\bar{T}}\,(1-\tau)$$

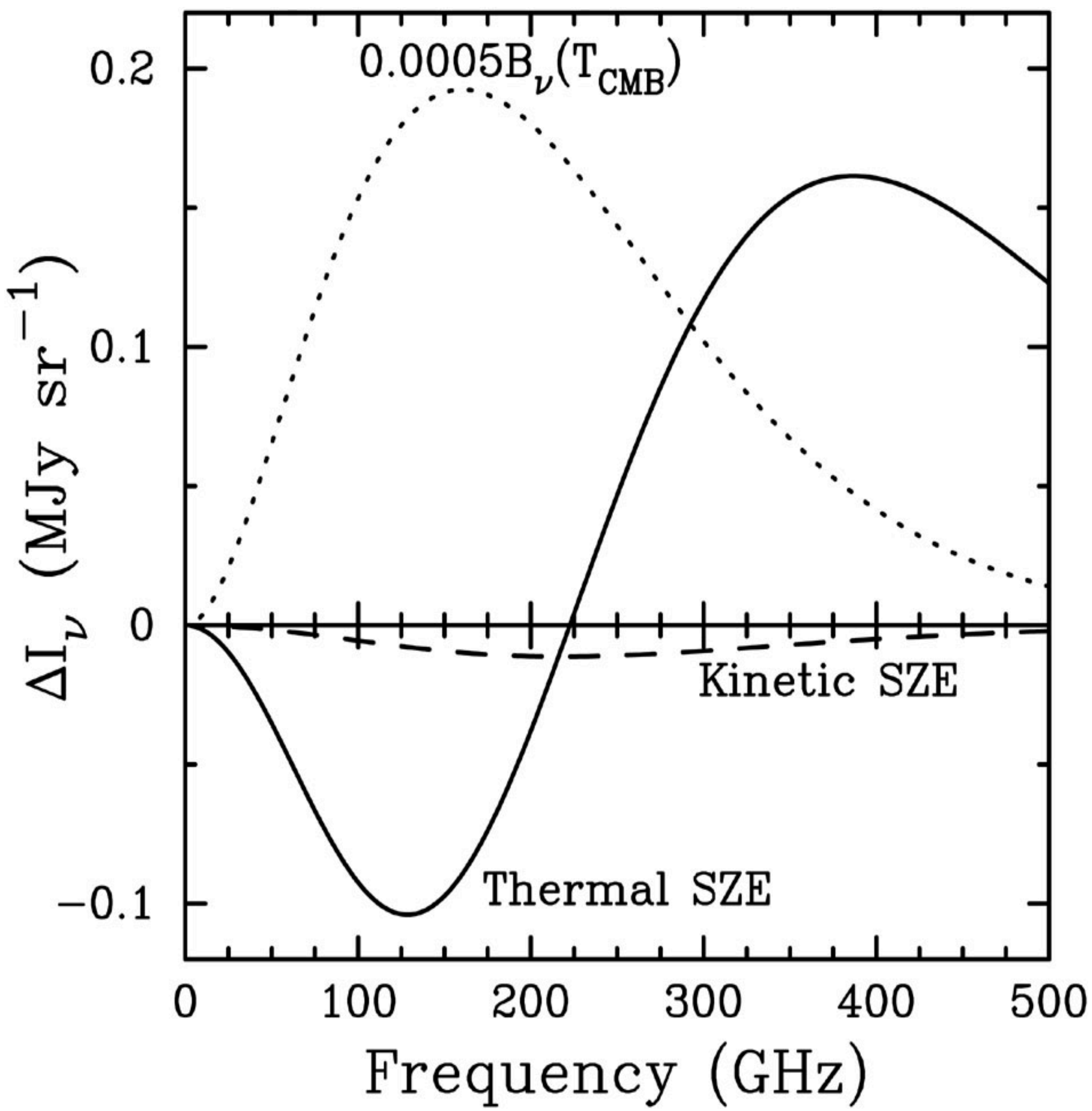
$$\hat{\tau}^{\rm QE}_{\boldsymbol{L}} \equiv - \frac{\int_{\boldsymbol{\ell}} \frac{\left(C^0_\ell + C^0_{|\boldsymbol{L}-\boldsymbol{\ell}|}\right)}{C^{\rm total}_\ell\, C^{\rm total}_{|\boldsymbol{L}-\boldsymbol{\ell}|}}\, \delta T_{\boldsymbol{\ell}} \delta T_{\boldsymbol{L}-\boldsymbol{\ell}}}{\int_{\boldsymbol{\ell}} \frac{\left(C^0_\ell + C^0_{|\boldsymbol{L}-\boldsymbol{\ell}|}\right)^2}{C^{\rm total}_\ell\, C^{\rm total}_{|\boldsymbol{L}-\boldsymbol{\ell}|}}}$$



Roy, van Engelen, Gluscevic, Battaglia 22

Sunyaev-Zel'dovich effect





kinetic Sunyaev-Zel'dovich effect