LiteBIRD's View on the Relativistic Sunyaev-Zeldovich Effect

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for the LiteBIRD Collaboration

Challenges at the CMB Frontier
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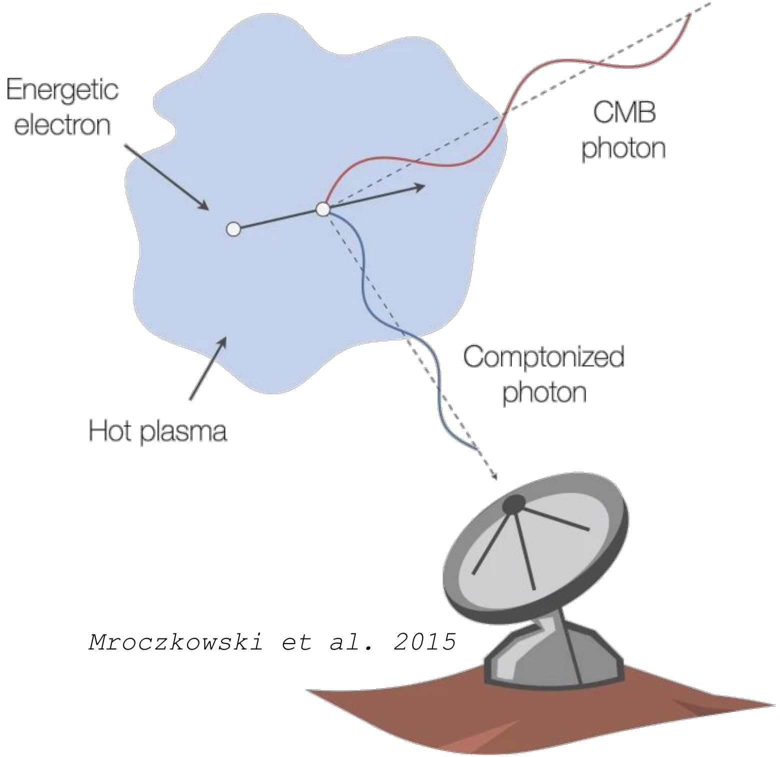
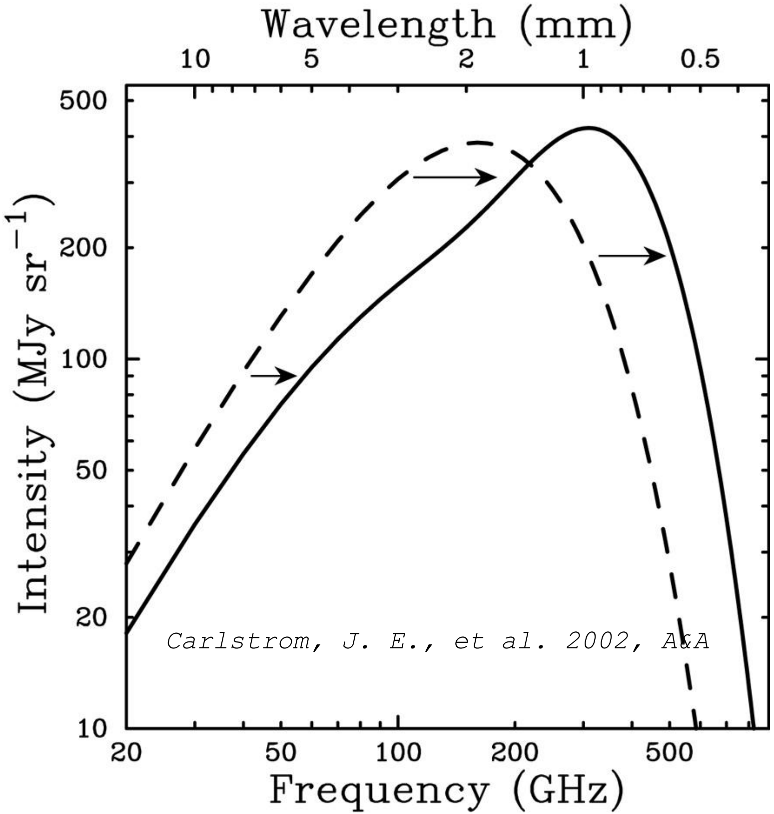
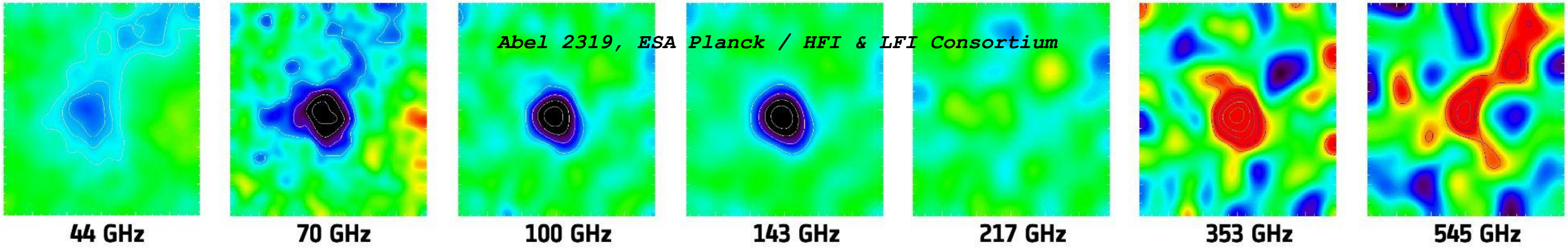
Sunyaev-Zeldovich Effect



Mroczkowski et al. 2015



Carlstrom, J. E., et al. 2002, A&A



$$\Delta I_{SZ} = y\, g(\nu)$$

$$y = \int \frac{k_B T_e}{m_e c^2} n_e \sigma_T dl$$

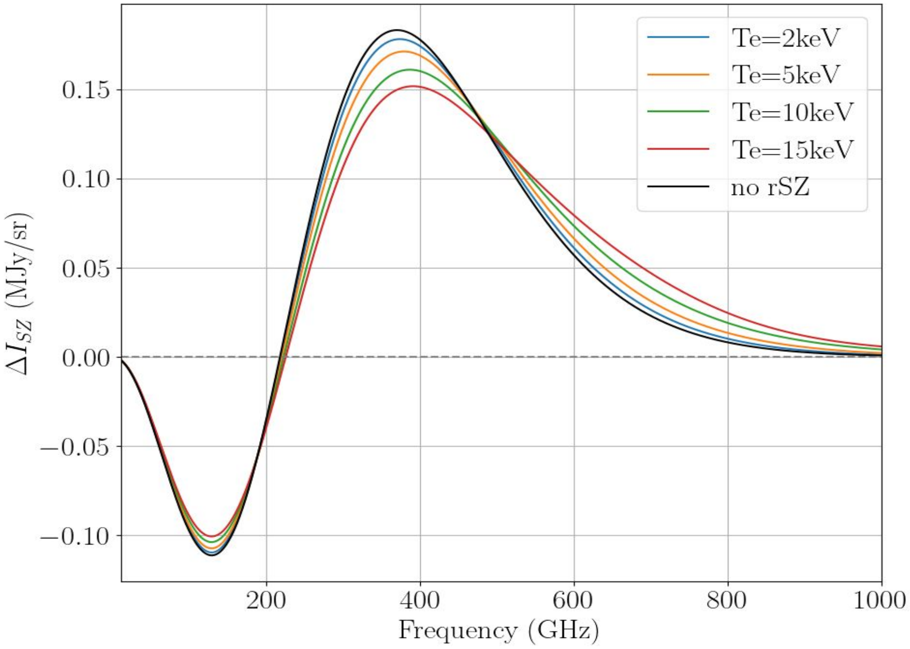
Non-relativistic Limit: $k_B T_e \ll m_e c^2$

Relativistic Correction to the Sunyaev-Zeldovich Effect

- Galaxy clusters can have electron temperatures

$$\sim 5 - 15\mathrm{keV}$$

$$\Delta I_{SZ}(\nu, \hat{n}) = y(\hat{n}) f(\nu, T_e(\hat{n}))$$



Neglecting rSZ for High T_e galaxy clusters

- Underestimation of the Compton parameter (y) of the cluster, Hurier, A&A, 2016, Erler et al., 2018
- Bias on the y-M scaling relation, Hurier, A&A, 2016
- Bias on tSZ power spectrum and $\sigma_{8,}$ Remazeilles et al., 2018
- Bias on H_0 from SZ/X-ray, Rephaeli, ApJ, 1995, Battistelli et al., 2003

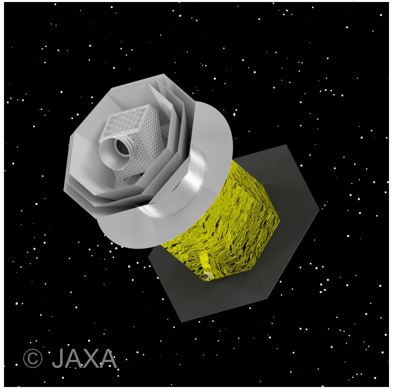
Measurement of T_e of galaxy clusters using rSZ

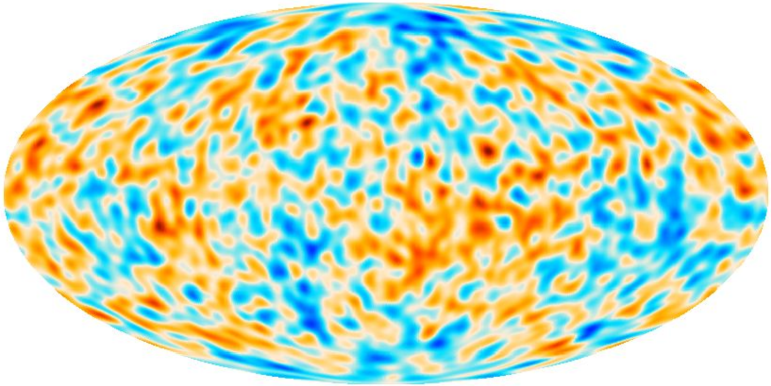
- Average Cluster Temperature through Stacking, Erler et al., MNRAS, 2018, Remazeilles and Chluba, MNRAS, 2025, Coulton et al, Phys. Rev. D, 2026

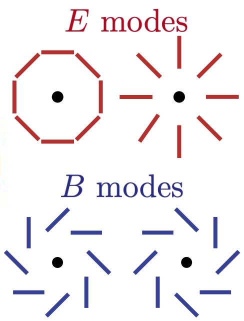
LiteBIRD overview

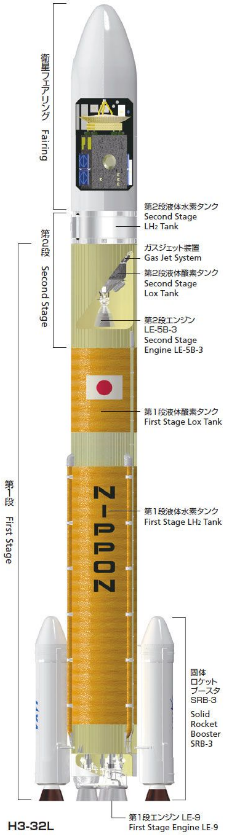
- Lite (Light) spacecraft for the study of *B*-mode polarization and Inflation from cosmic background Radiation Detection
- JAXA's L-class mission was selected in May 2019 to be launched by JAXA's H3 rocket on JFY2036
- Scientific goals: create all-sky, multi-band ultra-sensitive **microwave polarization maps**, test **inflationary models** through the measurements of **primordial gravitational waves**, and provide new insights into cosmology, particle physics and astrophysics
- **All-sky 3-year survey**, from Sun-Earth Lagrangian point L2
- Large frequency coverage (**40–402 GHz**) at **70–18 arcmin** angular resolution for precision measurements of the **CMB *B*-modes**
- Final combined sensitivity: **2.2 μK·arcmin**

LiteBIRD collaboration PTEP 2023









LiteBIRD reformation phase

LiteBIRD has been under **rescope studies to consolidate the mission's feasibility while keeping the same scientific objectives**

- Revisit the error budget
- **Simplify the mission configuration** (one single telescope instead of three; try to use existing technologies)
- **Simplify the cryogenic chain**
- Detectors to be procured by Europe
- New HWP design based on stacking 6 plates in Pancharatnam configuration, providing large bandwidth

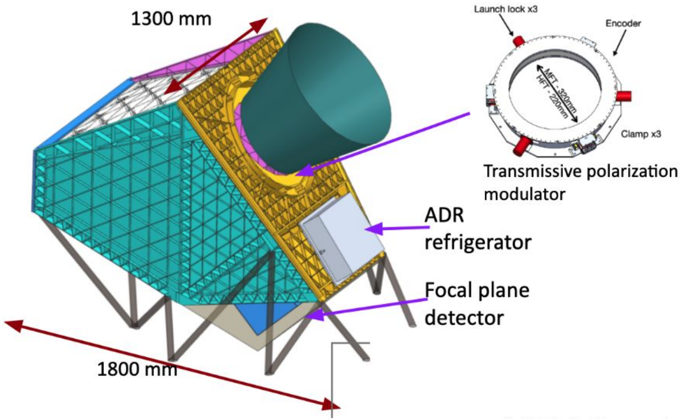
- **Two different configuration options** now being considered, both based on single Crossed-Dragone reflective telescope
- Option 1 (no HWP) requires a faster spin rate to minimize 1/f noise
- Option 2 is based on the possibility of using a wider-band HWP

Option 1

- Aperture 500 mm
- 40-570 GHz
- No HWP
- Spin rate 0.3 rpm

Option 2

- Aperture 500 mm
- 40-402 GHz
- Transmissive HWP
- Spin rate 0.05 rpm



Mapping the Hot Gas in the Universe

LiteBIRD data will reduce SZ map noise and foreground contamination by a factor ~10 compared to Planck.

Combining LiteBIRD with Planck adds the benefit of angular resolution.

Group activities

- Full-sky SZ signal map with LiteBIRD
- Structure Formation, Synergy with X-ray
- Relativistic SZ
- Missing Baryons in Filaments
- Constraint on σ8
- Constraint on CMB y-type Distortion

Remazeilles et al., JCAP, 2024

Sky Simulation

Frequency Channels	Frequency Range
LiteBIRD (15 channels) **(PTEP)***	40 – 402 GHz
Planck (9 channels)	30 – 857 GHz
Maps convolved with frequency-dependent Gaussian beams + Instrument noise.	

- **Framework and Foreground Components:** *Remazeilles et al., JCAP, 2024*
  - Using the Planck Sky Model (PSM)
  - Extragalactic: CMB, kinetic SZ, CIB, radio and IR point sources
  - Galactic: Thermal dust, synchrotron, free-free emission and AME
- **SZ Extension:** Explicit incorporation of relativistic SZ (rSZ) spectral distortions

*LiteBIRD is currently under rescoping, and its instrument specifications are subject to change.

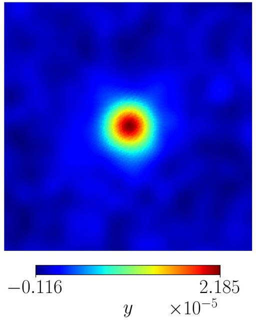
rSZ Moment Expansion and CILC Component Separation

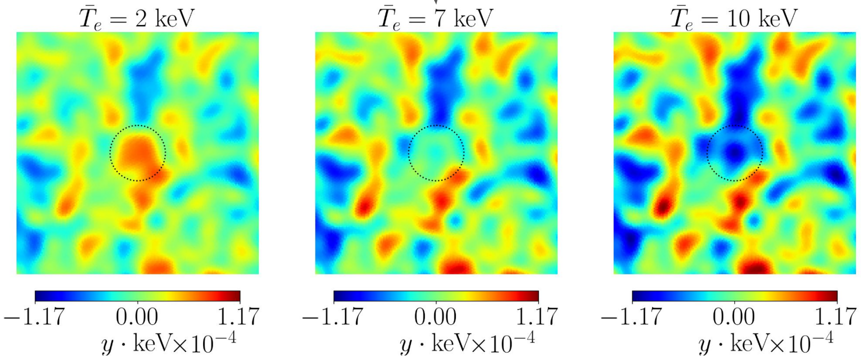
$$\Delta I_{SZ}(\nu,\hat{n}) = \underbrace{y(\hat{n})}_{0^{\mathrm{th}}\ \mathrm{Moment}} f(\nu,\bar{T}_e) + \underbrace{y(\hat{n})(T_e(\hat{n})-\bar{T}_e)}_{1^{\mathrm{st}}\ \mathrm{Moment}} \left.\frac{\partial f(\nu,T_e)}{\partial T_e}\right|_{T_e=\bar{T}_e}$$

Remazeilles and Chluba, MNRAS, 2020

$\bar{T}_e$: Pivot Temperature

Constrained Internal Linear Combination (CILC) Remazeilles et al., MNRAS (2011)





Preliminary Result

Angular resolution: 30 arcminutes

Coma Cluster: Input $T_e = 7.3\ keV$

MCMC Parameter Estimation with Cobaya (Torrado and Lewis, JCAP, 2021)

Modeling the rSZ Moment Maps:

$$Map_{0\text{th}} = \mathscr{B} * \left[y_{\text{cl}}\, \hat{y}(\theta)\right]$$

$$Map_{1\text{st}} = \mathscr{B} * \left[y_{\text{cl}} \left(T_e \hat{t}_e(\theta) - \bar{T}_e\right) \hat{y}(\theta)\right]$$

$$\hat{y}(\theta) = y_0 \left(1 + \frac{\theta^2}{\theta_c^2}\right)^{(1-3\beta)/2}$$

Spatial Profile Template for y

Normalised Isothermal β model

$$\beta = 1, \qquad \theta_c \sim 0.2\theta_{500}$$

$$\hat{t}_e(\theta) = \begin{cases} 1 & \theta \leq \theta_{500} \\ 0 & \theta > \theta_{500} \end{cases}$$

Spatial Profile Template for T_e

Top hat

Likelihood

$$\log \mathscr{L}(y_{\rm cl}, T_e) = -0.5 \sum_{\rm pix \in Aperture} \left(\mathbf{d}^T C^{-1} \mathbf{d} + \log |C| \right)$$

$$d_i = \mathrm{CILC}_i - m_i$$

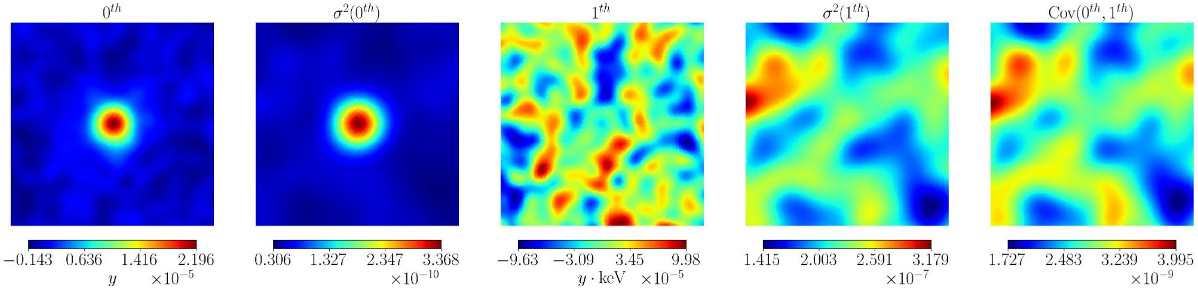
$$\mathrm{Aperture} = \sqrt{\theta_{500}^2 + \mathrm{FWHM}_{\rm beam}^2}$$

C: per pixel covariance between the 0^{th} and 1^{st} moments

Priors:

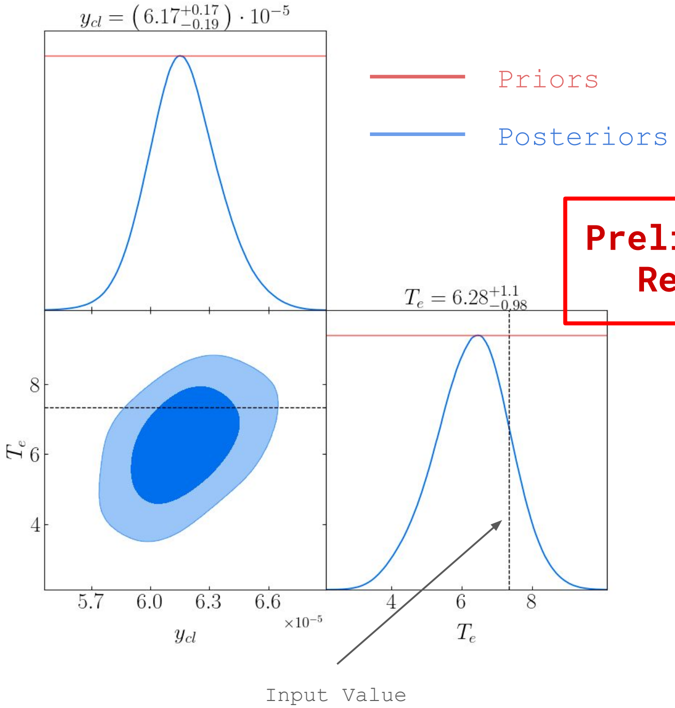
$$y_{\rm cl} \in [10^{-6}, 5 \times 10^{-4}]$$

$$T_e \in [0, 30]\ \mathrm{keV}$$

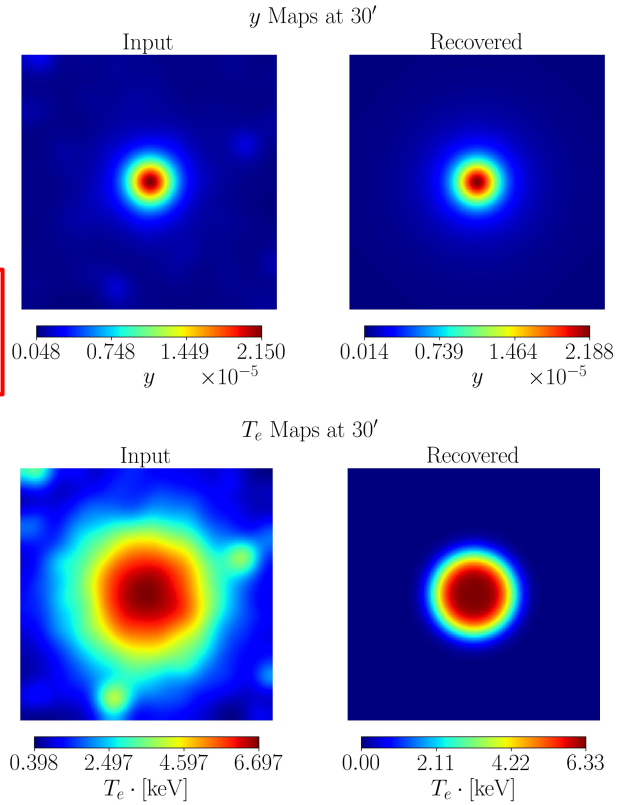


Preliminary Result

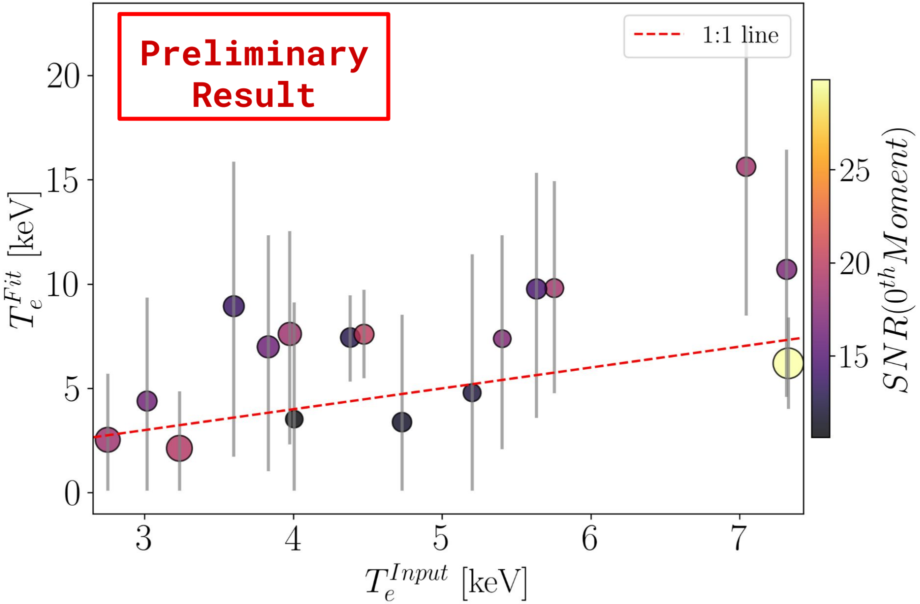
Fit Results for Coma Cluster



Preliminary Result



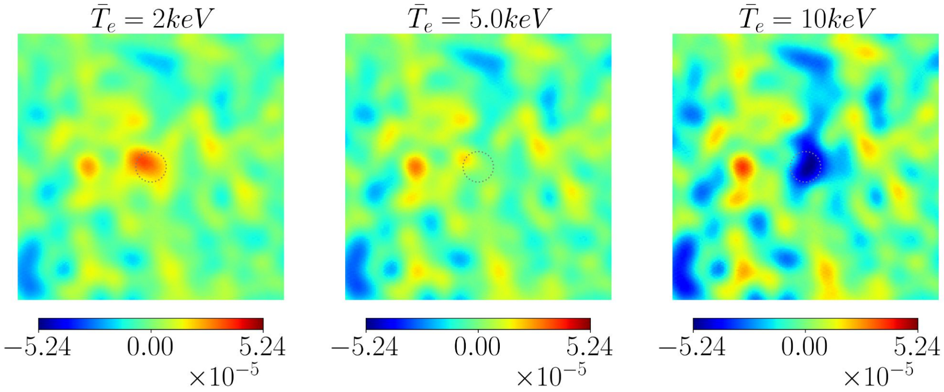
Electron Gas Temperature of Individual Galaxy Clusters



$$\text{Clusters} \in \theta_{500} > 15', SNR_{0^{th}} > 10, T_e > 2\text{keV}$$

Clusters with 95%CI > 15 keV excluded: Final cluster sample = 17

- 17 Clusters with $\langle T_e \rangle$ = 4.8 keV



Preliminary Result

Stacked 1st moment maps for 3 Pivot values. The null signal is observed at $\bar{T}_e = 5keV$, which is the closest Pivot value to the mean T_e of the selected clusters.

Conclusions

- Relativistic SZ effects provide a direct probe of the electron temperature of galaxy clusters.
- We develop a method to estimate the electron gas temperature of individual galaxy clusters based on: rSZ moment expansion + CILC + MCMC.
- Using a joint LiteBIRD and Planck simulation, it is possible to recover the electron gas temperatures of individual galaxy clusters.

Impact of LiteBIRD reformation:

- The revised configuration is not expected to significantly affect the ability to separate the rSZ moments in a LiteBIRD+Planck based analysis.
  - LiteBIRD frequency span remains essentially unchanged
  - Inclusion of Planck frequency channel
- We expect a slight increase in the noise level and residual foregrounds of the CILC maps leading to possible degradation in T_e sensitivity.

Thank you for your time!