We select a sub-sample of 772 clusters from the SZ-selected second Planck spectrum and constrain the relativistic tSZ + FIR model. Our approach is validated using mock data sets including simulated relativistic corrections. Uncorrelated galactic and extragalactic foregrounds are reduced in a matched filtering technique. The extracted spectrum shows the tSZ at high significance plus a FIR excess, which we include in our spectral model. We are able to measure the tSZ relativistic corrections at 2.2σ and constrain the mean temperature of the cluster sample to $4.4 \pm 2.0$ keV. Future instruments like CCAT-prime will improve on Planck with lower noise and better spatial resolution.

### References


**Abstract**

**What is the Sunyaev-Zeldovich Effect?**

The thermal Sunyaev-Zeldovich (tSZ) Effect is a spectral distortion of the cosmic microwave background (CMB) due inverse Compton scattering of CMB photons by free electrons in the ICM. Due to the high electron energies of several keV found in the ICM the full description of the tSZ requires relativistic corrections, which introduce a temperature dependence to the spectral shape. This allows to break the degeneracy of gas density and temperature. The tSZ can be written as a temperature shift relative to the CMB:

$$\frac{\Delta T_{\text{SZ}}}{T_{\text{CMB}}} = y f(s, T_e) \quad \text{with} \quad y = \frac{\sigma_T}{m_e c^2} \int_0^\infty n_e k_B T_e \, dl$$

Observing the relativistic tSZ is very challenging due to much brighter galactic and extragalactic FIR emission and only recently has a first detection been claimed.

**Figure 1**: Spectrum of the thermal SZ effect with relativistic corrections for a range of electron temperatures normalized to constant energy ($y = 10^{-4}$). The gray bands indicate the nine Planck frequency channels.

**Method**

- We select a sub-sample of 772 clusters from the SZ-selected second Planck cluster catalog used in this work. The cluster-free central part of the image traces the Galactic mask used for cluster selection.
- Uncorrelated galactic and extragalactic foregrounds are reduced in a matched filter approach.
- The extracted spectrum is fitted with a two component rel. tSZ + FIR model.
- Our approach is validated using mock data sets.
- We use auxiliary data from AKARI and IRAS at THz frequencies.

**Results**

**Figure 4**: Results for our sample of 772 galaxy clusters. Left: spectrum extracted after passing the Planck, IRAS, and AKARI maps through our matched filtering pipeline and stacking of the cluster positions. Right: marginalized 2D and 1D constraints on our model parameters. The tSZ signal of the sample is detected with high significance (31σ) and we obtain a 2.2σ measurement of the sample-average cluster temperature for which we find $4.4 \pm 2.0$ keV ($T_e = 6.9$ keV).

**Figure 5**: Results for the hottest 100 clusters as determined through an M-T-scaling relation. Left: as before, we show the spectrum extracted after passing the Planck, IRAS, and AKARI maps through our matched filtering pipeline and stacking of the cluster positions. Right: marginalized 2D and 1D constraints on our model parameters for the 100 hottest clusters. Although the average $y$-parameter of the clusters is roughly twice as high as for the full sample, the significance of the tSZ signal detection reduces to 23σ. We measure a higher sample-average cluster temperature of $6.0 \pm 1.7$ keV ($T_e = 8.5$ keV), but at a slightly reduced significance of 2.0σ.

**Conclusions**

Our work demonstrates that the relativistic tSZ can be measured with Planck at low significance. Stacking a large cluster sample provides the necessary signal-to-noise ratio, but THz fluxes remain uncertain. Matched filtering allows for an excellent level of foreground removal and performs better than any other approach tested. Using mock data, we were able to show that ignoring relativistic corrections to the tSZ will lead to biased estimates of the integrated Comptonization ($Y_{\text{SZ}}$), which in turn can bias mass estimates of clusters. Future experiments like CCAT-prime will improve on Planck’s capabilities by either providing higher spatial or spectral resolution, which will allow for a more effective separation of Galactic foregrounds, the clusters’ far infrared emission and the weak relativistic tSZ signal.