CCAT-prime & the quest for SZ Spectral Distortions

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CMB as a backlight: SZ effect

I. Lensing
II. Scattering
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\[ \frac{\Delta n}{n_0} = \frac{\Delta J}{J_0} = xy \frac{e^x}{e^x - 1} \left\{ \frac{x}{\tanh(x/2)} - 4 \right\}. \]

Sunyaev & Zeldovich, 1972

Planck/ESA
Relativistic SZ (rSZ) effect

For hot clusters with typical electron energy $kT_e \approx 5$ keV, the relativistic corrections to the SZ spectrum become significant.

$$f(x, T_e) = \left( x \frac{\exp(x) + 1}{\exp(x) - 1} - 4 \right) (1 + \delta_{SZB}(x, T_e))$$
rSZ effect applications

Erler et al. (2018)

\[ k_B \langle T_{SZ} \rangle = 4.4^{+2.1}_{-2.0} \text{ keV} \]

From Planck

From CCAT-p + SO

Erler et al. (in prep)

30% \( \tau_0 \) constraints from SZ measurements only!

15% effect at intermediate scales (massive clusters)

rSZ corrections on the tSZ power spectrum (Remazeilles et al. 2019)

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rSZ corrections on the tSZ power spectrum (Remazeilles et al. 2019)
We stand a very good chance to measure the rSZ-derived temperature in a single cluster for the first time!

This was prediction for CCAT-p-only 1k sq deg survey, for 4000 hours = 25 sq deg in 100 hours

Ideal for imaging one massive cluster
Nonthermal (ntSZ) effect: A new frontier

CMB photons will also scatter off other sources of free electrons, e.g. power-law distribution with a high-energy tail but in clusters it is ≲1% of the tSZ signal 😞

B_{avg} > 0.03 \mu G
from Planck data,
95% confidence

Muralidhara et al. (in prep)

With CCAT-prime and SO, order-of-magnitude better constraints on ntSZ-based B-field limits can be expected in the next ~5 years.
The kinematic SZ (kSZ) effect

kSZ provides estimates for the peculiar velocities, and in the limit of the linear perturbation theory, directly the growth rate

\[ \vec{v}(\vec{k}) = i \frac{d \ln D}{d \ln a} \frac{a H \delta(\vec{k}) \vec{k}}{k^2} \]

Dark energy parameter constraints from a CCAT 25m-like survey, with \( \sigma_v = 100 \) km/s (adapted from Bhattacharya & Kosowsky 2008)
kSZ with CCAT-prime

CCAT-prime predictions by Mittal et al. (2018)

kSZ measurements in the near future will not only constrain cosmology, but also search for the missing baryons (Maude’s talk), and inform about feedback processes in galaxy evolution.

Battaglia et al. (2017)

(results from stacking)
Adding CCAT-prime data to SO (93—280 GHz) does not make a significant difference in the **cluster number counts** (although it may help with sample purity).

So what is the most significant advantage? **One answer: Dust**
Far-IR bias on kSZ and rSZ

The short-wavelength data fitting includes a dust component to marginalize over its parameters. The long-wavelength data fitting does not marginalize over dust and creates a bias.

We build a dust model from the difference between the matched filtering and aperture photometry results. The $A_{\text{dust}}$ shown here lies at the upper limit of the allowed range. 😊

Also, only white noise is used to highlight these kSZ/rSZ biases.

Basu, Erler+ in prep.
See also Astro2020 White Paper, 1903.04944
A rich variety of SZ spectral sciences are expected become feasible this decade.

SZ temp and velocity measurements will have fundamental roles in cosmology.

High-Freq ($\geq 220$ GHz) data from CCAT-prime will be critical for all other SZ experiments.