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Detection of pairwise kSZ effect with DESI galaxy clusters and Planck in Fourier space

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Abstract

We report a $\sim 5.2\sigma$ detection of the kinetic Sunyaev–Zel'dovich (kSZ) effect in Fourier space, by combining the DESI galaxy groups and the Planck data. We use the density-weighted pairwise kSZ power spectrum as the summary statistic, and the detailed procedure of its measurement is presented in this paper. Meanwhile, we analyze the redshift space group density power spectrum to constrain its bias parameters and photo-z uncertainties. These best-fitted parameters are substituted to a nonlinear kSZ model, and we fit the measured kSZ power spectrum with this model to constrain the group optical depth $\bar{\tau}$. Selected by a varying lower mass threshold $M_{\rm th}$, the galaxy group catalogs with different median masses ($\tilde{M}$) are constructed from the DR9 data of the DESI Legacy Imaging Surveys. $\tilde{M}$ spans a wide range of $\sim 10^{13} - 10^{14} M_\odot/h$ and the heaviest $\tilde{M} \sim 10^{14} M_\odot/h$ is larger than those of most other kSZ detections. When the aperture photometric filter radius $\theta_{\rm AP}$ is set to be 4.2 arcmin, the $\tilde{M} = 1.75 \times 10^{13} M_\odot/h$ group sample at the median redshift $\tilde{z} = 0.64$ has the highest kSZ detection S/N = 5.2. By fitting $\bar{\tau}$s from various samples against their $\tilde{M}$s, we obtain a linear $\log\bar{\tau} - \log\tilde{M}$ relation: $\log\bar{\tau} = \gamma(\log\tilde{M} - 14) + \log\beta$, in which $\gamma = 0.55 \pm 0.1$. We also vary the aperture photometric filter radius and measure the $\bar{\tau}$ profiles of group samples, whose constraints on the baryon distribution within and around dark matter halos will be discussed in a companion paper.

Theory

The secondary anisotropy of the CMB temperature caused by the scattering off of CMB photons by free electrons with bulk motions is known as the kSZ effect. The change of the CMB temperature is:

$$\frac{\Delta T_{\rm kSZ}}{T_{\rm CMB}}(\hat{\boldsymbol{n}}) = -\int n_e(\hat{\boldsymbol{n}}, l)\sigma_{\rm T}\frac{\boldsymbol{v}\cdot\hat{\boldsymbol{n}}}{c}dl\,. \quad (1)$$

Data

CMB map: HFI 217 GHz of the public *Planck* Release 3 data.

Tracers: The galaxy group catalog provided by Yang et al. (2021):

Baseline sample : $\sim 5.7 \times 10^6$ clusters with $M > 10^{13.0}{\rm M}_\odot$/h.

Methodology

The estimator of the density-weighted pairwise kSZ power spectrum multipoles:

$$\hat{P}^\ell_{\rm kSZ}(\boldsymbol{k}) = -\frac{2\ell+1}{A}\int d^3s_1\int d^3s_2 e^{-i\boldsymbol{k}\cdot\boldsymbol{s}_{12}}\mathcal{L}_\ell(\hat{\boldsymbol{k}}\cdot\hat{\boldsymbol{n}}_{12})[\delta T(\boldsymbol{s}_1)\delta n(\boldsymbol{s}_2) - \delta n(\boldsymbol{s}_1)\delta T(\boldsymbol{s}_2)]\,. \quad (2)$$

The theorectical multipoles of density-weighted pairwise kSZ power spectrum is:

$$P^\ell_{\rm kSZ}(k) \simeq \frac{T_{\rm CMB}\bar{\tau}}{c}\cdot i\frac{aHf}{\boldsymbol{k}\cdot\hat{\boldsymbol{n}}}\cdot\frac{2\ell+1}{2}\int_{-1}^{1}d\mu\mathcal{L}_\ell(\mu)\frac{\partial}{\partial f}P_{\rm s}(\boldsymbol{k})\,. \quad (3)$$

where $P_{\rm s}$ is the galaxy power spectrum with photo-z damping:

$$P_{\rm s}(k,\mu) = \left(b_1 + b_2k^2e^{-k^2} + f\tilde{W}\mu^2\right)^2 P_{\rm m}(k)\frac{1}{1+k^2\mu^2\sigma_v^2/H^2}\cdot\frac{1}{1+k^2\mu^2\sigma_z^2/H^2}\,. \quad (4)$$

Aperture photometry (AP) filter

The AP filter, a 2-D compensated top-hat filter, is used to obtain kSZ signal. Filter sizes for different galaxy clusters:

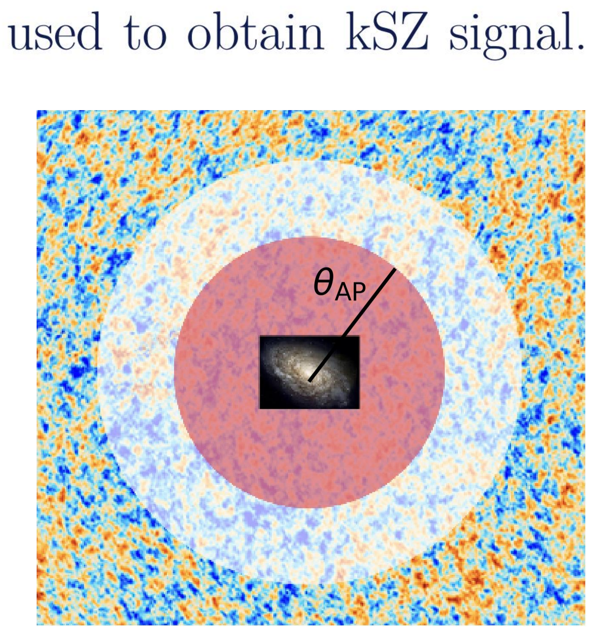
$\boldsymbol{\theta_{\rm AP}}$: The radius of the circle inside the AP filter.

AP filter:

$$W_{\rm AP}(\theta) = \frac{1}{\pi\theta^2_{\rm AP}}\begin{cases} 1, & \theta \le \theta_{\rm AP}\,, \\ -1, & \theta_{\rm AP} < \theta \le \sqrt{2}\theta_{\rm AP}\,, \\ 0, & \theta > \sqrt{2}\theta_{\rm AP}\,; \end{cases}$$

kSZ signal:

$$\Delta T^{\rm AP}_{\rm kSZ}(\boldsymbol{\theta}) = \int d^2\theta' W_{\rm AP}(\boldsymbol{\theta}-\boldsymbol{\theta}')T_{\rm map}(\boldsymbol{\theta}')\,.$$



Results

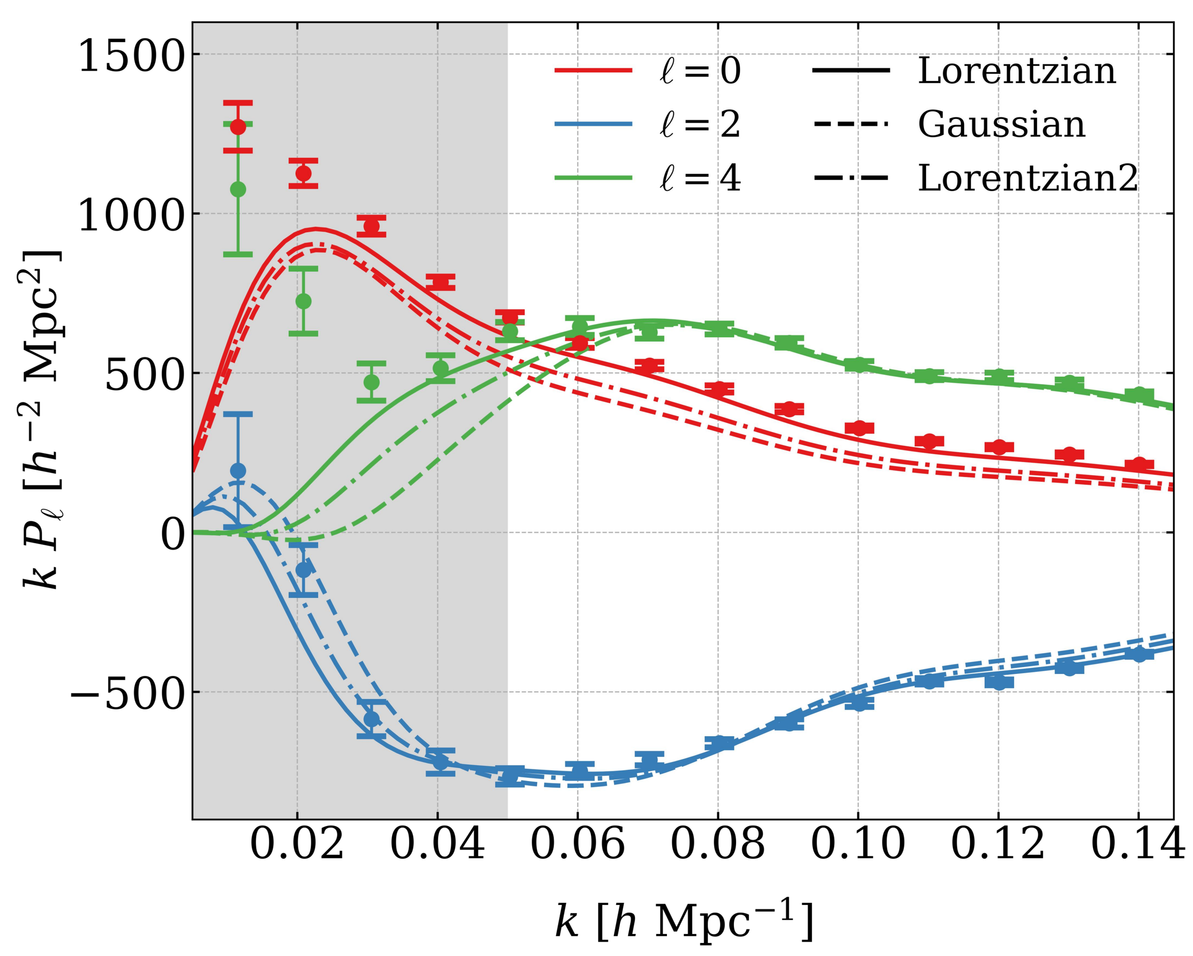


Figura 1: Power spectrum multipoles of the baseline sample compared with the theoretical templates, $P_{\rm s}$ (solid lines).

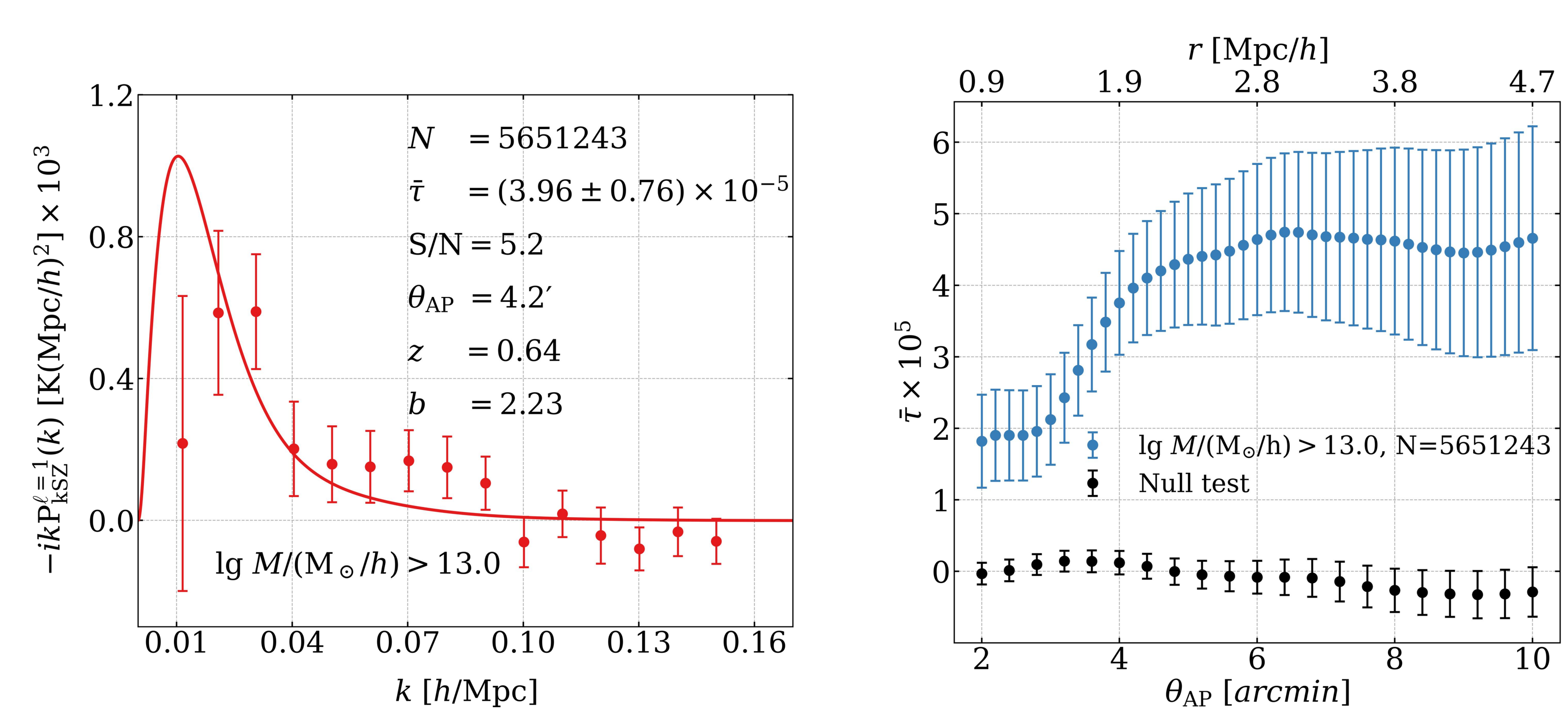


Figura 2: *Left:* The pairwise kSZ dipole measurements (points with error bars) compared with the theoretical template (solid line). *Right:* The measured $\bar{\tau}$ profile of the baseline sample (blue point with error bars) varies with $\theta_{\rm AP}$.

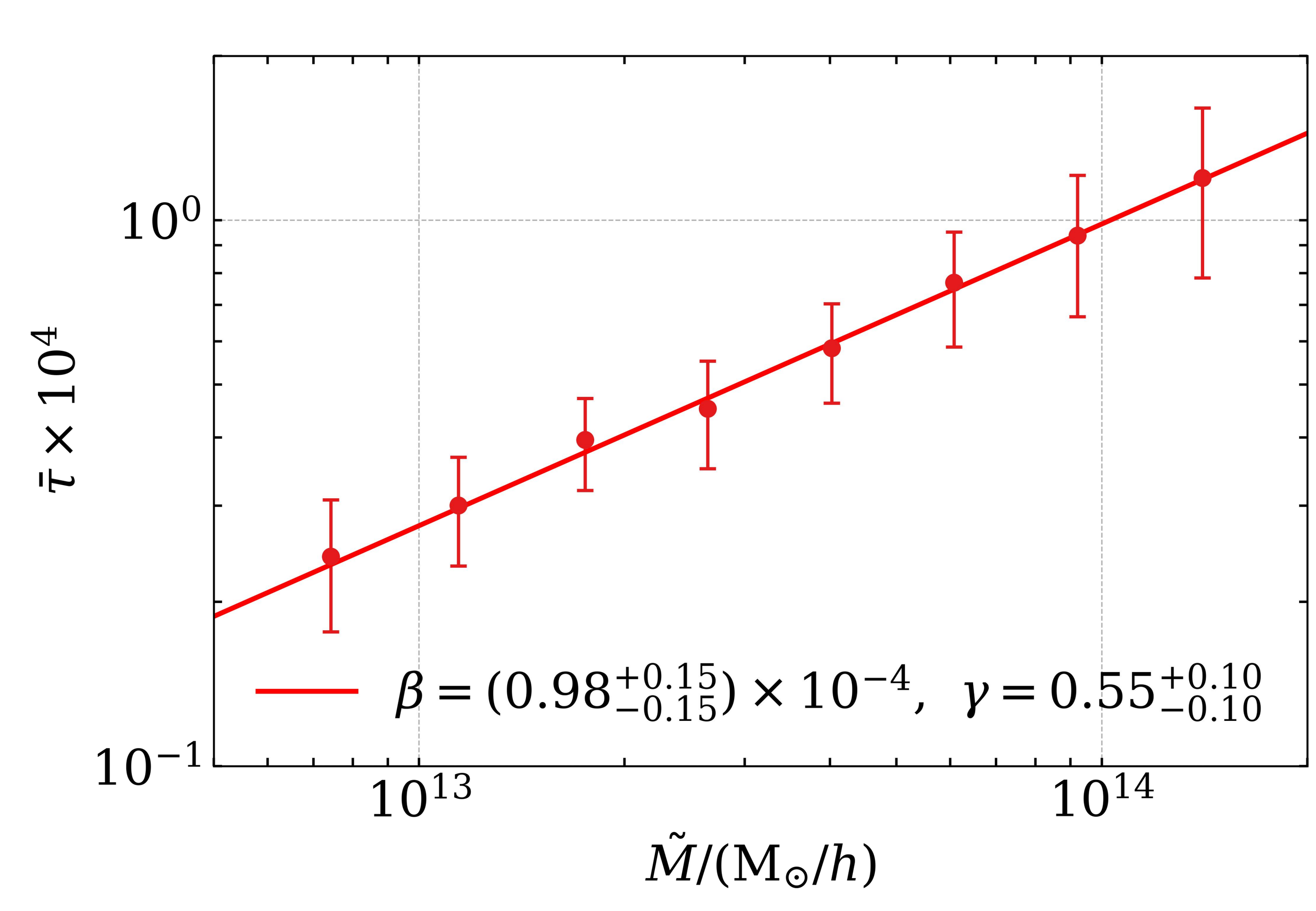


Figura 3: The points with error bars are measurements and the solid lines are the results of the fittings. The theoretical model: $\log\bar{\tau} = \gamma(\log\tilde{M} - 14) + \log\alpha$. The relevant results are shown in figure.