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The kSZ effect as a probe of the physics of cosmic reionization: the effect of self-regulated reionization

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We calculate the angular power spectrum of the Cosmic Microwave Background (CMB) temperature fluctuations induced by the kinetic Sunyaev-Zel'dovich (kSZ) effect from the epoch of reionization (EOR). We use detailed *N*-body simulation with radiative transfer to follow inhomogeneous reionization of the intergalactic medium (IGM). For the first time we take into account the "self-regulation" of reionization: star formation in low-mass atomic-cooling halos (LMACH, $10^8\ \mathrm{M}_\odot \lesssim \mathrm{M} \lesssim 10^9\ \mathrm{M}_\odot$) or minihalos (MH, $10^5\ \mathrm{M}_\odot \lesssim \mathrm{M} \lesssim 10^8\ \mathrm{M}_\odot$) is suppressed if these halos form in the regions that were already ionized or Lyman-Werner dissociated. In self-regulated reionization, the universe begins to be ionized early, maintains a low level of ionization for an extended period, and then finishes reionization as soon as high-mass atomically-cooling halos (HMACH, $\mathrm{M} \gtrsim 10^9\ \mathrm{M}_\odot$) dominate. While inclusion of self-regulation affects the amplitude of the kSZ power spectrum only modestly ($\sim 10\%$), it can change the duration of reionization by a factor of more than two.

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1. Result

1.1 Spot checking the previous constraints on the duration of reionization: more extended histories can give similar kSZ signals

Our predictions for the angular power spectrum induced by the kSZ effect at $l = 3000$ ($D^{\rm kSZ}_{l=3000} \equiv l(1+l)C^{\rm kSZ}_{l=3000}/2\pi$) are summarized in Table 1. Among the models we have explored in [1], L3 (which contains only HMACHs and does not have self-regulation) closely matches the scenarios explored in the above studies. For example, recently, using a new semi-numerical method based on a correlation between the smoothed density field and the redshift-of-reionization field found from radiation-hydro simulations of [2], [3] calculate the kSZ power spectrum coming from $z > 5.5$ and obtain the following scaling relation:

$$D^{\rm kSZ, z>5.5}_{l=3000} = 2.02\ \mu{\rm K}^2 \left[\left(\frac{1+\bar{z}}{11}\right) - 0.12\right] \left(\frac{\Delta z}{1.05}\right)^{0.47}, \quad (1.1)$$

Using $z_{50\%} = 9.1$ and $z_{75\%} - z_{25\%} = 0.9$ we find for L3, Equation (1.1) gives $D^{\rm kSZ, z>5.5}_{l=3000} = 1.5\ \mu{\rm K}^2$. This is in reasonable agreement with our result, $D^{\rm kSZ, z>5.5}_{l=3000} = 1.2\ \mu{\rm K}^2$.

However, the above formula significantly overestimates the amplitude of the kSZ power spectrum for L1: Equation (1.1) gives $D^{\rm kSZ, z>5.5}_{l=3000} = 2.4\ \mu{\rm K}^2$, whereas we find $D^{\rm kSZ, z>5.5}_{l=3000} = 1.3\ \mu{\rm K}^2$. In other words, despite the fact that L1 has a significantly more extended duration of reionization than L3 (by a factor of more than two), $z_{75\%} - z_{25\%} = 2.2$, the amplitude of the kSZ power spectrum increases only by 8%. Similarly, Equation (1.1) gives $D^{\rm kSZ, z>5.5}_{l=3000} = 1.5$ and $1.9\ \mu{\rm K}^2$ for L2 and L2M1J1, respectively, whereas we find $0.9\ \mu{\rm K}^2$ for both cases. Therefore, we conclude that Equation (1.1) is valid only for simple scenarios where the reionization history is roughly symmetric about the half-ionization redshift, but is invalid when self-regulation is included. Similar conclusions apply to [4] and [5].

Our results show that self-regulation makes the duration of reionization significantly more extended without changing the amplitude of the kSZ power spectrum very much. In other words, an extended period of low-level ionization in $z > z_{50\%}$ does not contribute much to the kSZ power spectrum at $l = 3000$.

References

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[0] This work presents a portion of results from [1]. For more detailed material regarding the results presented here, the readers should refer to [1].

Table 1: Global reionization history and kSZ signal

Label	Sources	$z_{\rm re}$	$\Delta z_{\rm re}$	$D_{l=3000}^{\rm kSZ,z>5.5}$ This work	$D_{l=3000}^{\rm kSZ,z>5.5}$ Mesinger et al.	$D_{l=3000}^{\rm kSZ,z>5.5}$ Battaglia et al.
L3	HMACHs	9.1	0.9	8.4	1.20	1.96
L1	HMACHs + LMACHs	9.5	2.2	8.3	1.27	1.94
L2	HMACHs + LMACHs	7.6	1.4	6.8	0.87	1.69
L2M1J1	HMACHs + LMACHs +MHs	7.7	2.1	6.8	0.90	1.69

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