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, $10^8 M_\odot \lesssim M \lesssim 10^{9} M_\odot$) or minihalos (MH, $10^5 M_\odot \lesssim M \lesssim 10^{8} M_\odot$) 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, $M \gtrsim 10^{9} M_\odot$) 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 $l = 3000 (D_{l=3000}^{kSZ} \equiv l(1+l)C_{l=3000}/2\pi)$ 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:

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

Using $z_{50\%} = 9.1$ and $z_{75\%} - z_{25\%} = 0.9$ we find for L3, Equation (1.1) gives $D_{l=3000}^{kSZ, z>5.5} = 1.5 \mu K^2$. This is in reasonable agreement with our result, $D_{l=3000}^{kSZ, z>5.5} = 1.2 \mu K^2$. However, the above formula significantly overestimates the amplitude of the kSZ power spectrum for L1: Equation (1.1) gives $D_{l=3000}^{kSZ, z>5.5} = 2.4 \mu K^2$, whereas we find $D_{l=3000}^{kSZ, z>5.5} = 1.3 \mu K^2$. 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 $D_{l=3000}^{kSZ, z>5.5} = 1.5$ and $1.9 \mu K^2$ for L2 and L2M1J1, respectively, whereas we find $0.9 \mu K^2$ 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


0This work presents a portion of results from [1]. For more detailed material regarding the results presented here, the readers should refer to [1].
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Table 1: Global reionization history and kSZ signal

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<th>Label</th>
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<th>$z_{re}$</th>
<th>$\Delta z_{re}$</th>
<th>$D_{kSZ,z&gt;5.5}^{L=3000}$</th>
<th>$D_{kSZ,z&gt;5.5}^{L=3000}$</th>
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<td>8.3</td>
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<td>1.4</td>
<td>6.8</td>
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