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Dark Radiation Isocurvature from Cosmological Phase Transitions

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Cosmological first order phase transitions are typically associated with physics beyond the Standard Model, and thus of great theoretical and observational interest. Models of phase transitions where the energy is mostly converted to dark radiation can be constrained through limits on the dark radiation energy density (parameterized by $\Delta N_{\rm eff}$). However, the current constraint ($\Delta N_{\rm eff} < 0.3$) assumes the perturbations are adiabatic. We point out that a broad class of non-thermal first order phase transitions that start during inflation but do not complete until after reheating leave a distinct imprint in the scalar field from bubble nucleation. Dark radiation inherits the perturbation from the scalar field when the phase transition completes, leading to large-scale isocurvature that would be observable in the CMB. We perform a detailed calculation of the isocurvature power spectrum and derive constraints on $\Delta N_{\rm eff}$ based on CMB+BAO data. For a reheating temperature of $T_{\rm rh}$ and a nucleation temperature T_*, the constraint is approximately $\Delta N_{\rm eff}$ $lesssim 10^{-5}(T_*/T_{\rm rh})^{-4}$, which can be much stronger than the adiabatic result. We also point out that since perturbations of dark radiation have a non-Gaussian origin, searches for non-Gaussianity in the CMB could place a stringent bound on $\Delta N_{\rm eff}$ as well.

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