Early-universe physics with CMB spectral distortions

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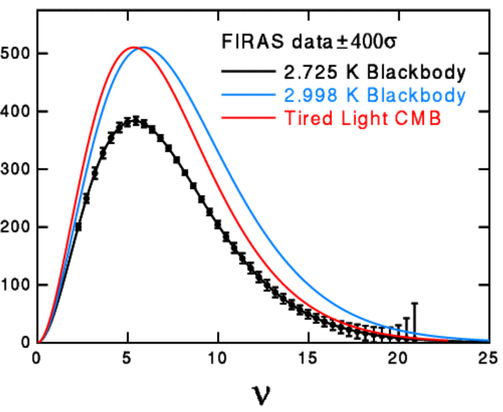
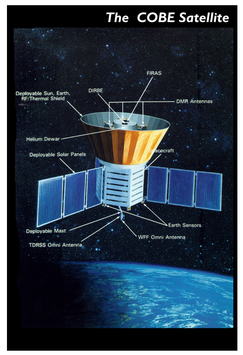
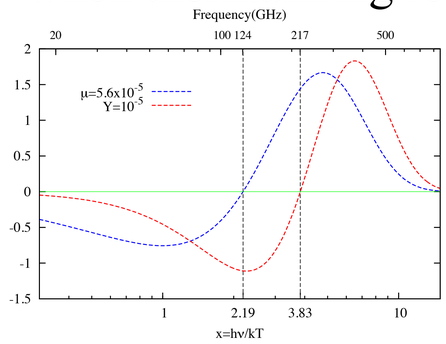
I. The CMB is a nearly perfect blackbody





$$\mu \leq 9 \times 10^{-5}, y \leq 1.5 \times 10^{-5}$$

II. Injected energy can distort the blackbody when thermalizing reactions decouple



Chemical potential (μ) distortions

$$f(E_\gamma, T, \mu) = \frac{1}{e^{\mu + h\nu/(k_B T)} - 1}$$

Compton y distortions

$$\Delta f(E_\gamma, T, \mu) = \frac{x e^x}{(e^x - 1)^2}\left(x\frac{e^x + 1}{e^x - 1} - 4\right) \quad x \equiv \frac{h\nu}{k_B T}$$

Probing early times ...

$$\mu \text{ epoch} : 4 \times 10^4 \ll z \ll 2 \times 10^6$$

$$\text{y epoch} : z \ll 4 \times 10^4$$

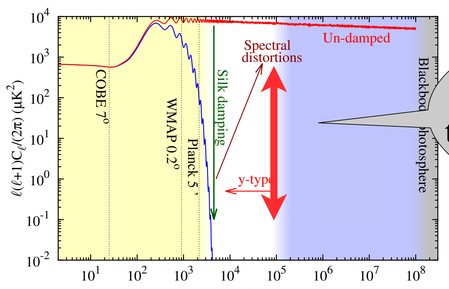
The National Science Foundation

III. Sources of spectral distortion (SD)

a. Dark matter decay/annihilation
b. Cosmic reionization $y \sim 10^{-7}$
c. Acoustic mode dissipation

$$\delta_\gamma \propto \cos(k c_s \eta) e^{-k^2/k_D^2}$$

Diffusion of photons out of wavefronts dissipates acoustic waves in baryon-photon plasma



Lost energy goes to spectral distortions!!

Probing small scales...

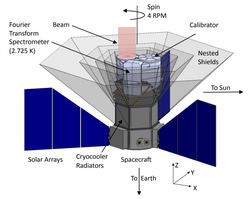
$$50 \text{ Mpc}^{-1} \ll k \ll 10^4 \text{ Mpc}^{-1} \quad \mu \text{ era}$$

$$k \ll 50 \text{ Mpc}^{-1} \quad y \text{ era}$$

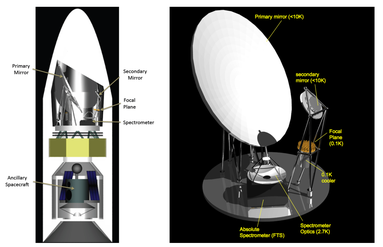
$$\mu \sim 10^{-8}, \quad y \sim 10^{-9}$$

IV. There is hope of detecting such SDs

PIXIE (NASA)
$200M Explorer



PRISM (ESA)
(billions and billions)



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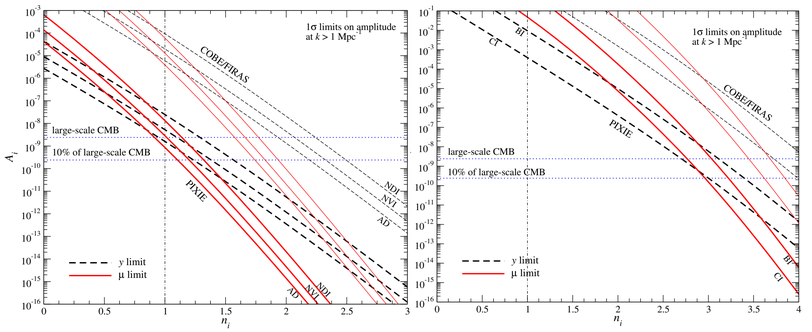
V. Entropy fluctuations and SD (from work with J. Chluba, arXiv:1304.4596)

Entropy fluctuations (CDM, baryon, neutrino)

$$S_{i\gamma} = \frac{\delta n_i}{n_i} - \frac{\delta n_\gamma}{n_\gamma} \neq 0$$

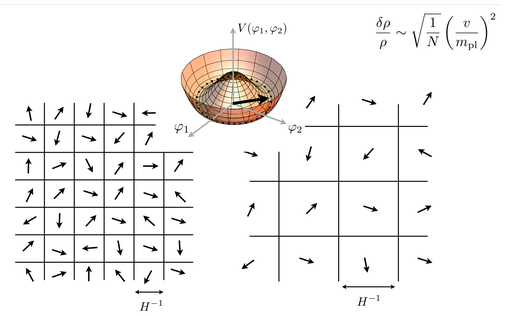


1) Extremely blue non-relativistic entropy flucts can be probed with SD experiments than CMB anisotropy

2) Mildly blue relativistic (neutrino) entropy fluctuations are better probed with SD experiments than CMB anisotropy

VI. Phase transitions and SD (with KICC fellow Mustafa Amin)

A global phase transition seeds density fluctuations, sourcing gravitational forces and exciting ***acoustic fluctuations and additional spectral distortions***



$$\frac{\delta\rho}{\rho} \sim \sqrt{\frac{1}{N}}\left(\frac{v}{m_{pl}}\right)^2$$

Saturating CMB anisotropy limits yields

$$\mu \sim 3 \times 10^{-9}$$

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