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Polarization Signatures of Clusters in the Microwave Background

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Abstract. Compton scattering of photons from ionised gas in galaxy clusters along the line of sight leaves an imprint in the polarization of the cosmic microwave background. We investigate this process taking account of the effects of relativistic electron velocity dispersion and primordial anisotropy on the frequency spectrum of the generated polarization. We also discuss the prospects of detecting such effects with the Planck survey.

1. Introduction

The cosmic microwave background (CMB) is expected to be polarized at the level of ~ 10 per cent of the temperature anisotropies, due to Compton scattering of anisotropic radiation through recombination. Galaxy clusters along the line of sight can distort this primordial polarization by further scattering (Sunyaev & Zel'dovich 1980; Zel'dovich & Sunyaev 1980). Detection of this effect would provide a new probe on cluster and cosmological physics, e.g. the possibility to reconstruct three-dimensional peculiar velocities, and to test isotropy at points on our past lightcone.

2. Polarization from Compton Scattering

Polarization is generated by a temperature quadrupole in the rest frame of the scattering electron. At dimensionless frequency $x = h\nu/(k_B T_{\mathrm{CMB}})$, the CMB monopole contributes to the polarization tensor if there is electron bulk motion V^a (at angle $\arccos \mu$ to the line of sight). As a thermodynamic equivalent dimensionless temperature,

$$\begin{aligned}\mathcal{P}_{ab}^{(0)} &= -\tfrac{1}{10}\tau[V_a V_b]^{\mathrm{TT}}\{\tfrac{1}{2}F + \Theta_{\mathrm{e}}[3F - 2(2F^2+G^2) + \tfrac{1}{2}F(F^2+2G^2)] \\ &\quad + V\mu[-\tfrac{1}{2}F + \tfrac{1}{4}(2F^2+G^2)] + \cdots\}.\end{aligned}$$

Here, $F = x\coth(x/2)$ and $G = x/\sinh(x/2)$, τ is the optical depth through the cluster, and V is the magnitude of V^a. The transverse, trace-free (TT) term $-[V_a V_b]^{\mathrm{TT}}$ shows that the polarization direction is normal to V^a and the photon propagation direction e^a. Thermal effects ($\Theta_{\mathrm{e}} = k_B T_{\mathrm{e}}/m_{\mathrm{e}}c^2$, with T_{e} the electron temperature) can contribute ~ 30 per cent of the signal for hot clusters ($k_B T_{\mathrm{e}} \sim 10\,\mathrm{keV}$) in the Wien region (Challinor et al. 2000).

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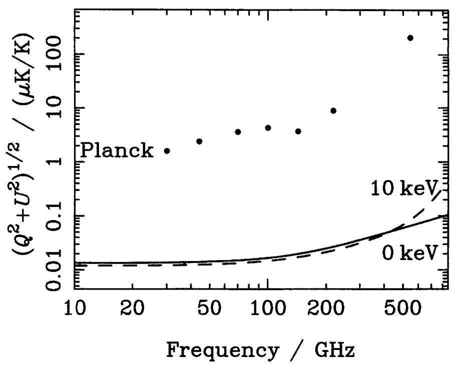

Figure 1. The brightness temperature of the degree of polarization compared to the current baseline Planck sensitivities. Only $\mathcal{P}_{ab}^{(0)}$ is included. The cluster has $k_{\mathrm{B}}T_{\mathrm{e}} = 0\,\mathrm{keV}$ (solid line), and $10\,\mathrm{keV}$ (dashed line), optical depth $\tau = 0.012$, $\mu = 1/\sqrt{3}$, and transverse velocity $1000\,\mathrm{km\,s^{-1}}$. Thermal corrections slightly increase the prospect for detection at high frequencies.

The CMB temperature quadrupole τ_{ab} contributes

$$\begin{aligned}\mathcal{P}_{ab}^{(2)} &= -\tfrac{1}{10}\tau\left([\tau_{ab}]^{\mathrm{TT}}\{1+\Theta_{\mathrm{e}}[-6F+\tfrac{1}{2}(2F^2+G^2)]\right.\\ &\quad \left. +V\mu(-2+F)\} - 2[V_{(a}\tau_{b)c}e^c]^{\mathrm{TT}} + \cdots\right).\end{aligned}$$

The geometry of the dominant terms follows the TT temperature quadrupole. At high frequencies $\mathcal{P}_{ab}^{(0)}$ is dominant. The polarization generated by the higher multipoles of the temperature anisotropy is discussed in Challinor et al. (2000).

3. Prospects for Detection

In Figure 1 we compare the magnitude of the polarization from the temperature monopole with the current baseline sensitivities in the polarized Planck channels. (The sensitivities are for a twelve month survey, and we have assumed the cluster fills the experimental beam.) The likely signals are around two orders of magnitude too low for direct detection with the Planck survey. However, statistical detection of the quadrupole contribution to the polarization may be possible by averaging the effects from many clusters within the coherence volume of the temperature quadrupole (Sazonov & Sunyaev 2000).

References

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