CMB ANISOTROPIES DUE TO COLLAPSING CLUSTERS

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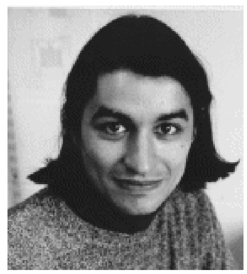

A new method arising from a gauge-theoretic approach to general relativity is applied to the formation of clusters in an expanding universe. The three cosmological models (Ω_0=1, Ω_Λ=0), (Ω_0=0.3, Ω_Λ=0.7), (Ω_0=0.3, Ω_Λ=0) are considered. A simple initial velocity and density perturbation of finite extent is imposed at the epoch $z = 1000$ and we investigate the subsequent evolution of the density and velocity fields for clusters observed at redshifts $z = 1$, 2 & 3. Photon geodesics and redshifts are also calculated so that the Cosmic Microwave Background anisotropies due to collapsing clusters can be estimated. We find that the central CMB temperature decrement is slightly stronger and extends to larger angular scales in the non-zero Ω_Λ case. This effect is strongly enhanced in the open case.

1 The Model

Our fully relativistic calculations are carried out in the context of a pressureless and spherically symmetric cluster formation model[1] which inevitably leads to non linear structures with large infall velocities. This may be realistic for distant clusters still in the process of formation. The initial conditions at $z = 1000$ are chosen so that the resulting cluster has an observed core radius $R_c = 0.23h_0^{-1}$ Mpc and a central density $\rho_c = 10^4 h_0^{1/2}$ p m^{-3}. The initial velocity field $u_i(r)$ is controlled by four parameters R_i, a, m and H_i. The initial linear extent of the perturbed region is R_i, beyond which the velocity is proportional to r. The magnitude of the perturbation is controlled by the velocity gradient a at the origin. The velocity perturbation for $0 \leq r \leq R_i$ is defined by a $(2m+1)$-degree polynomial of which the first m derivatives are matched at the boundaries (i.e. at $r = 0$ and $r = R_i$). The fourth parameter H_i is the Hubble parameter at $z = 1000$ so that, outside the perturbed region, the fluid is described *exactly* by a uniformly expanding FRW model $u_i(r) = H_i r$. Choosing the velocity gradient at the origin smaller than H_i results in the region $r < R_i$ moving inwards relative to the Hubble flow and eventually collapsing to form a cluster centred at the origin. The initial density perturbation is derived

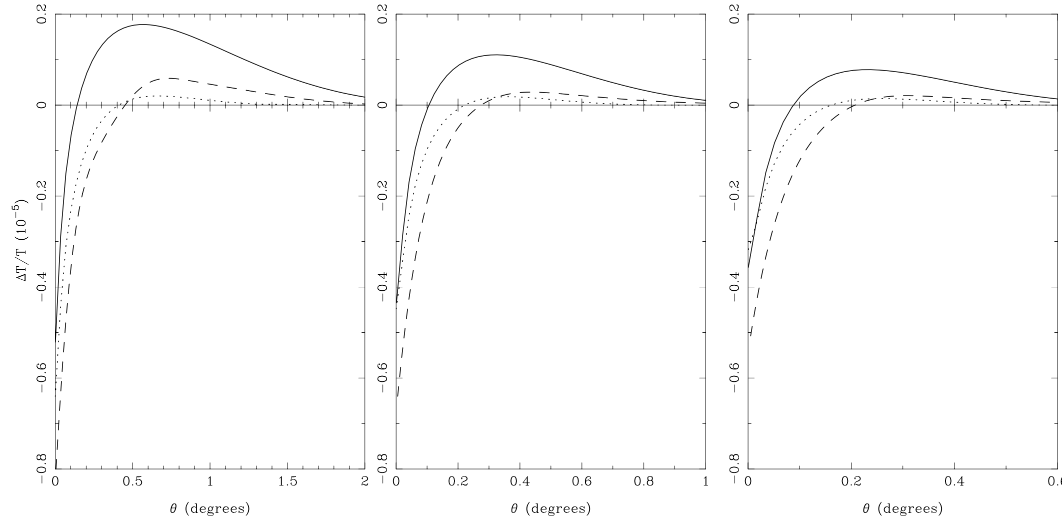

Figure 1: Profiles of $\Delta T/T$ for clusters at $z = 1$, 2 & 3 (left to right). The solid dashed and dotted lines ar for the (Ω_0=0.3, Ω_Λ=0), (Ω_0=0.3, Ω_Λ=0.7) and (Ω_0=1.0, Ω_Λ=0) cosmological models respectively.

directly from the velocity by assuming that the initial velocity and density profiles arose from primordial perturbations and that decaying modes can be ignored. At $z = 1$, 2, or 3, the observed density profile is well fitted by β-models[2] $\rho(r) = \rho_0 \left[1 + (r/R)^2\right]^{3\beta/2}$ and the best least-square fit is obtained for $\beta \simeq 2/3$.

2 Results

Rees & Sciama[3] (1968) suggested that the presence of an evolving structure on the line of sight of a Cosmic Microwave Background photon could significantly affect its observed temperature. This secondary gravitational effect can be described as follows: The potential well of a collapsing cluster becomes deeper over time so that the CMB photon has to *climb out* of a well deeper than that into which it *fell*, suffering a net loss of energy. As suggested in Rees & Sciama (1968) there is, however, a competing effect due to the extra time delay encountered by the photon. The overall effect can therefore be of either sign. For the cluster evolution model considered here we have estimated the temperature anisotropy as a function of the projected angle θ on the sky from the centre of the cluster. Profiles of $\Delta T/T$ are given in Fig. 1 for three cosmological models and for clusters at $z = 1$, 2 & 3. The magnitude of the effect gets smaller as the redshift of the cluster increases and the angular distribution of the anisotropy is strongly dependent upon the cosmological model[4]. In particular, for the case where the cluster is located at $z = 1$, the Open model ($\Omega_0 = 0.3$, $\Omega_\Lambda = 0.7$) estimate predicts a large and extended temperature *increment* on a scale of about one degree. In the case of the recently favoured ($\Omega_0 = 0.3$, $\Omega_\Lambda = 0.7$) cosmological model, it is interesting to note that the temperature decrement is systematically stronger and extends to larger angles than in the other two models.

References

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