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ANISOTROPY OF CMBR AND GAUGE INVARIANT COSMIC PERTURBATION THEORIES — SOME AMBIGUITIES AND PROBLEMS

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ABSTRACT

COBE's results on the anisotropy of the cosmic microwave background radiation (CMBR) is discussed. Some ambiguities in the linear GI cosmic perturbation theory are clarified. The problem of the last scattering surface and the deficiencies of the linear cosmic perturbation theory are mentioned. The possible ways to overcome the theoretical difficulties are discussed also.

Key Words : CMBR, perturbation theory, cosmology

I. THE ANISOTROPIES OF THE COSMIC MICROWAVE BACKGROUND RADIATION

The research on the cosmic microwave background radiation (CMBR) is the cornerstone of modern cosmology. Recently the improved measurement of its temperature, spectrum and anisotropy has given us a better understanding of the original and evolution of large scale structure of the Universe (Peebles 1993). The preliminary COBE(Cosmic Background Explorer) measurement of temperature anisotropy by Smoot and his collaborators(Smoot 1992) at the level of $(\delta T/T)_{\rm observ} = 1.2 \times 10^{-5}$ on angular scales great than 7 degrees, with a quadrupole term $(\delta T/T)_{\rm quad} = 6 \times 10^{-6}$ has been used to constrain competing theories. In near future, a new generation of CMBR explorer(White 1992) might be three magnitude higher precision than COBE. Therefore we need a more precise theoretical model to fit the observational data.

The physical basis for the comparison with the different model is the Sachs-Wolfe(SW) effects(Sachs & Wolfe 1967), in which CMBR photons traveling from the last scattering surface (LSS) to us are redshifted slightly more if they have to climb from an increased gravitational potential due to a density enhancement over the average one on LSS. The calculation of SW effect, which will give the main contribution to the anisotropy of the CMBR for angular scales large than 2 degree, which correspond to scales larger than the horizon at the time of last scattering ($z \approx 1000 - 1300$), has been repeated in detail by a number of different authors, each making improvements and clarifications. For a linear cosmic perturbation theory the most difficulty is caused by gauge problems. A one to one correspondence between points in the background and them in the physical spacetime defines a choice of gauge. Every observational quantity should be expressed by gauge invariant (GI) way. Up to now there are two sets of successful GI formalism: Bardeen's(Bardeen 1980) and Ellis-Bruni's(Ellis & Bruni 1989). The anisotropy of CMBR has been calculated using GI Bardeen's formalism(Panek 1986; Stoeger, Xu, Ellis and Katz 1995) and Ellis-Bruni's(Russ, Soffel, Xu and Dunsby 1993).

In this paper, we will clarify some ambiguition in the linear GI perturbation theory using in the anisotropy of CMBR. The deficiencies of the theory are indicated and the possible ways to overcome the difficulties are briefly mentioned.

II. TO CLARIFY SOME AMBIGUITIES

– For long time the separating the perturbation into scalar, vector and tensor in Bardeen's formalism was doubted whether the gauge would be involved(Stoeger, Ellis and Schmidt 1991). Any way, after summing up three parts (scalar, vector, tensor) the final expression of the anisotropy of CMBR is GI one, although an exact mathematical proof in general case has not been done yet.

– Not only the perturbation of temperature and density at LSS should be calculated, but also the perturbation of the precise placing of LSS using the definition of LSS in terms of constant free-electron density (Panek 1986). In the adiabatic case, the real temperature and density on LSS takes same value as on the background LSS in unperturbed space. Consequently in this case the temperature and density is constant over the real LSS. At beginning, one may be surprised for the conclusion. In fact, the definition of LSS makes the relation between the perturbation of temperature and the location of LSS. In adiabatic case, two perturbations are compensated each other. Now we also can understand why Sachs-Wolfe was doing a gauge dependent way and constant temperature on LSS, nevertheless their conclusion in adiabatic case is correct as Panek point out. We should point out Panek's specific calculation do not cover nonadiabatic situation, just in the paper of Stoeger, Xu, Ellis and Katz (1995) the calculation has included it.

– In normal SW effect, we can get the density perturbation to be three times the temperature perturbation. For a general mixture of baryons and radiation, in which the pressure is important(Stoeger, Ellis and Xu 1994). The density perturbation can reduce by up to 87% at the low density $\Omega_0 = 0.04$. It means that the low measured value of the CMBR anisotropy could be a higher value of density perturbation at the low density of Universe, which still allow the formation of galaxies and large scale structures.

III. THE THEORETICAL PROBLEMS

There are at least three important problems to be solved

– The thickness of LSS. The process of decoupling i.e. the transition of photons from a collisional one to free one does not happen instantaneously. The thickness of decoupling shell Δz is 150(Hogan, Kaiser and Rees 1982). Usually it is considered that the temperatures of the coupled matter and radiation (before last scattering) and uncoupled radiation (after last scattering) are both as $1/S(t)$, (i.e. $T_\gamma = T_m$) within the thickness, the finite time of decoupling should cause at most a second-order effect(Ellis 1996). The influence of thickness is negligible. But as we know, the temperature of matter T_m after decoupling is proportional to $1/S^2(t)$ (i.e. $T_m \neq T_\gamma$). Also how precisely to define LSS and its thickness is still a problem.

– The observational anisotropy of CMBR may be caused by voids and supercluster (attractor) (Meszaros 1994 and referenced therein). The key ideas of the theory of the redshift of light crossing a spherically symmetric structure were formulated by Rees & Sciama (1968). But for the most voids on superclusters their shapes are not spherically symmetric. But up to now we have no very efficient formalism to deal with such a problem. Maybe a second order perturbation theory could solve the problem(Sanz & Cayon 1996).

– The observational anisotropy of CMBR could be caused by gravitational wave(Smoot & Steinhardt 1993). As we know, in linear perturbation theory the influence of gravitational wave can not be included. A second order GI perturbation theory need to be established, then the gravitational wave could enter the formalism.

In summary, on improving definition of a physical LSS and a second order cosmic GI perturbation theory for CMBR might be urgently required in near future.

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REFERENCES

Bardeen, J.M. 1980, Phys. Rev. D, 22, 1882

Ellis, G.F.R. and Bruni, M. 1989, Phys. Rev. D, 40, 1804

Ellis, G.F.R. 1996, Private communication

Hogan, C.J., Kaiser, N. and Rees, M.J. 1982, Philos. Trans. R. Soc. London, A307, 97

Meszaros, A. 1994, ApJ, 423, 19

Panek, M. 1986, Phys. Rev. D, 34, 416

Peebles, P.J.E. 1993, in "Principles of Physical Cosmology" (Princeton Univ.Press)

Rees, M.& Sciama, D.W. 1968, Nature, 217, 511

Russ, H., Soffel, M.H., Xu, C. and Dunsby, P.k.S. 1993, Phys. Rev. D, 48 4552

Sachs, R.K. and Wolfe, A.M. 1967, ApJ, 147, 73

Sanz, J.L. and Cayon, L. 1996, Proc. Conf. Mapping, Measuring and Modelling the Universe, eds. P.Coles et al.

Smoot, G.E. et al. 1992, ApJ, 396, L1

Smoot, G.F. and Steinhardt, P.J. 1993, Gen. Relat. Grav., 25, 1095

Stoeger, W.R., Ellis, G.F.R. and Schmidt, B.C. 1991, Gen. Relat. Grav., 23, 1169

Stoeger, W.R., Ellis, G.F.R. and Xu, C. 1994, Phys. Rev. D, 49, 1845

Stoeger, W.R., Xu, C., Ellis, G.F.R. and Katz, M. 1995, ApJ, 445, 17

White, S.D.M., 1996, "The large scale structure of universe", Lecture in Univ. of Jena, Germany