Gamma-Ray Emission from Clusters of Galaxies by Intra-Cluster Cosmic Rays

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Abstract

The confinement of the Intra-Cluster Cosmic Rays (ICCRs) is investigated with a numerical solver of the diffusion equation. The number density of ICCR particles and the confinement timescale are estimated. The typical values are $N_c \sim 10^{-13}\mathrm{cm}^{-3}$ and $\tau \sim 100$Myrs. This indicates that the ICCRs are now in steady state and they cannot be confined during the Hubble time.

The γ-ray flux induced by ICCRs are also estimated. The emission process considered here is $pp \to \pi^0 \to 2\gamma$. The predicted flux is $\sim 10^{-11}$ photons/cm^2/s for the Coma and Virgo clusters. Because the upper limit of the γ-ray flux observed by the EGRET is $< 4 \times 10^{-8}$, these clusters cannot be observed by the EGRET. The detection limit of the GLAST is $\sim 10^{-9}$ and it is also difficult to detect the γ-rays by the GLAST.

Finally the contribution of the ICCRs to the cosmic γ-ray background is studied. The expected flux over the energy range 30MeV–10GeV (this range is the same as that of the EGRET) is $\sim 5\times10^{-7}$. This implies that the ICCRs contribution is a few percent to the background.

1 Introduction

It is observationally established that there is rather strong magnetic field in clusters of galaxies which strength is $\sim \mu$G and they are sufficiently turbulent (see Kronberg 1994 and references therein). The cosmic rays after confinement within galaxies are released to the intracluster space and diffuse out. They ICCRs exhibit a random-walk motion due to turbulent intracluster magnetic field. And thus they are confined within clusters of galaxies.

This confinement is pointed out by many people(Völk et al. 1996, Berezinsky et al. 1997, Colafrancesco and Blasi 1998). They assume the diffusion process as the resonant diffusion and estimate the diffusion coefficient. The typical values are $\sim 10^{29}$ cm^2/s by Vök et al. and Berezinsky et al. 1997), and $\sim 10^{26}$ cm^2/s by Colafrancesco and Blasi. This seems rather small because the mean free path corresponding to these values is smaller than 1pc.

The observational data implies that the turblent scale is the same as (or smaller than) 1kpc–10kpc (Kim et al. 1990, Feretti et al. 1995). If this scale is corresponding to the mean free path, the diffusion coefficient should be $\sim 10^{32}$ cm^2/s. Here we set this mean free path as parameter and we call it as l_{frs} hereafter.

The only question is the dependence on the l_{frs} of the ICCRs. Here l_{frs} is ranging from 1pc to 10kpc. We investigate this dependence and its apprications.

2 Steady State of the ICCRs

We use a numerical solver of the diffusion equation

$$\frac{\partial N}{\partial t} - \nabla(D\nabla N) + \frac{N}{\tau} = Q$$

with flux limitter (which implies that the diffusion flux is smaller than the free-streaming flux). The sources of ICCR is the normal galaxies in a cluster, and the outflow flux of each galaxies is assumed as that of our Galaxy.

In the case of the Coma cluster, the central density of ICCR particles is 2×10^{-14} particles/cm^3 for $l_{\rm frs}$ =10kpc, 2×10^{-11} for $l_{\rm frs}$ = 100pc, and 1×10^{-11} for $l_{\rm frs}$ =1pc. The confinement timescale is 17Myrs for $l_{\rm frs}$ =10kpc, 1Gyrs for $l_{\rm frs}$ =100pc, and 7Gyrs for $l_{\rm frs}$ =1pc. In intracluster space, it seems to be difficlut that the turblent scale is $\sim$ 1pc which is similar to that in our Galaxy, and hence it is unlikely that ICCRs are confined within clusters during the Hubble time($\sim$ 10Gyrs).

3 Gamma-ray Emission by ICCR

The deep inelastic scattering of the ICCR particles with the intracluster medium (ICM) results γ-ray emissions which is produced by neutral pion decay($pp \rightarrow \pi^0 \rightarrow 2\gamma$). The upper limit by the EGRET is $< 4 \times 10^{-8}$ photons/cm^2/s for the Coma cluster(Sreekumar et al. 1996). We estimate the γ-ray flux from the Coma cluster. The predicted flux is 10^{-13} for $l_{\rm frs}$ =10kpc, 9×10^{-12} for $l_{\rm frs}$ =100pc, and 10^{-10} for $l_{\rm frs}$ =1pc. This is well smaller than the limit of the EGRET, and it is good agreement with the observational result. Because these prediction is well smaller than the detection limit of the GLAST, the detection will be also difficult using the GLAST(Tsubaki and Sato 1999).

4 The Contribution to the γ-ray Background

By integrating over the redshift, the contribution of ICCR to the γ-ray background can be estimated. The overproduction of cosmic ray particles during star-burst era is also taken into account. We assume that the activity of the CR production is proportional to that of the supernova. Here the supernova rate calculated by Totani et al. is used. The evolution of the number density of clusters is assumed to be well predicted by Press-Schechter theory(Press and Schechter 1974). The predicted background flux is 5×10^{-7} photons/cm^2/s/sr, where the integreted flux from 30 to 100 MeV is $(4.26 \pm 0.14) \times 10^{-5}$, and that above 100 MeV is $(1.45 \pm 0.05) \times 10^{-5}$ (Sreekumar et al. 1998)

5 Conclusion

We conclude that the confinement of the ICCRs during the Hubble time is unlikely and they are in steady state now. The ICCR particle density is much smaller than that of the universal flux (and hence it is also smaller than that of our Galaxy). The γ-ray flux induced by ICCR is much smaller than the detection limit of any intruments we can use now and in near future. The contribtion of ICCR to the cosmic γ-ray background is small, but we cannot exclude the possibility that the contribution of the ICCR-induced γ-ray is dominant. More detailed study may be needed.

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