Z-bursts with Hot Dark Matter (Relic Neutrinos) generating the EUV and soft X-ray glow in Cluster of Galaxies

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Abstract

A process on the basis of the Standard Theory is proposed for the origin of the energy resources in the halo of Cluster of galaxies that glow in EUV and soft X-ray wavelengths. The resonant collisions (called Z-bursts) of extremely high energy (EHE, $E \geq 10^{21}$ eV) cosmological neutrinos with primordial neutrinos in Cluster of galaxies keep supplying a reasonable amount of energy deposition $\sim 10^{41-42}$ erg/sec in Clusters in terms of low energy electrons. High energy cascades of electrons and photons are efficiently contained within the Cluster due to magnetic winding, Inverse Compton, and two-photon processes. The effectiveness of the halo-glow process is constrained by the flux of cosmic EHE neutrinos, the gravitational over-density of primordial relic neutrinos, and their finite mass values. It is shown that the Z-burst mechanism can explain some of the energetics, spatial extent and lifetime of the observed glow in the halo of Cluster, provided that the flux of cosmic EHE neutrinos is as high as producing observed EHE cosmic rays ($E > 10^{20}$ eV) by the same mechanism.

1. Introduction

The recent XMM observation [1] on 7 clusters of galaxies has confirmed emission of EUV and soft X-rays from extended halo of several Mpc in diameter. This radiation was previously observed by the Einstein [2], ROSAT [3], and Beppo-SAX [4] in X-rays, and in EUV range (0.065 - 0.3 keV), by EUVE satellite [5], which stimulated the discussions on dark matter [6]. The luminosity of this spatially very extended radiation has been estimated as 10^{42-43} erg per cluster [7]. The ordinary account of the emission is the outflow of very hot gas from galaxies by some unknown and unsettled mechanism(s). Problems with this classical model can be found in its disability to explain the followings: (1) extendsive spatial dimension over 1 Mpc, (2) quasi-uniform (spherical) distribution of radiation, (3) steady balance of energy output and input to such a large scale, and

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(4) long lifetime (as long as the Hubble time). This paper presents the Z-burst mechanism of neutrinos for the possible energy resources that make Clusters glow in EUV and soft X-rays in the extended halo. It can be shown to reasonably satisfy the conditions for solving the above four difficult problems. Their energy deposition in a typical Cluster is close to 10^{41} erg/s. The Z-burst alone may not have to account for all the energies, because the central part energy can naturally be shared by ejection of very hot gas as well as by the emission of photons by Bremsstrahlung of cosmic ray electrons. The Z-burst process, however, suggests a substantial contribution in terms of high energy electron (and positron) spectrum as shown in the next section.

2. Energy Supply by Z-bursts for the Soft-X-ray Glow in the Clusters

It is already shown by Weiler [8] that EHE neutrinos (anti-neutrinos) at energies about 10^{21} eV interact with hot Dark Matter anti-neutrinos (neutrinos) with high resonance cross section at $E_{CMS} \sim 90$ GeV (mass of Z_0 intermediate boson), or $E_R = M_Z{}^2/2m_\nu = 4$ (eV/m_ν) $\sim 10^{21}$ eV in Laboratory System. This cross section is $4\pi\ G_F/2 = 4.2 \times 10^{-32}$ cm^2, and ~ 0.1 mfp for the diameter of the whole Universe. From Big Bang cosmology and on the Standard Model (SM) of particle physics, the probability for a neutrino with resonant energy to annihilate to a Z-burst within the distance across the cluster of galaxies is about 3×10^{-4} β. This local annihilation rate is much larger because our matter-rich portion of the Universe similarly clusters massive relic neutrinos by gravitation when $m_\nu > 0.1$ eV/c^2. The parameter β represents the over-density factor for the case of massive neutrinos. The ballpark value of the over-density has been discussed [8] for a Super-Cluster, $O(10^2)$, and for a Cluster, $O(10^3)$, respectively, by taking account of the average distances (~ 100 Mpc) between super-clusters having the diameter of ~ 20 Mpc. Each resonant neutrino annihilation produces a Z boson with a 70% branching ratio into hadrons. The stable decay products of Z-bursts are gamma rays, electrons, nucleons and neutrinos. Secondary nucleons can travel within the GZK path-length (< 50 Mpc), while most gamma rays (Fig.1 solid line) and electrons cascade down to low energies in Cluster due to the Inverse Compton and two-photon electron-pair production processes involving CMB photons within Cluster. While the hypothesis is not proved to explain the observed air showers above E_{GZK} (Fig.1), electrons and photons from them supply substantial amount of electromagnetic energies to gasses within a Cluster.

The uncertainty of the gas density $\sim 10^{-4}$ or 10^{-2}/cc does not matter in this mechanism, because electrons are fully contained in the Cluster region by non-negligible magnetic field (as high as μG), and the linear crossing radiation length is not applicable. Instead, the total path length for the Hubble time is to be applied. We should take it as a kind of total absorbing calorimeter at least for EHE-VHE energies, despite it is an optically thin space in conventional understanding. Electron windings and Inverse Compton by 2.7K CMB alter the whole sequence of electron containment in Cluster of galaxies.

The flux bound of EHE neutrinos can be estimated by assuming the observed EHECRs at 10^{20} eV as their secondary gamma-rays and nucleons (9). The estimated upperbound can be used to evaluate the Z-burst processes in Clusters. The energy flux is $\int$ E $\times$ $E^{-\alpha}$ dE $\sim$ E^2(dN/dE), which has a peak at $\sim 10^{21}$ eV, with 10^4 eV/cm^2 s sr of neutrino energy. In the Z-burst model, assumable primary neutrino spectrum is E^{-1}dE. Hence, the neutrino flux of 3 species at 10^{21} eV (1.6 $\times$ 10^9 erg per neutrino) is $\sim$ 2.5/ km^2 yr sr.

In the cluster's halo with the radius R $\sim$ 2 Mpc $\sim 6 \times 10^{19}$ km, massive relic neutrinos are presumably over dense ($\beta \sim 10^3$) over the Universe average (54/cc). They are non-negligible amount of targets for Z-bursts in resonant collisions with EHE neutrinos (mean free path $\sim$ 0.68 for a cluster with a 2Mpc radius). The energy deposition in the whole halo volume of a Cluster becomes $\sim 1.3\beta \times 10^{41}$ erg/s.

3. Plasma Temperature

The gas in the cluster is heated up by the energy deposition of ultra high energy neutrino through z-bursts up to 10^6 K. This heating rate, H, by z-busrt is estimated as

$$H_\nu = 4\pi J E_\nu n_\nu \sigma_\nu, \tag{1}$$

where J is the flux per solid angle of ultra high energy neutrinos, E_ν is the average energy deposited by a z-busrt, n_ν is the number density of relic neutrinos in the cluster, and σ_ν is the cross section of z-burst. Yoshida et al. 1998 estimated the energy spectrum of ultra high energy neutrinos and found it has a peak of $J \sim 10 \quad \mathrm{km}^{-2}\mathrm{yr}^{-1}\mathrm{str}^{-1}$ and $E_\nu = 10^{22}$ eV. In the Cluster, the number density, n_ν, of relic neutrinos with a mass of $0.01 \sim 10$ eV is likely to be as high as 5×10^4 cm^3 in Cluster, because of gravitational potential of Clusters.

$$H_\nu = 1.4 \times 10^{-31}\,\mathrm{erg\,s^{-1}} \left(\frac{J}{10\,\mathrm{km}^{-2}\mathrm{yr}^{-1}\mathrm{str}^{-1}}\right)\left(\frac{E}{1.6 \times 10^{10}\,\mathrm{erg}}\right)\left(\frac{n_\nu}{5 \times 10^4\,\mathrm{cm}^{-3}}\right). \tag{2}$$

On the other hand, the cooling rate, Λ_{ff}, by free-free emission of fully ionized plasma is

$$\Lambda_{ff} = 1.4 \times 10^{-27} T^{1/2} n_p^2, \tag{3}$$

where T is the temperature and n_p is the number density of proton (Rybick and Lightman 1979). For the equilibrium, $H_\nu = \Lambda_{ff}$, the temperature is obtained as close to the order required for accouting the observations.

$$T = 1.0 \times 10^6\,\mathrm{K} \left(\frac{\mathrm{n}}{10^{-4}\,\mathrm{cm}^{-3}}\right)^{-4} \left(\frac{\mathrm{n}_\nu}{5 \times 10^4\,\mathrm{cm}^{-3}}\right)^2 \left(\frac{\mathrm{J}}{10\,\mathrm{km}^{-2}\mathrm{yr}^{-1}\mathrm{str}^{-1}}\right)^2 \left(\frac{\mathrm{E}}{1.6 \times 10^{10}\,\mathrm{erg}}\right)^2 \quad (4)$$

4. Conclusions

It is shown that at least a part of the energies of UV and Soft-X glow in the halo of the cluster of galaxies should be contributed by the annihilation of etremely high energy neutrinos with relic neutrinos.

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