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High Energy Astrophysics

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The High Energy Background (Cont'd):

Galaxy Clusters

Galaxy clusters are the most massive gravitational structures in the universe with a hot diffuse plasma $T \sim 10^8 K$ that fills the intergalactic medium. Aside from their thermal bremsstrahlung emission, the hot plasma also reveals itself via the Sunyaev-Zeldovich effect discussed earlier.

The galaxy clusters are more than large sources of diffuse X-ray photons. They receive attention over the entire spectrum range from radio, to ultraviolet, to X-ray, and to γ-ray. It is now clear that cosmic rays in the intracluster medium play an important role and may be the source of non-thermal execesses in the ultraviolet and X-ray regimes.

The presence of relativistic electrons is suggested by the highly polarized radio luminosities $L_r \sim 10^{40} - 10^{42}$ erg s^{-1} measured from regions extending over Mpc scales. This synchrotron emission requires a large magnetic field $B > 0.1\ \mu G$ and highly relativistic electrons $\gamma > 100$, which are not associated with any particular galaxies. Such energetic electrons may diffuse only a few kpc from a source before losing their energy. The most likely scenario to constantly replace the lost energy, in order to account for the Mpc extension of the radio emission, is a secondary model that injects non-thermal electrons via decay of pions produced from the collision of high energy protons with Hydrogen in the intracluster medium. One should note, however, that the secondary model is not universally accepted. It is worth mentioning that the secondary model also predicts a γ-ray flux from the decay of neutral pions produced in proton-proton collisions. Whereas, in non-secondary models, the γ-ray emission is expected to be undetectable.

The X-ray luminosity $L_X \sim 10^{45}$ erg s^{-1} from galaxy clusters is typically interpreted as thermal bremsstrahlung by a hot plasma with a temperature in the $\sim 2-10$ keV range and a central density of $\sim 10^{-3}$ cm^{-3}. It has been observed in recent years that there is a slight excess above the thermal component starting at $\sim 20-25$ keV and extending to ~ 45 keV. The most common interpretation of this hard X-ray component is inverse Compton scattering between the non-thermal electrons and the cosmic microwave background photons. However, these electrons are also thought to be responsible for the radio emission. In order for both the radio and hard X-ray emissions be produced at the observed level, the implied magnetic field must be an order of magnitude below the observed value. For example, in the Coma cluster, Faraday rotation measurements suggest that $B \sim 6\,\mu G$. This is in sharp contrast with the inferred value of $B \sim 0.16\,\mu G$ to explain the hard X-ray via inverse Compton scattering. An alternative explanation of the hard X-ray emission involve Coulomb interactions between the cosmic rays in the intracluster medium and the thermal electrons, which produces a quasi-thermal electron component that is distinct from the power-law distribution due to decay of pions.

It is now clear that cosmic rays must be present in the intergalactic medium with sufficient numbers that affect the gas. It is likely that several mechanisms contribute to their distribution. This includes Fermi acceleration by shocks produced during cluster mergers, and deposition into the intergalactic medium by the relativistic jets in AGN's.