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A MECHANISM FOR INJECTION OF ULTRAHIGH ENERGY EXTRAGALACTIC COSMIC RAYS

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Abstract

Cosmic ray particles with the highest energies ($10^{19} \div 10^{20}$ev) could have an extragalactic origin. There is strong evidence that many active radio galaxies have dense stellar clusters in their core regions. A cluster about 0.1 pc in size could contain about 10^{11} stars. Assuming that a tenth of these are neutron stars with large magnetic fields, their motion can accelerate the ionized gas in the cluster by a relativistic Fermi process. Particles that are knocked on a number of times by these neutron stars can gain sufficient energy.
For protons, for instance, the energy gained in the second scattering is much greater than the minimum energy required by the Fermi injection process [Boccaletti 1971]. The minimum injection energies for heavier nuclei are about 10^{2} Gev for iron. Larger number of scattering can give considerably higher energies when the particle escape from the cluster. Also infall of gas from surrounding parts of the galaxy onto the cluster ensures sufficient supply of material (about 10^{-8} $M_{\odot}$ per year) to sustain the process over the lifetime of the cluster (about $5 \cdot 10^{9}$yr). The background flux of such extragalactic cosmic rays is estimated.

Introduction The origin of cosmic rays of the highest observed energies i.e. $\approx 10^{19} \div 10^{20}$ev continues to be debated. Bending by the galactic magnetic field (radius of curvature of trajectory of charged particles being given by $R \sim mv/Bq$), would suggest that the origin of the highest energy cosmic ray particles is extragalactic, i.e. they do not originate within our galaxy. Active galactic nuclei are known to be vast storehouse of energy and are associated with highly energetic astrophysical processes. One would naturally expect them to be also copious producers of extremely energetic particles. Here we consider a possible mechanism by which the cores of these active galaxies can inject such particles in the intergalactic medium.

Injection of cosmic rays bu dense stellar clusters A major difficulty of the Fermi model of cosmic ray acceleration is that for the increase in cosmic ray energy by scattering of magnetic field inhomogenities to exceed losses due to nuclear interactions the minimum injection energy for protons must be about 200 Mev, about 20 Gev for oxygen nuclei and 300 Gev for iron nuclei.

There is strong evidence that many active radio galaxies have dense stellar clusters in their core regions [Lynden Bell 1969]. A typical such cluster at the galactic core would have a radius of ~ 0.1 pc i.e. 10^{17}cm [Burbidge 1970] and could contain about 10^{11} stars within this region. Many galaxies are known to have such a dense concentration of stars in their central regions. Following Boccaletti et al [Boccaletti 1971] about a tenth of these or more could be neutron stars ar compact objects, with a magnetic moment $\mu \sim 10^{33}$erg G^{-1}. The magnetic field at a distance of ~ 10^{13}cm from centre of the dipole is 10^{-6}G, i.e. same as mean galactic field. The motion of the neutron star with a virial velocity in the cluster $v/c = \beta = (z)^{1/2} \simeq 0.4$ ($z = GM/Rc^2 \simeq 0.16$, is the redshift of a photon emuitted by the cluster), will accelerate the ionized part of the interstellar gas by a Fermi process. We assume 1% of the gas with a mean density of 1 particle per cm^3. is ionized. Particles leaving the cluster need a kinetic energy > $GMm/R \simeq 200$ Mev. We can estimate the energy gained by the particles that are knocked on by magnetic neutron stars. After the first scattering, the energy gained (with reference to the Earth) is $T^{(1)} \simeq 0.19\ mc^2(1 - \cos\chi)$ with a maximum energy of $T^{(1)}_{max} \simeq 0.38\ mc^2$ (i.e. back-scattering with scattering angle $\chi = \pi$). Using this for the impinging energy, the energy gained in second, third and fourth scatterings are similarly $T^{(2)}_{max} = 1.81\ mc^2$, $T^{(3)}_{max} = 5.39\ mc^2$, $T^{(4)}_{max} \simeq 13.8\ mc^2$ etc. So even at the second scattering energy gained is larger than minimum required for injection process. Similarly for oxygen and iron nuclei, the second scattering gives 30 Gev and 100 Gev respectively. So after a large number of scatterings, one would expect the particles to reach energies > 10^{17}ev (after about 20 scattering). The limiting energy would come from interaction with the microwave background which would give a bound of ~ $3 \cdot 10^{20}$ev for protons. Similarly for the other nuclei. With $10^{-2}cm^{-3}$ as density of ionized H_2, the number of protons which undergo first scattering by a star $\simeq 10^{32}s^{-1}$ giving a total of ~ 10^{42} particles s^{-1} for all the neutron stars. The number of protons that suffer a second scattering $\simeq 10^{41}s^{-1}$, the time between first and second scattering being ~ l/v (l is the mean free path) ~ 10^7s. The number of particles undergoing subsequent scatterings become fewer as their density in the cluster decreases, because of their greater kinetic energy and the effective cross-section for scattering becomes smaller. The probability for N consecutive scatterings in a distance R (~ the cluster size) is given by:

$P_N \simeq (x^N/N!)e^{-x}$, $x = R/l$, (l the mean free path); as the mean free path is very large we have $x \simeq 1$. So one can estimate the number of particles which can be accelerated to the highest energies after the requisite number of multiple scatterings. If there are a total of $\sim 10^{10}$ active galaxies with dense stellar cores in a region of 1 Gpc extent then the contribution of this process to the highest energy cosmic ray background flux can be estimated. The average relaxation time of the clusters can be taken as $\sim 5 \cdot 10^{9}$ yr. Then the total contribution to the background flux of such particles with energies $\sim 10^{19}$ ev or more works out at $\sim 10^{-18}$ cm^{2} s^{-1}. So we do have a plausible mechanism for accelerating cosmic rays to the highest observed energies.

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