Leptonic origin of the IceCube detected PeV neutrinos

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Introduction

Discovery of high energy cosmic ray (CR) electrons in astrophysical sources enriches our understanding in particle astrophysics. The current generation H.E.S.S [1](High Energy Stereoscopic System) experiment justifies the detection of TeV CR electrons of local origin (within 1 kpc). Later the Fermi-LAT collaboration also confirms up to TeV range for these electrons from their analysis on the CR electron/positron data samples collected during 2008 - 2009 [2].

Now, the most serious question is the attainment of such enormous energies by these lighter leptons. The usual acceleration mechanism in astroparticle physics, is the conventional Fermi-type process, the stochastic acceleration of particles interacting with strong shocks. A pre-acceleration state of particles to already high energies is a prerequisite in such type of acceleration mechanism. Accelerating light particles like electrons to high energies is even more problematic because the strong synchrotron radiation losses will limit the maximum attainable energy [3].

If strong energy losses in the environment by these particles could be avoided by the action of any physical process, one can realize these lighter should pick up to PeV/EeV energies. The rotation energy of a star (pulsar or magnetar) will be utilized to accelerate these lighter leptons through Langmuir waves generation in ionized plasma under strong magnetic field. It can be shown that the acceleration process proceeds with almost negligible energy losses [4].

When such energetic electrons/positrons interact with background radiating field (x-rays or gaseous matter) possibilities of PeV neutrino generation through some selective channels might take place. Then the origin of recently observed PeV neutrinos by the IceCube observatory might be interpreted as leptonic in fundamental origin [5].

Acceleration mechanism

The acceleration mechanism involves two principal steps. First, a continuous rotational energy loss of a neutron star supplies the energy to initiate Langmuir waves in dense plasma of the star containing electron - positron species. Secondly, these fast moving Langmuir waves will systematically and efficiently damp on the relativistic background electrons to boost them to even higher energies.

If the gyroradius of a particle lies within the acceleration region the attainment of such enormous energy is possible. An induced electric field from the rotation of magnetized neutron star might be responsible to accelerate lighter electrons up to nearly EeV range if energy losses are prevented. The Langmuir-Landau-Centrifugal-Drive (LLCD) exactly does the same by utilizing energies from rotational loss very efficiently [6]. For these waves to effectively supply their energy to electrons, the phase velocity of Langmuir waves must be comparable to the particle speed and is nearly the speed of light. These wave travel in the region where many particles i.e. electrons are available around them with little lower and higher speeds. But, in a given zone electrons with lower speed are generally greater in number than electrons with higher speed than the Langmuir waves. In the calculation the total energy by the beam electrons has come close to the following

$$\epsilon_{e^\pm} \approx \frac{n_p F_{\rm reac} \delta r}{n_{\rm GJ}}, \quad (1)$$

where $\rm F_{reac} \approx 2mc\Omega\xi r^{-3}$, $\delta\rm r \sim c/\Gamma$, and $\xi =$

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$(1 - \Omega^2 r^2/c^2)^{1/2}$ with Γ that measures the growth rate of Langmuir waves. The typical value of the Goldreich-Julian number density ($n_{\rm GJ}$) is $\approx 1.8 \times 10^{12}$ cm^{-3}. For the most optimum scenario the growth rate and the Landau damping rate ($\Gamma_{\rm LD}$) are comparable. Under these scenario, the LLCD will lead to the acceleration of electrons up to the of EeV range.

The energy degradation of these relativistic electrons might occur through the inverse Compton process in the Klein-Nishina regime. But, it can be shown that in the present scenario, the inverse Compton cooling is much slower than the LLCD occurrence time. Another possible mode of loss of energy may be through the synchrotron emission in magnetic field. But, the LLCD will suitably suppress the synchrotron mechanism of relativistic electrons. A very less probable quasi linear diffusion process cannot be excluded but probability of occurrence is extremely low. The curvature radiation mode does not have any countable impact on the LLCD.

Theory

The description of the state of LLCD activity is governed by 3 equations, the Euler equation, the continuity equation and the Poisson equation. These are

$$\frac{\delta p_\beta}{\delta t} + ikv_{\beta_0}p_\beta = v_{\beta_0}\Omega^2 r_\beta p_\beta + \frac{e_\beta E}{m} \qquad (2)$$

$$\frac{\delta n_\beta}{\delta t} + ikv_{\beta_0}n_\beta + ikn_{\beta_0}v_\beta = 0 \qquad (3)$$

$$ikE = 4\pi \sum n_{\beta_0} e_\beta, \qquad (4)$$

where β is the species index (e^+ and e^-), p_β and v_β are respectively the first order dimensionless momentum and the 0-th order velocity, m being the electron mass, c is the speed of light, e_β is the charge of species particle taking part in the process, and finally r_β is the radial coordinate of the corresponding species, n_β and n_{β_0} are perturbed and unperturbed components of of the density, E is the electric field and k represents the wave vector. The resulting equation from the mutual use of these three equations in the Langmuir mode is periodic and shows parametric instability. For an efficient LLCD to proceed, the inverse growth time scale of Langmuir waves should be smaller compared to the escape time scale.

Conclusions

In the work, it is shown that if several parameters in a region are suited to generate LLCD, then electrons may attain energies of the order of 10^{18} eV in a rotating neutron star with strong magnetic environment. When these energetic electrons interact with the background radiating zone or gases, possibility of PeV neutrino generation seems expected through some probable reaction channels . Then, the origin of PeV neutrinos detected at the IceCube might be of leptonic in fundamental origin.

Acknowledgments

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