Some aspects of LF-MF Radioemission associated with Extensive Ice Shower initiated by high energy neutrinos

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Abstract

High energy neutrinos passing through the earth initiate electron-photon showers in the Antarctic ice. Preliminary investigation made on the LF-MF radioemission (RE) emitted by the Extensive Ice Shower (EIS) was presented at the 27th ICRC, 2001. In this paper, some important aspects of LF-MF RE, viz. frequency spectrum, lateral distribution etc. from EIS having energy in the range $\sim 1PeV$ to $\sim 10EeV$ are studied theoretically. Applications of such investigation for studying behaviour of high energy neutrinos in ice are also discussed.

1. Introduction

Observation of Cosmic Rays(CR) with energy $> 10^{20}eV$ opens a new window to the physical world. To understand the observations of high energy CR, it is imperative to make complementary observations of VHE cosmic neutrinos [5]. Existing and proposed neutrino detection techniques are:
(i) Detection of optical Cherenkov photons to reconstruct the tracks of muons produced in charged current reaction,
(ii)Detection of neutrino induced EAS,
(iii)Detection of neutrinos through the coherent Radio Cherenkov Radiation (RCR) from the showers produced by neutrino interactions.

However, optical Cherenkov experiments are practically not feasible: experiments are too expensive. Air shower technique requires a huge area for particle detector array due to low density of air, again practically not feasible. Space based fluorescence experiments as well as lunar radio technique has a too high threshold. Only the RICE [6] technique based on neutrino detection through RCR in ice seems to offer a suitable combination of mass and threshold to detect GZK neutrinos at the rate of ~ 100 neutrinos per year [4]. Present experimental set up of RICE comprises of 18 half-wave VHF dipole receivers under ice. This investigation technique can be modified by introducing some more radio channels in the VLF-LF-MF band to carry out simultaneous investigation of RE at different frequencies from VLF to UHF. The basic model for Transition Radiation (TR) as production mechanism of LF-MF RE from neutrino induced showers in ice called

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EIS was given in our earlier paper [3]. The method for simultaneous detection of VLF-LF-MF and VHF-UHF RE was also discussed. Preliminary investigation made on the LF-MF RE at 1 PeV was presented at the 27th ICRC, 2001 [3]. In this paper, some important aspects of LF-MF RE associated with EIS are studied theoretically. Applications of such investigation for studying behaviour of high energy neutrinos in ice are also discussed.

2. Method

The model is based on the following:

(i) When a high energy electromagnetic cascade develops in normal matter, there arises a net $20 - 30\%$ negative charge excess due to Compton scattering and annihilation of positrons in flight. Askarayan [1] discovered this effect and noted that it should lead to a strong coherent RE.

(ii)When a charged particle moving uniformly in a medium enters another medium, radiation is emitted in the forward as well as backward direction. This radiation is called TR. When charged particles of the EIS cross the surface of separation of ice and air, the phenomenon of TR must occur. For the LF-MF band, all the charged particles of the shower may be assumed, for mathematical convenience, to be concetrated at a point instead of distribution over a region and only the negative charge excess, in effect, will contribute to the TR.

Askarayan effect of negative charge excess has been confirmed in SLAC experiment [4] . This experimental confirmation exhibits enormous potential of a technique based on this effect. The results of the SLAC experiment establishes a firm experimental basis for RF detection of high energy cascade in solid media, either through interaction within a dielectric (RCR) or via passage through interfaces (TR).

For a vertical EIS initiated by a high energy neutrino coming up through the earth, the magnitude of the horizontal and the vertical component of the electric field due to TR is given by [3]

$$\mathbf{E}_{wH} = \frac{\epsilon N e \lambda_2 \eta_2 \mathbf{k}}{2\pi^2 \upsilon \zeta} \cos\theta \tag{1}$$

and

$$\mathbf{E}_{wV} = \frac{\epsilon N e \eta_2 k^2}{2\pi^2 \upsilon \zeta} \cos^2\theta \tag{2}$$

where N=size of the EIS at the boundary surface,

ϵNe = negative charge excess,

$k = \frac{\omega}{c} = \frac{2\pi\nu}{c}$ = wave number,

${\lambda_1}^2 = \frac{\omega^2}{c^2}\chi_1 - k^2$; $\chi_1 = \epsilon_1\mu_1$; ϵ_1 = dielectric constant of ice,

${\lambda_2}^2 = \frac{\omega^2}{c^2}\chi_2 - k^2$; $\chi_2 = \epsilon_2\mu_2$; ϵ_2 = dielectric constant of air.

$\eta_2 = \frac{\frac{\epsilon_1}{\epsilon_2}+(\frac{v}{\omega})\lambda_1}{k^2-\chi_2\frac{\omega^2}{c^2}} - \frac{(\frac{v}{\omega})\lambda_1+1}{k^2-\chi_1\frac{\omega^2}{c^2}}$,

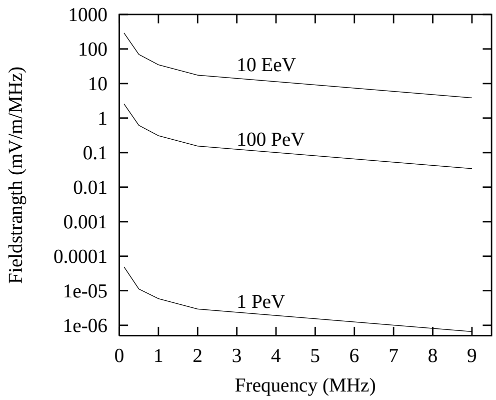

Fig. 1. Frequency spectrum of horizontal component.

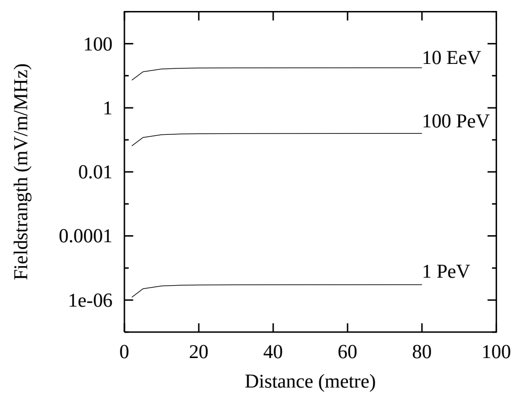

Fig. 2. Lateral distribution curve.

$\zeta = \lambda_2\epsilon_1 + \lambda_1\epsilon_2$,

$\tan\theta = \frac{Z}{R}$, where Z= height of the antenna above the ice surface, R= distance of the antenna from the shower axis.

Theoretical graphs of ϵ- depth for energies 1 PeV, 100 PeV and 10 EeV can be obtained from extrapolation done on the basis of ϵ- depth graphs [2] for lower energies viz 1 TeV, 10 TeV and 100 TeV.

3. Results

Fig.1 gives the frequency spectrum for neutrino energies 1 PeV, 100 PeV and 10 EeV. Lateral distribution of fieldstrengths for different neutrino energies are given in fig.2. Fig. 3 shows the depth- ϵ graph for energies 1 PeV, 100 PeV and 10 EeV.

4. Discussion

From the equations (1) and (2), it is seen that the fieldstrength scales linearly with the negative charge excess and hence with the neutrino energy. This is demonstrated by the fig. 1 and Fig. 2. Fig.2 shows that the fieldstrength attains saturation value after some core distance. But in practice, fieldstrengths will decrease after some distance due to absorption in the atmosphere. It is also seen from eqn (1) and (2) that LF-MF fieldstrengths from EIS is a function of charge excess, neutrino energy and core position and high fieldstrengths may be observed at this band of frequencies. Hence, if an array of LF-MF antenna is installed on Antarctic ice surface above the VHF-UHF antenna of RICE [5] project and fieldstrengths of each of these antenna systems are measured taking coincidences, then from equations (1) and (2), ϵ, N and core co-ordinates can be calculated for each neutrino event. Such values can be calculated for VHF-UHF channel also for the same neutrino events. Knowing ϵ and N, depth of first interaction can be estimated from the graphs of fig 3 for different neutrino

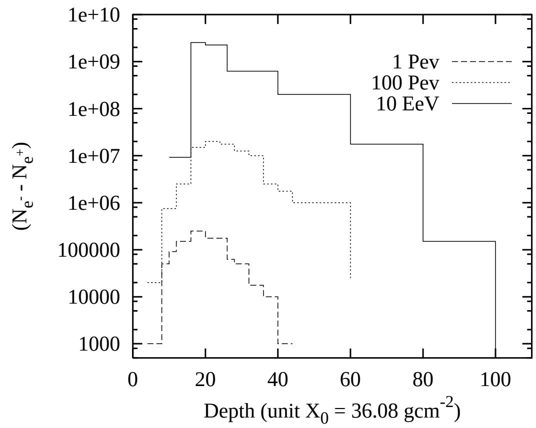

Fig. 3. Depth vs negative charge excess plot in ice.

energies.Thus, an investigation on the dependence of depth of first interaction on neutrino energy will give a picture of behaviour of neutrinos in ice.

5. Conclusion

On the basis of the present investigation on some important characteristics of LF-MF RE from EIS initiated by high energy neutrinos, it is concluded that simultaneous detection of LF-MF and VHF-UHF RE from EIS will give information on different characteristics as well as behaviour in ice of high energy neutrinos coming from CR sources.

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References

1. Askarayan G., Soviet Physics JETP 14, p 441 (1962); AskarayanG., Soviet Physics JETP 21, p 658 (1965).
2. J.Alvarez-Muniz and E.Zas, Proc. of the RADHEP 2000 Workshop, (AIP, NewYork, 2001), p 117.
3. R.S. Kalpana and D.Pranayee, Proc. 27th Int. Cos. Ray Conf. , Hamburg, HE.3, p 1309 (2001) .
4. Saltzberg D. et al., Proc. of the RADHEP 2000 Workshop, (AIP, NewYork, 2001), p 225.
5. Seckel D., Proc. of the RADHEP 2000 Workshop, (AIP, New York, 2001), p 196.
6. Seckel D. et al.,Proc. 27th Int. Cos. Ray Conf. , Hamburg, HE.3, p 1137 (2001).