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Characteristics of VLF-LF radio emission (RE) from Giant Air Shower (GAS)

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Experimental works on radiation and particle component of Giant Air Showers (GAS) are going on in different laboratories all over the globe. In this paper, a theoretical investigation is made on different components of VLF-LF radio emission associated with GAS. Findings of this work will be reported at the conference.

1. Introduction

Studies of Giant Air Showers (GAS) is one of the major challenges in recent times. Nature, origin, acceleration mechanism and high energy (HE) interaction associated with the cosmic ray (CR) particle producing GAS is still not clear.

Results obtained over last two decades using broad air shower detectors, such as Fly's Eye, AGASA and the Yakutsk installation, have made it possible to collect database of UHE cosmic rays. AGASA group has reported 57 events of energy > 4x 10^{19} eV and 8 events with E >10^{20} eV [1].

At present much attention is being given on detection of neutrino with E >10^{19} eV, investigating the radio emission (RE) emitted by neutrino initiated showers, viz, Extensive Ice Showers (EIS) and Lunar Regolith Showers(LRS)[2,3,4,5,6], since detection of such neutrino will be useful for solving the GZK puzzle. As the neutrino astronomy based on Radio method originates from the extensive study of RE from EAS, for concretising the theoretical model of radio method of neutrino detection, support from the investigation of RE from GAS is very much essential. Moreover, at present quite a good number of Giant Shower Projects is in successful operation (Augur, G.U., Yakutsk etc). These two factors point towards the necessity of investigation of RE from GAS.

Observed higher field strengths from EAS in the LF-MF band may be due to Transition Radiation (TR) mechanism which is different from RCR. Field strength due to TR mechanism shows an increasing trend as the frequency is lowered [7].

Hence, in this paper different characteristics of RE associated with GAS is investigated in the light of TR mechanism.

2. Method

When a charged particle moving uniformly in a medium, enters suddenly into another medium, radiation is emitted in the forward as well as backward direction. This radiation is called Transition Radiation (TR).When the particles of EAS hit the ground, the phenomenon of TR must occur. For the VLF-LF band all the charged particles of the shower may be assumed, for mathematical convenience, to be concentrated at a point instead of distribution over a region and only the excess negative charge, in effect, will contribute to TR.

For a particle of charge e moving with relativistic velocity v crossing the boundary plane Z = 0 at t = 0, the radiation field in the first medium is given by

$$\overline{E}'_{\omega 1} = \frac{ek^2\eta_1}{2\pi^2 v\varsigma}\hat{n}_z \sin(\lambda_1 z) + \frac{ek\lambda_1\eta_1}{2\pi^2 v\varsigma}\sin(\lambda_1 z) + i\frac{ek^2\eta_1}{2\pi^2 v\varsigma}\hat{n}_z \cos(\lambda_1 z) + i\frac{ek\lambda_1\eta_1}{2\pi^2 v\varsigma}\cos(\lambda_1 z) \quad (1)$$

For a vertical air shower, the magnitude of the vertical component of the field is

$$\overline{E}_{\omega v} = \frac{\varepsilon N e \eta_1 k^2 \cos^2\theta}{2\pi^2 v\varsigma} \quad (2)$$

Where N = Total number of shower particles at ground level

εNe = excess negative charge, $k = \omega/c$ = wave number

λ_1^2 = $(\omega/c)^2\chi_1 - k^2$: $\chi_1 = \varepsilon_1 \mu_1$ and $\lambda_2^2 = (\omega/c)^2\chi_2 - k^2$: $\chi_2 = \varepsilon_2 \mu_2$

η_1 = $\dfrac{\varepsilon_2/\varepsilon_1 - v/\omega\lambda_2}{k^2 - (\omega^2/c^2)\chi_1} + \dfrac{-1 + v/\omega\lambda_2}{k^2 - (\omega^2/c^2)\chi_2}$

ζ = $\lambda_2 \varepsilon_1 + \lambda_1 \varepsilon_2$

$\varepsilon_1, \varepsilon_2$ = dielectric constant of the first and second medium

μ_1, μ_2 = permeability of the first and second medium

$\tan\theta$ = Z/R , Z = height of the antenna from the ground, R = core distance

The Eq. 2 can be used for calculating the field strength for air shower striking the ground. The number of excess electrons in the shower is obtained by assuming $\varepsilon = 20\%$ [8]. Number of shower particles hitting the ground for different primary energy (E_p) and different primary particles is estimated from N_{max} and S_{max} [9,10].

3. Result

Frequency spectra for vertical component of field strength obtained from Eq. 2 is presented in Fig.1 for gamma initiated, proton-initiated and iron-initiated shower with $E_p = 10^{18}$ eV.

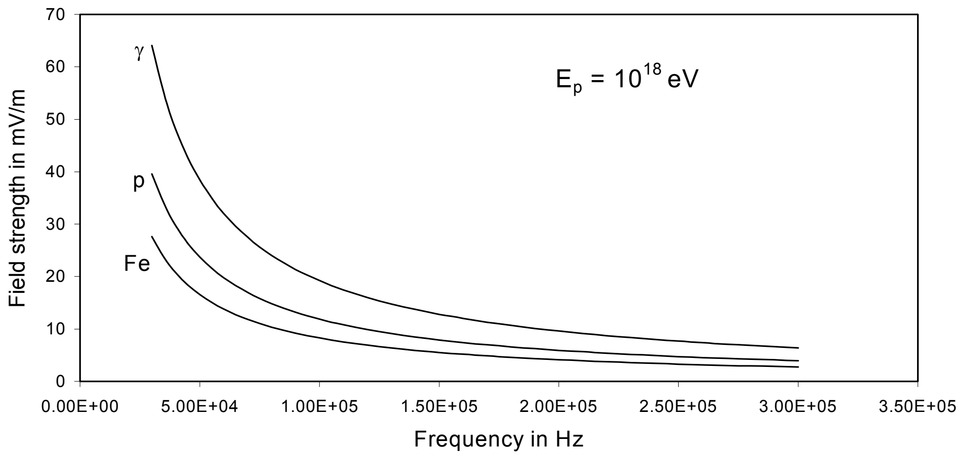

Figure. 1 Frequency spectra of vertical component of Field strength

Fig. 2 shows frequency spectra for vertical component of field strength for gamma initiated, proton-initiated and iron-initiated shower with $E_p = 10^{19}$ eV.

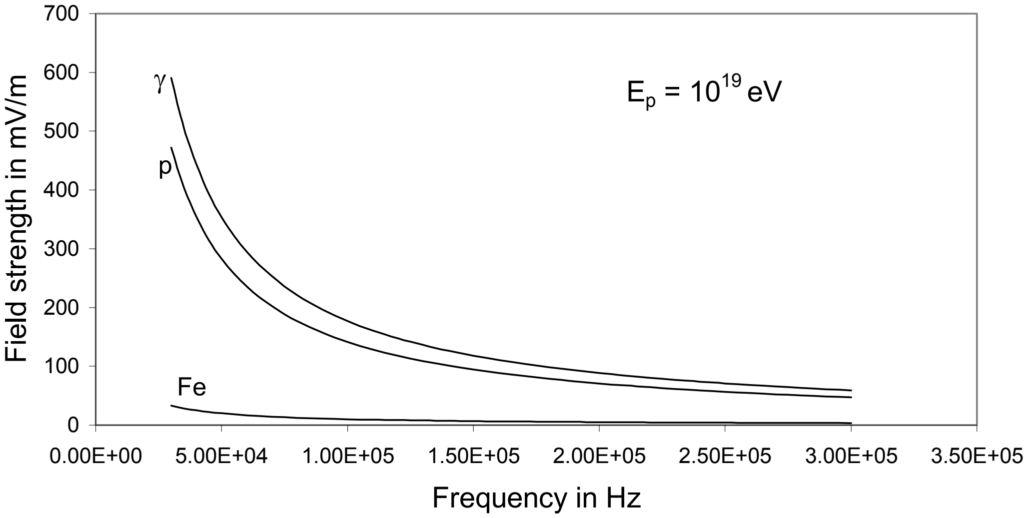

Figure. 2 Frequency spectra of vertical component of Field strength

Variation of vertical component of field strength at 100 kHz with primary energy (E_p), for proton-initiated shower is presented in Fig. 3.

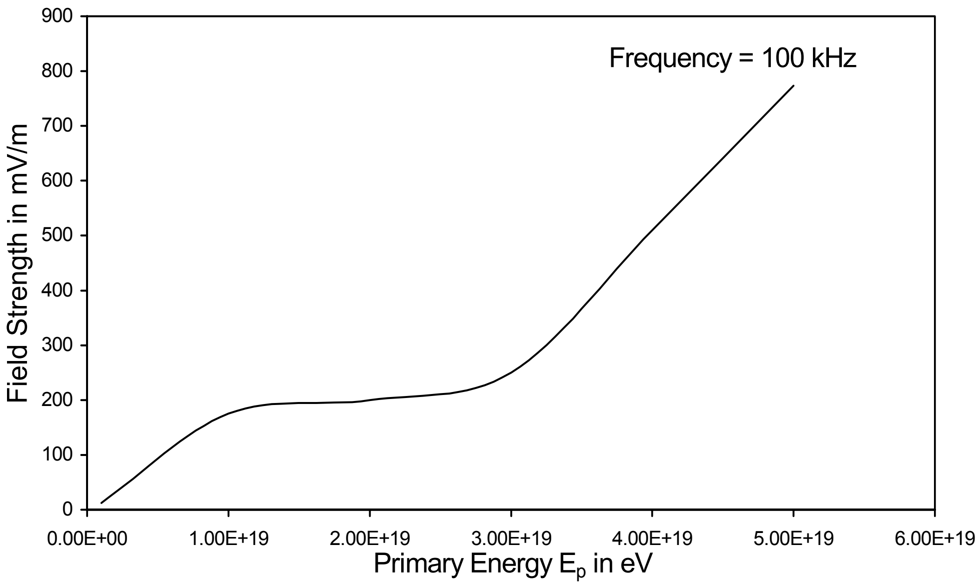

Figure 3. Variation of vertical component of Field strength with Primary Energy E_p for proton initiated shower.

4. Discussion and Conclusions

Frequency spectra for gamma initiated, proton-initiated and iron-initiated shower shows that with lowering of frequency field strength increases (Fig. 1), for primary energy, $E_p = 10^{18}$ eV. For a particular frequency, field strength for gamma initiated shower is maximum whereas for iron-initiated shower is minimum.
For primary energy, $E_p = 10^{19}$ eV field strength due to gamma and proton initiated showers increases more rapidly than iron-initiated shower towards the lower frequency region. Field strength due to gamma initiated shower is slightly higher than the proton initiated shower for this energy range (Fig. 2).
Field strength due to proton initiated shower shows an increasing trend as the energy of the primary particle increases up to $E_p = 10^{19.5}$ eV.

The encouraging result of this investigation may be useful for detecting Giant Air Shower by radio method. Radio detection of GAS will be a sophisticated and cost effective technique.

As Eq. 2 has three unknowns, simultaneous measurement of field strength at a minimum of three antennas at different positions, along with conventional particle detector array, will make it possible to estimate shower size, N and core distance, R.

Hence from graphs similar to Figs. 1 and 2, primary particle may be identified. However, for improved accuracy of the final results more characters of VLF-LF radio emission are to be investigated.

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