Radioemossion from the lunar surface due to extragalactic particle-lunar regolith interaction.

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Abstract

An ultrahigh particle, neutrino or charged cosmic ray particle, entering the lunar regolith, can initiate an electron-photon cascade which gives rise to Radio frequency Cherenkov Radiation (RCR) .Detailed investigations on theoretical as well as experimental aspects of the RCR are going on in different labs of the globe.
The electron component of the electron photon cascade, on crossing the moon-vacuum interface, can emit Transition Radiation (TR) also.
In this paper, a method is outlined for investigating the TR pulses with the help of moon based as well as earth-based detectors.

Introduction

Coherent radio emission associated with Extensive Air Showers (EAS) was theoretically predicted by Askaryan in 1962 [1] and experimentally detected by Jelley et al. in 1965 [2]. This detection of electromagnetic radiation (optical Cherenkov radiation and radio emission) which are initiated as a result of interaction of particles from galactic and extragalactic cosmic ray (CR) sources with the earth's atmosphere, has opened a new direction to study the whole spectrum of radiation from ~50 KHz to ~550 MHz [3]. The study of physics or astrophysics of ultra high energy cosmic ray (UHECR) are intimately linked with the emerging field of neutrino astronomy and it has opened a new branch "Ultra High Energy Neutrino Astronomy". The detection of UHE neutrinos will open a new window to the farthest and most energetic phenomena in the universe.

The theory of radio emission in dense materials was formulated by Askaryan. He suggested that the particle cascade resulting from the interaction of a HE particle in a dense medium would not be electrically neutral [1] since Compton scattering knocks electrons from the material into the shower. In addition, the positrons in the shower could annihilate in flight. The net negative charge should lead to strong radio and microwave Cherenkov emission (at HF-VHF band) for showers that propagate within a di-electric. An UHE neutrino entering the lunar regolith can initiate an electron-photon cascade and hence emits RCR. For LF-MF band, the most probable production mechanism is the coherent Transition Radiation (TR). Because the particles are charged and relativistic, passage of the beam through any interface induces strong radio frequency transition radiation.

The plausibility of Askaryan's suggestions combined with more recent modeling and analysis has led to a number of experimental searches for high energy neutrinos by exploiting the effect at energies from 10^{16} eV in Antarctic ice upto 10^{20} eV or more in lunar regolith, using large ground based radio telescopes. RCR pulses have been studied theoretically and experimentally for many years by different groups all over the world [4,5]. The first attempt to detect the RCR pulses from the Moon with the help of earth based detectors was made by T. Hankins et al. in 1996. They were using the Parkes 64m radio telescope with a wideband (1187-1662MHz) receiver and high time resolution (of few ns) oscilloscope, but till now no genuine pulse is detected. Another attempt was made by Gorham et al. in 1999 with the Goldstone Lunar Ultra-high Energy neutrino experiment (GLUE) in NASA .They were using NASA Goldstone 70m and 34m antennas and the observations was made at S-band (2.2-2.3 GHz). An L-band (1.6 GHz) receiver was used at 70m antenna simultaneously with S-band receiver. No pulses of expected duration are observed till date.

However, the negative results of these two experiments are followed by two excellent laboratory experiments by UCLA/NASA group of Physics [6] which confirms the negative charge excess mechanism as the origin of RCR pulses. At present, Kalyazin 64m radio telescope is one of the most suitable tool for searching the CR pulses from the Moon's surface.

Recently another experimental project, LORD(Lunar Orbital Radio Detection)[7] was proposed and started its development. An array of antennae of decimeter wavelength band is installed on board of a satellite orbiting the moon. Antennae search the lunar surface within line-of-sight range and detect short radiopulses of nanosecond duration.

The charged particles of the electron-photon cascade, initiated in the lunar regolith while crossing the moon-vacuum interface, can emit TR. In 1961. G. A. Askaryan among other things suggested to search for radio signals from particle cascades developing in lunar ground using antennae placed on the surface of the Moon.[8].

In this paper, a method is proposed for detection of TR pulses originated from the interactions of neutrinos (from UHECR sources) and lunar regolith with the help of Moon based detectors.

Method

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 Transition Radiation (TR). For a neutrino initiated shower in lunar regolith, crosses the moon-vacuum interface, TR must occur. For a particle of charge e moving with relativistic velocity v along z-axis and crossing the interface at z=0, t=0, the radiation field in the vacuum is given by,

$$\vec{E}'_{\omega 2} = \vec{e}'_{\omega 2} e^{i\lambda_2 z} \qquad (1)$$

For a neutrino initiated shower having zenith angle ϕ, the magnitude of the vertical component of the TR field is obtained as

$$\vec{E} = \frac{\varepsilon N e \eta_2 k^2}{68.9228\pi^2 \nu\zeta}\cos^2\theta - 0.11\phi \qquad (2)$$

where N = Size of the LRS at the boundary surface

$\in$ Ne = Excess negative charge

$k = \omega/c = 2\pi\nu/c$ = wave number,

$$\lambda_1^2 = \frac{\omega^2}{c^2}\chi_1 - k^2 \quad ; \quad \chi_1 = \in_1 \mu_1$$

$$\lambda_2^2 = \frac{\omega^2}{c^2}\chi_2 - k^2 \quad ; \quad \chi_2 = \in_2 \mu_2$$

$\in_1$, $\in_2$ are dielectric constant of lunar regolith and air respectively,
μ_1, μ_2 are permeability of lunar regolith and air respectively,

$$\eta_2 = \frac{\in_1/\in_2 + (v/\omega)\lambda_1}{k^2 - \chi_2\omega^2/c^2} - \frac{(v/\omega)\lambda_1 + 1}{k^2 - \chi_1\omega^2/c^2}$$

$$\zeta = \lambda_2 \in_1 + \lambda_1 \in_2$$

$$\tan\theta = Z/R$$

Z = height of the antenna above the ice surface
R = distance of the antenna from the shower axis
ϕ = zenith angle.

Experimental method

i) Radio antennas (a minimum of five) of frequency < 1MHz are to be erected at the lunar surface to register TR pulses.

ii) Output of radio channels is to be applied to a coincidence circuit and the output of the coincidence circuit is to be taken to trigger the recording system employed for detecting the pulse height of individual channels.

iii) Fieldstrengths at five different positions of antennas are to be measured.

iv) Frequency of the output of the coincidence circuit is to be raised to some suitable VHF frequency for transmission to some earth based radio telescopes.

3. Result

Preliminary investigations on frequency spectrum and variation of fieldstrength with zenith angle are given on fig 1 and fig2.. The depth vs negative charge excess graph (fig3) is obtained from the results of findings from Saltzberg et al [9].

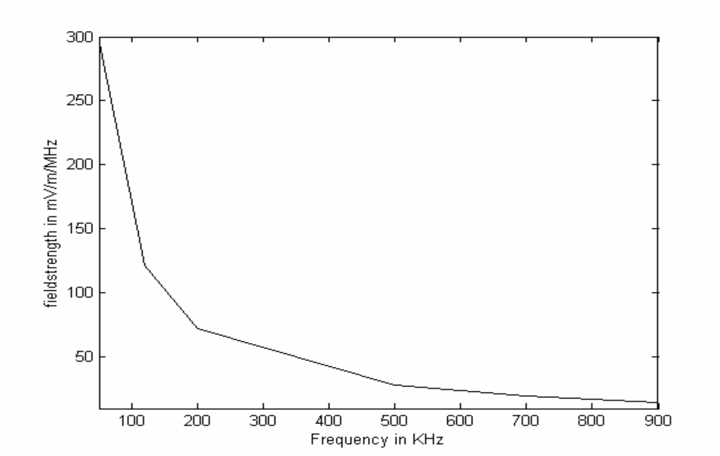

Fig1:Frequency spectrum of vertical component

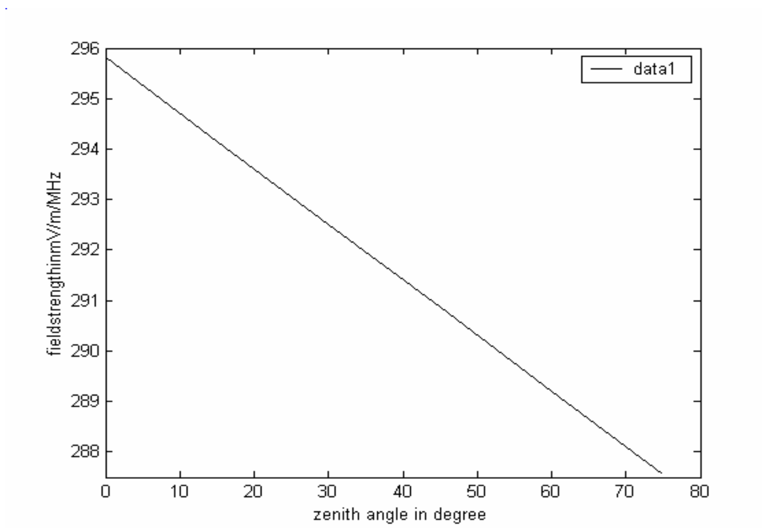

Fig2: Variation of fieldstrength with zenith angle

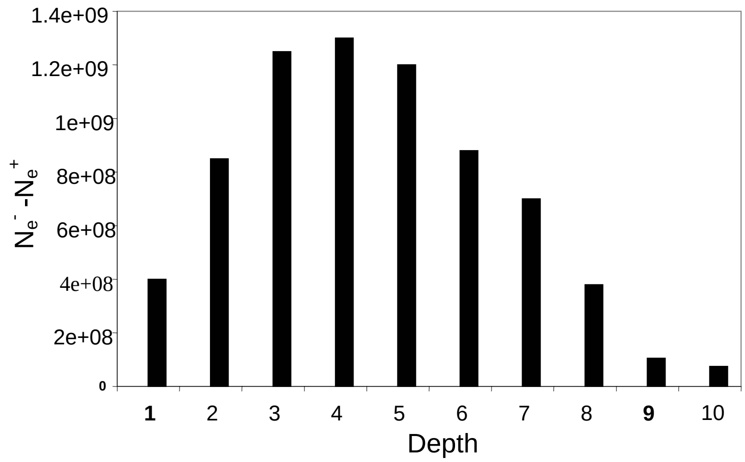

Fig 3: Depth vs negative charge excess

Discussion & Conclusion:

From eqn (2) , it is seen that the fieldstrength scales linearly with the negative charge excess and hence with the neutrino energy. Also it is seen that high fieldstrengths may be observed at this LF-MF band of frequencies. Measuring fieldstregths at five different positions, parameters ε, N, core co-ordinates and ϕ can be estimated by using equation (2) by the method of steepest descent or by Artificial Neural Nets. Knowing N and ε, depth of first interaction can be estimated from fig 3 for different neutrino energies, from which interaction characteristics of neutrino in lunar regolith can be obtained. Thus from the method proposed, detection of UHE neutrinos is expected with the help of moon based detectors also, which will play an important role in understanding a number of cosmologically significant phenomena.

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