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# Radio Detection of Cosmic Rays and Neutrinos on the Moon

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## Abstract

Detection of Ultra High Energetic Cosmic Rays and Neutrinos (UHECRv) using the Moon surface has been a hot topic in astrophysics in recents years. For the first time, we present the opportunities for the radio detection of UHECRv using a single antenna and a digital receiver on the Moon's surface and show that such an experiment perfectly complements ground-based observations of UHECRv.

## 1. Introduction

Lunar Radio eXplorer (LRX), is an experiment initially planned for the European Lunar lander mission but can be adapted for other Lunar lander missions. LRX uses a tripole antenna with 2.5 m length (tip to tip) and a sensitive digital receiver in a spectral range of 5 kHz-100MHz. The experiment aims to observe radio emissions on the Lunar surface. Technical requirements and science cases of LRX are described in details in [6,7]. One of the scientific aspects of LRX is to detect the radio pulses caused by UHECRv.

It has been well known that Moon surface can act as a detector for UHECRv [1]. Using the well-known 'Askaryan Effect' the UHECRv interacttion with a dielectric medium such as Moon regolith which results in propagation of coherent radio pulses known as Cherenkov radiation. The radio spectrum extends up to microwave frequencies (cm wavelengths) in dielectric solids but it also reaches a peak at lower frequencies [8], which is within the frequency range of LRX. The intensity of radio emission depends on the energy of cosmic ray particles. The detectable signal is identified with the distance to the observer (i.e Antenna), sensitivity of the receiver and electromagnetic properties of Lunar regolith.

The radio emission contains important information about the energy and the composition of UHECRv. In addition, the LRX is capable of localising the radio emission [2] which could hint towards the possible source of these high energetic particles, i.e. neutrinos or cosmic rays as the first penetrate much deeper in the lunar regolith.

We briefly introduce the analytical methods for UHE Neutrinos and CR using LRX characteristcs and Lunar regolith parameters. The results are discussed and compared with those from LOw Frequency ARray (LOFAR) [8,9] and Lunar Orbiter Radio Detector (LORD) [4] as examples of ground based and lunar orbiter observations.

## 2. UHECRv Detection

An analytical method was presented in [3] to calculate the aperture for UHE neutrinos colliding with Moon. The aperture consists of the physical area in the antenna FoV times a complex function which represents the probability of Neutrino detection in the area. The function is defined by Cherenkov radiation properties in the Lunar environment and the LRX antenna parameters. We modified the method by taking into account the attenuation of lunar regolith and used the LRX parameters. The LRX antenna is assumed to be 3 m above the moon surface which is an estimate for the height of lunar lander. As the Moon is opaque to the UHE neutrinos, both downward and upward neutrinos can produce the Cherenkov radiation. Also surface roughness can play a role by scatterring the radiation [3]. However, analysis shows that at LRX frequencies the major contribution is from downward neutrinos and the effect of surface roughness can be neglected. Typical numbers for refractive index of lunar regolith (1.73) and sublayers (2.5) have been used in the aperture calculation. Knowing the aperture and standard models of neutrinos flux densities, one can estimate the number of detected events for a certain period. A schematic of UHECRv apertures in the presence of

LRX antenna is illustrated in Figure 1. For neutrino events which occur inside the regolith, the radio emission is partially attenuated. The maximum detecting area is the distance from the antenna where the intensity of Cherenkov radiation is greater than the minimum detectable electric field by LRX receiver. The total aperture for UHE neutrino then becomes a virtual cone which covers both the events on the surface and those occurs inside the lunar regolith (Fig.1).

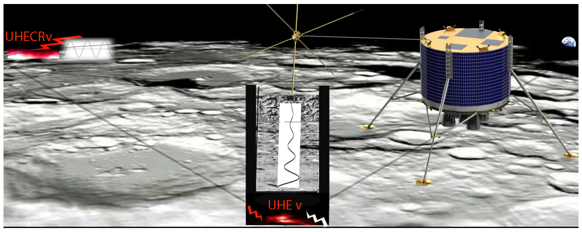


Figure 1: A sketch of UHECRv detection by LRX

The method in [3] has been developed in [5] for detection of UHE Cosmic Rays which collides with Moon. The main difference is that CR, containing energetic primary particles, can not penetrate through the Lunar regolith therefore only surface impacts are taken into account.(downward CR, upper left in Fig. 1). For surface events, the radio emission is propagated in Lunar exosphere so attenuation is neglected. Again the event rate is estimated using the known CR flux density models and calculated aperture.

## 3. Results

The flux densities of UHECRv for one year LRX observation is plotted in Figure 2. For LRX CR , the two blue curves represent two different CR energy regimes. Events at higher energy level (solid blue curve) generate more intense radio emission and the detectable aperture for these events are within a radius of 5 km from the antenna. Based on the cosmic ray flux model (dashed green line, [5]) about 15 events are predicted for one year of observation. The blue dashed curve belongs to low energy events which are only detectable within 50 m from the antenna. With the current design (One antenna and 5KHz-100 MHz bandwidth) the event rate is .01 for a one year LRX mission so more antennas with broader bandwidth will be required to detect the low energy CR events. For neutrino impacts the detecting area can be as far as 20 km away from the antenna on the moon surface or 600 m deep inside the regolith. Considering neutrino flux density models (dashed black [5] and pink [9]), a noticable total number of 20000 UHE neutrino events for one year of observation by LRX is achievable. This rate is compatible with the events rate predicted for large telescope arrays such as LOFAR (solid black line, [8,9]) or Lunar orbiter observations (e.g. LORD, solid red line, [4] ; Tripole on a satellite, solid green line, [9]).

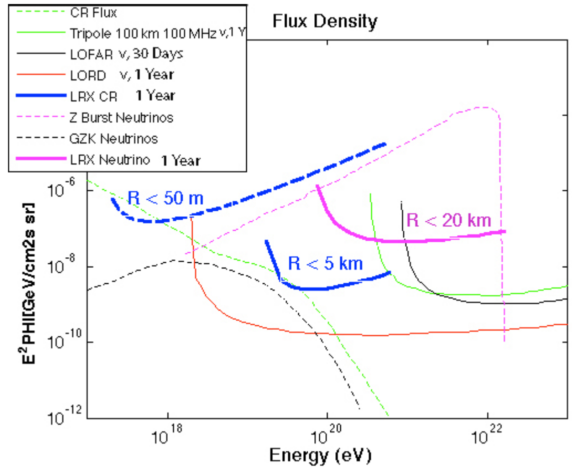


Figure 2: Flux densities for UHECRv and predicted aperatures for the LRX

## 4. Conclusion

Considering future lunar missions, we present the possibility of UHECRv detections using only a single tripole antenna on the Moon surface. For one year observation, a significant number (15 CR and 20000 Neutrinos) of events is expected which is comparable with those for large ground based radio arrays. In addition, the LRX experiment is designed to cover the frequencies which is not accessible from the Earth (<10 MHz) and is much less affected by terrestrial RFI.

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