PROCEEDINGS OF SCIENCE

La Luna: Lovell Attempts LUnar Neutrino Acquisition

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Recent measurements by the Pierre Auger array have found evidence for the Greisen-Zatsepin-Kuzmin (GZK) cut off in the high energy spectrum of cosmic rays. Interactions of cosmic rays with energies of greater than ~0.05 ZeV with the cosmic microwave background are expected to produce high energy neutrinos. It has been suggested that neutrino interactions in the Moon can give rise to showers of particles, which through the Askar'yan charge excess mechanism can produce Cherenkov emission in the radio, detectable from the Earth. Here we describe a preliminary experiment at 21 cm with the Lovell telescope, which produces limits comparable with those from other radio telescopes. Use of VLBI telescopes in coincidence would eliminate local impulsive RFI and also possibly be able to measure the width of the Cherenkov cone

10th European VLBI Network Symposium and EVN Users Meeting: VLBI and the new generation of radio arrays
Manchester, UK
September 20-24

 http://pos.sissa.it

PoS(10th EVN Symposium)097

1.Introduction

The study of ultra-high-energy (UHE) neutrinos has the potential to be an important tool in the study of many energetic astronomical phenomena. Neutrinos with energies in excess of 10^{20}eV are predicted to be produced by processes such as gamma-ray bursts, active galactic nuclei, topological defects and decays of massive relic particles [1]. UHE neutrinos can also be used to probe the standard model of particle physics as they are produced as a by-product of the interaction between UHE cosmic rays and photons from the cosmic microwave background. A cut-off in the cosmic ray spectrum was predicted by Greisen and independently by Zatsepin and Kuzmin [2,3] for proton energies above 10^{19}eV. Subsequent decay of the pions and muons results in a strong flux of high energy neutrinos.

In 1962 Askar'yan [4] suggested that particle showers in dense media could emit coherent Čerenkov radiation at radio frequencies. A whole series of radio observations of pulses from cosmic ray cascade showers produced in the Earth's atmosphere then resulted (see e.g. Spencer 1969 [5]). He also suggested that detectors dropped onto the lunar surface could be used to detect comic-ray-induced particle showers within the Moon. In 1989 Dagkesamanskii and Zheleznykh proposed that the same mechanism could also be used to look for radio emissions from the Moon due to UHE neutrino interactions, postulating that the emission could be detected by using Earth-bound radio telescopes [6].

A number of experiments using radio telescopes have subsequently been undertaken. The first was by the Parkes telescope [7] at 1.2-1.7 MHz, the next used the Goldstone (GLUE) [8] at 1.8-2.2 GHz, and further experiments using the Kalyazin Radio Telescope [9], WSRT [10], ATCA [11] and the EVLA (RESUN) [12] were also undertaken. None of these experiments found definitive pulses from the moon, though useful upper limits have been found. Future observations planned with LOFAR and SKA are expected to have greatly increased sensitivity [10].

2. Our Observations

An opportunity for trial observations with the Lovell telescope arose in 2009 and 2010, as part of an undergraduate MPhys project. Observations were taken on 3 Nov 2009 and again in a more extensive run on 11 May 2010 at 1418 MHz with 32 MHz bandwidth. Data were recorded on a Tektronix TDS1012 oscilloscope on LH and RH polarization channels. The interaction length of neutrinos at the energies expected (~ 1 ZeV $=10^{21}$ eV) is around 36 km [12] and so the signals are expected to come only from the limb of the moon. The pulses are broad band and so are expected to be bandwidth limited in our receiver. The radiation is expected to be linearly polarised and therefore give equal signals in our two circularly polarised channels. Observations were made at the centre, on the limb and offset from the moon by 2 degrees for comparison. Note that the beam width of the telescope was 10 arc min. The total observing time on the limb of the moon was 4.3 hrs, however a slow response in downloading data to disk from the oscilloscope resulted in a live-time total of 1 hr. 6 simultaneous and clear events were found from a total rate of 1800 /hr – similar both on and off the moon, i.e. limited by local impulsive interference. A typical pulse is shown in figure 1.

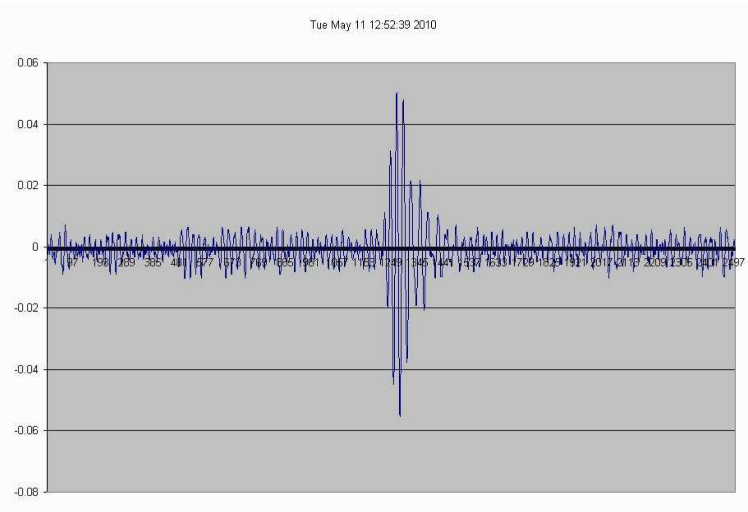

Figure 1 Typical pulse profile. The vertical scales is in mV, the horizontal scale has a total length of 2.5 µsec

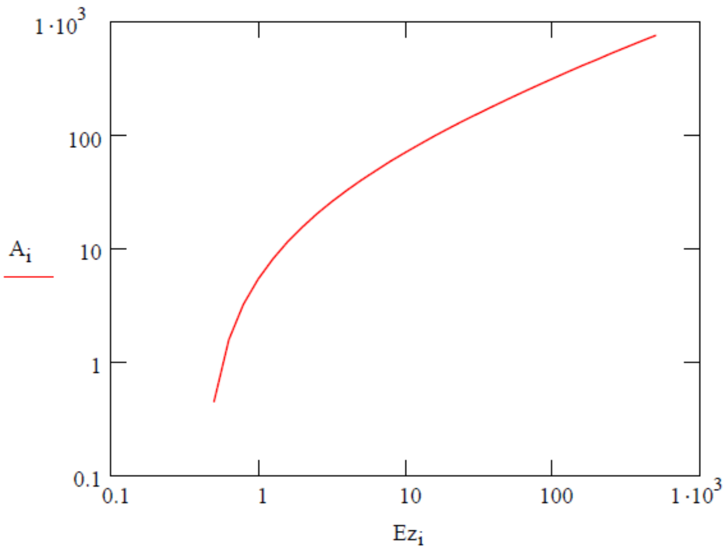

Figure 2 Plot of effective aperture *A* (in Km^2 sr) *vs* neutrino energy *Ez* in ZeV

The expected peak electric field of a Cherenkov pulse from the moon is $E = 0.024 E_Z$ µVm^{-1}MHz^{-1} [12] where E_Z is the energy of the neutrino in ZeV. The rms noise level of the Lovell receiver depends on the telescope effective area, the receiver noise temperature and the bandwidth. The signal on the limb of the moon was 5 dB above the background sky and with a 32 MHz bandwidth the resulting 4-sigma detection level was 0.01 µVm^{-1}MHz^{-1}. This effectively sets a lower limit to the energy detectable with the telescope of 0.4 ZeV.

The effective aperture of the moon depends on the product of the total cross sectional area, the total solid angle of the neutrinos (4π if isotropic), and the detection probability which depends on details of the interactions. Most calculations use Monte-Carlo simulations, e.g. [13]. However Gayley et al. [14] derive analytic approximations, allowing for the intrinsic radio spectrum and scattering by the irregular surface of the lunar regolith [12,13]. Figure 2 shows the results for our measurements assuming that the telescope covers 10/30π of the lunar limb (for a 10 arc min beam on a 30 arc min diameter moon). The 90% confidence level upper limit for neutrino flux is given by

$$F < 2.3\frac{1}{tA(E_Z)}$$

where t is the integration total time. Our measurements give an upper limit of 2.2 x 10^3 events km^{-2} yr^{-1} sr^{-1}, compared with a limit of 1 km^{-2} yr^{-1} sr^{-1} from the RESUN experiment [12].

2.1 Scattering

Refraction by the irregular surface of the moon is expected to result in a beam pattern with an rms width ~0.2 $\lambda^{-0.22}$ radians or 8.5 degrees at 21 cm. A global VLBI array on the Earth would subtend a maximum angle of 1.9 degrees at the moon, and so there is the possibility that a VLBI array could begin to measure the scattering and hence surface roughness.

3.Conclusions

Our experiment showed that use of the Lovell telescope for a search for neutrino events on the moon was feasible. However a large commitment of observing time of several hundred hours would be required to obtain competitive upper limits to neutrino rates. More efficient observations could be made if the whole limb was visible – either by the use of a lower frequency, e.g. 408 MHz, or by using a smaller telescope, both at the expense of a higher lower energy limit above 1 ZeV. Note that the GZK energy is much lower at around 0.01 ZeV. Coincidence techniques would reduce the impulsive noise background, and a bespoke recording system could eliminate dead time. The 25-m class telescopes available in VLBI would be able to cover the moon at 1.4 GHz, and provide perhaps the best coincidence regime as well as being able to study some details of the emission Multi-bit recording techniques will however be required.

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