Ultra-High Energy Particle Detection with the Lunar Cherenkov Technique

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Abstract

The lunar Cherenkov technique is a promising method to resolve the mystery of the origin of the highest energy particles in nature, the ultra-high energy (UHE) cosmic rays. By pointing Earth-based radio-telescopes at the Moon to look for the characteristic nanosecond pulses of radio-waves produced when a UHE particle interacts in the Moon's outer layers, either the cosmic rays (CR) themselves, or their elusive counterparts, the UHE neutrinos, may be detected. The LUNASKA collaboration aims to develop both the theory and practice of the lunar Cherenkov technique in order to utilise the full sensitivity of the next generation of giant radio telescope arrays in searching for these extreme particles. My PhD project, undertaken as part of the collaboration, explores three key aspects of the technique.

In the first three chapters, I describe a Monte Carlo simulation I wrote to model the full range of lunar Cherenkov experiments. Using the code, I proceed to calculate the aperture to, and resulting limits on, a UHE neutrino flux from the Parkes lunar Cherenkov experiment, and to highlight a pre-existing discrepancy between existing simulation programs. An expanded version of the simulation is then used to determine the sensitivity of past and future lunar Cherenkov experiments to UHE neutrinos, and also the expected event rates for a range of models of UHE CR production. Limits on the aperture of the Square Kilometre Array (SKA) to UHE CR are also calculated. The directional dependence of both the instantaneous sensitivity and time-integrated exposure of the aforementioned experiments is also calculated. Combined, these results point the way towards an optimal way utilisation of a giant radio-array such as the SKA in detecting UHE particles.

The next section describes my work towards developing accurate parameterisations of the coherent Cherenkov radiation produced by UHE showers as expected in the lunar regolith. I describe a 'thinning' algorithm which was implemented into a pre-existing electromagnetic shower code, and the extensive measures taken to check its veracity. Using the code, a new parameterisation for radiation from electromagnetic showers is developed, accurate for the first time up to UHE energies. The existence of secondary peaks in the radiation spectrum is predicted, and their significance for detection experiments discussed.

Finally, I present the data analysis from three runs of LUNASKA's on-going observation program at the Australia Telescope Compact Array (ATCA). The unusual nature of the experiment required both new methods and hardware to be developed, and I focus on the timing and sensitivity calibrations. The loss of sensitivity from finite-sampling of the electric field is modelled for the first time. Timing and dispersive constraints are used to determine that no pulses of lunar origin were detected, and I use my simulation software to calculate limits on an UHE neutrino flux from the experiment.

Disclosure

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

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C.W. James, R.M. Crocker, R.D. Ekers, T.H. Hankins, J.D. O'Sullivan, R.J. Protheroe, *Limit on ultrahigh energy neutrino f ux from the Parkes Lunar Radio Cherenkov experiment*, Monthly Notices of the Royal Astronomical Society, **379** (2007) 1037-1041. ©2007 The Authors. Journal compilation ©2007 RAS.

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