

Lunar Radio Detection of Ultra-High-Energy Particles

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Abstract

Ultra-high-energy cosmic rays, and their expected counterpart neutrinos, are the most energetic particles in nature, and their origin remains unknown. The detection of these particles is key to identifying their origin, but is complicated by their low flux, which necessitates the use of extremely large detectors. The largest potential aperture for detecting the most energetic of these particles is offered by the lunar radio technique, which makes use of the Moon as a detector, using ground-based radio telescopes to search for nanosecond-scale radio pulses from particles interacting in the lunar regolith, and it is this technique that is the subject of this thesis.

In this thesis I present a description of the most sensitive lunar radio experiment to date, conducted in 2010 with the Parkes radio telescope as part of the LUNASKA project, including a comprehensive test of the purpose-built Bedlam backend used in this experiment. The signal-processing strategy is explored in great detail, with an extensive discussion of the statistics of stochastic signals, and an optimal strategy is described which compensates both for known effects such as ionospheric dispersion and for previously-unidentified effects such as phase ambiguity from frequency downconversion. A series of cuts is outlined which successfully removes all anthropogenic radio interference, the first time this has been accomplished for a lunar radio experiment without the benefit of a coincidence filter operating between multiple channels. After these cuts, no radio pulses are observed; this null detection allows limits to be placed on the fluxes of ultra-high-energy cosmic rays and neutrinos.

To place this experiment in context, I perform a review of the null detections published for previous lunar radio experiments, including detailed analyses of their experimental techniques, based on the rigorous treatment applied in the above work. In several cases, I find previously-unidentified problems which significantly limit the sensitivity of previous experiments. Finally, I improve on existing analytic models for calculating the sensitivity of lunar radio experiments to ultra-high-energy cosmic rays and neutrinos, allowing a comparison with a range of possible future experiments, and comment on future prospects for this technique.

Declaration

I, Justin Derek Bray, certify that 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 in my name 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. In addition, I certify that no part of this work will, in the future, be used in a submission in my name for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide.

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Acronyms

ADC	Analog-to-Digital Converter
ADU	Analog-to-Digital Unit(s)
AEST	Australian Eastern Standard Time
AGN	Active Galactic Nucleus/Nuclei
ANITA	ANtarctic Impulsive Transient Antenna
ARA	Askaryan Radio Array
ASKAP	Australian Square Kilometre Array Pathfinder
ATCA	Australia Telescope Compact Array
CMB	Cosmic Microwave Background
CODE	Centre for Orbit Determination in Europe
CR	Cosmic Ray
CROME	Cosmic Ray Observation by Microwave Emission
EVLA	Expanded Very Large Array
FIR	Finite Impulse Response
FORTE	Fast On-orbit Recording of Transient Events
FWHM	Full Width at Half Maximum
GLUE	Goldstone Lunar Ultra-high-energy neutrino Experiment
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GRB	Gamma-Ray Burst
GZK	Greisen-Zatsepin-Kuz'min
HBA	High-Band Antenna
IF	Intermediate Frequency
INL	Integral Non-Linearity
IONEX	IONosphere map EXchange
JEM-EUSO	Japanese Experiment Module — Extreme Universe Space Observatory

LCP	Left Circularly Polarised
LO	Local Oscillator
LOFAR	LOw Frequency ARray
LPM	Landau-Pomeranchuk-Migdal
LUNASKA	Lunar Ultra-high-energy Neutrino Astrophysics with the Square Kilometre Array
MLT	Magnetic Local Time
MWA	Murchison Widefield Array
PAF	Phased Array Feed
RCP	Right Circularly Polarised
RESUN	Radio EVLA Search for Ultra-high-energy Neutrinos
RF	Radio Frequency
RFI	Radio-Frequency Interference
RICE	Radio Ice Cherenkov Experiment
RMS	Root Mean Square
SEFD	System Equivalent Flux Density
SKA	Square Kilometre Array
SNR	Signal-to-Noise Ratio
STEC	Slant Total Electron Content
TEC	Total Electron Content
TECU	Total Electron Content Unit(s)
UHE	Ultra-High Energy
UHECR	Ultra-High-Energy Cosmic Ray
UT	Universal Time
VCV	Véron-Cetty & Véron
VLA	Very Large Array
VLBI	Very Long Baseline Interferometry
VTEC	Vertical Total Electron Content
WGS84	World Geodetic System 1984
WSRT	Westerbork Synthesis Radio Telescope