A search for lunar radio Cerenkov from high-energy neutrinos

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or

"Daddy, did you find any timrons?"

by

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ABSTRACT

A search for Cerenkov emission in the radio-frequency range resulting from the particle cascade of an ultrahigh-energy neutrino on the near surface of the Moon is described. The expected peak of the pulse of 1-s duration, dispersed by propagation through the Earth's ionosphere, with an amplitude of approximately 400 Jy was not detected in approximately 10 h of observations.

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Fig. 1 - A scheme of RAMHAND - Radio Moon Hadron and Neutrino Detection
Neutrino detectors

- Homestake Gold Mine (Solar neutrinos) \( V = 400 \text{ m}^3 \)
- Existing Extensive Air-shower Arrays. \( A = 10-20 \text{ km}^2 \)
- Proposed Extensive Air-shower Arrays. (Fly’s Eye, EAS-1000, etc.) \( A = 100-1000 \text{ km}^2 \)
- Underground Water Detectors. (Kamiokande, etc.) \( V = 10^3 - 10^4 \text{ m}^3 \)
- Optical Deep Water Muon and NeutrinoDetector (DUMAND) \( V = 10^7 \text{ m}^3 \)
- Antarctic Ice - radio antennas in or on ice \( V = 10^9 - 10^{10} \text{ m}^3 \)
- Moon

\[
\begin{align*}
A &= 10^7 \text{ km}^2 \\
V &= 10^{14} \text{ m}^3
\end{align*}
\]

*Fly’s Eye has seen $< 1$/yr events for $10^{20}\text{eV}$ hadrons*
Objective:
Test the hypothesis that $E > 10^{20}$ eV neutrino interaction cascades in the near 10 m of the Moon produce \textit{a} of radio Cerenkov emission.

Strategy:
Look for short, dispersed radio pulses.
Use existing equipment where possible.
Observational Parameters:

Telescope:  Parkes 61-m telescope, New South Wales, Australia

Time:  Full Moon to avoid daytime terrestrial interference, 40 hr over 3 days, 17-19 Jan 1995.

Receiver:  SSB, L Band (1.2 - 1.9 GHz)

Frequency:  1.25 MHz (± 250 MHz)

Bandwidth:  475 MHz to get 2-ns time resolution

Beamwidth:  13 arc min
(Moon ~ 30 arc min, hence reduced sensitivity at Moon's limb.)
Sensitivity:

System Noise: 450 Jy (1 Jy = 10^{-26} W/m^2/Hz)

Expected Flux: 1200 Jy for $E_\nu = 10^{20}$ eV neutrino event.

Trigger Detectors:

Square law (power) detectors

Two 100-MHz bands, 100 MHz apart.

Coincidence of two pulses (duration 7.5 ns $\leq t \leq 20$ ns) required, with 10 ns delay of higher frequency channel.
Sampling:
Two circular polarizations

Total Bandwidth: $2 \times 500 \text{ MHz}$

Quadrature Sampling:
2 ns/sample, 8 bits/sample
500 samples/event (1 µs per event)
(250 samples before trigger,
 250 samples after trigger.)
Trigger Point

\[ \text{Jan-95} \quad 16:27:49 \]

Detected Signal 1300-1400 MHz

Detected Signal 1500-1600 MHz

- Edge SMART (GLITCH)
- SET-UP SMART TRIGGER
- trigger on 1 2 3 4 Ext Ext:0 DALLON
- for pattern Absent

width < 20.0 ns OFF
& width > 7.5 ns OFF

500 NS/s

Present 1H*2H
7.5 ns < pw < 20.0 ns

NORMAL
Flux (Janskys)

Counts per second

$T_{\nu} = 10^{19}$ eV

$E_{\nu} = 10^{20}$ eV

Expected event rate

two channels with delay

one channel

Standard deviations above zero detector power

False alarm rates
Duration of dispersed impulse:

\[ \tau_d = 0.012 \Delta \nu \text{ STEC } \nu^{-3} \]

\[ \Delta \nu = \text{Bandwidth (} 500 \times 10^6 \text{ Hz)} \]

\[ \nu = \text{Center Frequency (} 1425 \times 10^6 \text{ Hz)} \]

\[ \text{STEC} = \text{Slant Columnar Electron Content} \]

\[ = \text{Typically } 5 \times 10^{12} \text{ el/cm}^2 \text{ (night)} \]

\[ = 15 - 25 \times 10^{12} \text{ el/cm}^2 \text{ (day)} \]

\[ \tau_d \approx 20 \text{ ns (night)} \]

\[ \approx 50 - 150 \text{ ns (day)} \]

Dedispersion processing gain:

\[ g_d \equiv \frac{\text{de-dispersed pulse amplitude}}{\text{dispersed pulse amplitude}} \]

\[ \approx \tau_d \Delta \nu \]

\[ \approx 10 \text{ (night)} \]

\[ \approx 25 - 75 \text{ (day)} \]
Total Electron Content (e/cm²)

Time (microseconds)

Freq: 1425.000 (1175.000–1675.000) MHz
Sample Rate: 500.0 MHz. ntb: 512 nsb: 512
Detection Criteria

An event must meet one of the following criteria:

Must arrive at the trigger time.

Must appear in circular polarization channels.

Dedispersion reconstruction must produce an impulse with the dispersion value.
Moon
File: LL950117.0191
Freq: 1425.000 (1175.000–1675.000) MHz
Sample Rate: 500.0 MHz. ntb: 512 nsb: 512
Strategy, phase 2:

- Anti-coincidence on terrestrial interference.

- Use full 500 MHz
  (2 × 5 channels × 100 MHz) for incoherent dedispersion for trigger generation.

- Consider using 1400 MHz and 600 or 400 MHz. Dispersion delays 200–400 ns.

- Use spatial coincidence: two antennas with trigger communication.

- Match filter to expected waveform.
Conclusions

If the flux of $10^{20}$-eV neutrinos was as high as predicted, we should have seen 20–25 events.

Therefore we can set some upper limits:
$E_\nu \leq 0.7 \times 10^{20} \text{ eV}$

or the flux of $10^{20}$-eV neutrinos is at least an order of magnitude less than the predictions.

Larger telescope??

Areceibo’s 1.5-arcmin beam at $\lambda 21$ cm $\Rightarrow$ 1 event/30 hours
• Mark Lotter, Scientific Devices, Sydney, Australia, for loan of LeCroy 9354L oscilloscope.

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• Australia Telescope National Facility for sabbatical year support.

• The Parkes Radio Telescope is operated as part of the ATNF, a division of CSIRO.

• Project Phoenix of SETI Institute for use of the wideband receiver.

• Jiping Wu, Australian Ionospheric Prediction Service for STEC predictions.