The MIDAS Experiment: A New Technique for the Detection of Extensive Air Showers

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Microwave Detection of Air Showers

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Molecular Bremsstrahlung Emission

- EAS particles dissipate energy through ionization
- Produces plasma with $T_e \sim 10^4 - 10^5$ K
- Free electrons produce Bremsstrahlung emission in microwave regime from interaction with neutral air molecules
- Emission is unpolarized and isotropic

Potential exists for an FD-like detection technique capable of measuring the shower’s longitudinal development with nearly 100% duty cycle, limited atmospheric effects and low cost
Plasma density determines level of signal coherence

Fully coherent plasma: $P_{\text{tot}} = (N_e)^2 \times P_1$

Incoherent plasma: $P_{\text{tot}} = N_e \times P_1$

Beam tests results suggest coherent emission

However, due to large physical extent of shower plasma, EAS emission has an unknown level of coherence

G-H fits suggest the plasma scaling in the beam may not match EAS scaling

**MIDAS Prototype system**

\[ I_{0,sh} = 2.8 \times 10^{-16} \text{ W/m}^2/\text{Hz} \]
\[ E_0 = 3.4 \times 10^{17} \text{ eV} \]

@ 10 Km

\[ I = 2.8 \times 10^{-24} \text{ W/m}^2/\text{Hz} \]

Detection Threshold

\[ E_{\text{quad}} \sim 2 \times 10^{18} \text{ eV} \]
\[ E_{\text{lin}} \sim 10^{19} \text{ eV} \]

\[ \Delta I = \frac{k_B T_{\text{sys}}}{A_{\text{eff}} \sqrt{\Delta t \Delta f}} \]

\[ \begin{align*}
T_{\text{sys}} &= 100K \\
A_{\text{eff}} &= 10 \text{ m}^2 \\
\Delta t &= 100\text{ns} \\
\Delta f &= 1\text{GHz} \\
\end{align*} \]

\[ \Delta I = 1.6 \times 10^{-23} \text{ W/m}^2/\text{Hz} \]


<table>
<thead>
<tr>
<th>Large collection area</th>
<th>(~ 10 \text{ m}^2)</th>
<th>Use 4.5m dish already installed at U of C</th>
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<tr>
<td>Pixel field of view</td>
<td>(~1.5^\circ \sim \lambda/D)</td>
<td>Extended C-Band</td>
</tr>
<tr>
<td>Total field of view</td>
<td>(~15^\circ)</td>
<td>(~50) channels</td>
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<td>Time domain</td>
<td>100 ns resolution</td>
<td>Fast power detector</td>
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<td>Trigger for fast transient events</td>
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<td>Flash ADC acquisition with FPGA trigger</td>
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4.5 Meter Prime Focus Parabolic Reflector

90° Alt
100° Az
Camera

- 53 Commercial Extended C-Band Feeds
- Feed Horn + LNA + Down Converter (3.4-4.2 GHz to ~ 1GHz)
- 13K noise floor, 70 dB amplification
- 20° x 10° FOV
\[ n_{\text{adc}} = n_0 - k \ P_{\text{dB}} = n_0 - k \ \log(P_{\text{lin}}) \]
Trigger

FLT: 1 μs running sum, over threshold trigger
Each feed has self-regulated threshold to hold rate at 100 Hz

SLT: require 3 FLT within 20 μs for specified pixel patterns, noise rate 0.2 Hz

High-Level Veto: Inhibits trigger when SLT exceeds preset value. Filters periods of noise bursts improving livetime.

Clean periods (1s latency) between 95% and 50% of the total DAQ time (typical, we had days below 10%)
Calibration

Log periodic antenna is directed at feeds sending 5 μs pulses

Allows for relative calibration, test of synchronization, and system timing

Soon we will deploy a low cost patch antenna permanently on the telescope for continued long term calibrations
Astrophysical sources provide a calibration of system temperature.

Sun

\[ \Delta n_{adc} = 10 k \log\left(1 + \frac{P_{sun}}{P_{sys}}\right) \]

\[ \Delta n_{adc} \approx 2500 \]

Nobeyama Radio Observatory

\[ F_{sun} = 88 \times 10^{-22} W/m^2/Hz \]

\[ F_{sys} \approx 3.3 \times 10^{-22} W/m^2/Hz \]

\[ F_{sys} = \frac{2k_B T_{sys}}{A_{eff}} \]

\[ T_{sys} = 120K \]

also have observed moon (sun/100) and crab nebula (sun/1000)
MC Simulated Events

![Image of MC Simulated Events](image-url)

- **Pixel Traces**
- **Trigger Traces**

**Event 7**

- **First**
- **Last**

**E = 1.15 \times 10^{16} \text{ eV} - \Theta = 41.4\degree - R_p = 15.2 \text{ km}**
Event (thermal noise)
Noise Event

noise is likely due to aviation interference
Baseline for two channels over ~40 days of data taking

Baseline varies less than 1 dB over the period

Continued calibration with patch antenna will help explain the periodic fluctuations
Candidate Event
MC Event
Conclusions

• Developed a self-triggering FD analog to explore the molecular bremsstrahlung emission in EAS

• Improvements currently underway:
  • Modifying trigger to better match patterns seen in MC
  • Addition of 1 GHz band-pass filter to deal with noise bursts
  • Installation of patch antenna for continued calibration

• Plan to install the set-up in Argentina at the Pierre Auger Observatory to look for coincident detections
Extra Slides
Installed a 1GHz band-pass filter, greatly reduced power in bursting lines.

Should eliminate periods of deadtime due to noise bursts and make the system more stable.
Trigger Improvements

Peak at 4 pixels triggered, 3 pixel events have low SNR

4-Pixel Patterns across the whole camera

Reduces noise events significantly
Better match for MC data