EAS RADI O DETECTION
RECENT RESULTS & OUTLOOK
J. Rosner  RADHEP 2000  UCLA 11/17/00

Collaborators: K. Green, D. Suprun, K. Travis, J. Wilkerson (=> NIM, in preparation)
Help from M. Cassidy, B. Fick, L. Fortson, J. Fowler, P. Gall, B. Newport, R. Ong, S. Oser-

Radio pulse can add shower information
Prototype for possible Auger add-on

Open questions: height, p/Fe
Pulse generation mechanisms
Some early observations
Installation at CASA (Dugway, Utah)
Interference Sources
Sensitivity
Considerations for Auger

Only upper limits on a signal at present - still processing data and establishing calibrations
After 14 visits CASA site is now closed; Auger site for future work
MOTIVATION + HISTORY
Auxiliary information on shower:
Height
Primary composition
\[ E = 1.5 \times 10^{-26} \, \text{V/m} \, \text{(time in s)} \]
Apparent source direction
\[ \nu_{\text{max}} (\text{MHz}) \sim 10^6 / R^2 (\text{cm}) \]
for coherent pulse

Mechanisms:
1. Charge excess
   \[ \Rightarrow \]
2. $U \times B_0$, charge separation
3. Atmospheric discharge (R Wilson)

Early measurements: Jodrell Bank
Haverah Park 55 MHz
BasJE (Chacaltaya)
Gran Sasso Few MHz, vert.
Akeno pol.
Yakutsk

No unanimity on pulse size, $\nu$
Try to detect at few $\mu$V m$^{-1}$ MHz$^{-1}$
PREVIOUS OBSERVATIONS

Haverah Park (’60s–’70s)

\[ P = \frac{\varepsilon_0}{10^{17}} \text{ eV shower} \]

\[ \varepsilon_0 = \frac{20}{10^{17}} \frac{\varepsilon_p}{\sin \alpha \cos \theta} \frac{R}{R_0} \text{ \( \mu \text{V m}^{-1} \text{ MHz}^{-1} \)} \]

angle between axis k and Earth \( \leq 35^\circ \)

BASJE (Chacaltaya)
Yakutsk 1991 ICRC (Dublin)
Gran Sasso (Few MHz, vert. pol.)
Akeno
Gauhati Univ. (110 MHz, HF, LF)
SENSITIVITY RECALIBRATION

Initial Haverah Park claim: $s = 20$
Re-evaluated: $s = 1.6 \ (0.6 \mu \text{V m}^{-1} \text{ MHz}^{-1} \ \text{at 100 m})$
Atrashkevich+: $s = 9.2 \ (3.4 \mu \text{V m}^{-1} \text{ MHz}^{-1})$

Compare with Jodrell Bank: (T. Weekes 11/16/00)
Power $\sim 4 \times$ galactic noise

$\mathcal{E}_\nu^{\text{Gal}} = 1-2 \mu \text{V m}^{-1} \text{ MHz}^{-1}$

$\Rightarrow$ signal $\mathcal{E}_\nu = 2-4 \mu \text{V m}^{-1} \text{ MHz}^{-1}$ @ $5 \times 10^{16} \text{eV}$

Cross-check: signal $10^{-12} \text{W} = \frac{V_{\text{pkz}}^2}{2R}$

For $R = 50 \Omega$ $V_{\text{pkz}} = 10 \mu \text{V}$

$V = 30 \ G^{\frac{1}{2}} \ \frac{\mathcal{E}_0}{\nu} \ \mathcal{E}_\nu \ \left[H. \ R. \ Allan\right]$

Antenna gain (take = 5)

Take $2.75/44$

$2.4 \mu \text{V m}^{-1} \text{ MHz}^{-1}$

at $5 \times 10^{16} \text{eV}$

Implies $\sim 5 \mu \text{V m}^{-1} \text{ MHz}^{-1}$ at $10^{17} \text{eV}$,
favoring Atrashkevich+
**GAUHATI UNIVERSITY RESULTS**

1970-2000

- : Ple. detector
- : Radio detector

<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>$E_0^0 (\mu V m^{-1} MHz)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>$49.4 \pm 18.9$</td>
</tr>
<tr>
<td>9</td>
<td>$138 \pm 39$</td>
</tr>
<tr>
<td>44</td>
<td>-</td>
</tr>
<tr>
<td>60</td>
<td>-</td>
</tr>
<tr>
<td>80</td>
<td>-</td>
</tr>
<tr>
<td>110</td>
<td>$1.96 \pm 0.28$</td>
</tr>
<tr>
<td>220</td>
<td>$0.40 \pm 0.12$</td>
</tr>
</tbody>
</table>

* Transition radiation from particles hitting the ground?

VLF (< 500 kHz) pulses also claimed at AKENO (Suga +)
PULSE CHARACTERISTICS

Time and frequency profile:

Intensity $\propto E_p$ likely
High-freq. components die off far from shower axis
Heavy primaries?
Higher showers
Higher freqs.? (Aspect ratio)
Higher intensity for given $E_p$?

Polarization
Charge excess $\Rightarrow (\text{looking down axis})$
Charge separation: $\mathbf{\Omega} \times \mathbf{B}$ horizontal (or vertical if large electrostatic $\mathbf{E}$)
RF BACKGROUND

Atmospherics
- Lightning, other discharges
- Irreproducible pulses?

Man-made sources
- Radio, TV, satellites
- Broad-band (e.g., ignition)
- Electronics of the expt.

Galactic noise
Meteor scatter

Receiver noise

Ionosphere
- Night
- Day

City
Receiver
- (300 K)

Galactic

Note day/night difference below 30 MHz

\[ \varepsilon_v (\mu V \text{ m}^{-1} \text{MHz}^{-1}) \]

\[ \nu (\text{MHz}) \]
THE CASA/MIA SITE
80 miles SW of Salt Lake City

I.D.  

WYO.

I-80

CASAS/MIA

Salt Lake City

Provo

I-15

Delta

Proposed Auger Array

(1350 sq. mi.)
EXPECTED RATES AT CASA

Trigger: few x 10^{-4} eV  20 Hz

\geq 10^{15} eV  \sim 1 \text{ Hz}

\geq 10^{16} eV  \sim 1/2 \text{ min}

\geq 10^{17} eV  \sim 1/4 \text{ hr}

\geq 10^{18} eV  \sim 2/\text{mo}...

Useful level for signal above galactic noise level 15m spacing

Array sketch: 2933 x 33 boxes

Radio

Fly's Eye

RF noise surveys  \sim 1/2 \text{ km}

16 \mu patches

(MIA) 0: in trigger

Access roads
CORE LOCATIONS GIVING TRIGGERS
1702 showers
Solid lines: boundaries for sensitivity calculation

Core locations

Antenna

Trigger on coincident pulses from 7 of 8 outer muon patches
THE RADIO SHACK AT CASA

MASH trailer

½ km → Dorne and Margolin log periodic antenna ($60 from Fair Radio) mounted on top of mobile search-light tower

MiniCircuits ZFL-500LN preamp: 26 dB gain

Store pulse digitally on a fast scope (Tek 540B)

Time vs. frequency: J. Wilkerson, U. of Wash.
UNPROCESSED DATA
FILTER OUT $\leq 25$ MHz SIGNALS FROM TV, FM

Event 22717/2938437480, no processing
26 dB of preamplification
23-250 MHz bandpass

25-80 MHz feature (broad-band)
- Don't yet know if magnitude is consistent with galactic noise
RF BACKGROUND, CHICAGO
Log periodic antenna on roof of
Enrico Fermi Institute

Log periodic, E-W pol., aimed at zenith 11/14/00

10 dB of attenuation
23-250 MHz bandpass
~40 dB higher than at Dugway
FOURIER COMPONENTS
(LARGE MAGNITUDES
RENORMALIZED)

Renormalized spectrum of signals at CASA site (broad-band)

Phases kept the same
SIMULATED SIGNAL
and frequency spectrum
used HP arbitrary waveform
generator to produce actual pulse

Analytic form

Calculated
-20 ft @ 12.8 M/s
Based on

Simulated pulse after broad-band filtering

Generated by ampl. wavetorm gen.

25 MHz ≤ f ≤ 250 MHz

Broad-band filter

Simulated signal after
Effect on transient detection
WAVELET DENOISING

Denoised with Symmlet 10, L=4

Simulated signal at t=0 after Fourier shrinkage
SIMULATED SIGNAL AFTER NARROW-BAND FILTERING
25 MHz \leq f \leq 37 MHz
Generated by arb. waveform gen.

Simulated pulse after narrow-band filtering

Note longer ringing

Based on
-20 \leq t \leq 12.8 ms

Find less sensitivity to simulated signal in narrow-band data
TIME VS. AMPLITUDE OF TRANSIENTS
CASA HV on all stations
Fourier coefficient shrinkage and wavelet denoising applied to data

Time vs. amplitude, 1/98 transients, CASA HV on

Amplitude of maximum

Time relative to trigger (microseconds)

Number of entries (833 total)

Time of maximum transient

↑

Accumulation of transients in range (-5.5 to -7) μs

CASA-related
CASA HV DISABLED

Phototubes not producing signals
No digitization on CASA boards
No pulses sent to central trailer

No accumulation in $-7 \leq t \leq -5.5 \mu s$

Observed transients were apparently due to signals produced by CASA itself.

<table>
<thead>
<tr>
<th>Total sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E-W$ Pol.)</td>
</tr>
<tr>
<td>$-4 \times \text{thi}$</td>
</tr>
</tbody>
</table>
CASA HV PARTIALLY DISABLED
No HV on boxes closer than 100 m from antenna

Time vs. amplitude, 1/98 transients, CASA HV on > 100 m from ant.

No significant accumulation
Transients appear to be due to nearby CASA boxes
SENSITIVITY ESTIMATE

Best denoising so far:

\[ V_{\text{ant}} \approx 260 \mu V \text{ visible above noise} \]

\[ V_{\text{ant}} = 30 G \frac{S_\nu}{\nu} \epsilon_\nu \]

\[ S_\nu = 30 \text{ MHz} \]

\[ \frac{\nu}{\nu} = 39 \text{ MHz} \]

\[ \Rightarrow \epsilon_\nu \approx 5 \mu V \text{ m}^{-1} \text{ MHz}^{-1} \]

\[ G = 5 \text{current} \]

Pulses should be visible under study.

This would be given by a $10^{17}$ eV
Shower at 100 m impact parameter
under the most optimistic estimates

Problem: whole array should see $10^{17}$
eV showers only every few hours;
most are farther from ant. than 100 m

Triggers taken (broad-band, low-noise
data acquisition)

<table>
<thead>
<tr>
<th>Ant. pol.</th>
<th>CASA HV on</th>
<th>HV off</th>
<th>Partial HV</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-W</td>
<td>4503</td>
<td>857</td>
<td>1834</td>
<td>7194</td>
</tr>
<tr>
<td>N-S</td>
<td>677</td>
<td>641</td>
<td>366</td>
<td>1821</td>
</tr>
<tr>
<td>Total</td>
<td>5180</td>
<td>1498</td>
<td>2200</td>
<td>9015</td>
</tr>
</tbody>
</table>

Represented by $\approx 50$ hr. of data
UPPER LIMITS ON RATES
North-South (NS) and East-West (EW) antenna polarizations

\[ R^* (E_x > E_x^0) = \frac{0.788}{(E_x^0)^2} \]

\[ R^* (E_y > E_y^0) = \frac{0.966}{(E_y^0)^2} \]

Cf. Atrashkevich + S = 9.2
Interim conclusion: not competitive
Detect CASA-related RF transient
Monitored trigger requests from boxes: within \( \pm \frac{1}{2} \mu s \) of them
No signal yet from shower
Should precede CASA-related transient (at least by PMT delay)
Still exploring improved methods for removing constant RF Sigs.
Limited by 8-bit dynamic range of scope
Data taken with various configs.
of boxes near antenna disabled
May help to characterize CASA-related transient better
May investigate reflection of distant TV signals from shower ion trail
Channels 3, 6, 8, 12
AUGER CONSIDERATIONS

Receiving sites

- How far from axis for E \geq 10^{18}
- Dedicated DAQ system
- Replace scope and PC
- RF interference at site
- Survey desirable
- Switching power supplies?
- Prototype systems - study of compatibility?

Power budget

- Solar power at each Auger site: 10 W total budget
- Fast digitization & memory may be power-hungry

Cost

- Mainly in DAQ; front end is cheap. \leq 3K/station
SOUTHERN HEMISPHERE AUGER SITE
Malargüe, Argentina
3500 Stations
1.5 km spacing
Hexagonal lattice
60-100 evt./yr. above $10^{20}$ eV
STATION PLACEMENT
(ENGINEERING ARRAY)

Malargüe, Argentina
Southern Hemisphere Auger Site
N. Hemisphere Auger Site
Millard Co., Utah (S. of Delta)
CONCLUSIONS

No "golden signal" seen for RF transient associated with cosmic ray air showers.

May be able to set useful limits relevant to (some) previous claims.

Useful lessons learned if the technique is to be tried in conjunction with Auger.