EAS RADIO DETECTION
RECENT RESULTS & OUTLOOK

J. ROSNER RADHEP 2000 UCLA 11/17/00
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Help from M. Cassidy, B. Fick, L. Fortson, J. Fowler, R. Gall, B. Newport, R. Ong, S. Oser

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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

$\mathcal{E} = 1.5 \times 10^{-26} \ddot{\theta}$ V/m (time in s)

apparent source direction

$\nu_{max}(\text{MHz}) \sim 10^6 / R^2(\text{m})$ for coherent pulse

Mechanisms:

① Charge excess

⇒ ② $v \times B_{\oplus}$ charge separation

③ Atmospheric discharge (R Wilson)

Early measurements: Jodrell Bank

Haverah Park 55 MHz

BasJE (Chacaltaya) ״

Gran Sasso | Few MHz, vert. pol.

Akeno

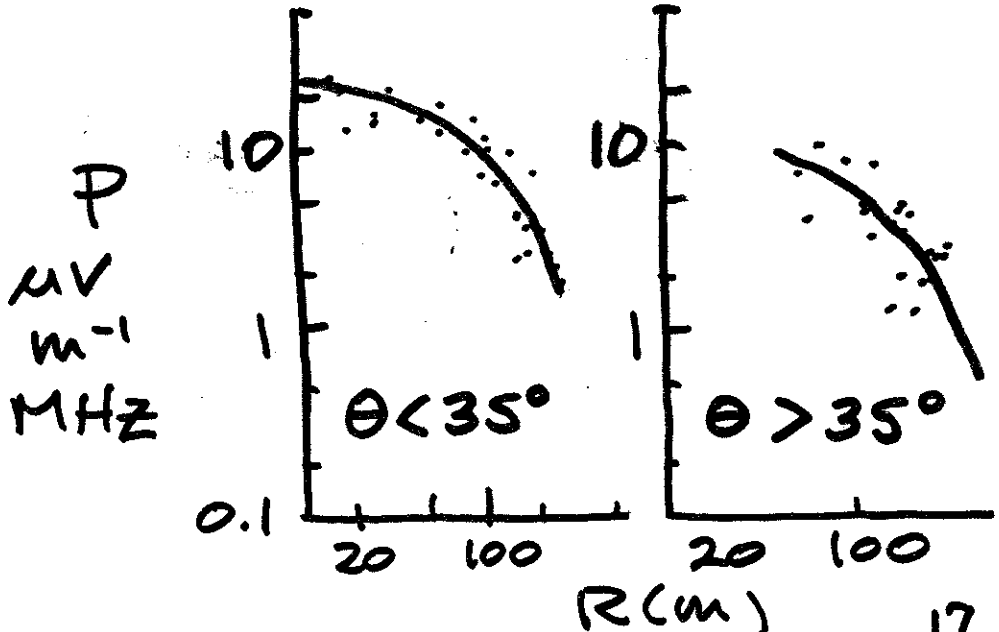
Yakutsk

No unanimity on pulse size, ν

Try to detect @ few $\mu V\, m^{-1}\, MHz^{-1}$

PREVIOUS OBSERVATIONS*†‡

Haverah Park ('60-s - '70s)



(*Some)

†No unanimity on optimum frequency, polarization

‡ EMP work relevant?

P: $\mathcal{E}_\nu$ normalized to 10^{17} eV shower

$$\mathcal{E}_\nu = (20) \frac{\mathcal{E}_p}{10^{17}\,\text{eV}} \sin\alpha \cos\theta \, e^{-R/R_0} \quad \mu\text{V m}^{-1}\,\text{MHz}^{-1}$$

"s" (20)

α: angle between axis & $\vec{B}_{Earth}$

θ: zenith angle

R_0: 110 m ±10 for ν = 55 MHz, $\theta < 35°$

BASJE (Chacaltaya)

YAKUTSK 1991 ICRC (Dublin)

Gran Sasso	Few MHz, vert. pol.	1993 ICRC (Calgary)
Akeno		
Gauhati Univ.	110 MHz, HF, LF	

SENSITIVITY RECALIBRATION

Initial Haverah Park claim: $s = 20$

Re-evaluated: $s = 1.6$ ($0.6\,\mu V\,m^{-1}\,MHz^{-1}$ at 100 m) ←

Atrashkevich +: $s = 9.2$ ($3.4\,\mu V\,m^{-1}\,MHz^{-1}$)

Compare with Jodrell Bank: (T. Weekes 11/16/00)

Power ~ 4 × galactic noise
↑
$\mathcal{E}_\nu^{Gal} \simeq 1\text{-}2\,\mu V\,m^{-1}\,MHz^{-1}$

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

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

For $R = 50\,\Omega$ $\boxed{V_{pk} = 10\,\mu V}$

$$\boxed{V = 30\, G^{1/2}\, \frac{\delta\nu}{\nu}\, \mathcal{E}_\nu}$$ [H.R. Allan]

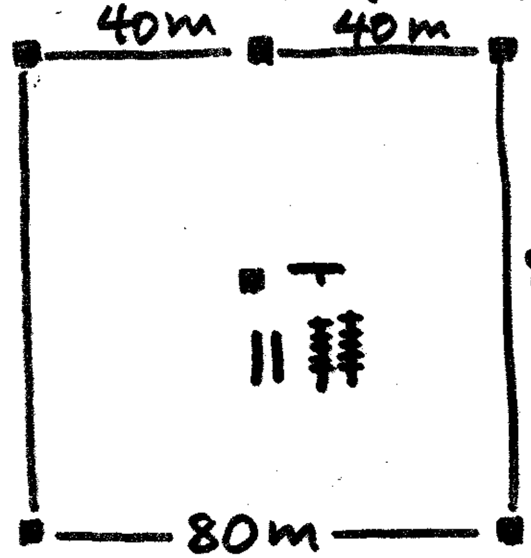
- G: Antenna gain (take = 5)
- $\frac{\delta\nu}{\nu}$: Take 2.75/44
- $\mathcal{E}_\nu$ ⇒ $2.4\,\mu V\,m^{-1}\,MHz^{-1}$ at 5×10^{16} eV

⇑

Implies ~$5\,\mu V\,m^{-1}\,MHz^{-1}$ at 10^{17} eV, favoring Atrashkevich +

GAUHATI UNIVERSITY RESULTS

1970-2000



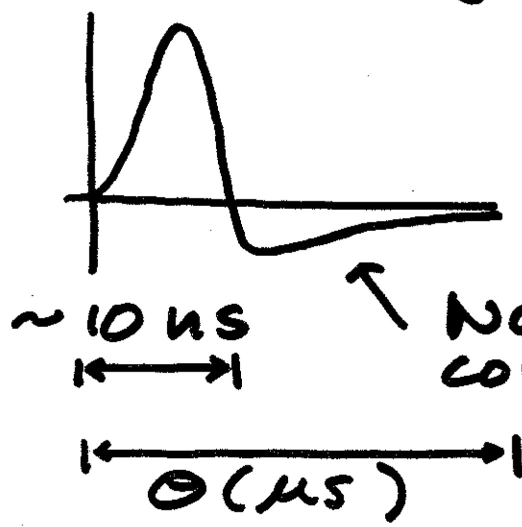
Freq. (MHZ)	$\mathcal{E}_\nu^0$ (μV m^{-1} MHz) Datta (1987)	Barthakur (1978)
* 2	494 ± 189	-
9	138 ± 39	-
44	-	3.7 ± 0.2
60	-	3.4 ± 0.2
80	-	2.2
110	1.96 ± 0.28	-
220	0.40 ± 0.12	-

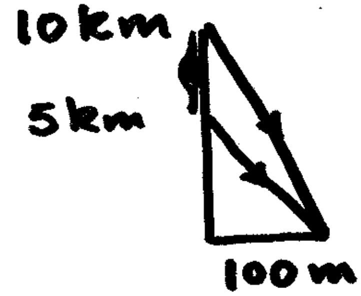
* Transition radiation from particles hitting the ground?

VLF (< 500 kHZ) pulses also claimed at AKENO (Suga +)

PULSE CHARACTERISTICS

Time and frequency profile:





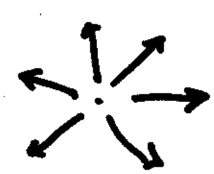
Intensity $\mathcal{E} \sim E_p$ likely

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 ⇒  (looking down axis)

Charge separation: $\underline{v} \times \underline{B}$ horiz.

(or vert. if large electrostatic $\underline{\mathcal{E}}$)

RF BACKGROUNDS

Atmospherics
- Lightning, other discharges
- Irreproducible pulses?

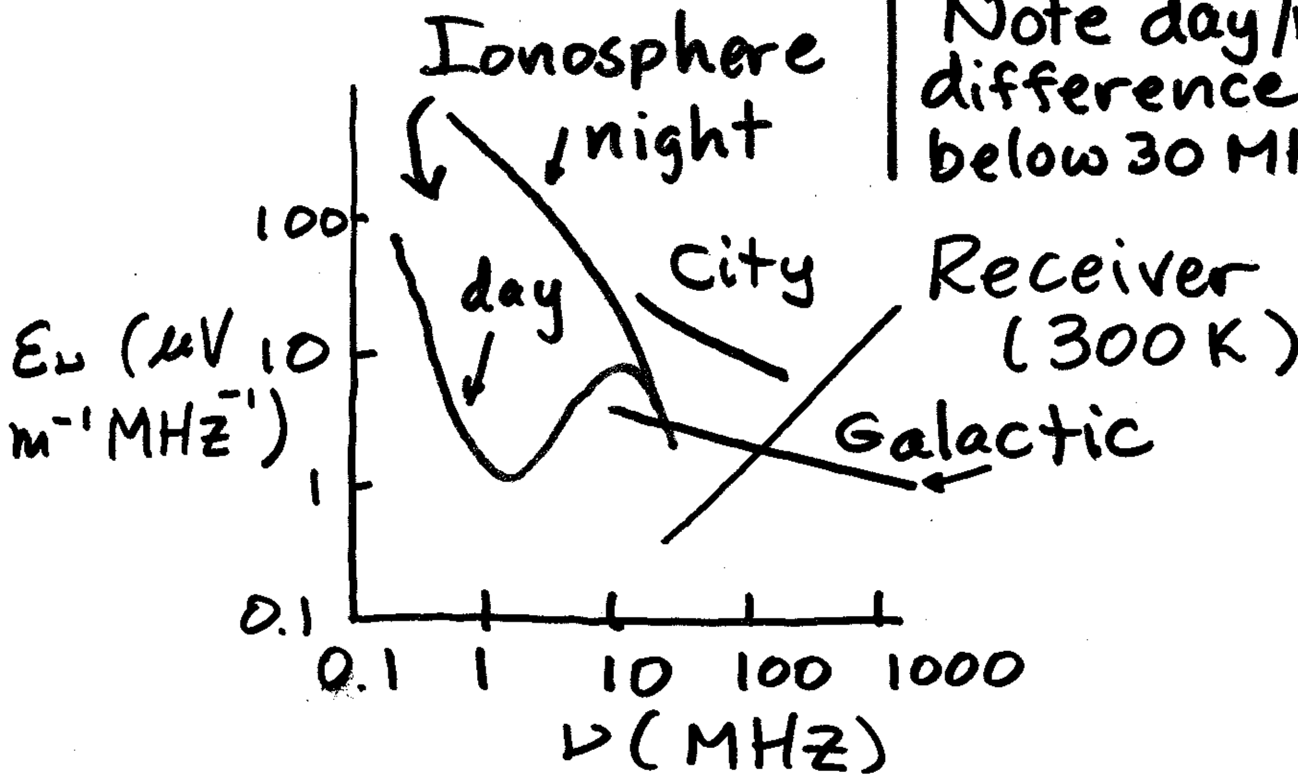
Man-made sources
- Radio, TV, satellites
- Broad-band (e.g. ignition)
- Electronics of the expt.

Galactic noise

Receiver noise

Meteor scatter

Note day/night difference below 30 MHZ



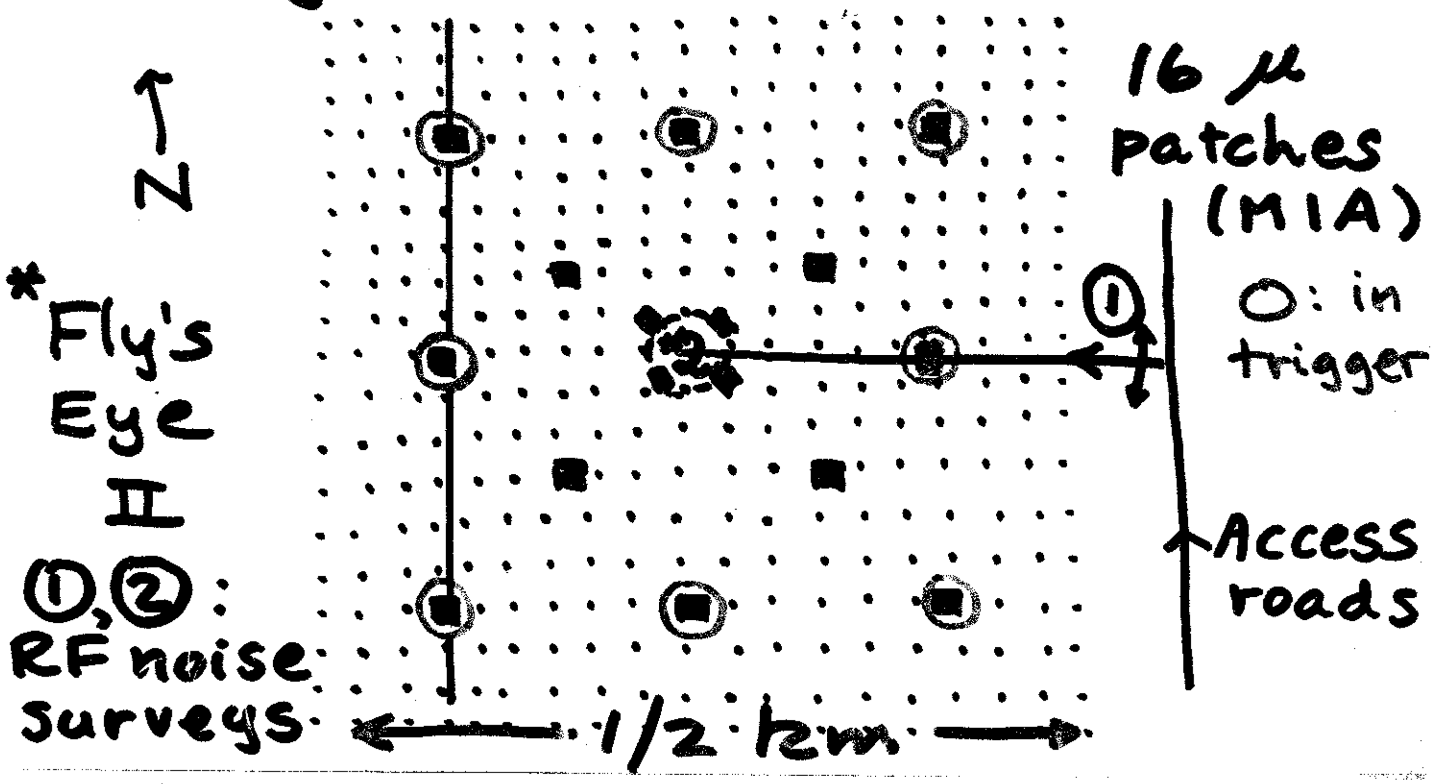
THE CASA/MIA SITE
80 miles SW of Salt Lake City

EXPECTED RATES AT CASA

Trigger: few $\times 10^{14}$ eV	20 HZ
$\geq 10^{15}$ eV	~ 1 HZ
$\geq 10^{16}$ eV	~ 1/2 min
$\gtrsim 10^{17}$ eV	~ 1/4 hr
$\gtrsim 10^{18}$ eV	~ 2/mo. . .

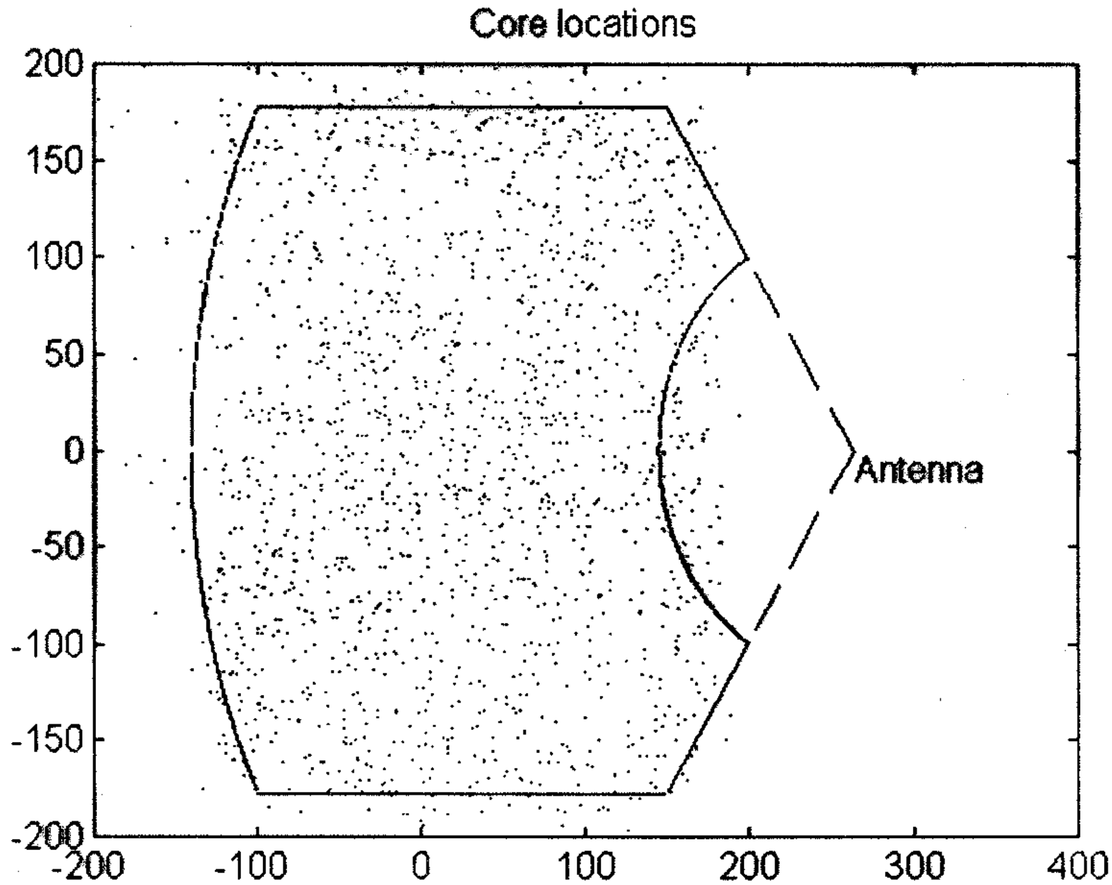
Useful level for radio signal above galactic noise level (→ $\gtrsim 10^{17}$ eV)

Array sketch: 29 ~~33~~ × 33 boxes ← 15m spacing



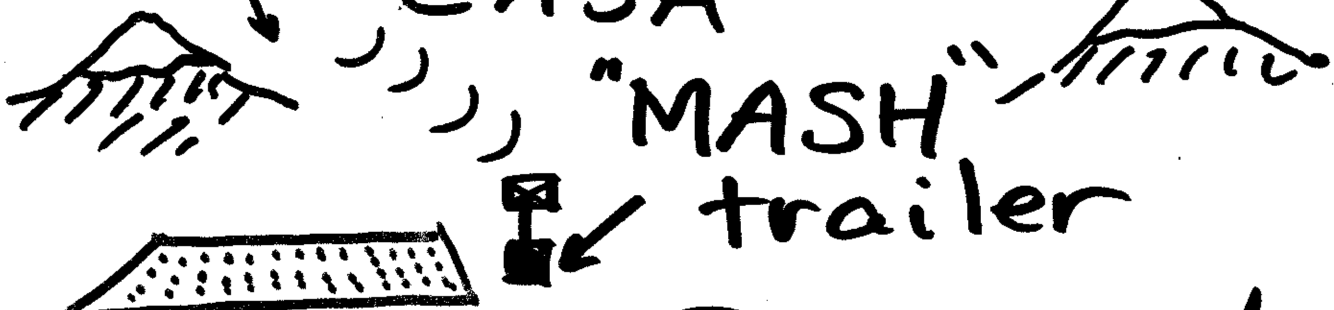
CORE LOCATIONS GIVING TRIGGERS
1702 showers

Solid lines: boundaries for sensitivity calculation



Trigger on coincident pulses from 7 of 8 outer muon patches

THE RADIO SHACK AT CASA "MASH"



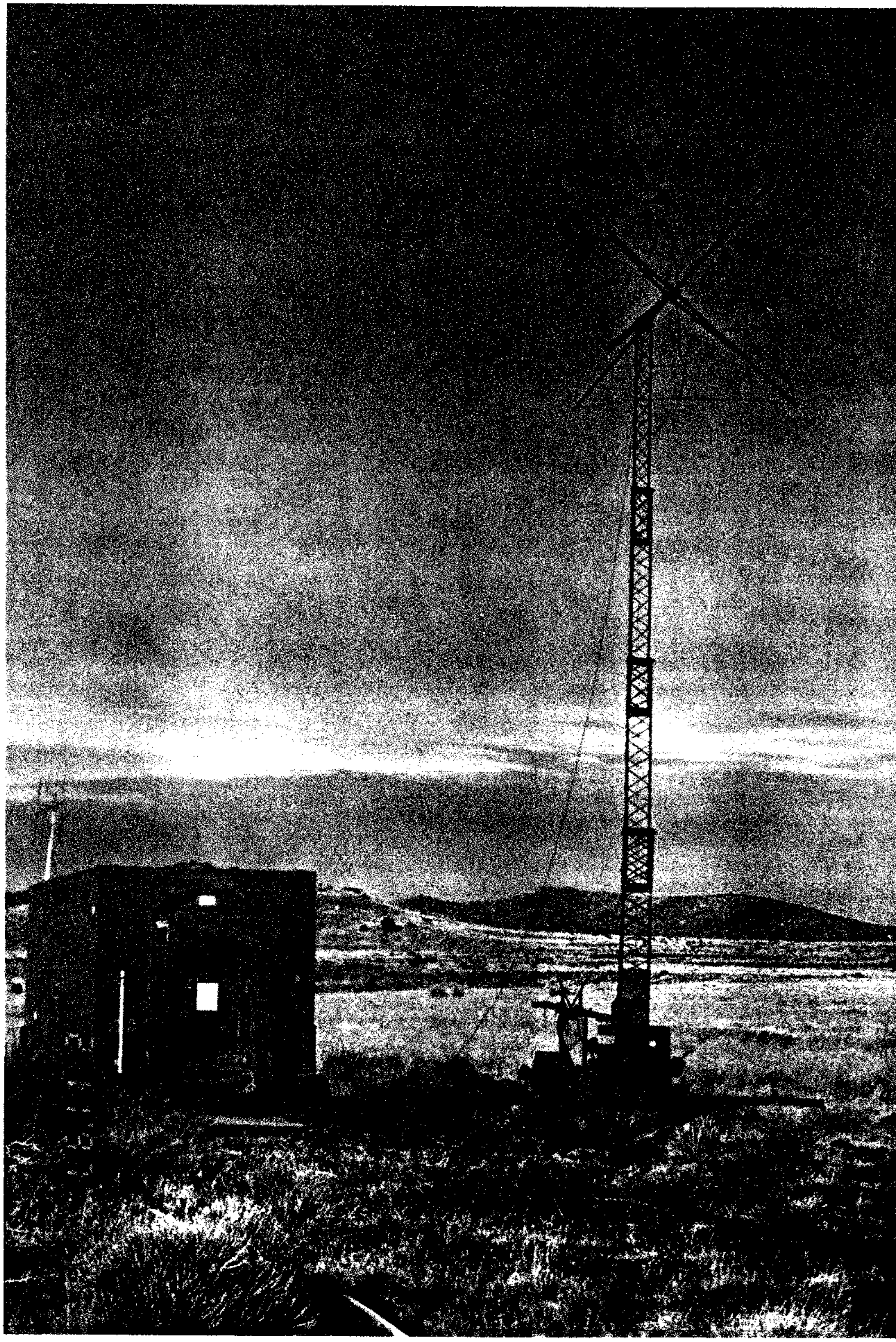
← 1/2 km →

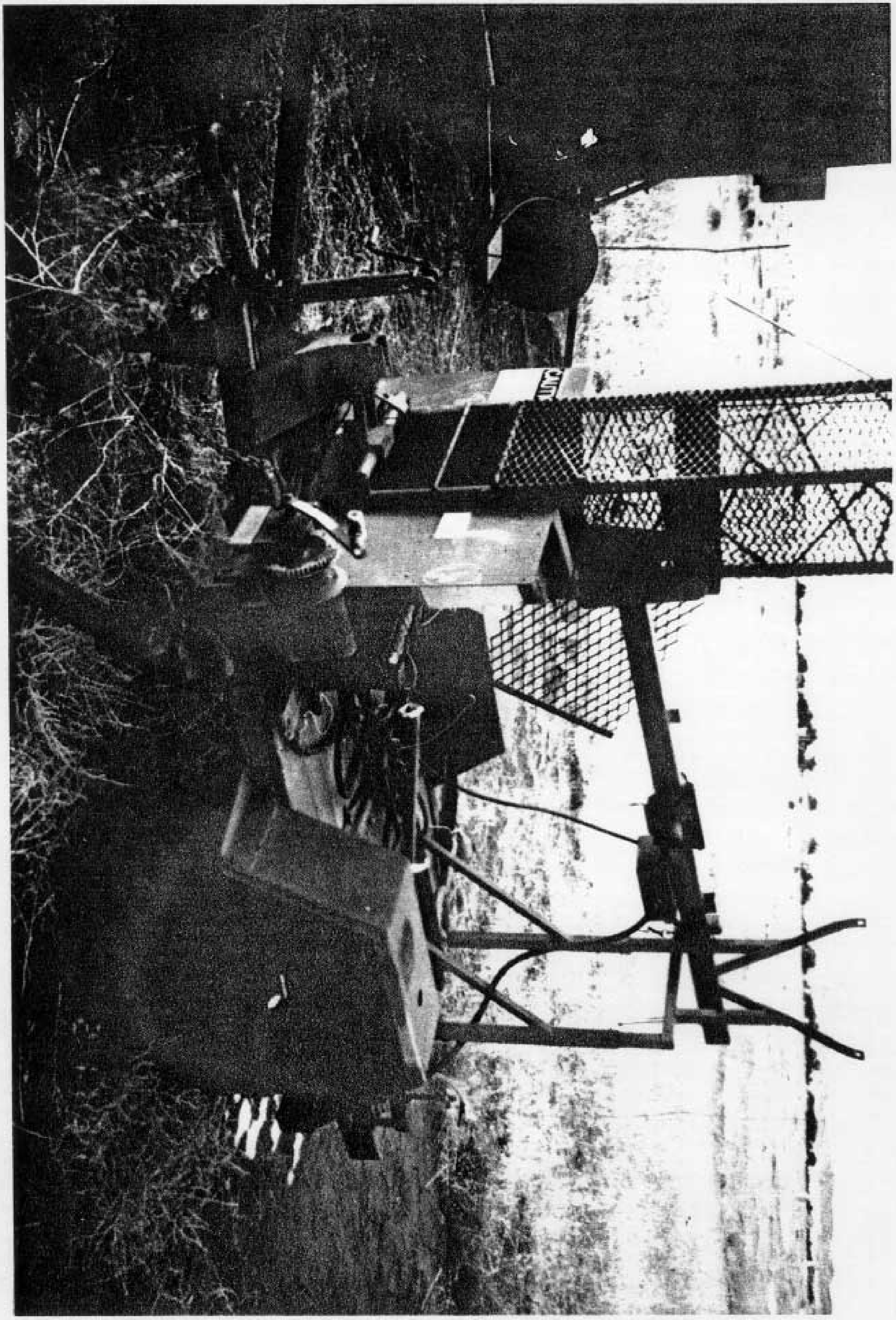
Dorne and Margolin log periodic antenna ($60 from Fair Radio) mounted on top of mobile search-light tower

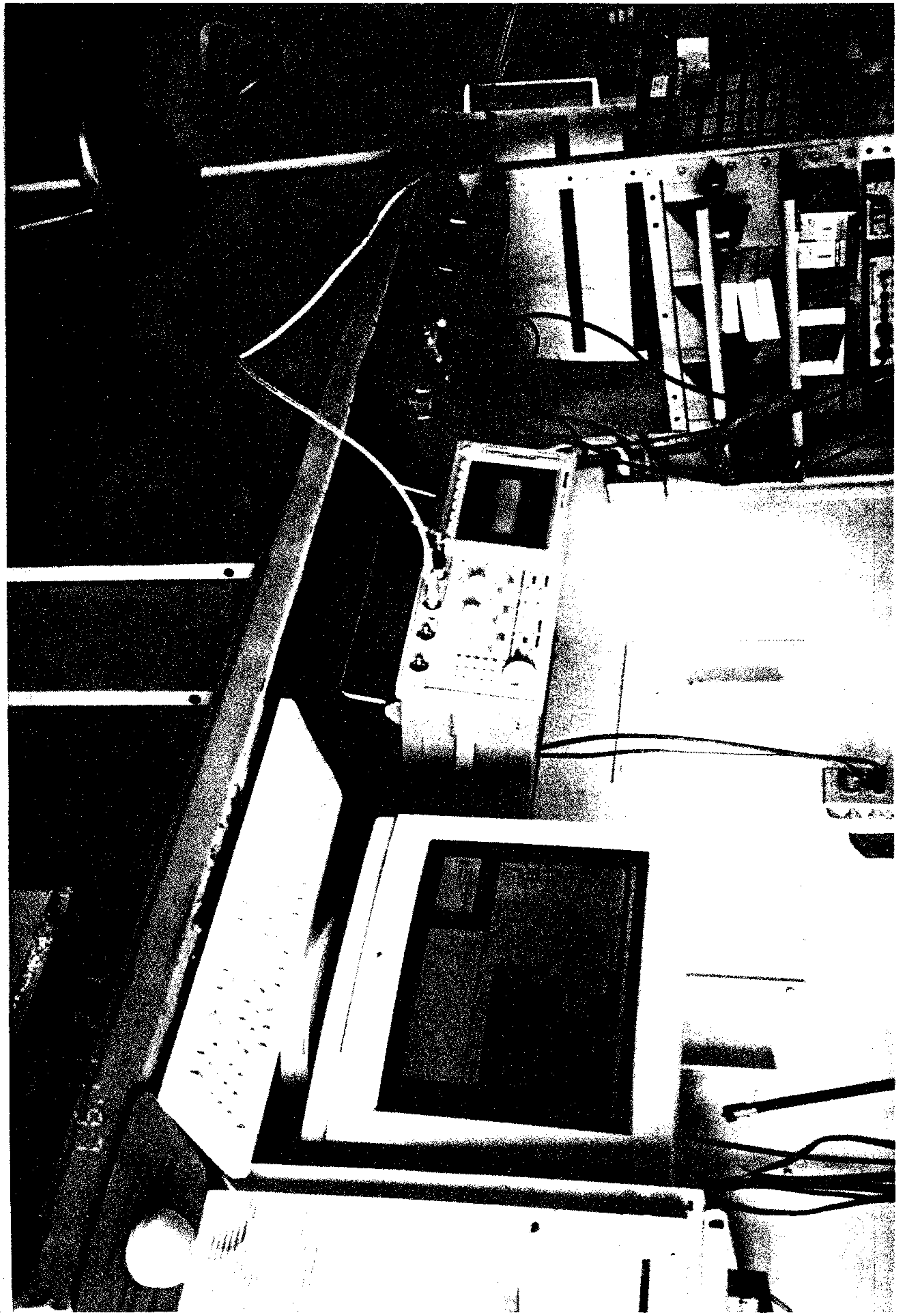
MiniCircuits ZFL-500LN preamp: 26 dB gain

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

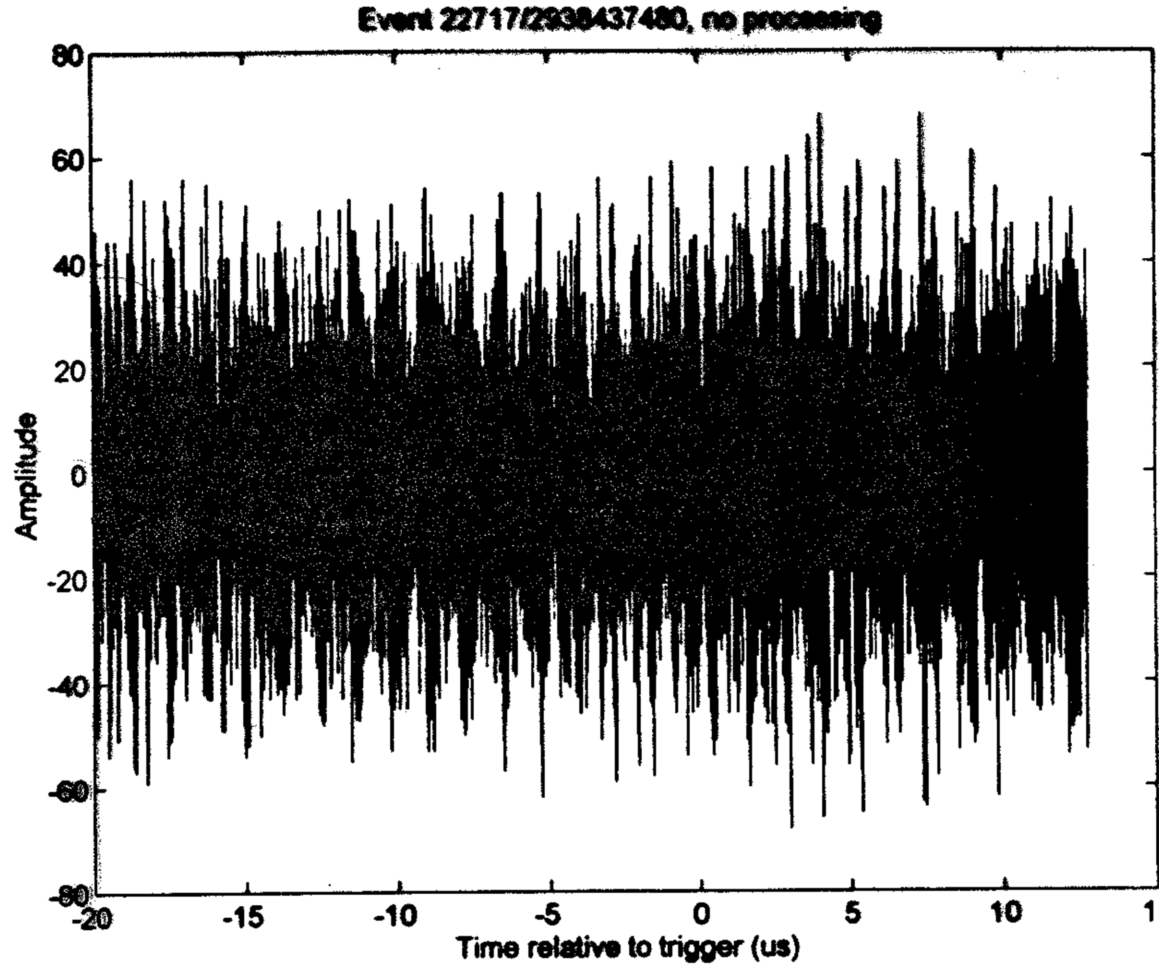
Time vs. frequency: J. Wilkerson, U. of Wash.





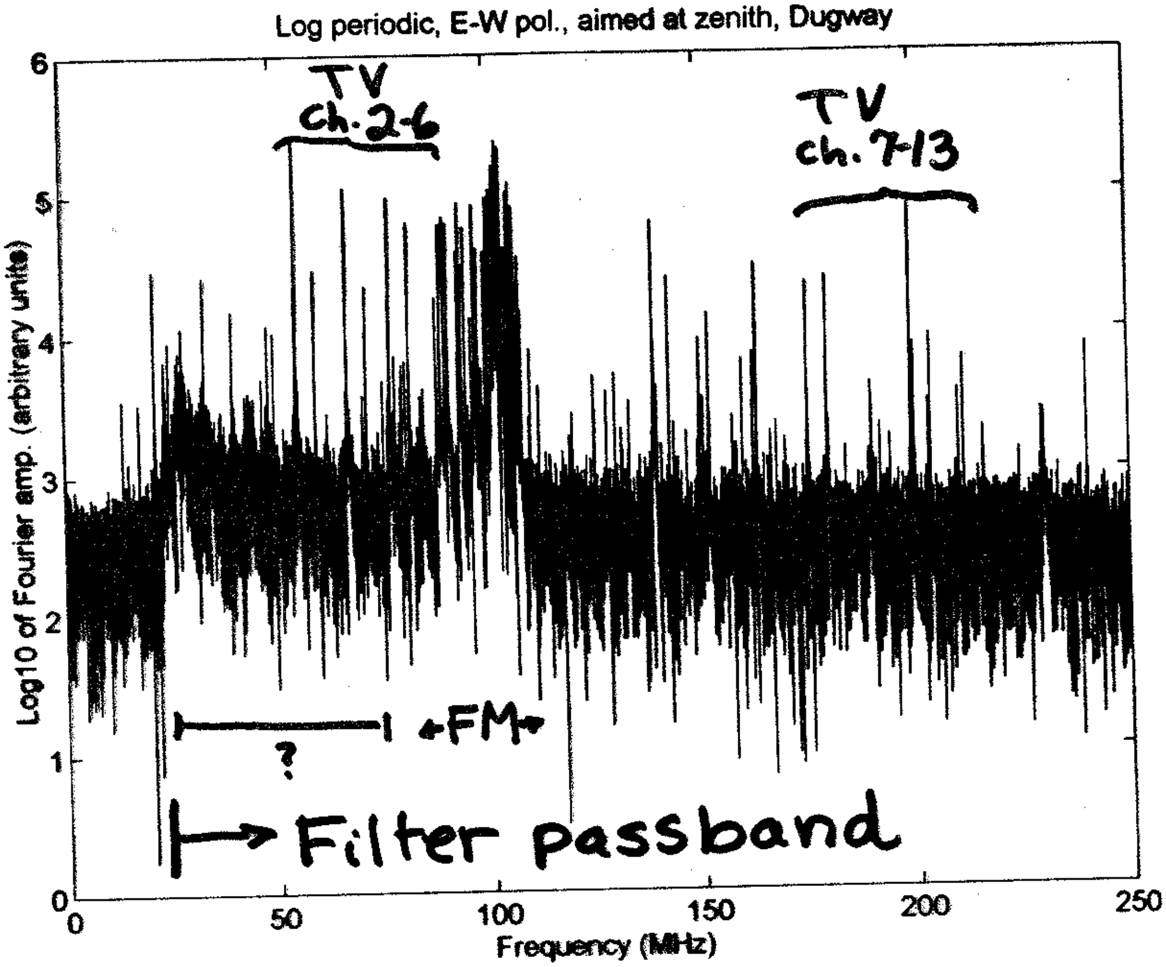


UNPROCESSED DATA
FILTER OUT $f \lesssim 25$ MHZ
SIGNALS FROM TV, FM



RF BACKGROUND, DUGWAY

Log periodic antenna up 35 feet



26 dB of preamplification

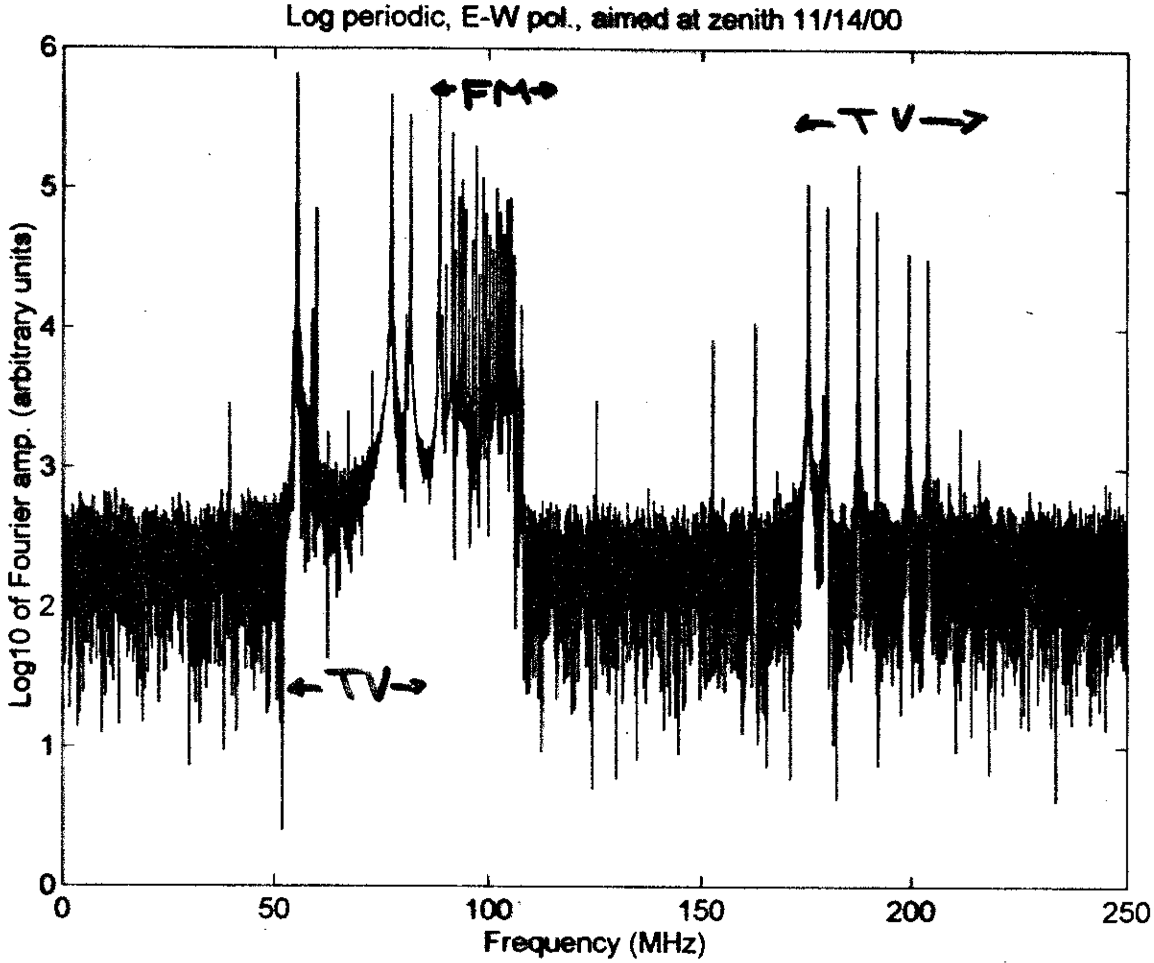
23-250 MHZ bandpass

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

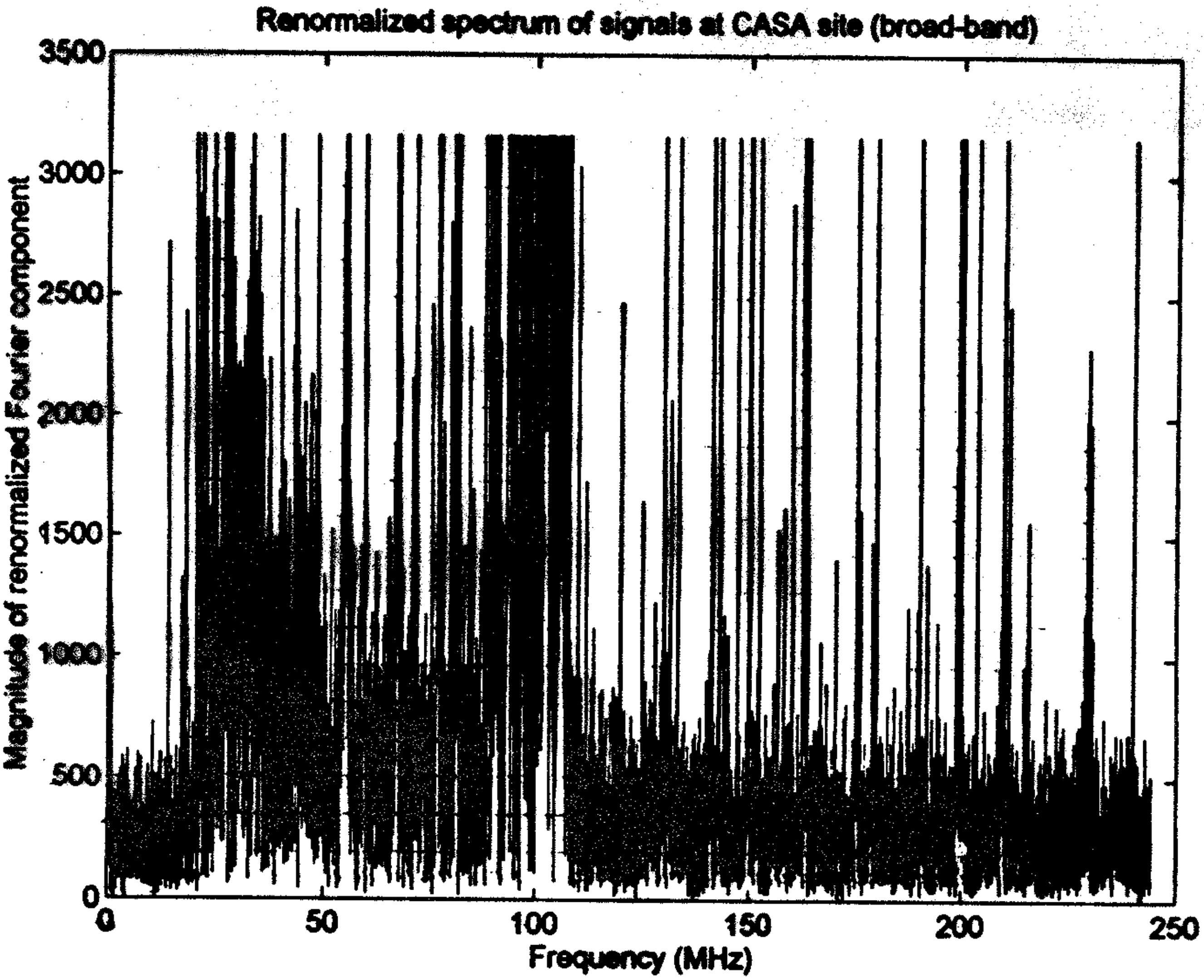


10 dB of attenuation

23-250 MHZ bandpass

~40 dB higher than at Dugway

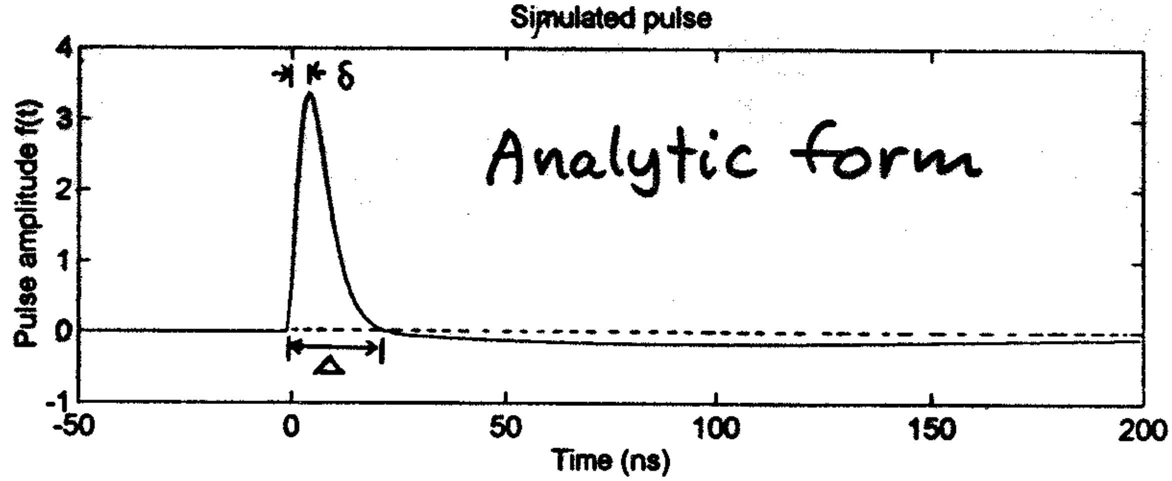
FOURIER COMPONENTS (LARGE MAGNITUDES RENORMALIZED)

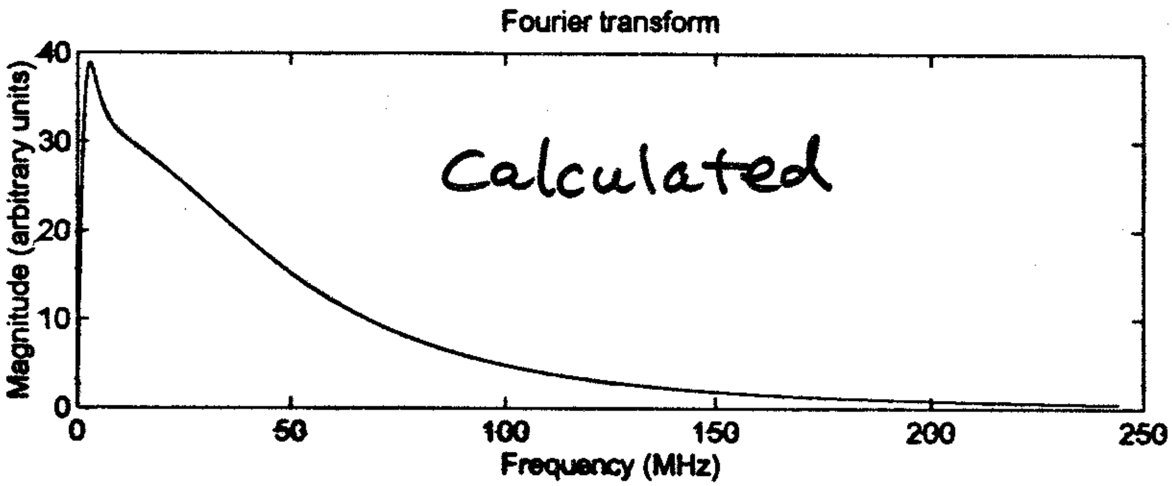


Phases kept the same

SIMULATED SIGNAL

and frequency spectrum
used HP arbitrary waveform generator to produce actual pulse

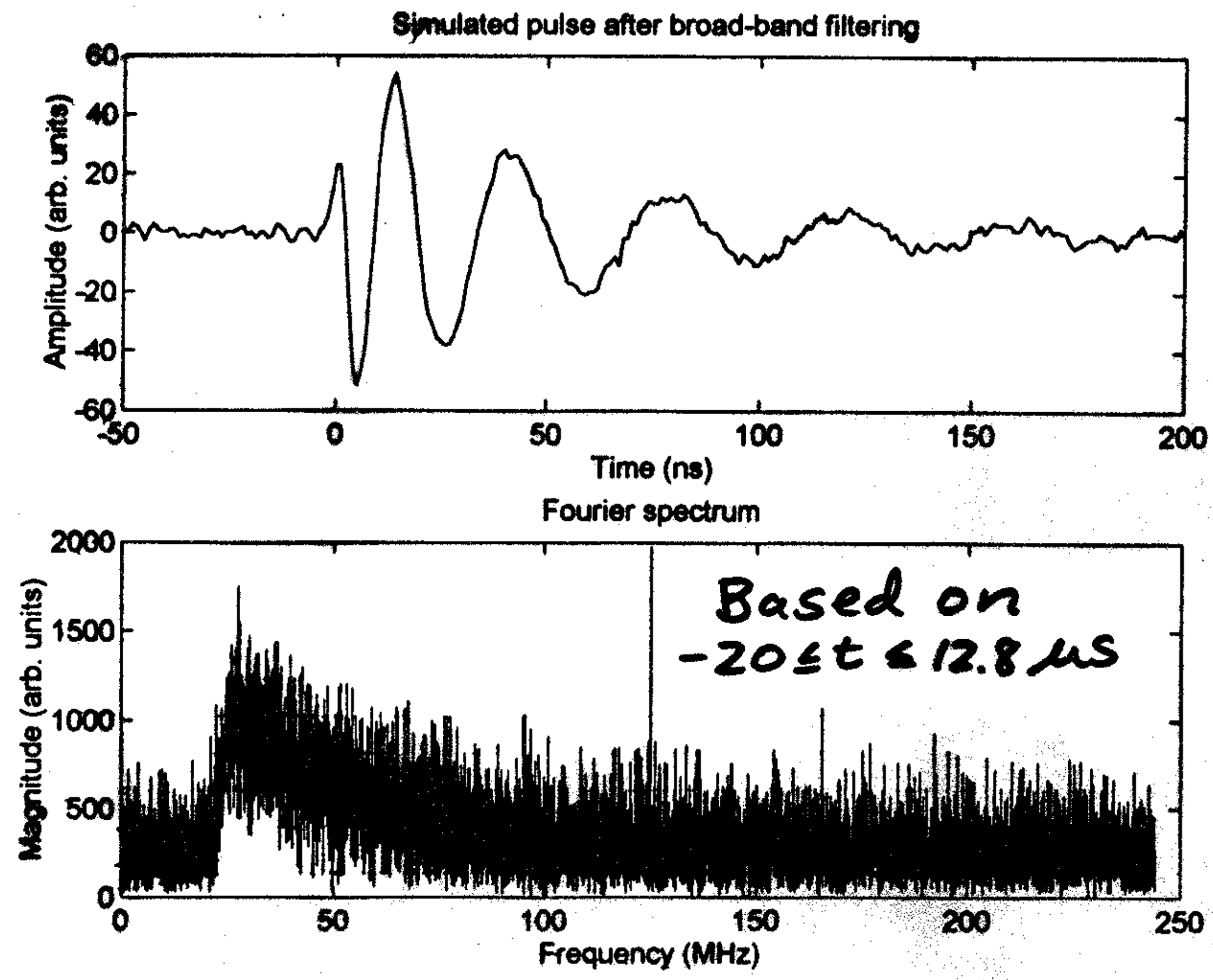




SIMULATED SIGNAL AFTER BROAD-BAND FILTERING

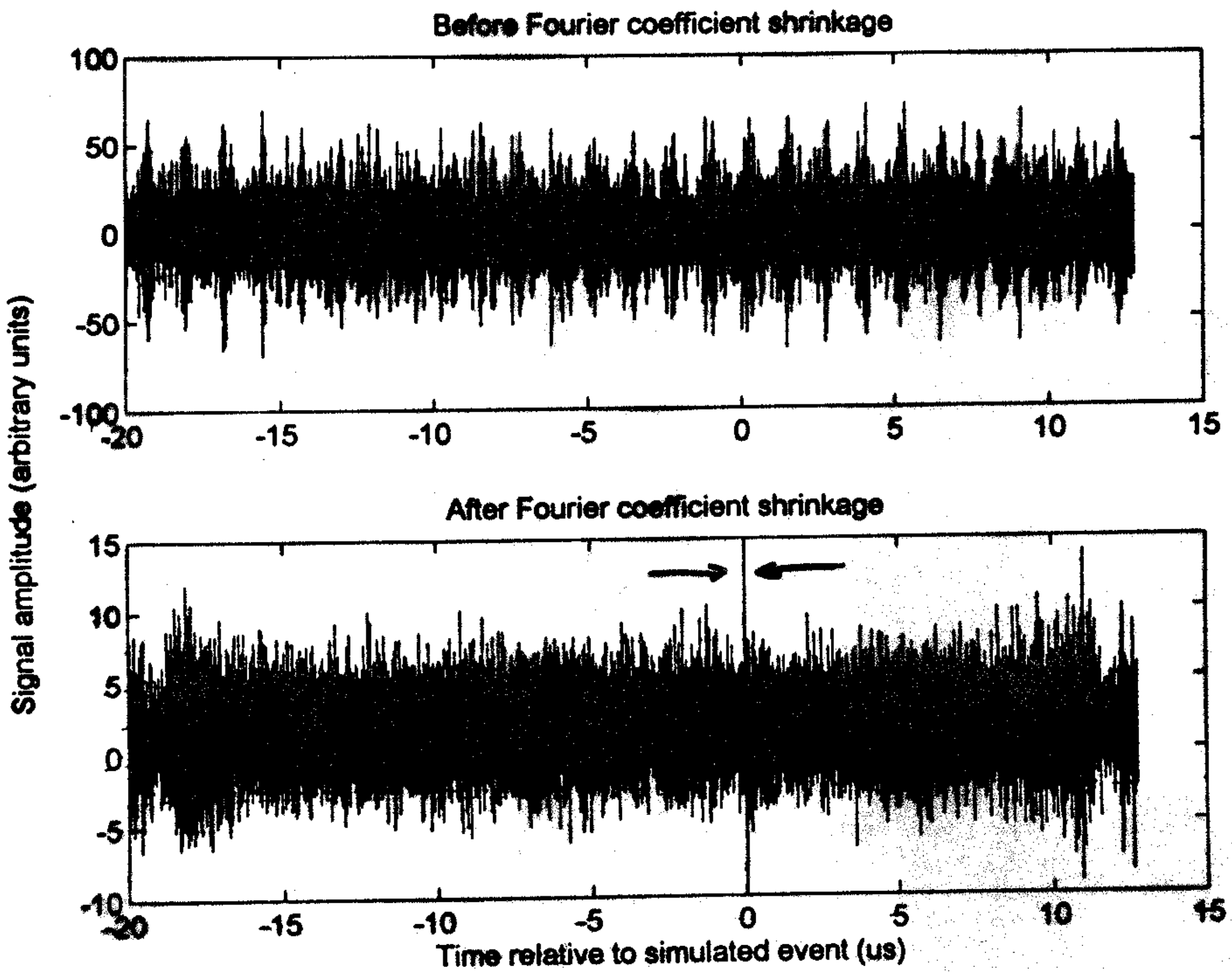
$25 MHz \le \omega \le 250 MHz$

Generated by arb. waveform gen.

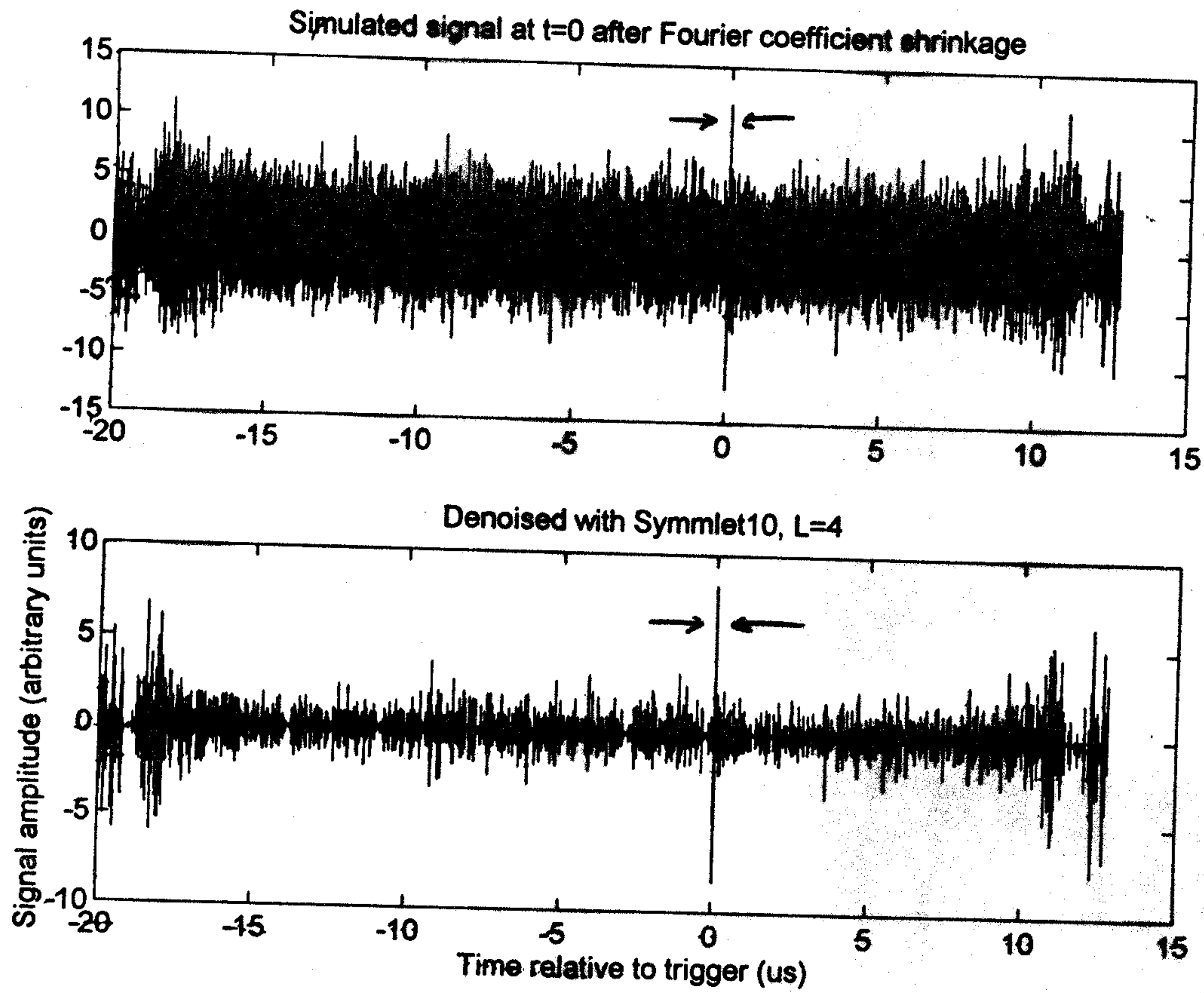


EFFECT ON TRANSIENT DETECTION

Artificial signal added at $t = 0$



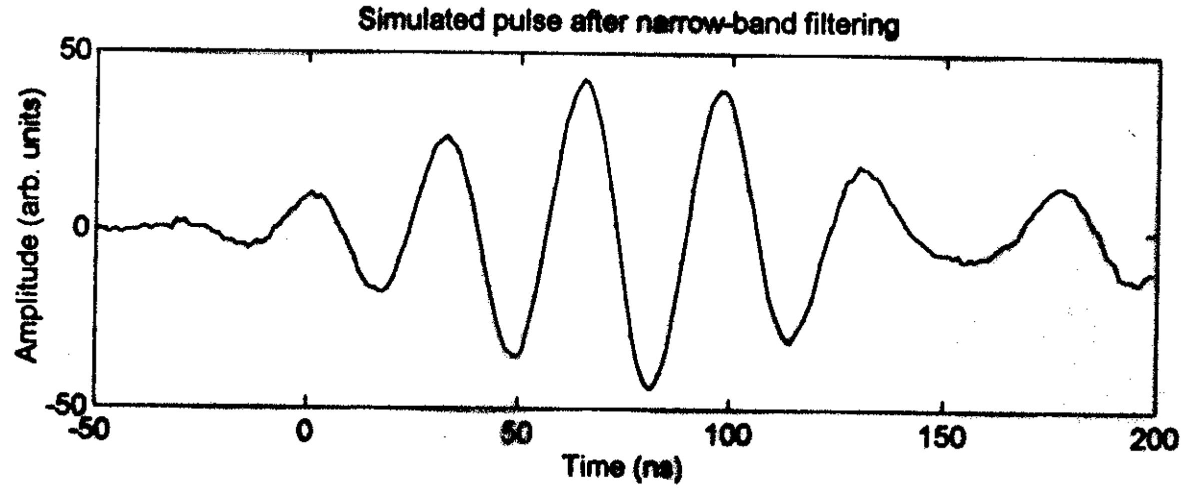
WAVELET DENOISING



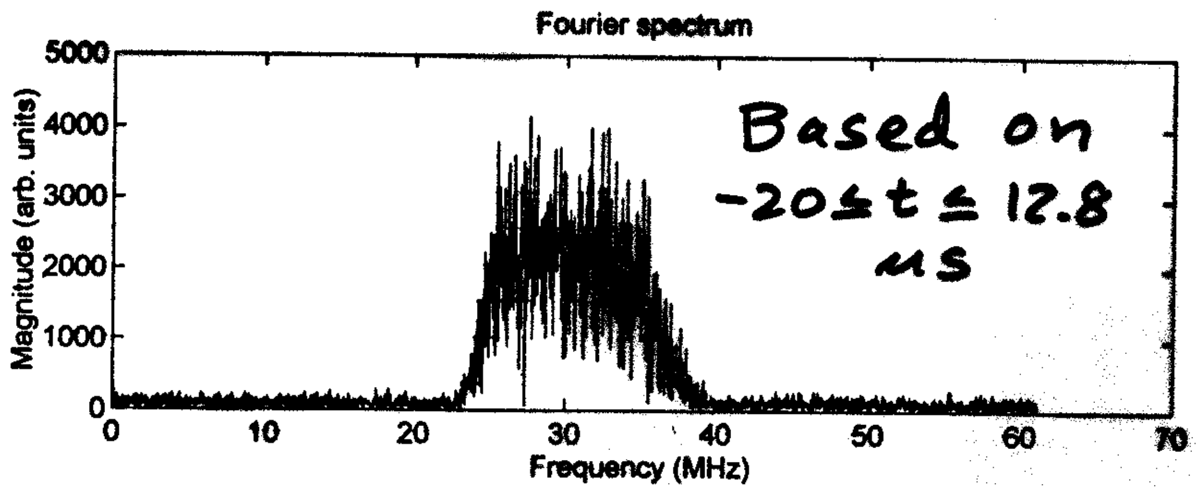
SIMULATED SIGNAL AFTER NARROW-BAND FILTERING

$25\ \text{MHz} \le \nu \le 37\ \text{MHz}$

Generated by arb. waveform gen.



Note longer ringing



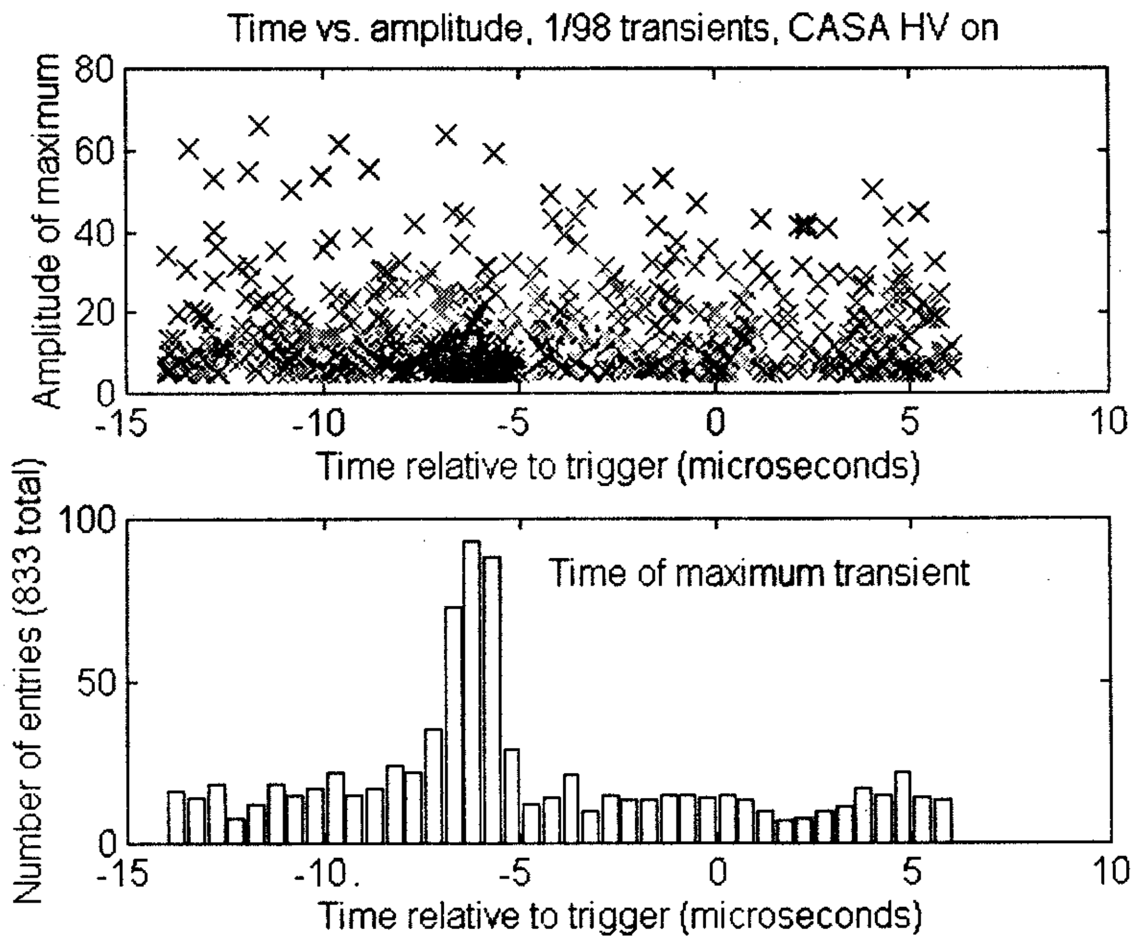
Based on $-20 \le t \le 12.8$ μs

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

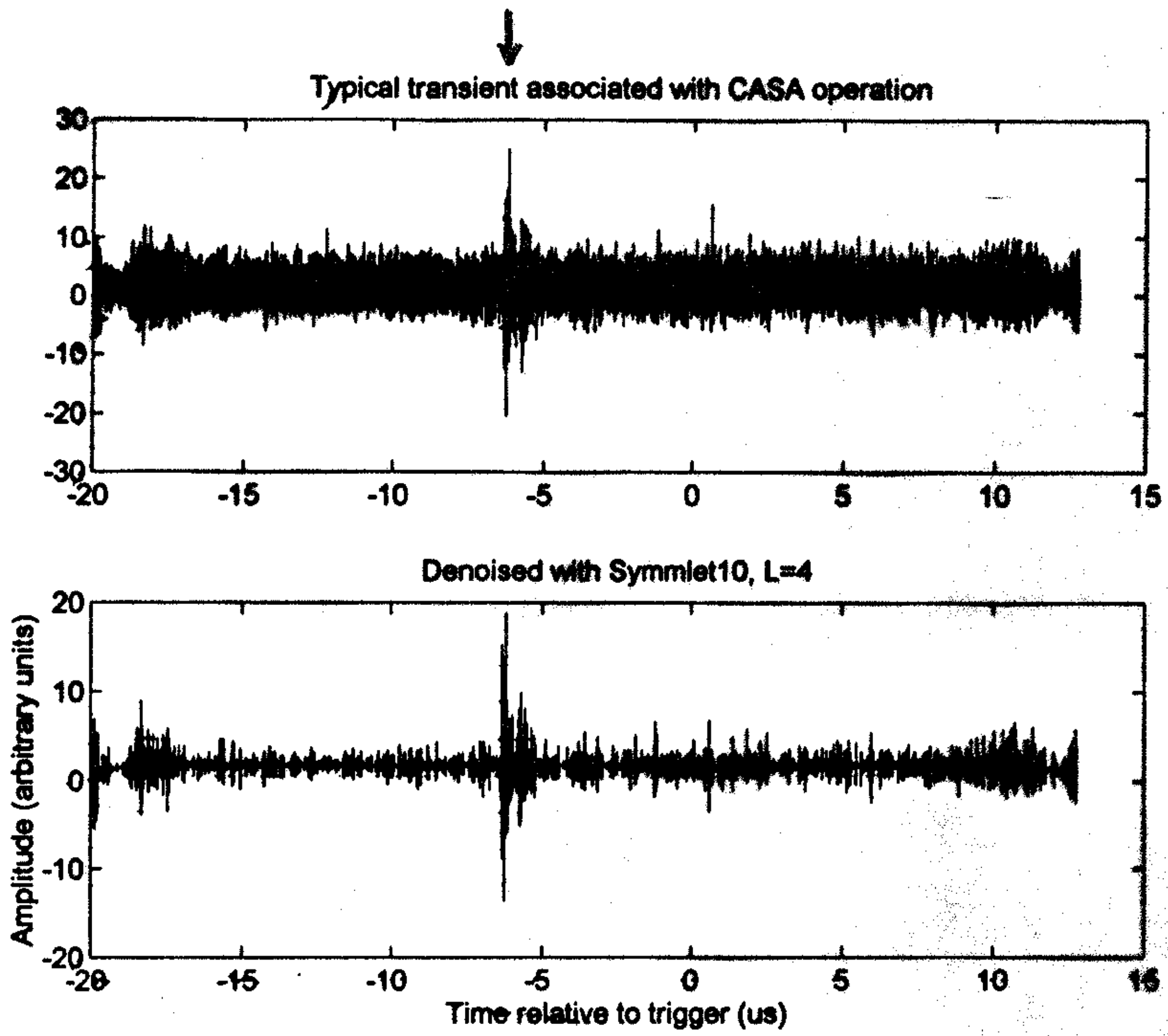


↑

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

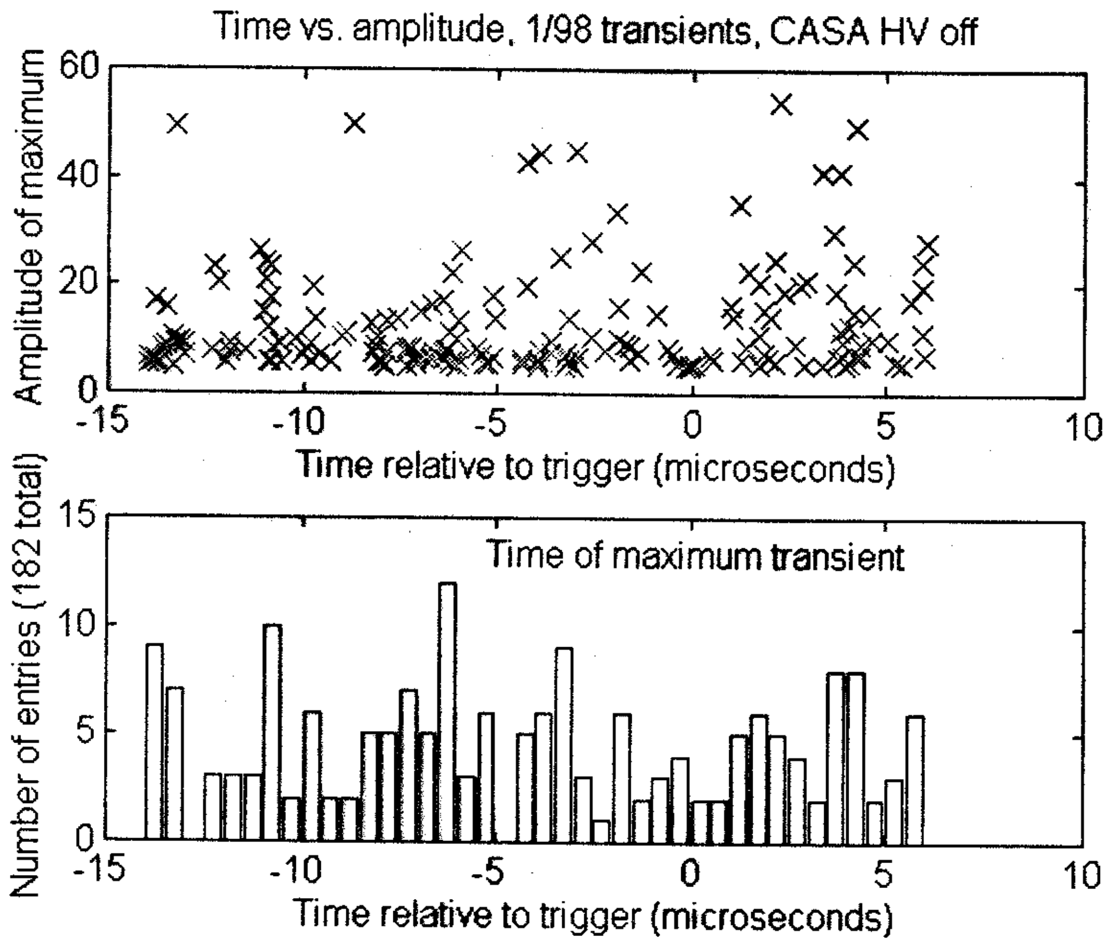
CASA-related

TYPICAL TRANSIENT



CASA HV DISABLED

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



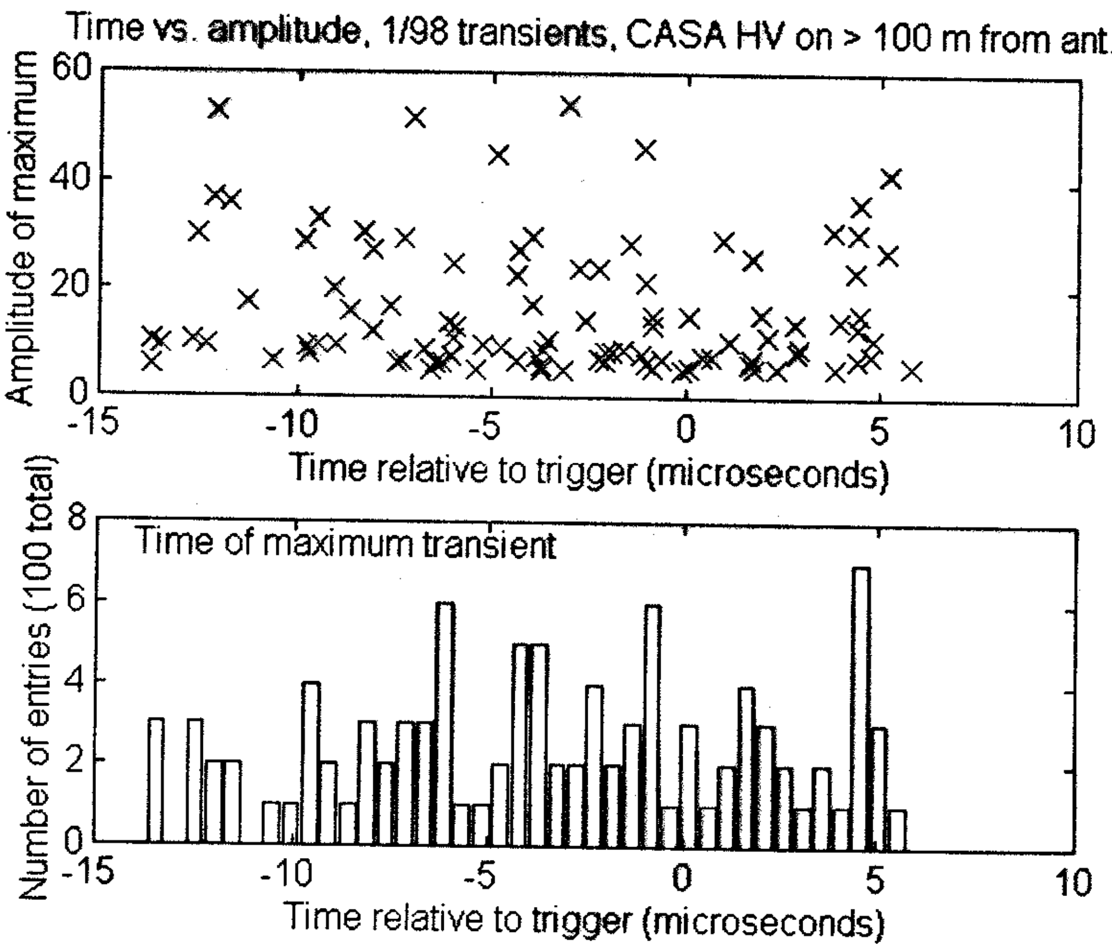
No accumulation in $-7 \leq t \leq -5.5 \mu s$

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

Total sample (E-W pol.) ~4x this

CASA HV PARTIALLY DISABLED

No HV on boxes closer than 100 m from antenna



No significant accumulation

Transients appear to be due to <u>nearby</u> CASA boxes

SENSITIVITY ESTIMATE

Best denoising so far:

Expect $V_{ant} \sim 260\,\mu V$ visible above noise

$$V_{ant} = 30\,G^{1/2} \frac{\delta\nu}{\bar{\nu}} \mathcal{E}_\nu$$

$\delta\nu = 30$ MHZ

$\bar{\nu} = 39$ MHZ

$G = 5$ ← currently under study

⇒ $\mathcal{E}_\nu \gtrsim 5\,\mu V\, m^{-1}\, MHz^{-1}$ pulses should be visible

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

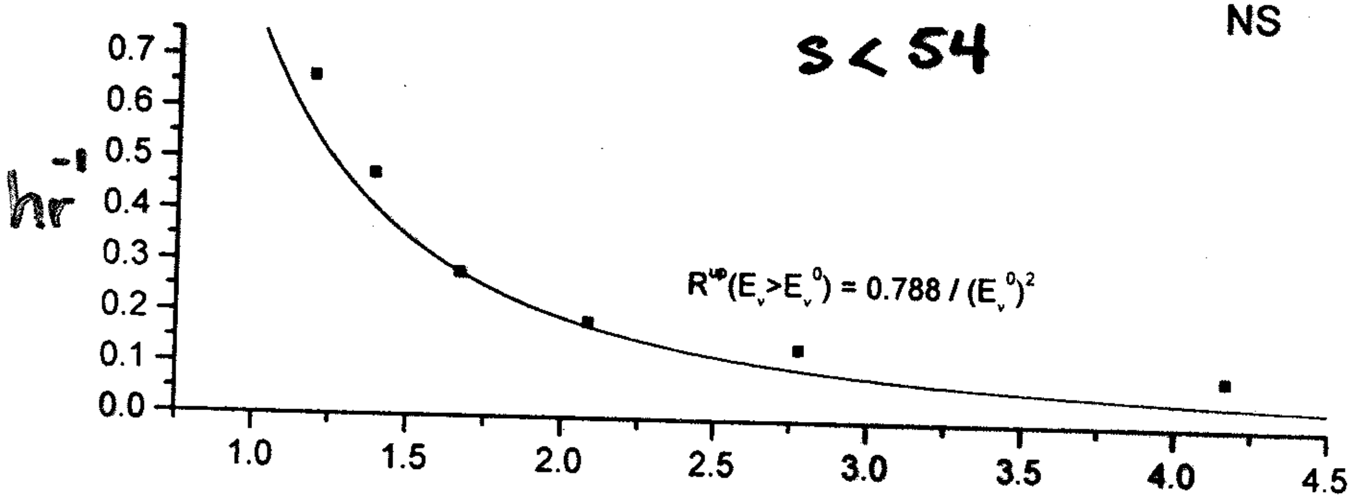
Triggers taken (broad-band, low-noise data acquisition)

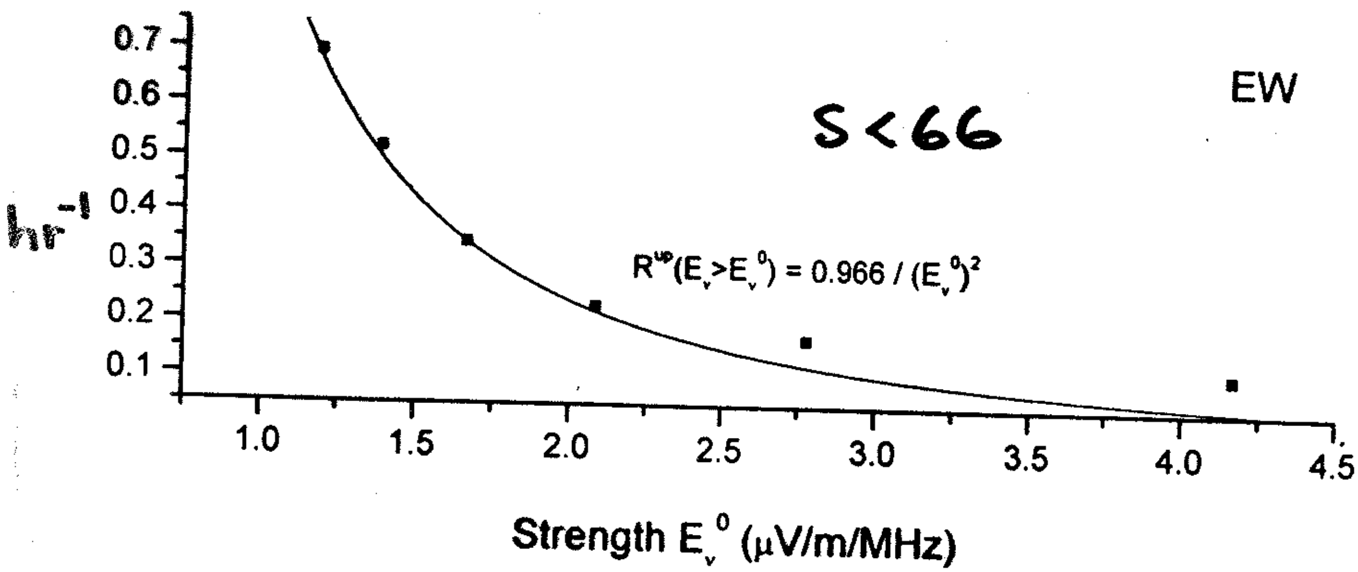
Ant. pol.	CASA HV on	HV off	Partial HV	Total
E-W	4503	857	1834	7194
N-S	677	641	366	1821
Total	5180	1498	2200	9015

↑ (1498) Represents ≈ 50 hr. of data

UPPER LIMITS ON RATES

North-South (NS) and East-West (EW) antenna polarizations





Cf. Atrashkevich + $S = 9.2$

Interim conclusion: not competitive

OUTLOOK (11/00)

- Detect CASA-related RF transient
  - Monitored trigger requests from boxes: within $\lesssim \frac{1}{2}\,\mu s$ 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

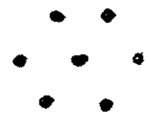
AUGER CONSIDERATIONS

Receiving sites
- How far from axis for $E \geq 10^{18}$ eV
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. $\lesssim$ 3K / station

SOUTHERN HEMISPHERE AUGER SITE

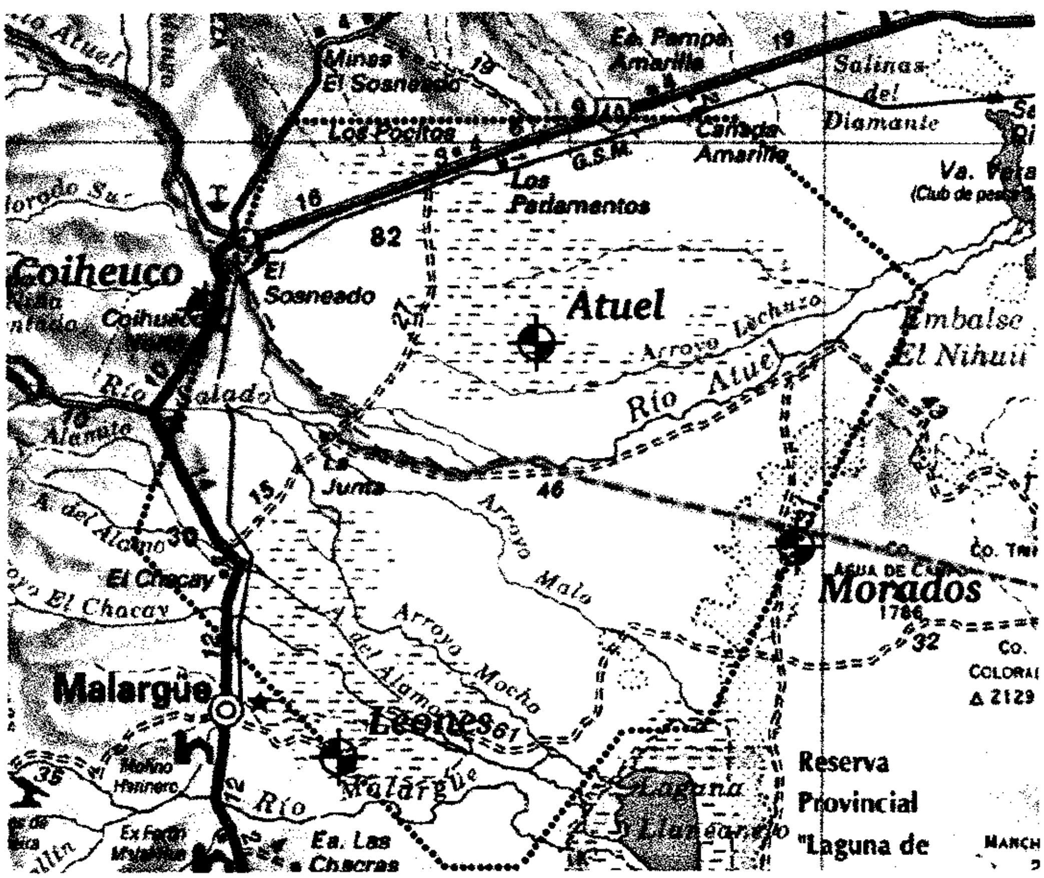
Malargüe, Argentina

3500 Stations

1.5 km spacing 

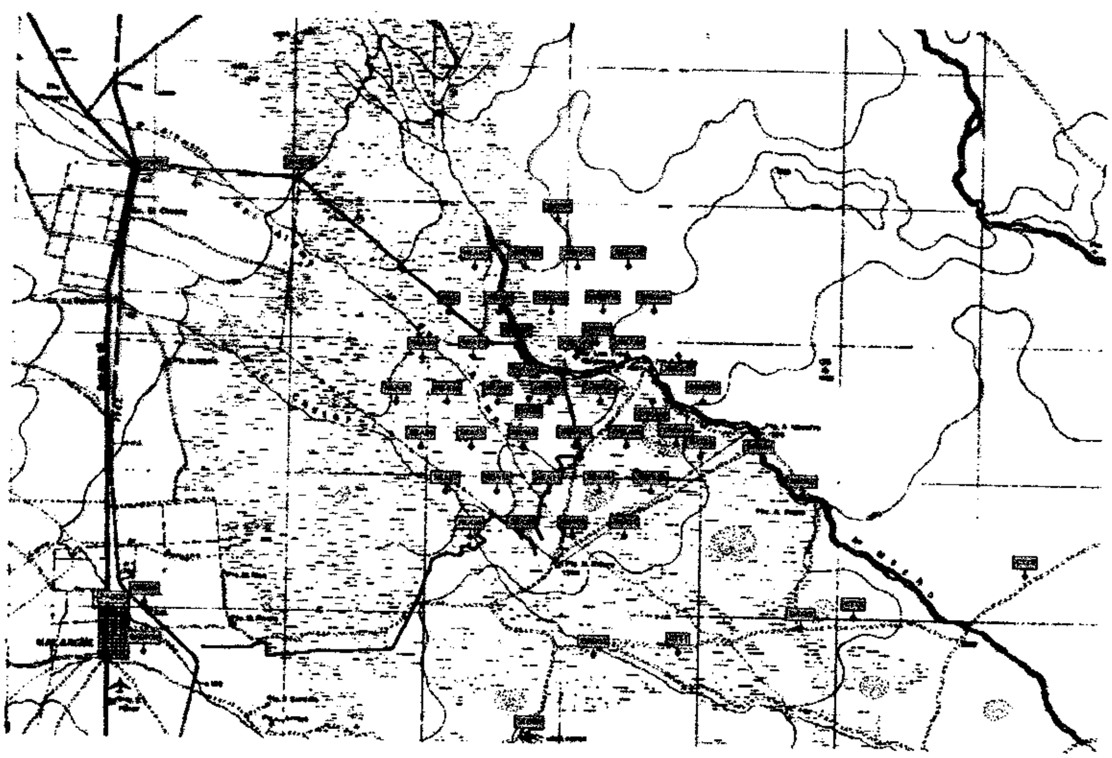
Hexagonal lattice

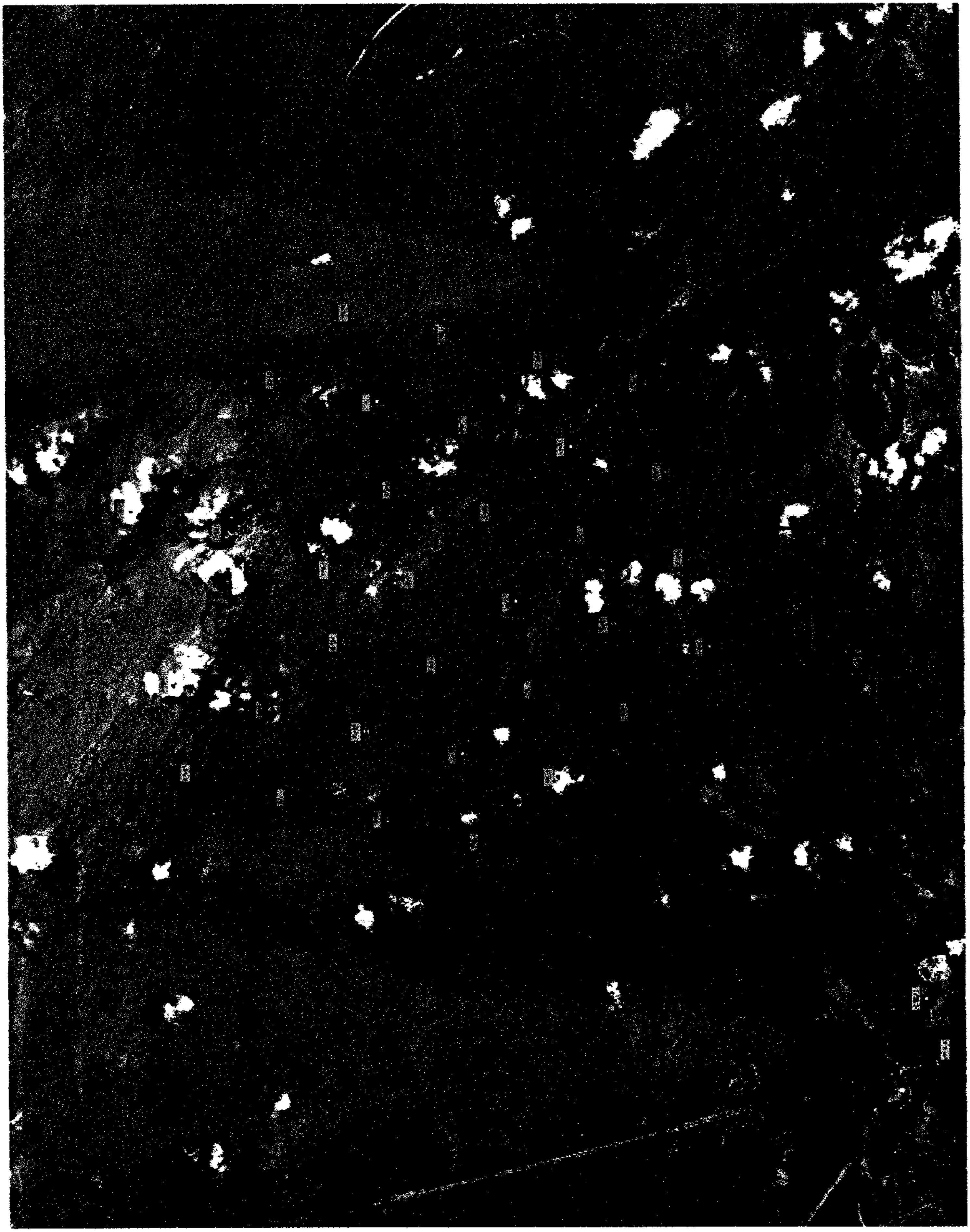
60-100 evt./yr. above 10^{20} eV



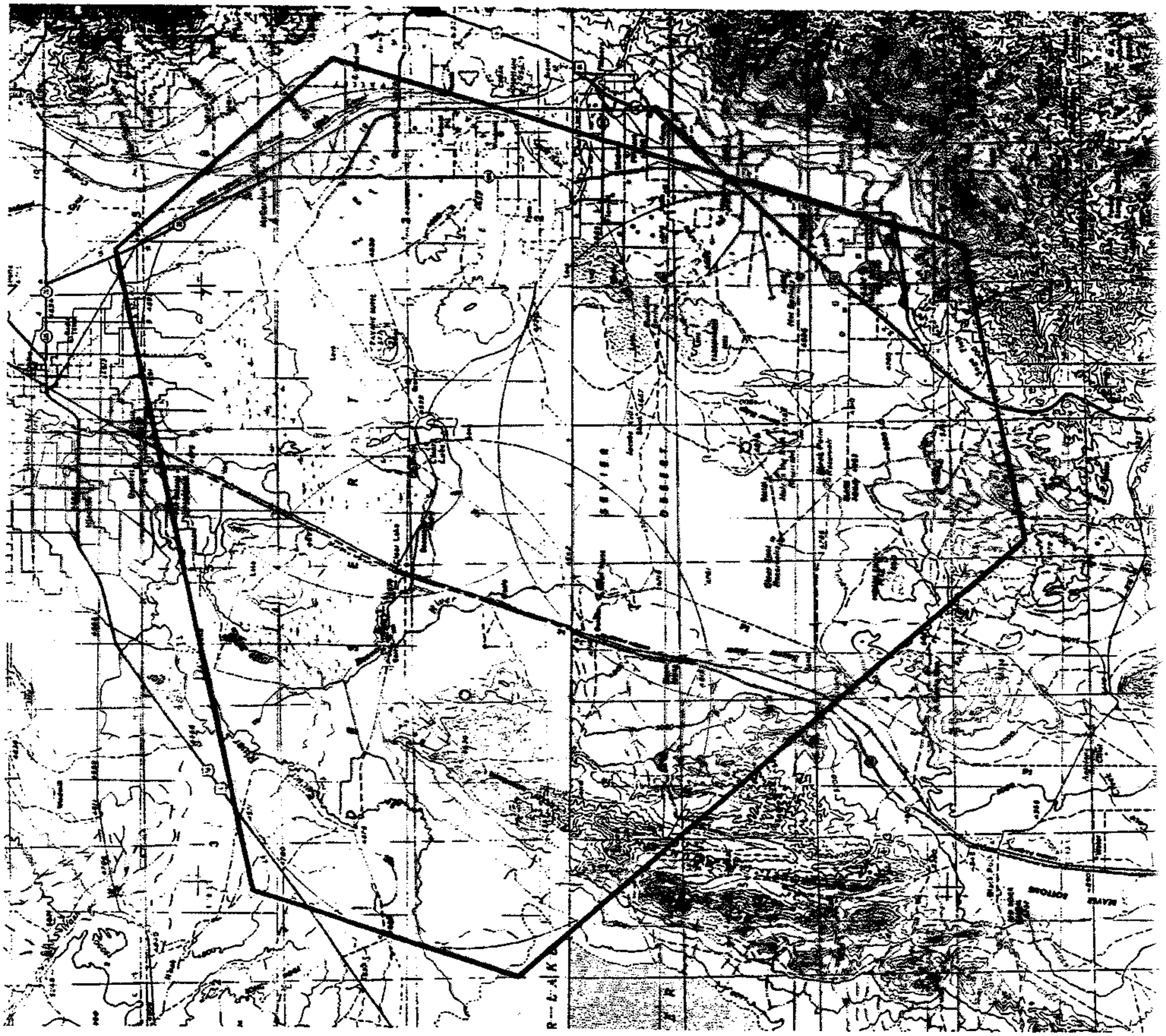
STATION PLACEMENT (ENGINEERING ARRAY)

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