Appendix B

Radio Pulse Detectors

B.1 Motivation

As a result of work in the 1960's and 1970's [159, 160], some of which has continued beyond then (see, e.g., [161, 162, 163, 164]), it is recognized that air showers of energy 10^{17} eV are accompanied by radio-frequency pulses, whose polarization and frequency spectrum suggest that they are due mainly to the separation of positive and negative charges of the shower in the Earth's magnetic field [165]. The most convincing data have been accumulated in the 30–100 MHz frequency range. However, opinions have differed regarding the strength of the pulses, and atmospheric and ionospheric effects have led to irreproducibility of results. In particular, there may also be pulses associated with cosmic-ray-induced atmospheric discharges [166]. There are reports of detection at MHz or sub-MHz frequencies [161, 162, 163], which could be associated with such a mechanism. Signals above 100 MHz have also been reported [164].

A study is being undertaken of the feasibility of equipping the Auger array with the ability to detect such pulses. It is possible that the higher energy of the showers to which the array would be sensitive would change the parameters of detection. Before a design for large-scale RF pulse detection can be produced, it has been necessary to retrace some of the steps of the past 30 years by demonstrating the existence of the pulses for 10^{17} eV showers, and by controlling or monitoring some of the factors which led to their irreproducibility in the past. RF pulses may be able to provide auxiliary information about primary composition and shower height [160].

In this Appendix we describe the prototype activity at the CASA/MIA site, note related activities, and set forth some considerations regarding plans for the Auger project. More concrete plans for RF detection at Auger must await the outcome of the ongoing work at the CASA/MIA site.

B.2 CASA/MIA Prototype setup

In order to verify the claim [159, 160] that 10^{17} eV showers are accompanied by RF pulses with significant energy in the 30–100 MHz range, a prototype detector has been set up at the CASA/MIA site in Dugway, Utah. This section describes the status of that effort.

B.2.1 Large-event trigger

A trigger based on the coincidence of several muon "patches" was set to select "large" showers with a rate of 30 – 50 per hour [167]. The MIA Patch-Sum trigger was sent into a fan-in/fan-out. From this, the signal was put into a LeCroy 821 Discriminator, amplified, and sent over a cable to a trailer located just to the east of the CASA array. The location of the trailer outside the array was dictated by the intense RF noise within the array determined by surveys taken in 1995.

The electronics was set to trigger at 7 of the eight outermost muon patches. This was estimated to correspond to a minimum shower energy of about 2×10^{16} eV, based on the rate at 10^{18} eV of 1/km^2/day/sr. At this level good correlation could be established between trigger pulses and events recorded by the CASA data acquisition system.

B.2.2 Monitoring of RF noise environment

It was a concern that the RF noise of the local electronics and the presence of an extensive lightning-protection array might dictate the placement of the RF pulse detection system outside the periphery of the array. The behavior of a single CASA board was investigated at the University of Chicago. The various clock signals were detected at short distances (< 1 m) from the board, but a much more intense set of harmonics of 78 kHz emanated from the switching power supplies. These harmonics persisted well above 100 MHz. At 144–148 MHz, they overlapped, leading to intense broad-band noise.

A spectrum analyzer, obtained from the now-defunct SSC Laboratory, was used to make a broad survey of the RF noise at the CASA site in various frequency ranges and at various locations. Surveys indicated considerable noise within the array, but a much lower level sitting just outside the array. Consequently, it was decided to set up a special trailer for monitoring RF pulses just to the east of the array.

B.2.3 Data acquisition

A log-periodic antenna sensitive to 26 – 170 MHz was mounted about 30 meters to the east of the CASA boundary, at an elevation of about 10 meters to place it just above the lightning protection grid. A digital storage scope was used to register filtered and preamplified RF data on a rolling basis. These data were then captured and stored upon receipt of a large-event trigger.

The experiment was repeated using successively greater amounts of amplification and narrower band-pass filters. Data were taken using two systems on two separate computers (at different times), allowing for analysis both by Wilkerson and students at the University of Washington and by Rosner at Chicago. Wilkerson's data are still being processed, so the preliminary results to be mentioned below will be based on Rosner's analysis.

B.2.4 Results

The most recent configuration involved feeding the signal from the antenna through Mini-Circuits BHP-25 and BLP-30 filters, with 6 dB points of 23 and 39 MHz, a Mini-Circuits ZFL-500LN preamplifier with 26 dB of gain, a Mini-Circuits BBP-30 bandpass filter with 6 dB points 24.5 and 37 MHz, and another ZFL-500LN preamplifier. This configuration was arrived upon after numerous runs in which efforts were made to minimize noise from sources such as computers, monitors, and the preamplifiers themselves. It was employed for an 8-1/2 hour run during which 305 triggers were received. Each trigger caused 50 μs of RF data, centered around the trigger and acquired at 1 GSa/s, to be saved on a Tektronix TDS540B digitizing oscilloscope. These data were then passed using a GPIB interface to a Dell XPS200s Pentium computer, where they were stored for future analysis.

Events were scanned for large positive peaks. Three points each exceeding 15.2 mV on the oscilloscope input were demanded within a window of 10 ns, in order to eliminate both constant background noise and very-high-frequency transients. If an event contained such a peak, the largest peak within an associated group of duration less than 300 ns was then identified and its height was plotted as a function of time relative to the trigger pulse. The results are shown in Fig. B.1(a).

A clear signal is visible in the window between -10 and -5 μs relative to the trigger. The trigger pulse itself requires several μs to be formed at the CASA site, and an additional 2.15 μs to propagate to the RF detection trailer. Consequently, the signal is likely to be due to the prompt RF signal associated with showers.

The pulses within the window from -10 to -5 μs in Fig. B.1(a) are associated with showers whose cores nearly all lie east of the center of the CASA array, as shown in Fig. B.1(b). This result is in accord with the rapid decrease of pulse intensity with distance from the core observed by the Haverah Park group [160].

B.2.5 Near-term plans

A total of more than 5000 triggers, obtained under various conditions of filtering, preamplification, and noise reduction, remains to be analyzed. Preliminary results from runs in September and December of 1996 indicate that about 1 in 10 of these triggers may contain information on RF pulses from air showers. Shower sizes, core locations, and incident shower angles will be correlated with time, duration, and intensity of radio bursts. Data must also be collected with the CASA detector disabled (leaving only the MIA trigger), in order to

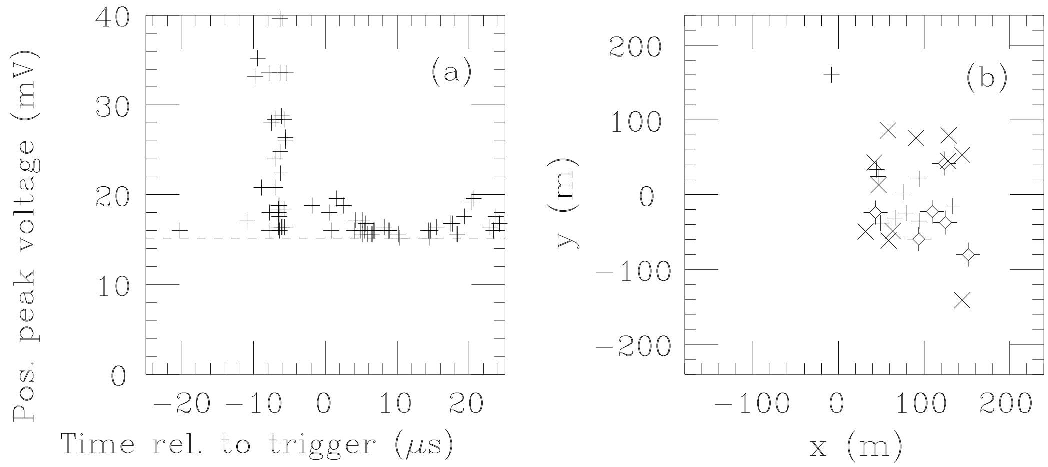

Figure B.1: (a) Maximum pulse height as a function of arrival time relative to trigger. (b) Distribution of cores with respect to center of CASA array for events in (a) between 10 and -5 μs. $\times$: $15.2 < V_{\rm pk} < 20$ mV; $+$: $20 \leq V_{\rm pk} < 30$ mV; fancy points: 30 mV $\leq V_{\rm pk}$. Here $(x, y) =$ core position (east, north) of array center. The antenna was located at $(x, y) \simeq (270, 0)$ m.

exclude the possibility that signals are due to pulses involved in CASA data transfer.

A non-imagining Cherenkov light array (BLANCA) has recently been added at the CASA site. RF data will be collected during at least one period when BLANCA is active in order to utilize the additional information that BLANCA may provide on shower energy and primary composition.

Still to be performed are experiments which seek to monitor RF pulses at lower frequencies and at greater distances from the array. For these pulses, whose strengths may be correlated with atmospheric electric fields, it is planned to monitor such fields with the help of a field mill, which Rosner has recently constructed. A group working at the AGASA array in Japan [161] has detected pulses associated with large air showers (typically above 10^{18} eV) at frequencies below 500 kHz. These pulses are of several microseconds duration. While they can be associated with cores more than 1 km away from the antenna, they do not always occur, even for very large showers. It is suspected that they may be associated with an atmospheric discharge mechanism. Consequently, once suitable low-frequency filters are found to eliminate signals from the AM broadcast band and the 284 kHz air traffic control beacon at Dugway, a survey of pulses below 500 kHz will be undertaken at Dugway. Simultaneous monitoring of electrostatic atmospheric electric field gradients at ground level will provide at least a first look at the possibility that a discharge mechanism is involved.

Wilkerson was engaged in projects at Los Alamos whose aim was detection of electromagnetic pulses, including those possibly produced by cosmic-ray-induced electromagnetic discharges, with frequencies in the 30 – 100 MHz range. Part of this work included building hardware for self-triggering on short duration wide-band RF pulses. Many of the pulse identification, fast-digitization and memory problems are identical to those for pulse detection at CASA/MIA. Time-frequency plots have been obtained which are exactly those one would generate in a survey at CASA/MIA. Wilkerson has also encountered similar requirements for digitization of SNO data. His estimate is that one can use Maxim MAX 100 A/D chips for less than $1K per channel, but that feeding their output into memory may well amount to another $1K per channel. Other references on digitizers have been obtained [168, 169].

Wilkerson has moved his data acquisition system to CASA and has taken data from the digitizing scope for analysis at the University of Washington. Time-frequency plots obtained for a day's data in September, 1996, already showed behavior consistent with Fig. B.1. In the near future the RF pulse detection system will be activated with a suitable set of filters, in order to detect pulses from air showers without the need for an external trigger.

In the future the spectrum analyzer obtained by Rosner may of help in detecting potential sources of interference to RF communications in the Auger project.

B.3 Related activities

B.3.1 Status of GHz detection

David Wilkinson, who visited the University of Chicago during the spring of 1995, has promised to look into the power radiated at frequencies of several GHz, where new opportunities exist associated with the availability of low-noise receivers. These techniques have now been implemented in the RICE project [170], which seeks to detect pulses with frequency components around 250 MHz in Antarctic polar ice.

B.3.2 Other options

Dispersion between arrival times of GPS signals on two different frequencies may serve as a useful monitor of air shower activity. The possibility of correlation of large showers with such dispersion events will be investigated.

It may be possible at the CASA/MIA site to monitor commercial broadcast signals in the 55 - 88 MHz range to detect momentary enhancements associated with large showers, in the same sense that meteor showers produce such enhancements. Television Channels 3 and 6, for which no nearby stations exist, offer one possibility.

B.4 Considerations for Auger project

At present we can only present a rough sketch of criteria for detection in the 30–100 MHz range. Data would be digitized at a 500 MHz rate at each station and stored in a rolling manner, with at least 20 microseconds of data in the pipeline at any moment. Upon receipt of a trigger signaling the presence of a "large" shower ($> 10^{18}$ eV), these data would be merged into the rest of the data stream at each station.

Per station, we estimate the following additional costs, in US dollars, for RF pulse detection:

Two antennas and protection circuitry:	200	(a)
Mounting hardware:	100	(b)
Cables and connectors:	200	(c)
Preamps:	500	(d)
Digitization and memory electronics:	2000	(e)
Total per station:	3000	(f)

(a) Two military-surplus log-periodic antennas; crossed polarizations. Difference signal to be detected.

(b) Highly dependent on other installations at site. Antennas are to be pointed vertically but optimum elevation not yet determined.

(c) Antennas are mounted near central data acquisition site of each station, but sufficiently far from any sources of RF interference such as switching power supplies.

(d) Commercial GaAsFET preamps and gas discharge tubes.

(e) Subject to prototype development experience. Power requirements not yet known.

(f) The number of stations to be equipped with RF detection will depend on prototype experience.

The above estimate assumes that one can power the preamps and DAQ electronics from the supply at each station without substantial added cost. It also assumes that a "large-event trigger" will be available at each station. A further assumption is that the difference signal suffices to characterize the pulse. Additional preamplification and DAQ electronics may be required if this is not so. One consideration may be the acquisition of antennas robust enough to withstand extreme weather (particularly wind) conditions.

For detection at frequencies above or below 30–100 MHz, the criteria are not yet well enough developed to permit any cost estimate.

Appendix C

Auger Project Participants

C.1 Auger Collaboration Membership

The Auger Collaboration was formally established during a meeting in Paris at UNESCO headquarters in November 1995. The official list of collaborators and institutes (as of January 1997) is given here. In the following list, Group Representatives (Collaboration Board members) are indicated by a "*" and their e-mail addresses are indicated for the group. The (S) indicates the PhD students.

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