The Discovery of Radio Pulses from Extensive Air Showers

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Summary

- The Pre-history
- The Idea
- The Experiment
- The Results
- The Follow Up
THE INTERNATIONAL WORKSHOP ON VERY HIGH ENERGY GAMMA RAY ASTRONOMY
OCTACAMUND - INDIA. September 20-25, 1982

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How it came about:

Prehistory:

- Possible Radar detection: Blackett and Lovell (1941)
- Cherenkov Radiation from EAS: Jelley (1958)
- Jodrell Bank Experiment (1947)

The Scene in 1962:

- Collaboration between J.V. Jelley (Atomic Energy Research Establishment, Harwell, U.K.) and N.A. Porter (Physics Department, University College, Dublin, Ireland)

- Using the atmospheric Cherenkov Technique
to do Very High Energy Gamma Ray Astronomy:
Glencullen, Ireland 1962-66
The Experiment at Jodrell Bank

Sequence of Events:

- Paper in Russian by Alikhanyan on Detection of Neutrinos on Moon; noted by N.A. Porter and brought to J.V. Jelley's attention (1963)
- Paper by Askaryan on detection of radio emission from EAS referenced
- Correspondance between Jelley and Porter re feasibility of experiment to detect radio emission from EAS
- Decision to seek aid of radio astronomers; Jelley and Weekes visit Cambridge and discuss experiment with Ryle and Graham-Smith
- Graham-Smith moves to Jodrell Bank as Assistant Director; Jodrell bank to provide the radio telescope, Harwell-UCD to provide the EAS trigger and manpower
- Some history of cosmic ray studies at Jodrell Bank
- Fear that J.B. would get the credit for successful experiment
- Small EAS array designed at UCD; built and tested at Harwell (Spring, 1964)

Radio Technique:
- 24 hours
- Sensitive
- Inexpensive
- Expensive
EXCESS NEGATIVE CHARGE OF AN ELECTRON-PHOTON SHOWER AND ITS COHERENT RADIO EMISSION

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Submitted to JETP editor March 24, 1961

We investigate the excess of electrons in an electron-photon shower. This excess is caused by annihilation of the positrons in flight and by the Compton and 6-electrons in the cascade. It is shown that at the maximum of the shower the excess may comprise ten percent of the total number of shower particles. The Cerenkov radiation from this excess charge in a dense medium is estimated. It is indicated that this radio emission from showers produced by high-energy accelerator particles or cosmic rays in blocks of dense matter can be recorded and used. The possibility of recording radio waves from penetrating particle showers in the moon’s ground, by apparatus dropped on the lunar surface, and in underground layers on the Earth in which radio waves can propagate, is also noted.

1. EXCESS NEGATIVE CHARGE OF ELECTRON-PHOTON SHOWER

Three processes contribute to the formation of an excess of electrons in a cascade, namely annihilation of the positrons in flight and dragging of the Compton and 6-electrons into the shower cascade. Let us estimate this excess charge.

We write the equation for the average number of electrons n_ and of positrons n_ with energies of interest to us in the form

n_ = \Phi (t) - n_ /\tau_ + \dot{n}_, C, \quad \dot{n}_ = \Phi (t) - n_ /\tau_,

where \Phi (t, n_6, n_7) is a function of the electron and positron pair production by \gamma rays and shower particles, \dot{n}_6, \dot{C} is the number of Compton and 6-electrons with energies of interest to us produced per unit time by the quanta and shower particles, \tau_ is the lifetime of the charged particles prior to energy loss to production of the \gamma quanta. We put 1/\tau_ = 1/\tau_ + 1/\tau_6, where \tau_6 is the lifetime of the positron prior to annihilation.

Subtracting the equation for n_ from the equation for n_ we obtain for the excess particles \nu

\nu + \nu/\tau_ = n_ /\tau_ + \dot{n}_, C = n_ /\tau_.

It is easy to see that \nu < \tau_ and therefore \nu < n_ /\tau_. Inasmuch as \tau_ = T_1 /c and \tau_ = 1/\sigma_0 e 0 c, where the annihilation cross section is

\sigma_ = \pi^2 /2 \gamma /m_0^2 E_0 \ln (2E_0 /m_0^2),

and the radiational length

l_0 = 137/4Z^2 \gamma^2 \ln (183Z^2),

we obtain

\nu /\tau_ \approx 137/4Z^2 \gamma^2 \ln (183Z^2) \approx 1Z^2.

This ratio is independent of the density of the medium, and depends only on its atomic number Z and on the particle energy. For example, when Z = 10, with a mean particle energy at the maximum of shower development E = 10^6 ev, we obtain \nu /\tau_ \approx 0.1, i.e., the number of moving electrons in the shower can exceed the number of positrons by some ten percent.

2. COHERENT RADIO EMISSION FROM THE SHOWER

The presence of a moving uncompensated charge in a shower may increase by many orders of magnitude a flash of Cerenkov, bremsstrahlung, or transition radiation in the radio range. Various possibilities of recording cosmic showers by radio emission bursts have been discussed numerous times (see, for example, [13]). Coherent amplification of the radio emission from the excess charge increases the chances of registering
(2) Current Element

(1) Dipole

Coherent if wavelength is longer than t

Current

Shower Core

Geomagnetic Effect
The Experiment: I

\[ S \propto d \nu \\propto N (en)^2 \\propto \eta \\propto \frac{1}{10^9} \\text{kHz} \]

\[ \approx 4 \% \]

Design

- Choice of Frequency, Bandwidth
- BBC at 44 Mhz 00.00 → 09.00 P.M.
- Dipole Array \( Y_m \)
- Analog Recording
- Background
- Delays
- EAS Trigger

\[ I_{16} \text{eV} \approx 4 \% \]

\[ \nu \approx 44 \text{kHz}, \nu D \approx 40 \text{kHz} \]

\[ S \approx 1.1 \times 10^{-12} \text{ watt} \]

\[ N \approx 2.8 \times 10^{-13} \text{ watt} \]

Minimum detectable field strengths for a half-wave dipole antenna at different receiver frequencies, in a bandwidth of 1 MHz.
The Experiment: II
Layout of Jodrell Bank Experiment

Setting Up at Jodrell Bank, July, 1964

4 sections,
2Δλ by 3Δλ
Area ~ 1,700 m²
T~ 450 °K
The Experiment: III

EAS Array

![Diagram of EAS Array](image)

Fig. 1 - The layout of equipment as used throughout this experiment.

Battery-powered

Geiger Tray.

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RADHEP-2000

November 16-18, 2000

Trevor Weekes, SAO
The Experiment: IV

Delays

![Diagram of the experiment setup]

**Fig. IV.7 Geiger Counter Delay**

**Fig. IV.8 Radio Pulse Position Histogram**

RADHEP-2000  November 16-18, 2000  Trevor Weekes, SAO
The Experiment: V

Recording System
Results: I

Jodrell Bank, August, 1964

• One quarter array completed
• Nightly operation
• The Mad Hatter's Tea Party
• Daily Record
• First run August 19, 1964
• Joys of scope photography
• Be more careful!
• Success?
• Celebration

The First Event

FIRST PULSE (enlarged scale)

Verification?

• Eight more nights of operation
• Decision time
• Full array, November-December, 1964 — Model 1965
• Six large events, 4500 triggers, \(10^{16}\) eV
• \(5 \times 10^{16}\) eV
• 1 eV per event
RADIO PULSES FROM EXTENSIVE COSMIC-RAY AIR SHOWERS

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AND

Prof. F. G. SMITH and R. A. PORTER
University of Manchester, Nuffield Radio Astronomy Laboratories, Jodrell Bank

VARIOUS proposals have been considered for the detection of large cosmic-ray air showers by radio techniques. Neither the original proposal of pulse radar nor the passive detection of Čerenkov radiation at microwave frequencies now appears to be feasible. A reassessment of the possibilities of Čerenkov radiation at longer wavelength has, however, been stimulated by the recent suggestion that a considerable enhancement of the intensity may be expected in the radiation from an electron-photon cascade. This is due to a fractional negative charge excess $\varepsilon$ arising from the annihilation of positrons in flight. For a shower with a total of $N$ particles, the radiation intensity at low frequencies is proportional to $(\varepsilon N)^2$ $\delta \nu$ within a bandwidth $\delta \nu$ at a frequency $\nu$, and the enhancement factor is $\varepsilon^2 N$ over that from $N$ particles radiating incoherently. In a typical shower of primary energy $E_0 \sim 10^{14}$ eV, for which $N \sim 10^7$ and the electron and positron energies are of order $10^8$ eV, we expect $\varepsilon \sim 0.1$, and $\varepsilon^2 N \sim 10^4$.

If we consider a shower front as a disk of thickness $t$ and area $S$ incident vertically close to an aerial array of area $A$, two conditions must be satisfied to achieve the maximum mutual coherence: (i) the wavelength $\lambda$ must exceed $t$, and (ii) the radiation from all parts of the shower front must arrive in the same relative phase at all elements of $A$. In such a shower $t \sim 2$ m (ref. 4) and the effective radius of the shower is $\sim 50$ m (ref. 5), so that these conditions are reasonably satisfied for $\lambda \geq 4$ m and for altitudes $> 3$ km.

The present experiment was conducted on the basis of favourable estimates of the expected yield from this enhanced Čerenkov radiation. Cosmic-ray showers in the energy region $10^{15}$--$10^{16}$ eV were detected at a rate of $\sim 3.2$ h$^{-1}$ with a simple array of three Geiger-Müller counter trays $C$ (Fig. 1) operated in coincidence (resolving time 5 usec). These detectors also included smaller counters which operated a hodoscope; the display on this
Follow-up Experiments:

1. Replace EAS array by Channel light telescope 2 x 10^13 sr
   10^4 cm² - no upper radio fula

2. Radar Telenets (15 m) @ 150 MHz, 20 - 1 kHz
   No radio fula at 150 MHz
   Time "m" at 44 kHz
   Consistent well in coherence

Possible Alternative Mechanisms:

(a) Cosmic rays hitting receiver/amplifier
(b) Reflection of TV signal
(c) Brain stimulation
(d) Transition Radiation
(e) Induction at Aerial
(f) Molecular emission
Radio Pulses from Extensive Air Showers.

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(ricevuto il 17 Giugno 1966)

Summary. — Radio pulses of short duration (\(< 0.15 \mu s\)) have been observed at a frequency of 44 MHz (\(\lambda = 6.8 \text{ m}\)), in coincidence with extensive cosmic-ray air showers having \(\sim 5 \cdot 10^6\) particles. The energies of these pulses ranged from \(\sim 10^{-12} \text{ erg}\) (receiver noise level) to \(\sim 10^{-9} \text{ erg}\). The preliminary results reported briefly elsewhere\(^{(19,27)}\) were consistent with the hypothesis that the observed pulses arose as a result of enhanced Čerenkov radiation at low frequencies\(^{(19)}\). However, following the treatment of Kahn and Lerche\(^{(14)}\), it is evident that the observed energy of the radiation is also consistent with charge separation effects in the earth's magnetic field. Experiments at a higher frequency (150 MHz, \(\lambda = 2 \text{ m}\)), and a tentative analysis of the pulse-height spectrum, suggest that the radiation observed is enhanced by effects of mutual coherence among the particles in the shower. The paper concludes with a discussion of other alternative radiation mechanisms.
This large transit telescope, as it became known, was a great success. Early in the autumn of 1947 we tried some experiments with it to detect the cosmic ray showers but by that time the new instrument was proving to be so valuable in other fields of work that we eventually gave up the cosmic ray experiment.¹

¹ By a strange twist of fate a successful experiment to detect the emission of pulses of radio energy from cosmic ray showers was carried out at Jodrell Bank in 1964 by Prof. Graham Smith and his colleagues. As far as I am aware the radio echo experiment which I originally proposed has never been revived.

² Miss Ella Ryder, subsequently Mrs. Ella Bradley, who still works part of the day at Jodrell.
A radio system for the detection of air showers.

Porter, C. D., Mageen, D., Munncahaney, L. T., Magnecks, N. A.,

EAS 28

In conclusion then the assessment of the technique by Greisen (98) at the London Conference might be considered. "The technique is barely in its infancy, and too little is known about it to justify elaborate predictions. However, we feel confident that this achievement is a significant breakthrough, and that further study will reveal ways of obtaining types of information about the showers that were not available by other means. The signal will not, of course, be sensitive to fine details like the structure of the shower core; nor does the method seem adaptable to surveying at the same time all directions in which showers may arrive. However, it appears that the method may offer new orders of angular resolution; and it may complement particle detectors by being sensitive to the condition of the showers far above ground level. Also it will be able to detect showers in steeply inclined directions, in which the particles are absorbed before reaching the ground. Time will probably reveal many other possibilities that are not apparent at this early stage."