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Measurements of radio pulses from EAS and their dependence on shower parameters

N Mandolesi, G Morigi and G G C Palumbo
Consiglio Nazionale delle Ricerche, Laboratorio di Tecnologie e Studio delle Radiazioni Extraterrestri, Via de' Castagnoli, 1, 40126 Bologna, Italy

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Abstract. One year's data on radio pulses from EAS at three frequencies (46, 65, 110 MHz) from the Medicina array have been analysed. The dominance of the geomagnetic production mechanism is confirmed. The frequency spectrum between 46 and 65 MHz appears to be flat. The detected electric field strength E_ν has been considered as a measure of primary particle energy, and its value is correlated to shower size N and particle density ρ at 50 and 100 m from the shower axis in order to study EAS longitudinal fluctuations. Errors on each measured quantity are discussed, and it is shown that fluctuations are present.

1. Introduction

Evidence for fluctuations in the longitudinal development of extensive air showers (EAS) can be a clue in understanding the nature of the primary cosmic ray particles. Fluctuations in shower development can be seen, for instance, in measuring EAS sizes or densities of electrons near the shower core. On the other hand, one needs energy dependent parameters like muon size N_μ or density of particles at about 500 m from the shower axis (the well known parameter ρ_{500} measured at Haverah Park) which are relatively independent of fluctuations. The radio field strength E_ν near the shower axis, has also been shown (Allan *et al* 1975) to be a parameter independent of fluctuations, which measures primary energy. With these parameters at hand, investigations of the radio emission from EAS can be carried out in order to gain information about primary cosmic rays.

2. Experimental procedure

In order to investigate these problems, measurements have been carried out using the Medicina EAS array at three antenna sites with antennae tuned to 46, 65 and 110 MHz respectively. All frequencies had EW and NS polarizations. EAS were triggered by an array of six 1 m^2 plastic scintillators (figure 1). The results presented here refer to showers detected during the period February 1973–May 1974. Preliminary results on a small sample of data have been presented elsewhere (Mandolesi *et al* 1973). The Medicina array triggers on showers of size $N > 5\times10^5$ particles and for each shower detected one obtains θ the zenith angle, Φ the azimuth angle, the coordinates of the shower core and the shower size N. The accuracy of the shower axis location is found to

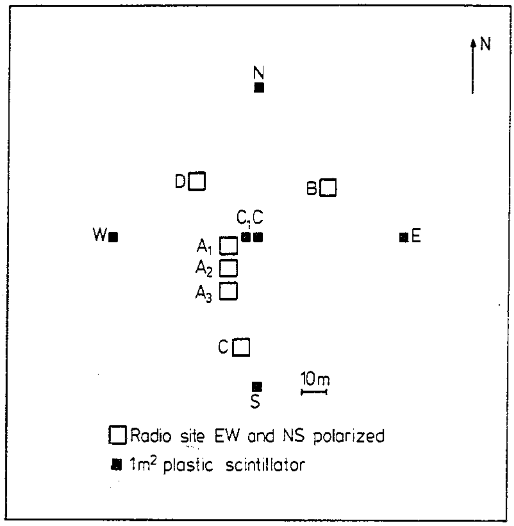

Figure 1. The Medicina EAS array. $A_1 = 46$ MHz, $A_2 = 65$ MHz, $A_3 = 110$ MHz. Data from antenna sites B, C and D are not included in the present work.

within about 5 m. The triggering mode is a 3-fold coincidence in which one of the scintillators involved is always the central counter C plus any two of the outer ones (see figure 1). The average rate registered throughout the experiment was around 3 EAS h^{-1}. Only showers with $\theta < 35°$ are included in the present analysis. The data discussed here refer to showers detected only during clear weather conditions since anomalous results have been obtained during thunderstorms. The nature of these anomalous showers has been previously discussed (Mandolesi *et al* 1974) and also recently noticed by others (Allan *et al* 1975, Atrashkevich *et al* 1975).

3. Experimental results

To investigate the nature of the radio pulse production mechanism, only data from the two lower frequencies, namely 46 and 65 MHz, have been used since the NS 110 MHz channel was found to saturate.

The ratio of the two measured components of the electric field strength (E_{EW}/E_{NS}) has been compared with the expected values calculated according to the two models of geomagnetic charge separation and charge excess (Allan 1971). The results are shown in table 1. It can be seen that the geomagnetic mechanism is by far the dominant cause

Table 1. Percentage of showers where the measured value E_{EW}/E_{NS} agrees with the given mechanism.

Frequency ν (MHz)	Geomagnetic charge separation (%)	Charge excess (%)
46	77	35
65	87	15

of pulse production although some contribution from charge excess may not be excluded. This must be a qualitative indication only because it is very difficult to place in a more quantitative form due to the errors on the measured electric field strength which are hard to evaluate. In what follows, typical errors on the measured values of the electric field strength through gain and temperature variations etc in the electronics are about 30%. From the result obtained (table 1), one can nevertheless feel reasonably confident that the bulk of the observed radio signals is of geomagnetic origin and so an attempt can be made to verify the predictions of the theory (Allan 1971). Radio lateral distributions in this case are not informative because, with the Medicina array, showers are detected mostly near the core and radio signals measured mainly at distances $R<150$ m from the axis where the lateral distribution is predicted to be fairly insensitive to shower fluctuations. Furthermore, radio lateral distributions are best measured with many antenna sites observing a single shower at the same time rather than by grouping similar showers which fall at various R. Three more antenna sites have been constructed and are now in operation; the results will be given in a following paper.

The lateral distributions obtained, however, appear to agree with predictions (Hough 1973) and previous measurements (Allan *et al* 1975, Atrashkevich *et al* 1975), even for measurements very close to the shower axis; they are in fact rather flat.

The frequency spectrum has been obtained from the average values of $E_\nu/\sin\alpha$ (in μV m^{-1} MHz^{-1}) at three frequencies (here E_ν is the electric field strength at frequency ν and α is the angle between the shower axis and the earth's magnetic field). The values obtained are given in table 2 where the standard deviations represent point scatter and

Table 2. Average field strength values $E_\nu/\sin\alpha$ for our three frequencies for $R<100$ m.

Frequency ν (MHz)	$E_\nu/\sin\alpha$ (μV m^{-1} MHz^{-1})
46	14±7
65	14±6
110	16±11

are larger than errors on single measurements. Here again the 110 MHz values show large scatter because of the previously mentioned uncertainties in field strength measurements. The distribution of measured values of $E_\nu/\sin\alpha$ at 65 MHz for distances $R<100$ m is shown in figure 2.

The field strength appears to be very nearly constant between 46 and 65 MHz and this is in good agreement with theoretical calculations (Hough 1973). An experiment sensitive to fluctuations in longitudinal shower development should include a parameter uniquely related to primary energy as well as one or more parameters strongly affected by shower development, as has been suggested by Dixon *et al* (1973). It has been shown theoretically and experimentally (Allan *et al* 1975, Atrashkevich *et al* 1975) that the electric field strength E_ν can be considered as a measurement of the primary energy E_p.

The shower size N or particle densities ρ near the core, on the other hand, strongly reflect the depth of the shower maximum and the depth of the first primary interaction (Dixon *et al* 1973, Marsden 1971). One can then use these parameters in order to detect fluctuations in shower development. Figure 3 shows $E_\nu/\sin\alpha$ as a function of

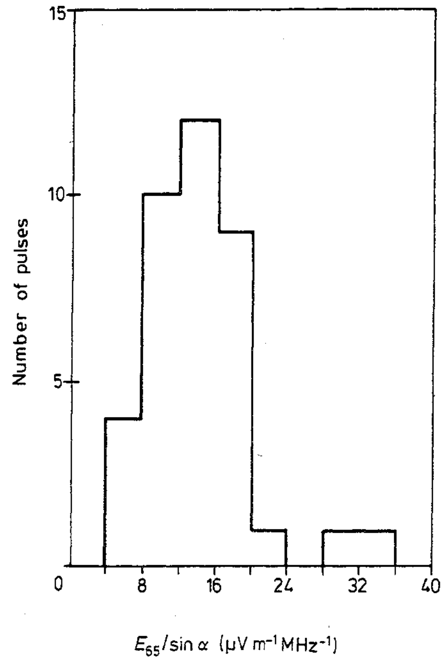

Figure 2. Distribution of the electric field strength measured at 65 MHz for distances $R < 100$ m from the shower axis. The mean value is $14 \pm 5\ \mu\text{V m}^{-1}\ \text{MHz}^{-1}$ (see table 2).

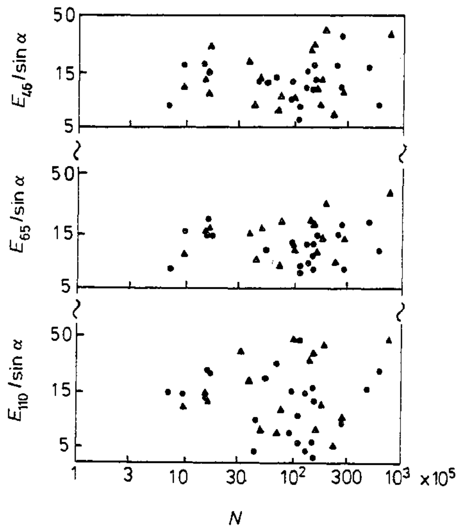

Figure 3. Measured electric field strength (in $\mu\text{V m}^{-1}\ \text{MHz}^{-1}$) at the three frequencies against shower size N for two ranges of distance from the shower axis. ▲, $50 < R \leq 100$ m; ●, $R \leq 50$ m.

size N. Different symbols indicate measurements with $R < 50$ m and $50 < R < 100$ m from the axis for the three frequencies. Because of the possible uncertainties intrinsic to our array in estimating the value of N however, the same values of E_ν normalized to

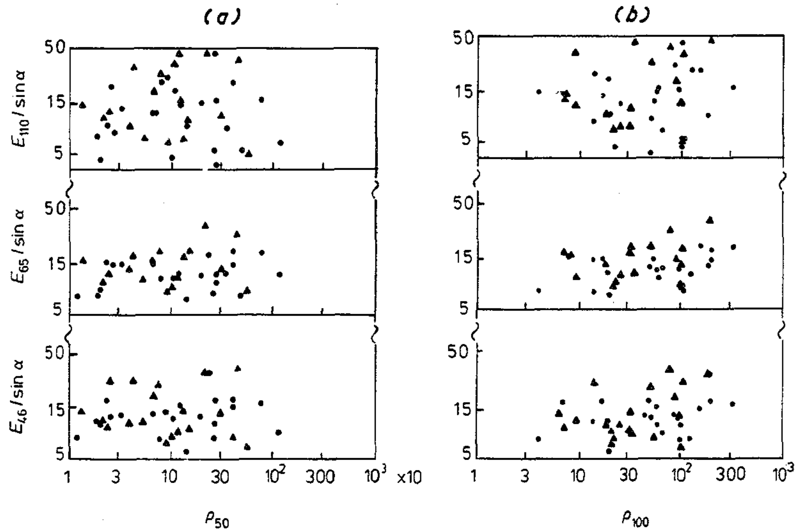

Figure 4. Measured electric field strength (in $\mu V\ m^{-1}\ MHz^{-1}$) at the three frequencies as a function of particle density: (*a*) at 50 m from the shower axis; (*b*) at 100 m from the shower axis, ▲, $50 < R \leqslant 100$ m; ●, $R \leqslant 50$ m.

$\sin\alpha$ have been plotted against the corresponding particle densities at 50 m (figure 4(*a*)) and 100 m (figure 4(*b*)) from the shower axis.

These quantities are more reliable because they are measured values whereas a model is needed to estimate *N*, and errors can also be experimentally evaluated using the two adjacent scintillators C and C_1 at the centre of the array (figure 1).

In figure 5, the histogram of the ratio

$$(\rho_{C_1} - \rho_C)/\rho_C$$

is shown (ρ_C and ρ_{C_1} represent the particle densities in scintillators C and C_1 respectively). It was found that for about 240 showers, the standard deviation on density measurements is 44%.

This value was taken to be a representative one for errors in measurement and sampling on ρ_{100}. Although large, these errors do not account for the entire spread of values for ρ_{50} and ρ_{100} in figure 4. This spread, it should be noted, is of the same order of magnitude as the spread of values in figure 3.

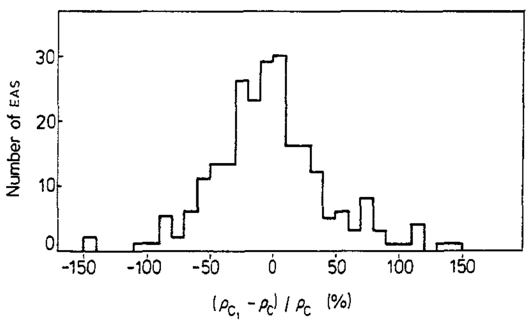

Figure 5. Counting rate differences in the two adjacent scintillators C and C_1 (see figure 1) for 239 showers; $\sigma = 44\%$.

4. Conclusions

The data from the Medicina array indicate that fluctuations are present. We evaluated the contribution due to EAS longitudinal fluctuations from the spread in the distribution of ρ_{50} and ρ_{100} assuming that the standard deviations of $E_\nu/\sin\alpha$ imply only small variations in E_p. The Moscow group (Atrashkevich *et al* 1975) has evaluated the intrinsic spread of the measured values of $E_\nu/\sin\alpha$ normalized to N_μ (i.e. to E_p) and they found that the relative RMS is less than 30% for distances between 50 and 150 m from the shower axis. We find that the standard deviations for the average values of $E_\nu/\sin\alpha$ at 46 and 65 MHz are 50% and 40% respectively. These values are slightly larger than the one given by Atrashkevich *et al* (1975) because of a lack of normalization to a parametric sensitive to primary energy; however they take into account the intrinsic spread in primary energy, which evidently is not too large. This substantiates our previous statement that the spread found for $E_\nu/\sin\alpha$ implies only a small variation in E_p. If the spread in ρ is due to three independent causes, i.e.: errors in measurement and sampling, intrinsic spread in E_p and longitudinal shower development fluctuations, quantitatively one obtains the standard deviations of table 3 which are due, in this hypothesis, to longitudinal fluctuations alone. These values, it must be pointed out, are in good agreement with Monte Carlo theoretical calculation for primary protons (Marsden 1971, Dixon *et al* 1973).

Table 3. Relative standard deviations of ρ_{50} and ρ_{100} at 46 and 65 MHz indicating the amount of intrinsic longitudinal shower fluctuations.

	46 MHz	65 MHz
ρ_{50}	102%	100%
ρ_{100}	69%	75%

The same indications have been obtained by the Moscow group (Atrashkevich *et al* 1975) measuring radio lateral distributions at large distances from the core. Their conclusion is that the observed fluctuations are indicative of the presence of a proton component in the primaries. The Haverah Park group however (Allan *et al* 1975) has come to the conclusion that such an effect cannot be detected. Therefore, the evidence from the experimental side is not conclusive.

Acknowledgments

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