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The Distribution of Time Intervals between Cosmic Ray Showers—A Study of the Randomness of Cosmic Ray Arrival Times

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Abstract

It has recently been reported that cosmic ray showers arrive in an appreciably nonrandom manner with an excessive number of short time intervals between showers. We have investigated the distribution of time intervals between showers of size $N_e \gtrsim 10^5$ and find that if there is any excess of short intervals it must be $\lesssim 5\%$.

It is conventional to assume that high energy cosmic rays are detected in the vicinity of the Earth at random times. Any deviations of massive particle primaries from random arrival distributions are expected only due to the lack of isotropy in the source distribution of particles such as might cause a time correlation on a diurnal basis. Weekes (1971) has pointed out that if gamma rays contribute to the high energy cosmic ray flux, nonrandom variations might occur on a time scale of pulsar periods. We might also add that gamma-ray bursts might also provide very high energy correlated photons. However, the (poorly) measured energy spectra of photons from these sources would not lead one to expect to detect an appreciable correlated flux in the extensive air shower energy range. Bhat *et al.* (1979) have recently studied the distribution of time intervals between cosmic ray showers of primary energy $\geqslant 10^{14}$ eV over rather short time periods (up to ~ 150 s) and appear to find an excess of intervals between showers in the time period range from 1 to 25 s. This they suggest may be associated with a lack of small scale irregularities in the interstellar medium. We have studied the time interval distribution for cosmic ray showers of sea-level size $N_e \gtrsim 10^5$ (primary energy $\gtrsim 10^{15}$ eV) over the time range from 0 to 1200 s to search for this effect. The search has so far proved unsuccessful.

Our experimental work has been carried out at the Buckland Park Air Shower Array of the University of Adelaide (Crouch *et al.* 1977). This array consists of eleven 1 m^2 plastic scintillators with a total enclosed area of $\sim 30\,000$ m^2. Showers are detected when two detectors separated by $30\sqrt{2}$ m trigger in coincidence at levels of six particles and eight particles. The mean trigger rate is ~ 8 h^{-1}. The distribution of detected shower sizes is shown in Fig. 1 and there is a median shower size of $\sim 2 \times 10^5$ as determined by shower analyses employing all eleven scintillators.

When a coincidence is detected, the local time, detector densities, relative arrival time of particles at the detectors, barometric pressure, etc. are all recorded on magnetic tape for further analysis. In order to allow for the recording of these data and those from other subsidiary experiments, a dead time of 30 s is built into the coincidence system and further coincidences are inhibited for this time. Since we record the local time of each event, it is possible for us to determine the time between any of our events merely by an examination of their relative arrival times. The local clock records times to the nearest second and the time between any pair of recorded events is therefore known to roughly this accuracy. We have examined our data recorded over a period of 17 months and determined the distribution of time spacings of these events. This distribution is shown in Fig. 2.

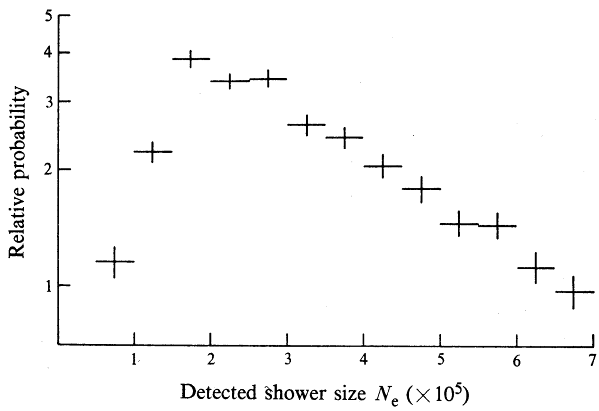

Fig. 1. Distribution of the relative probability of shower sizes detected by the Buckland Park Array.

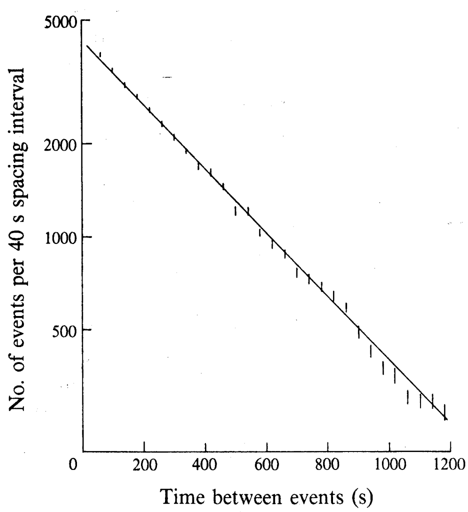

Fig. 2. Distribution of time spacings between events detected and recorded for routine analysis. In this mode of operation, the array has a built-in dead time of 30 s. The line has a slope corresponding to the best fit exponential with a time constant of 415 s.

The period of particular interest to Bhat *et al.* (1979) was the interval from 1 to 25 s and the recording dead time of our system precludes us from obtaining any significant information within this period using our routinely recorded data. We have therefore run a second independent time interval experiment to investigate this period. We take the outputs of the two triggering discriminators and look for *all* coincidences between them irrespective of any dead time in the main array recording system. These coincidence pulses are then fed to a Commodore PET computer which uses its internal clock to measure and record the interval between each pair of events. We are thus able to obtain a time interval distribution for all our air shower events. This experiment has been run for a period of one month and 1493 intervals have been recorded up to 390 s. These data are displayed in Fig. 3.

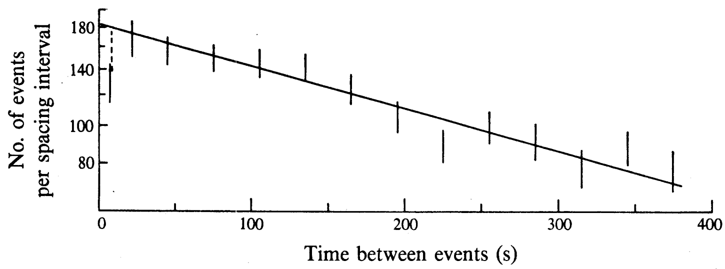

Fig. 3. Distribution of time spacings between air shower events with a recording system having minimal dead time. The first spacing bin is corrected for dead time effects as shown by the dashed error bars. The line has the same form as that shown in Fig. 2.

The distribution of intervals between random events is well known to be of an exponential form (see e.g. Reif 1965). The most probable interval is the shortest and the probability of obtaining a given interval decreases exponentially as the ratio of the period to mean period increases, i.e.

$$\text{Prob(spacing)} \propto \exp(-\text{spacing}/\text{'mean spacing'}).$$

Figs 2 and 3 show our experimental spacing distributions and it is clear that the extensive air showers which we observe (those with a shower size $N_e \gtrsim 10^5$) arrive in a random manner and produce exponential interval distributions. Fig. 2 shows that there is a good fit for spacings between 30–1200 s and Fig. 3 indicates that this fit also is acceptable to the intervals below 30 s. Roughly 7% of all possible events are lost in the 30 s dead time associated with the data of Fig. 2 but this does not materially affect the randomness argument for the data displayed. Some events ($\sim$7%) which contribute to the first bin in Fig. 2 actually correspond to spacings of less than 30 s due to the non-observation of inhibited coincidences.

There is no obvious suggestion of any deviation from an exponential distribution in Fig. 2, in particular there is no clear steepening at small time intervals. We have checked this by determining the 'mean spacing' in fits to the exponential over different periods. As may be seen from the following values of the 'mean spacing', the slope of the exponential is not significantly steeper at smaller periods:

All available data	415 ± 4 s
Spacings up to 200 s	395 ± 22 s
Spacings from 440 to 1200 s	418 ± 8 s

Any excess that there might be is limited by the statistical uncertainty in the bins at lower spacings and is $\lesssim 2\%$ (σ).

Fig. 3 shows our direct check on periods less than 30 s. Any dead time associated with these data is much less than 1 s. It has only a small effect but a correction is included in the lowest spacing bin. Fig. 3 includes a line of similar slope to the data in Fig. 2 and it is clear that this is a perfectly adequate fit. The data obtained for spacings below 30 s show again that any excess must be $\lesssim 5\%$, much less than that obtained by Bhat *et al.* (1979).

Our data are for showers whose primary energies are an order of magnitude greater than those studied by Bhat *et al.* using their atmospheric Cerenkov technique. It may be that our inability to confirm their observations is due to this increase in energy and hence the difference in radius of gyration of the primary cosmic ray in the galactic magnetic field. On the other hand, in order to obtain a good exponential form to the spacing distribution, it is necessary that the experimental apparatus be maintained in a very stable manner over the full period of the experiment (see e.g. Clay 1974). In particular, discrimination thresholds must be kept stable in terms of input amplitudes. This is very difficult for atmospheric Cerenkov experiments where the background light is continually changing due to the motion of the heavens, and the photomultiplier detector gains may be dependent on the background light. It may be that the experiment of Bhat *et al.* suffered to a small extent from this difficulty.

An alternative possibility might be that the high energy cosmic ray flux contains a correlated component (e.g. photons) with a cutoff at $\sim 10^{14}$ eV. If this is so, one might search for point sources for the correlated events.

To conclude, the distribution of time intervals between cosmic ray showers has been studied for showers with sea-level size $N_e \gtrsim 10^5$. No nonrandom effects have been found greater than a statistical uncertainty of $\sim 5\%$ in the time interval below 30 s. The experiment thus fails to confirm the observations made by Bhat *et al.* (1979) using atmospheric Cerenkov techniques.

Acknowledgments

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