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INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part III

# III-2-11. Photography of Extensive Air Showers in Cerenkov Light

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Several authors have shown that Cerenkov light from extensive air showers can be detected above the background light of the night sky; and that showers of primary energy about $10^{13}$ eV can be observed at high counting rate with a simple optical system and photomultiplier at sea level[1,2]. Since the Cerenkov light from a particle in air is emitted at directions close to the particle direction, the angular distribution of light from the shower should be centred about the shower direction; this combination of high counting rate with directional properties at low energies presents attractive possibilities for use of the night sky technique in the search for showers initiated by primary $\gamma$-rays. Work in Sydney[3], and in Dublin, however[4], implies that the angular distribution of light from the showers is very wide, because of Coulomb scattering of the shower electrons, so that selection of shower directions by optical methods will be unreliable. The alternative method, of using timing techniques with several detectors, which has been used successfully at higher energies[4,5], would be difficult to extend into the region $10^{13}$–$10^{12}$ eV where $\gamma$-rays are expected, and has limited directional accuracy. Similar difficulties arise in the application of the method to studies of the development of the showers, and to detection of large showers at very great distances from the axis. More direct and reliable information could be obtained if the light from the showers could be photographed directly.

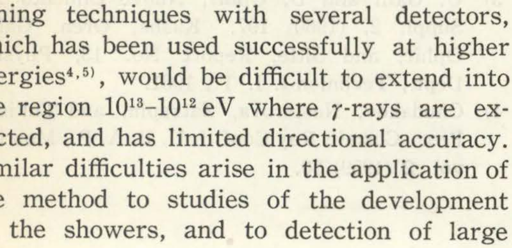


Fig. 1.

We have used an image intensifier system (Fig. 1), triggered by amplified pulses from a five-inch photomultiplier, in an attempt to photograph the showers. The system consisted of a Schmidt mirror of 30 cm diameter, and nominal aperture f/0.5, but with usable area only 300 cm². It had an acceptance cone of half-angle 17° about the zenith, and was focussed for infinity on the 5-inch photocathode of an image intensifier (Westinghouse WX 4171). This was run continuously, and integrated night sky light over the decay time of the P 15 phosphor, nominally 1μsec. It was coupled optically to a 3-stage cascaded intensifier, (R.C.A. C 73491) which was normally gated off, and which was followed by an intensifier orthicon with kinescope display. The intensifier system was previously used with a scintillation chamber, and is described elsewhere[6]. In the night sky experiment we were limited by background, and the system was operated at a gain of the order $10^4$, well below that possible. The experiment was carried out at the Agassiz Observatory of Harvard University (100 metres a.s.l.).

Light pulses were accepted by the photomultiplier trigger over a cone of half angle 50°, so that selection was isotropic over the field of view of the Schmidt system, but not all selected showers were visible to it. The minimum detectable pulse for a receiver of this type has been estimated at 14 photons/cm² by Barclay and Jelley[7], and corresponds to a shower size of about $5 \times 10^4$ particles at sea level.

Operation was possible under clear sky conditions for a period of eight hours, and

32 shower pulses were observed. A random pulse was applied a few second after each Čerenkov pulse, to obtain a comparison picture. Ten of the Čerenkov photographs show bright spots, 2°-5° in diameter (Fig. 2). Some of these are circular, but some have appreciable ellipticity. The variation of intensity over the spots cannot be measured, but some of the events show orthicon blackout at the centre, indicating appreciable brightness variation. No spots of comparable size or brightness were observed in any of the 32 comparison pictures, though stars appear on both Čerenkov and random exposures. On covering the system, the field becomes dark.

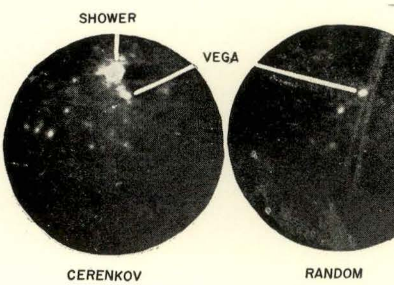


Fig. 2.

In one case, first magnitude star $\alpha$-lyrae (Vega), also appears in both exposures, and this can be used to obtain a lower limit for the brightness of the spot. The duration of the gating pulse was 2 $\mu$ sec, but it is known from previous work with the system that the effective integration time is about 10 $\mu$ sec, arising mainly from a slow component in the first phosphor. For continuous incoming light, equilibrium is reached, and the number of photons observed should depend only on the duration of the gating pulse, but there is probably some contribution from light leakage through the un-gated tube. We can set the contribution from Vega, therefore, only between the limits 2 photons/cm$^2$ (for a 2 $\mu$ sec exposure), and 10 photons/cm$^2$ (for a 10 $\mu$ sec exposure). From the film density we estimate that the shower pulse intensity is at least five times that from the star, or from 10 to 50 photons/cm$^2$; consistent with that expected for a triggering system of the type used. The evidence indicates that we are photographing Čerenkov light from air showers.

The centres of the shower spots can be determined to an accuracy approaching 0.1°, but it remains to be proved that this is in fact the true direction of the shower. Calculations from cascade theory, which predict an angular distribution consistent with that observed by the Sydney group, indicate a progressive displacement of the mean direction of the light from the true direction of the shower as the distance of the shower core from the detector increases. This displacement reaches a value of about 2° at a distance of 250 metres, and since the lateral distribution of light is very flat, appreciable contributions to the total rate would be expected from large distances[5]. There is also, however, a progressive broadening of the angular distribution of the light with distance, and the development of a marked ellipticity. It would appear feasible, at energies of $10^{12}$-$10^{13}$ eV, where the displacements are less serious than at higher energies, to obtain angular resolutions better than 1° with either an image intensifier system; or with photomultipliers, using an anticoincidence system to reject pulses having a broad angular spread. The use of an intensifier system at low energies is limited by the necessity of integrating the background light of the sky over a time long enough to switch on the system after the pulse has arrived. Work is in progress in Dublin on the construction of an optical delay system, using a large coelostat mirror, by which it is hoped to eliminate phosphor storage, and to carry out a survey of likely sources of $\gamma$-rays, using a field of view of about 3°. Photographic recording of images from a five-stage magnetically focussed tube will be used, with a one-metre f/0.5 paraboloid mirror.

At higher energies, where the available light flux is greater, the method of light storage used in this experiment would be feasible, and the intensifier technique appears to have possibilities in the study of shower development, the detection of the rare multiple core showers, whose existence is established statistically[8,9], but about which little is known; and in the detection of very large showers at great distances from the axis.

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# III-2-12. Cerenkov Radiation from E.A.S.

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Exploratory experiments have been made using narrow angle detectors of the atmospheric Cerenkov light emitted by E.A.S. whose size, core location and direction of incidence were determined with a scintillator array. The results are consistent with a proposed interpretation which leads to the conclusions (i) that the angular distribution of the light is broad and is determined by the Coulomb scattering of the emitting electrons, (ii) that the Cerenkov light pulse received is to a first approximation proportional to the mean particle density integrated along the axis of the detector and (iii) that for such a detector close to the shower axis the maximum contribution to the detected light pulse from most of the detected showers is generated below an altitude of one kilometre.

## Introduction

As has been pointed out by Chudakov[1] the Čerenkov radiation emitted by an air shower in its traversal of the atmosphere, together with its size on reaching ground-level, may be expected to provide information about the development of the shower through the atmosphere.

With this same purpose in mind experiments were commenced in Sydney in 1957. A directional Čerenkov detector was used consisting of one or more photomultipliers at the focus of a parabolic mirror staring into the night sky as part of the Sydney scintillator array. From this array were obtained the shower size, core location and direction of each shower recorded (Brennan *et al*[2]). With this apparatus light pulses were ob-

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