

APPLICATION OF IMAGING TO THE ATMOSPHERIC CHERENKOV TECHNIQUE

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1. Introduction. Turver and Weekes (1977) proposed using a system of phototubes in the focal plane of a large reflector to give an air Cherenkov camera for gamma ray astronomy. A more detailed description of a detector based on the 10m Optical Reflector at the Whipple Observatory was given by Weekes (1981) and Fegan et al. (1983). Preliminary results with a 19 element camera have been reported previously (Cawley et al. 1983). In 1983 the camera was increased to 37 pixels; it has now been routinely operated for two years and some results are presented at this conference (OG 2.3-1, 2.1-11, 2.2-9, 2.7-3, and 2.4-4). In this paper we present a brief physical description of the camera, its mode of operation, and the data reduction procedures; the Monte Carlo simulations on which these are based are also reviewed.

2. The Camera. Each of the 37 camera pixels is a 5cm diameter RCA phototube, 6342A (S11 photocathode). The phototube layout is shown in figure 1; to allow space for the magnetic shields the spacing between centers is 6.25cm. The focal plane scale is 1° per 12.5cm; the useful area of each photocathode is equivalent to 0.36° so that the useful coverage of the full 3.5° diameter field is approximately 50%.

A typical integral pulse height spectrum for a single camera pixel is shown in figure 2 and the trigger level, corresponding to 45 ± 12 photoelectrons, indicated. The absolute gain of each pixel was determined at monthly intervals using an Americium light source which had been previously calibrated against a muon Cherenkov telescope. The relative gain correction was determined by uniformly illuminating all pixels with a pulsed N₂ light source; this was done at the beginning and end of each night's observation.

3. Operating Mode. Observations were only attempted when sky conditions were excellent. Each set of observations consisted of a pair of tracking scans over the same range of azimuth and elevation angles. In one of these, the ON run,

the reflector was directed at the suspected source. The OFF run was offset by 30 minutes of Right Ascension. The order of ON and OFF runs was interchanged to reduce the possibility of systematic errors.

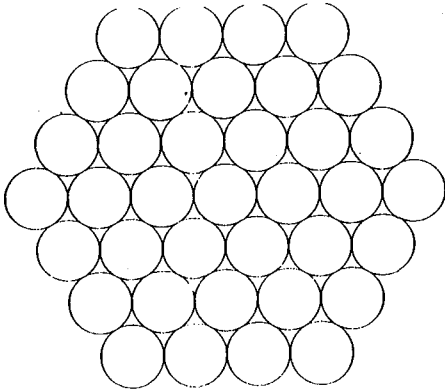


FIG. 1 Phototube Layout

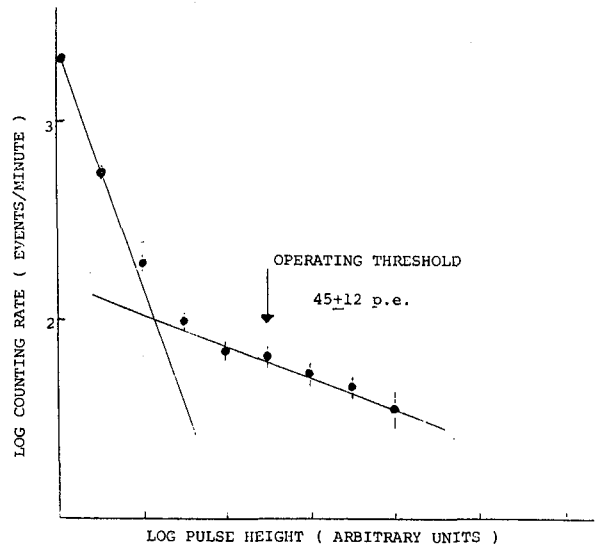


FIG. 2 Integral Pulse Height Spectrum

4. Simulations. The original concept of the camera (Weekes 1981) was based on the Monte Carlo simulations of Rieke (1969) which gave the average features of 250 gamma-ray initiated showers. Realistic estimates of the performance of the camera required that fluctuations be taken into account as well as the geomagnetic field. To optimise the selection of gamma rays, hadron-initiated showers must also be simulated.

Three sets of simulations of shower images measured by the Whipple Observatory camera are discussed below; because the conditions assumed are somewhat different, it is not possible to compare these quantitatively. Some large qualitative differences are apparent and are unexplained.

(a) Durham simulations. The Durham Monte Carlo program, which was previously used to evaluate the performance of the 10m reflector in a single detector mode (Browning and Turver 1975), was used to simulate the response of the camera to 300 and 1000 GeV gamma-ray initiated showers (Turver, private communication, 1983). The results were quite different from those expected, with fluctuations dominating the shape and orientation of the shower images. The angular width of the shower was smaller than that of the background events measured by the camera (MacKeown et al. 1983); the orientation of the shower major axis showed little correlation with the position of the shower relative to the optic axis and thus suggested that

detailed processing of the shower images would be of limited value.

(b) Altai simulations. Plyasheshnikov and Bignami (1984) have used a compressed Monte Carlo method to evaluate the effectiveness of imaging in improving the sensitivity of the atmospheric Cherenkov technique. They simulated the response of a 10m reflector to both gamma-ray and proton initiated showers for energies from 0.1 to 2.0 TeV. They concluded that there was no difference between the average size of two kinds of images but the orientation i.e. radiating out from the center, would permit the preferential selection of gamma-ray initiated showers. This conclusion is in obvious disagreement with (a). They also suggest that the greater fluctuations along the major axis in proton-initiated showers could be used statistically to discriminate against the proton background.

(c) Leeds simulations. Hillas (this conference OG9.5-3) has simulated the response of the 10m reflector to both photon and proton-initiated air showers taking into account the optical parameters of the 10m reflector. He has simulated the expected response of the system to a proton-initiated background using typical operating parameters. The agreement between the simulated and measured background is good and suggest that the experimental parameters have been realistically accounted for.

Significant differences are found between the gamma-ray and proton shower images; in particular the angular size of the gamma-ray shower is almost a factor of two smaller than that of the proton image. In addition the gamma rays originating from a point source on axis are radially distributed as predicted in (b). Because the angular size of the images is comparable to the pixel size, this radial distribution is difficult to measure with the Whipple Observatory camera.

5. Data Reduction Procedures. All data is reduced off-line using a variety of selection algorithms designed to optimise the detection of a gamma ray signal. Because there is some disagreement between the simulations it is not possible to isolate a single algorithm that will maximise the selection efficiency. Instead the development of an algorithm is an iterative process with the selection criteria initially based on the simulations and modified after feedback from tests on actual data suspected to contain a gamma-ray source that can be regarded as a standard candle.

After calibration, data is sorted according to the following general criterion: (a) all data, (b) data sorted according to total brightness (shower energy), (c) data sorted by size and/or shape, (d) data sorted by orientation, (e) some combination of the above.

An early selection, suggested by the Durham gamma-ray

simulations, was the use of the parameter, r to select compact (small angular size) showers as candidate gamma rays. $r = (p_1+p_2)/\text{total}$, the fraction of the light intercepted by the camera that is contained in the two highest pixels). This is confirmed by the Leeds simulations which show that the greater angular size of proton showers arises from greater width along the major axis caused by the greater penetration of the proton shower and along the minor axis caused by hadron interactions in the proton shower.

Following the Plyasheshnikov and Bignami (1984) the effectiveness of a selection procedure is the improved signal-to-noise ratio

$$h = \frac{A'_\gamma}{A_\gamma} \left(\frac{A'_h}{A_h} \right)^{-1/2}$$

where A_γ and A_h refer to the collection areas for gamma-ray and proton showers without selection and the dashed values are the post-selection values. h can be evaluated from the simulations where the source and background spectrum must be taken into account. The factor (A'_h/A_h) can be evaluated empirically since it is the ratio of event rate after and before selection. At the zenith this is 0.016. Using the Durham simulations A'_γ/A_γ is 0.5; the Leeds simulations indicate a higher value, so that $h > 4$ at the zenith. It falls off with zenith angle becoming ineffective for $z > 300$. As discussed in Hillas (1985) the combination of r with other measured parameters can be expected to significantly improve the value of h .

Using the method described in Weekes (1976) and the Durham simulations, we derive the effective energy threshold, $E = 200$ GeV and the gamma-ray collection area ($A'_\gamma = 9.4 \times 10^3 \text{m}^2$).

6. Acknowledgements. This work was supported by the U.S. Department of Energy, the Smithsonian Scholarly Studies Fund and National Board of Science and Technology of Ireland.

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