THE UNIVERSITY OF DURHAM MARK III VERY HIGH ENERGY GAMMA RAY TELESCOPE

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ABSTRACT

A new very high energy gamma-ray telescope employing the atmospheric Cerenkov light technique and currently nearing completion is described. The telescope is designed to have capability as both a wide angle instrument (4 degree field of view) for sky survey work and as a narrow field of view instrument (1.35 degrees) for conventional drift-scanning and tracking modes of operation. The telescope consists of two 10 sq. m. mirrors operated in fast coincidence with multiple phototube assemblies at the prime focus of each mirror. The design philosophy of the instrument is discussed and comparisons of its performance with our previous telescopes are made.

1.INTRODUCTION

During the period 1981 - 1984 we operated a very high energy gamma-ray (> 1000 GeV) facility at Dugway, Utah, U.S.A (1). This facility initially comprised an array of four telescopes, each consisting of three 1.5 m diameter searchlight mirrors focussed onto three phototubes. Each set of phototubes was operated in fast coincidence, which enabled us to maintain a high gain and singles counting rate (~ 30 kHz) but have a negligible accidental (noise) coincidence rate.

In an attempt to overcome the restrictive optics enforced by the use of f(0.4) searchlight mirrors and to optimise the mirror design for VHE gamma-ray astronomy, in 1983 one of the telescopes was remirrored with purpose-built mirrors. Mirrors of focal length 2.2 m were employed which gave a 1.25 degree field of view using 2" phototubes, compared with the original field of view of 1.75 degrees. Operation of the modified (Mark II) system along side the original (Mark I) system has shown that the narrowing of the field of view has achieved its design objective in improving the ratio of detected gamma-rays to background cosmic ray events for discrete objects. We believe that the geometrical aperture of the Mark II telescope is near optimum, eliminating a maximum number of off-source protons but allowing detection of all gamma-rays from a point source in the centre of the field of view.

The Dugway facility has proved successful during its four years of operation. Numerous sources of VHE gamma rays have been discovered or confirmed. The strongest source detected to date (4U0115 +63,(2)) required observation for 25 hours to give a detection significant at the 4.4 σ level, with proportionally longer periods required for weaker sources. When available observing time is taken into account, this limits the number of thorough examinations of source candidates to 3-4 per year with the original telescopes. Clearly, to fully exploit this energy range of the electromagnetic spectrum, a much more sensitive telescope is required.

2.TELESCOPE DESIGN The Mark III telescope will be capable of operating in three distinct modes:-

(a) Sky survey work where a large solid angle (for reasonable sky coverage), combined with good gamma ray/proton ratio, is required.

(b) Tracking of possible pulsed sources where a small telescope opening angle is desirable giving mimimum acceptance of background cosmic rays.

(c) Drift scan mode where a moderate opening angle is required to enable the source to be within the field of view for a reasonable time.

The design philosophy adopted is one of having a ring of six off-axis detector channels surrounding the on-axis one to satisfy requirement (a). Such an arrangement enables seven adjacent areas of sky to be viewed when in sky survey mode with the advantages of background reduction achievable with a narrow angle system. When operating in tracking mode, such an arrangement of seven channels enables six simultaneous off-source measurements to be made, allowing a continuous monitor of the nearby background conditions. The telescope design allows for the addition of a second ring of twelve phototubes, thus allowing a trebling of the area surveyed in a given time. The telescope has been designed so that photomultiplier packages can be easily changed. For example, in drift scan mode of operation we have the option of employing larger phototubes, thus increasing the aperture.

The Mark III telescope comprises a light collector of 20 sq. m. deployed as two 10 sq. m. dishes. A third smaller mirror of 3 sq. m. located between these two allows 3-fold fast coincidence to further reduce accidental noise counts.

A number of different techniques of mirror construction have been investigated. The goal has been to produce mirrors with physical characteristics well suited to the observation of Cerenkov light, which are both light, cheap and easy to produce. Our starting point was the mirrors successfully used on the Mark II telescope which were 0.6 m diameter and machined out of solid aluminium plate and polished. We have investigated pressing and spinning thin aluminium sheet, thermo-forming perspex, bonding thin aluminium sheet to a solid former and pressing thin glass mirrors. The method of manufacture adopted is the bonding of aluminium honeycomb to high reflectivity anodised aluminium sheet after stretching over a former. The method produces mirrors with spot size less than 0.1 degree. The telescope comprises 112 0.6 m diameter mirrors giving 2x10 sq m flux collectors with focal lengths of 2.5 m.

The telescope is mounted on an alt-azimuth mount and is steered under computer control by two DC electric servomotors. Direction sensing is by two absolute digital shaft encoders, giving position resolution of 0.1 degrees.

The main requirement for photomultipliers used in Cerenkov light work is unusual. We require a tube with a low noise performance under conditions of high photocathode illumination. In Figure 1 we show the noise performance of a number of tubes under conditions of photocathode illumination typical of a night sky Cerenkov experiment. The very rapid increase of noise counts with photomultiplier gain noted for the 5" tube (RCA 4522) mitigates against its use although this tube has been extensively used to date. We have selected fast 3" tubes (EMI 9821) as our prime tube when operating in tracking mode.

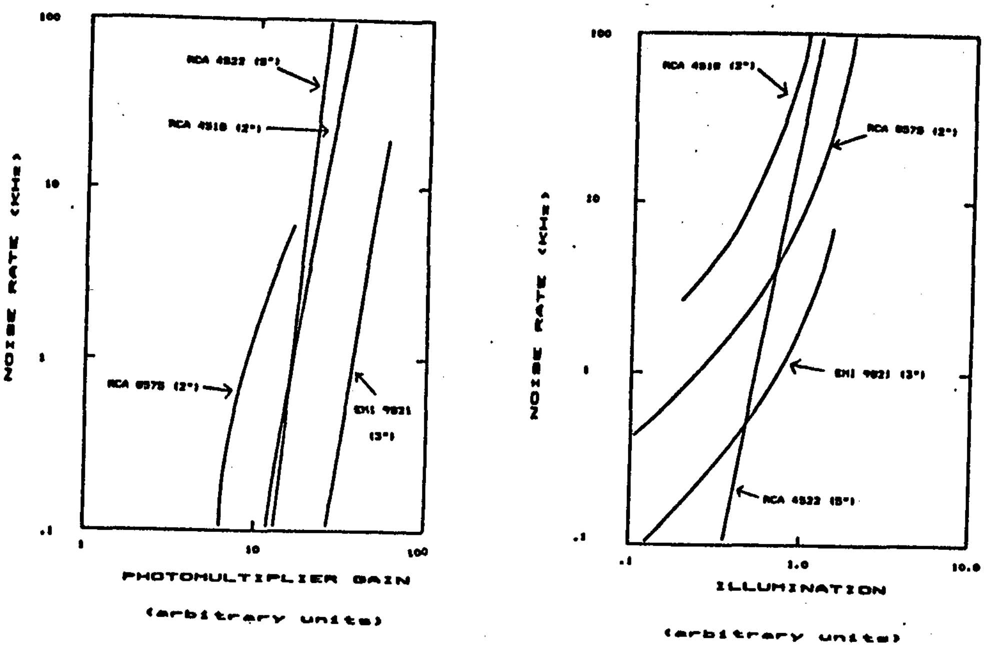

Figure 1. The variation of noise count rate (for a discrimination level typical of our experimental conditions) with phototube gain for constant illumination (a) and illumination level for constant gain (b) for a number of fast photomultipliers. In Fig. 1(b), the RCA 4522 is run at a lower gain than the other tubes.

Our experience with the Mark II telescope and our calculations of Cerenkov emission by gamma-ray showers (3) lead to a best choice of 1.35 degrees for the opening angle of the new telescope. With 3" diameter photomultipliers, this implies a mirror focal length of 2.5 m and an f-number of ~1 for our deployed area. Scaling from the count rates achieved with the Mark I and II telescopes and using our measurements of phototube characteristics leads to an estimation of a counting rate of >200 per minute per phototube pair with a single telescope. This should enable sources of comparable strength to those already established to be detected at the 3σ level in one night's observing time. In addition a useful search for unknown periodicity in e.g. Cygnus X-3 would become feasible.

3.ELECTRONICS

With 15 channels of analogue information to be recorded when operating in survey mode (and the possibility of increasing to ~40 at a later date), the use of CAMAC with its high channel density and high speed as the data recording standard becomes neccessary. Each PMT signal is amplified and discriminated, and fast concidences between the signals from the two mirror units are generated. On each coincidence, the pulse heights are digitized using a fast ADC, and the time of occurrence of the event is recorded. The heart of the data logging system is a purpose built MC 68000-based microprocessor system. In order to have a system dead-time of less than 0.5 ms to avoid possible data loss, it is neccessary to employ a true 16-bit processor to run the CAMAC bus as close to its maximum rate as possible. Total dead-time with this system is 0.3 ms per event.

The data from each event, along with house-keeping information every minute is recorded on a 3M cartridge drive system with a capacity of 68 Mbyte per tape. We have incorporated a system of recording minimum information (event time only) for events occurring within the system dead time to enable recording of very intense short term bursts of events.

We control the telescope with six microcomputers running on a local area network and communicating with the 68000 data logger. One of these computers is responsible for the steering of the telescope, a second acts as master controller for the experiment and the others are responsible for analysing and displaying the status of the experiment on a continuous basis.

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