AN OBSERVATORY TO STUDY 10^{10} TO 10^{17} EV GAMMA RAYS

Trevor C. Weekes
Whipple Observatory, Harvard-Smithsonian Center for Astrophysics

Abstract

A facility is described which incorporates many of the best features of existing gamma ray telescopes at a single site. In addition to reducing the flux sensitivity in some energy ranges, it permits the measurement of the energy spectrum over seven decades of energy.

1. Introduction. Ground-based gamma-ray astronomy has matured from a discipline with a small number of detections requiring confirmation to one in which there are several sources that are well-established (Cyg X-3, the Crab, Her X-1) but which now demand more detailed observations before the emission mechanisms can be understood. In at least one source, Cyg X-3, there is some question concerning the nature of the observed particles. All of the sources show evidence for time variability. Since many techniques, whose absolute sensitivities are poorly understood, have been employed and since many of the detections do not have large statistical significance, it is difficult to derive an energy spectrum that can be compared with source models. The energy spectrum in the range 10^{14} - 10^{16} eV is particularly interesting since there is the possibility of detecting the absorption dip caused by pair production on the 3^o K microwave background.

A single facility which combines the best features of the many techniques used to cover the energy range from 10^{10} to 10^{18} eV would eliminate the ambiguity arising from the use of different techniques at different epochs. Below we describe in qualitative terms a Very High Energy Gamma Ray Observatory and then list its advantages for each decade of the energy range covered.

2. Physical Description. The observatory will consist of a combination of pointed atmospheric Cherenkov telescopes and all-sky particle detector arrays. It will be located on a mountain plateau at an altitude of about 3.0 km. The array will cover an area of approximately 1.8×10^8 m^2 which must be reasonably flat for ease of construction and access. A central control room will house the recording electronics, the on-line computer, the atomic clocks and the operators.

(a) Atmospheric Cherenkov detectors. This array will consist of a central large reflector (with aperture in the range 15-20m) surrounded by six reflectors of 10m aperture on the corners of a hexagon and at a distance of 75m from the center (figure 1). These atmospheric Cherenkov telescopes will be modeled on the Whipple Observatory 10m

Optical Reflector. Each will be composed of tessellated segments but the f number will be larger to give a greater depth of focus. Variable focal length segments will be used to improve the optical figure and reduce the light path difference across the reflector. The reflectors will be protected by domes to preserve the mirror coatings and also to permit the reflectors to operate as air Cherenkov muon telescopes under cloudy or brightmoon conditions. Each reflector will be equipped as an imaging device with an array of phototubes at its focus. The number and size of phototubes will be chosen so as to have a pixel diameter of 0.25° and a field of view of 3.4° (e.g. 169 tubes of diameter 4 cm). The telescopes will operate in parallel and will track the position of a suspected source.

The particle detector array will consist of 1m^2 scintillators with fast timing, arranged in a hexagonal 25m grid spacing as shown in figure 2. The inner seven detectors will be clusters of five scintillators; the total number of scintillators will be 65. When any three adjacent detectors exceed a two particle level, a readout command will be generated. The read out will include the pulse size, the relative time of arrival at each detector and the absolute time.

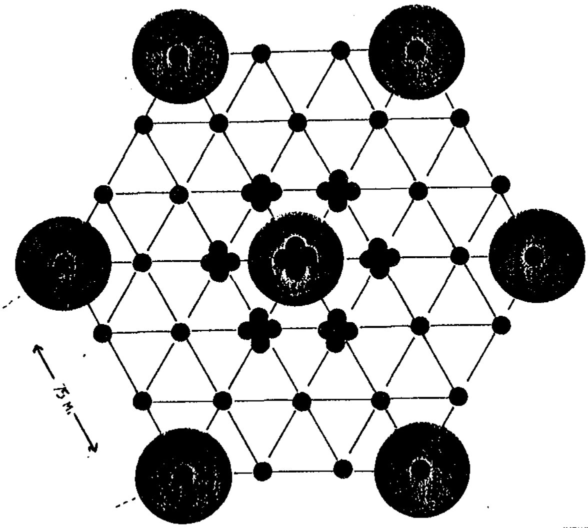

Figure 1. Seven large reflectors with spacing of 75 m.

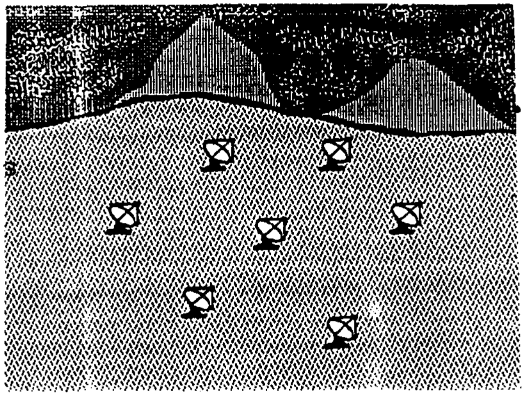

Figure 2. Layout of full array. Large circles are large reflectors; small circles are scintillators. Grid spacing is 25m.

3. Operating Mode. The facility will actually consist of five separate gamma-ray telescopes, which will operate in overlapping energy ranges with the advantage that cross-calibration will be straightforward. The ranges covered are shown in figure 3 and the telescopes are described below.

(a) Low energy atmospheric Cherenkov telescope; (LEACT) in this mode the central light detector will be operated in coincidence with one or more of the outer light detectors at a very low threshold to detect the minimum energy gamma-ray showers. Using fast electronics, small pixels and large mirror areas, it will be possible to achieve an energy threshold close to 10 GeV. This will have two important advantages: (a) it will overlap with the upper end of the coverage available with EGRET on the GRO (b) it opens up a new, and previously unexplored, region of the electromagnetic spectrum in which the background contributions from Cherenkov light deficient proton-initiated air showers will be small (Turver and Weekes, 1978). The light levels will be too low for energies below 100 GeV to permit full use to be made of the imaging technique but the reduced proton background will compensate for the loss of angular resolution.

(b) Imaging Telescope (IT); this will operate on the same principle as the existing telescope at the Whipple Observatory in the energy range 10^{11} to 10^{13} eV. However each shower will be seen by at least three telescopes so that both the angular resolution and collection area will be improved: a factor of ten improvement in minimum flux sensitivity is estimated. Recent Monte Carlo simulations (Hillas, this conference OG 9.5-3) indicate that, for showers that are well sampled, it will be possible to differentiate the primary (electromagnetic or hadronic). High energy (10^{13} - 10^{14} eV) events will saturate the central pixels but their shapes and energies can be determined from the outer pixels.

(c) Wide angle Cherenkov detector (WACD); the centroid of the Cherenkov light image for a gamma ray initiated shower of primary energy 10^{12} eV, with impact parameter 100m from the detector axis, falls 1° from the center of the field. The lateral distribution of Cherenkov light falls off beyond 100m. However a sensitive detector will have a large collection area for showers of energy 10^{13} eV whose impact parameters are in the range 100-250m; the centroid of their light distribution will fall in the ring of phototubes 1.5° from the axis. By triggering on signals in the outer pixels of the adjacent detectors the collection area for air showers is in the range 10^{13} to 10^{15} eV will be $\sim 10^{5}$ m^2. This large collection area (a hundred times greater than a small particle array detector) will compensate for the small duty cycle (<10%) of the atmospheric Cherenkov detector.

(d) Gas Cherenkov Muon Telescope (GCMT); the small duty cycle of the atmospheric detectors can be increased by having the reflectors housed in light-tight domes (which can be opened for night-sky use). Under dark conditions, the imaging reflectors can easily detect the Cherenkov light ring from single particles (muons) within the dome. If the dome is large enough to permit the reflectors to track sidereally, then sources can be tracked under cloudy or moonlit conditions (or even during the day if the dome is sufficiently light-tight). The collection area for muons is essentially that of the optical collector 75m^2 This mode would only be justified if it is shown that the directional anisotropies detected in the direction of Cygnus X-3 result from showers with a high component of muons (Samorski and Stamm (1983); Marshak et al. (1985)).

(e) Particle Air Shower Array (PASA); at mountain altitude this conventional array of particle detectors will have an energy threshold close to 10^{14} eV and a high energy cut-off dictated by exposure time and flux levels. Using state-of-the-art fast phototubes and electronics, the angular resolutions will be $\sim 1^o$. There will be considerable overlap with the atmospheric Cherenkov detectors although the particle array will act as an all-sky monitor and the light-detectors will track specific sources.

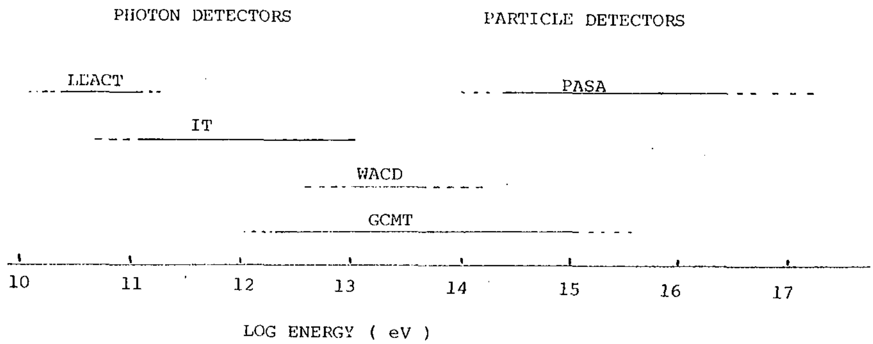

Figure 3. Distribution with energy.

4. Discussion. The facility described above involves no new technology; rather it requires a duplication and concentration of existing telescopes at an optimum site. It also requires an investment on a scale not normally associated with ground-based cosmic ray experiments.

References.

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Samorski, M., Stamm, W., (1983), 18th ICRC. 11, 244.
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