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Gamma-rays above 100 GeV

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The Cherenkov light technique for the ground-based detection of ultra-high energy γ-rays is described and some of the most significant measurements are reported. Improvements in experiments leading to increases in sensitivity are outlined and the aims of future work are discussed.

1. Introduction

The detection of a source of ultra-high energy γ-rays (defined here as having energy above 100 GeV) is an unambiguous indication of the presence of particles in that source that have energies greater than those of the detected γ-rays. The earliest γ-ray experiments were at these high energies and they involved the application of the ground-based atmospheric Cherenkov light technique by Galbraith & Jelley (1953, 1955) and Chudakov & Nesterova (1955). This technique, which has been reviewed recently by Porter & Weekes (1978), Ramana Murthy (1979) and Grindlay (1980), is still the sole basis of measurements at energies in excess of 100 GeV and will remain so in the foreseeable future.

The basis of the technique is the detection of the Cherenkov photons produced in the atmosphere by the electron cascade that is initiated by the primary γ-ray. Broadly speaking, a γ-ray of 1000 GeV will produce a cascade of 1000 electrons at the maximum of the cascade development, which occurs at a depth in the atmosphere of about 250 g cm^{-2} (10 km above sea level, see figure 1). These electrons will, in turn, produce a Cherenkov light pulse of diameter 100–200 m with photon densities of typically 30 ph m^{-2}; the light pulse will pass the observation level in a time less than 5 ns.

In most experiments to date the equipment has been simple and comprised one or more flux collectors ('surplus' searchlight mirrors of area 1–2 m^2) combined with a fast photon detector. The detection of the faint signal against the sky background is not difficult if coincidence techniques are used; the difficulties arise from the large numbers of other (similar) signals which are induced by the isotropically arriving primary protons of similar energy. The most frequently adopted solution to this problem is to drift scan across the source region and search for the enhancement in count rate expected from the γ-rays as the source transits. Various techniques to reduce the response to proton primaries have been suggested.

The Mount Hopkins Observatory 10 m flux collector is the sole example of large-scale, purpose-built equipment constructed with the principal and still important aim of achieving the lowest energy threshold for the detection of γ-rays. This makes possible ground-based measurements at energies near to those of space experiments. In the last two decades about

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twenty experiments with the use of Cherenkov light techniques have been made. Work is currently in progress by groups at the Crimean Astrophysical Observatory, the Tata Institute, the Smithsonian–University College, Dublin collaboration, the University of Durham and Iowa State University.

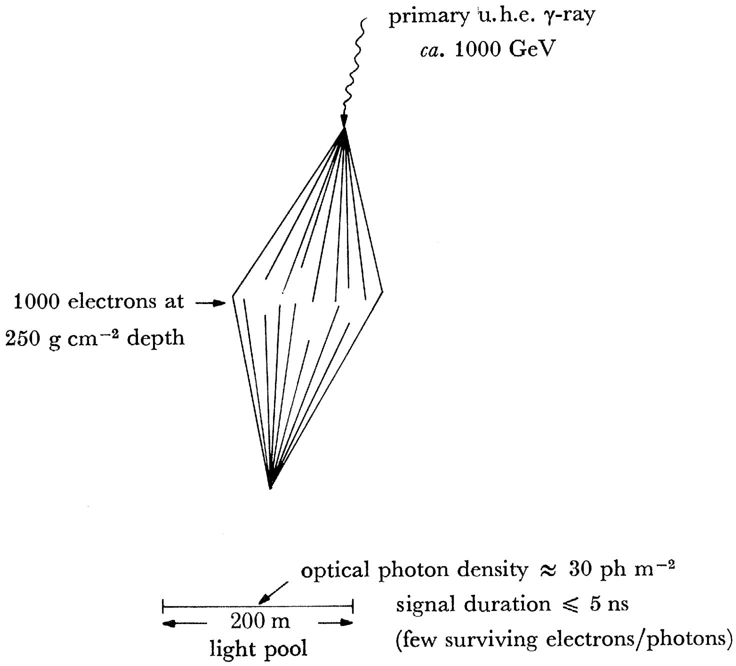
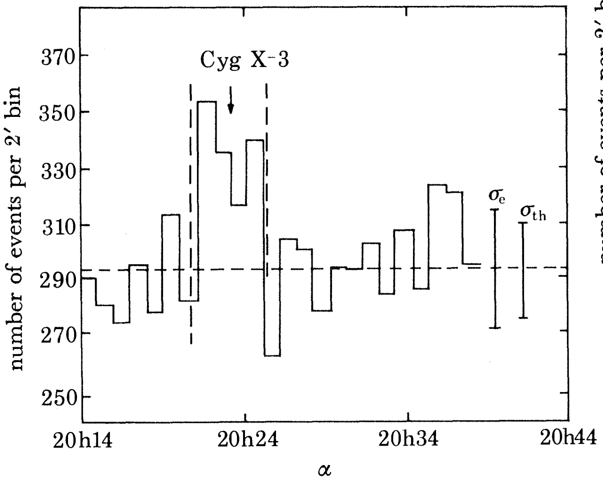


FIGURE 1. Detection of γ-rays with the ground-based Cherenkov light technique.

2. MEASUREMENTS TO DATE

Observations have been made of a wide variety of objects. One of the most important results is from the measurements of Cygnus X-3 made during the last eight years by Stepanian and his colleagues at the Crimean Astrophysical Observatory. In 1972, after the outburst of radio emission, Cygnus X-3 was monitored at γ-ray energies above 1000 GeV, and Vladimirski *et al.* (1973) obtained the data shown in figure 2. Subsequently, more data were obtained from a duplicate experiment at a different observatory by Mukanov *et al.* (1979) which also showed the characteristic 4.8 h periodicity of Cygnus X-3. This latter experiment yielded the data shown in figure 3. Evidence for a detected pulsed flux from Cygnus X-3, entirely the work of the Soviet group, is summarized in table 1.

There is evidence, from recent high energy measurements, of peaks in the phase diagram in the ultra-high energy γ-ray signal from Cygnus X-3. These peaks occur at phases of about 0.2 and 0.75. There may be some indication that since 1972 the relative strengths of these two peaks have altered. The recent measurements of Stepanian (1980, this symposium) and Danaher *et al.* (1980, this symposium, p. 637) suggest that in 1979–1980 the dominant feature of the Cygnus X-3 ultra-high energy (u.h.e.) signal was the interpulse at a phase of 0.75, rather than the main pulse previously observed at a phase of 0.2. Figure 4 summarizes data for γ-rays of energy above 35 MeV (Lamb *et al.* 1977), the X-ray light curve (Elsner *et al.* 1980) and the u.h.e. γ-ray signal, Danaher *et al.* (1980). These measurements suggest that the asymmetry of the X-ray light curves, the SAS-2 γ-ray peak and the u.h.e. feature occur at the same phase. One interpretation of these data with the model suggested by Bignami *et al.* (1977) suggests a fast, young pulsar as the collapsed object of the X-ray binary system. In this case a pulsed u.h.e. γ-ray signal may be expected with a period shorter than that of the Crab pulsar. Detection of such pulsed γ-radiation will be strong evidence in favour of this model. (The X-ray signal is dominated by the d.c. component and modulation has not yet been detected.) It is of interest to note that according to this model, the modulation of the signals will be greatest for radiation of the greatest frequencies and the phase will be constant for measurements at all frequencies. Some evidence for this behaviour may already exist, as is shown in figure 4.



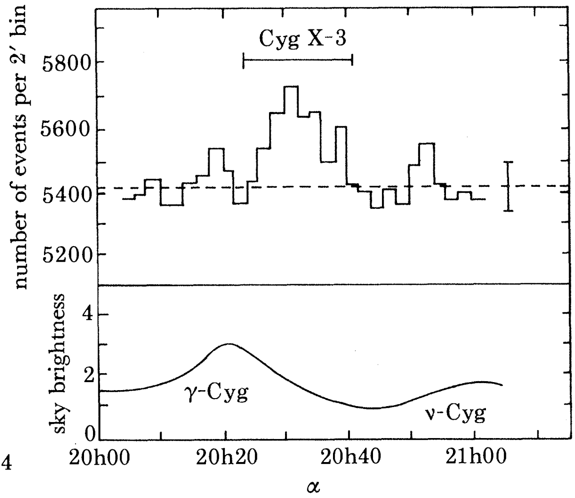


FIGURE 2. Evidence for the first detection of u.h.e. γ-rays from Cygnus X-3 (Vladimirsky *et al.* 1973).

FIGURE 3. Recent measurements of the u.h.e. γ-rays from Cygnus X-3 (Mukanov *et al.* 1979).

TABLE 1. THE FLUX OF U.H.E. γ-RAYS FROM CYGNUS X-3

year of report	energy / eV	flux / $\mathrm{cm^{-2}\,s^{-1}}$	phase of peak intensity	reference
1973	$>10^{12}$	$2.0 \pm 0.4 \times 10^{-10}$	—	*Proc. 13th Int. C.R. Conf.*, vol. 1, p. 4
1974	$>2 \times 10^{12}$	2×10^{-10}	0.1–0.2 0.7–0.8	*Soviet Astron. Lett.* **1**, 57
1975	$>2 \times 10^{12}$	3×10^{-11}	0.35 and 0.65	*Proc. 14th Int. C.R. Conf.*, vol. 1, p. 119
1977	$>2 \times 10^{12}$	—	0.1–0.3	*Proc. 15th Int. C.R. Conf.*, vol. 1, p. 131
1979	$>5 \times 10^{12}$ (total)	$1.1 \pm 0.2 \times 10^{-10}$	—	*Proc. 16th Int. C.R. Conf.*, vol. 1, p. 143
	$>2.5 \times 10^{12}$ (pulsed)	$1.6 \pm 0.4 \times 10^{-10}$	0.157–0.21	
1980	$>2 \times 10^{12}$	—	0.7–0.8 peak dominant	A. A. Stepanian (private communication)

A second well established significant result (providing the first evidence of extragalactic γ-rays) came with the detection by Grindlay (1975) of the nearby radiogalaxy Centaurus A using the Narrabri stellar interferometer. A flux of $2.0 \times 10^{-10}\ \mathrm{cm^{-2}\,s^{-1}}$ was measured and interpreted by the author as emission from Compton synchrotron processes in the compact nucleus of the galaxy.

The study of pulsars, which forms the basis of much recent work, relies on the additional filtering against the proton signals which is possible by using the pulsar timing information available from measurements at other frequencies (see Sreekantan, this symposium). NP0532 has attracted the greatest interest in measurements, and the results are summarized in figure 5. It is clear that the spectrum of γ-rays from the Crab nebula is steepening beyond 1 GeV.

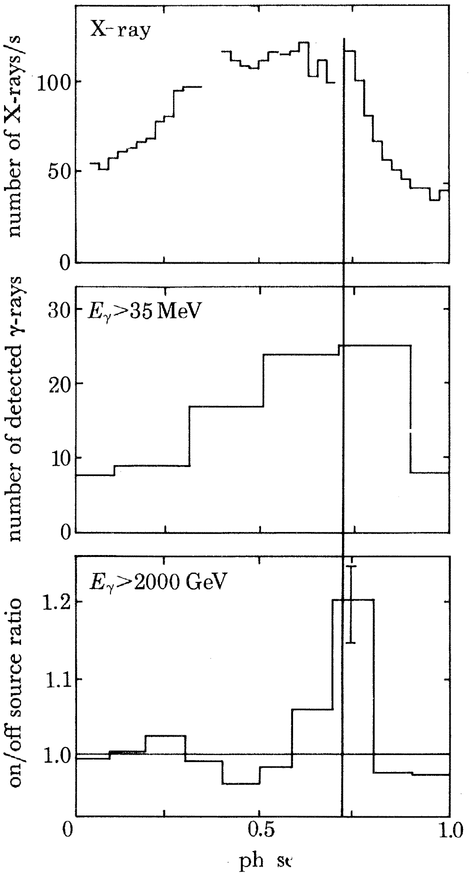


FIGURE 4. The phase diagrams for X-rays, and 35 MeV and u.h.e. γ-rays, from Cygnus X-3.

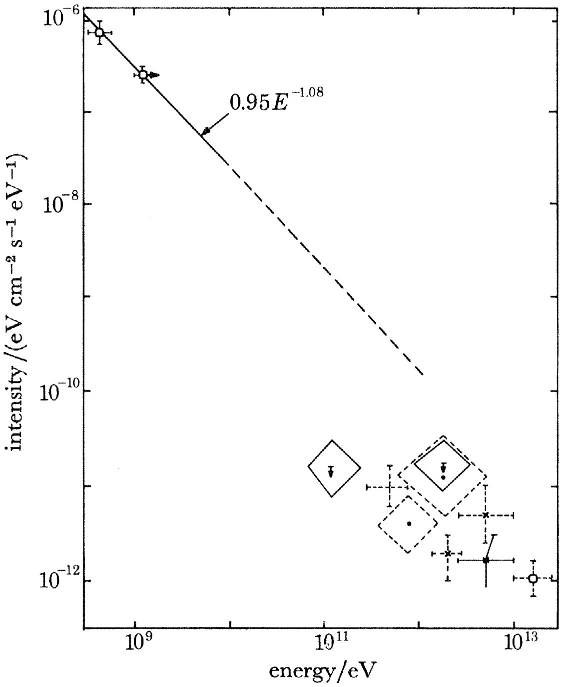


FIGURE 5. The energy spectrum of the Crab pulsar showing fluxes and upper limits, from various workers (after Porter & Weekes 1978). High energy measurements: ——, upper limit; – – –, apparent flux.

TABLE 2. THE FLUX LIMITS FOR U.H.E. γ-RAYS FROM VARIOUS OBJECTS

type	example	flux limit/(cm^{-2} s^{-1})
COS-B sources	—	typically < 1–1.5×10^{-10} at $E_\gamma \gtrsim$ 300 GeV
extra-galactic objects	3C273	$< 3.9 \times 10^{-11}$ at $E_\gamma \geqslant$ 300 GeV $< 8.3 \times 10^{-12}$ at $E_\gamma \geqslant$ 5000 GeV
galactic plane	—	possible detection at *ca.* 10^{-10} at $E_\gamma >$ 100 GeV

Further conclusions with a view to fitting all the observations are difficult; variations in phase and amplitude for the signals will be required to fit all the high energy γ-ray data. Other signals from, for example, CP0950 and the Vela pulsar also lead to the conclusion that high energy γ-rays from pulsars may be variable.

In addition to these measurements of fluxes, useful limits have been obtained on a wide range of objects, some of which are indicated in table 2.

3. NEW TECHNIQUES FOR ENERGIES ABOVE 100 GeV

There have been important improvements in technology recently which are relevant to Cherenkov light measurements and which hold the promise of increased sensitivity for γ-ray experiments.

Microelectronics. The small-scale experiments that typify earlier Cherenkov light studies could now expect to reliably record at modest cost increased amounts of information for each detected shower. It is hoped that this will contribute to improvements in the rejection of signals due to primary protons. For example, many early experiments simply noted the frequency of the coincidence signals recorded by two dishes as the source region passed through the large field of view of the detectors. Experiments may now be planned to record time of arrival and the photon density from each photomultiplier in a complex system, as well as having the benefits of computer-controlled tracking systems for the flux collectors (see Gibson *et al.*, this symposium).

Large reflectors. It is now possible to contemplate new large-area mirror systems since developments in solar energy research have made available mirrors of adequate quality for γ-ray astronomy at reasonable cost. For example, mirrors of the size of the Mount Hopkins flux collector may now be produced for about £30,000 each. (It is unfortunate that the locations of most existing solar collectors are unsuited to γ-ray astronomy owing to their proximity to large cities.)

Computer simulations. It has been possible for the last five years or so to combine large computing power with the known physics of the cascade development to simulate thoroughly and reliably the Cherenkov light provided by primary γ-rays and protons (see, for example, Browning & Turver 1977). Typical data illustrating the light pool in a 100 GeV γ-ray-initiated shower from these simulations are shown in figure 6. These calculations are important for the design of experiments that enhance the rejection of protons in favour of γ-rays (Turver & Weekes 1978). They are also essential for the interpretation of existing experimental data with the most obvious need to determine the energy response of and the sensitive area exposed by the system.

Two new experimental approaches are planned by us which incorporate, in varying degrees, the benefits of these improvements:

(i) *The University of Durham fast timing experiment*

Air shower techniques employed by the University of Durham group and previously used by Tornabene (1979) in γ-ray astronomy are being developed for u.h.e. γ-ray studies. They involve fast timing of the Cherenkov light signal by using four triple-dish systems separated by about 75 m (see figure 7). Each detector comprises a total of three 1.5 m diameter light collectors, a threefold coincidence specifying a detector response. Accurate timing of the passage of the light front past each dish system will enable accurate measurement of the arrival directions of the γ-rays (to less than about 1°) within the field of view of the equipment (*ca.* 2°). A rejection of many of the proton-initiated events that register in the 2° field of view of the

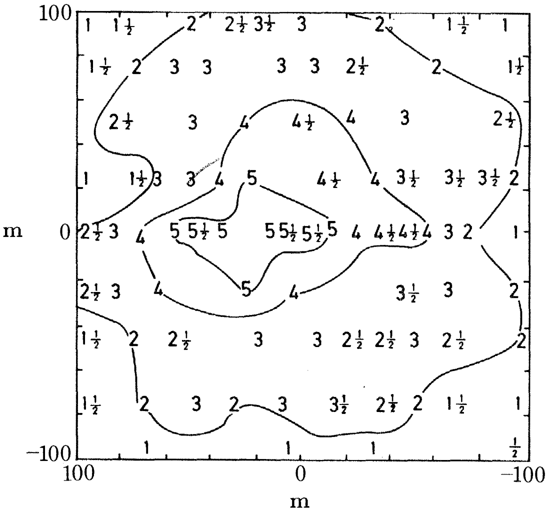


FIGURE 6. The density contours, in ph m^{-2}, of the light pool computed for an altitude of 2380 m above sea level in a 100 GeV γ-ray shower.

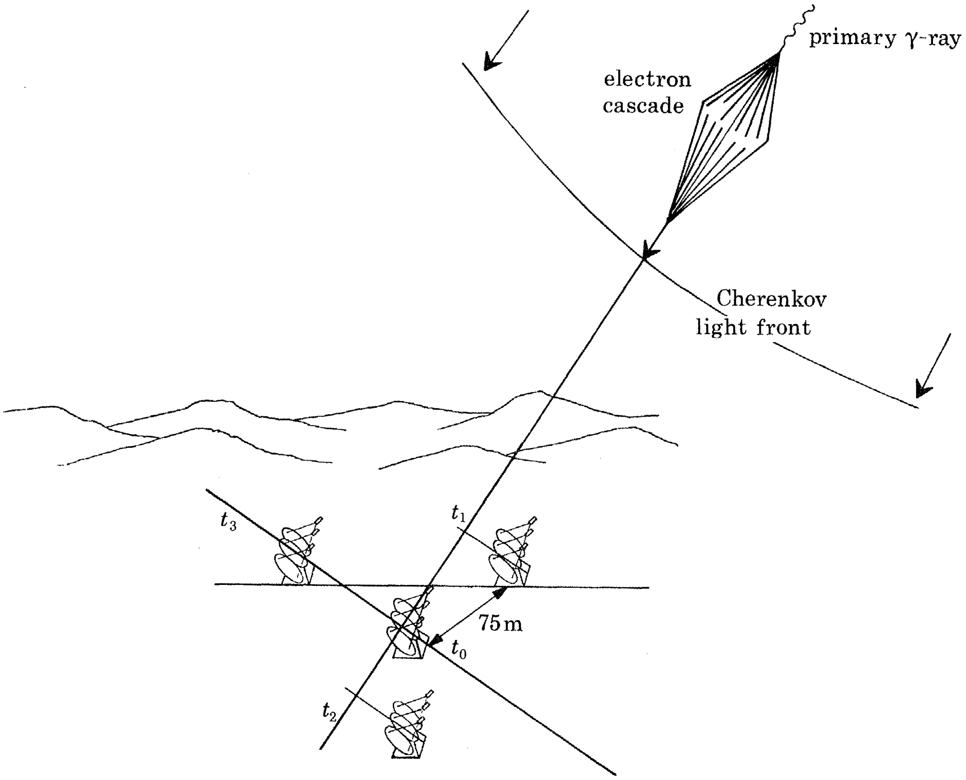


FIGURE 7. The University of Durham fast timing detector array. The accurate times of arrival of the light signal at each detector (t_0, t_1, t_2, t_3) allow the arrival direction to be precisely determined.

system will be possible on the basis of the failure of their arrival direction (derived from timing) to align with the source position. Increases in sensitivity over existing measurements at energies around 1000 GeV are anticipated as a result of the rejection of many protons from off-source regions.

In addition the four triple-dish systems may each operate in the conventional drift scan mode, the source being observed at all times by one of the systems. This possibility is of importance in monitoring Cygnus X-3 to establish the form of the high energy γ-ray light curve.

A programme of measurements on Cygnus X-3 is planned for the summer of 1981 with this equipment and will include a search for pulsation in the recorded signals on a timescale of 1–20 ms.

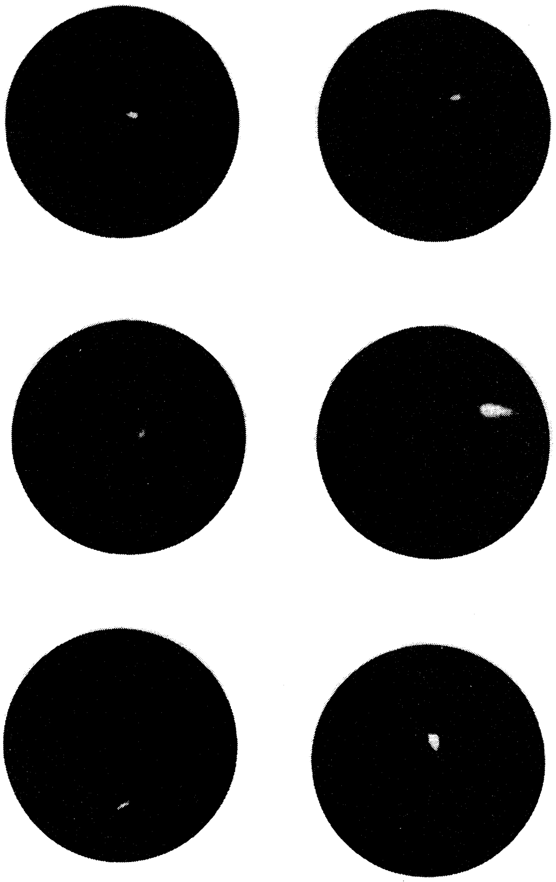


FIGURE 8. Images of Cherenkov light against the night-sky; taken with a fast wide angle (±12°) image intensifier camera system by an M.I.T.–University College Dublin team in the early sixties. (Photograph: courtesy of J. White).

(ii) *Two-dimensional image of the light signal*

(*a*) *The angular spread of Cherenkov light.* Just as the lateral spread of the light at the detector level can be exploited to improve the directional accuracy so also can the angular spread of the light as recorded in a wide angle camera be used to give improved angular resolution, energy resolution and even composition resolution.

Figure 8 shows a selection of shower light images as recorded by a fast image intensifier night-sky camera; these remarkable pictures were taken in the early sixties by a joint team from the Massachusetts Institute of Technology and University College, Dublin. Although the cosmic ray energies represented here are in the range 10^{15}–10^{16} eV (much higher than we are normally concerned with in γ-ray astronomy), the shapes will be the same at lower energies.

The angular spread of the Cherenkov light arises primarily from the scattering of shower electrons; the general shape of the shower light spot comes from the relative geometry of the shower trajectory and the detector axis (see figure 9). A shower whose trajectory coincides with the detector axis gives a radially symmetric light spot. The shapes of the light spots have been predicted by Monte-Carlo shower simulations (Rieke 1969; Browning & Turver 1977); the series shown in figure 10 is for a 10^{11} eV γ-ray shower where the separation between the shower trajectory and the detector axis is varied. As the separation, d, increases the 'ellipticity' of the shower spot increases and the peak of the light distribution shifts along the major axis towards the tail of the comet.

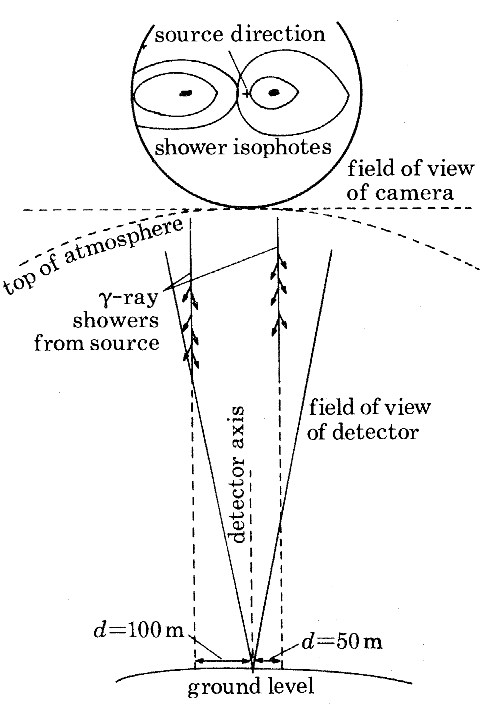


FIGURE 9. The geometry of Cherenkov image detection showing how the 'elliptical' images in figure 8 are produced.

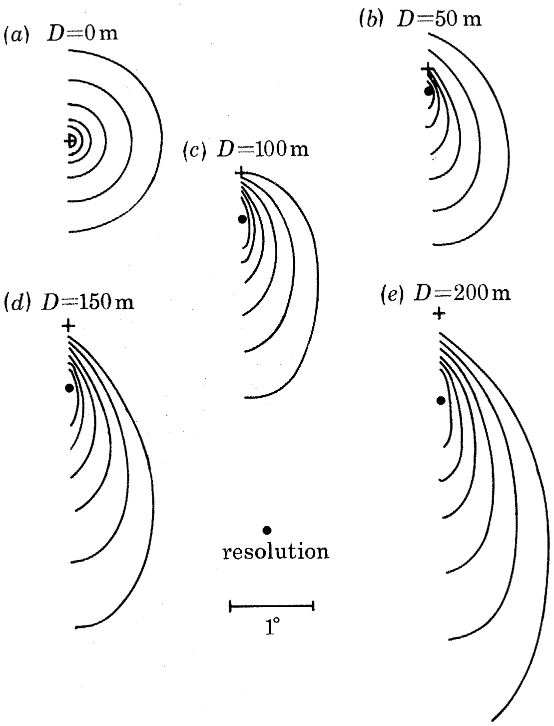


FIGURE 10. Predicted shapes of Cherenkov light images as a function of the separation between parallel shower and detector axes. (Rieke 1969.)

The arrival direction of the primary can be determined from an analysis of the isophotal contours of the light spots. This determination is limited only by the accuracy of the isophotal light measurement and by fluctuations in the air shower development; the accuracy could be ± 0.1° (Jelley 1967). Since the Cherenkov light output is a calorimetric component of the shower, a good measure of the energy of the primary particle can be obtained by integrating the total light in the shower image. The limitation here is shower fluctuations.

The collection area for γ-ray detection, A_γ, is limited by the displacement of the light maximum with d, and the small aperture of the conventional detector. For a 1° detector the maximum d is about 50 m giving a collection area $A_\gamma \approx 10^4$ m^2. For a wide angle camera, d can be as large as 200 m giving an increase in A_γ by a factor of eight.

Since a proton-initiated shower develops deep in the atmosphere and has a penetrating particle component, the light spot from a proton shower is different from that from a γ-ray for the same separation and energy. It may be possible to distinguish the nature of the two from a careful examination of the two images but in practice this requires an independent determination of d.

(*b*) *Camera systems*. The technical difficulties associated with Cherenkov light imaging are the requirement for large apertures, wide fields, short exposures and image storage; the last mentioned is needed until an auxiliary system indicates that an event has occurred. The system used to photograph the shower spots in figure 8 used a state-of-the-art 1960 camera consisting of three stages of image intensification, phosphor storage and photographic recording. The energy threshold was 10^{15} eV; the system was difficult to operate and was not used for γ-ray astronomy. With the use of present day two-dimensional detectors it would be much easier to achieve the same sensitivity. Image intensifiers with photocathodes of diameter 12.5 cm are now available and micro-channel plates can be gated very quickly making image storage time much shorter. Solid state devices (C.C.D., C.I.D.) can provide a high quality digital read-out which can be stored in a continuously updated buffer and which is only recorded if an event has occurred. Although this kind of system is more practical it is still necessary to have an optical telescope of large aperture if the energy threshold is to be reduced. Since the scale of structure in a shower image is about 10′, the high quality of optical telescopes and high resolution of conventional imaging devices is overkill and unnecessary.

(*c*) *Mount Hopkins Observatory camera*. The reflectors used in conventional atmospheric Cherenkov detectors have an optical quality that is almost optimum for direct imaging; unfortunately the focal plane scale is too large to be easily matched to image detectors. Since few picture elements (pixels) are necessary to record a Cherenkov image, discrete detectors (phototubes) can be used. The advantage of this kind of system is that phototubes have a high gain, are readily available and are well tried in Cherenkov work. After an event has occurred (determined by some preset triggering criteria) it is necessary to interrogate each phototube and convert the light signal into a digital signal which can be recorded.

With the Mount Hopkins Observatory (M.H.O.) 10 m optical reflector the focal plane scale is 12.5 cm/deg and the angular resolution is 20 minutes of arc. A convenient imaging arrangement, therefore, is a cluster of 37 phototubes each of diameter 5 cm giving a full field of almost 3°. A preliminary estimate of the sensitivity of this system can be obtained by using the light images predicted for 10^{11} eV γ-ray primaries (Rieke 1969). These have been scaled to 10^{12} eV by assuming linearity. In figure 11*a* the pixel field is overlaid on the image, where the central element is pointing at the source and $d = 50$ m. The output of each phototube is then proportional to the amount of light intercepted by each pixel; the result is shown in figure 11*b* as photoelectrons per pixel, the collection area being taken as 60 m² and the quantum efficiency being 20 %. The noise per pixel per 10 ns integration is 4 photoelectrons so the signal:noise is large.

A realistic estimate of the sensitivity that can be achieved with this system will require a Monte-Carlo simulation of the response for 10^{12} eV protons in γ-ray showers. Rough estimates indicate that the improvement in sensitivity over previous observations with the 10 m reflector would be by a factor of 10–100 in the 10^{12}–10^{13} eV energy range. This system is now under development as a collaboration between the Smithsonian Astrophysical Observatory, University College, Dublin and the Universities of Durham, Hawaii and Iowa State.

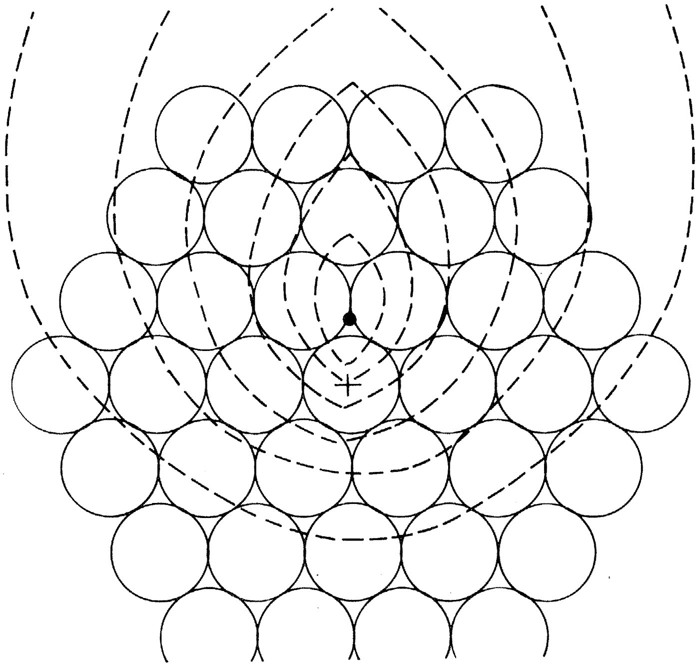


FIGURE 11*a*. The proposed configuration of 37 phototubes on the M.H.O. 10 m reflector shown superimposed on the Cherenkov image of a shower with $d = 50$ m; its arrival direction is the centre of the phototube array.

13 60 60 13

10 51 283 51 10

3 14 284 284 14 3

1 3 15 109 15 3 1

0 2 5 5 2 0

0 1 1 1 0

0 0 0 0

FIGURE 11*b*. The predicted number of photoelectrons per phototube for the case shown in 11*a*; the noise per tube is four photoelectrons.

4. ENERGY REGION BELOW 10^{11} eV

The motivation to decrease the energy threshold of the atmospheric Cherenkov technique below the present limit of 10^{11} eV is to bridge the gap with satellite experiments which currently cut off at 2 GeV. It is fortunate that observations in this region may be particularly sensitive because of the physics of the air shower process. As the energy decreases an increasing portion of the proton shower's energy goes into muons which are poor Cherenkov radiators (Turver & Weekes 1978); thus below 10^{11} eV the ratio of Cherenkov light intensity away from the core of a γ-ray to that of a proton shower shows a rapid increase (see figure 12). The proton background which dominates the flux sensitivity is thus reduced, and Cherenkov experiments in this energy range will be sensitive to fluxes that are only a small percentage of the cosmic ray background.

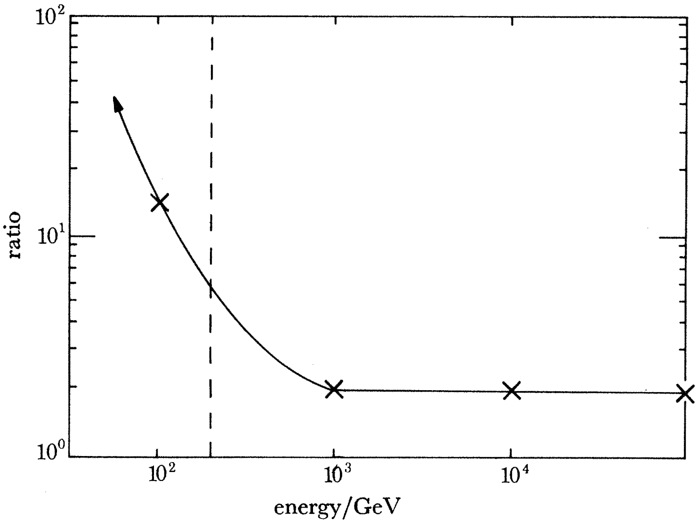


Figure 12. The ratio of intensity of Cherenkov light from γ-ray and proton-initiated air showers at a typical distance (100 m) from the shower axis showing that proton-initiated showers are Cherenkov deficient below 10^{11} eV (Turver & Weekes 1978).

The energy threshold of a simple detector is inversely proportional to the diameter of the light collector. An energy threshold of 10^{11} eV requires an effective aperture of 5–10 m. To get to 10^{10} eV requires an aperture of 50–100 m; such apertures would have been out of the question a few years ago but the development of large concentrators for solar energy research makes this energy threshold a realistic possibility. It is unfortunate that the usual solar concentrator is crude even by γ-ray standards and often introduces a time spread in the light paths from the various elements. In practice it is better to have the mirror area distributed amongst several adjacent concentrators than in one single concentrator such as the C.R.T.F. in Albuquerque, New Mexico.

Lamb (1980, private communication) plans to use the two 11 m solar concentrators at the Jet Propulsion Laboratory in 1981 and anticipates an energy threshold of 5×10^{10} eV.

If the two systems described in this paper are to be regarded as second-generation atmospheric Cherenkov systems, then a third-generation experiment can be conceived of which consists of a combination of the lateral and angular array concepts. Four optical reflectors of aperture 10–15 m would be required and would be operated in coincidence to give the required energy resolution. The reflectors would be located at the corners of a square of side 50 m, this spacing being required for the time-of-arrival measurements and to discriminate against local muons. At least one of the reflectors should have an angular resolution of 10′ and should be equipped with a large aperture fast camera (see figure 13).

This kind of system would cover the range 10^{10}–10^{13} eV with a minimum flux sensitivity that is a factor of one hundred lower than is available with current experiments.

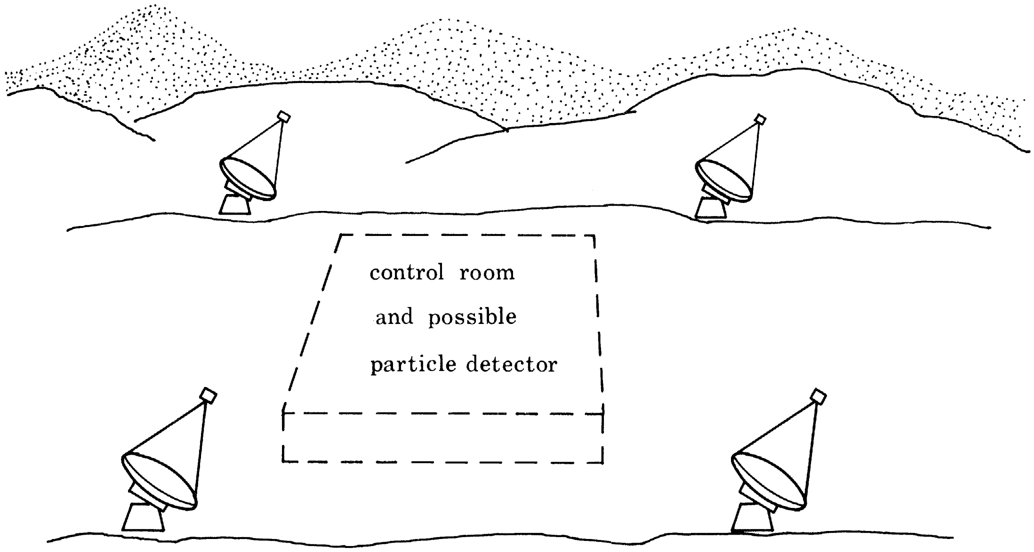


FIGURE 13. The proposed configuration of a Cherenkov experiment that would cover the energy range 10^{10}–10^{13} eV by using the imaging and timing techniques discussed above; each reflector would have an aperture of 10–15 m and the separation would be 50–100 m.

5. ASTROPHYSICAL SOURCES

High energy photons must come from high energy particles; high energy γ-ray astronomy is thus the tracer of high energy particle activity in the universe. The energy processes that govern the acceleration of high energy particles are amongst the most exotic in astrophysics; only γ-ray astronomy can probe these processes at their source and point unambiguously to the presence of cosmic ray particles.

All arguments used to justify point source γ-ray astronomy in the 100 MeV region can be applied at 10^{12} eV with even greater force; together with observations at other wavelengths, the observation of 10^{12} eV γ-rays can elucidate the high energy processes that must be at the heart of the source. A case in point is Cygnus X-3 which apart from the γ-ray observations would appear to be an ordinary X-ray binary with no direct evidence for on-going high energy particle activity.

If relativistic electrons or photons are present in a source it is almost inevitable that they will produce γ-rays of slightly lower energies. The mechanism by which the photons are produced depends on the conditions in the source, i.e. the presence of magnetic fields, particles and other photons. At very high energies the processes that are important are: bremsstrahlung, Compton scattering, pion decay and curvature radiation. The emission spectra by these mechanisms will be power laws with few distinctive features; it is only by measurement over many decades that the predicted differences between the various mechanisms can be seen. Observations above 10^{12} eV thus complement the 100 MeV observations with the added advantage that the range of the Cherenkov technique is over many decades.

By their very nature γ-rays are associated with very high energy processes in unstable and often explosive sources; it is to be expected that γ-ray sources, particularly at the highest energies, will exhibit time variations, some of which will not be seen at lower energies. This factor makes the interpretation of γ-ray observations difficult and may explain why sometimes the observations appear to be in conflict. Time variability can only be ascertained by long-term monitoring programmes and since satellite experiments have only a finite lifetime these observations can best be made with a ground-based technique. The long-term monitoring programme of pulsars by the Tata group, and of Cygnus X-3 by the Crimean Astrophysical Observatory group, are examples of areas where the atmospheric Cherenkov technique can play a unique role.

The continued improvement of sensitivity in the 100 MeV range, in particular the upcoming Gamma-Ray Observatory, offers a new challenge to ground-based observers; not only will it be necessary to measure the high energy spectrum of weaker sources but an opportunity will be provided for a programme of long-term monitoring of many sources.

In the decay of pions produced in the collision of relativistic charged particles with nuclear matter, equal numbers of γ-rays and neutrinos are produced. In dense sources the photons may be absorbed in subsequent interactions whereas the neutrinos can emerge unattenuated. Complementary γ-ray and neutrino observations can trace out conditions within dense sources. The detection of γ-rays without neutrinos points to an electron production mechanism.

The threshold for point source neutrino astronomy (in planned experiments such as DUMAND) is 10^{12} eV with a flux sensitivity very similar to that which can be achieved in atmospheric Cherenkov experiments. Since the latter are simpler and less expensive they can be used as a pointer to the number and nature of detectable neutrino sources.

Finally, in table 3 we list the various classes of source which will be the immediate objective of the new generation of u.h.e. γ-ray experiments. Discoveries at other wavelengths over the

TABLE 3. THE CLASSES OF SOURCE THAT WILL BE OF IMMEDIATE INTEREST FOR THE NEXT GENERATION OF U.H.E. γ-RAY EXPERIMENTS

source class	*examples*	*current status*	*objective of future observations*
pulsars	CP 0532 (Crab)	possible detection	confirm and monitor
	CP 0833 (Vela)	possible detection	confirm and monitor
	CP 0950	possible detection	confirm and monitor
	others	upper limits	detection
supernovae	Crab nebula	upper limit	improve sensitivity to set lower limit to magnetic field
	others	upper limit	detection
binaries	Cygnus X–3	detection	search for fast periodicity; measure 4.8 hour light curve
	Circinus X–1	—	detection
	other binaries	—	detection
SS433	SS433	—	detection
100 MeV emitters	CG195+1	upper limits	re-observe with better sensitivity
	CG135+1	upper limits	re-observe with better sensitivity
	others	—	detection
Galaxy	galactic plane	possible detection	confirm detection and map intensities with latitude and longitude
	galactic centre	upper limit	detection
radio galaxies	Centaurus A	detection	look for variability
	M87	upper limit	detection
	Cygnus A	upper limit	detection
quasars and active nuclei	3C273	upper limit	detection; coordinate with observed variability at other wavelengths
	BL LAC	upper limit	
	others		

next few years will no doubt augment this list as will (we hope) the chance detection of other high energy sources.

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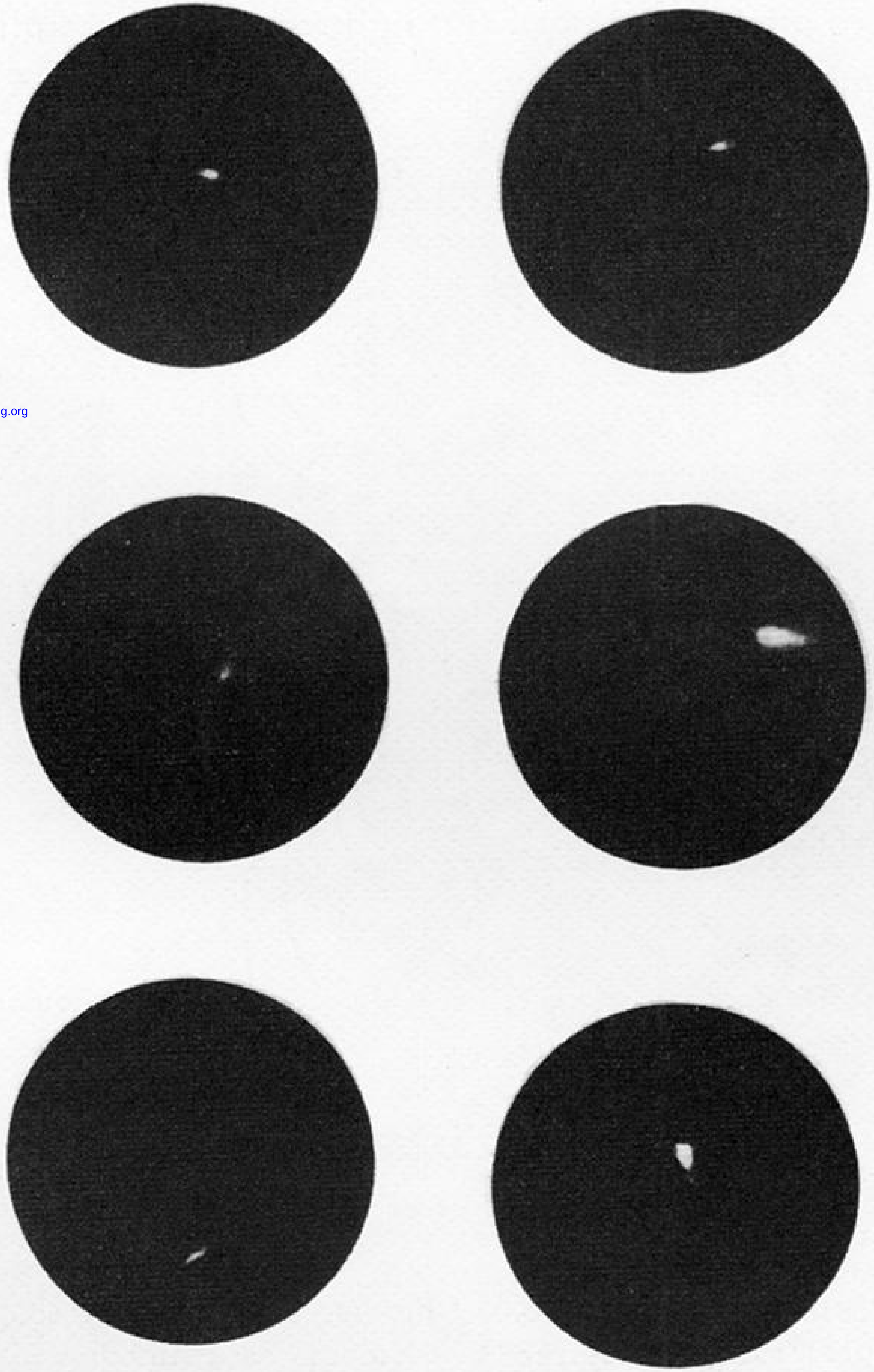

IGURE 8. Images of Cherenkov light against the night-sky; taken with a fast wide angle (± 12°) image intensifier camera system by an M.I.T.–University College Dublin team in the early sixties. (Photograph: courtesy of J. White).