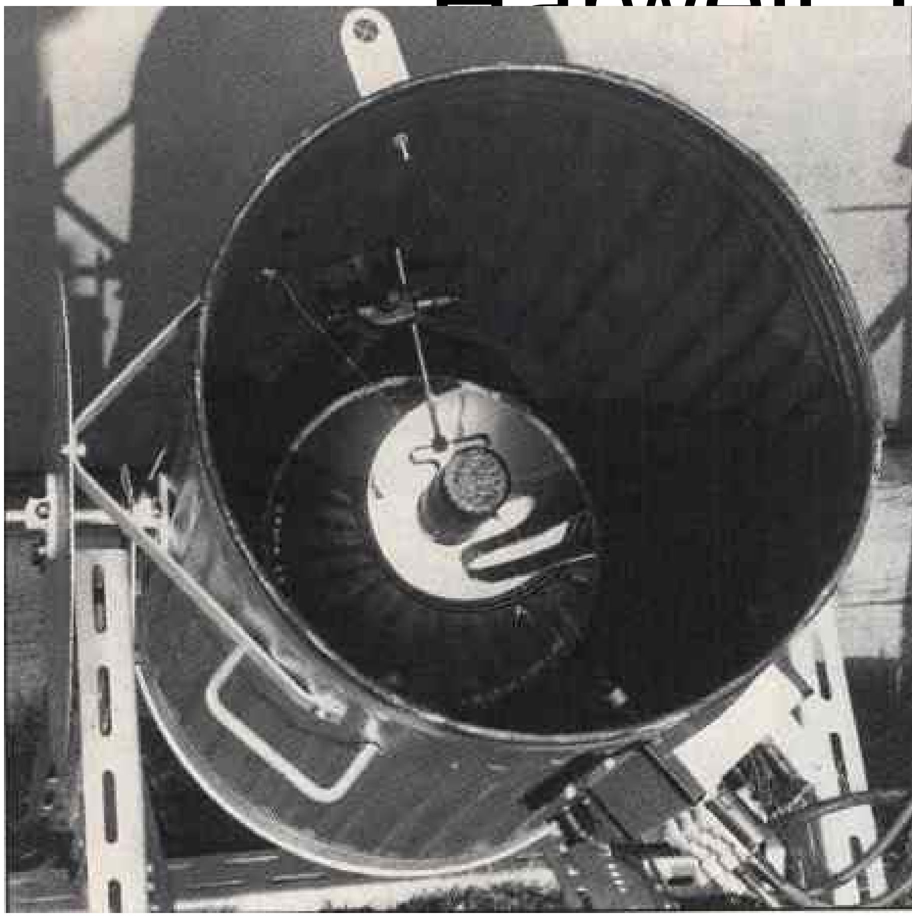
How we got from there to here?

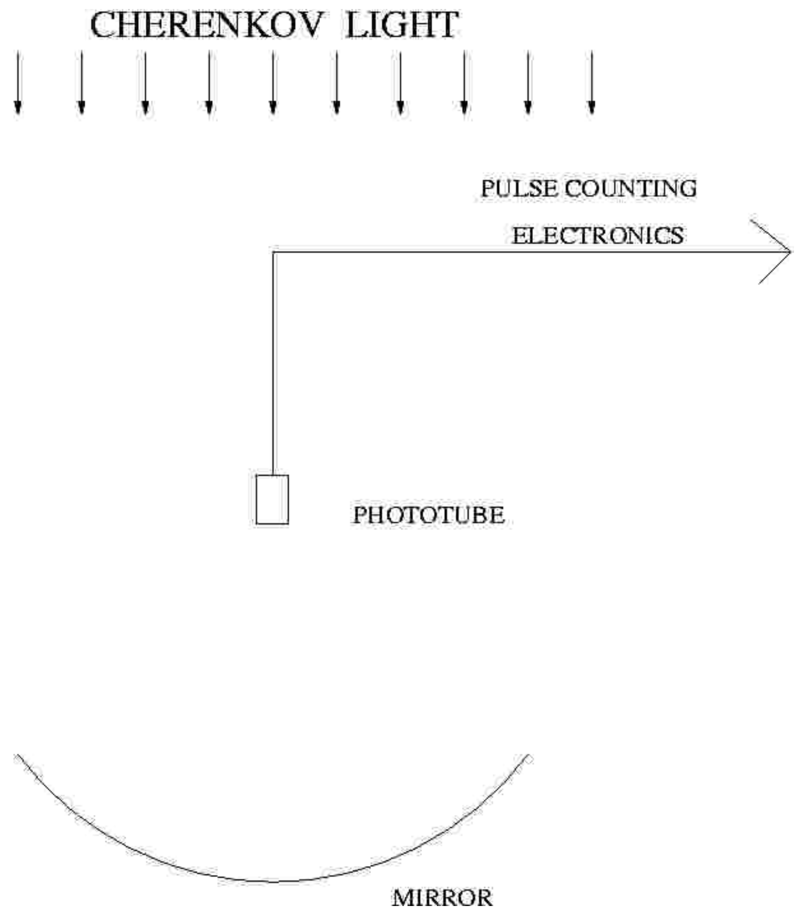
Trevor Weekes

In the beginning…..

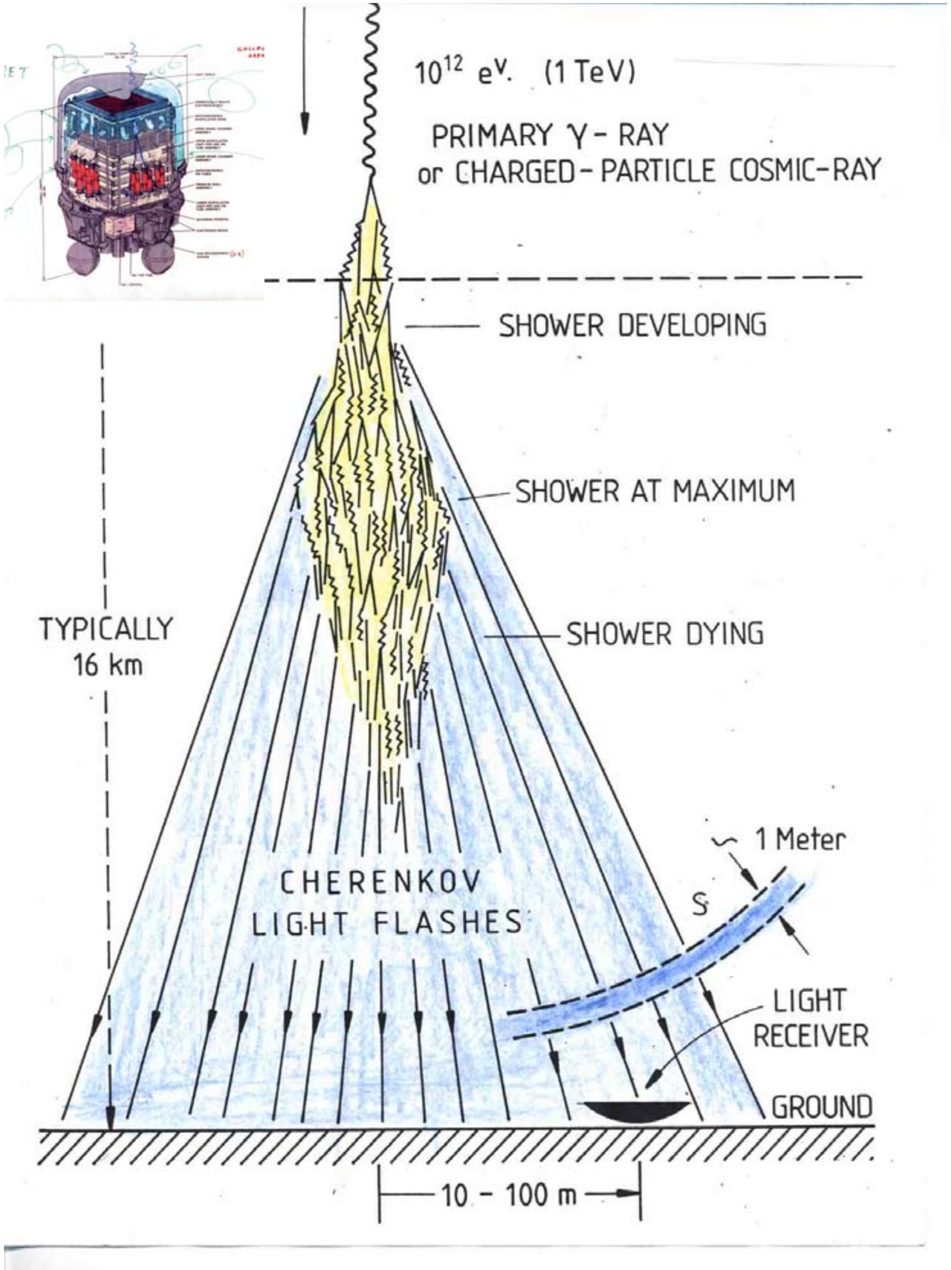
- 1948 P.M.S. Blackett (Nobel Laureate) points out that 1/10,000 of night-sky light should come from cosmic rays
- Previously Cherenkov light only detected in solids and liquids
- 1953 Galbraith and Jelley (A.E.R.E, Harwell) postulate that Cherenkov light might be detectable as light pulse from air shower

Simple Optical Detector at Harwell, U.K. 1951





Experiment in a garbage can, Galbraith and Jelley, 1953



USE OF ATMOSPHERIC CHERENKOV TECHNIQUE TO DETECT SMALL AIR SHOWERS

Simple Technique,
Simple Detectors,
Small Budgets

Perhaps the technique could be used to do gamma-ray astronomy?

Gamma-ray Astronomy: Motivation

Seminal paper by Phillip Morrison, 1958

AN AIR SHOWER TELESCOPE
AND THE DETECTION OF 10^{12} eV PHOTON SOURCES

Giuseppe Cocconi *
CERN - Geneva.

1) This paper discusses the possibility of detecting high energy photons produced by discrete astronomical objects. Sources of charged particles are not considered as the smearing produced by the magnetized plasmas filling the interstellar spaces probably obliterates the original directions of movement.

5). Here are some numerical estimates.

The Crab Nebula: Visual magnitude of polarized light m = 9.
Magnetic field in the gas shell $H \simeq 10^{-4}$ gauss.
Therefore: $U_\gamma = 10^{12}\,eV$ and $R(10^{12}\,eV) \approx 10^{-3.2}\ m^{-2}\,s^{-1}$.

The signal is thus about 10^3 times larger than the background (2). Probably in the Crab Nebula the electrons are not in equilibrium with the trapped cosmic rays, and our estimate is over-optimistic. However, this source can probably be detected even if its efficiency in producing high energy photons is substantially smaller than postulated above.

M87, the Jet Nebula: m = 13.5 $H \simeq 10^{-4}$ gauss.
$R(10^{12}\,eV) \simeq 10^{-5}\,m^{-2}\,s^{-1}$, still well above the background (2). For this object our evaluation is probably not fundamentally wrong.

Also proposed at higher energies independently by Giuseppe Cocconi, 1959

Cherenkov Technique used for Gamma Ray Astronomy

Crimea Experiment 1960-1965

(supernova remnants, radio galaxies)

First Generation Atmospheric Cherenkov Telescope

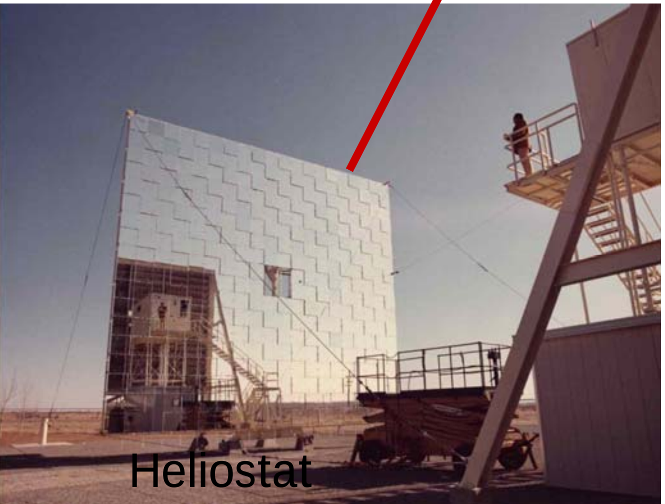
Glencullen, Ireland ~1962-66

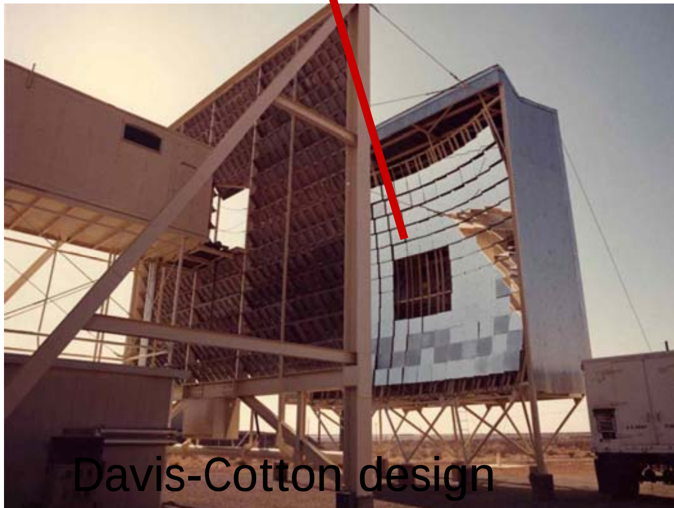
University College, Dublin group led by Neil Porter (in collaboration with J.V.Jelley)

WWII Surplus: Gunmount, searchlight mirrors

(quasars (AGN), variable stars)

First Smithsonian venture into VHE gamma-ray used Solar Furnace at Natick, MA ~ 1965-6.
Gamma-ray Astronomy Group led by Giovanni Fazio





First Gamma-ray Experiment at Whipple Observatory, 1967-8

Work on the Mt. Hopkins Observatory proceeds at an astonishing pace. The laser and Baker-Nunn systems are now installed and operating and the large optical reflector is scheduled to arrive by the end of next month. In preparation for the LOR installation, Trevor Weekes (above, left) and George Rieke have conducted seeing tests with two movable searchlight reflectors. Look carefully – some outcroppings at the base of Mt. Hopkins are visible upside-down in the reflector.

Whipple Observatory, 1967-8

(wide spot on the road)

Some familiar sources!

THE ASTROPHYSICAL JOURNAL, Vol. **154**, November 1968

A SEARCH FOR DISCRETE SOURCES OF COSMIC GAMMA RAYS OF ENERGIES NEAR 2×10^{12} eV

G. G. FAZIO AND H. F. HELMKEN
Smithsonian Astrophysical Observatory and Harvard College Observatory, Cambridge, Massachusetts

G. H. RIEKE
Mount Hopkins Observatory, Smithsonian Astrophysical Observatory, Tubac, Arizona, and Harvard University, Cambridge, Massachusetts

AND

T. C. WEEKES*
Mount Hopkins Observatory, Smithsonian Astrophysical Observatory, Tubac, Arizona
Received September 3, 1968

ABSTRACT

By use of the atmospheric Čerenkov nightsky technique, a study has been made of the cosmic-ray air-shower distribution from the direction of thirteen astronomical objects. These include the Crab Nebula, M87, M82, quasi-stellar objects, X-ray sources, and recently exploded supernovae. An anisotropy in the direction of a source would indicate the emission of gamma rays of energy 2×10^{12} eV. No statistically significant effects were recorded. Upper limits of $3\text{–}30 \times 10^{-11}$ gamma ray cm^{-2} sec^{-1} were deduced for the individual sources.

Whipple 10 m Telescope, completed in 1968
First purpose-built gamma-ray telescope and still going strong!

Only weak discrimination against background

No Credible Sources were detected

Smithsonian gamma-ray effort closed down 1978

Cherenkov Shower Imaging using Image Intensifiers (1960-65) and Stereo Detectors (1972-76)

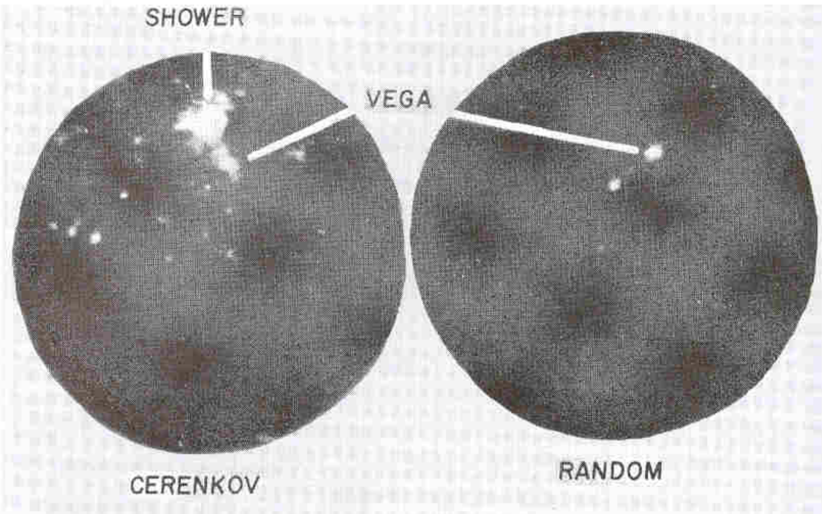
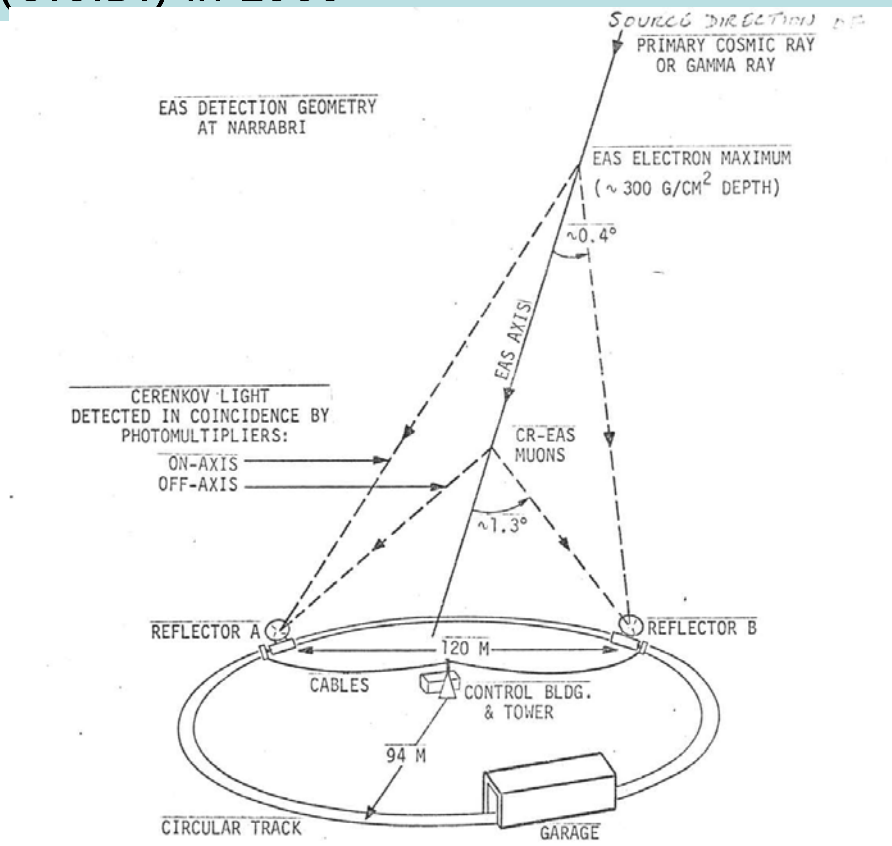


Image Intensifier Pictures of Cherenkov light Image from Cosmic Ray Air Shower.
On short time-scale images are brighter than bright star (Vega).
Work by David Hill (M.I.T.) and Neil Porter (U.C.D.) in 1960

Josh Grindlay demonstrates value of stereo imaging with two-pixel system (Double Beam Technique) at Mt. Hopkins and Narrabri (1972-76)



Atmospheric Cherenkov Imaging Technique, c. 1977

Convert 10 m optical reflector into large fast camera of 10 m aperture

Finite number of pixels

(37 --> 370)

Short exposures (30 nsec)

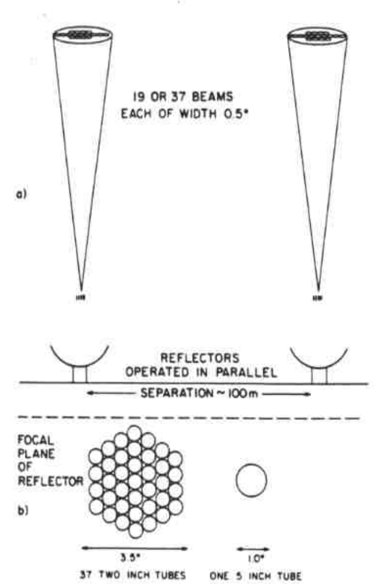


Figure 7. (a) The stereoscopic imaging system proposed in 1977. (b) The focal plane layout of pmt's is contrasted with a conventional detector.

A Source at last!

THE ASTROPHYSICAL JOURNAL, **342**:379–395, 1989 July 1

OBSERVATION OF TeV GAMMA RAYS FROM THE CRAB NEBULA USING THE ATMOSPHERIC CERENKOV IMAGING TECHNIQUE

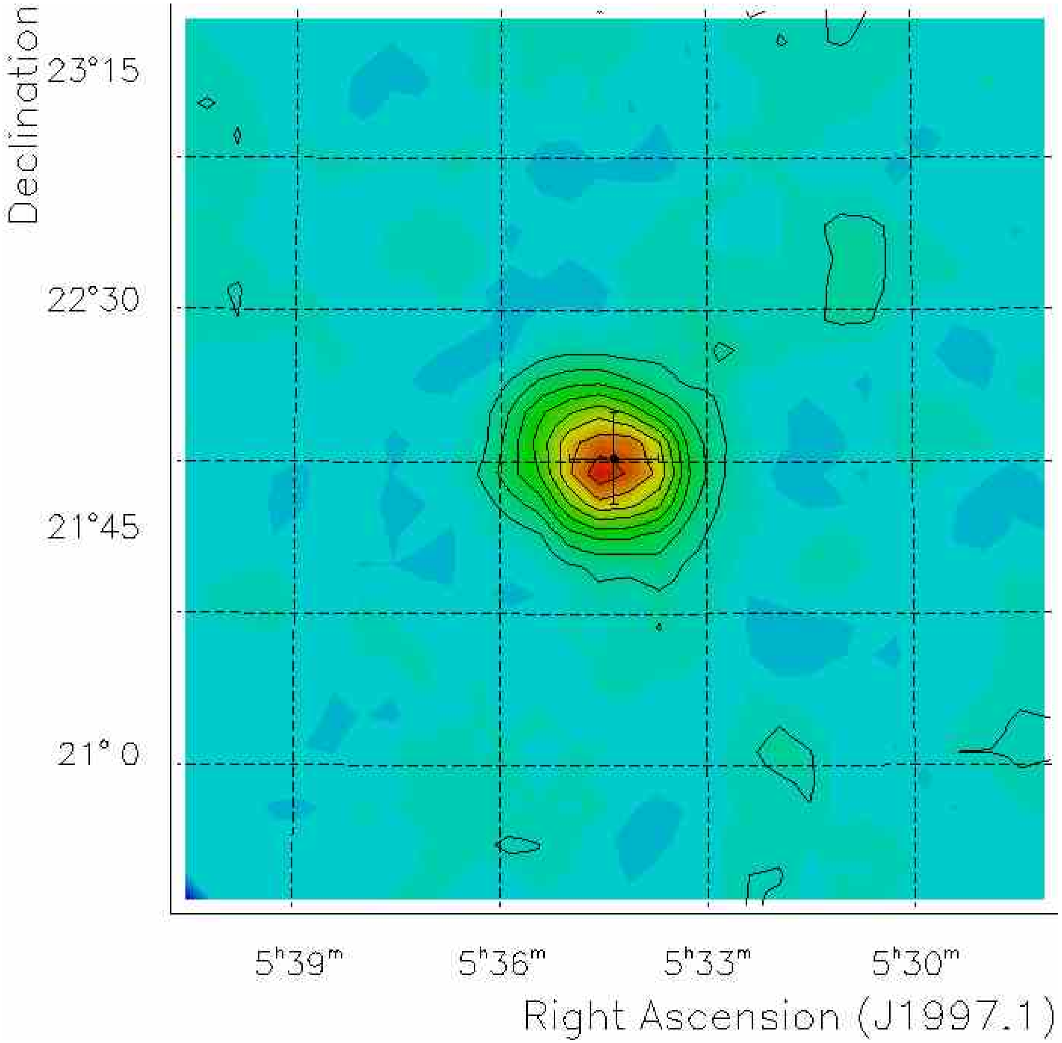
T. C. WEEKES,[1] M. F. CAWLEY,[2] D. J. FEGAN,[3] K. G. GIBBS,[1] A. M. HILLAS,[4] P. W. KWOK,[1] R. C. LAMB,[5] D. A. LEWIS,[5] D. MACOMB,[5] N. A. PORTER,[3] P. T. REYNOLDS,[1,3] AND G. VACANTI[5]

Received 1988 August 1; accepted 1988 December 9

ABSTRACT

The Whipple Observatory 10 m reflector, operating as a 37 pixel camera, has been used to observe the Crab Nebula in TeV gamma rays. By selecting gamma-ray images based on their predicted properties, more than 98% of the background is rejected; a detection is reported at the 9.0 σ level, corresponding to a flux of 1.8×10^{-11} photons cm^2 s^{-1} above 0.7 TeV (with a factor of 1.5 uncertainty in both flux and energy). Less than 25% of the observed flux is pulsed at the period of PSR 0531. There is no evidence for variability on time scales from months to years. Although continuum emission from the pulsar cannot be ruled out, it seems more likely that the observed flux comes from the hard Compton synchrotron spectrum of the nebula.

The Crab Nebula as Very High Energy Gamma Ray Source



Whipple Observatory
1986…success at last!

Supernova 1054 A.D.

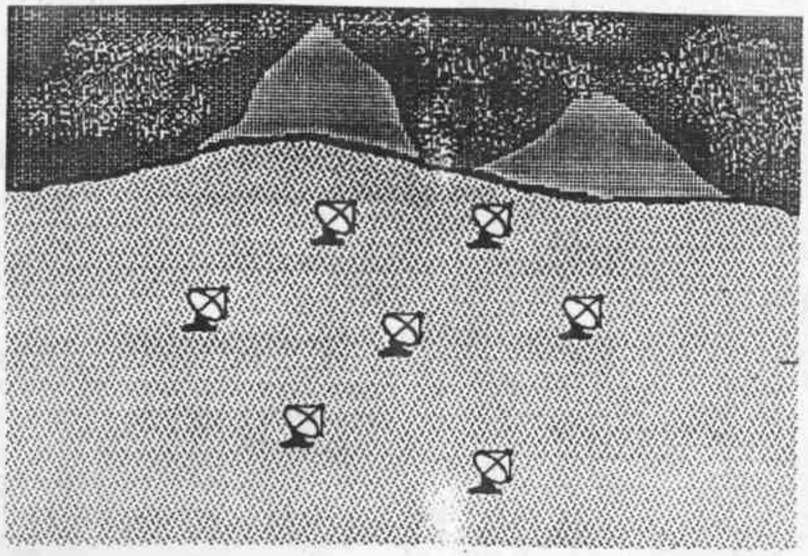
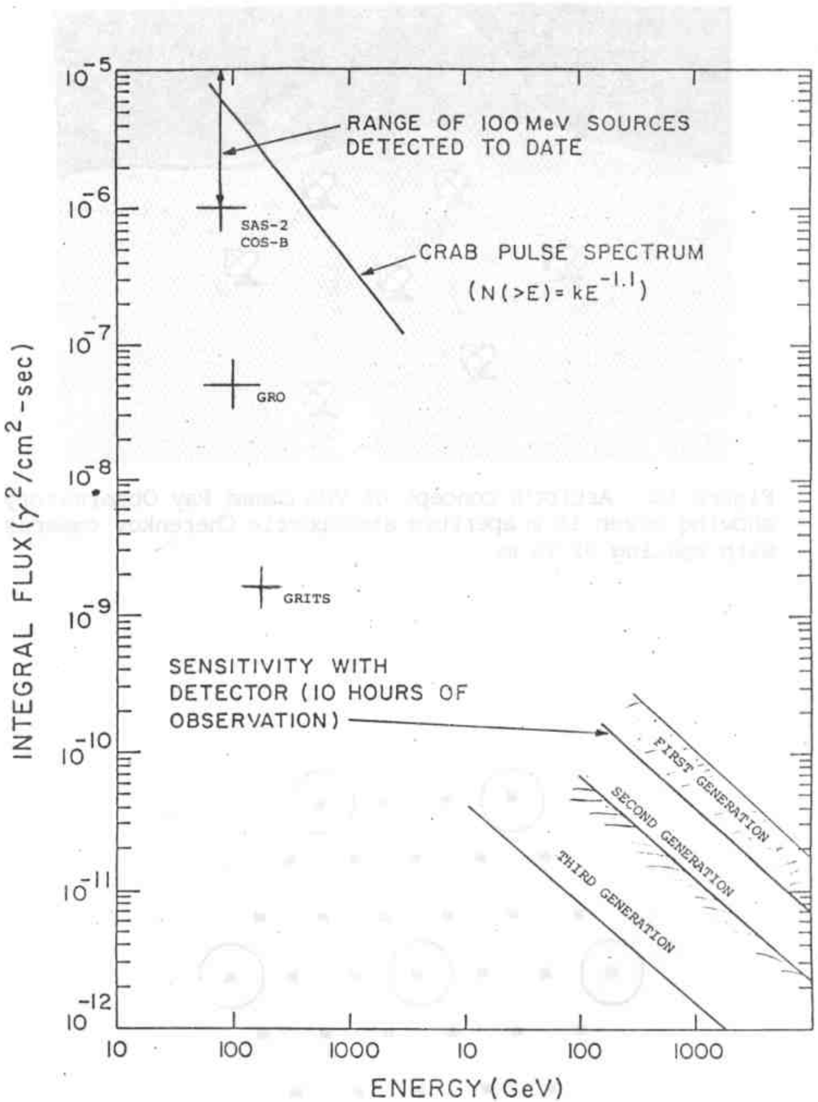


Figure 1a. Artist's concept of VHE Gamma Ray Observatory showing seven 15 m aperture atmospheric Cherenkov cameras with spacing of 75 m.

An array of ACIT's was first proposed in 1984 (prior to the detection of the Crab Nebula).

(NASA Workshop, Space Lab. Science, Baton Rouge, 1984)

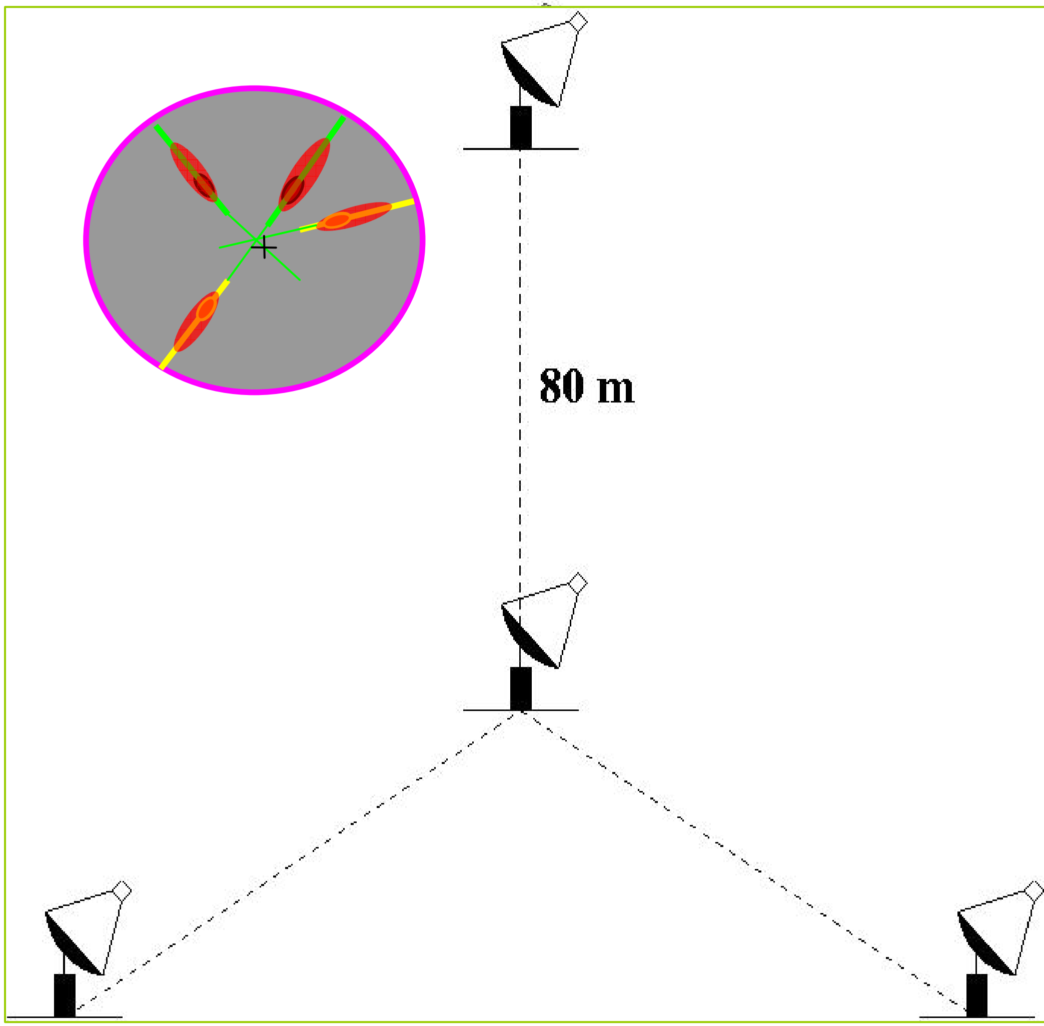
This is the configuration that was later adopted for VERITAS.



VERITAS Concept: 1996 →2003

VERITAS Philosophy

- Better Flux Sensitivity
- Array of "12 m" telescopes
- Imaging Cameras
- Improved Optics
- Improved Camera
- High Data Rate
- Flexible Operation
- Sub-arrays
- Reliable Operation
- New Technology where proven.



Brief History of GeV-TeV ground-based Gamma-ray Astronomy

- First Generation Systems 1960 – 1985
    - Weak or no discrimination
    - Crimea, Dublin, Whipple, Narrabri, ……….
- Second Generation Systems 1985 – 2003
    - Atmospheric Cherenkov Imaging Telescopes
- Whipple, Crimea, CAT, HEGRA, Durham, CANGAROO

……

- Third Generation Systems 2003 – 2010
    - Arrays of Large ACITs
    - MAGIC-2, HESS-5, CANGAROO-III, VERITAS-4
- Fourth Generation Systems 2010 -
    - TBD

TeV Sources

Zero

~ 10

> 100

1000?

Decadal Review 2000-2010

TABLE ES.1 Prioritized Initiatives (Combined Ground and Space) and Estimated Federal Costs for the Decade 2000 to 2010[a,b]

Initiative	[covered] $M)
Major Initiatives	
Next Generation Space Telescope (NGST)[d]	1,000
Giant Segmented Mirror Telescope (GSMT)[d]	350
Constellation-X Observatory (Con-X)	800
Expanded Very Large Array (EVLA)[d]	140
Large-aperture Synoptic Survey Telescope (LSST)	170
Terrestrial Planet Finder (TPF)[e]	200
Single Aperture Far Infrared (SAFIR) Observatory[e]	100
Subtotal for major initiatives	2,760
Moderate Initiatives	
Telescope System Instrumentation Program (TSIP)	50
Gamma-ray Large Area Space Telescope (GLAST)[d]	300
Laser Interferometer Space Antenna (LISA)[d]	250
Advanced Solar Telescope (AST)[d]	60
Square Kilometer Array (SKA) technology development	22
Solar Dynamics Observatory (SDO)	300
Combined Array for Research in Millimeter-wave Astronomy (CARMA)[d]	11
Energetic X-ray Imaging Survey Telescope (EXIST)	150
Very Energetic Radiation Imaging Telescope Array System (VERITAS)	35
Advanced Radio Interferometry between Space and Earth (ARISE)	350
Frequency Agile Solar Radio telescope (FASR)	26
South Pole Submillimeter-wave Telescope (SPST)	50
Subtotal for moderate initiatives	1,604
Small Initiatives	
National Virtual Observatory (NVO)	60
Other small initiatives[f]	246
Subtotal for small initiatives	306

operating

We have come a long way!

1967 - 2007