Giovanni and the Gamma-Ray Program at SAO

Trevor Weekes

NRC Postdoc at SAO, 1967-8

Gamma-ray Astronomy: Prediction

IL NUOVO CIMENTO VOL. VII, N. 6 16 Marzo 1958

On Gamma-Ray Astronomy.

P. MORRISON
Department of Physics, Cornell University - Ithaca, N. Y.

(ricevuto il 22 Dicembre 1957)

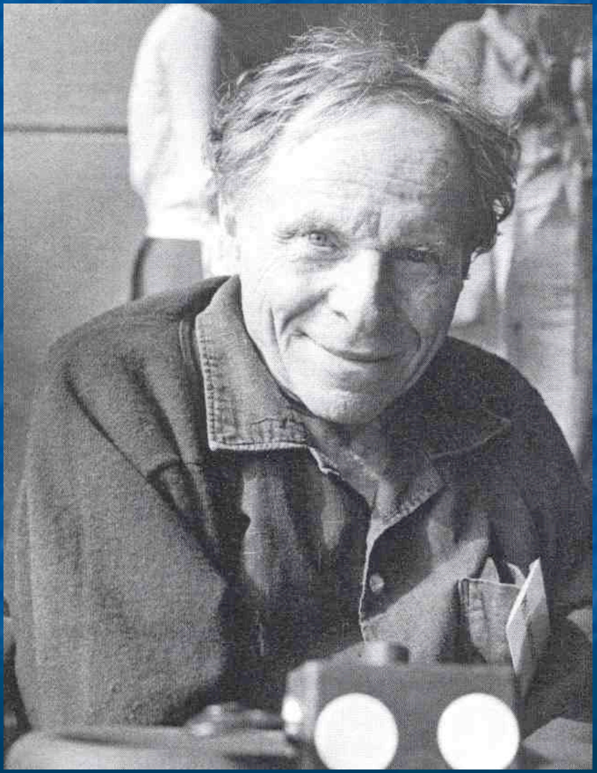
Summary. — Photons in the visible range form the basis of astronomy. They move in straight lines, which preserves source information, but they arise only very indirectly from nuclear or high-energy processes. Cosmic-ray particles, on the other hand, arise directly from high-energy processes in astronomical objects of various classes, but carry no information about source direction. Radio emissions are still more complex in origin. But γ-rays arise rather directly in nuclear or high-energy processes, and yet travel in straight lines. Processes which might give rise to continuous and discrete γ-ray spectra in astronomical objects are described, and possible source directions and intensities are estimated. Present limits were set by observations with little energy or angular discrimination; γ-ray studies made at balloon altitudes, with feasible discrimination, promise valuable information not otherwise attainable.

1. – The nature of the problem.

Astronomy is based on information carried by incoming radiation of optical frequencies. The photons in this channel retain the momentum with which they were originally emitted: with precision in direction, subject only to a rather easily interpreted Doppler shift in magnitude. On the other hand, such photons are very indirectly related indeed to the processes, generally nuclear in nature, which form the ultimate source of the radiated energy.

Insofar as energy-releasing processes are thermonuclear in nature, they proceed deep in stellar interiors, screened by dense layers of matter. We cannot hope to obtain direct signals from such regions (except by way of the still unexploited neutrino channel). But it is increasingly clear that energy-releasing processes of quite different type are also of importance for the evolution of

Seminal paper by Phillip Morrison, 1958



In the beginning.....

A Directional High Energy Gamma Ray Counter

G. G. Fazio and E. M. Hafner
Department of Physics and Astronomy
University of Rochester, Rochester, New York

Abstract A directional cerenkov counter has been developed for detection of energetic gamma rays from balloons and satellites. It is sensitive to photons whose directions lie within a 10-degree cone. It is completely insensitive to backward fluxes and almost completely insensitive to charged particles.

Review of Scientific Instruments, 1962

Journal of Geophysical Research Vol. 72, No. 9 May 1, 1967

The OSO 1 High-Energy Gamma-Ray Experiment

G. G. Fazio
Smithsonian Astrophysical Observatory and Harvard College Observatory Cambridge, Massachusetts

E. M. Hafner
Department of Physics and Astronomy University of Rochester, Rochester, New York

Previous authors have reported several attempts to detect a solar γ-ray flux in the energy ... type 7817), bonded to lucite light pipes through an intermediate thin disk of clear, flexible plastic

OSO-1

Reviews of Geophysics Vol. 3, No. 2 May 1965

The Gamma-Ray Spectrum of the Sun

Joseph F. Dolan
Astronomy Department, Harvard University, Cambridge, Massachusetts and Institute for Space Studies, NASA, New York, New York

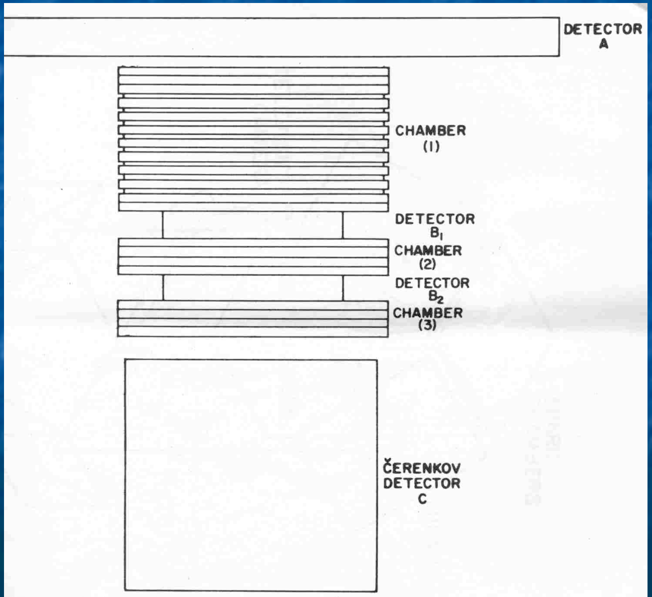
G. G. Fazio
Smithsonian Astrophysical Observatory and Harvard College Observatory, Cambridge, Massachusetts

Abstract. The γ-ray spectrum ($h\nu > 10$ kev) emitted by the sun is investigated and approximate fluxes at the earth are predicted on the basis of a simple solar-flare model. The object of this paper is to determine what new information about the sun and, in particular, solar flares we can learn from the detection of this radiation. We also investigate which part of the spectrum is most feasibly detectable and which part yields the most direct information on solar-flare structure. Our calculations indicate the fol-

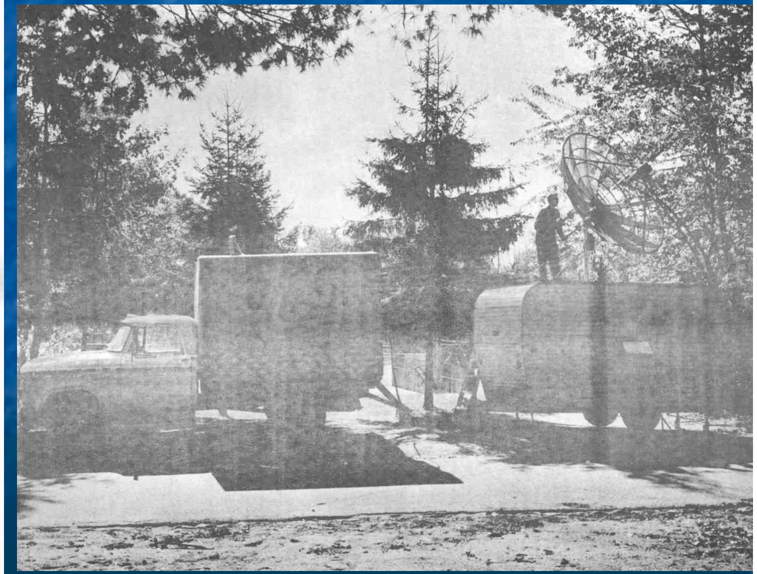
Balloon Program at SAO

VIDICON SPARK CHAMBER DETECTOR FOR GAMMA-RAY ASTRONOMY*

H. F. Helmken and G. G. Fazio
Smithsonian Astrophysical Observatory
and
Harvard College Observatory
Cambridge, Massachusetts

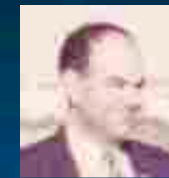


Geometry of the spark chamber and lead glass Čerenkov detector.



1967

Gas Cherenkov Balloon Telescope



A LARGE-AREA GAS-ČERENKOV DETECTOR FOR HIGH-ENERGY GAMMA-RAY ASTRONOMY

J. DELVAILLE, K. GREISEN, D. KOCH and B. McBREEN

Cornell University, Ithaca, N.Y., U.S.A.

and

G. FAZIO, D. HEARN, and H. HELMKEN

Smithsonian Astrophysical Observatory, Cambridge, Mass., U.S.A.

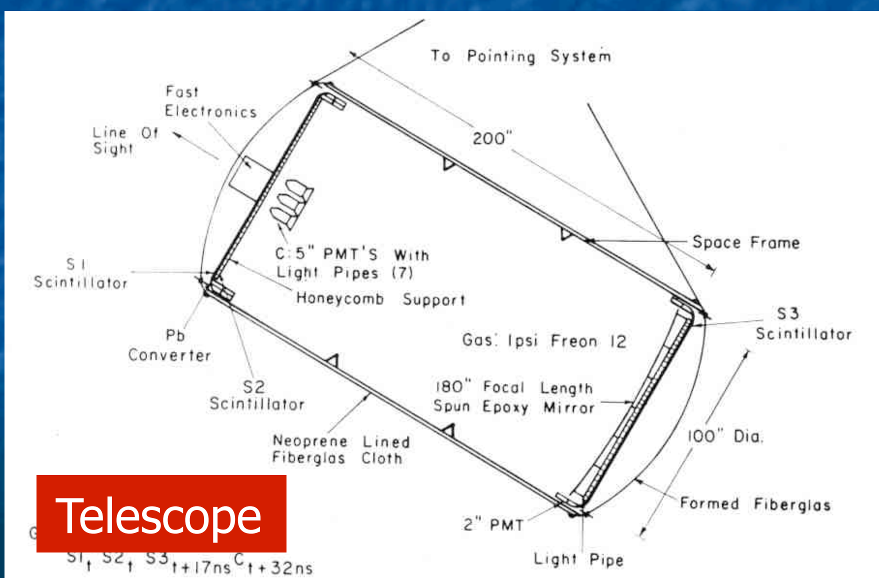
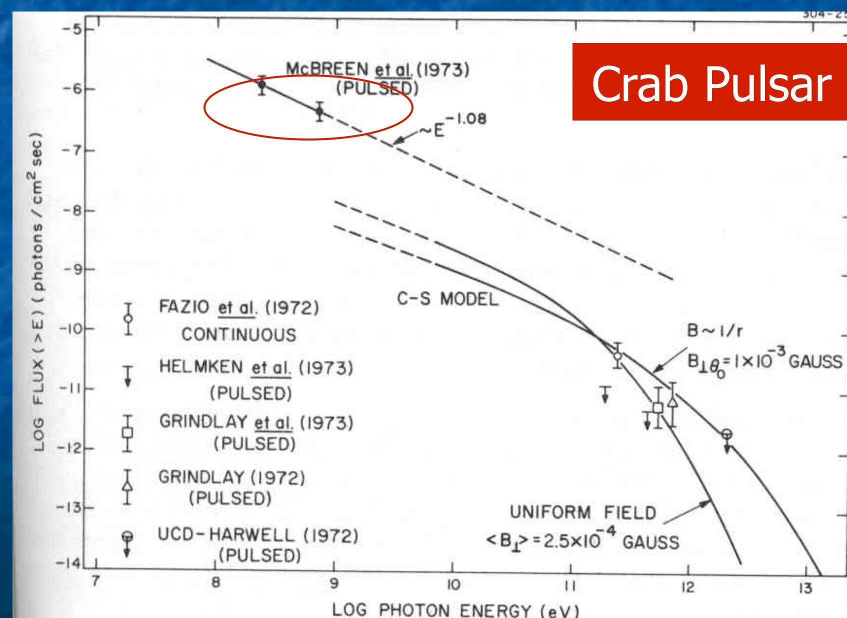


Fig. 1. Schematic diagram of the gas-Čerenkov detector built at Cornell University.



Giovanni as Gamma-ray Pundit

Report of the X-Ray and Gamma-Ray Panel
September 1968

Recommended Program in High-Energy Astronomy

WILLIAM L. KRAUSHAAR, *Chairman;* GEOFFREY BURBIDGE, GIOVANNI G. FAZIO, WILLIAM A. FOWLER, HERBERT FRIEDMAN, RICCARDO GIACCONI, LAURENCE E. PETERSON, NANCY G. ROMAN (NASA contact)

24. HIGH-ENERGY DISCRETE SOURCES*

G. G. FAZIO

Smithsonian Astrophysical Observatory and Harvard College Observatory, Cambridge, Mass. 02138, U.S.A.

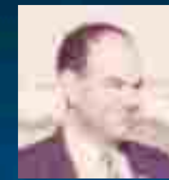
Abstract. The origin of the gamma-radiation from the galactic plane and the region near the galactic center is still uncertain. However, during this meeting, several groups reported evidence for discrete sources of cosmic gamma-rays. Most of the sources are located near the galactic plane, and some are associated with X-ray sources. The galactic gamma-radiation may be due to these previously unresolved sources. Other sources detected may be associated with variable radio galaxies.

The Crab Nebula still remains the most investigated source at gamma-ray energies. Pulsed emission from NP 0532 was detected in the 10 to 30 MeV region, but no continuous emission was observed. At the highest energies, pulsed emission was reported at $\sim 10^{12}$ eV. Continuous emission from the Crab Nebula was observed at $\sim 10^{11}$ eV; the radiation may be time variable.

The recent gamma-ray experiments on Apollo 15 and 16 and the ESRO satellite TD-1 are described, as well as future experiments on the satellites SAS-B, COS-B, and HEAO-B.

* Dr Fazio arranged and led the panel discussion on this topic. The other panel members were: B. Agrinier, G. Frye, H. Helmken, R. Hillier, G. Hutchinson, D. Kniffen, J. Kurfess, K. Pinkau, G. Share and T. C. Weekes.

Gamma-ray Pundit



METHODS OF EXPERIMENTAL PHYSICS, VOL. 12
ASTROPHYSICS
Part A: Optical and Infrared

ACADEMIC PRESS, INC.

7. X-RAY AND GAMMA-RAY DETECTION BY MEANS OF ATMOSPHERIC INTERACTIONS: FLUORESCENCE AND ČERENKOV RADIATION*

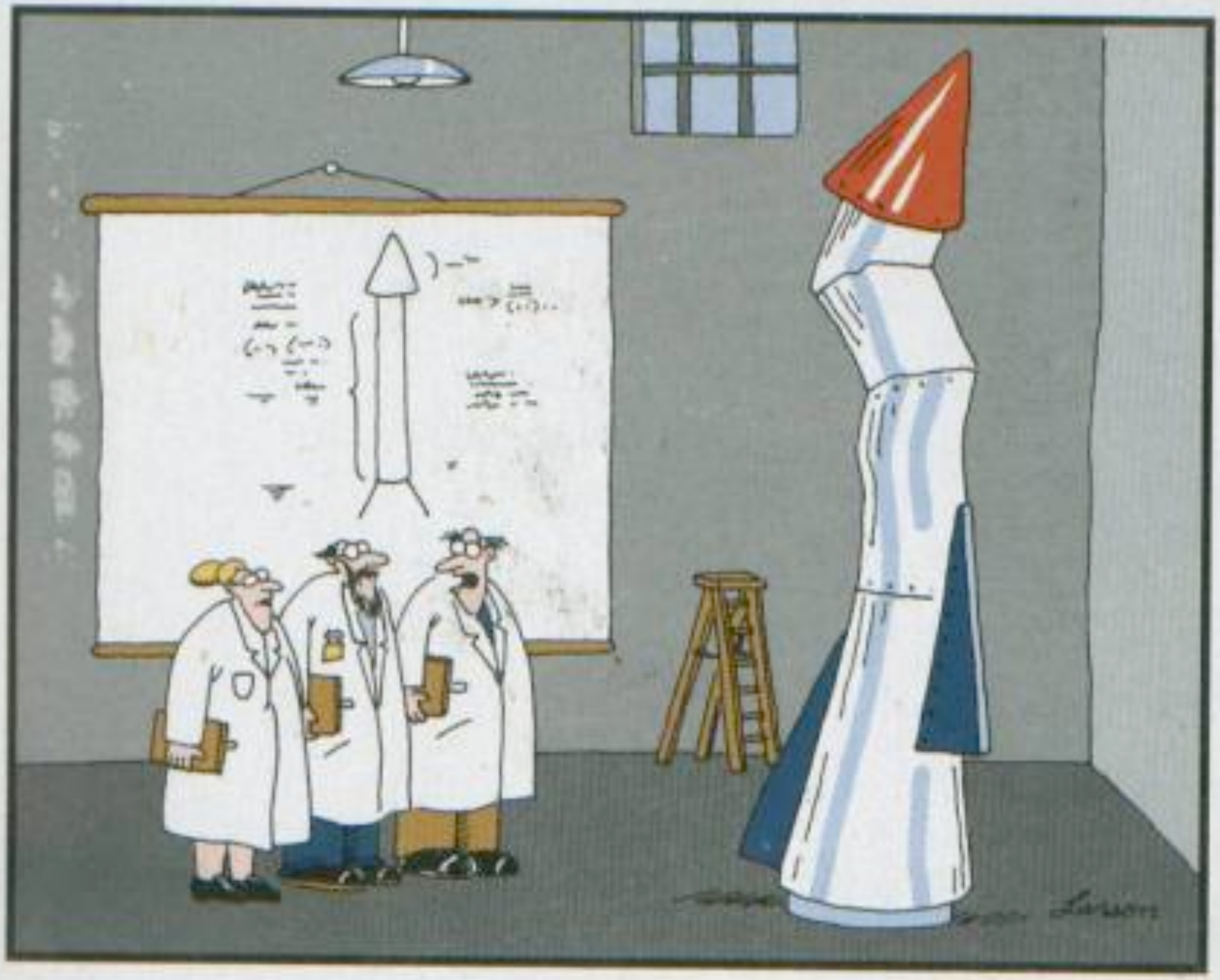
(Reprinted from Nature, Vol. 225, No. 5236, pp. 905-911, March 7 1970)

Nature Review

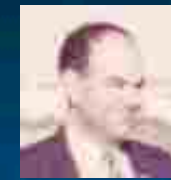
High-energy Gamma-ray Astronomy

by
G. G. FAZIO
Smithsonian Astrophysical Observatory,
and Harvard College Observatory,
Cambridge, Massachusetts

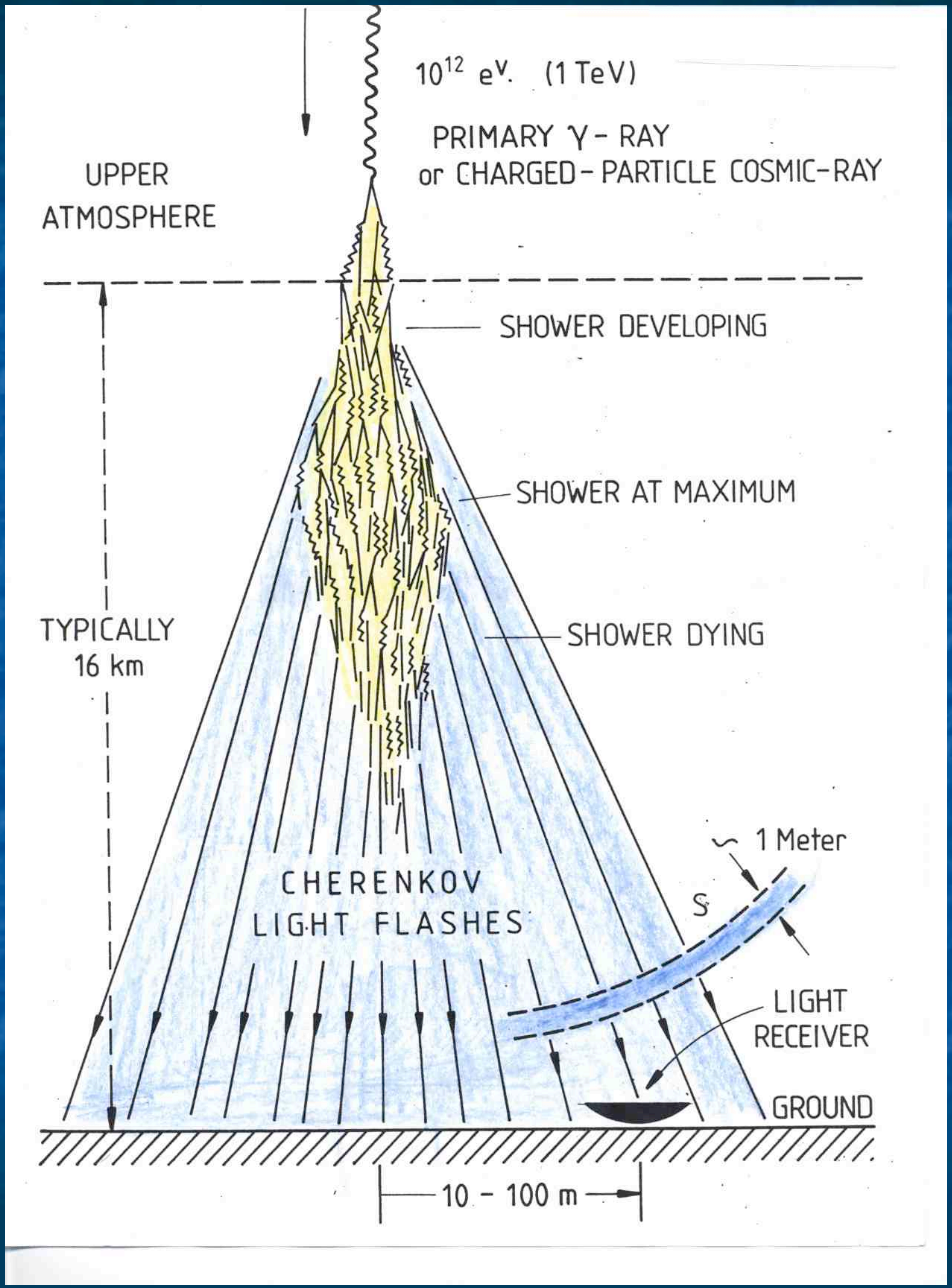
Gamma-ray astronomy above 10 MeV is difficult from the experimental point of view, but promising data are beginning to appear, as this survey progress report shows.



"It's time we face reality, my friends. …
We're not exactly rocket scientists."



Giovanni decides to try his hand at ground-based gamma-ray astronomy



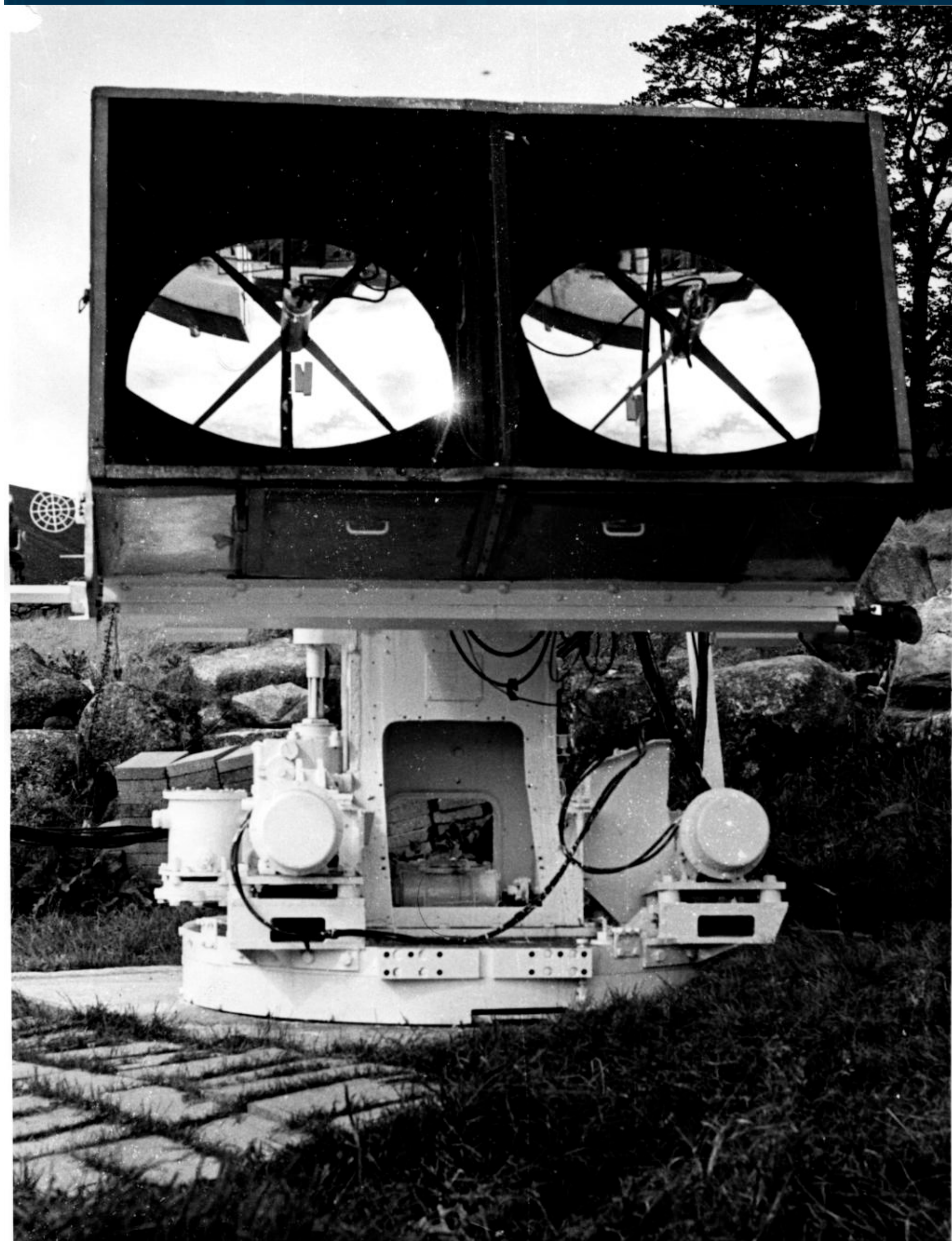
COULD HE USE OF ATMOSPHERIC CHERENKOV DETECTOR TO GAMMA-RAY ASTRONMY?

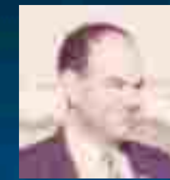
Simple Technique,
Simple Detectors,

But previous efforts had come to naught!

First Smithsonian venture into VHE gamma-ray used Solar Furnace at Natick, MA ~ 1965-6.
Exploratory Effort by Giovanni Fazio and Henry Helmken

Some cheap labor required!





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

SAO agrees to build large optical reflector as gamma-ray telescope, 1966

An experiment to search for discrete sources of cosmic gamma rays in the 10^{11} to 10^{12} eV region[1]

G. G. Fazio and H. F. Helmken

Smithsonian Astrophysical Observatory and Harvard College Observatory, Cambridge, Mass., U.S.A.

G. H. Rieke[2]

Physics Department, Harvard University, Cambridge, Mass., U.S.A.

and T. C. Weekes[3]

Smithsonian Astrophysical Observatory, Cambridge, Mass., U.S.A.

Received June 21, 1967

A large optical reflector, designed to detect the Cerenkov radiation produced in the night sky by cosmic gamma rays, is being built for operation in the spring of 1968. The $f/0.7$ reflector will have an effective aperture of 34 ft, consisting of a mosaic of 252 2-ft hexagonal mirrors supported on a fully steerable frame. The mirrors will be front-aluminized so that by use of

[1] Presented at the Tenth International Conference on Cosmic Rays, held in Calgary, June 19–30, 1967, OG-15.
[2] NSF predoctoral fellow.
[3] NAS–NRC postdoctoral associate; on leave of absence from University College, Dublin, Ireland.

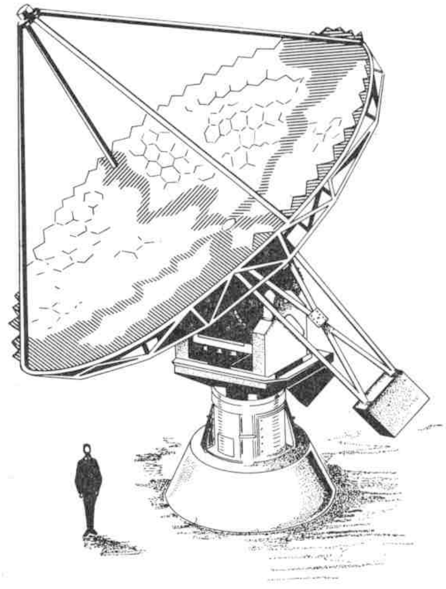


Fig. 1. Artist's impression of the large optical reflector on Mount Hopkins.

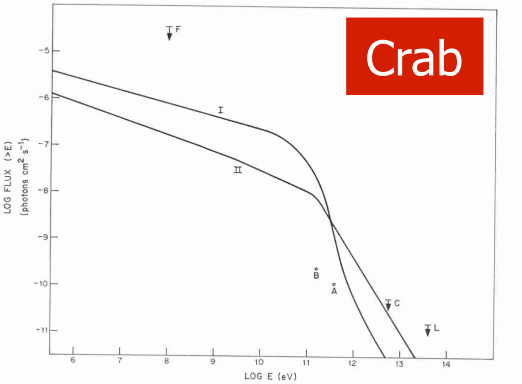


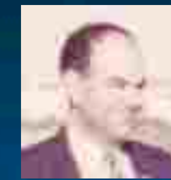
Fig. 3. Predicted integral gamma-ray flux from Crab nebula. I: $d = 1\,100$ pc (Gould 1965). II: $d = 1\,700$ pc. F, C, L = upper limits (Fazio *et al.* 1967; Chudakov *et al.* 1964; Long *et al.* 1966). A, B = sensitivities predicted with this instrument.

10^{th} I.C.R.C., Calgary, 1967

10th I.C.R.C., Calgary, 1967

TCW, Henry Helmken, Giovanni Fazio, John Jelley (Harwell), Graham Smith (Jodrell Bank), Neil Porter (U.C.Dublin)

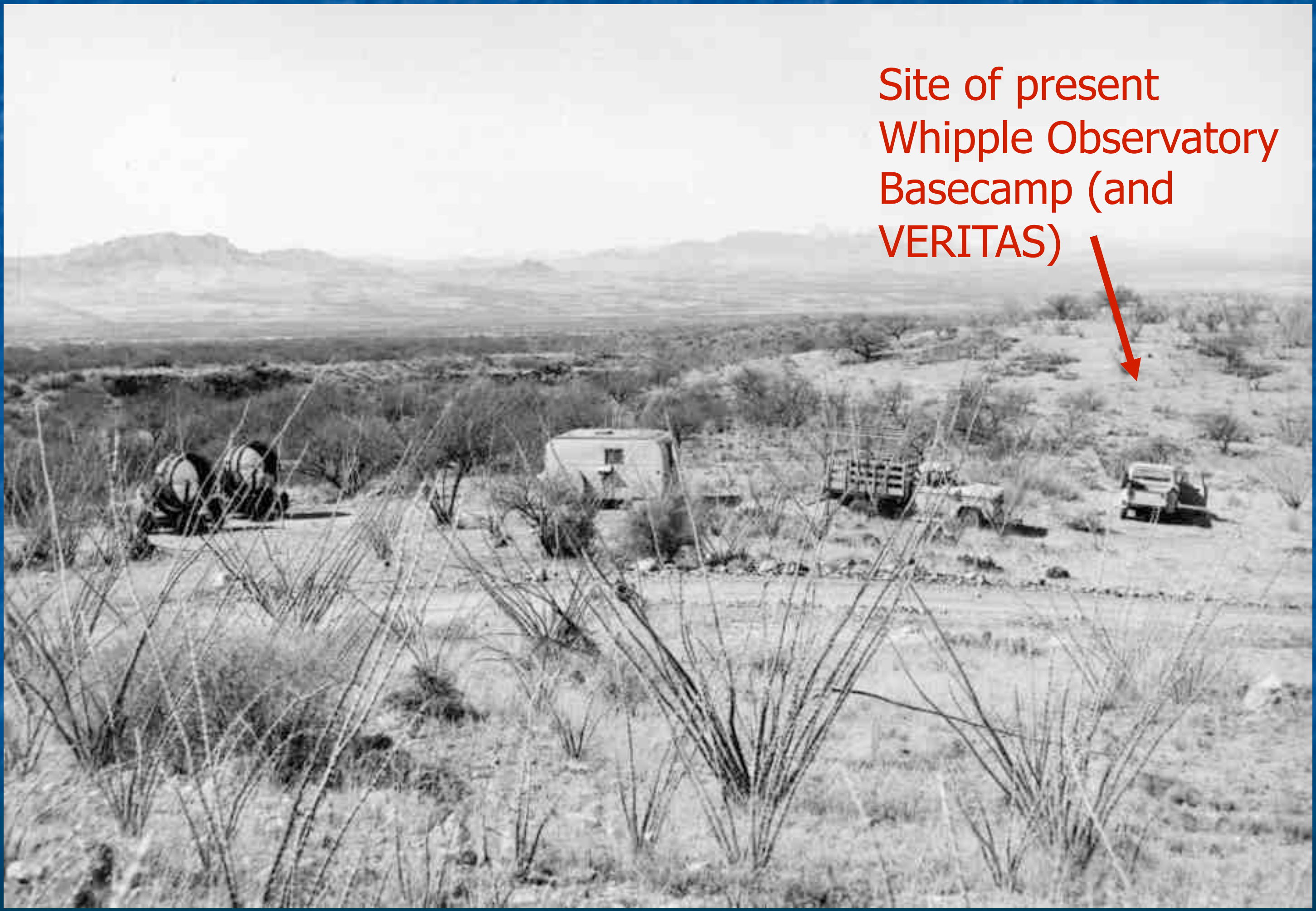
First Gamma-ray Experiment at Whipple Observatory, 1967-8



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

(a wide spot on the road)



Upper Limits on 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

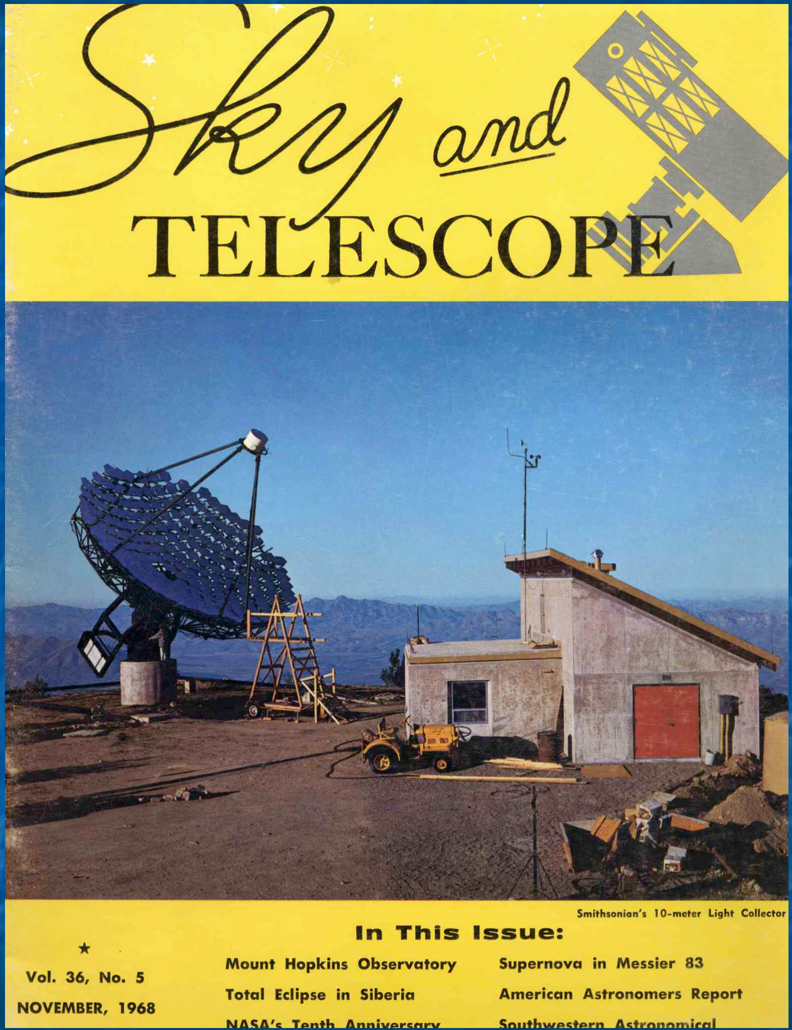
T. C. WEEKES*
Mount Hopkins Observatory, Smithsonian Astrophysical Observatory, Tubac, Arizona

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.

Fazio completes the 10 m Telescope in 1968
First purpose-built gamma-ray telescope
Prototype for all future telescopes



Dedication of Mount Hopkins (Whipple) Observatory, 1968

Whipple 10 m Telescope

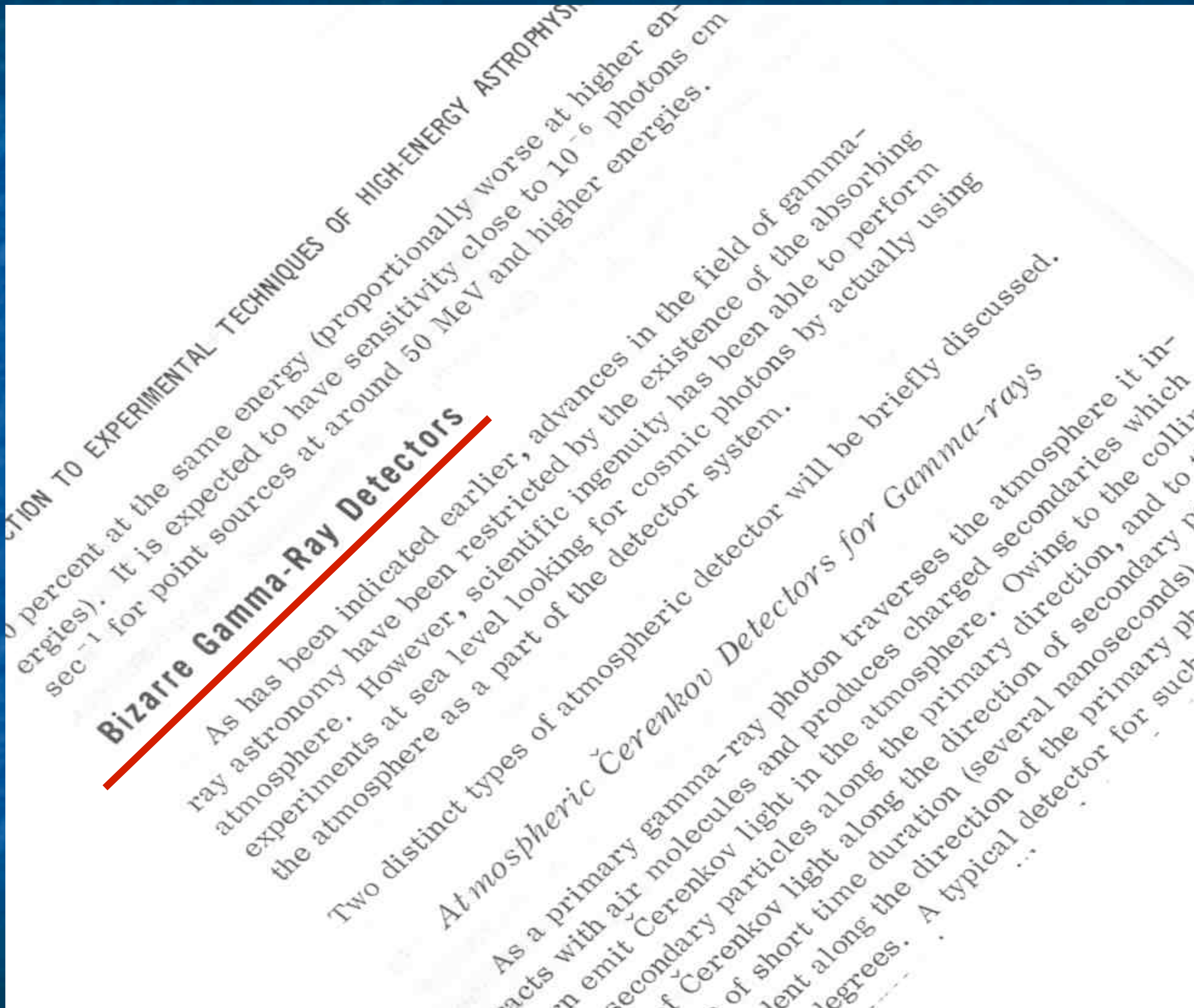
Only weak discrimination against cosmic ray background

No Credible Sources were detected

Smithsonian gamma-ray effort closed down 1978

"I never expected anything to come out of it!"

Not mainstream gamma-ray astronomy


...TION TO EXPERIMENTAL TECHNIQUES OF HIGH-ENERGY ASTROPHYS...

...0 percent at the same energy (proportionally worse at higher en-
ergies). It is expected to have sensitivity close to 10^{-6} photons cm
sec^{-1} for point sources at around 50 MeV and higher energies.

Bizarre Gamma-Ray Detectors

As has been indicated earlier, advances in the field of gamma-
ray astronomy have been restricted by the existence of the absorbing
atmosphere. However, scientific ingenuity has been able to perform
experiments at sea level looking for cosmic photons by actually using
the atmosphere as a part of the detector system.

Two distinct types of atmospheric detector will be briefly discussed.

Atmospheric Čerenkov Detectors for Gamma-rays

As a primary gamma-ray photon traverses the atmosphere it in-
...racts with air molecules and produces charged secondaries which
...rn emit Čerenkov light in the atmosphere. Owing to the collim...
...secondary particles along the primary direction, and to th...
...of Čerenkov light along the direction of secondary p...
...e of short time duration (several nanoseconds)...
...dent along the direction of the primary ph...
...degrees. A typical detector for such...

1976 SAO gamma-ray group disperses to longer (lesser) wavelengths!

Review by Ogelman in Goddard School 1968

Seeds for new approach to gamma-ray astronomy: Cherenkov Shower Imaging using Image Intensifiers (1960-65) and Use of Stereo Detectors (1972-76)

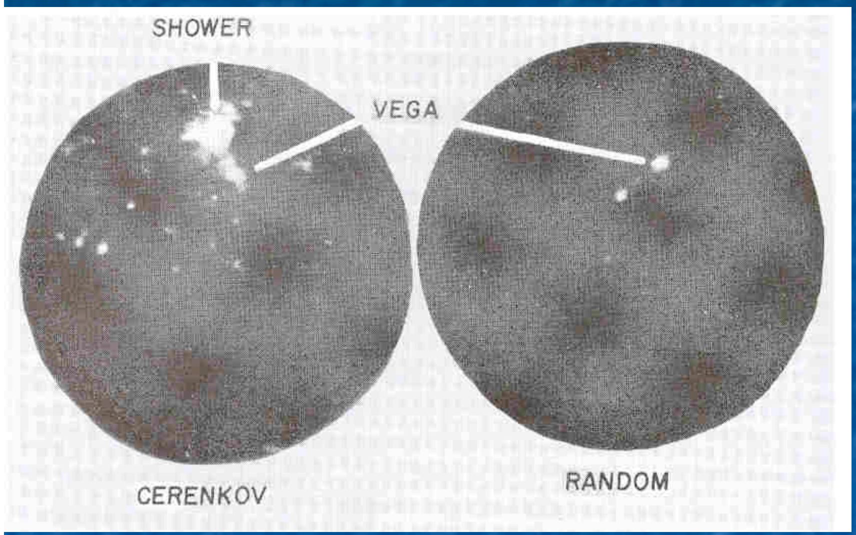
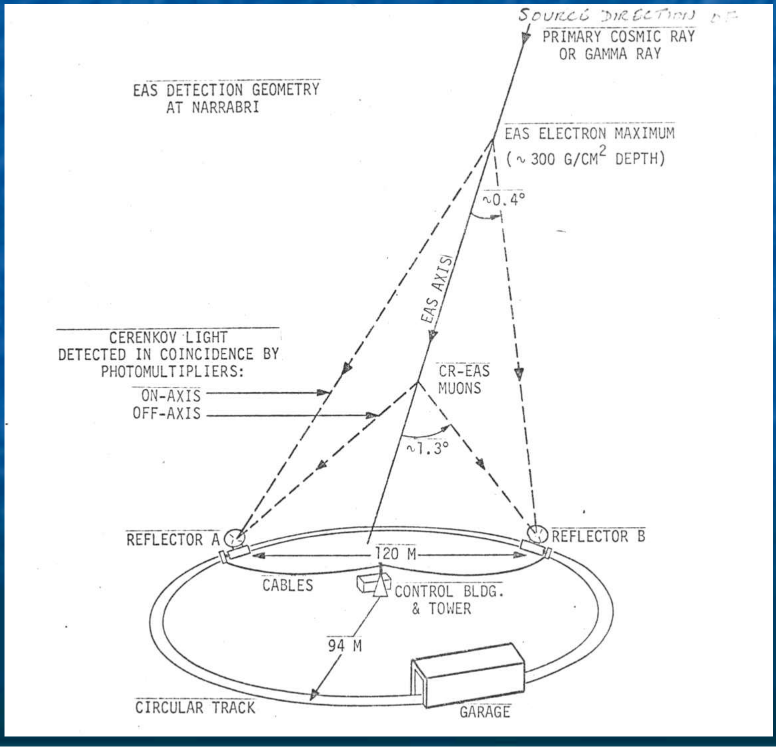


Image Intensifier Pictures of Cherenkov light Image from Cosmic Ray Air Shower.
On short time-scale images are brighter than bright star (Vega).
Work by David Hill (M.I.T.) and Neil Porter (U.C.D.) in 1960



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)

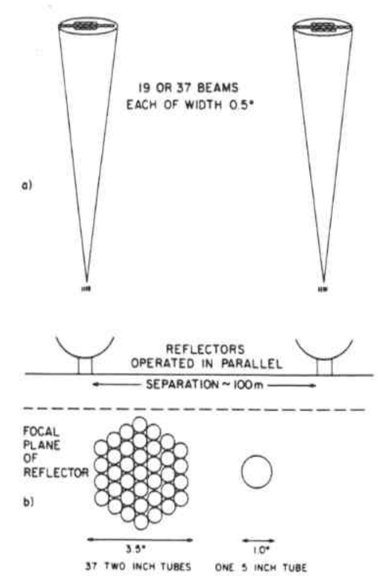
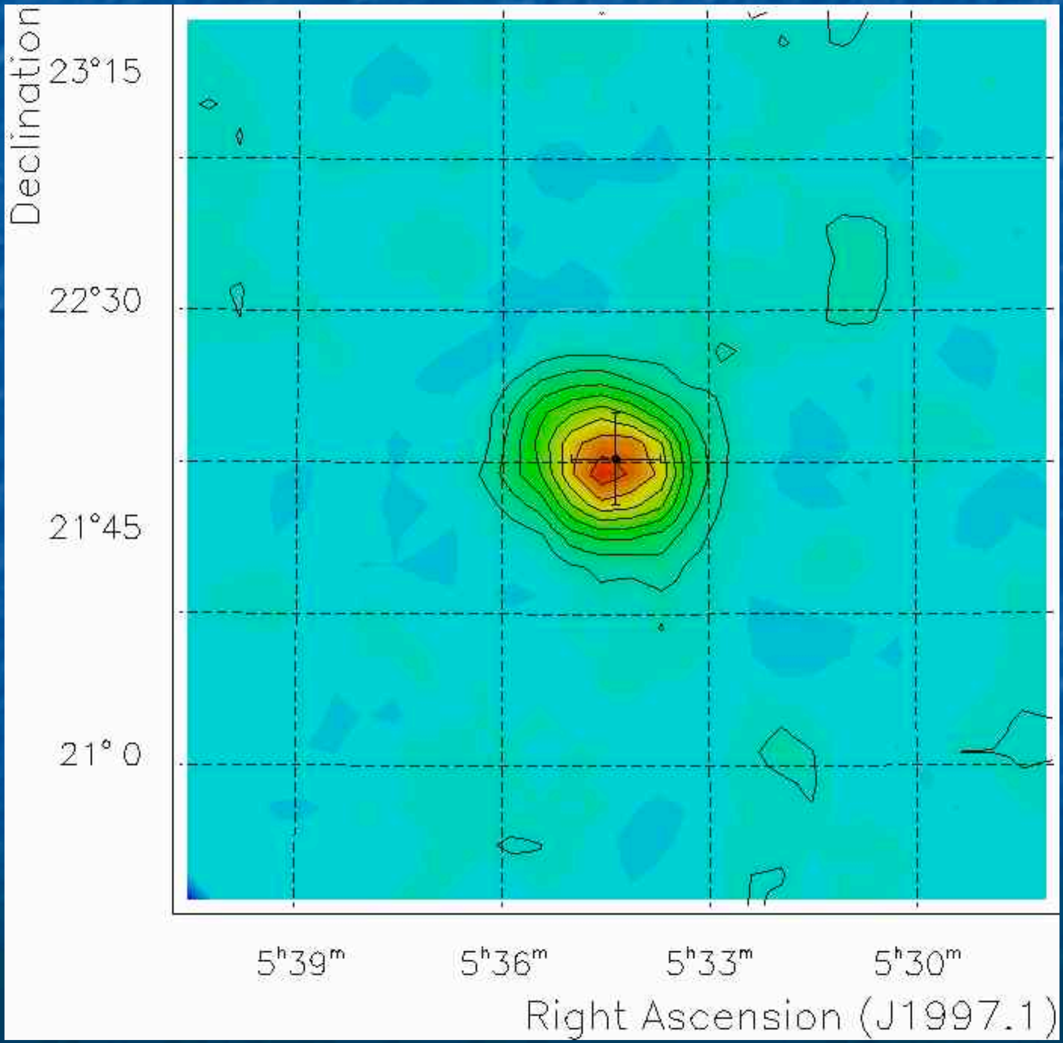


Figure 7. (a) The stereoscopic imaging system proposed in 1977. (b) The focal plane layout of pmt's is contrasted with a conventional detector.

Funding from DOE, 1982

Crab Nebula = First Very High Energy Gamma Ray Source



Whipple Observatory
1986…success at last!

Supernova 1054 A.D.

Blazars also detected!

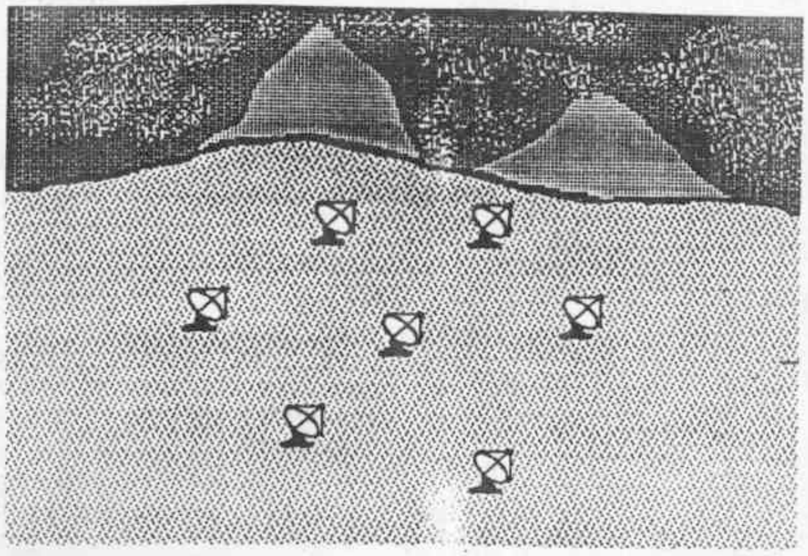
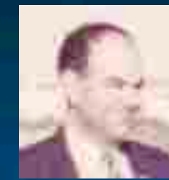
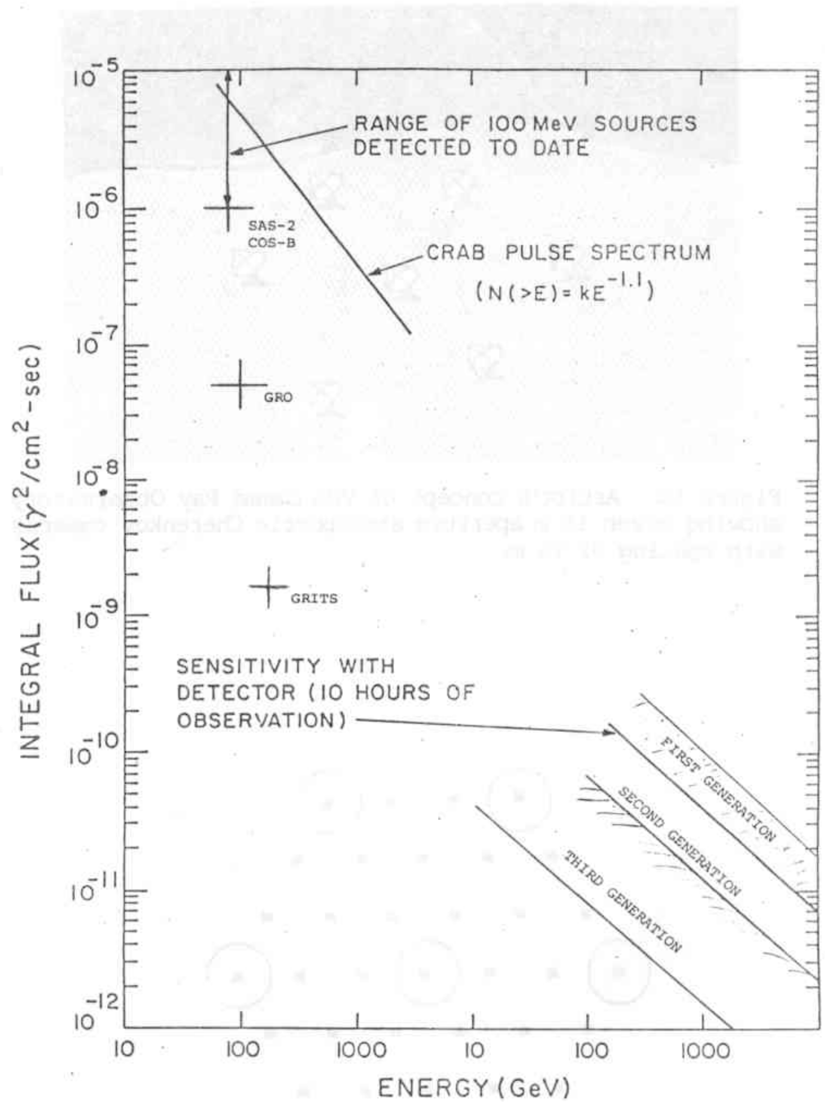


Figure 1a. Artist's concept of VHE Gamma Ray Observatory showing seven 15 m aperture atmospheric Cherenkov cameras with spacing of 75 m.



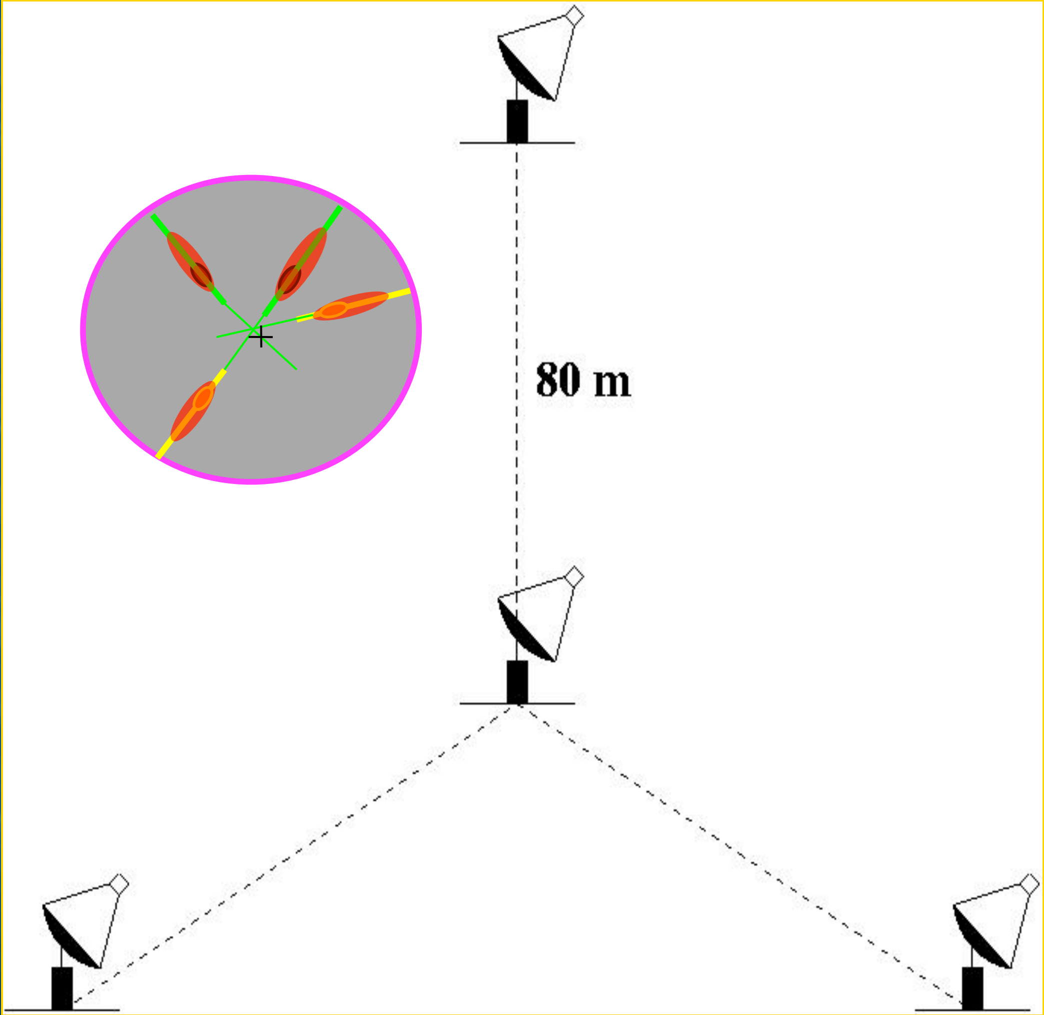
- An array of ACIT's was first proposed in 1984 (prior to the detection of the Crab Nebula).
- (NASA Workshop, Space Lab. Science, Baton Rouge, 1984)
- This is the configuration that was later adopted for VERITAS.



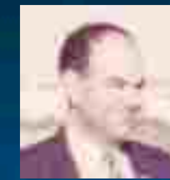
VERITAS Concept: 2000

VERITAS Philosophy

- Better Flux Sensitivity
- Array of "12 m" telescopes
- Imaging Cameras
- Improved Optics
- Improved Camera
- High Data Rate



VERITAS, first light in April, 2007



Instrument:

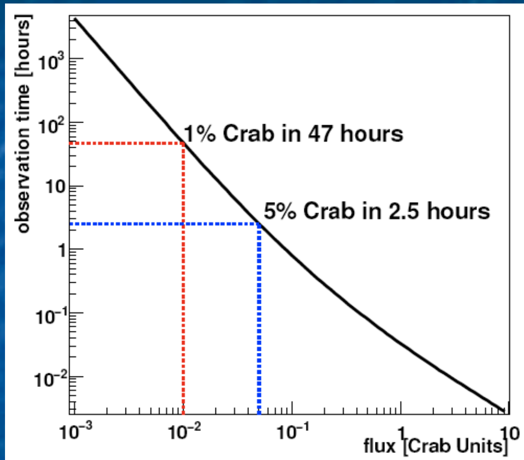
- Four 12-m telescopes
- 500-pixel cameras (3.5° FoV)
- FLWO, Mt. Hopkins, Az (1268 m)

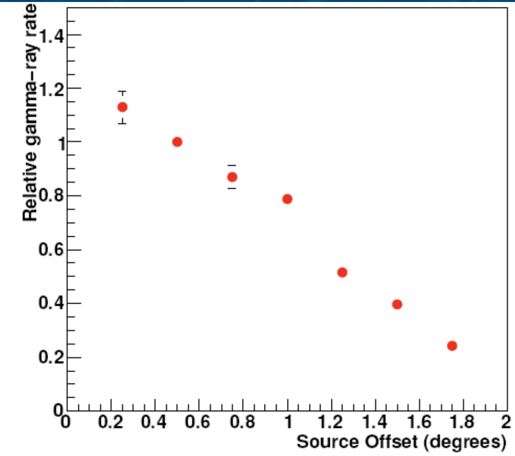
Specifications:

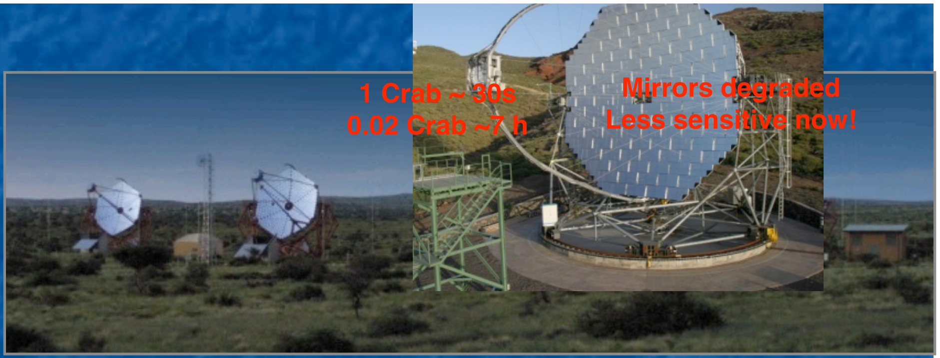
Energy threshold	~ 150 GeV
Source location	< 0.05°
Energy resolution	~ 10-20 %

VERITAS Sensitivity

- Energy Range: ~100 GeV to ~30 TeV
- Crab-rate (triggered γ-rays @ 20º): 37 min^{-1}
- Pointing: ~90″ (Conservatively)
- Angular resolution: r_{68} < 0.14º
- Energy resolution: ~15-20%







HESS

VERITAS has achieved its proposed sensitivity!

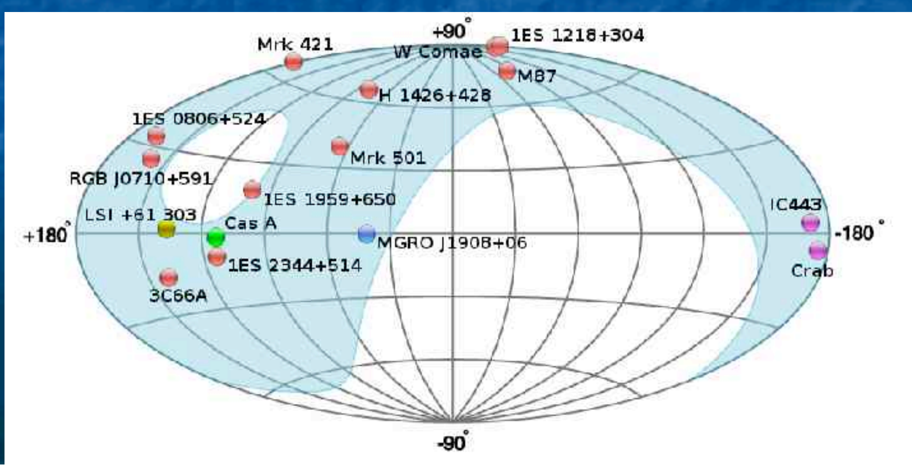
1 Crab ~ 80
0.02 ~ 13 h
0.005 Crab ~130 h

1 Crab ~ 250s
0.02 Crab ~60 h

MAGIC

More than 100 TeV sources now known.
Sources detected with high sensitivity by VERITAS:

- GALACTIC
  - Crab Nebula (plerion)
  - LSI +61 303 (binary)
  - IC433 (SNR)
  - Cas A (SNR)
  - MGRO J1908 (dark)
  - Boomerang (SNR)
- EXTRAGALACTIC
  - Mrk 421 (blazar)
  - Mrk 501 (blazar)
  - H1426+42 (blazar)
  - 1ES1959 (blazar)
  - 1ES2344 (blazar)
  - 1ES1218 (blazar)
  - M87 (radio galaxy)
  - RGB J0152+017 (blazar)
  - 1ES0806 (blazar)
  - W Comae (blazar)
  - 3C66a (blazar)
  - RGB J0710+591 (blazar)



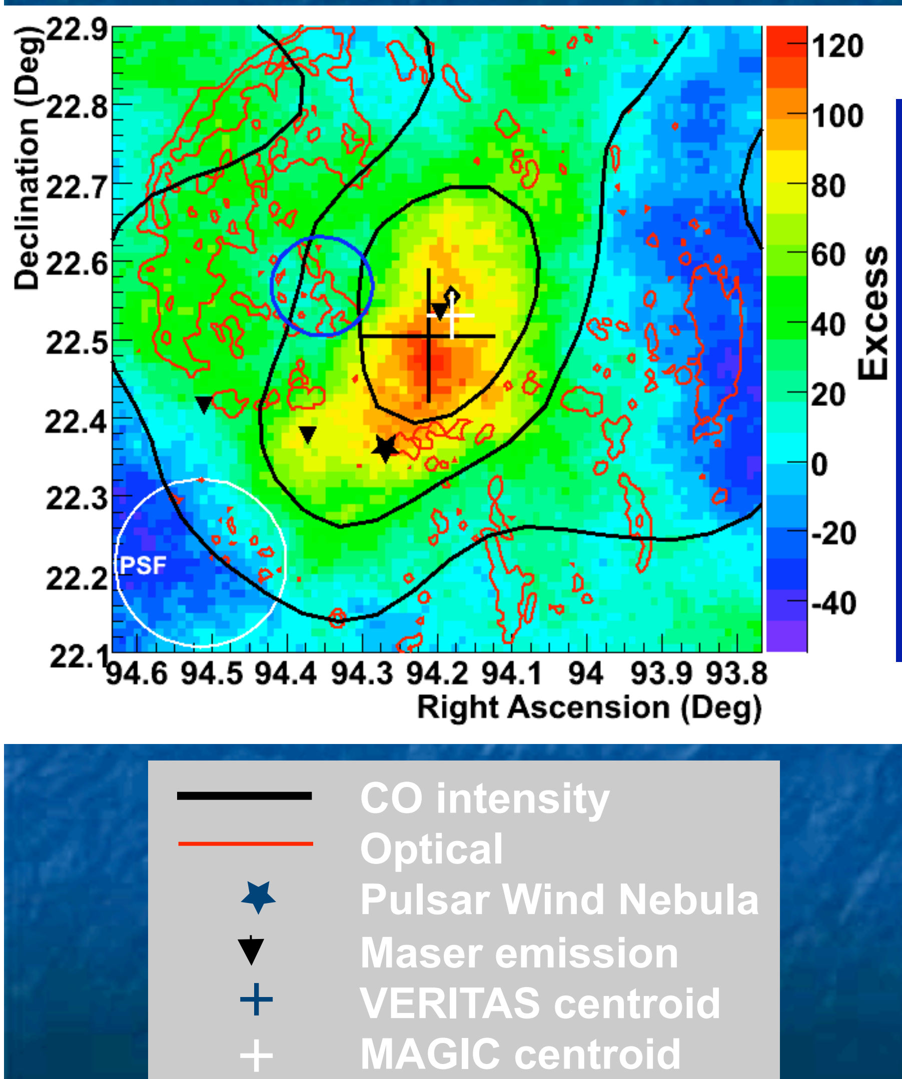
Galactic Sources

Holy Grail of TeV Gamma-ray Astronomy:

Find the Unambiguous Source of Hadronic Cosmic Rays

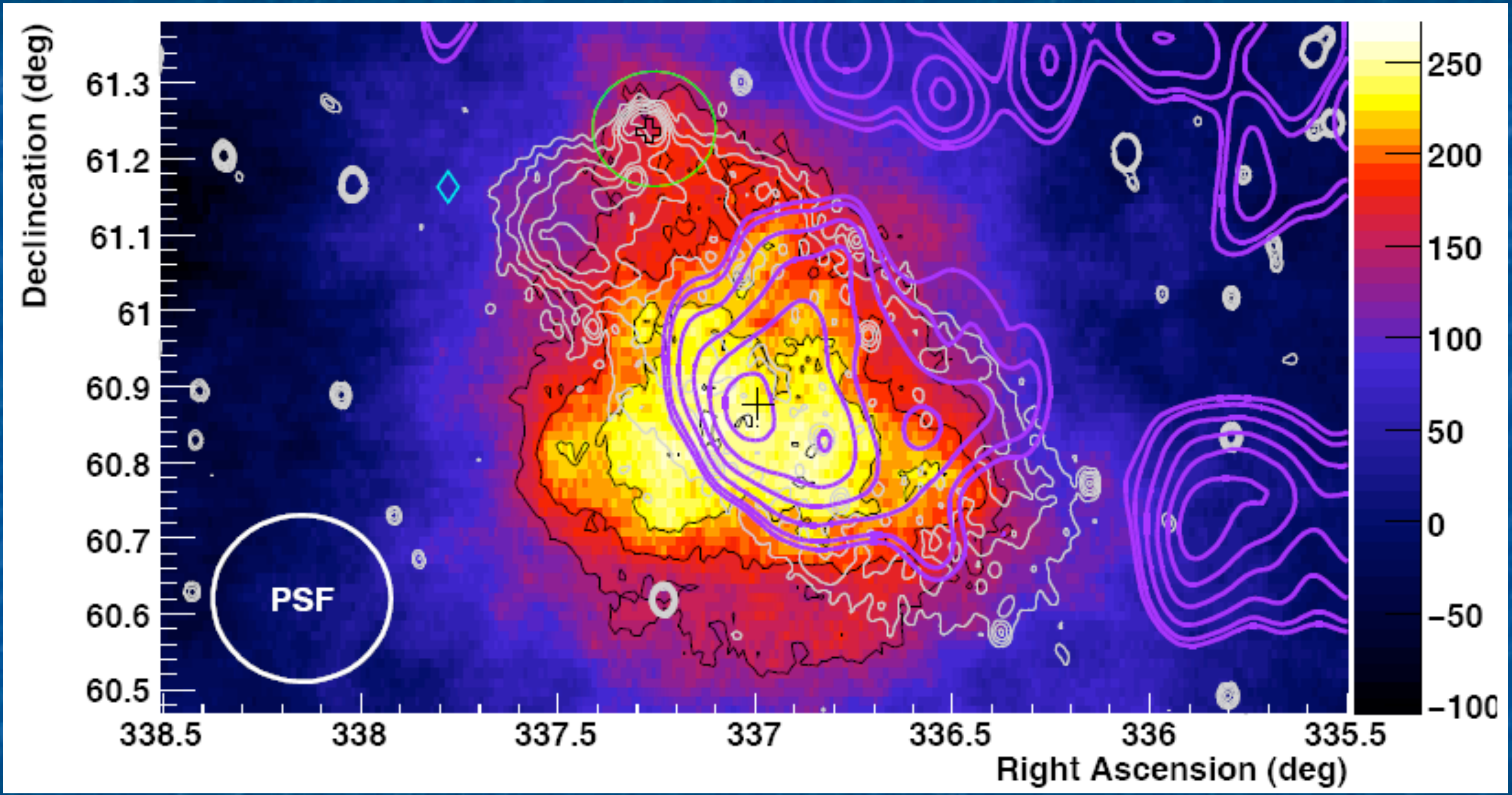
(Most Galactic Sources can be attributed to Electron Progenitors)

IC 443 Supernova Remnant



- Brightest TeV emission overlaps densest region of molecular cloud, as indicated by CO contours
  - Not coincident with radio/optical shell or PWN
- Maser emission implies SNR shock is interacting with cloud
- TeV emission could be from
  - CR-induced pion production in cloud
  - Relic electrons produced by the pulsar at early times and trapped in the molecular cloud

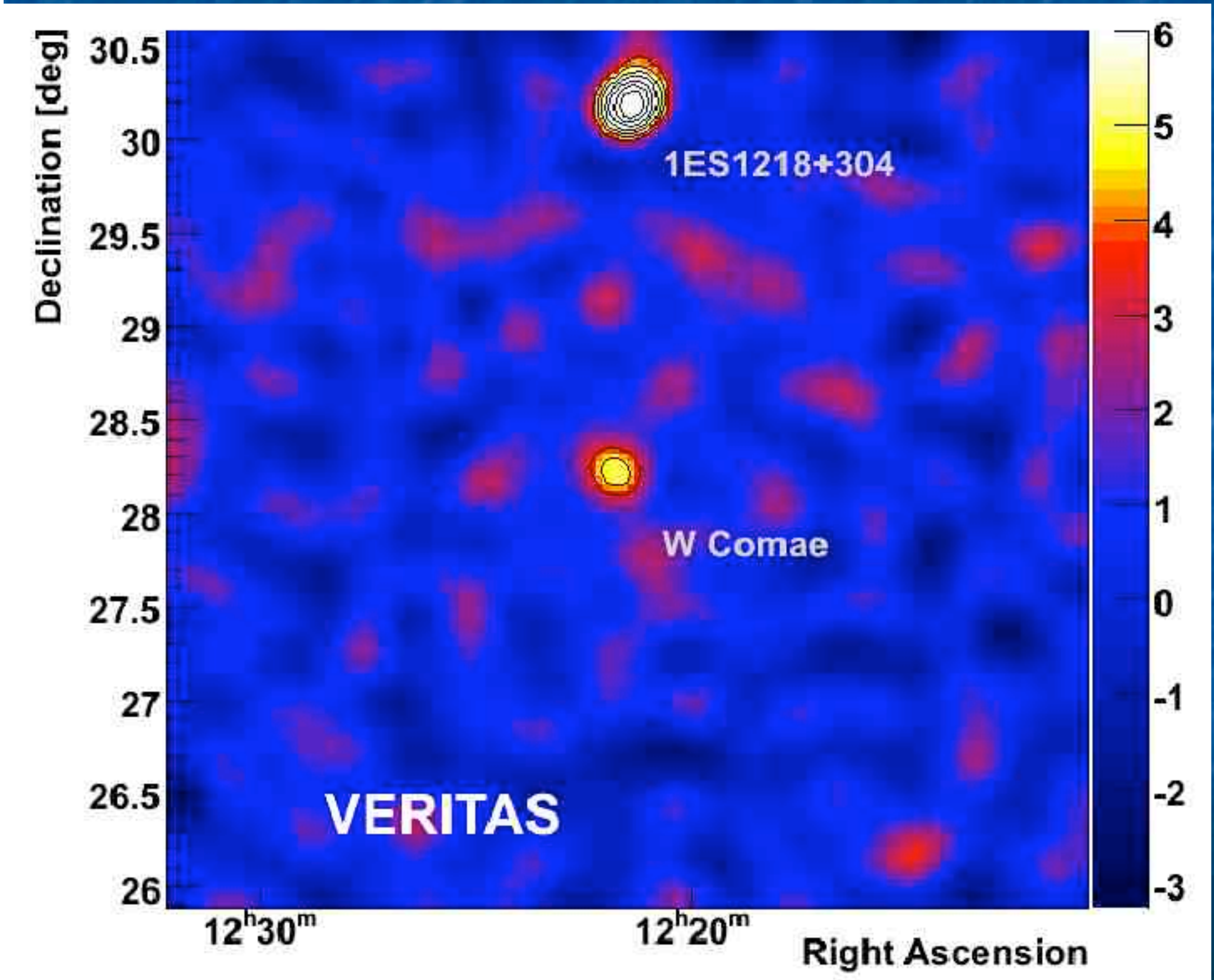
Boomerang Nebula:



Extragalactic TeV Astronomy

- Surprising Number of Extragalactic Sources (two dozen and counting))
- Less Extragalactic Background Light attenuation than expected
- Most complete catalog of any source type

1ES1218+304 and W Comae are in same field of view!

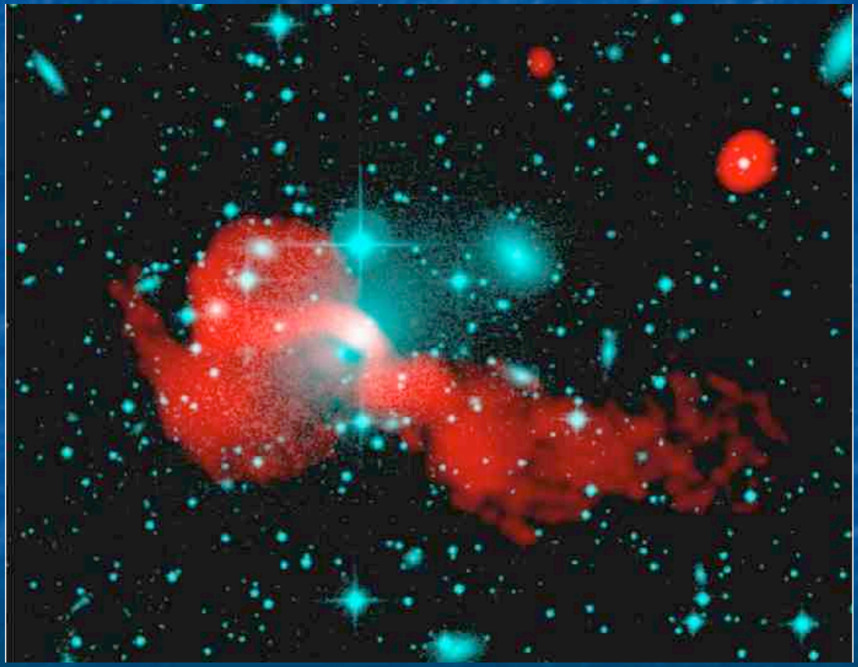


z = 0.182

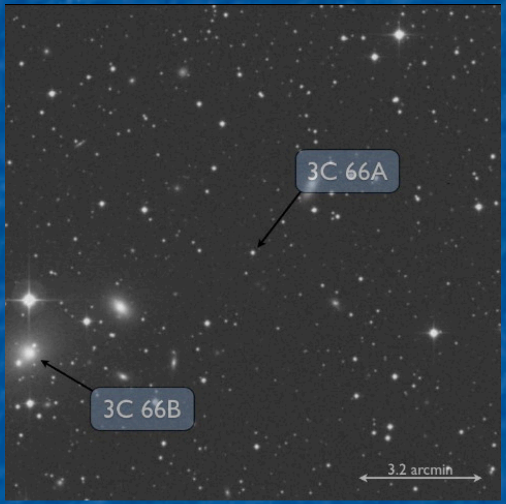
z = 0.104

3C66

Radio source, 3C66 was suggested as TeV gamma-ray source by group at Crimean Astrophysical Observatory in 2002
Radio Galaxy (double lobe) 3C66b (z=0.02) and Blazar (IBL) 3C66a (z=0.444?) within 0.12 degree.
Detection confirmed by MAGIC who based on positional information, spectrum identified it with the radio galaxy, 3C66b

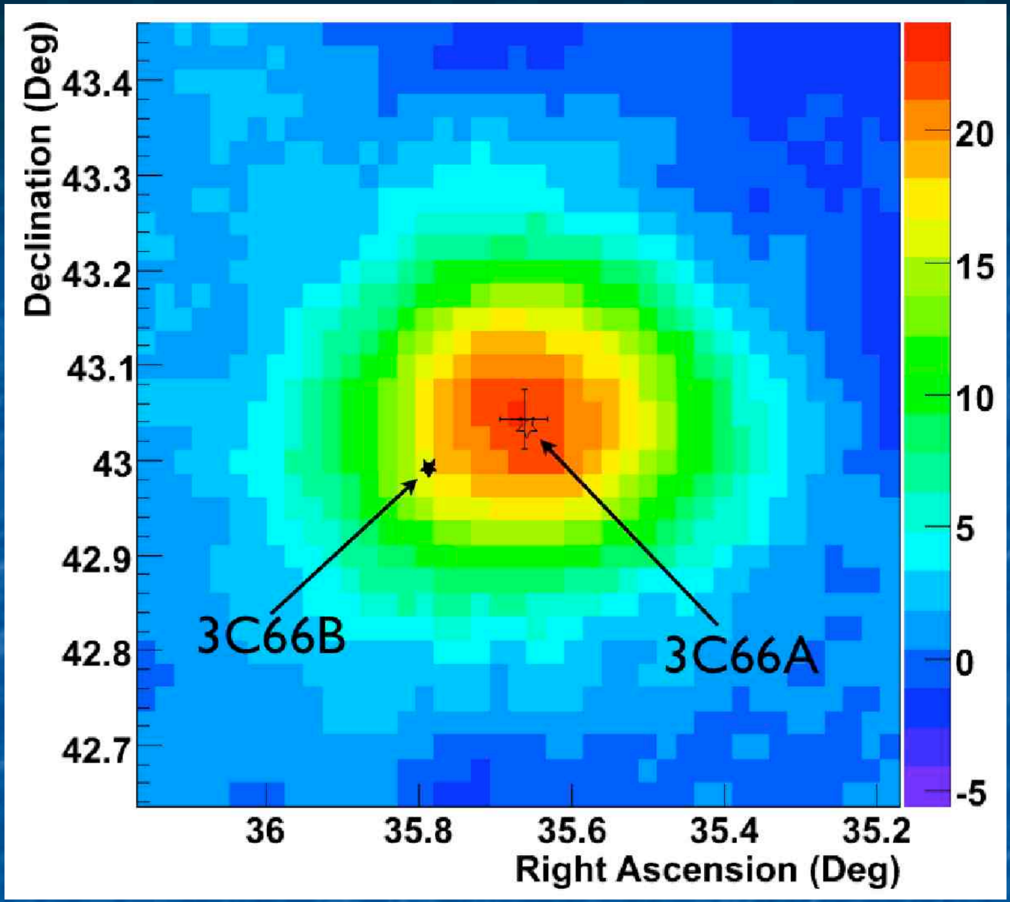


Composite image:
Red = Radio
Blue = Optical



Optical only

3C66a



VERITAS Gamma-ray Image

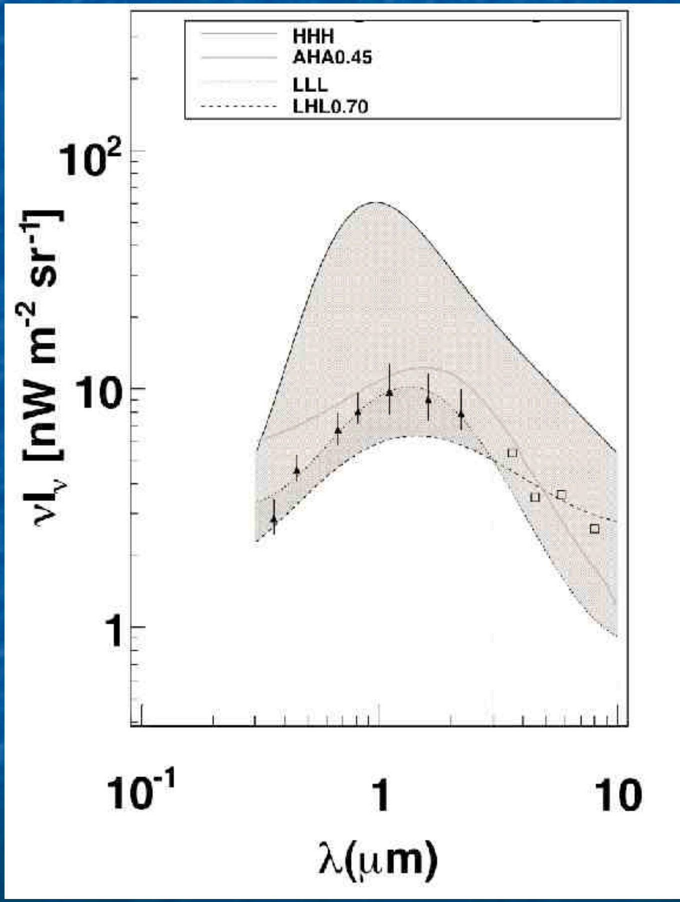
Source detected by VERITAS in 2007-8
30 hours of observation
21 sigma
Variable
Also seen by Fermi
Spectral Index ~ 4.1 (soft)

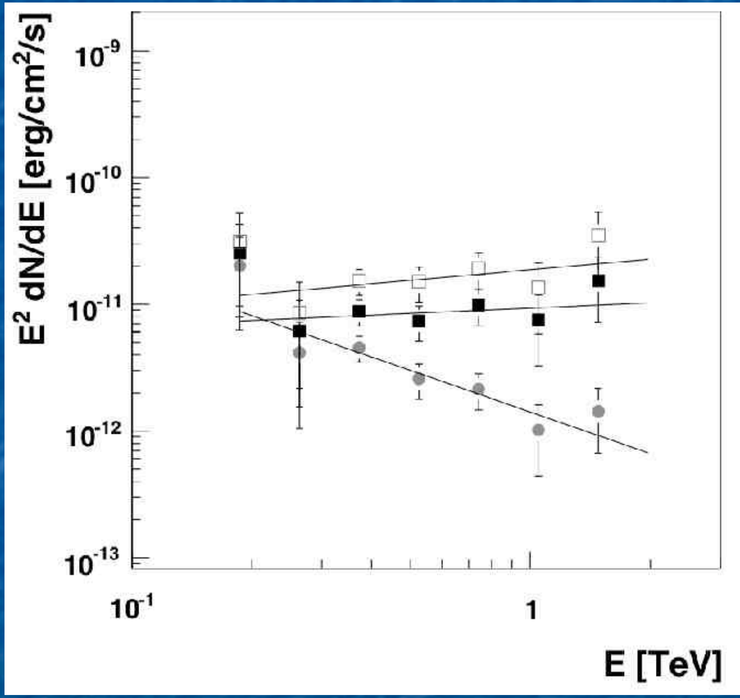
On basis of position VERITAS identifies source with 3C66a
Redshift uncertain 0.444?
Another IBL!

Absorption by EBL

Pair Production by EBL:

gamma-ray + infrared photon -> electron pair





EBL

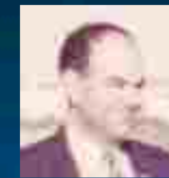
Intrinsic Spectral Index

Measured: -3.08

With EBL:

-2.32
or
-1.78

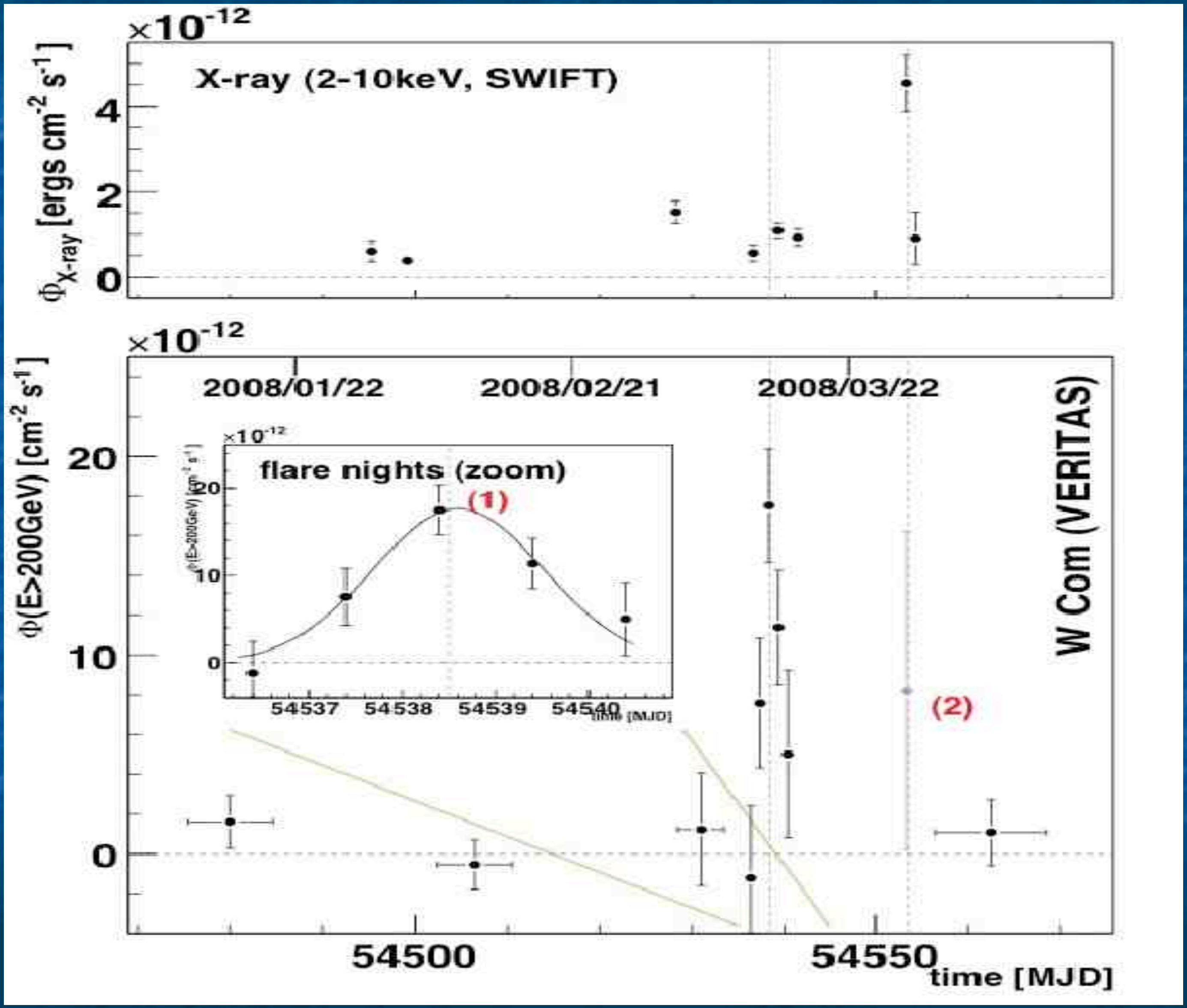
With Giovanni's help, ground-based gamma-ray astronomy has come a long way! 1966 - 2009



By pioneering the construction of the Whipple 10m Gamma-ray Telescope he laid the groundwork for all future developments!

Thank you, Giovanni!

W Comae, blazar



All the TeV signal was in a few days

No correlation with X-rays

1ES1218+304 flaring