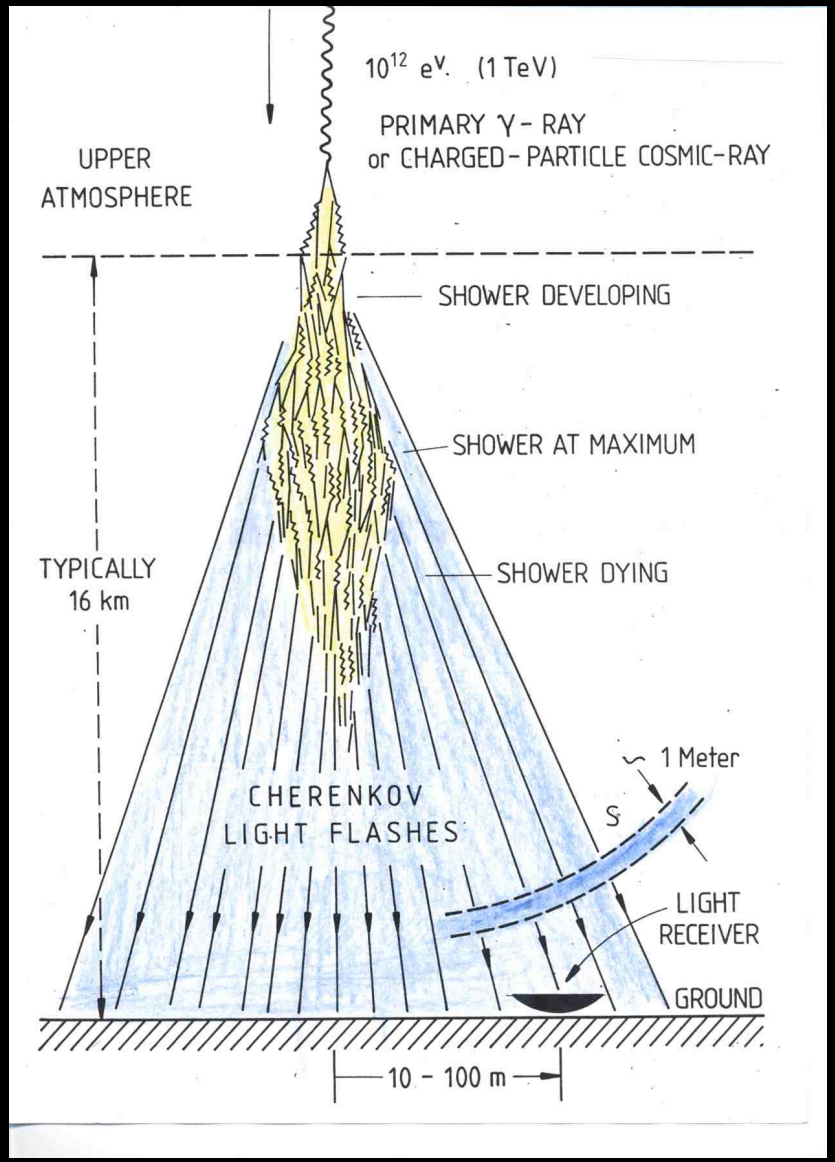
The New Generation of Imaging Air Cherenkov Gamma-Ray Telescopes

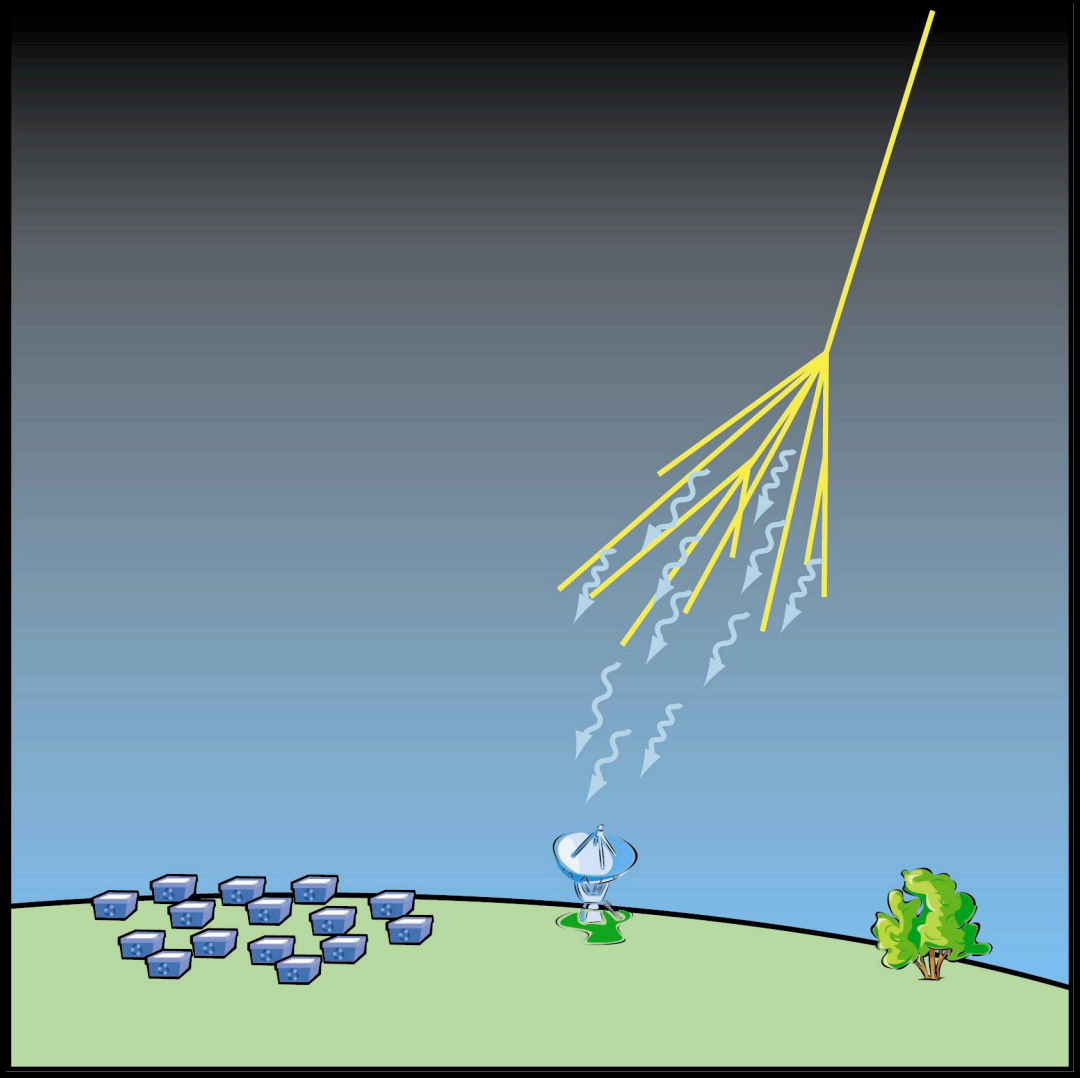
Simon Swordy - U. Chicago (s-swordy@uchicago.edu)

Physics Principles Behind Air-Cherenkov Astronomy Identified in 1950s.....

Light Flashes are Briefly Brighter than Fluctuations in Night Sky



IACT Technique



As with Air Shower Arrays:

Atmosphere = Calorimeter

Traditional Air Shower Array

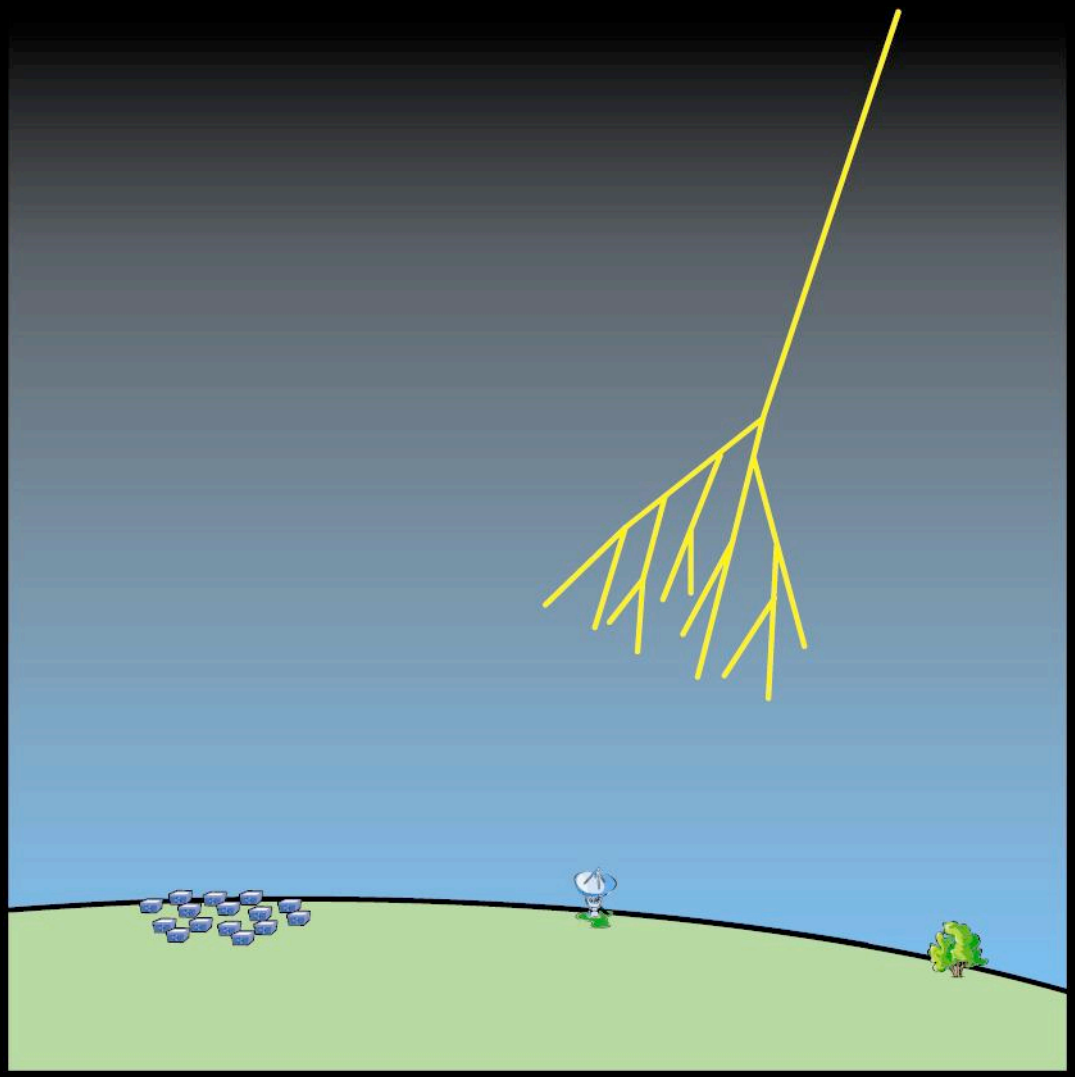
Samples shower at end of development

Atmospheric Cerenkov Tel.

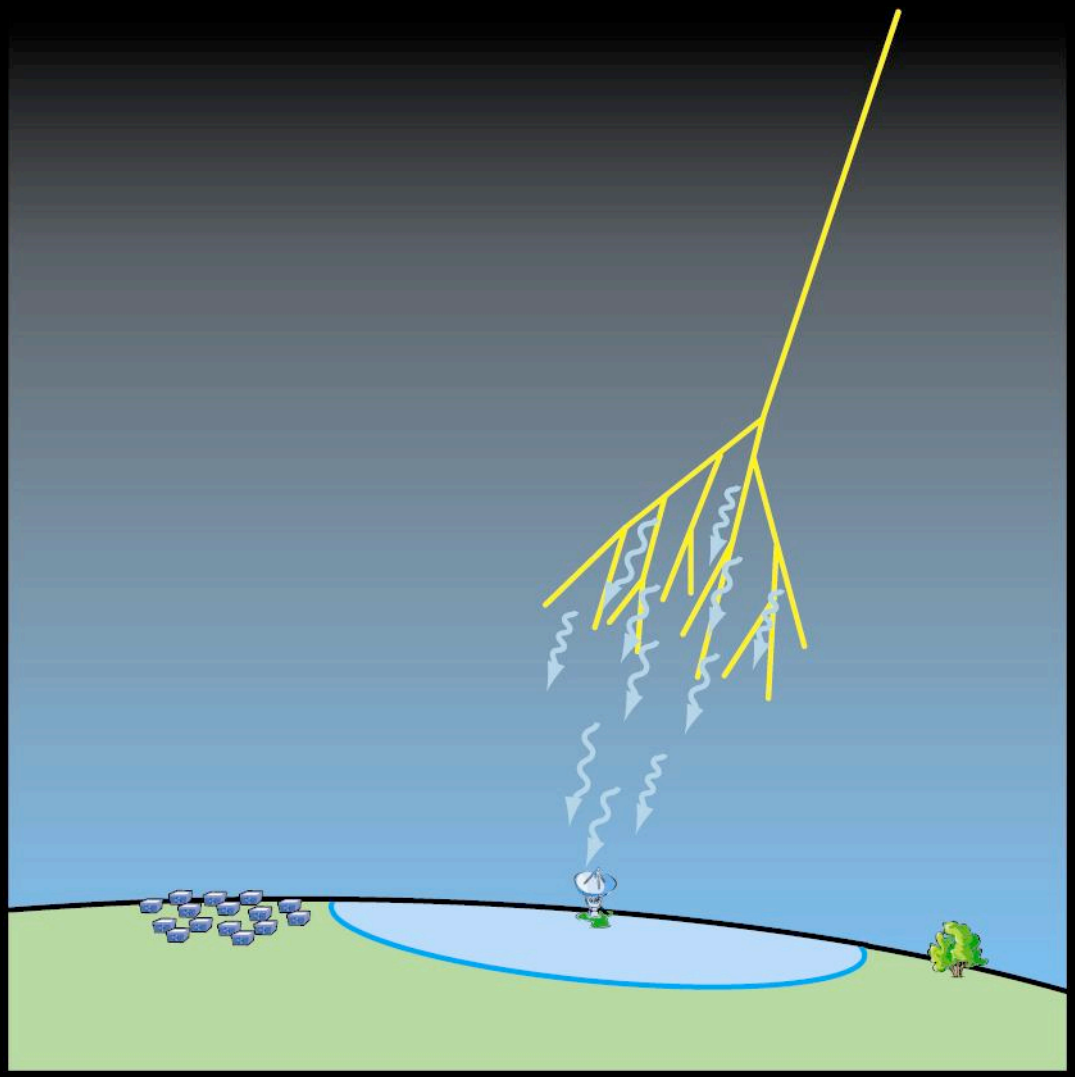
Samples Cerenkov Light throughout shower development

- Primary Energy
- Arrival Direction
- Composition

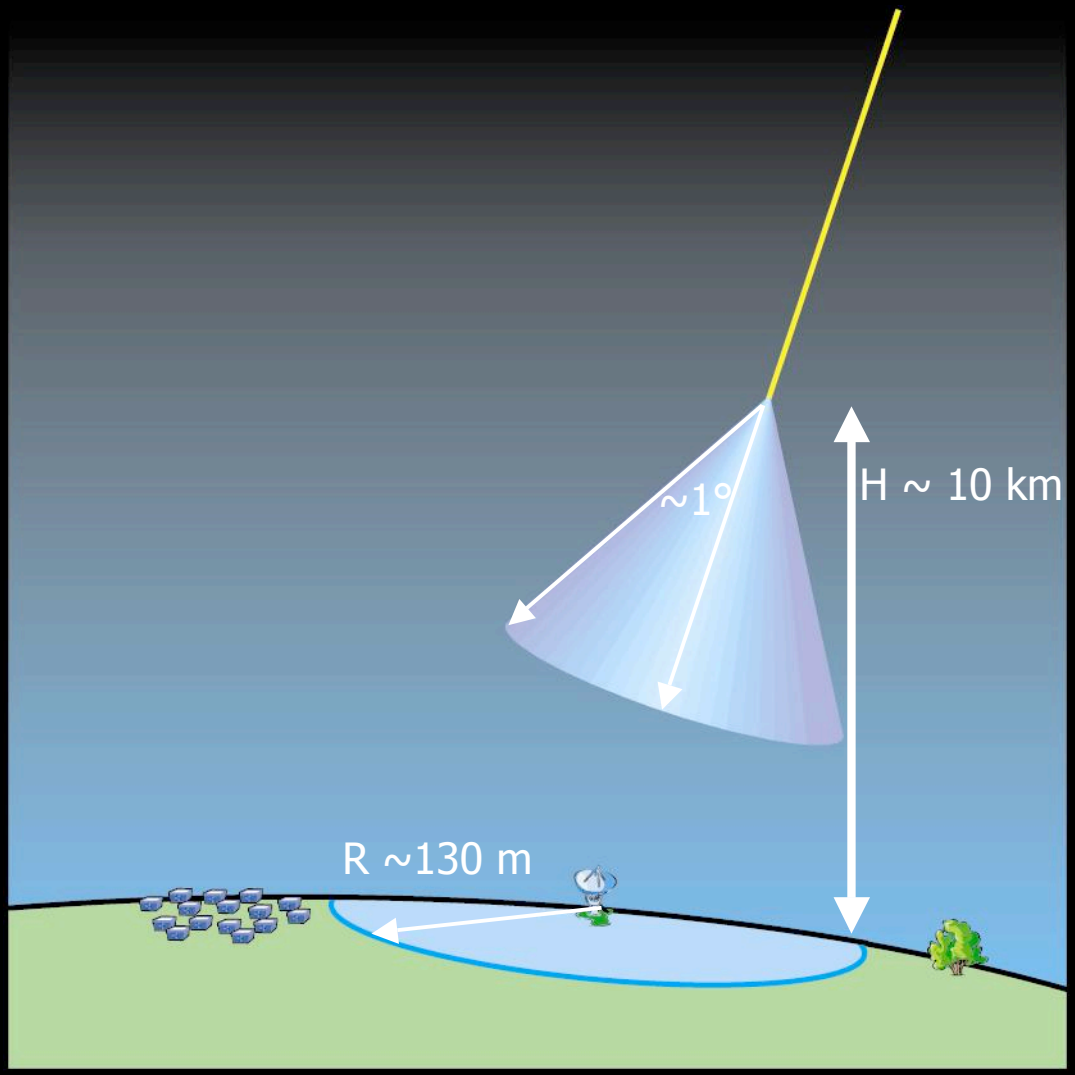
Atmospheric Cerenkov Basics

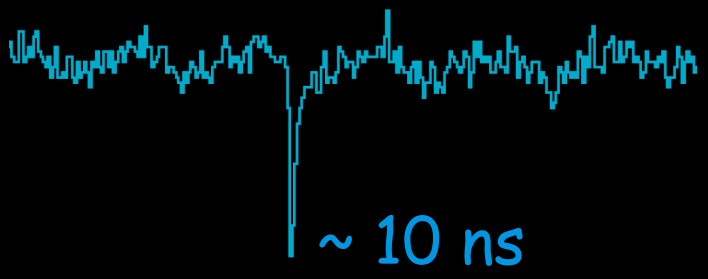


Atmospheric Cerenkov Basics

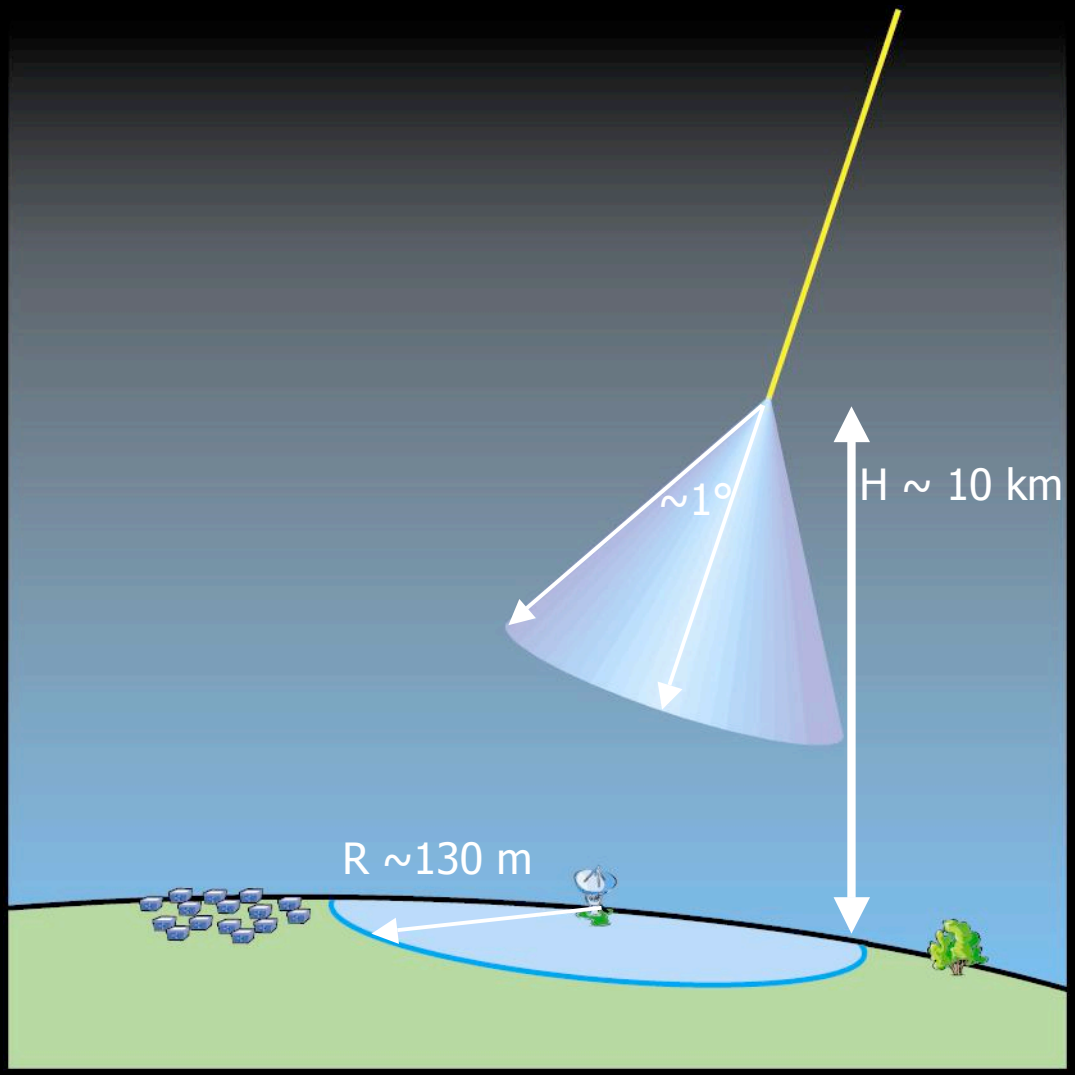


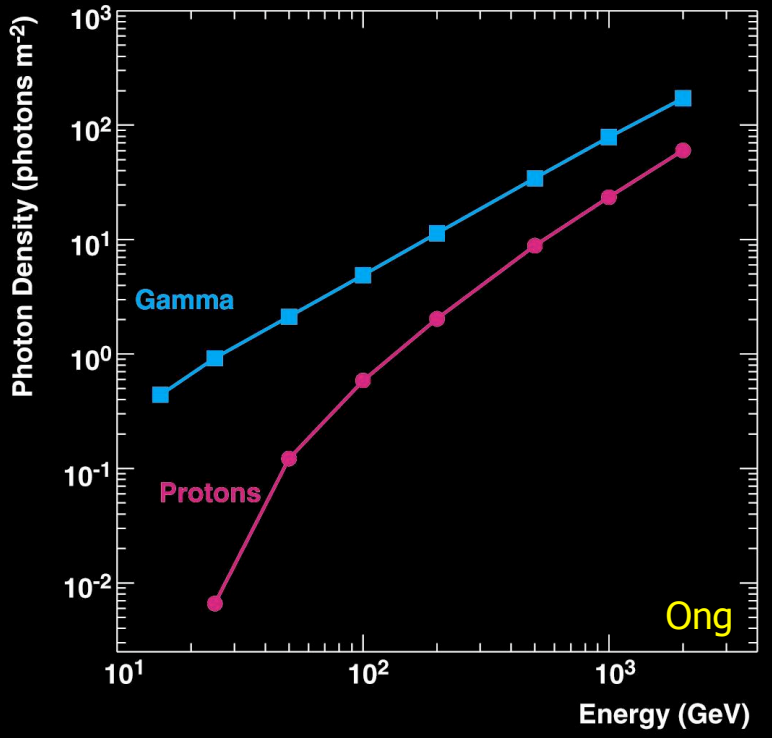
Atmospheric Cerenkov Basics





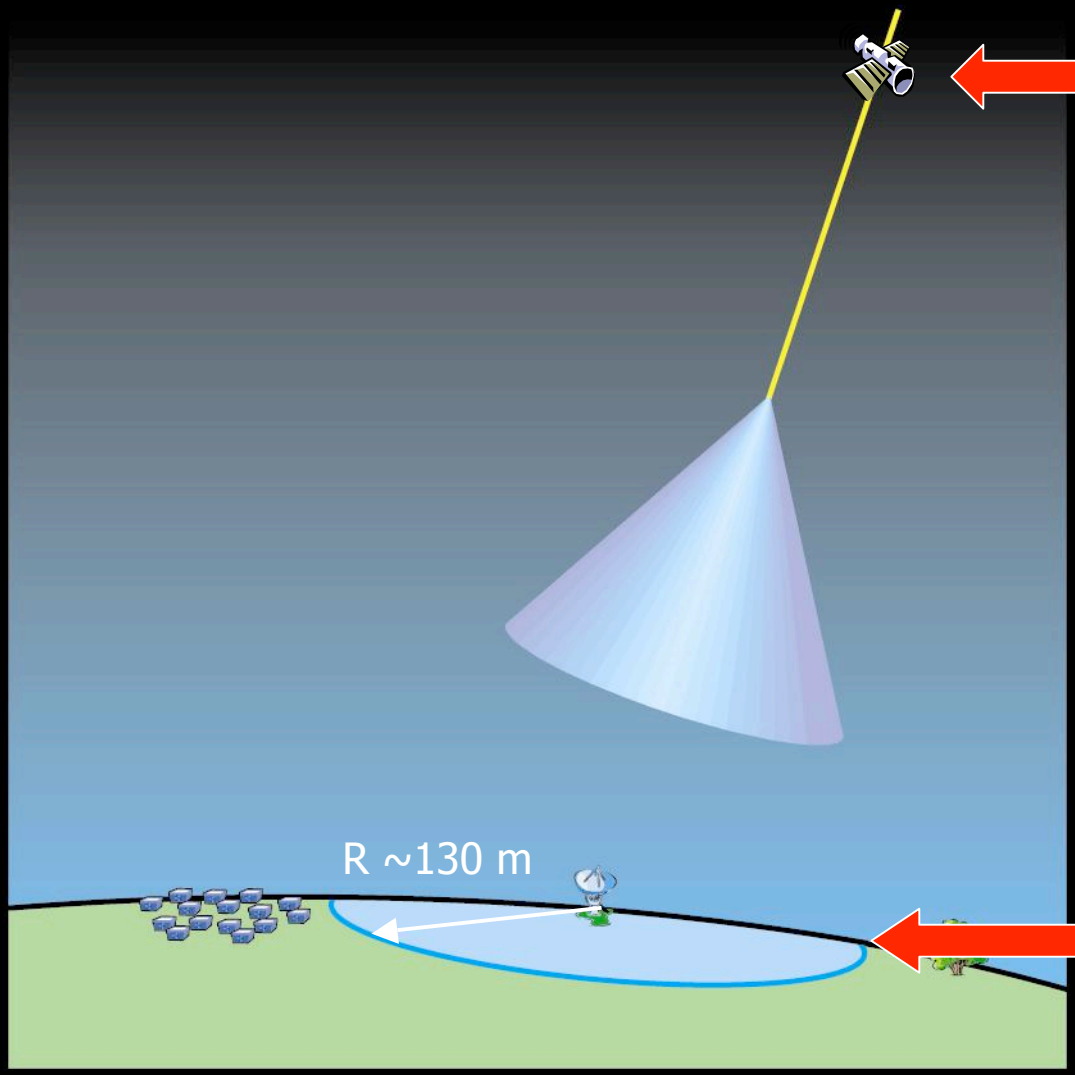
Atmospheric Cerenkov Basics





1 TeV:
~ 100 ph/m²
300 – 600 nm

Effective Area

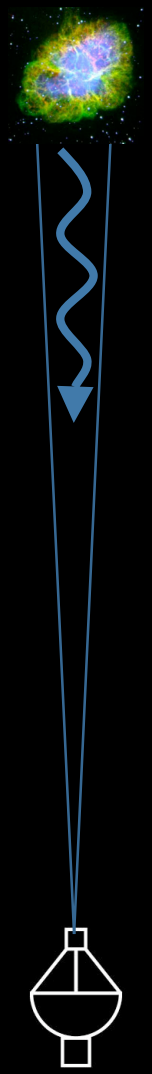


$A \sim 1\ m^2$

$A \sim 0.1\ km^2$

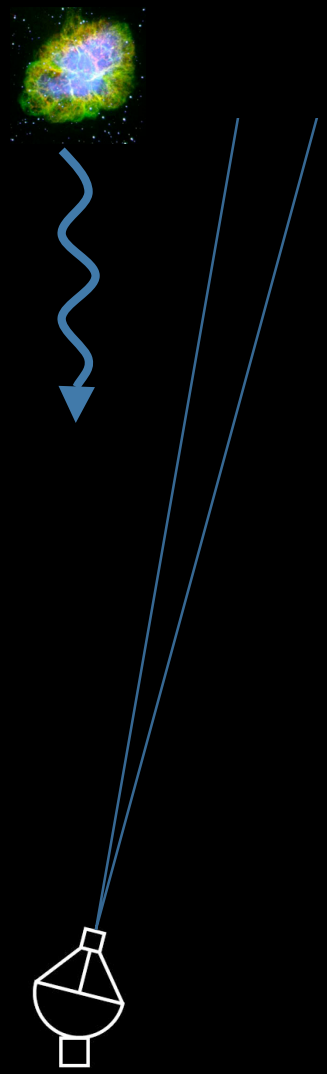
Atmospheric Cerenkov Technique

"On-Source"

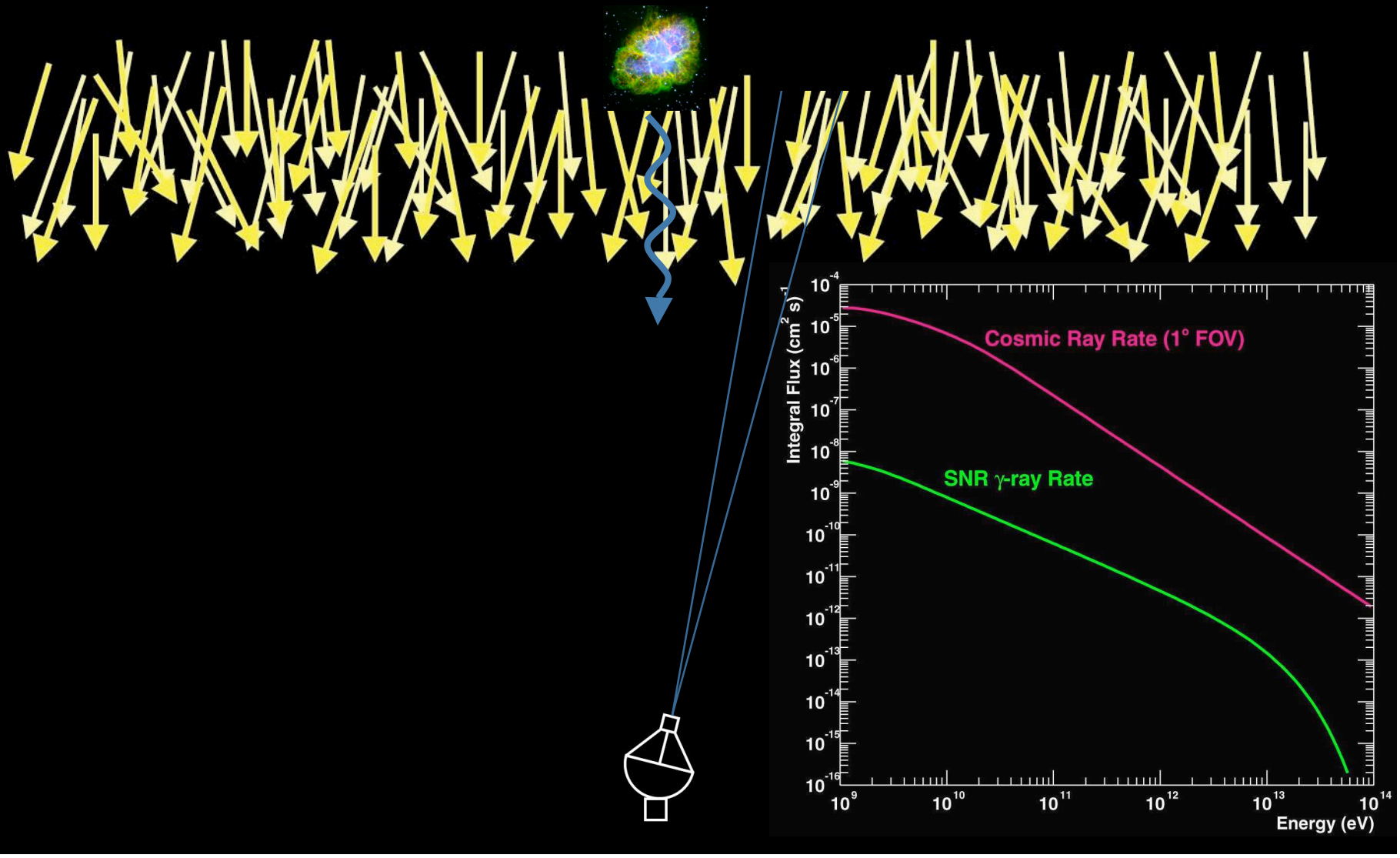


Atmospheric Cerenkov Technique

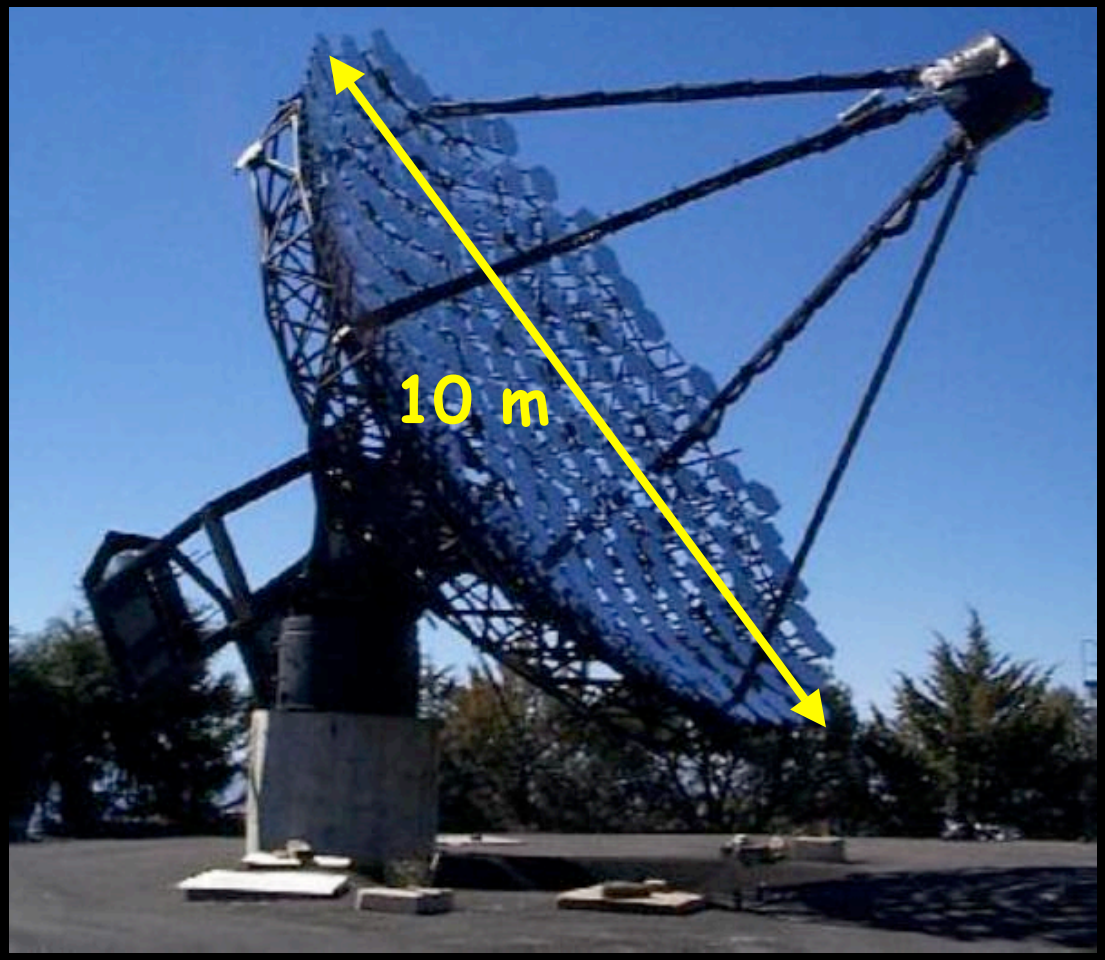
"Off-Source"



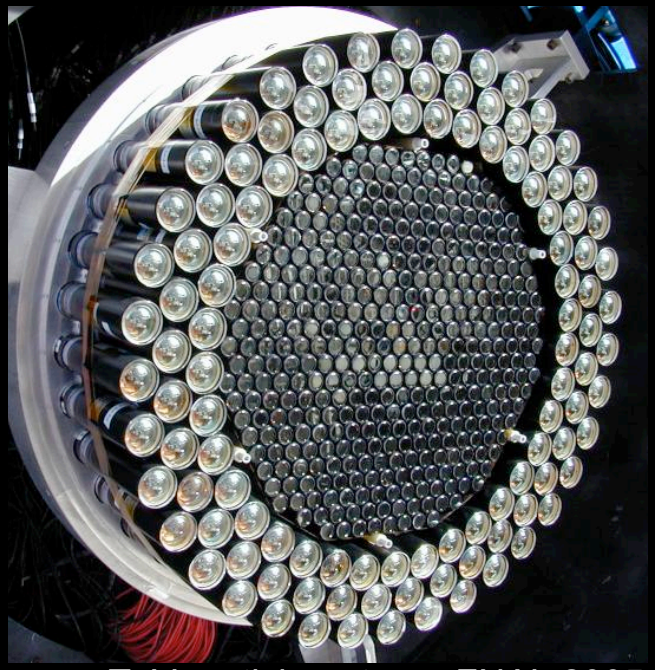
Atmospheric Cerenkov Technique



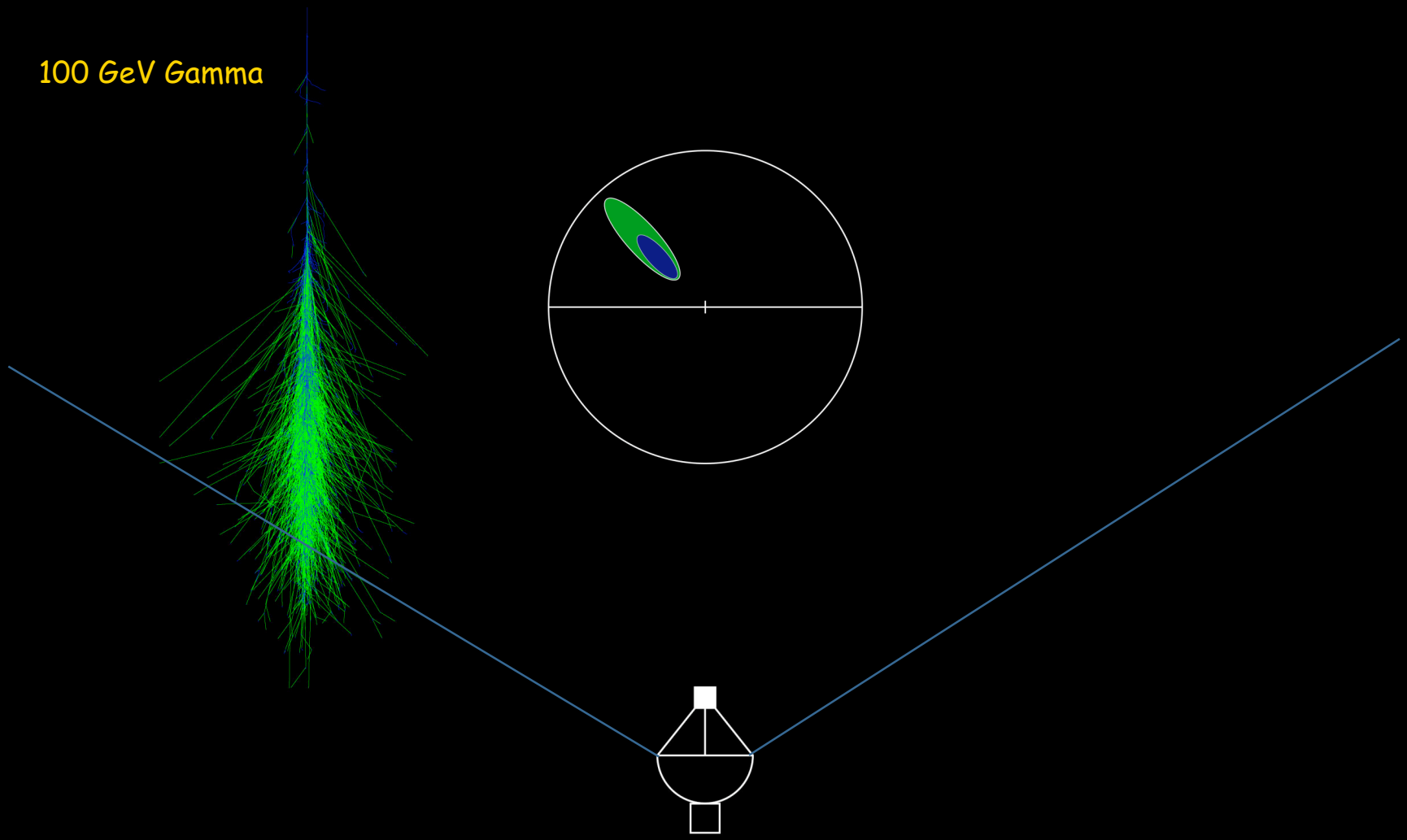
Cerenkov Imaging - Whipple



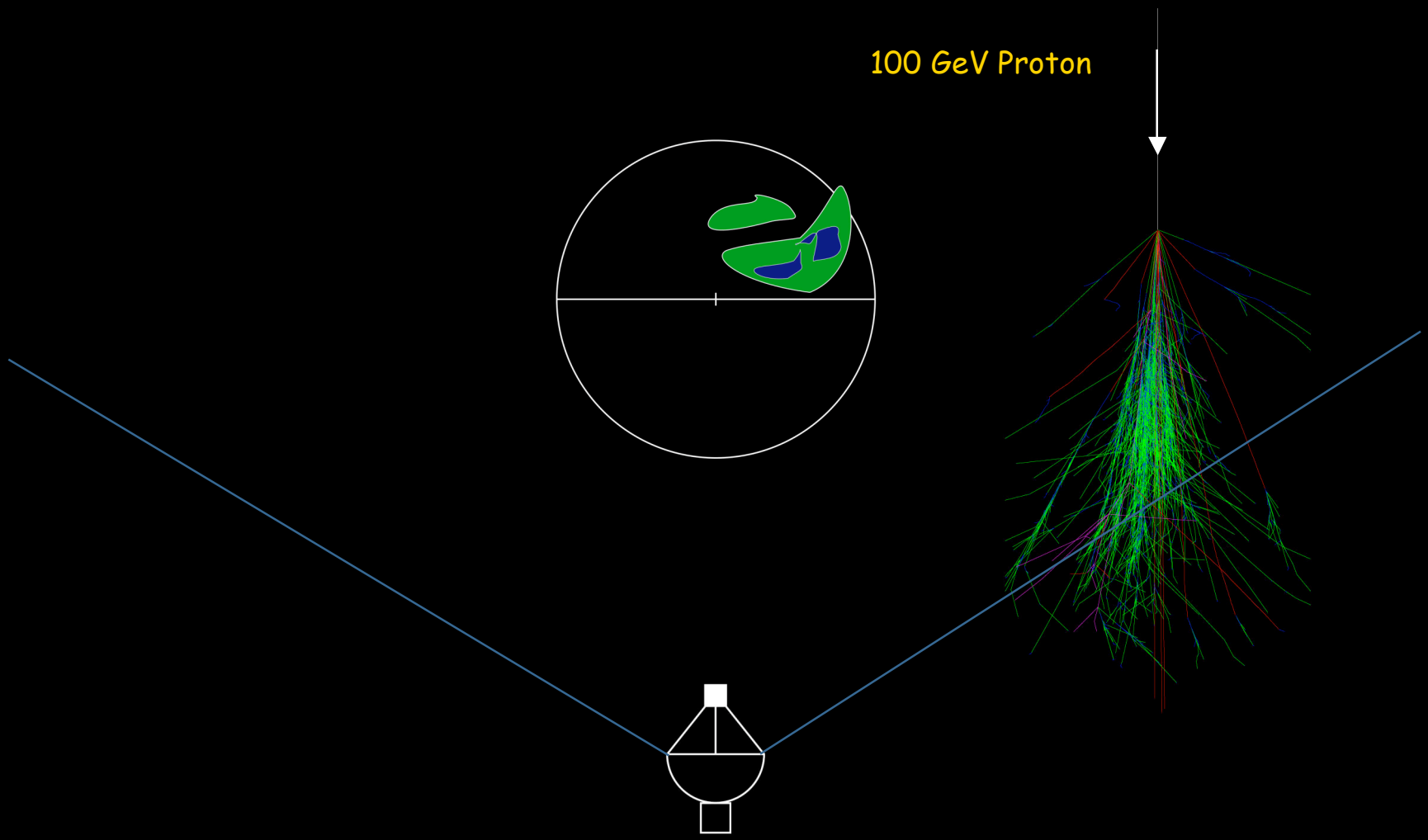
379 PMTs



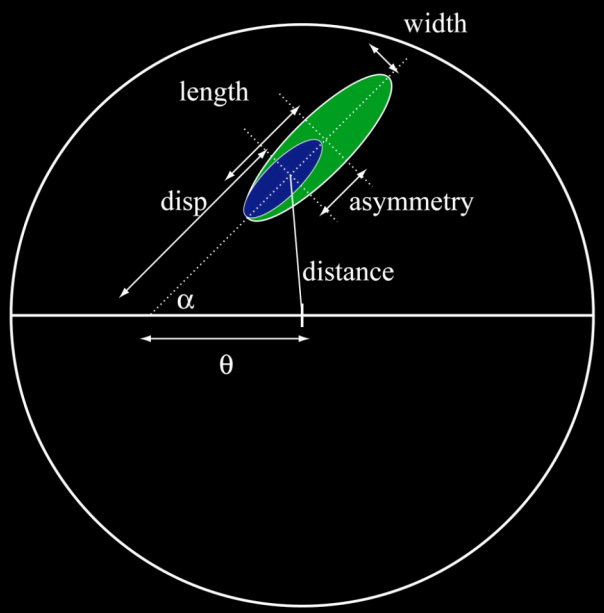
Cerenkov Imaging



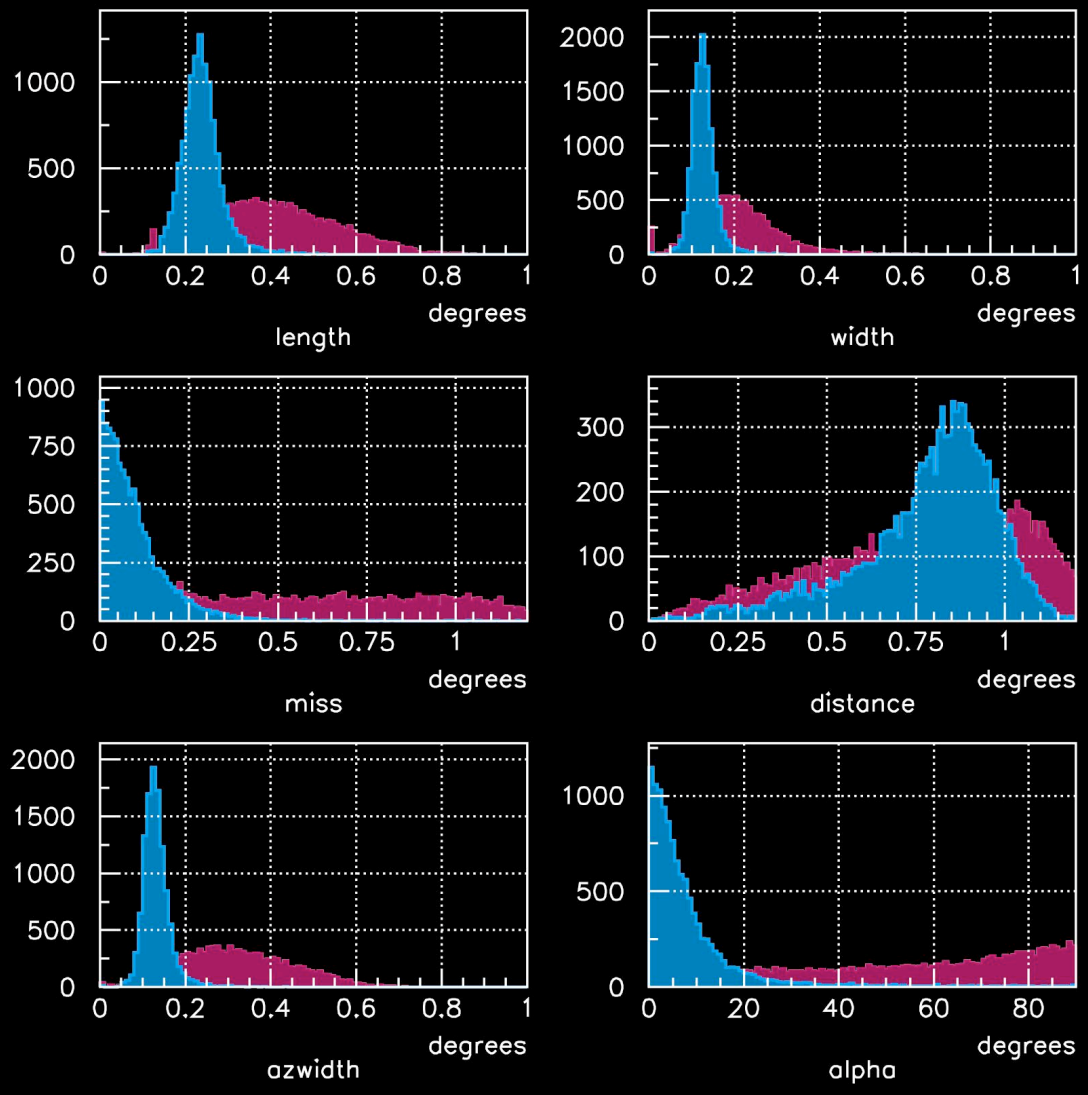
Cerenkov Imaging



Hillas Parameters



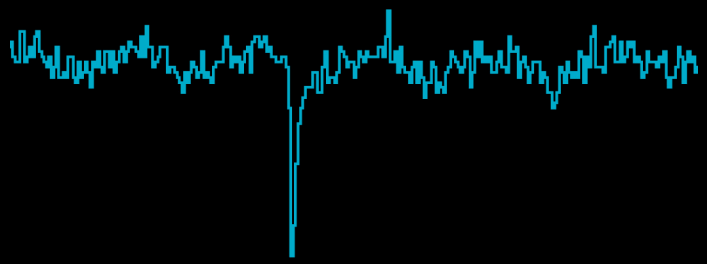
Hillas Parameter Distributions

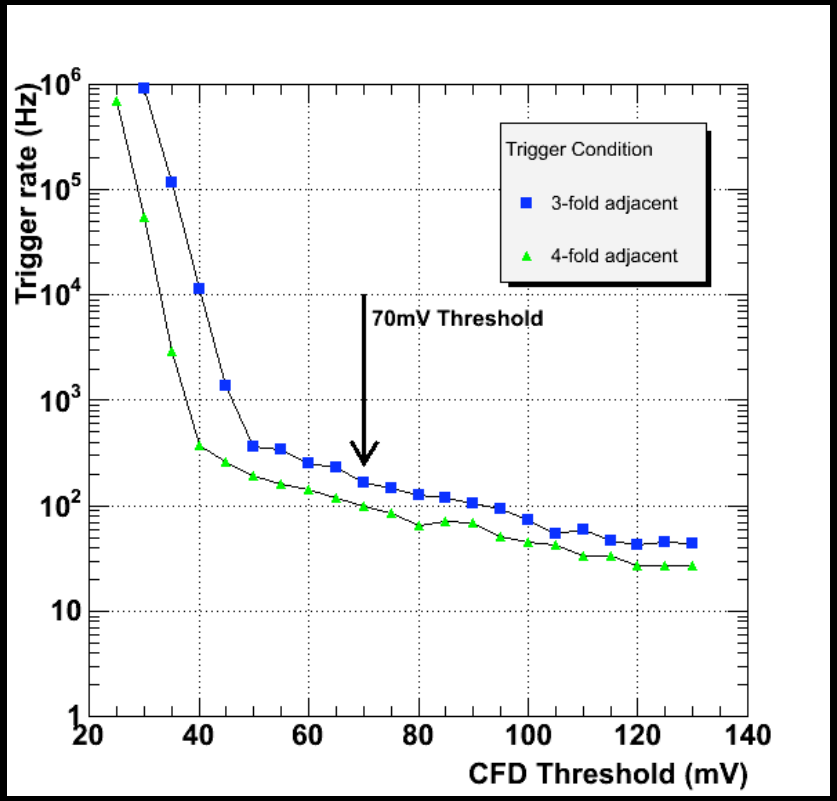


>99.7 % Hadron Reject.

50% Gamma Retention

Energy Thresholds



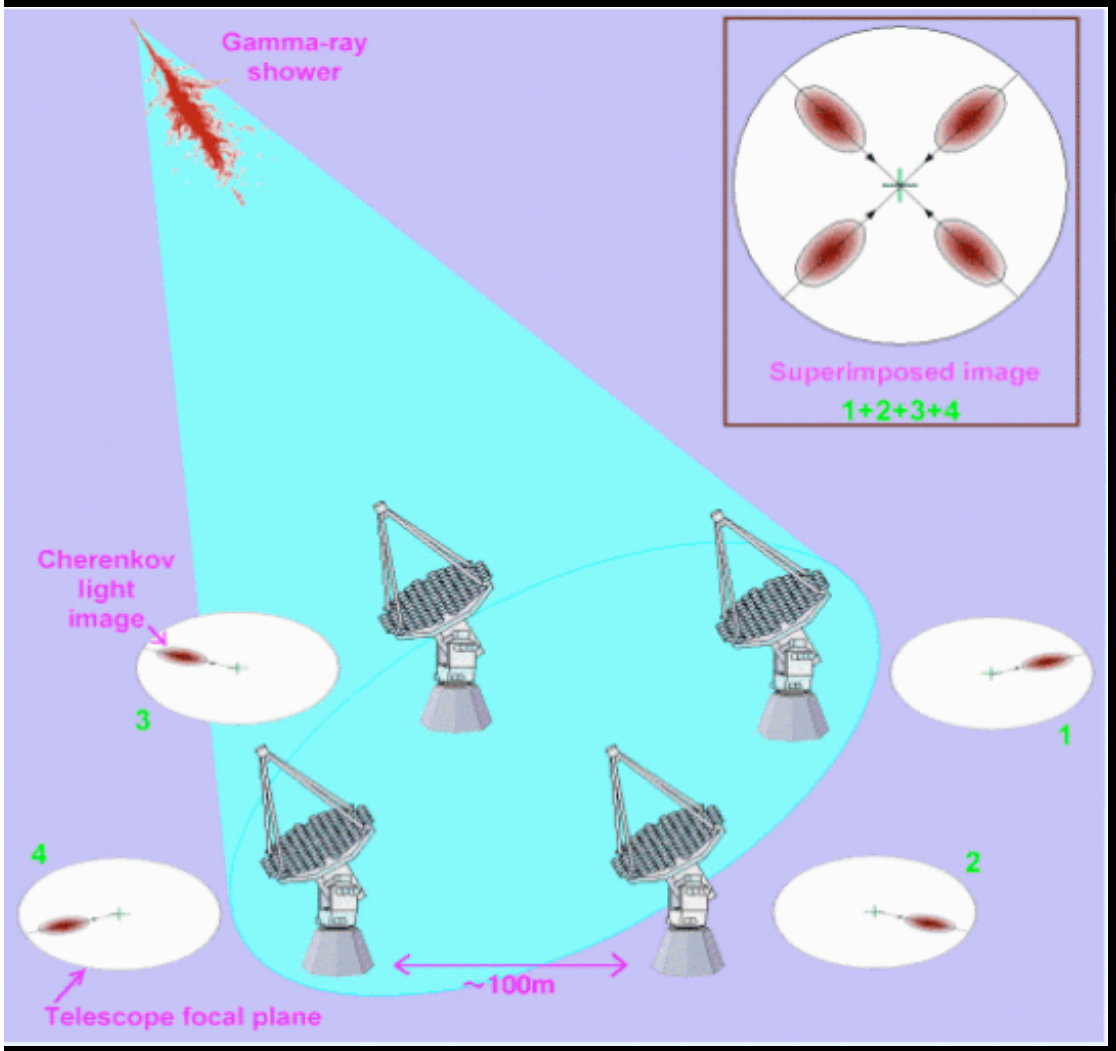


S/B $\propto\sqrt{}$ Mirror Area

S/B $\propto 1/\sqrt{}$ Integration Time

Thresholds ~ 50-150 GeV, for ~12m dish and 20ns

Array Imaging



from CANGAROO www site

Multiple Telescopes:
improve angular resolution
improve energy resolution
reduce background
eliminate muons
improve stability

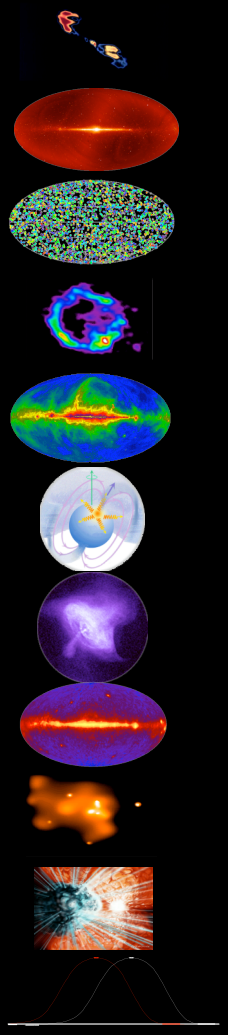
IACT - Imaging Air Cerenkov Telescope

Development of the IACT

- First Generation Systems 1960 – 1985
  - Weak or no discrimination
  - Lebedev, Glencullen, Whipple, Narrabri, Crimea….
- Second Generation Systems 1985 – 2004
  - Atmospheric Cherenkov Imaging Telescopes
  - Whipple, Crimea, CAT, HEGRA, Durham, SHALON, CANGAROO……
- Third Generation Systems 2004 –
  - Arrays of Large IACTs
  - MAGIC, HESS, CANGAROO-III ……. VERITAS
- Fourth Generation Systems?
  - Watch this space!

ACIT Sources
Zero
~ 12
-> 100
1000?

Science Snapshots



Active Galactic Nuclei

Extragalactic Background Light

Gamma Ray Bursts

Shell-type Supernova Remnants

Galactic Diffuse Emission

Gamma-ray Pulsars

Plerions

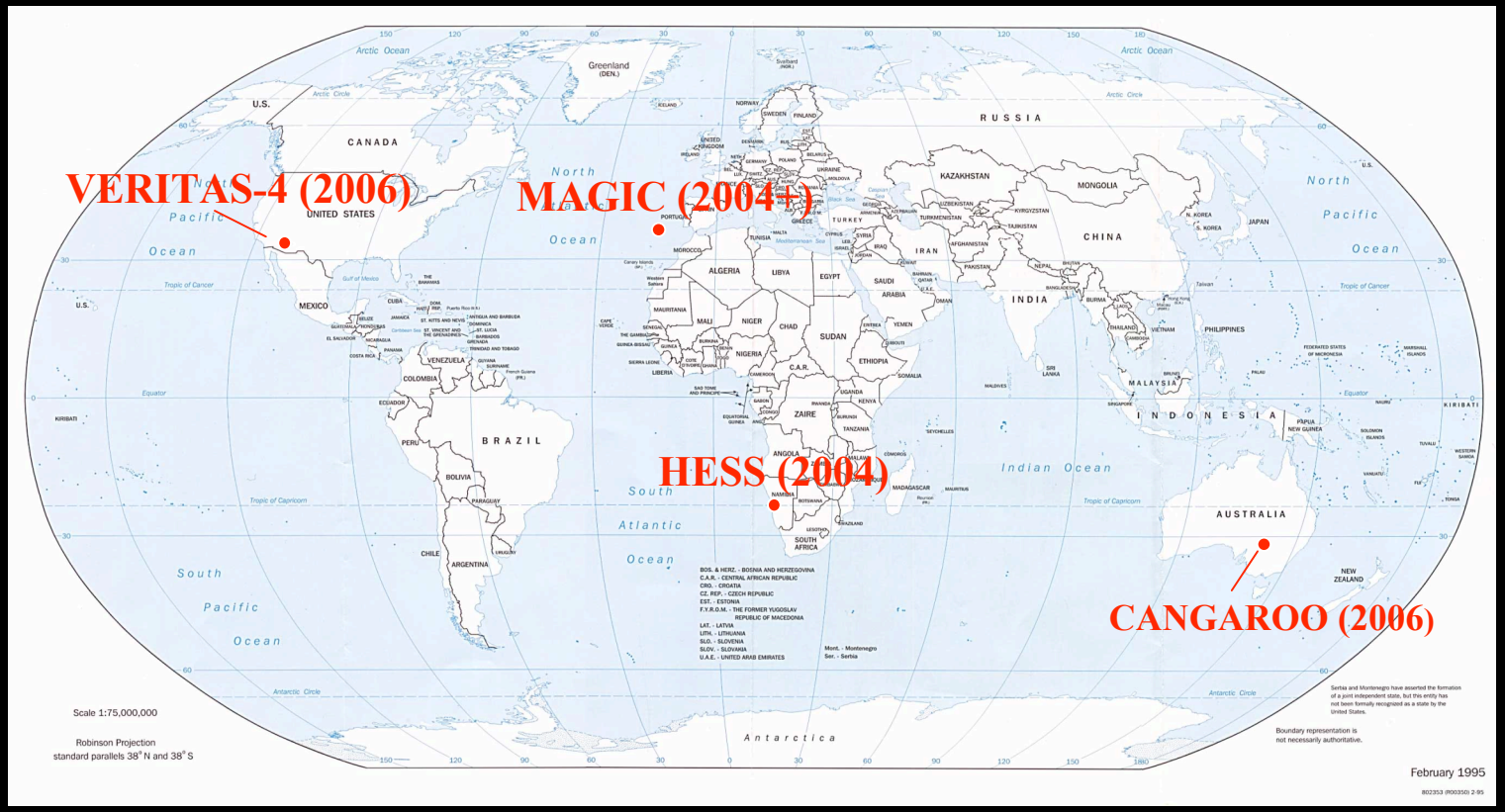
Unidentified Galactic EGRET Sources

Dark Matter (Neutralino Annihilation)

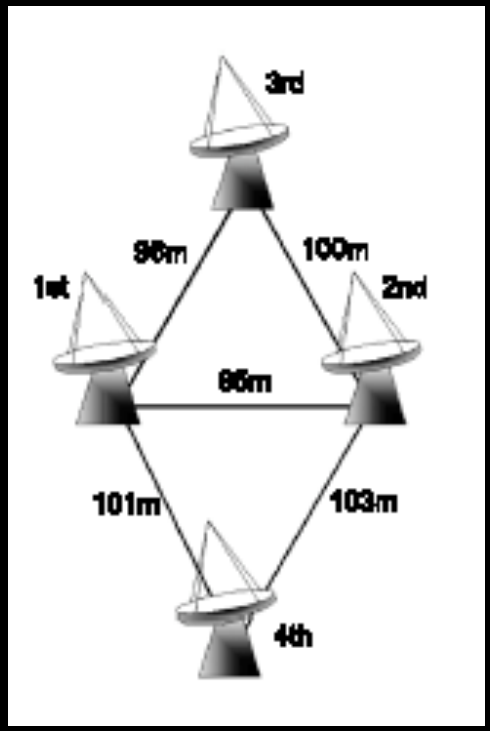
Cosmic Ray Origin

Lorentz symmetry violation

The World-Wide Network of 3rd Generation IACTs

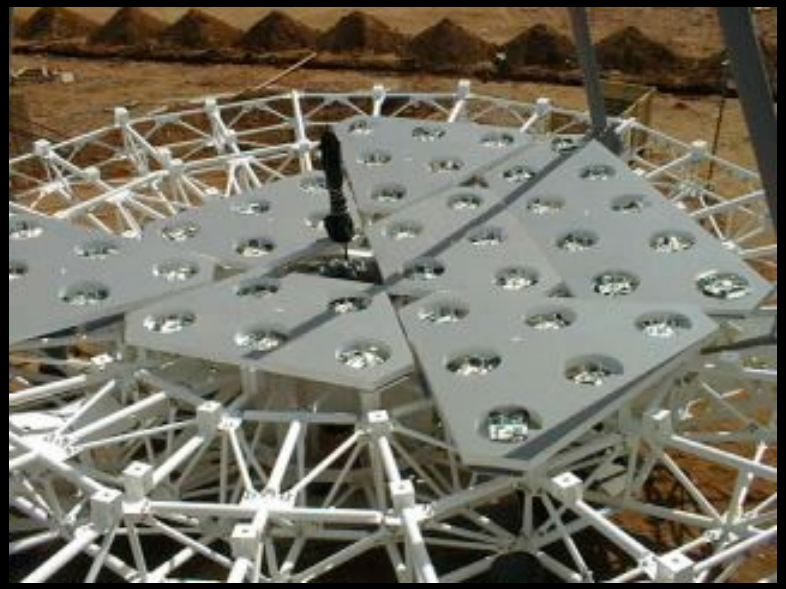


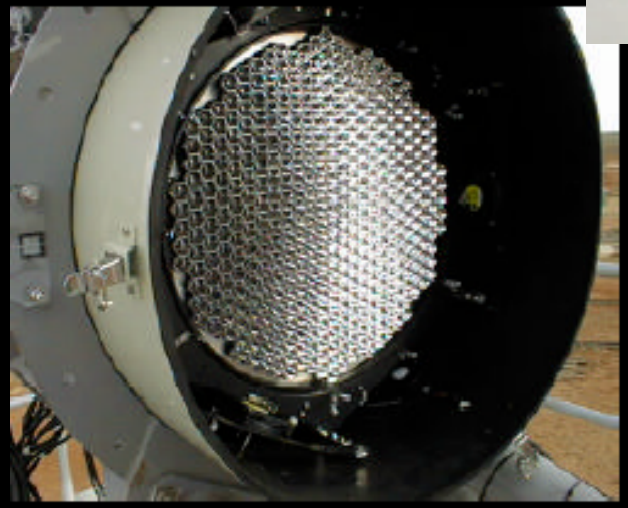
CANGAROO-III* - Japan/Australia Site: Woomera, Australia)
(for details see http://icrhp9.icrr.u-tokyo.ac.jp/)

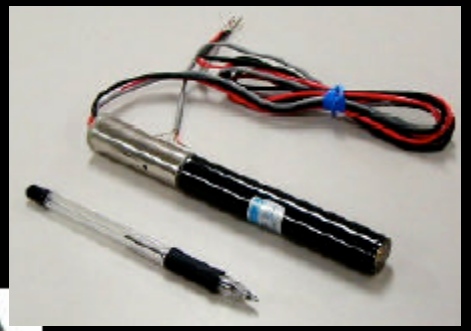


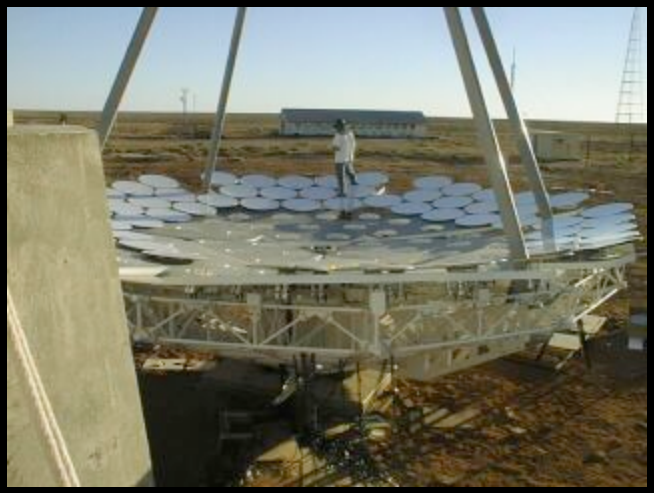
* Collaboration of Australia and Nippon for a Gamma Ray Observatory in the Outback

- Telescopes 10m w/8m focal length
- Array of 4 telescopes
- 57 m^2 light collecting area per telescope
- New Cameras 427 3/4" PMTs, 0.17 degree pixels
- 4 degree FOV
- Electronics - TDC & gated ADC





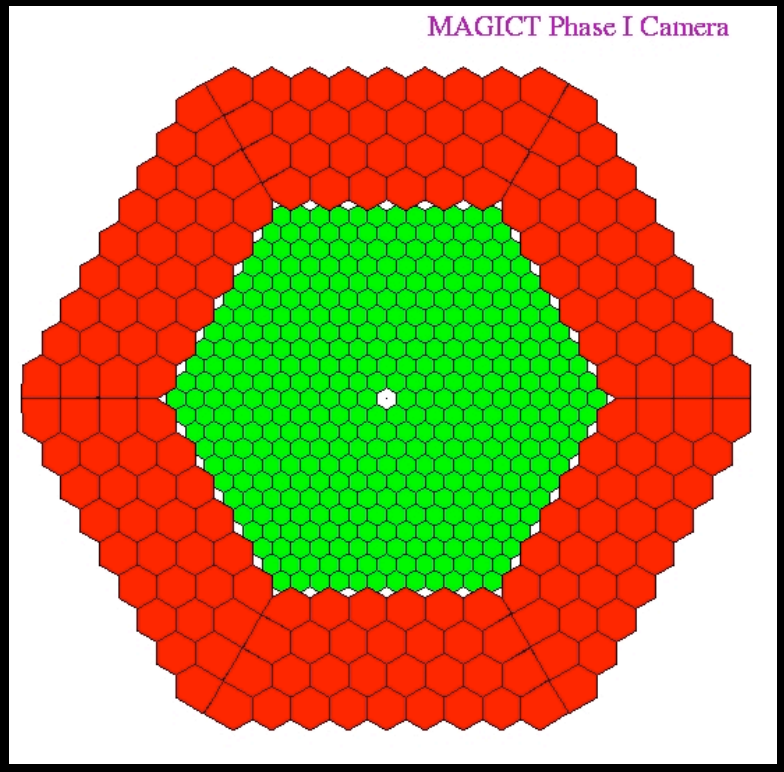


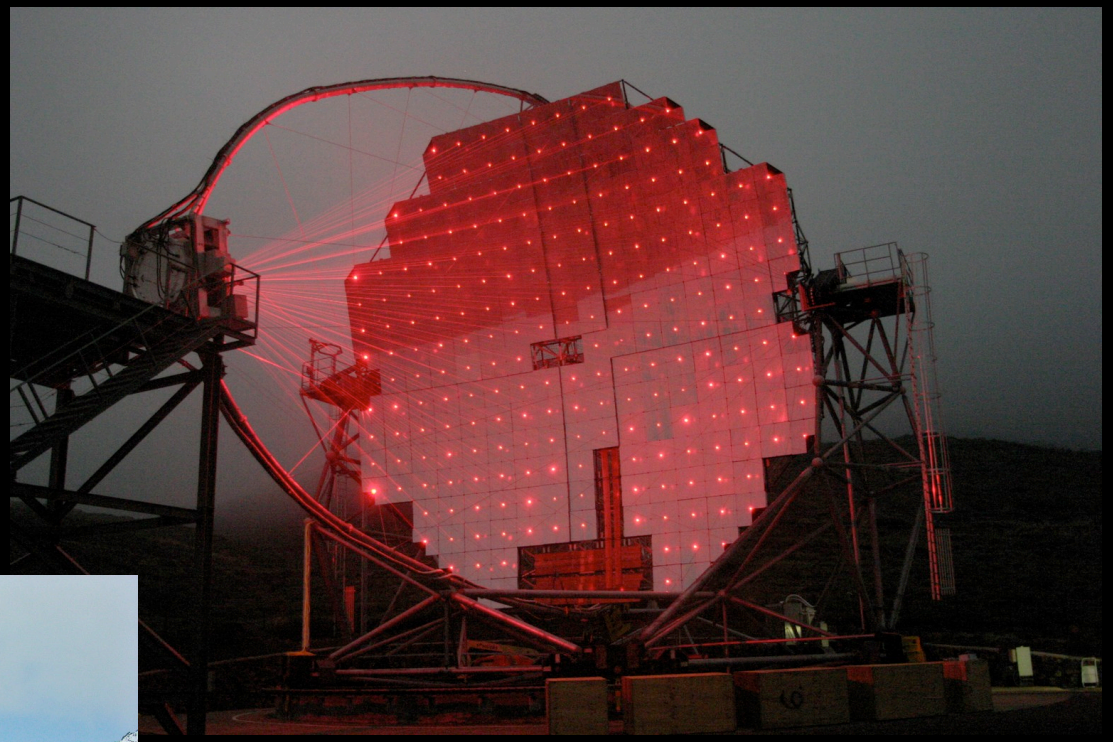


Construction of telescopes complete in March 2004

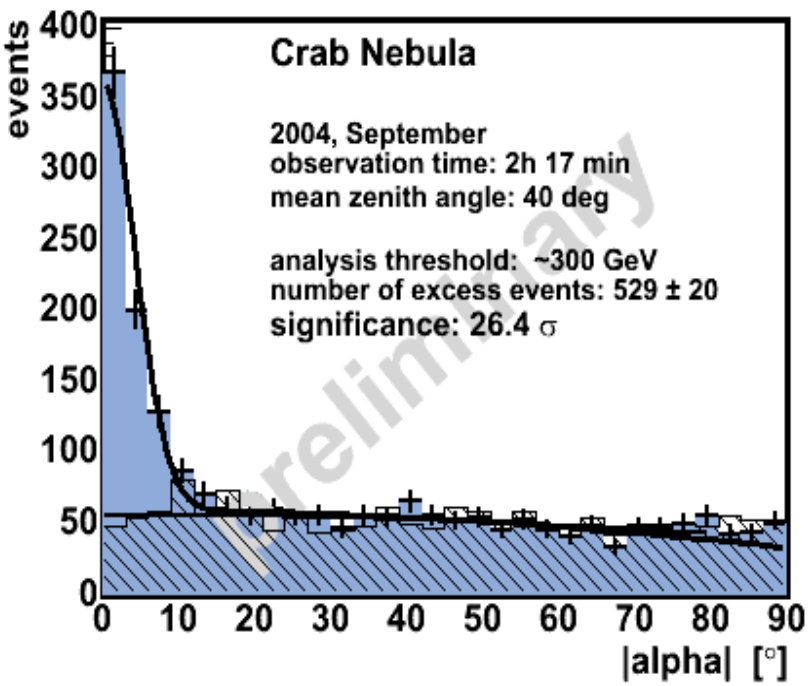
MAGIC - Germany/Spain/Italy/Swiss (mostly) - Site: Canary Islands
(see http://wwwmagic.mppmu.mpg.de)

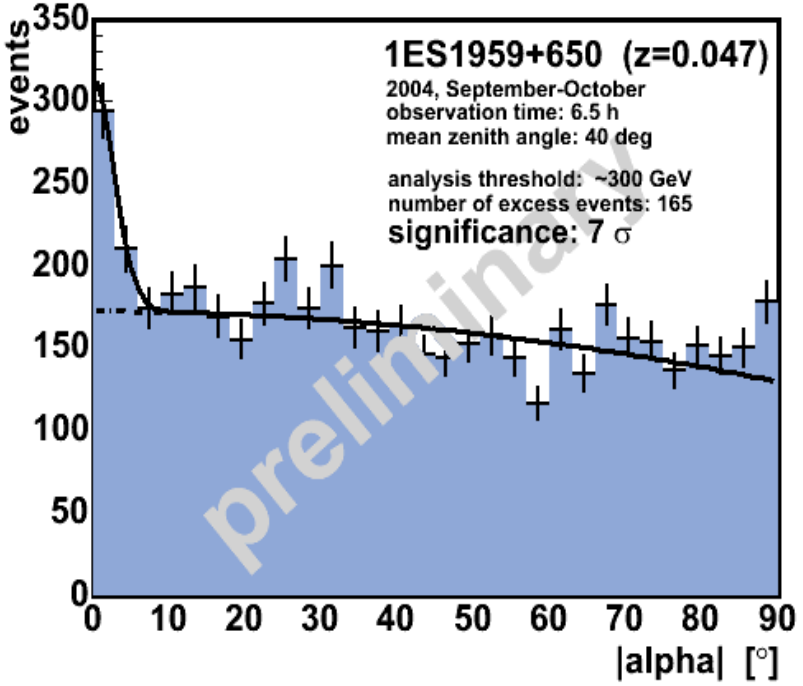
- Telescope 17m f~1
- 239 m^2 light collecting area
- Cameras 396 1" PMTs, 0.08 degree pixels + 180 1.5", 0.13 degree
- 3.5 degree FOV
- Electronics - 300MHz FADC -> 1GHz FADC
- 20 second slew capacity (40tons!) for GRB
- MAGIC II being planned





Some preliminary results from MAGIC - La Thuile, 2005

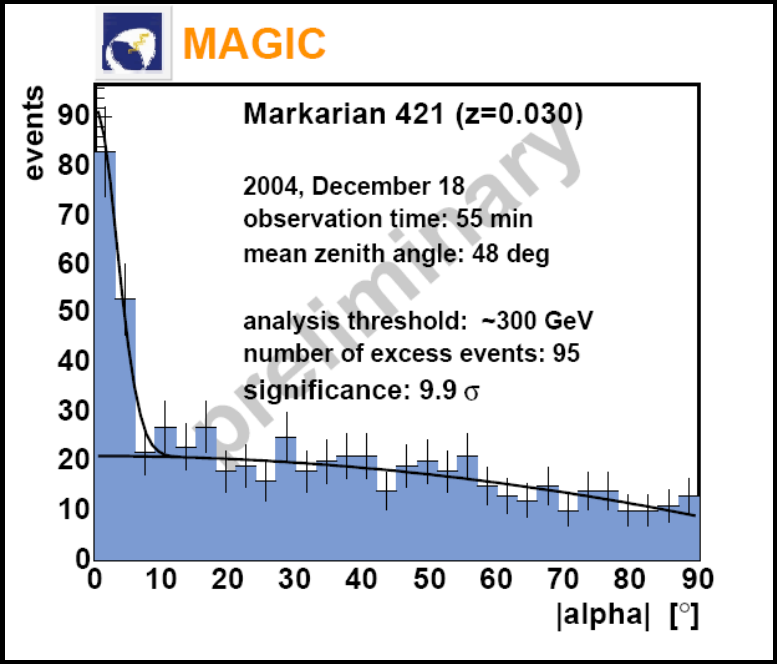


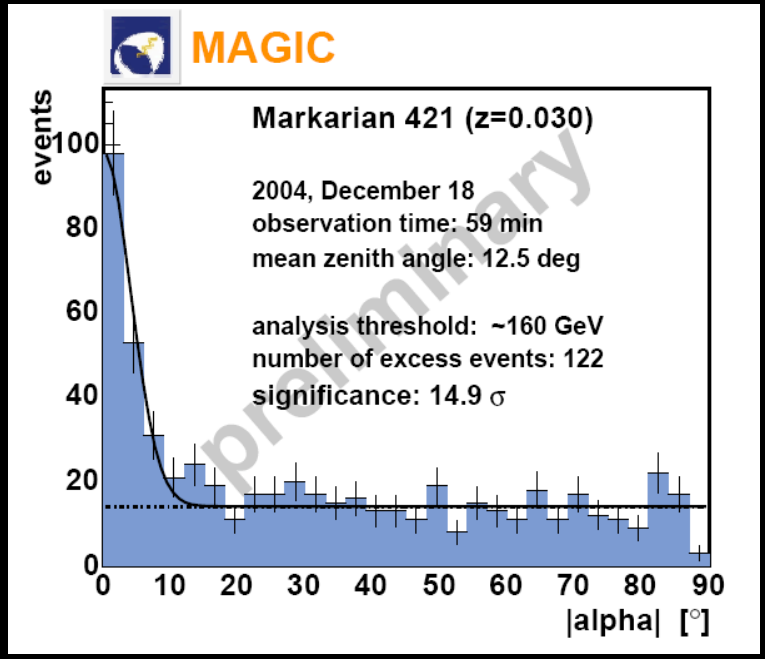


Crab Nebula: Size >2000 ph
Significance: 26.4 σ Excess events: 529 ± 20

1ES 1959 + 650: Size >2000 ph
Significance: 7.0 σ Excess events: 165

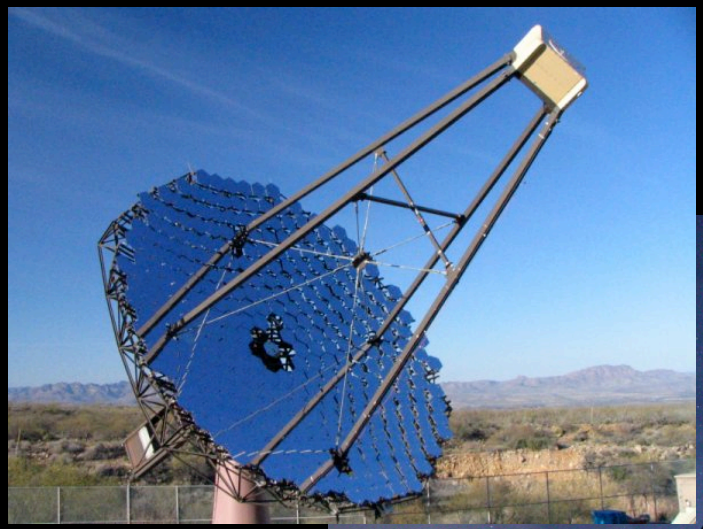
Markarian 421

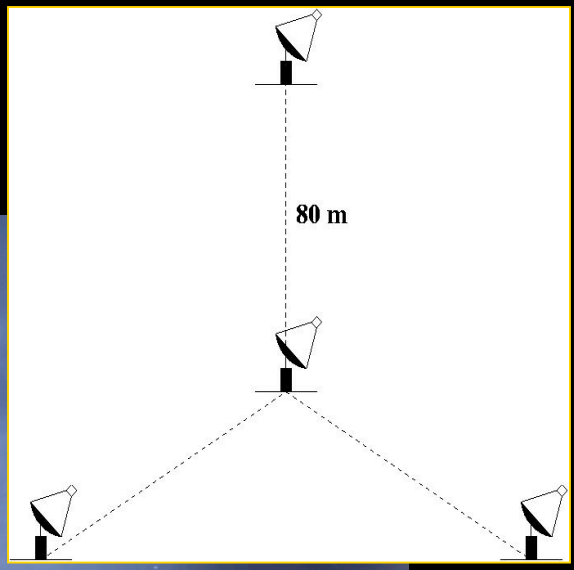




VERITAS* - USA/Canada/UK/Ireland - Site: Arizona

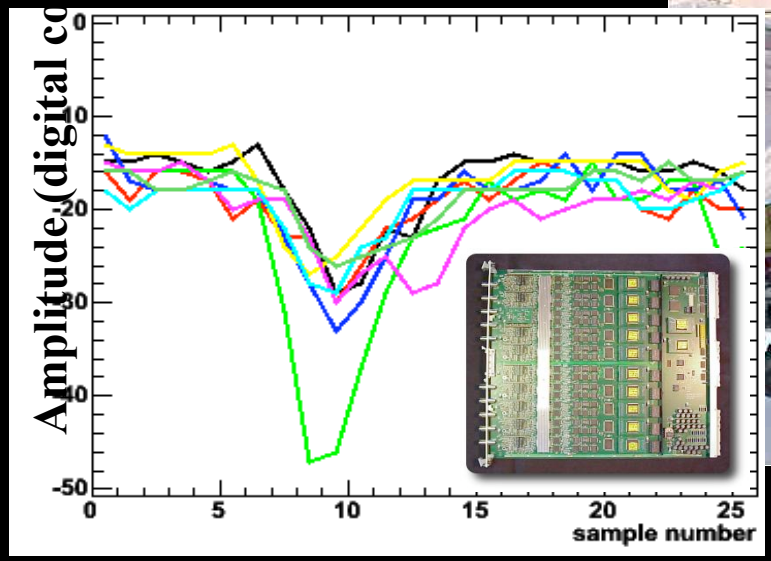
(see http://veritas.sao.arizona.edu/)



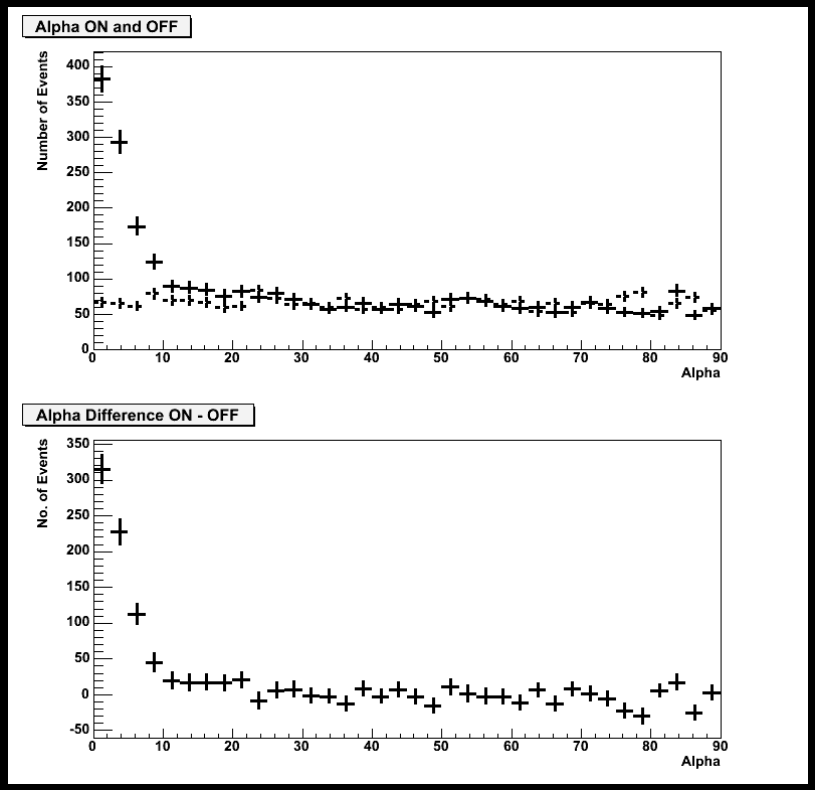


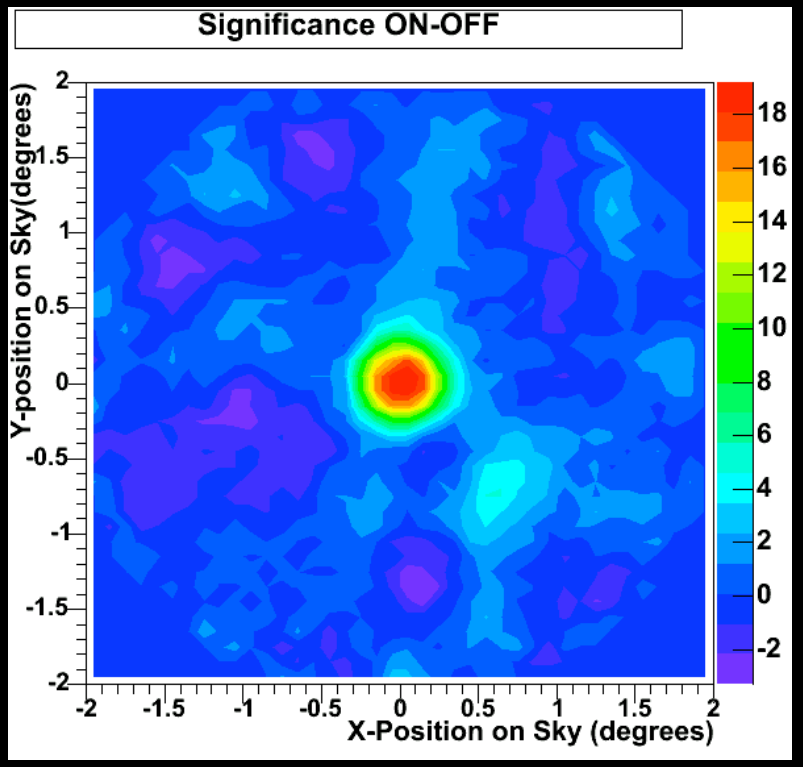
* Very Energetic Radiation Imaging Telescope Array System

- Telescope, 12m diameter f1
- 4 telescope array, 80m spacing
- 110 m^2 light collecting area
- Cameras 499 3/4" PMTs, 0.15 degree pixels
- 3.5 degree FOV
- Electronics - 500MHz FADC
- Array level trigger

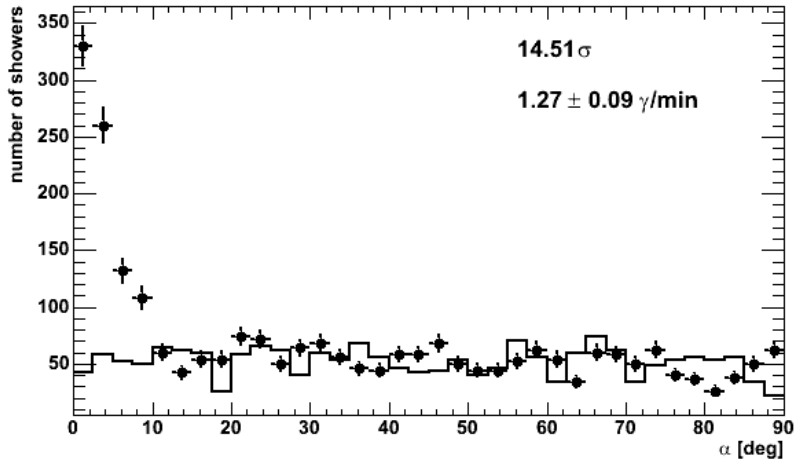


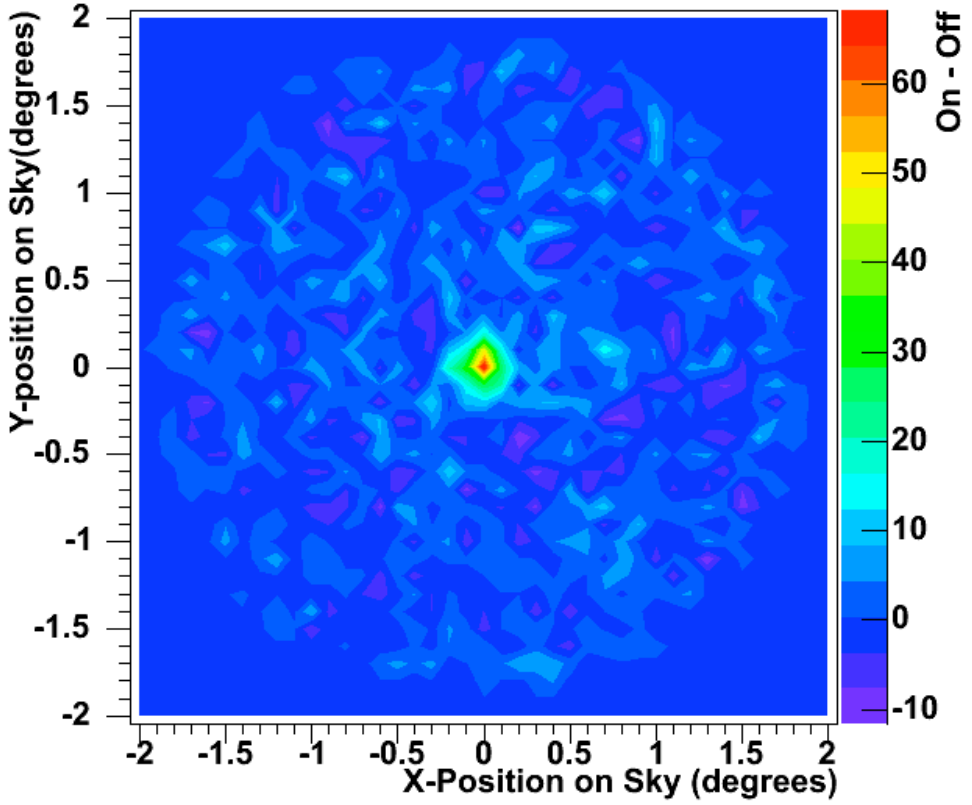
Crab Nebula
4.37 hours ON; +21.1 sigma
2.56 gammas/minute
10.1 sigma/sqrt(time in hours)



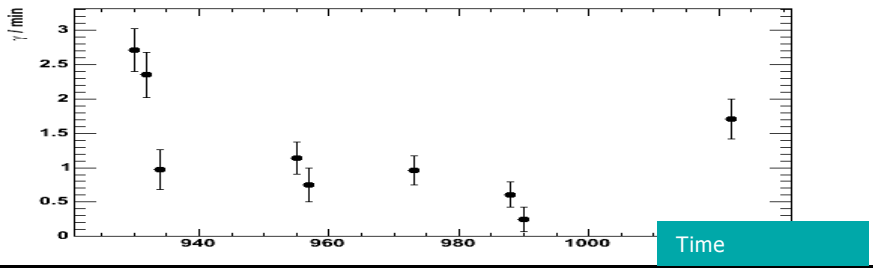


Markarian 421
5.6 hours ON +14.51 sigma





Light Curve

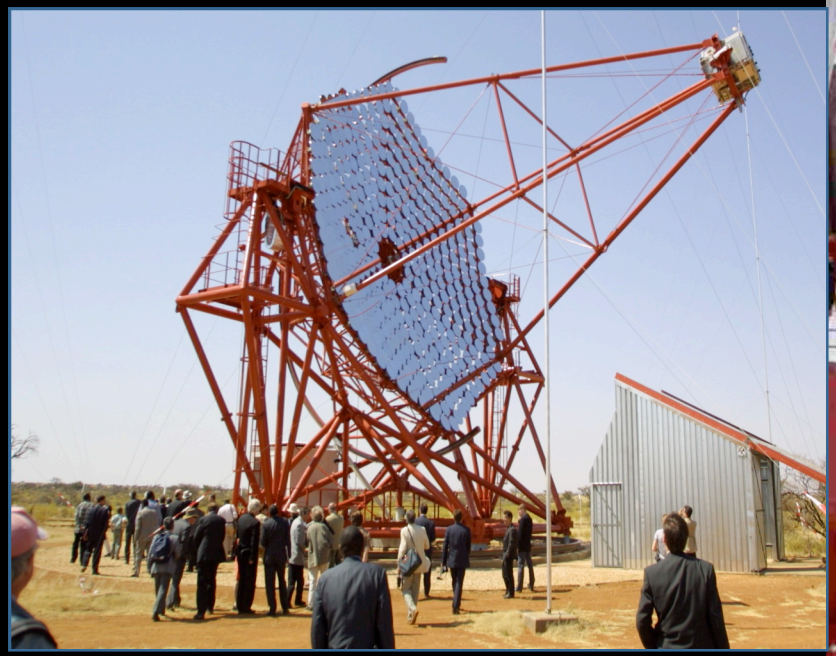


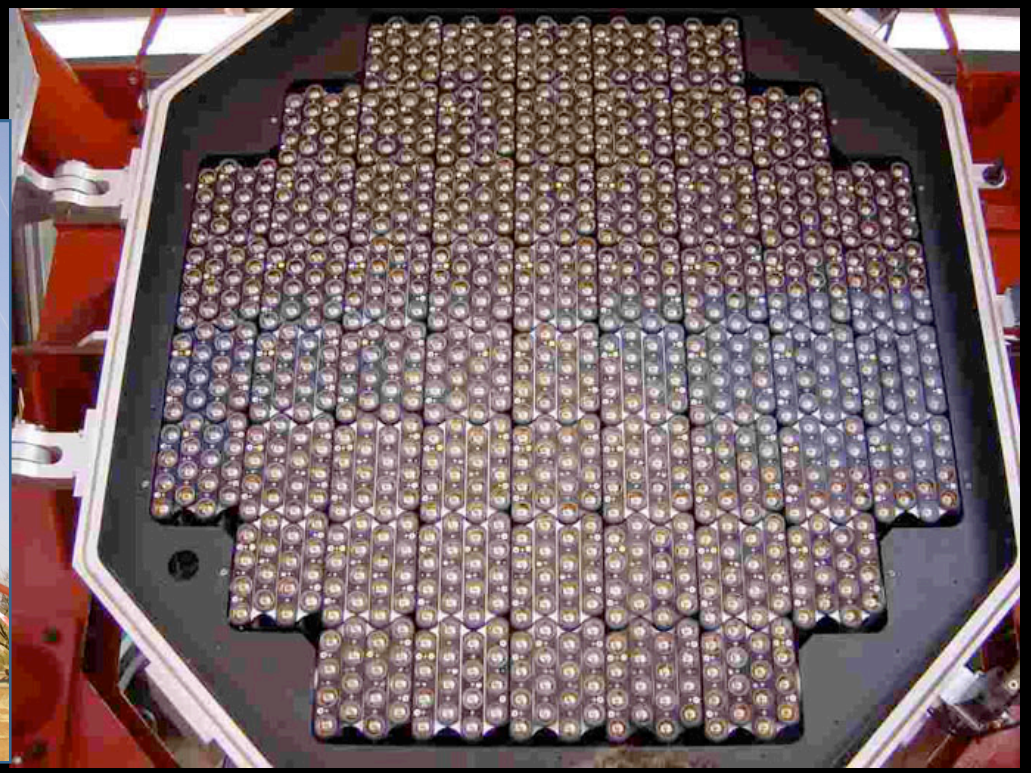
HESS* - Germany/France/+others - Site: Namibia

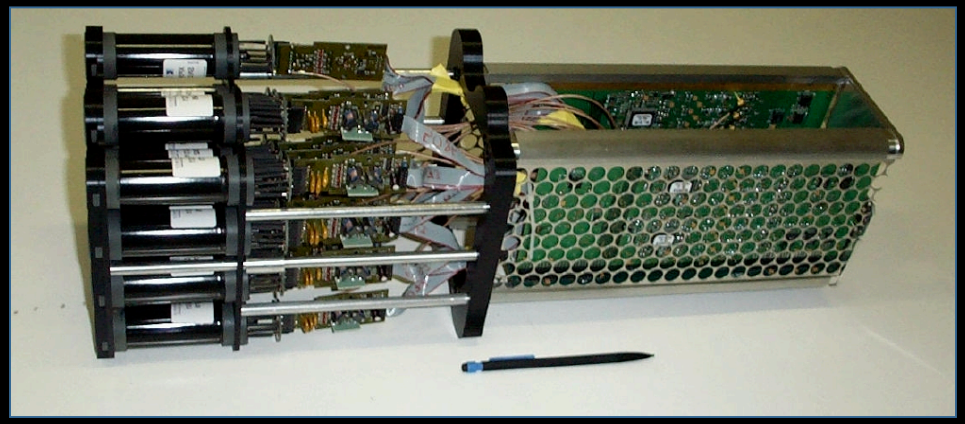
(see http://www.mpi-hd.mpg.de/hfm/HESS/)

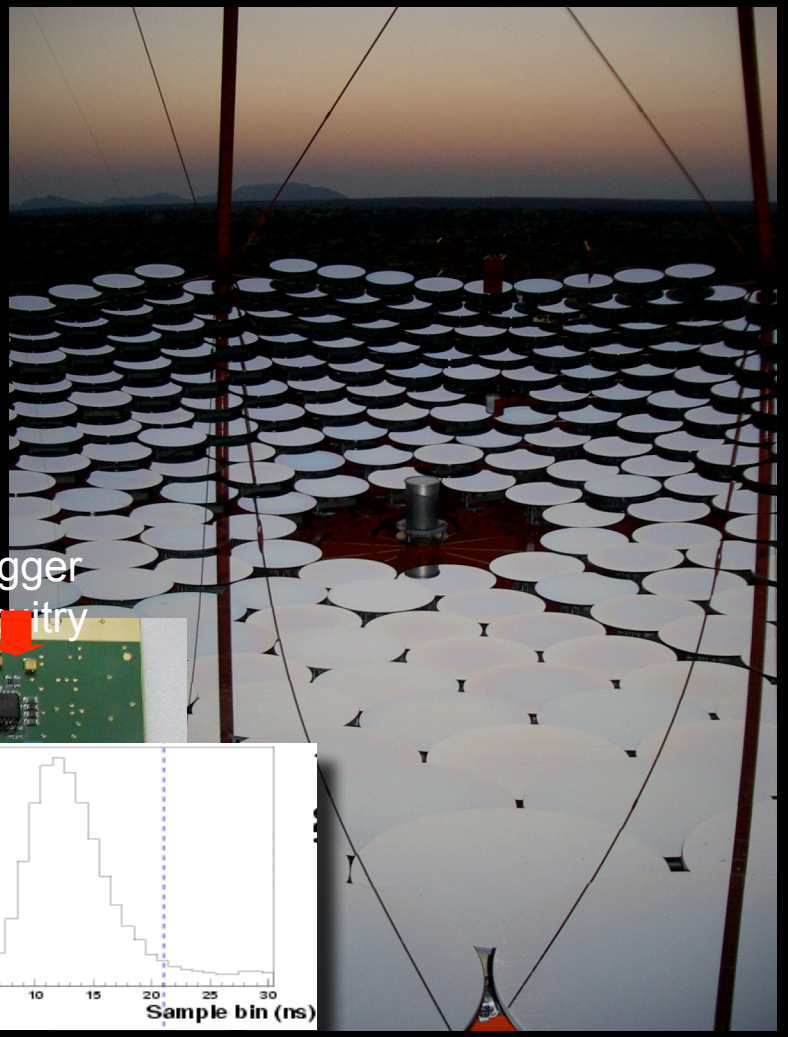
* High Energy Stereoscopic System

- Telescope, focal length 15m
- 4 telescope square array, 120m spacing
- 107 m^2 light collecting area
- Cameras 960 1" PMTs, 0.16 degree pixels
- 5 degree FOV
- Electronics - ARS Chip
- Larger (~30m) central telescope planned





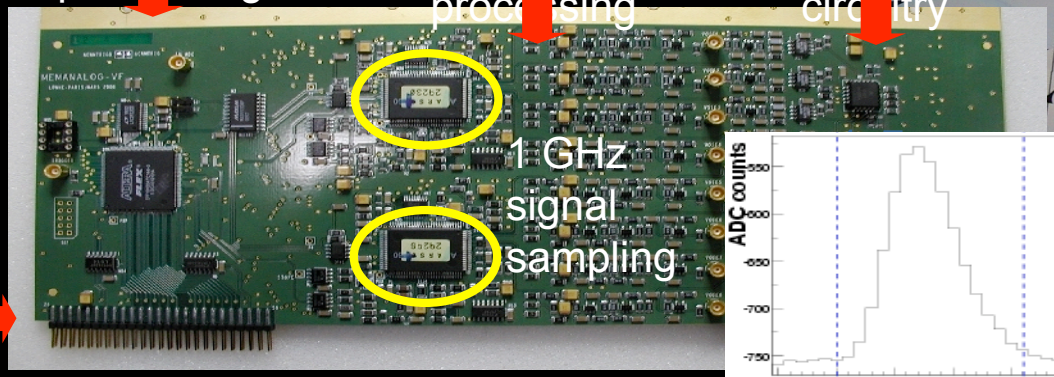




Digital signal processing

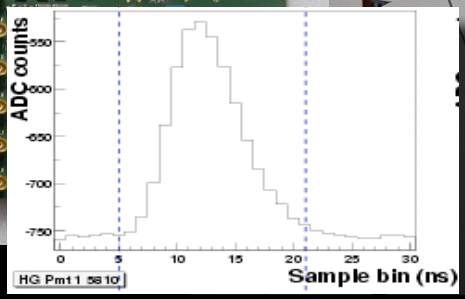
Analog signal processing

Trigger circuitry

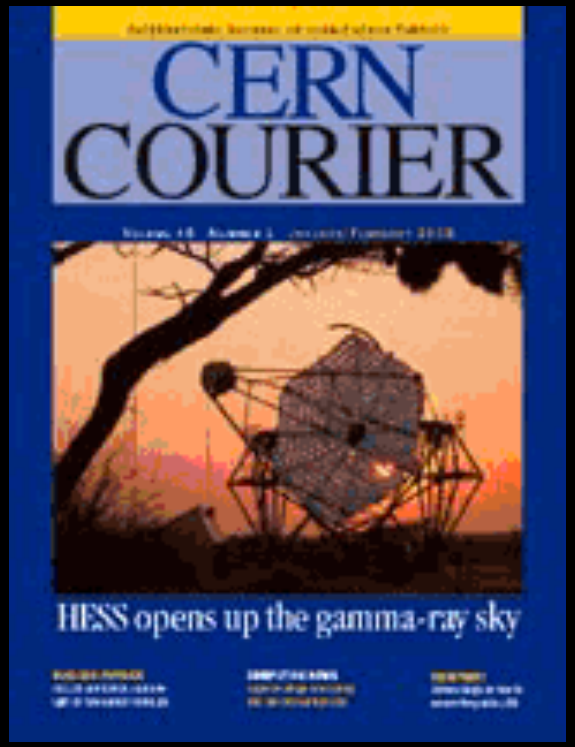


1 GHz signal sampling

Readout bus



HESS - SNR RXJ1713



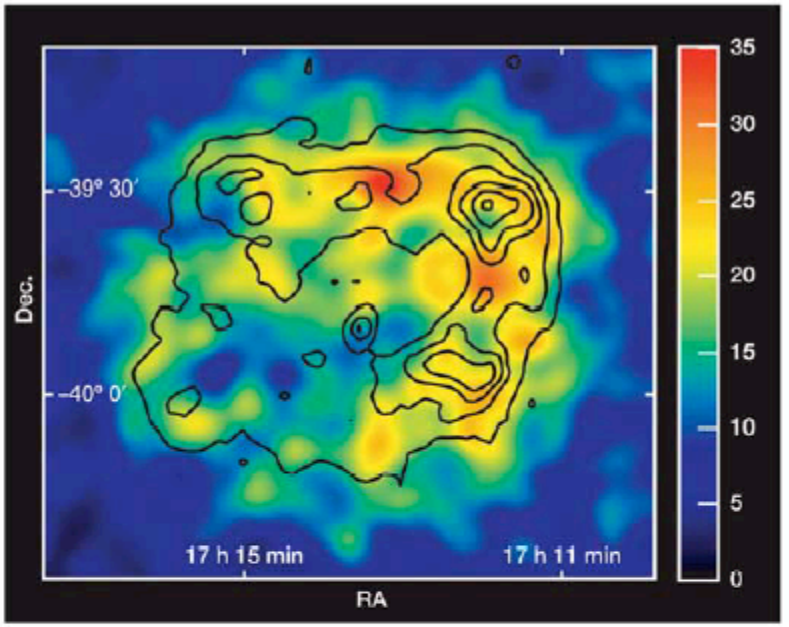


Figure 2 γ-ray image of the SNR RX J1713.7 − 3946 obtained with the HESS telescopes. Hard cuts were applied to select well-reconstructed γ-like events above 800 GeV. The map is smoothed as in Fig. 1, having the same scale in units of counts. The linear colour scale is in units of counts. We note that no background subtraction or camera-efficiency corrections have been applied. This demonstrates that the structures seen are not artefacts of the analysis but real and visible in the raw post-cuts data (the background in the field of view is at a level of about five counts, and the efficiency across the SNR changes by less than 10%). This image, obtained with a partial array during construction, demonstrates the ability of HESS to map extended objects. The superimposed (linearly spaced) contours show the X-ray surface brightness as seen by ASCA in the 1–3 keV range for comparison[25]. Note that the angular resolution of ASCA is comparable to that of HESS which enables direct comparison of the two images. RA, right ascension; dec., declination.

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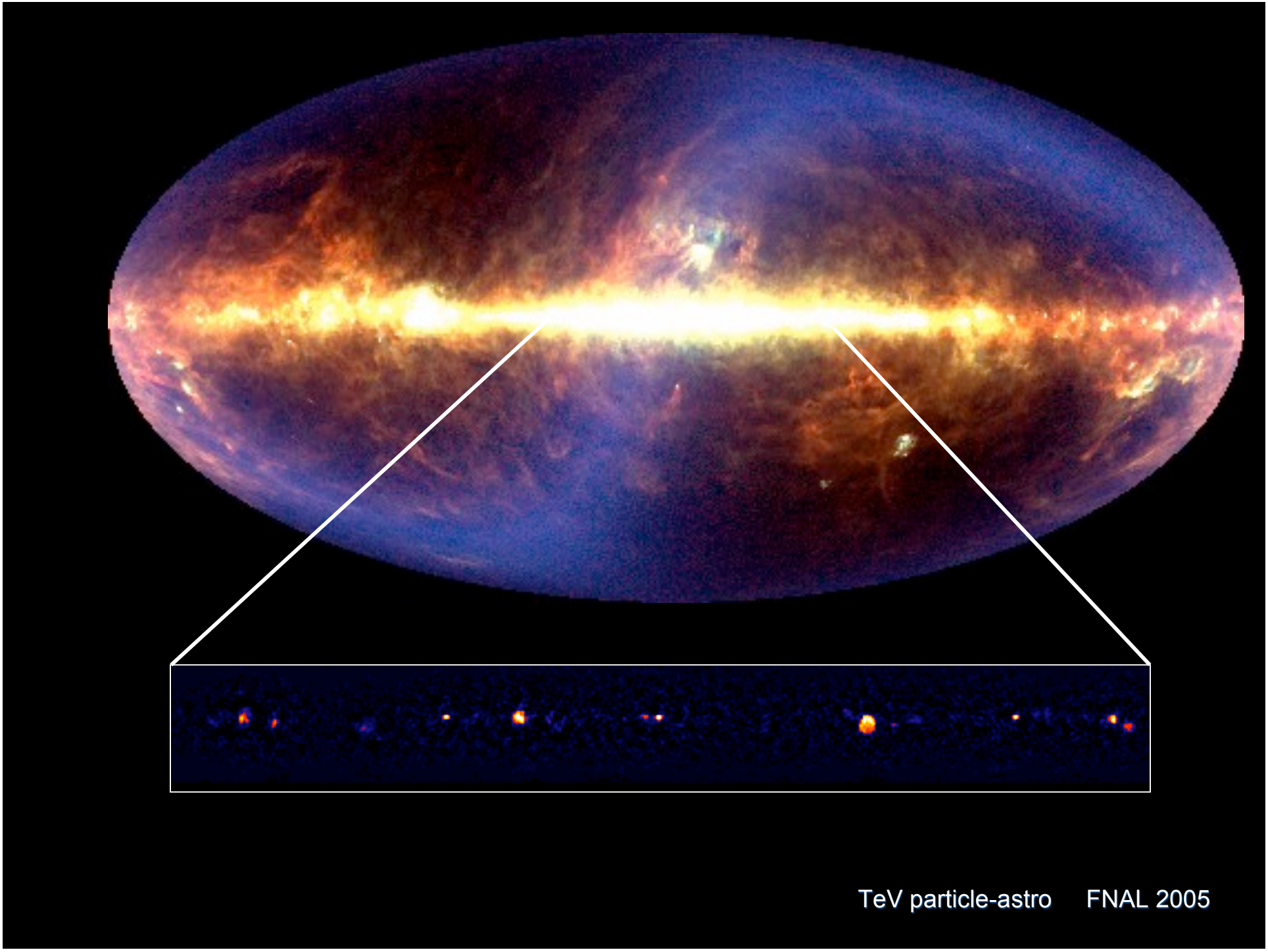
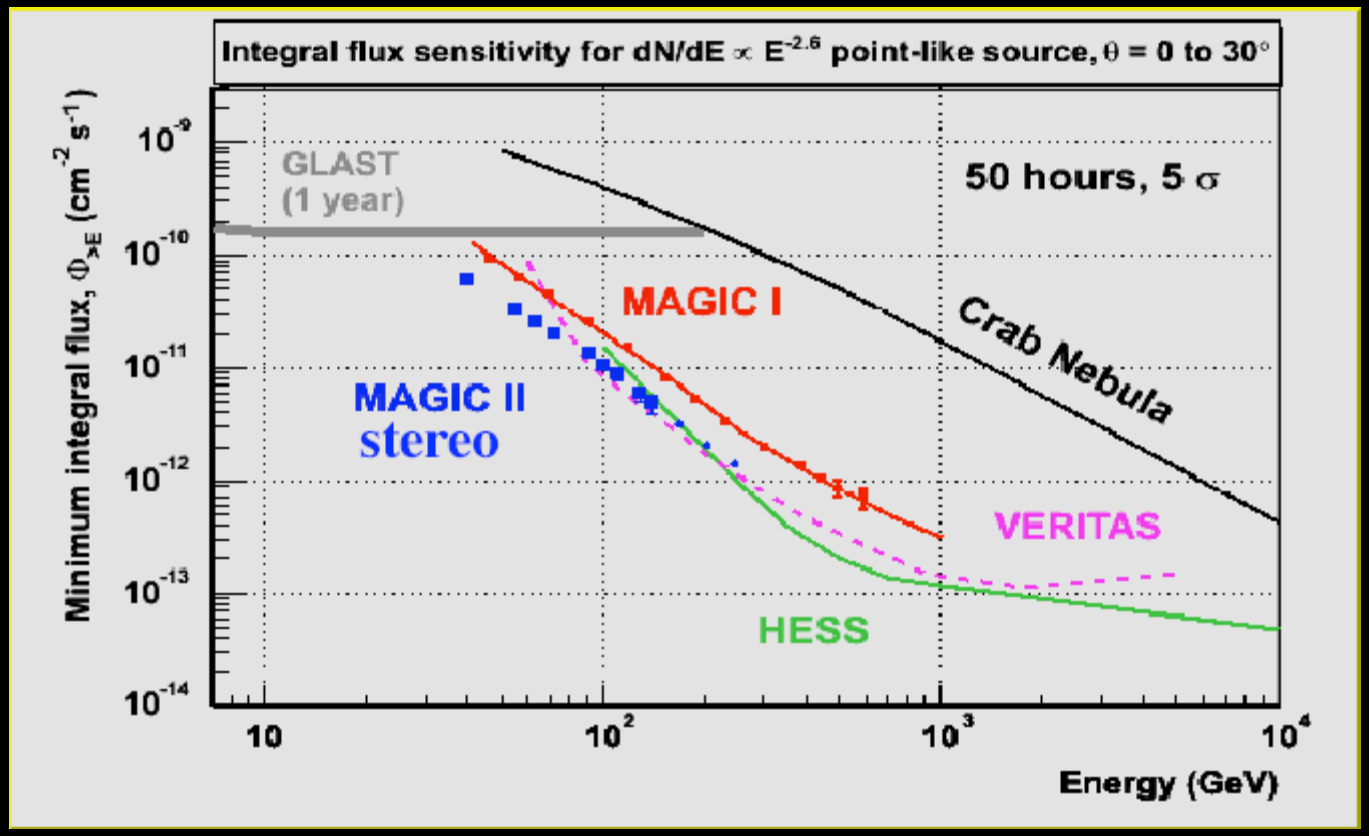
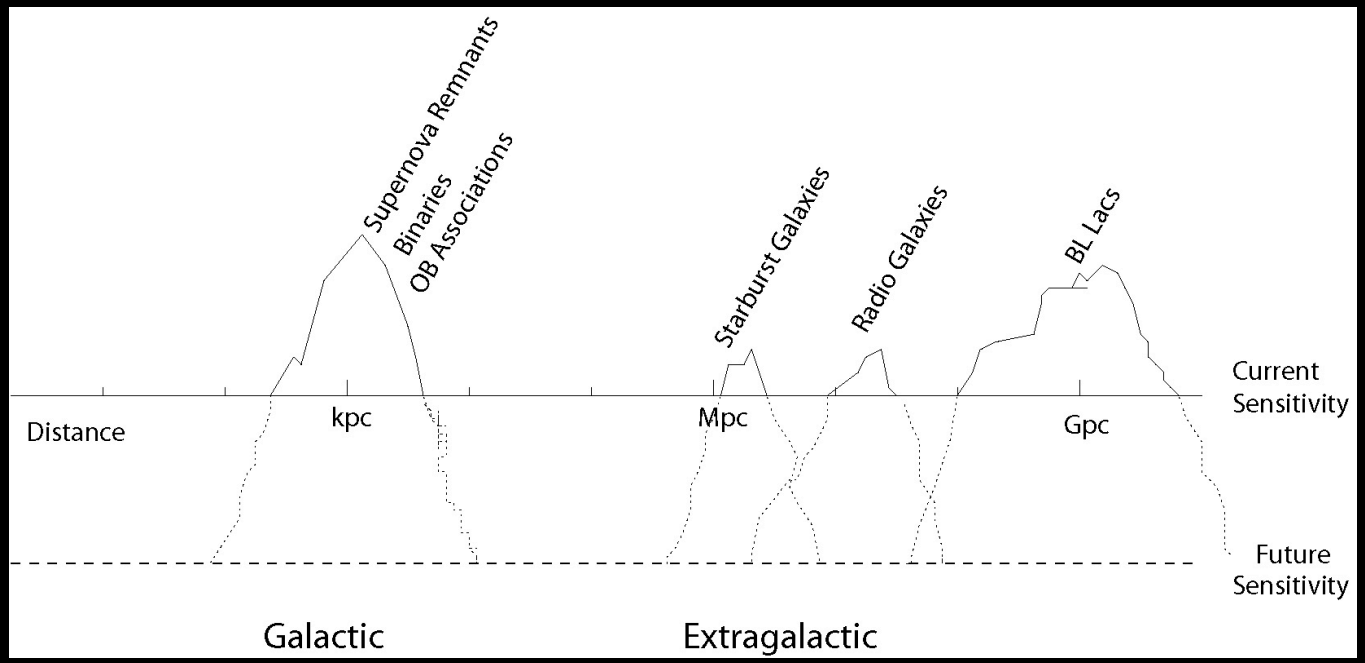

TeV particle-astro FNAL 2005


Integral flux sensitivity for dN/dE ∝ E^-2.6 point-like source, θ = 0 to 30°
Minimum integral flux, Φ>E (cm^-2 s^-1)
10^-9
10^-10
10^-11
10^-12
10^-13
10^-14
GLAST
(1 year)
50 hours, 5 σ
MAGIC I
Crab Nebula
MAGIC II
stereo
VERITAS
HESS
10
10^2
10^3
10^4
Energy (GeV)

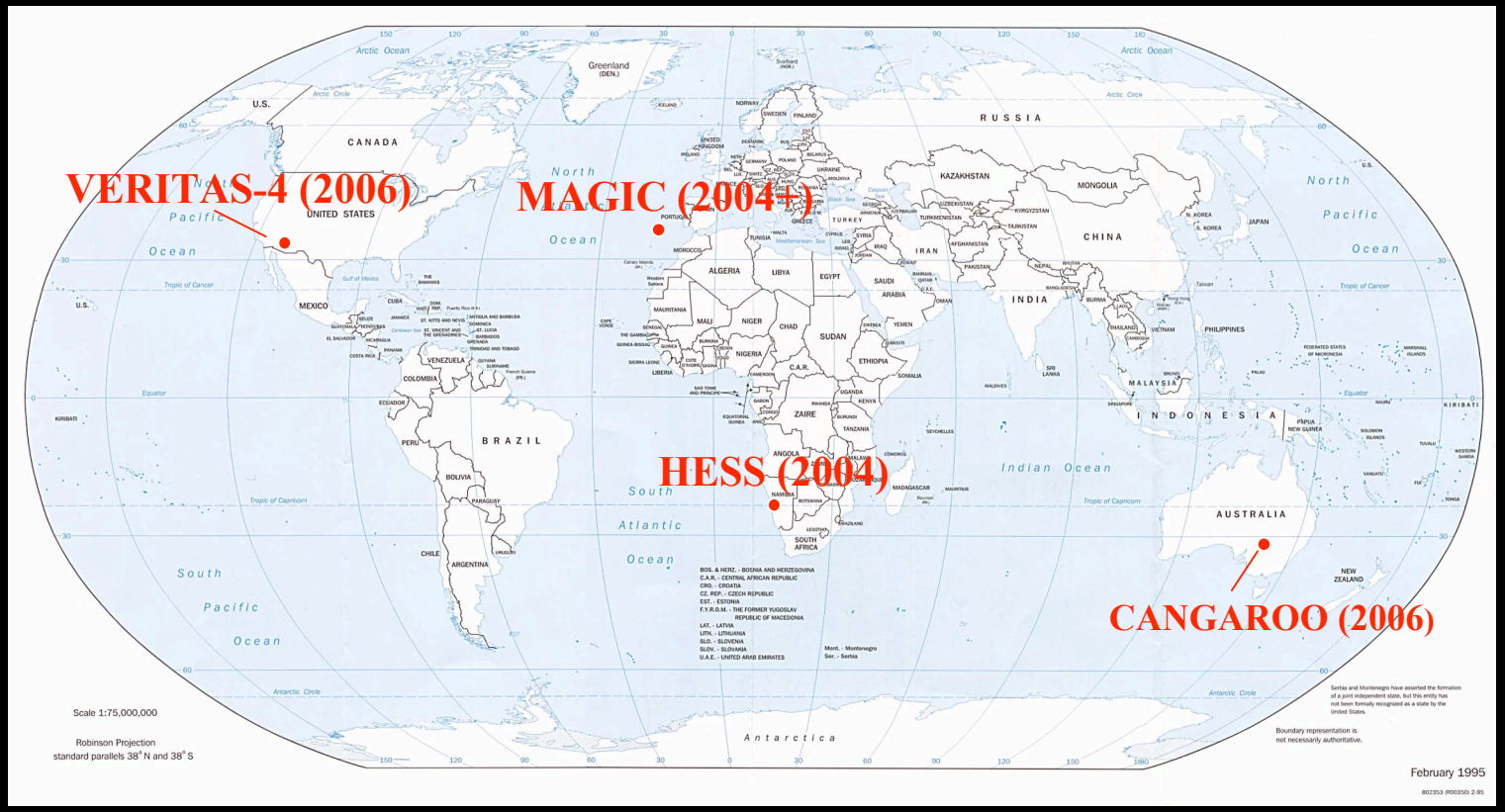
(from MAGIC)

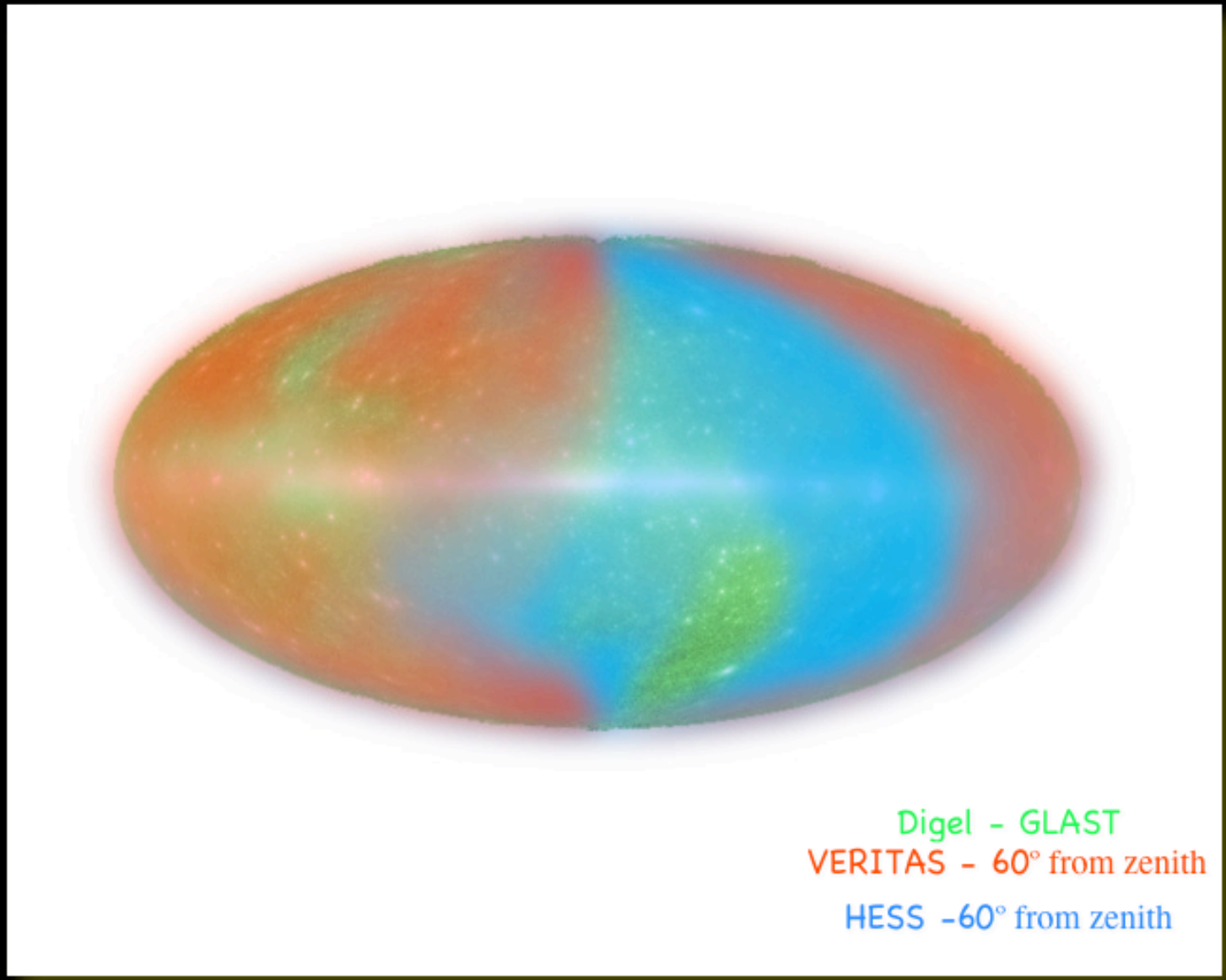
At VERITAS symposium at Adler 2003 T. Weekes ~12 sources, 50/50 galactic/extragalactic, and.....

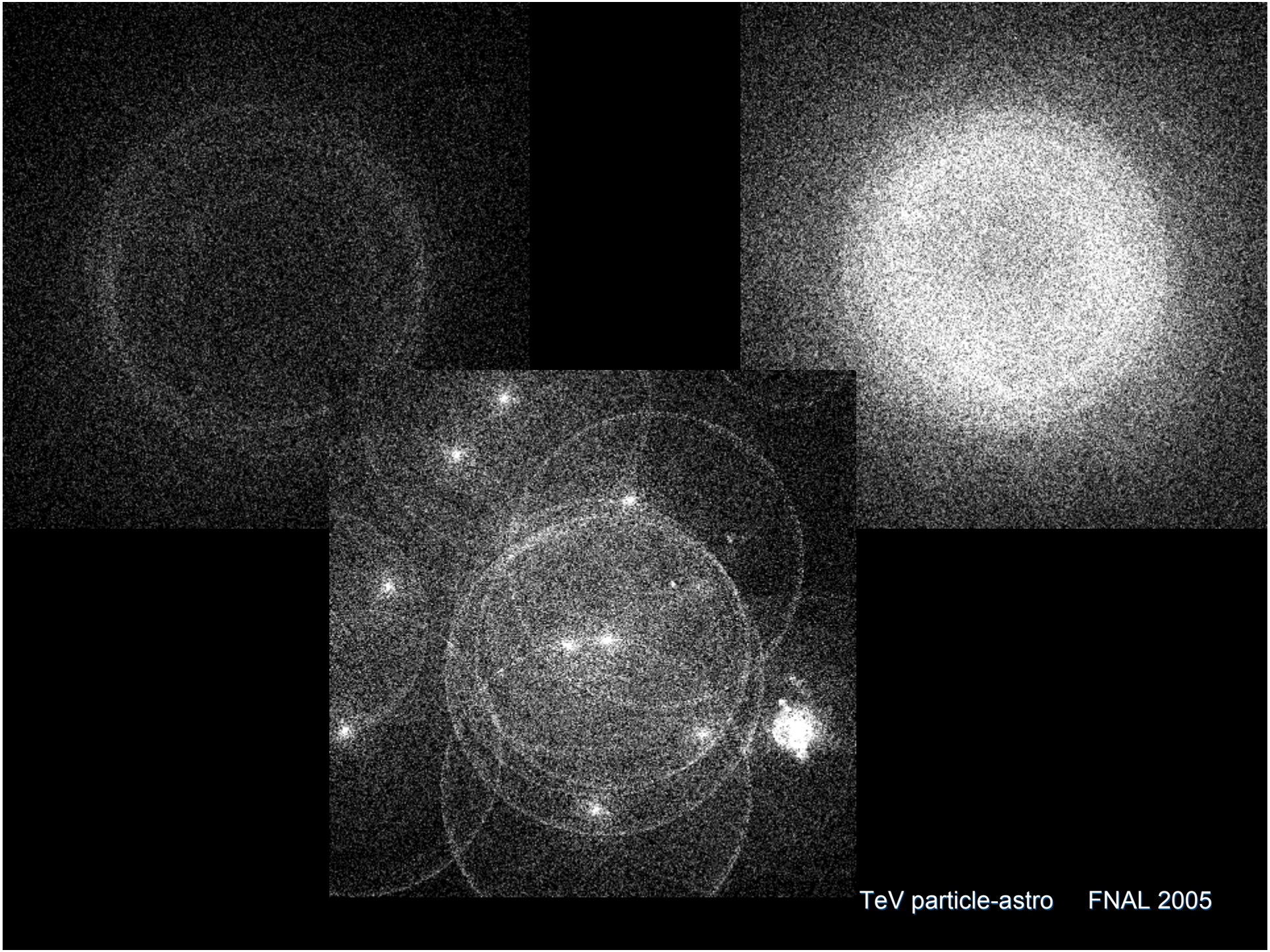


- CANGAROO - operational 2006
- MAGIC - operational 2004
- VERITAS - operational 2006
- HESS - operational 2004 -> many new sources, IMAGES!

The World-Wide Network of 3rd Generation IACTs




Digel - GLAST
VERITAS - 60° from zenith
HESS -60° from zenith


TeV particle-astro FNAL 2005