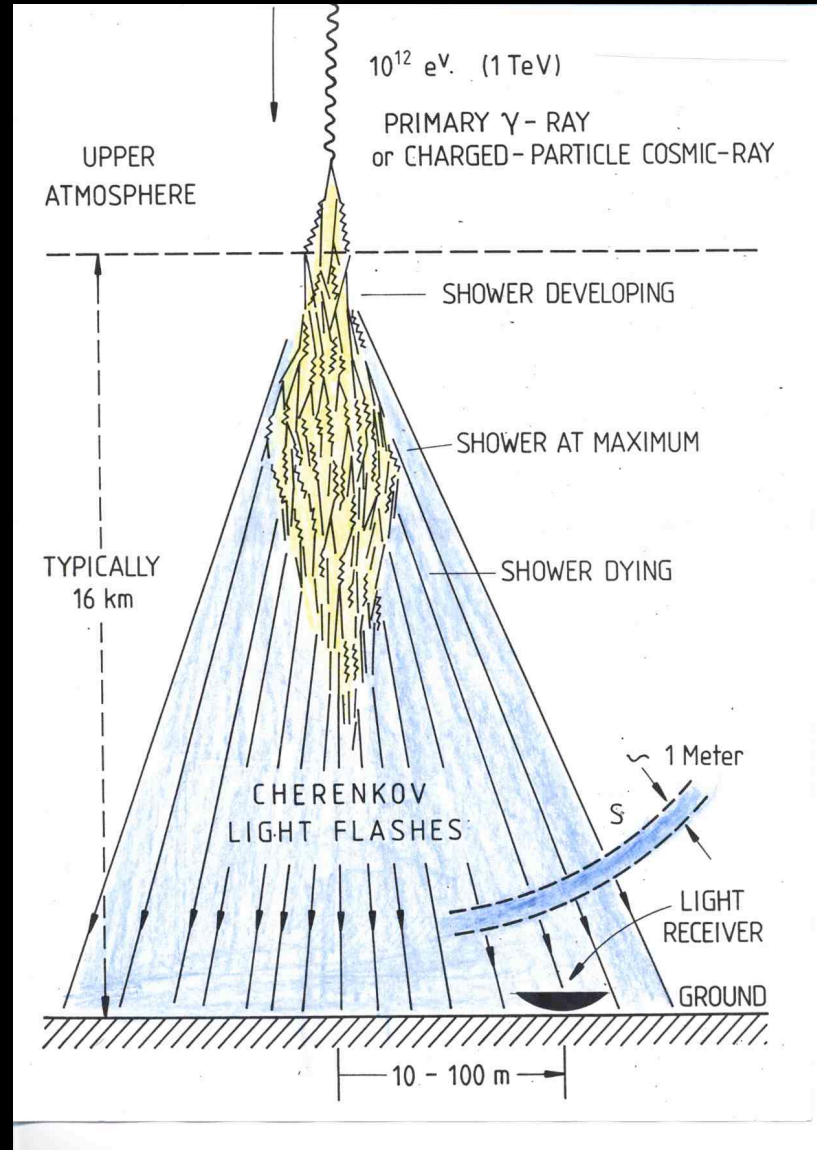


The New Generation of Imaging Air Cherenkov Gamma-Ray Telescopes

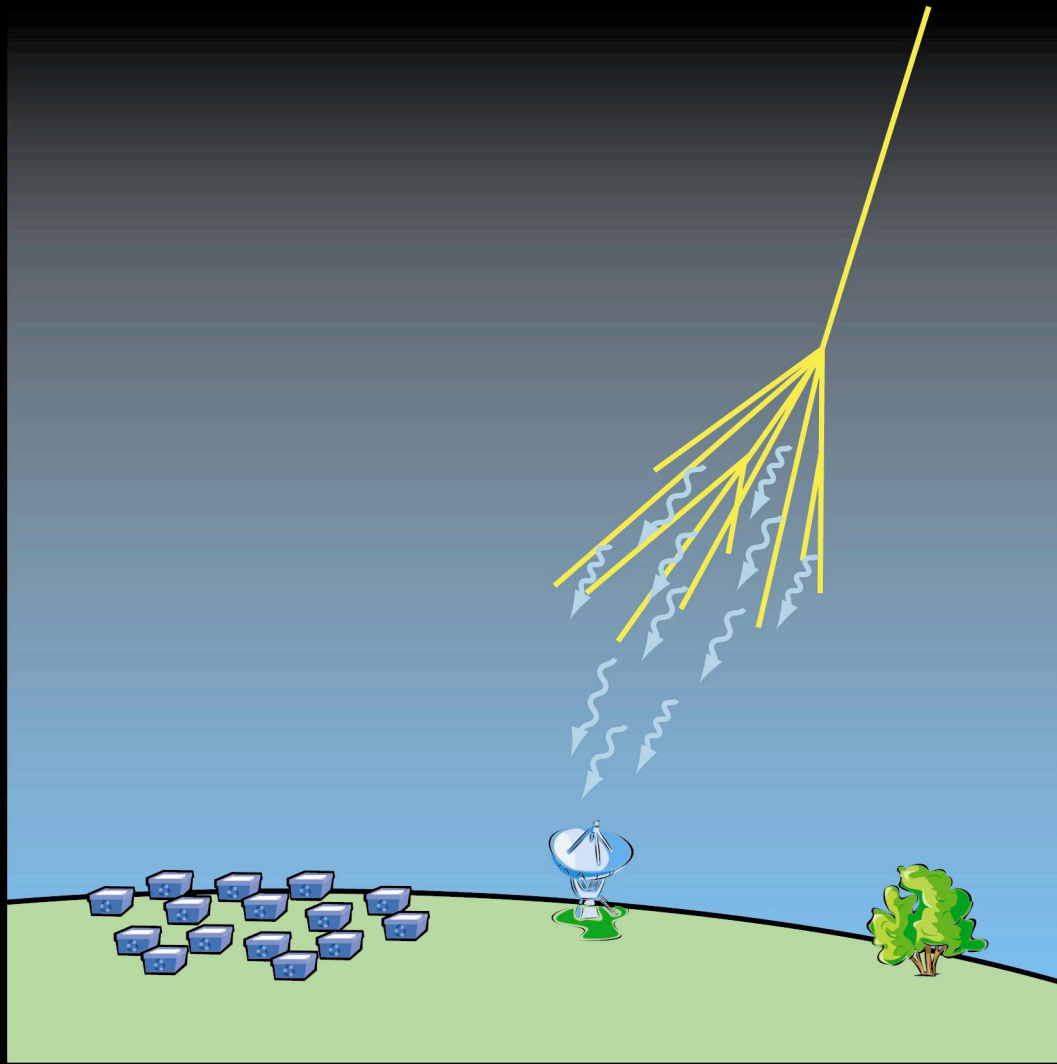
Simon Swordy - U. Chicago (s-swordy@uchicago.edu)

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

Light Flashes are Briefly
Brighter than Fluctuations
in Night Sky



IACT Technique



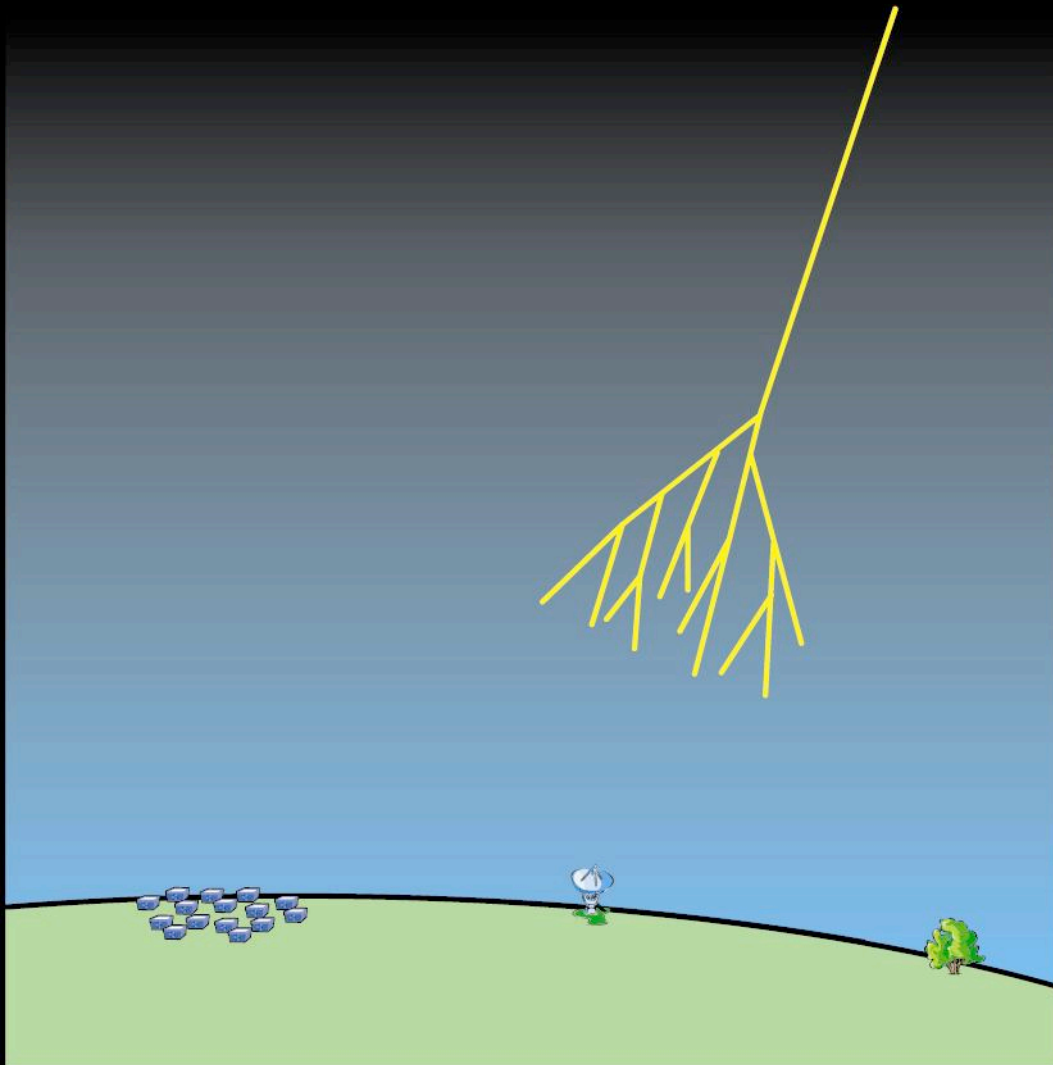
As with Air Shower Arrays:
Atmosphere = Calorimeter

Traditional Air Shower Array
Samples shower at end
of development

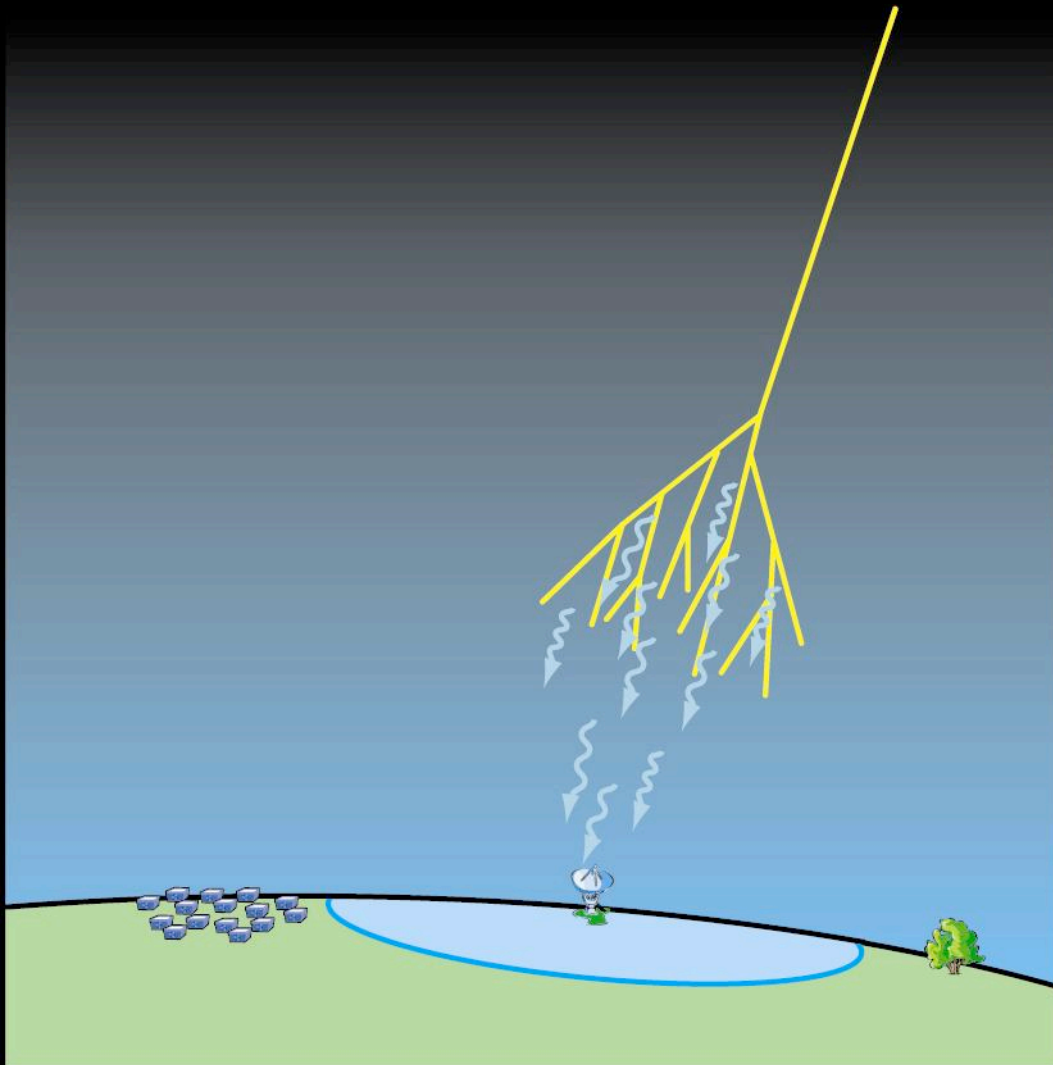
Atmospheric Cerenkov Tel.
Samples Cerenkov Light
throughout shower
development

- Primary Energy
- Arrival Direction
- Composition

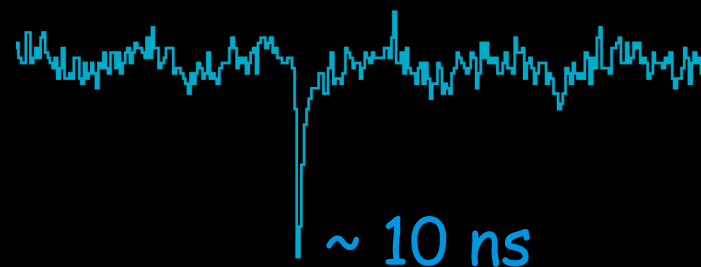
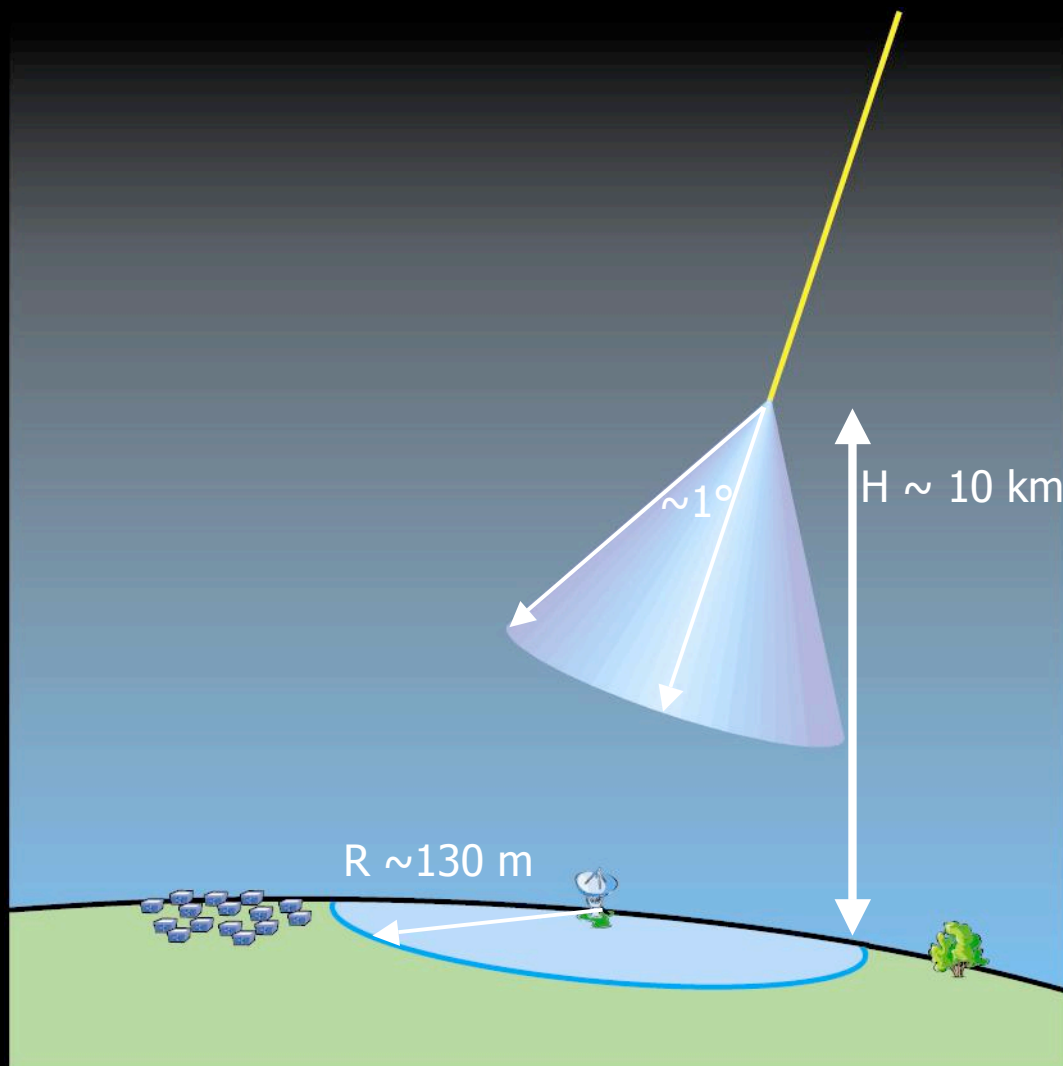
Atmospheric Cerenkov Basics



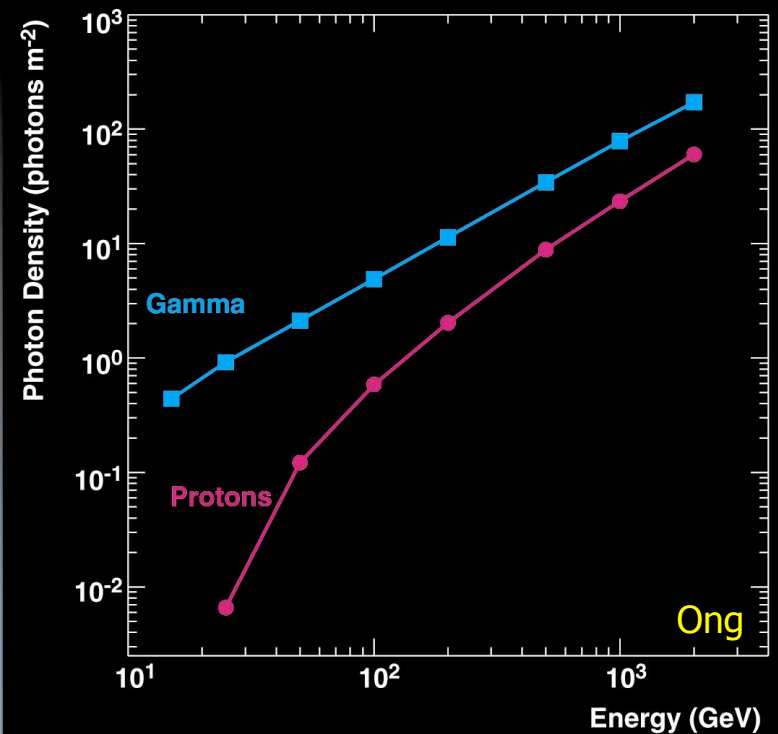
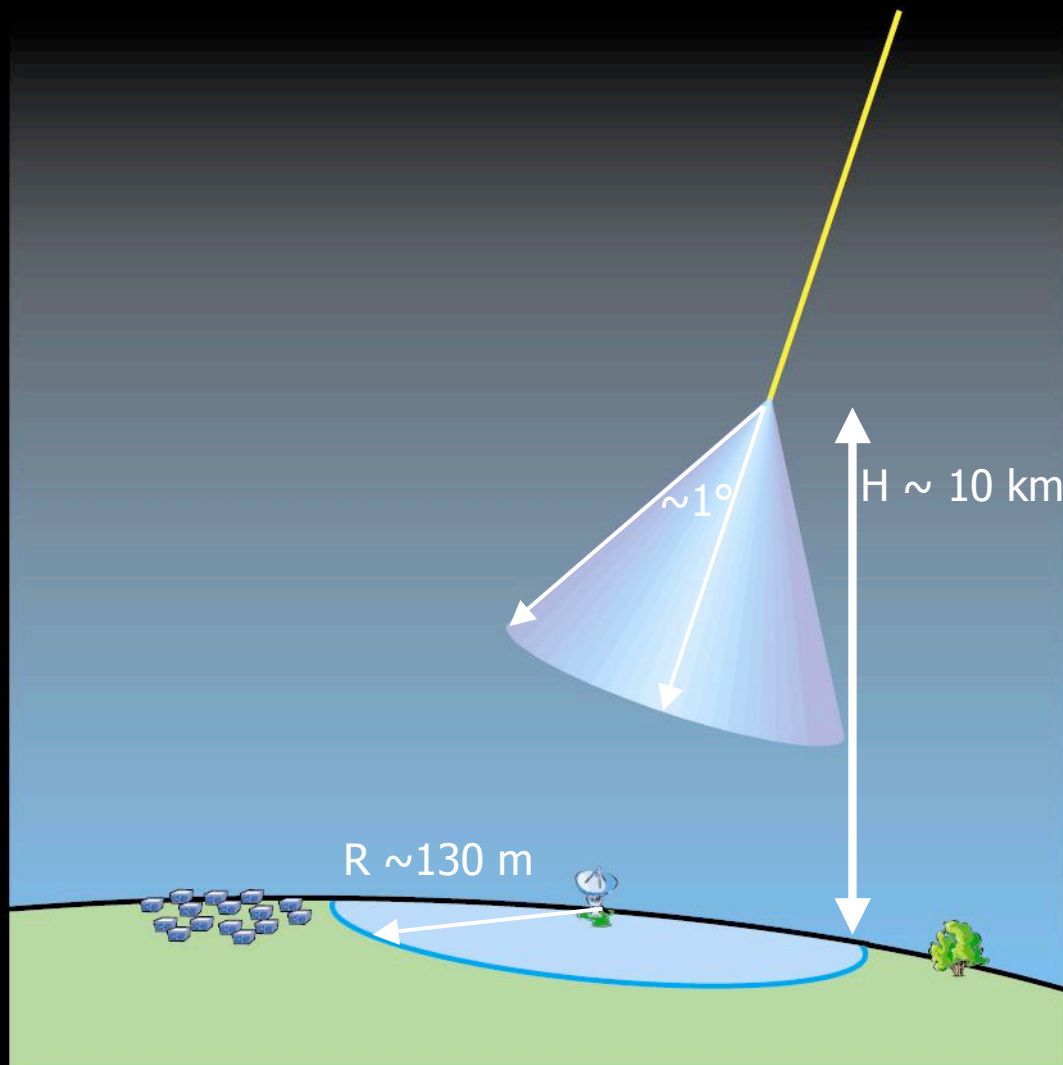
Atmospheric Cerenkov Basics



Atmospheric Cerenkov Basics

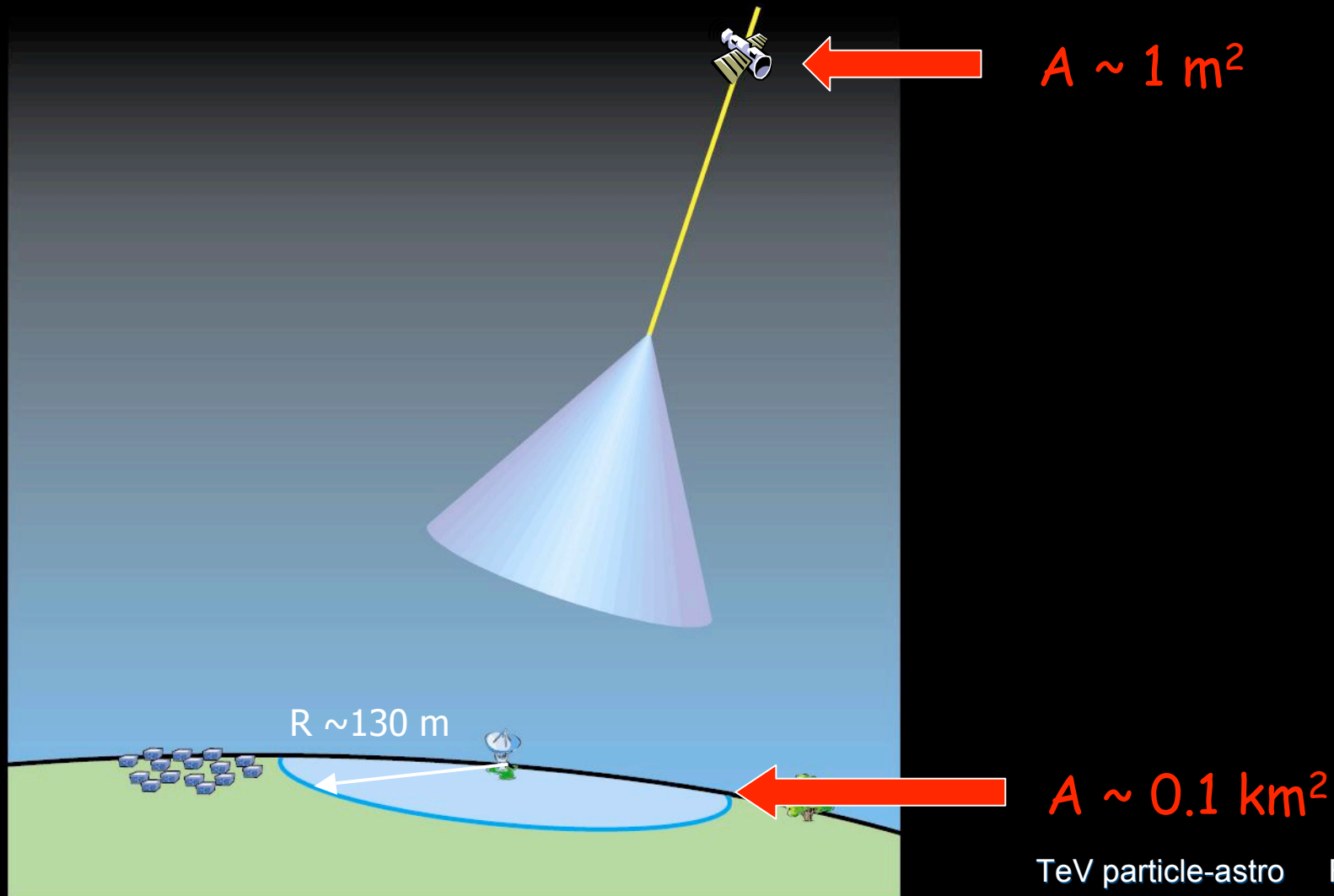


Atmospheric Cerenkov Basics



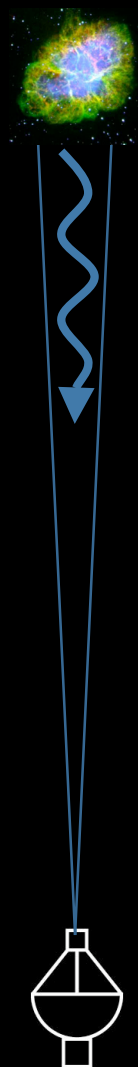
1 TeV:
 $\sim 100 \text{ ph/m}^2$
300 - 600 nm

Effective Area



Atmospheric Cerenkov Technique

"On-Source"

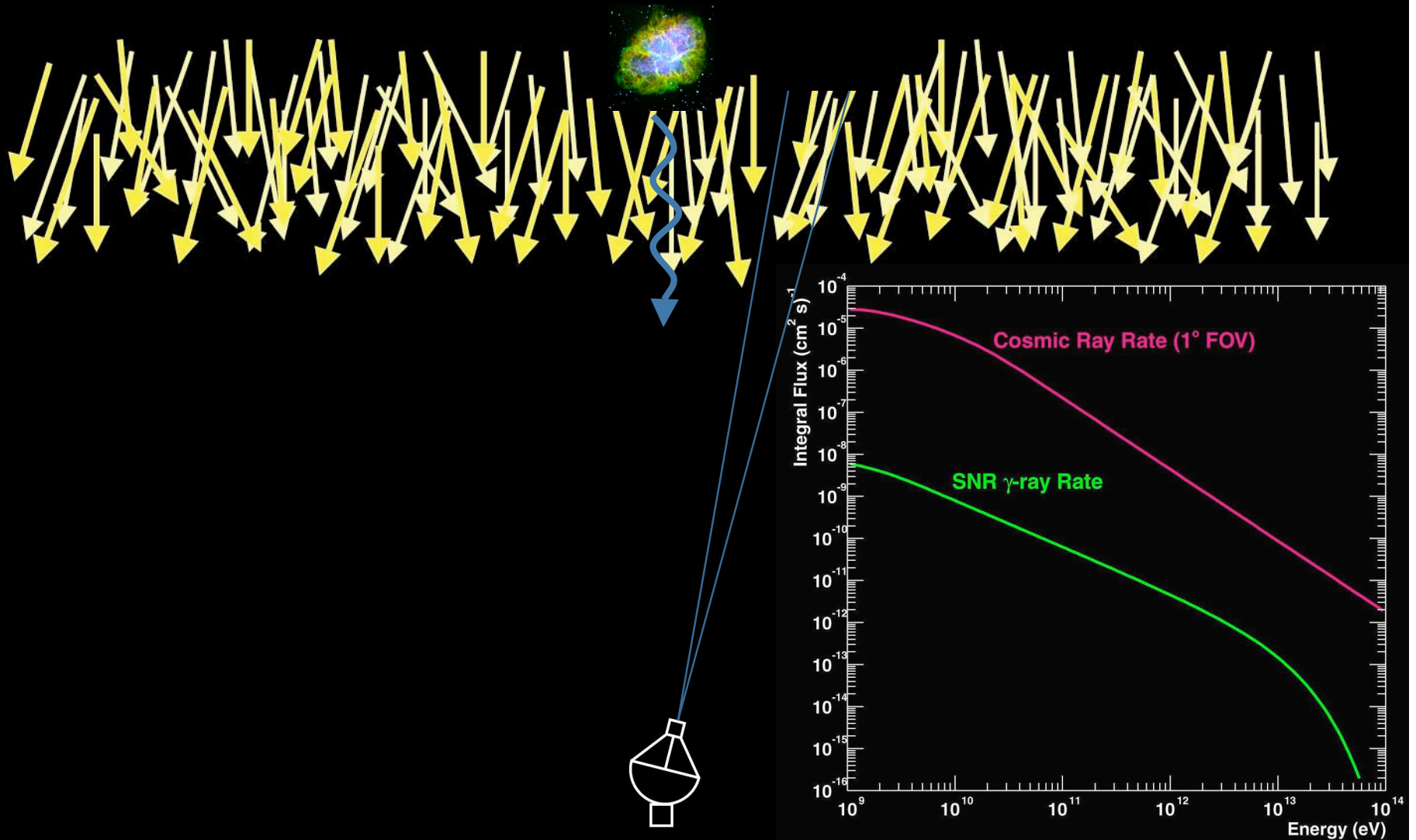


Atmospheric Cerenkov Technique

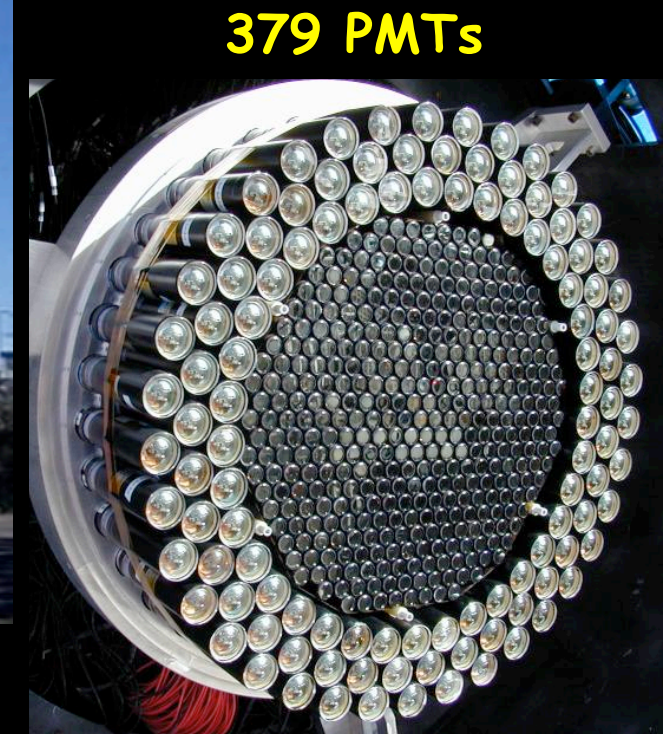
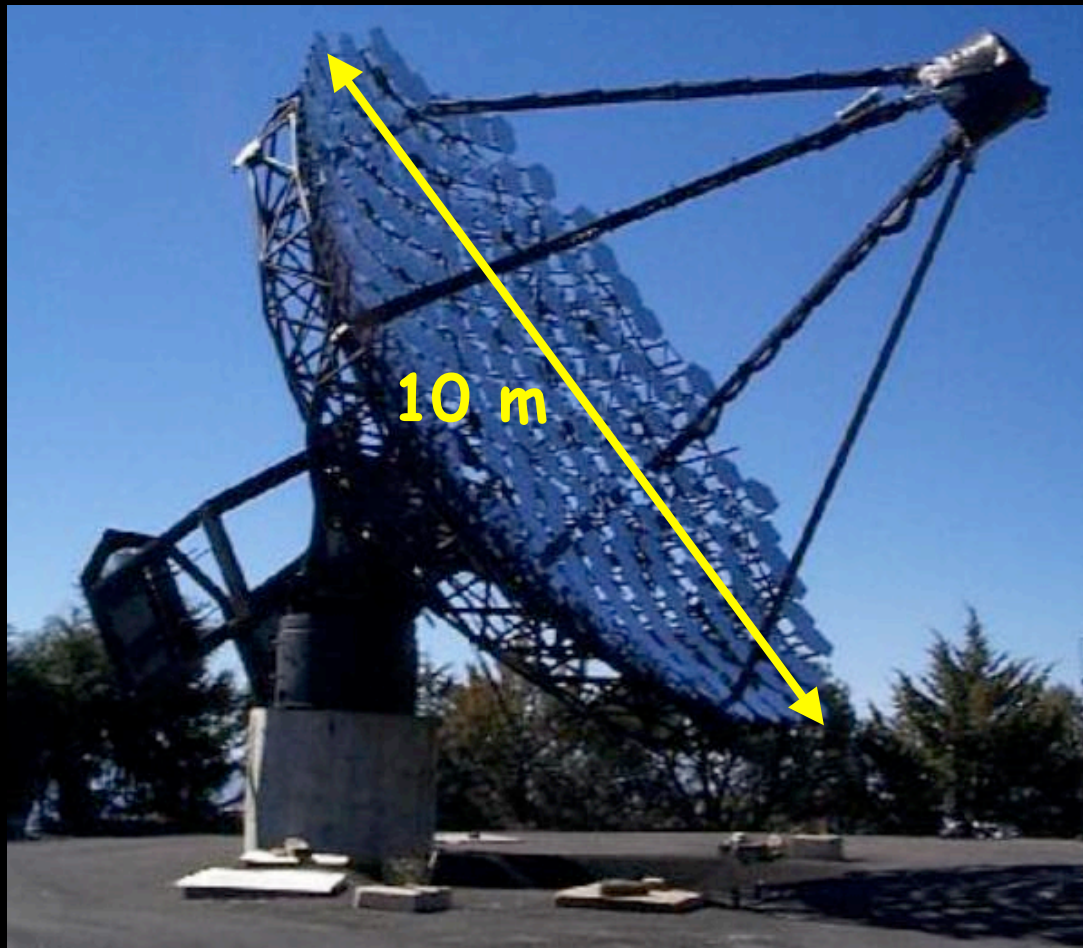
"Off-Source"



Atmospheric Cerenkov Technique



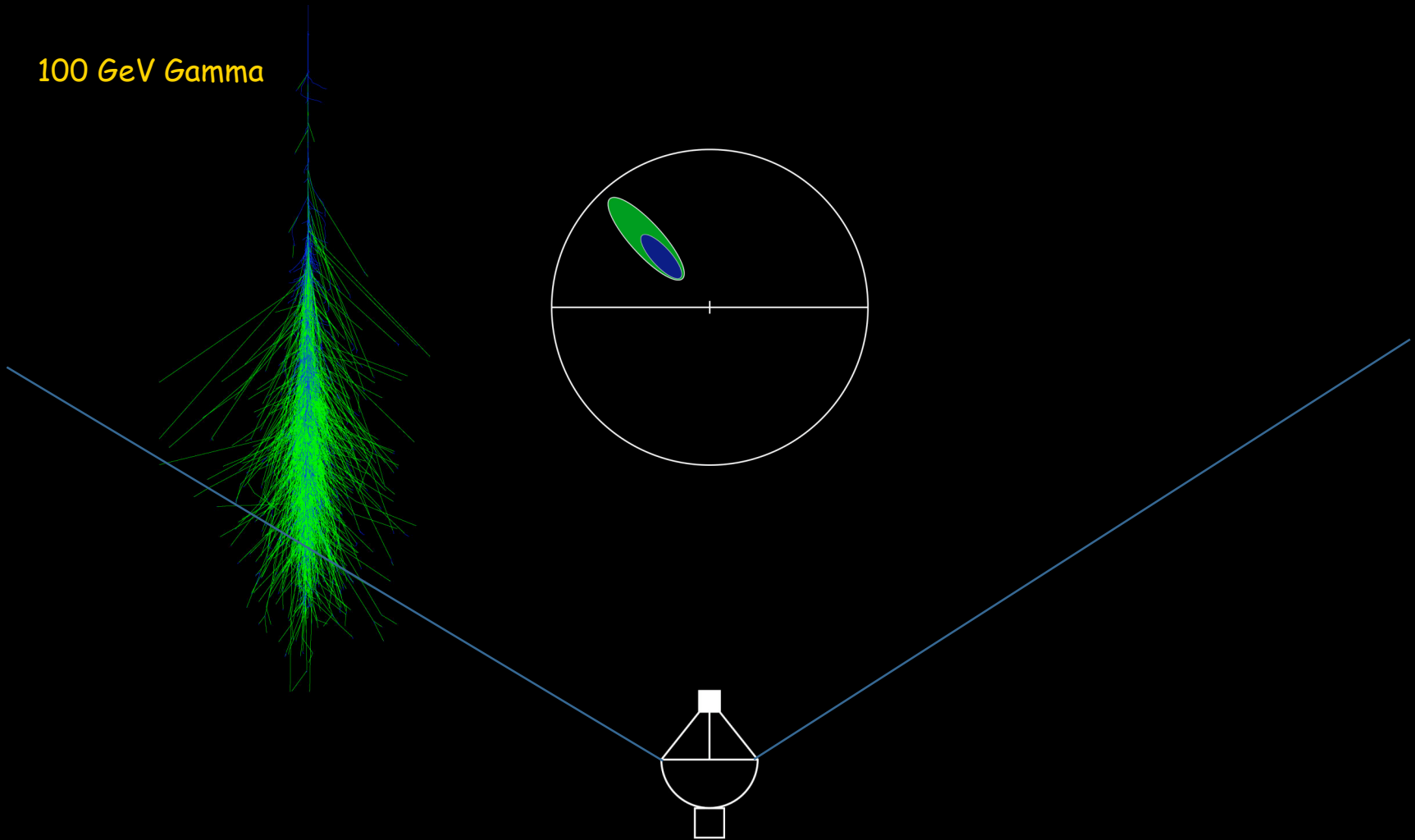
Cerenkov Imaging - Whipple



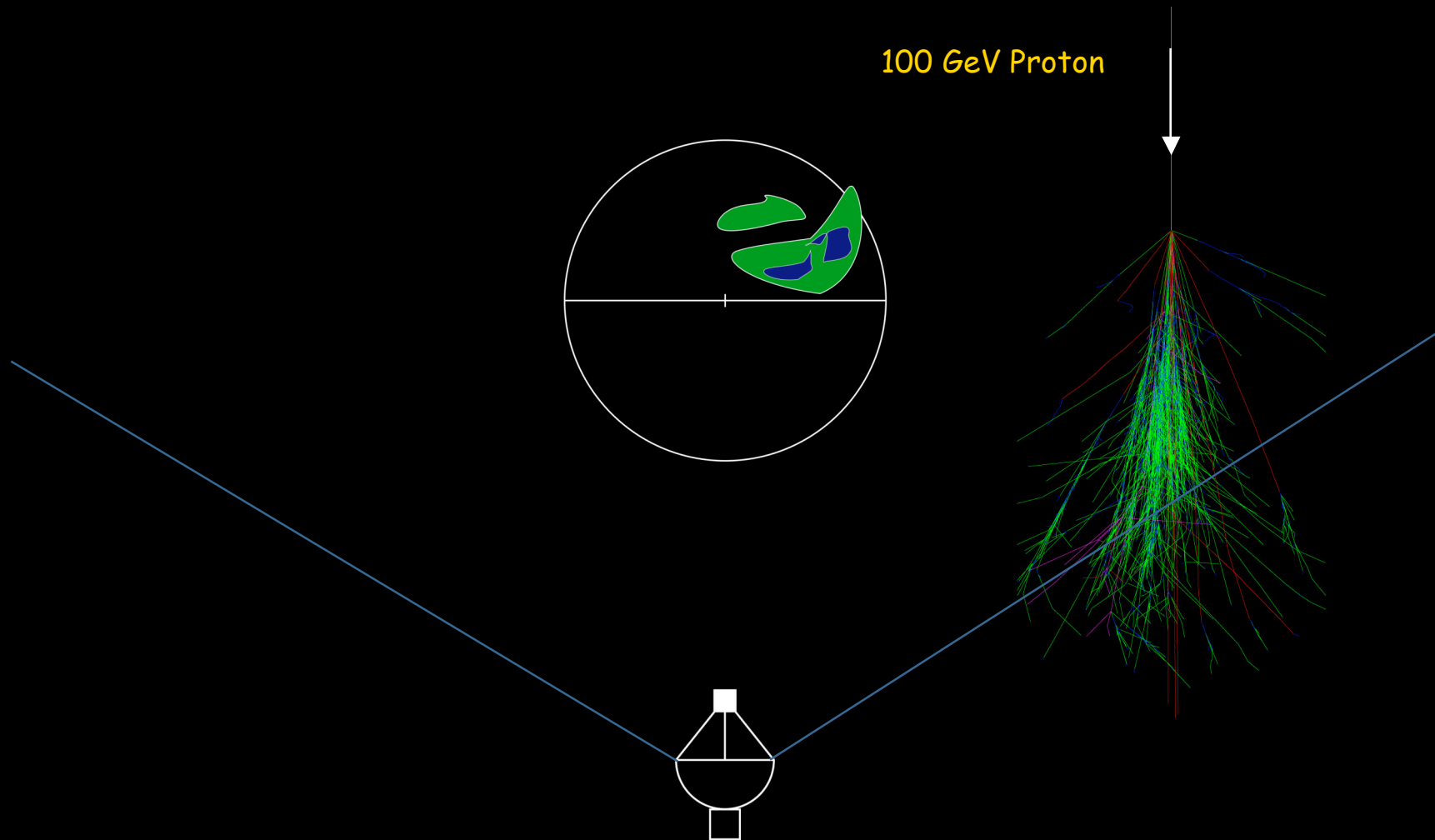
TeV particle-astro FNAL 2005

Cerenkov Imaging

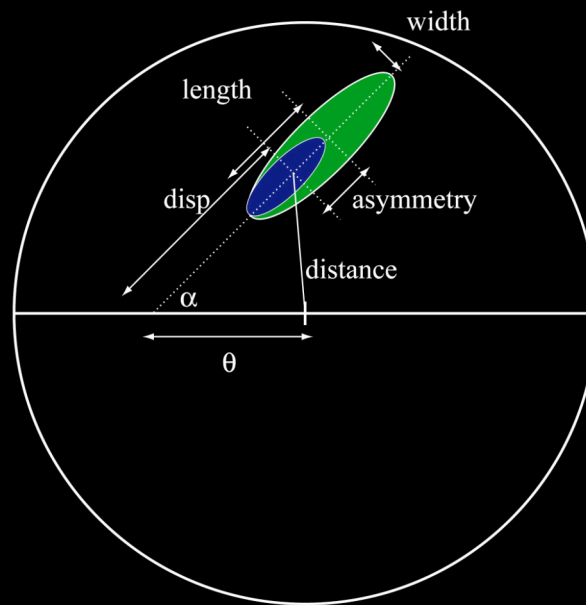
100 GeV Gamma



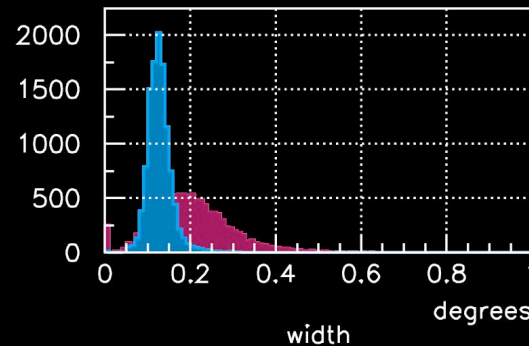
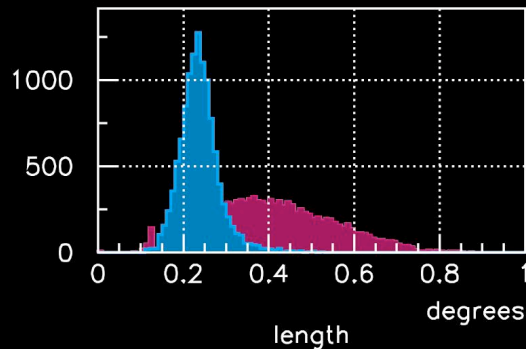
Cerenkov Imaging



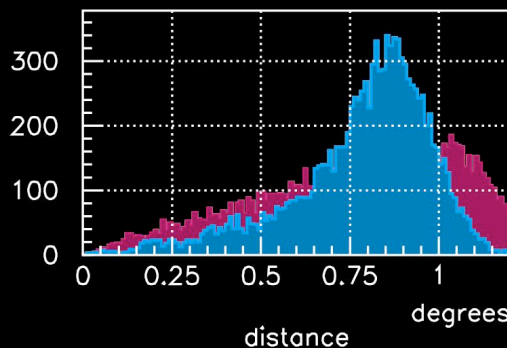
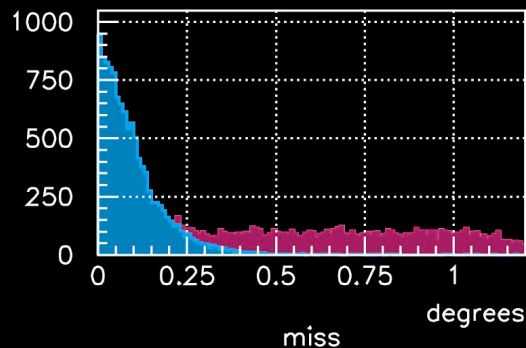
Hillas Parameters



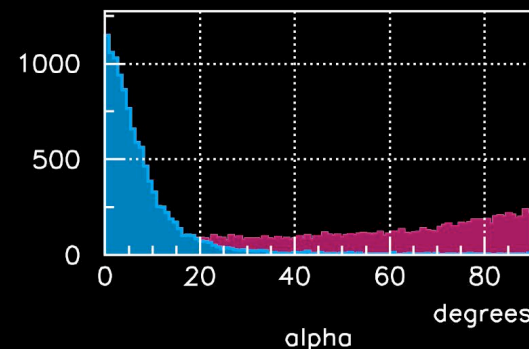
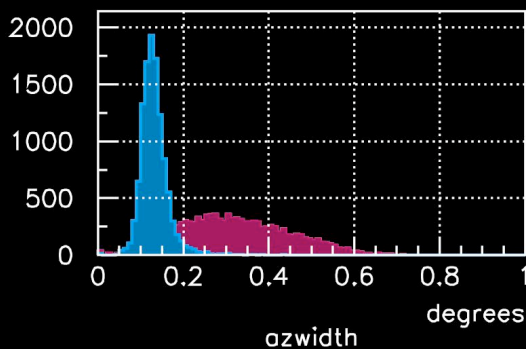
Hillas Parameter Distributions



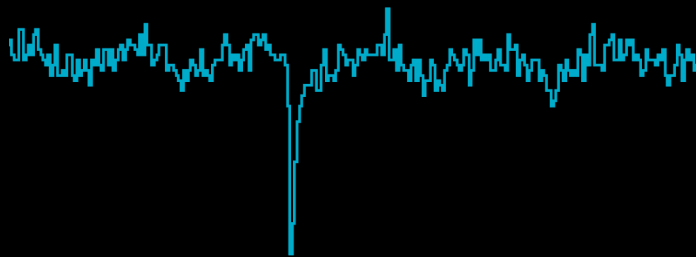
>99.7 % Hadron Reject.



50% Gamma Retention



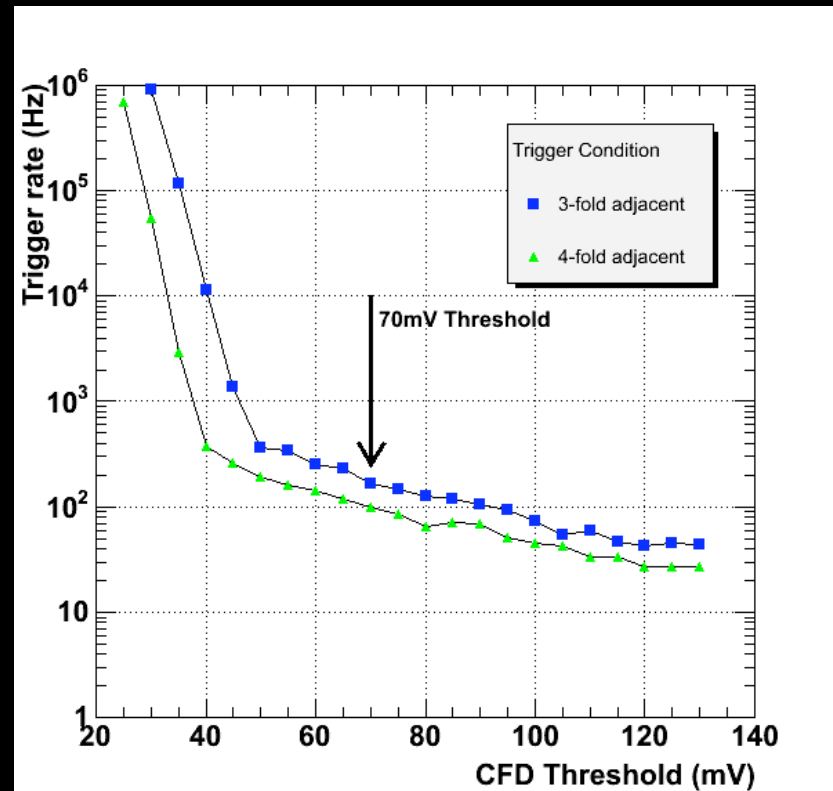
Energy Thresholds



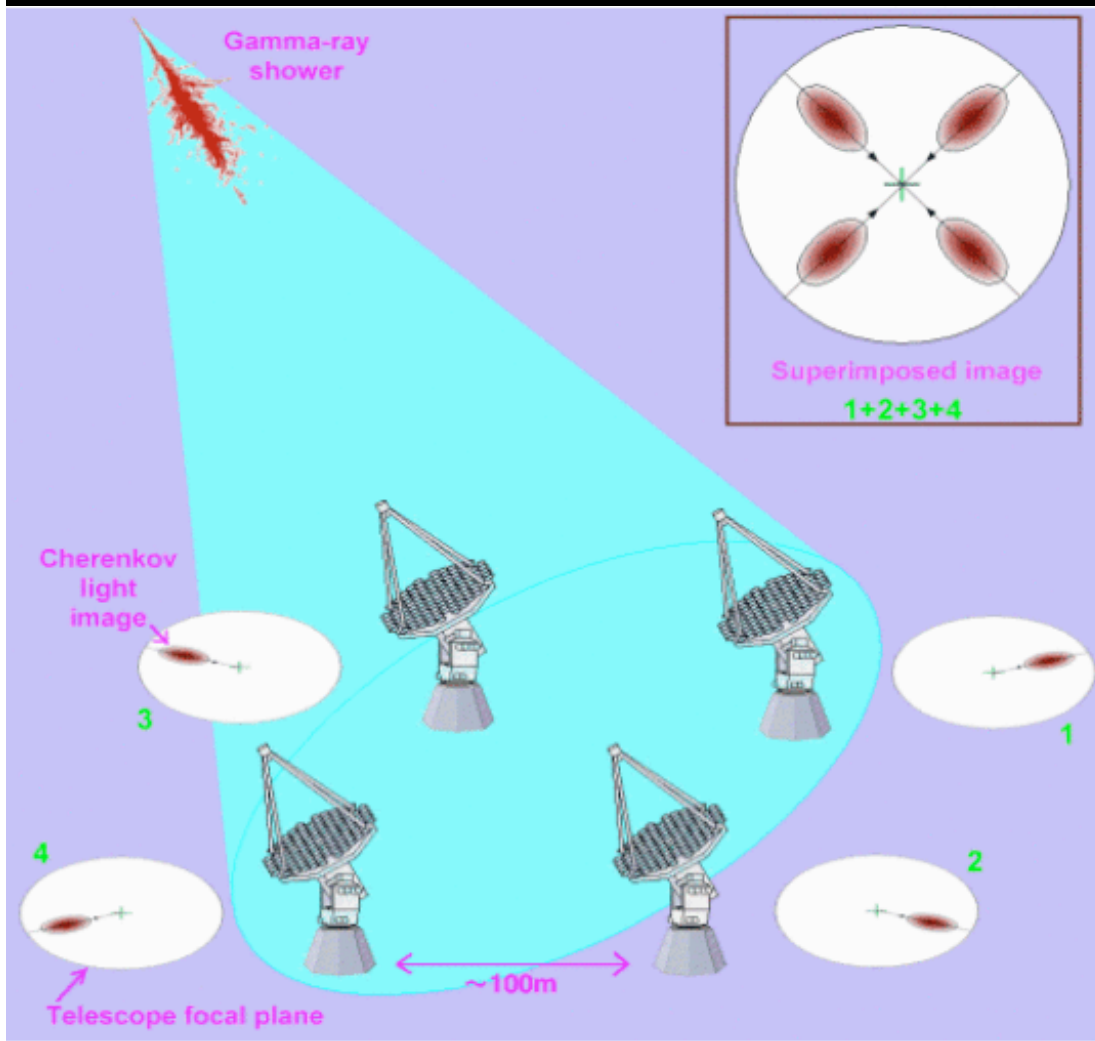
$S/B \propto \sqrt{\text{Mirror Area}}$

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

Thresholds $\sim 50\text{-}150$ GeV, for $\sim 12\text{m}$ dish and 20ns



Array Imaging



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

IACT - Imaging Air Cerenkov
Telescope

from CANGAROO [www site](http://www.cangaroo.net.au)

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

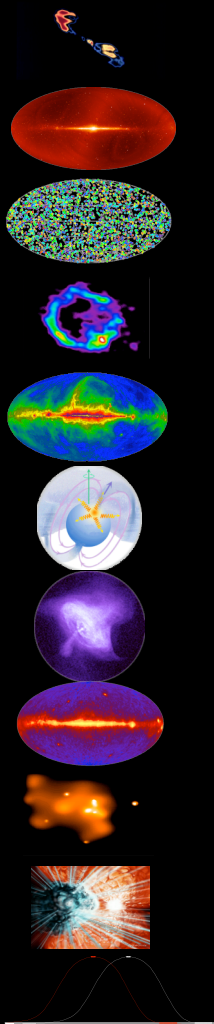
Zero

~ 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)

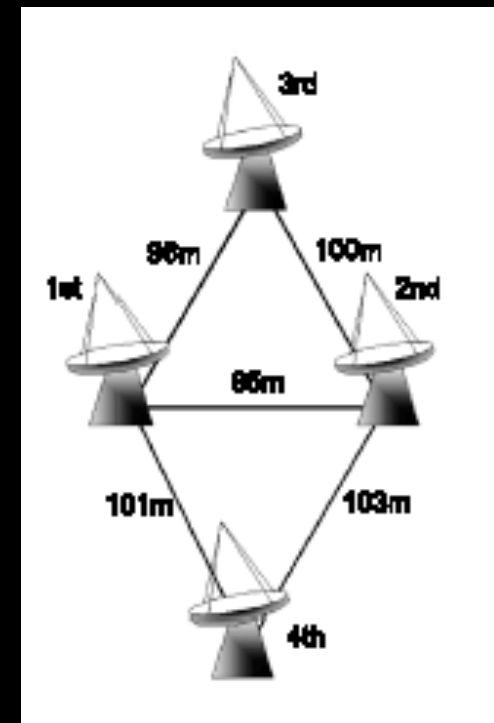
Cosmic Ray Origin

Lorentz symmetry violation

The World-Wide Network of 3rd Generation IACTs

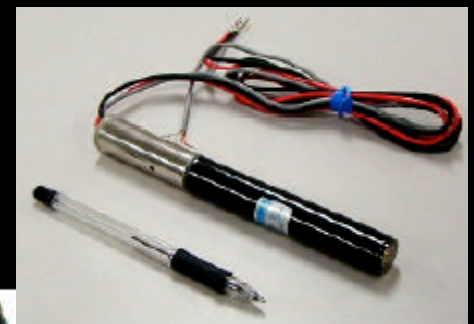
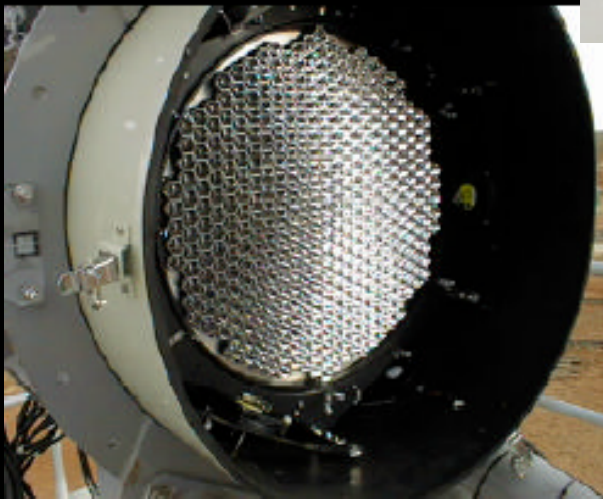
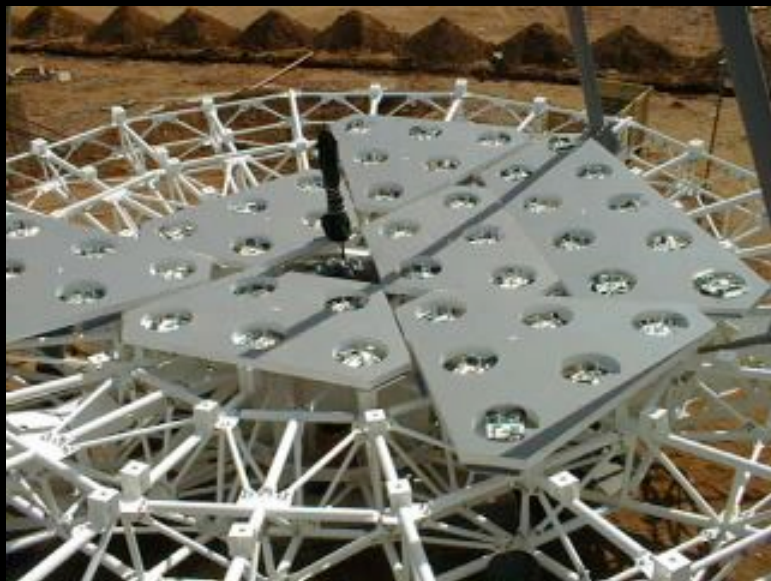


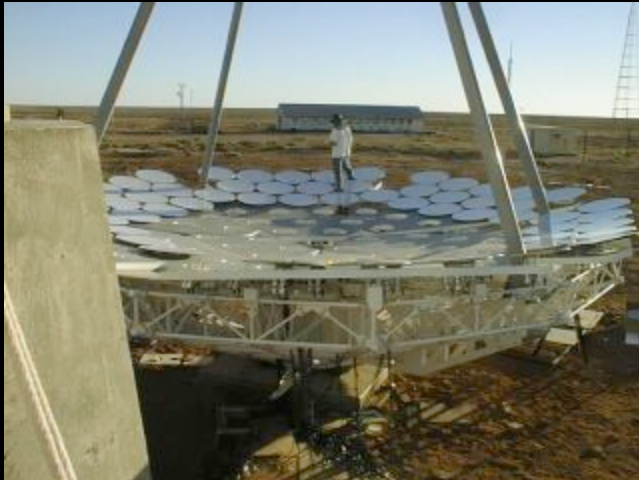
CANGAROO-III* - Japan/Australia Site: Woomera, Australia)
(for details see <http://icrhp9.icrr.u-tokyo.ac.jp/>)



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

- Telescopes 10m w/8m focal length
- Array of 4 telescopes
- 57 m² light collecting area per telescope
- New Cameras 427 3/4" PMTs, 0.17 degree pixels
- 4 degree FOV
- Electronics - TDC & gated ADC



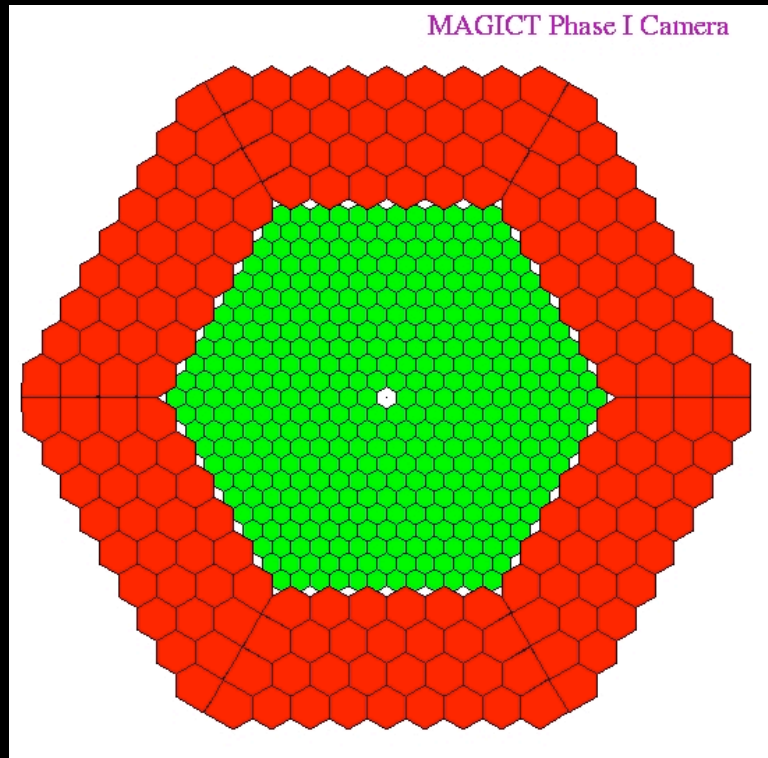


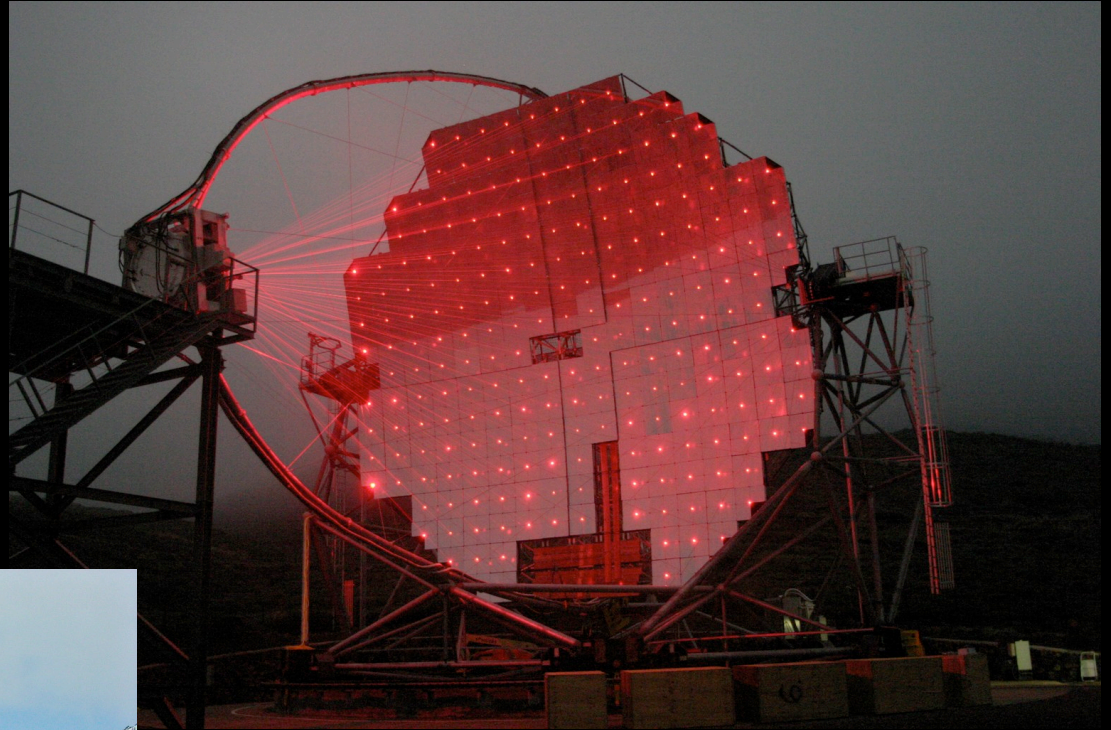
Construction of telescopes complete in March 2004

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



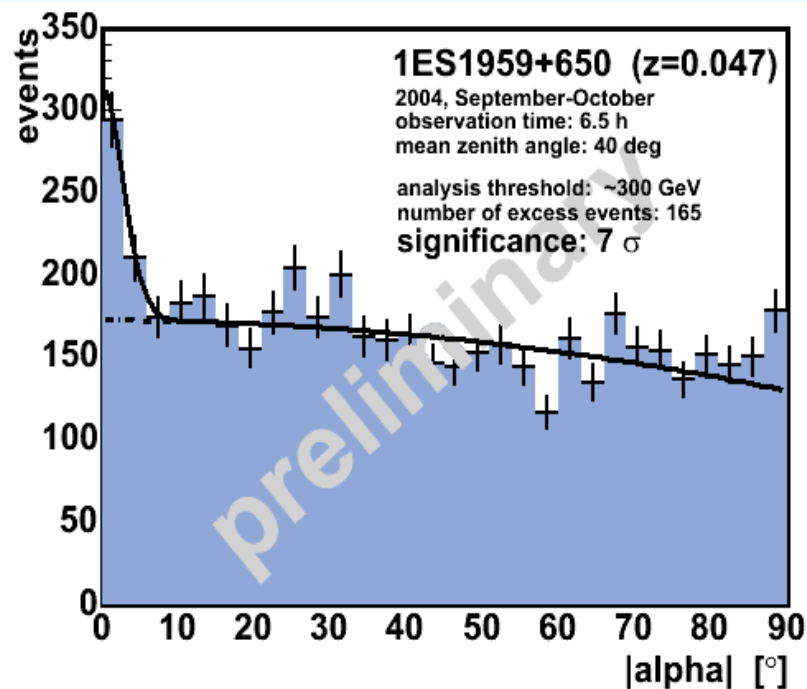
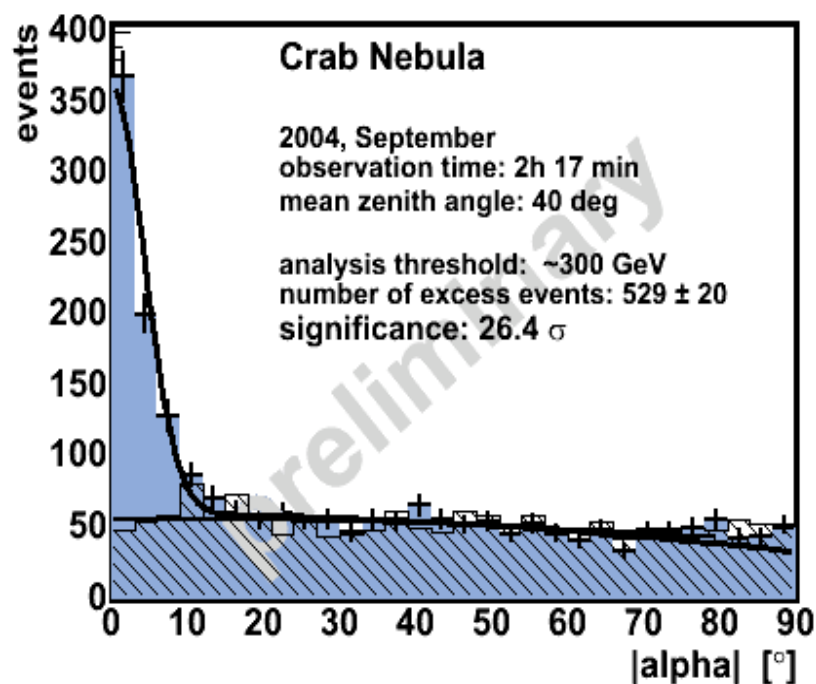
- Telescope 17m $f \sim 1$
- 239 m² light collecting area
- Cameras 396 1" PMTs, 0.08 degree pixels + 180 1.5", 0.13 degree
- 3.5 degree FOV
- Electronics - 300MHz FADC $\rightarrow$ 1GHz FADC
- 20 second slew capacity (40tons!) for GRB
- MAGIC II being planned





TeV particle-astro FNAL 2005

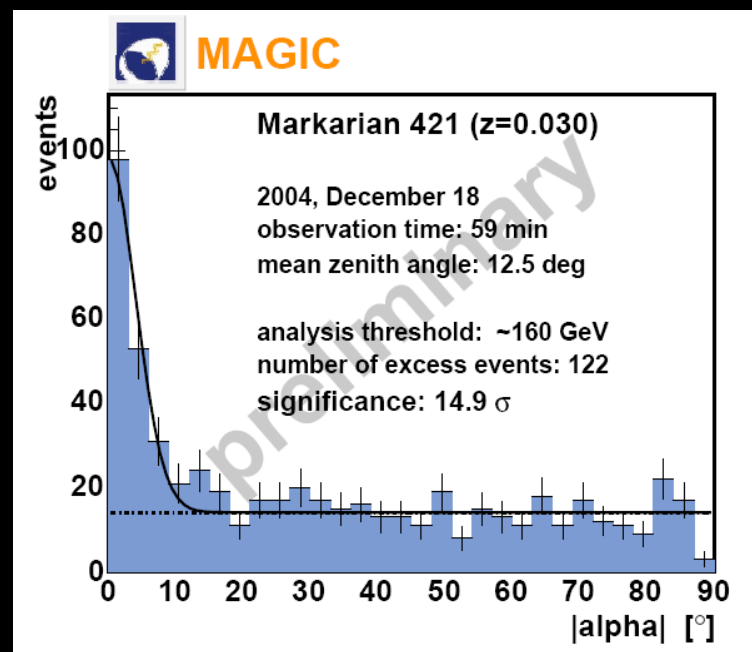
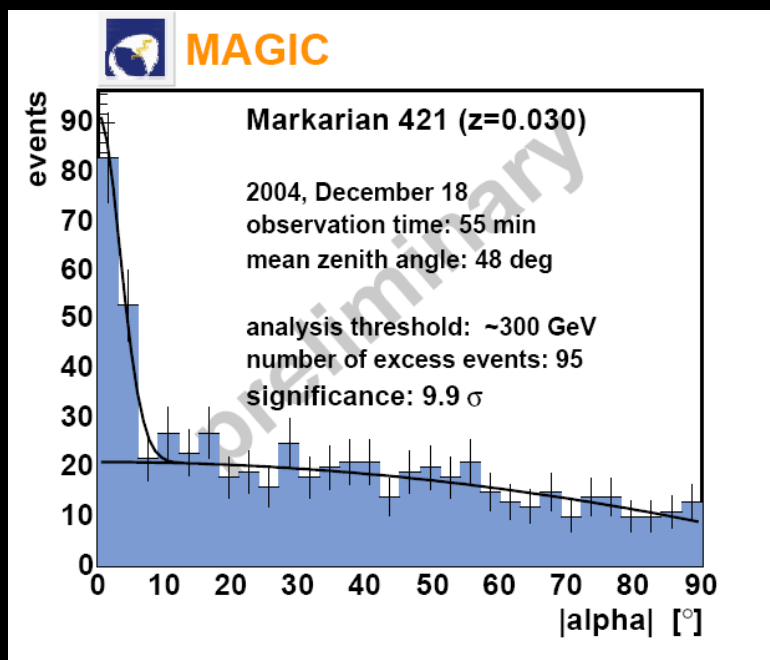
Some preliminary results from MAGIC - La Thuile, 2005



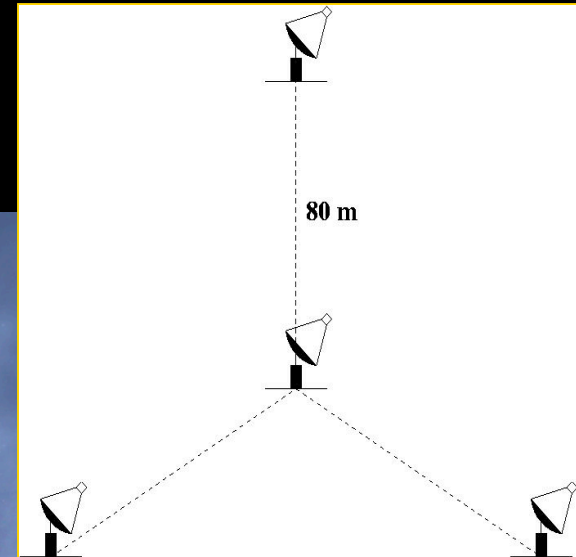
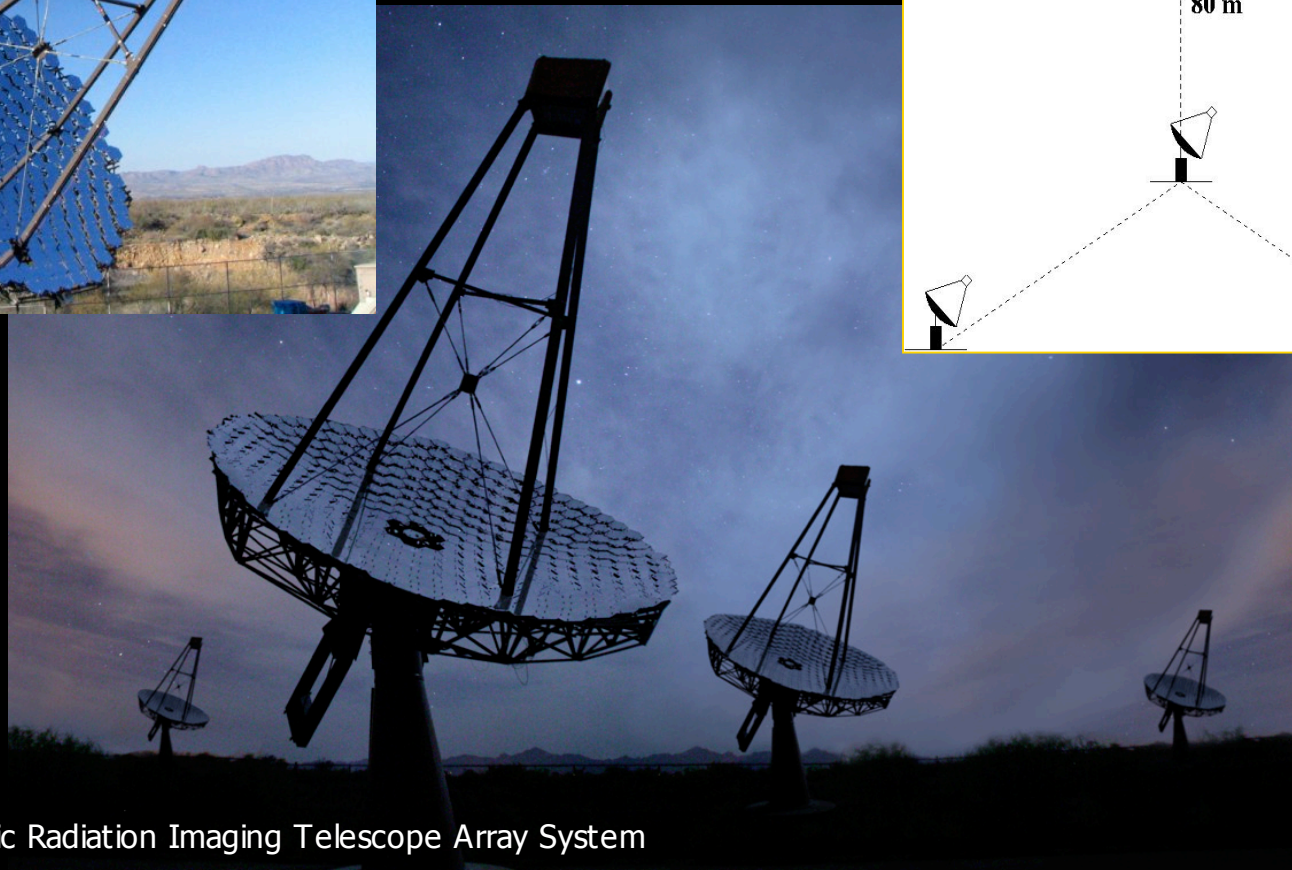
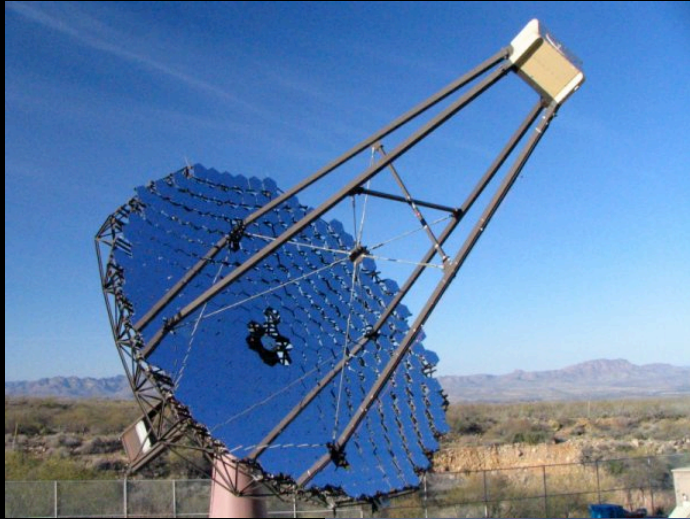
Crab Nebula: Size >2000 ph
Significance: 26.4σ Excess events: 529 ± 20

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

Markarian 421



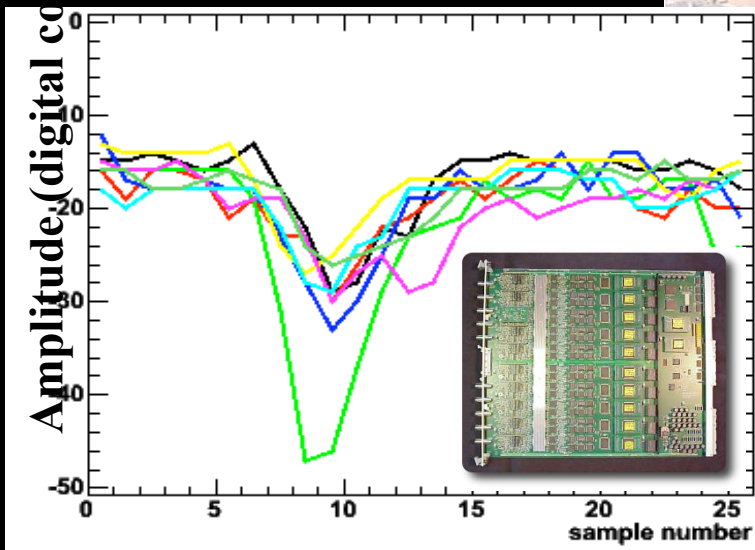
VERITAS* - USA/Canada/UK/Ireland - Site: Arizona
(see <http://veritas.sao.arizona.edu/>)



* Very Energetic Radiation Imaging Telescope Array System

TeV particle-astro FNAL 2005

- Telescope, 12m diameter f1
- 4 telescope array, 80m spacing
- 110 m² light collecting area
- Cameras 499 3/4" PMTs, 0.15 degree pixels
- 3.5 degree FOV
- Electronics - 500MHz FADC
- Array level trigger





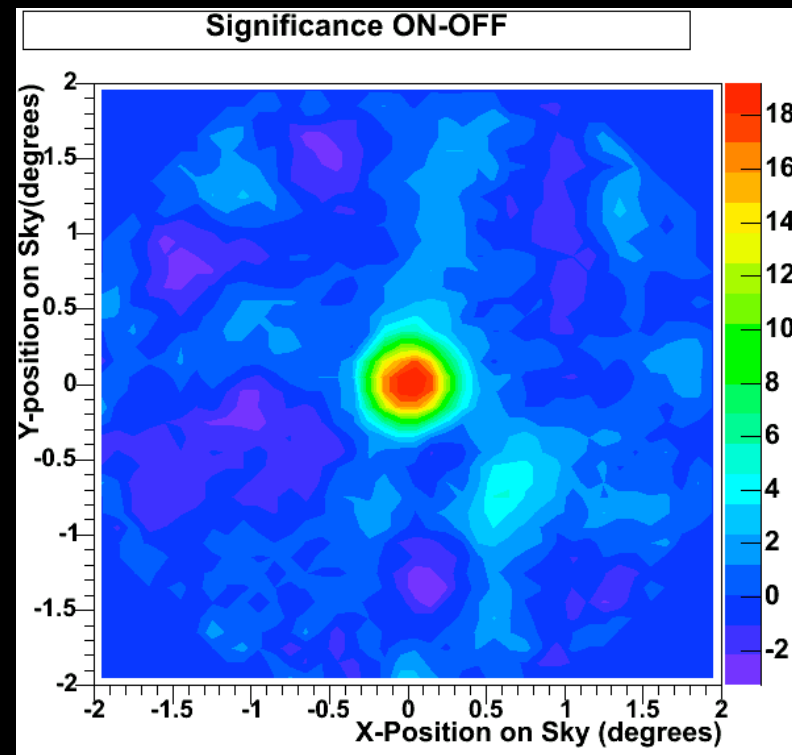
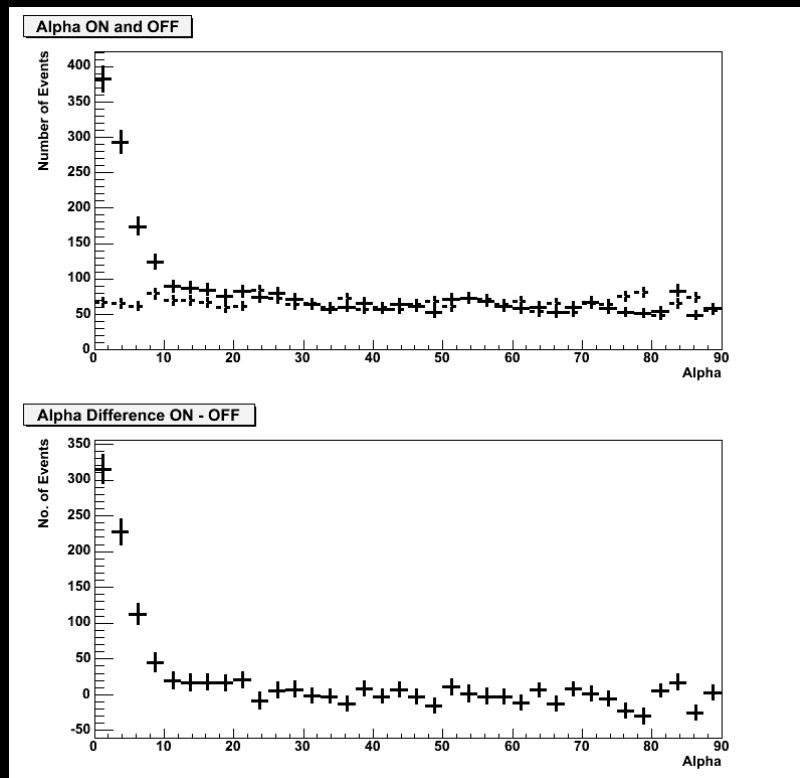
TeV particle-astro FNAL 2005

Crab Nebula

4.37 hours ON; +21.1 sigma

2.56 gammas/minute

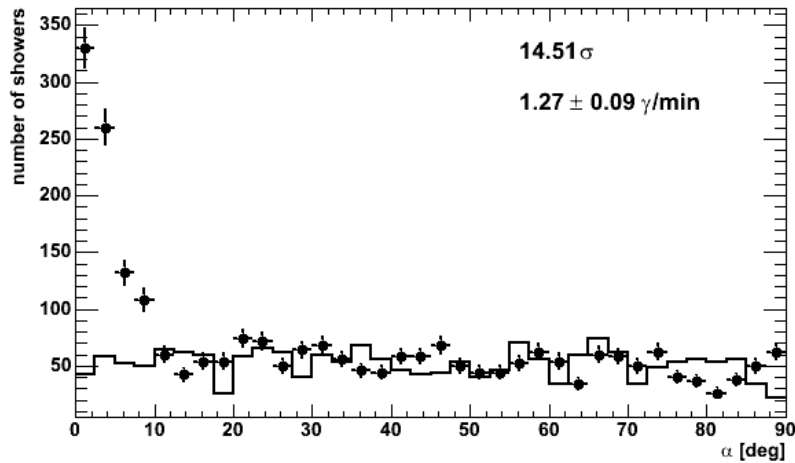
10.1 sigma/sqrt(time in hours)



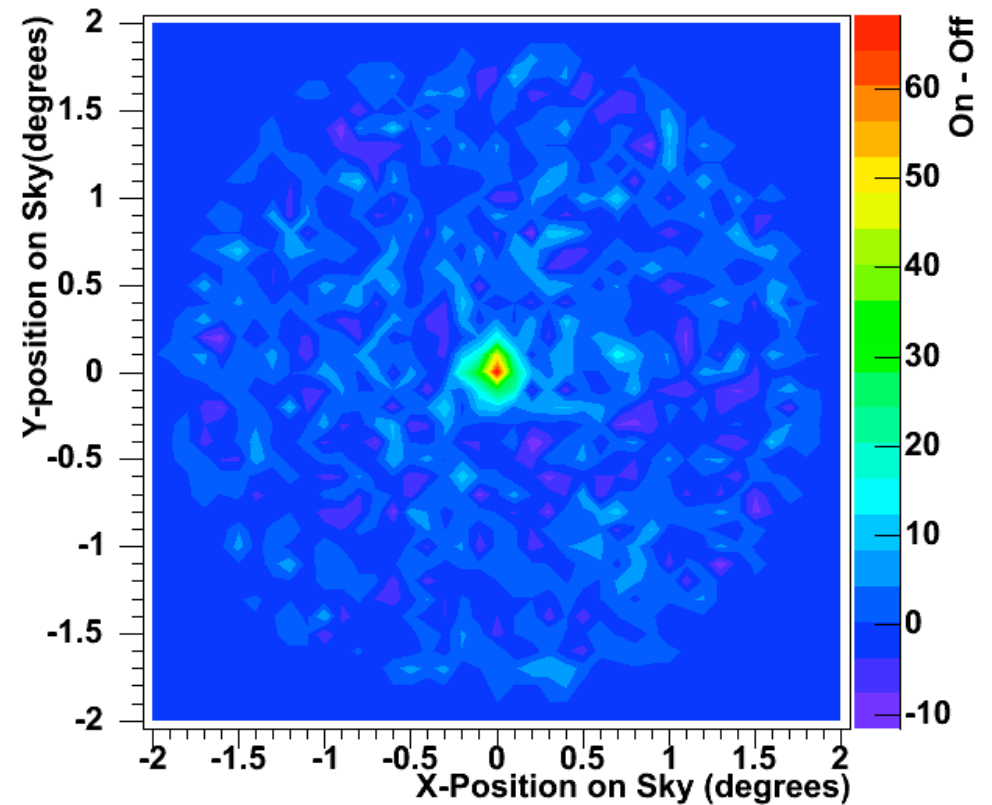
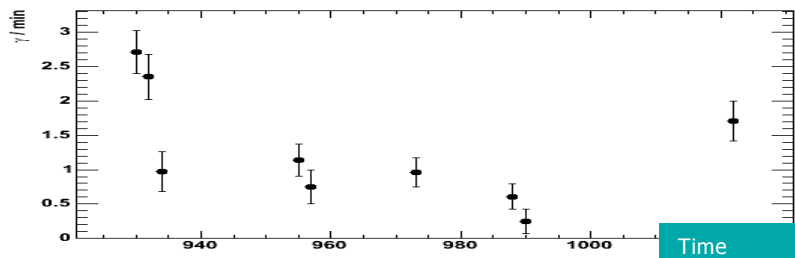
Markarian 421

5.6 hours ON

+14.51 sigma



Light Curve



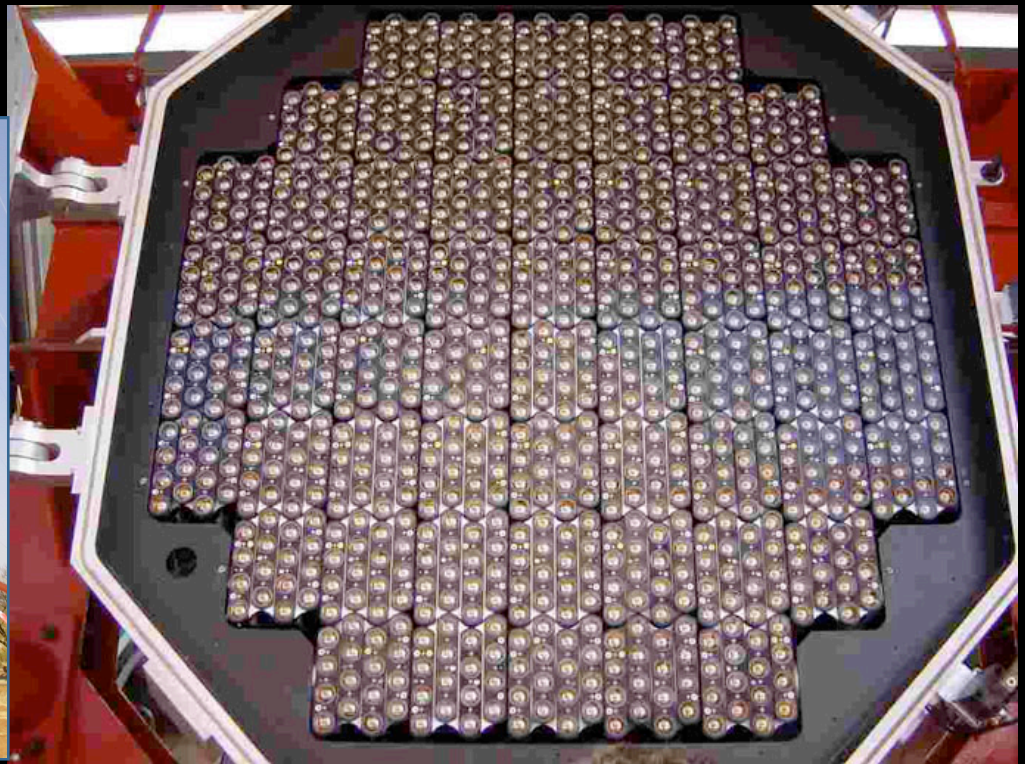
HESS* - Germany/France/+others - Site: Namibia

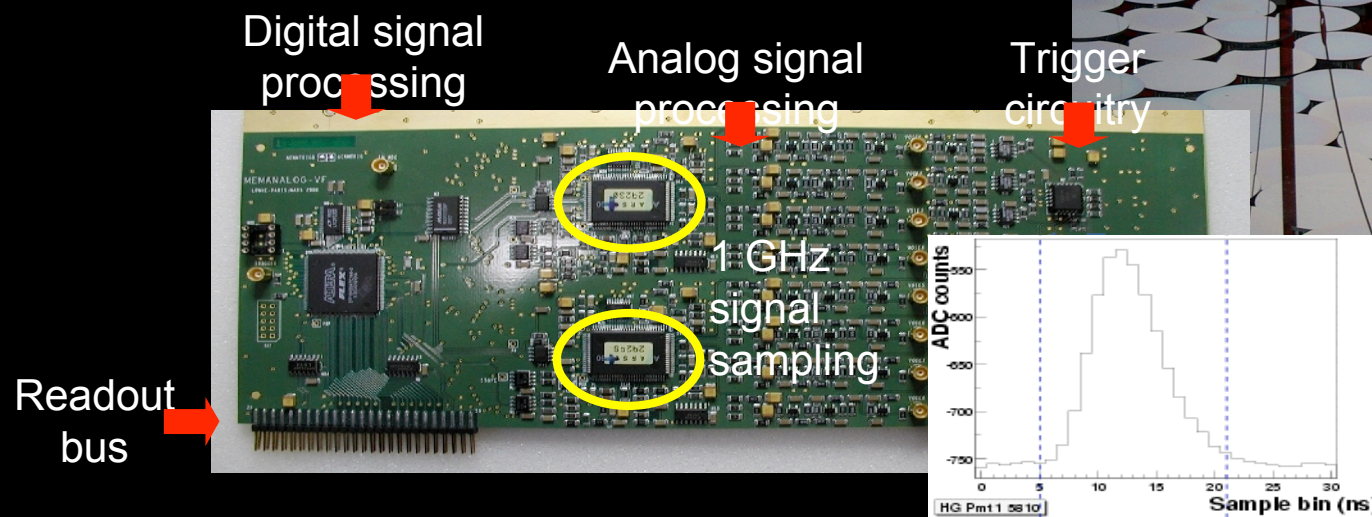
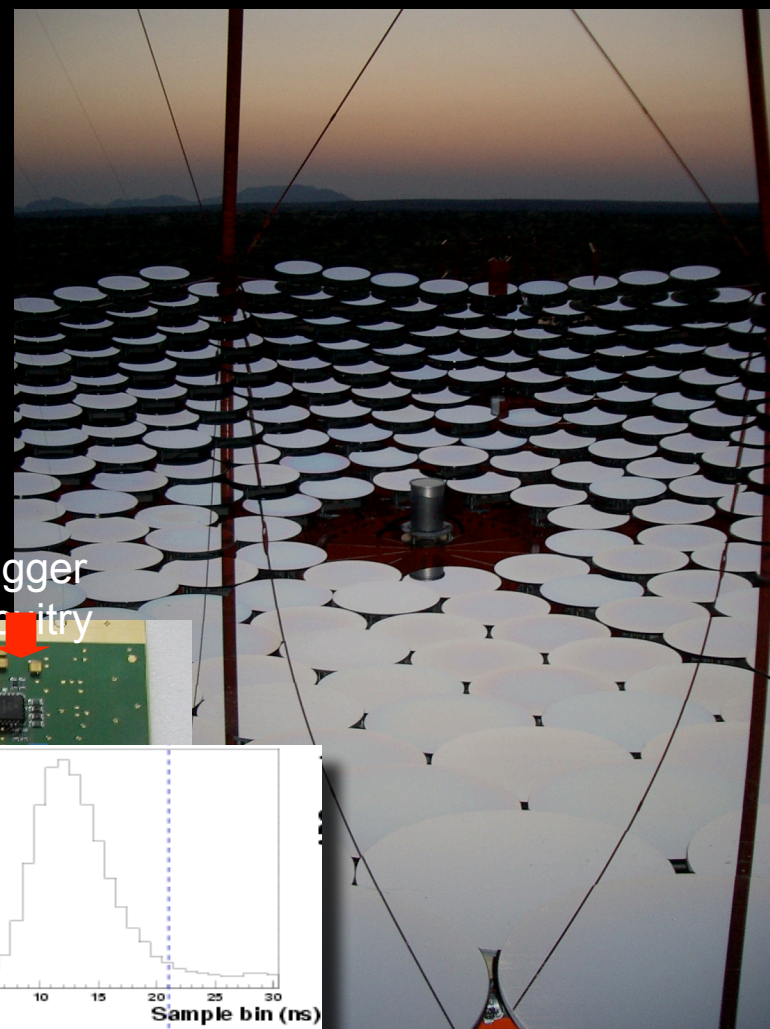
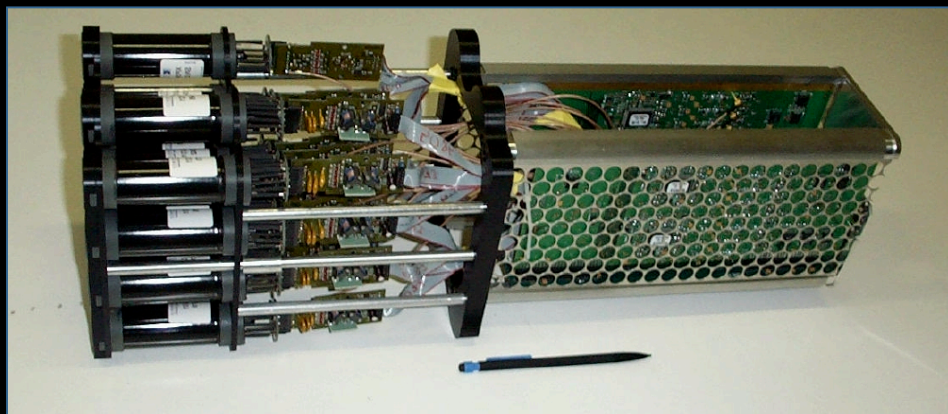
(see <http://www.mpi-hd.mpg.de/hfm/HESS/>)



* High Energy Stereoscopic System

- Telescope, focal length 15m
- 4 telescope square array, 120m spacing
- 107 m² light collecting area
- Cameras 960 1" PMTs, 0.16 degree pixels
- 5 degree FOV
- Electronics - ARS Chip
- Larger (~30m) central telescope planned





HESS - SNR RXJ1713

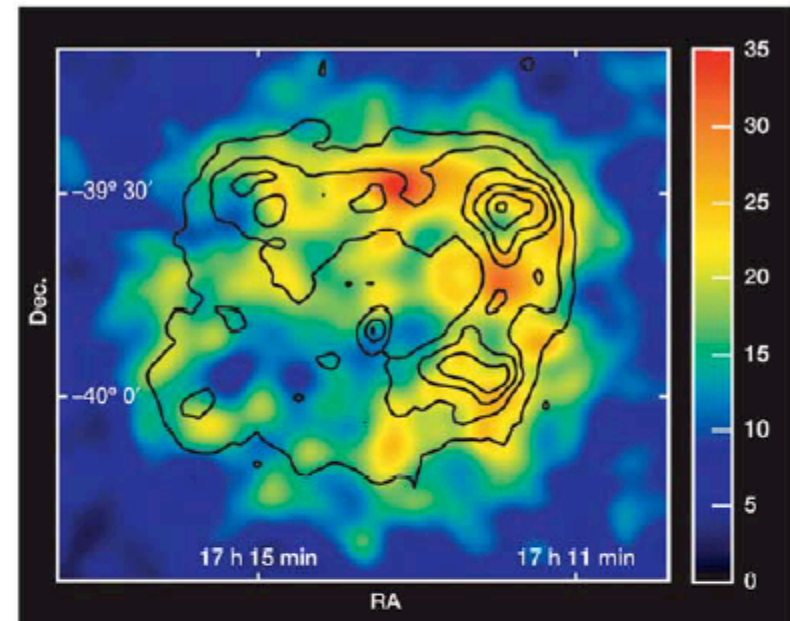
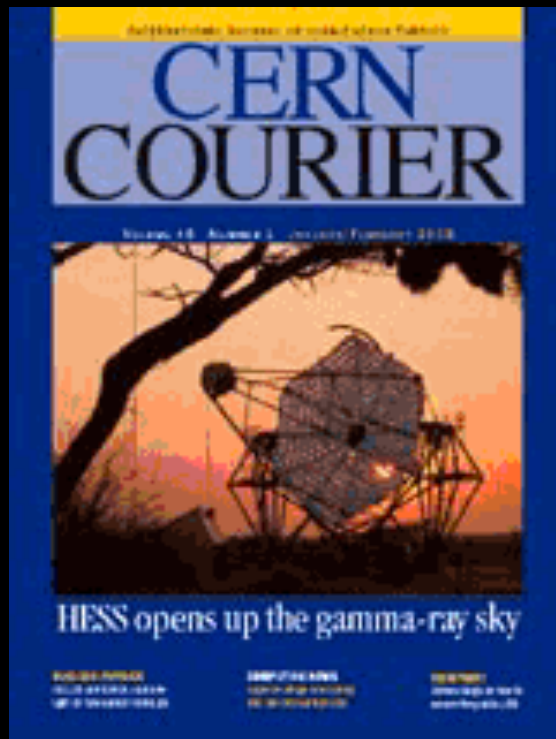
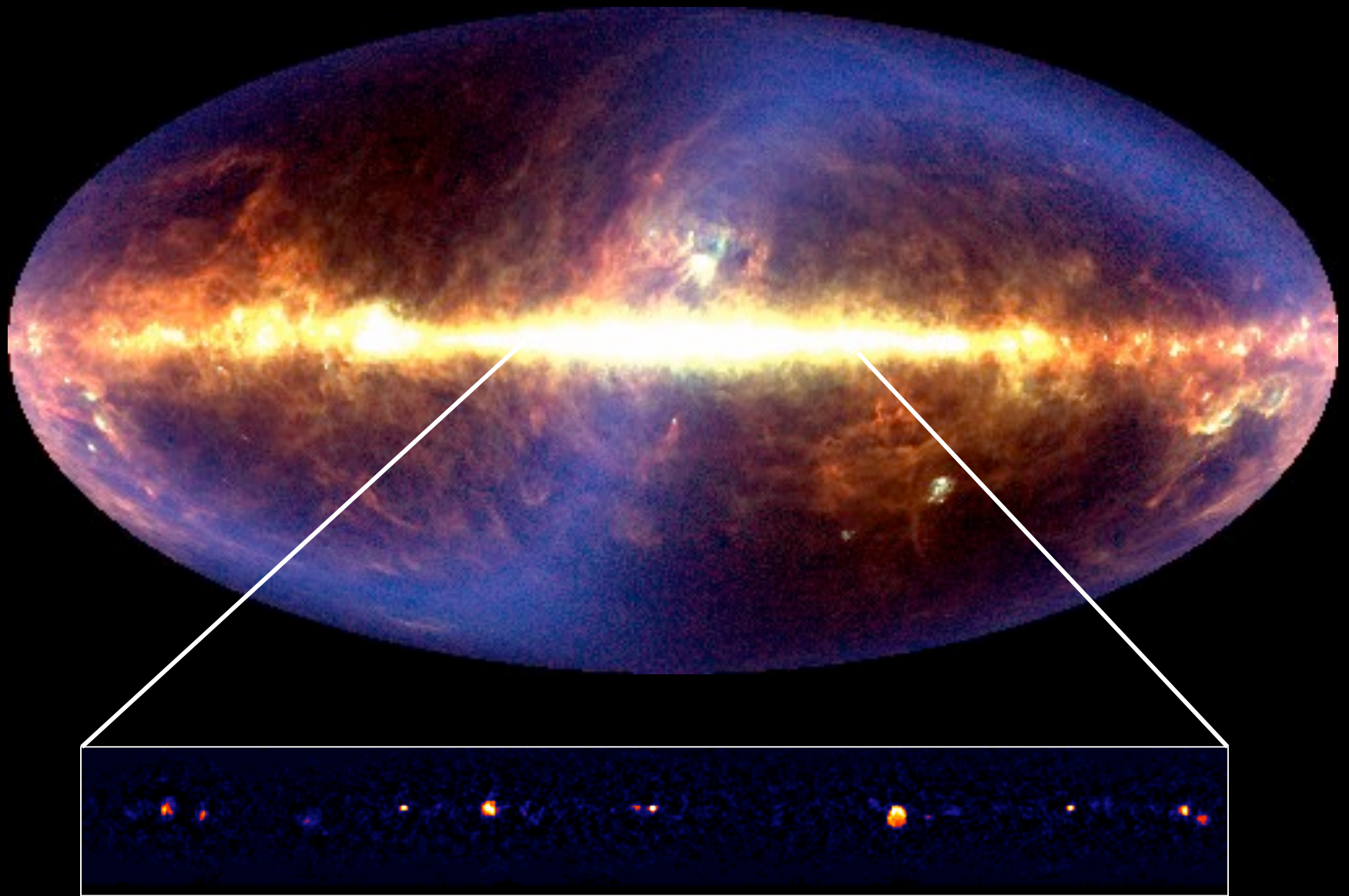


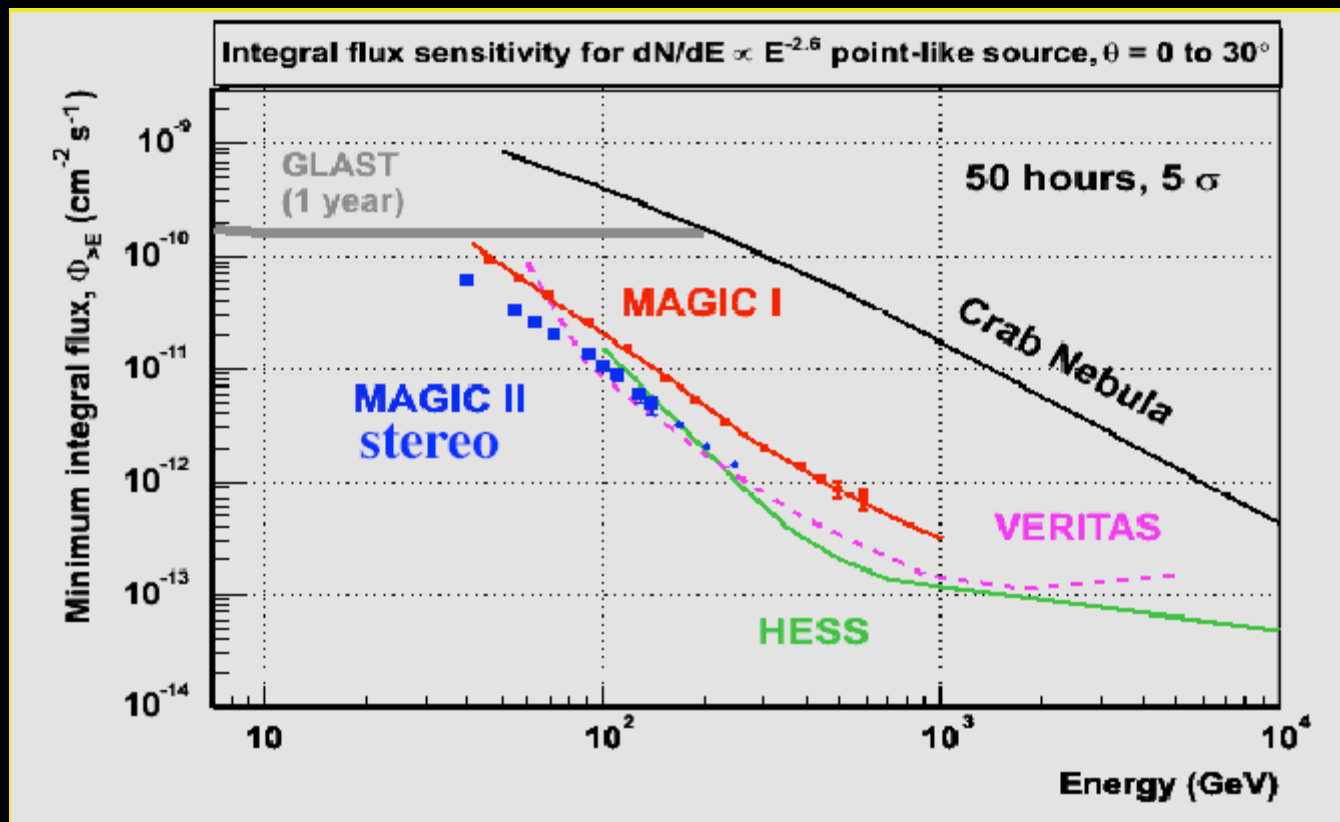
Figure 2 γ -ray image of the SNR RX J1713.7 – 3946 obtained with the HESS telescopes. Hard cuts were applied to select well-reconstructed γ -like events above 800 GeV. The map is smoothed as in Fig. 1, having the same scale in units of counts. The linear colour scale is in units of counts. We note that 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 comparison²⁵. 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.

Publishing Group

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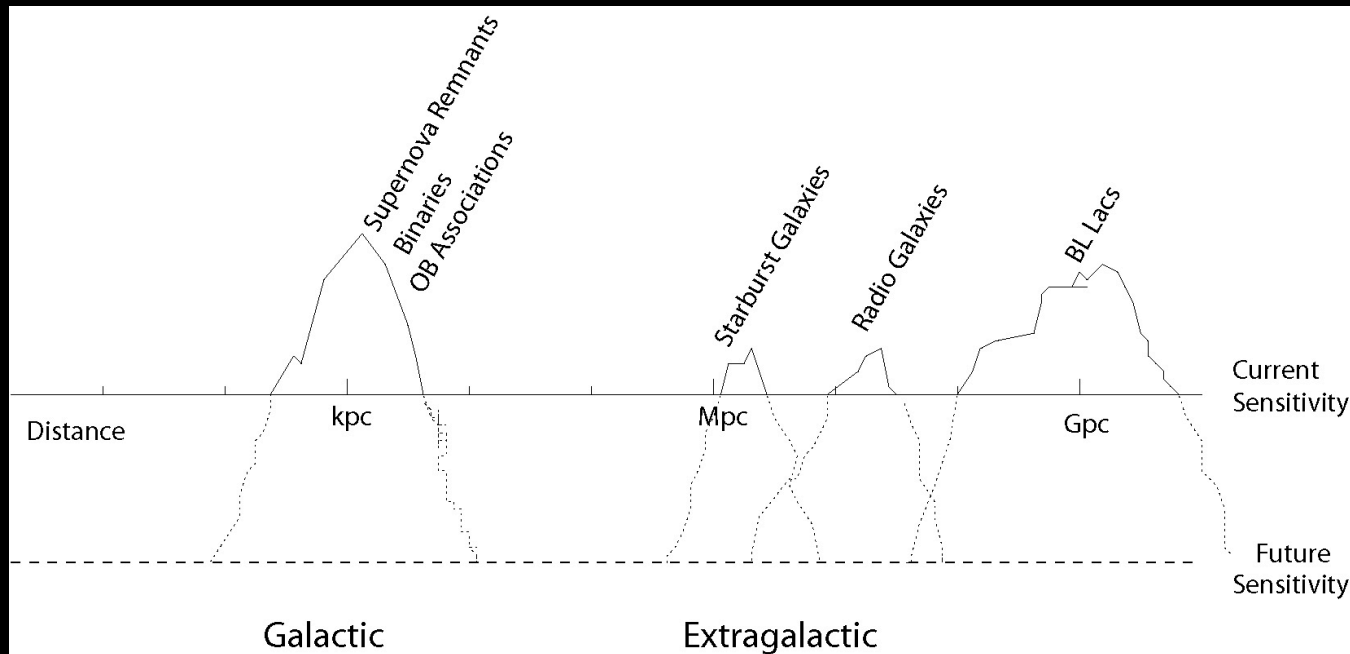


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(from MAGIC)

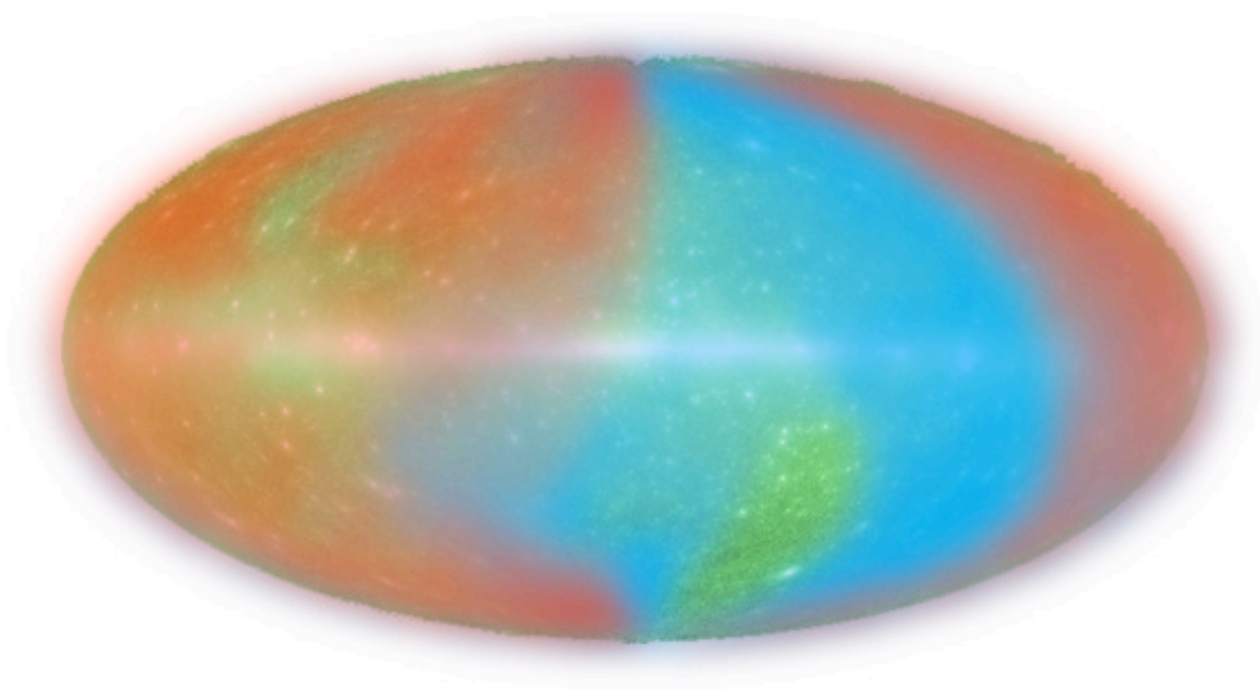
At VERITAS symposium at Adler 2003 T. Weekes ~12 sources, 50/50 galactic/extragalactic, and.....



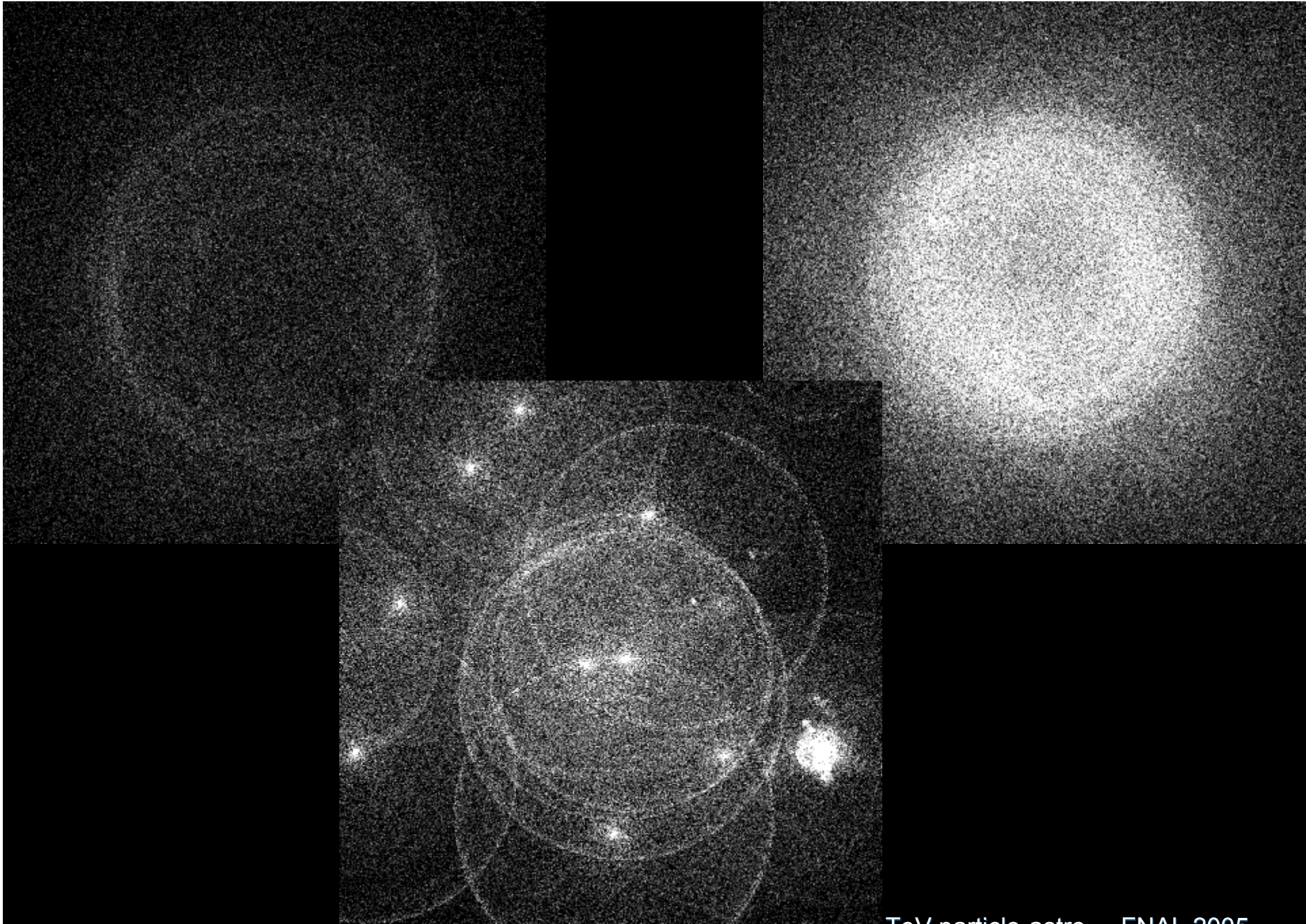
- CANGAROO - operational 2006
- MAGIC - operational 2004
- VERITAS - operational 2006
- HESS - operational 2004 -> many new sources, IMAGES!

The World-Wide Network of 3rd Generation IACTs





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



TeV particle-astro FNAL 2005