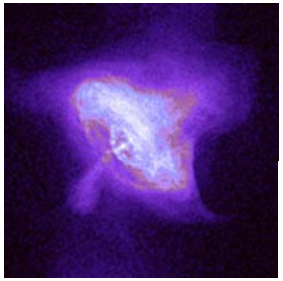
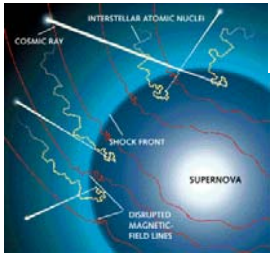
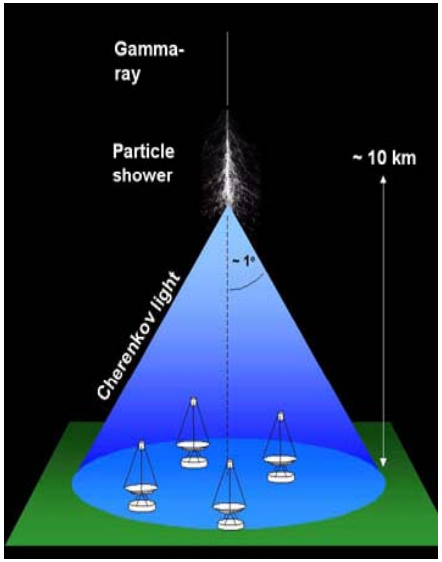
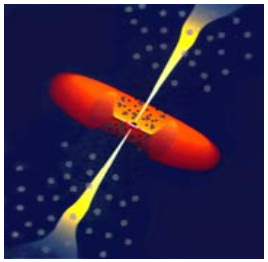
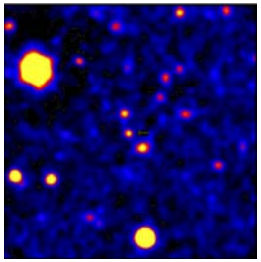
VHE Astrophysics with VERITAS











Outline

Scientific Motivation

- A "New Astronomy"
- Physicist's Viewpoint
  - ➔ *Astrophysical TeV accelerators*
  - ➔ *Origin of Cosmic Rays*
  - ➔ *Probes of new physics, cosmology*

Experimental Technique

The VERITAS project

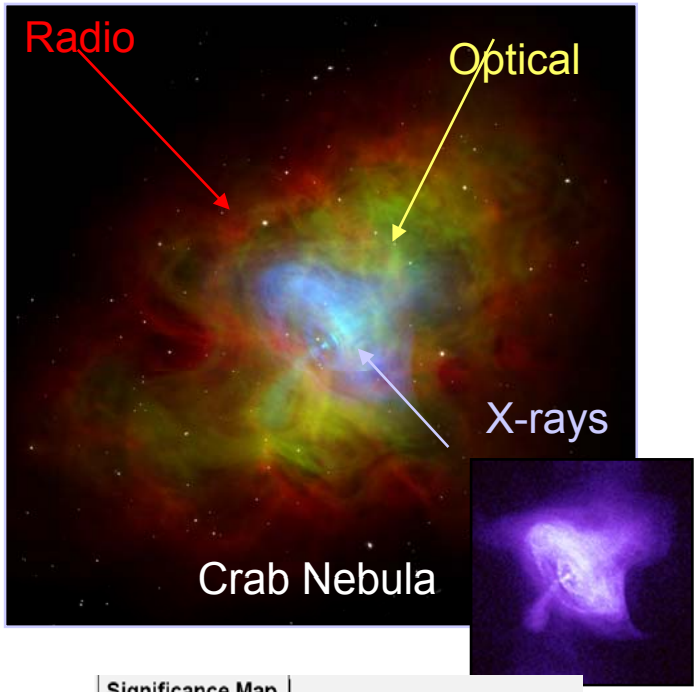
- Description, operation, & performance
- Results from first year of operation
- Science program 2008-2012

Future Prospects

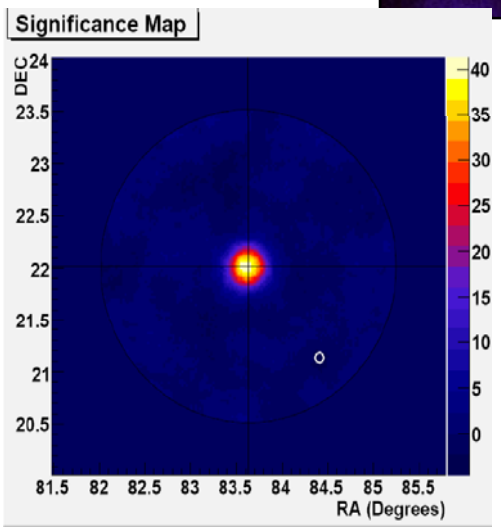
- GLAST & AGIS

A New Astronomy

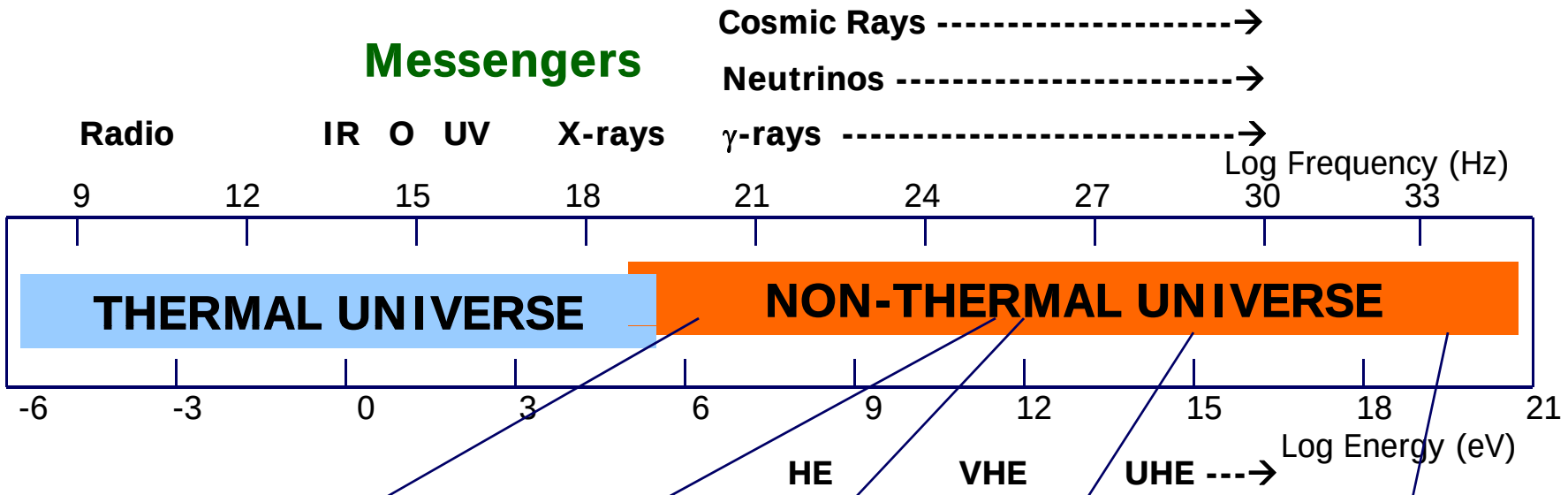
- Before 1940's – Astronomy only used visible light.
- New wavebands (radio, IR, X-ray, γ-ray) change our picture of the universe
  - Different spatial scales
  - Different time scales
  - Different emission processes
  - New physics
- Other messengers (cosmic rays, neutrinos, grav. waves)

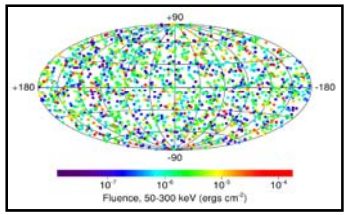


TeV γ-rays

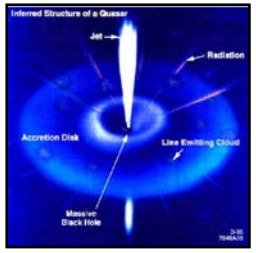


New Windows & New Messengers

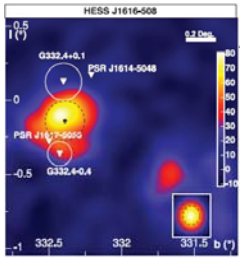




Gamma-Ray Bursts (GRBs)

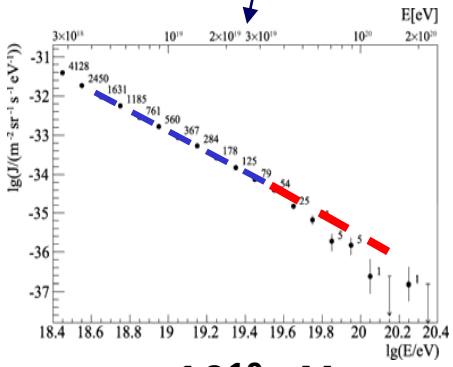


Active Galactic Nuclei (AGN)



"Dark" TeV Accelerators

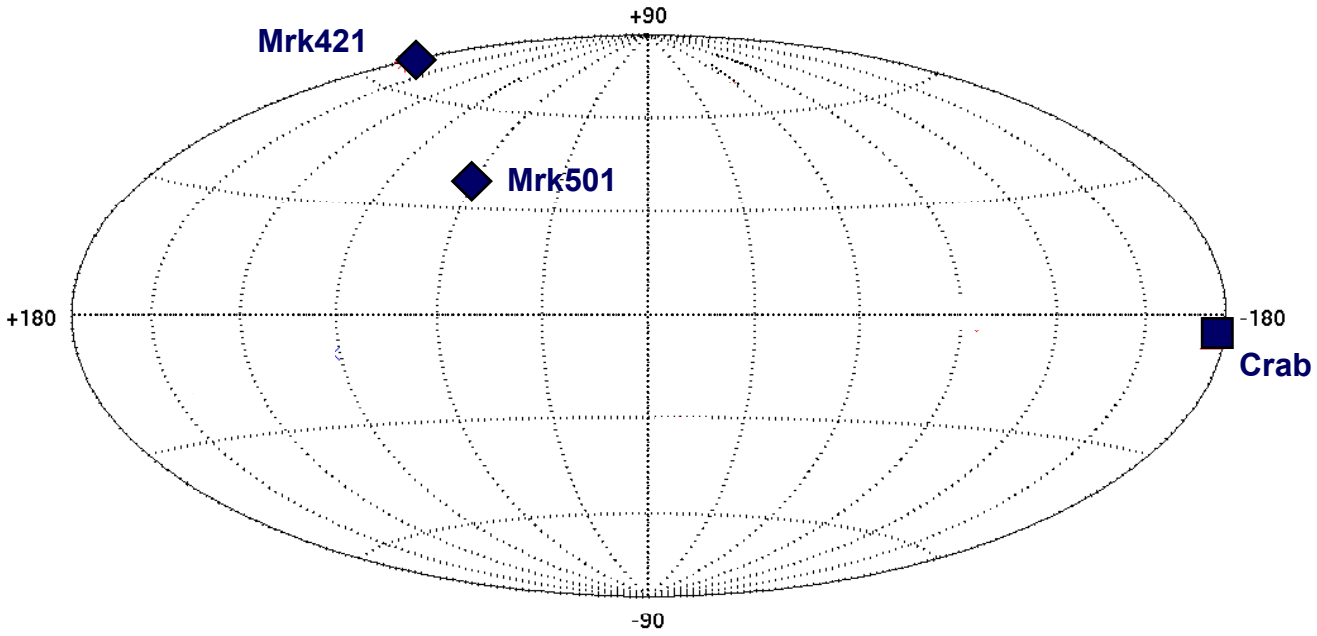
PeV ν's



$>10^{19}$ eV Particles

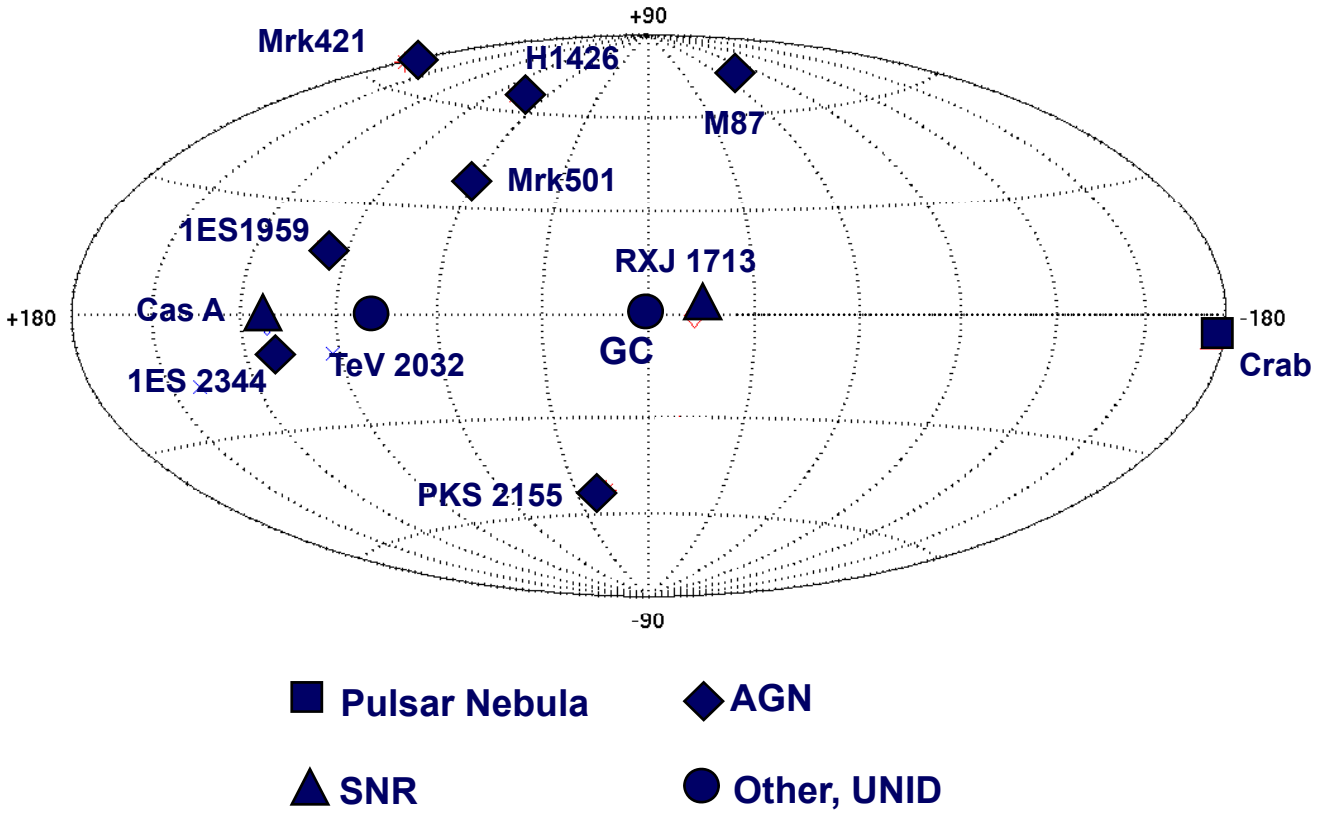
The TeV γ-ray Sky - 1995

3 sources



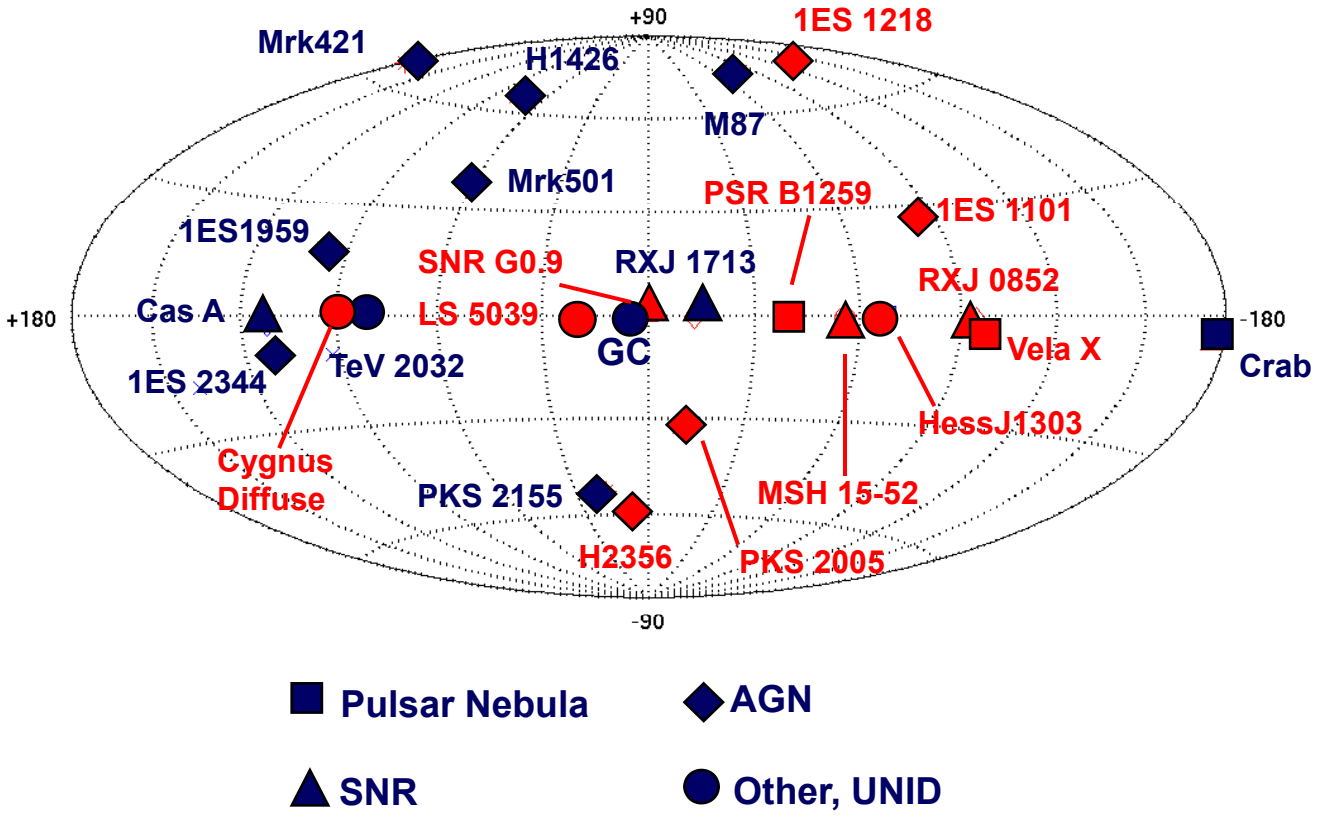
The TeV γ-ray Sky - 2003

12 sources



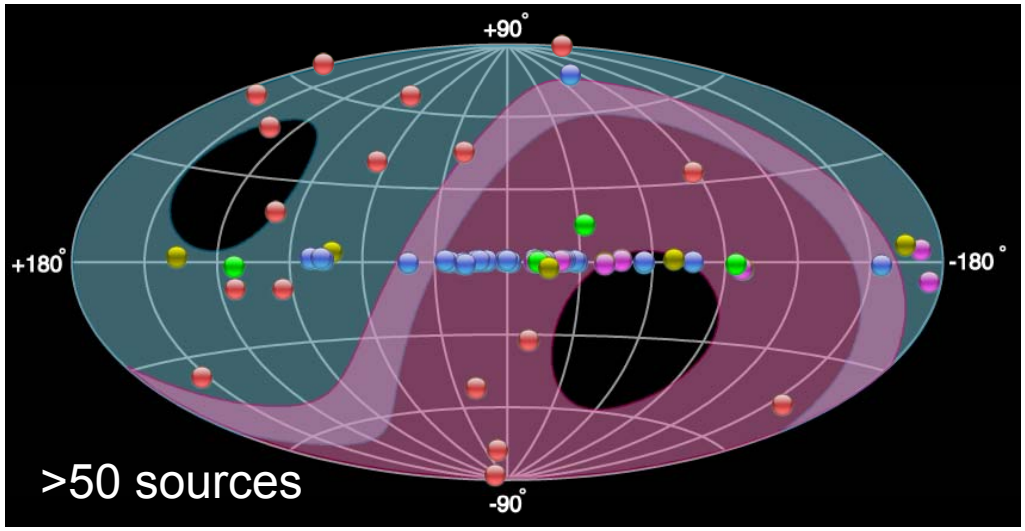
The TeV γ-ray Sky - 2006

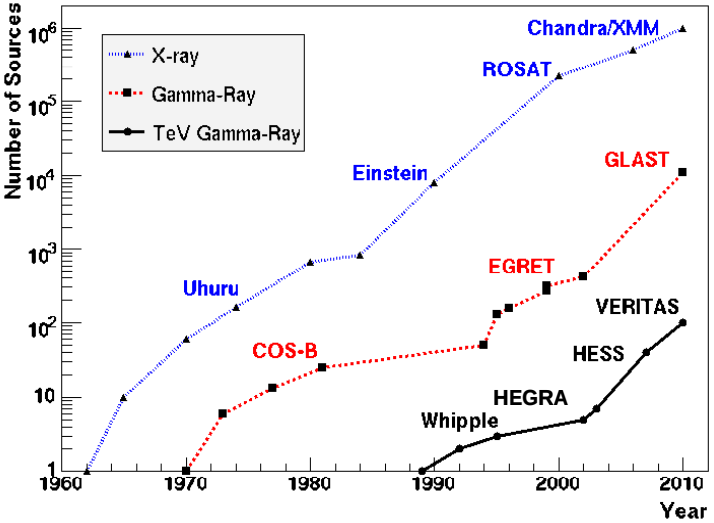
30+ sources



The TeV γ-ray Sky - 2008

http://tevcat.uchicago.edu/





AGN
Shell Type Supernova
Pulsar Wind Nebula
Radio Galaxy
X-ray Binary
UNID

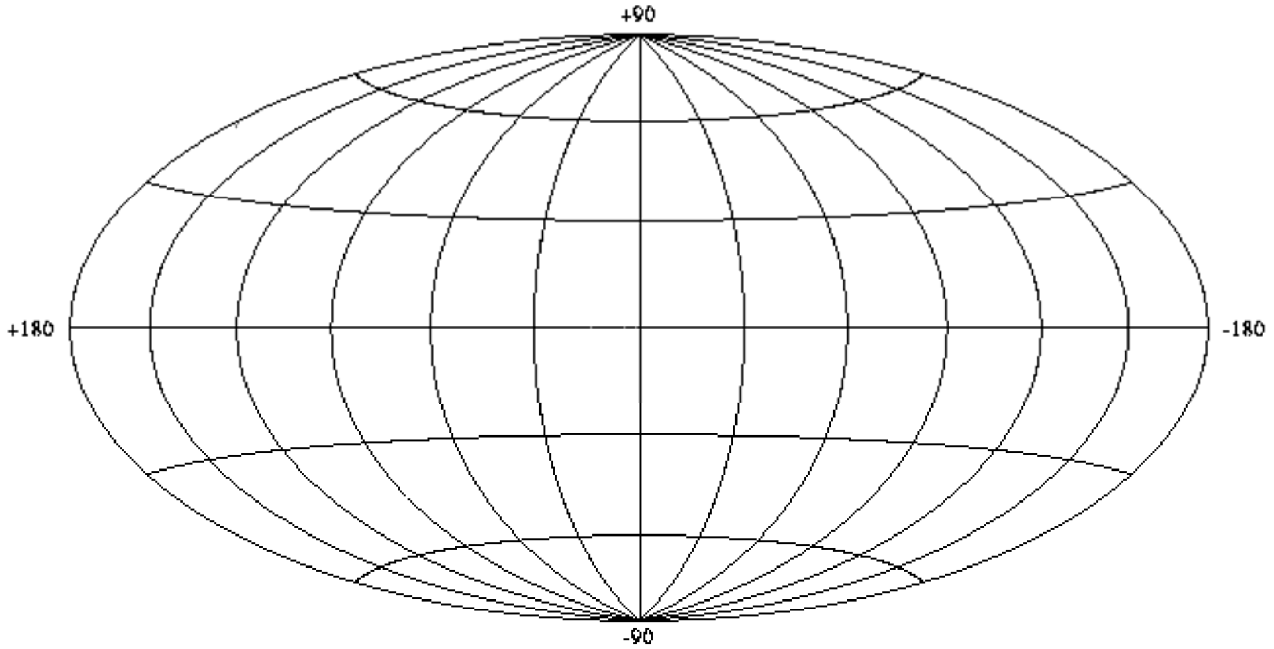
- Explosion in number of sources.
- Discovery of numerous source classes.

Almost all discoveries made by Atmospheric Cherenkov Telescopes

Whipple detected first sources: Crab, AGN

2008: New Cherenkov arrays have now seen ~50 sources, mostly Galactic.

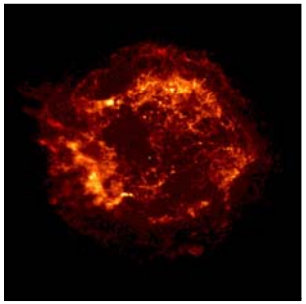
High-Energy Neutrino Sky



No sources yet.

A Wide Variety of Sources …

Supernova Remnants

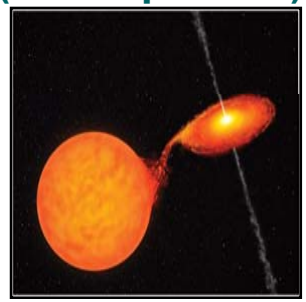


Shocks

Pulsars/PWN

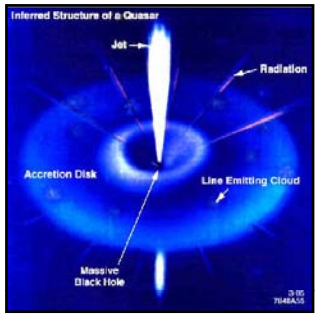
NS dynamo
Winds

HMXBs (microquasars)



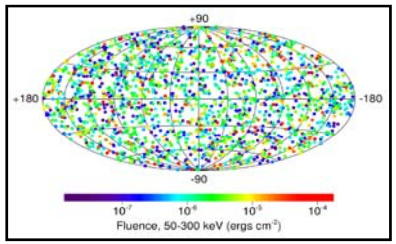
Accretion-powered jets, colliding winds, or …?

Active Galactic Nuclei



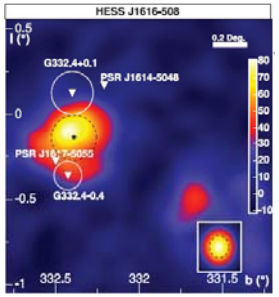
Jets

Gamma-Ray Bursts



Massive star collapse
Int./ext. shocks

Dark accelerators…

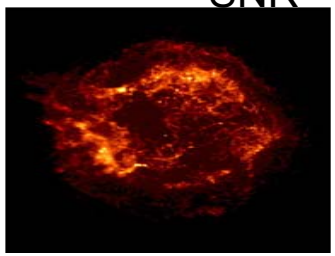


???

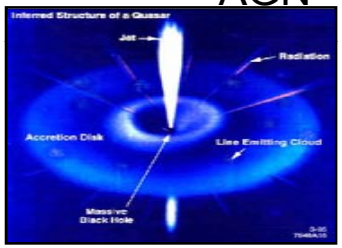
... and accelerators

Putting the zoo to work

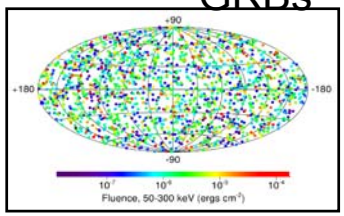
SNR

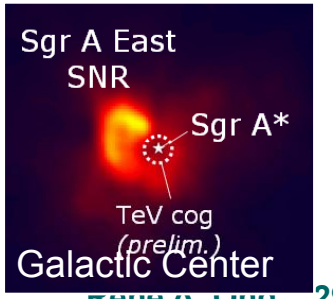


AGN

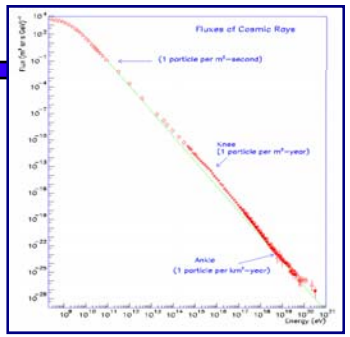


GRBs



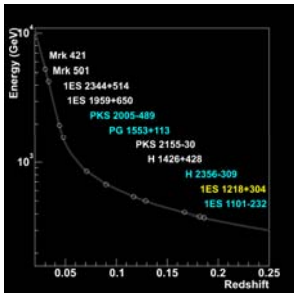


Origin of cosmic rays

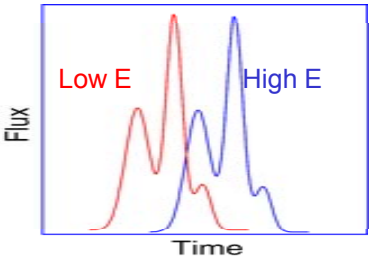


?

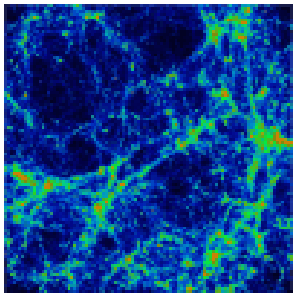
Cosmological γ-ray horizon



Tests of Lorentz invariance



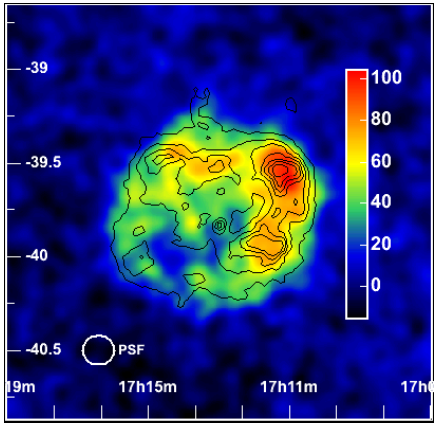
Cold dark matter (WIMP) searches



Origin of Cosmic Rays = SNRs ?

Why (VHE) gamma-rays?

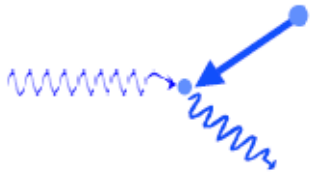
- Unlike cosmic rays, not deflected by interstellar magnetic fields.
- *Tracers* of parent particle populations.



SNR RXJ 1713-3946

Accelerated electrons → VHE γ-rays

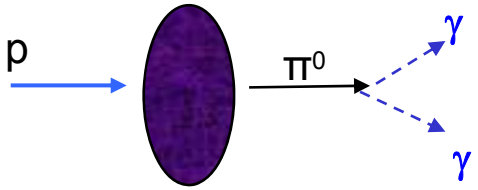
Up-scattering of soft photons



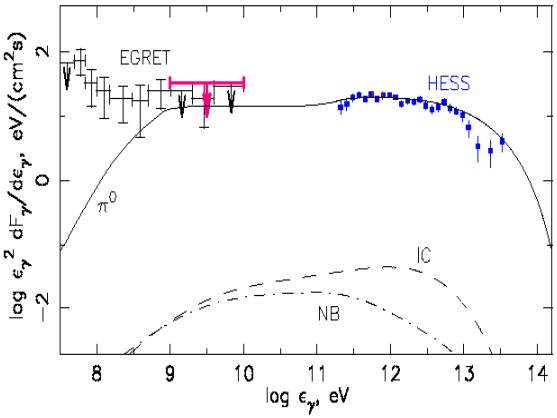
Inverse Compton Scattering

Accelerated protons → VHE γ-rays

Target interaction, π^0 decay



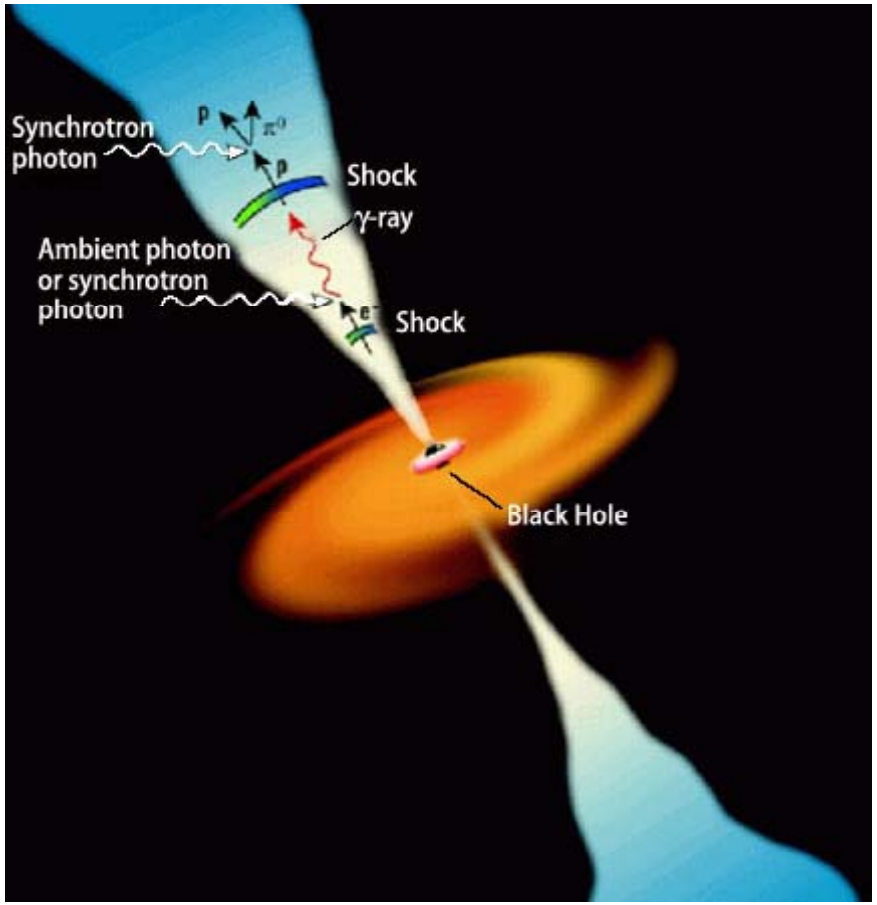
Target material



Spectral Energy Distribution

Evidence for SNR acceleration of CRs, but case is far from settled.

AGN



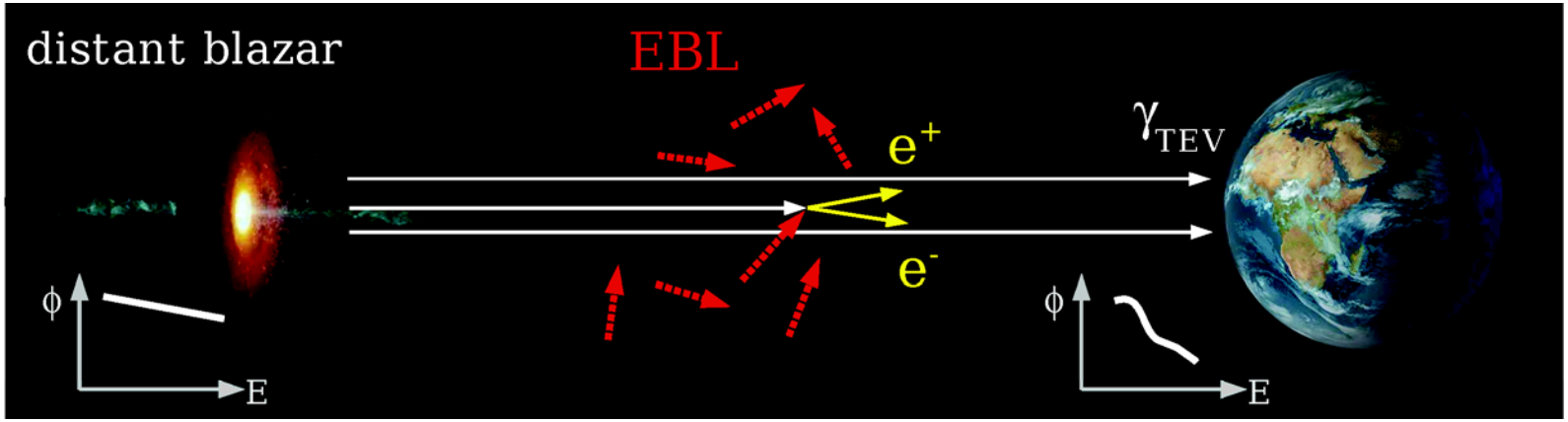
Active Galactic Nuclei

- High-luminosity extragalactic objects
  - ➔ Probe properties of the universe at large distances
- Variable

So far, AGN observed in VHE γ-rays are mostly:

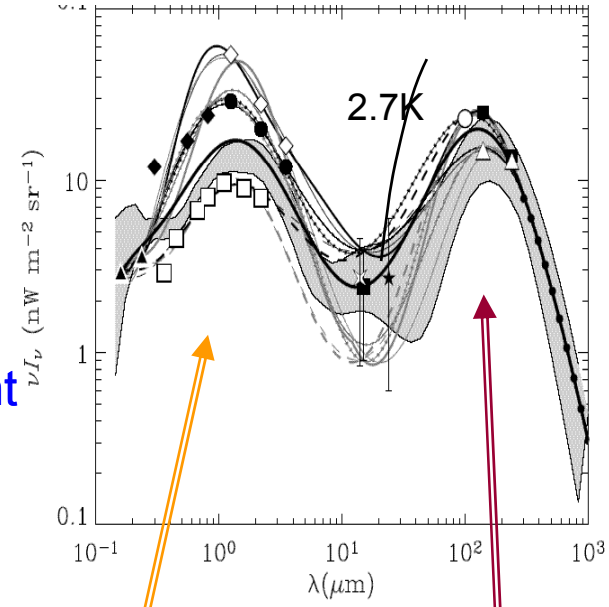
- Blazars
  - ➔ Jets aligned with line of sight
- Nearby: $z < 0.2$

Extragalactic Background Light (EBL)



Diffuse extragactic background light (how much light since recombination?)

- Complements direct measurment in Optical, IR: *foregrounds.*
- Indirect: absorption signature for distant sources.



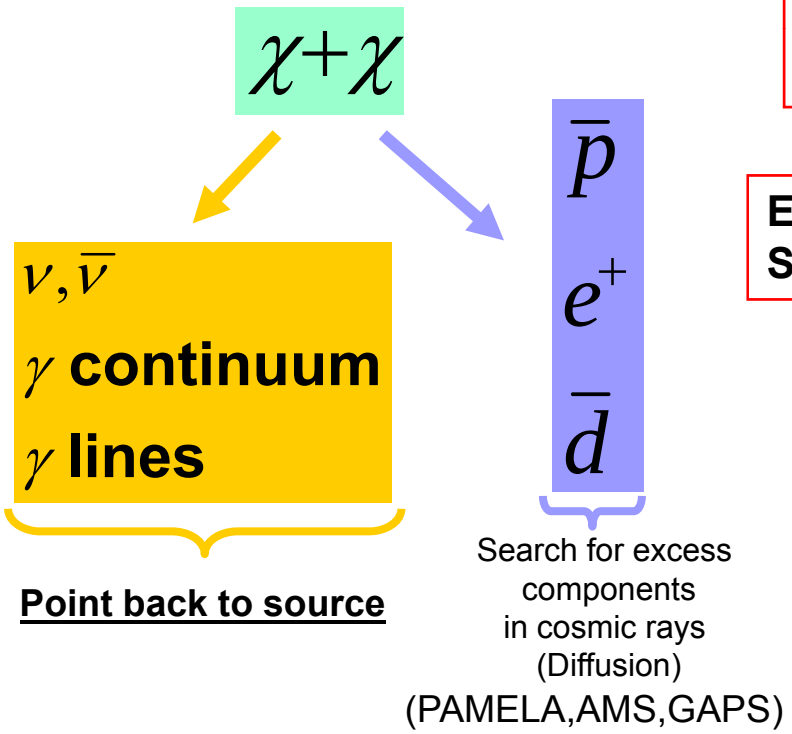
Red shifted stellar light

Red shifted dust light

Indirect Detection of Dark Matter

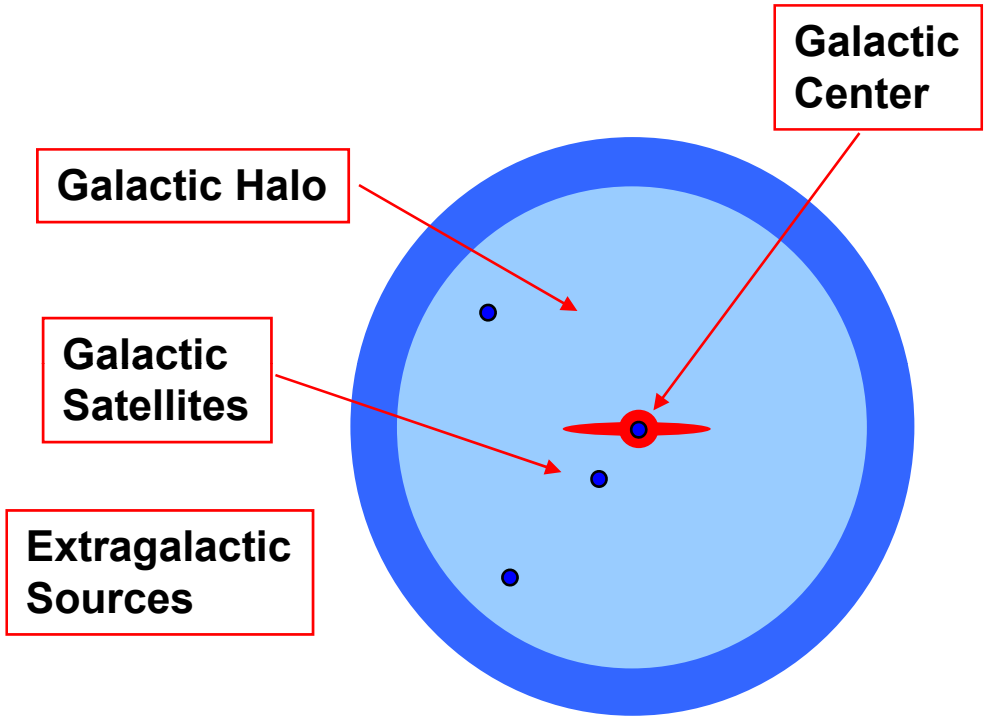
Hypothesis: DM = WIMPs

- High WIMP density in certain locations.
- WIMP annihilation → γ, ν etc.



Point back to source

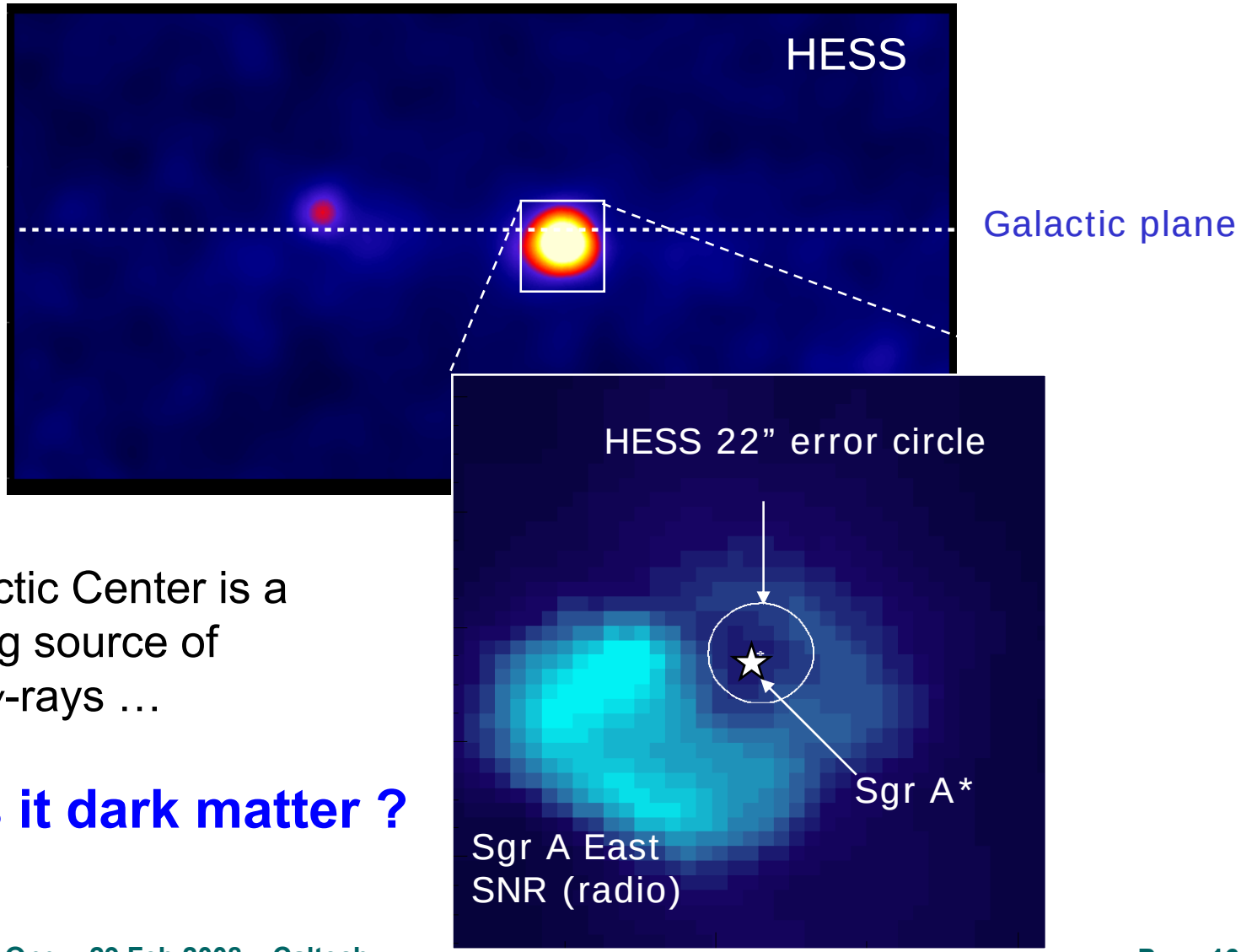
Search for excess components in cosmic rays (Diffusion) (PAMELA,AMS,GAPS)



Complementary approach to direct detection & LHC.

Key components of IDDM PFC Proposal: UCLA,UCI,Caltech.

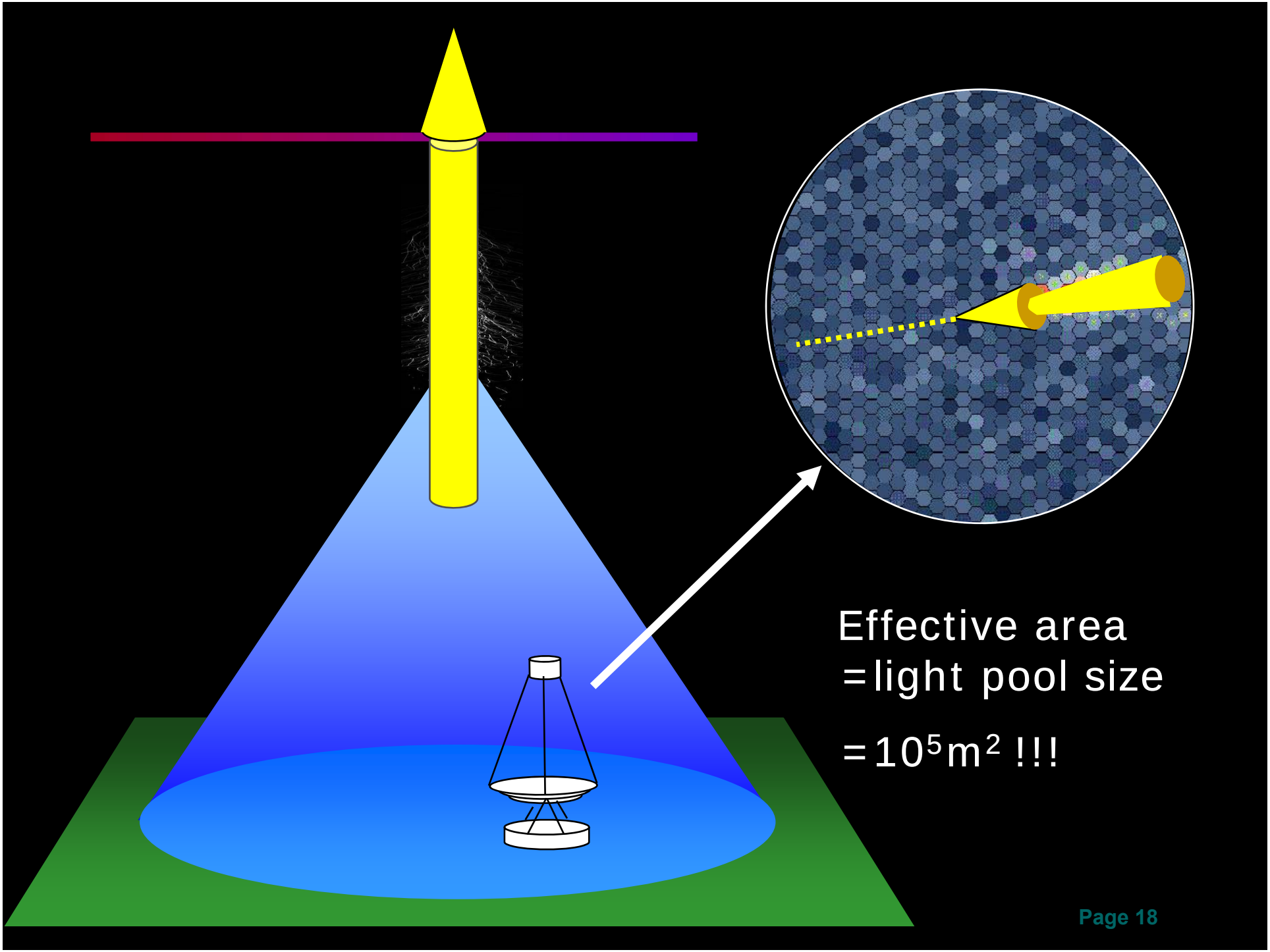
The Galactic Center



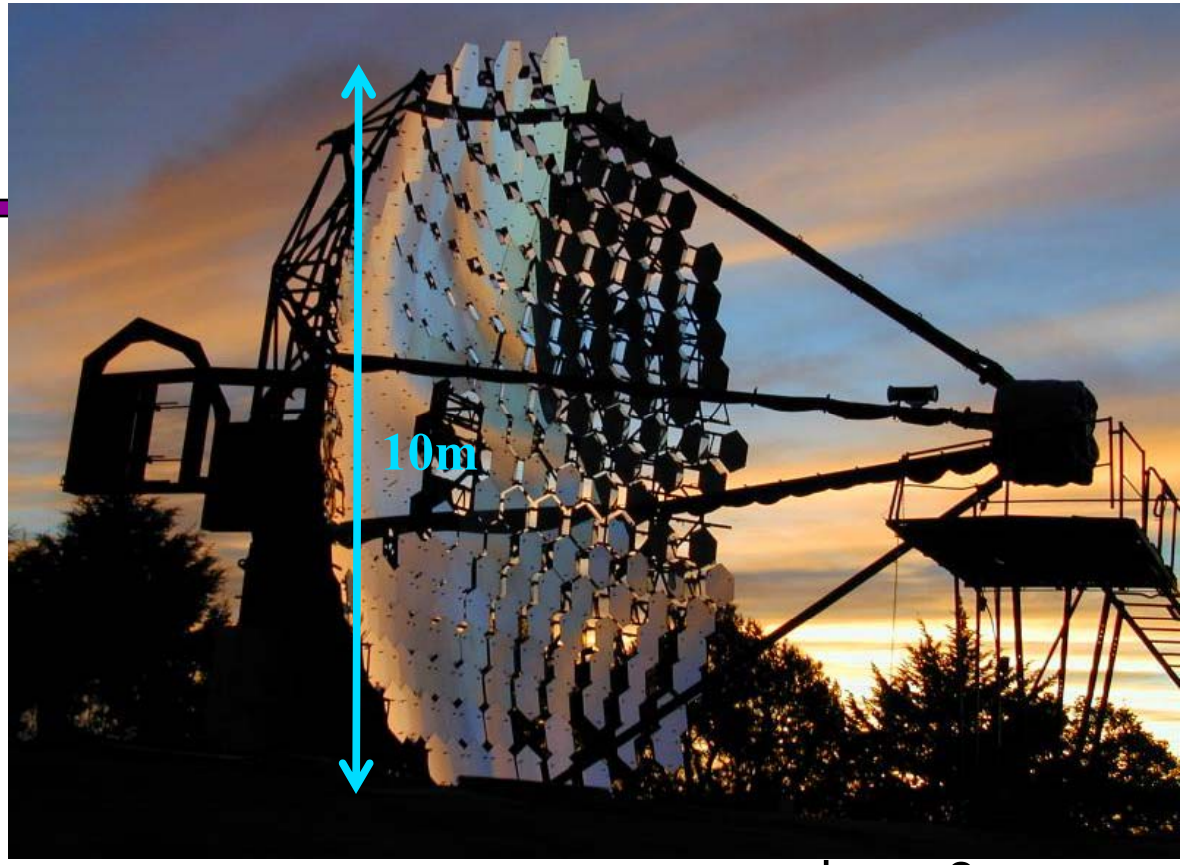
Galactic Center is a strong source of TeV γ-rays …

is it dark matter ?

Experimental Technique

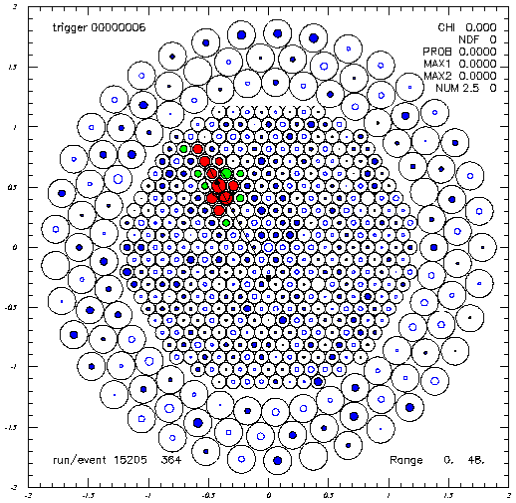

Effective area
=light pool size
=10⁵m² !!!

Whipple 10m Telescope



- The Whipple 10m (1968-).
- Added Tracking and an Imaging Camera.
- Increased the mirror area to ~100m^2.

gamma ray?



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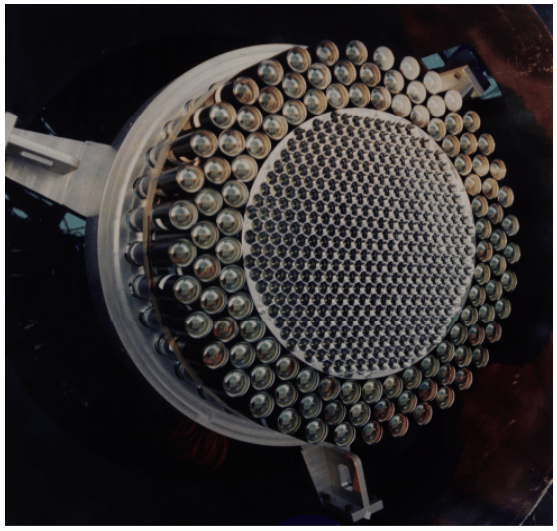
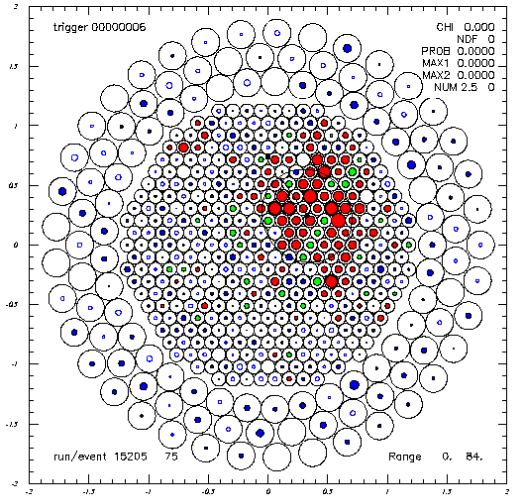
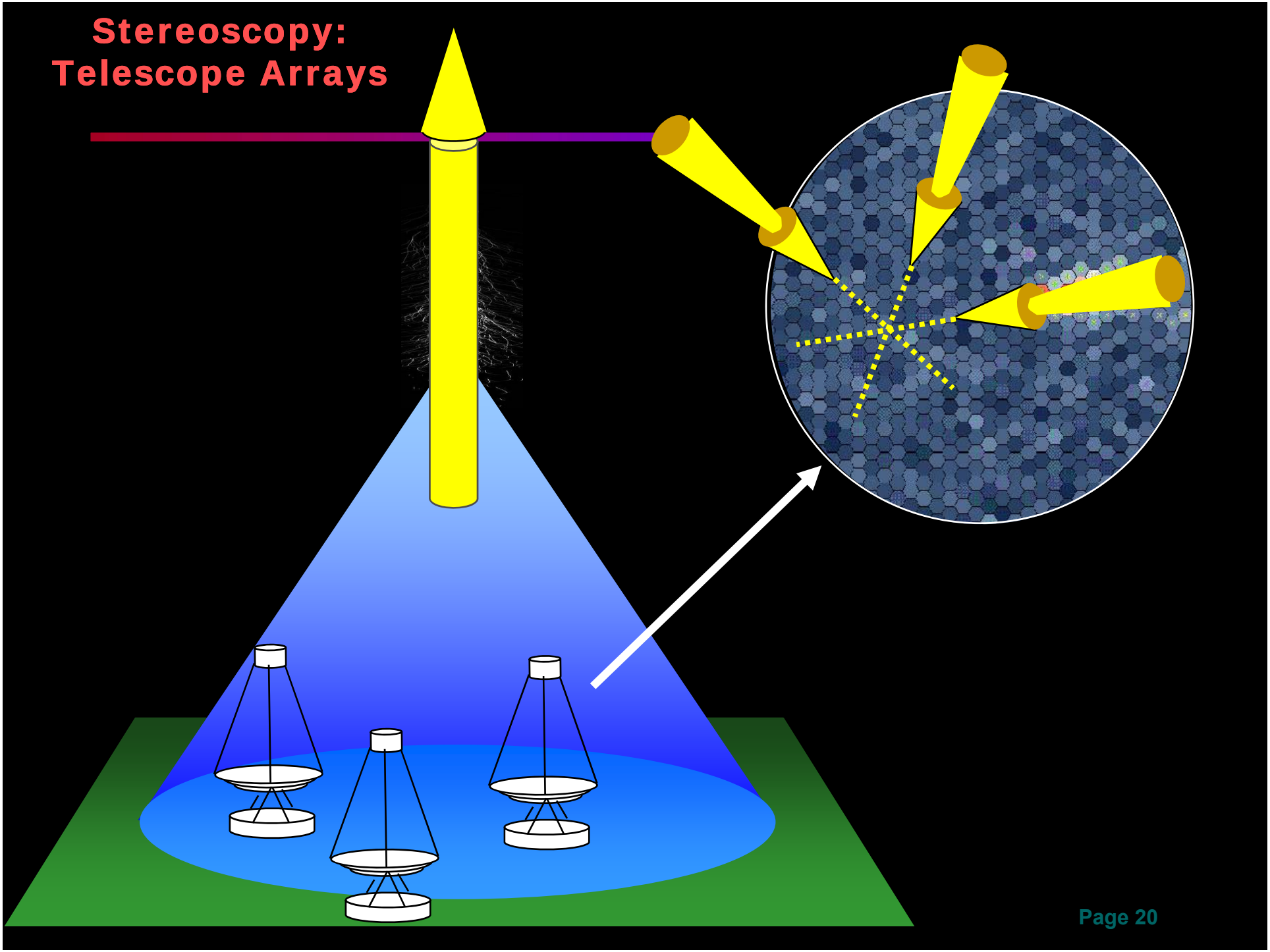


cosmic ray?



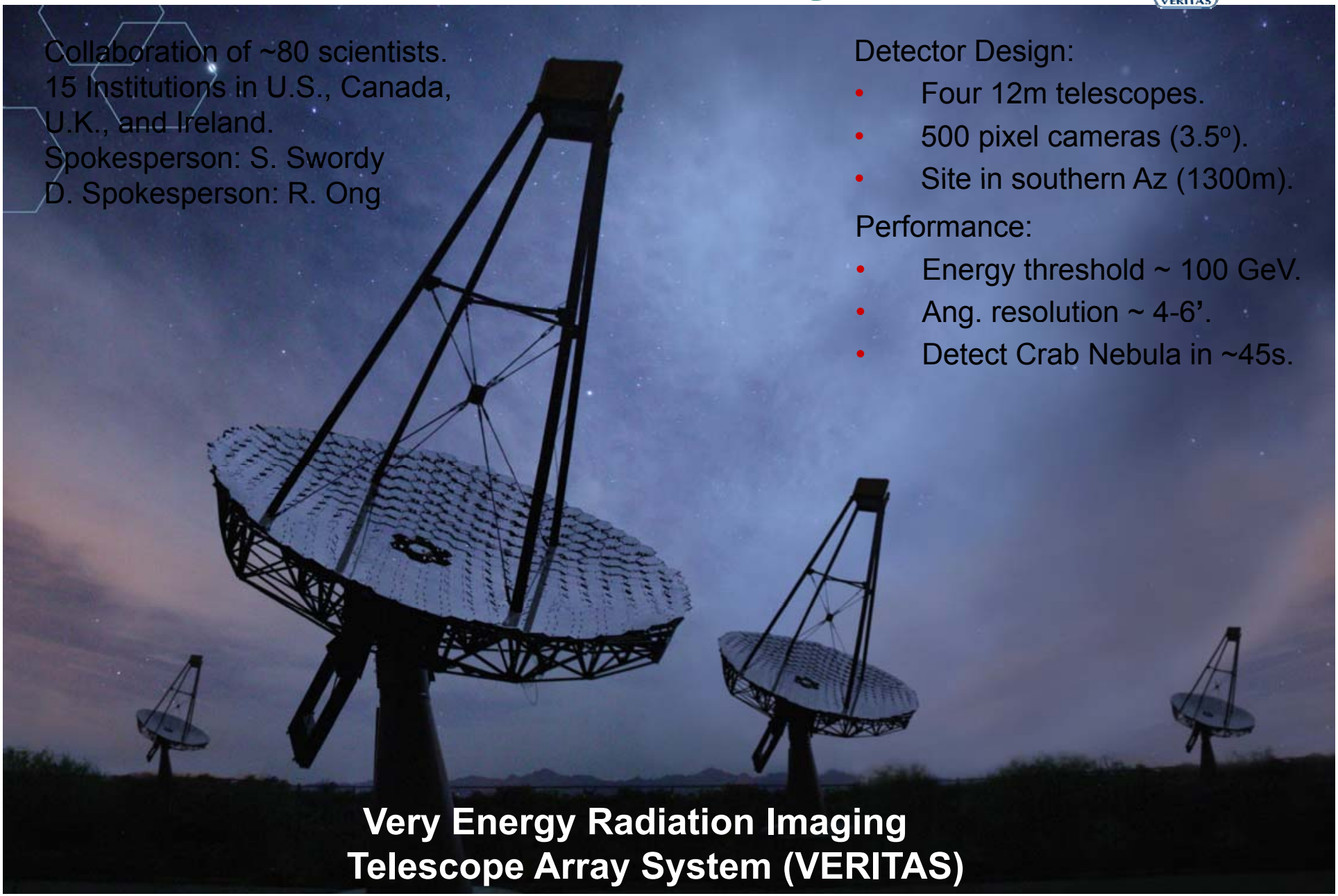
Stereoscopy: Telescope Arrays



Major New VHE Telescopes

GLAST (2008)

VERITAS



Collaboration of ~80 scientists.
15 Institutions in U.S., Canada, U.K., and Ireland.
Spokesperson: S. Swordy
D. Spokesperson: R. Ong

Detector Design:

- Four 12m telescopes.
- 500 pixel cameras (3.5º).
- Site in southern Az (1300m).

Performance:

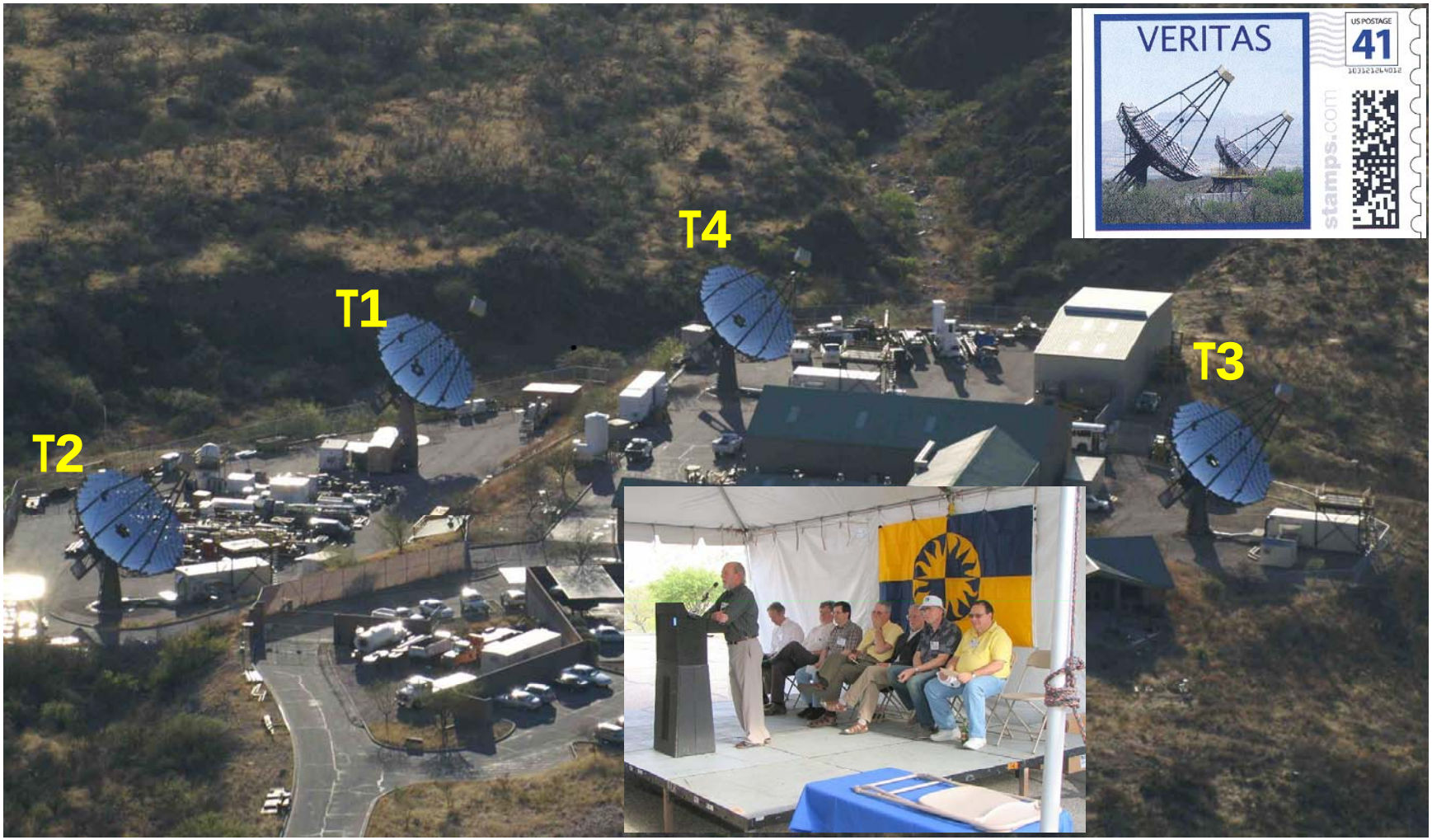
- Energy threshold ~ 100 GeV.
- Ang. resolution ~ 4-6'.
- Detect Crab Nebula in ~45s.

Very Energy Radiation Imaging Telescope Array System (VERITAS)

Bumps in the Road

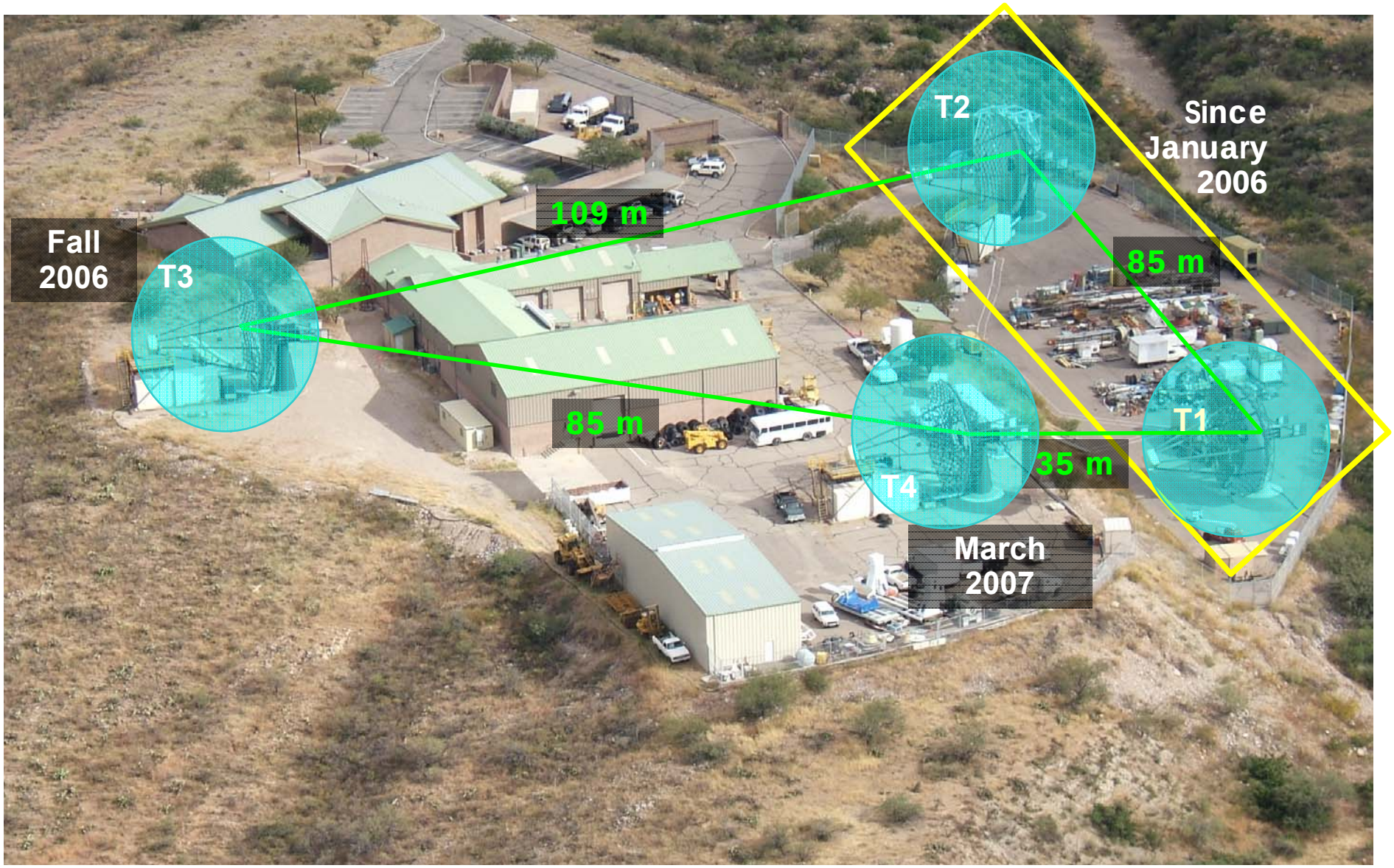
VERITAS – April 2007

F.L. Whipple Basecamp Mt. Hopkins, AZ (1300m a.s.l.)



First Light Celebration, 04/28/07

Telescope Layout



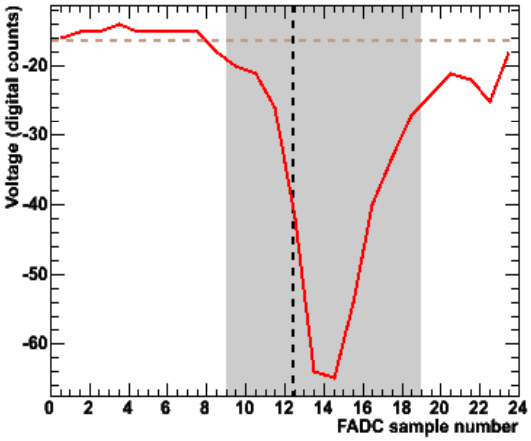
Telescope and Camera

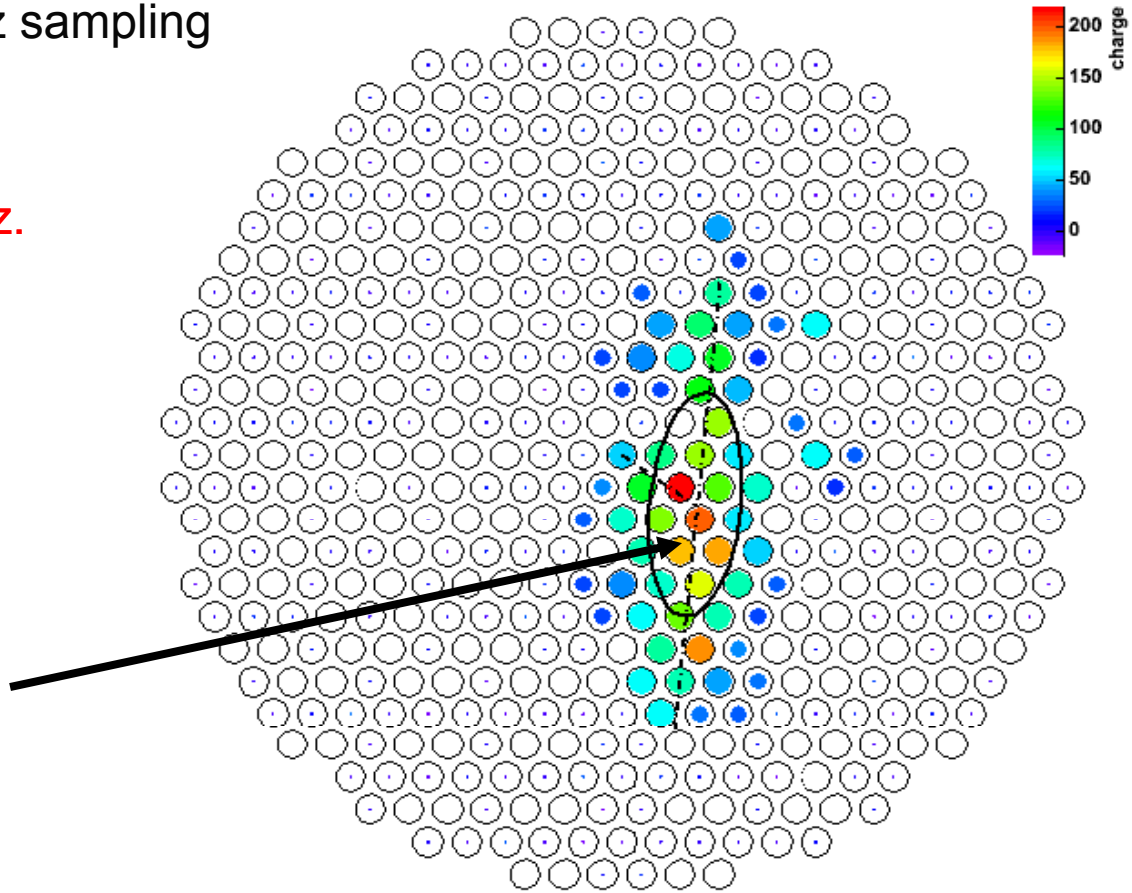
12m reflector, f1.0 optics

500 pixel Camera

VERITAS Data Acquisition

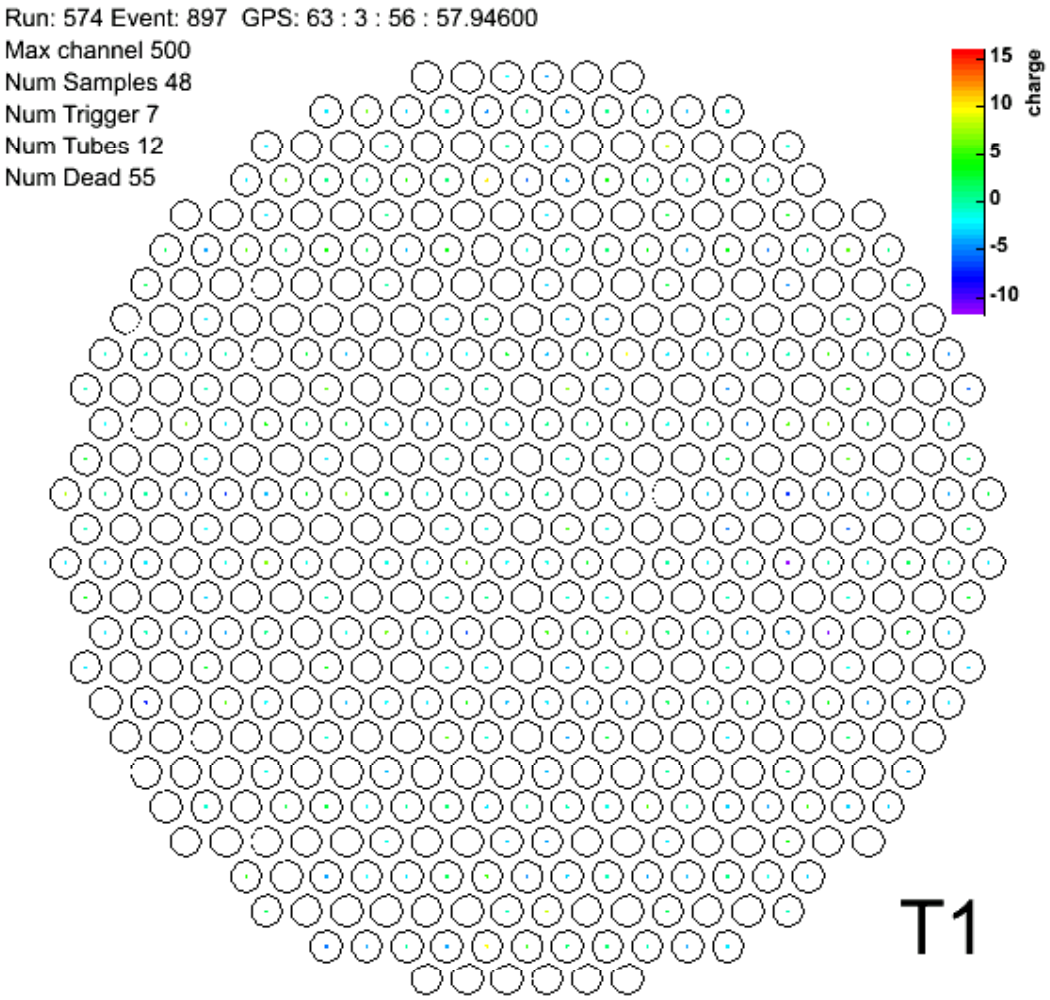
- PMTs digitized with 500 MHz sampling FADCs
  - 24 samples/channel.
  - <6% deadtime @ 250 Hz.





Telescopes meet all specifications.

Telescope 1 Movies

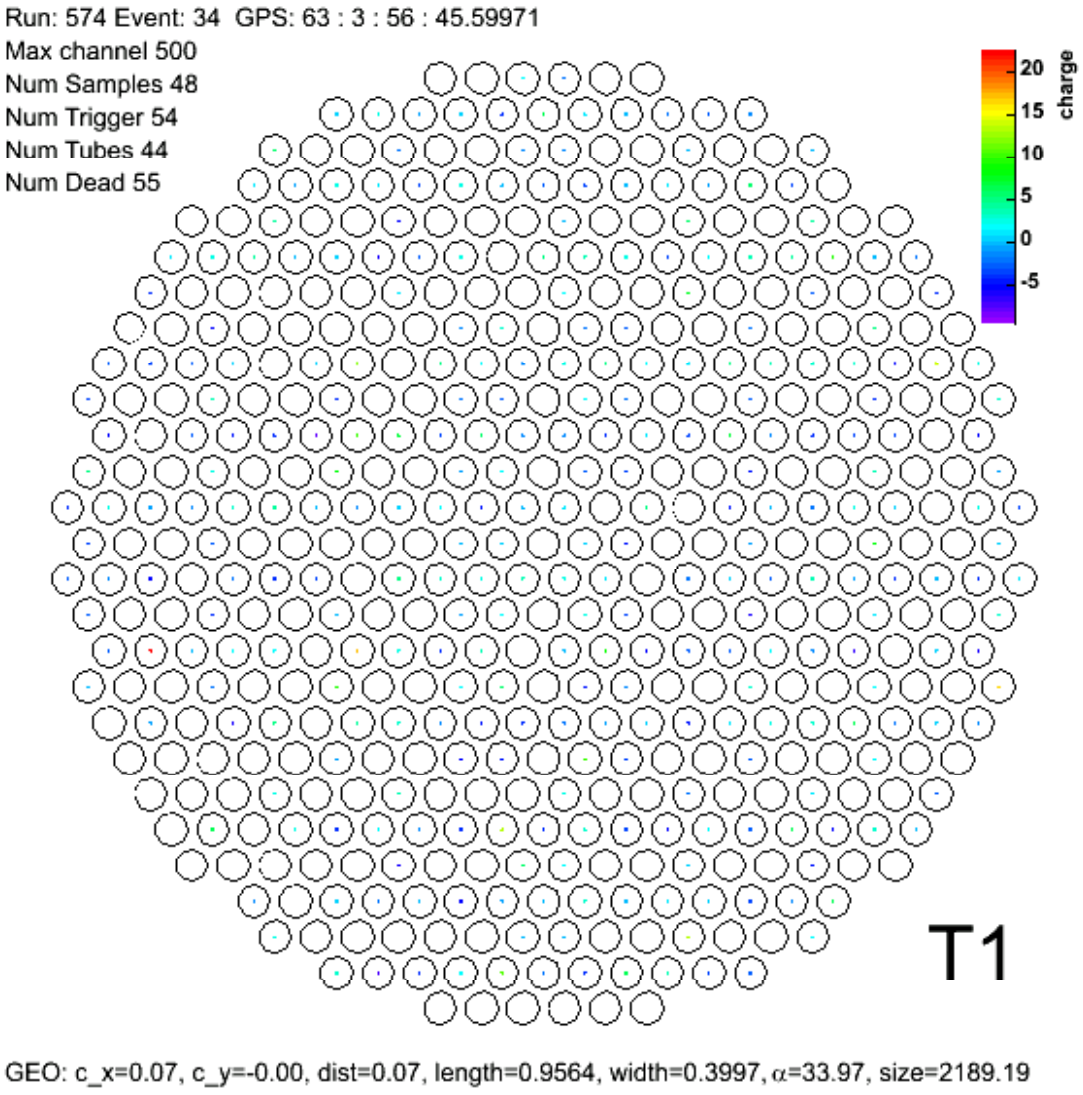


γ-ray

GEO: c_x=0.27, c_y=-0.58, dist=0.63, length=0.1599, width=0.0763, α=2.98, size=811.76

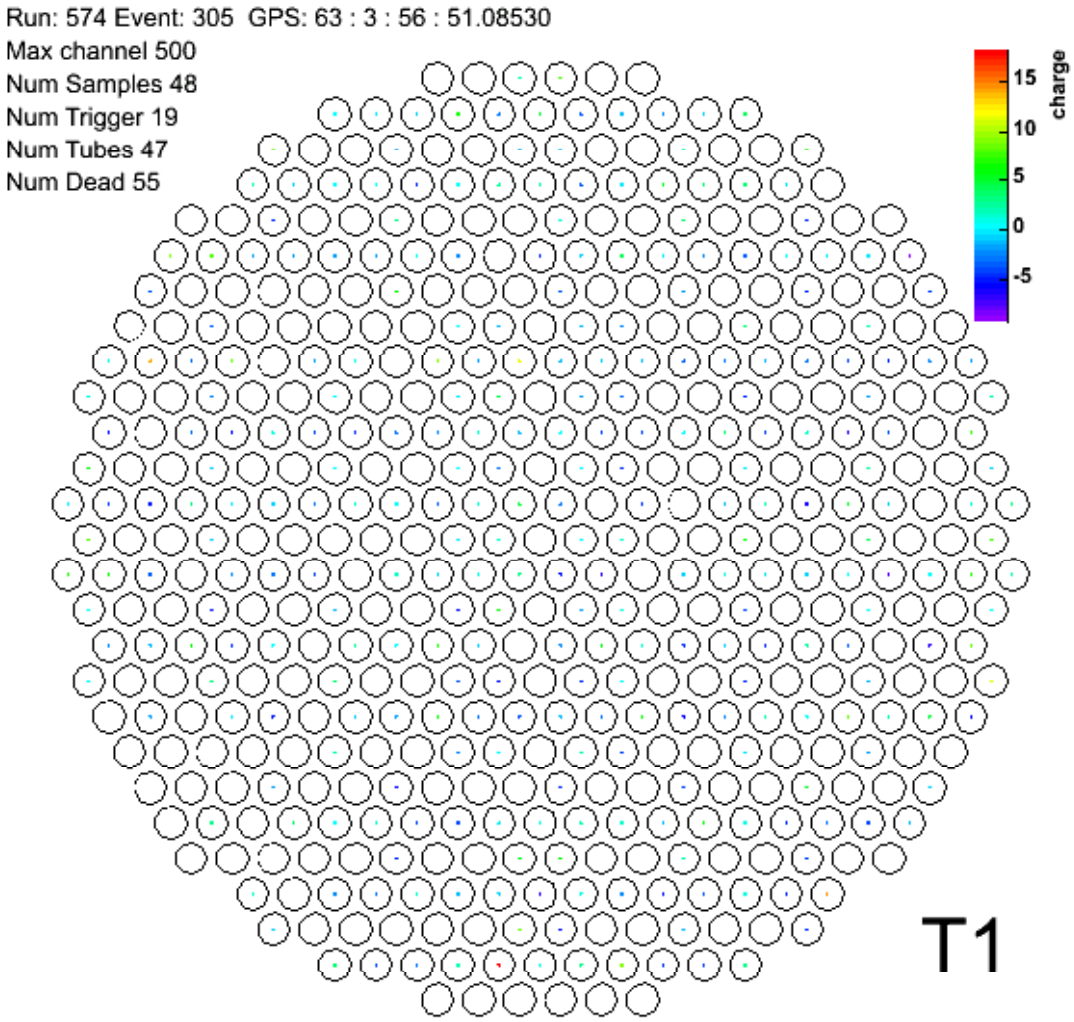
Telescope 1 Movies

Cosmic Ray



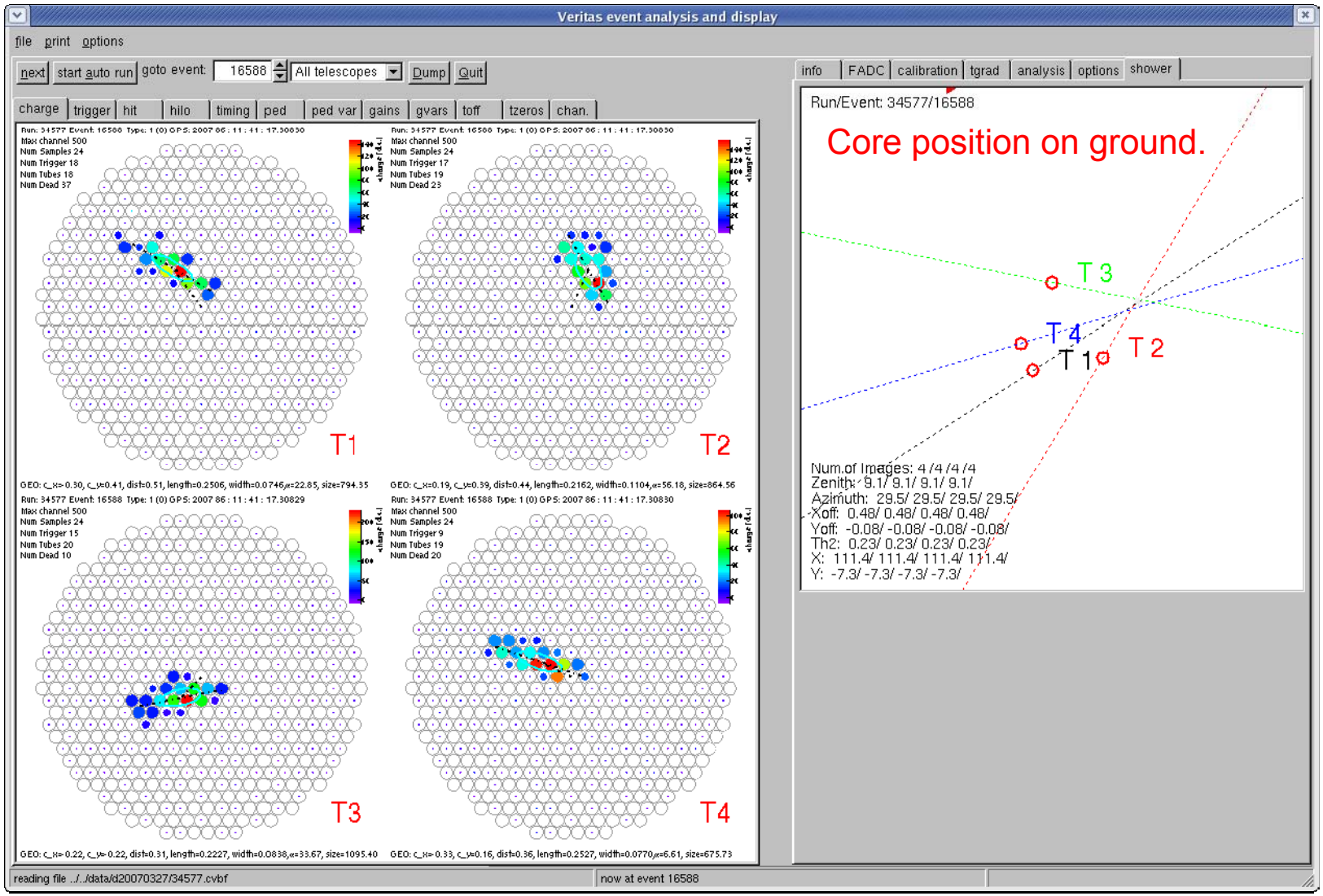
Telescope 1 Movies

Muon Ring

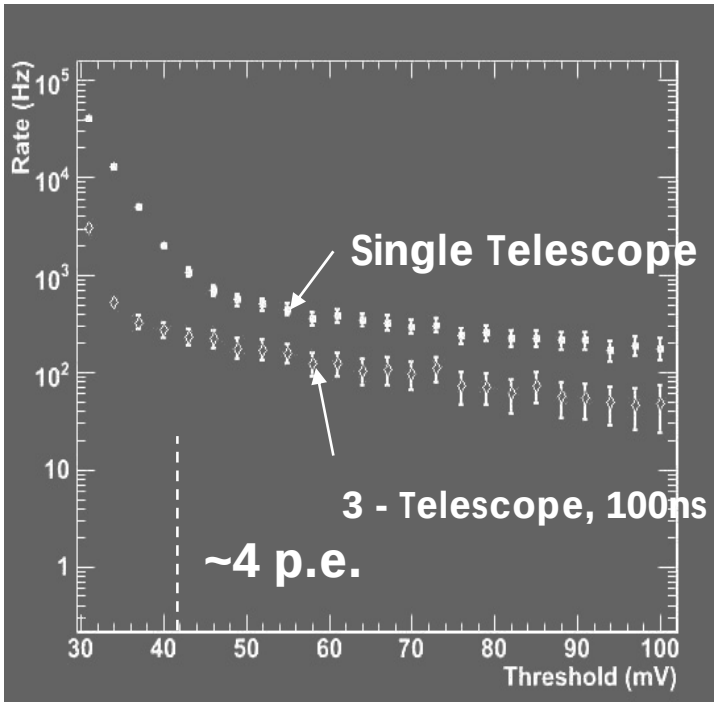


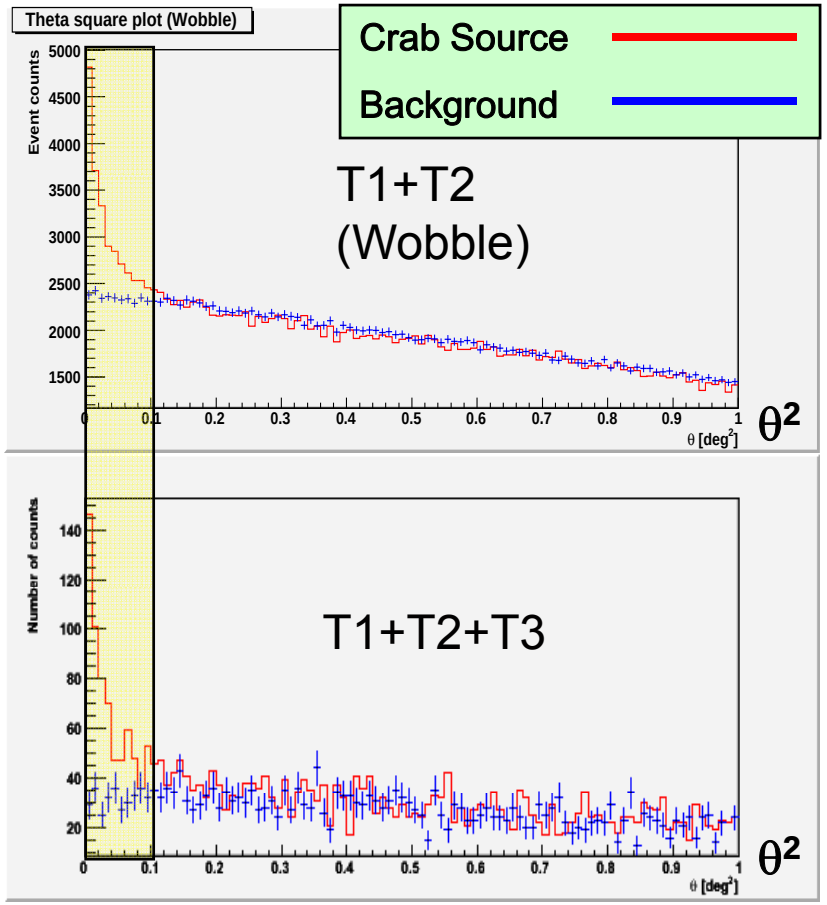
GEO: c_x=0.73, c_y=0.07, dist=0.73, length=0.6909, width=0.5157, α=75.47, size=2350.66

Typical 4 Telescope Event



VERITAS Performance I





Three Level Trigger

L1 – CFD (4 p.e.)

L2 – Telescope (pattern)

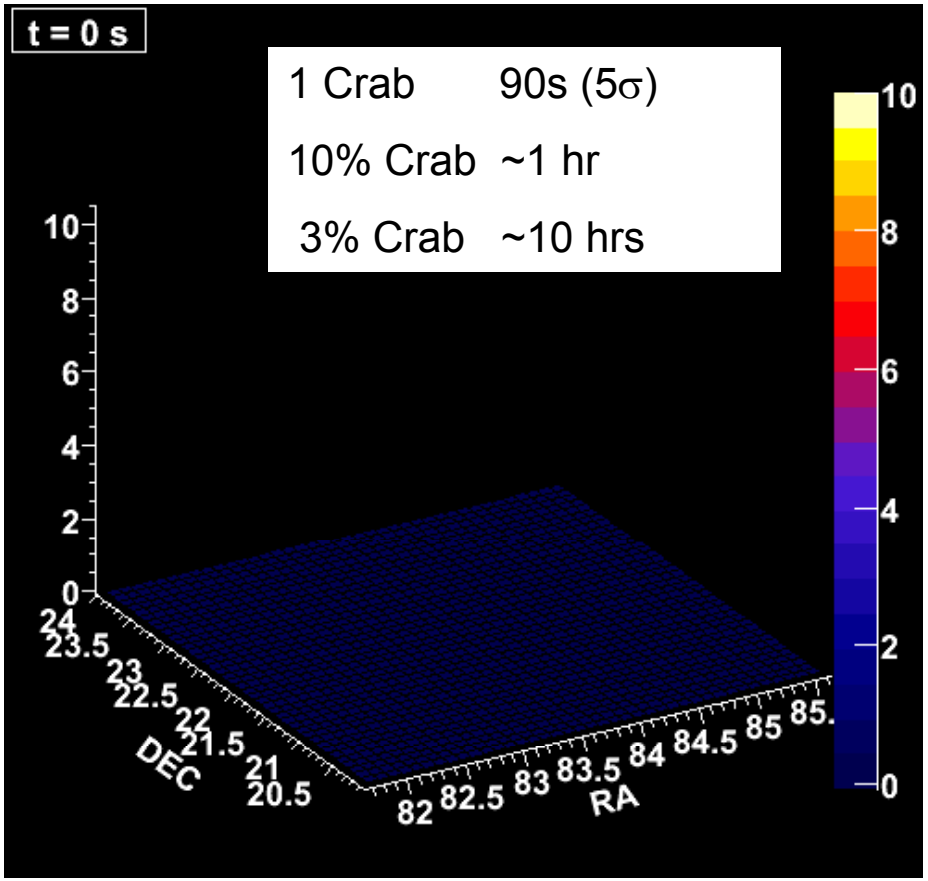
L3 – Array (~ 150 Hz)

Angular Resolution

2, 3 Telescope Crab Data

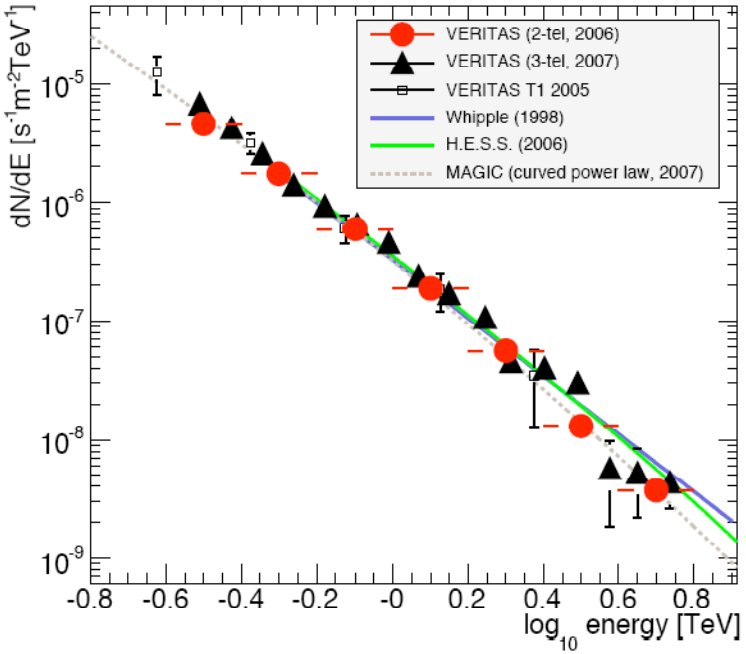
Single γ resolution < 0.1^{o}

Crab Nebula – Now a Calibration !



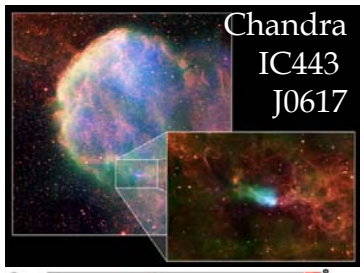
•significance ~35 σ/√hour for three telescope array (8 γ/min)

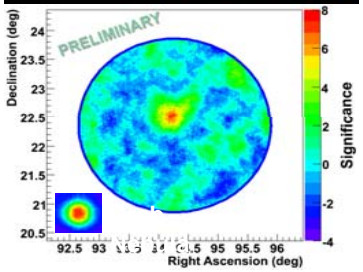
Energy spectrum



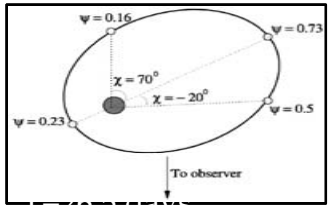
- 3 telescope array: Γ=-2.43±0.05, $F(E>1\ TeV)=(3.1\pm0.16)\times10^{-7}\ m^{-2}s^{-1}$

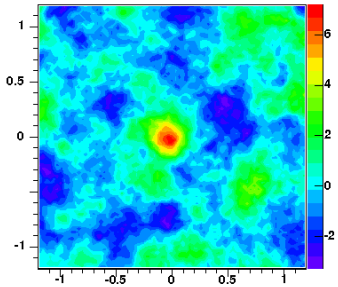
First-Year VERITAS Detections



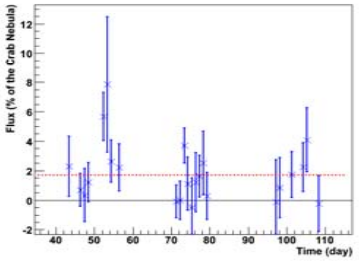


SNR IC 443

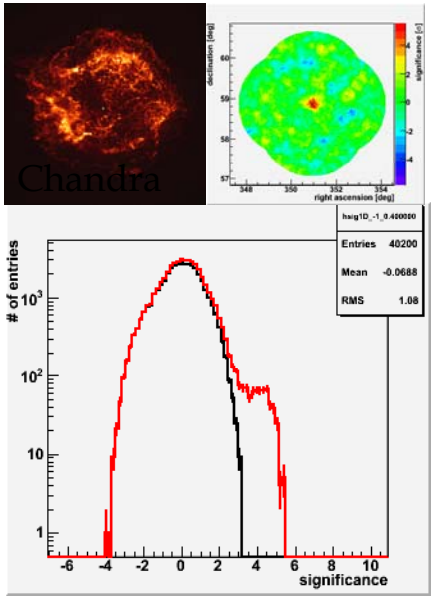




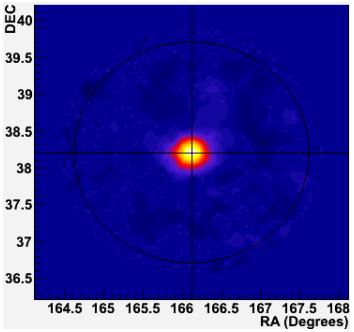
XRB LSI +61



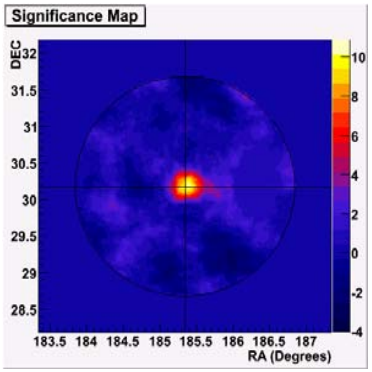
M87 Radio Galaxy



SNR Cassiopeia A



Blazar Mrk 421
z=0.03



Blazar 1ES1218+30
z=0.182, 2nd most distant VHE blazar

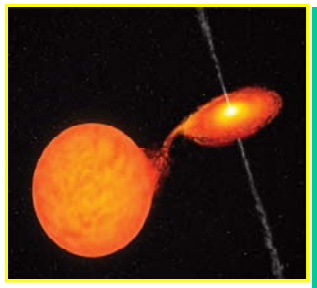
And ….

Blazar 1ES 2344+514

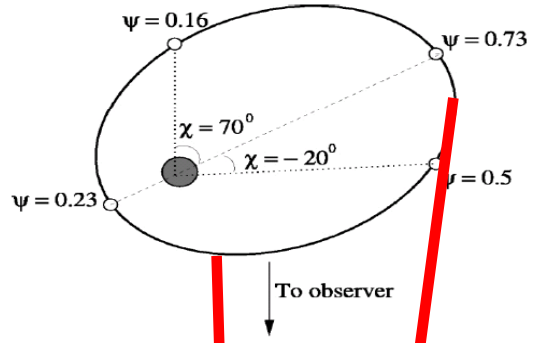
Blazar Mrk 501

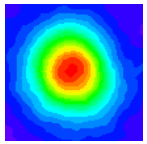
. . .

Microquasar LSI +61 303

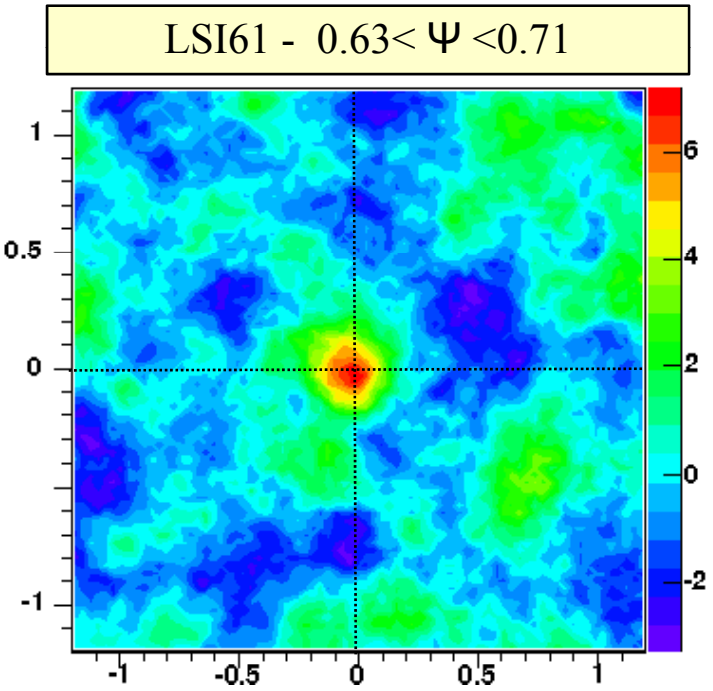


- HMXB located at 2 kpc distance
- Be Star coupled with NS
- 26.5 day orbital cycle



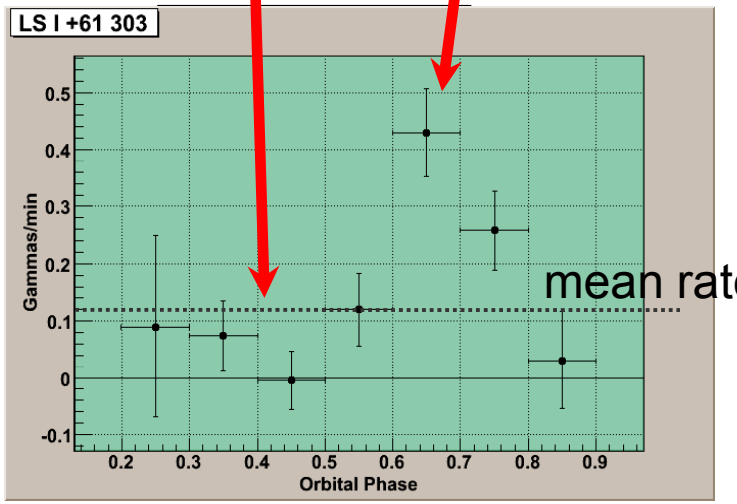


Crab Spot



VERITAS 3 Telescopes

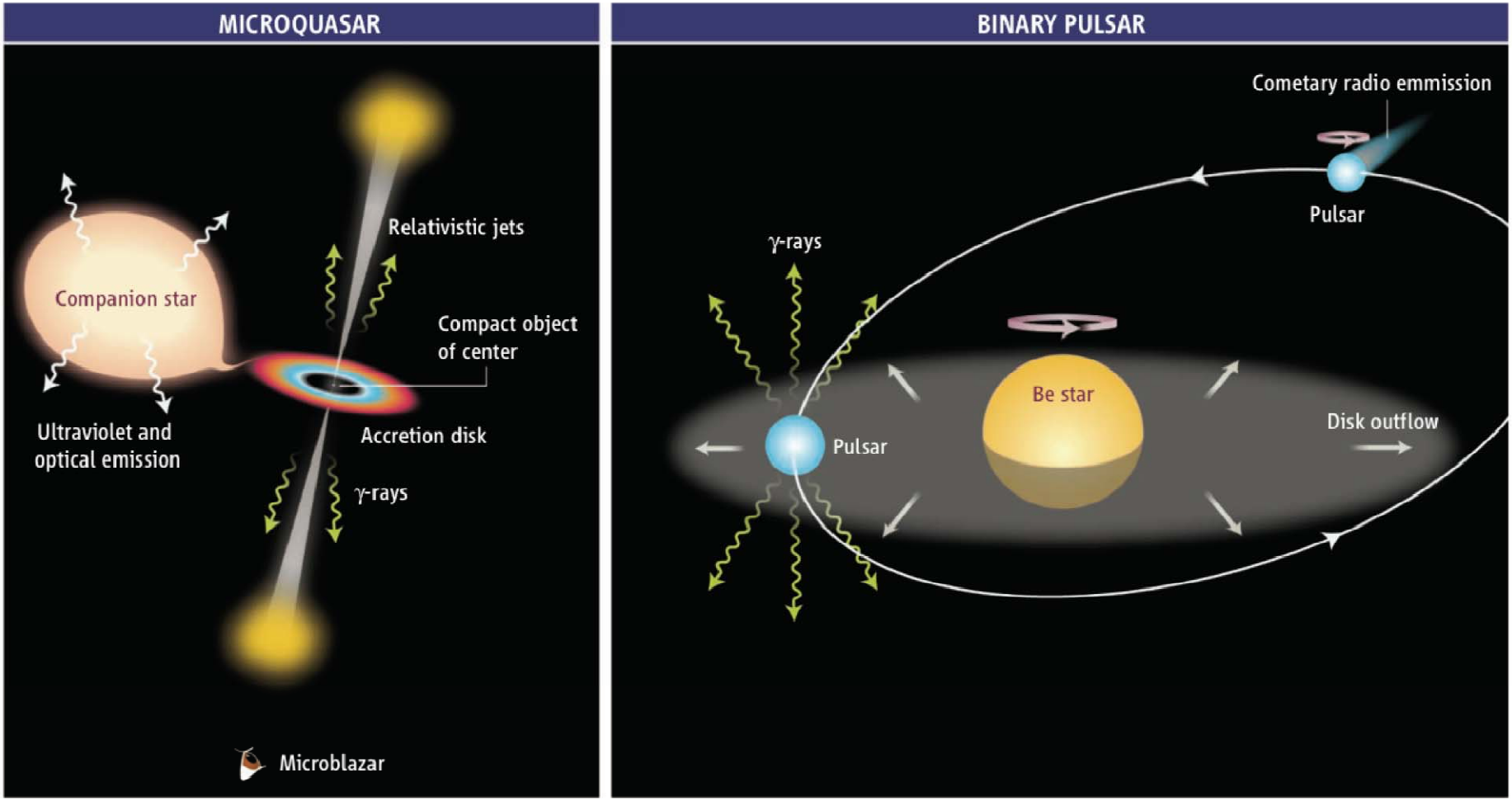
8.3 hrs, 7.1σ, 7% Crab



VERITAS

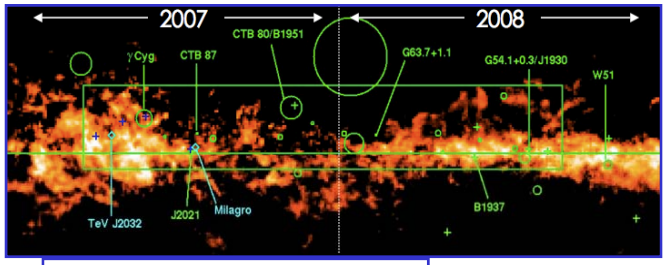
Rate versus orbital phase.

LSI +61 303 HE Emission

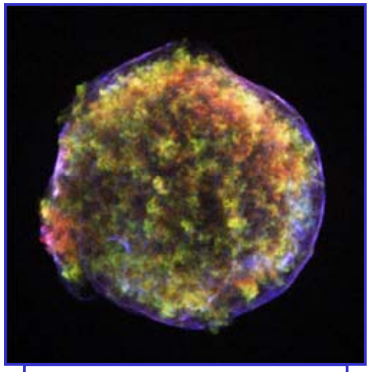


from: Mirabel (Science 309, 714, 2006)

Key Science Projects

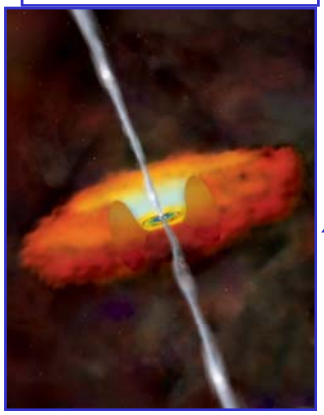


SKY SURVEY

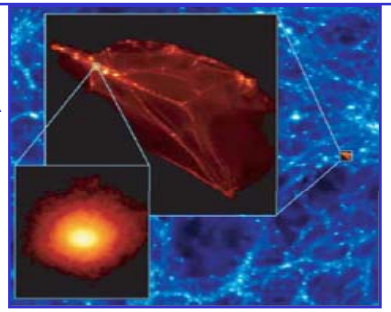


SNRs/PWN

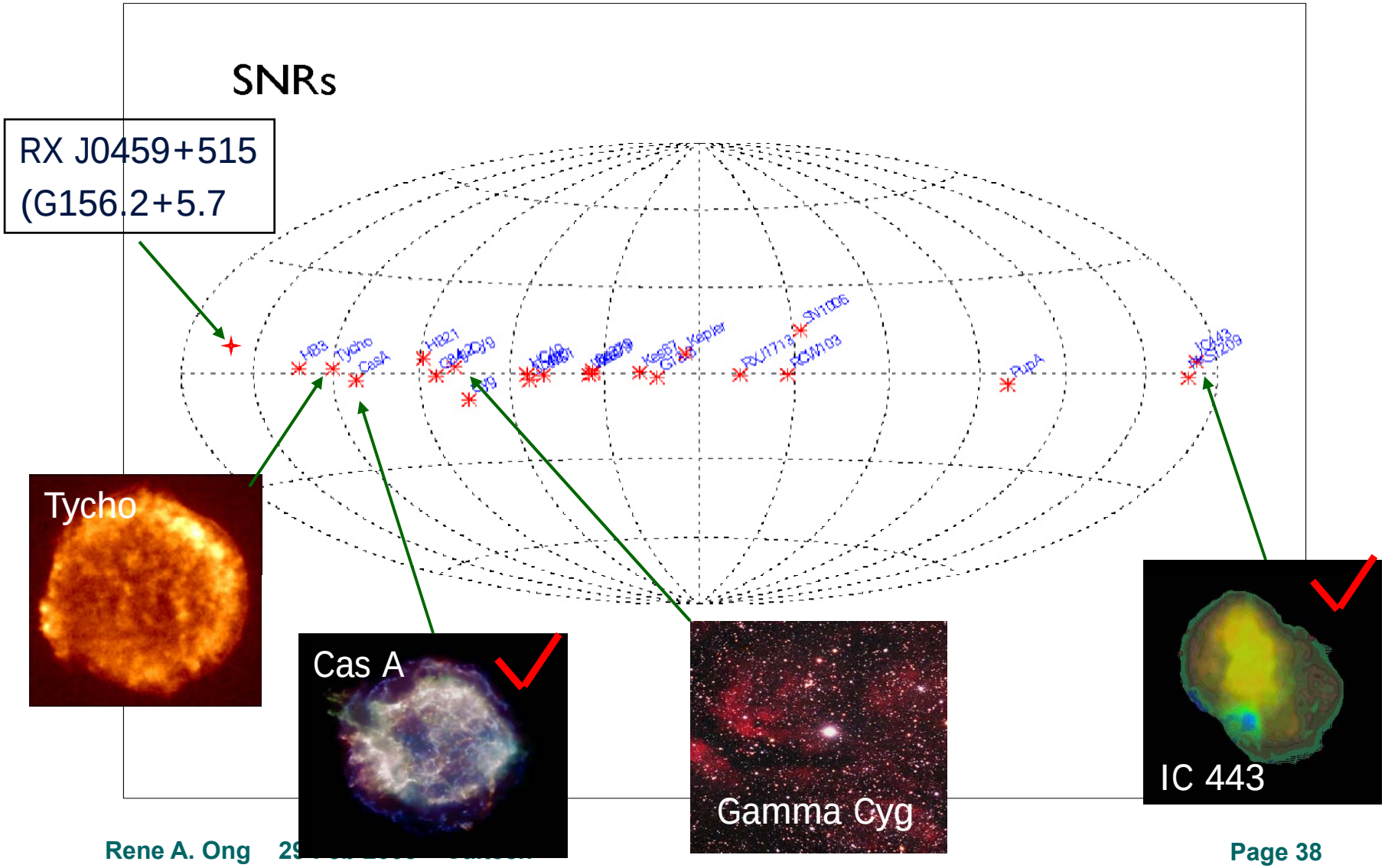
BLAZARS



DARK MATTER



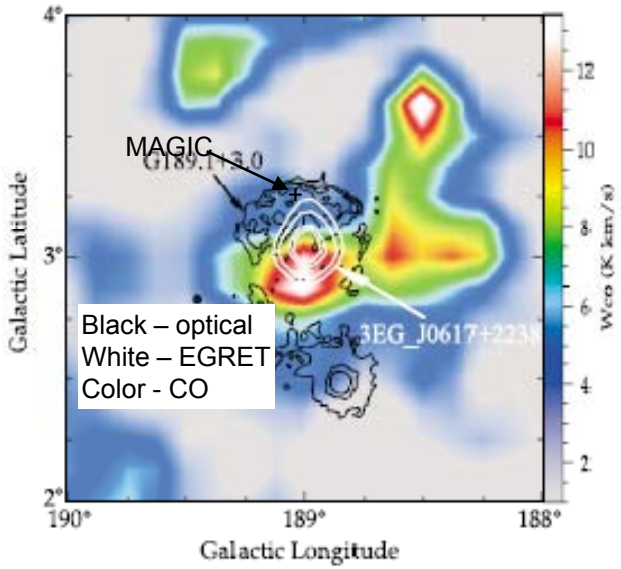
Supernova Remnants (SNRs)



Discovery of SNR IC 443

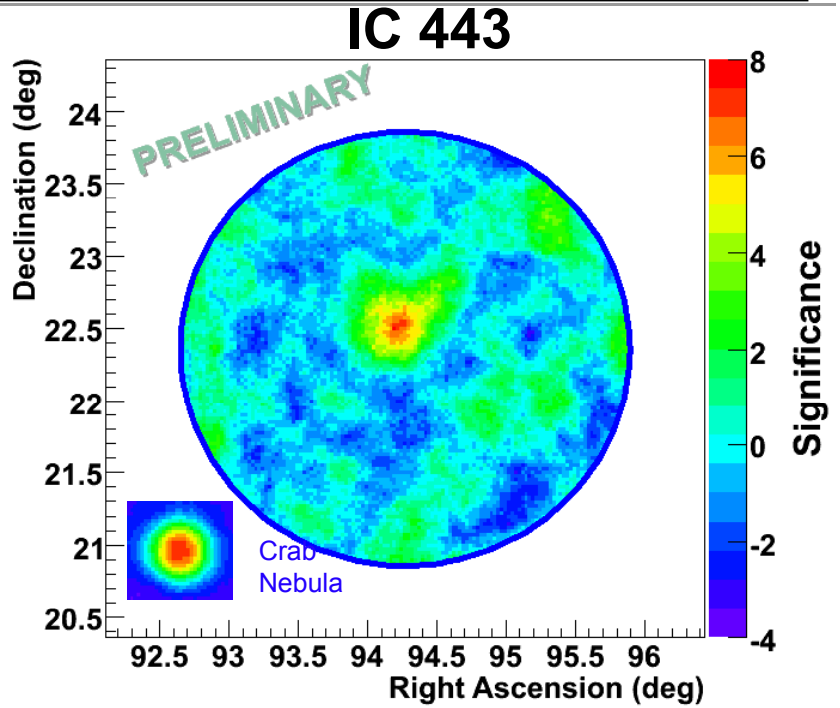
Figures from Torres *et al.* Phys. Rep. 382, 303 (2003)
MAGIC point from Albert *et al.* astro-ph/0705.3119v1

EGRET source (overlaps remnant)



Discovered by MAGIC and VERITAS

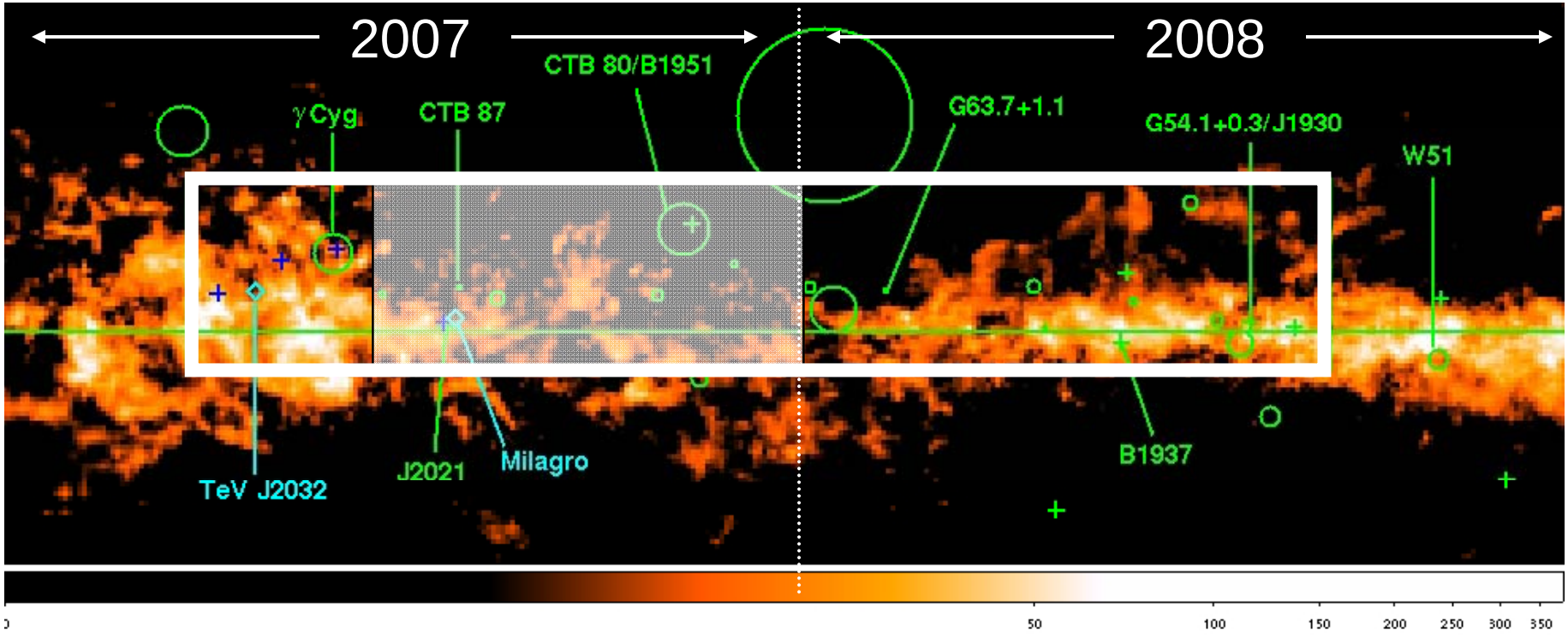
- VHE source position agrees with interaction zone of molecular cloud.



- VERITAS observation/detection
  - ~16 hours of data (3-tel. array)
  - 7.1 σ detection
  - Flux F(E>200 GeV) ~3% Crab Flux

Consistent with MAGIC's 5.7 σ detection in 29 hrs.

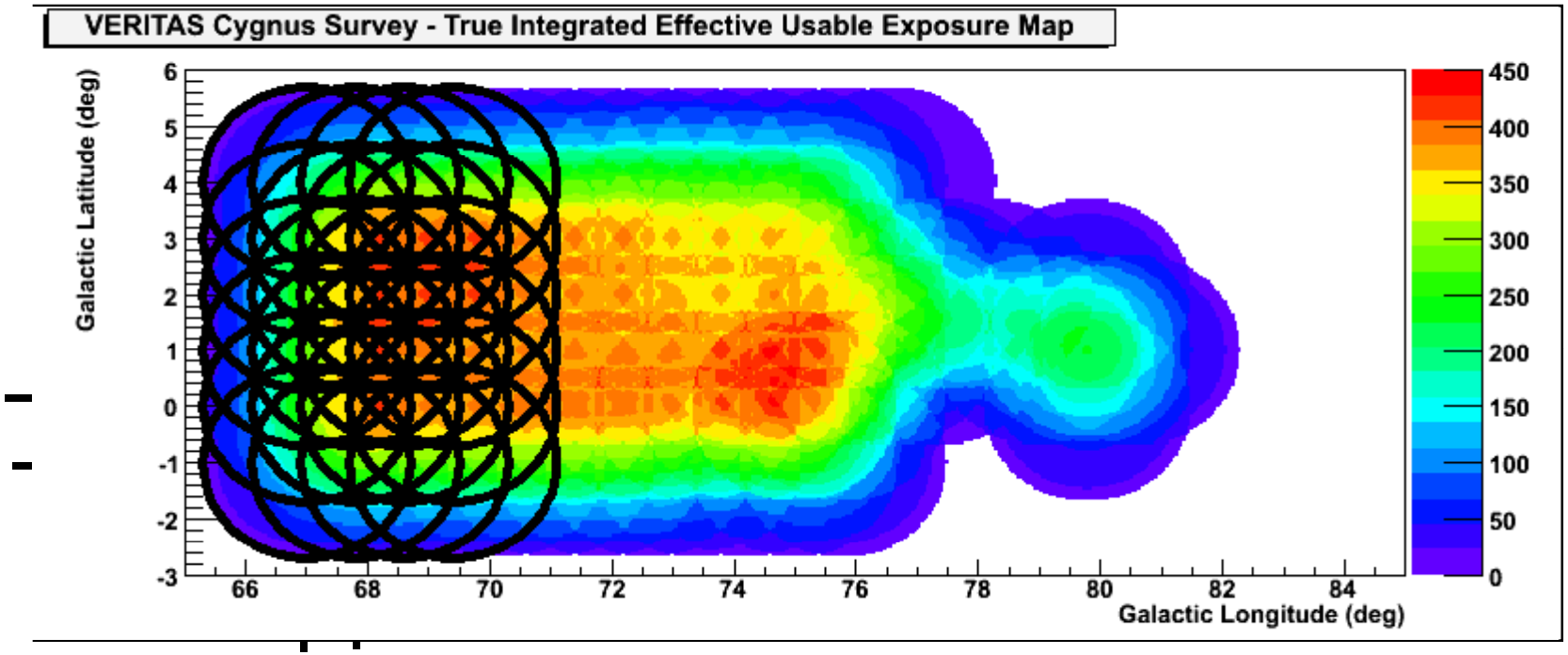
VERITAS Sky Survey



2 year program: survey of Cygnus region (-1 < b < 4 and 52 < l < 82)

- Many targets of interest (SNRS, PWN, EGRET sources, X-ray binaries, VHE sources).
- Discovery potential (dark accelerators in particular).

Observation Strategy, Status



Makes full use of 1.7 camera FOV

Observations began in April 2007

Crucial: Understand our sensitivity
Keep trials factors low
Follow-up strategy

Optimizing analysis strategy before “opening the box.”

What's next for VERITAS ?

LOTS!

- Observing: we are in first year of 5+ year program.
- Spectra and modelling: source mechanisms.
- Images: extended sources (SNRs, PWN, etc.).
- MWL studies: radio, optical, X-ray, γ-ray.
- GLAST overlap: alerts, calibration, science.
- Upgrade possibilities: e.g. new cameras.
- …

FUTURE PROSPECTS

Next 5-10 years will be exciting period for this field:

VERITAS will survey the northern TeV sky with great sensitivity, complementing:

GLAST (GeV, in space)

HESS (TeV, S. Hemisphere)

IceCube (ν, South Pole)

Farther in the future:

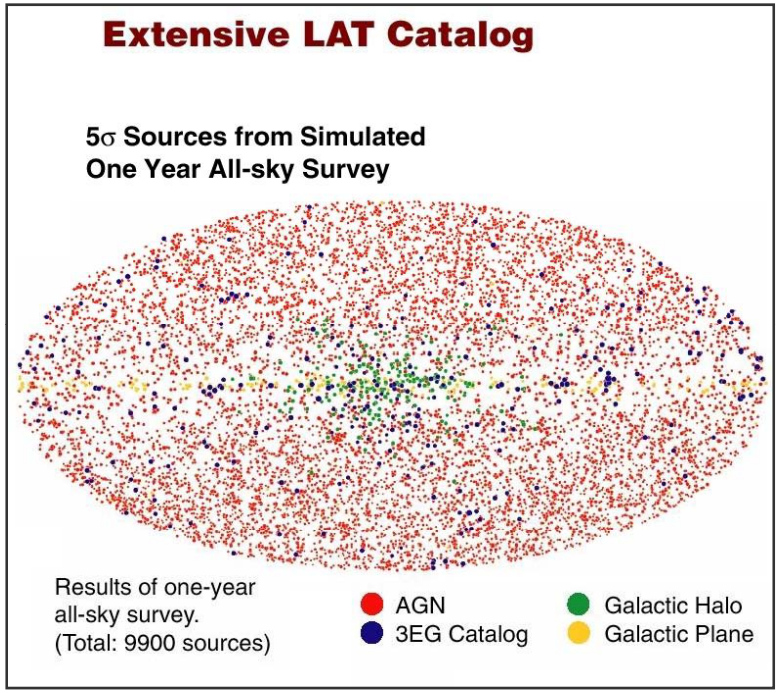
- Astrophysics at GeV & TeV energies with large km^2 Cherenkov Telescope arrays.

GLAST Satellite Telescope

GLAST LAT Instrument:

- Si-strip tracker
- CsI calorimeter
- Anti-coincidence veto

GLAST: Low E, wide FOV.
VERITAS: High E, large sensitvity.



Simulated sky map from 1 year survey.

Launch in May 2008.

AGIS (Advanced Gamma Imaging System)

AGIS:

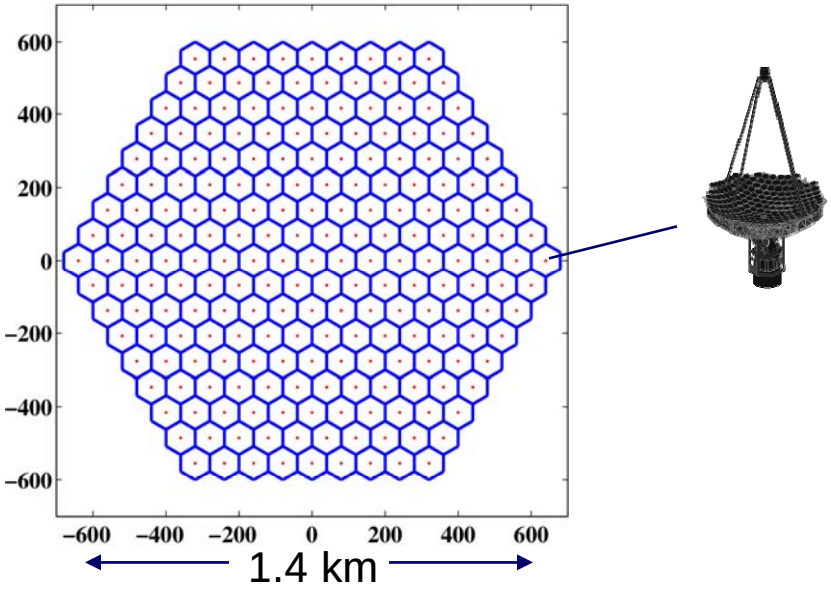
Large (1 km^2) array.

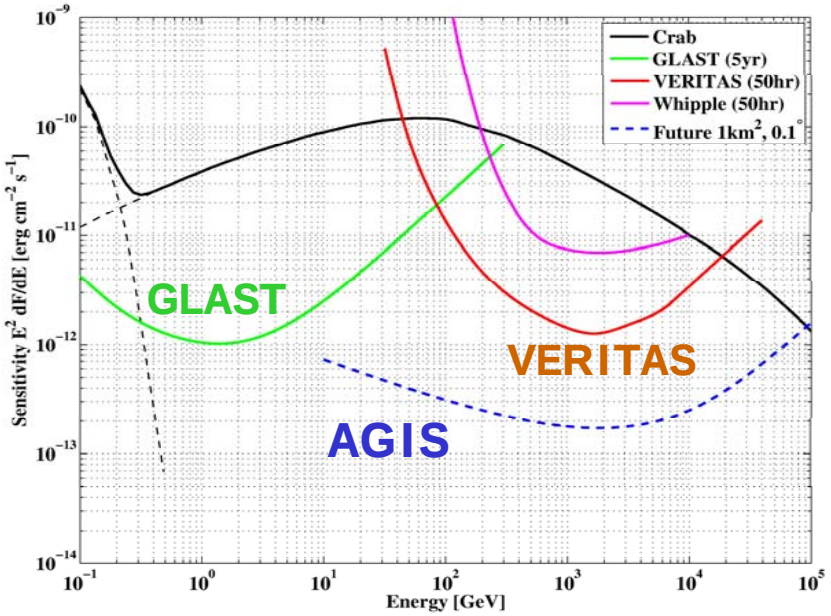
- ~50-75 telescopes, aperture 8-20m.

Much more sensitive than GLAST/VERITAS.
CTA project in Europe – well underway.

APS White Paper study.
$100M class experiment.

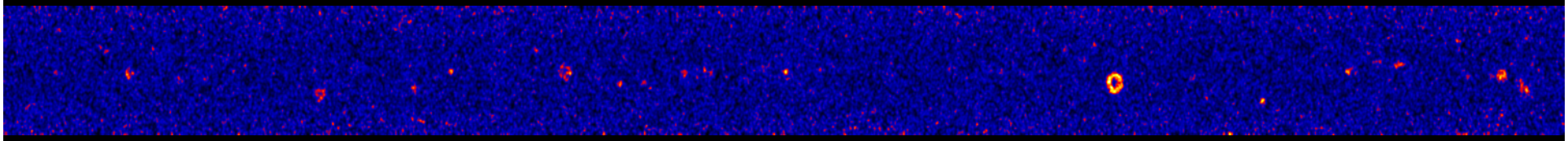
AGIS Concept
0.04-200 TeV, large FOV, 1' PSF per photon



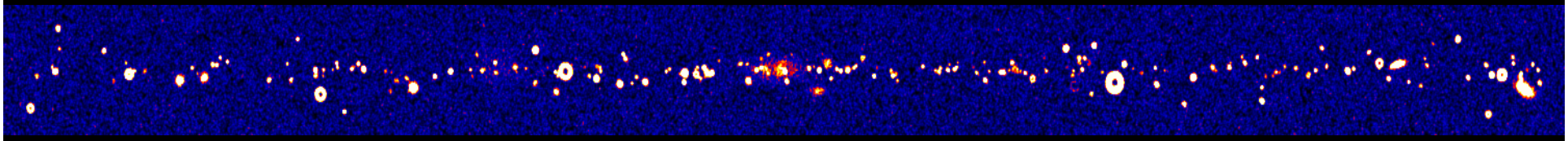


Future TeV Source Sensitivity

HESS/VERITAS Simulation



AGIS/CTA Simulation



Summary

- VHE particles provide unique tests of the limits of physical laws. Probe astrophysics in regimes not yet explored. Possibility for discovery of physics beyond our standard models.

- Exciting discoveries of many, unexpected sources of VHE gamma-rays. But still, most of the sky remains unexplored.

  → **VERITAS is now operational and getting exciting results.**

- New Astronomy of TeV γ-rays and neutrinos should reveal many surprises over the next 5-10 years.

"The real voyage of discovery consists, not in seeking new landscapes, but in having new eyes."

Marcel Proust (1871-1922)