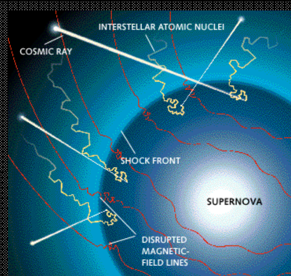
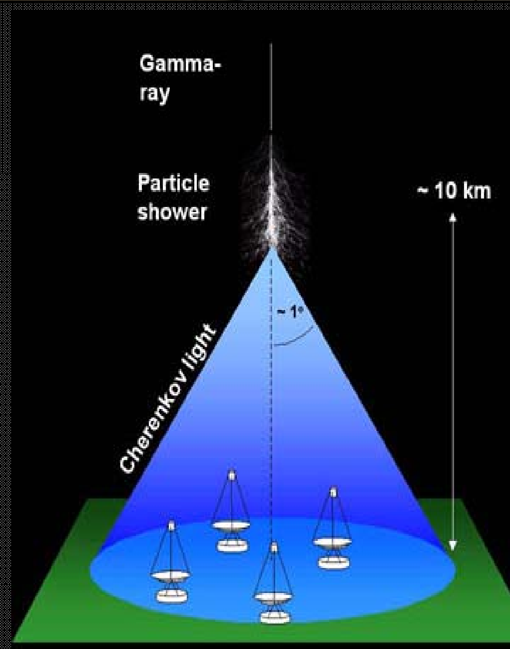
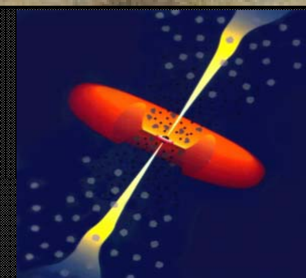
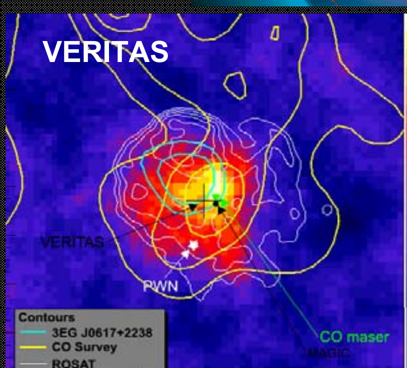
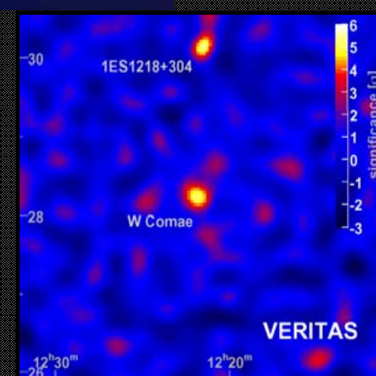
Viewing the Universe with γ-ray Eyes











Rene A. Ong

SC AAPT

02 May 2009

Outline

Scientific Motivation

- A “New Astronomy”
- Physicist’s Viewpoint
  - ➔ *Astrophysical Terra-eV accelerators*

    1 TeV = 10^{12} eV
  - ➔ *Probes of new physics (e.g. dark matter)*

Experimental Technique

The VERITAS Project

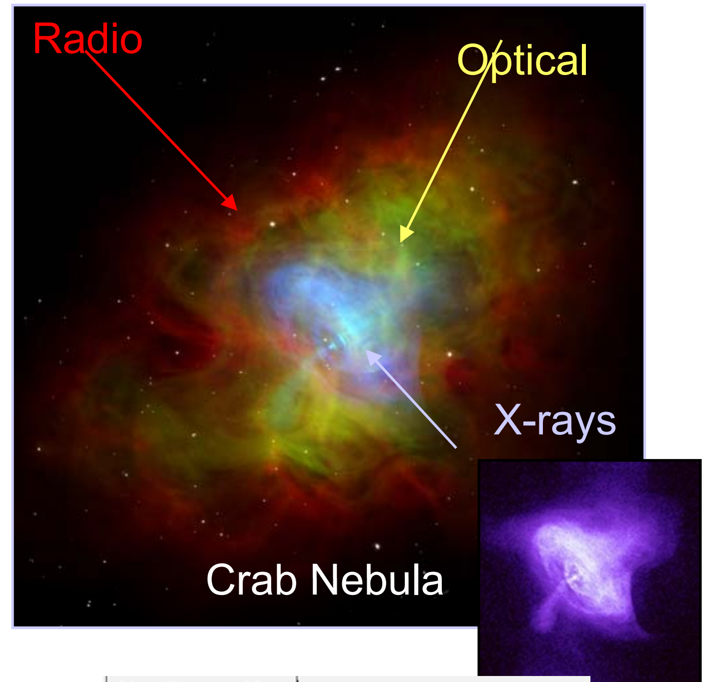
- Description, performance.
- Highlights of results from 18 months.
- Fermi Gamma-ray Space Telescope (FGST)

Future

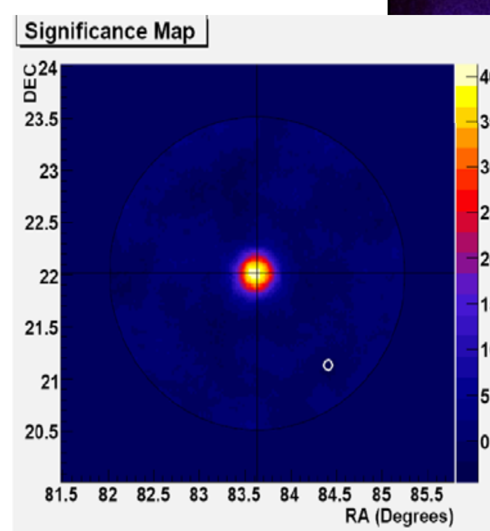
A New Astronomy

- 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 too ! (cosmic rays, neutrinos, & gravitational waves).

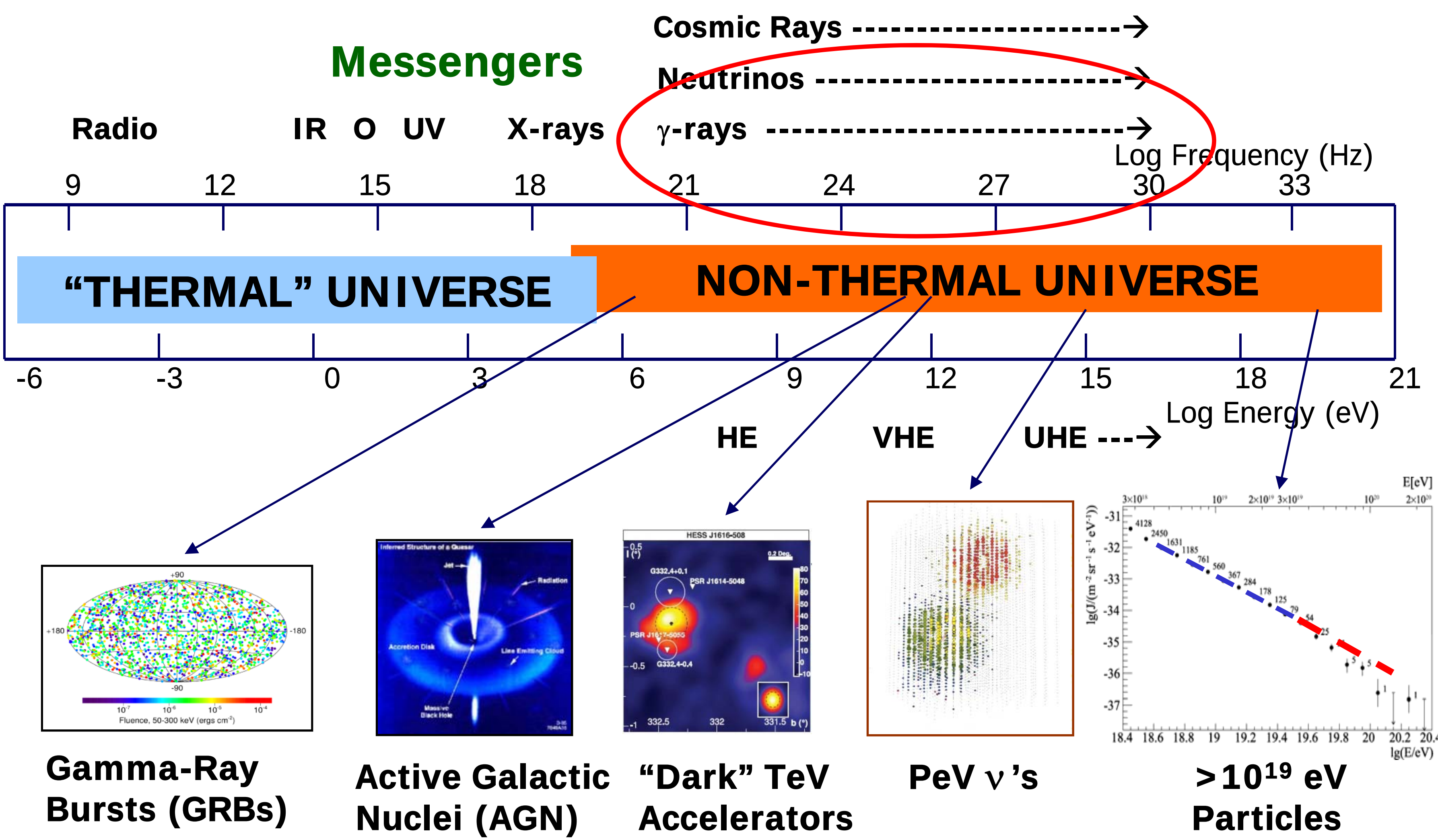
Here we focus on TeV γ-rays.



TeV γ-rays



New Windows & New Messengers

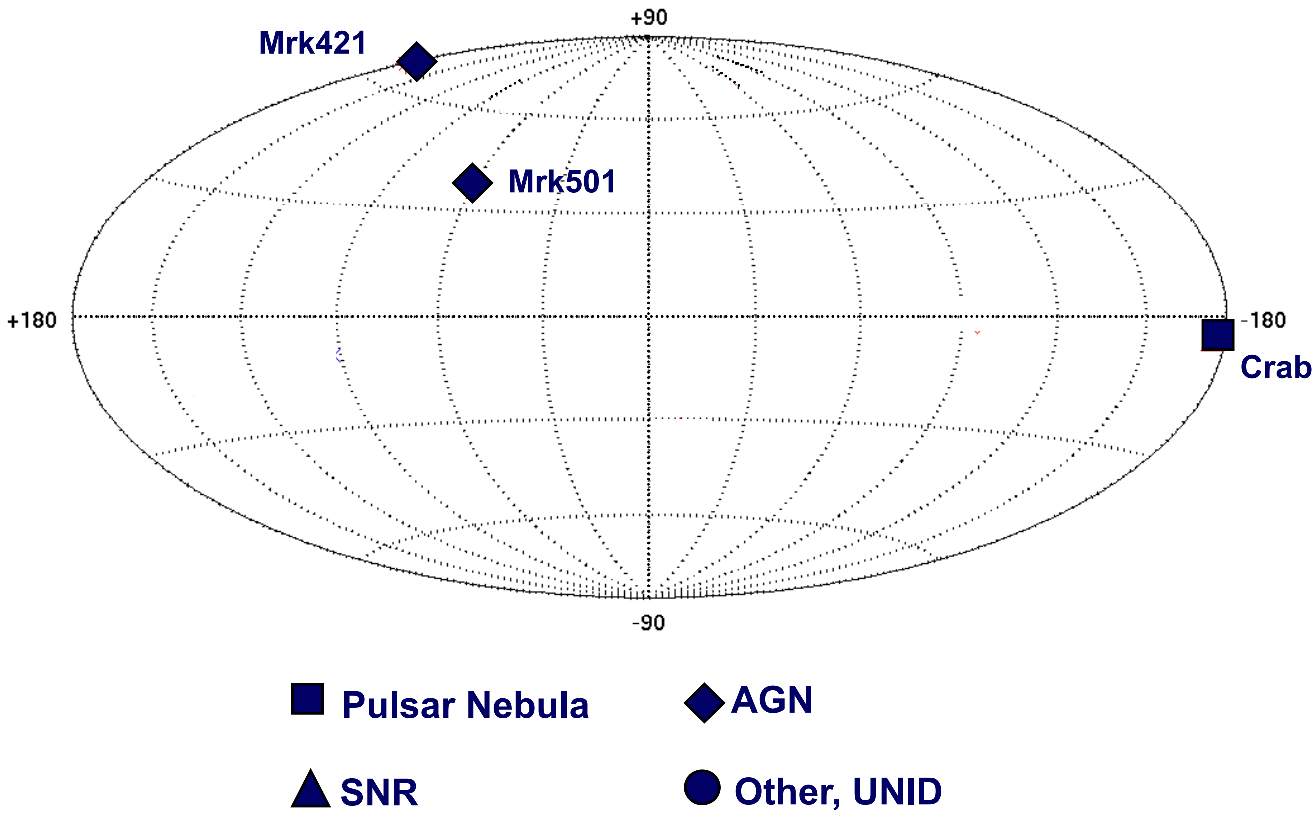


But, do TeV γ-ray sources even exist ?

YES !

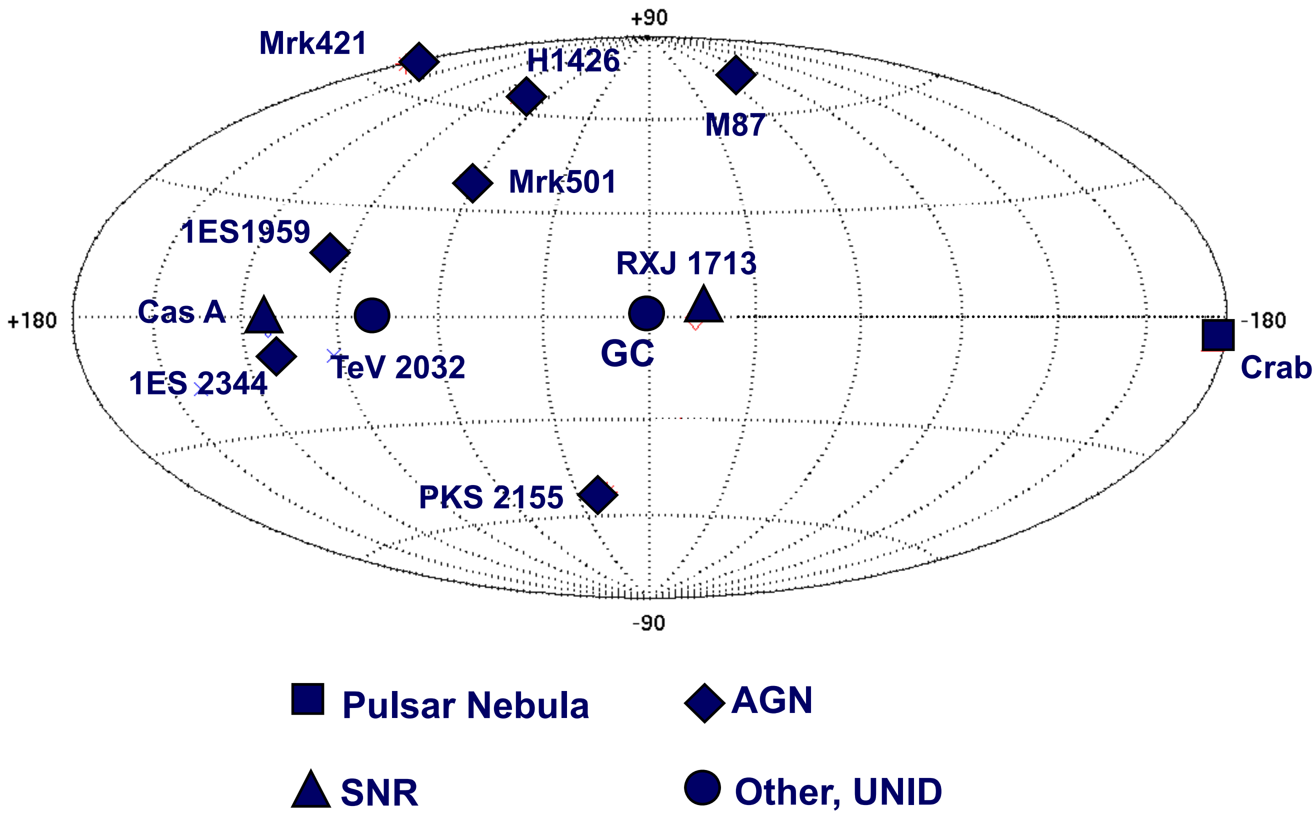
The TeV γ-ray Sky - 1998

3 sources

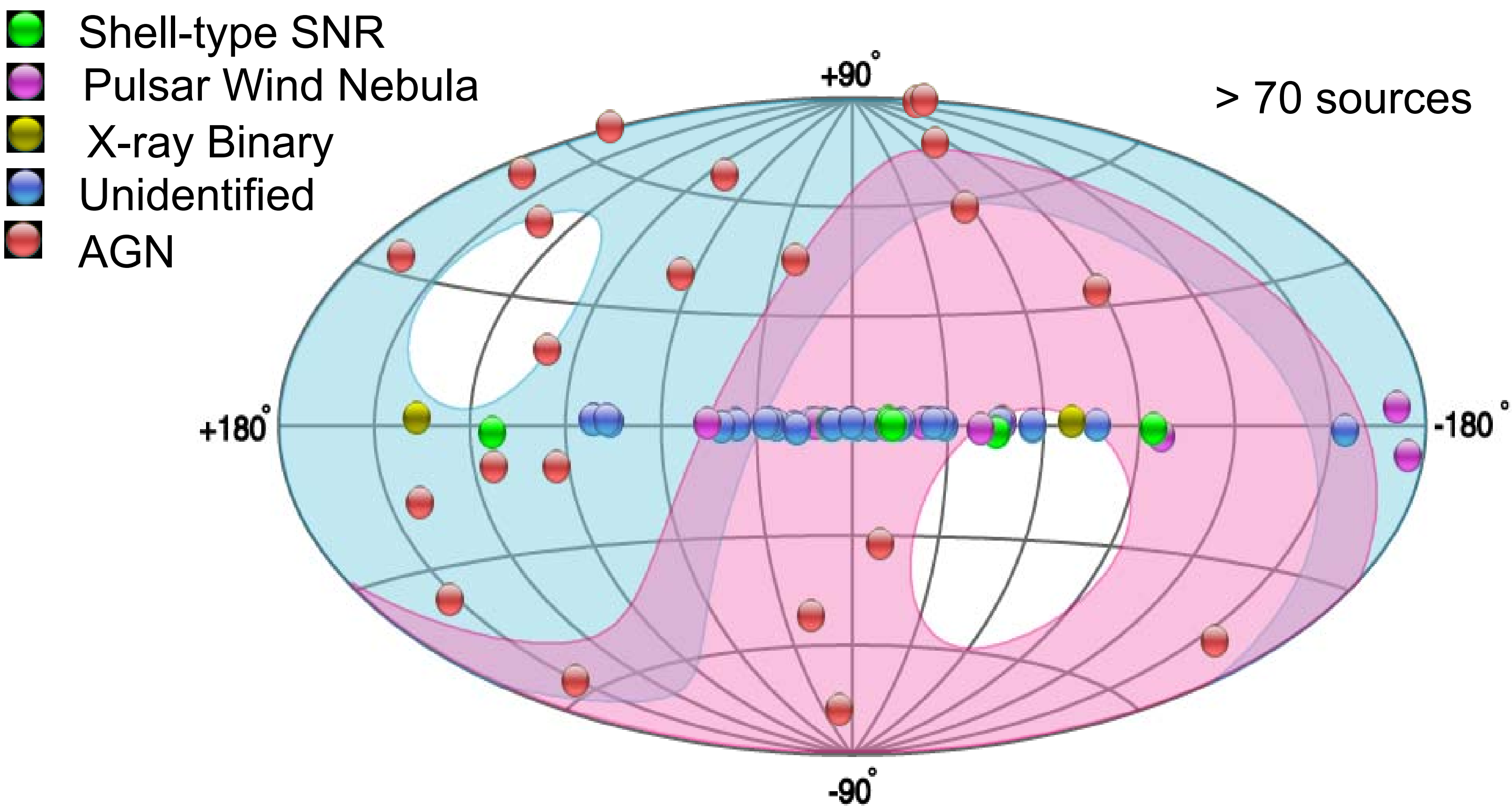


The TeV γ-ray Sky - 2003

12 sources



The TeV γ-ray Sky - 2009

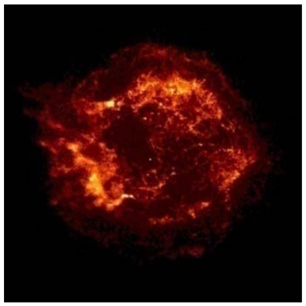


- Explosion in number of sources.

(Almost all) discoveries made by <u>Atmospheric Cherenkov Telescopes</u>

A Wide Variety of Sources …

Supernova Remnants

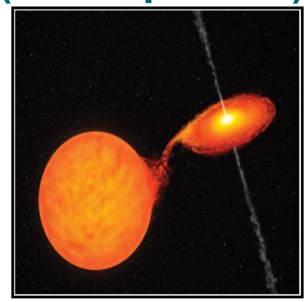


Shocks
Fermi Mechanism

Pulsars/PWN

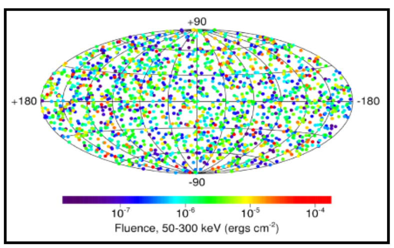
NS dynamo
Winds

HMXBs (microquasars)



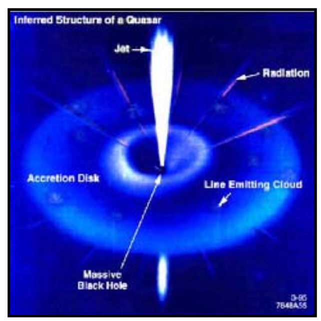
Accretion-powered jets, colliding winds, or …?

Gamma-Ray Bursts



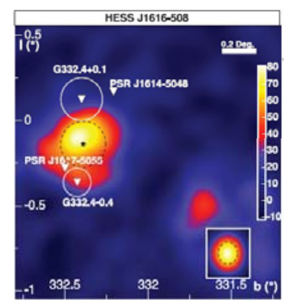
Massive star collapse
Int./ext. shocks

Active Galactic Nuclei



Massive BH
Jets

Dark accelerators…

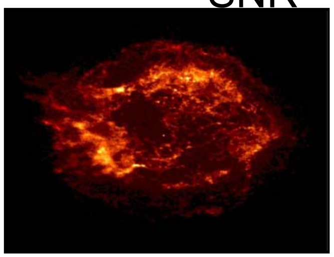


???

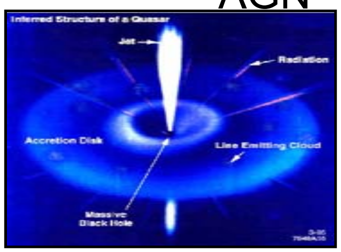
… and accelerators.

Key Physics Issues

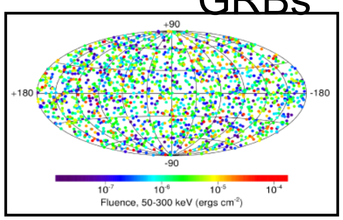
SNR

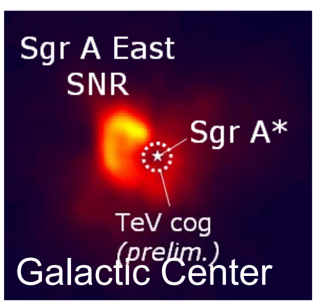


AGN



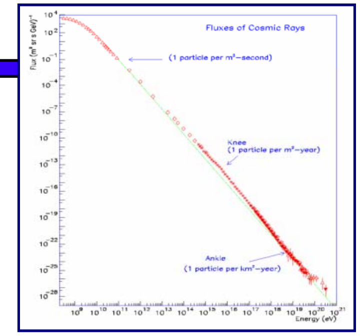
GRBs



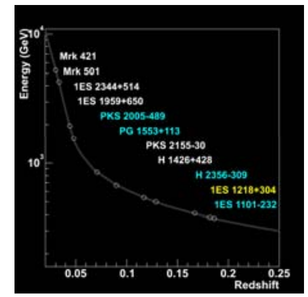


?

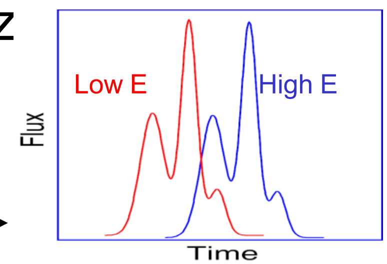
Origin of
cosmic rays



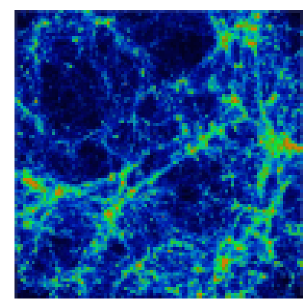
Cosmological
γ-ray horizon



Tests of Lorentz
invariance



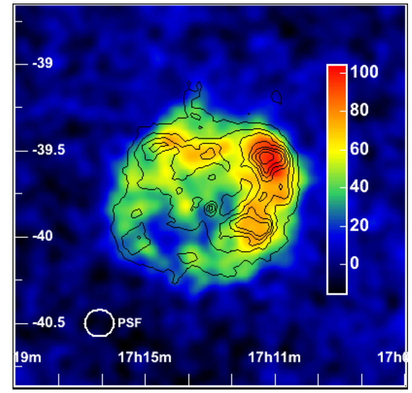
Cold dark matter
(WIMP) searches



Supernova Remnants: Origin of CR's ?

Why (VHE) gamma rays?

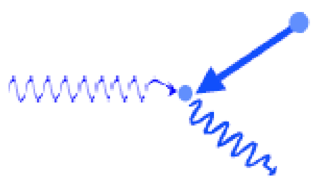
- Unlike cosmic rays, *not deflected* by interstellar magnetic fields.
- *Tracers* of parent particle populations – those particles accelerated by shocks.



SNR Image (RXJ 1713-3946)

Accelerated electrons → VHE γ-rays

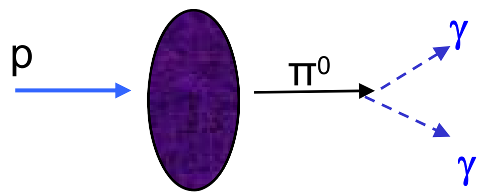
Up-scattering of soft photons



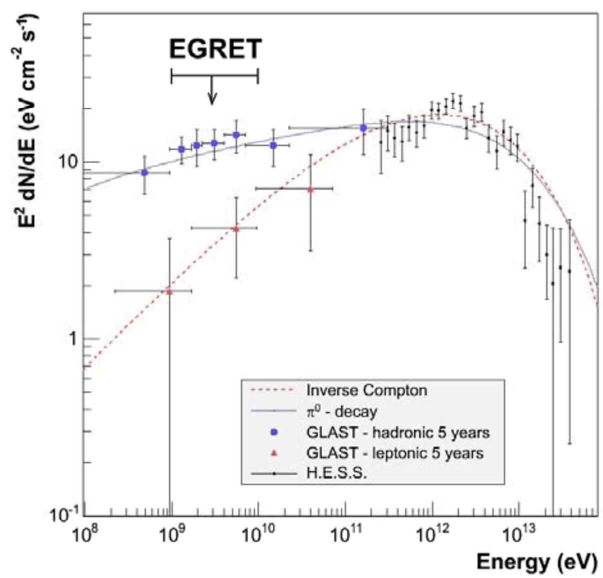
Inverse Compton Scattering

Accelerated protons → VHE γ-rays

Target interaction, π^0 decay



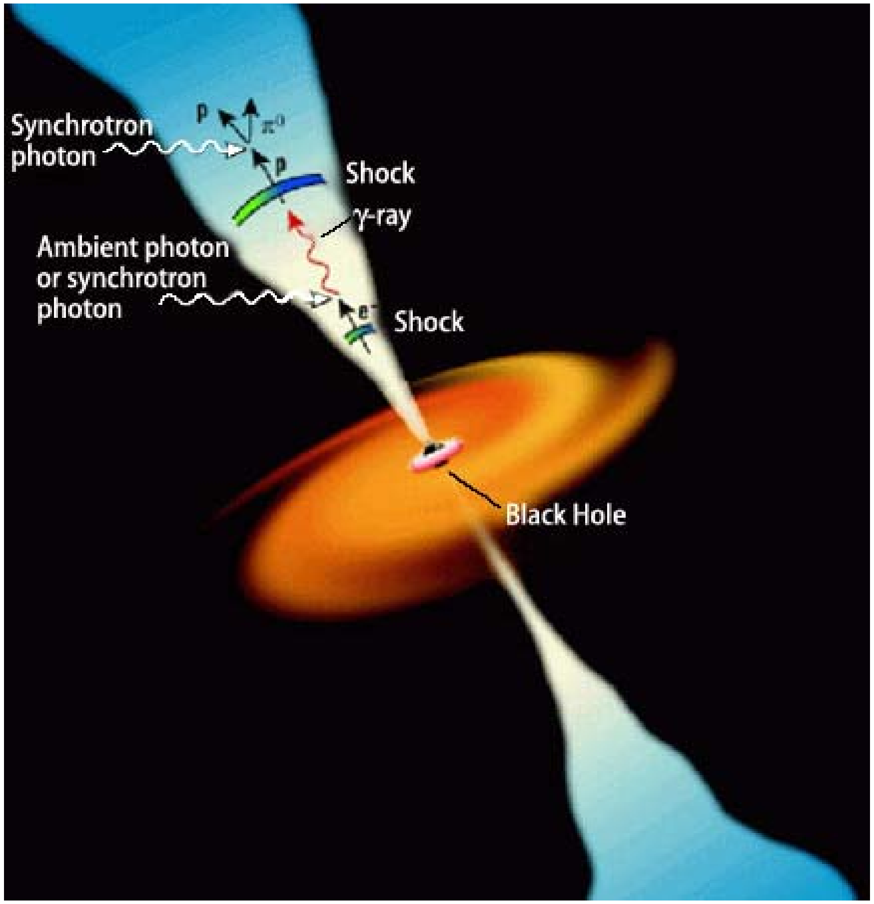
Target material



Spectral Energy Distribution

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

Active Galaxies



AGN cartoon

Active Galactic Nuclei

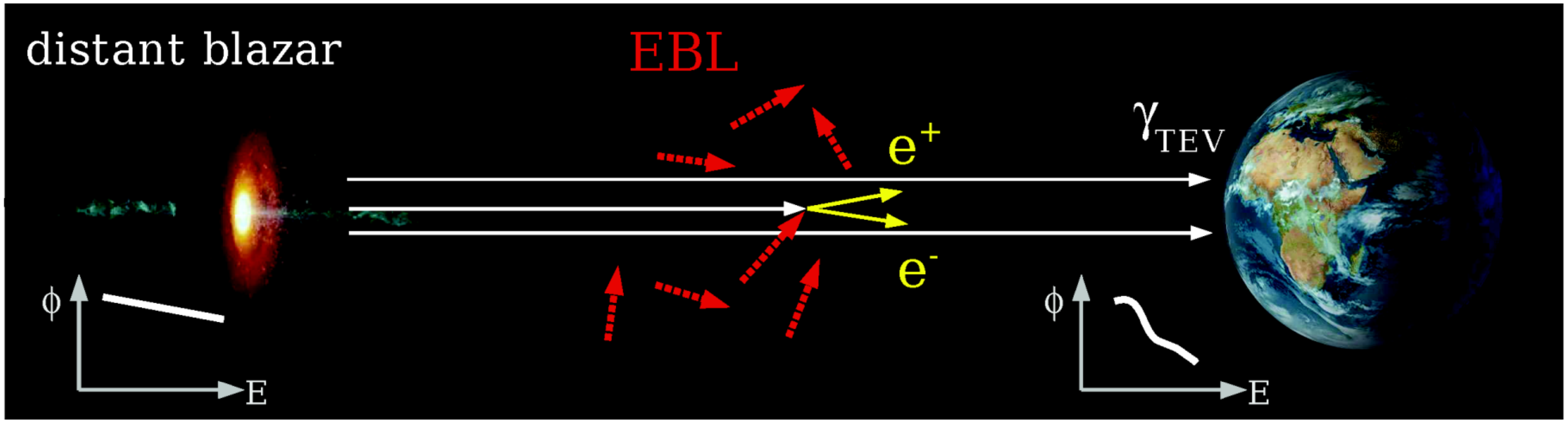
- High-luminosity extragalactic objects
  - ➔ Probe properties of the universe at large distances
- Variable!
- Jets powered by accretion on to supermassive BH

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

- **Blazars**
  - ➔ Jets aligned with line of sight
- Nearby: $z < 0.25$, EBL cutoff.
- Soft spectrum $\Gamma > 3.0$.

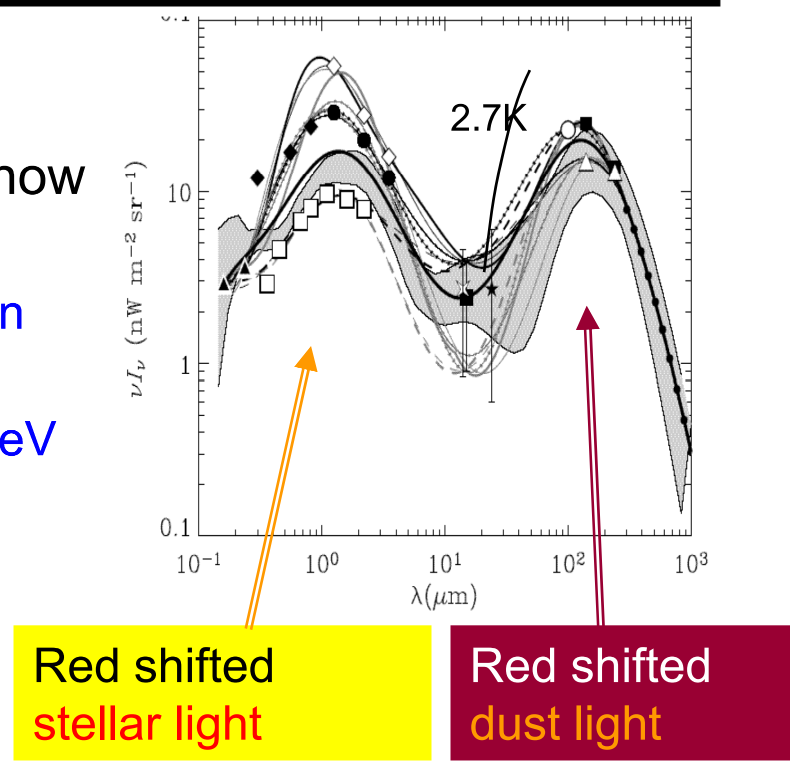
But not all are like this !

Extragalactic Background Light (EBL)



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

- Complements direct measurment in Optical, IR: *difficult.*
- Absorption signature in 50-1000 GeV band for distant sources.



Search for Cold Dark Matter

Hypothesis:

- Cold dark matter – decays or annihilates to give γ signal.

Target regions with:

- Favorable DM distributions.

$\chi + \chi$

$\nu, \bar{\nu}$

γ **continuum**

γ **lines**

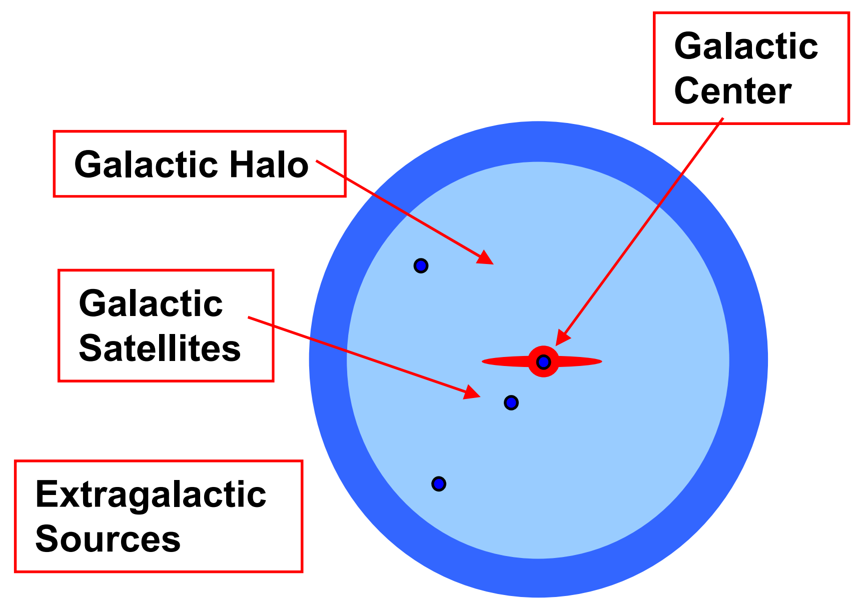
Point back to source

$\bar{p}$

e^{+}

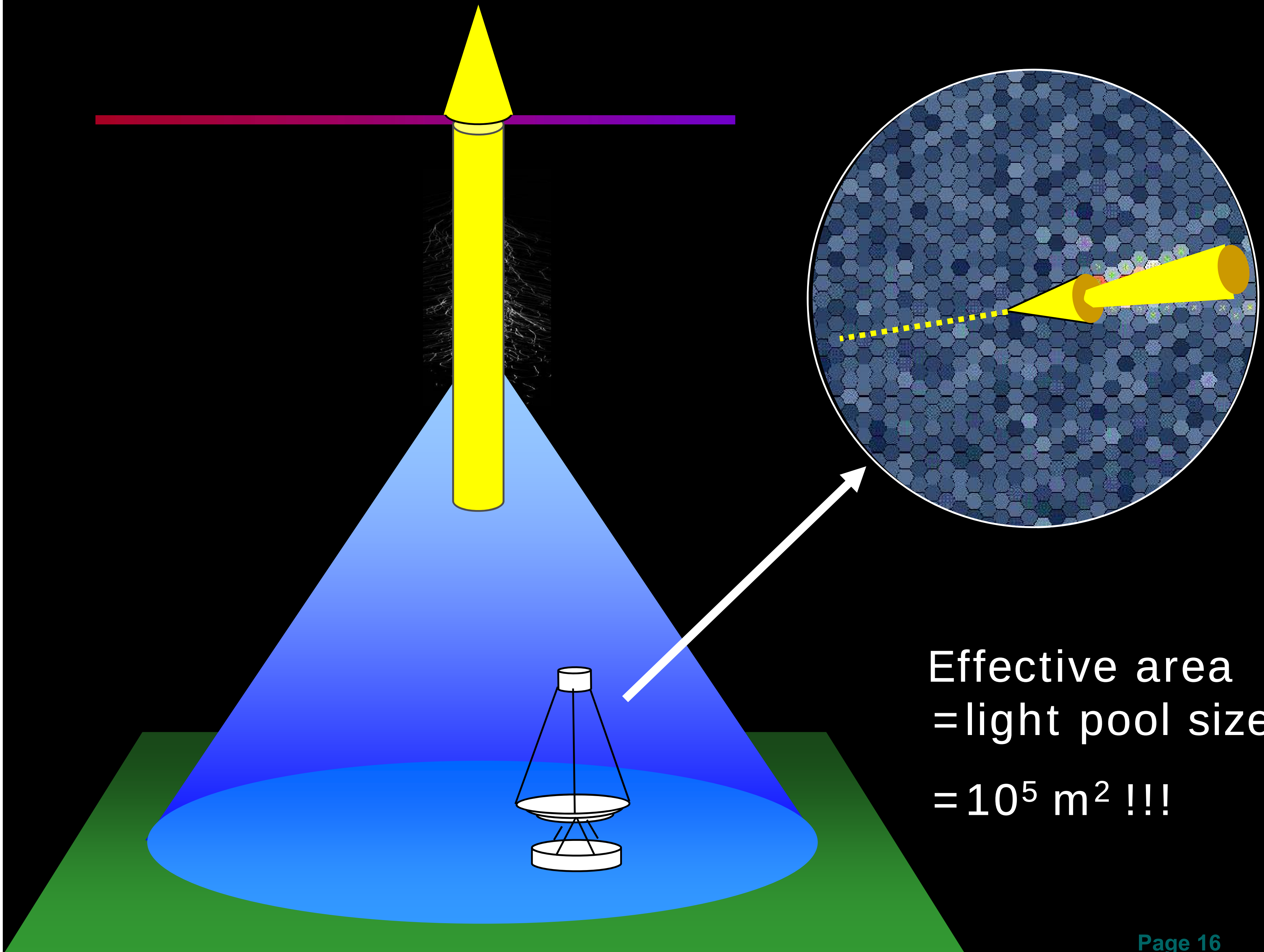
$\bar{d}$

Anti-Matter



Complementary approach to direct detection & LHC.

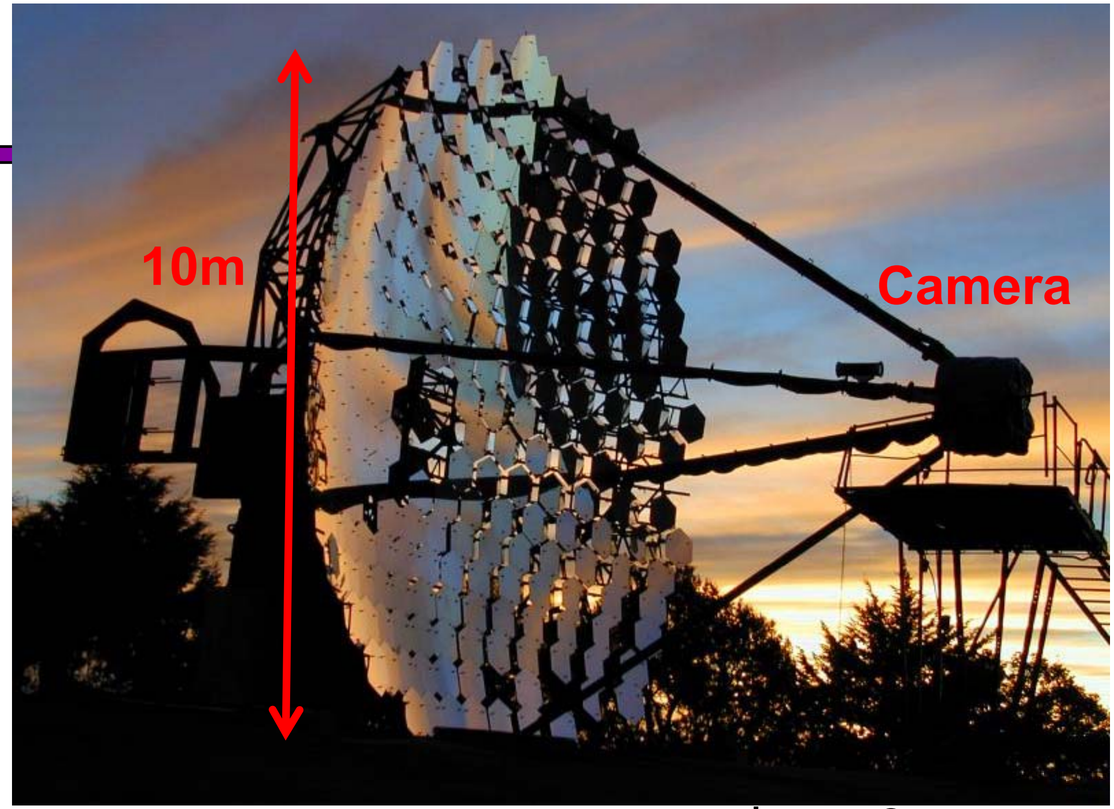
Experimental Technique



Effective area
=light pool size

$=10^5\ m^2$!!!

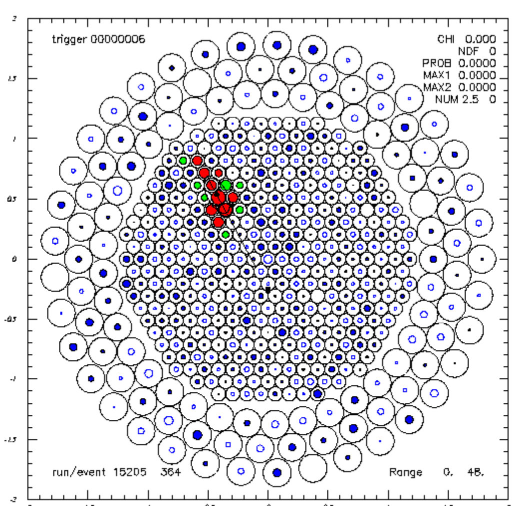
Whipple 10m
γ-ray Telescope



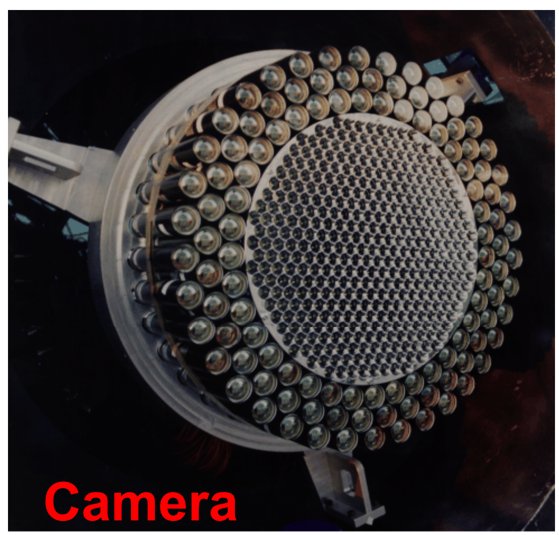
- The Whipple 10m (1968 -).
- Pioneered use of imaging:
  T. Weekes et al.

- Made first source detections
Crab in 70 hours of observing.

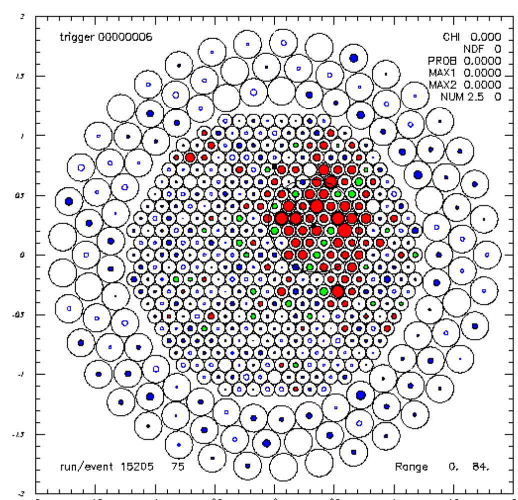
gamma ray?



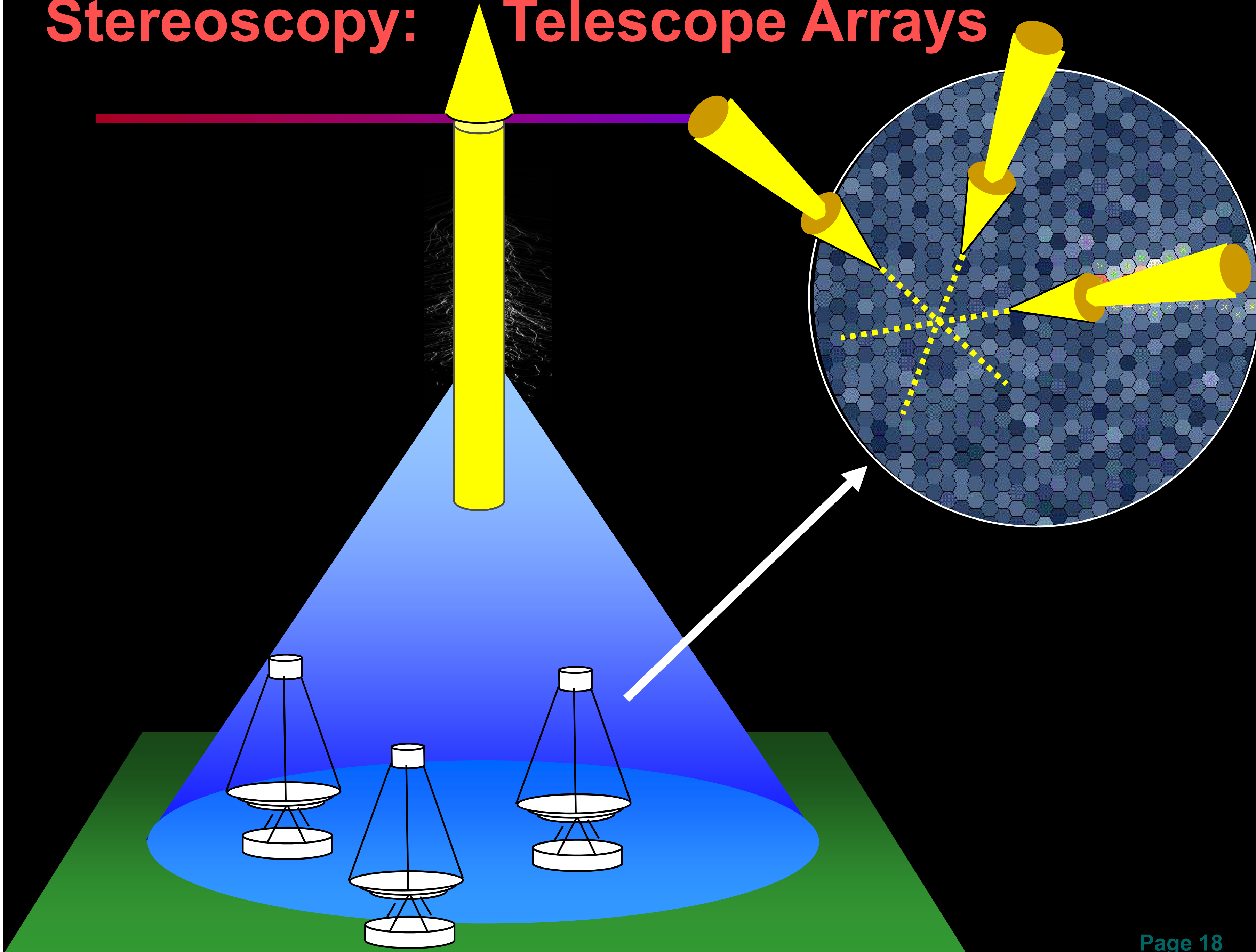
ch



cosmic ray?



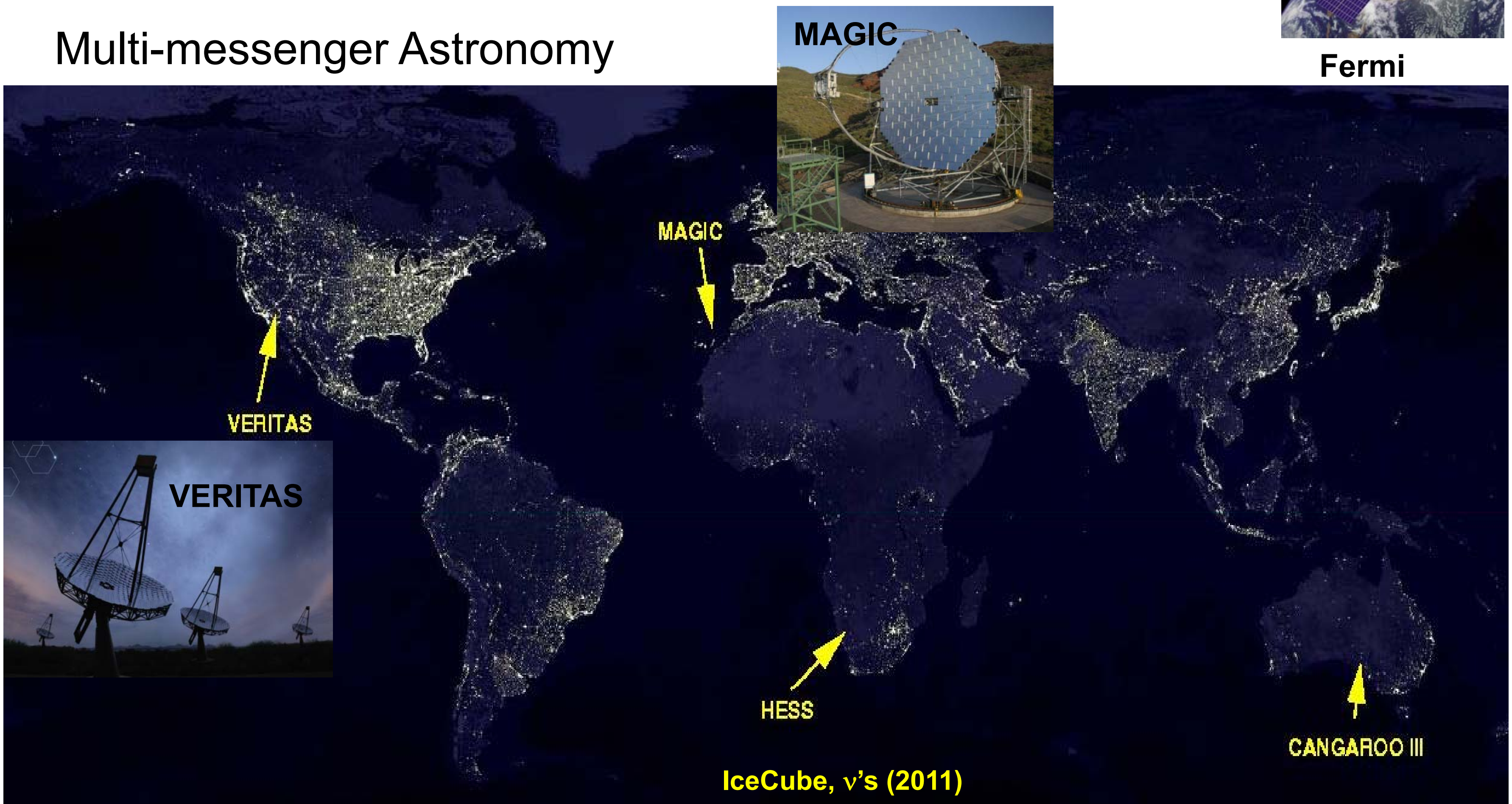
Stereoscopy: Telescope Arrays



Major VHE Telescopes

Fermi

Multi-messenger Astronomy



VERITAS

Collaboration of ~80 scientists.
15 Institutions in U.S., Canada, U.K., and Ireland.

Detector Design:

- Four 12m telescopes.
- 500 pixel cameras (3.5^{o}).
- 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: Mt. Hopkins, AZ

U.S.:
Adler Planetarium
Argonne National Lab
Barnard College
DePauw Univ.
Grinnell College
Iowa State Univ.
Purdue Univ.
Smithsonian
Univ. of California, Los Angeles
Univ. of California, Santa Cruz
Univ. of Chicago
Univ. of Delaware
Univ. of Iowa
Univ. of Massachusetts
Univ. of Utah
Washington Univ., St. Louis

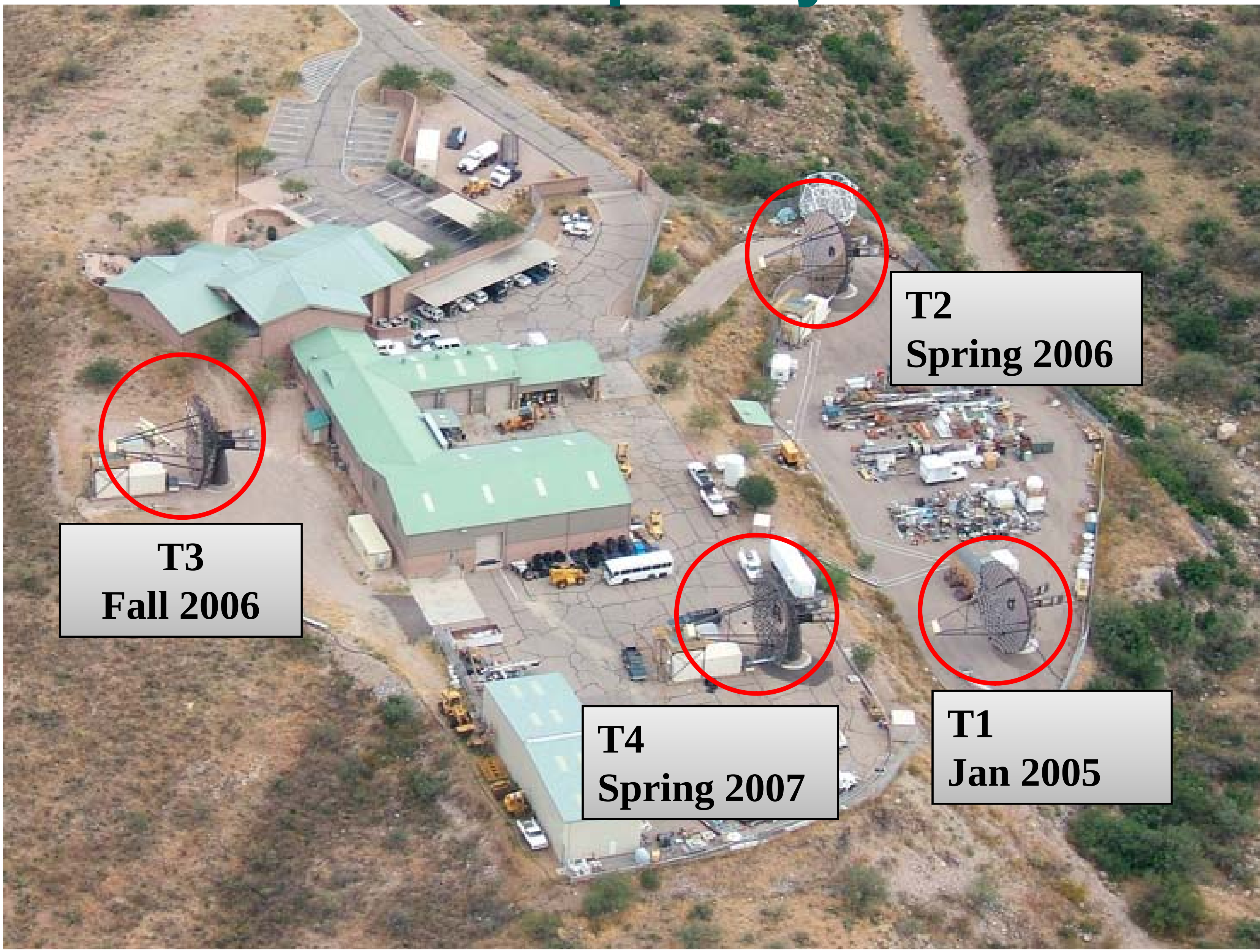
Canada:
McGill Univ.

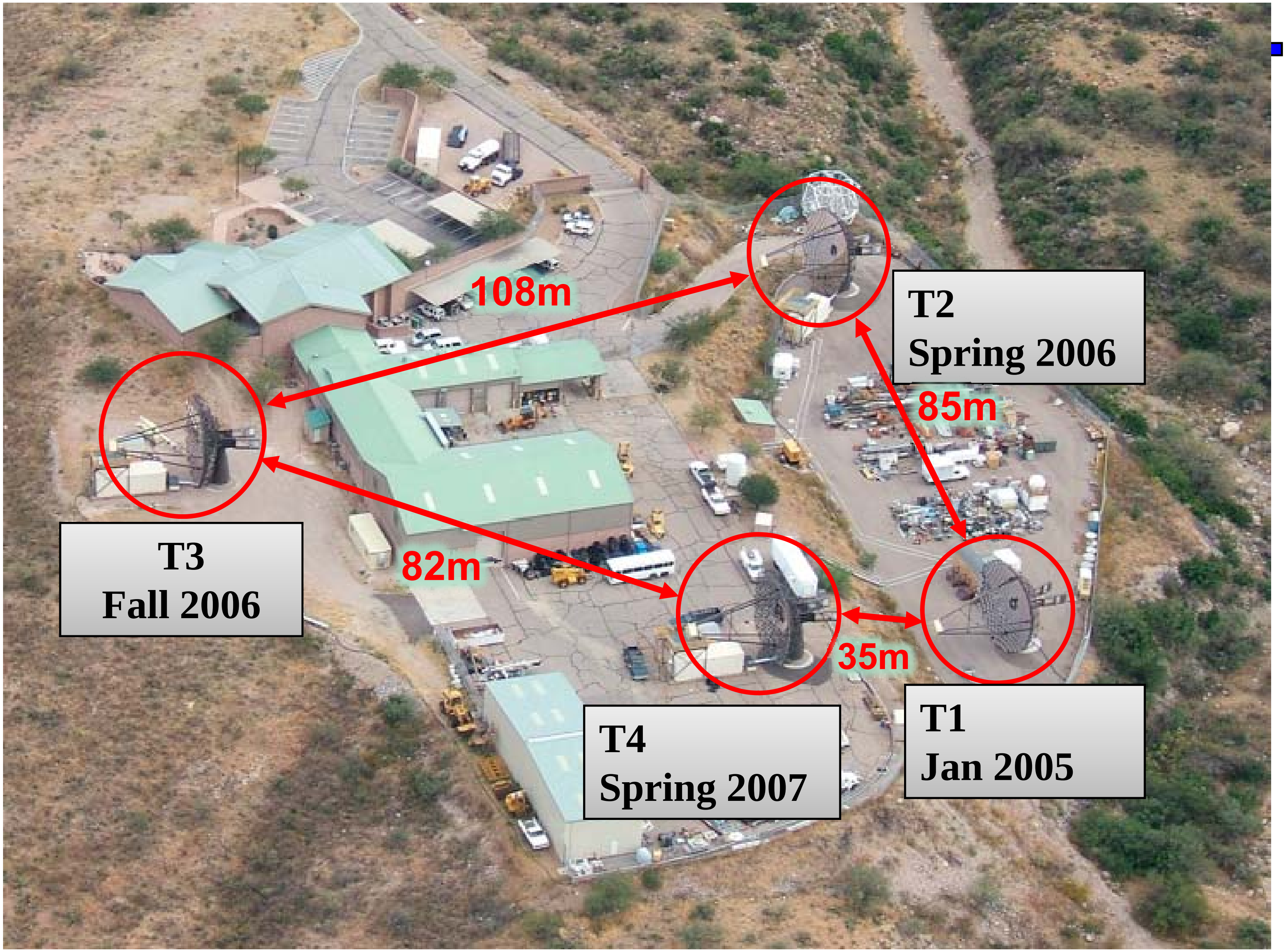
U.K.:
Leeds Univ.

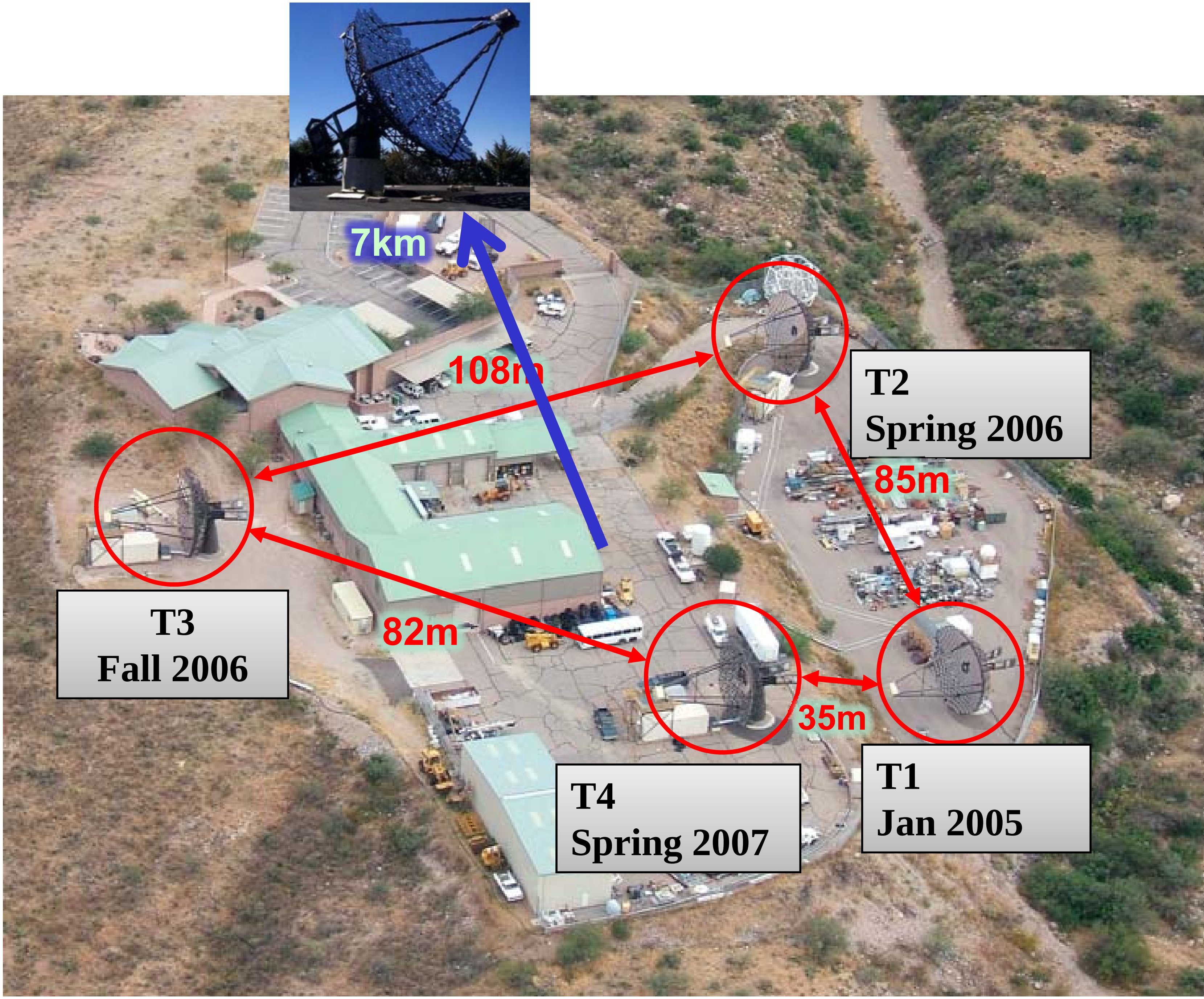
Ireland:
Cork Inst. Tech.
Galway-Mayo Inst. Tech.
Nat. Univ. Ireland, Galway
Univ. College Dublin

+ ~25 Associate Members

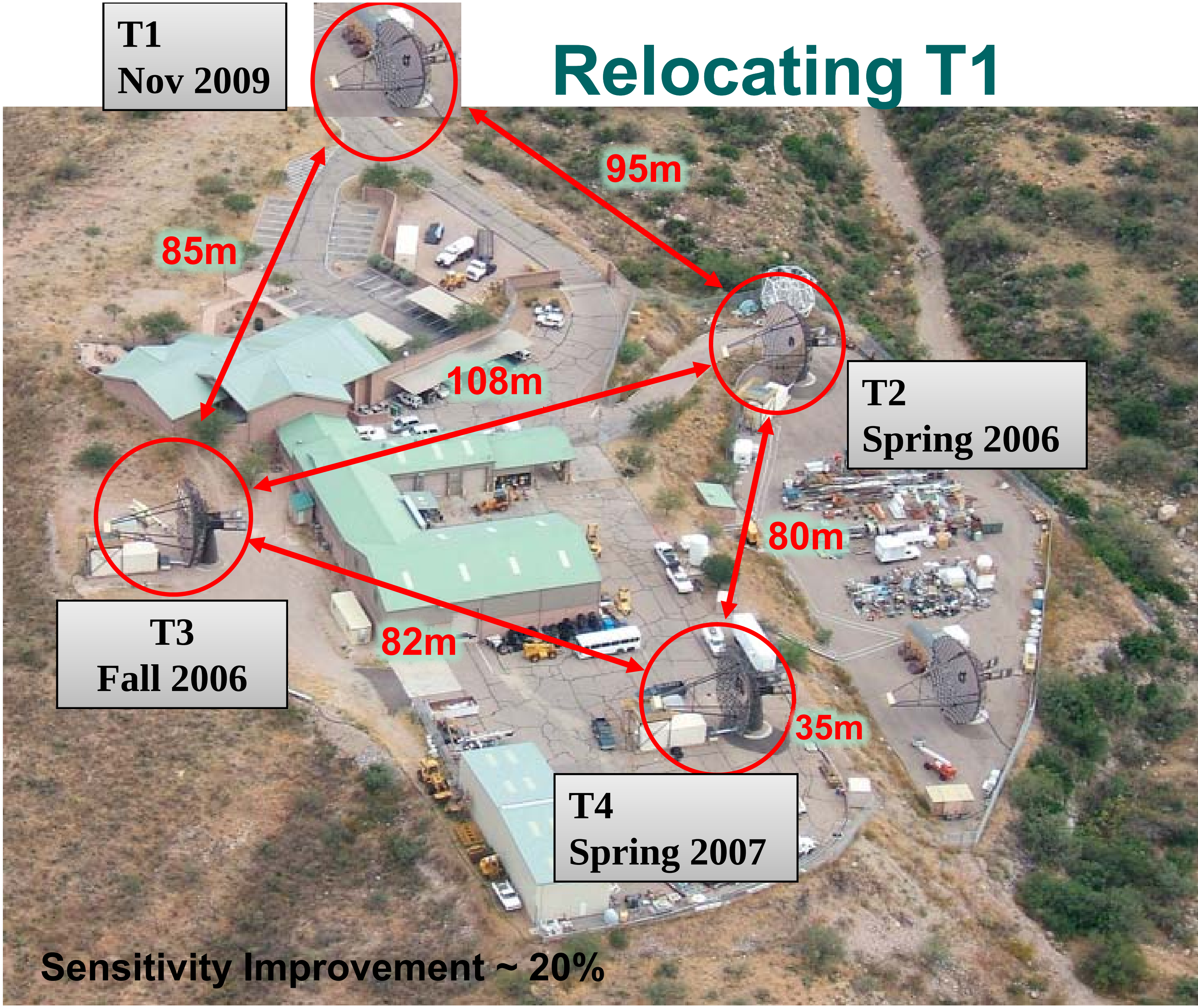
Telescope Layout




108m
T2
Spring 2006
85m
T3
Fall 2006
82m
35m
T4
Spring 2007
T1
Jan 2005


7km
108m
85m
82m
35m
T2
Spring 2006
T3
Fall 2006
T4
Spring 2007
T1
Jan 2005

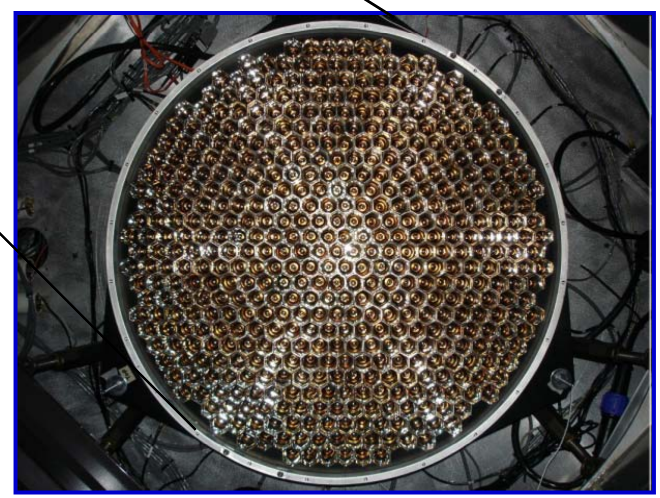
Relocating T1



A VERITAS Telescope

12m reflector, f1.0 optics

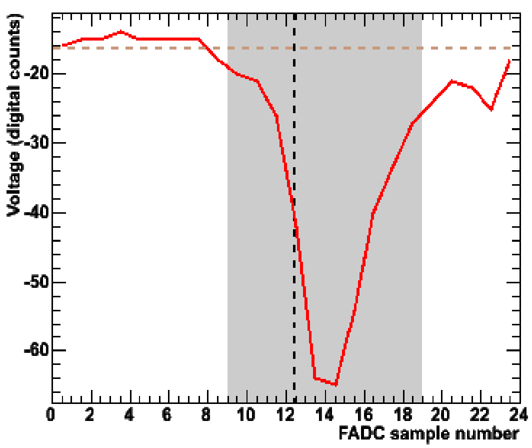
350 Mirror Facets

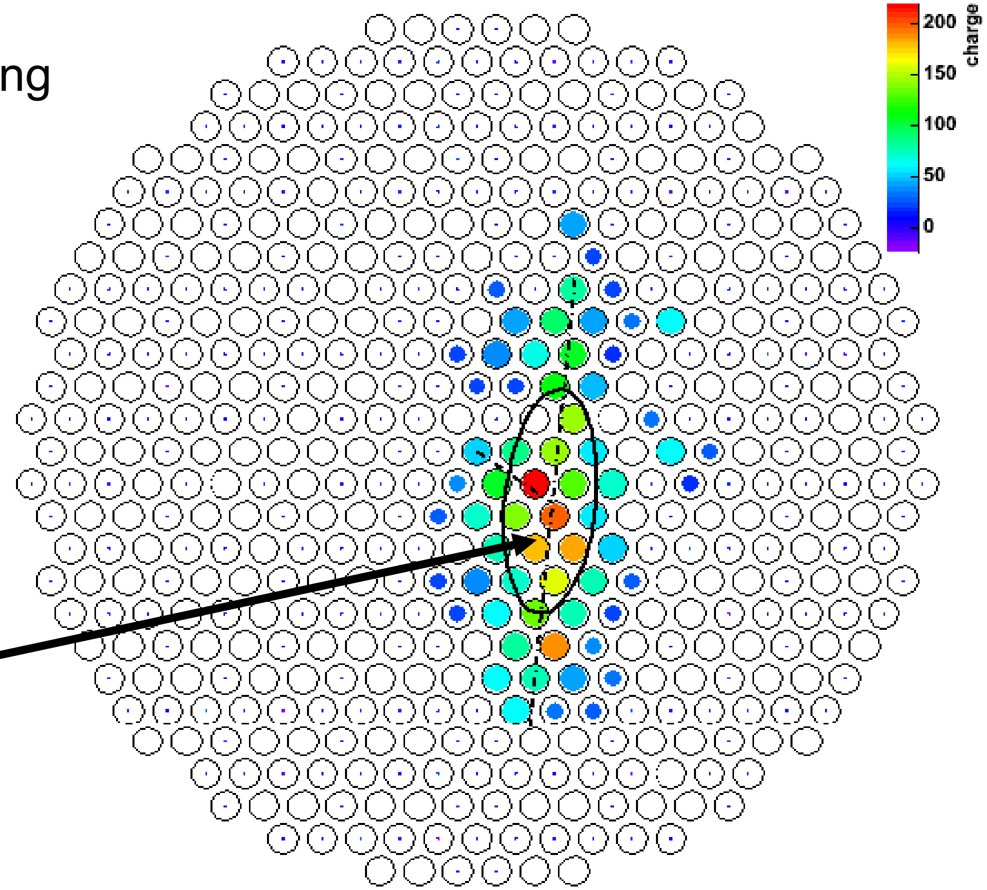


500 pixel Camera

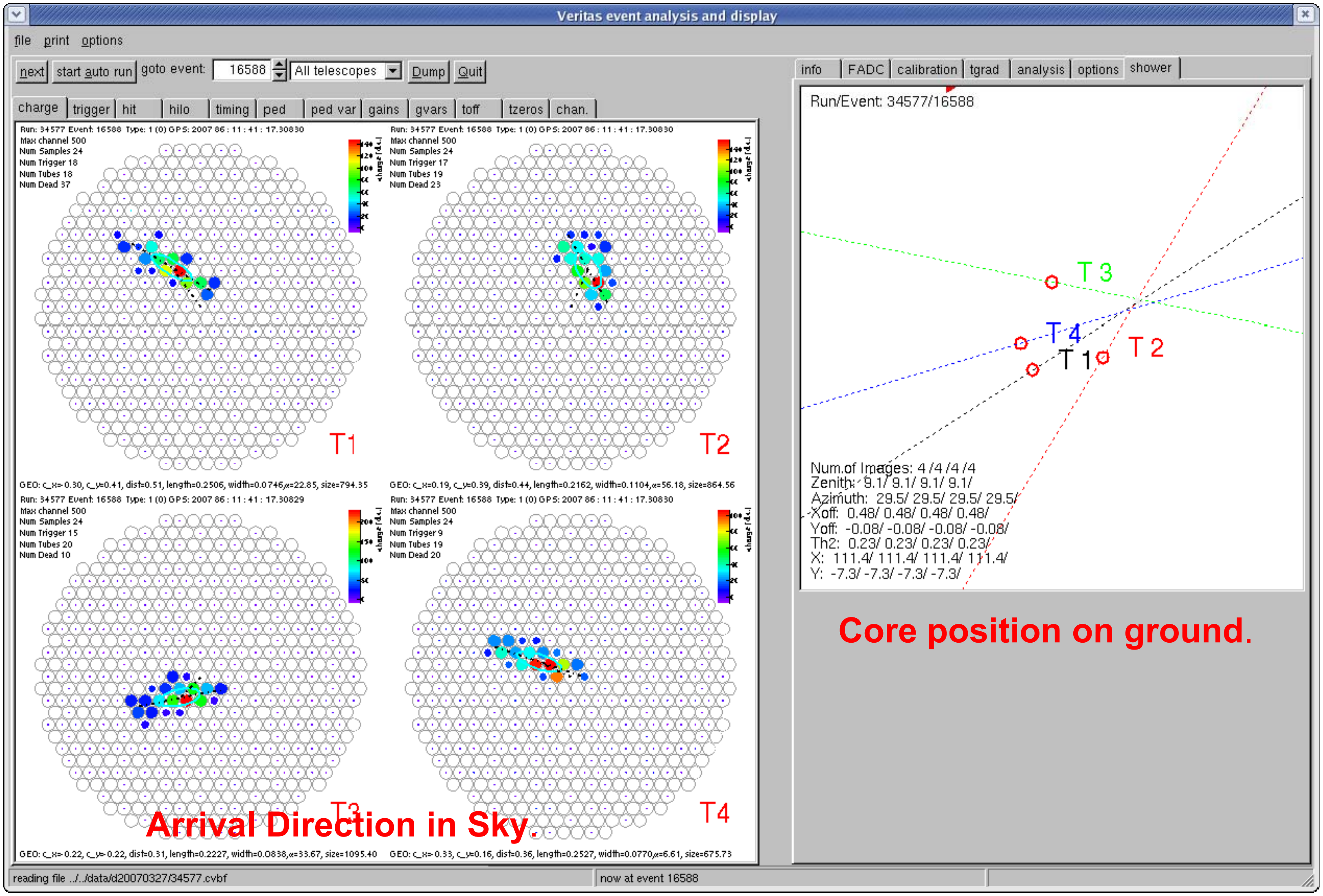
VERITAS Data Acquisition

- PMTs digitized with 500 MHz sampling FADCs





Four-Telescope Event



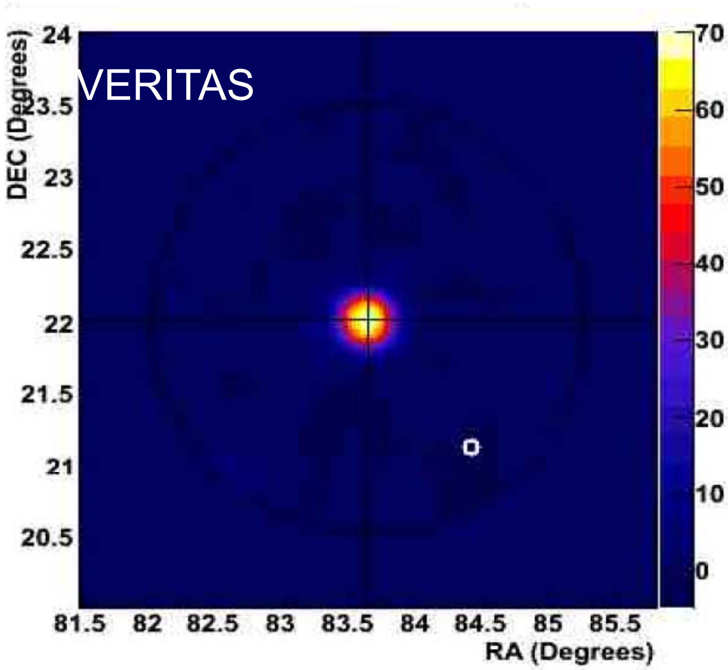
Crab Nebula – Now a Calibration !

VERITAS Sensitivity:

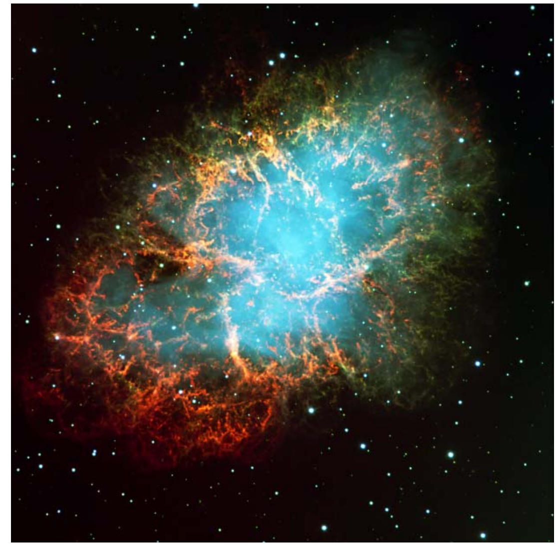
1 Crab 45s (5σ)

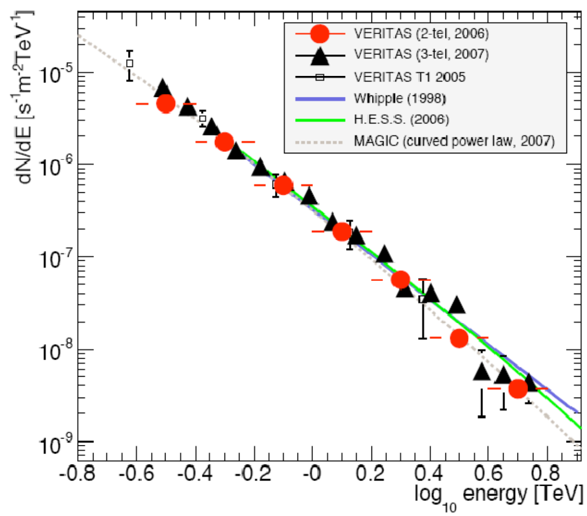
5% Crab ~2.5 hr

1% Crab ~40 hrs



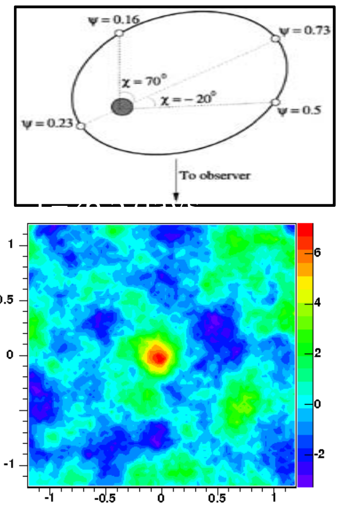
Angular resolution 3'-6'
Pointing accuracy < 75''



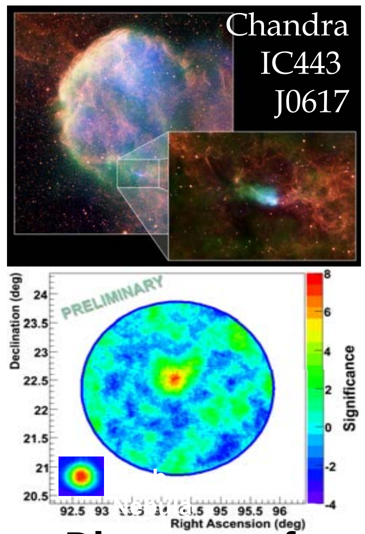


Energy spectrum

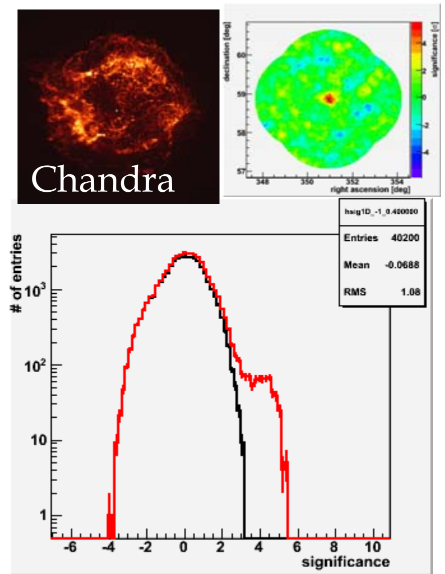
VERITAS First-Year Results



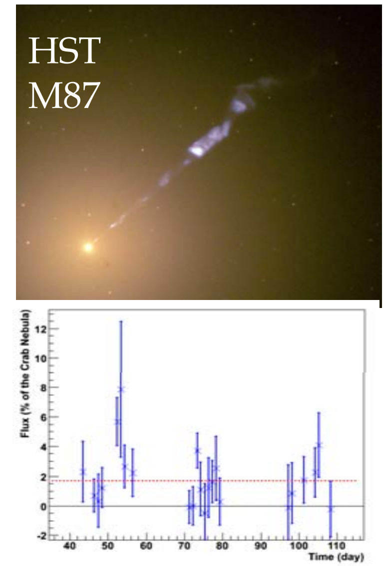
XRB LSI +61



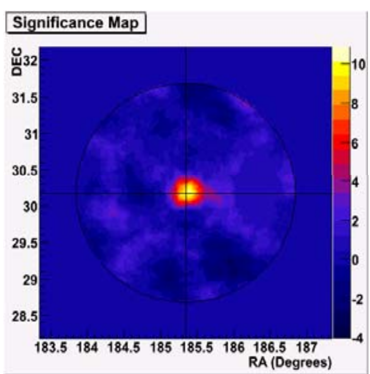
Discovery of SNR IC 443



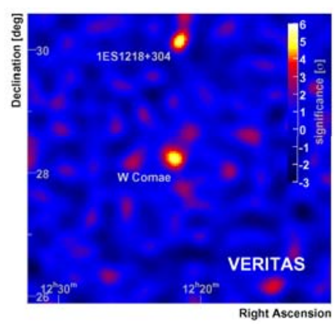
SNR Cassiopeia A



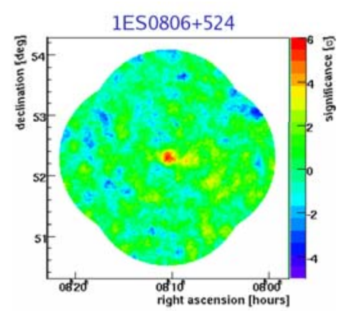
M87 Radio Galaxy



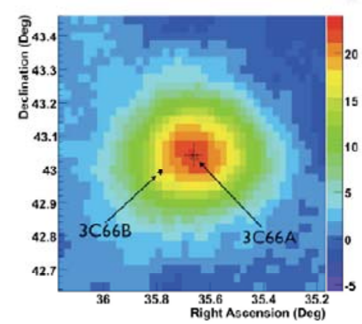
Blazar 1ES1218+30
z=0.182, 2nd most distant VHE source



Discovery of Blazar W Comae
z = 0.102



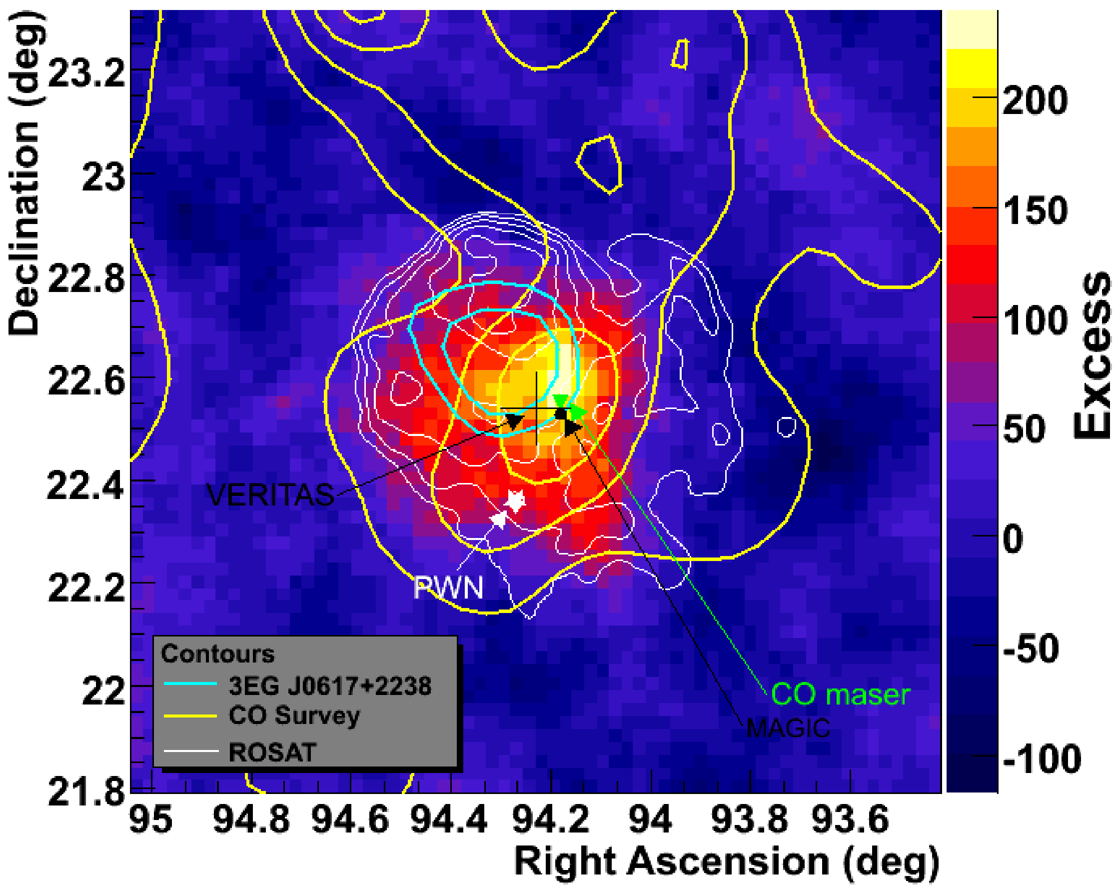
Discovery of Blazar 1ES 0806
z = 0.138



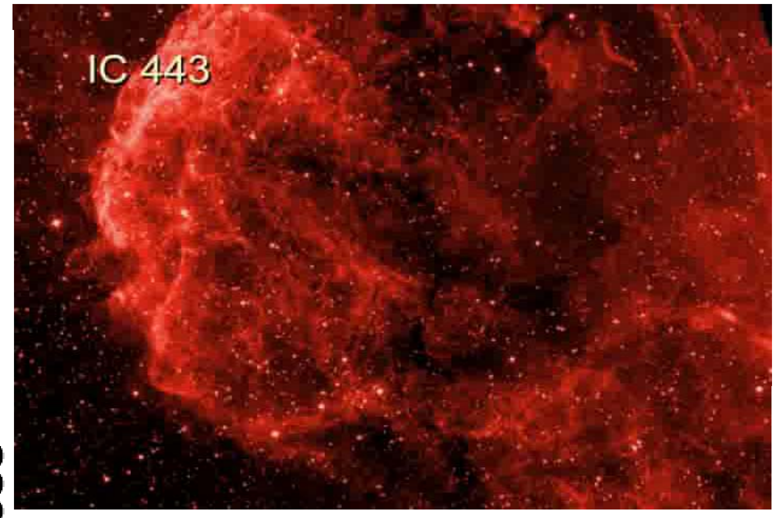
Discovery of Blazar 3C 66A, z = 0.444
Most distant source ?

Supernova Remnant IC443

Excess Map (smoothed)



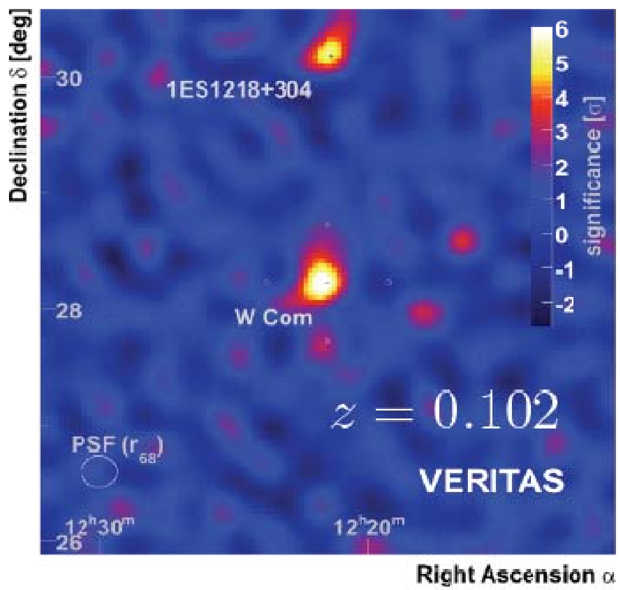
Acciari et al.,ApJ (2009)..



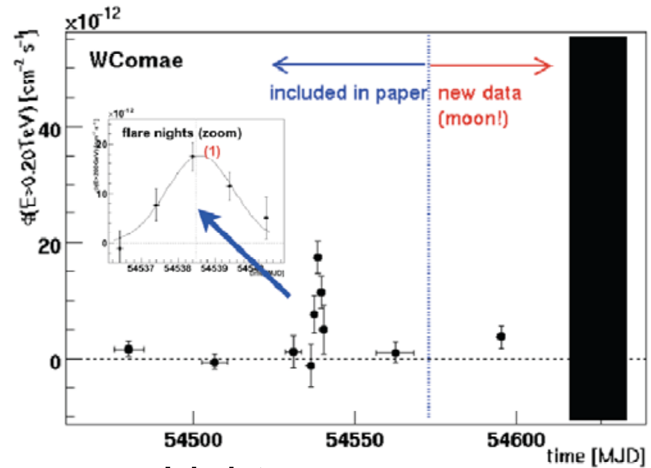
- VERITAS/MAGIC co-discovery, 2007.
- Overlap with CO indicating molecular cloud along line of sight.
- Maser emission suggests SNR shock interacting with cloud.
- TeV emission could be
  - **CR-induced pion production in cloud**

New Blazars with VERITAS

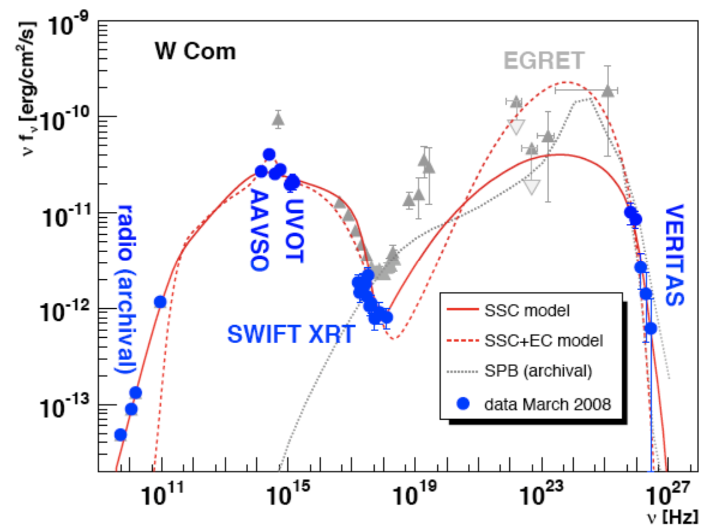
- W Comae: VERITAS discovery
  - **2 flares, 1 taken in moonlight.**
  - **First IBL discovered at VHE.**
  - **Simultaneous Swift data.**



Two AGN in the same field.



Light curve

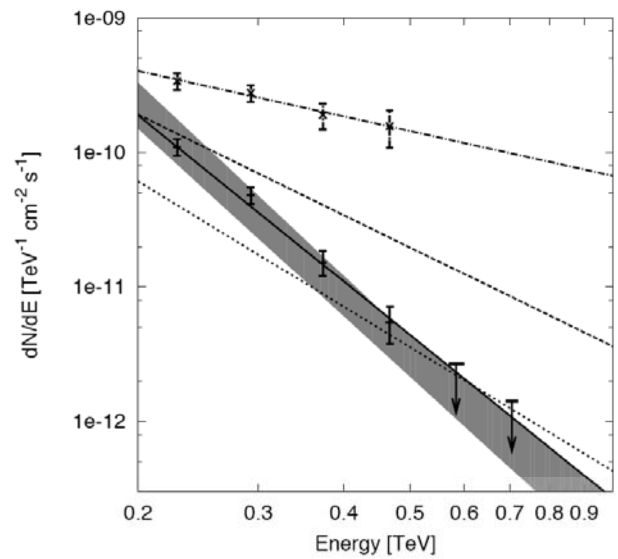


Broad-band SED, EC preferred.

Astrophysical Journal, 684, L73, 2008

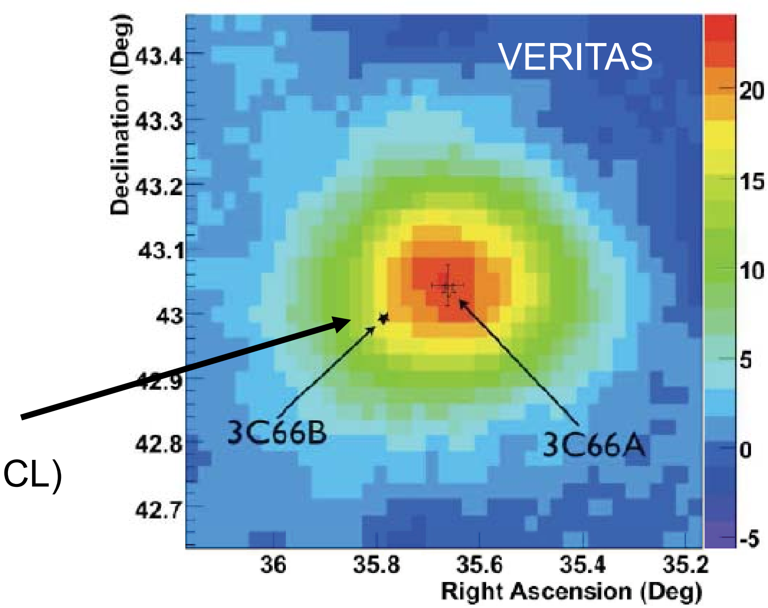
New Blazars with VERITAS

- 3C66A
  - **Distant AGN Z= 0.444.**
  - **VERITAS excludes 3C66B (in 2008) at 4.3σ.**



Controvery:
Blazar
or
Radio
galaxy?

MAGIC claims 3C66B (@85% CL) in 2007



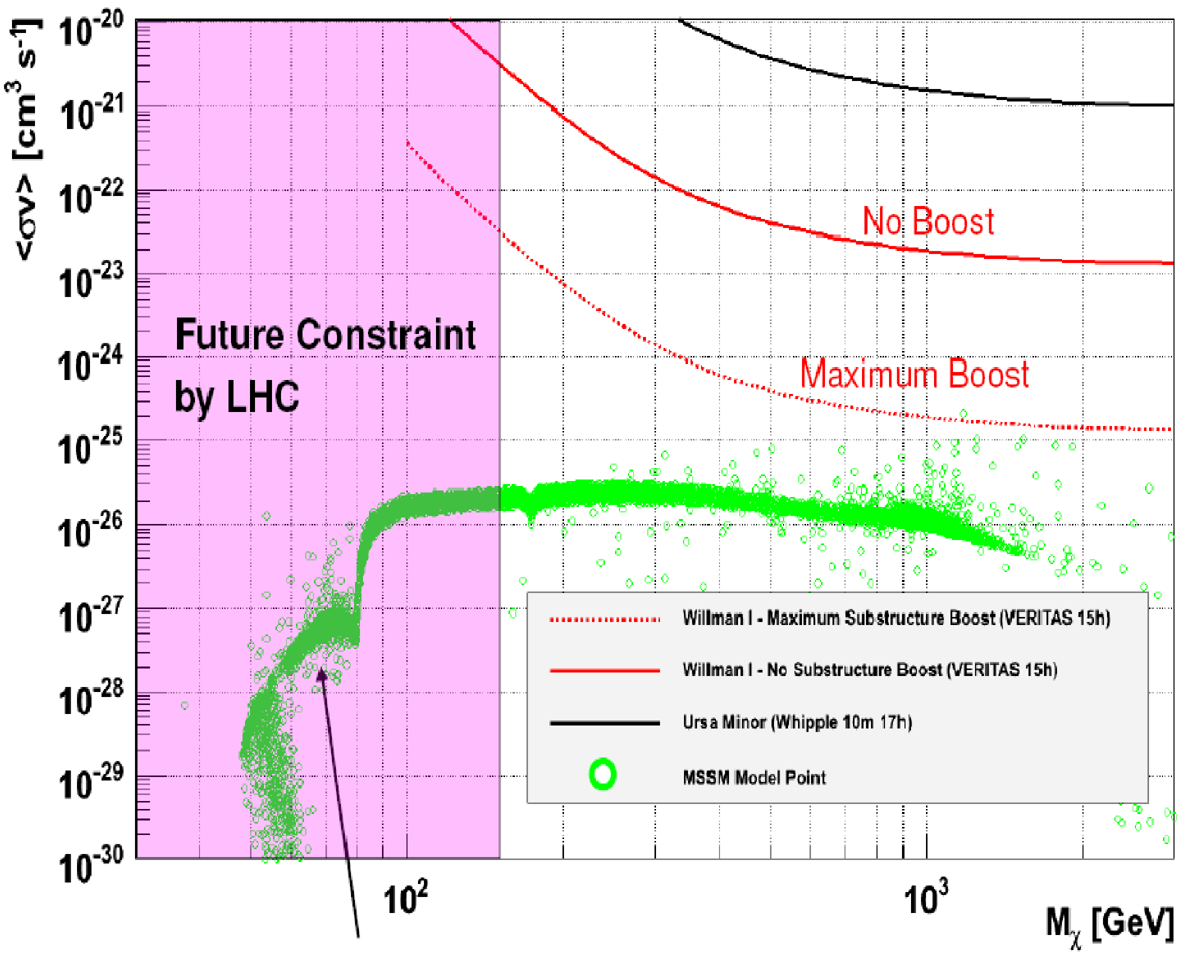
Very soft spectrum
Γ = 4.1 +/- 0.4 +/- 0.6

\

Acciari et al., ApJ, (2009); astro-ph/0901.4527.

Dark Matter Search: Dwarf Galaxies

Recent VERITAS observations:
Draco, Ursa Minor, Willman I



Whipple 10m
Ursa Minor constraint

VERITAS (and 15 hr data)
Willman I constraints
derived from
Strigari et al. 2007

<σv>:
Thermal average of product
σ: WIMP self -annihilation x-sec
v: WIMP velocity

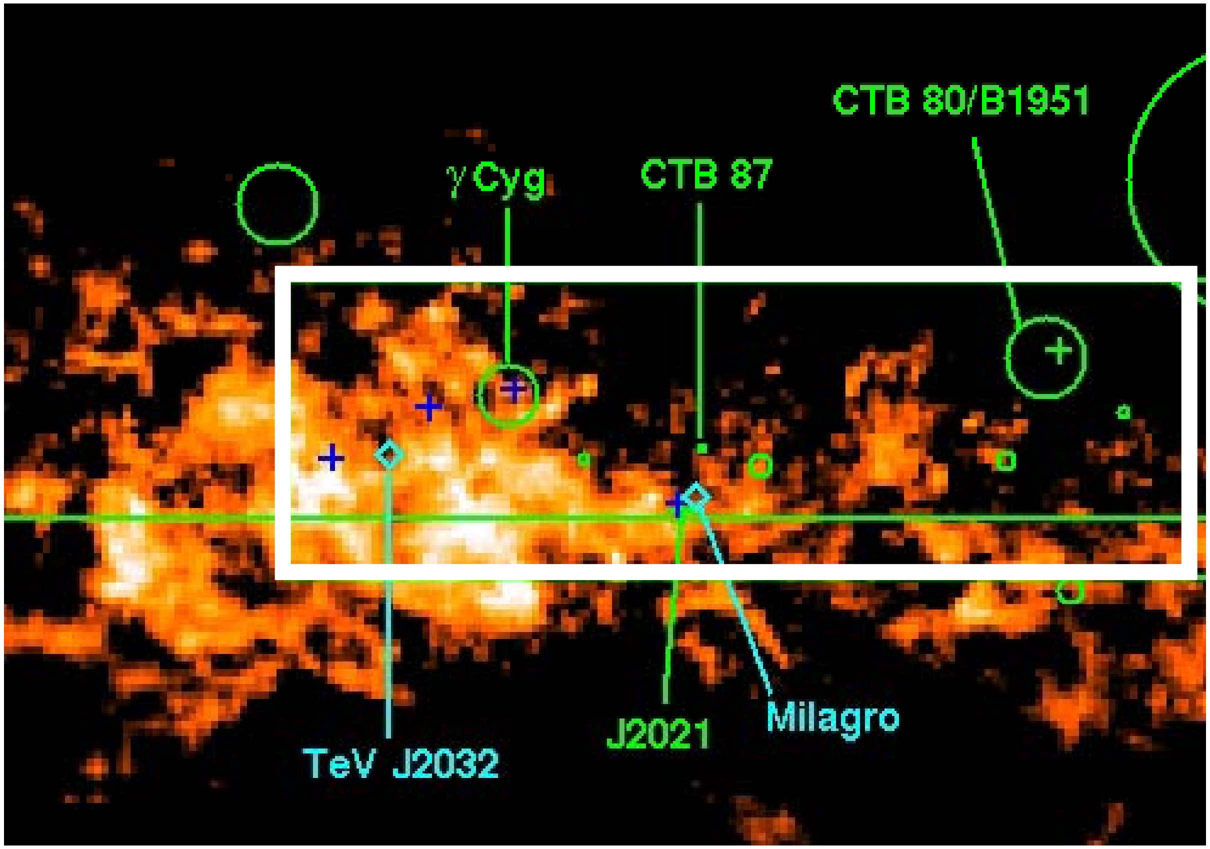
Minimal Supersymmetric extensions to Standard Model (MSSM) allowed by WMAP

What's next for VERITAS ?

LOTS!

- New Results: to be announced this summer.
- Observing: we are in 2nd year of 5+ year program.
- Fermi Gama-Ray Space Telescope overlap.
- MWL studies: radio, optical, X-ray, γ-ray.
- Upgrade possibilities: e.g. new cameras, triggers.
- …

VERITAS Sky Survey



SNR/PWN

TeV Unidentified

EGRET (GeV)

X-ray binaries

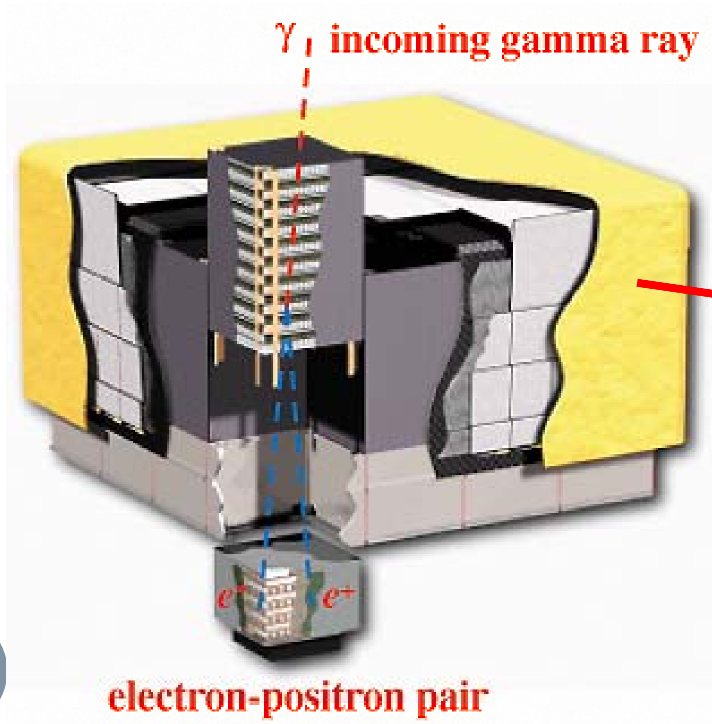
Other possible source types:
star clusters/star-forming regions, Wolf-Rayet stars

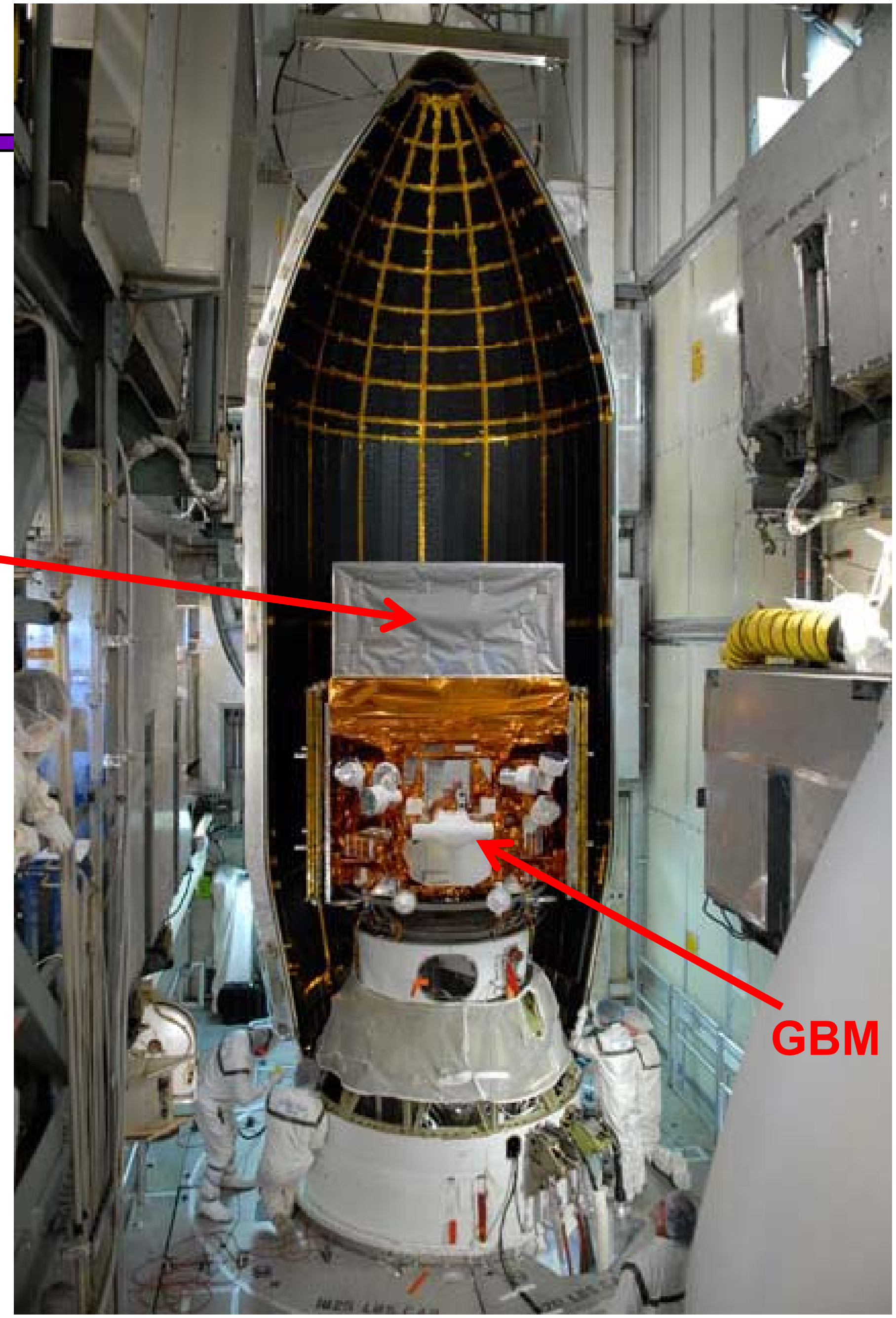
..or the completely unexpected !

- 2 year project, covering 150 deg^2.
- Ambitious---originally intended a larger region, but getting enough time is challenging (region best visible in July/August moonsoon season).
- 150 hrs data taken so far, <u>results this summer</u>.

Fermi GST

Large Area Telescope (LAT)





LAT images the sky one photon at a time: γ-ray converts in LAT to an electron and a positron ; direction and energy of these particles tell us the direction and energy of the photon

Fermi-LAT science objectives

> 2000 AGNs
blazars and radiogal = f(θ,z)
evolution z < 5
Sag A*

10-50 GRB/year
GeV afterglow
spectra to high energy

γ-ray binaries
Pulsar winds
μ-quasar jets

Possibilities
starburst galaxies
galaxy clusters
measure EBL
unIDs

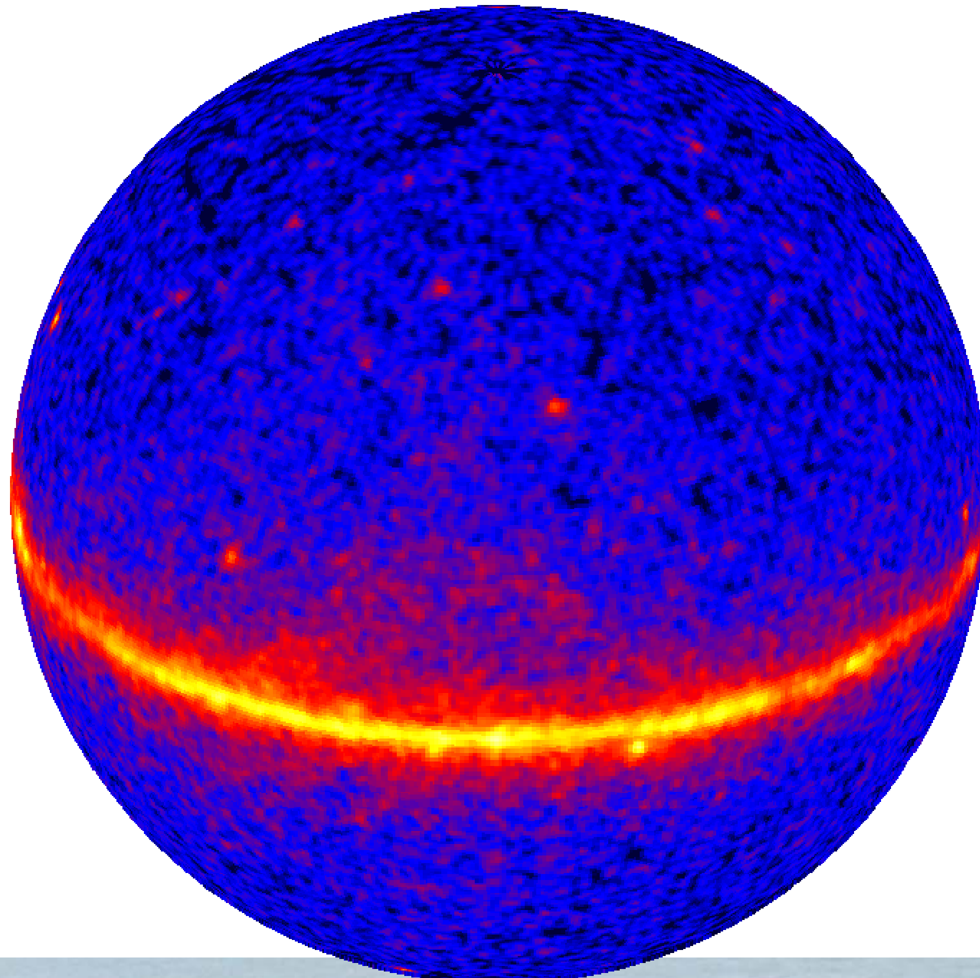
Dark Matter
neutralino lines
sub-halo clumps

Cosmic rays and clouds
acceleration in Supernova remnants
OB associations
propagation (Milky Way, M31, LMC, SMC)
Interstellar mass tracers in galaxies

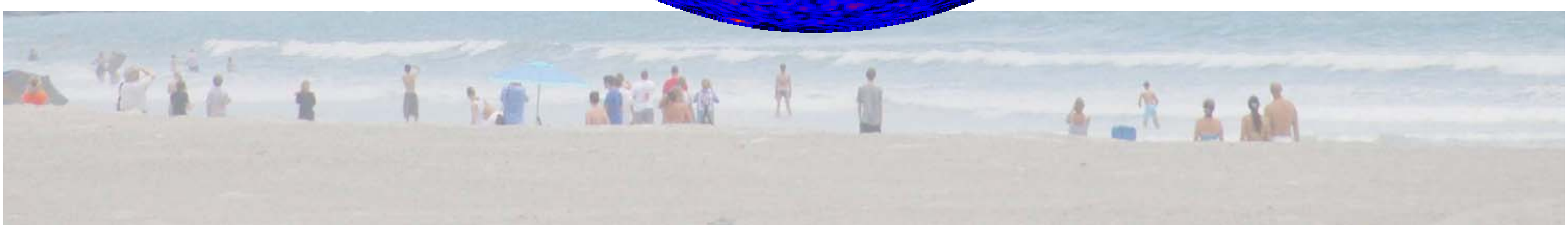
Pulsars
emission from radio and X-ray pulsars
blind searches for new Gemingas
magnetospheric physics
pulsar wind nebulae

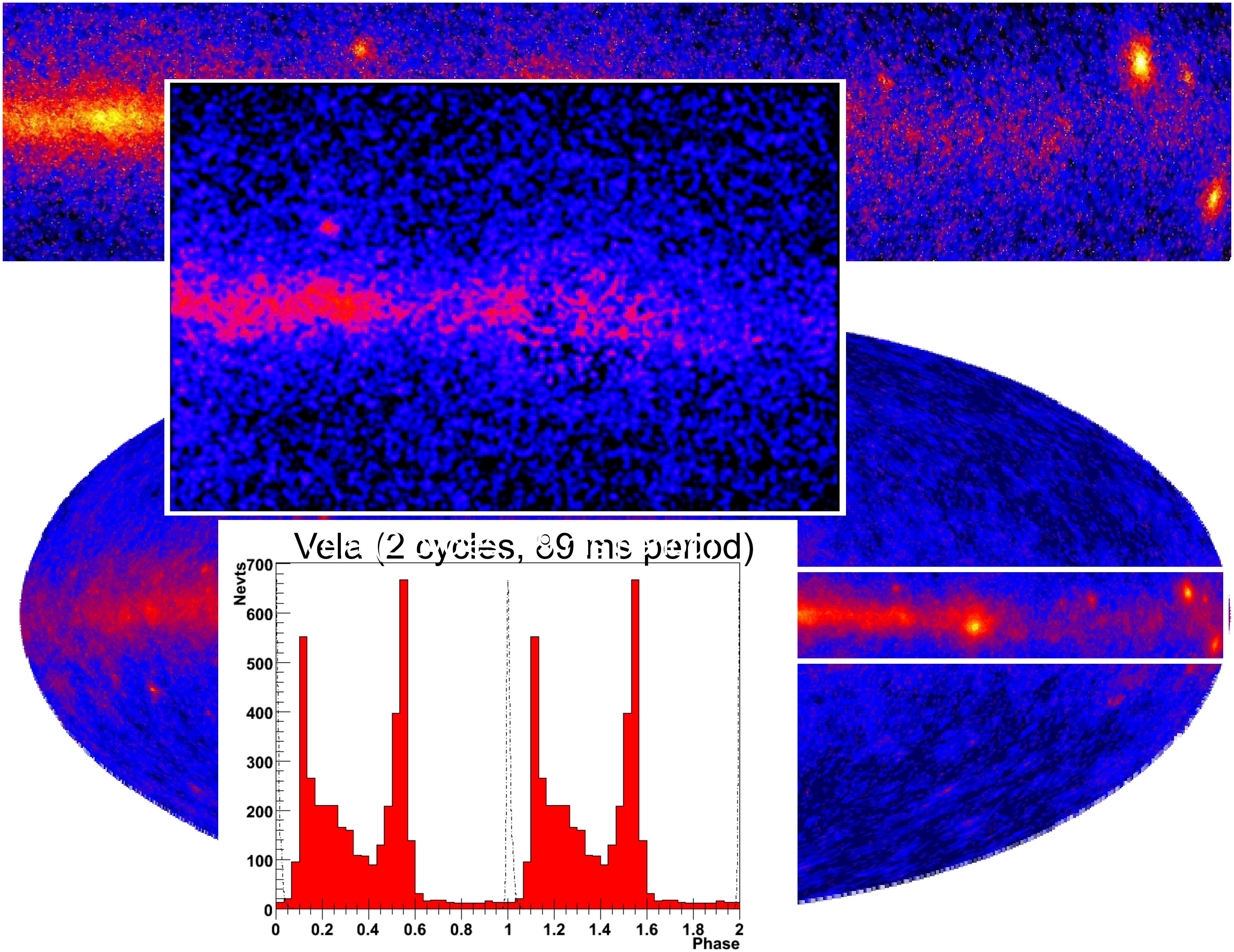
Launch from Cape Canaveral Air Station
11 June 2008 at 12:05PM EDT.

First Light FGST-LAT



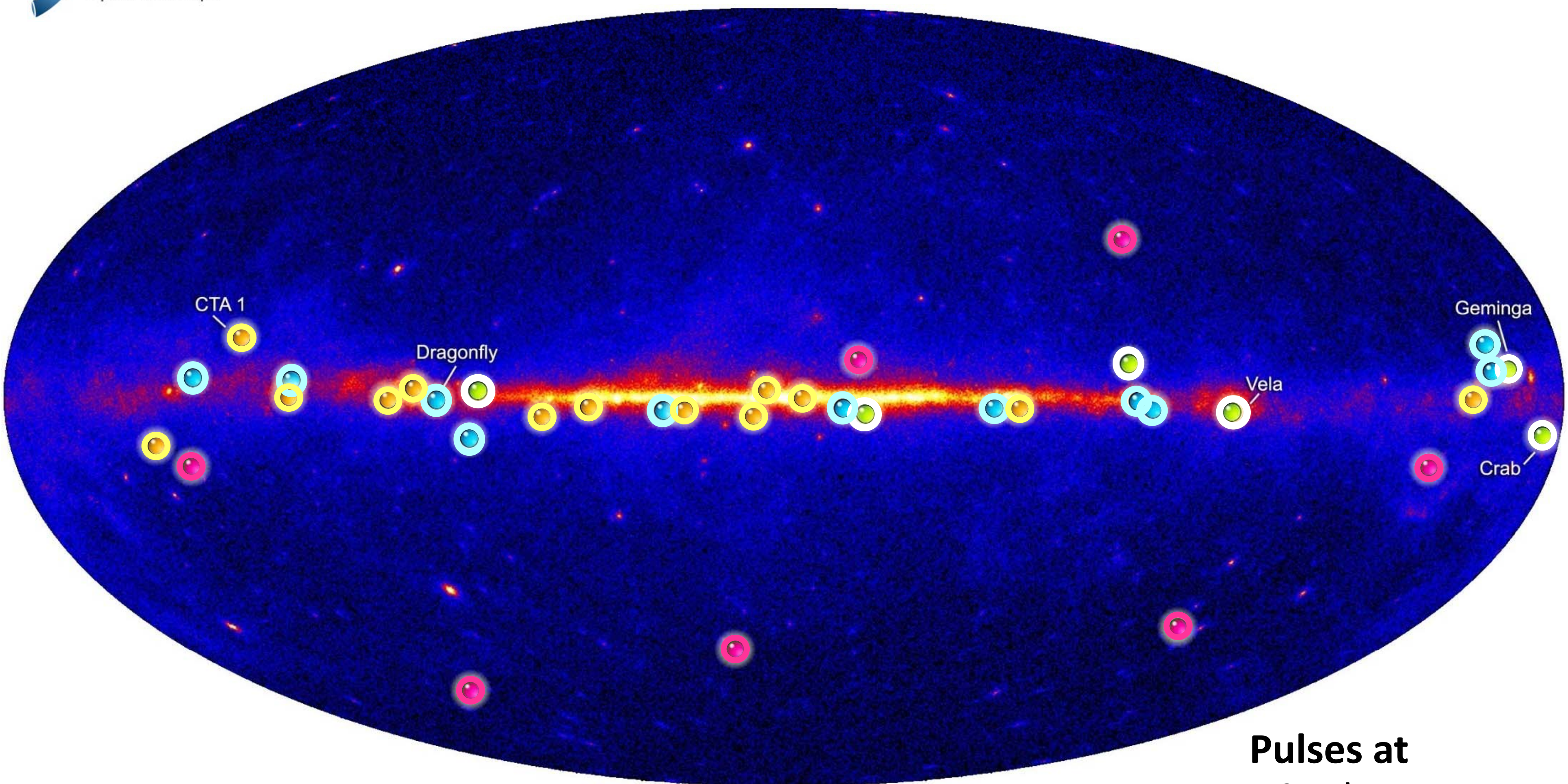
- ~4-day First Light exposure, June 30 – July 3, 2008.
- Orthographic projection.
- Comparable to EGRET on CGRO!




Vela (2 cycles, 89 ms period)
Nevts
700
600
500
400
300
200
100
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Phase

Fermi
Gamma-ray
Space Telescope

The Pulsing γ-ray Sky

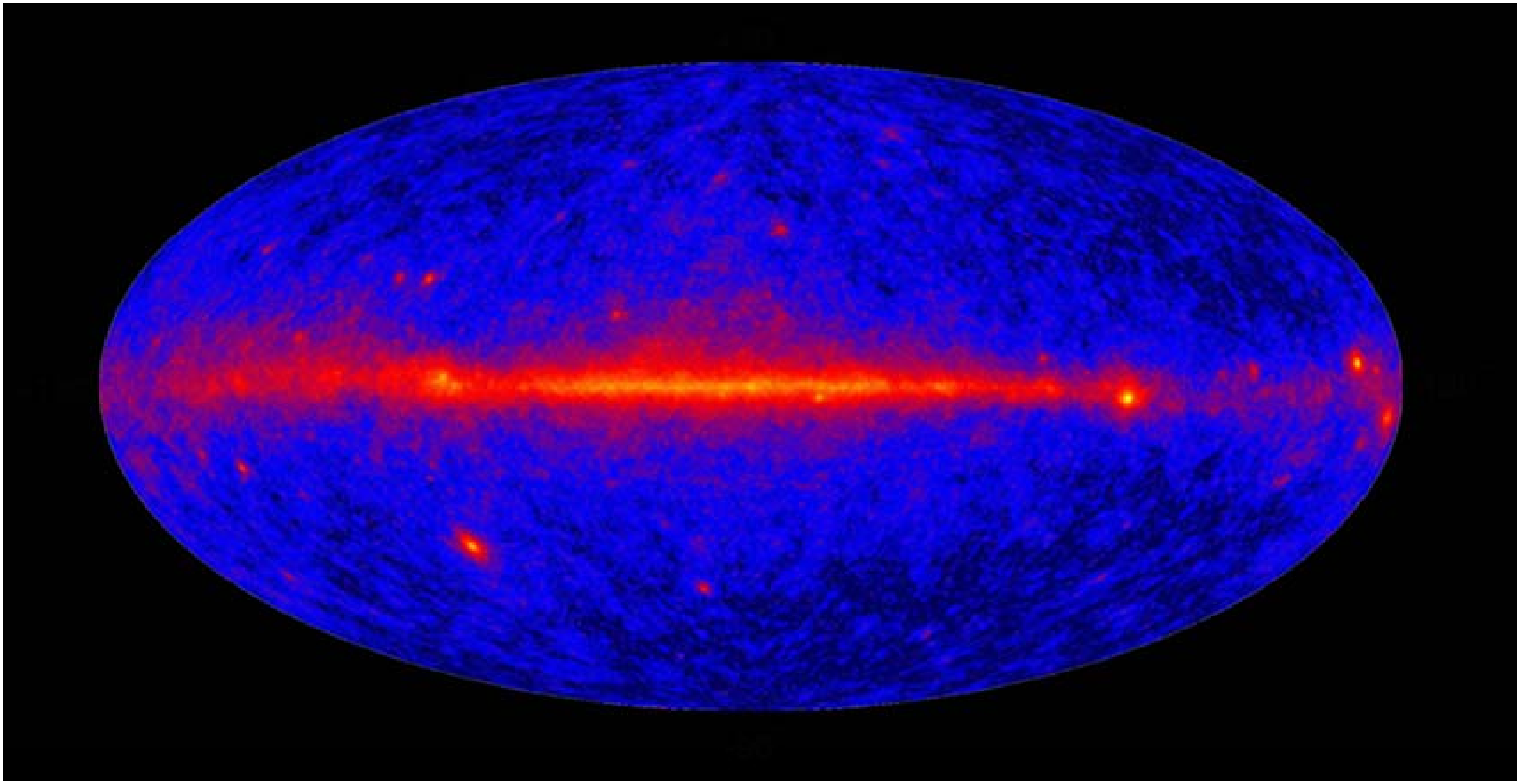


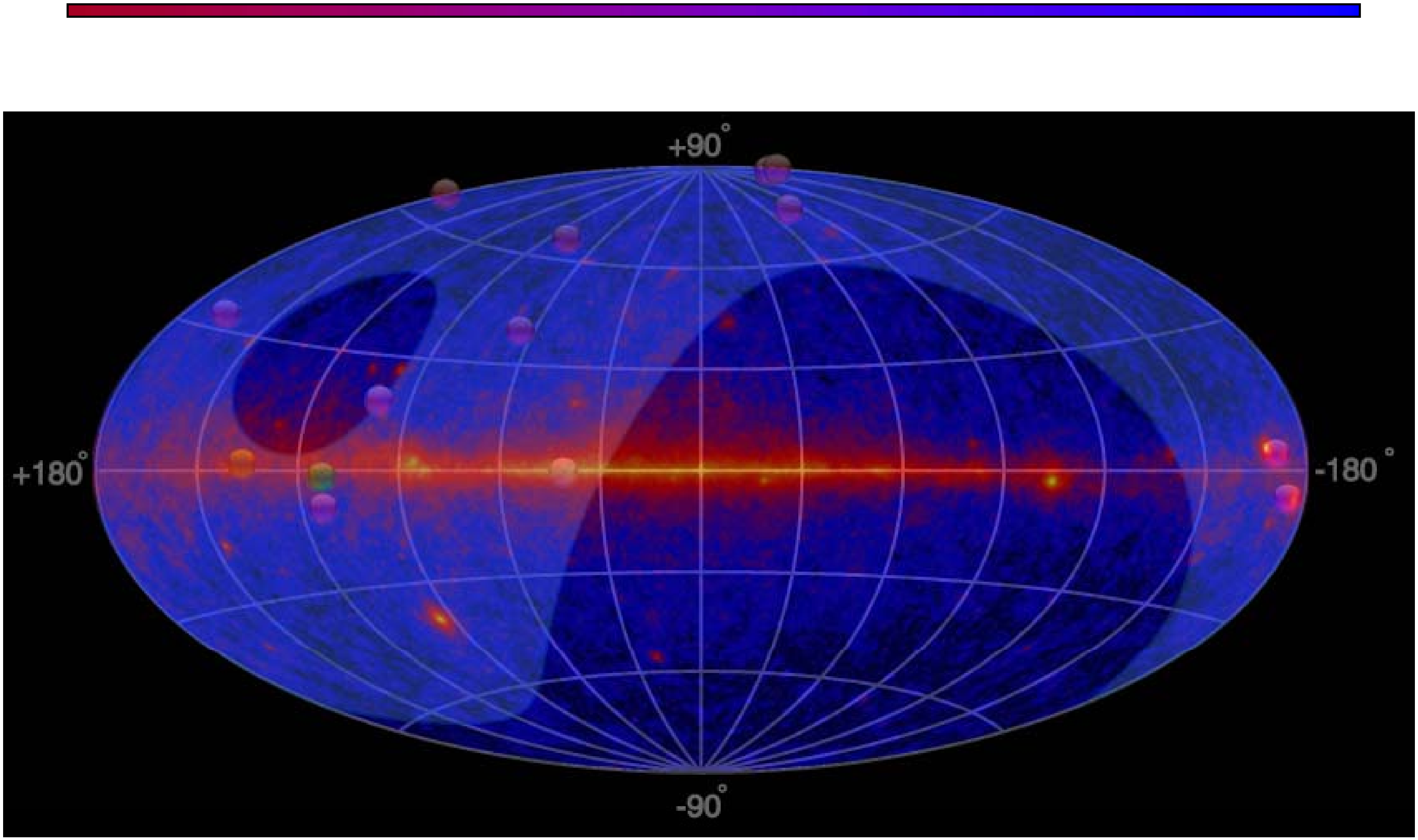
Pulses at $1/10^{th}$ true rate

Fermi Pulsar Detections

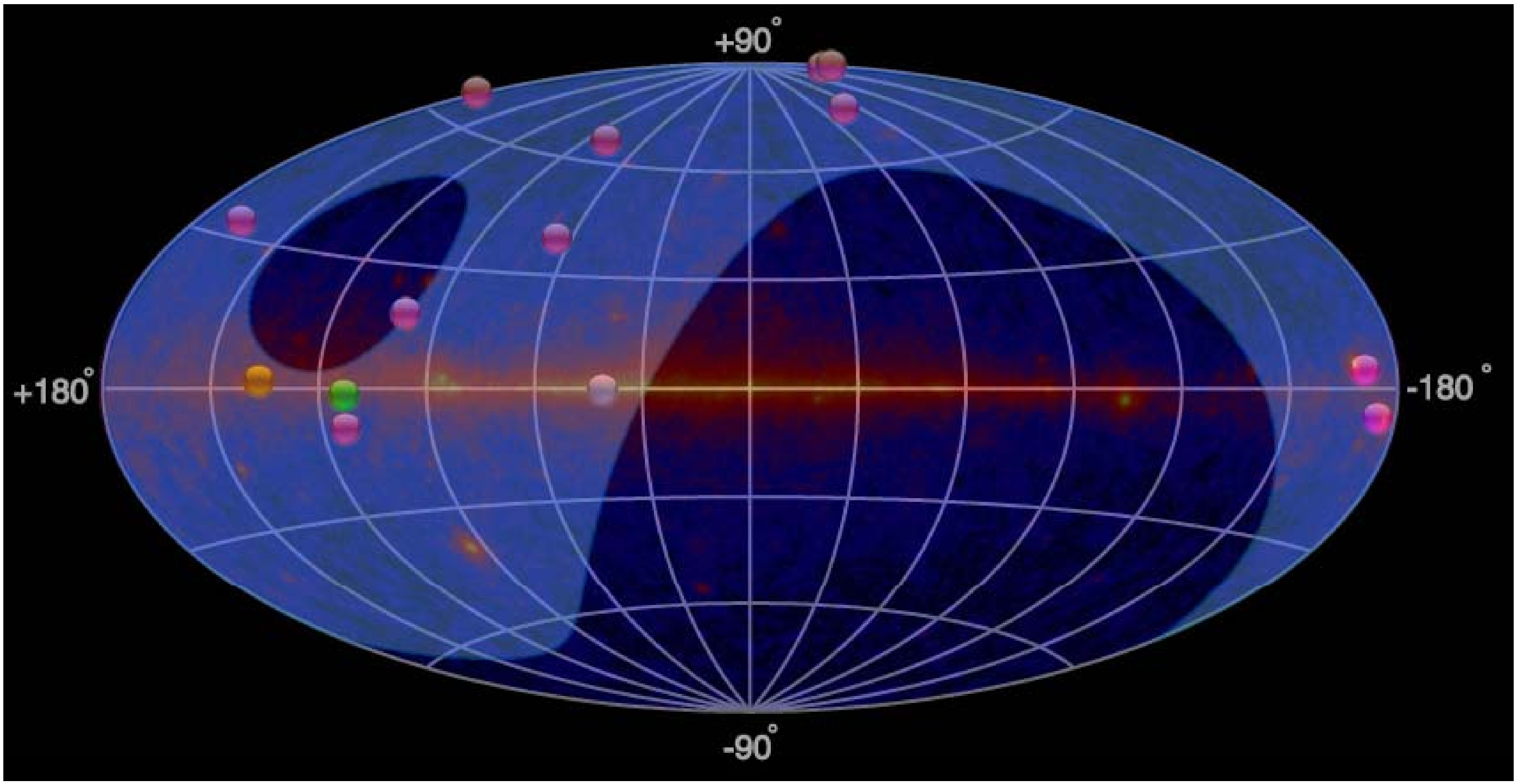
- New pulsars discovered in a blind search
- Millisecond radio pulsars
- Young radio pulsars
- Pulsars seen by Compton Observatory EGRET instrument

Fermi γ-ray Sky (Feb 2009)

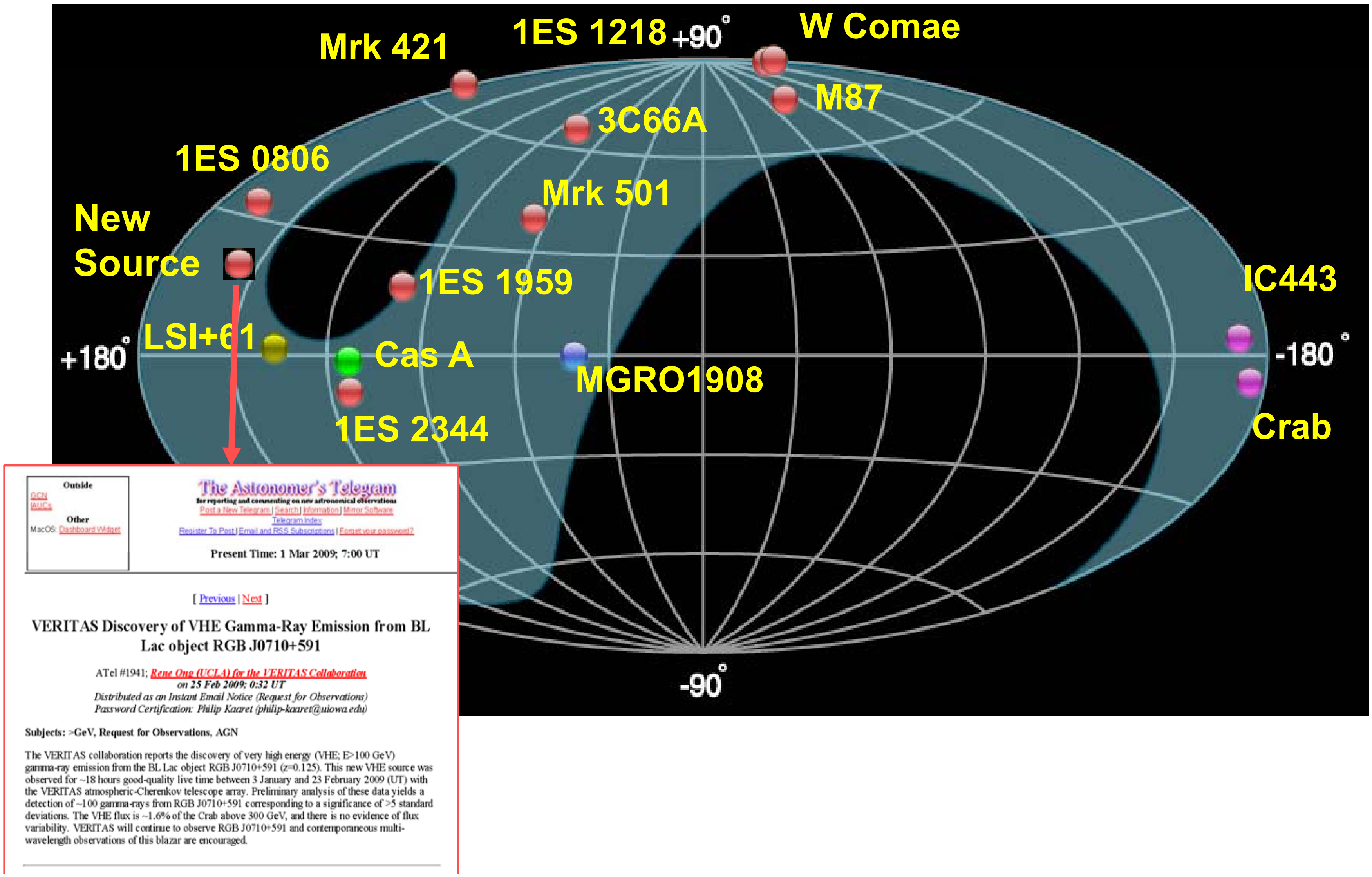




+90°
+180°
-180°
-90°


+90°
+180°
-180°
-90°

VERITAS Source Catalog (18 mo)



Outside
GCN
IAUCs
Other
MacOS: Dashboard Widget

The Astronomer's Telegram
for reporting and commenting on new astronomical observations
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Present Time: 1 Mar 2009; 7:00 UT

[Previous | Next]

VERITAS Discovery of VHE Gamma-Ray Emission from BL Lac object RGB J0710+591

ATel #1941; *Rene Ong (UCLA) for the VERITAS Collaboration*
on 25 Feb 2009; 0:32 UT
Distributed as an Instant Email Notice (Request for Observations)
Password Certification: Philip Kaaret (philip-kaaret@uiowa.edu)

Subjects: >GeV, Request for Observations, AGN

The VERITAS collaboration reports the discovery of very high energy (VHE; E>100 GeV) gamma-ray emission from the BL Lac object RGB J0710+591 (z=0.125). This new VHE source was observed for ~18 hours good-quality live time between 3 January and 23 February 2009 (UT) with the VERITAS atmospheric-Cherenkov telescope array. Preliminary analysis of these data yields a detection of ~100 gamma-rays from RGB J0710+591 corresponding to a significance of >5 standard deviations. The VHE flux is ~1.6% of the Crab above 300 GeV, and there is no evidence of flux variability. VERITAS will continue to observe RGB J0710+591 and contemporaneous multi-wavelength observations of this blazar are encouraged.

FUTURE

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

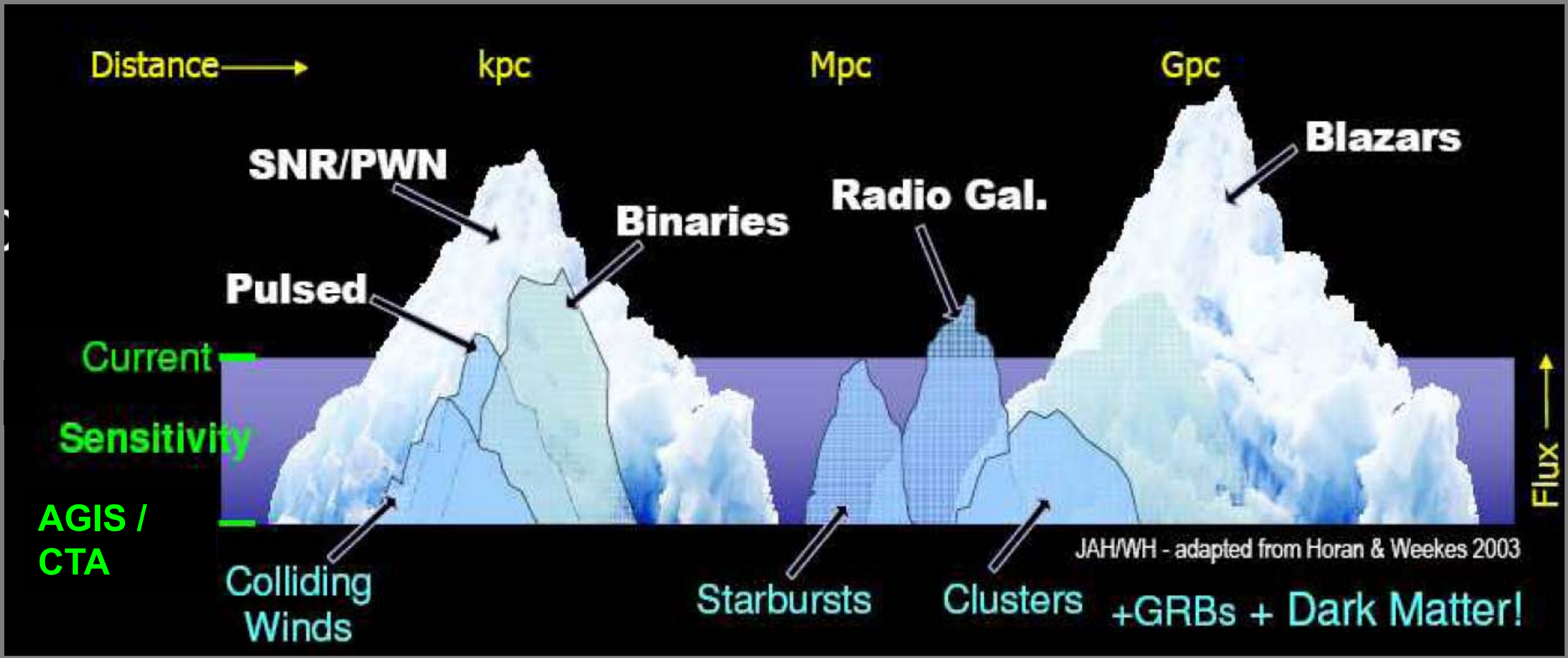
VERITAS will survey the northern TeV sky with great sensitivity, complementing:

Fermi GST (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.

The Next Generation



- Populations of fainter sources we have yet to probe.
- TeV source confusion may be starting to be an issue.
  - **very deep observations to get morphology, disentangle sources**
- Need larger source populations to get away from source idiosyncrasies.
- Next few years with Fermi may help to answer questions
  - **…but not completely.**
  - **…and we will have many new sources !**

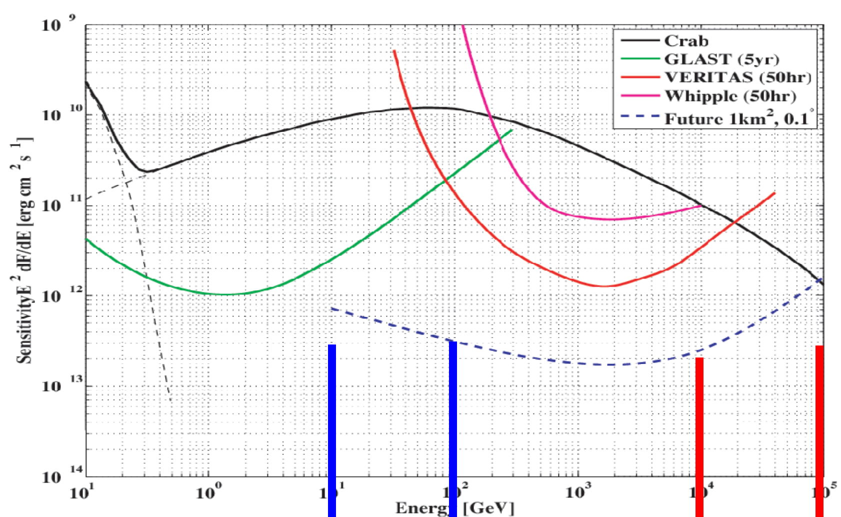
AGIS (Advanced Gamma Imaging System)

Large (1 km^2) array.

- ~50-75 telescopes, aperture 8-20m.
- \$100-150M class observatory.

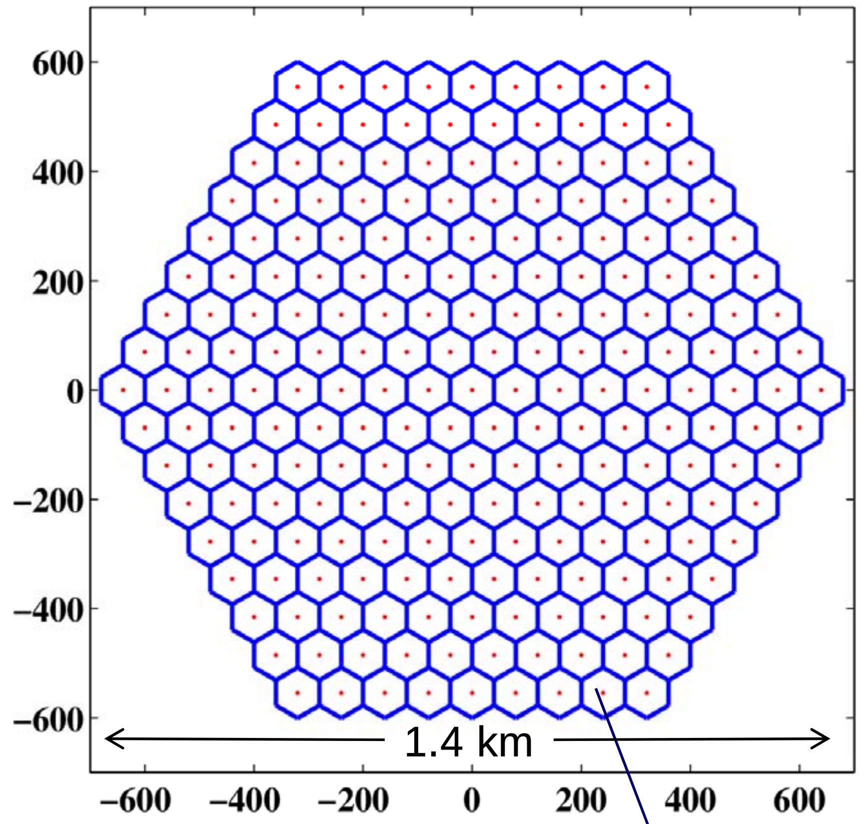
Much more sensitive than FGST/VERITAS..
APS White Paper study, collaboration formed.

CTA (Europe) – considerable momentum.



Transition to Fermi Regime (GRBs, etc.)

Spectral cutoffs (acceleration mechanisms)



8-10m telescope
Wide-field


AGIS
dvanced Gamma-ray Imaging System)
Institutions:
ADLER
ANL
Barnard
Delaware
IAFE
Iowa State
LANL
McGill
Penn State
Purdue
SAO
Stanford/KIPAC
UNAM
UC, Los Angeles
UC, Santa Cruz
U. Chicago
U. Iowa
Utah
Yale
Washington U.
Wide-Field
Schwarzschild-Coudet Telescope

Summary

- VHE γ-rays 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 and Fermi are now both operational and getting exciting results**.

- New Astronomy of TeV γ-rays (and neutrinos, grav. waves) should reveal many surprises over the next 10 years.

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

Marcel Proust (1871-1922)