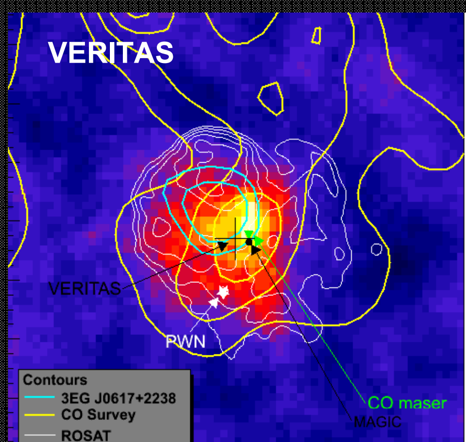
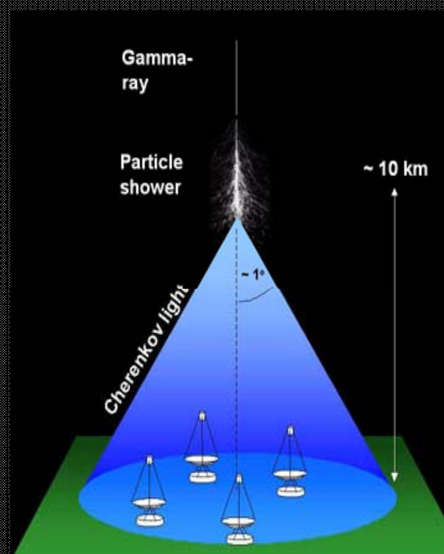
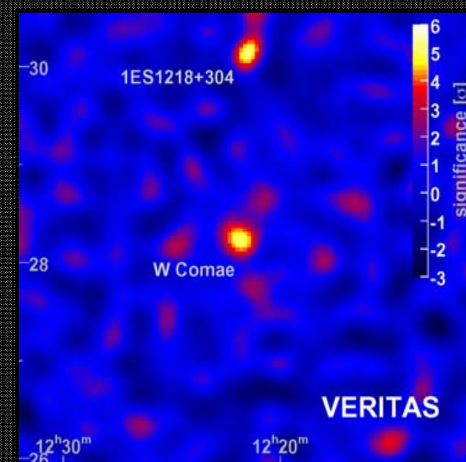
VERITAS Explores the TeV γ-ray Sky







Outline

Scientific Motivation

- A “New Astronomy”
- Physicist’s Viewpoint
  - ➔ *Astrophysical TeV accelerators*
    (1 TeV = 10^{12} eV)
  - ➔ *Origin of Cosmic Rays, understanding black holes …*
  - ➔ *Probes of new physics*

Experimental Technique

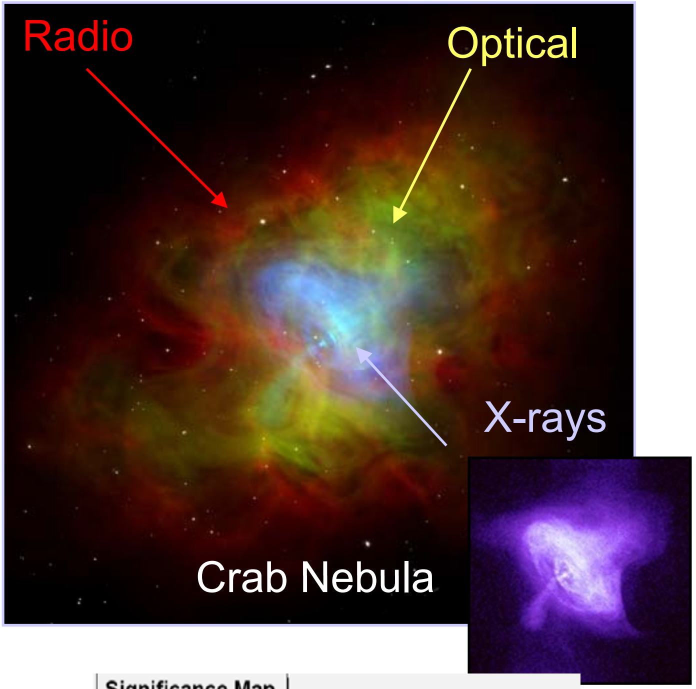
The VERITAS Project

- Description, performance, operations
- Science Highlights – some brand new results !
- (Fermi Gamma-ray Space telescope)

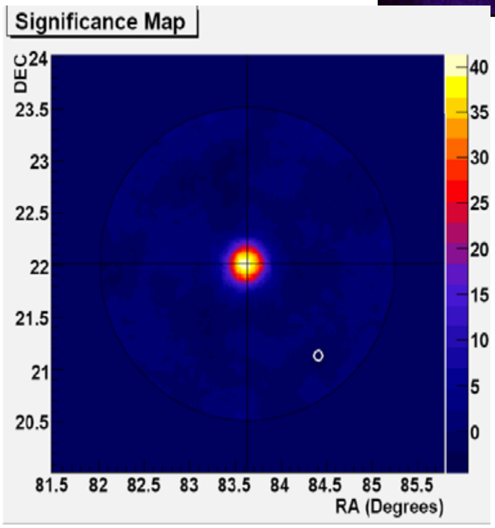
Future

A New Astronomy

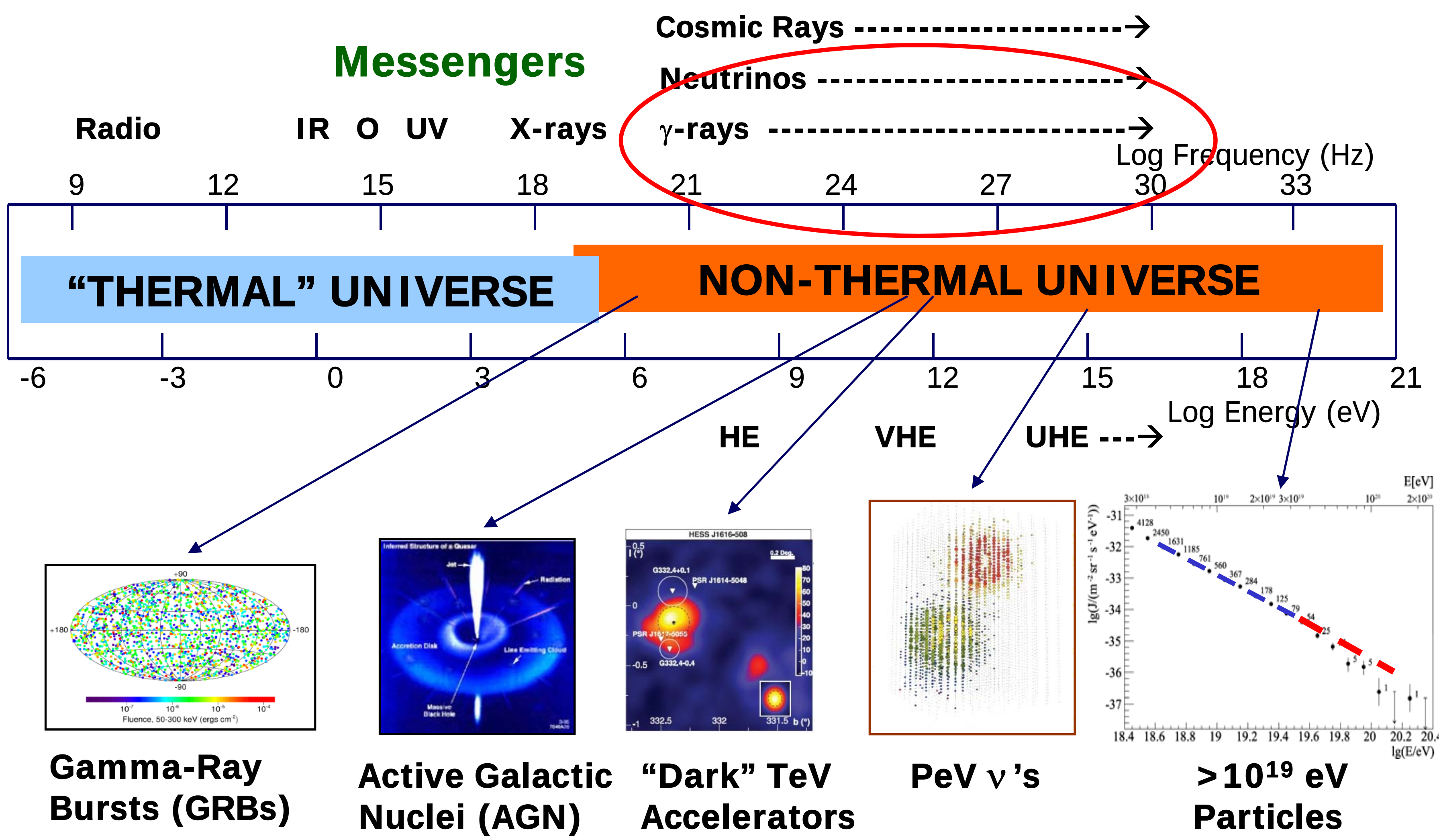
- Before 1940's – Astronomy only used visible light.
- New wavebands (radio, IR, X-ray, γ-ray) change our picture of the universe
  - Different spatial scales
  - Different time scales
  - Different emission processes
  - New physics
- Other messengers (cosmic rays, neutrinos, grav. waves)



TeV γ-rays

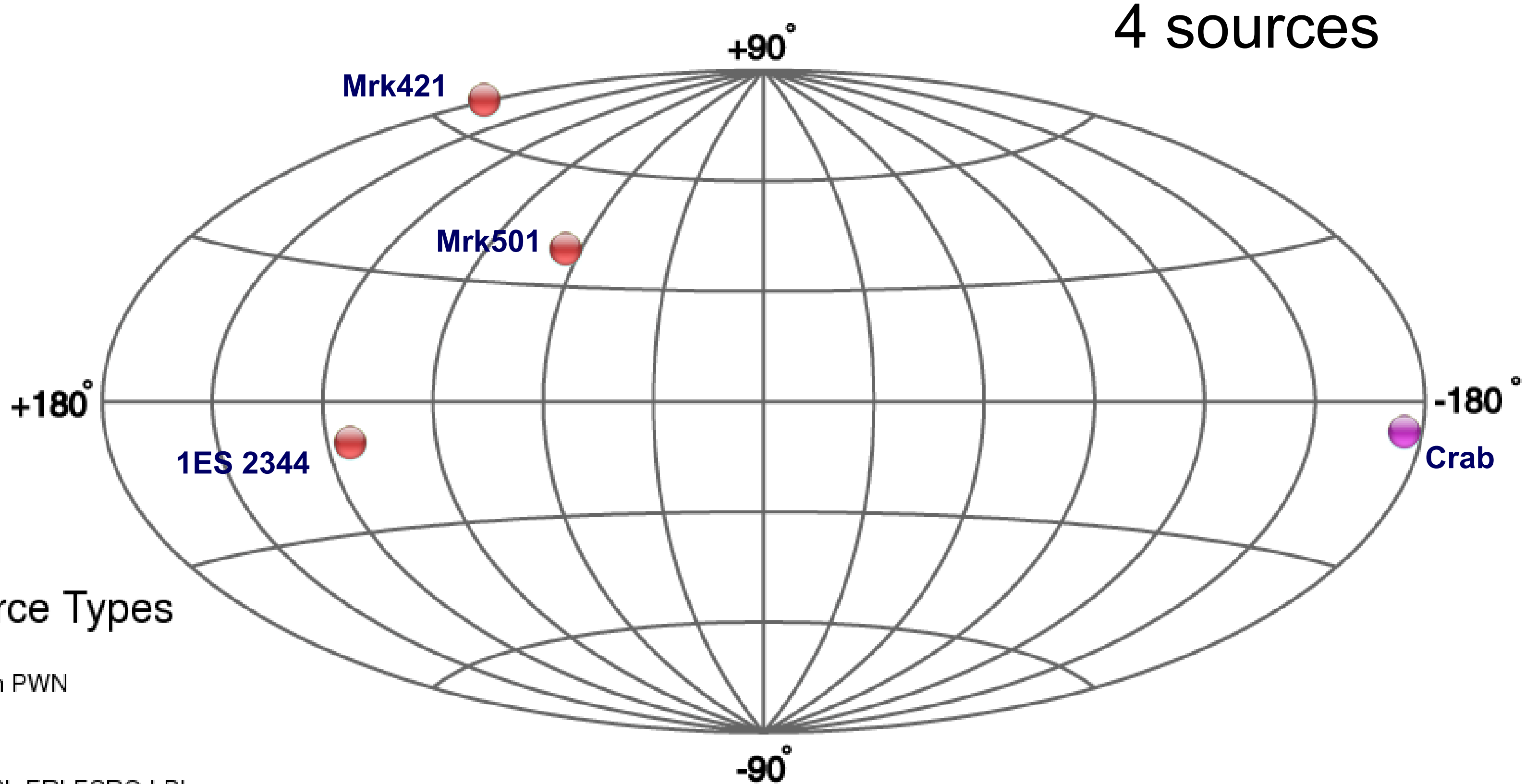


New Windows & New Messengers



The TeV γ-ray Sky - 1999

4 sources



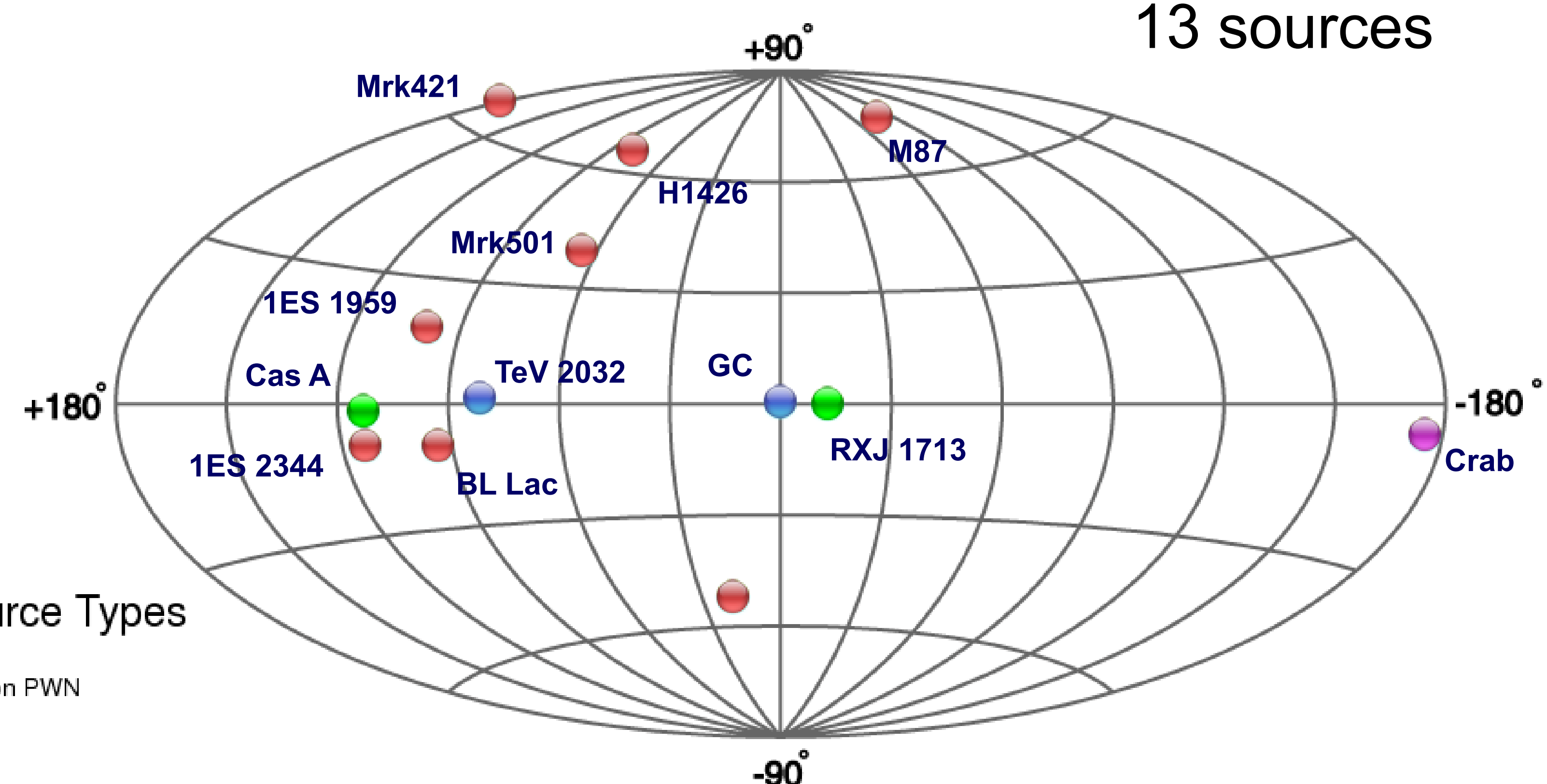
Source Types

Plerion PWN

HBL IBL FRI FSRQ LBL

The TeV γ-ray Sky - 2004

13 sources



Source Types

Plerion PWN

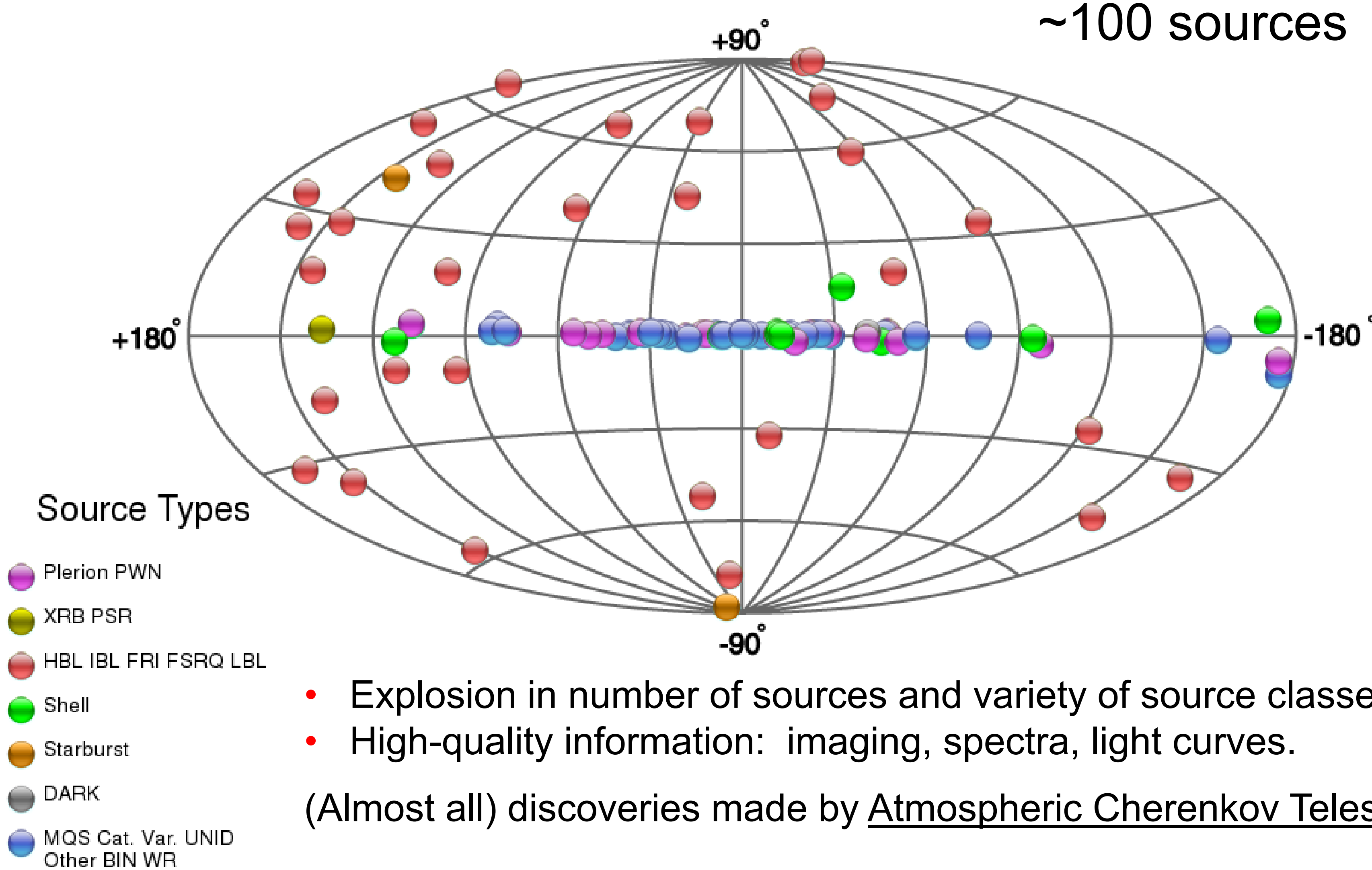
HBL IBL FRI FSRQ LBL

Shell

MQS Cat. Var. UNID
Other BIN WR

The TeV γ-ray Sky - 2009

~100 sources

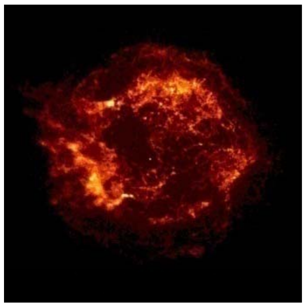


- Explosion in number of sources and variety of source classes.
- High-quality information: imaging, spectra, light curves.

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

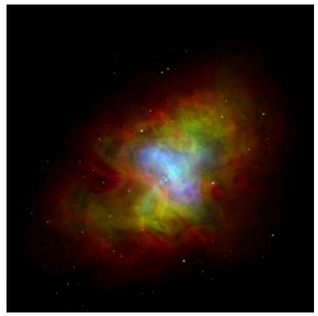
A Wide Variety of Sources …

Supernova Remnants



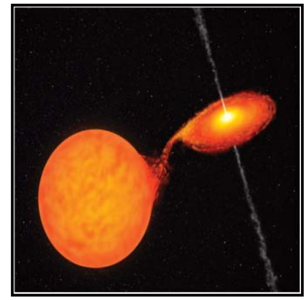
Shocks
Fermi mechanism

Pulsars/PWN



NS dynamo
Winds

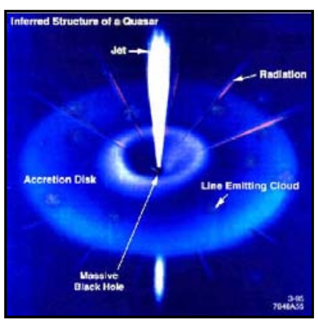
HMXBs (microquasars)



Accretion-powered jets,
Colliding winds, or …?

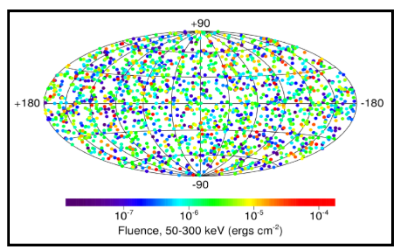
GALACTIC

Active Galactic Nuclei



SMassive BH
Jets

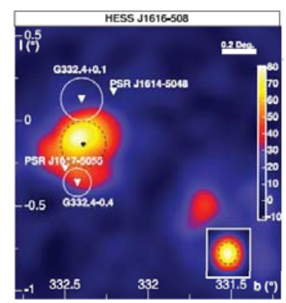
Gamma-Ray Bursts



Massive star collapse
Relativistic shocks

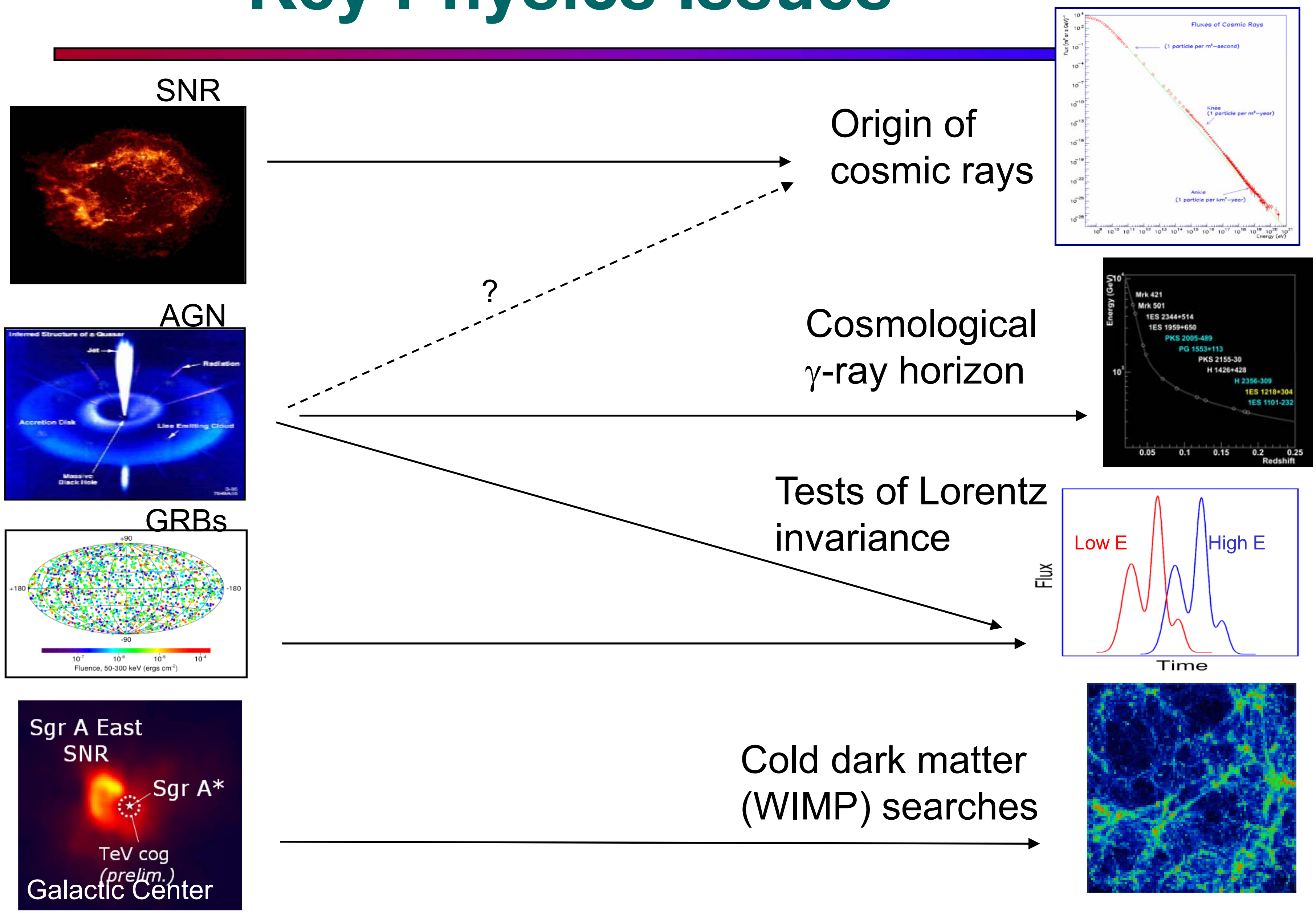
EXTRA-GALACTIC

Dark accelerators…



???

Key Physics Issues



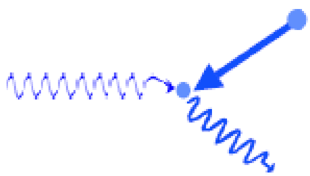
Origin of Cosmic Rays = SNRs ?

Why (VHE) gamma rays?

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

Accelerated electrons → VHE γ-rays

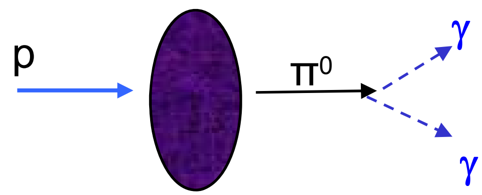
Up-scattering of soft photons



Inverse Compton Scattering

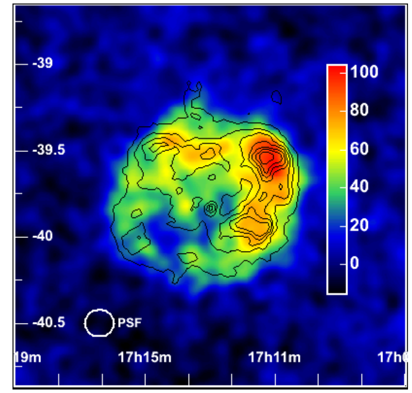
Accelerated protons → VHE γ-rays

Target interaction, π^0 decay

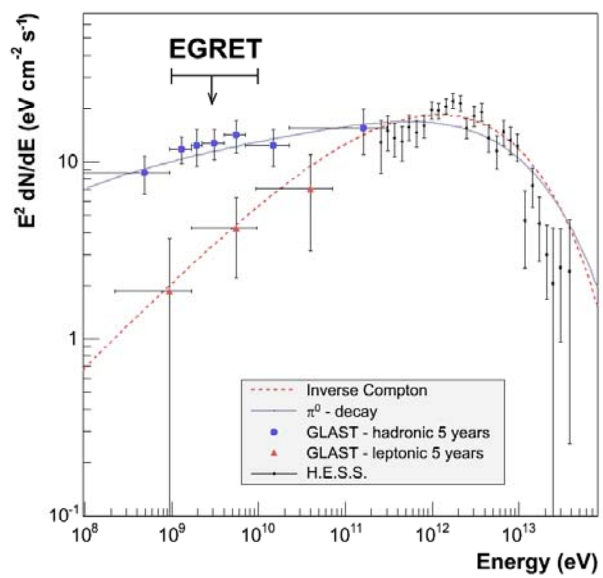


Target material

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

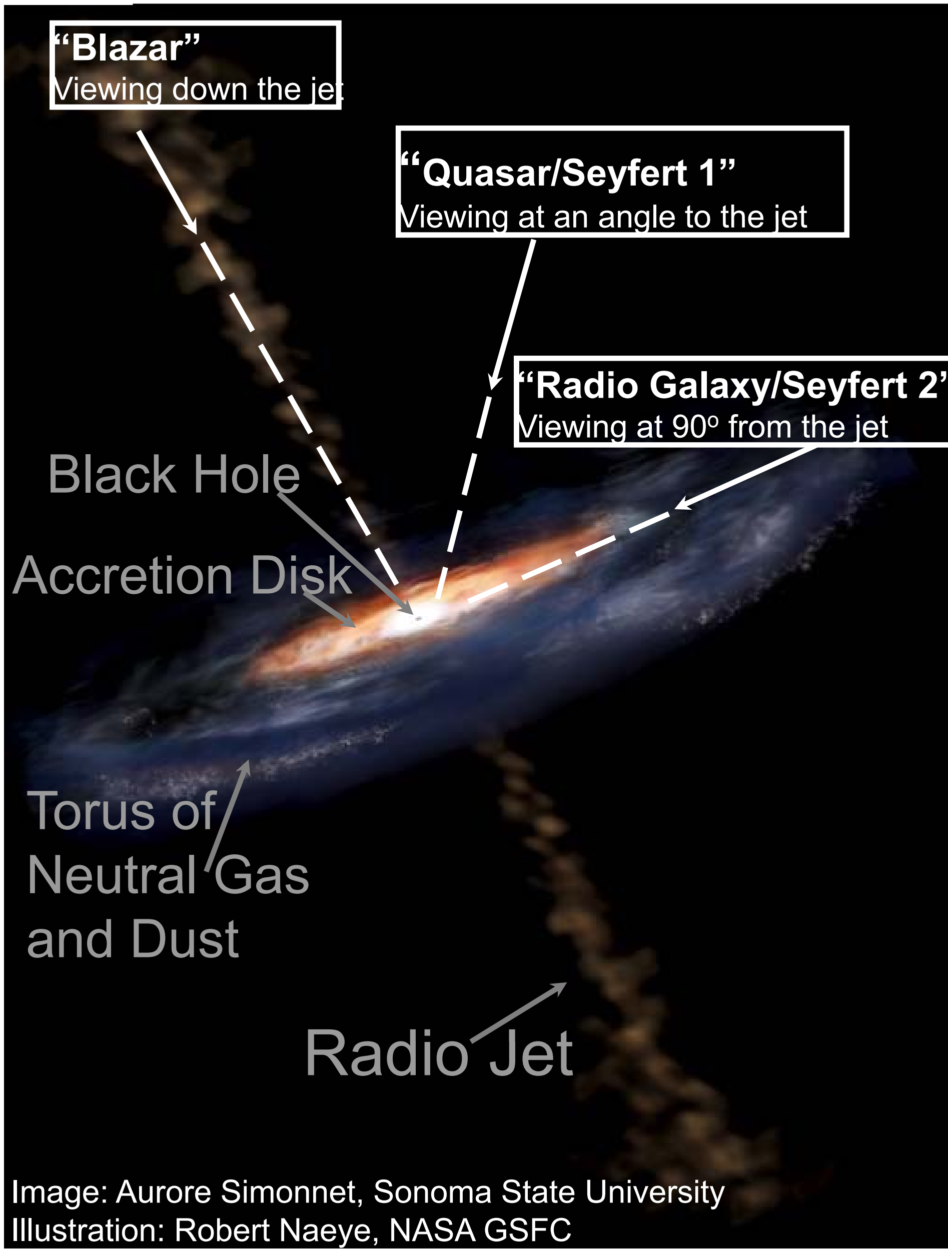


SNR Image (RXJ 1713-3946)



Spectral Energy Distribution

Active Galaxies



Active Galactic Nuclei (AGN)

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

So far, AGN are generally:

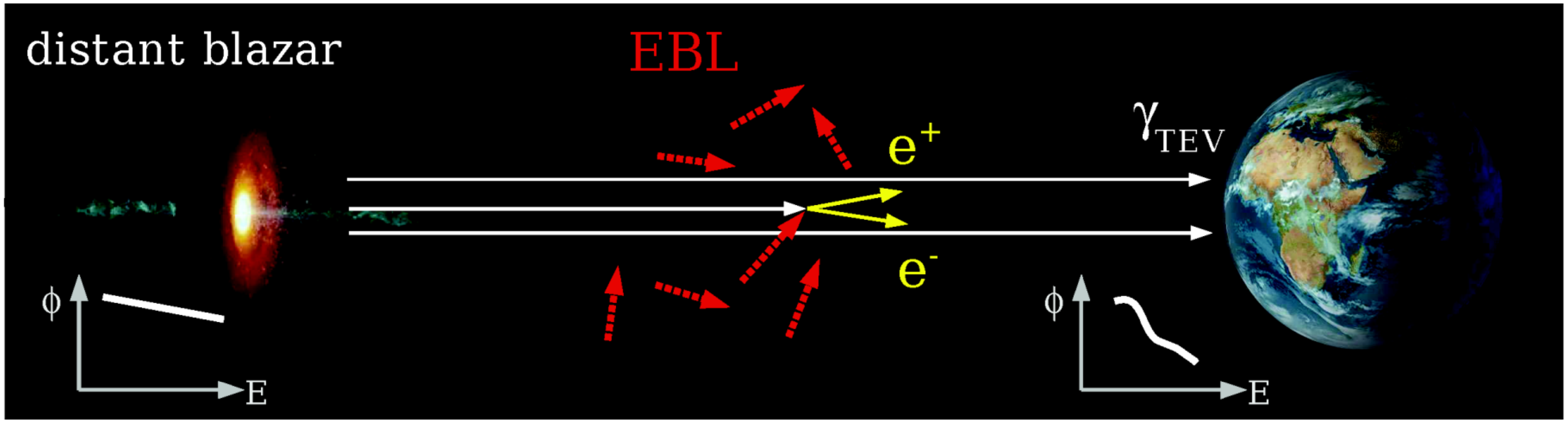
- Blazars
  - Jets aligned with line of sight

But also radio galaxies (e.g M87)

- Jet viewed from the side

What are the relevant acceleration, emission, propagation mechanisms ?

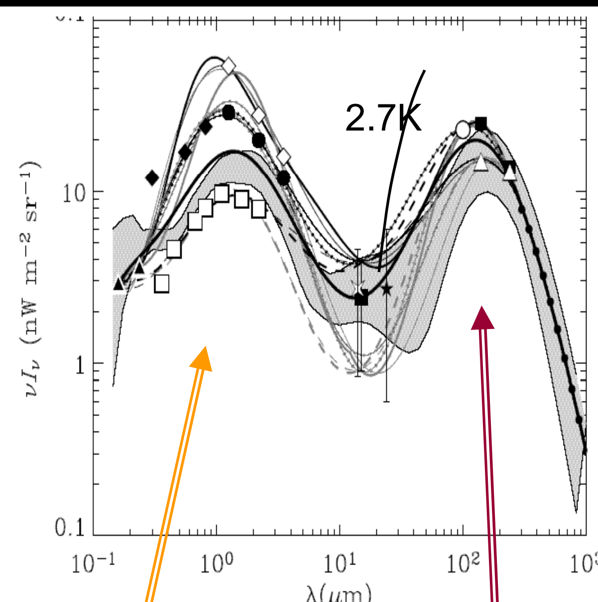
Extragalactic Background Light (EBL)



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.

VHE γ-ray measurements provide important constraints on the cosmological radiation fields.



Red shifted stellar light

Red shifted dust light

Search for Cold Dark Matter

Hypothesis: DM = WIMPs

- Indirect detection of WIMP annihilation → γ, ν etc.

$\chi + \chi$

$\nu, \bar{\nu}$

γ **continuum**

γ **lines**

Point back to source

(VERITAS, Fermi,IceCube)

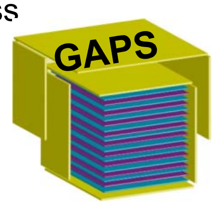
$\bar{p}$

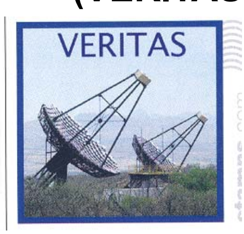
e^{+}

$\bar{d}$

Search for excess in cosmic rays

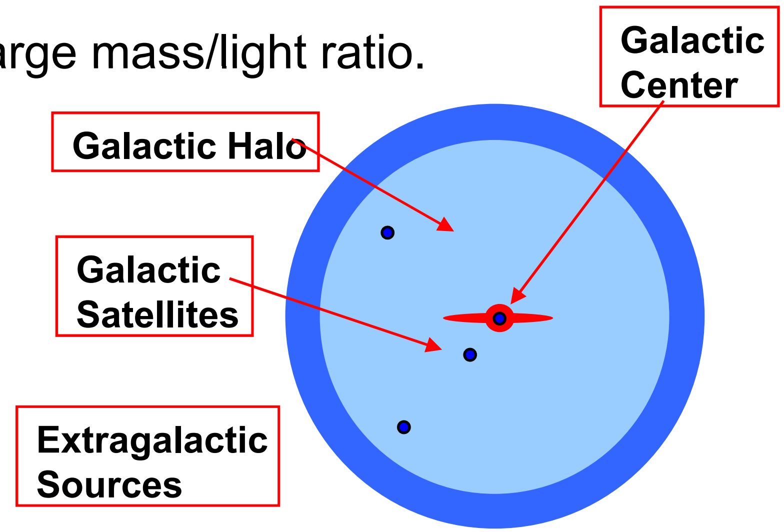
(AMS,GAPS)

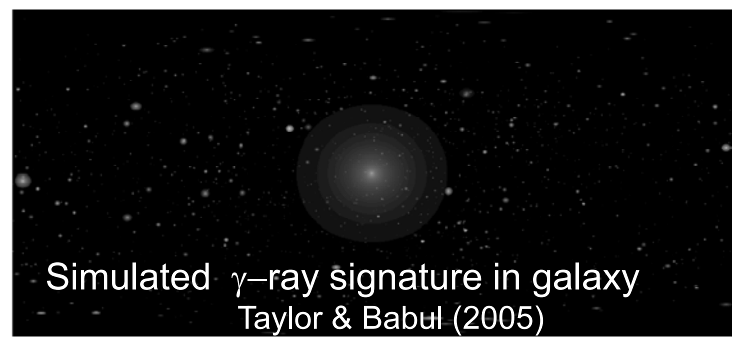




Target regions with:

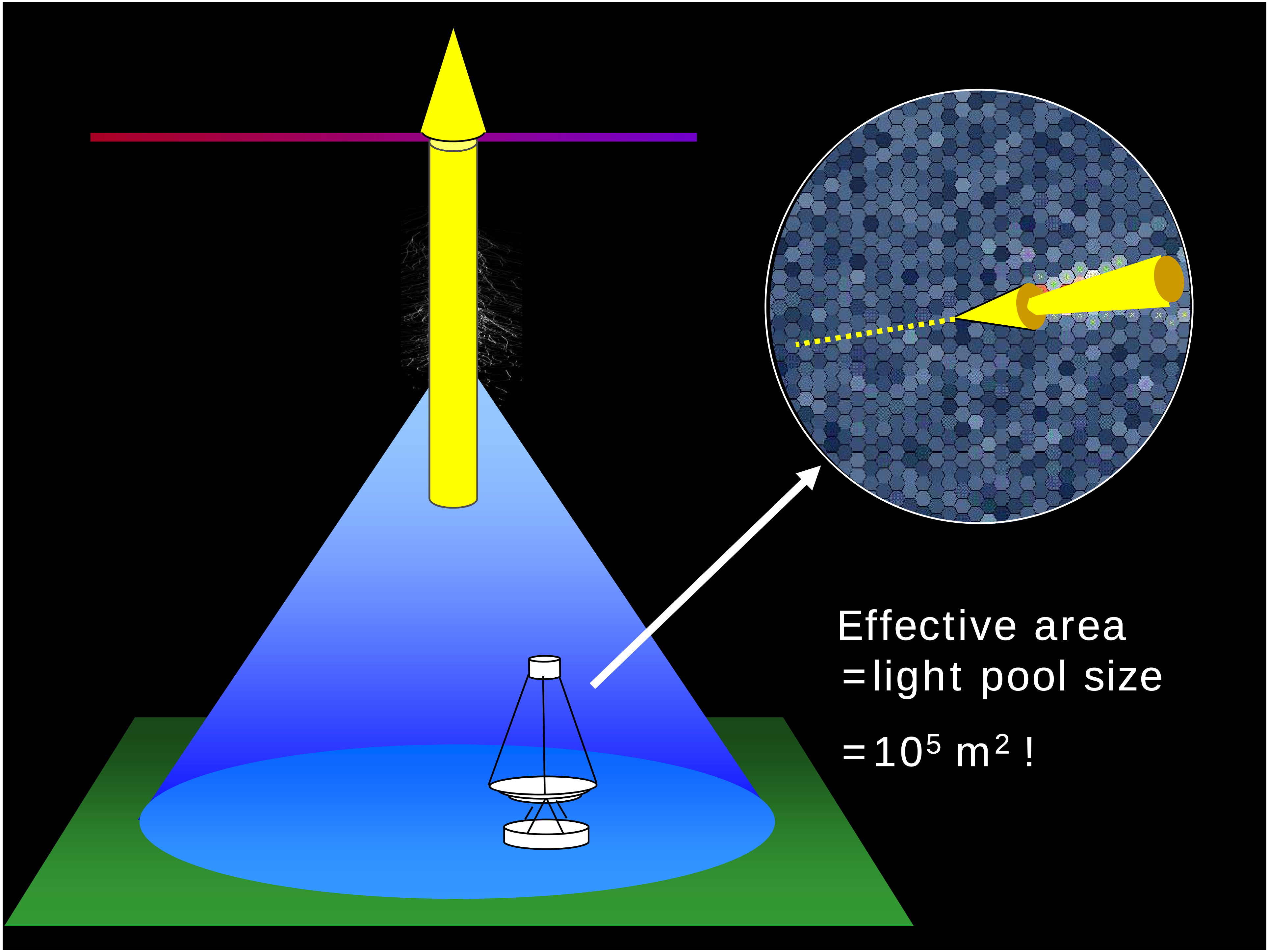
- Favorable DM distributions.
- Large mass/light ratio.





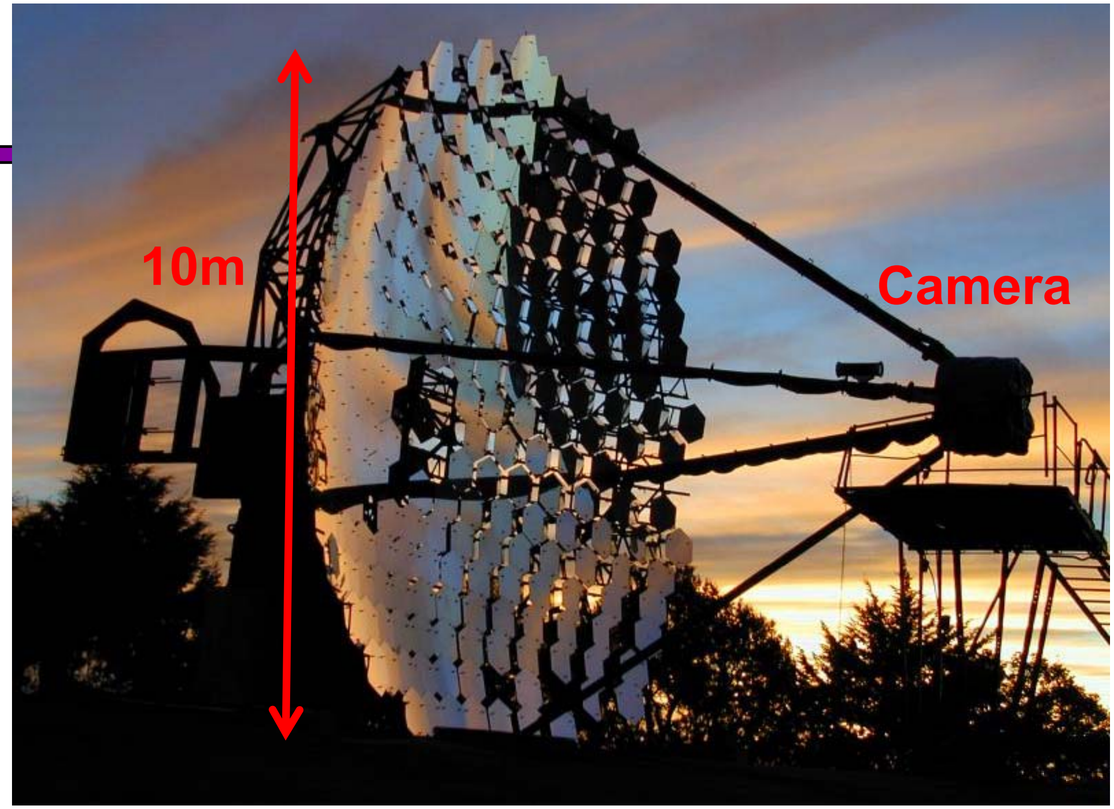
Complementary approach to direct detection & LHC
Eventual goal is to do DM astronomy !

Experimental Technique

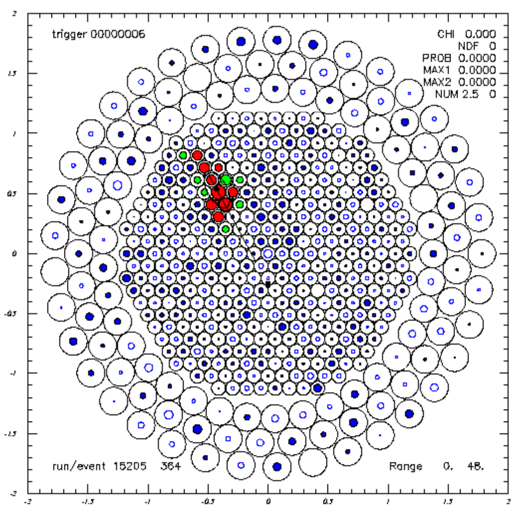

Effective area
=light pool size
=10^5 m^2 !

Whipple 10m
γ-ray Telescope

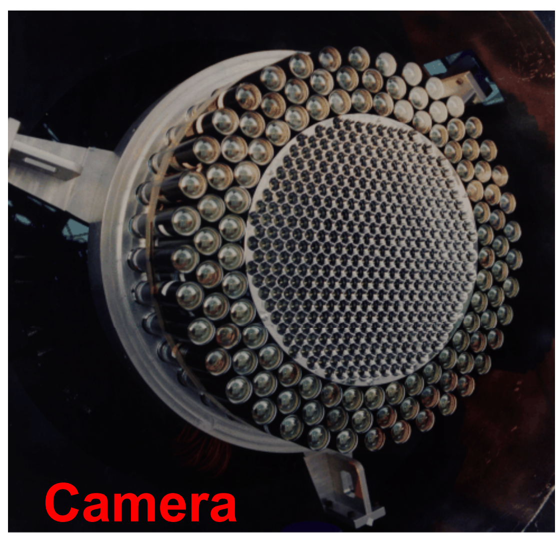
- The Whipple 10m (1968 -)
- Pioneered use of Imaging.
  (T. Weekes et al.)
- Made first source detections.
  (Crab Nebula in ~90 hours)



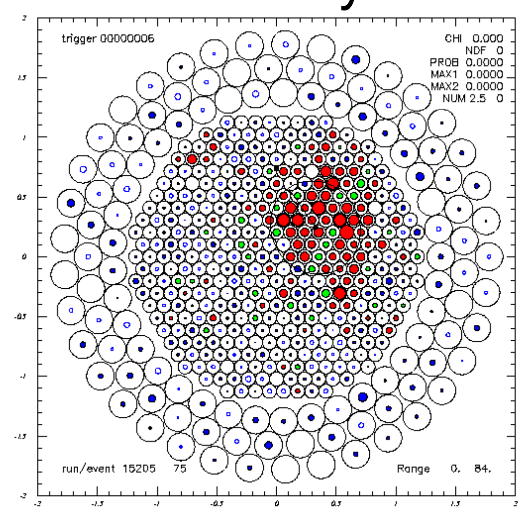
gamma ray?



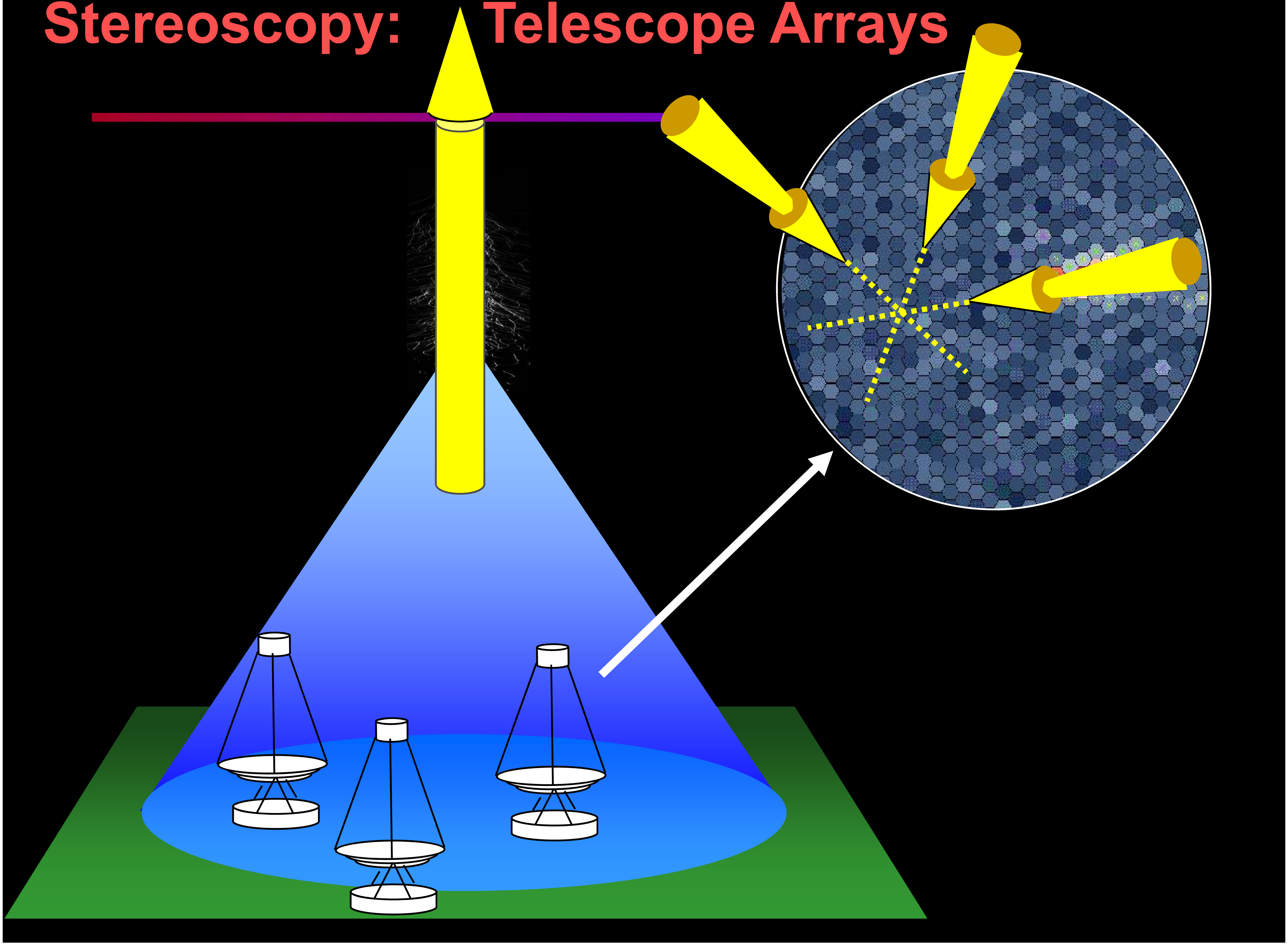
ch



cosmic ray?



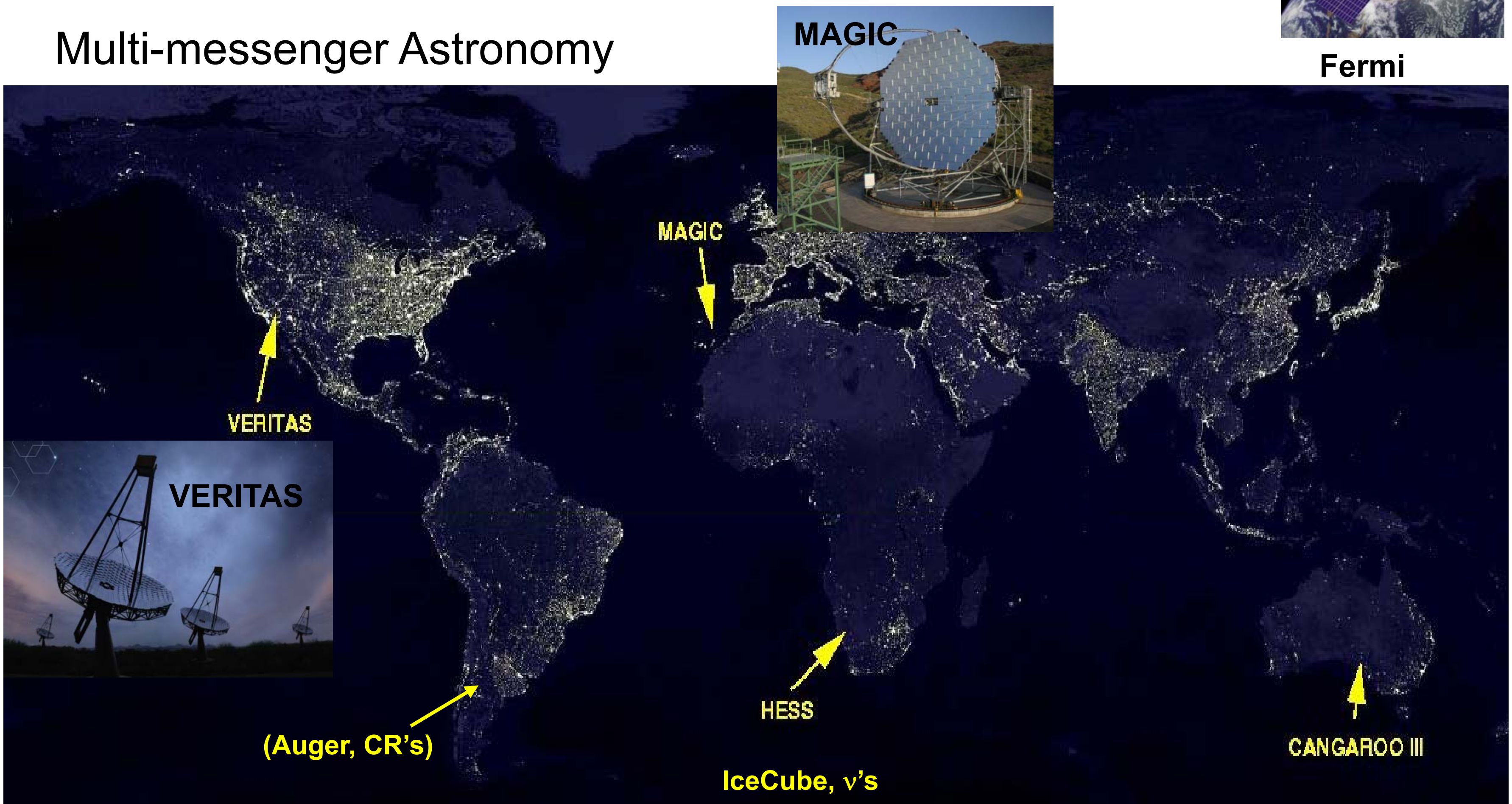
Stereoscopy: Telescope Arrays

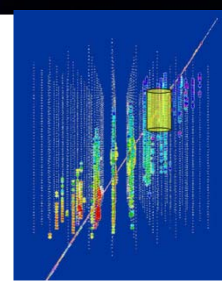


Major VHE Telescopes

Fermi

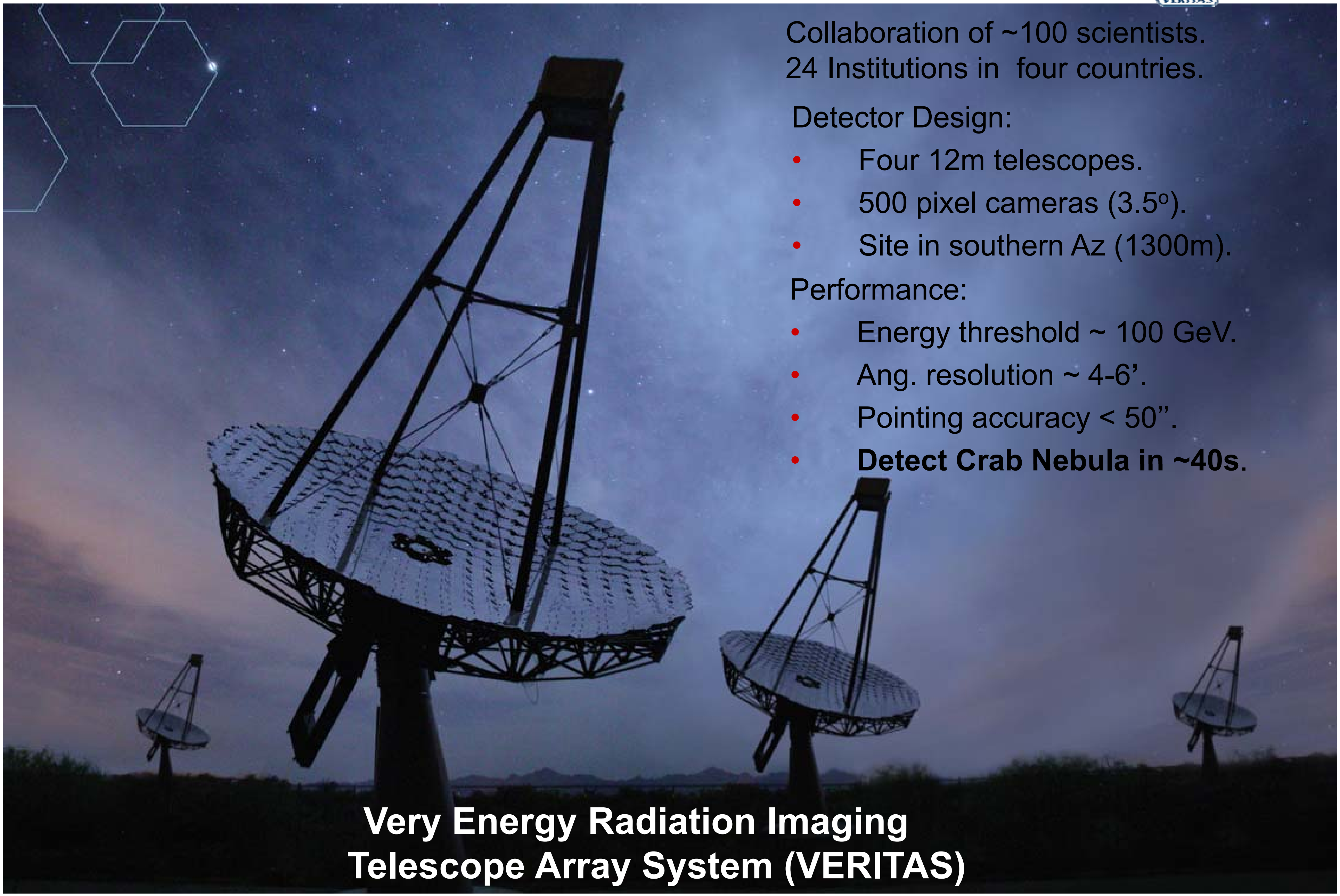
Multi-messenger Astronomy





IceCube

VERITAS



Collaboration of ~100 scientists.
24 Institutions in four countries.

Detector Design:

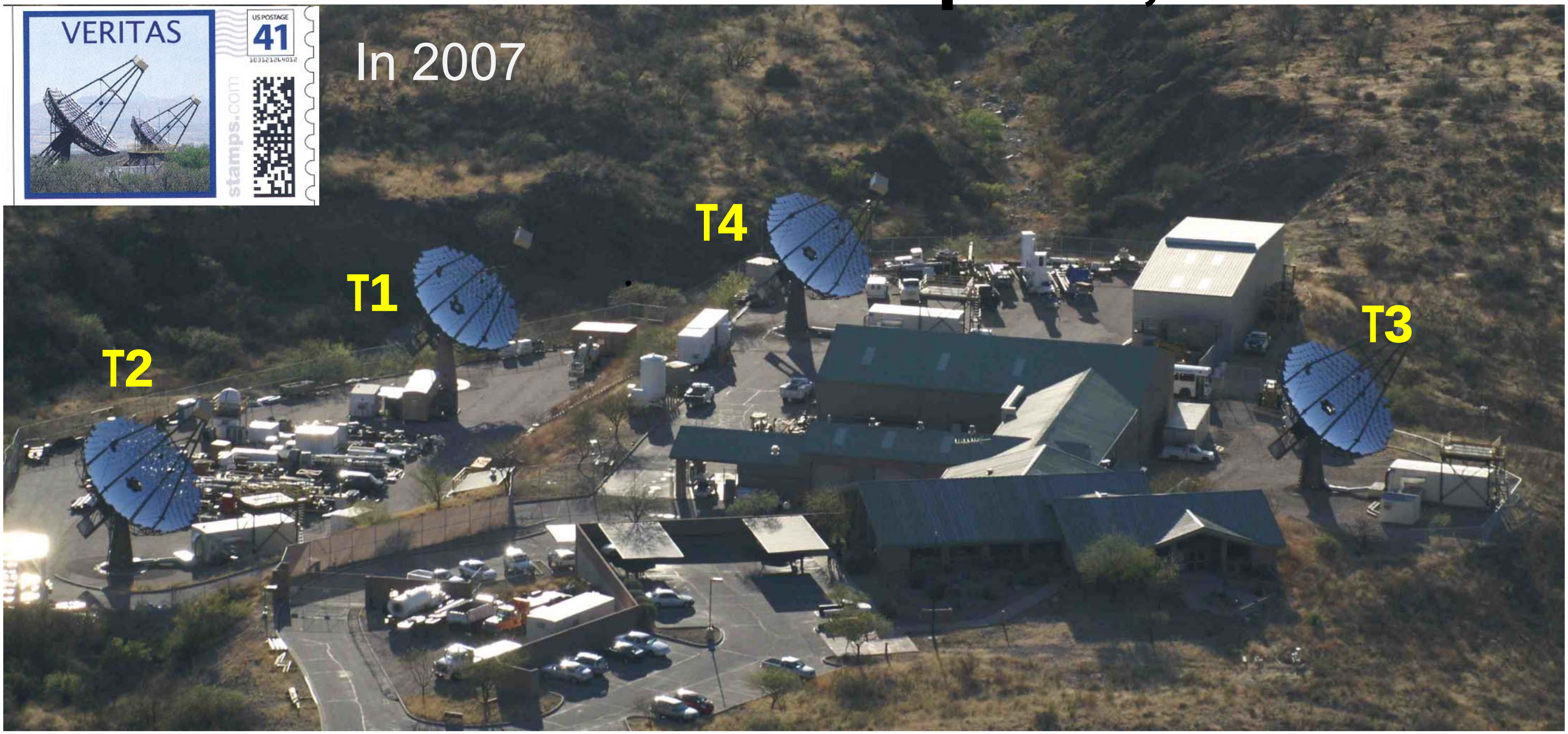
- Four 12m telescopes.
- 500 pixel cameras (3.5^{o}).
- Site in southern Az (1300m).

Performance:

- Energy threshold ~ 100 GeV.
- Ang. resolution ~ 4-6'.
- Pointing accuracy < 50''.
- **Detect Crab Nebula in ~40s**.

Very Energy Radiation Imaging Telescope Array System (VERITAS)

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.:

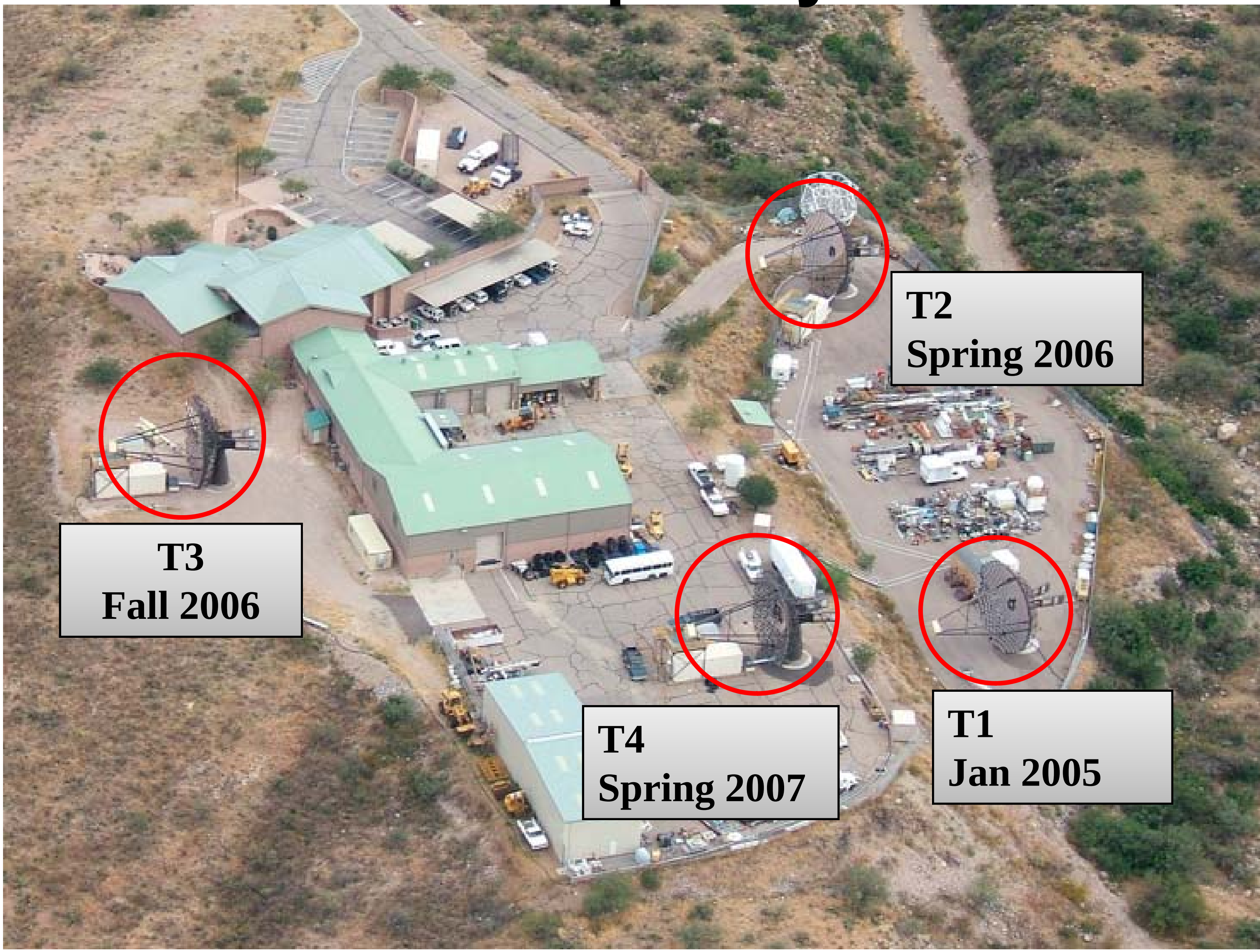
Leeds Univ.

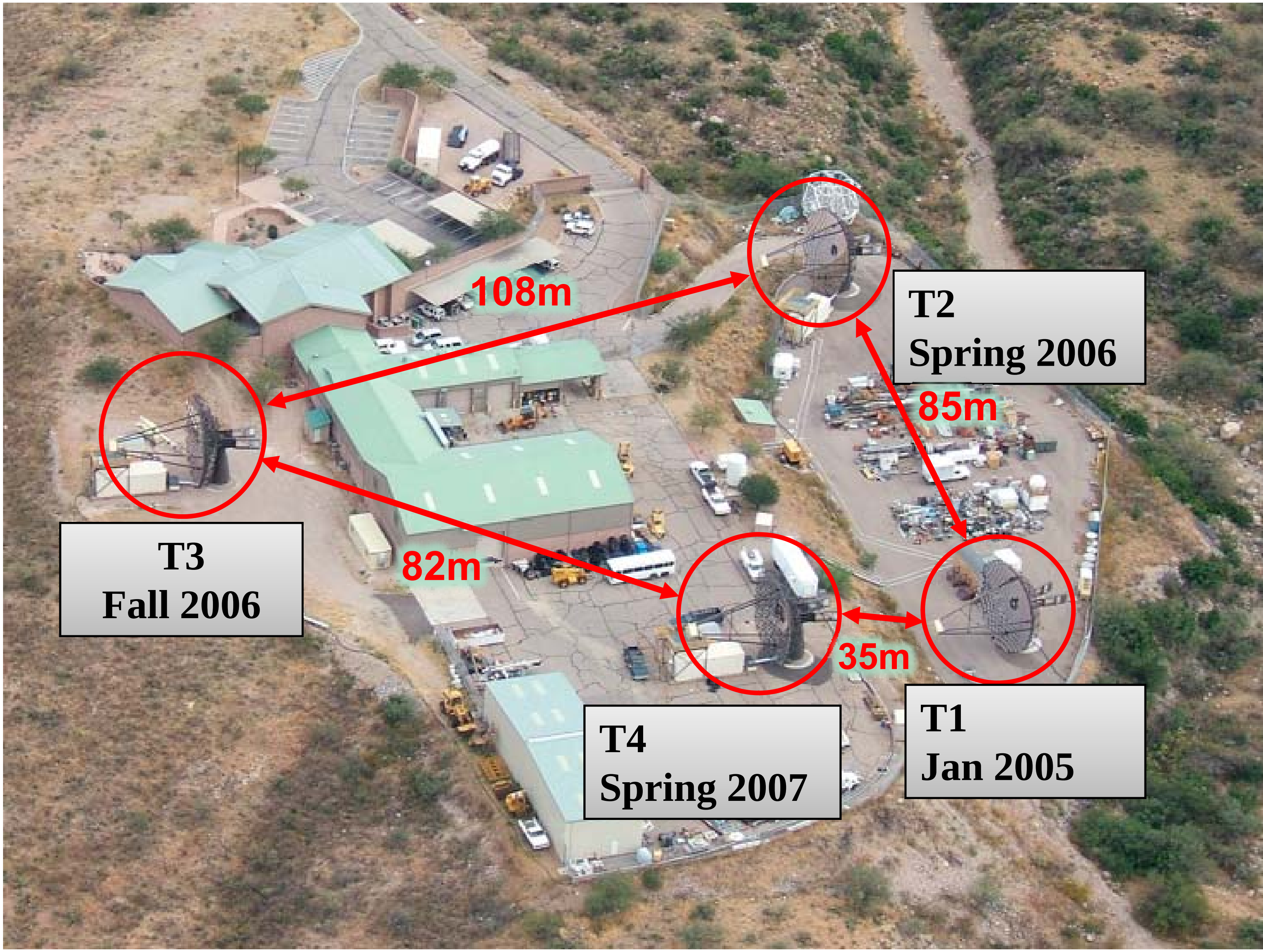
Ireland:

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

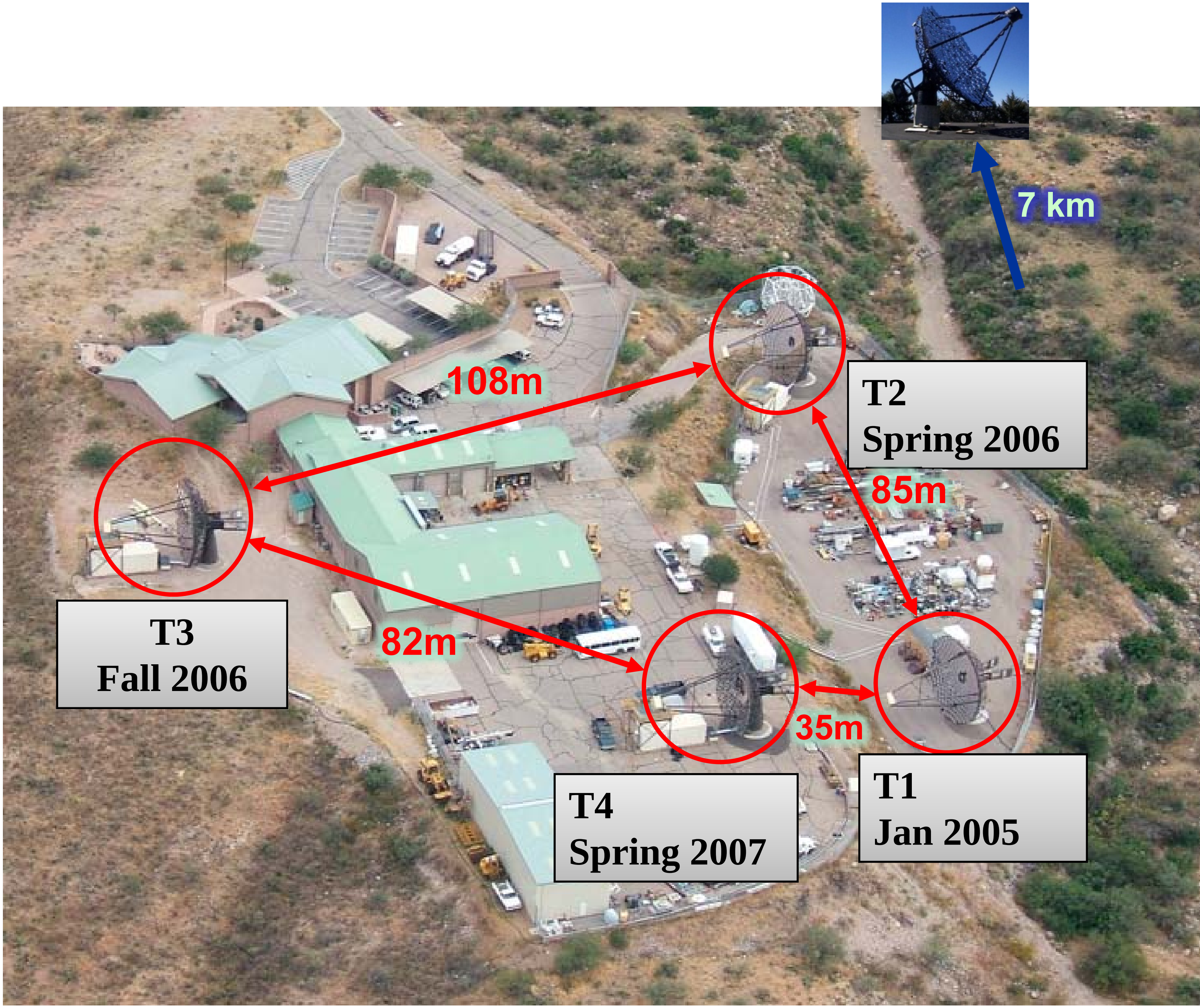
+ ~25 Associate Members

Telescope Layout

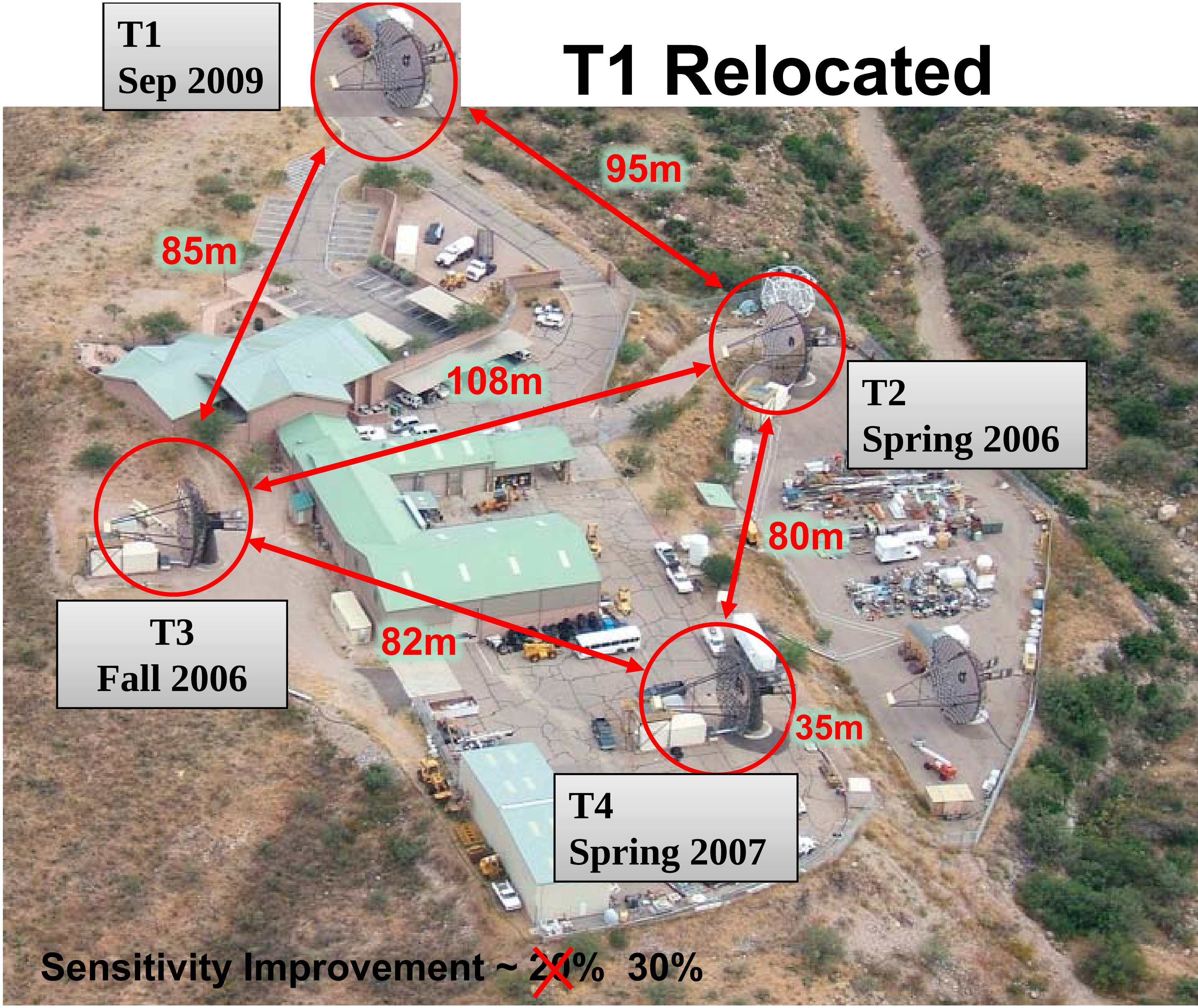




108m
T2
Spring 2006
85m
T3
Fall 2006
82m
35m
T4
Spring 2007
T1
Jan 2005


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

T1 Relocated

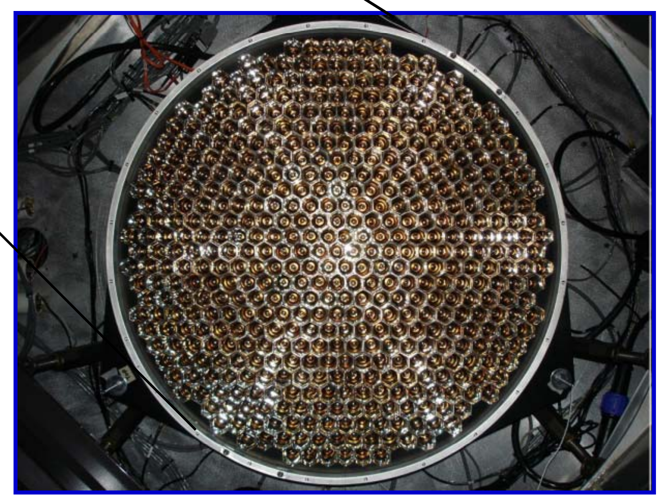


VERITAS (2010)

A VERITAS Telescope

12m reflector, f1.0 optics

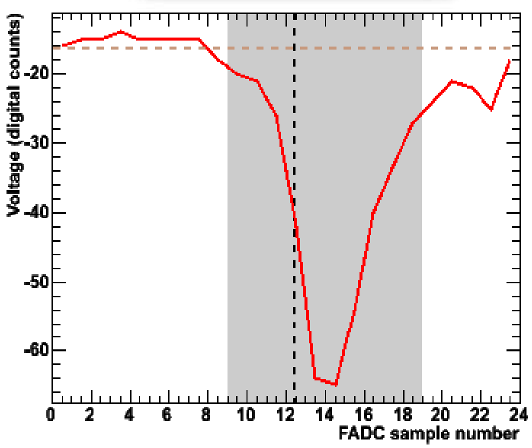
350 Mirror Facets

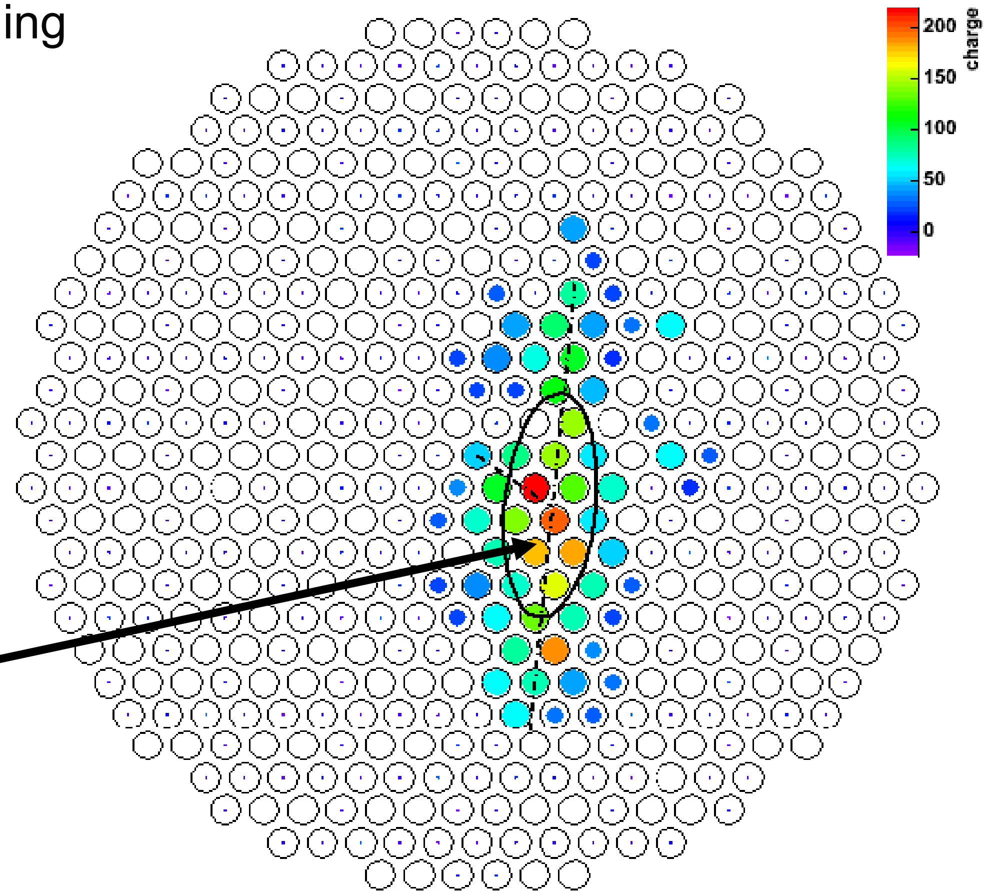


500 pixel Camera

VERITAS Data Acquisition

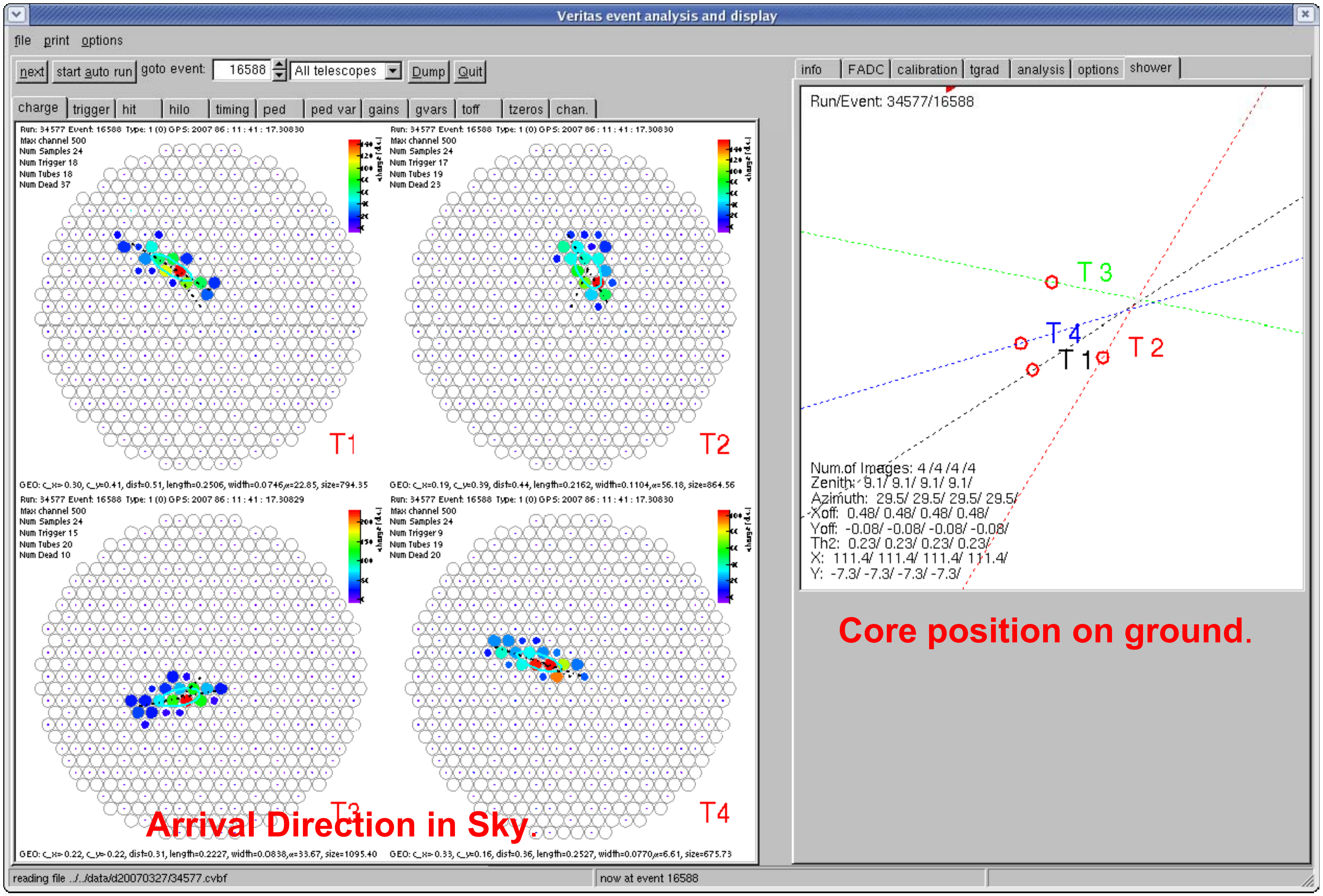
- PMTs digitized with 500 MHz sampling FADCs
  - 20 samples/channel.
  - <10% deadtime @ 250 Hz.





Timing & Amplitude on all channels.

Four-Telescope Event



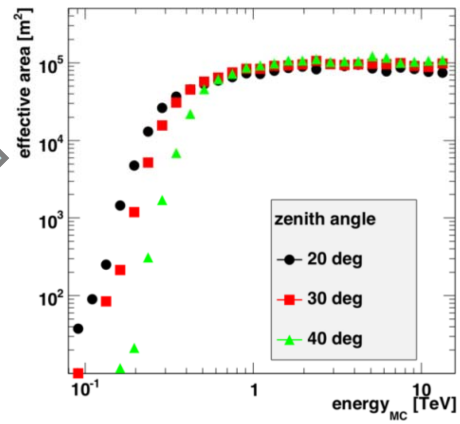
VERITAS Performance

Canonical Performance Values:

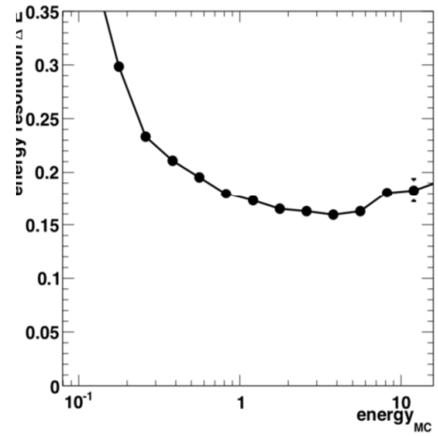
- ❑ Energy Range: 100 GeV – 30 TeV (spectra >150 GeV)
- ❑ Energy Resolution: 15% – 20%

- ❑ Crab Rate ~ 50 / min (trigger)
- ❑ Sensitivity: 5% Crab in < 2.5 h
  1% Crab in < 50 h

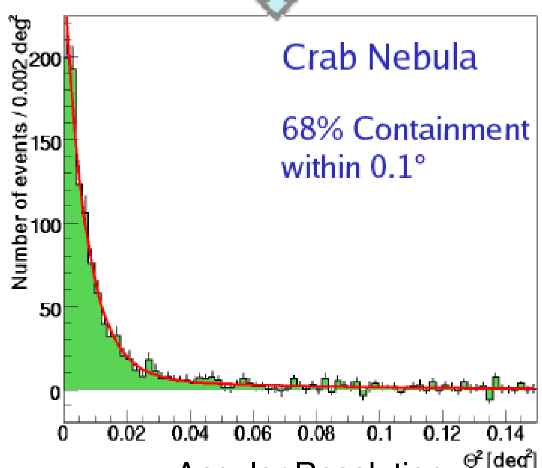
- ❑ Angular Resolution: $r_{68} < 0.1°$
- ❑ Pointing Accuracy: < 50′′



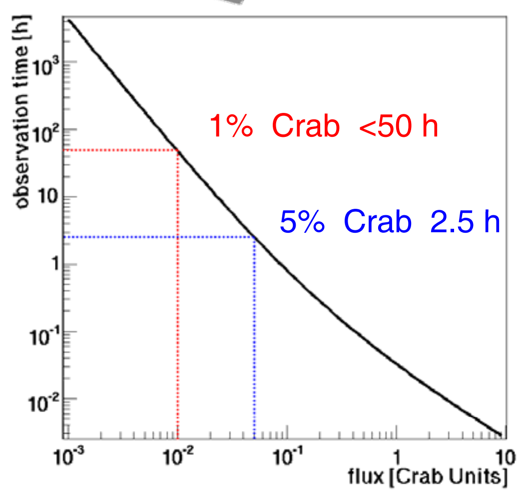
Effective Area (std. cuts)



Energy Resolution



Angular Resolution



Pt. Source Sensitivity

Operational & Analysis Improvements:

- ❑ "Hard" and "Soft" cuts permit improved E range, sensitivity.
- ❑ Enhanced reconstruction techniques give better sensitivity: **1% Crab ~ 40 h.**
- ❑ Future improvement: better PSF & new array configuration.

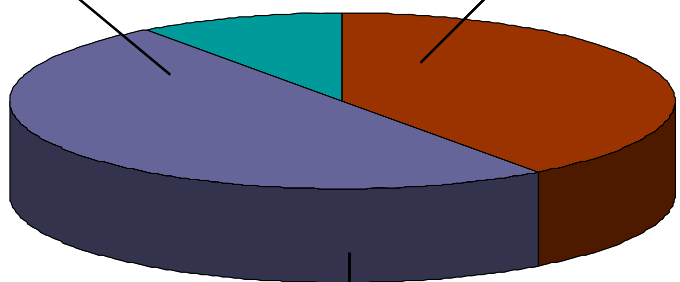
Observation Strategy 2007-09

Discretionary (10%)

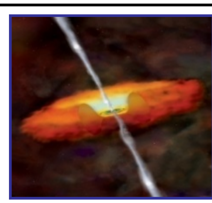
- ToO's, GRBs
- Higher risk sources

Observing Proposals (40%)

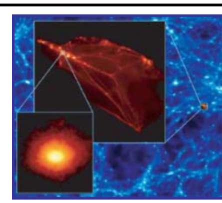
- Science WG's & TAC



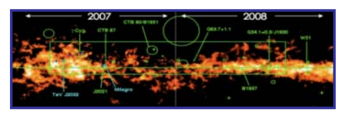
Key Science Projects (50%)



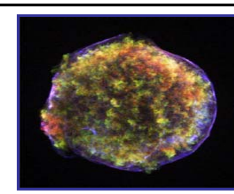
BLAZARS



Dark Matter



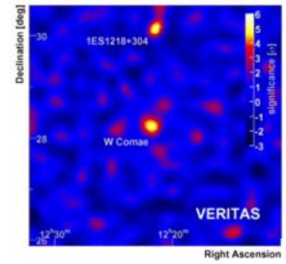
Galactic Plane Survey



SNRs/PWN

- **800 hours/year Dark Time + 25% Moonlight (= 1000 hours total).**
- **> 95% Data taken with all four telescopes operational.**

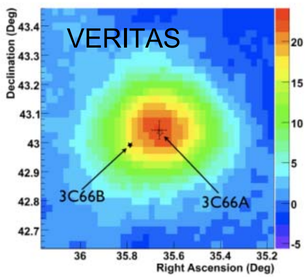
VERITAS Science Highlights (so far)



W Comae & 1ES 1218+304

2007:

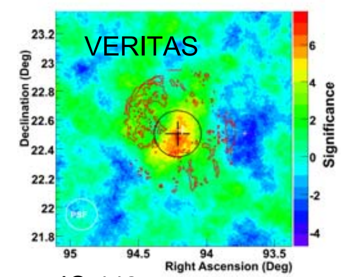
- **Detection of SNR IC 443 (w. MAGIC).**
- Detection binary LS I +61 303, confirming variability.
- Detection of blazar 1ES 1218+304 and radio galaxy M87.



3C 66A

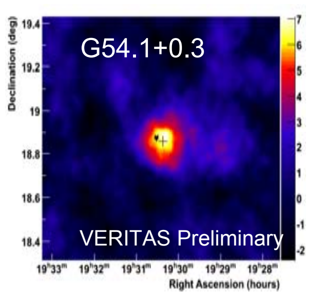
2008:

- Detection of blazar 1ES 2344+514, correlated TeV flare with X-ray.
- **Discovery of blazar 1ES 0806+524 (ATEL #1415).**
- **Discovery of blazar W Comae (ATEL #1422), a new LBL.**
- Detection of SNR Cas-A.
- **Discovery of blazar 3C 66A (ATEL #1753), the first IBL.**

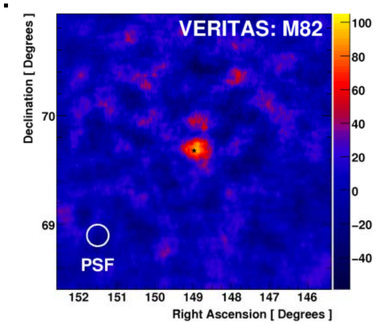


IC 443

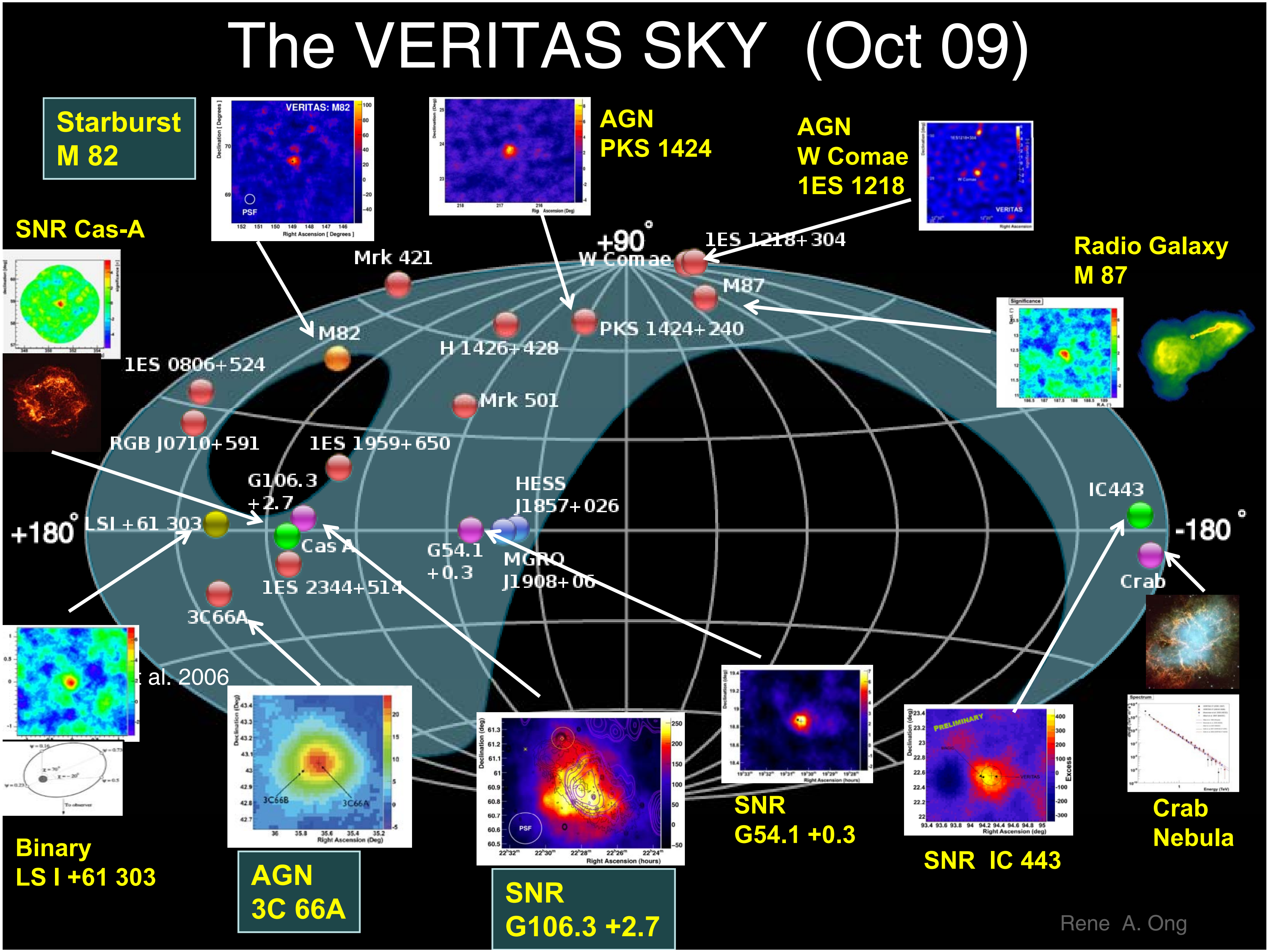
2009:



- Measurement of source extent of SNR IC 443.
- Simultaneous MWL observations of Mrk 421 reported (w. MAGIC).
- **Discovery of blazar RGB 0710 (ATEL #1941).**
- MWL observations of LS I +61 303 (w. Swift, RXTE).
- **Radio imaging of TeV emission region of M87 (w. MAGIC, HESS, VLBA).**
- Evidence for variability in HESS J0632+057.
- **July 09 (ICRC): 5 New Sources**
  Discovery of M82 – starburst galaxy
  Discovery of 2 new Galactic sources and 2 new AGN.



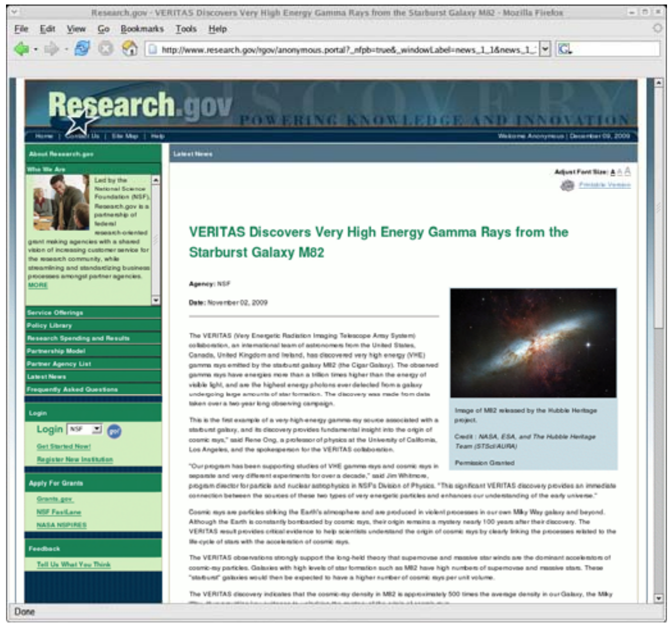
- **2010: First results from Sky Survey**
  Discovery of 5 new sources (2 AGN, 3 unidentified)



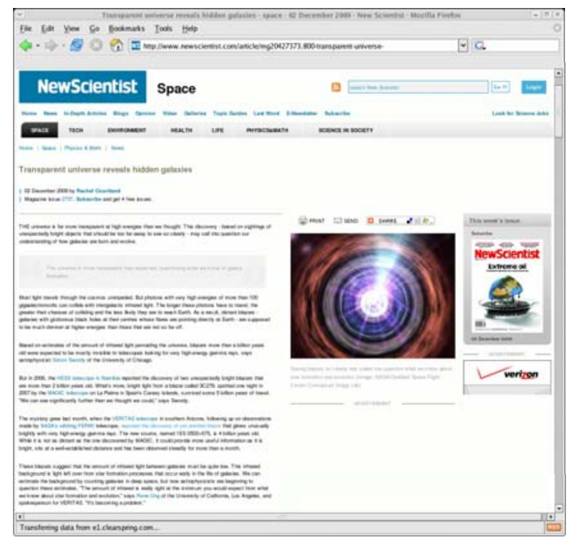
The VERITAS SKY (Oct 09)
Starburst M 82
VERITAS: M82
PSF
Right Ascension [Degrees]
AGN PKS 1424
AGN W Comae 1ES 1218
VERITAS
SNR Cas-A
Radio Galaxy M 87
Significance
+90°
W Comae
1ES 1218+304
Mrk 421
M87
M82
H 1426+428
PKS 1424+240
1ES 0806+524
Mrk 501
RGB J0710+591
1ES 1959+650
G106.3 +2.7
HESS J1857+026
IC443
+180°
LSI +61 303
Cas A
G54.1 +0.3
MGRO J1908+06
-180°
Crab
1ES 2344+514
3C66A
al. 2006
3C66B
3C66A
Right Ascension (Deg)
PSF
Right Ascension (hours)
PRELIMINARY
Right Ascension (deg)
Spectrum
Binary LS I +61 303
AGN 3C 66A
SNR G106.3 +2.7
SNR G54.1 +0.3
SNR IC 443
Crab Nebula
Rene A. Ong

Recent High Profile Results

M 87



M 82



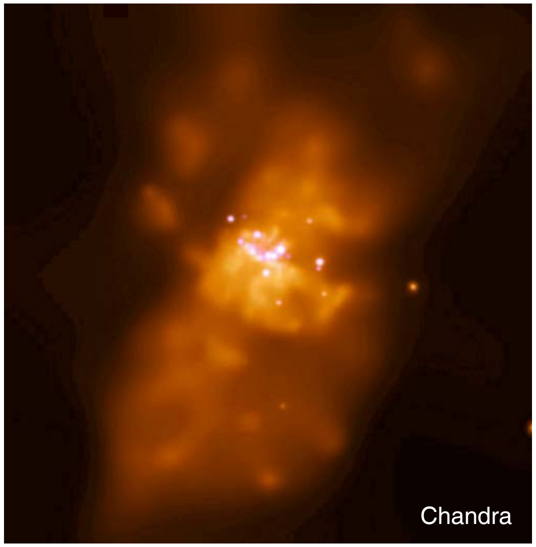
1ES 0502+675

NEW: Starburst Galaxy M 82

- **M82: Prototype starburst galaxy**
  - Interacting with group of galaxies over ~300 Myrs.
  - Tidal forces → active starburst region (HST shows > 200 massive star clusters.
  - SMBH < 3 x 10^7 M_{sun}, but no AGN activity.

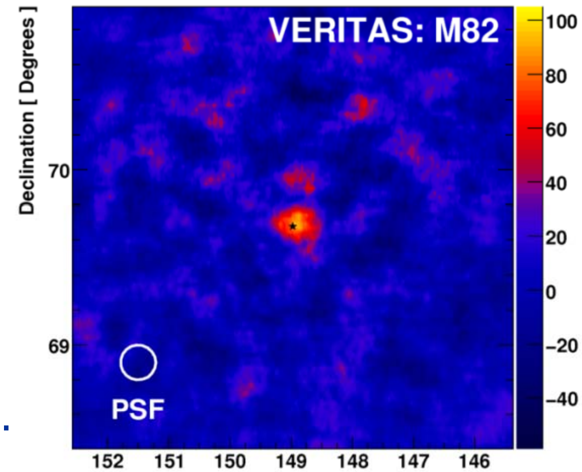

NASA, ESA, The Hubble Heritage Team, (STScI / AURA)

- **Starburst Region**
  - High star formation and SNR rate.
  - High CR density (from radio emission).
  - High gas density ~ 150 /cm^3.
  - γ-rays from cosmic rays interacting with gas and photon fields. Gives insight onto origin of CR's.
  - Previous limits < 10% Crab (HEGRA, Whipple).

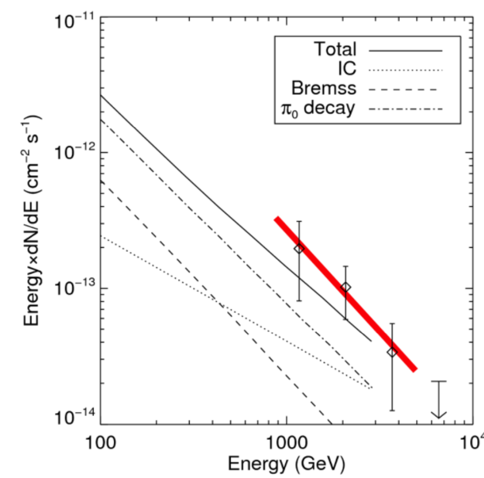

Chandra

NEW: Starburst Galaxy M 82

- **VERITAS Data & Analysis**
  - 2007-09: 137 h live time.
    Extremely long exposure.



- **Detection !**
  - Small signal, but consistent with point source at M82.
  - Many systematic checks.
  - Among weakest VHE sources ~0.8% Crab.
  - Fermi (GeV) subsequently announced M82 detection.



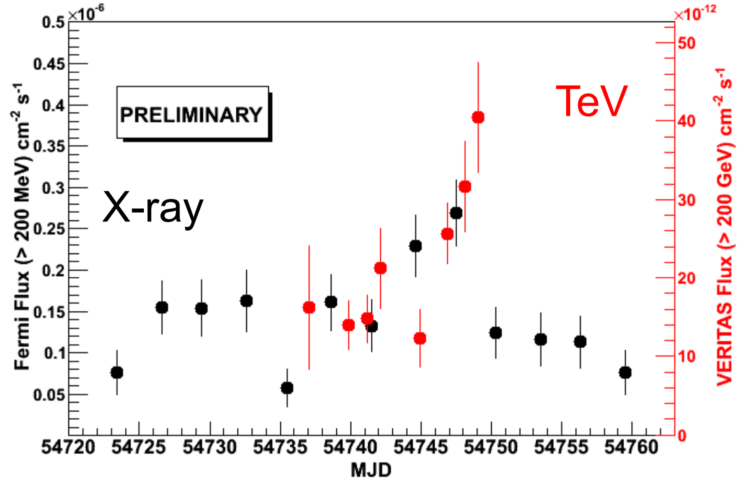
- **Interpretation**
  - **First detection of extragalactic VHE source not clearly associated with AGN activity.**
  - Consistent with predictions, general nature of CR interactions. In principle, a whole new set of extragalactic sources now accessible.

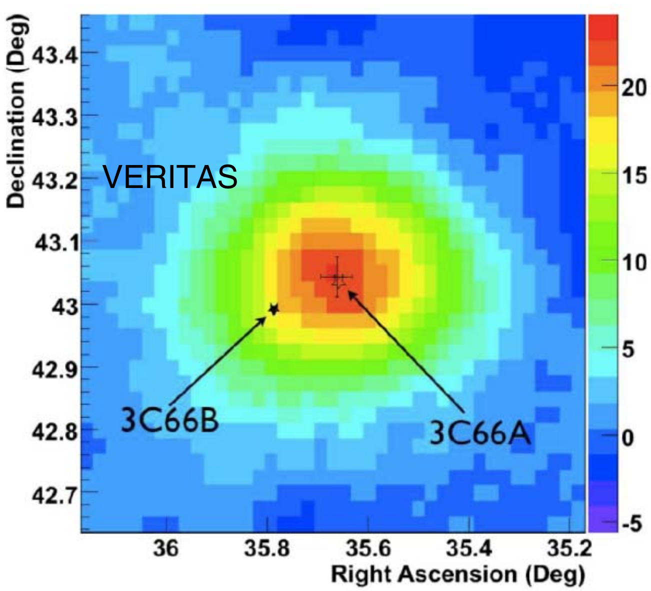
"A Connection between Star Forming Activity and Cosmic Rays in the Starburst Galaxy M 82," V. Acciari et al., Nature, 02 November 2009.

3C 66A: A Typical VERITAS Blazar

- 3C 66A
  - Int. BL Lac at nominal z=0.44.
  - **VERITAS discovery 21σ, 33h, Flare !**
    ATEL #1753, V.A. Acciari et al., ApJ 693, L104 (2009)
  - Soft spectrum: $\Gamma = 4.1 \pm 0.4_{stat} \pm 0.6_{sys}$ (due to absorption ?) .

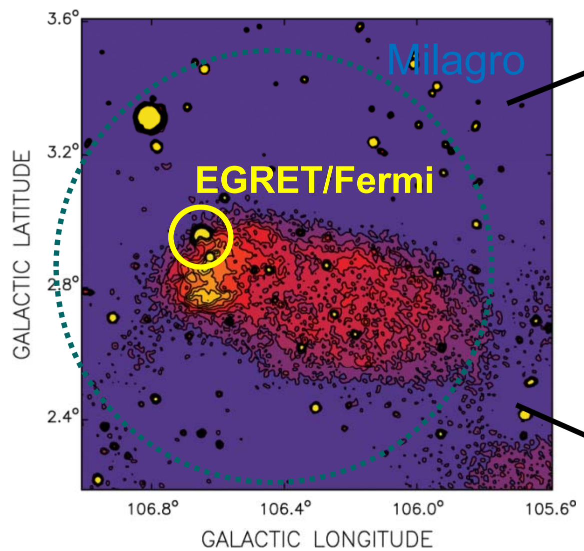
TeV γ-ray flare
Correlated with X-rays, also Fermi

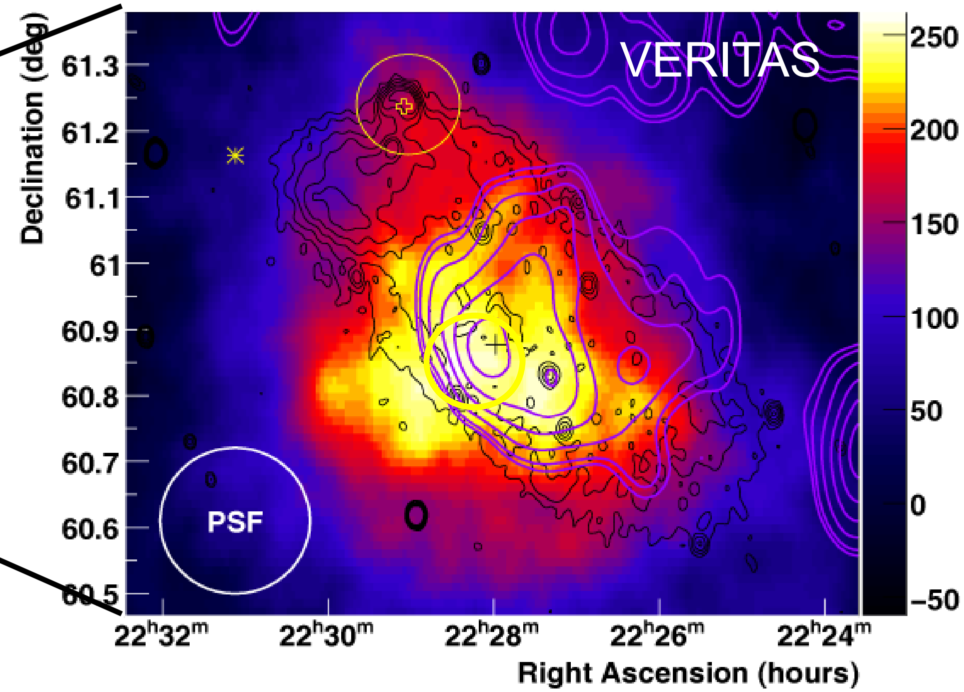




- MAGIC reports 3C66B 0.12° away. 5.4σ in 54 h from 2007 data.
- VERITAS data excludes 3C66B at 4.3σ.
- **VERITAS clearly detects this very distant object; this has clear implications for understanding the EBL.**
  (Paper in works with Fermi-LAT).

NEW: SNR G106.3 +2.7 (“Boomerang”)





- G106.3 +2.7
  - Energetic pulsar PSR and SNR E-dot ~ 2 x 10^{37} erg/s, age ~ 10 ky.
  - EGRET error ellipse Fermi-LAT pulsar J2229.0+6114.
  - Milagro reports > 10 TeV emission from region.

- VERITAS Results
  V. A. Acciari et al., ApJ 703, L6 (2009).
  - 33 h data, solid detection, flux ~5% Crab.
  - Clearly extended, peak overlaps CO.
  - $\Gamma = 2.3 \pm 0.3_{stat} \pm 0.3_{sys}$, hard power-law spectrum.

Points towards Hadronic Origin

Dark Matter Searches

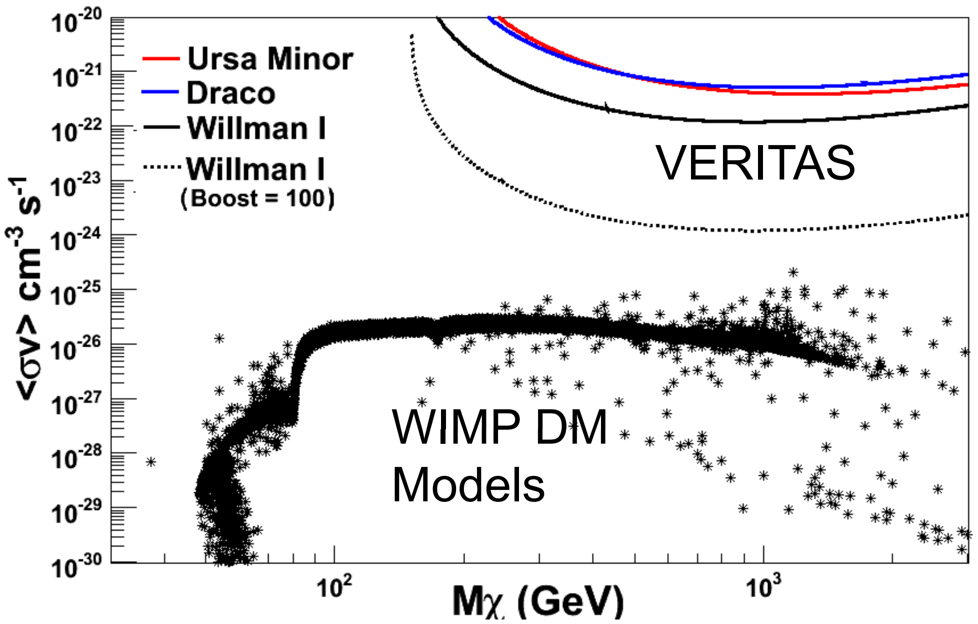
- VERITAS DM Program

- Comprehensive program, ~ 7% of observing time, variety of objects:

  Dwarf Galaxies (Draco, Willman I)
  Local Galaxies (M32, M33)
  Globular Clusters (M5)
  Galaxy Clusters (Coma)

- **So far, no Detections**
  → Limits on 7 candidate sources
  Observations to continue, now including Galactic center.

VERITAS limits on dwarf galaxies



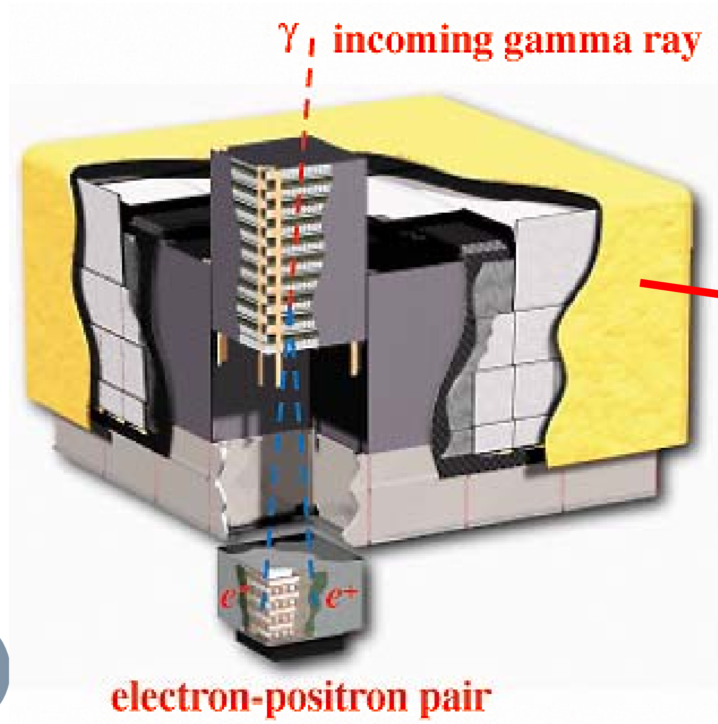
What's next for VERITAS ?

Many Things !

- New Results: 6 new sources in last six weeks.
- Observing: completed 2 years of >5 year program.
- Fermi Gamma-Ray Space Telescope: important overlap.
- Spectra and modelling: → source mechanisms.
- MWL studies: radio, optical, X-ray, γ-ray.
- Upgrade: new cameras, toplogical trigger.
- …

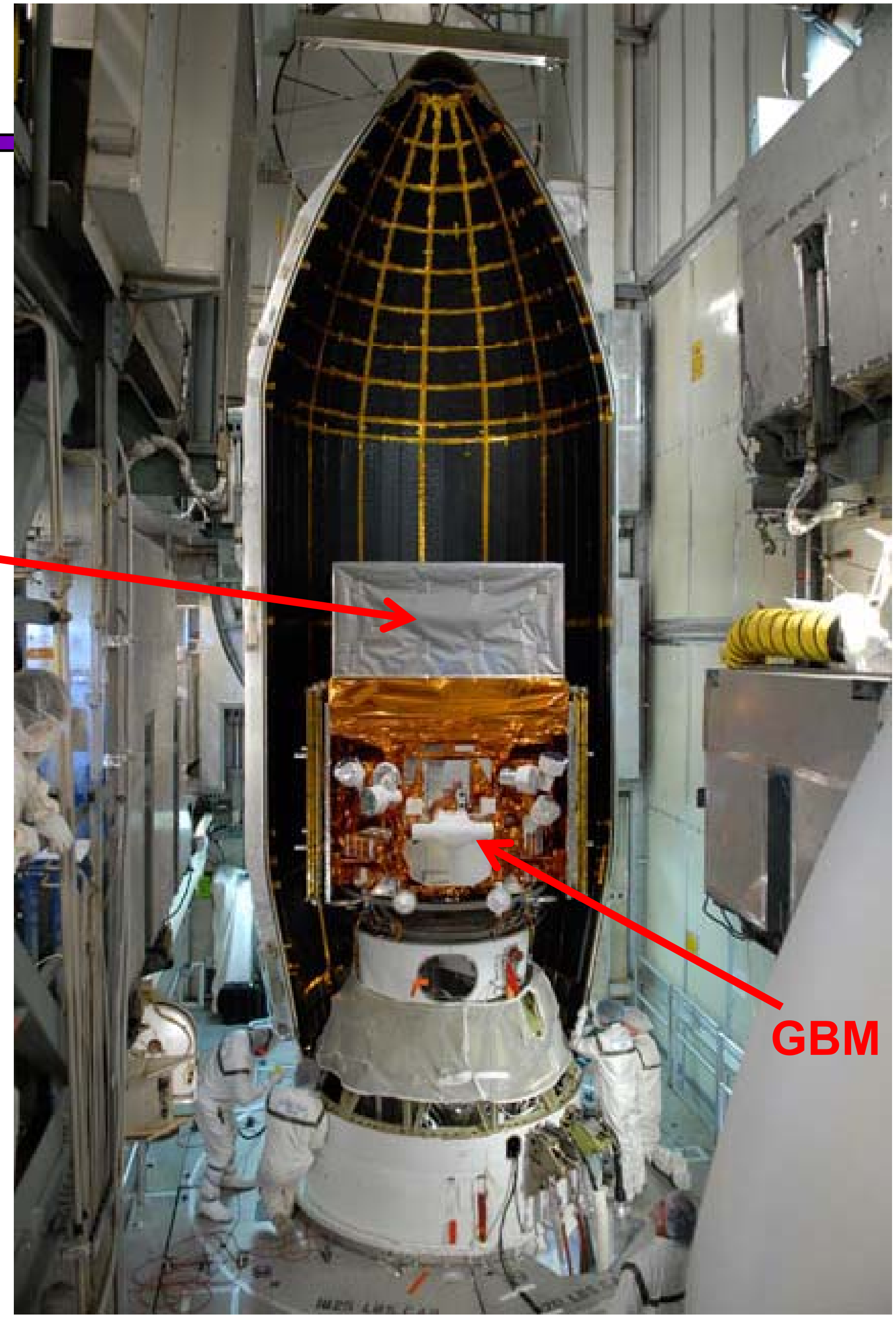
Fermi GST

Large Area Telescope (LAT)

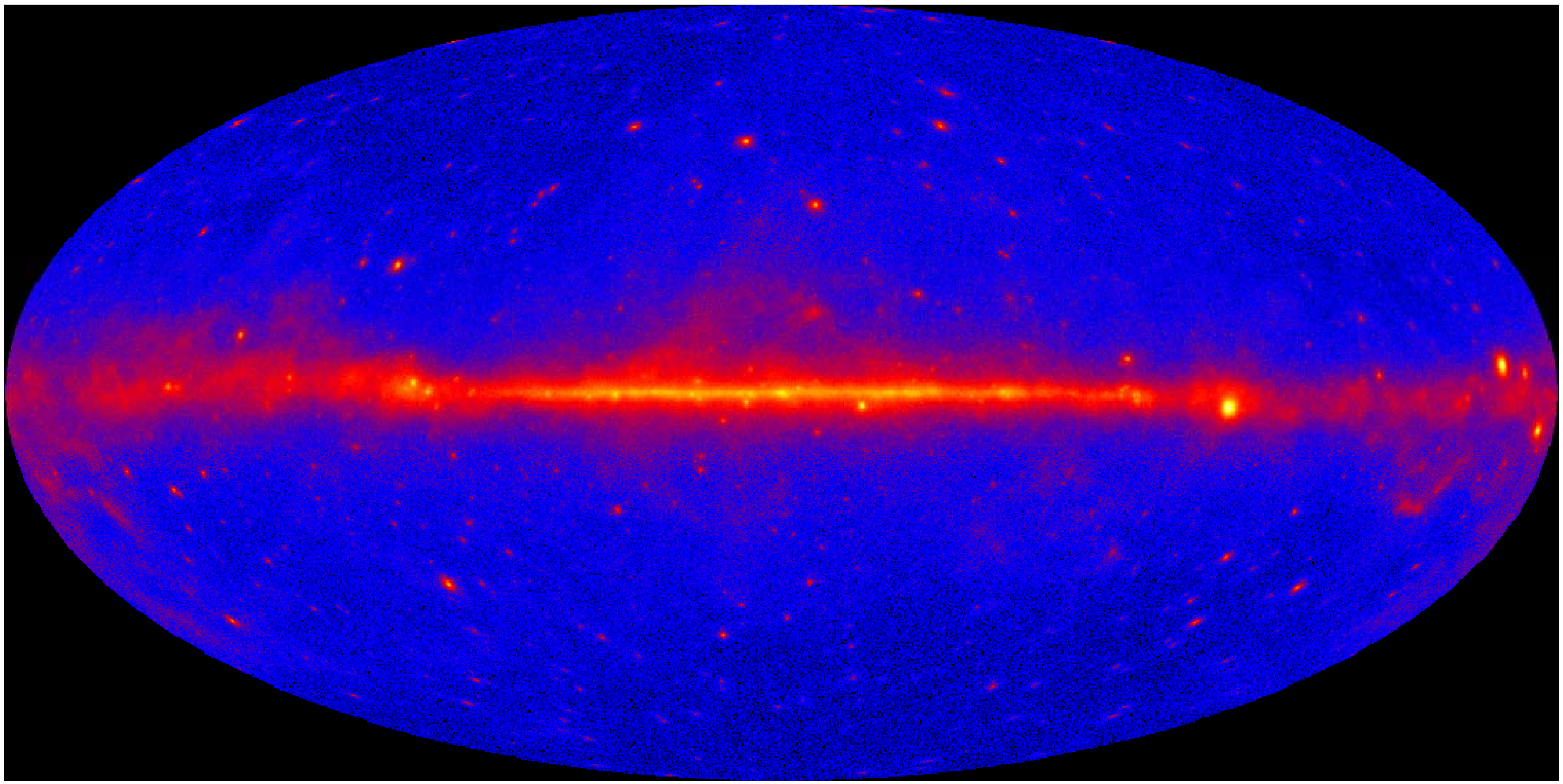


γ-ray converts in LAT to an electron and a positron ; tracking these give us the direction and energy of the photon.

Launched from Cape Canaveral
11 June 2008



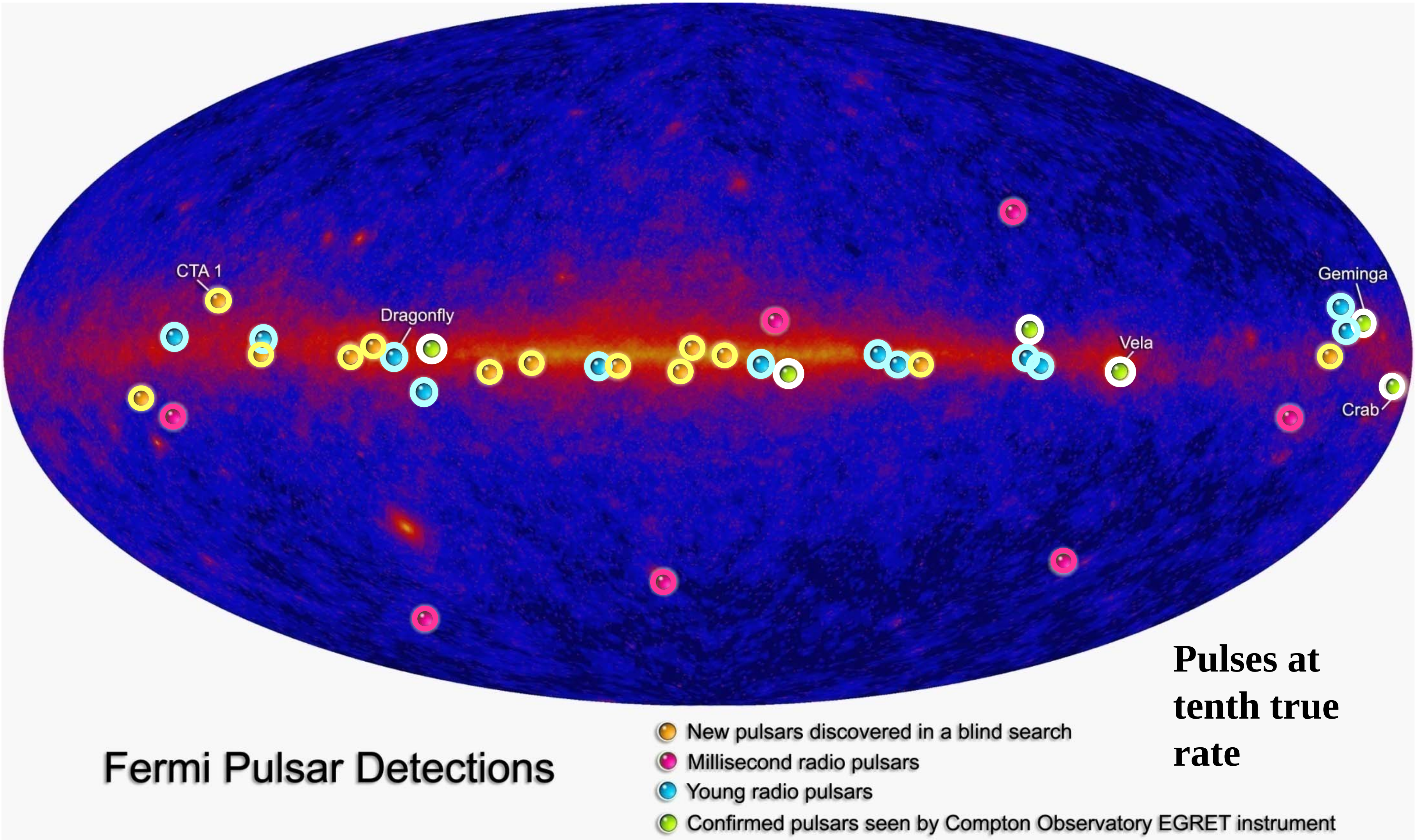
Fermi γ-ray Sky after 1 year



Fermi basically sees the same types of sources as TeV telescopes.

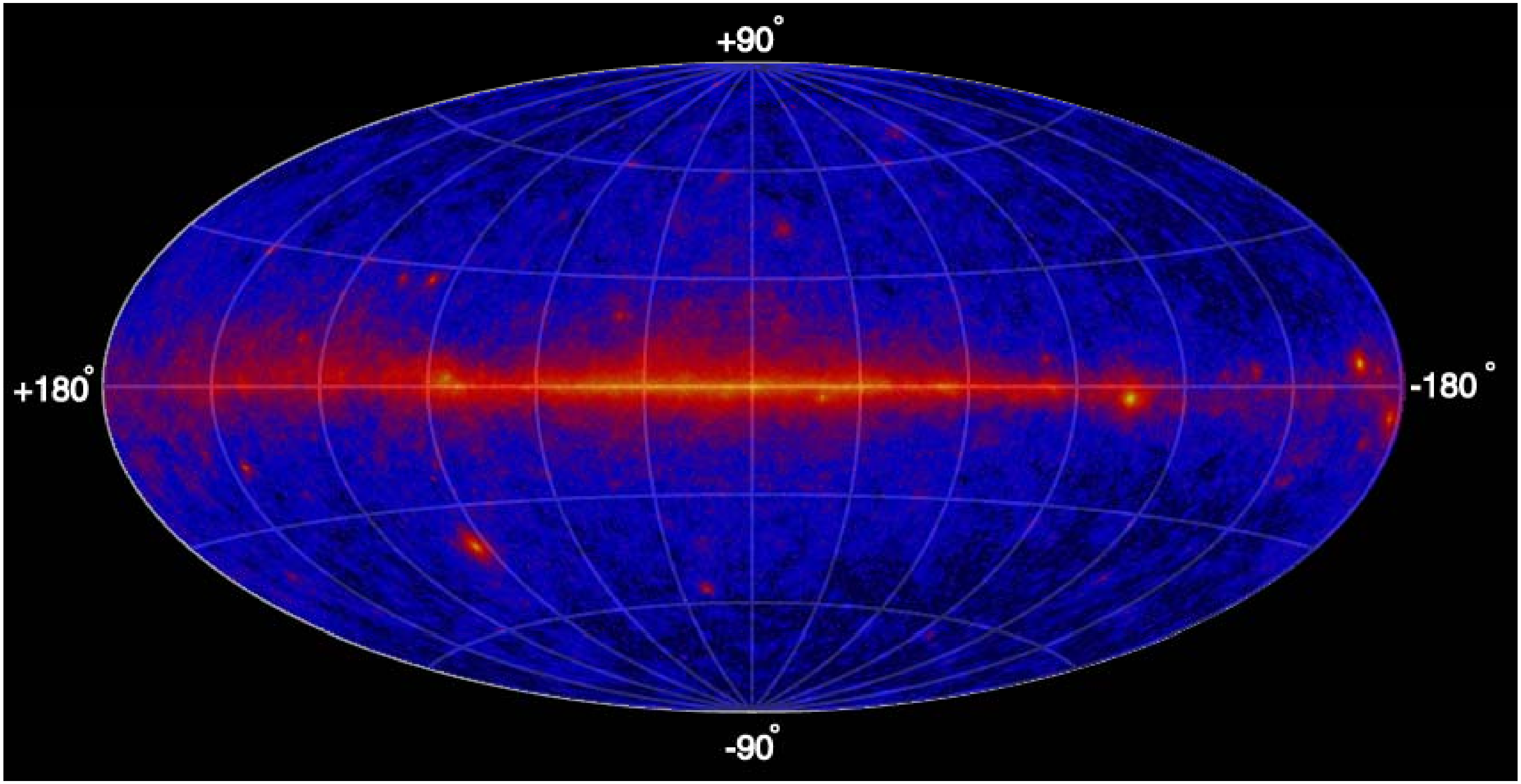
(main exceptions: diffuse emission, pulsars and GRBs).

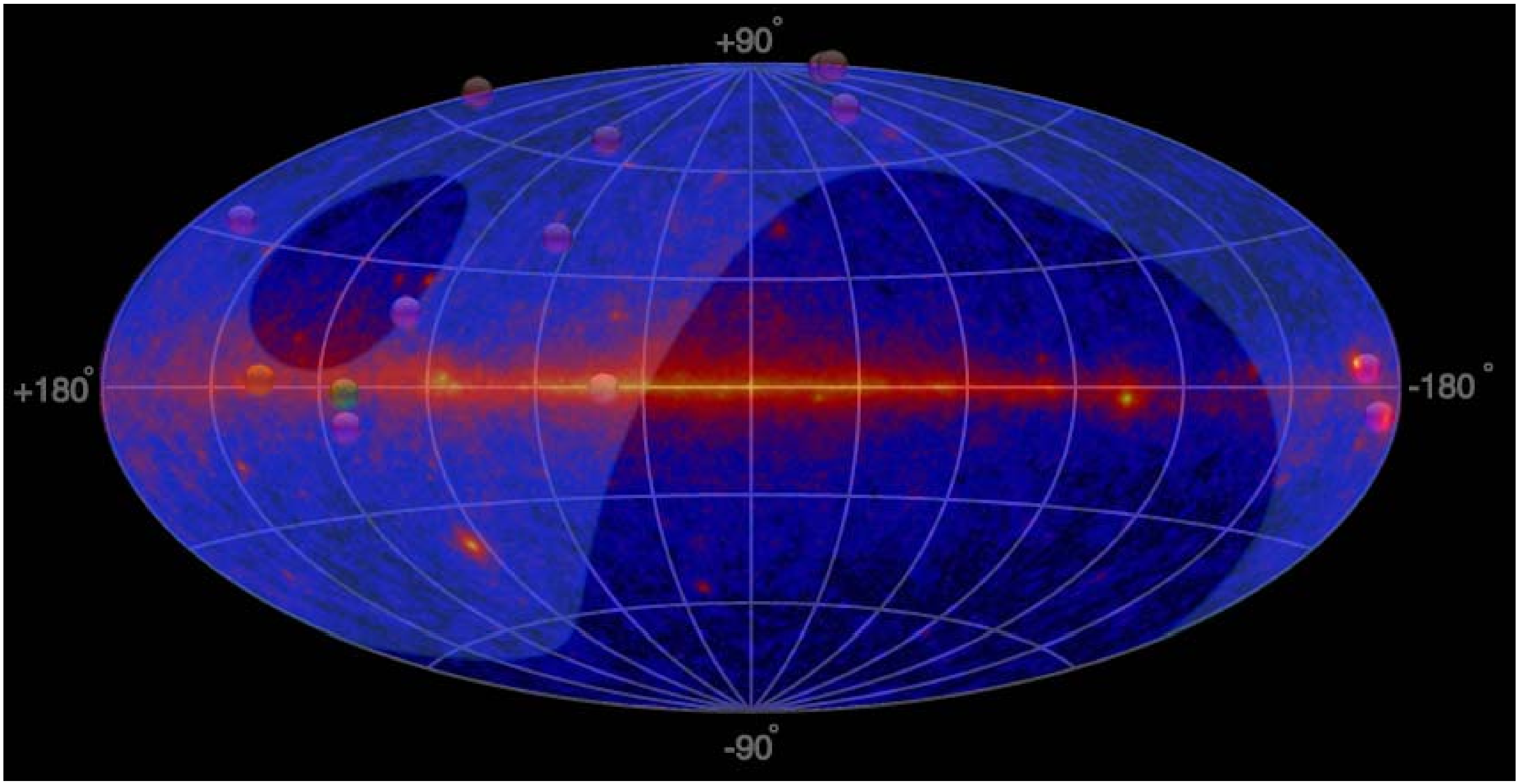
γ-ray Pulsars Detected by Fermi

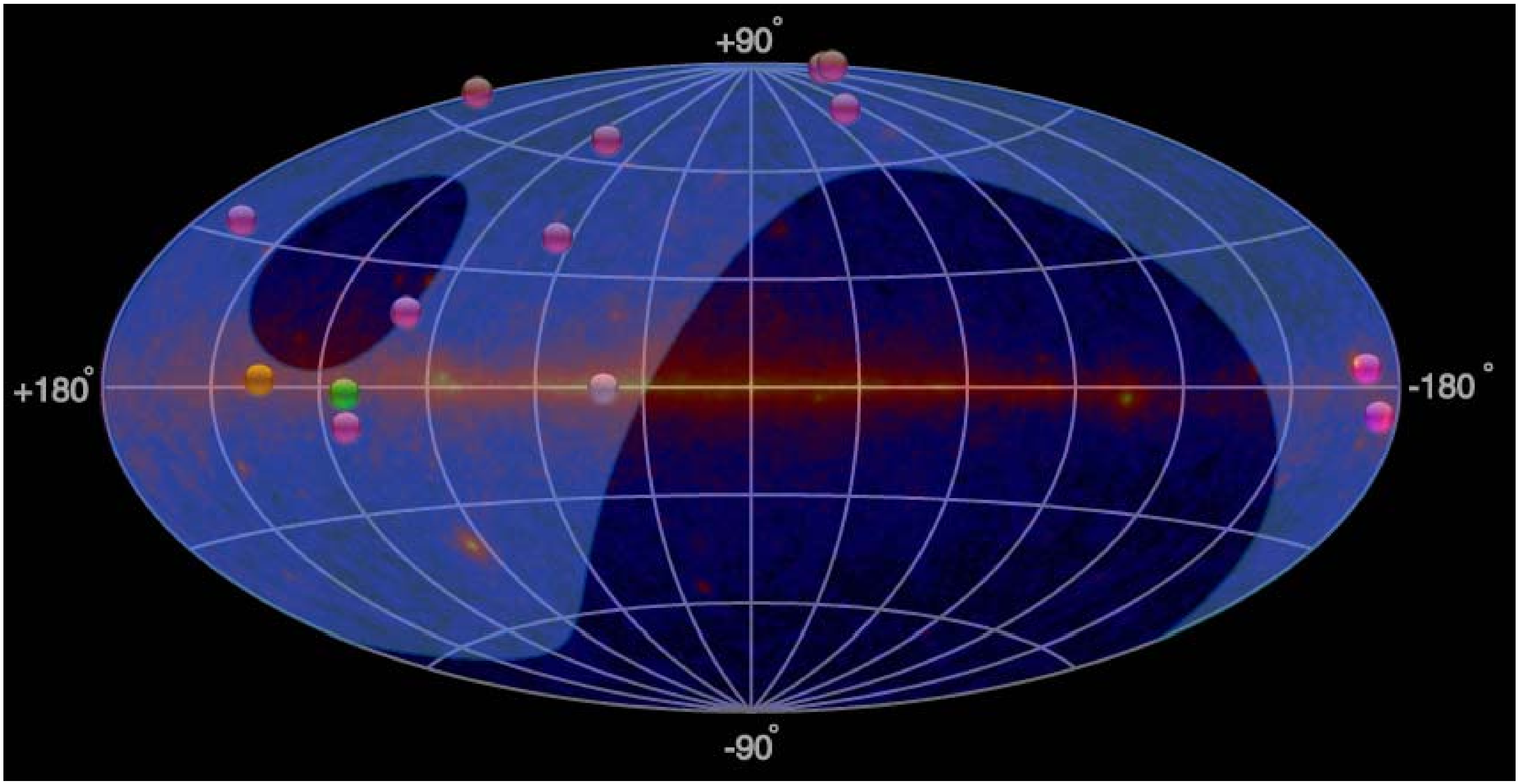


Pulses at tenth true rate

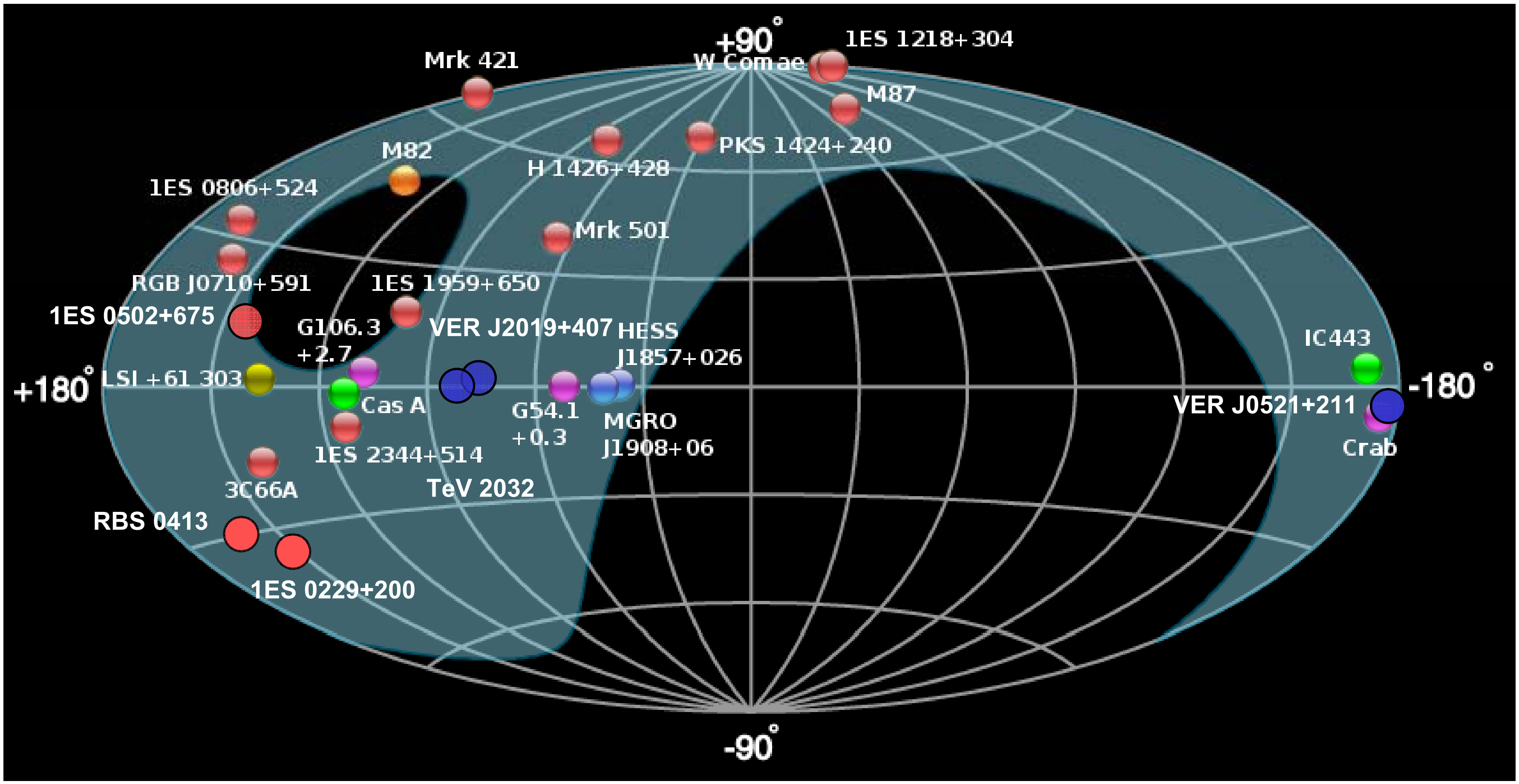
The Fermi (GeV) Sky



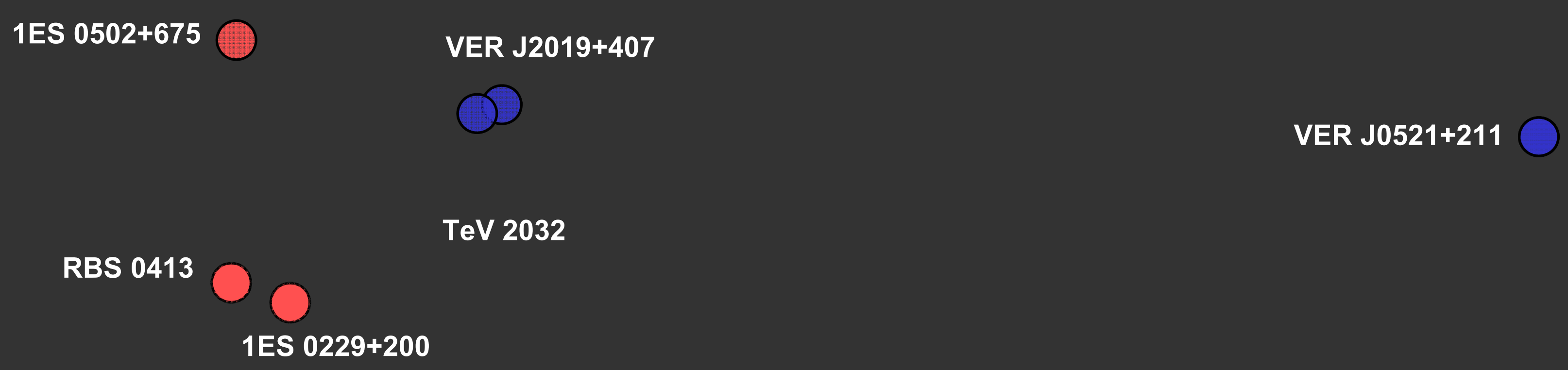

+90°
+180°
-180°
-90°


+90°
+180°
-180°
-90°

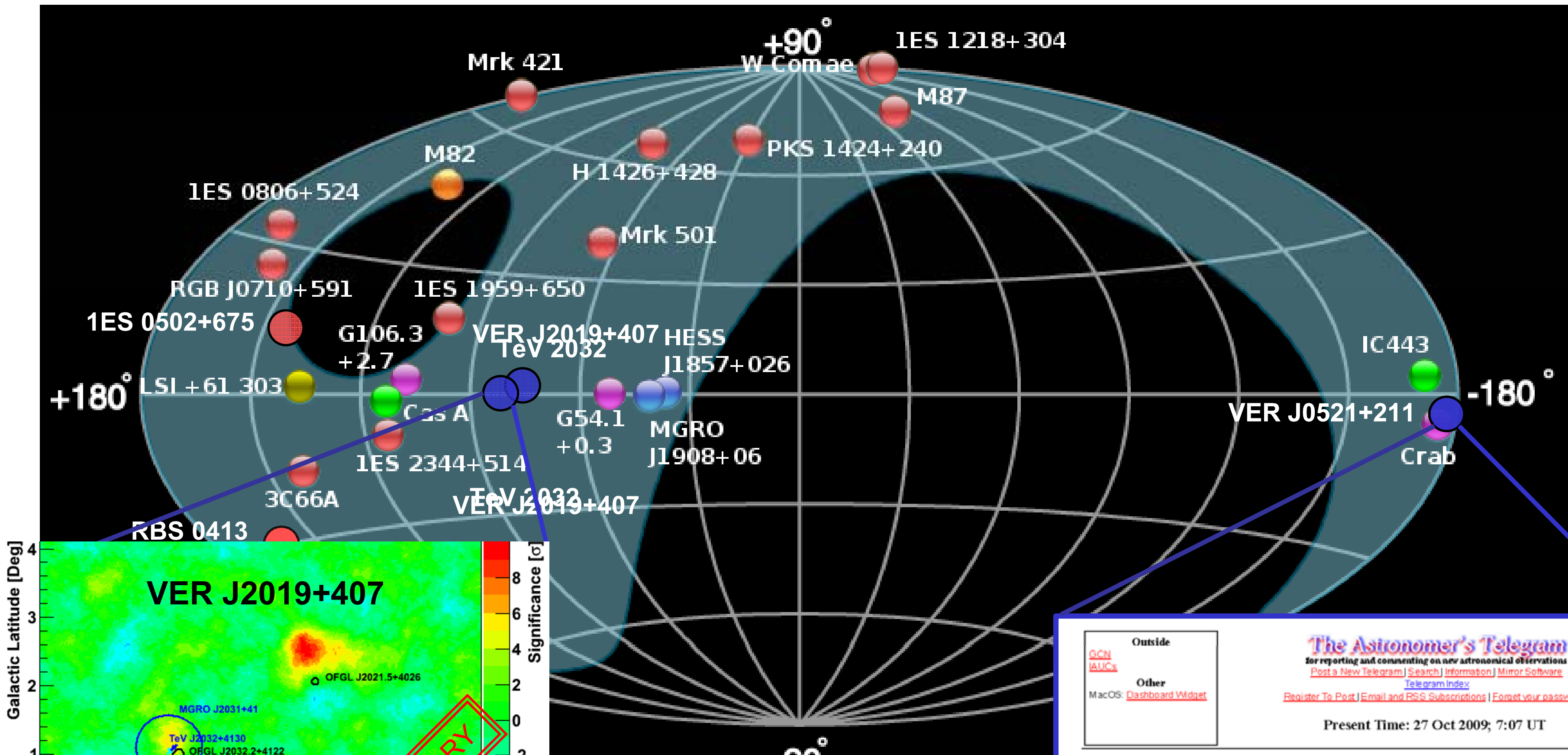
The VERITAS Sky (2010)



The VERITAS Sky (2010)

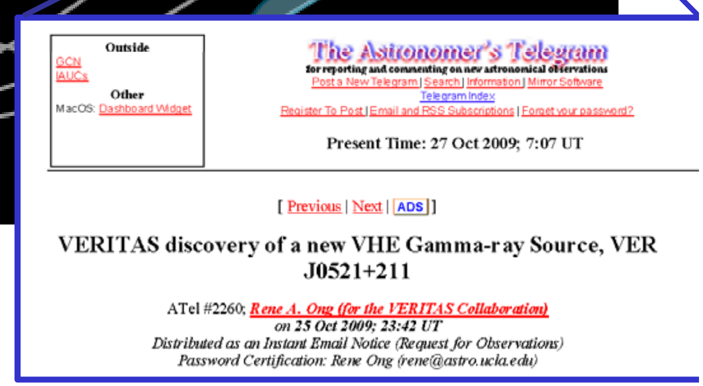


The VERITAS Sky (2010)



???

So far,
28 sources detected
6 source categories


The Astronomer's Telegram
for reporting and commenting on new astronomical observations
Post a New Telegram | Search | Information | Mirror Software
Telegram Index
Register To Post | Email and RSS Subscriptions | Forget your password?
Outside: GCN, IAUCs
Other: MacOS: Dashboard Widget

Present Time: 27 Oct 2009; 7:07 UT

[Previous | Next | ADS]

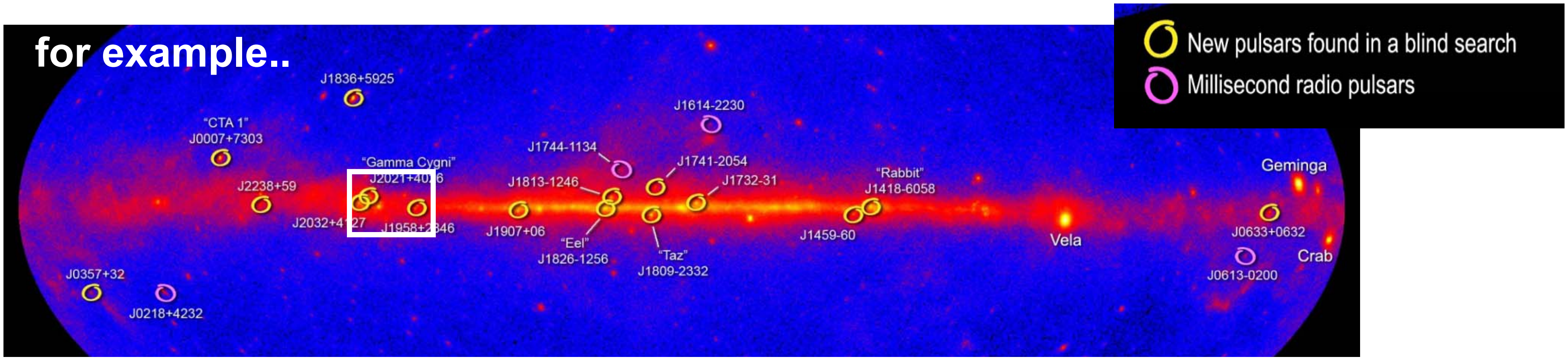
VERITAS discovery of a new VHE Gamma-ray Source, VER J0521+211

ATel #2260; *Rene A. Ong (for the VERITAS Collaboration)*
on 25 Oct 2009; 23:42 UT
Distributed as an Instant Email Notice (Request for Observations)
Password Certification: Rene Ong (rene@astro.ucla.edu)

New AGN ?

VERITAS Sky Survey: Motivation

- Efficient method of searching for new sources over a large region



- *Un-biased* indication of source population

- Southern hemisphere well-surveyed
  - HESS Galactic plane survey, ~14 sources in initial survey
- Best limits in northern hemisphere sky : HEGRA's Galactic plane survey
  - -2˚ < l < 85˚, flux upper limits: 15% Crab to several Crab

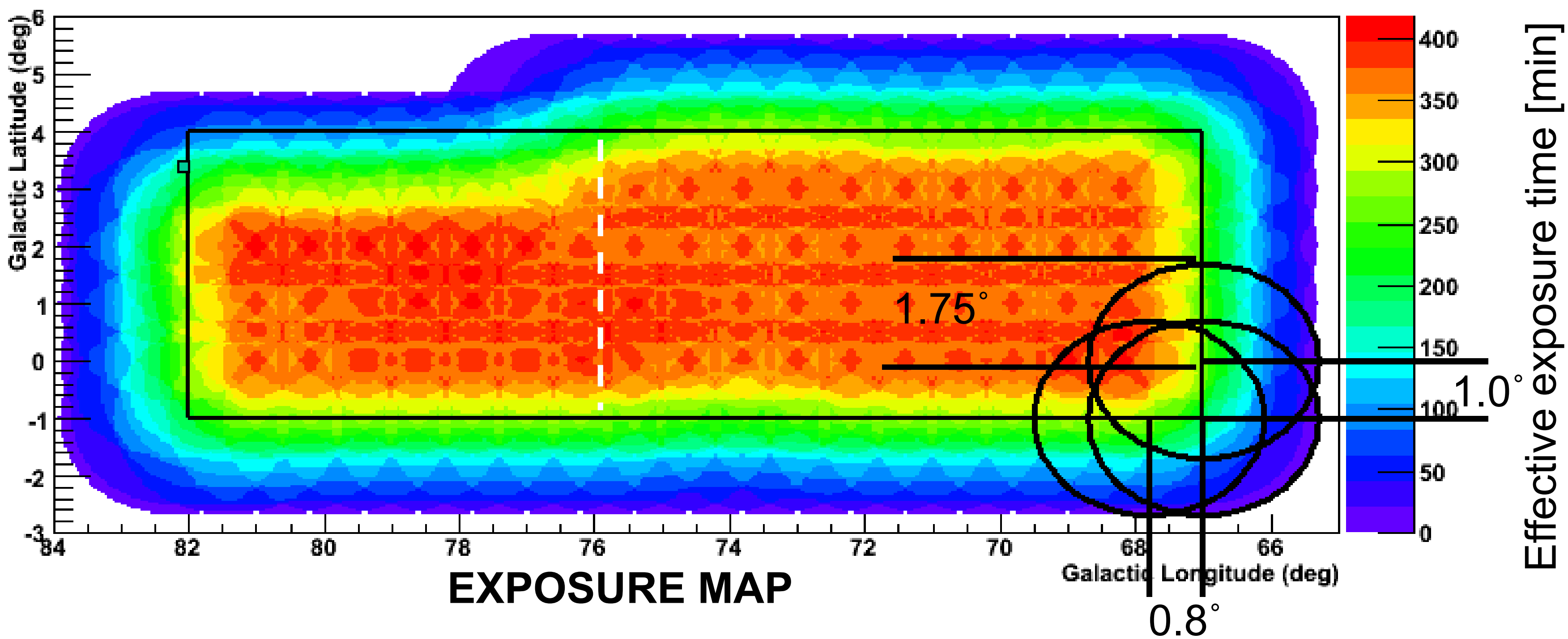
- Size and choice of region based on
  - VERITAS sensitivity and FOV
  - Material distribution, density of potential TeV γ-ray emitters (SNR, PWN, high E-dot pulsars, EGRET unidentified sources..)

VERITAS Sky Survey: Strategy

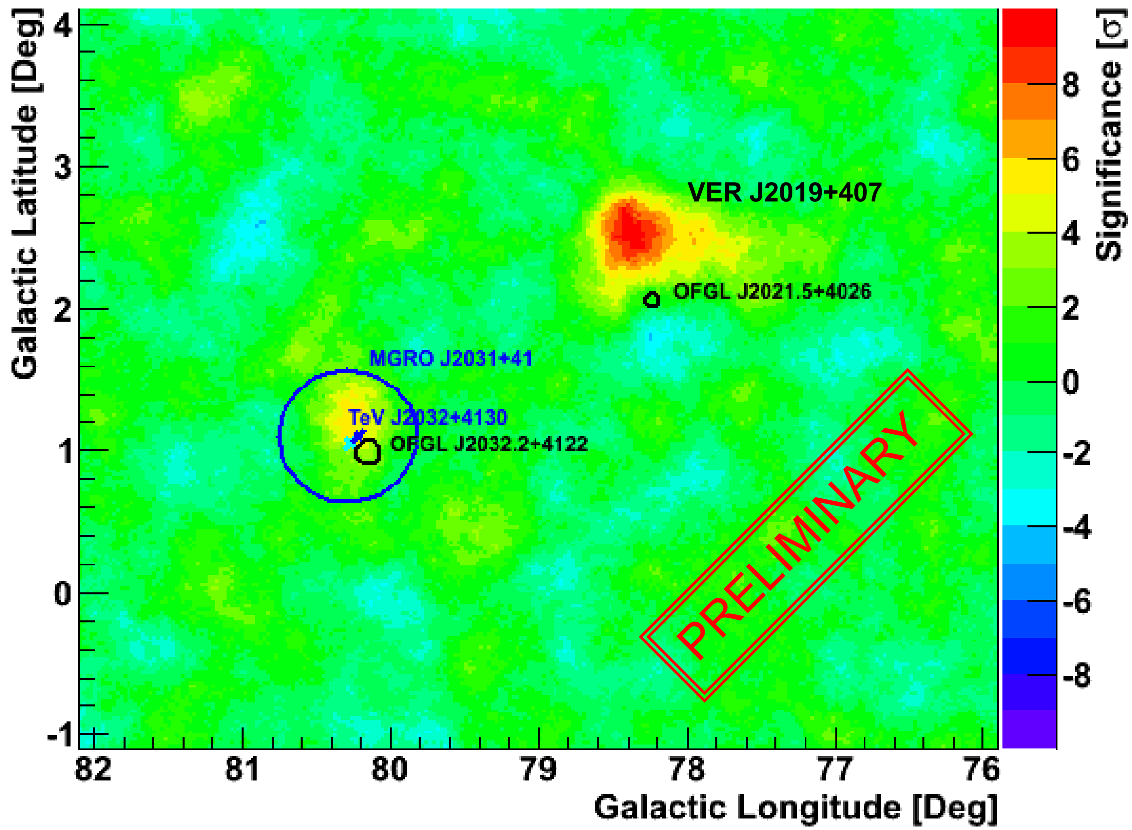
Most sensitive survey of the Galactic plane in N. Hemisphere at TeV γ-ray energies.

Made possible by good VERITAS off-axis sensitivity

- Survey covers region 67˚ < l < 82˚, -1˚ < b < 4˚
- ~6 hrs effective exposure at every location (before follow-up).
- ~112 hours in base survey, ~56 hours follow-up.



One Interesting Region



- VER J2019+407
  - **New VERITAS source**
- TeV J2032+4130
  - known source, first detected by HEGRA
  - Likely associated: MGRO J2031+41, 0FGL J2032.2+4122 (LAT pulsar)
  - Detection: >5σ at nominal position (no trials)

- Partial survey map, generated with standard threshold extended source analysis
- Includes all data in survey region taken to this point
- Exposure uneven due to followup (more intensive followup around VER J2019+407 than around TeV J2032+4130)

FUTURE

Next 5-10 years will be very exciting for this field.

VERITAS will survey the VHE γ-ray sky with great sensitivity, complementing:

Fermi-LAT (GeV γ-rays, in space)
IceCube (ν, South Pole)
Auger (UHECR, S. Hemisphere)

In the future:

- HAWC: 1 TeV air shower array (proposed, Mexico).
- Large 1 km^2 array of atm. Cherenkov telescopes.
  CTA = Cherenkov Telescope Array

VERITAS Upgrade (2010-2012)

- We plan to replace the PMT cameras and L2 trigger system to significant improve the sensitivity and energy threshold.

CAMERA Upgrade

PMT replacement with high efficiency PMTs.

Increase photon collection by ~35%.

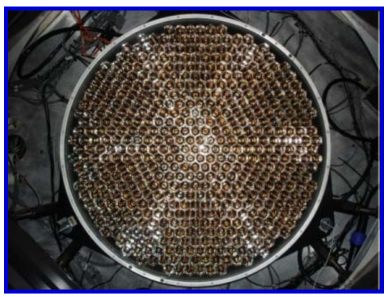
Improves background rejection, E_{th}, sensitivity.

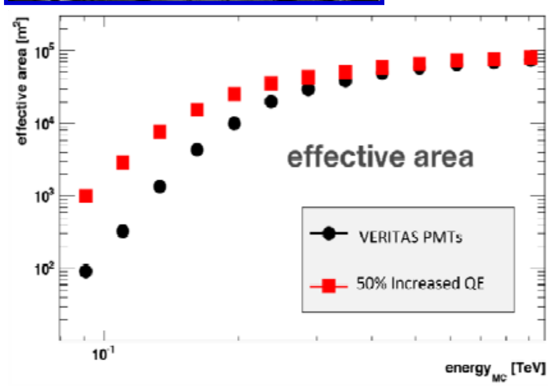
TRIGGER Upgrade

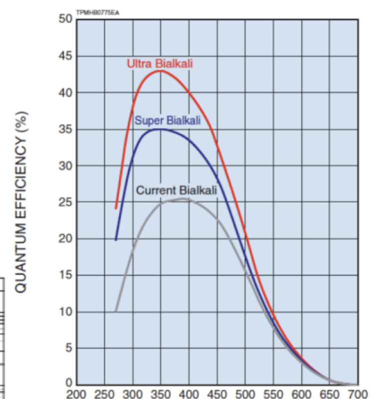
Smaller coincidence window

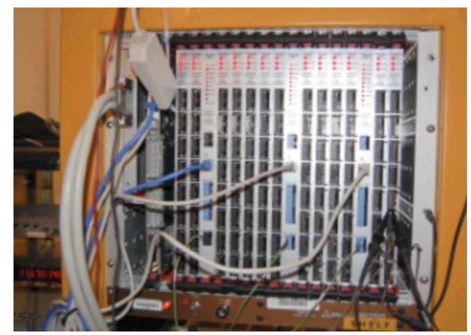
Topological Trigger

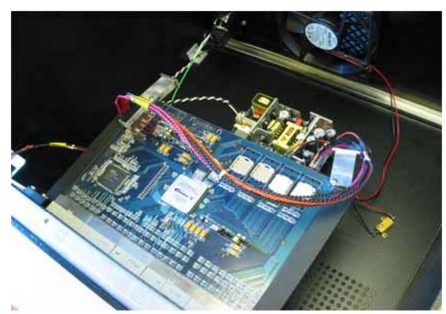
Improves E_{th} and CR event rejection.







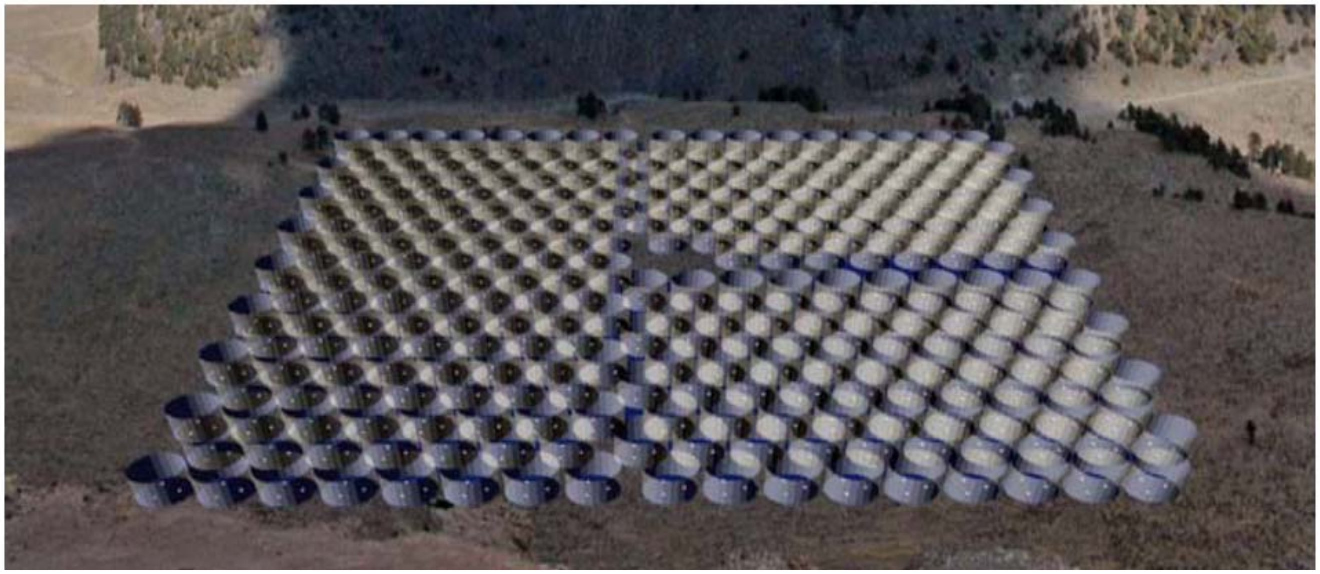


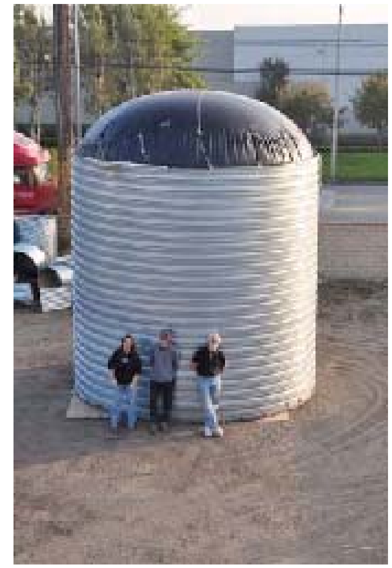


Prototype Trigger Systems

Upgrade now funded through NSF MRI R2

HAWC





HAWC array of water tanks at high altitude (operational by 2014 ?)

Prototype tank

- HAWC Design

- Measures the air shower particles that reach ground level.
- Main advantages: high-duty cycle, wide field-of-view.
- Higher E threshold (TeV), not as sensitive as atm-Cherenkov.

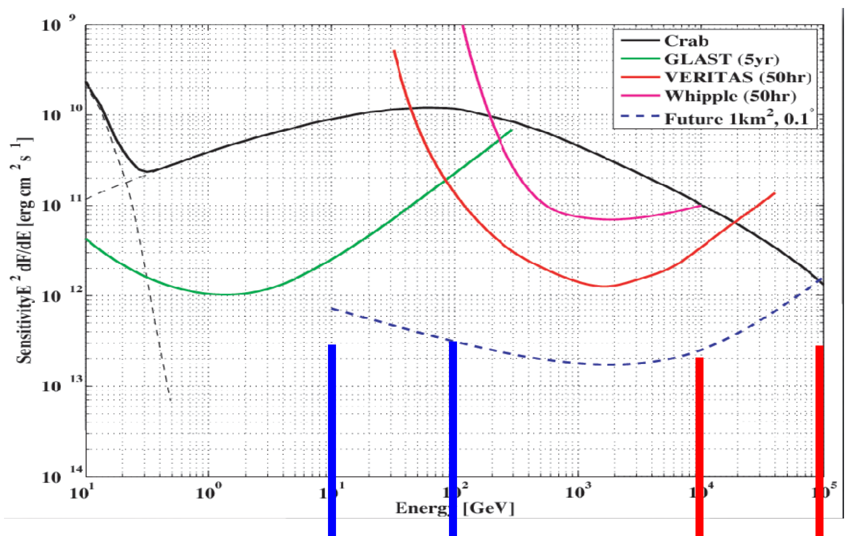
1 km^2 Atm. Cherenkov Array

Large (1 km^2) array.

- 50+ telescopes, aperture 8-20m.
- $300-400M class observatory, 2 sites.

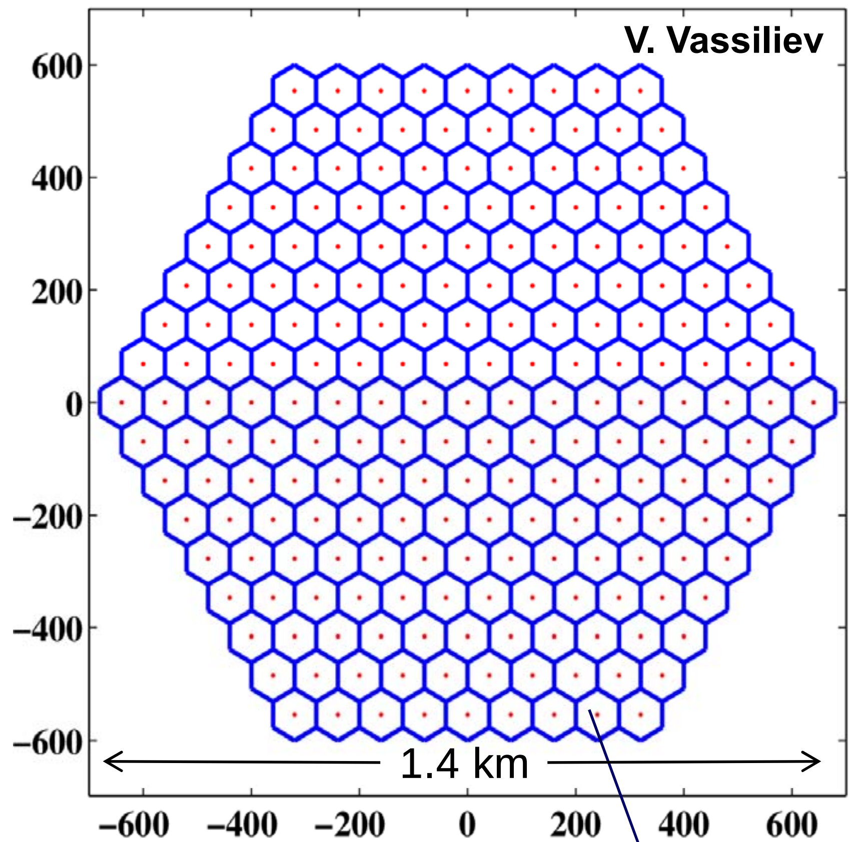
Factor of >10 more sensitive than VERITAS.

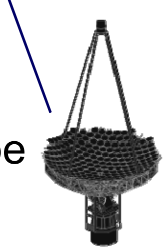
AGIS (U.S.) & CTA (Europe) in Design Phase.



Transition to Fermi Regime (GRBs, etc.)

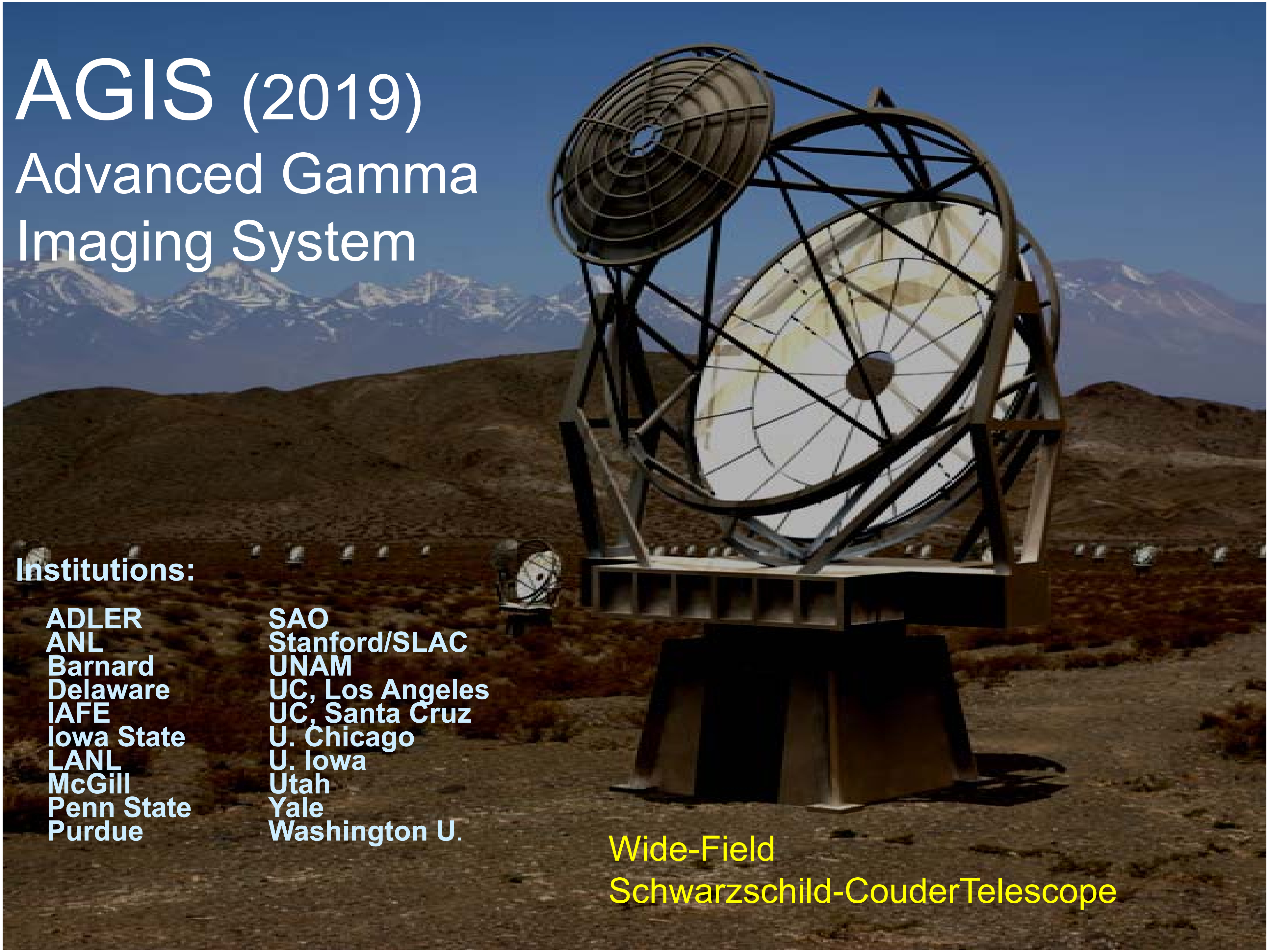
Spectral cutoffs (acceleration mechanisms)





10-12m telescope
Wide-field
8-10^o FoV

AGIS (2019)
Advanced Gamma Imaging System

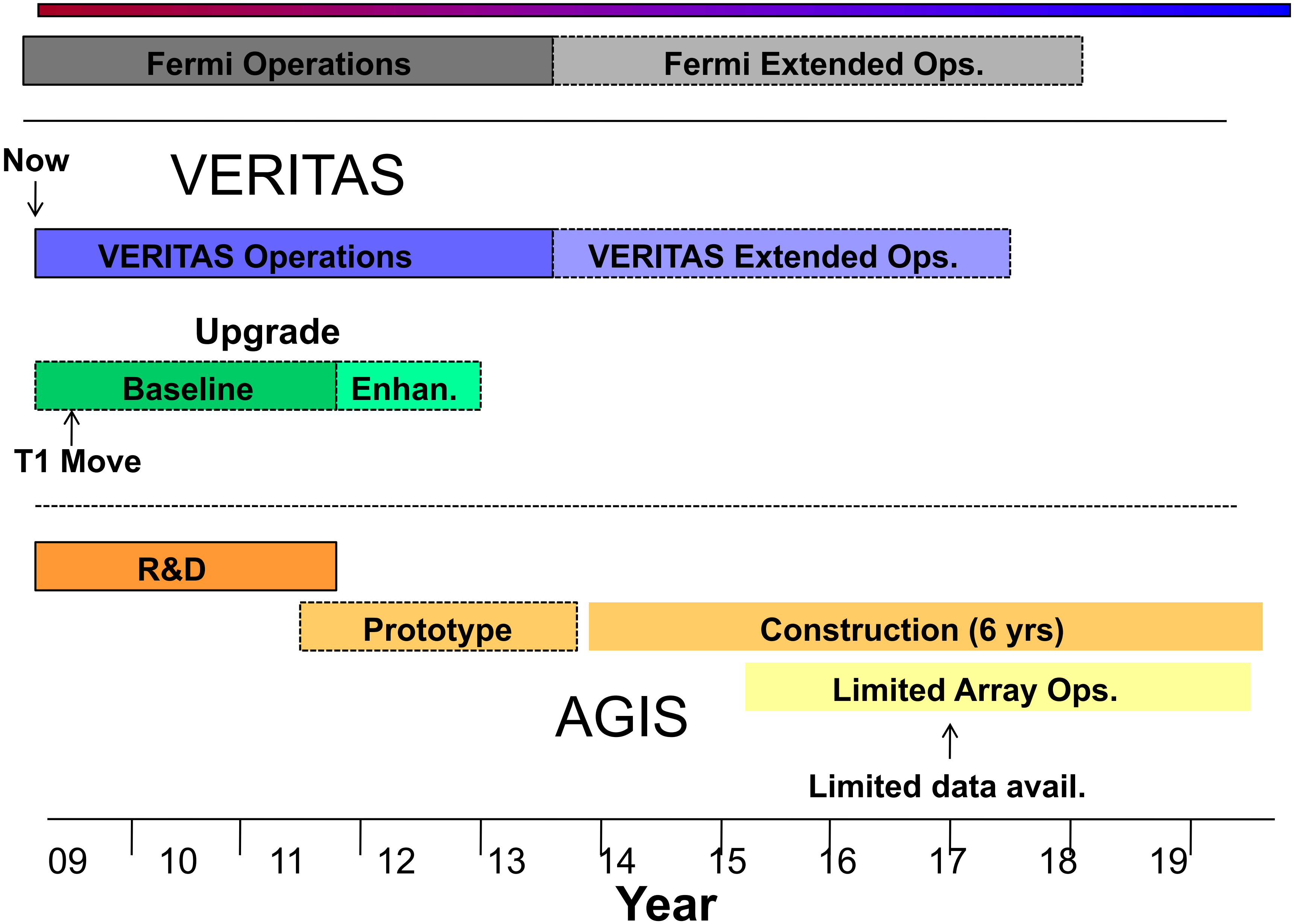


Institutions:

ADLER	SAO
ANL	Stanford/SLAC
Barnard	UNAM
Delaware	UC, Los Angeles
IAFE	UC, Santa Cruz
Iowa State	U. Chicago
LANL	U. Iowa
McGill	Utah
Penn State	Yale
Purdue	Washington U.

Wide-Field
Schwarzschild-CouderTelescope

Timeline for Future



Summary

- VHE γ-rays probe astrophysics of extreme physical conditions, as yet not well explored. There is also discovery potential for physics beyond our standard model.

- Exciting discoveries of many, unexpected sources of VHE γ-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)

Fezziwig Press & Photography (http://stujenks.typepad.com)