The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

2036-24

International Workshop: Quantum Chromodynamics from Colliders to Super-High Energy Cosmic Rays

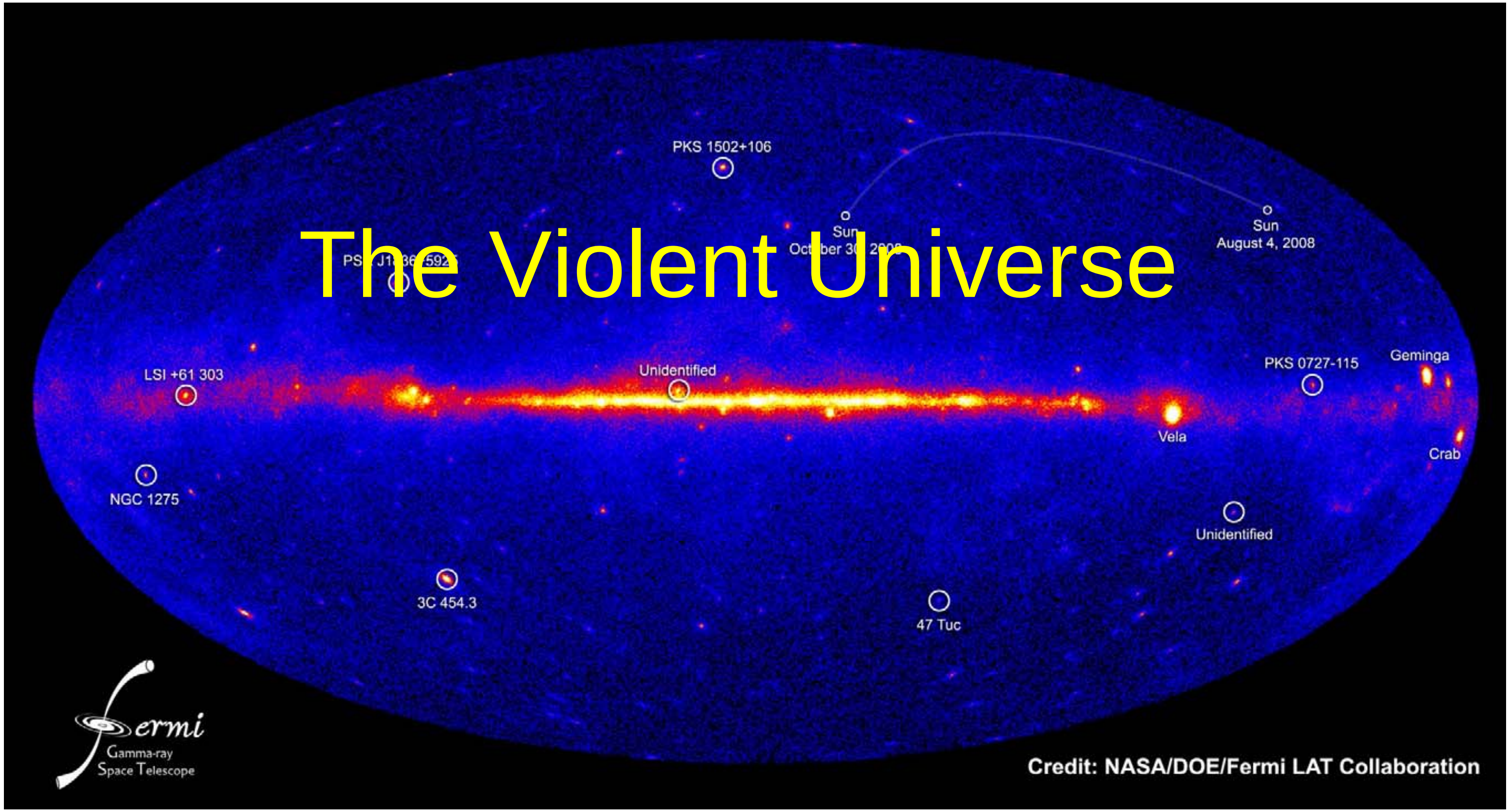
25 - 29 May 2009

The Violent Universe

Guido Barbiellini and Francesco Longo

University of Trieste, Department of Physics and INFN
Trieste

The Violent Universe



Guido Barbiellini and Francesco Longo

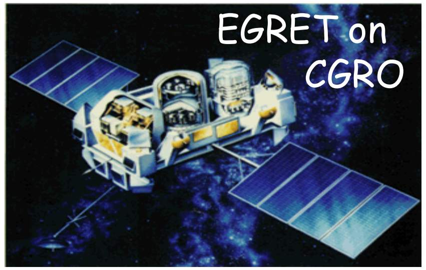
Department of Physics, University of Trieste and INFNTrieste

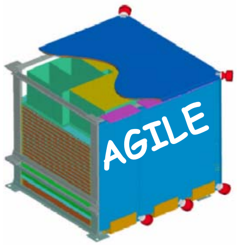
Summary

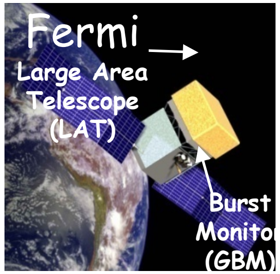
- Brief Introduction to Gamma-ray Astrophysics
  - The Main Questions
- HE Gamma-ray astrophysics
  - From EGRET to AGILE and Fermi
- VHE Gamma-ray astrophysics
  - Imaging Cerenkov Telescopes
  - Extensive Air Shower detectors
  - Towards the future

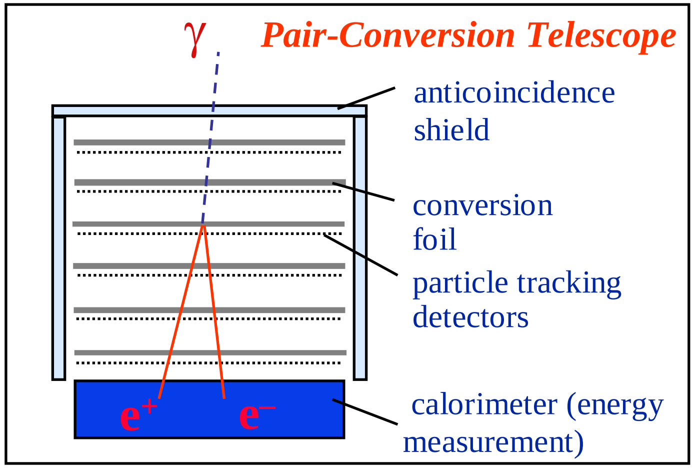
Gamma-ray Experiment Techniques

- Space-based:
  - use pair-conversion technique



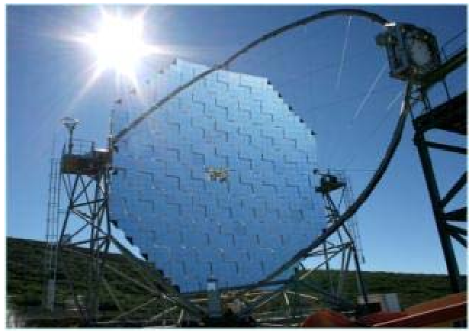




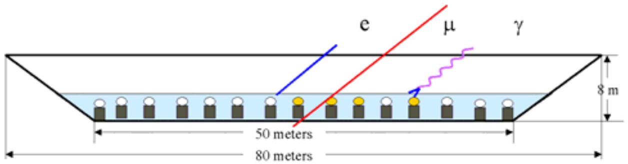


- Ground-based (VHE shower info reaches gnd):
  - Airshower Cerenkov Telescopes (ACTs)

    image the Cerenkov light from showers induced in the atmosphere. Examples: Whipple, STACEE, CELESTE, VERITAS, MAGIC, HESS



  - Extensive Air Shower Arrays (EAS)



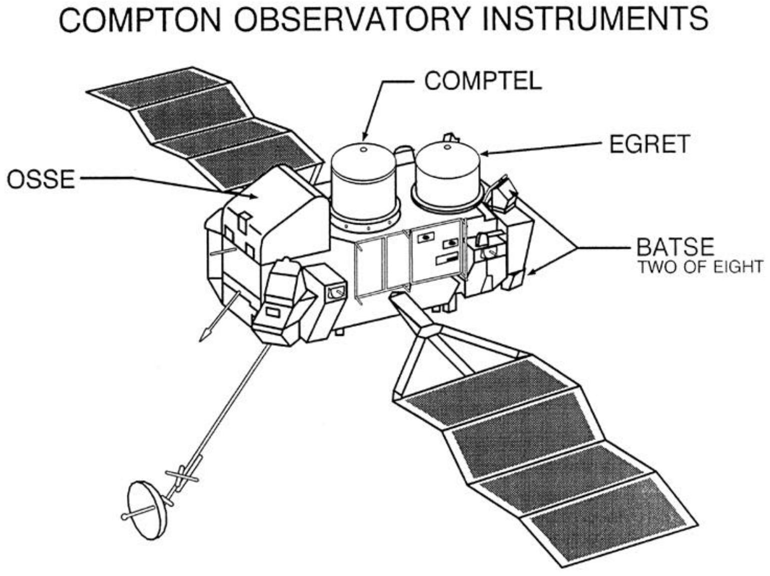
Directly detect particles from the showers induced in the atmosphere. Examples: MILAGRO, ARGO

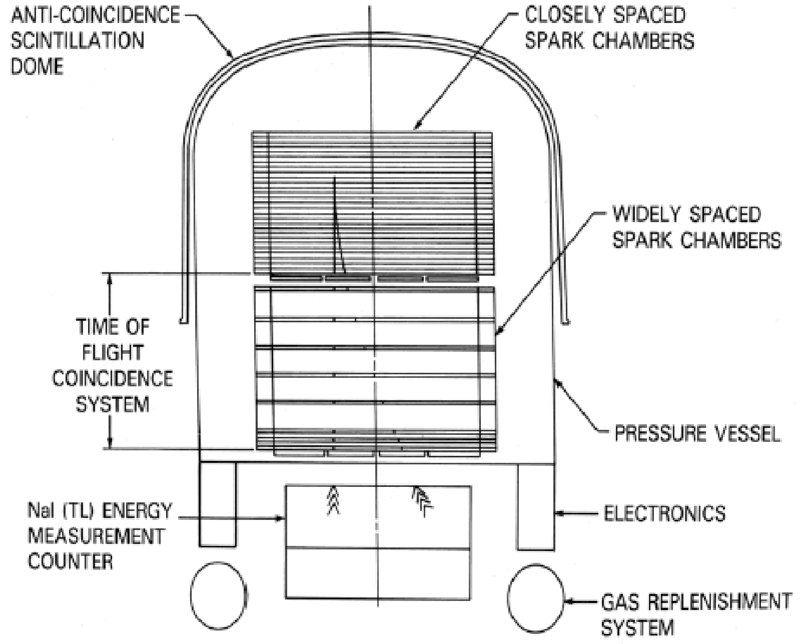
Key questions for Gamma-Astrophysics

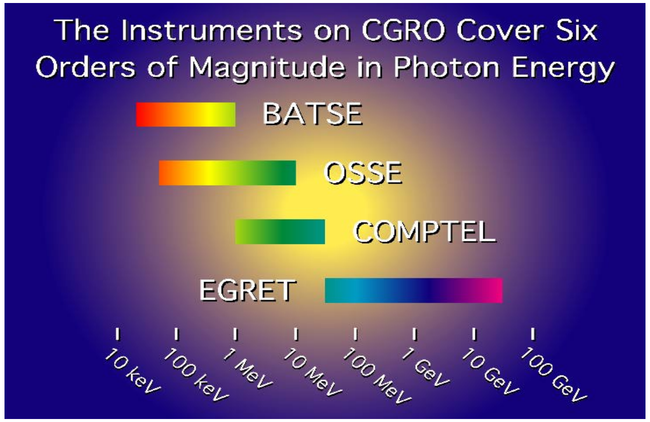
- Black Holes
  - Supermassive BH – AGN
  - Stellar BH – Galactic Gamma-ray binaries
  - Stellar BH – Gamma Ray Bursts
- Compact objects
  - Electromagnetic fields in strong Gravitational fields
- The origin of cosmic-rays
  - Particle acceleration – the Fermi mechanism
- The Nature of Dark Matter
- Photon propagation over cosmological distances

The EGRET Legacy

EGRET



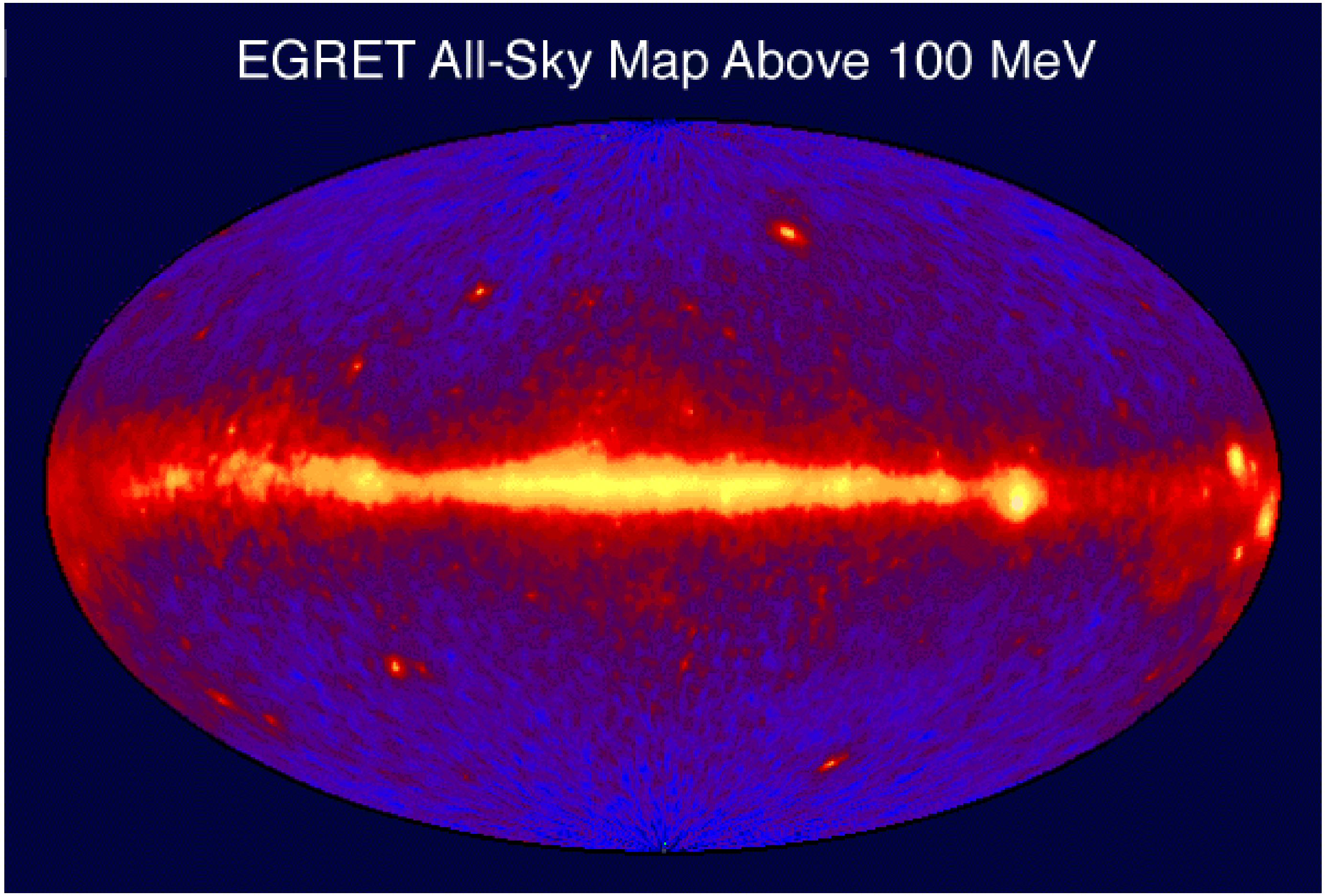




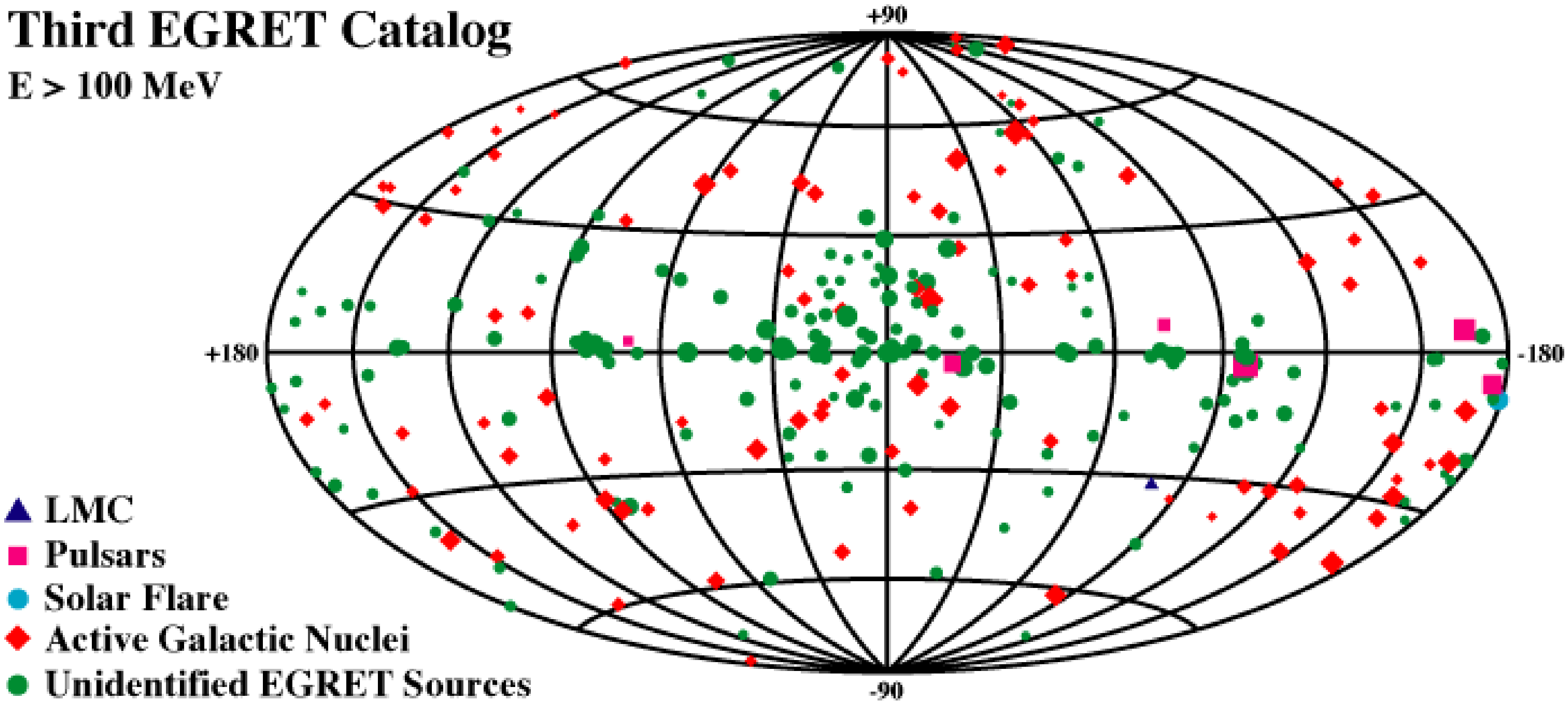
EGRET

- 1991-2000
- 30 MeV - 30 GeV
- AGN, GRB, Unidentified Sources, Diffuse Bkg

The Legacy from EGRET

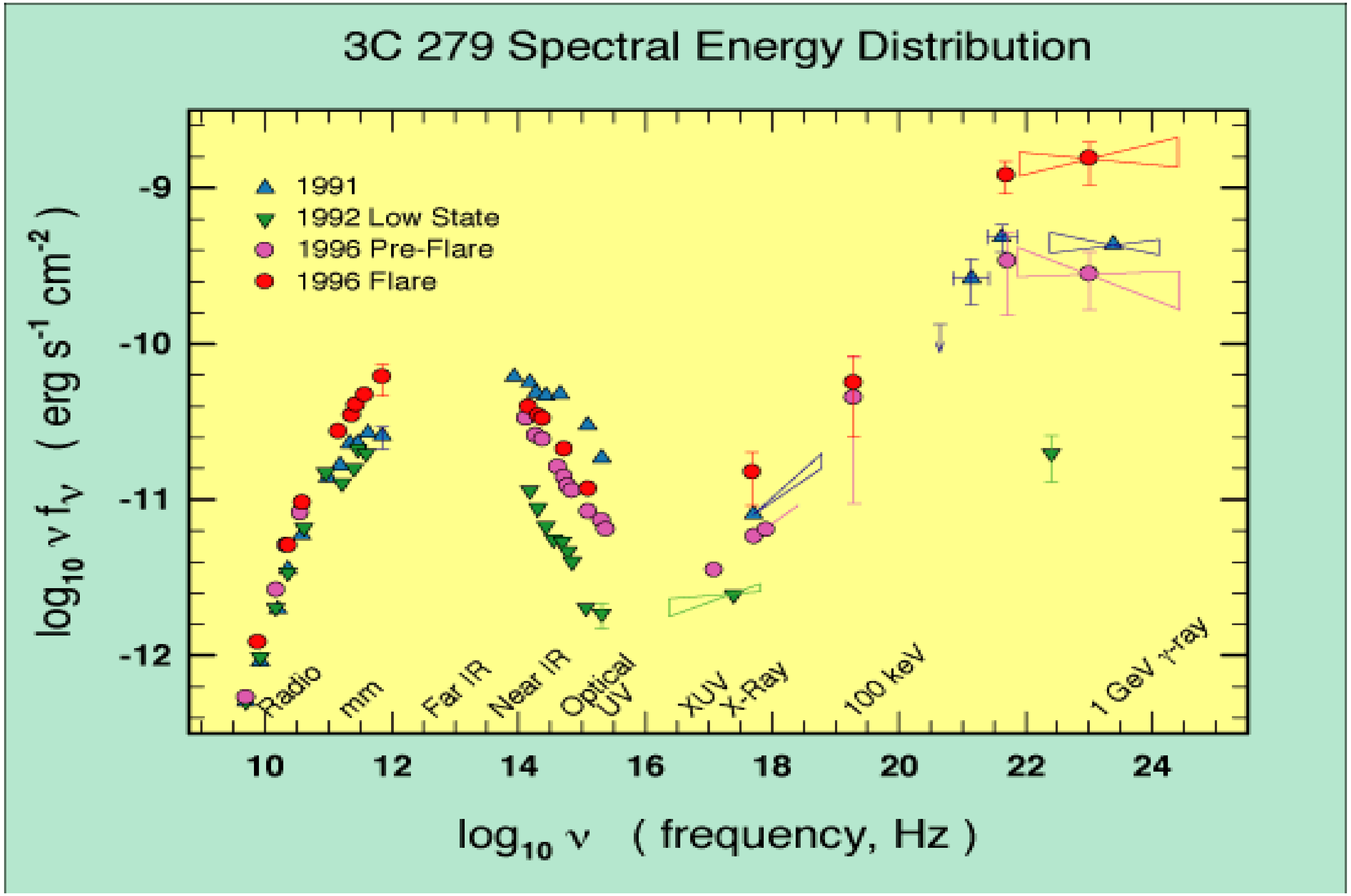


EGRET Gamma-ray Sources

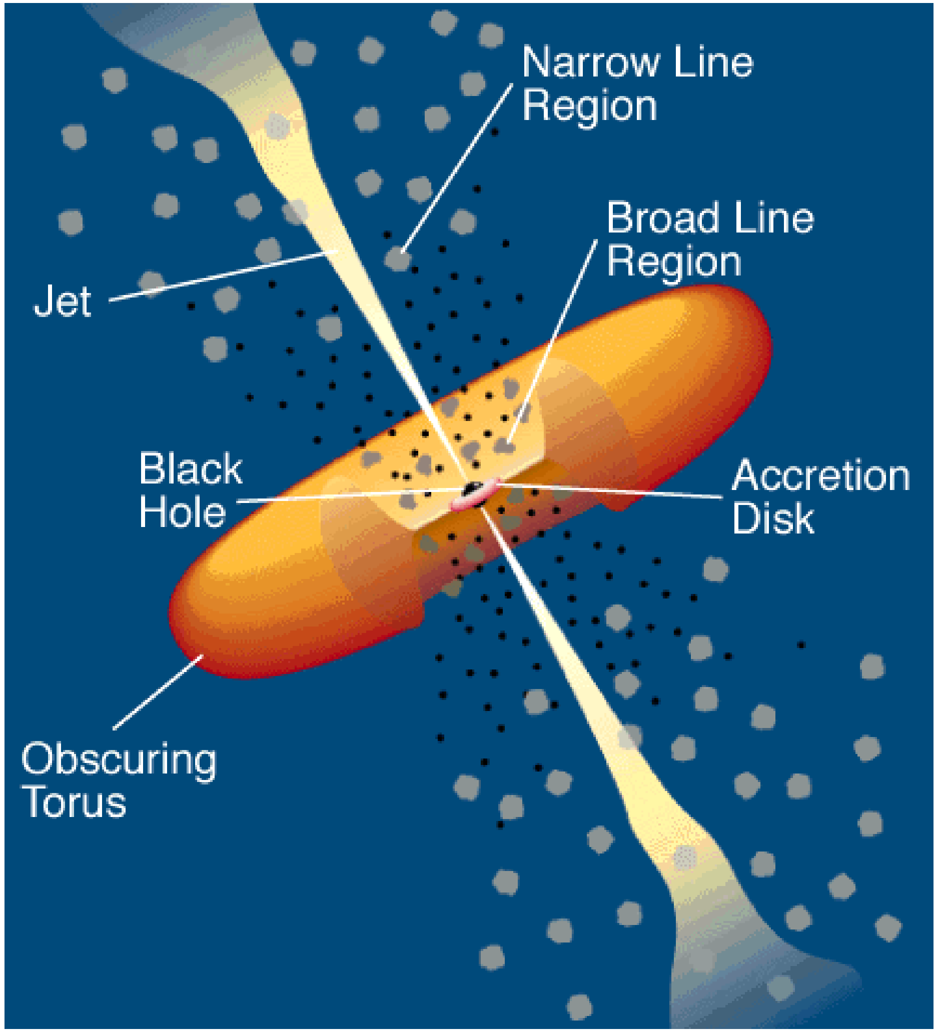


Challenge # 1

- Need simultaneous multiwavelength data to study variability and emission processes

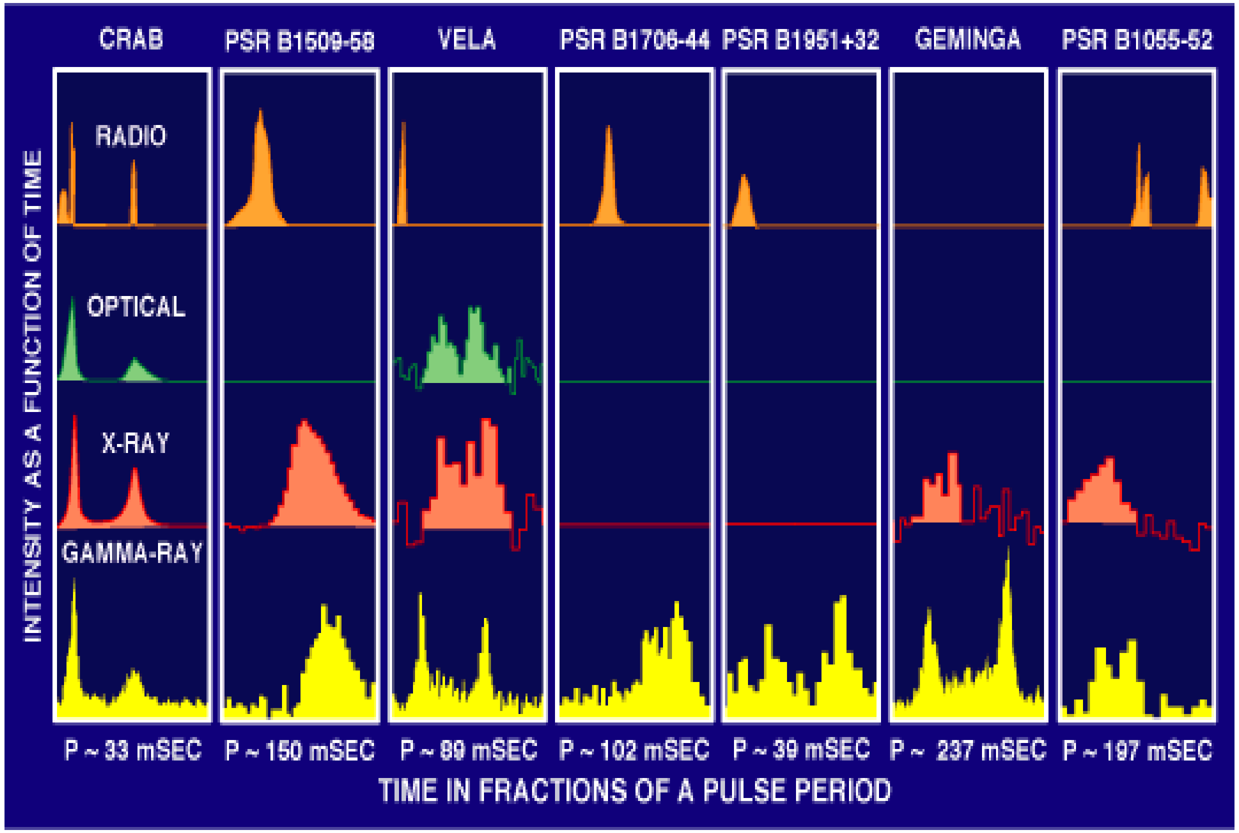


Active Galactic Nuclei

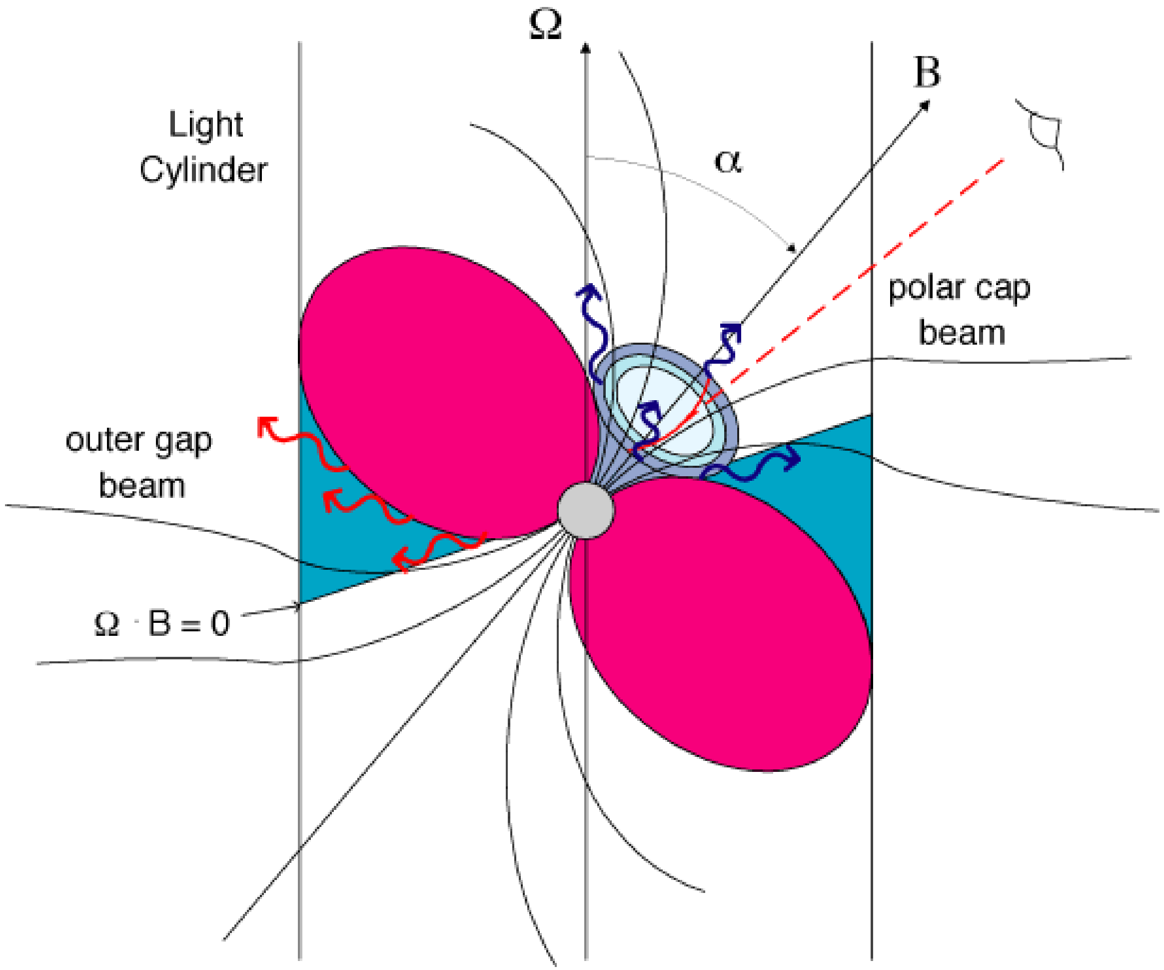


Challenge # 2

- Need more exposure and optimal timing (and radio monitoring) to discover more gamma-ray PSRs.



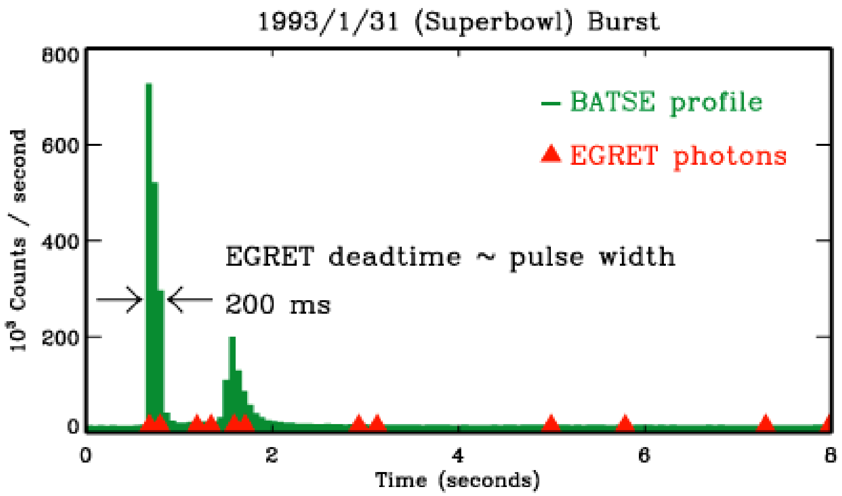
Pulsars



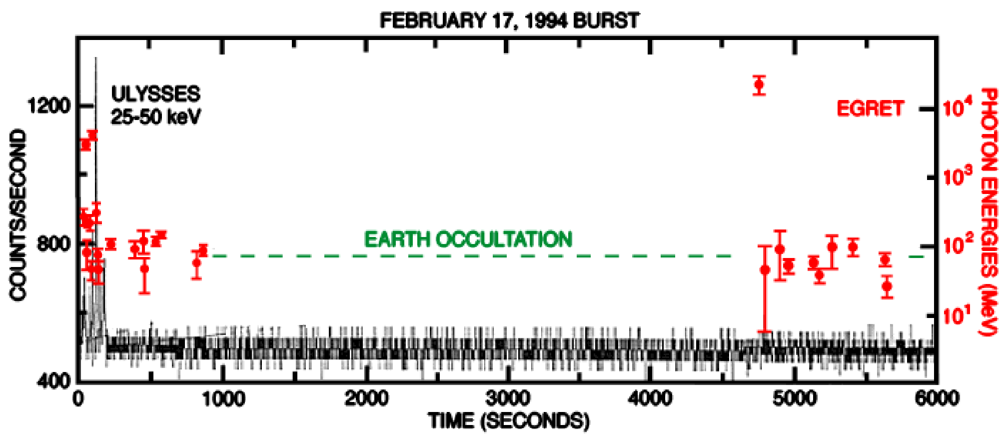
Challenge # 3

- Need fast timing for gamma-ray detection (improving EGRET deadtime, 100 msec → 100 microsec or less).

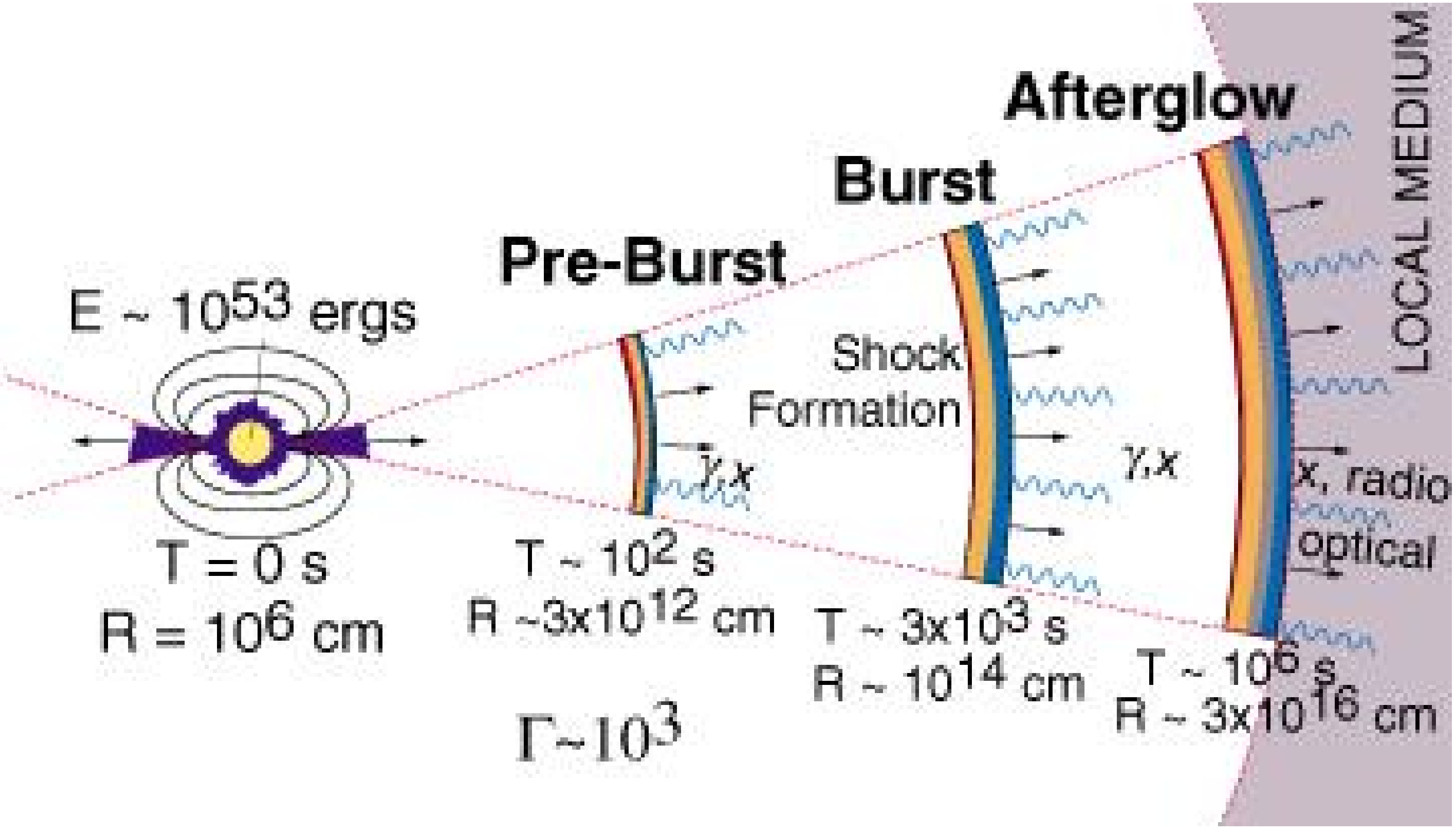
Prompt Emission (GRB 930131)



Delayed Emission (GRB 940217)



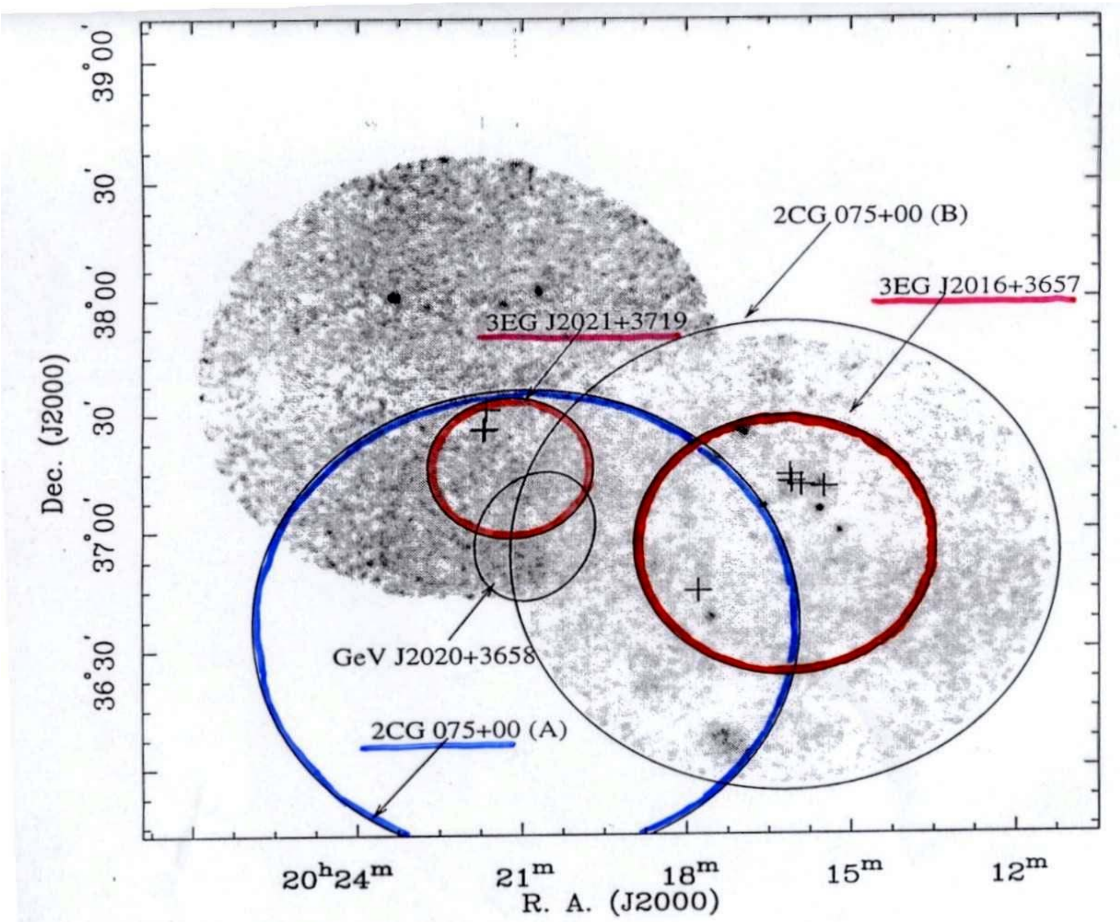
GRB



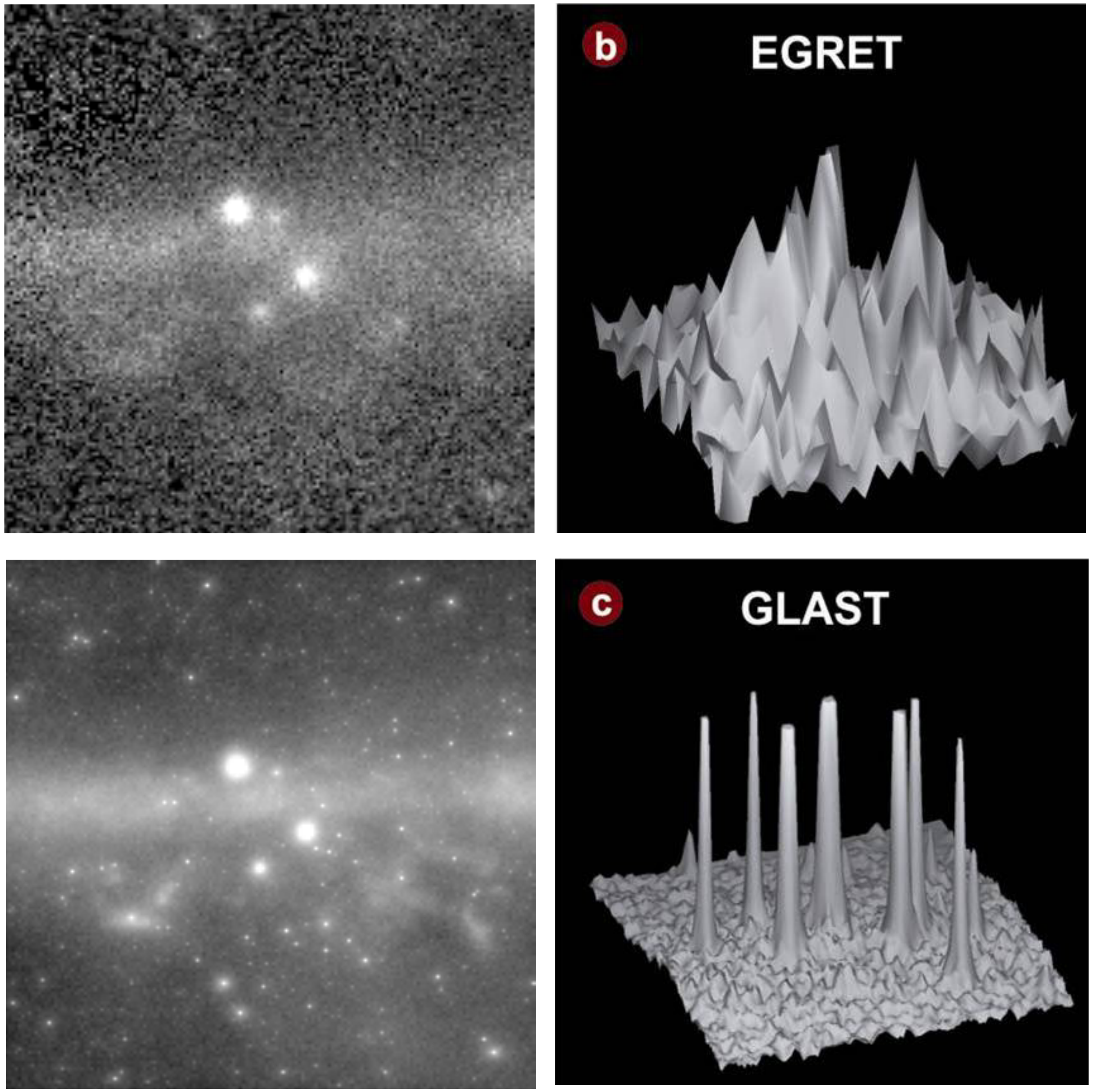
Afterglow
Burst
Pre-Burst
E ~ 10^53 ergs
Shock
Formation
γ,x
γ,x
LOCAL MEDIUM
x, radio
optical
T = 0 s
R = 10^6 cm
T ~ 10^2 s
R ~3x10^12 cm
T ~ 3x10^3 s
R ~ 10^14 cm
T ~ 10^6 s
R ~ 3x10^16 cm
Γ~10^3

Challenge # 4

- Need arcminute positioning of gamma-ray sources (improving EGRET error box radii by a factor of 2-10).



Technology impact -- PSF

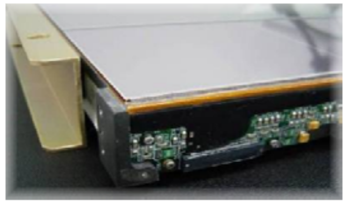


Cygnus region (15^0 x 15^0), $E\gamma$ > 1 GeV

EGRET
(1991-2000)
Phases 1-5

Spark chamber

- **sense electrode spacing ~mm**
- **sensitive layer depth ~cm**
  - ***up to 28 hit over >1m***

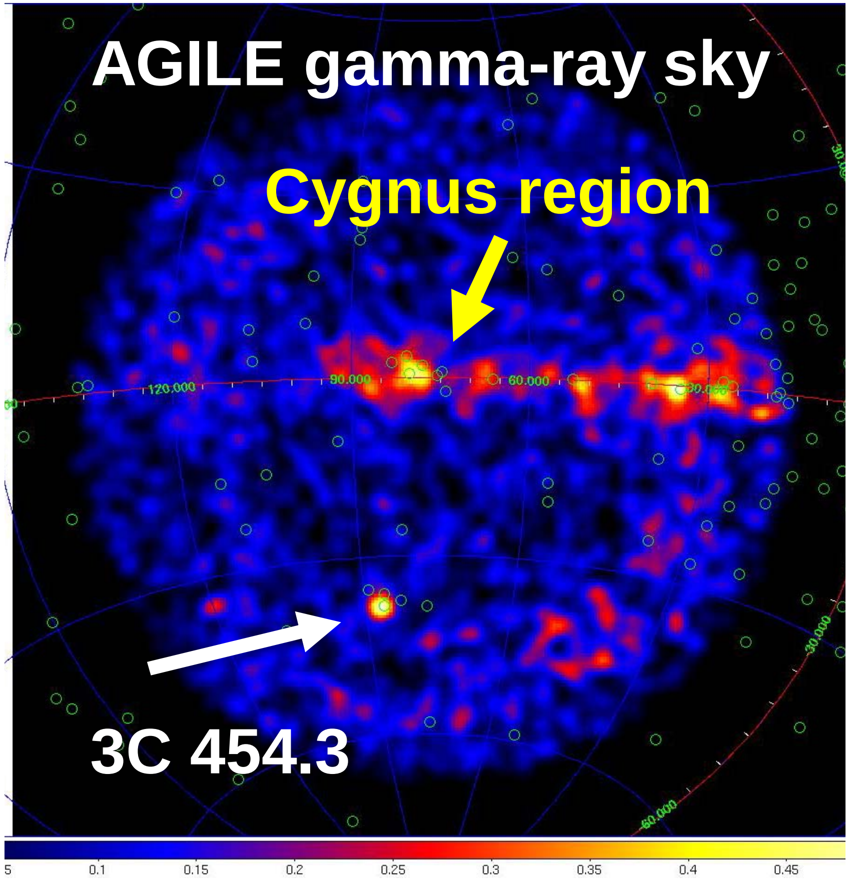


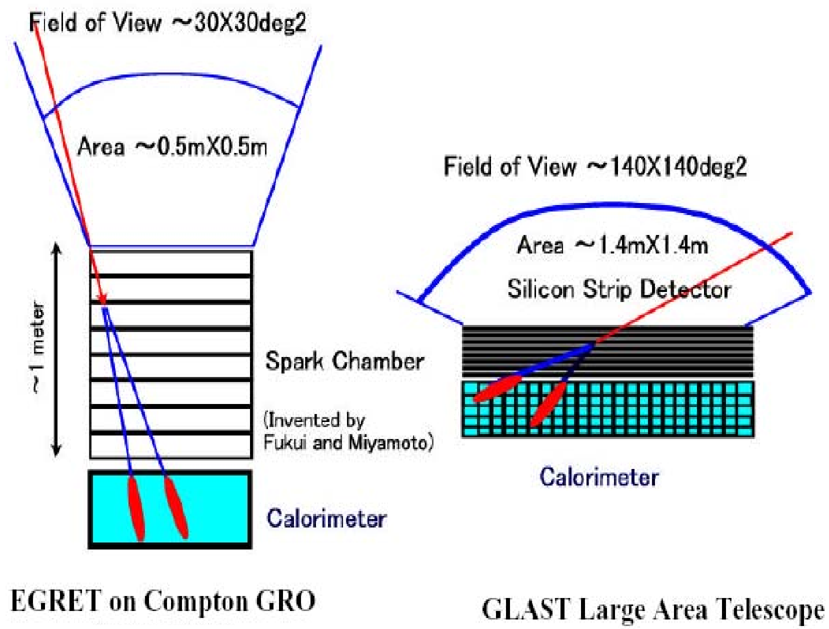
LAT
(2007- >2012)
1-yr simulation

Si-strip detectors

- **sense electrode spacing ~0.2mm**
  - ***better single hit resolution***
- **sensitive layer depth ~0.4mm**
  - ***up to 36 hit over 0.8m***
  - ***converter proximity to minimize MCS***

Technology impact - FoV

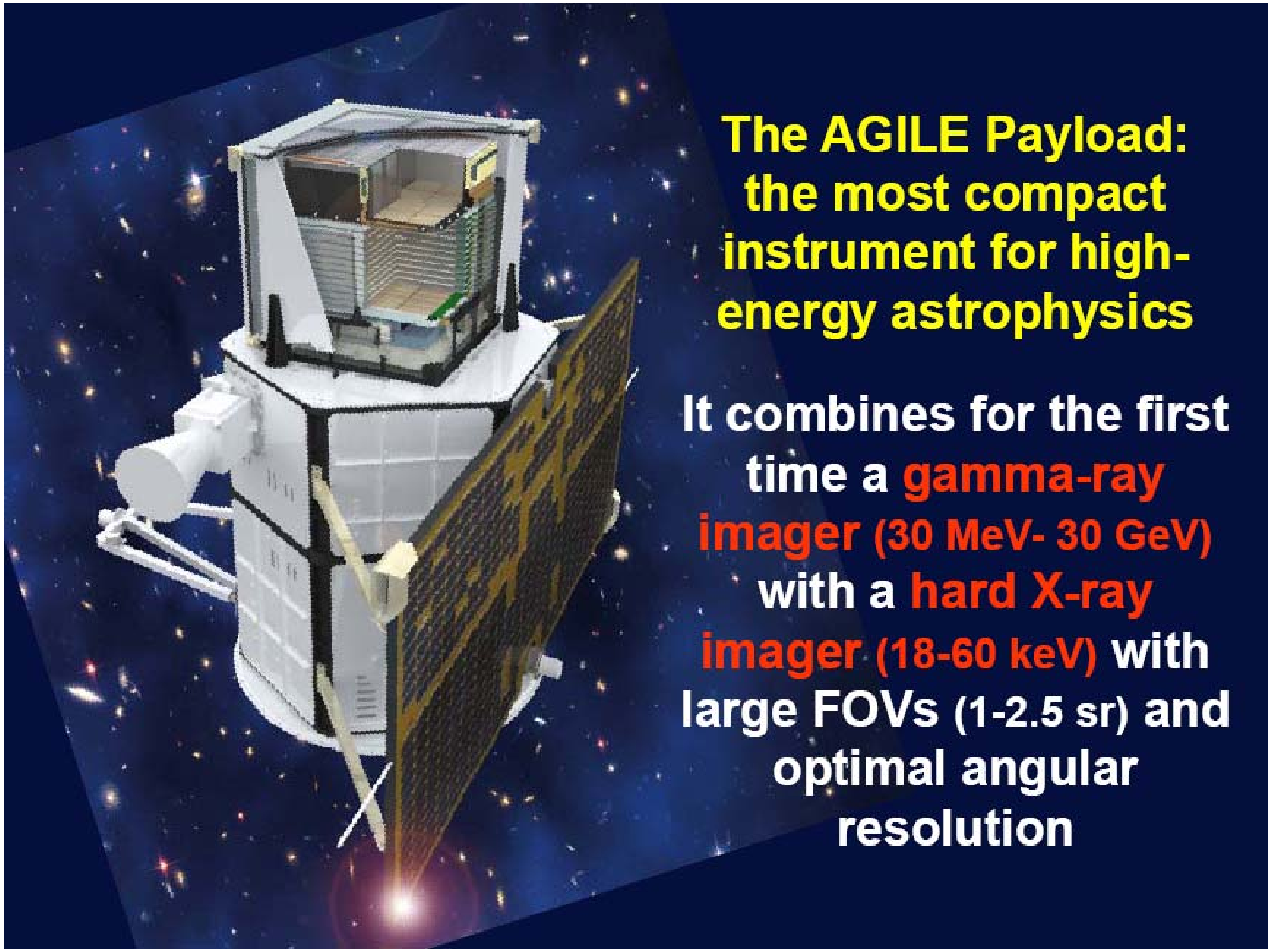




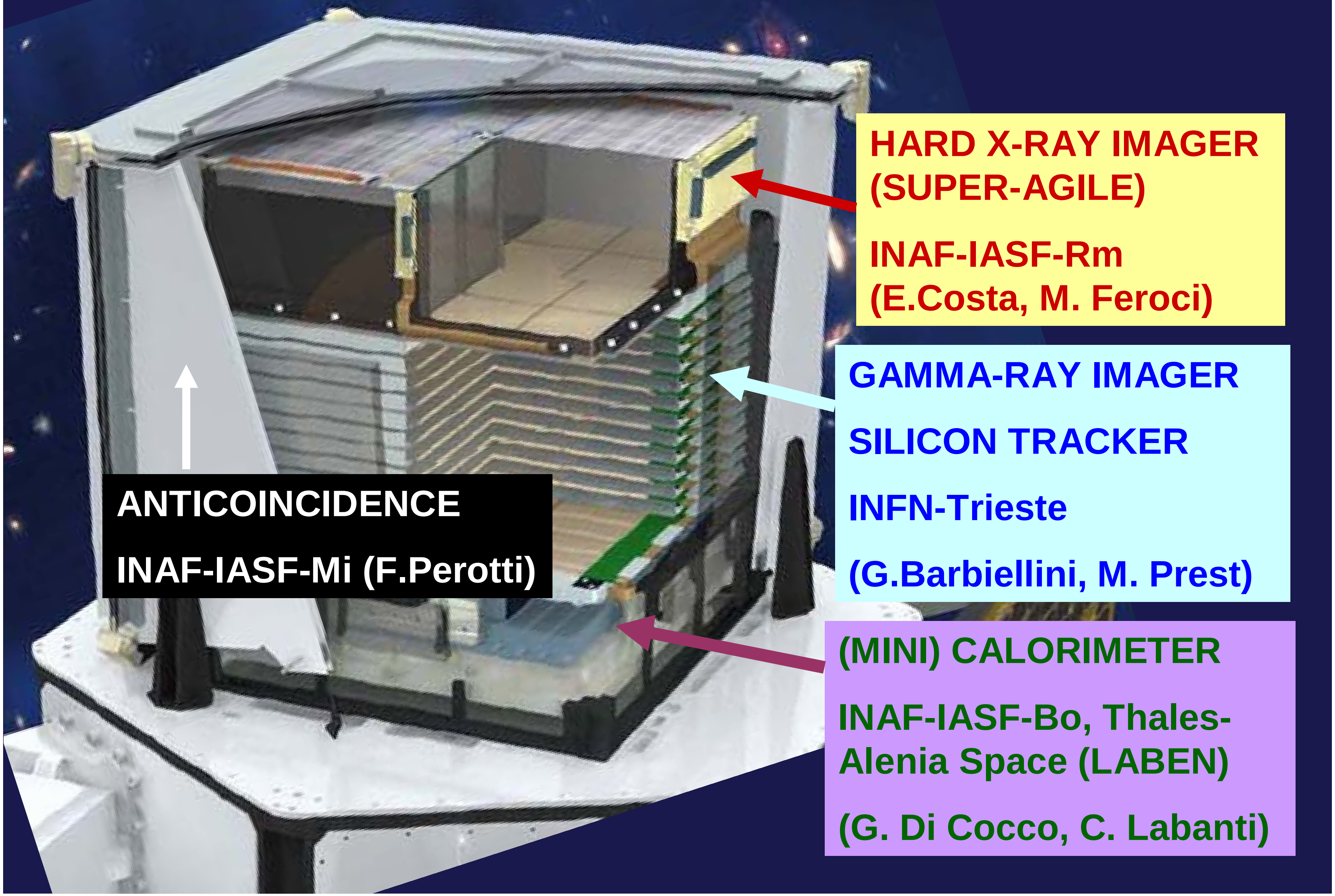
AGILE

AGILE

AGILE instrument



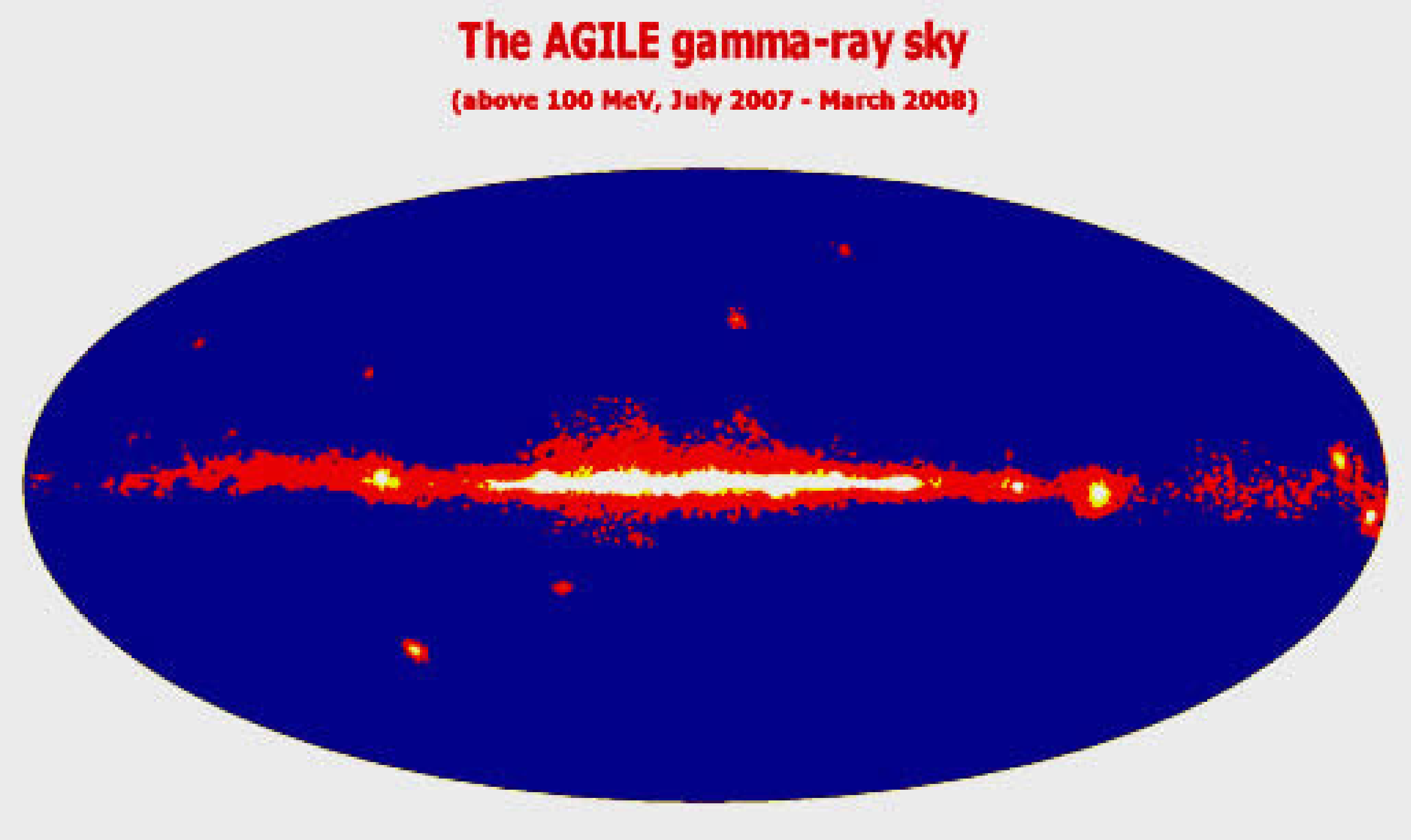
AGILE: inside the cube…



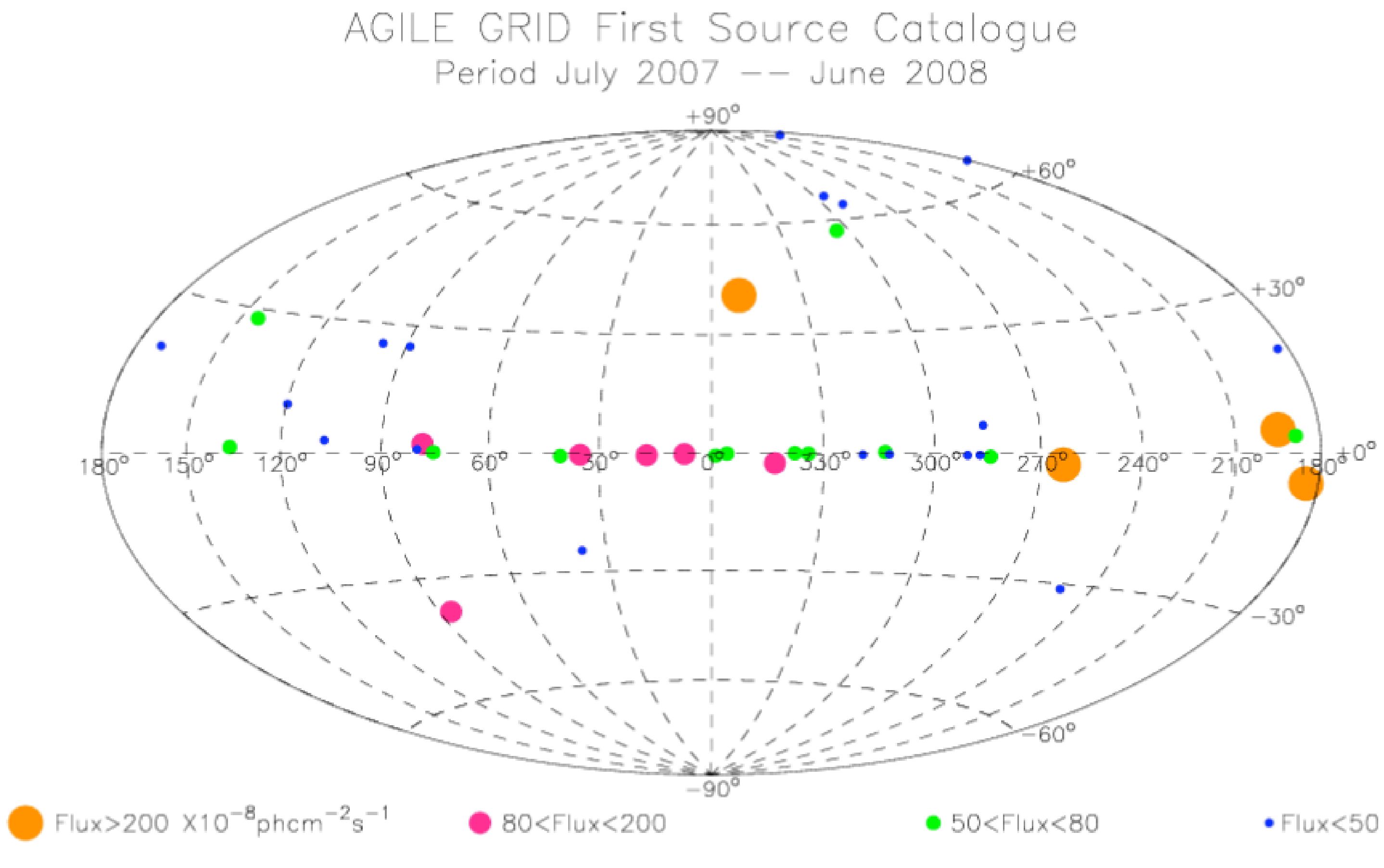
The AGILE tracker

AGILE launch

The AGILE sky

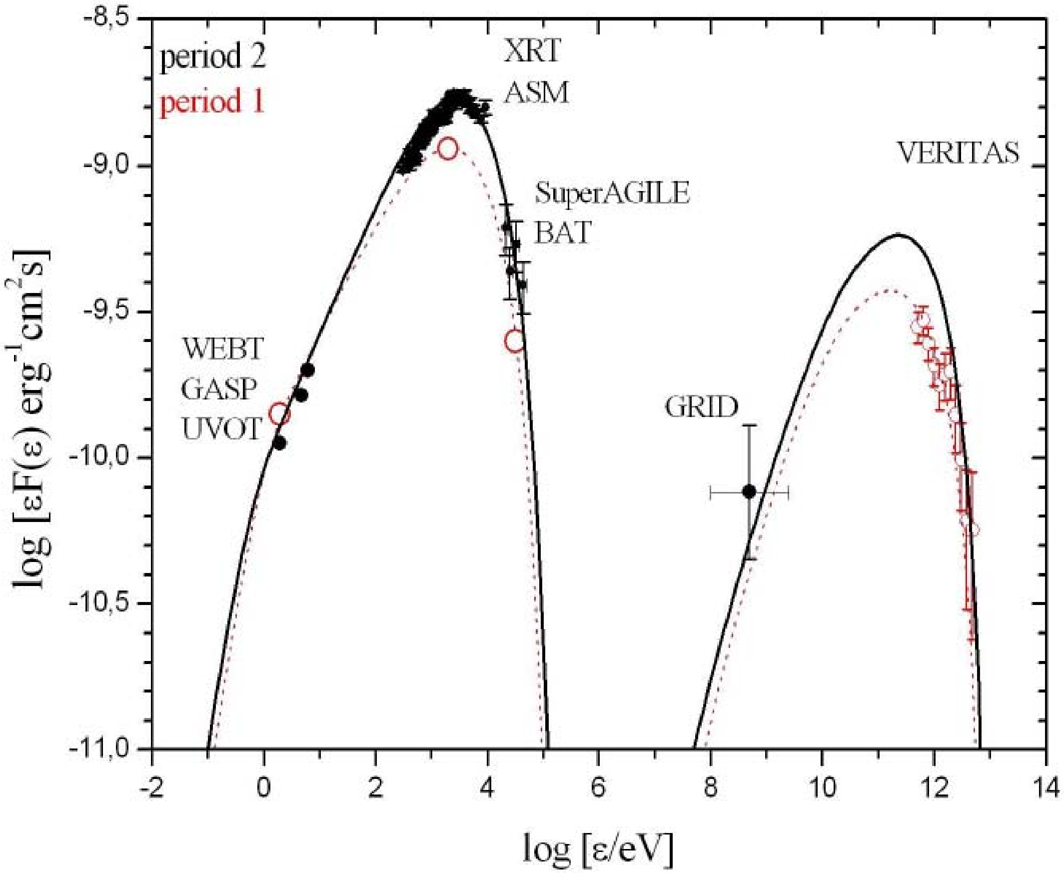


AGILE sources



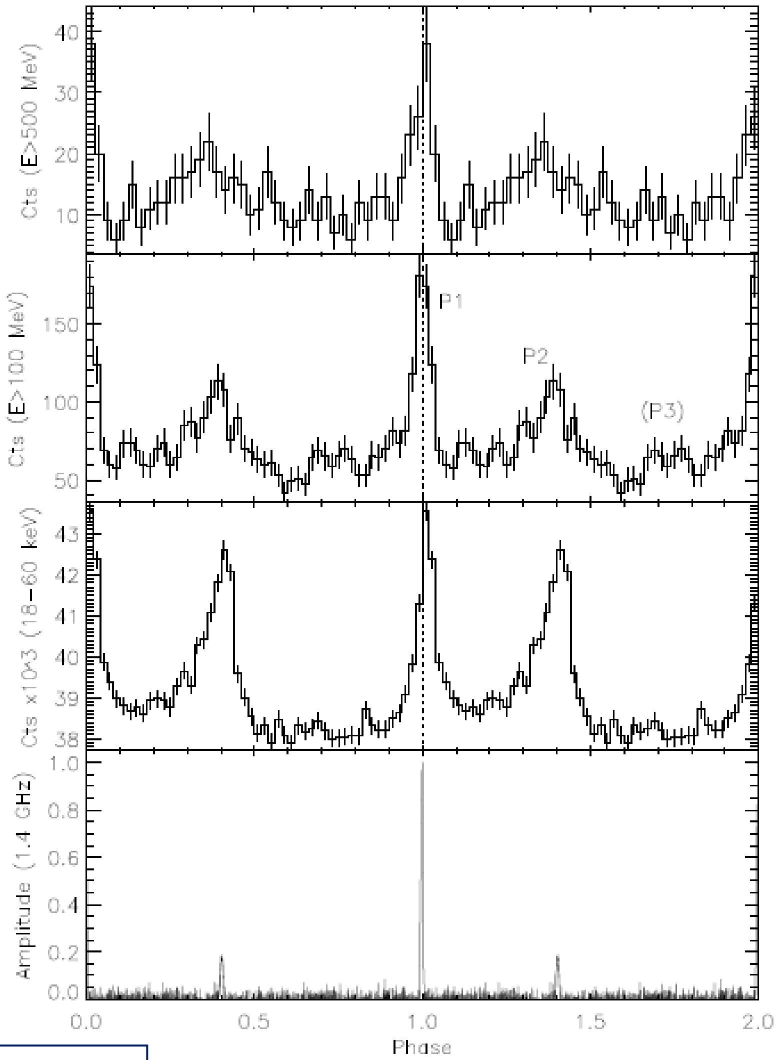
Pittori et al. 2009

Challenge # 1 – AGN
joint campaign with MAGIC and VERITAS on Mkn 421



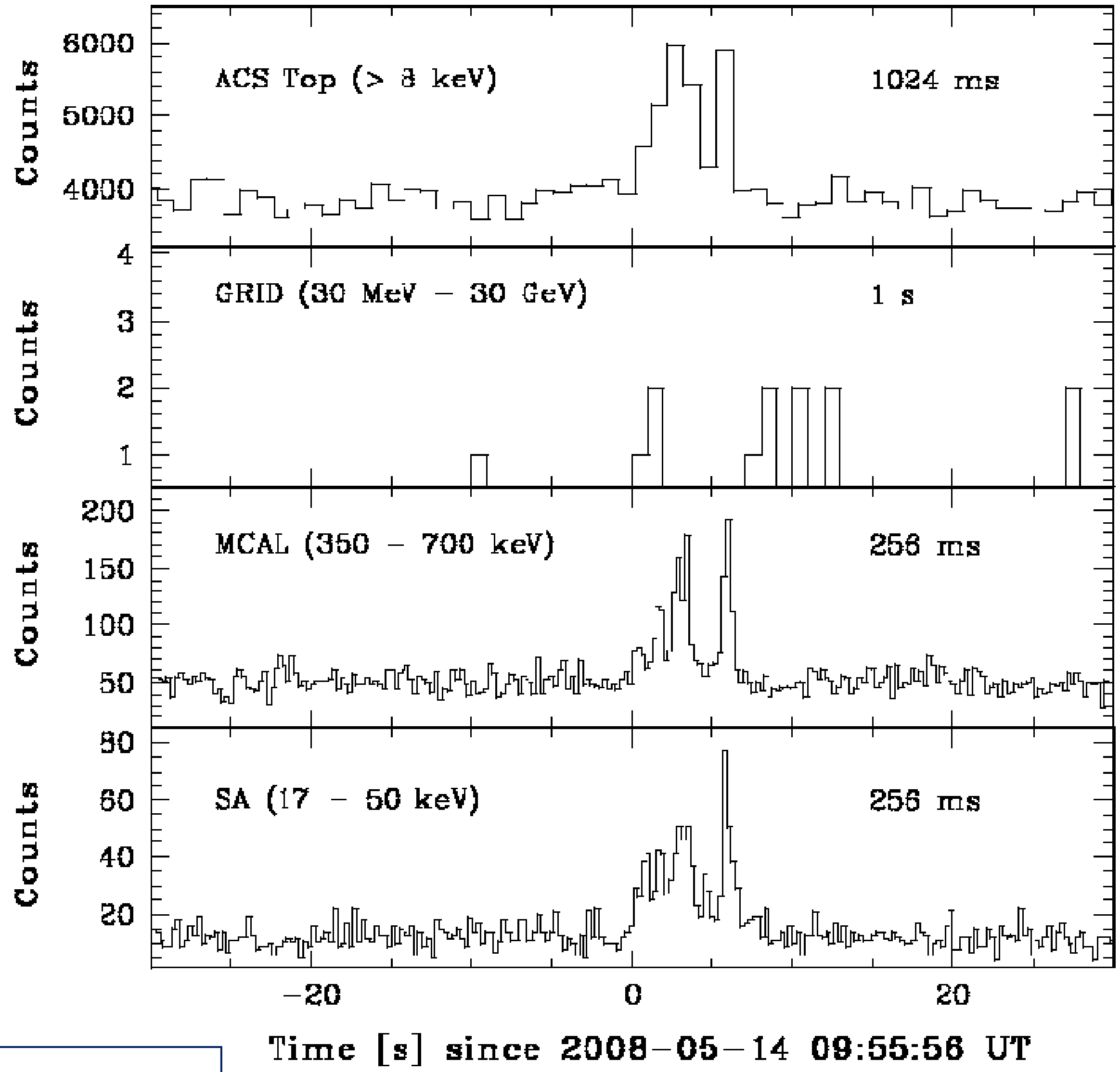
Donnarumma et al. 2009

Challenge # 2 – Pulsar
High Precision Timing (eg. Crab)



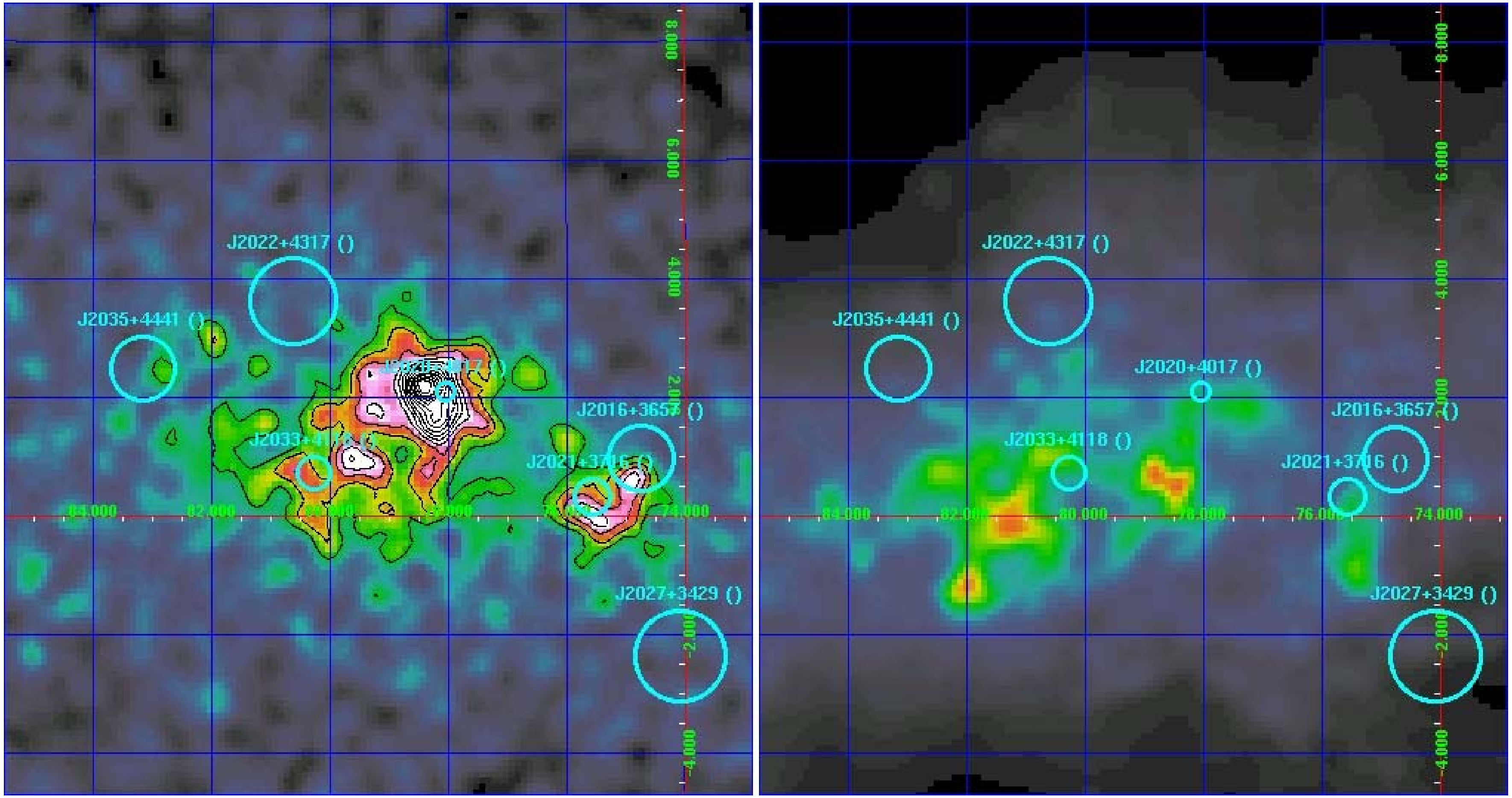
Pellizzoni et al. 2009

Challenge # 3 – GRB



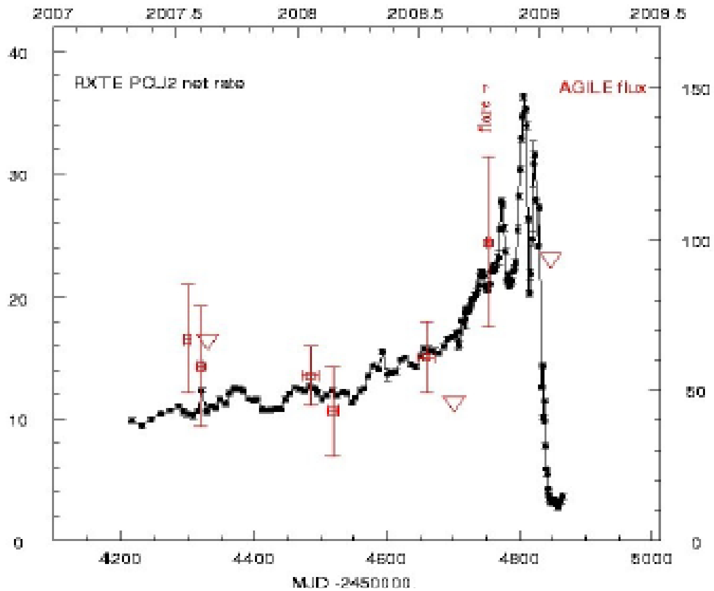
Giuliani et al. 2008

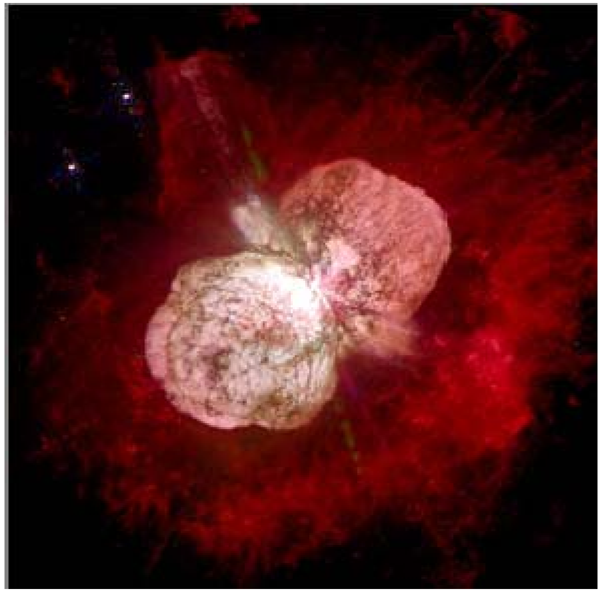
Challenge # 4 – Unidentified

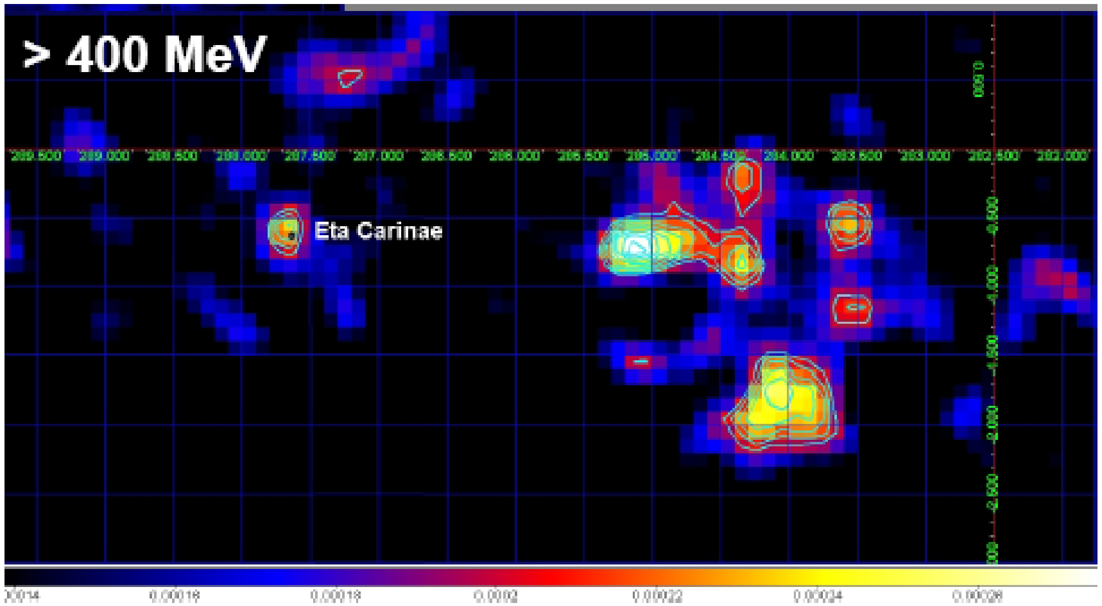


Chen et al. in prep.

The Carina field



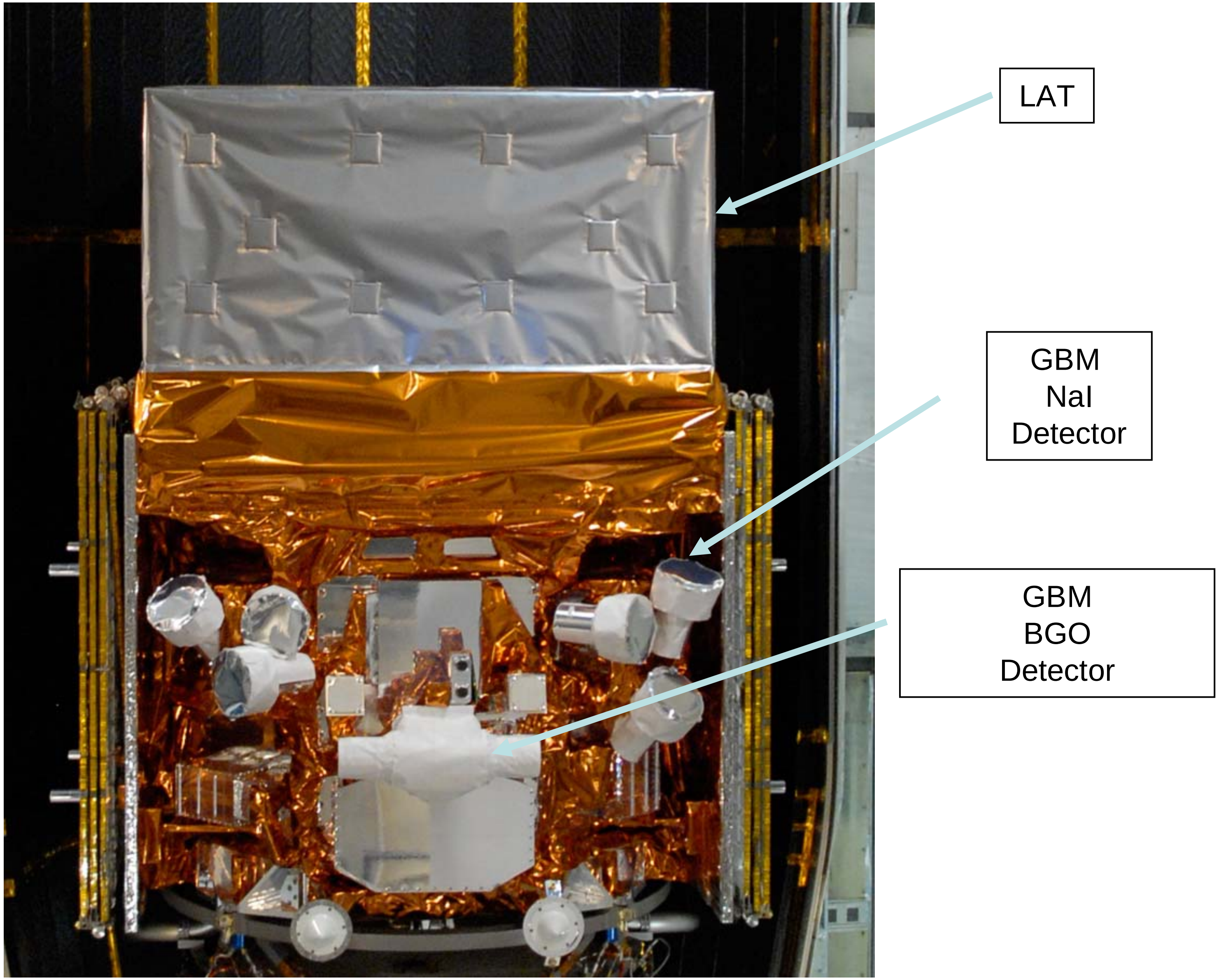




Tavani et al. 2009

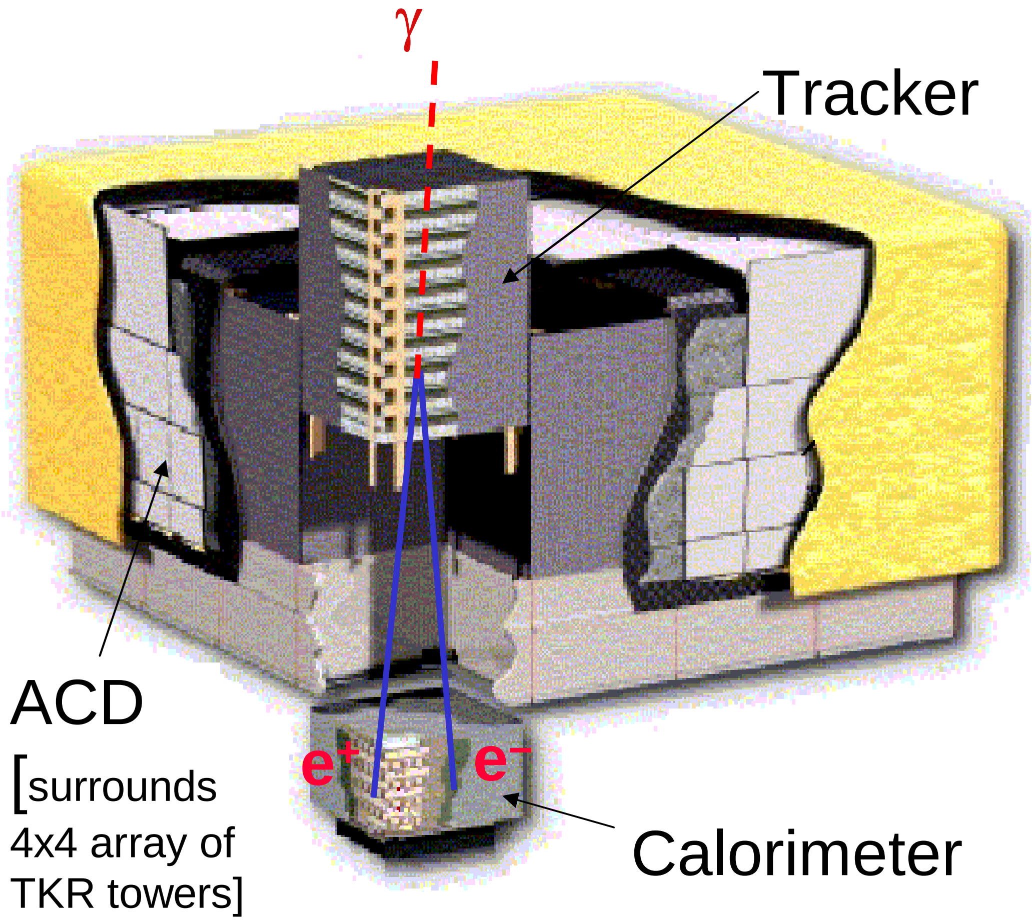
Fermi LAT

The Fermi Observatory



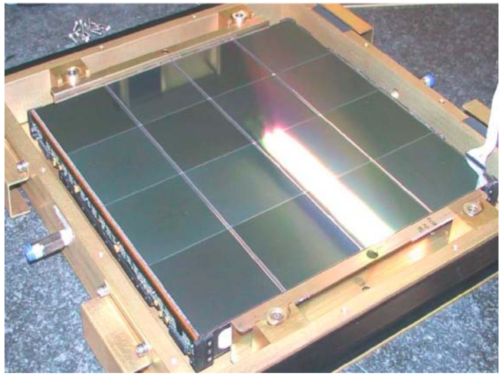
Overview of LAT

- Precision Si-strip Tracker (TKR)
  18 XY tracking planes. Single-sided silicon strip detectors (228 μm pitch) Measure the photon direction; gamma ID.
- Hodoscopic CsI Calorimeter(CAL)
  Array of 1536 CsI(Tl) crystals in 8 layers. Measure the photon energy; image the shower.
- Segmented Anticoincidence Detector (ACD) 89 plastic scintillator tiles. Reject background of charged cosmic rays; segmentation removes self-veto effects at high energy.
- Electronics System Includes flexible, robust hardware trigger and software filters.

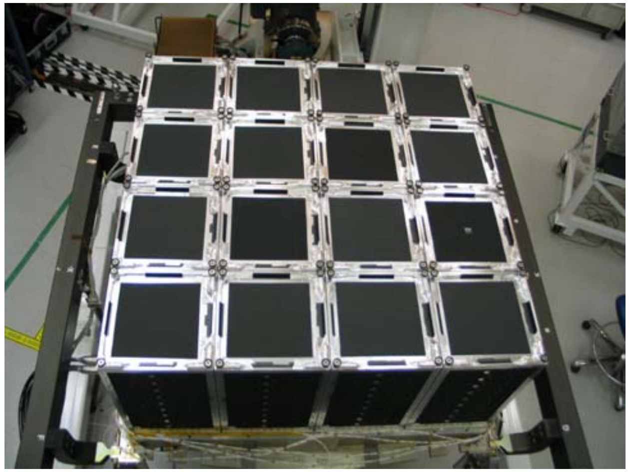


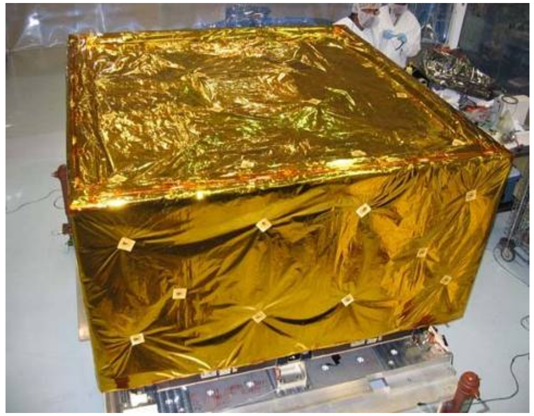
Systems work together to identify and measure the flux of cosmic gamma rays with energy 20 MeV - >300 GeV.

LAT Construction: An International Effort



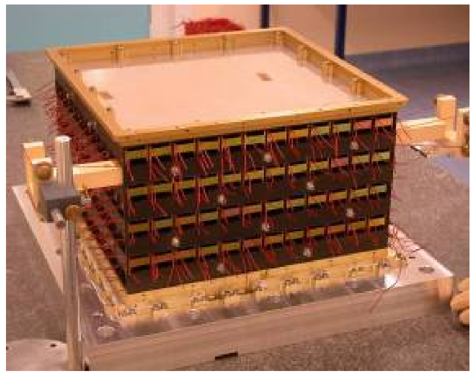
Integration &
Data System: US





ACD: US

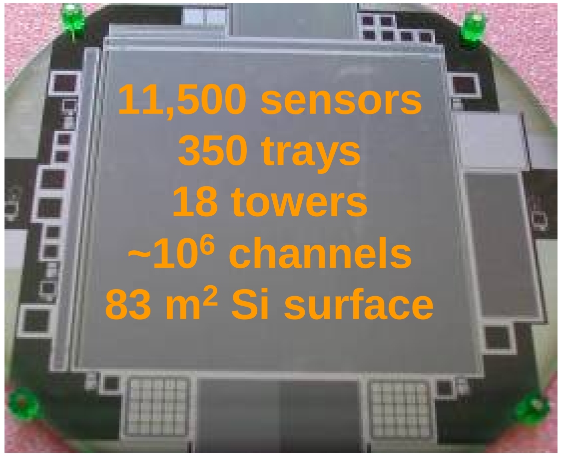
Tracker: US, Italy, Japan

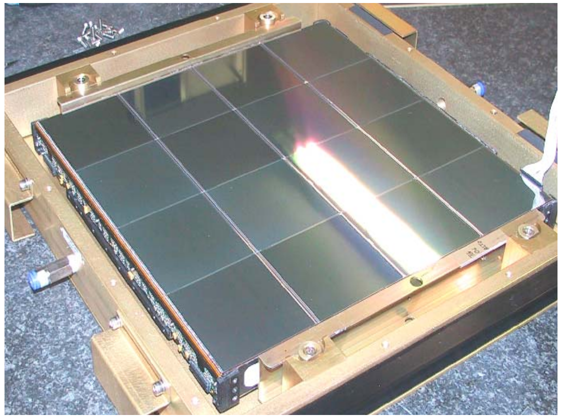


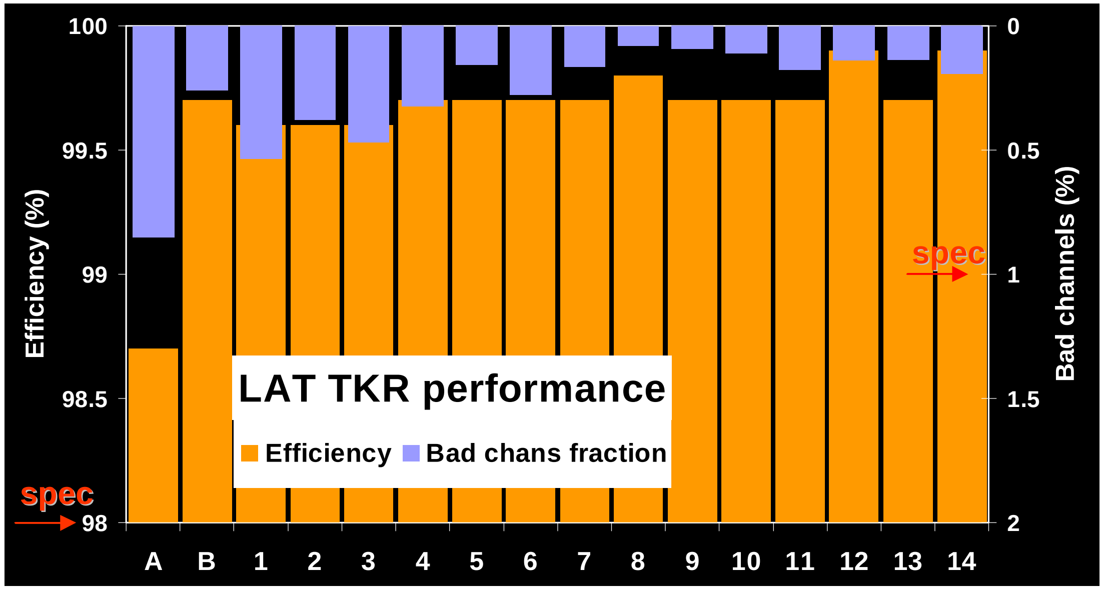
Calorimeter: US, France, Sweden

LAT Silicon Tracker

team effort involving physicists and engineers from Italy (INFN & ASI), Japan*, and the United States*







Fermi Launch

- Launch from Cape Canaveral Air Station 11 June 2008 at 12:05PM EDT
- Circular orbit, 565 km altitude (96 min period), 25.6 deg inclination.

Fermi Gamma-ray Space Telescope

GLAST renamed *Fermi* by NASA on August 26, 2008

http://fermi.gsfc.nasa.gov/

" Enrico Fermi (1901-1954) was an Italian physicist who immigrated to the United States. He was the first to suggest a viable mechanism for astrophysical particle acceleration. This work is the foundation for our understanding of many types of sources to be studied by NASA's Fermi Gamma-ray Space Telescope, formerly known as GLAST. "

THE UNIVERSITY OF CHICAGO
CHICAGO 37 · ILLINOIS
INSTITUTE FOR NUCLEAR STUDIES

March 12, 1949

Professor G. Cocconi
Cornell University
Laboratory of Nuclear Studies
Ithaca, New York

Dear Cocconi:

Excuse my answering in English your letter, since by doing so I can dictate to my secretary. I have been very much interested by your statement that you have evidence of the existence of large showers up to 10^{17} eV.

The reason why, according to the theory on the origin of cosmic rays that I have proposed, no electrons should be found, is that I postulate the existence throughout the interstellar space of a magnetic field with an intensity of about 10^{-5} - 10^{-6} gauss. If this assumption is correct, the radiation loss for a fast electron is quite large and prevents it from acquiring a sizeable energy. This mechanism of energy loss by electrons is much more efficient in removing fast electrons than the mechanism of the inverse Compton effects discussed by Feenberg and Primakoff. On the other hand, the existence of this last effect is much less hypothetic because all that is needed to produce it is the existence of the stellar light in the space traversed by the cosmic rays during their life. I have not read the article of Feenberg and Primakoff with particularly great attention, but as far as I can see, their conclusions seem to me to be sound.

You probably know that Teller recently has maintained that the cosmic radiation may be of solar origin and may be held within the limits of the planetary system by some suitable kind of magnetic field. Even if this hypothesis is correct, one could hardly expect to find electrons of high energy in the cosmic radiation. Probably the main reason to eliminate them is the same inverse Compton effect considered by Feenberg and Primakoff, which becomes much stronger because the particles are supposed to travel in the vicinity of the sun and are exposed, therefore, to a much stronger radiation than they would be in the interstellar space.

For all these reasons, it seems to me highly improbable that electrons of as high energy as you mention could be found in the cosmic radiation. On the other hand, all these arguments should not be over estimated, and an experimental check on them, if possible, is certainly worth while.

I ~~am sending~~ will send to you a copy of my manuscript, as soon as reprints are available.

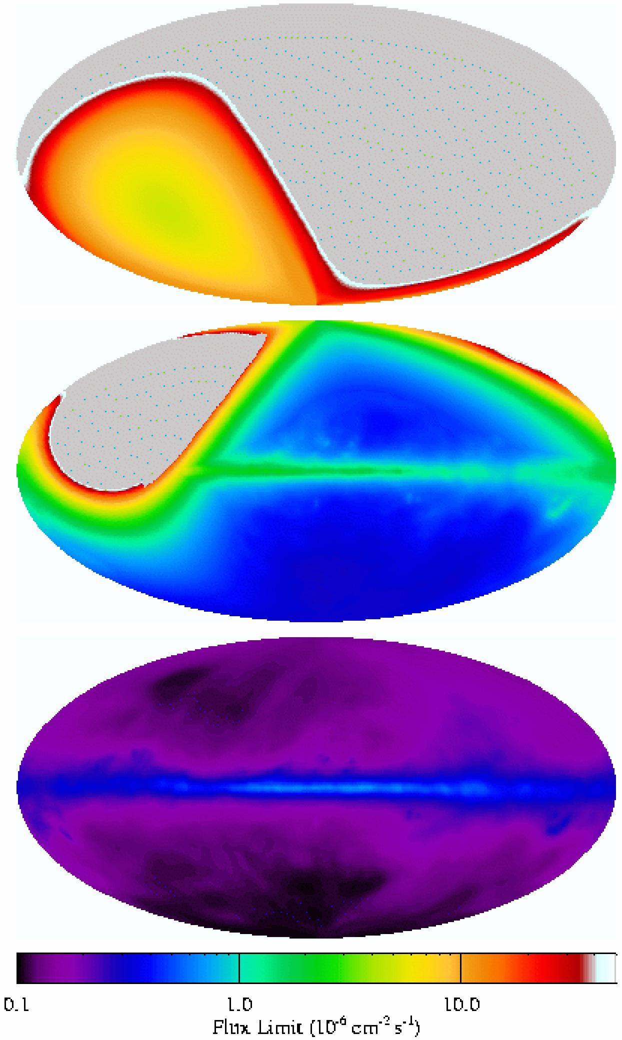
Very sincerely yours,

Enrico Fermi

Enrico Fermi

EF:al
encl.

Observation Mode

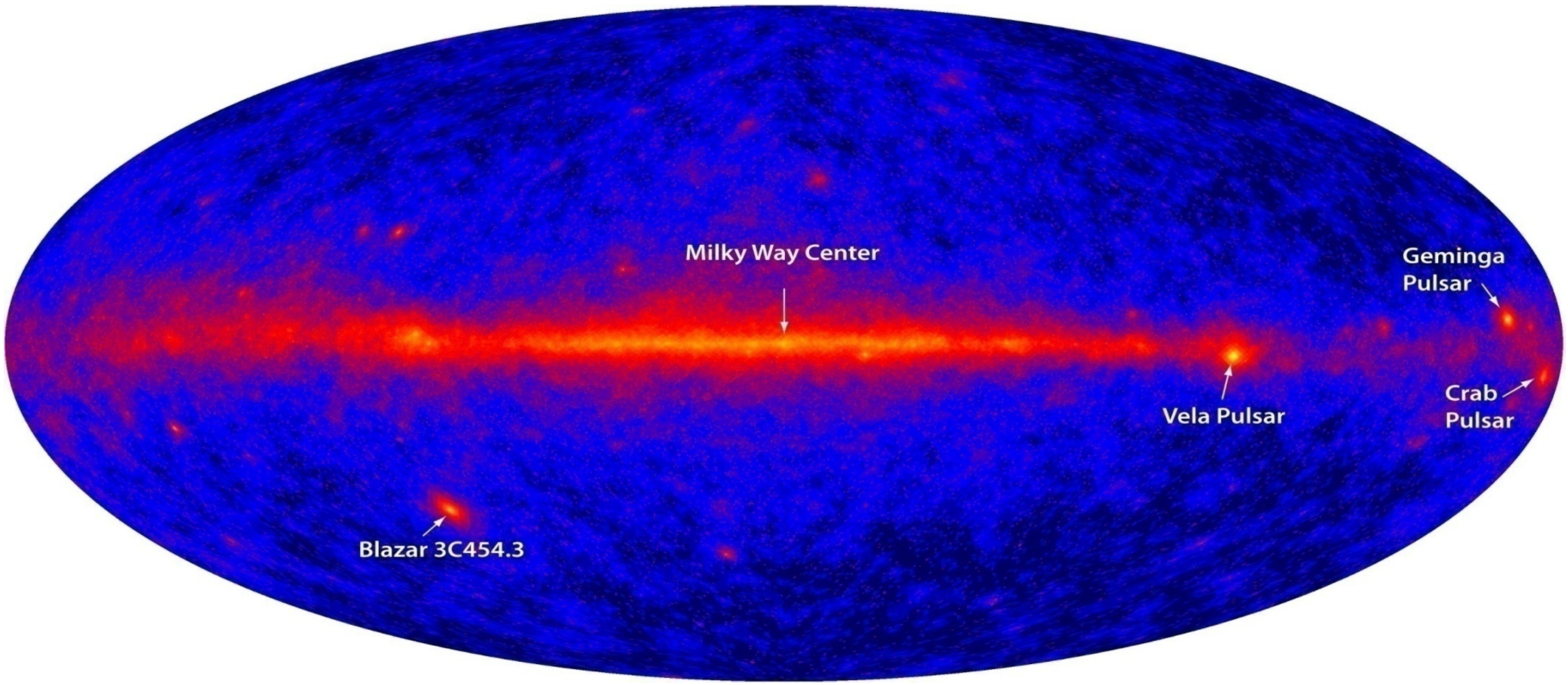


The field of view of the LAT is huge > 20% of the sky.

Rocking mode provides an efficient way of observing the entire sky with reasonably uniform exposure on timescales of hours.

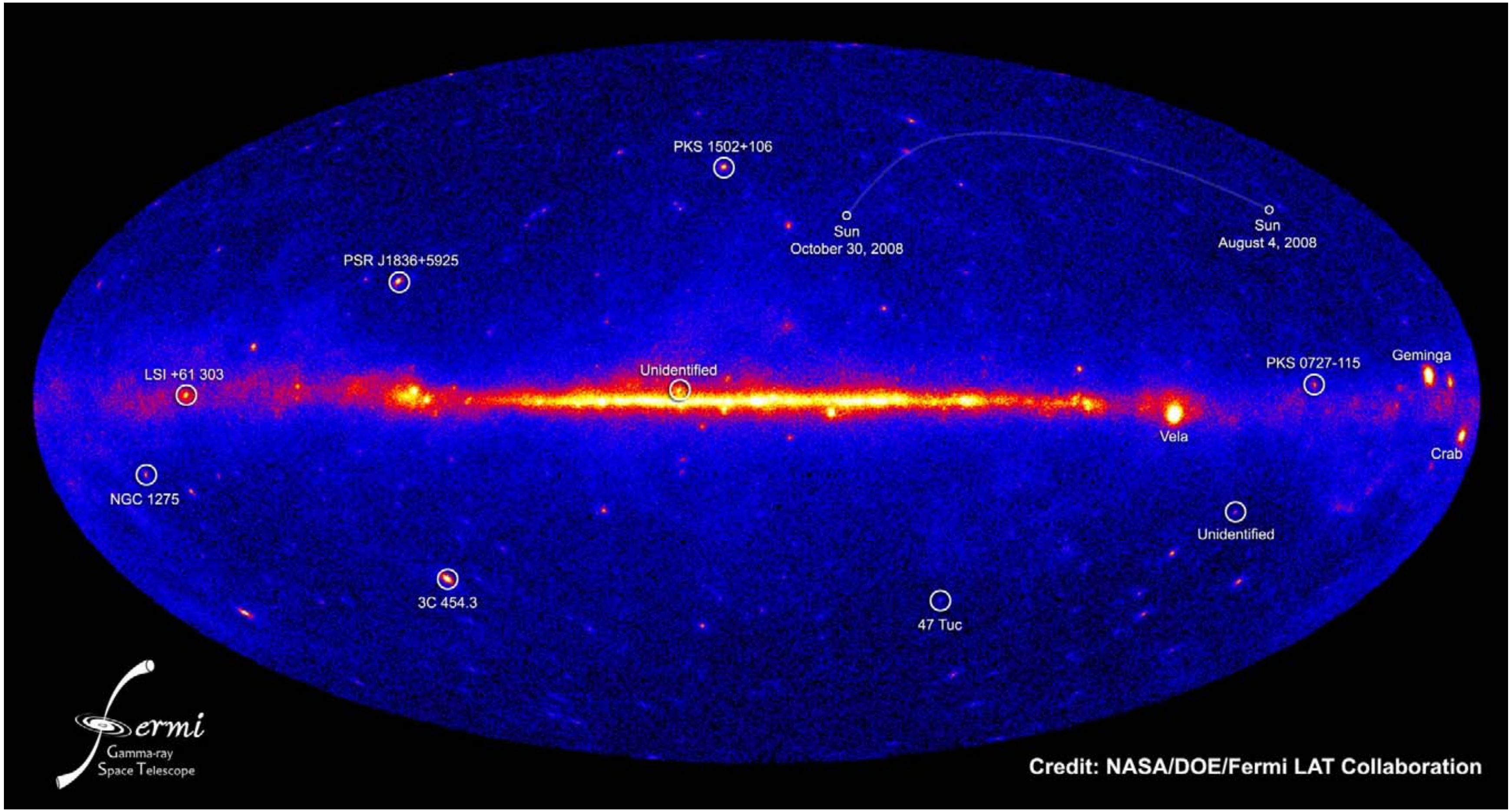
more exposure → greater sensitivity
more coverage → excellent for monitoring the sky on timescales from hours to years

Fermi LAT First Light

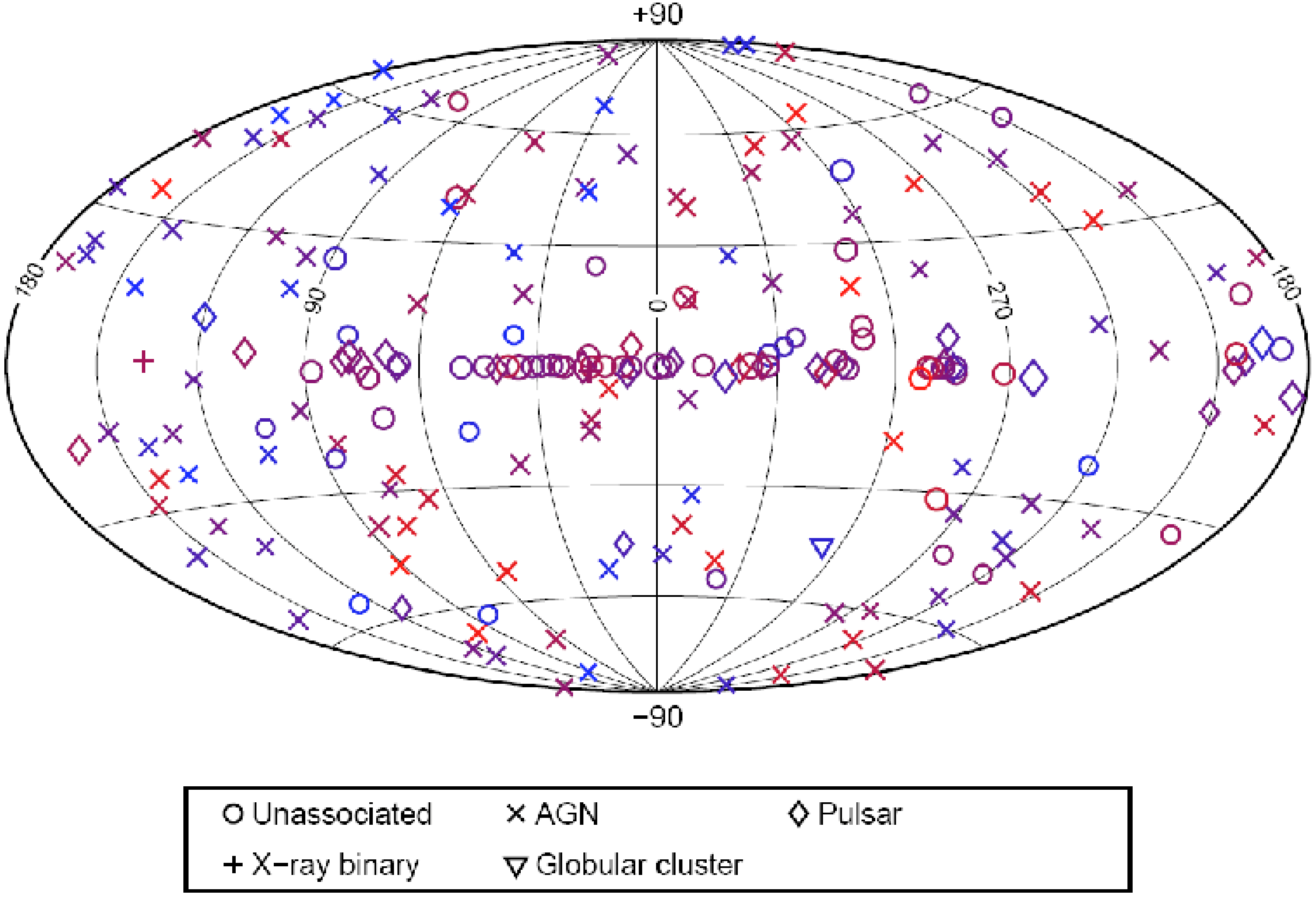


Four days of all-sky survey engineering data.

Fermi LAT 3 months image



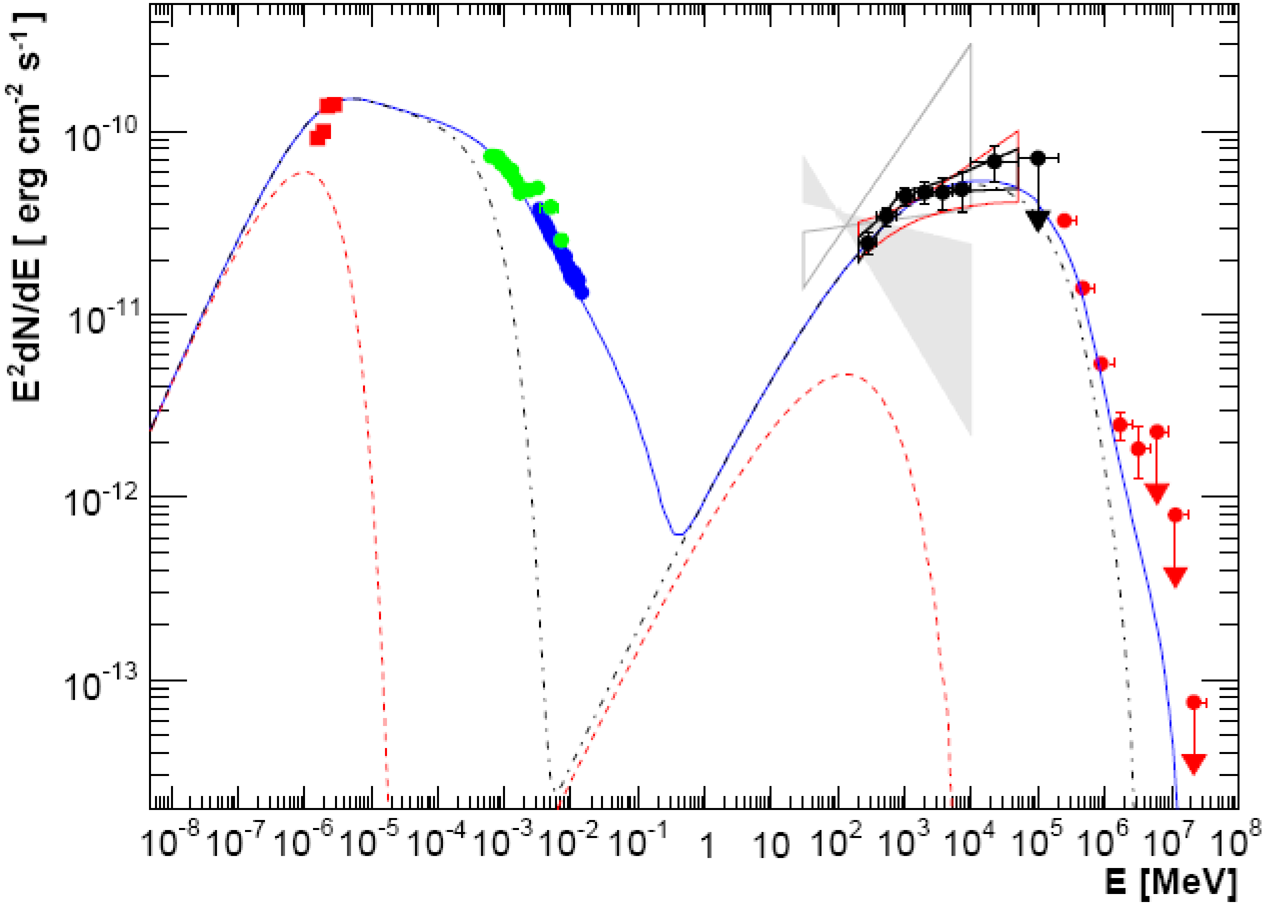
LAT bright source list



Abdo et al. 2009

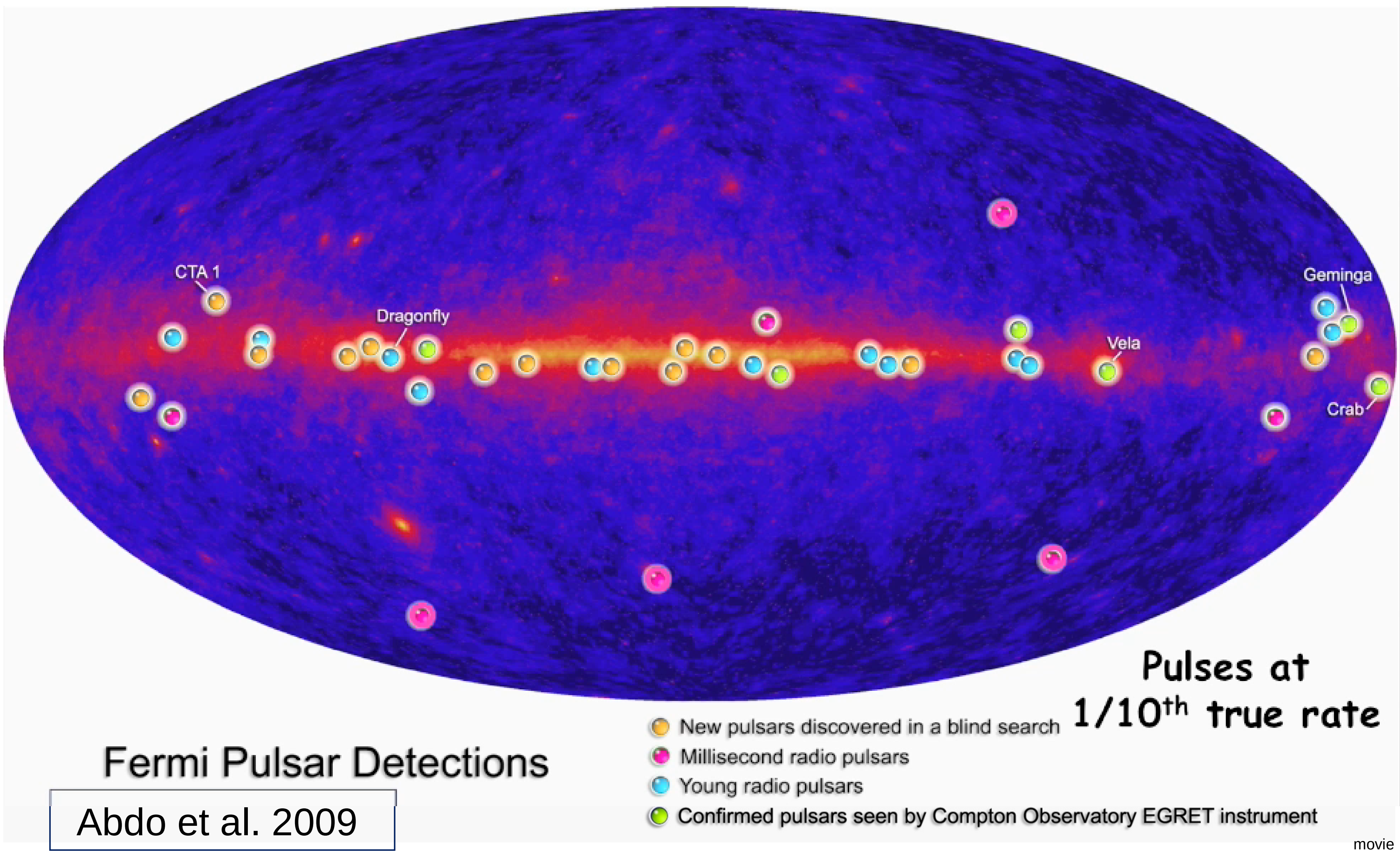
Challenge # 1 – AGN

Joint campaign on PKS 2155 with HESS



Aharonian et al. 2009

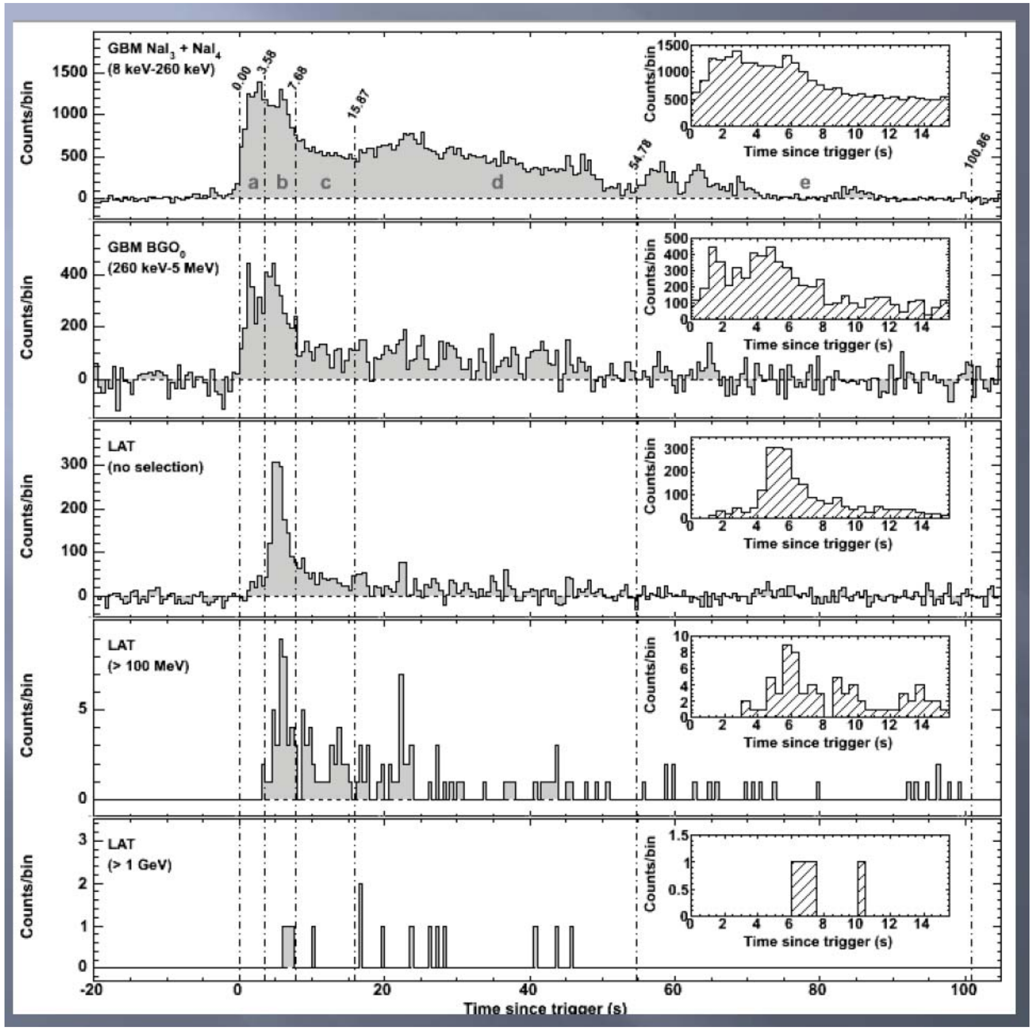
Challenge # 2 – Pulsars
Blind Search



Abdo et al. 2009

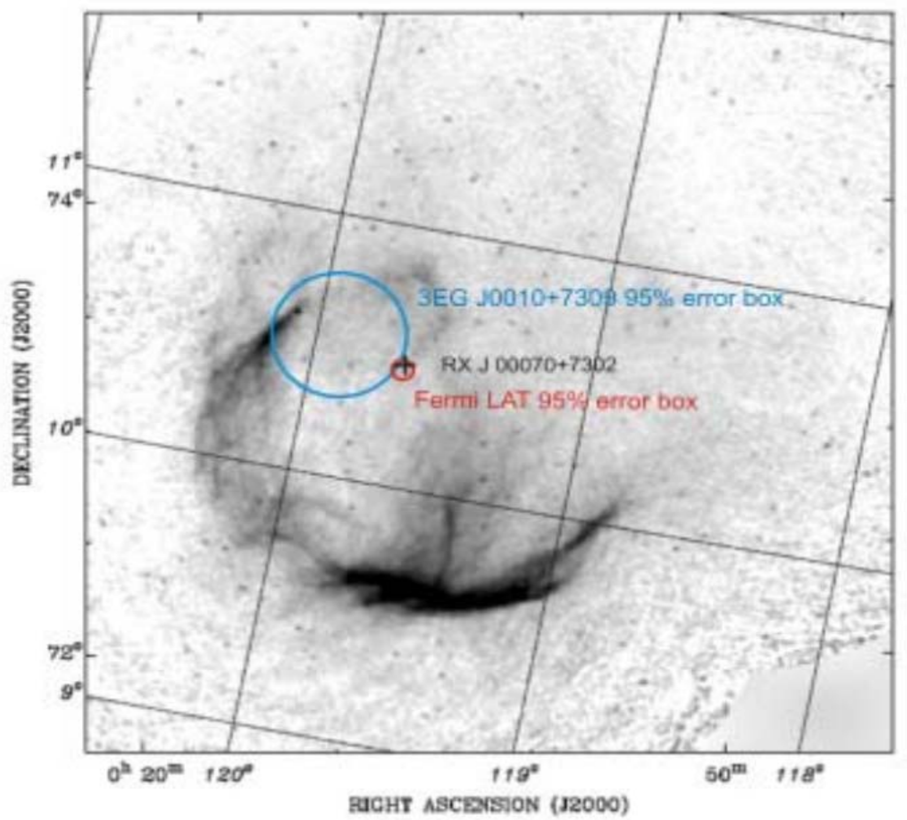
movie

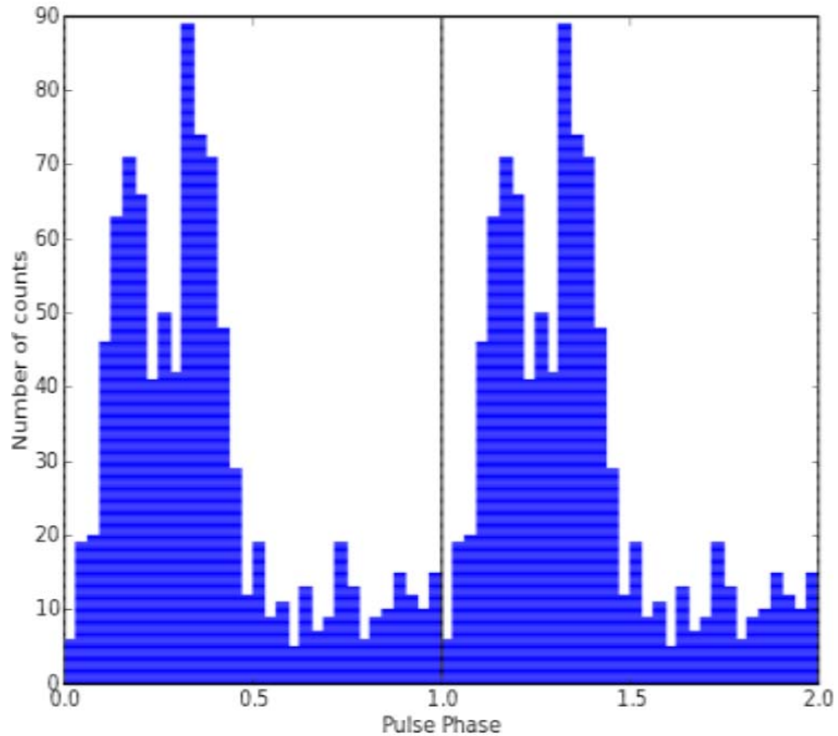
Challenge # 3 – GRB



Abdo et al. 2009

Challenge # 4 – Unidentified CTA 1 Discovery

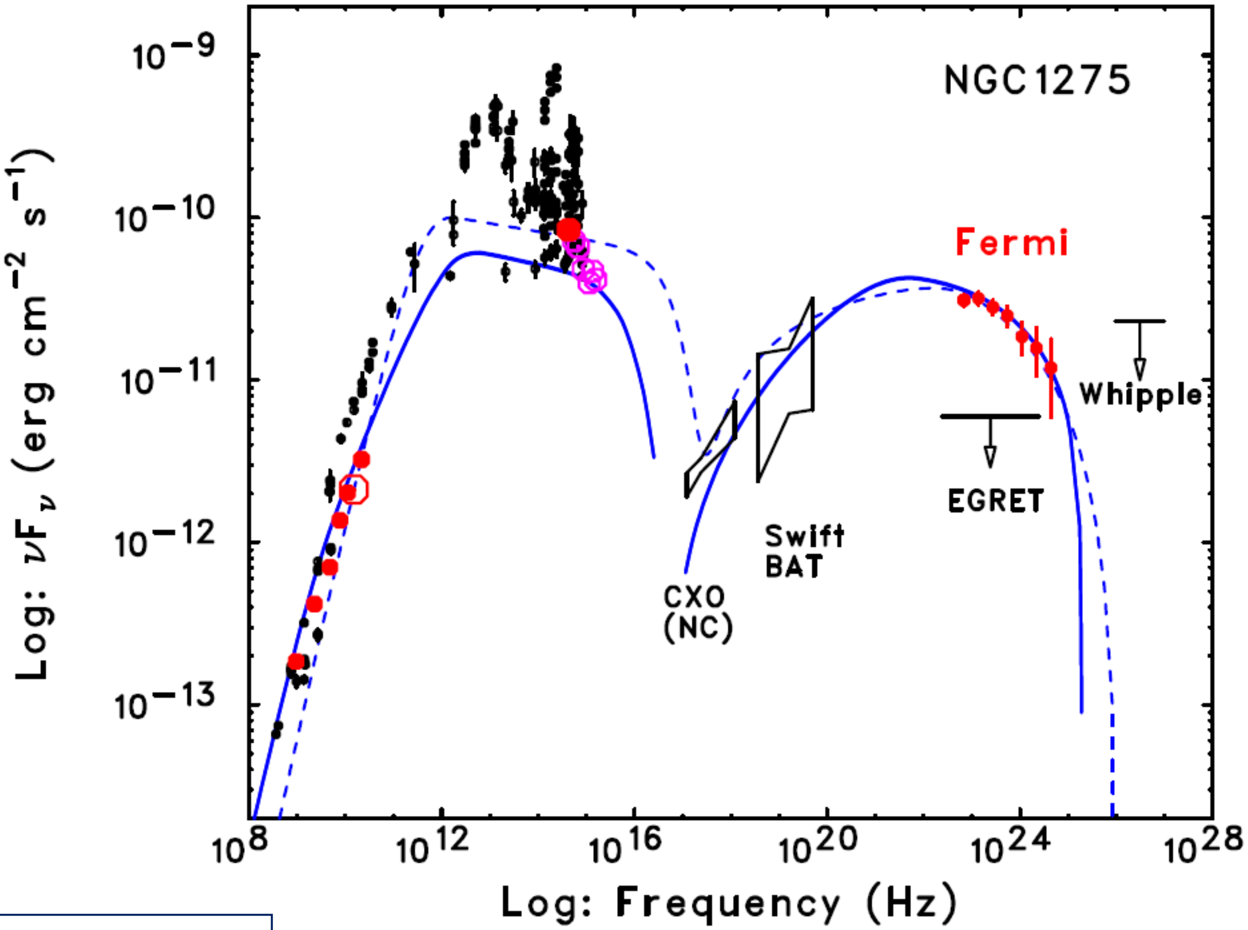




Abdo et al. 2008

Extragalactic objects

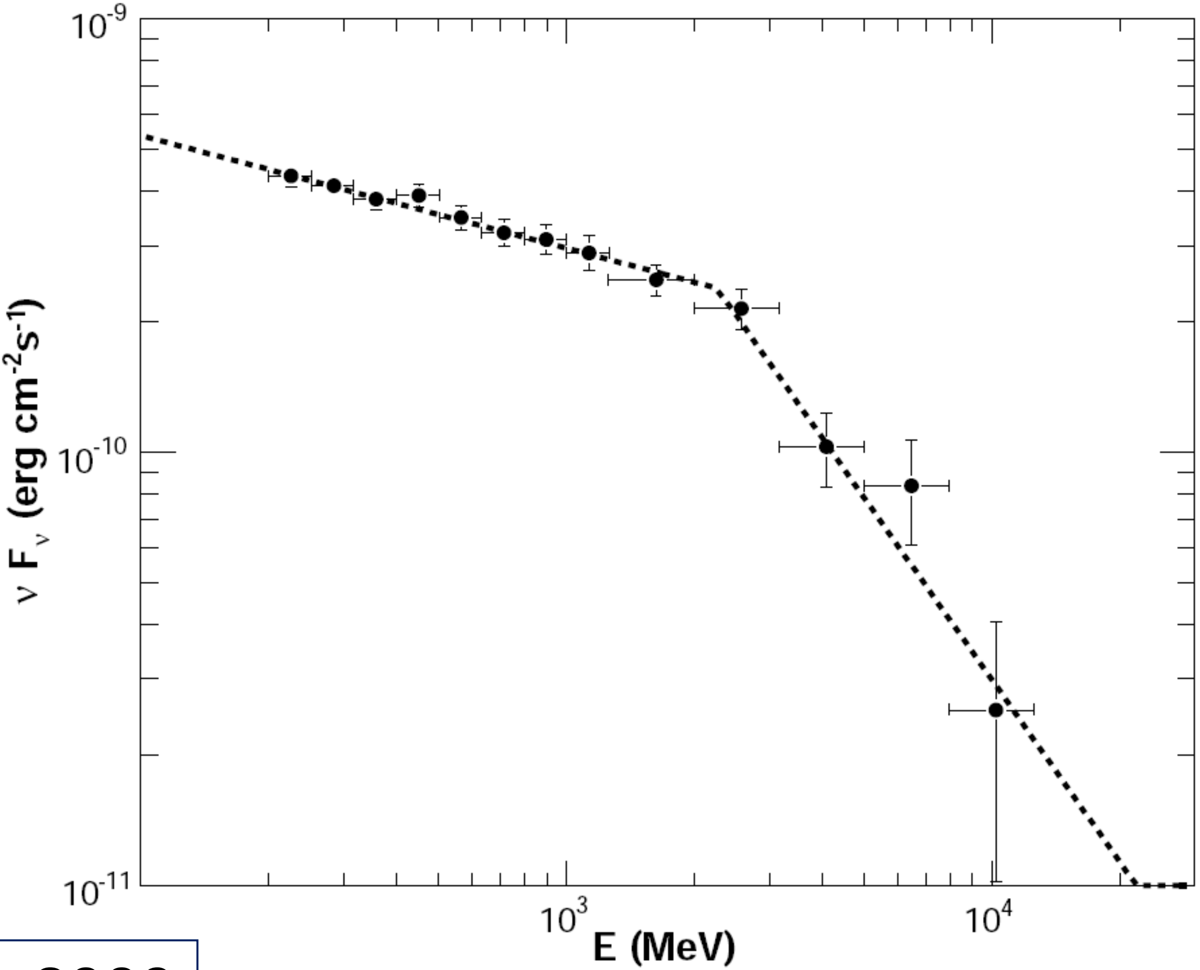
- Radio Galaxy NGC 1275 in Perseus cluster



Abdo et al. 2009

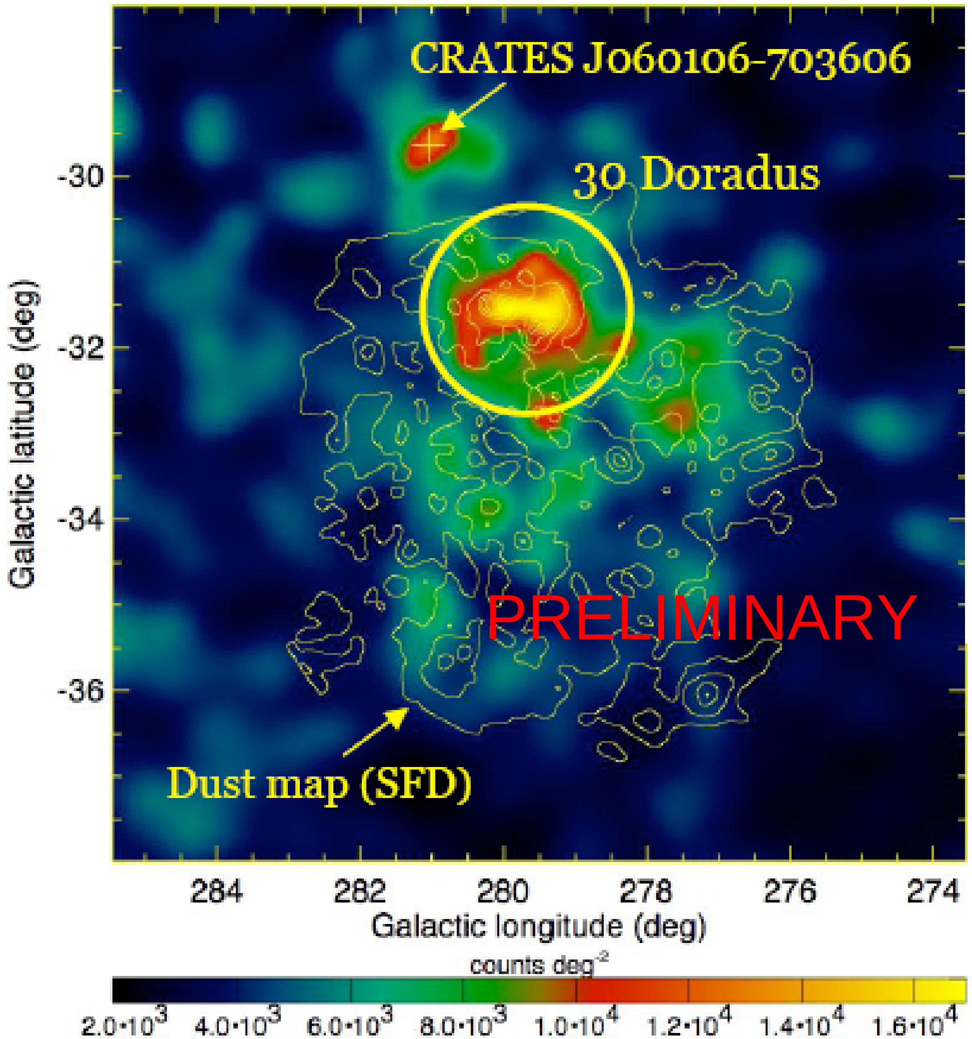
Extragalactic objects

- 3C454.3 spectral break

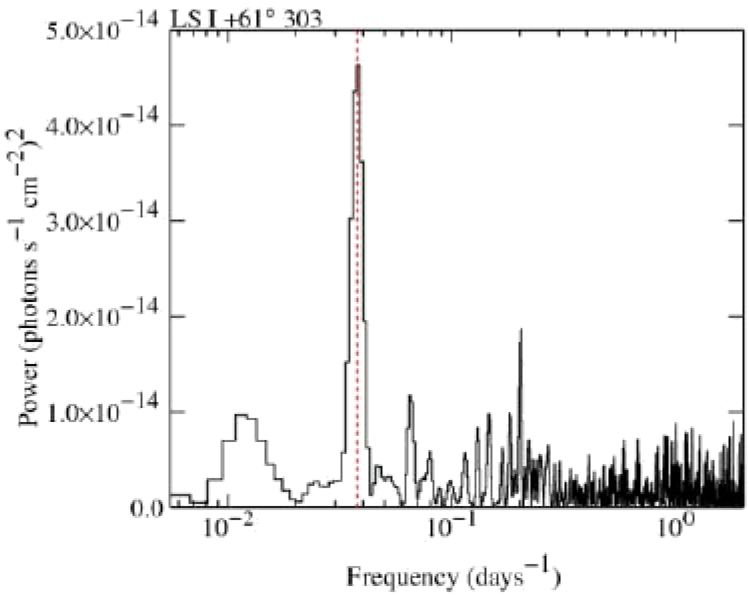


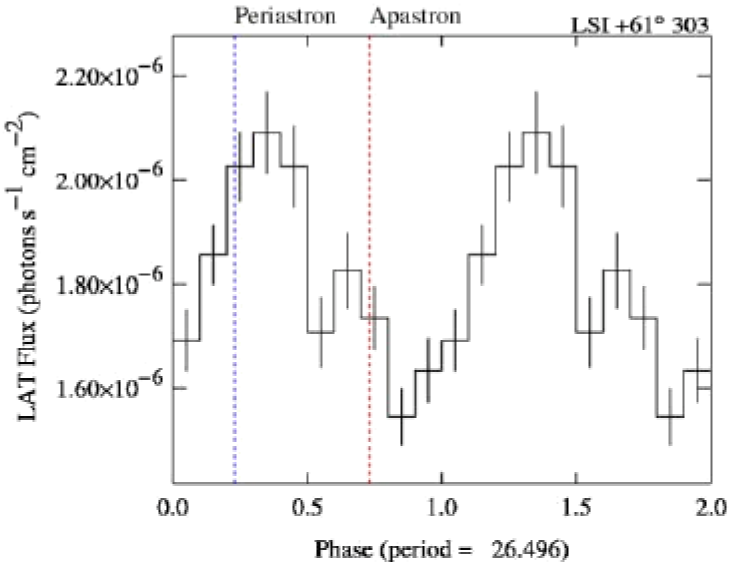
Abdo et al. 2009

Large Magellanic Cloud



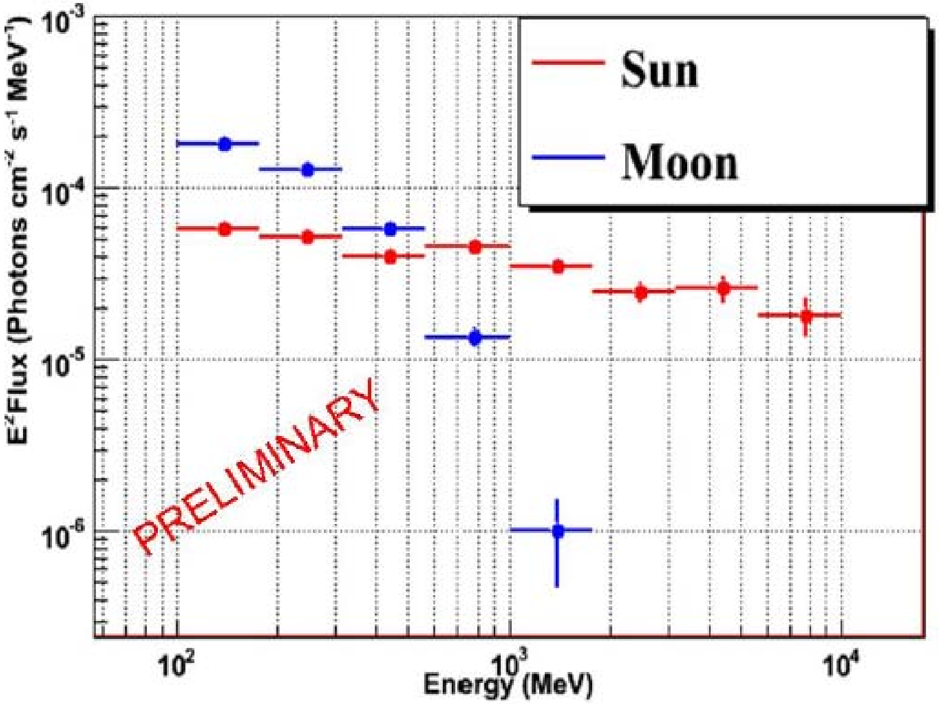
The Gamma binary LSI 61+303

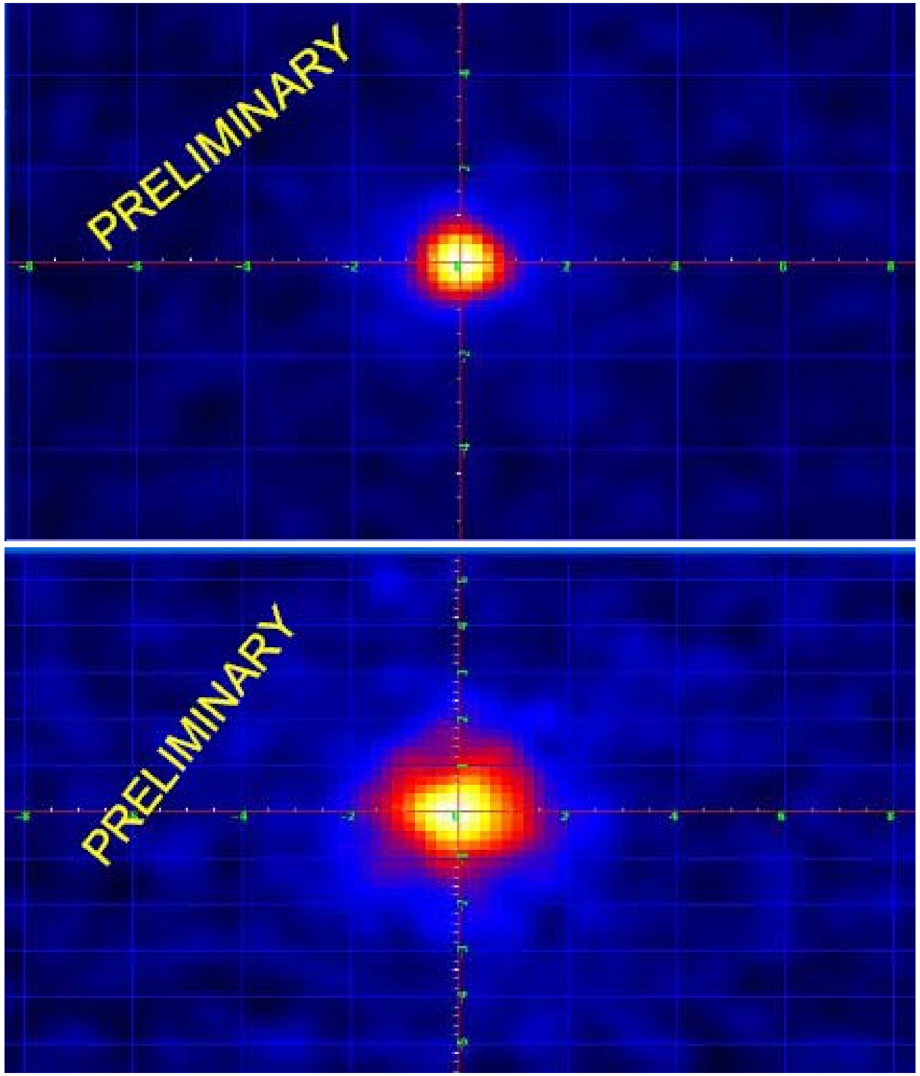




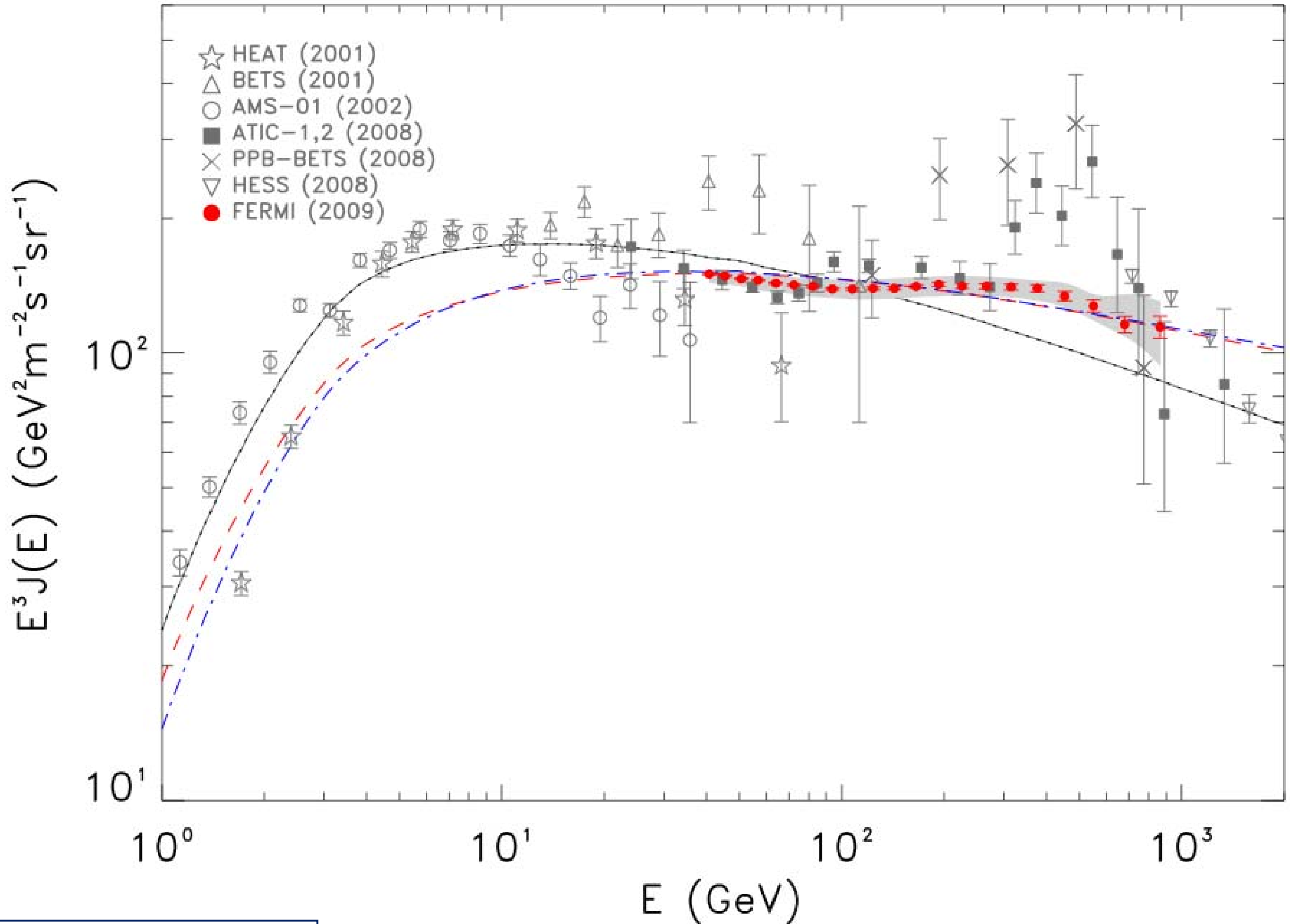
PRELIMINARY

The Sun and Moon





The e^+e^- spectrum



Abdo et al. 2009

HE astrophysics

- The “golden age”?
- Extragalactic sky
  - Population studies
  - High redshift GRB
  - Multiwavelenght studies
- Galactic sky
  - Pulsars
  - Gamma-ray binaries candidates
  - New Identification
- Search for DM in progress

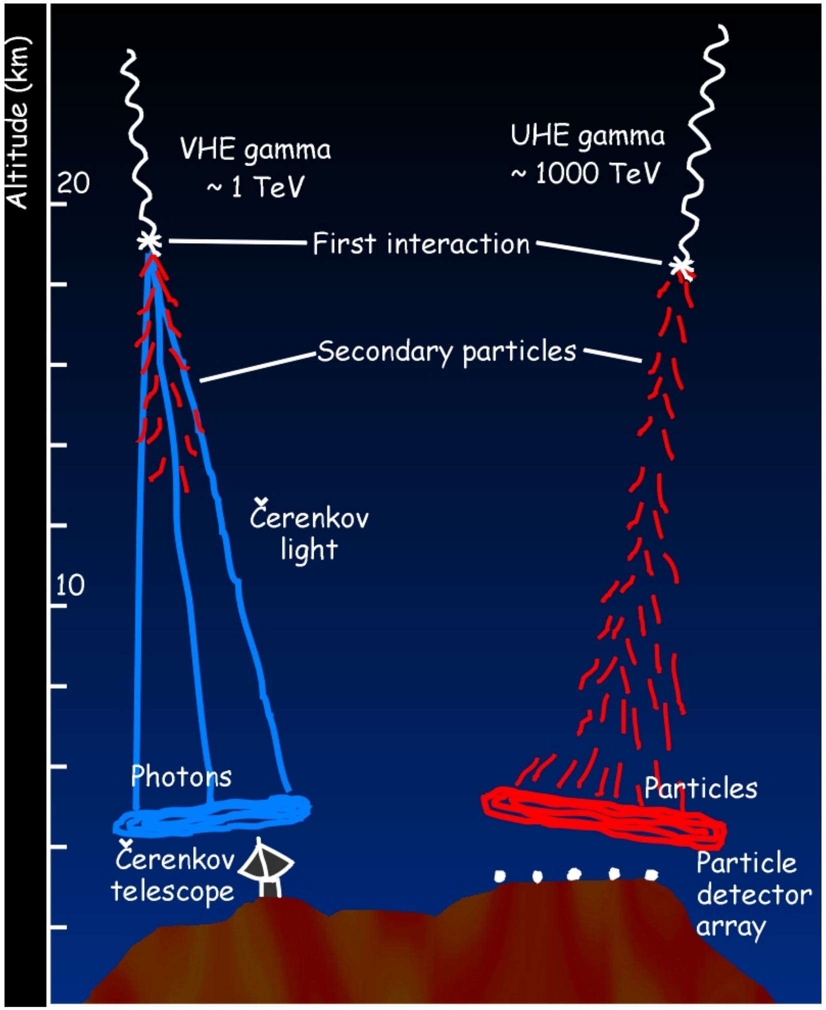
VHE gamma-astrophysics

Complementary Capabilities

Parameter	Ground-based		Space-based
	ACT	EAS	Pair
angular resolution	good	fair	good
duty cycle	low	high	high
area	large	large	small
field of view	small	large	large & can repoint
energy resolution	good	fair	good w/ smaller systematic uncertainties

The next generation of ground-based and space-based facilities are well matched!

Ground detectors: EAS vs. IACT (Cherenkov)



- EAS (Extensive Air Shower): detection of the charged particles in the shower
- Cherenkov detectors: (IACT): detection of the Cherenkov light from charged particles in the atmospheric showers

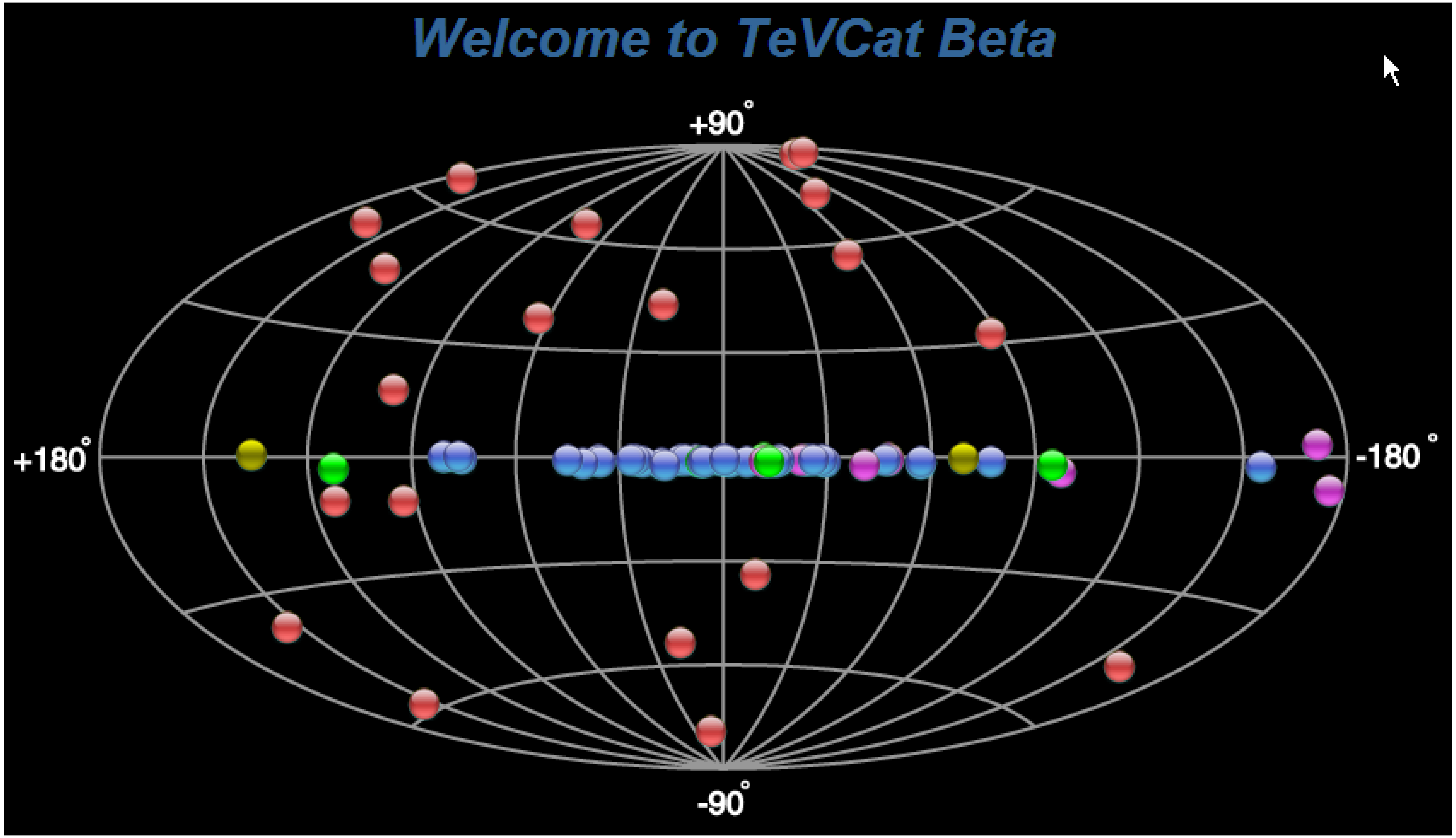
MAGIC-II just inaugurated!


VERITAS

The High Energy Stereoscopic System (H.E.S.S.)

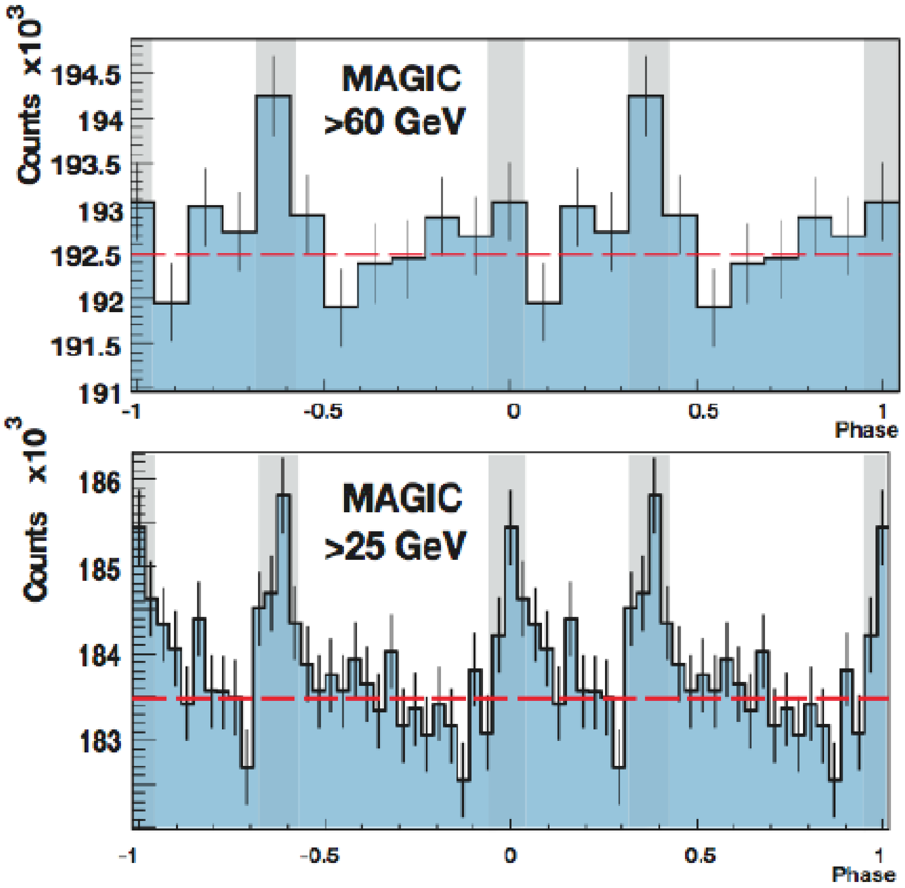
CANGAROO

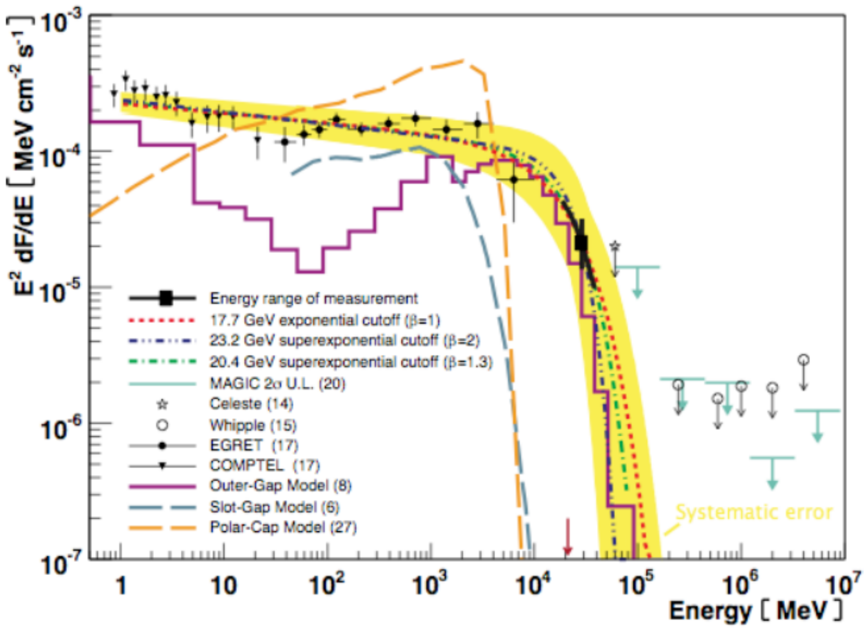
TeV Source Catalog



http://tevcat.uchicago.edu/

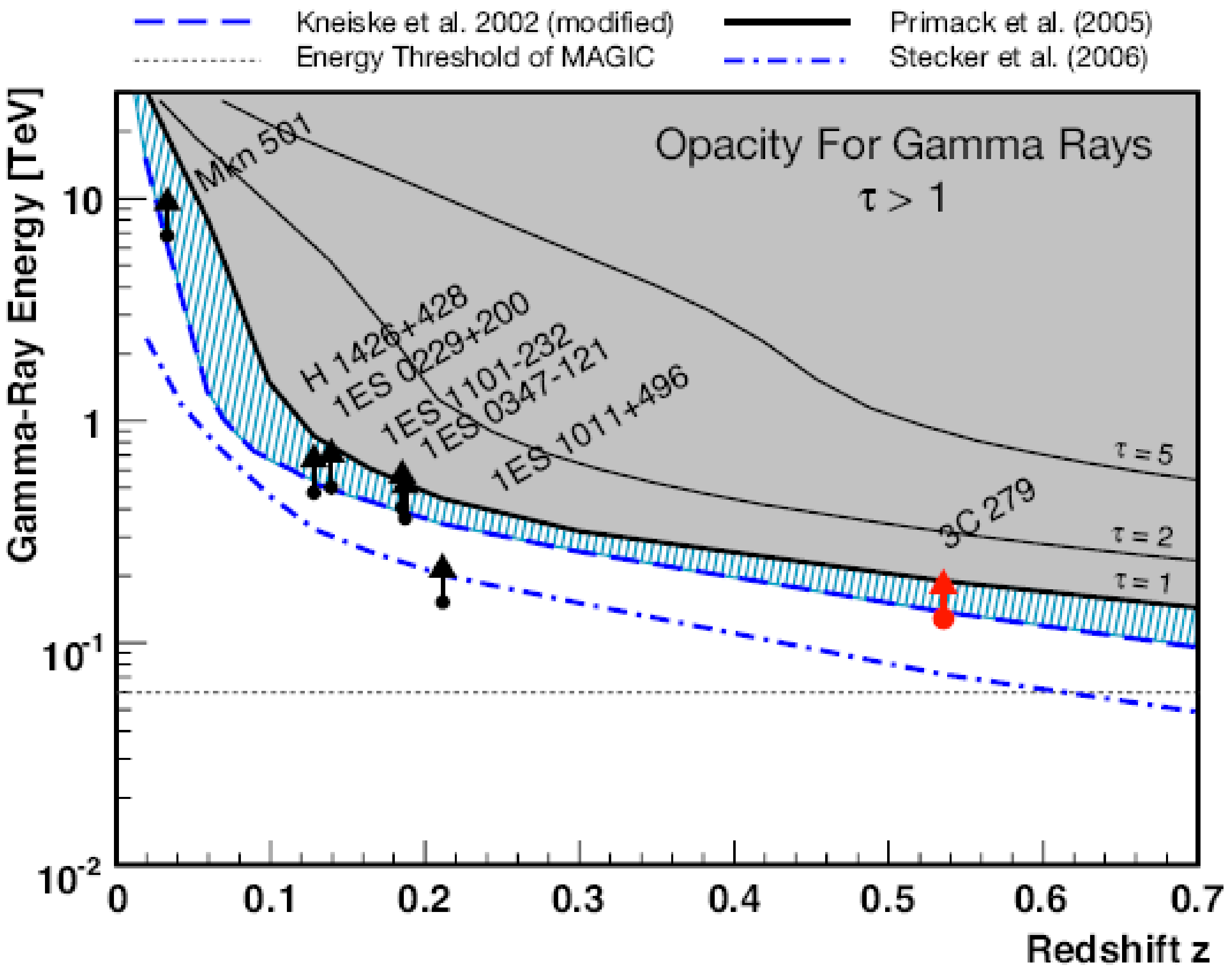
MAGIC – the Crab PSR





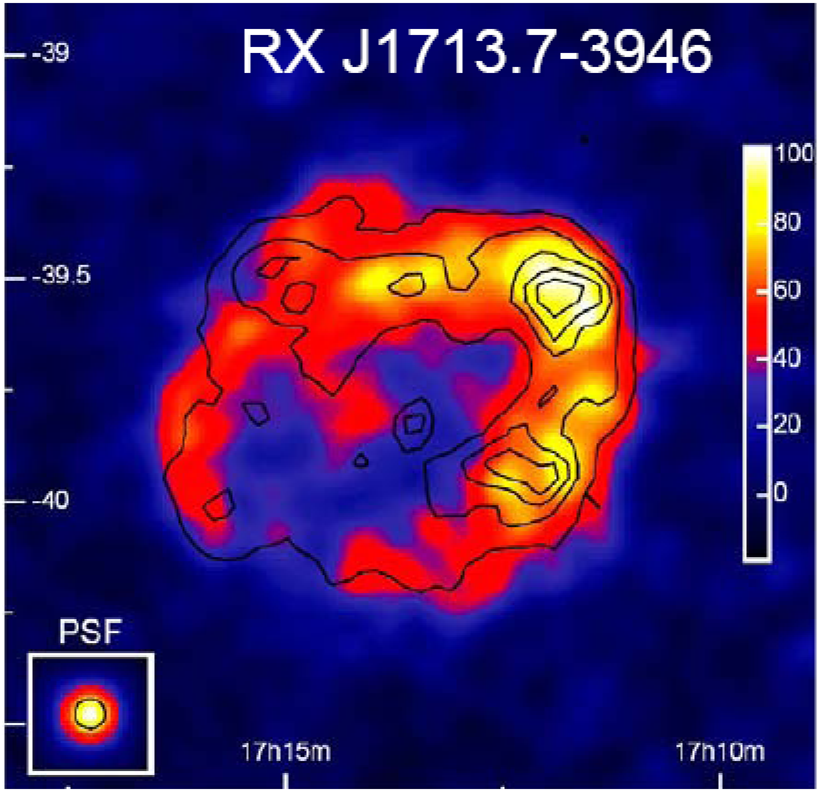
Albert et al. 2008

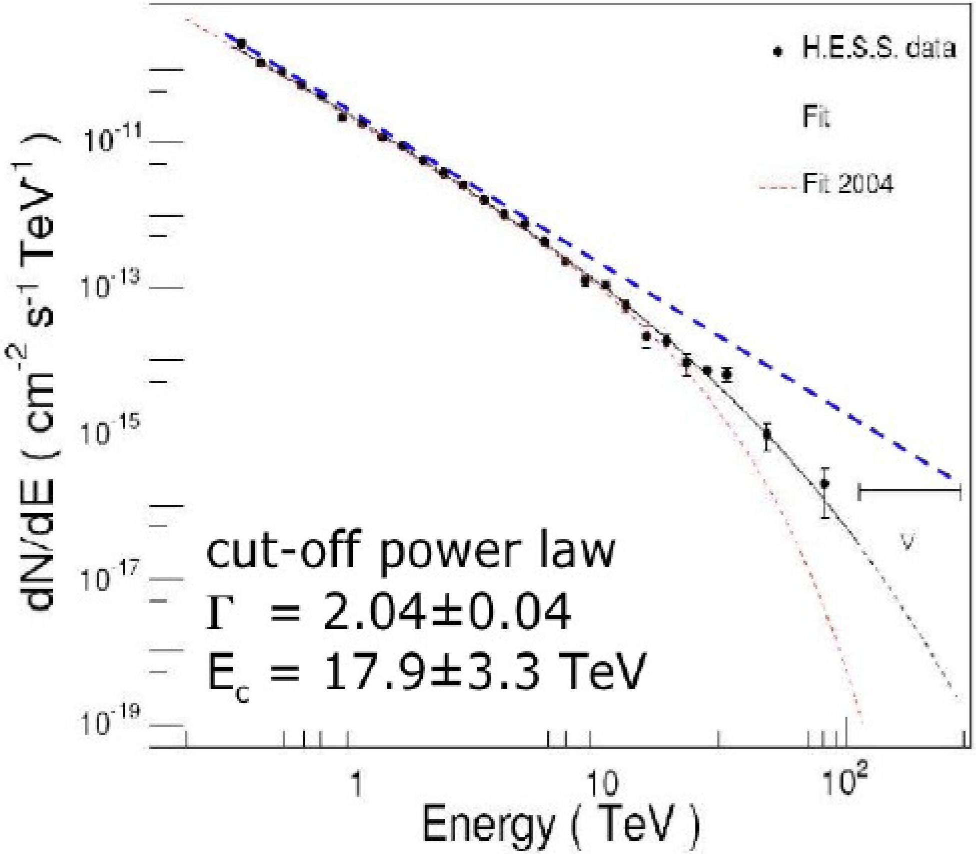
MAGIC – 3C279



Albert et al. 2008

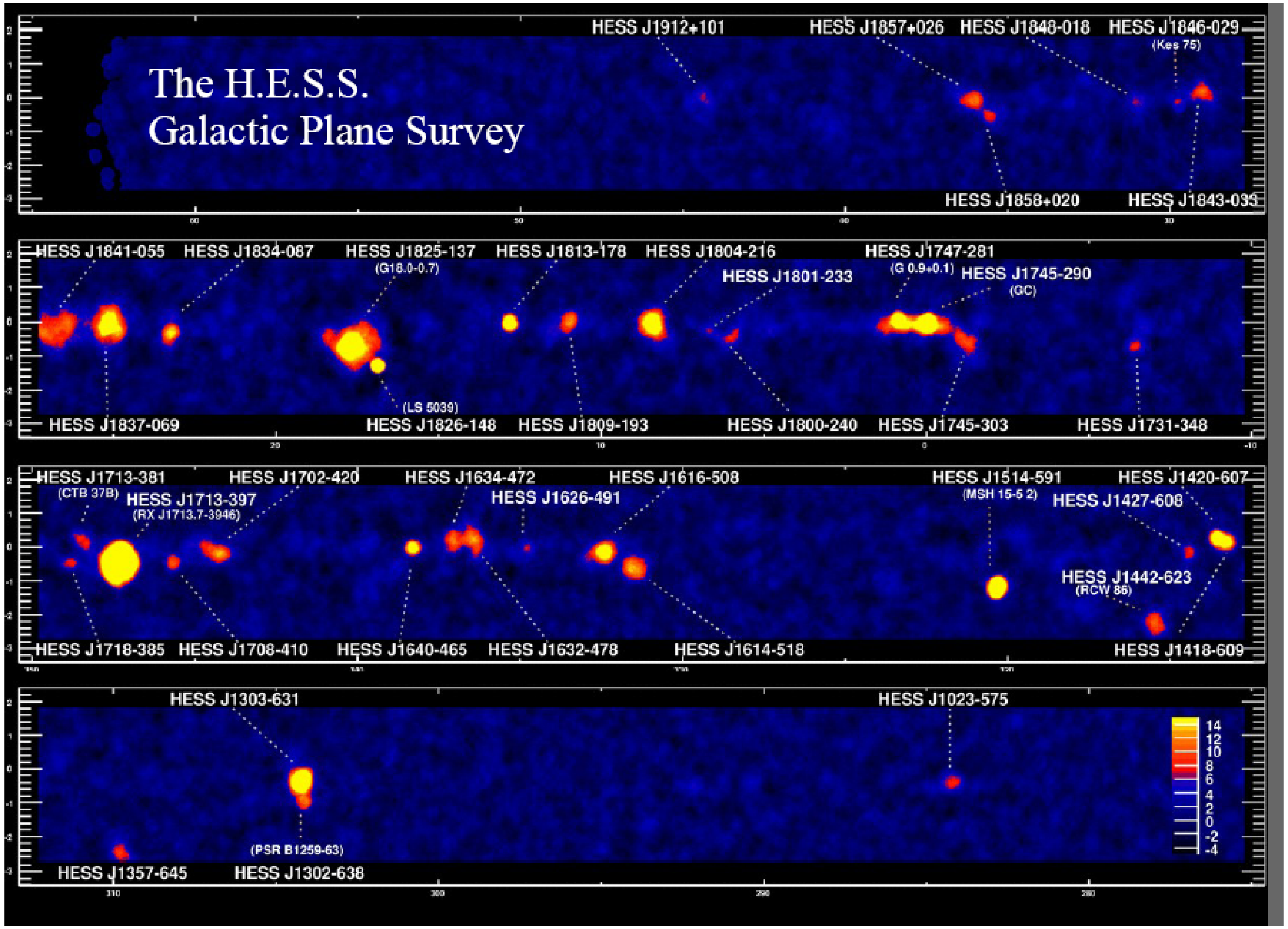
HESS – SNR in VHE gamma





Aharonian et al. 2004

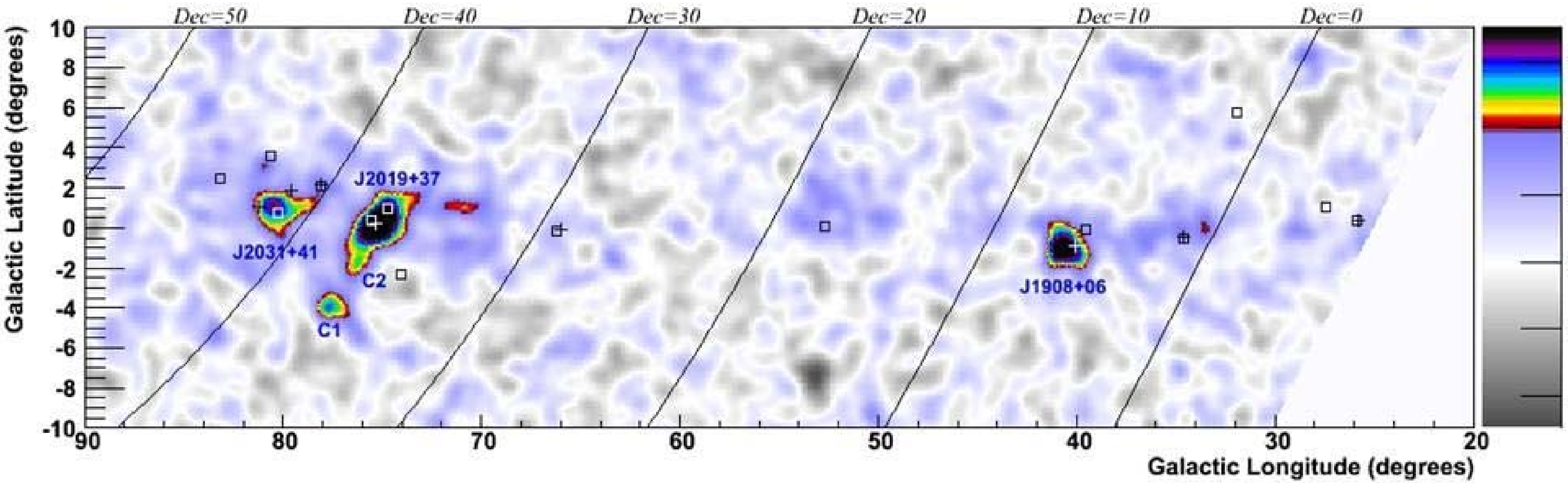
HESS – The Galactic Plane survey



Aharonian et al. 2006

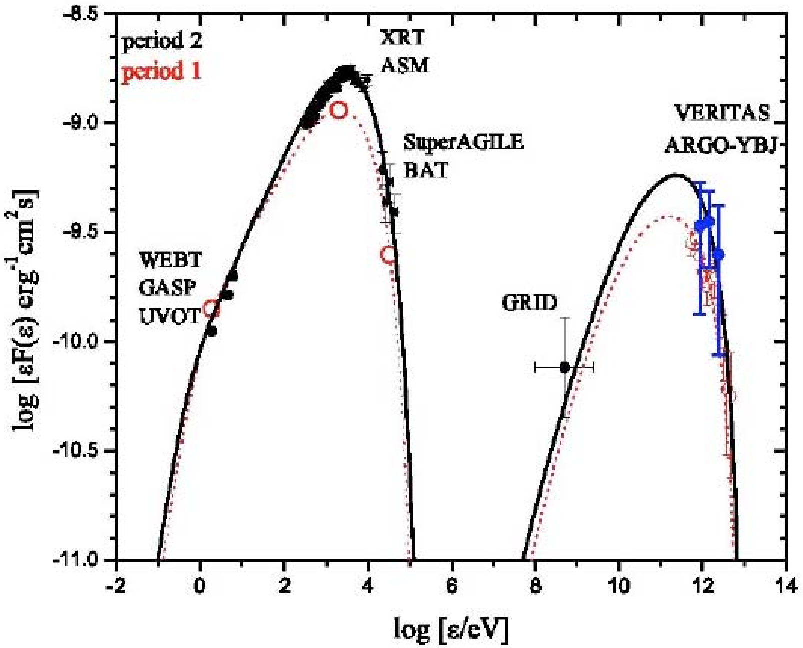
MILAGRO

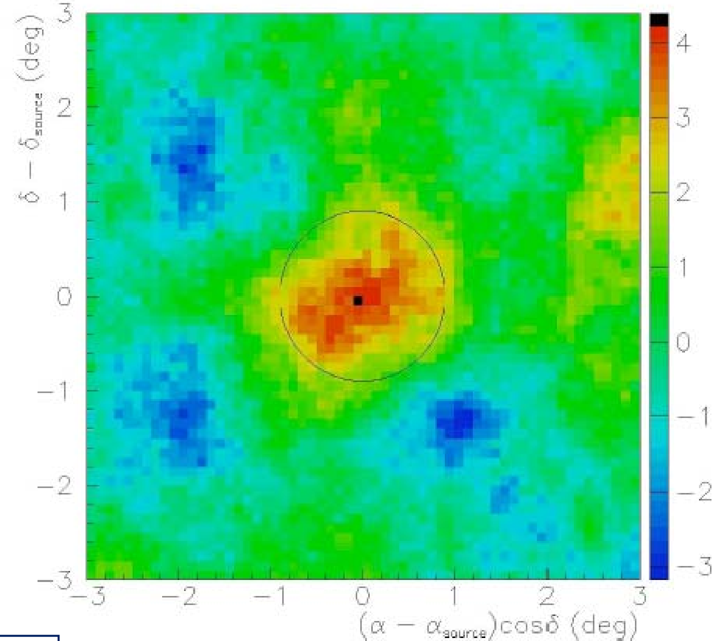
Cherenkov in water, Arizona



Abdo et al. 2008

ARGO-YBJ

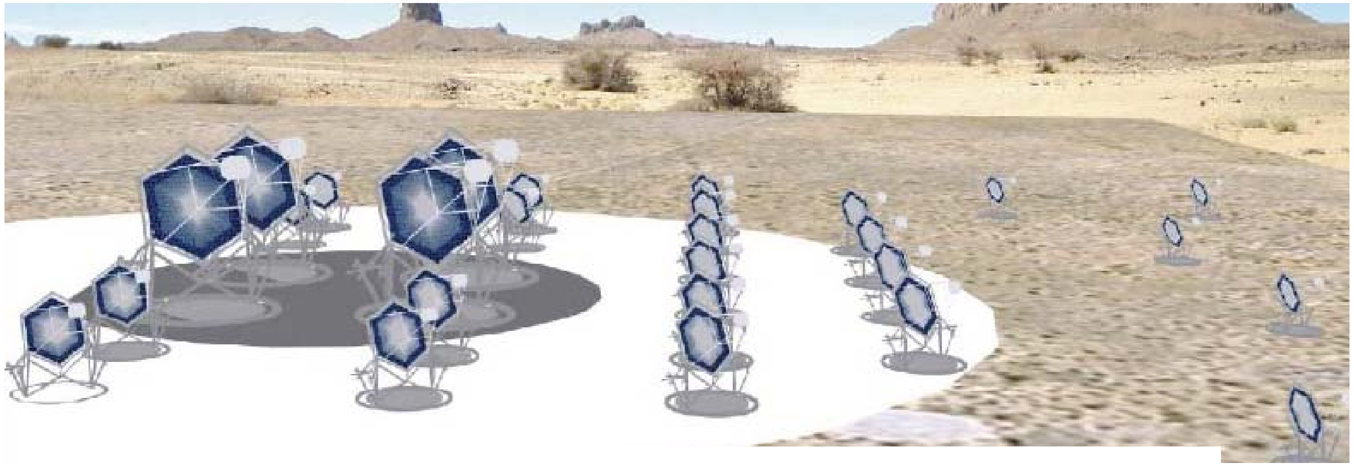


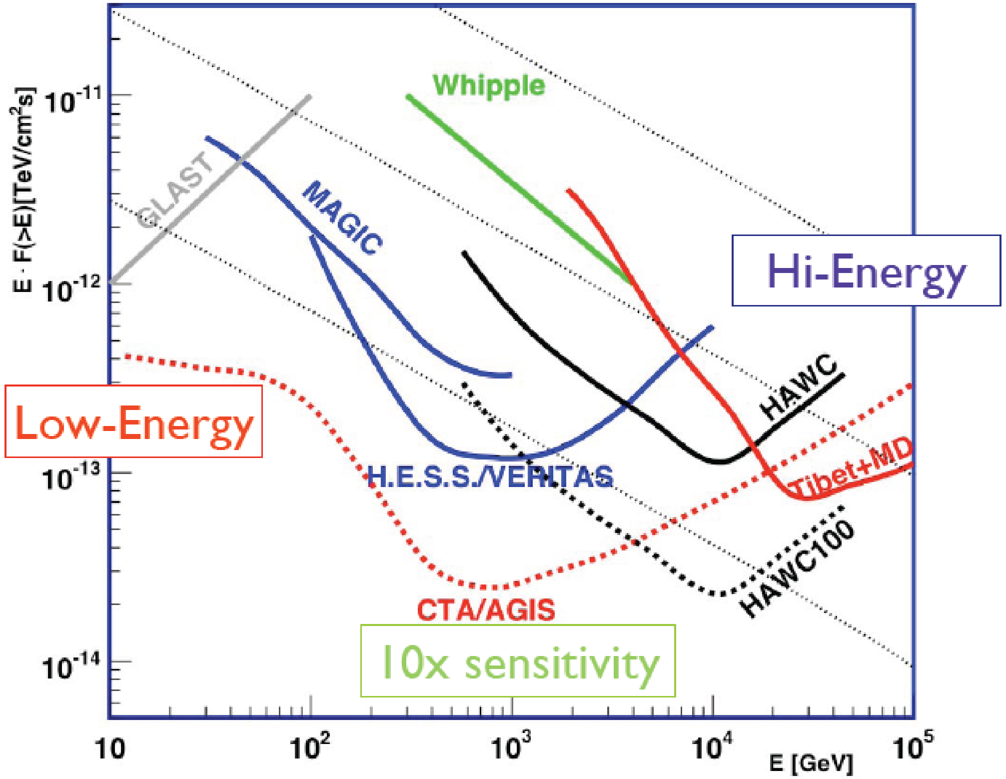


4.2 σ

Vernetto et al. 2009 – RICAP 2009

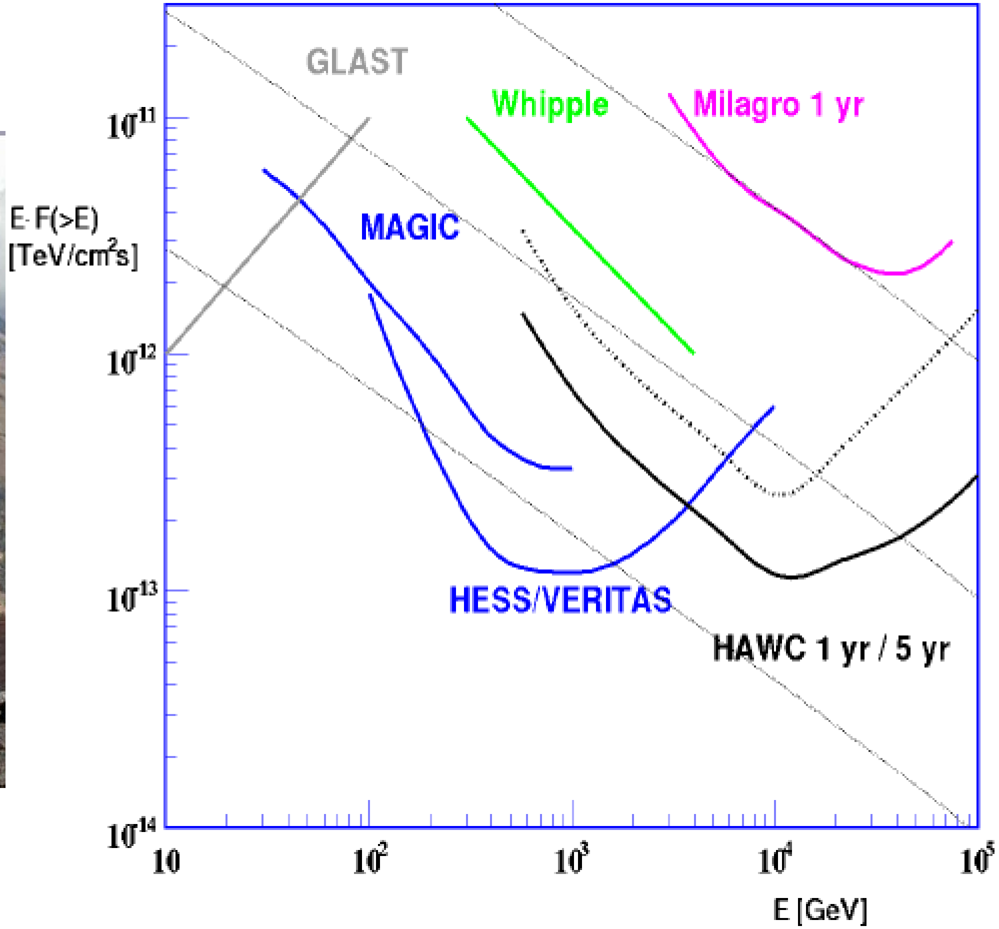
CTA





Whipple
GLAST
MAGIC
Hi-Energy
HAWC
Low-Energy
H.E.S.S./VERITAS
Tibet+MD
HAWC100
CTA/AGIS
10x sensitivity
E · F(>E)[TeV/cm²s]
E [GeV]

HAWC


GLAST
Whipple
Milagro 1 yr
MAGIC
HESS/VERITAS
HAWC 1 yr / 5 yr
E·F(>E)
[TeV/cm²s]
E [GeV]

VHE gamma astrophysics

- Extragalactic sky
  - Photon propagation studies
- Galactic sky
  - CR acceleration studies
  - Source class population
- Search for DM in progress

Conclusions

- The Gamma-ray Astrophysics is a very active field
- Benefit of Particle and Astrophysics community knowledge
- The fun is just started … !