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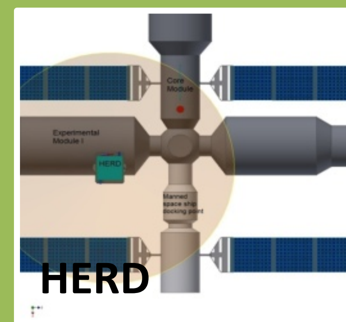

Gamma Astronomy: a short technical and historical review

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Outline

1) Introduction to VHE Gamma Astronomy physics
2) Gamma Astronomy in Space
3) Gamma Astronomy at ground
4) Perspectives

Gamma-ray astronomy: short history

- Prediction of nuclear gamma-rays
  Hayakawa 1952; Morrison 1958
- Ground-based Cherenkov:
  Jelly (1953), Chudakov (1960-)
- Prediction of emission from the Crab nebula Cocconi 1959 [nuclear]; Gould 1965 [inverse Compton]
- Satellites: OSO-3 (1967-68), SAS-2 (1972-73), COS-B (1975-82)
- Compton Gamma Ray Observatory
  EGRET/COMPTEL/OSSE/BATSE (1991-2000)
- Imaging Cherenkov:
  Whipple, CANGAROO, HEGRA (1980's-1990's)

VHE Cosmic Gamma rays

Originally: Particle Physics domain ($E\gamma$ > few GeV):

* INSTRUMENTS: Particle detectors

* TECHNIQUES: Experimental particle physics analysis

* PHYSICS: Address questions on the frontiers of our fundamental physics knowledge.

VHE Cosmic Gamma rays

Presently: (Still) highest energy messengers detectable from our universe which:

- Are stable particles

- Interact enough to be "easily" detected

- Are not deflected by cosmic magnetic fields

=> allow to pinpoint and identify the source

VHE Cosmic Gamma rays

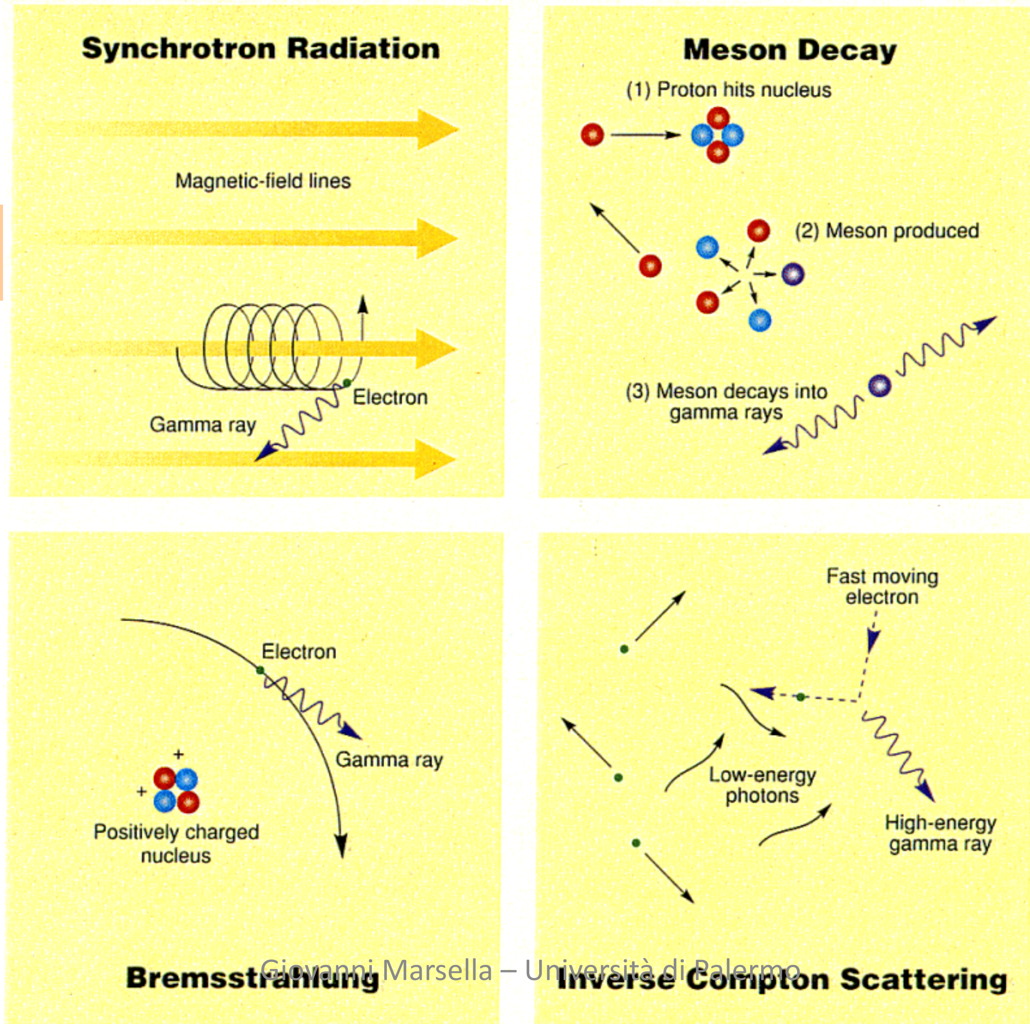
=> Highest energy open window for the observation of our universe

GAMMA-RAY ASTRONOMY

Gamma-ray emission mechanisms

- Gamma-rays are produced in inherently *non-thermal* processes!

$e^{\pm} + B$

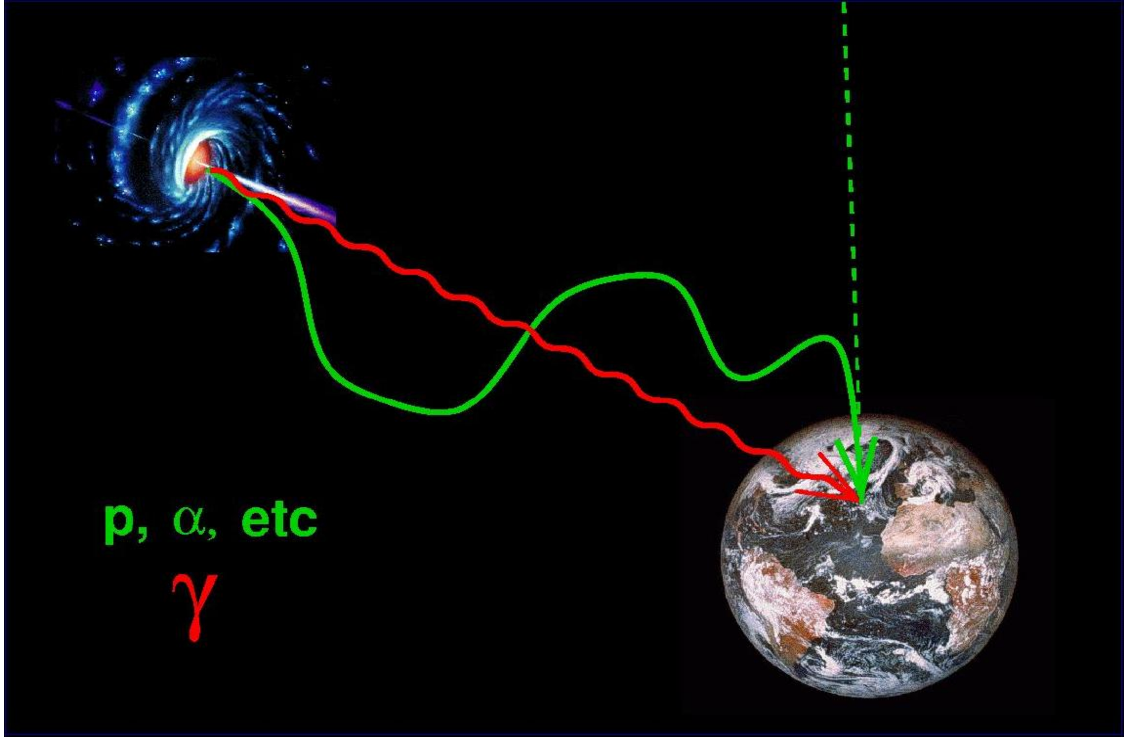


p + matter

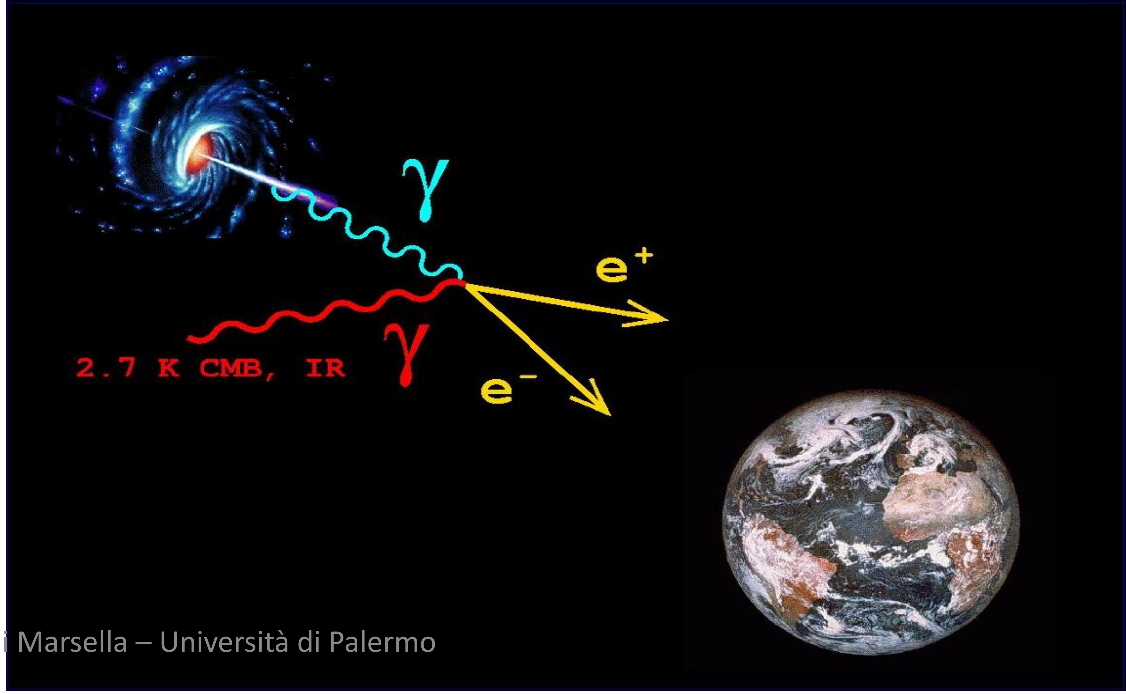
$e^{\pm}$ + matter

$e^{\pm} + h\nu$

Source Studies



Propagation Studies

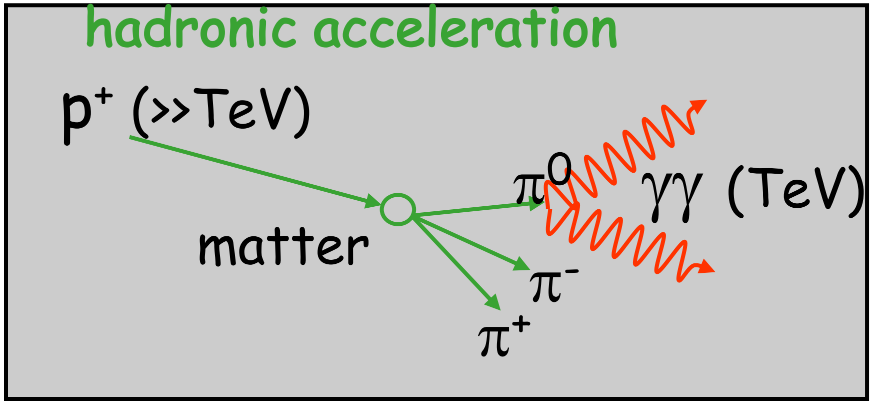


1) Study the source: production mechanisms

VHE gamma rays are produced in the most energetic and violent phenomena in the universe:

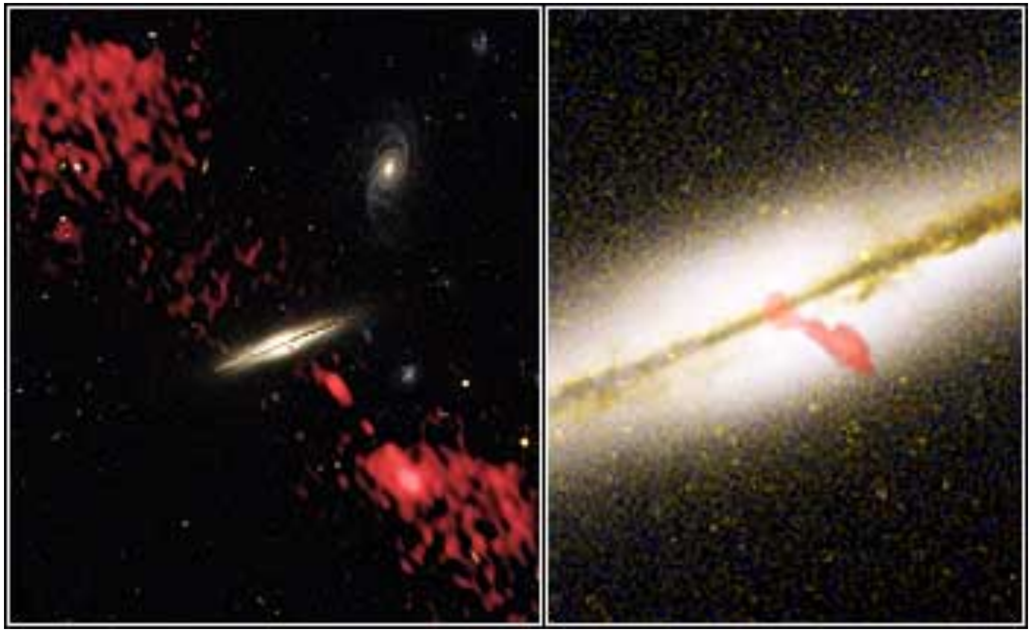
A) COSMIC ACCELERATORS

- Hadron accelerators: p X -> π -> gamma



1 - Through conversion of the strongest gravitational potential energies into particle accelerations near compact accreting objects (Black Holes, Neutron Stars,..)

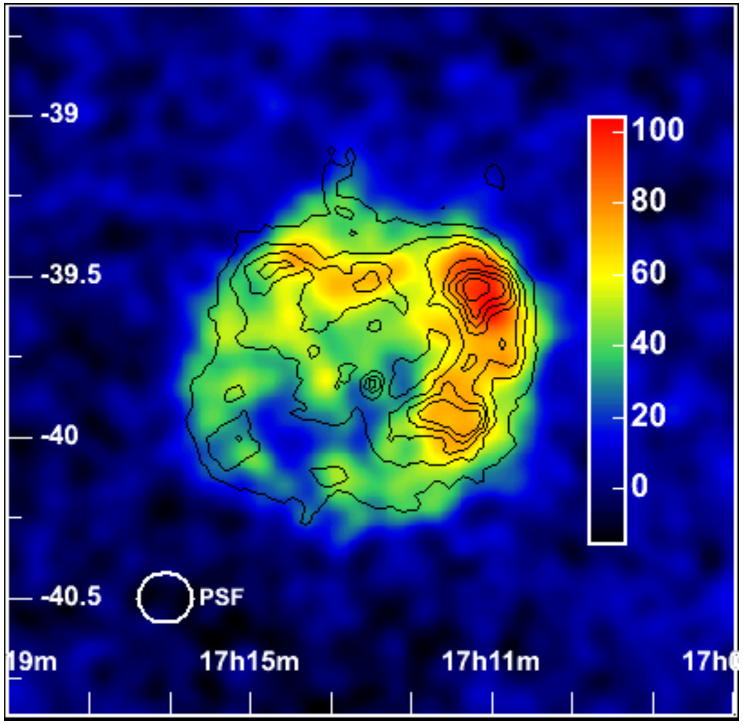
=> Unique LAB to study extreme accreting GRAVITATIONAL INTERATION



QUASAR:
Galaxy 0313-192

2 - In shocks due to big explosions in compact object formation (supernovae, hipernovae, collapses,…)

=> Acceleration in expanding shock waves



Supernova Remnant:
RX J1713-3946

3 - In interactions of strong plasma winds with magnetic fields or other winds (plerions, wind shocks,…)

=> Acceleration in wind collisions

Pulsar Wind Nebula:
Crab

B) HEAVY PARTICLE ANNIHILATION OR DECAY

Through the annihilation or decay of very massive or energetic objects:

dark matter, very massive particles at unification scales, relics of universe phase transitions, primordial black holes,…

=> Tool to search for new, massive, particles and objects.

2) Study the propagation in the cosmic medium

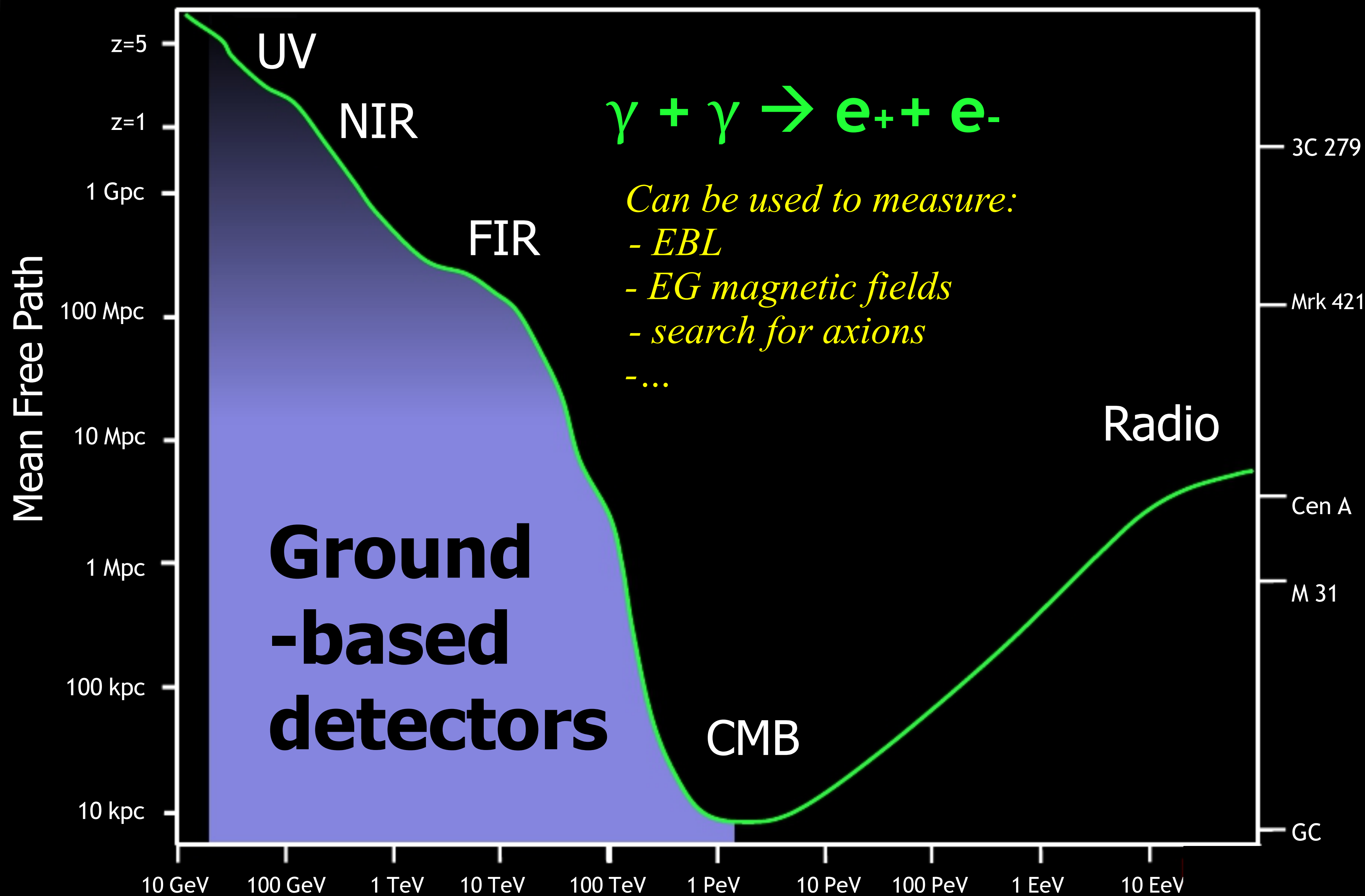
VHE gamma rays are, so far, the most energetic messengers reaching us through a determinable path: **explore the structure of intergalactic medium**:

- at long distances: produced in sources at cosmological distances from us: explore relic fields

- at the shortest distances: probe space-time at the highest energies

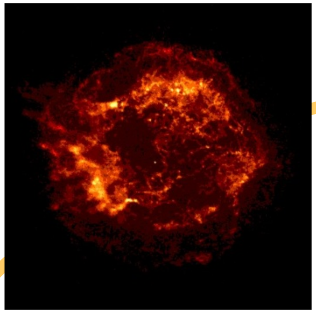
=> they allow us to address important questions in fundamental physics and cosmology

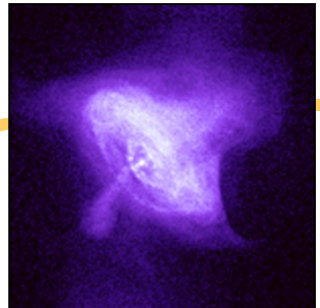
The γ Horizon : a nuissance ?



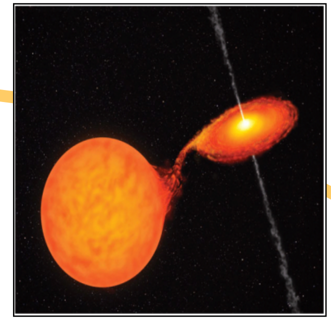
The VHE γ-ray Physics Program

SNRs

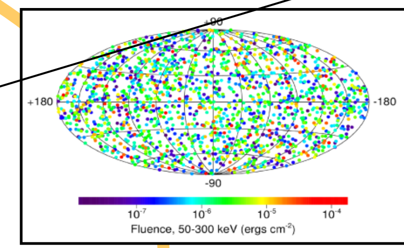




Pulsars



Binary systems

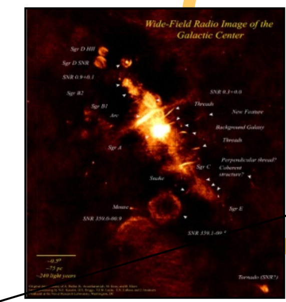


GRBs

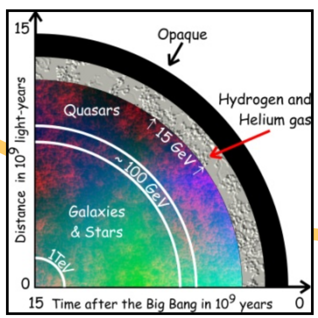
Origin of Cosmic Rays

Galactic

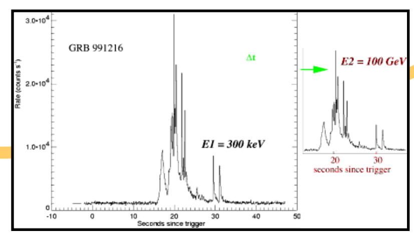
Extragalactic



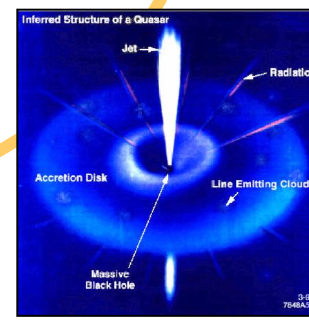
Cold Dark Matter



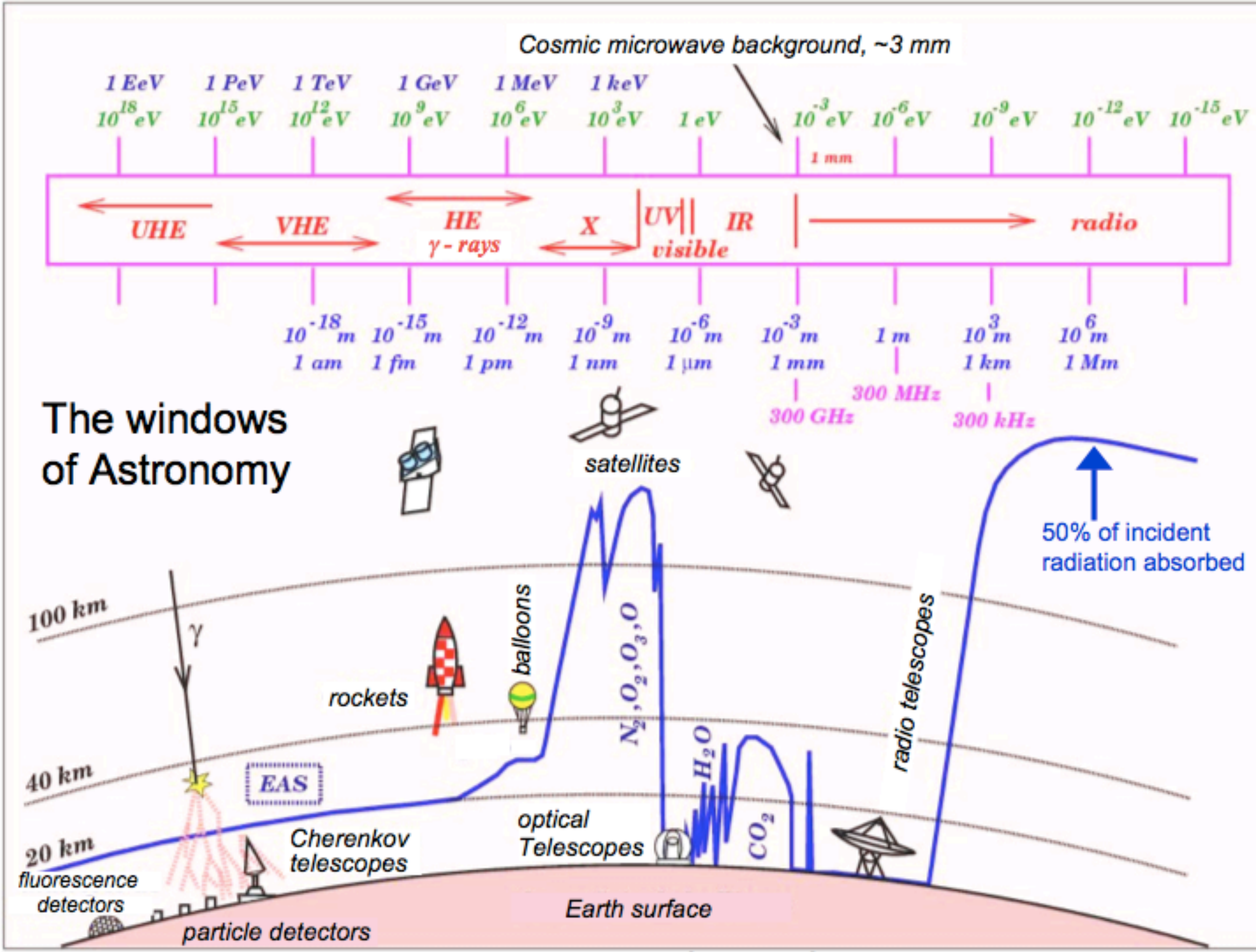
Cosmological γ-Ray Horizon



Test of the speed of light invariance



AGNs

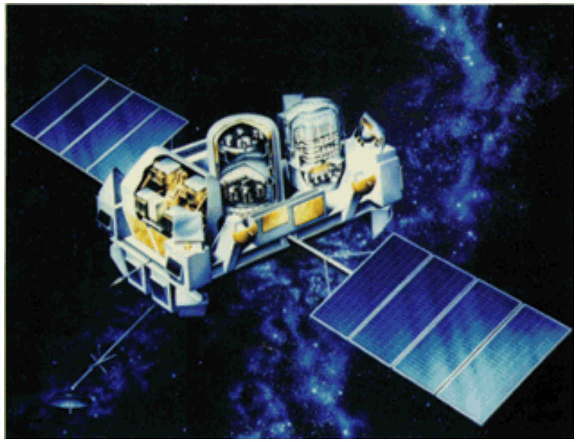


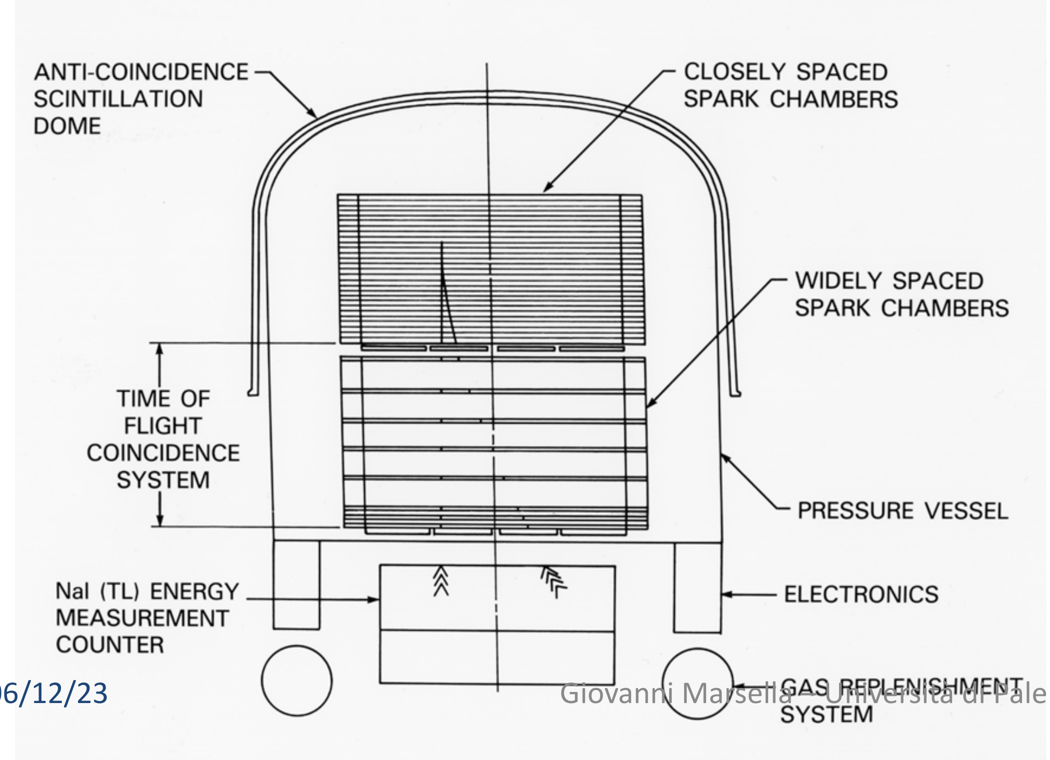
The windows of Astronomy
Cosmic microwave background, ~3 mm
1 EeV
1 PeV
1 TeV
1 GeV
1 MeV
1 keV
10^{18} eV
10^{15} eV
10^{12} eV
10^{9} eV
10^{6} eV
10^{3} eV
1 eV
10^{-3} eV
10^{-6} eV
10^{-9} eV
10^{-12} eV
10^{-15} eV
1 mm
UHE
VHE
HE
γ - rays
X
UV
visible
IR
radio
10^{-18} m
10^{-15} m
10^{-12} m
10^{-9} m
10^{-6} m
10^{-3} m
1 m
10^{3} m
10^{6} m
1 am
1 fm
1 pm
1 nm
1 μm
1 mm
1 km
1 Mm
300 GHz
300 MHz
300 kHz
satellites
50% of incident
radiation absorbed
100 km
40 km
20 km
γ
rockets
balloons
N_2, O_2, O_3, O
H_2O
CO_2
radio telescopes
EAS
Cherenkov
telescopes
optical
Telescopes
fluorescence
detectors
particle detectors
Earth surface

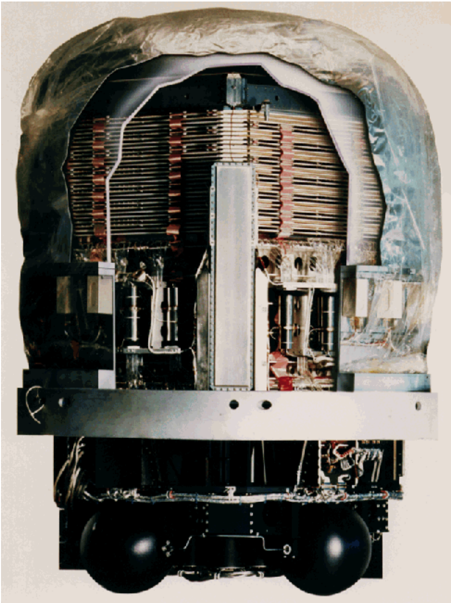
- Gamma Astronomy in Space

CGRO/EGRET

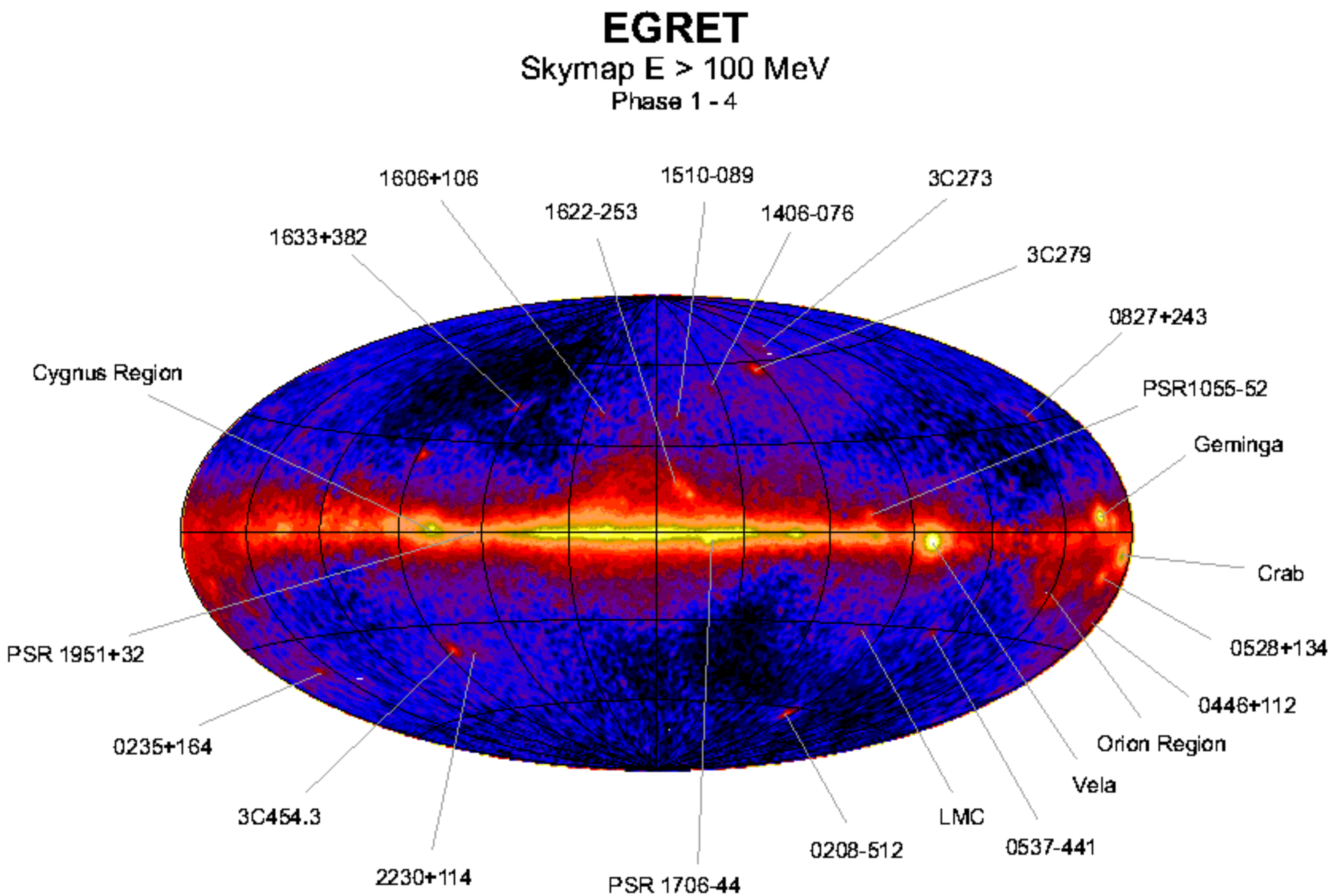
- Apr 1991 – Jun 2000
- 30 MeV – 30 GeV
- $\theta_{67\%}$=5.85°(100 MeV/E)$^{0.534}$







EGRET Allsky Map



Diffuse gamma-ray spectrum

- Flatter than expected ($E^{-2.75}$): why?
  ⇒ Flatter proton/electron spectrum??

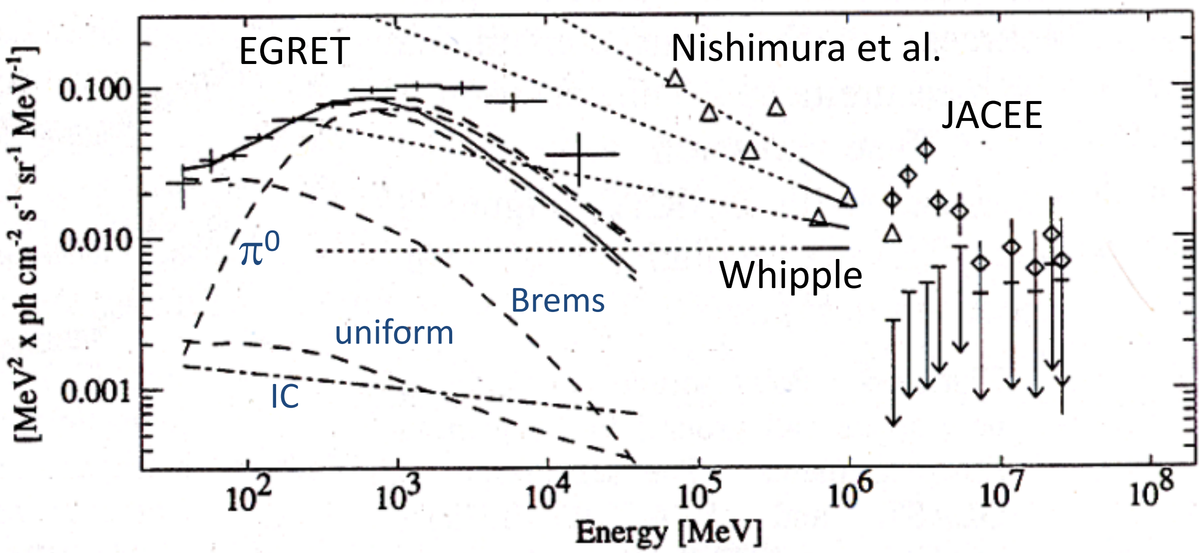
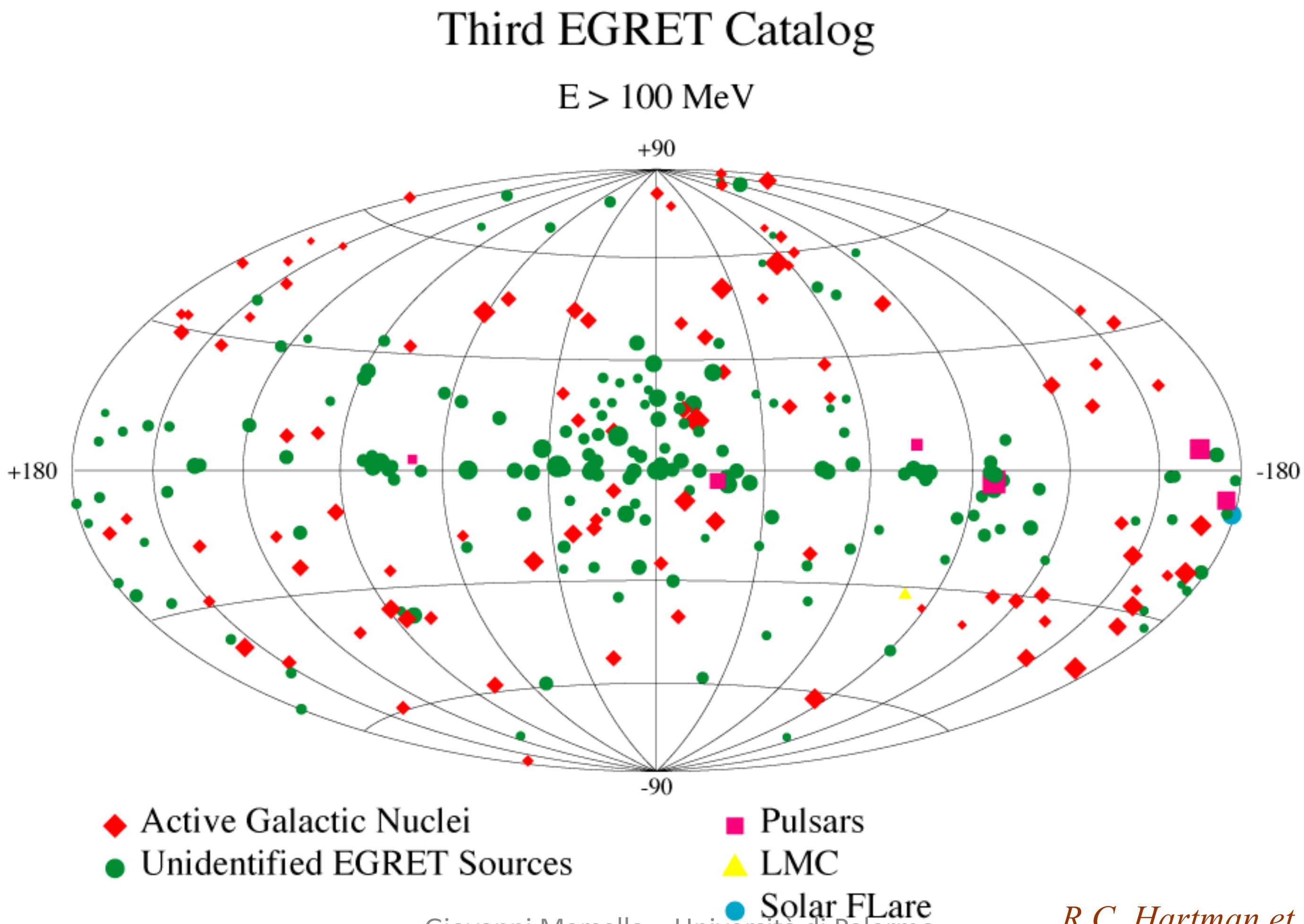


Figure 8. Measurement of the Galactic diffuse emission > 50 GeV with the Whipple telescope [29] extrapolated to the EGRET energy range on the assumption of single power-law spectral indices of 2.0, 2.2, 2.4, and 2.6. The spectral index must be ≤2.4 to be consistent with the EGRET observations, shown as ±1 σ data points. The unpointed balloon results from Nishimura et al. [28] and the JACEE experiment [27], taken at 4 gm/cm^2 and 5.5 gm/cm^2, shown as triangles and diamonds, respectively, should be treated as upper limits. The JACEE results corrected for the atmospheric contribution are shown as upper limits.

S. Hunter, Heidelberg WS, 2000

Third EGRET catalog



R.C. Hartman et al., ApJS, 1999

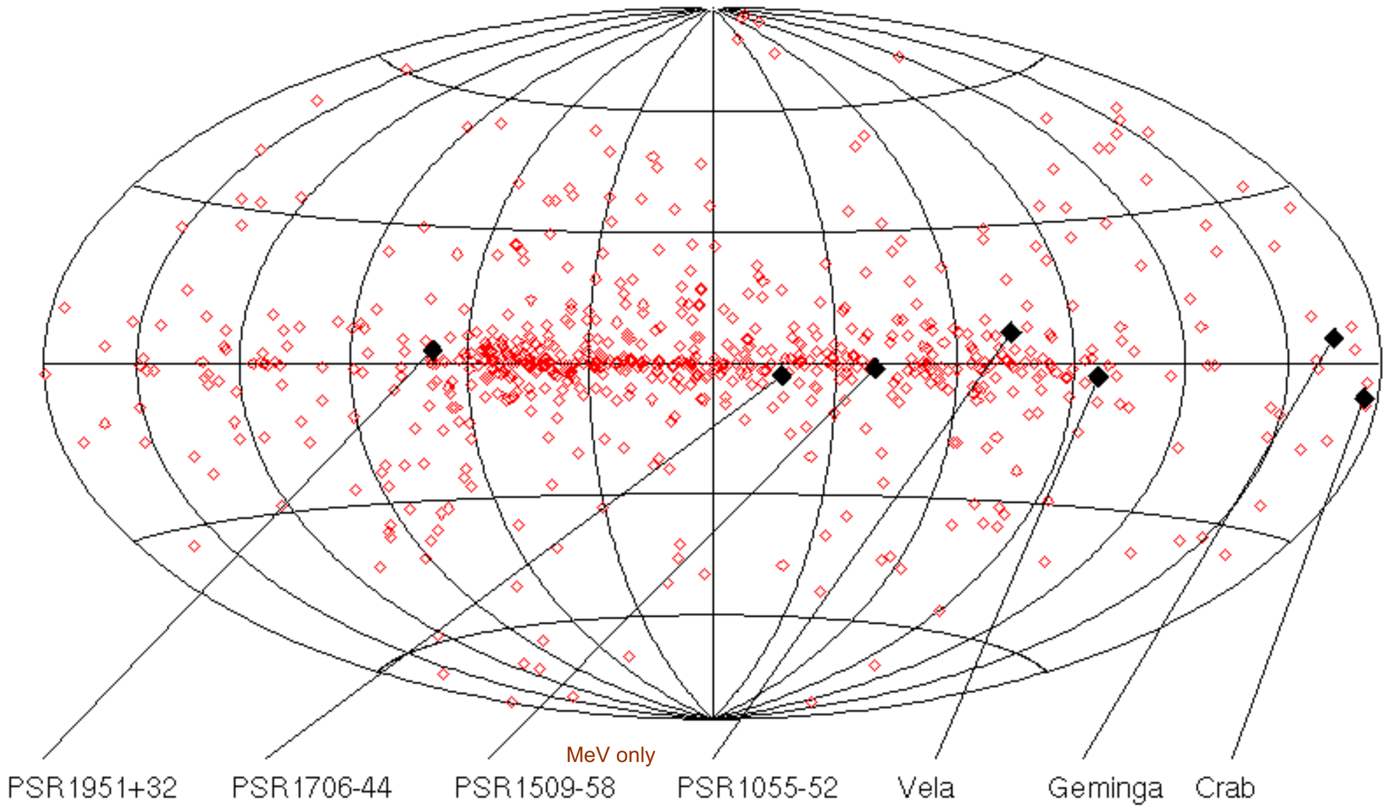
EGRET point source summary

Pulsars	5
AGN (mostly blazars)	66 27 (marginal)
Radio galaxy (Cen A)	1 (marginal)
Unidentified (Some may be SNRs)	170
Large Magellanic Cloud	1
Solar flare	1
Total	*271*

R.C. Hartman et al., ApJS, 1999

Pulsars

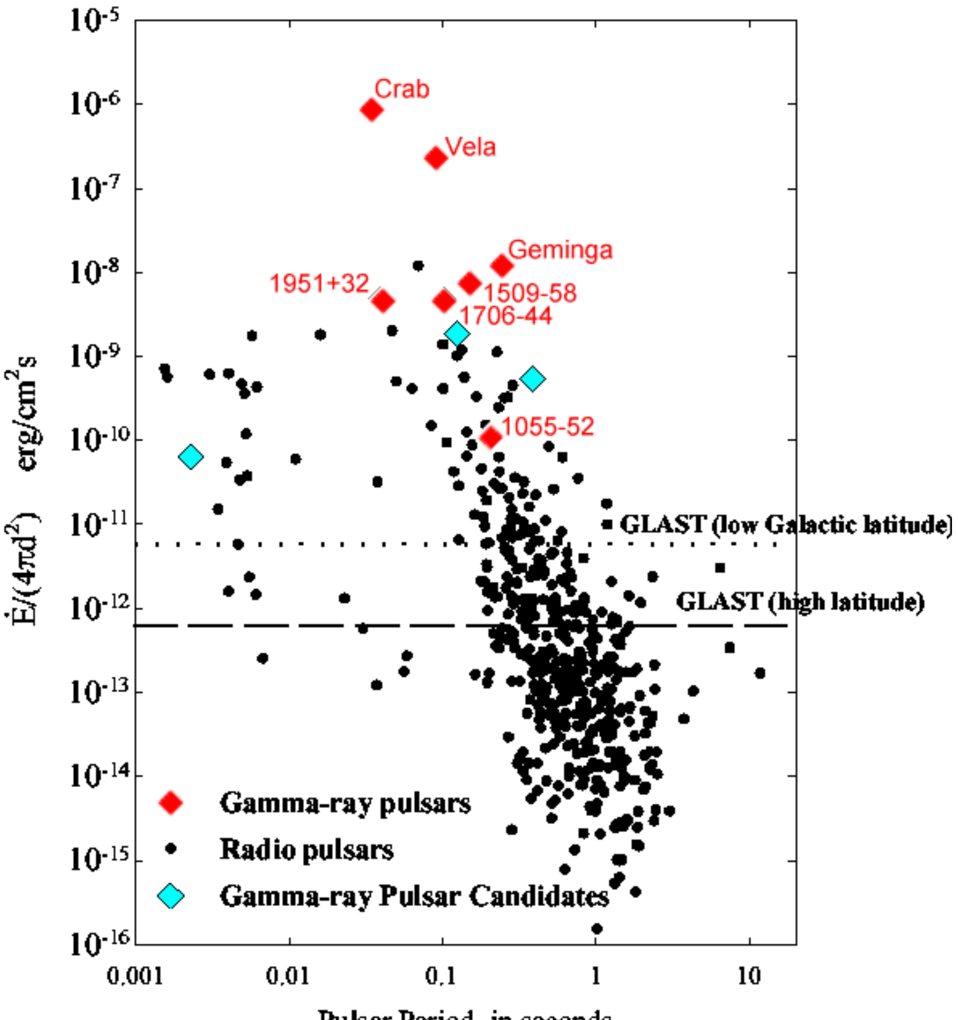
Radio *Princeton catalog (706 pulsars), 1995*

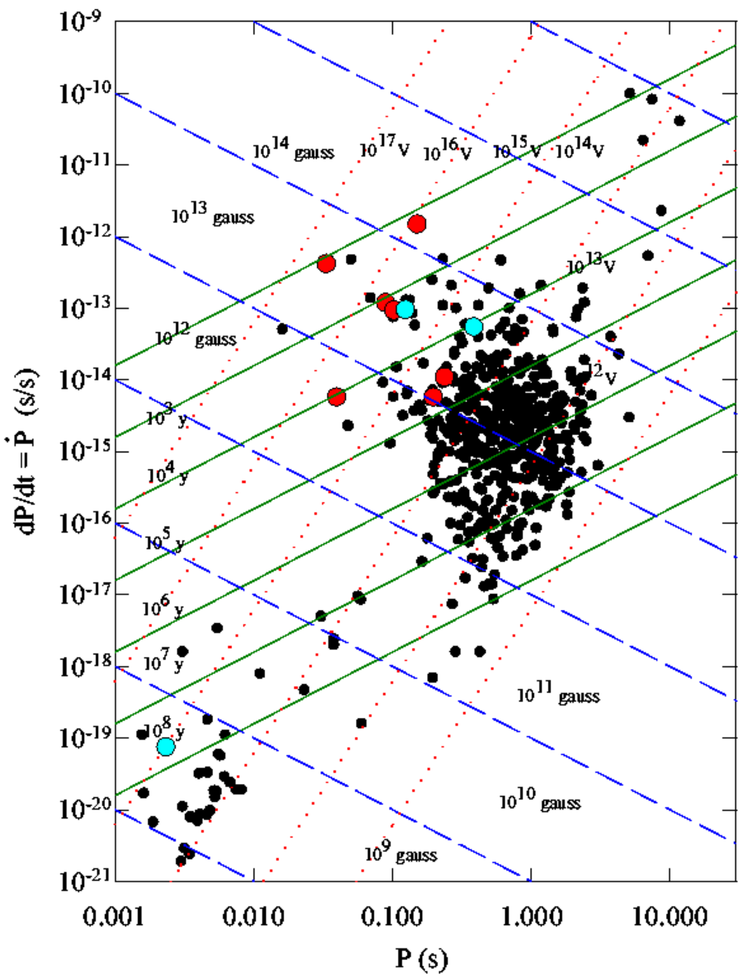


(GeV candidates: 1046-58, 0656+14, J0218+4232)

GeV *Thompson, Heidelberg WS, 2000*

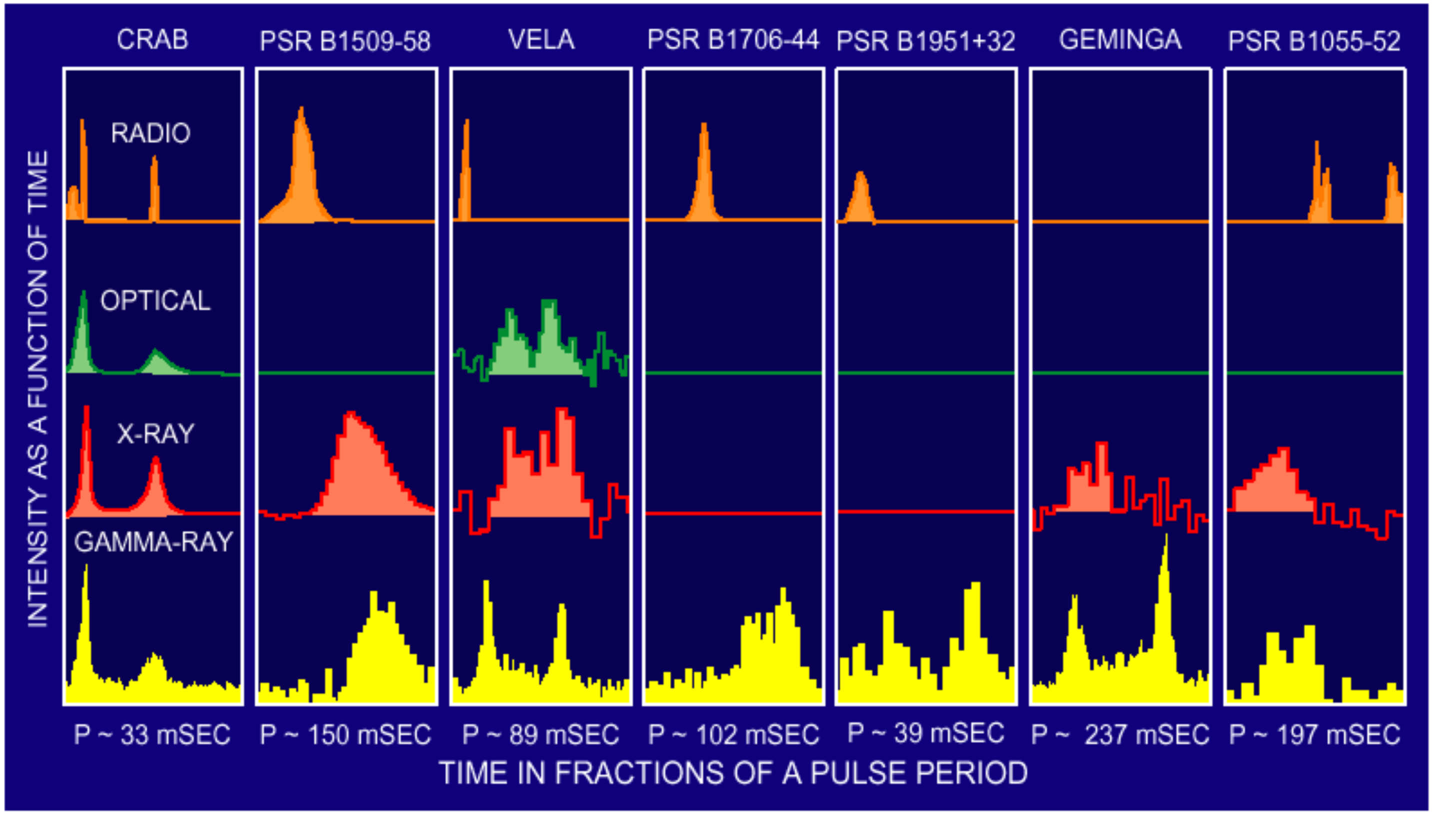
Pulsars : radio vs gamma-ray





Thompson, Heidelberg WS, 2000

Gamma-ray pulsar light curves



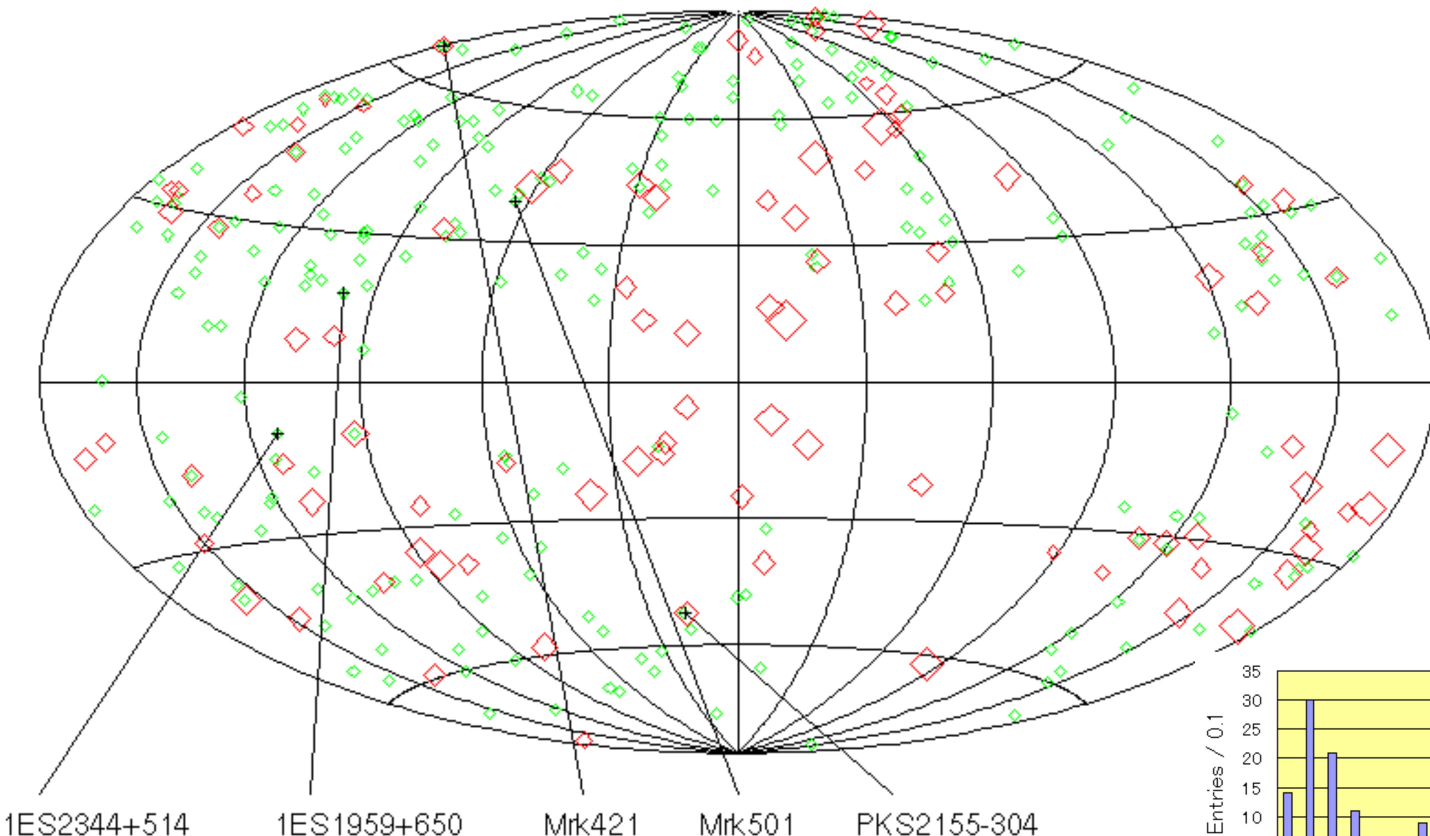
Multiwavelength light curves of the seven pulsars detected with EGRET. A flat line in the radio, optical or X-ray bands means that no such pulsation has been detected. GLAST should provide gamma-ray light curves for several dozen pulsars, which combined with the pulse shapes measured at other energies will severely constrain theoretical models for pulsar emission.

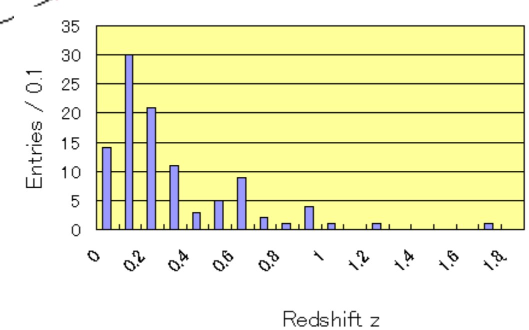
GLAST proposal

BL Lac's and EGRET AGNs

RED *EGRET 3rd catalog AGNs*

Green *Padovani & Giommi MN 1995*





TeV *Whipple, HEGRA, CAT, 7TA, Durham*

Gamma-ray blazars

H(igh freq. peaked) BL
≈ X(-ray selected) BL

L(ow-freq. peaked) BL
≈ R(adio-selected) BL

- Mostly FSRQ and BL Lac's

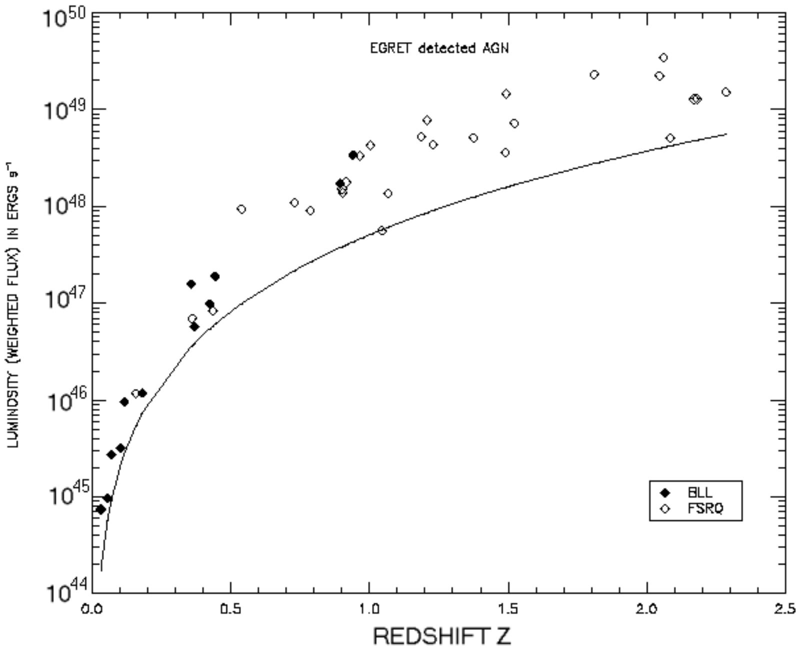


FIG. 7.—Luminosity vs. redshift for blazars detected by EGRET. The BL Lac objects are indicated with filled symbols. The typical detection threshold for EGRET is shown as the solid curve.

Mukherjee et al. ApJ 1997

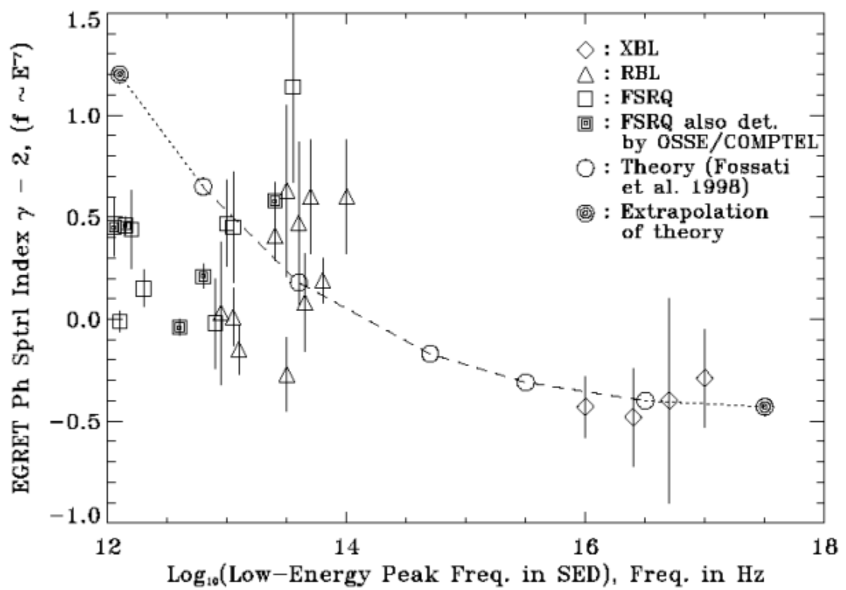
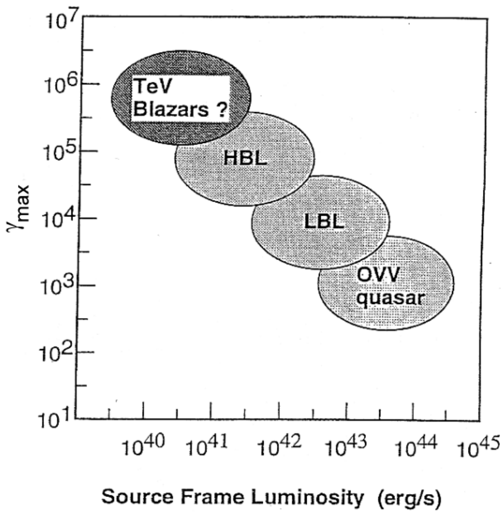


FIG. 1.—EGRET photon spectral index $\gamma - 2$ vs. $\log_{10}$ (low-energy peak frequency in SED) for EGRET-detected blazars.

Lin et al. ApJ 1999

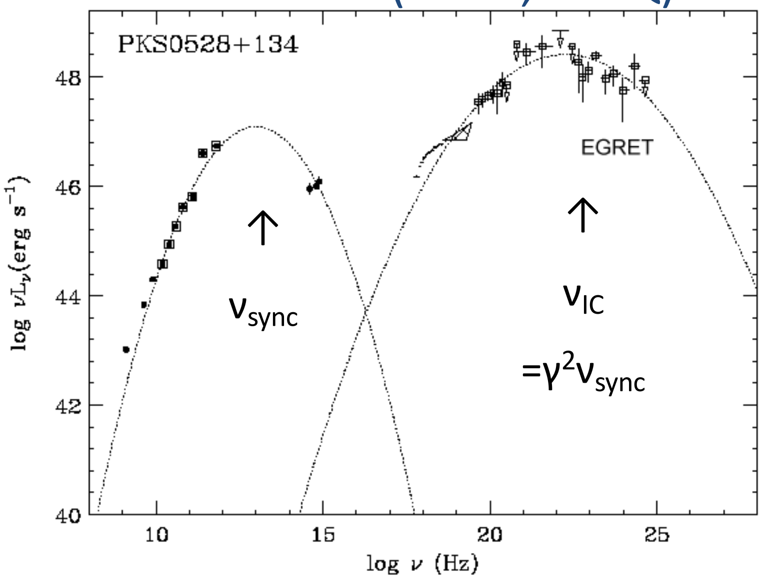
Multiwavelength spectrum of AGNs

- Double-peaked structure
  = synchrotron + inverse Compton

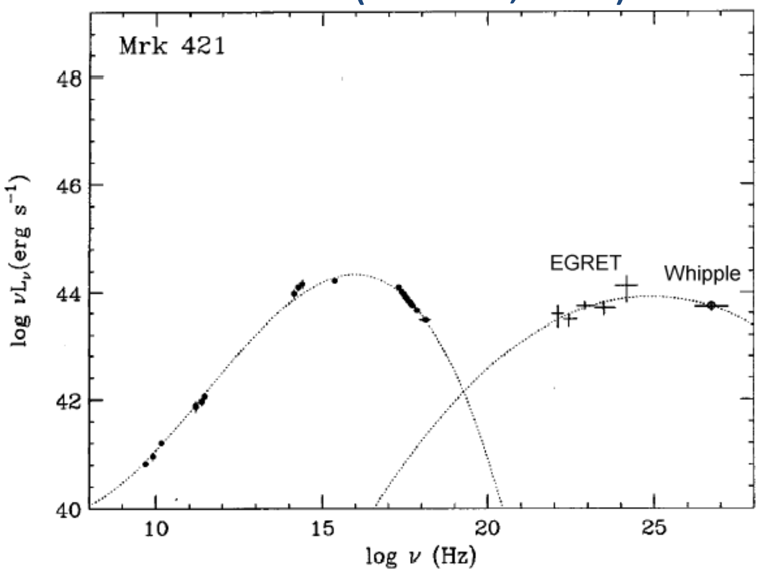


Kataoka, Ph.D 2000

PKS0528+134 (z=2.1, FSRQ)



Mrk 421 (z=0.03, XBL)



Kubo et al. ApJ 1998

EGRET unidentified sources

- Low vs High latitude
- Persistent vs Variable

- Geminga-like pulsars?
- SNRs?
- OB associations?
- Gould belt?

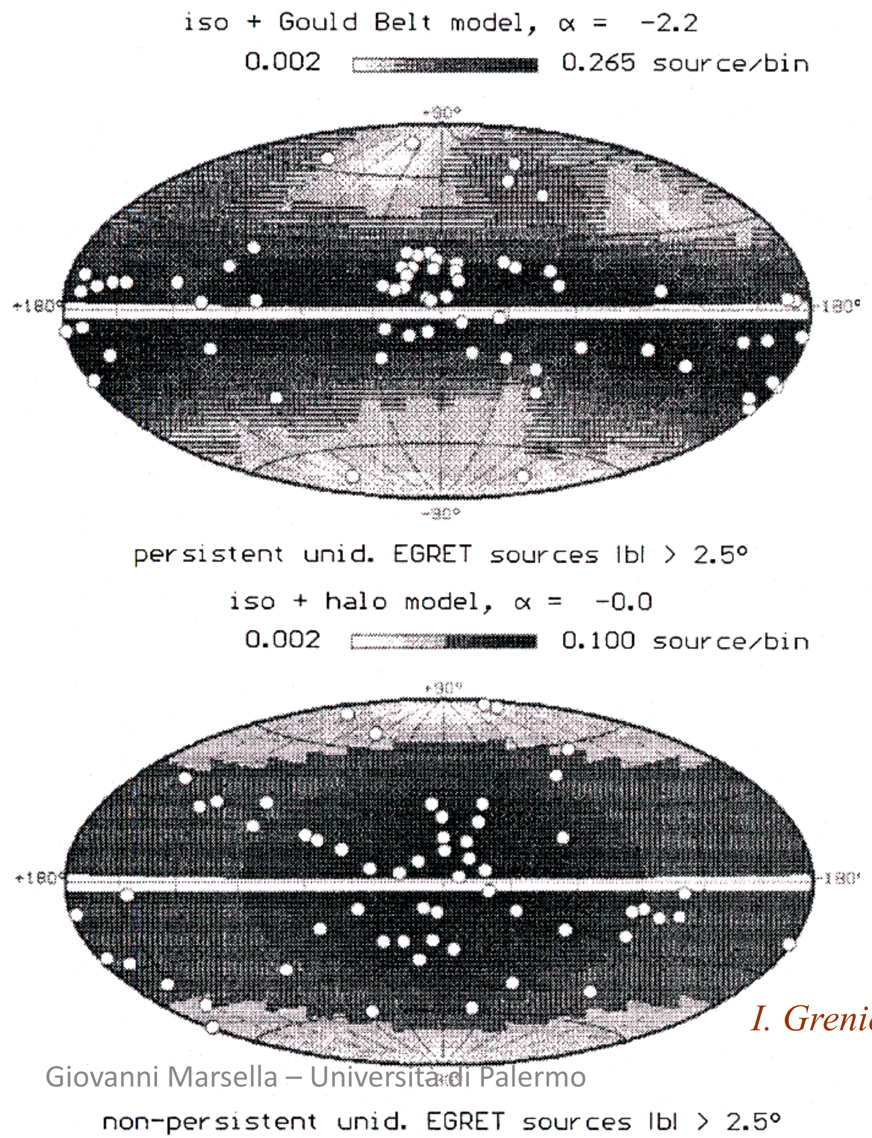


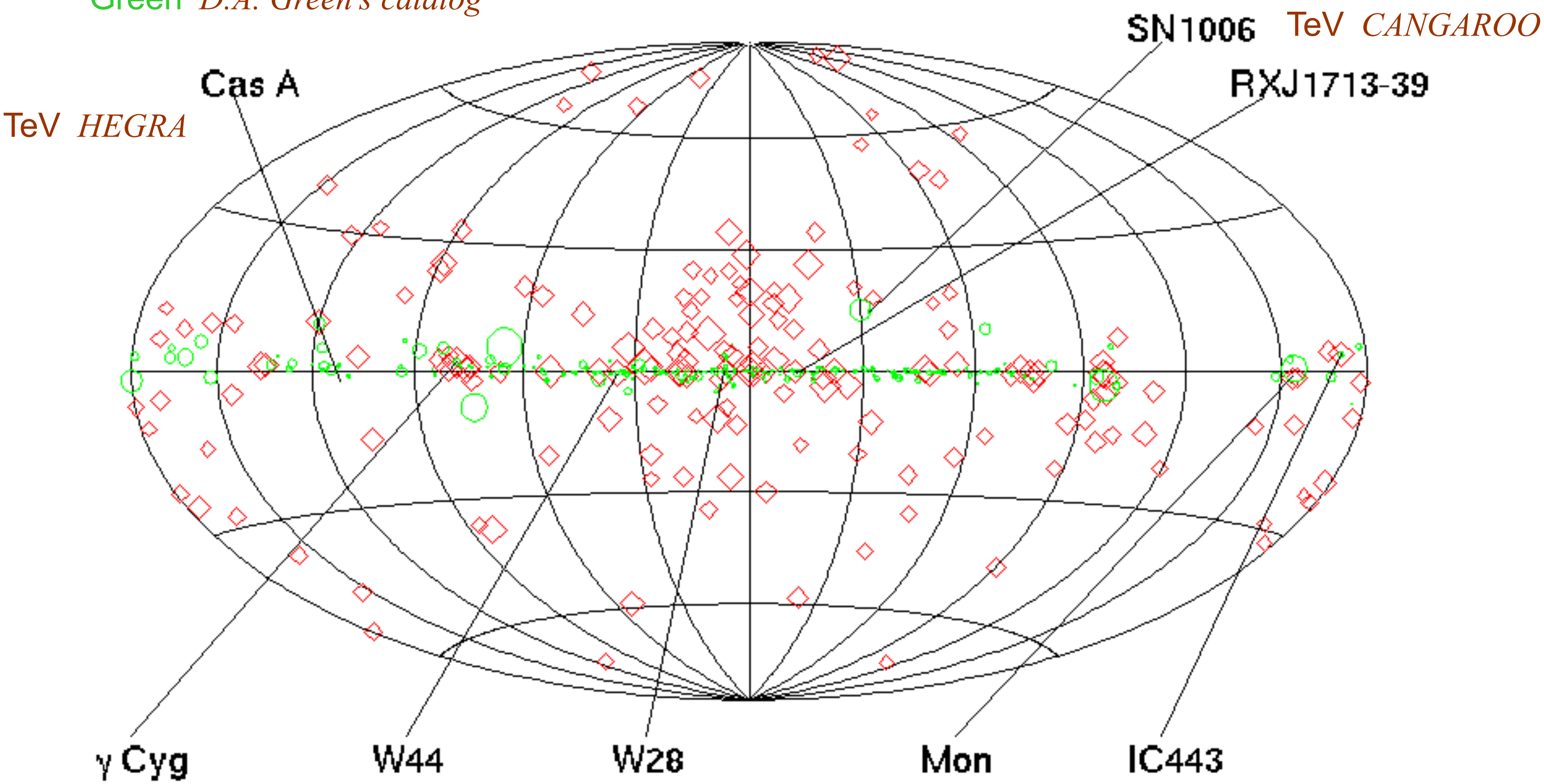
FIGURE 3. (l,b) maps of unidentified EGRET sources (p sources in (a), $\overline{\text{p}}$ sources in (b)) and source counts predicted from a combination of an isotropic distribution and (a) a Gould Belt population as traced by its young massive stars, (b) a homogeneous Galactic halo population, 20 kpc in radius. Predicted counts take into account the non-uniform sensitivity of the survey.

I. Grenier, GeV-TeV WS, 1999

EGRET unIDs and SNRs

RED *EGRET 3rd catalog unID*

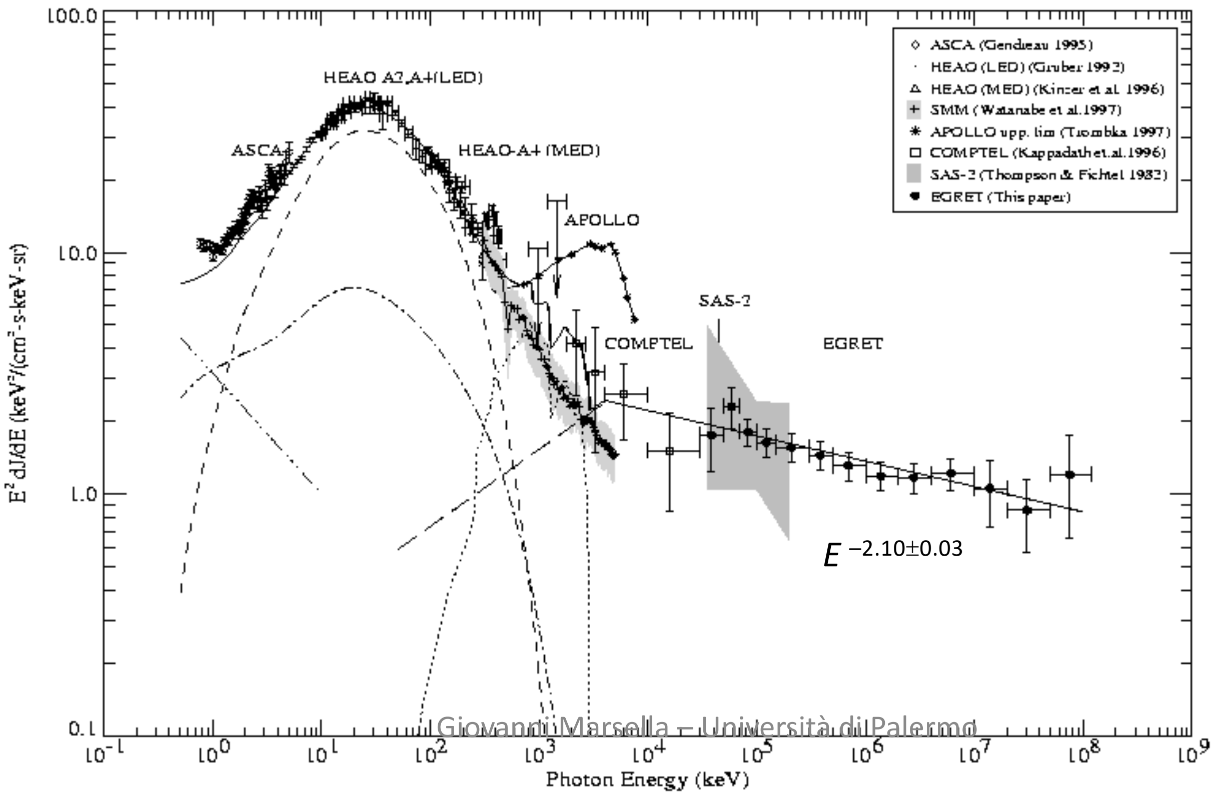
Green *D.A. Green's catalog*



GeV *Esposito et al. ApJ 461, 1996*

Extragalactic diffuse gamma-rays

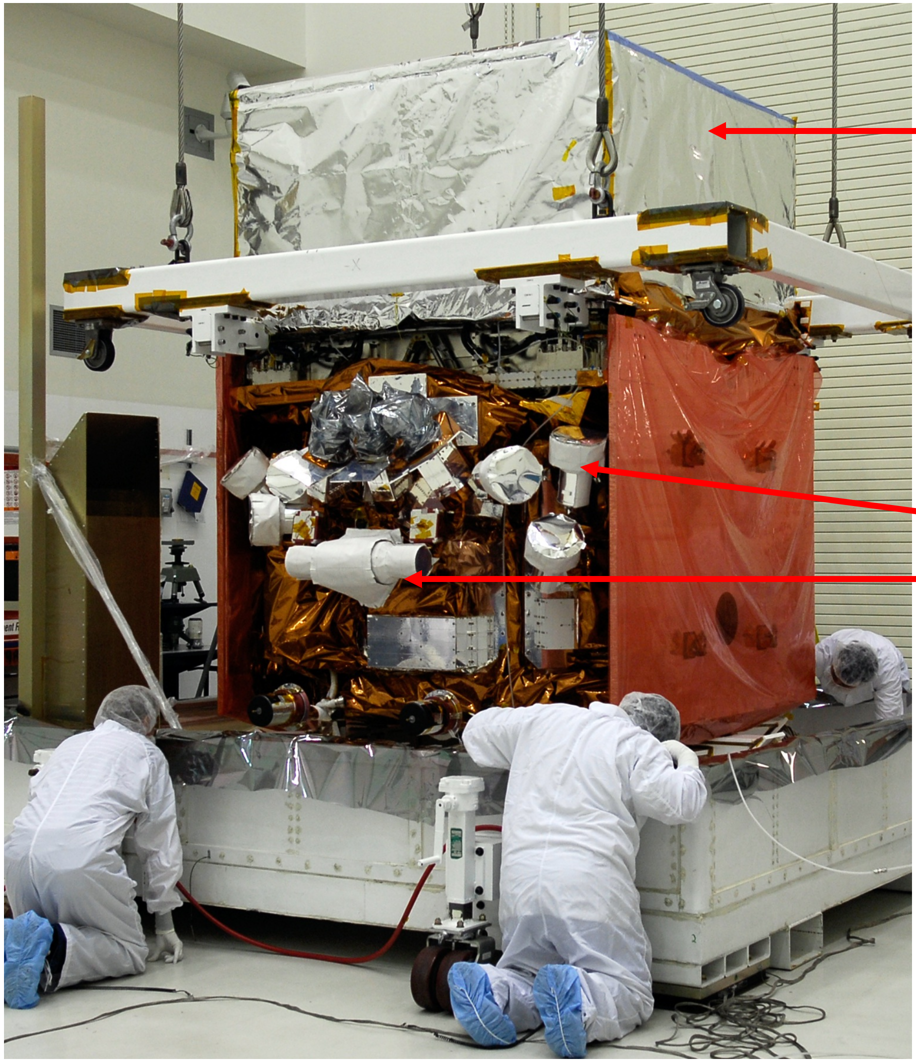
- Single power-law $E^{-2.10\pm0.03}$ (30 MeV-100 GeV)
- Unresolved point sources (ex. Blazars etc.)? Upscattered CMB?



P. Sreekumnar et al., ApJ 1998

- AFTER EGRET

Fermi Gamma-ray SpaceTelescope



Large Area Telescope

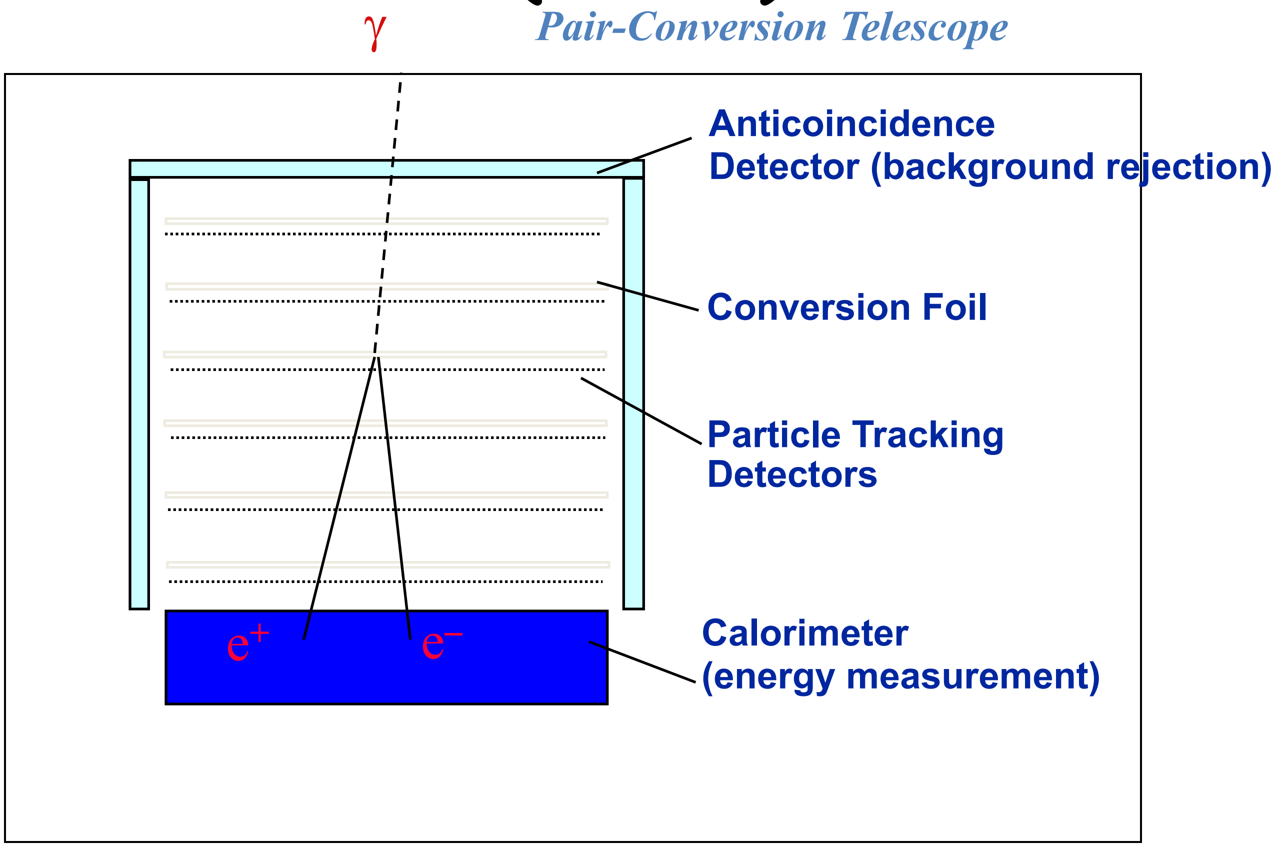
LAT

GLAST Burst Monitor

GBM

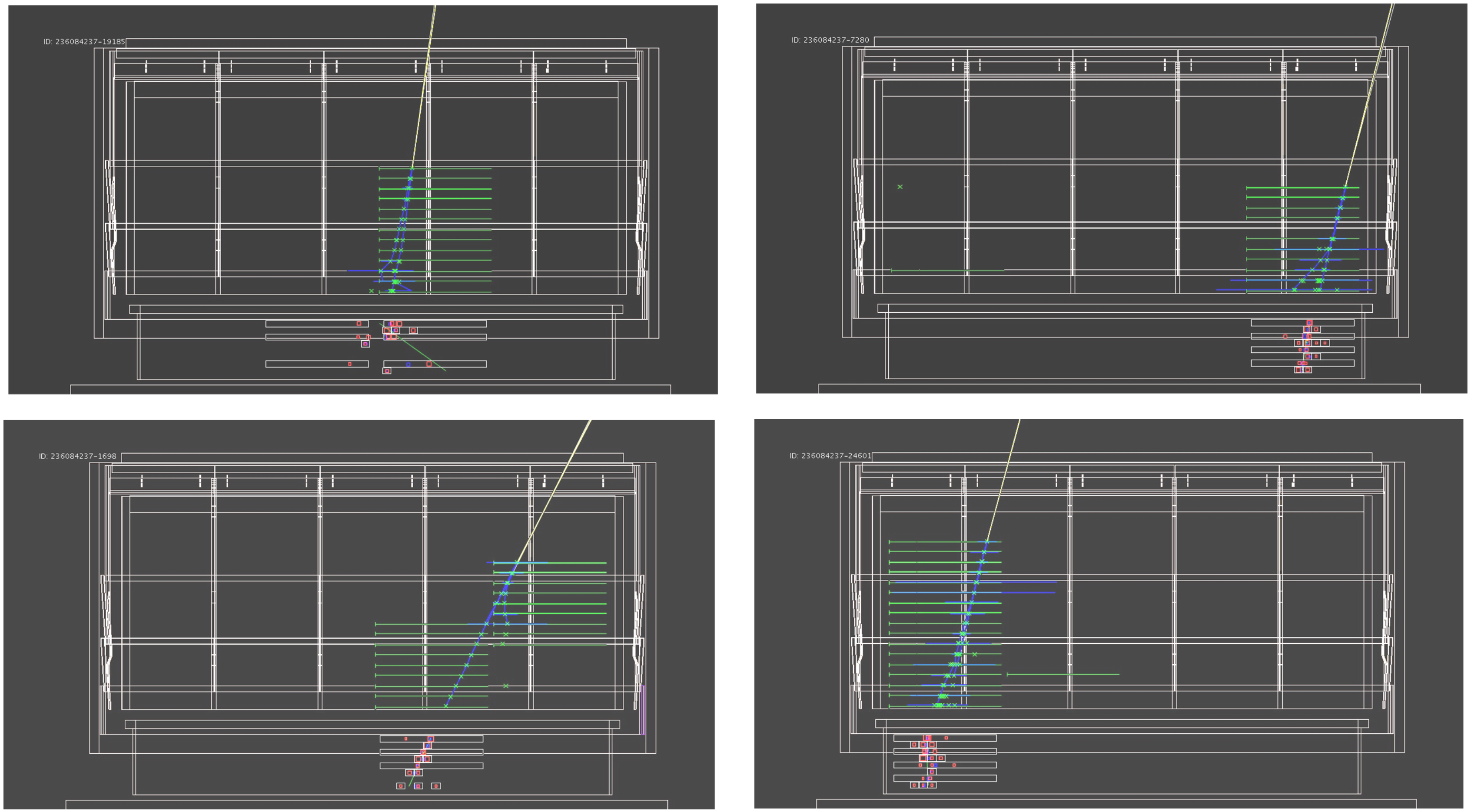
Successors to EGRET and BATSE on the Compton Gamma Ray Observatory

Fermi Large Area Telescope (LAT)



- Gamma rays interact by pair production, the conversion of the gamma-ray energy into two particles – an electron and a positron (really an antiparticle); LAT is a particle detector.

LAT Gamma Candidate Events



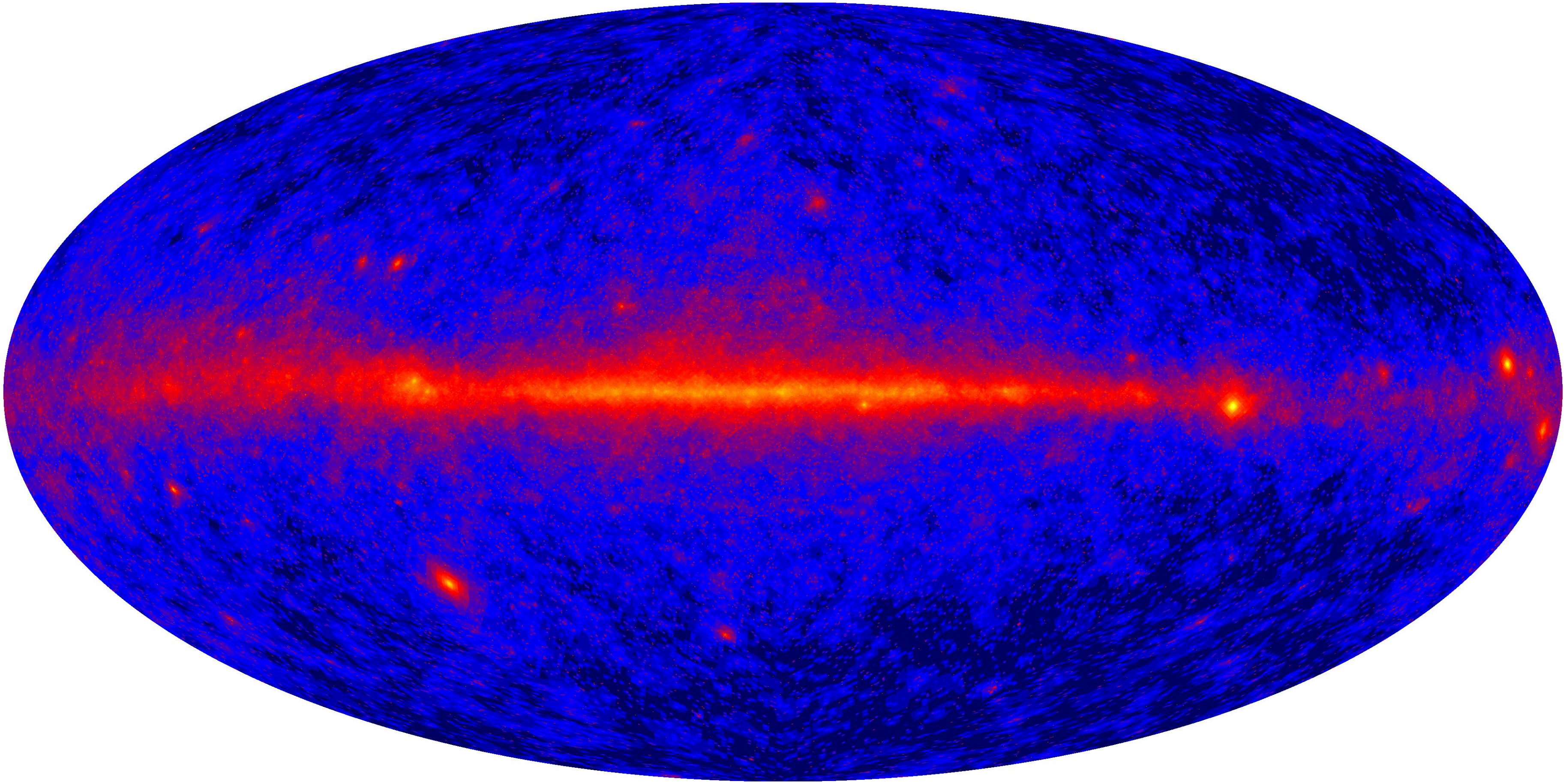
The green crosses show the detected positions of the charged particles, the blue lines show the reconstructed track trajectories, and the yellow line shows the candidate gamma-ray estimated direction. The red crosses show the detected energy depositions in the calorimeter.

What is Fermi seeing?

- A key point - because gamma rays are detected one at a time like particles, the Fermi telescopes do not have high angular resolution like radio, optical or X-ray telescopes. No pretty pictures of individual objects.
- Instead, Fermi trades resolution for field of view. The LAT field of view is 2.4 steradians (about 20% of the sky), and the GBM field of view is over 8 steradians.
- The Fermi satellite is operated in a scanning mode, always looking away from the Earth.
- The combination of huge field of view and scanning means that the LAT and GBM view the entire sky every three hours!

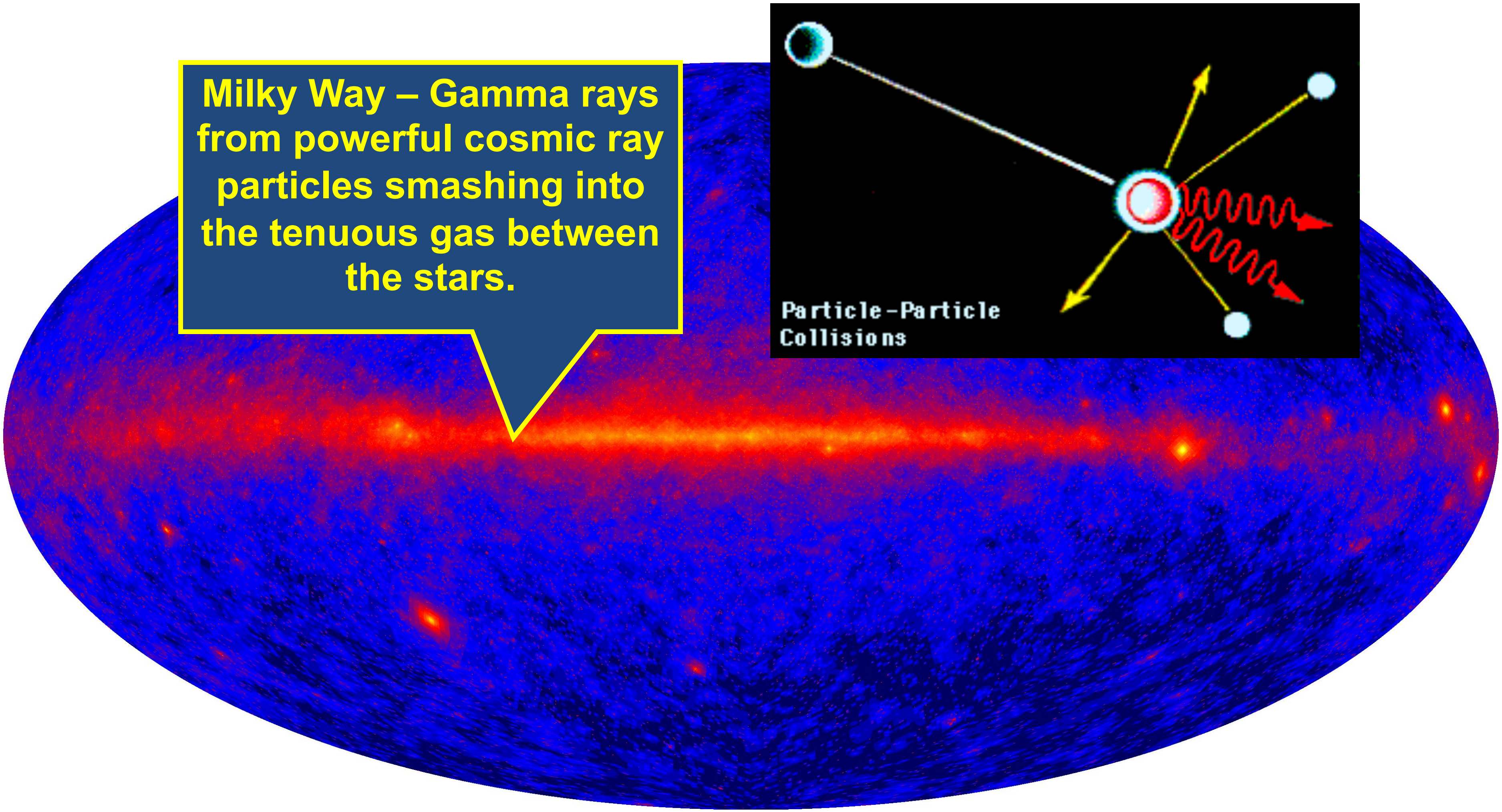
Large Area Telescope First Light!

The full gamma-ray sky projected onto a surface - Galactic coordinates



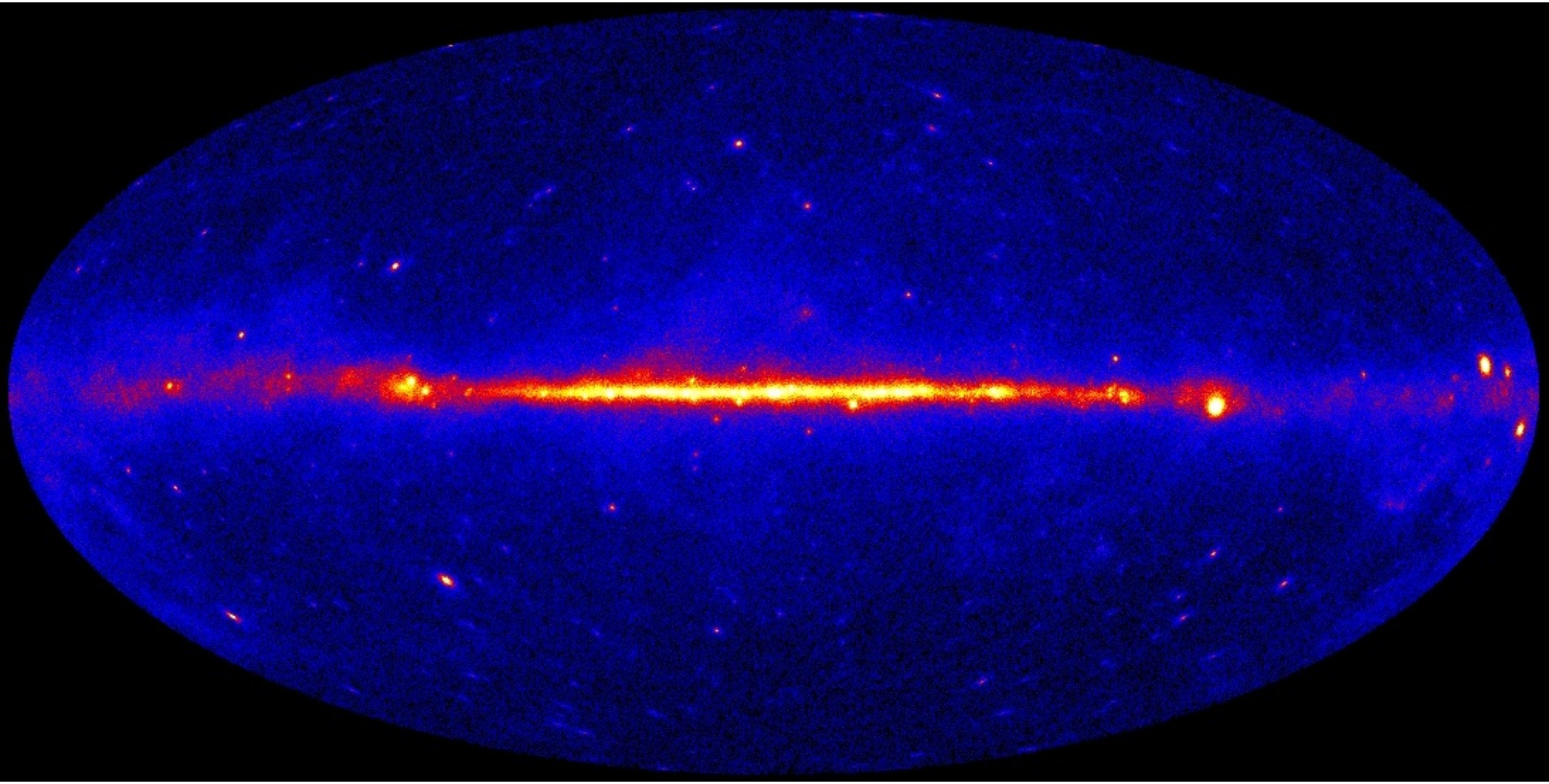
The Fermi Large Area Telescope sees the whole gamma-ray sky every three hours. This is an important feature, because the high-energy sky is constantly changing. This image represents just four days of observations.

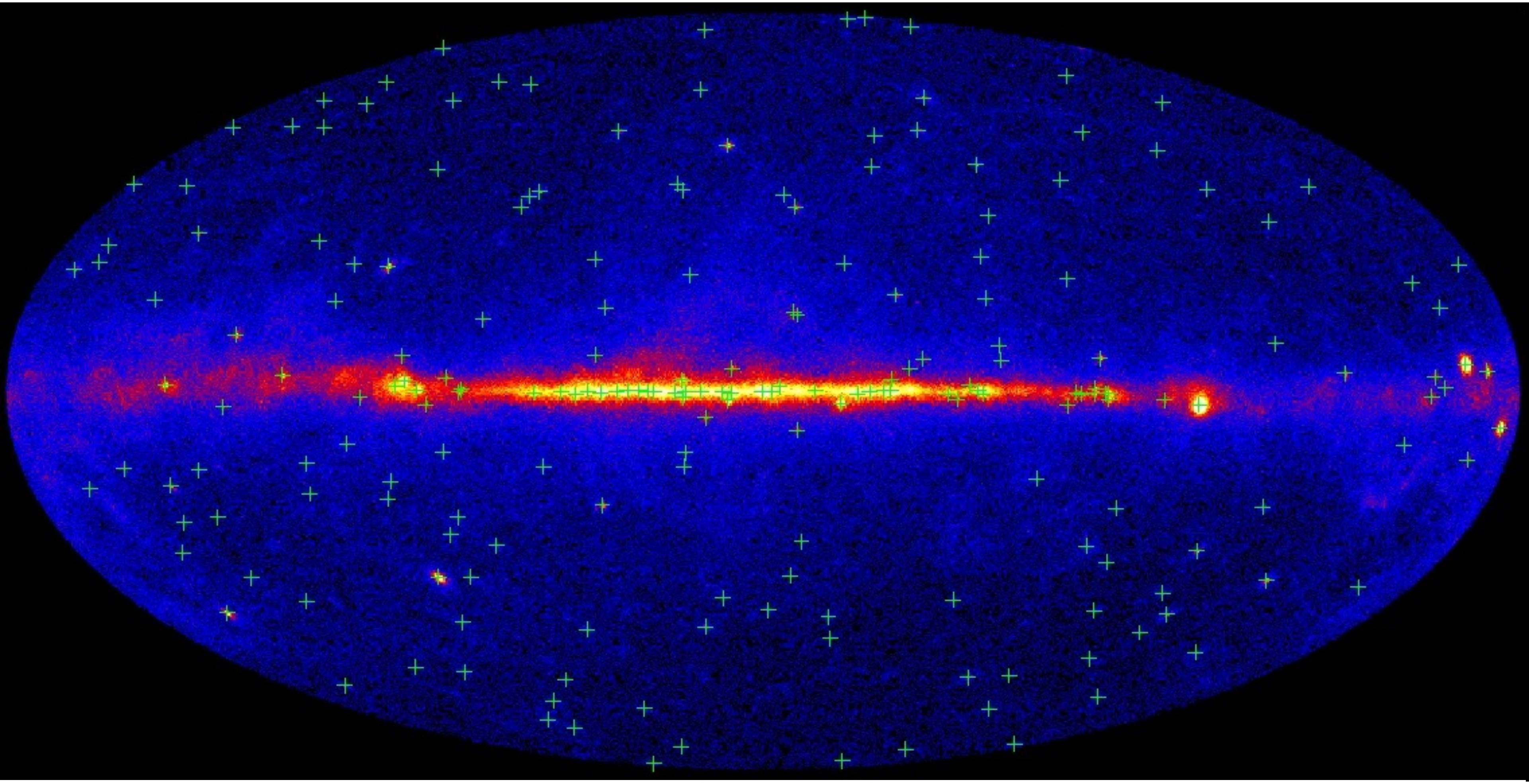
What is going on in the gamma-ray sky?



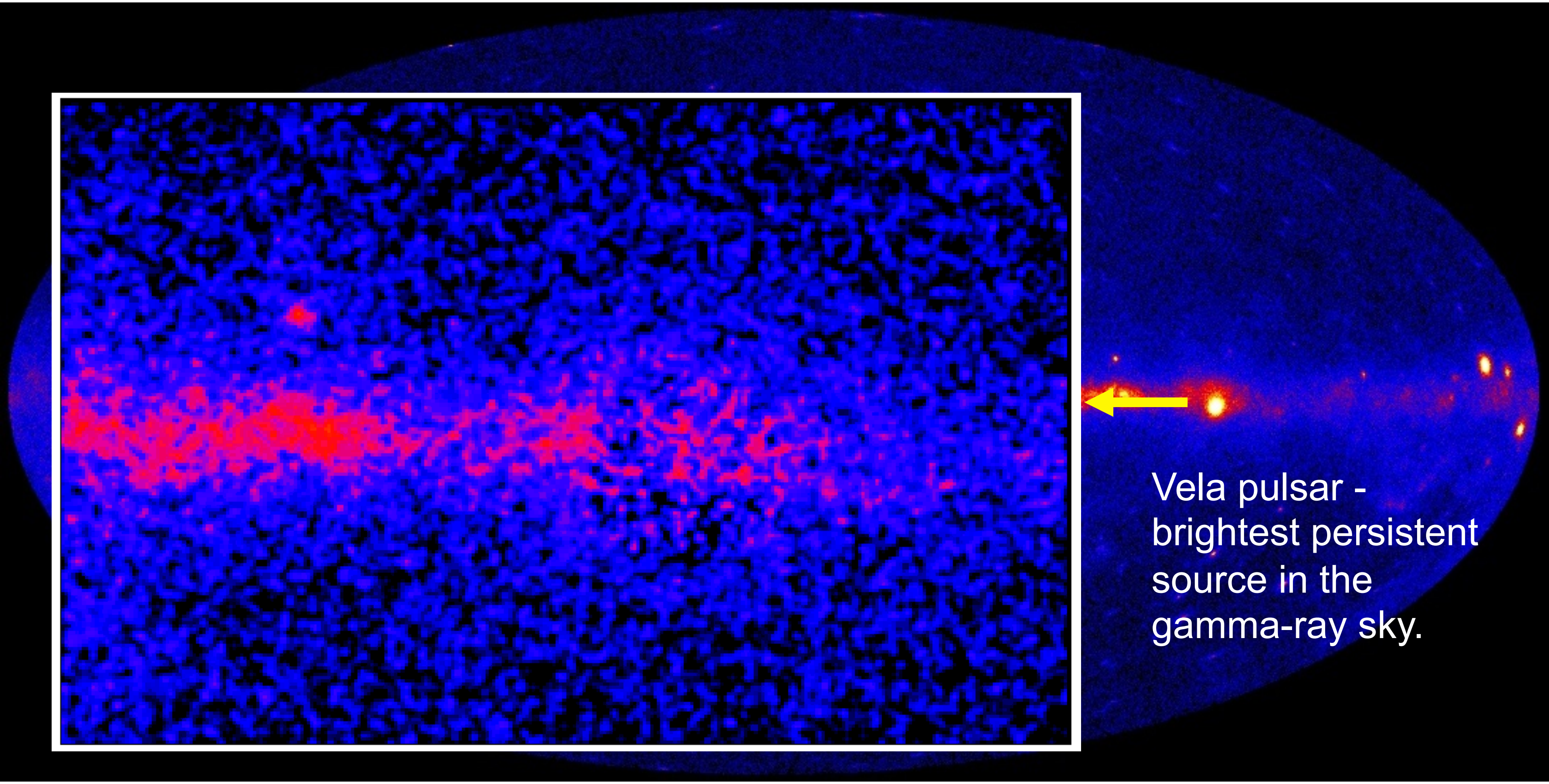
Milky Way – Gamma rays from powerful cosmic ray particles smashing into the tenuous gas between the stars.

Three months of LAT scanning data

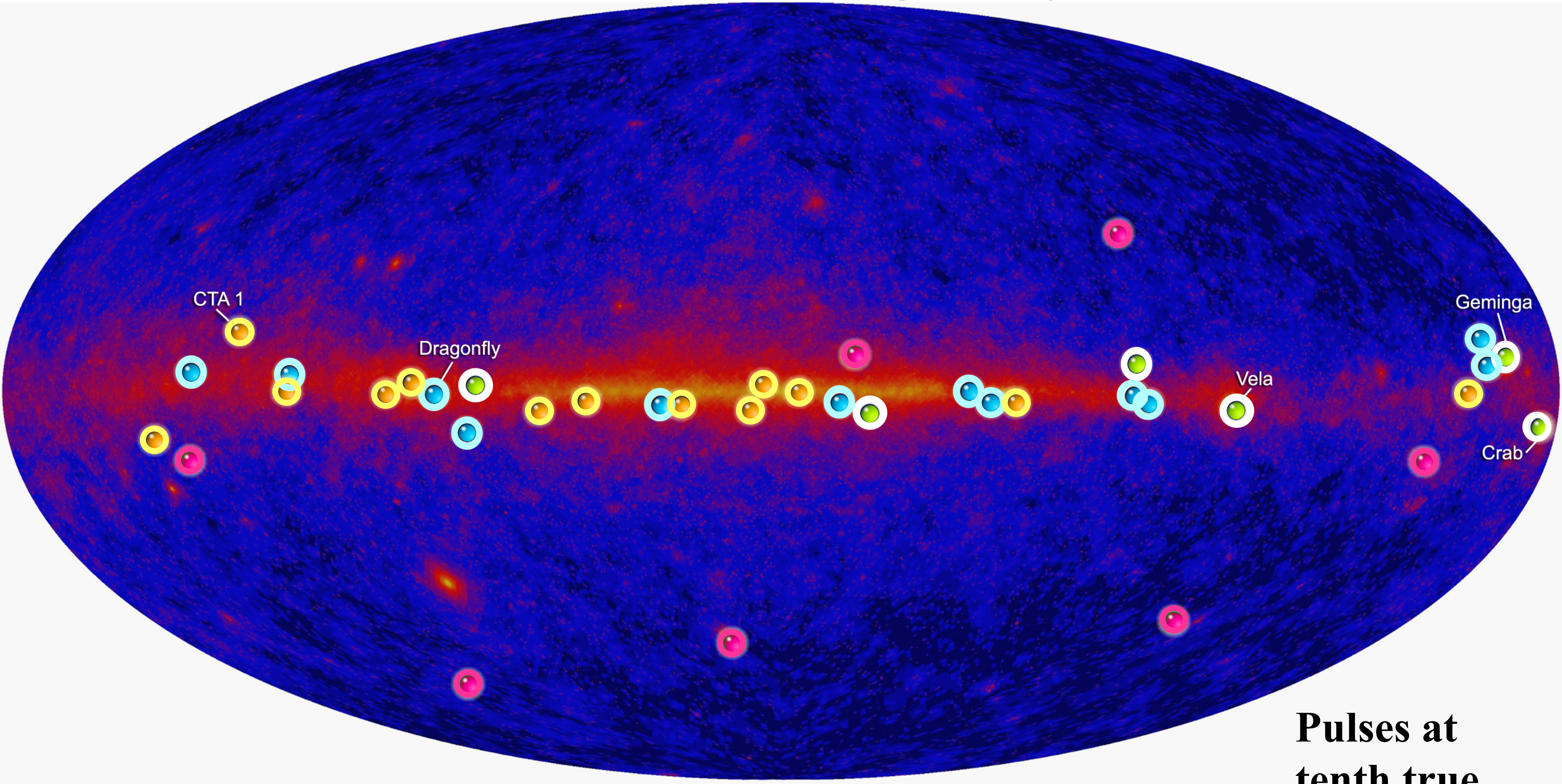




Pulsars - rapidly rotating neutron stars



The Pulsing Sky

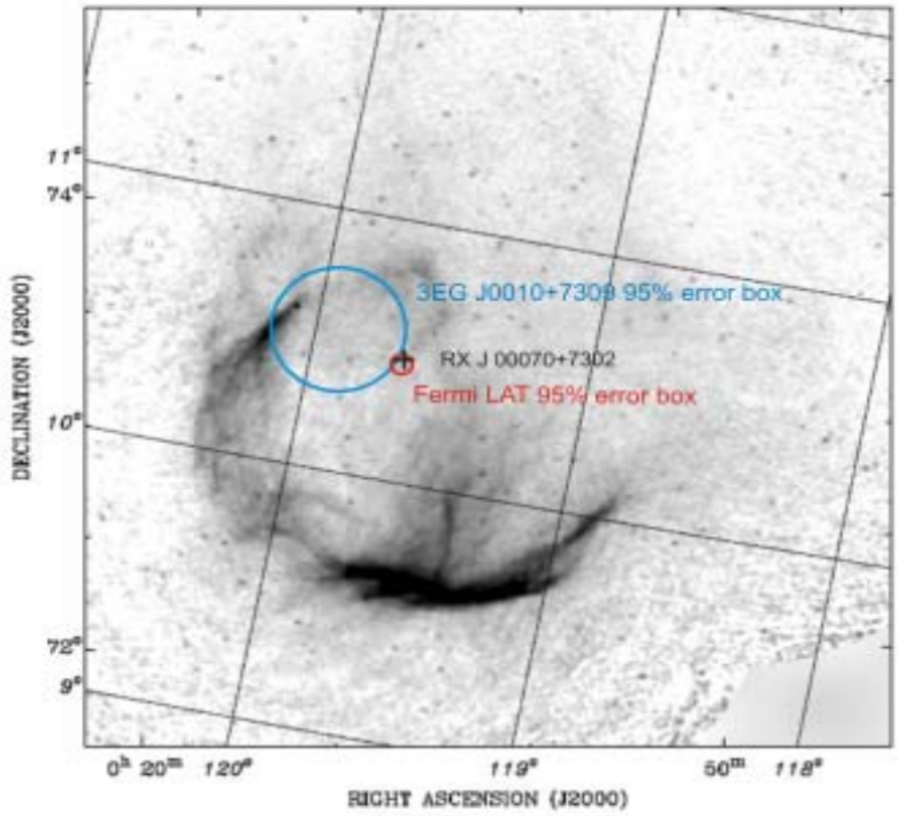


Pulses at tenth true rate

Fermi Pulsar Detections

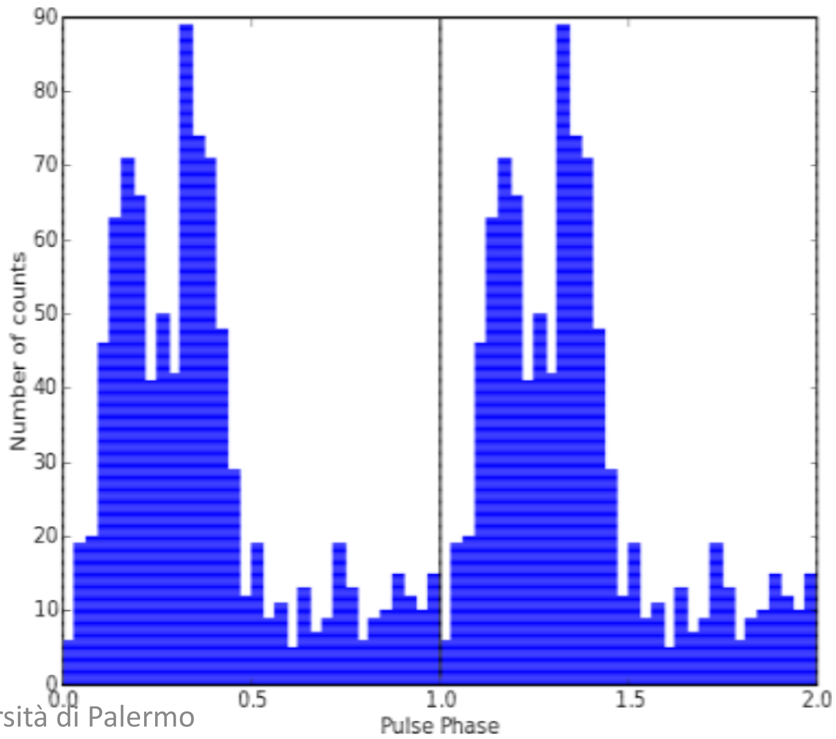
- New pulsars discovered in a blind search
- Millisecond radio pulsars
- Young radio pulsars
- Confirmed pulsars seen by Compton Observatory EGRET instrument

LAT discovers a radio-quiet pulsar!



13 pulsars have now been found in blind searches of LAT data.

P ~ 317 ms
Pdot ~ 3.6E-13
Characteristic age ~ 10,000 yrs

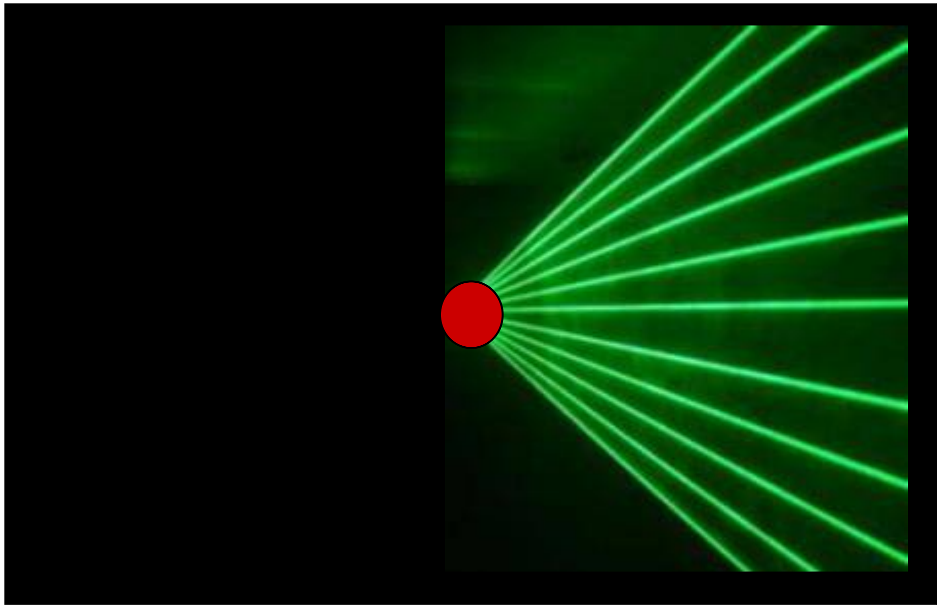


Location of EGRET source 3EG J0010+7309, the Fermi-LAT source, and the central X-ray source RX J0007.0+7303

Gamma-only Pulsars: Beamshape

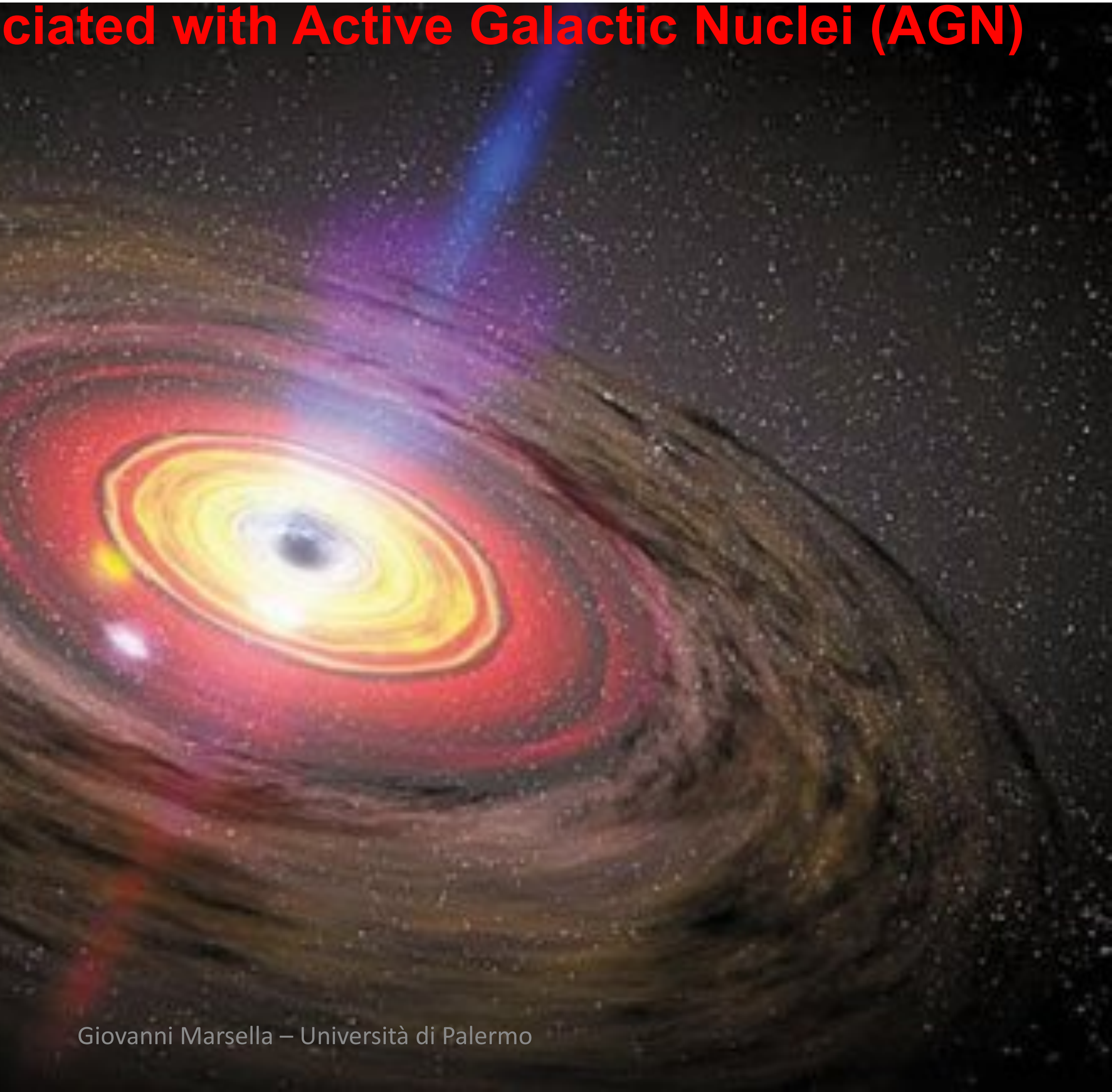
Traditional 'Lighthouse' Beam

Wide 'Fan beam'



Gamma-ray-only pulsars open a new window on these exotic and powerful objects, helping us learn how they work and how they influence our Galaxy.

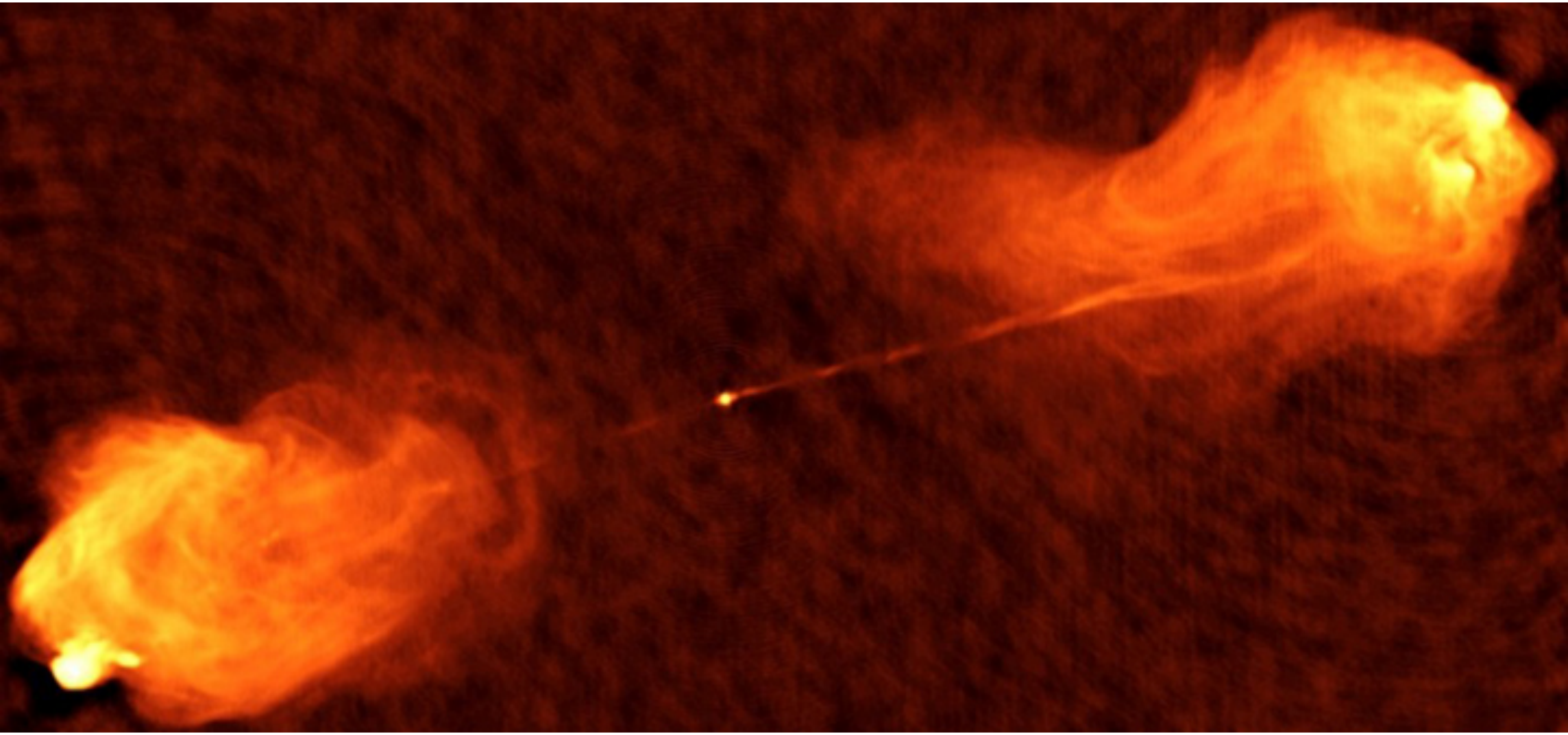
Over half the bright sources seen with LAT appear to be associated with Active Galactic Nuclei (AGN)



- Power comes from material falling toward a supermassive black hole
- Some of this energy fuels a jet of high-energy particles that travel at nearly the speed of light

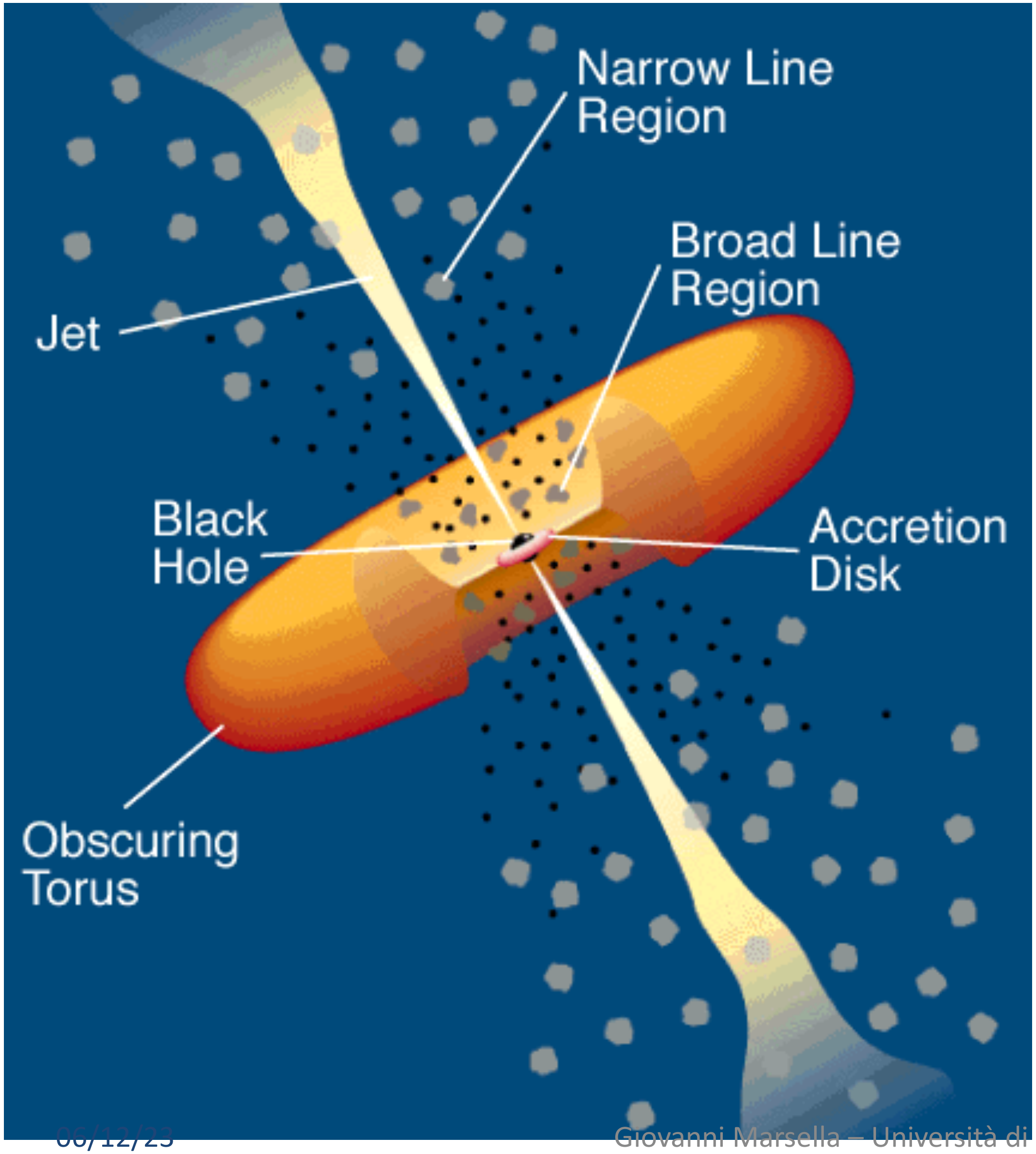
How are the jets produced?

What keeps them tightly collimated over hundreds of thousands of light-years?



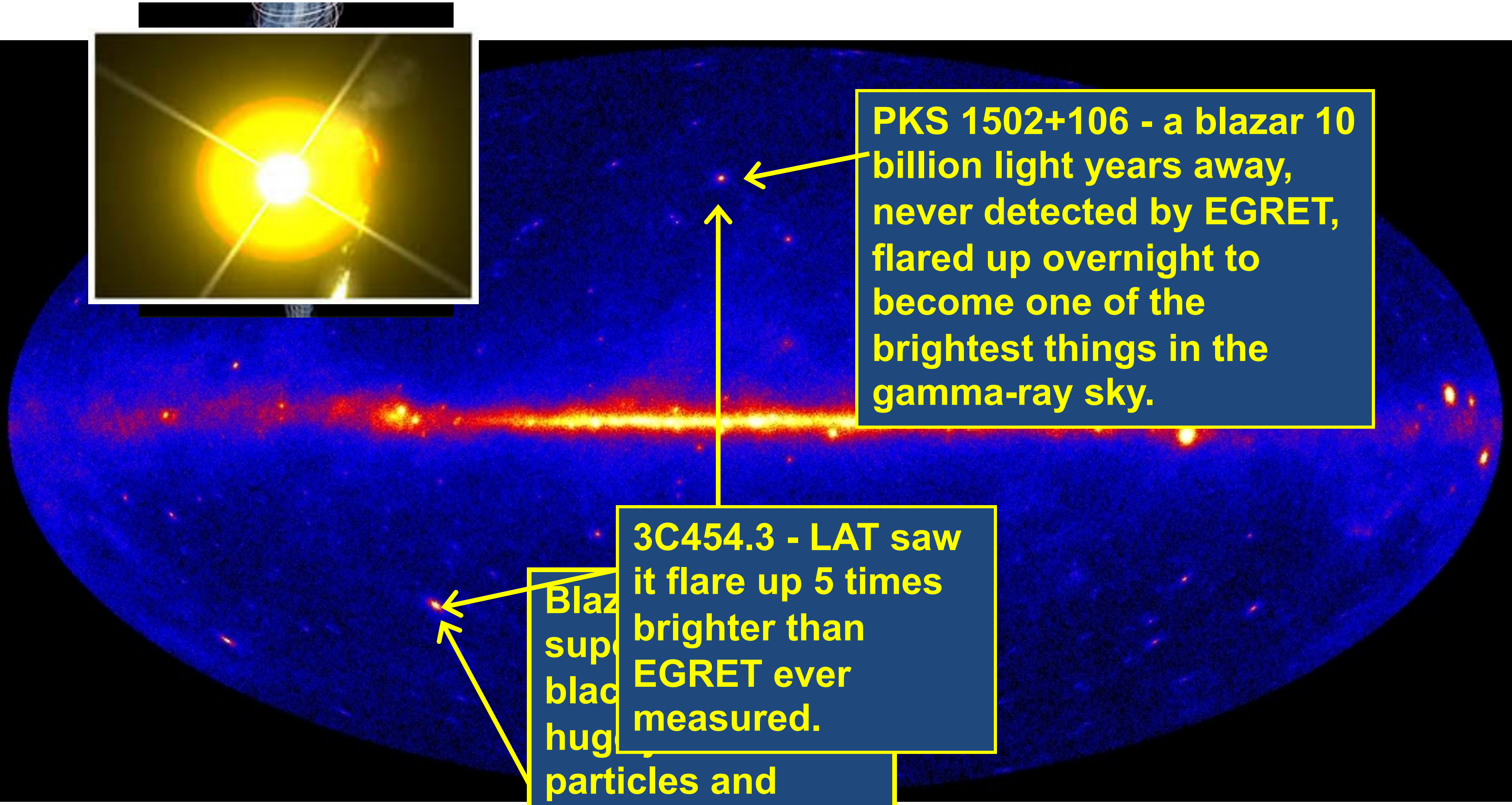
Radio image of Cygnus A

AGN

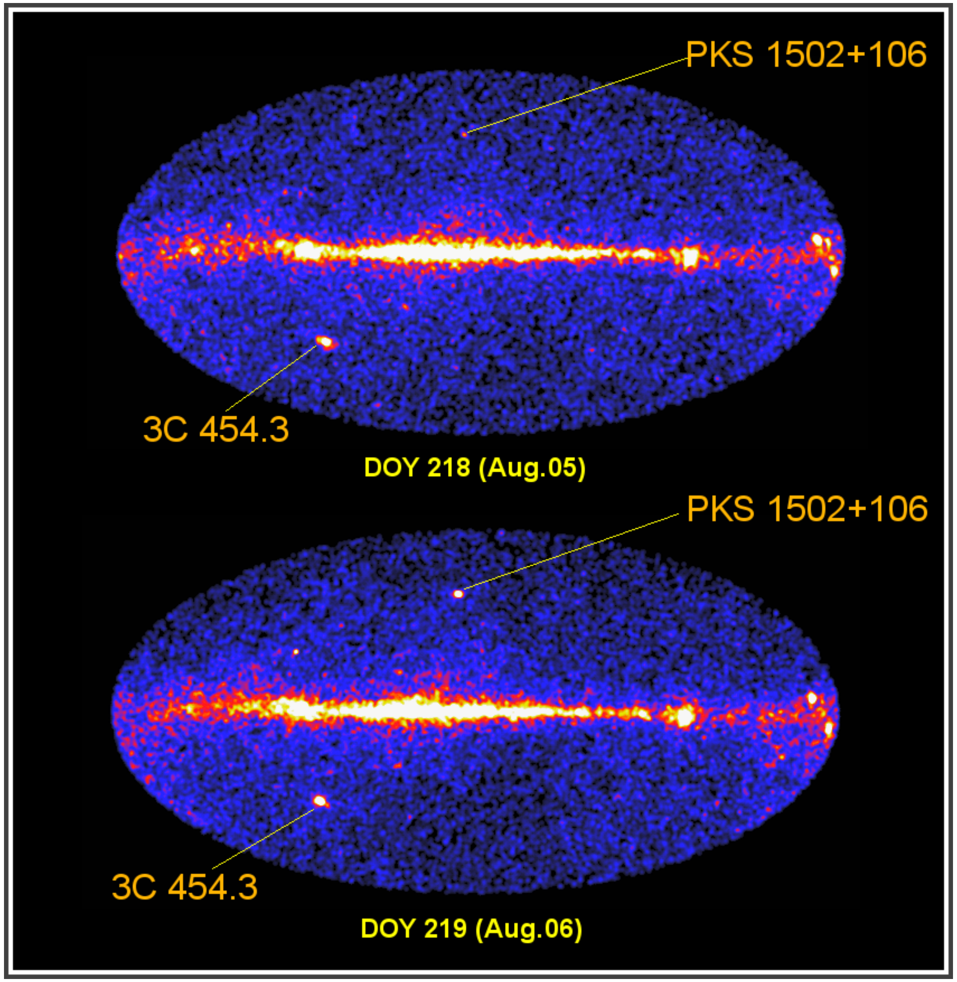


- **Unified models of AGN suggest that different types of AGN are really defined by how we see them.**
- **When such jets are pointed at Earth, we see what is called a *blazar***
- **Gamma rays are an important way to learn how these jets operate**

Gamma rays from blazars

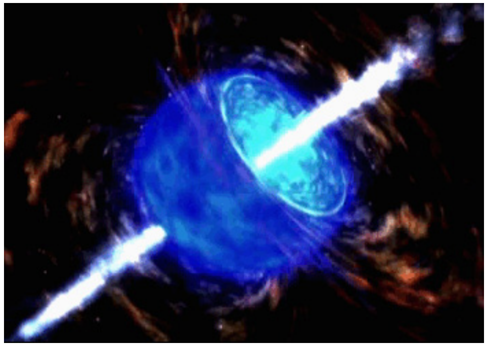


Flaring sources

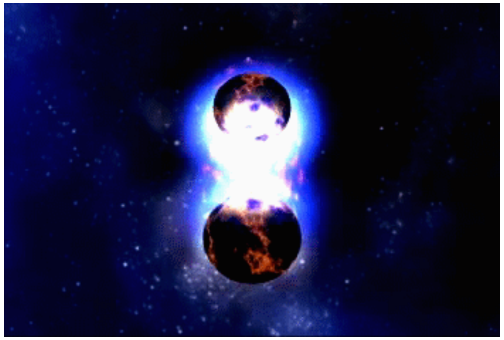


- Automated search for flaring sources on 6 hour, 1 day and 1 week timescales.
- 13 Astronomers telegrams
  - Discovery of new gamma-ray blazars PKS 1502+106, PKS 1454-354
  - Flares from known gamma-ray blazars: 3C454.3, PKS 1510-089,3C273, AO 0235+164, PSK 0208-512, 3C66A, PKS 0537-441, 3C279
  - Galactic plane transients: J0910-5041, 3EG J0903-3531

Gamma-ray bursts come in at least three flavors

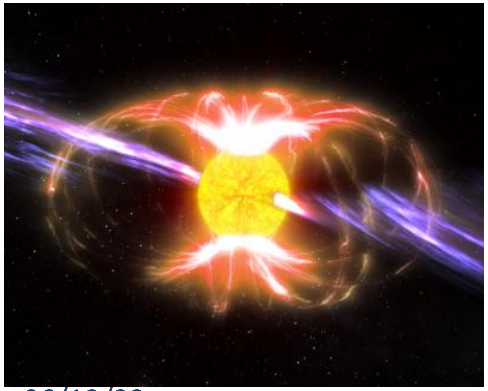


Collapsars: A rapidly spinning stellar core collapses and produces a supernova, along with relativistic jets that can produce long GRBs



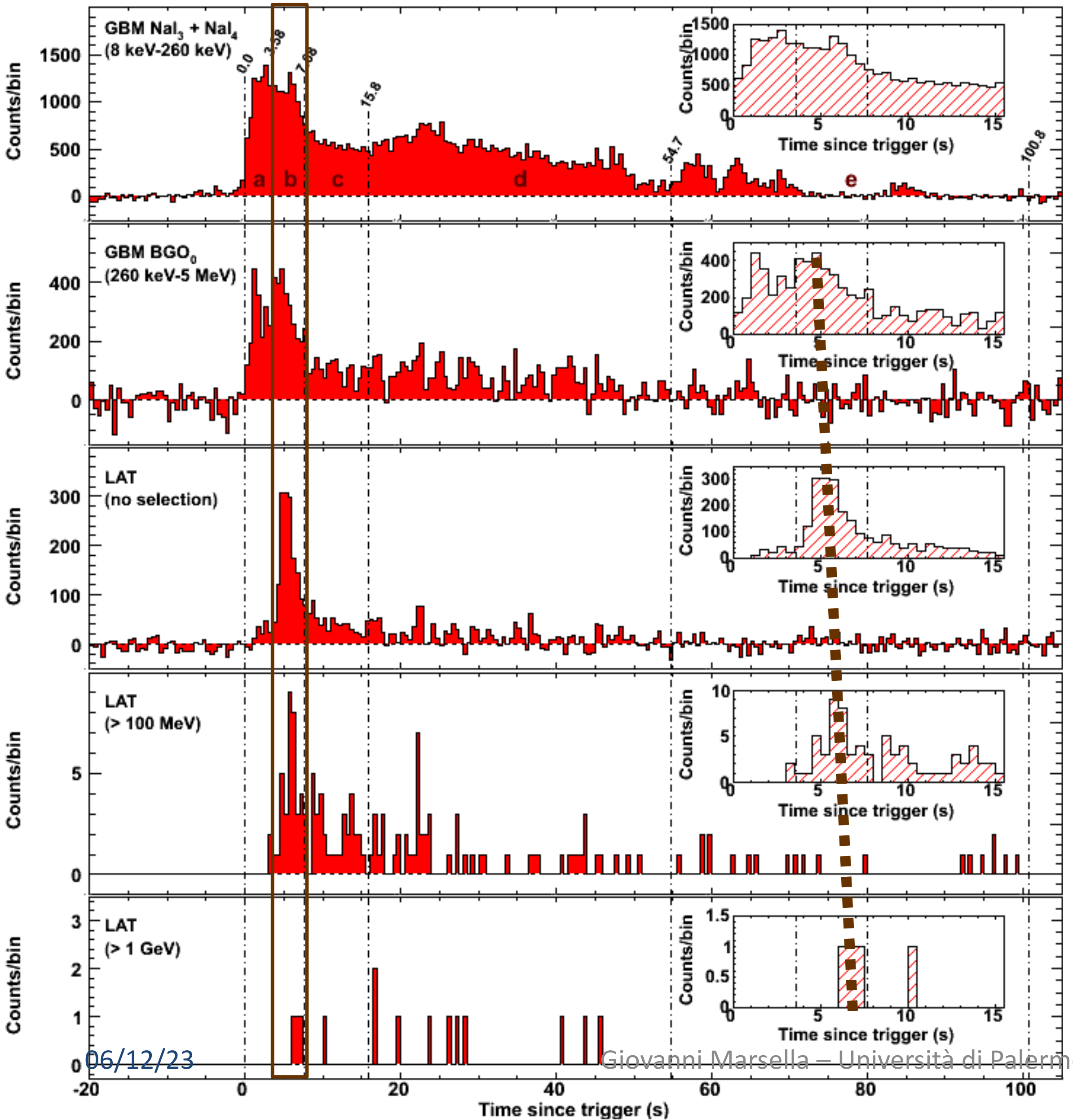
Compact Mergers: Two neutron stars, or a neutron star and a black hole, collide and merge, producing a jet that gives rise to a short GRB

In both these cases, the burst probably produces a black hole.



Magnetars: Neutron stars in our Galaxy or nearby galaxies with extremely strong magnetic fields can give off powerful bursts that resemble short GRBs

Multiple detector light curve



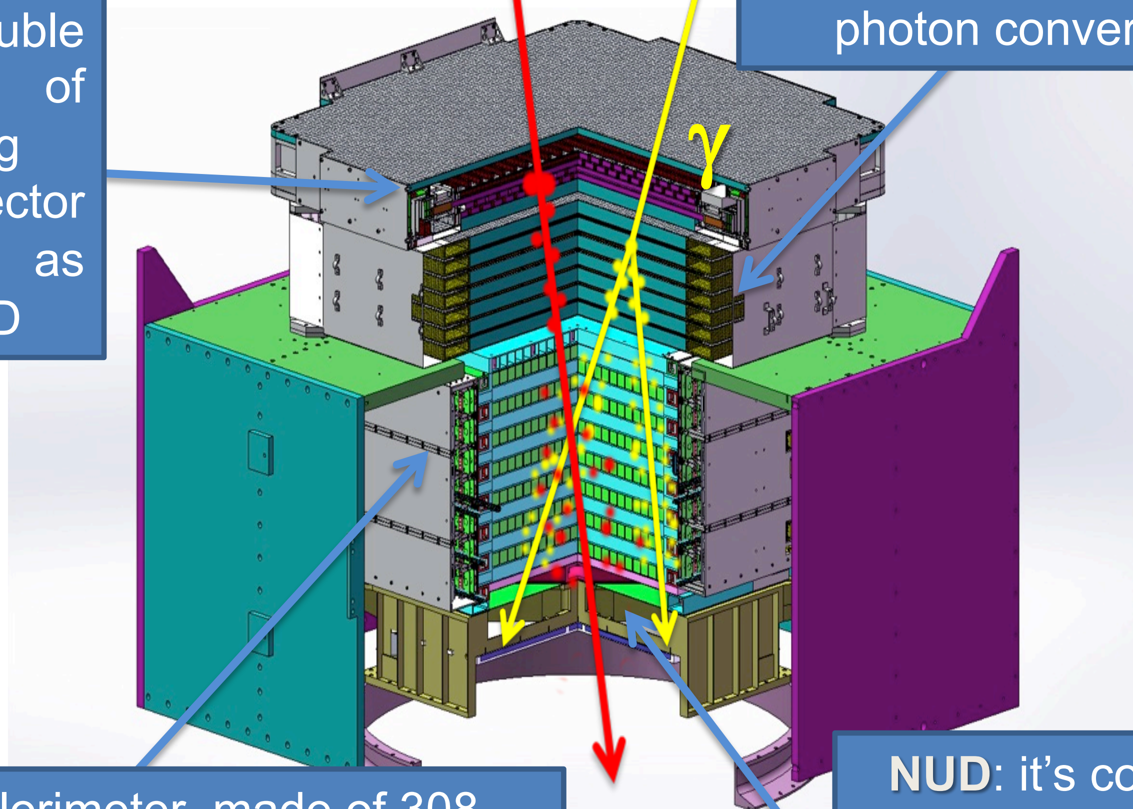
- The bulk of the emission of the 2nd peak is moving **toward later times as the energy increases**
- Clear signature of **spectral evolution**

DAMPE DETECTOR

75k readout channels + temperature sensors

STK: 6 tracking double layers + 3 mm tungsten plates. Used for particle track and photon conversion

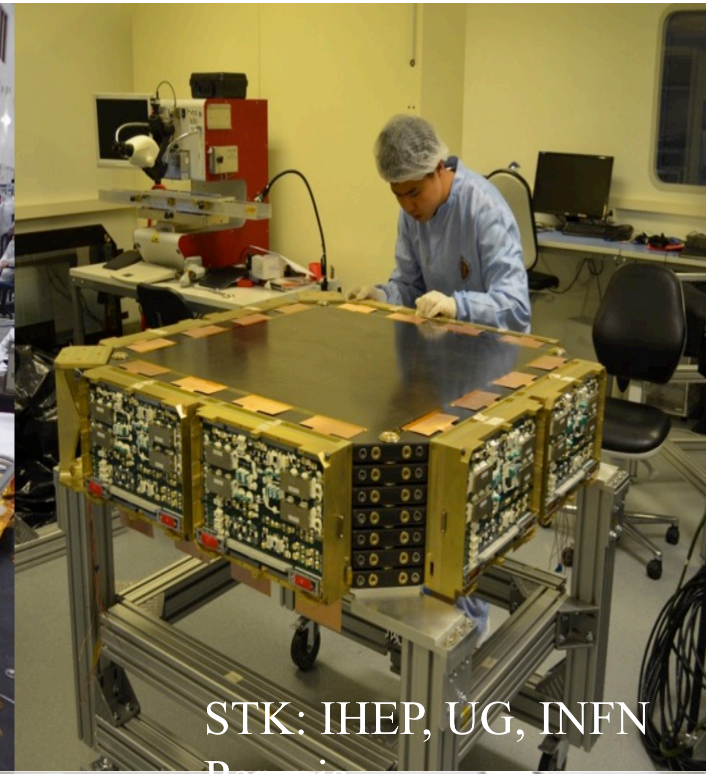
PSD: double layers of scintillating strip detector acting as ACD + PID



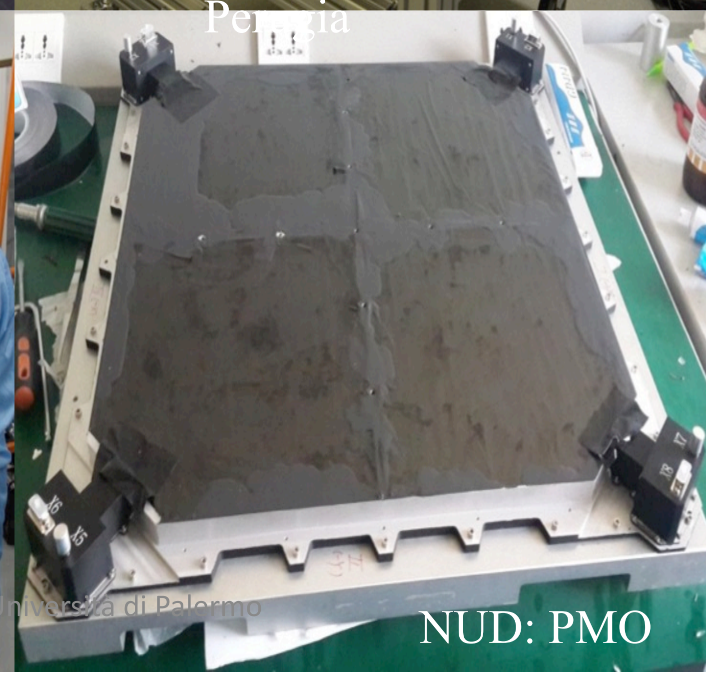
BGO: the calorimeter made of 308 BGO bars in hodoscopic arrangement (~32 radiation lengths). Performs both energy measurements and trigger

NUD: it's complementary to the BGO by measuring the thermal neutron shower activity. Made up of boron-doped plastic scintillators


PSD: IMP
2015/08/01


STK: IHEP, UG, INFN


BGO: USTC & PMO


NUD: PMO

Scientific Objectives of DAMPE

- High energy particle detection in space
  - Study of the cosmic e, γ spectra and Search for DM signatures
  - Study of cosmic ray (nuclei) spectrum and composition
  - High energy gamma ray astronomy

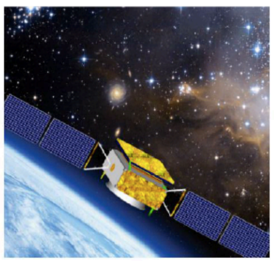
Detection of 10 GeV - 10 TeV e/γ, 100 GeV - 500 TeV CR
Excellent energy resolution and tracking precision
Complementary to Fermi, AMS-02, CALET, ISS-CREAM, …

- Follow-up mission to both Fermi/LAT and AMS-02
  - Extend the energy reach to the TeV region, providing better resolution
  - Overlap with Fermi on gamma ray astronomy
  - Run in parallel for some time

Cosmic Rays

3 Major Scientific goals

Cosmic ray physics

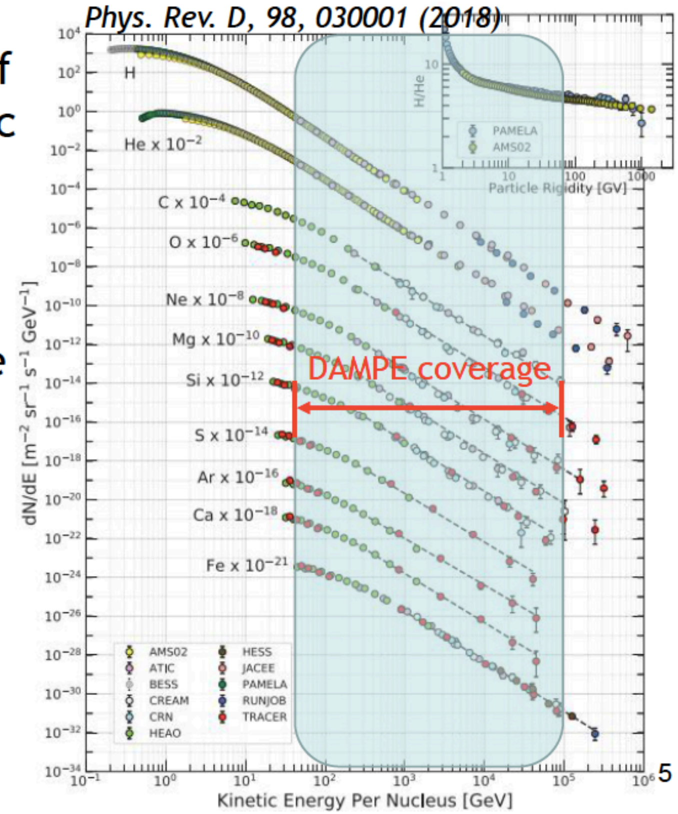


γ-ray astronomy

Dark matter indirect detection

- Precision measurements of cosmic ray spectra: cosmic ray origin, acceleration, and propagation

- The spectra above TeV are not well measured due to limited statistics of direct detection experiments



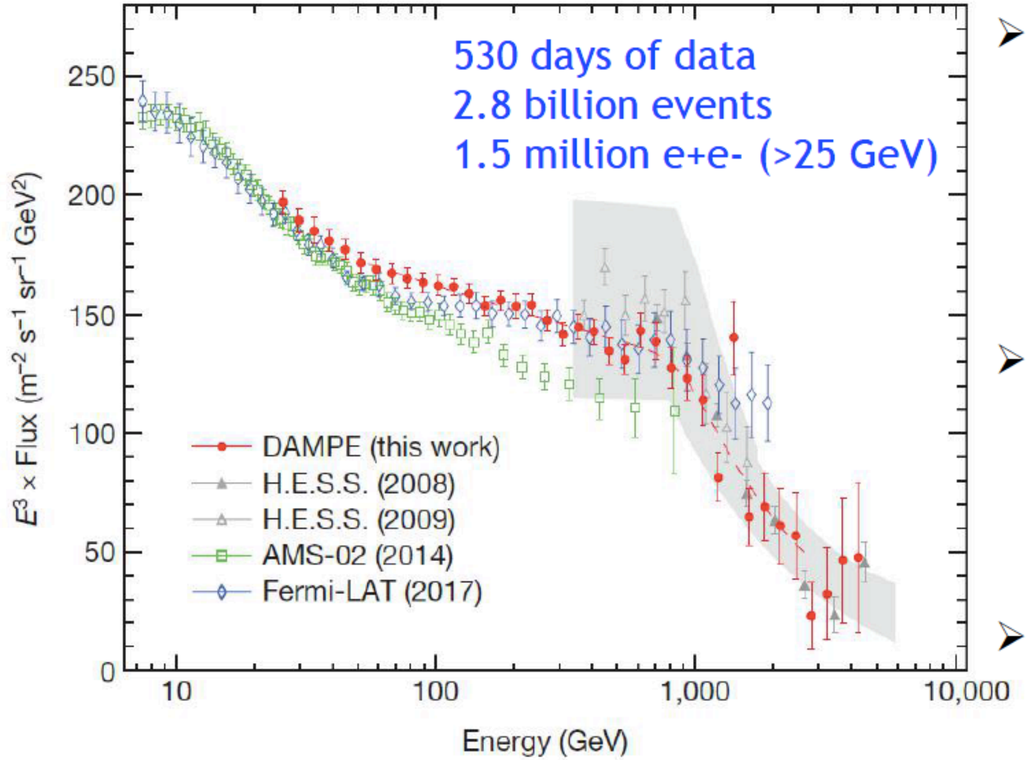
Detector Performance

Table 1: Summary of DAMPE instrument parameters and Expected performance

Parameter	Value
Energy range of γ–rays/electrons	5 GeV–10 TeV
Energy resolution of γ–rays/electrons	$\leq$ 1.5% at 800 GeV
Energy range of protons/heavy nuclei	50 GeV–100 TeV
Energy resolution of protons	$\leq$ 40% at 800 GeV
Effective area at normal incidence (γ–rays)	1100 cm^2 at 100 GeV
Geometric factor for electrons	0.3 m^2 sr above 30 GeV
Photon angular resolution[a]	$\leq 0.2^\circ$ at 100 GeV
Field of View (FoV)	~1.0 sr

Note: a. For the 68% containment radius.

e⁺+e⁻ Spectrum

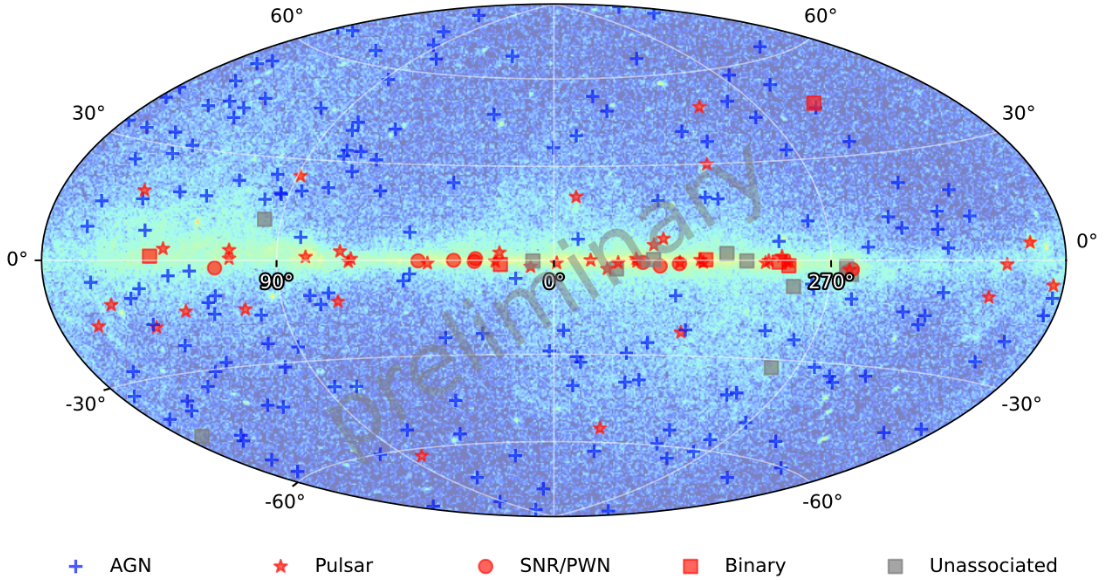


- Three different PID methods give very consistent results on event-by-event level
- Direct detection of a spectral break at ~1 TeV with 6.6σ confidence level
- Analysis with new data is on-going

Nature, 552, 63 (2017)

Gamma-Rays: Sky Map & Sources

~250 point sources detected an studies in 7 years



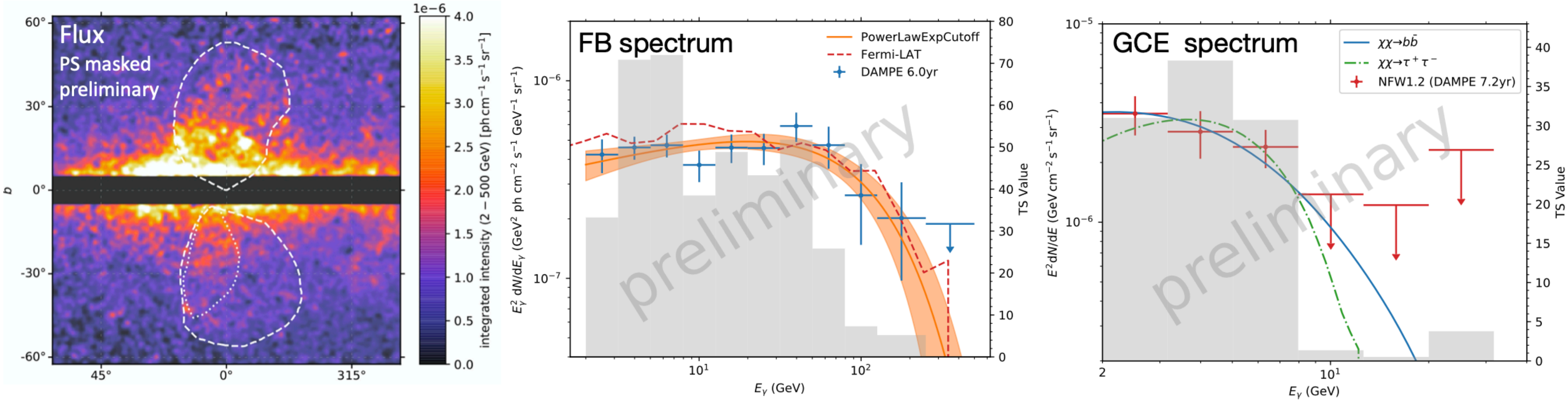
Source Type	Number
AGN	175
Pulsar	46
SNR/PWN	10
Binary	6
Unassociated	11
Total	248

14 times full-sky coverage in 7 years, ~ 300'000 photons total

See talk by Z.-Q. Shen,
poster by K.-K. Duan

Gamma-Rays: Fermi Bubbles, Galactic Center

Fermi Bubbles (FB) — diffuse structures discovered by FERMI LAT, associated with Galactic Centre (DAMPE FB detection at ~17.8σ)



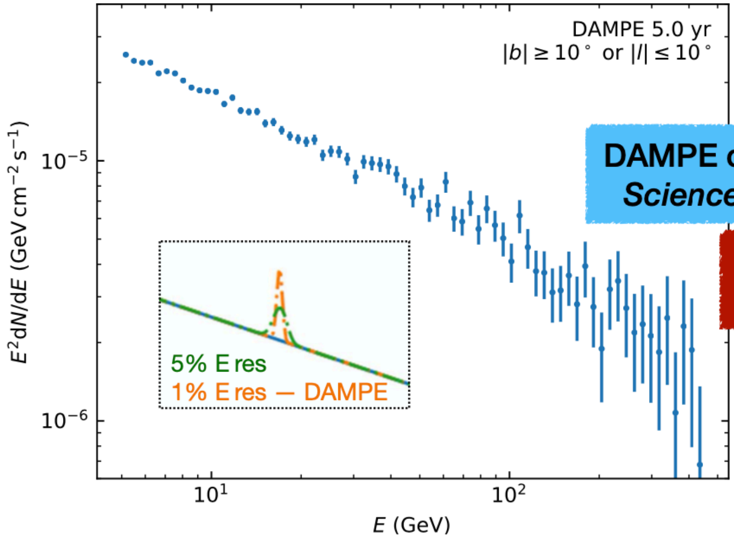
- FB: 6-year spectrum well consistent with FERMI, curved at 3.7σ, weak excess in the Cocoon (~3.3σ)
- **Galactic Center Excess (GCE)** detected at ~7.9σ, with 7.2 years of DAMPE data

See talk by Z.-Q. Shen, poster by Z.-Q. Shen

Gamma-Rays: Line Search

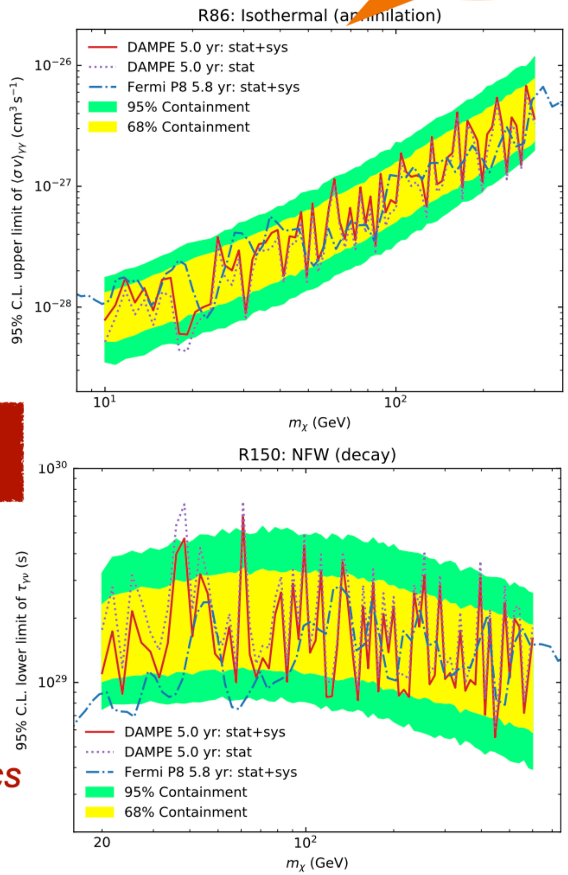
New!

- **Excellent energy resolution**
  - Sensitivity comparable with Fermi LAT (in spite lower geometrical acceptance)



DAMPE collab. and Y.-F. Liang, *Science Bulletin* 67, 7 (2022)

Talk by Z.-Q. Shen (5358492)



Most stringent limits on DM decay lifetime with DM mass < 100 GeV

Extending further with higher statistics & better photon ID (in process…)

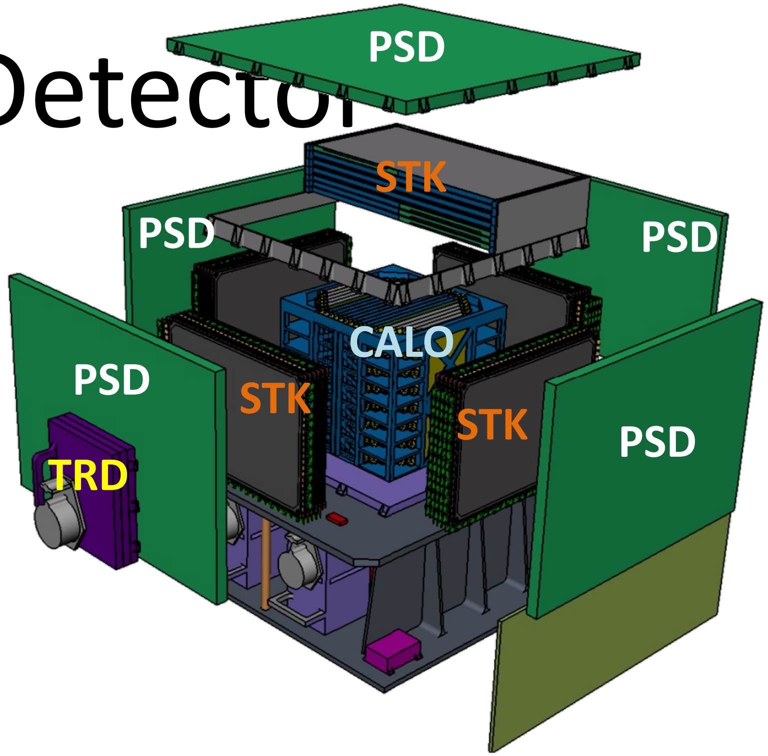
Herd- The Detector

Calorimeter (CALO): 3D, e/γ/CR energy, e/p discrimitation

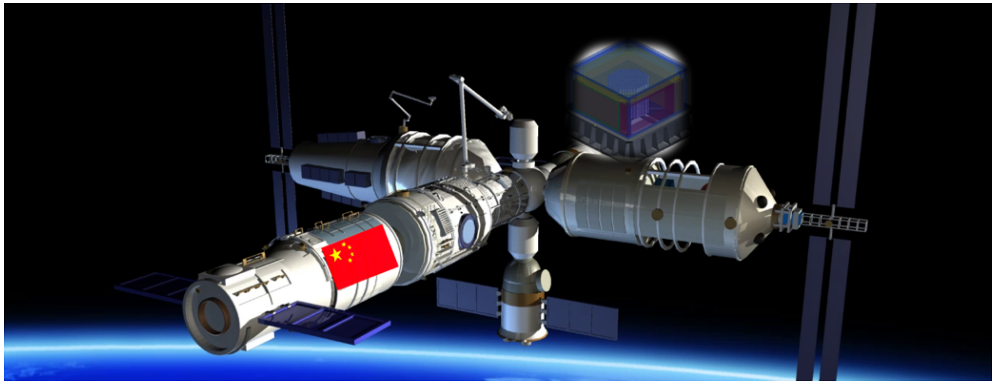
Tracker (5 STK «silicon tracker» or 1 STK + 4 FIT «fiber tracker»): particle trajectory, charge identification

PSD «plastic scintillator detector»: 5 sides, low energy γ, charge identification

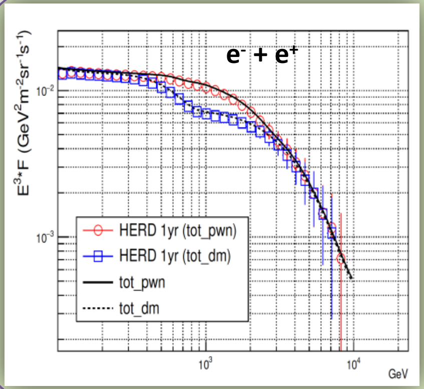
TRD «transition radiation detector»: energy calibration



Mass	< 4 t
Envelope dimensions	~ 2.3 x 2.3 x 2.6 m^3
Field of View	± 70°
Power consumption	~ 1200 W
Lifetime	> 10 years (with in-orbit replacements)



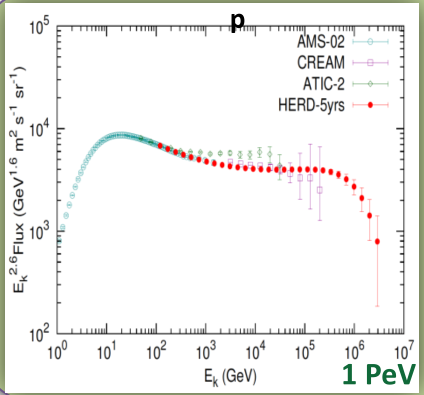
HERD: Obiettivi e performance



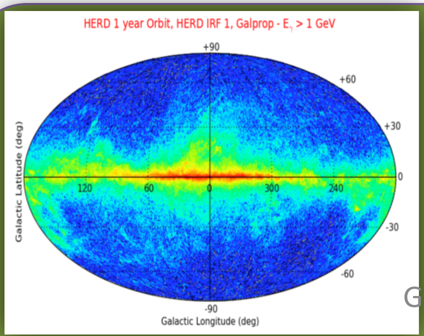
Search for signatures of annihilation/decay products of **dark matter** in

- energy spectrum and anisotropy of high energy electrons (10 GeV – 100 TeV)
- γ-rays (500 MeV – 100 TeV)

10 TeV



Measurements of **energy spectrum and composition** of primary cosmic rays from 30 GeV to PeV.



Wide FOV monitoring of gamma-rays from 500 MeV to study gamma-ray bursts, active galactic nuclei and galactic microquasars.

expected performance

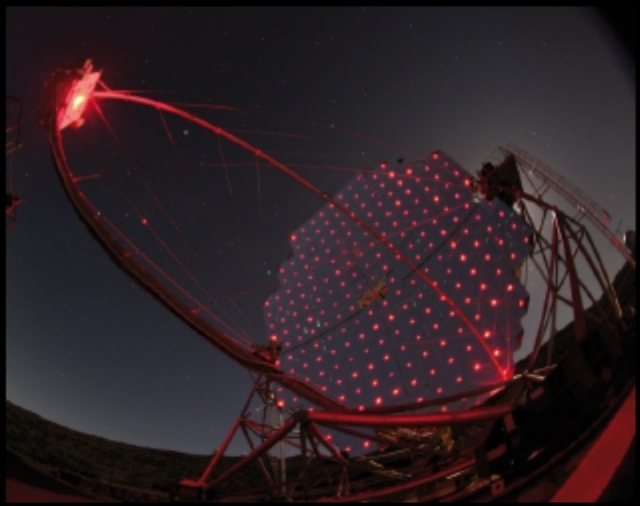
Energy range (e/γ)	10 GeV – 100 TeV
γ low energy range	500 MeV – 10 GeV
Energy range (nuclei)	30 GeV – 3 PeV
Angular resolution (e/γ)	0.1° @10 GeV
Charge resolution (nuclei)	10 % – 15 % for Z = 1 – 26
Energy resolution (e/γ)	< 1 % @200 GeV
Energy resolution (p)	20 % @100 GeV - PeV
e/p separation power	> 10^{-6}
Geometric factor (e)	> 3 $m^2 sr$ @200 GeV
Geometric factor (p)	> 2 $m^2 sr$ @100 GeV

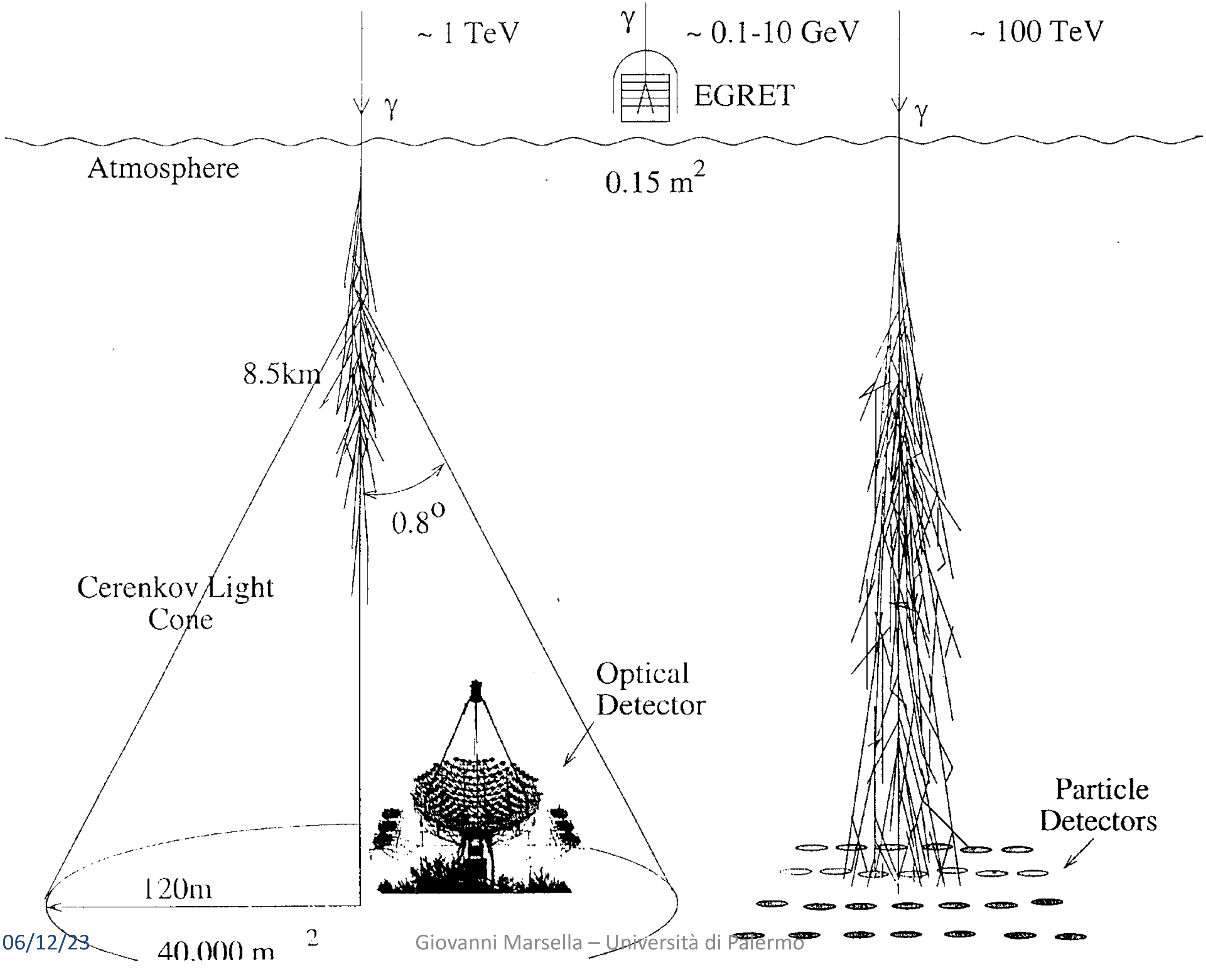
- Gamma Astronomy at ground

Why (mainly) ground-based?

- High energies
  - Only way to build sensitive >TeV instruments
- High statistics /short timescales
  - Large collection areas O(km2)
- Precision (IACTs)
  - Superior angular resolution

- Limitations?
  - IACTs
    - Smallish duty cycle
    - Smallish field of view
  - Ground particle detectors
    - Modest resolution and background rejection power
  - Complementary approaches

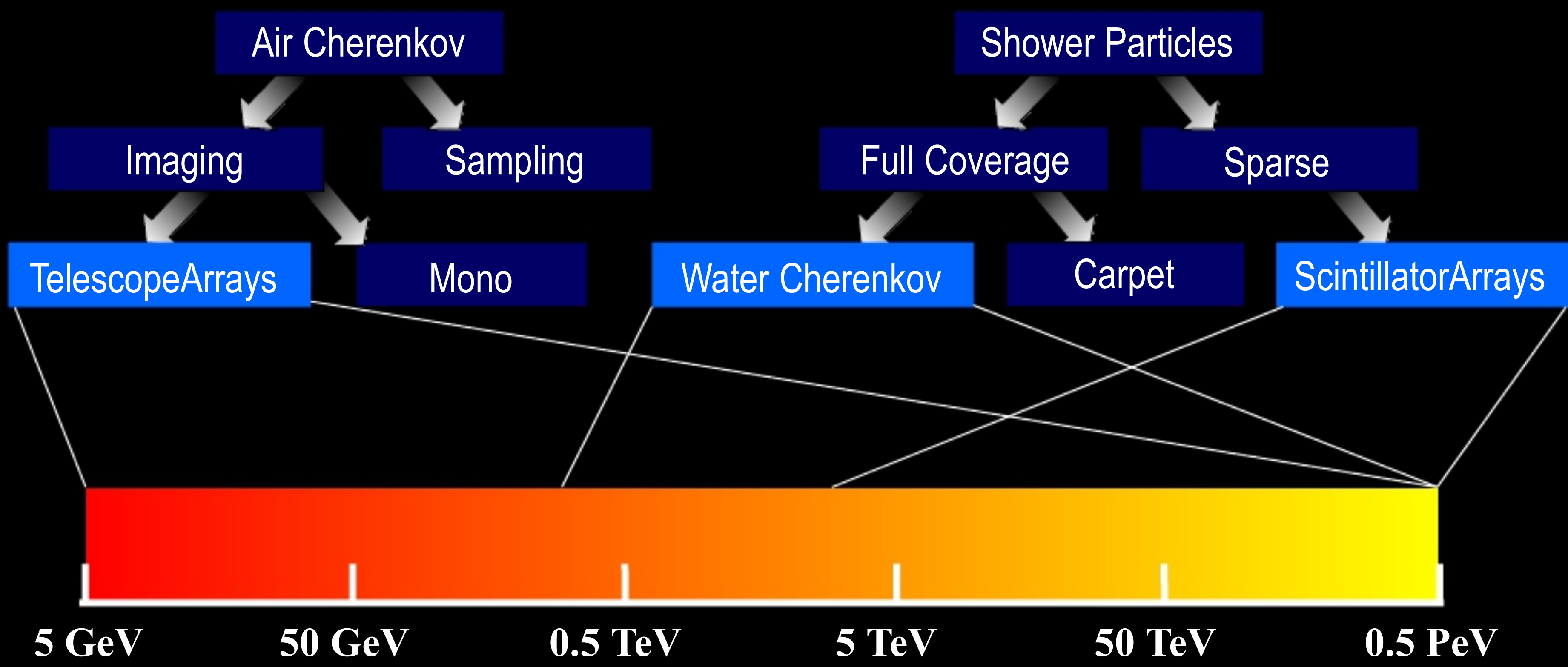



~ 1 TeV
γ
~ 0.1-10 GeV
~ 100 TeV
EGRET
γ
γ
Atmosphere
0.15 m2
8.5km
0.8o
Cerenkov Light
Cone
Optical
Detector
Particle
Detectors
120m
40.000 m 2

Techniques

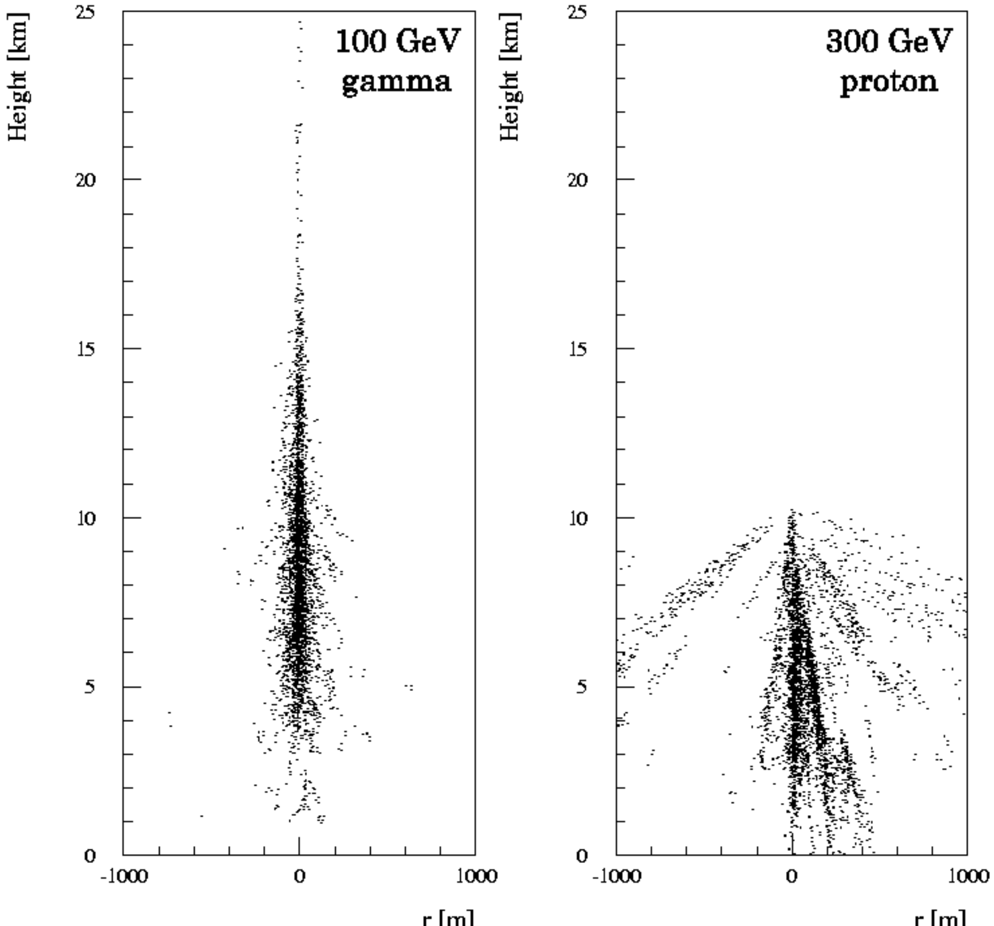
HDGS2008

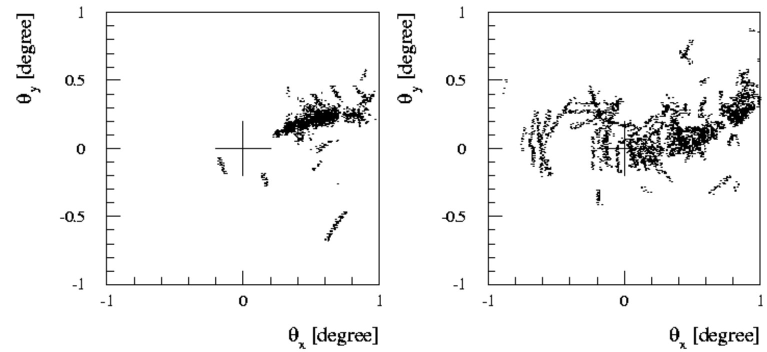
UNIVERSITY OF LEEDS



- Many different approaches have been tried
  - Not all have stood the test of time
  - Major projects planned using three of them

Imaging Cherenkov technique





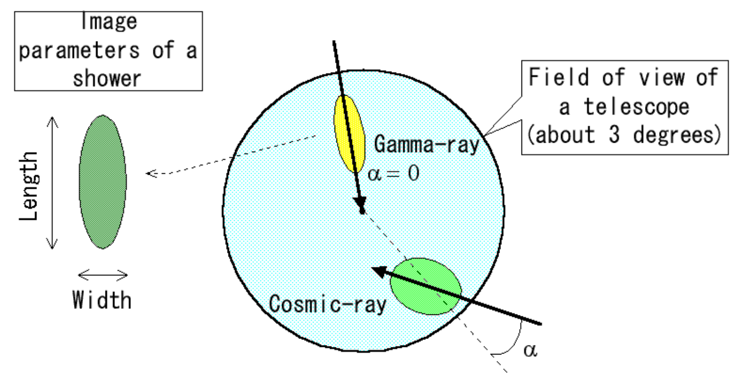
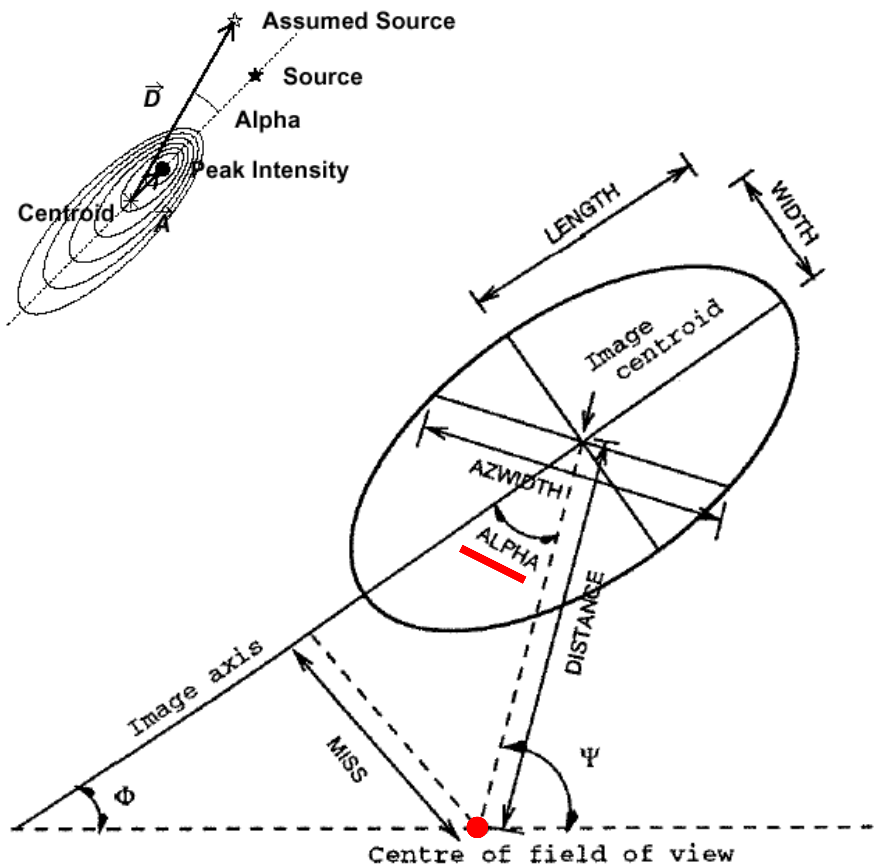
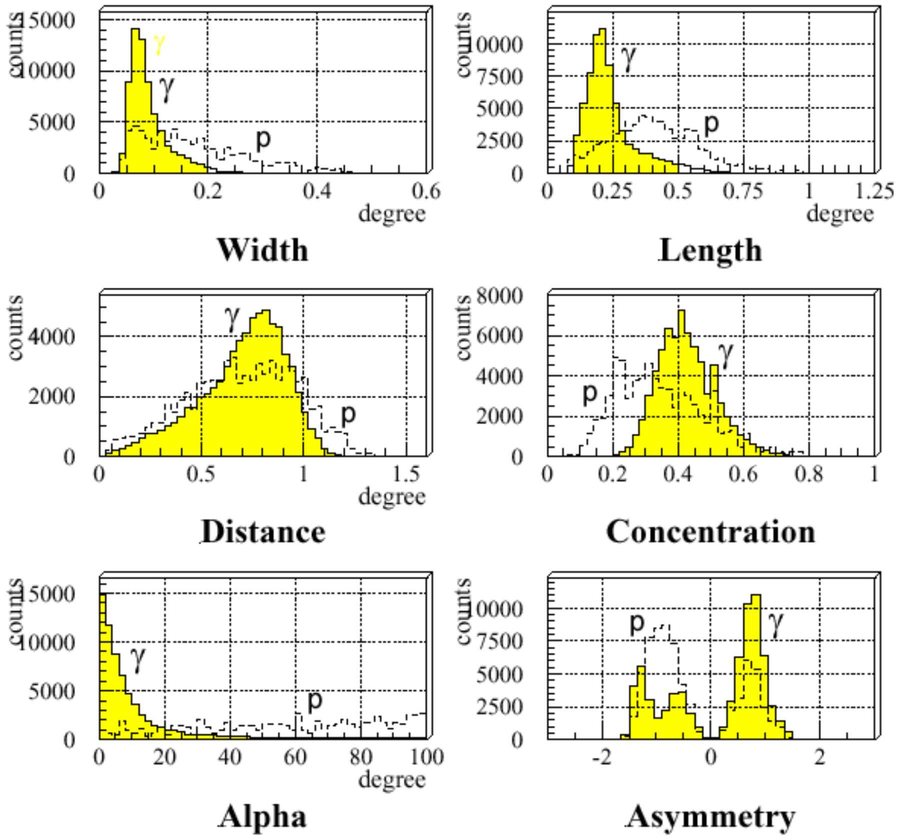


Image parameters



D.J. Fegan, J.Phys.G, 1997

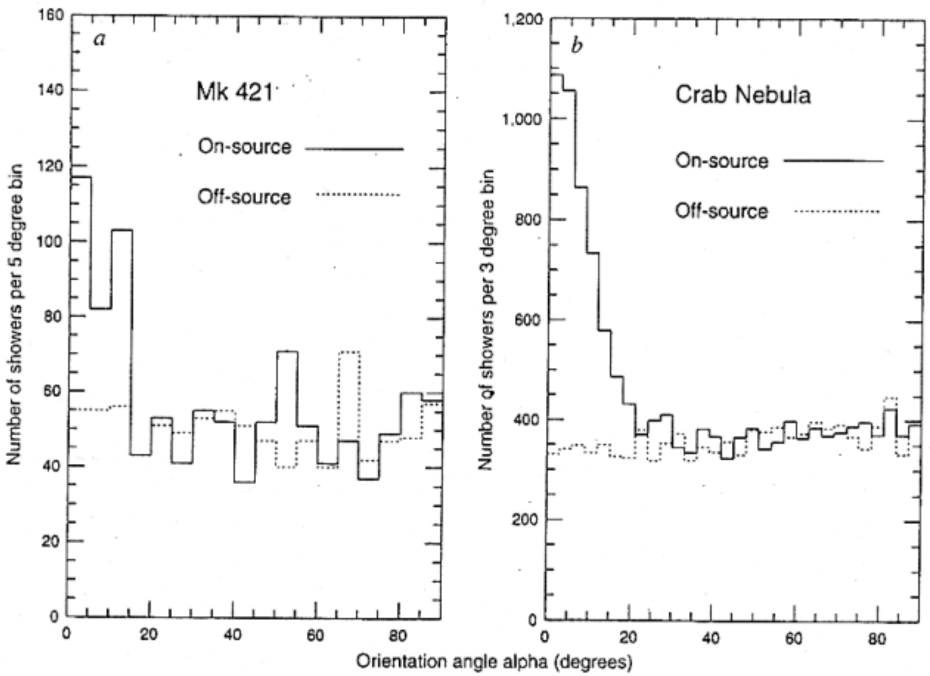


(Simulation)

Example of image cut analysis

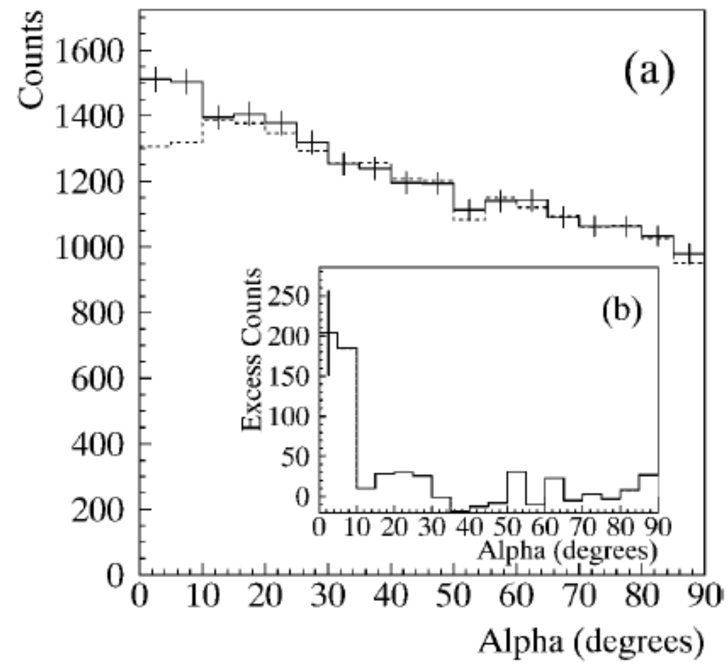
- Hadron rejection power ～100

Whipple



M. Punch et al., Nature, 1992

CANGAROO (Vela)



T. Yoshikoshi et al., ApJ, 1997

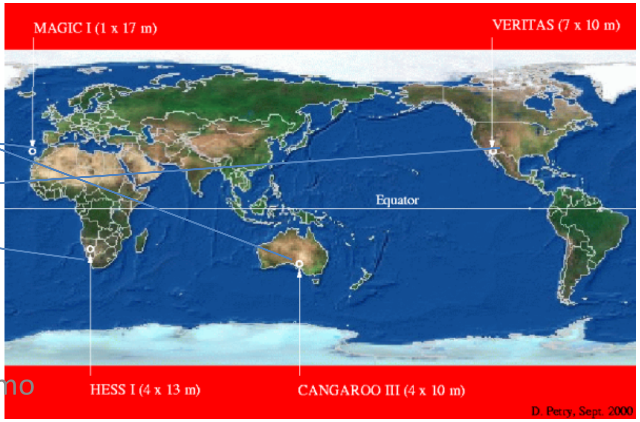
TeV catalog 2000

Classification	Object	Group	Remark
Grade A (>5σ, multiple)	Crab PSR1706-44 Mrk 421 Mrk 501	Many CANGAROO, Durham Many Many	Plerion Plerion AGN (BL Lac) AGN (BL Lac)
Grade B (>5σ)	SN1006 Vela RXJ1713.7-3946 PKS2155-304 1ES1959+650 BL Lac	CANGAROO CANGAROO CANGAROO Durham Utah7TA Crimea	SNR Plerion SNR AGN (BL Lac) AGN (BL Lac) AGN (BL Lac)
Grade C (strong but with some qualifications)	Cas A Cen X-3 1ES2344+514 3C66A Geminga B1509-58	HEGRA CT Durham Whipple Crimea Crimea CANGAROO	SNR X-ray binary AGN (BL Lac) AGN (z=0.44) Pulsar Plerion

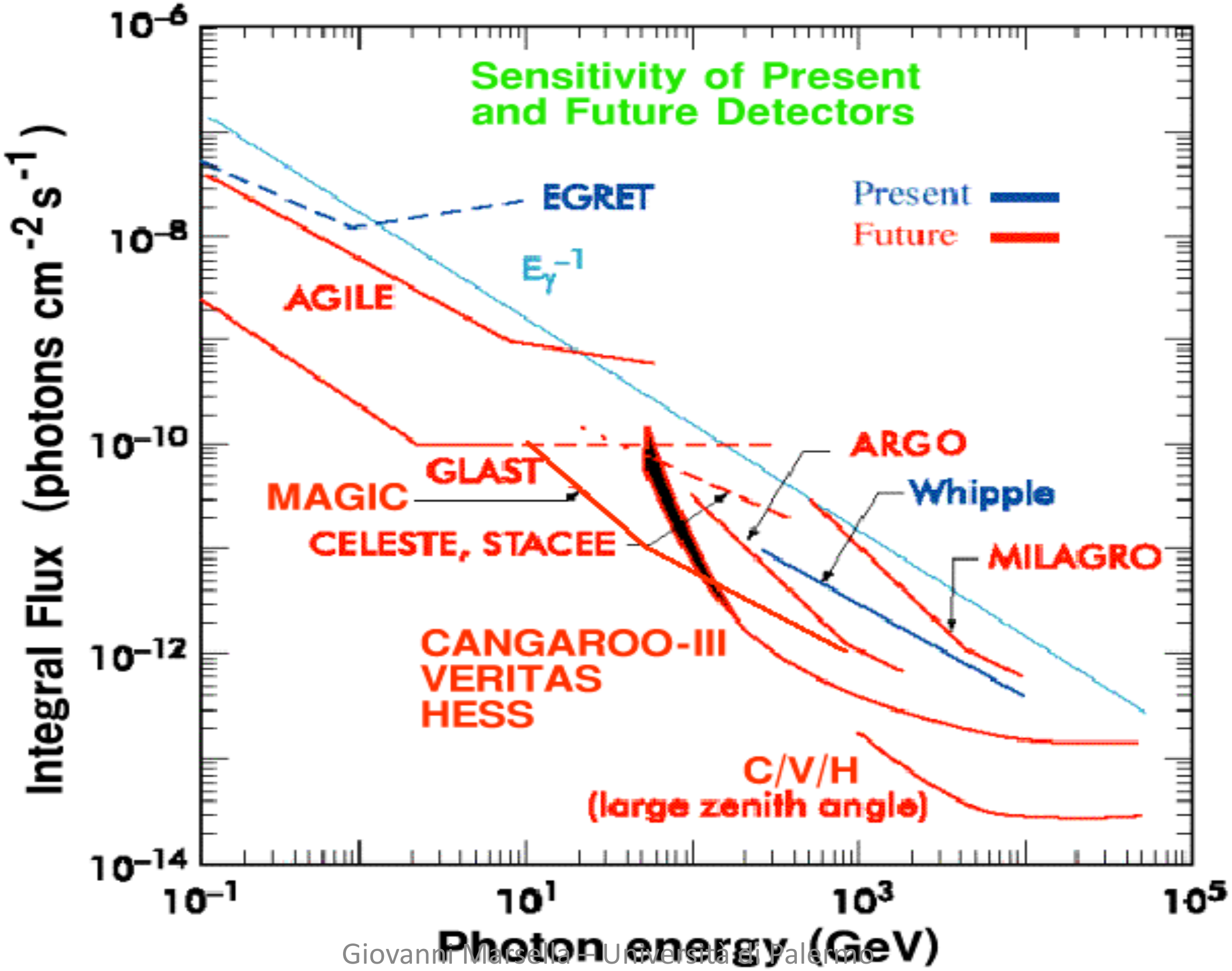
T.C. Weekes, Heidelberg WS, 2000

Next generation projects

- Satellites
  MeV: INTEGRAL 15keV-10MeV, 2002-
  ACT (Advanced Compton Telescope) 300keV-20MeV, 2008?
  GeV: AGILE 30MeV-50GeV, 2003-
  GLAST 20MeV-300GeV, 2005?
- Ground-based
  CANGAROO-III 4×10m, Australia, 2000-2004-
  MAGIC 1×17m, Canary Island, 2001-
  HESS 4×12m, Namibia, 2002-
  VERITAS 7×10m, Arizona, 2004-



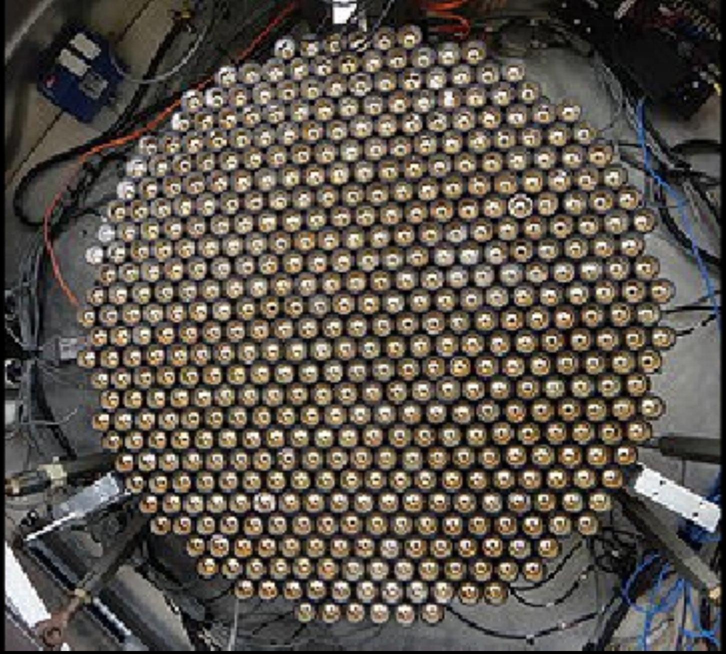
Sensitivity of future detectors

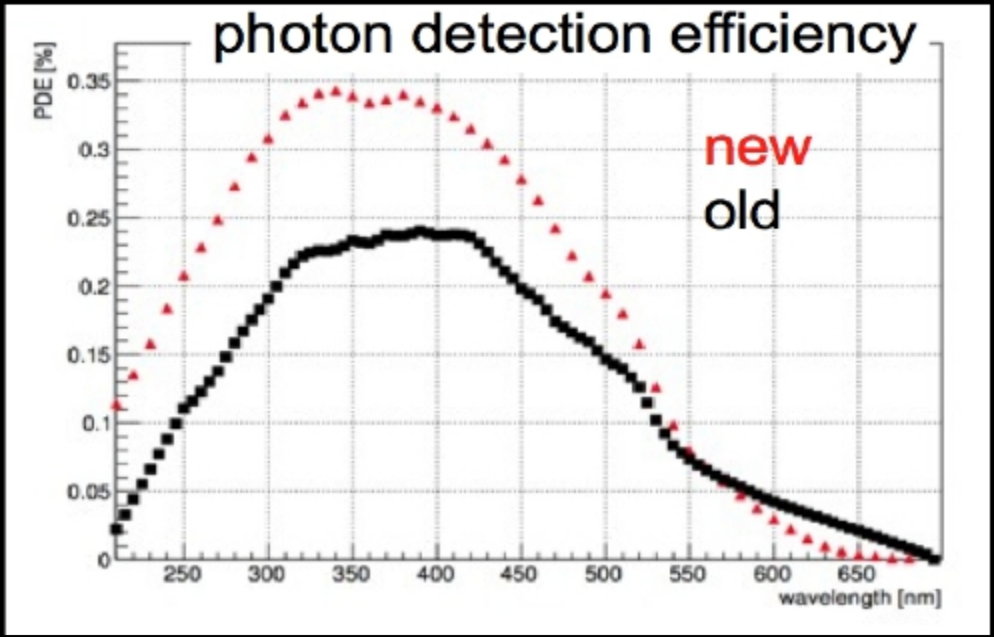


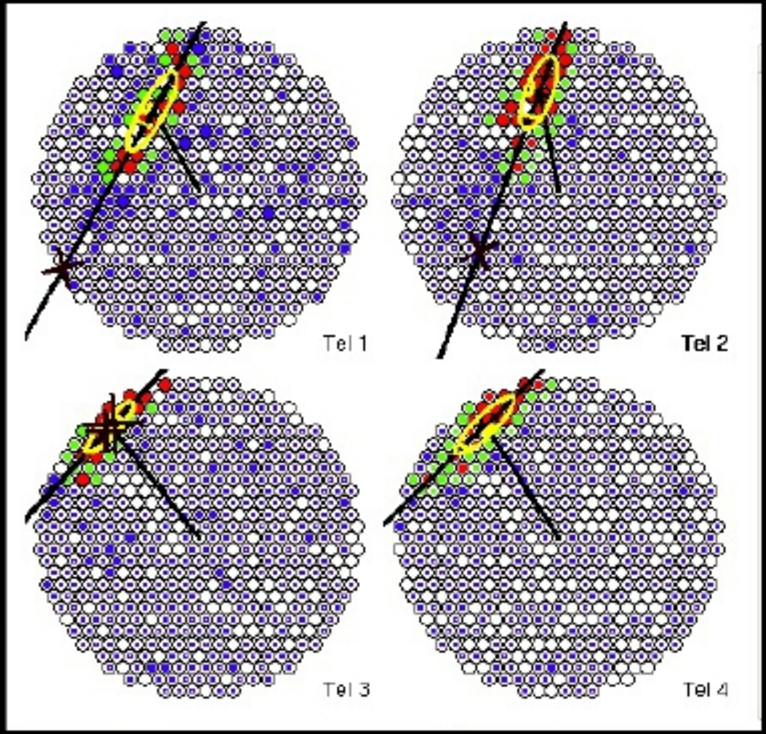
VHE Instruments examples

VERITAS

- 4x 12m telescopes in Arizona
- Upgrade completed Sept. 2012
  - New PMs and new trigger system for all four cameras
  - Lower threshold, improved sensitivity

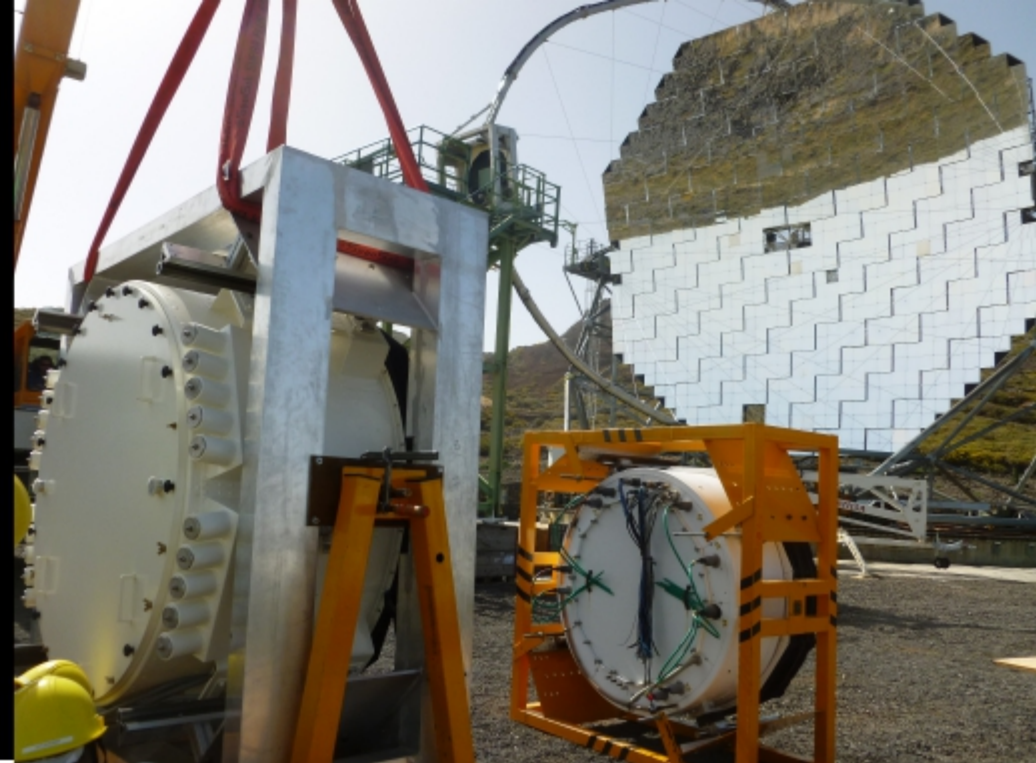


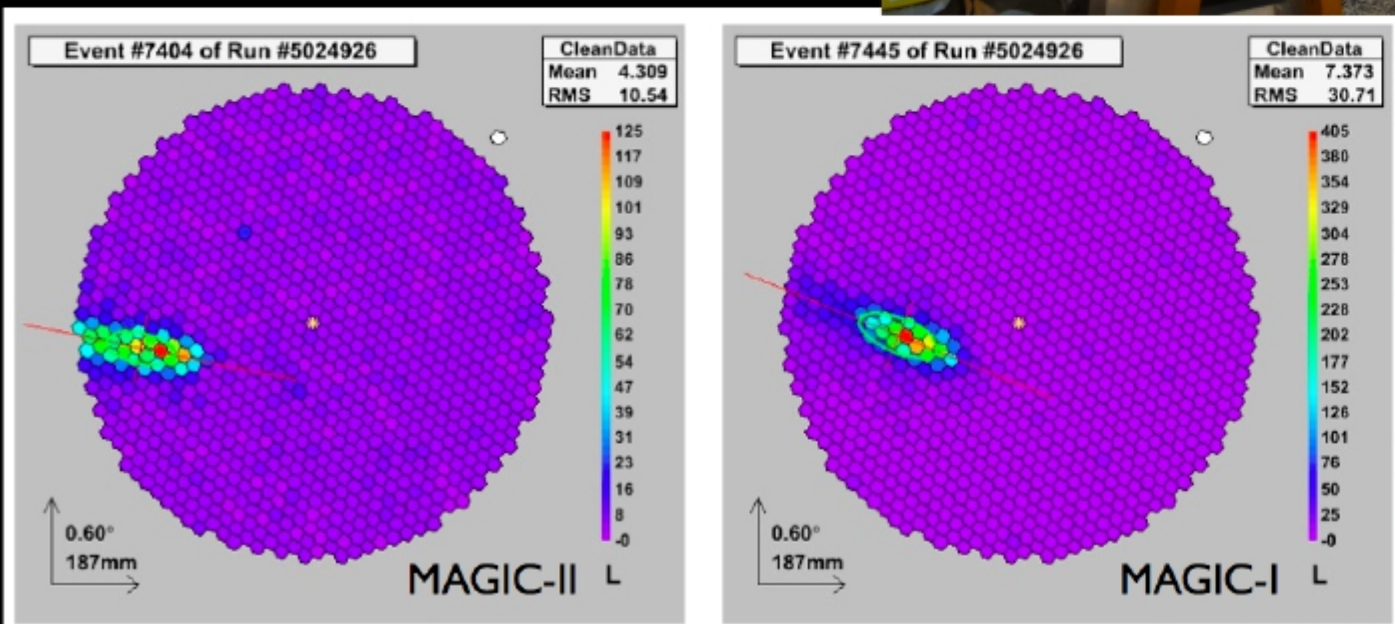




MAGIC

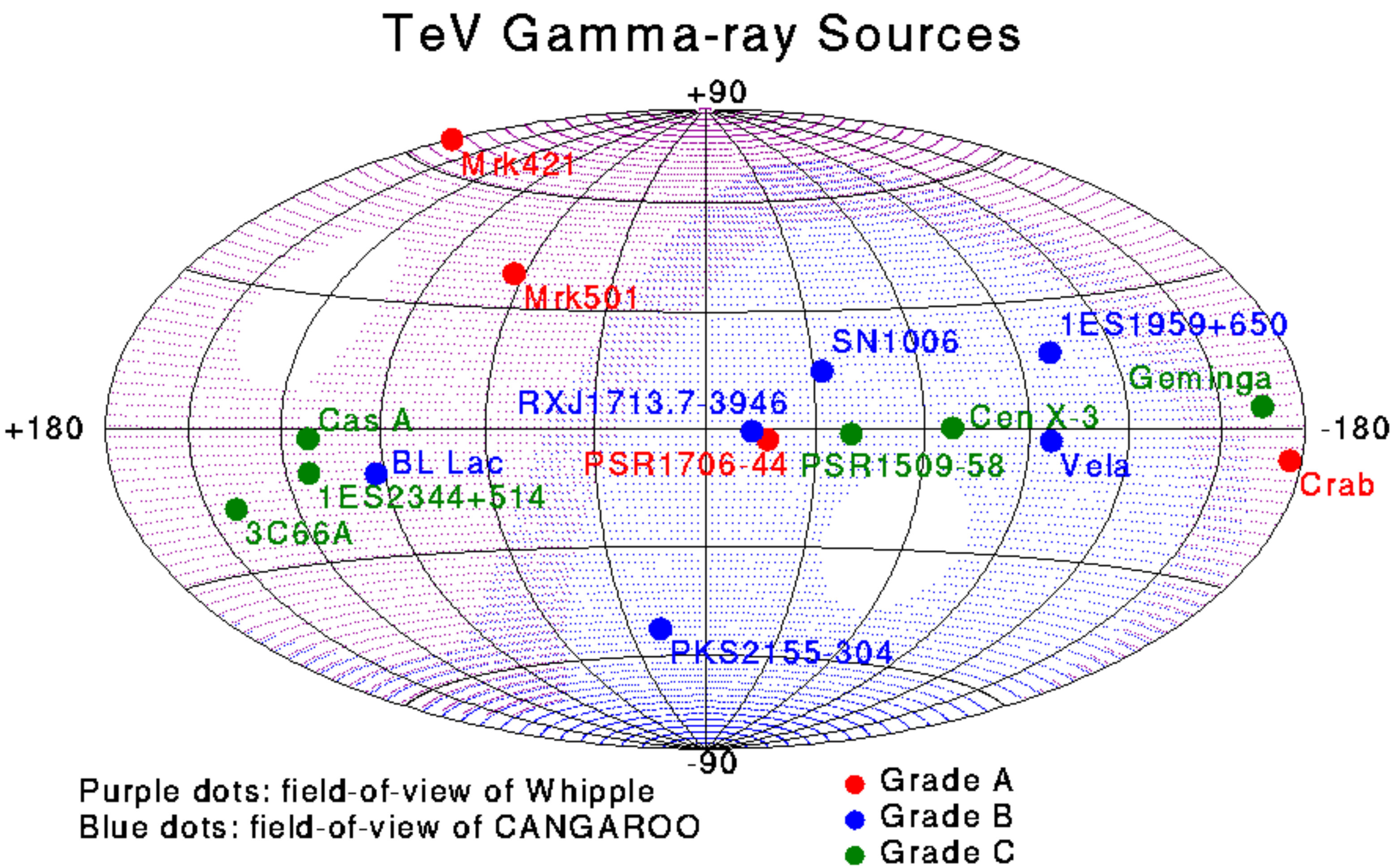
- 2_{nd} 17 m telescope finished 2009
- Upgrade DAQ + new MAGIC-I camera finished fall 2013
  - Both now 1039 pixel, 3.5 degree FoV






HESS
HESS-1: 4×12m tels
HESS-2: +28m tel.
Completed mid-2012

TeV sky 2000


TeV Gamma-ray Sources
+90
-90
+180
-180
Mrk421
Mrk501
SN1006
1ES1959+650
Geminga
RXJ1713.7-3946
Cas A
Cen X-3
BL Lac
PSR1706-44
PSR1509-58
Vela
Crab
1ES2344+514
3C66A
PKS2155-304
Purple dots: field-of-view of Whipple
Blue dots: field-of-view of CANGAROO
Grade A
Grade B
Grade C

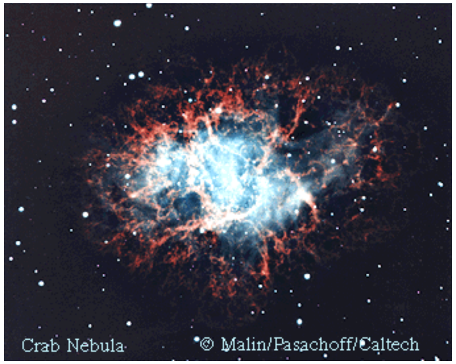
TeV observations of Plerions

Table 1 TeV Observations of Plerions

Object Name	**Exposure time (hours)**	**Flux/Upper Limit x $10^{-11} cm^{-2} s^{-1}$**
EVERYONE		
Crab Nebula	$\rightarrow \infty$	7.0 ($>$ 400GeV)
CANGAROO		
PSR 1706-44	60	0.15 ($>$1TeV)
Vela Pulsar	116	0.26 $(E/2\ TeV)^{-2.4}$ TeV^{-1}
Durham		
PSR 1706-44	10	1.2 ($>$300GeV)
Vela Pulsar	8.75	$<$5.0 ($>$300GeV)

S. Fegan, astro-ph/0102324

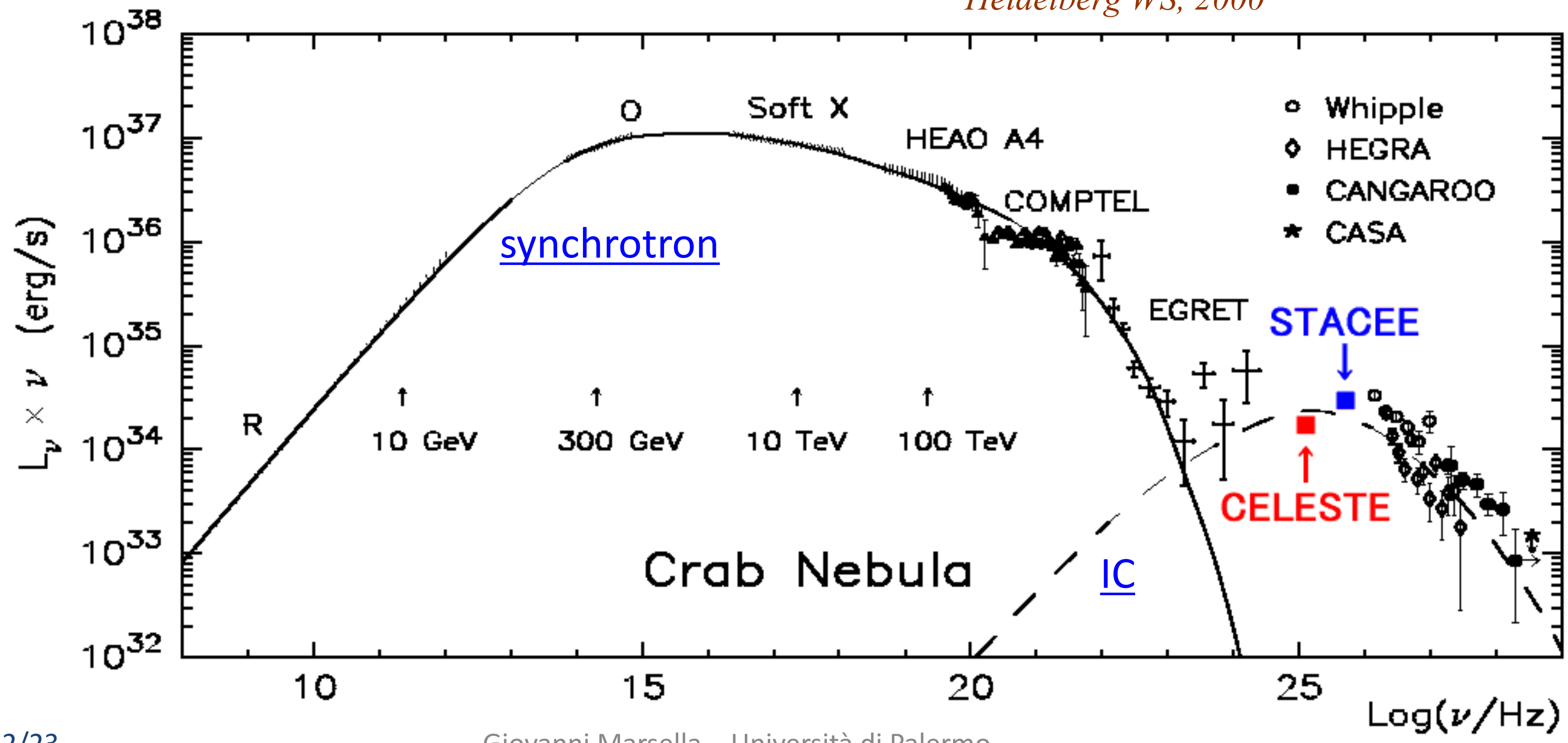
Crab nebula



- Unpulsed spectrum

Aharonian & Atoyan, astro-ph/9803091 /

Heidelberg WS, 2000



Crab pulsar spectrum: where is the cutoff?

Musquere, 26th ICRC, 1999

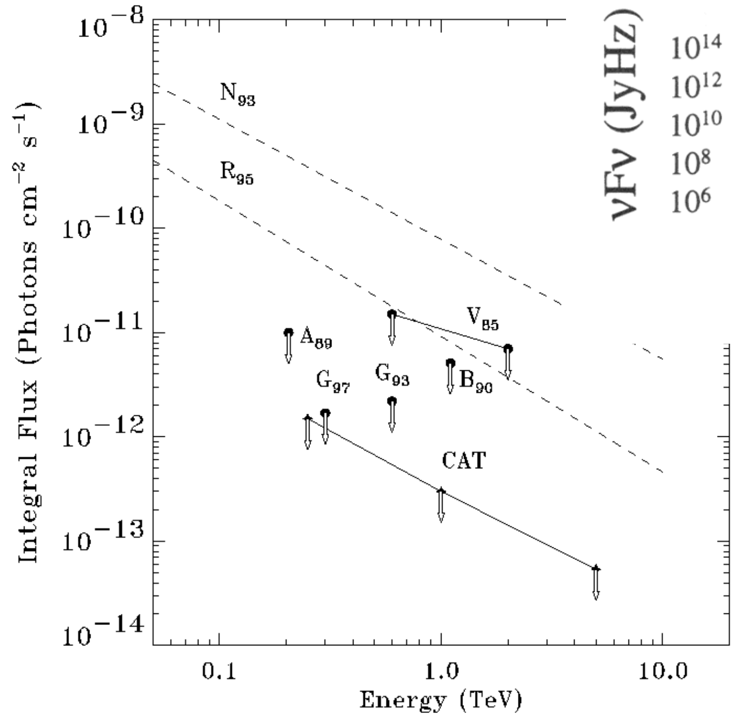
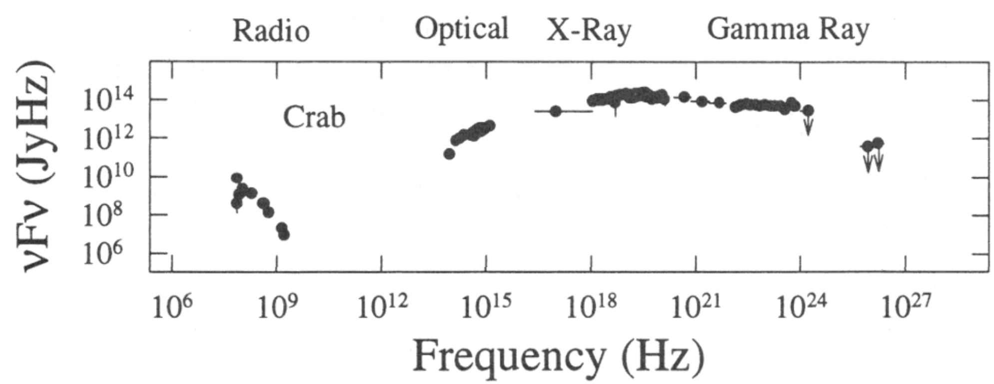
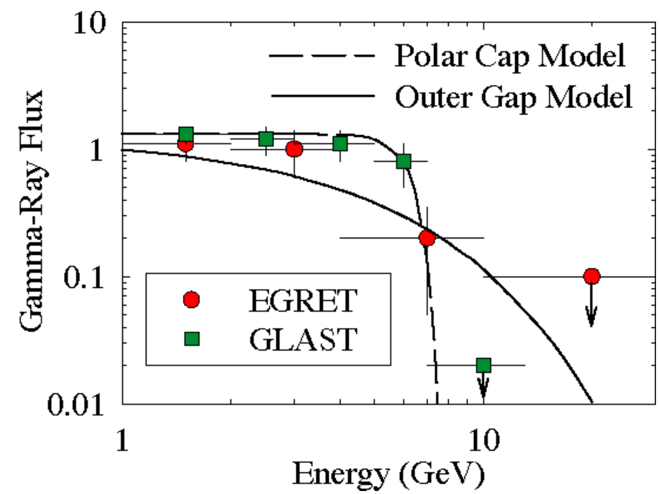


Figure 1: Upper limits on the pulsed integral flux reported for the Crab pulsar. B_{90} : Bhat et al. 1990; V_{85} : Vishwanath et al. 1985; A_{89} : Akerlof et al. 1989; G_{93} : Goret et al. 1993; G_{97} : Gillanders et al. 1997. The dashed lines represent the extrapolations of the EGRET integral pulsed flux. N_{93} : Nolan et al. 1993 (Full energy range); R_{95} : adapted from Ramanamurthy et al. 1995 (above 1 GeV)





TeV observations of shell-type SNRs

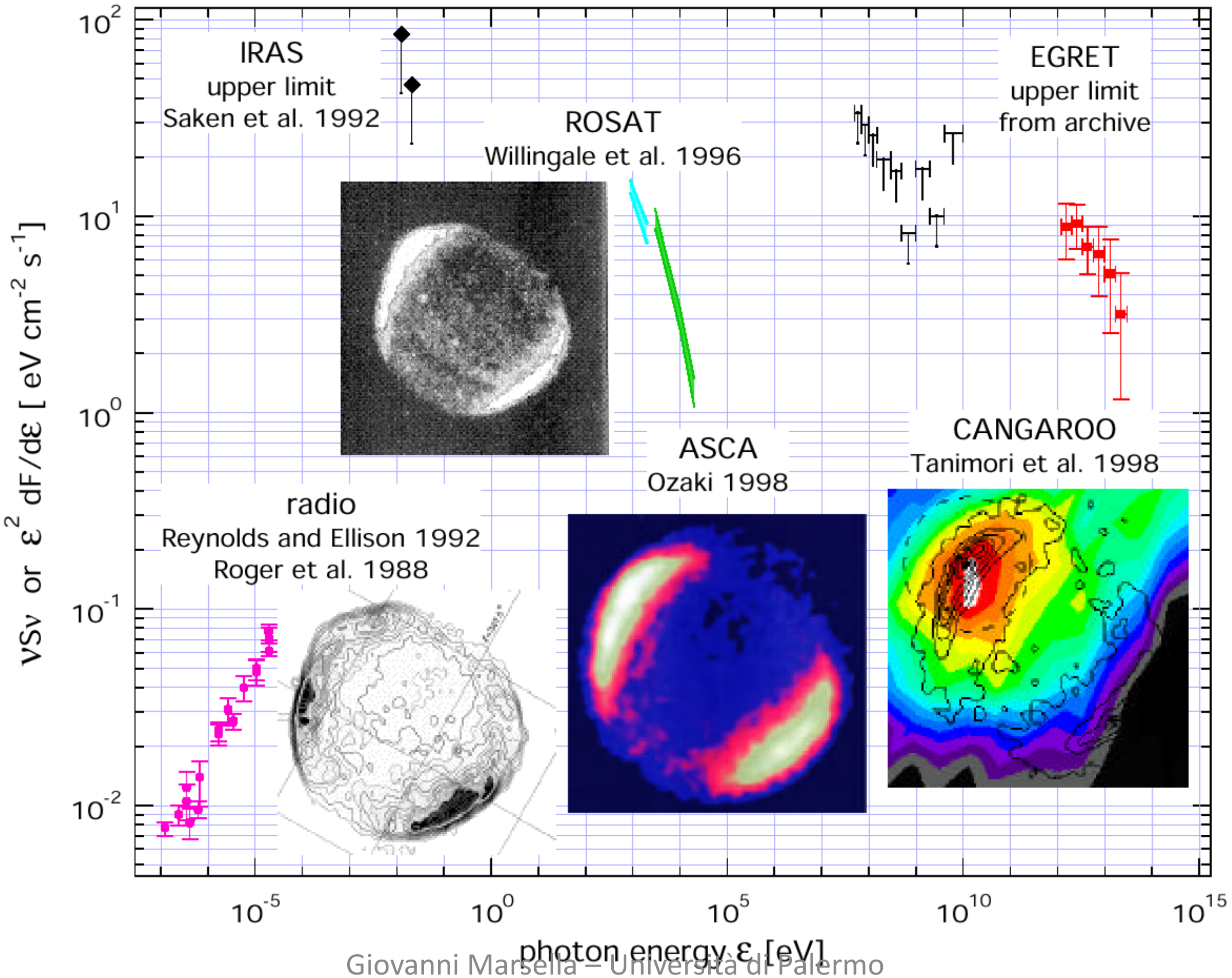
Table 2 TeV Observations of Shell-type SNR

Object Name	Exposure time (hours)	Flux/Upper Limit x $10^{-11} cm^{-2} s^{-1}$
CANGAROO		
RXJ 1713.7-3946	66	0.53 ($\geq$1.8 TeV)
SN1006	34	0.46 ($\geq$1.7 TeV)
W28	58	<0.88 (> 5 TeV[a])
HEGRA		
Cas A	232	0.058 (> 1 TeV) [b]
γ-Cygni	47	<1.1 (>500GeV)[c]
Durham		
SN1006	41	<1.7 (>300GeV)
Whipple		
Monoceros	13.1	<4.8 (>500GeV)
Cas A	6.9	<0.66 (>500GeV)
W44	6	<3.0 (>300GeV)
W51	7.8	<3.6 (>300GeV)
γ-Cygni	9.3	<2.2 (>300GeV)
W63	2.3	<6.4 (>300GeV)
Tycho	14.5	<0.8 (>300GeV)
CAT		
CasA	24.4	<0.74 (>400GeV)

[a] A different definition of Energy Threshold is used
[b] Evidence for emission at the 4.9σ level (Pühlhofer et al. 2001)
[c] Limits converted from Crab units using flux of Hillas et al. 1998

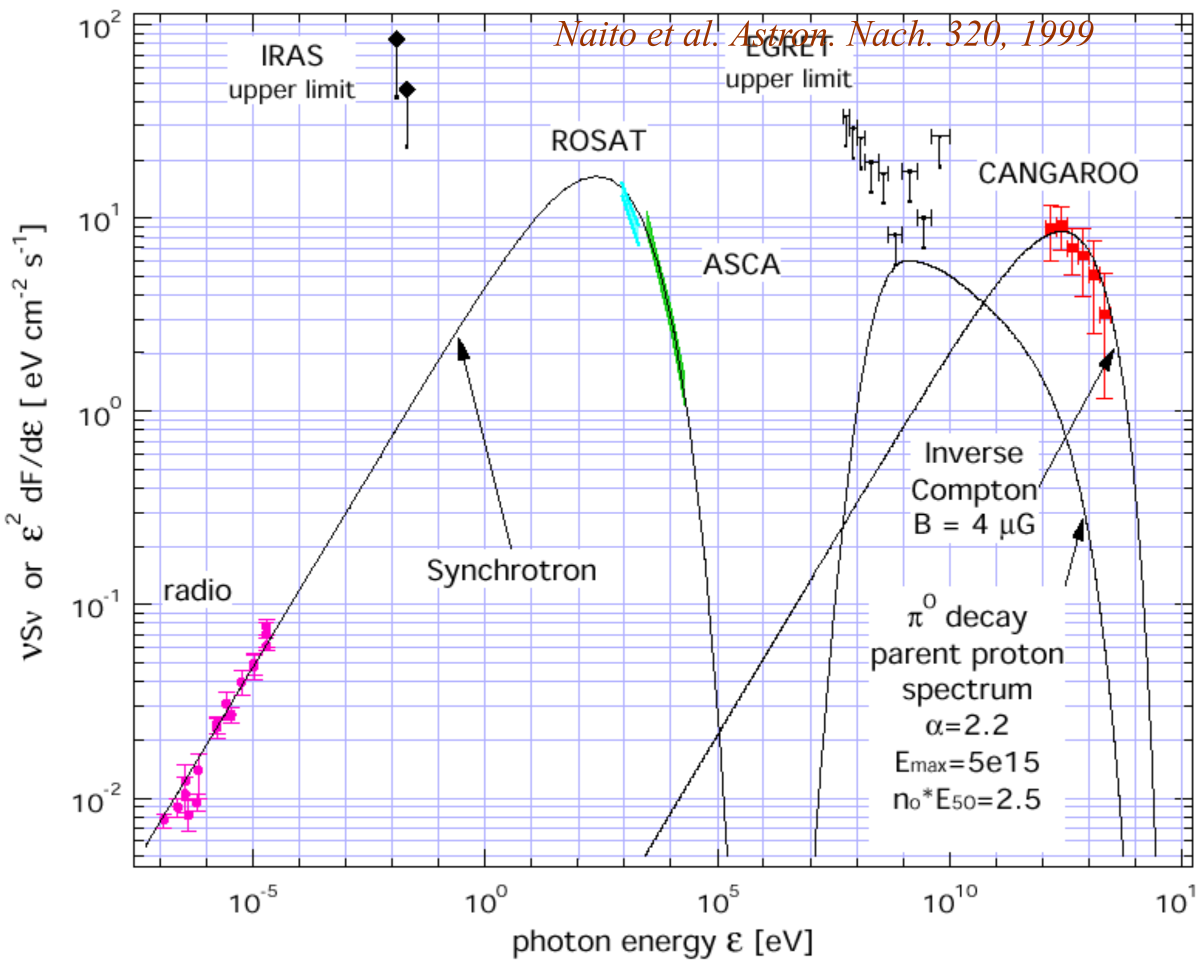
S. Fegan, astro-ph/0102324

Supernova remnant: SN1006



SNR: SN1006 - interpretation

- Synch+IC
- Only IC?
- No pro-tons?



TeV observations of AGNs

Source	Energy (GeV)	Flux ($\times 10^{-11} cm^{-2} s^{-1}$)	Group	EGRET source
<u>Blazars: XBL</u>				
Markarian 421	260	variable	Whipple, HEGRA, CAT	yes
$z = 0.031$				
Markarian 501	260	variable	Whipple, HEGRA, CAT, TA	no
$z = 0.034$				
1ES2344+514	300	variable	Whipple	no
$z = 0.044$				
PKS2155-304	300	variable	Durham	yes
$z = 0.116$				
1ES1959+650	600	variable	TA	no
$z = 0.048$				
<u>Blazars: RBL</u>				
3C66A	900	variable	Crimea	yes
$z = 0.44$				

(Detection of 1ES1426+428 (z=0.13) is claimed by Whipple but not published)

Krennrich, astro-ph/0101120

AGN: Mrk 421 variability

- Time scale < a few hours
- Correlation with X-ray flux

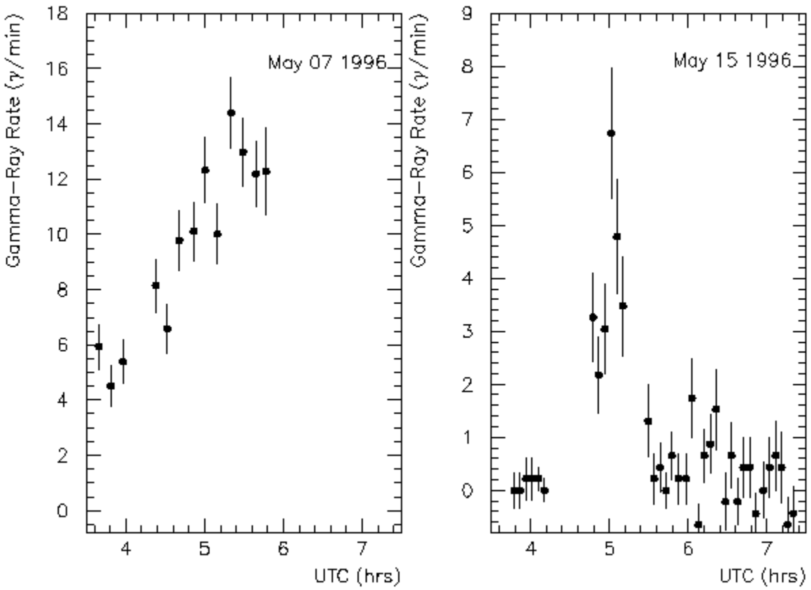
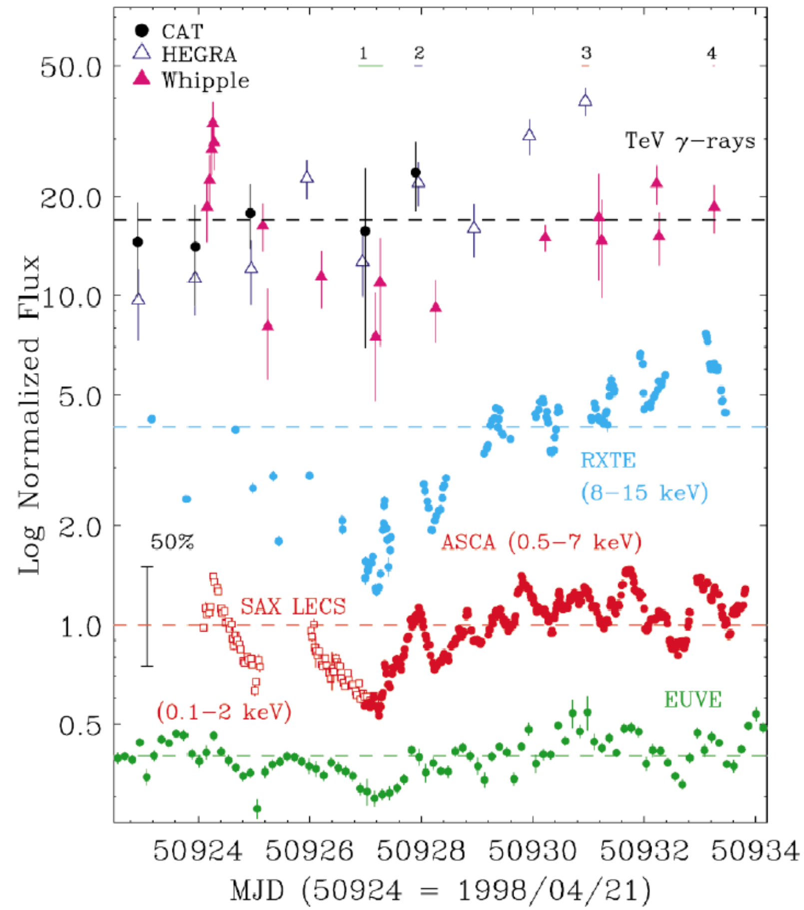


Figure 4. Flux of TeV photons from Mrk 421 as a function of time for two separate flares, indicating variability on the time scale < few hours [35]

Gaidos et al., Nature, 383, 1996



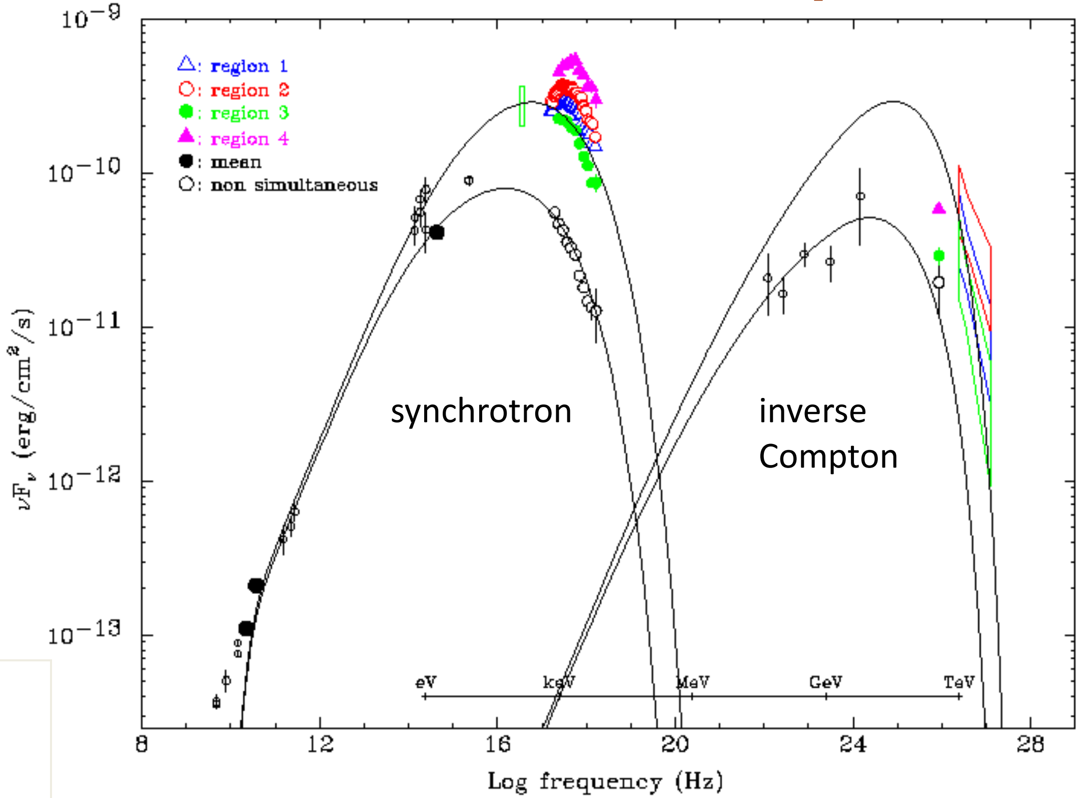
Takahashi et al. ApJ 542, 2000

AGN: Mrk 421 spectrum

z=0.031

- Synchrotron + inverse Compton model works well
  $\Rightarrow e^{\pm}$ origin
- Proton model still possible

Takahashi et al. ApJ 542, 2000



One-zone SSC model

δ=14, B=0.14G

AGN: TeV gamma-ray absorption by IR background

IR Background

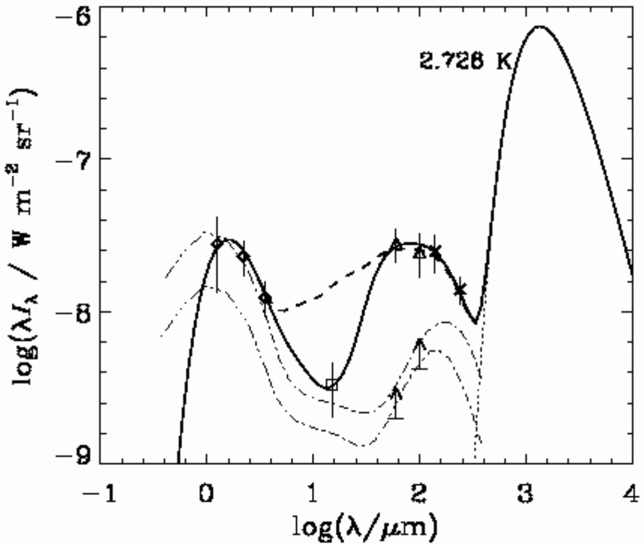


Figure 1: Infrared background radiation field. Recent determinations from DIRBE [6] (diamonds), ISOCAM[7] (square), DIRBE[8] (triangles), and FIRAS[9] (crosses) are compared with the models of Malkan and Stecker[2] (dot-dash curves; the dot-dot-dot dash curves are an extrapolation of the Malkan and Stecker models used in ref. [20]. The lower limits are from ref. [10]. In this paper we model the IR background by the solid curve; thick dashed curve is allowed if the ISOCAM point is considered a lower limit.

Mean free path for e^+e^- pair production

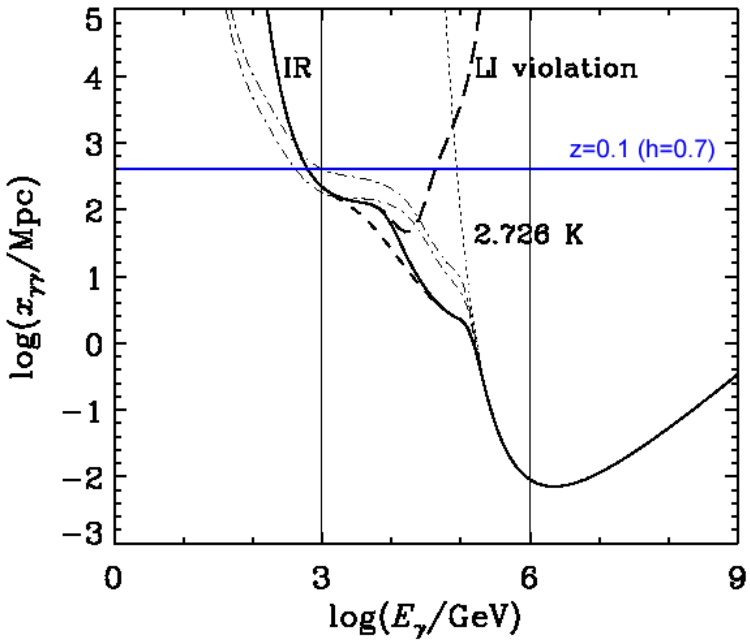


Figure 2: Mean free path for photon-photon pair production in the infrared–microwave background radiation. The curves correspond to those in Fig. 1 except that the effect of Lorentz Invariance violation discussed in Section 4 is shown by the long dashed curve.

Protheroe et al. astro-ph/0005349

AGN: Mrk 501 spectrum

z=0.033

Crisis?↓

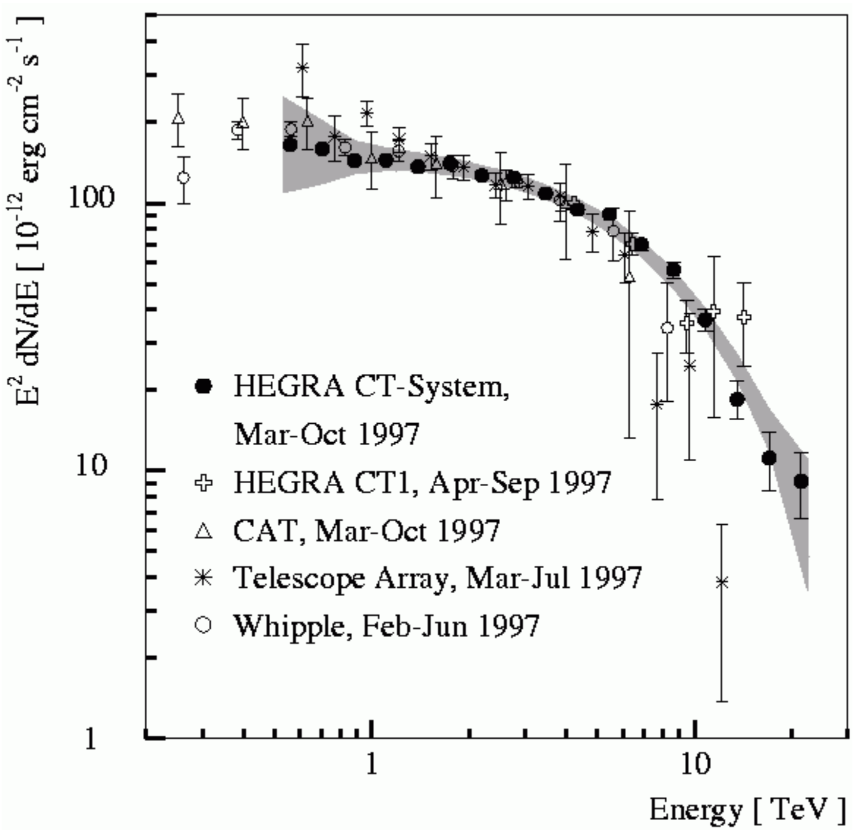


Fig. 12. The Time-averaged spectrum of Mrk 501 during 1997,

Aharonian et al. A&Ap 349, 1999

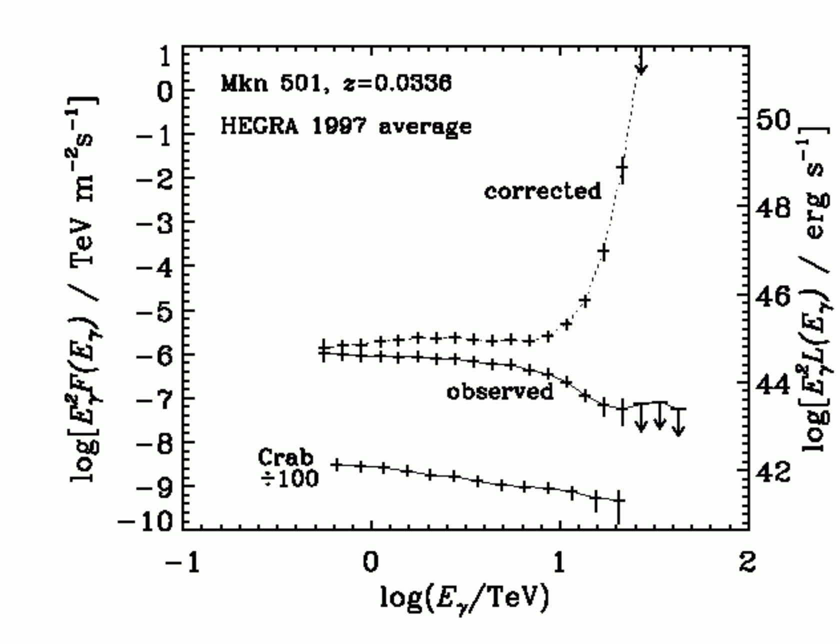


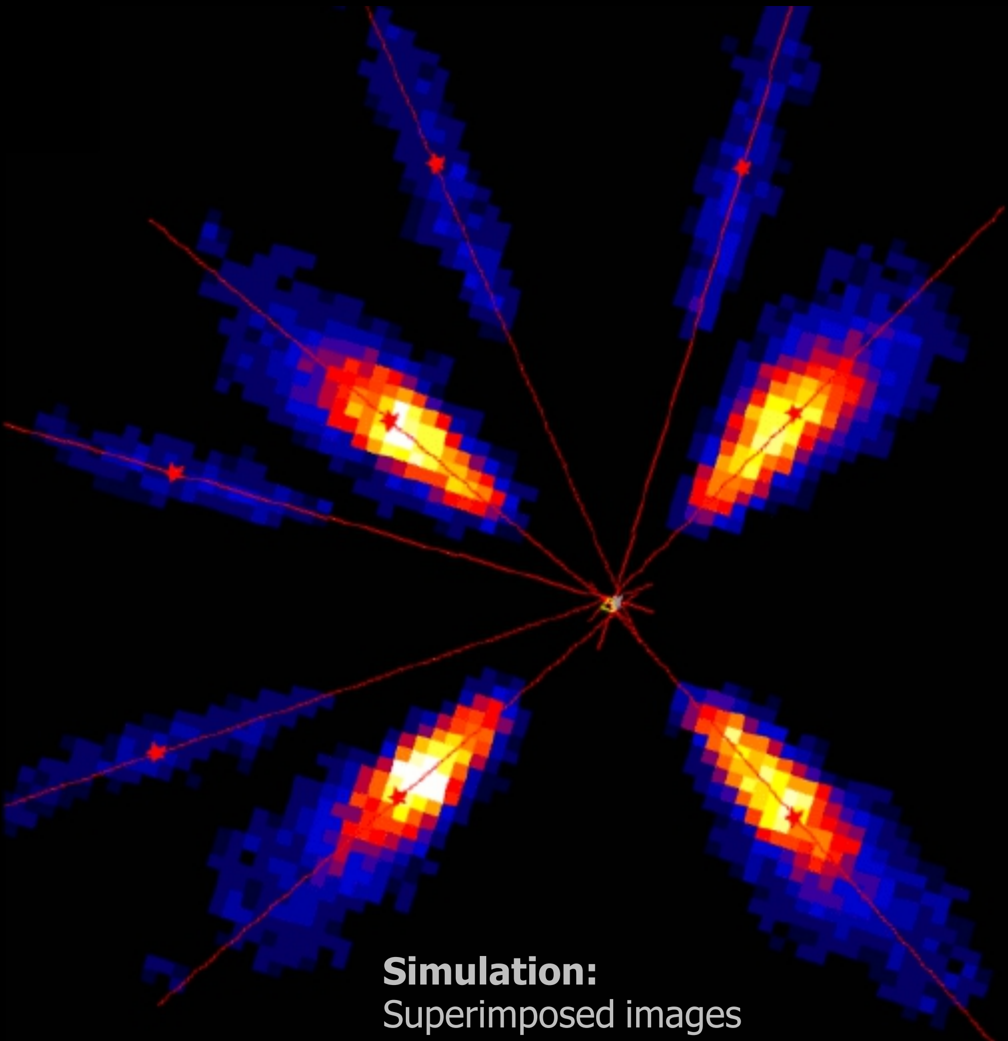
Figure 3: The time-averaged spectrum of gamma-rays from Markarian 501 observed in 1997[18] is compared with the spectrum of the Crab Nebula observed in 1997–8[21, 22]. The spectrum of Markarian 501 after correction for absorption in the infrared background is also shown assuming $H_0 = 65$ km s^{-1} Mpc^{-1}. The right hand scale shows the luminosity for Markarian 501.

Protheroe et al. astro-ph/0005349

How to do better with IACT arrays?

- More events
  - More photons = better spectra, images, fainter sources
    - Larger collection area for gamma-rays
- Better events
  - More precise measurements of atmospheric cascades and hence primary gammas
    - Improved angular resolution
    - Improved background rejection power

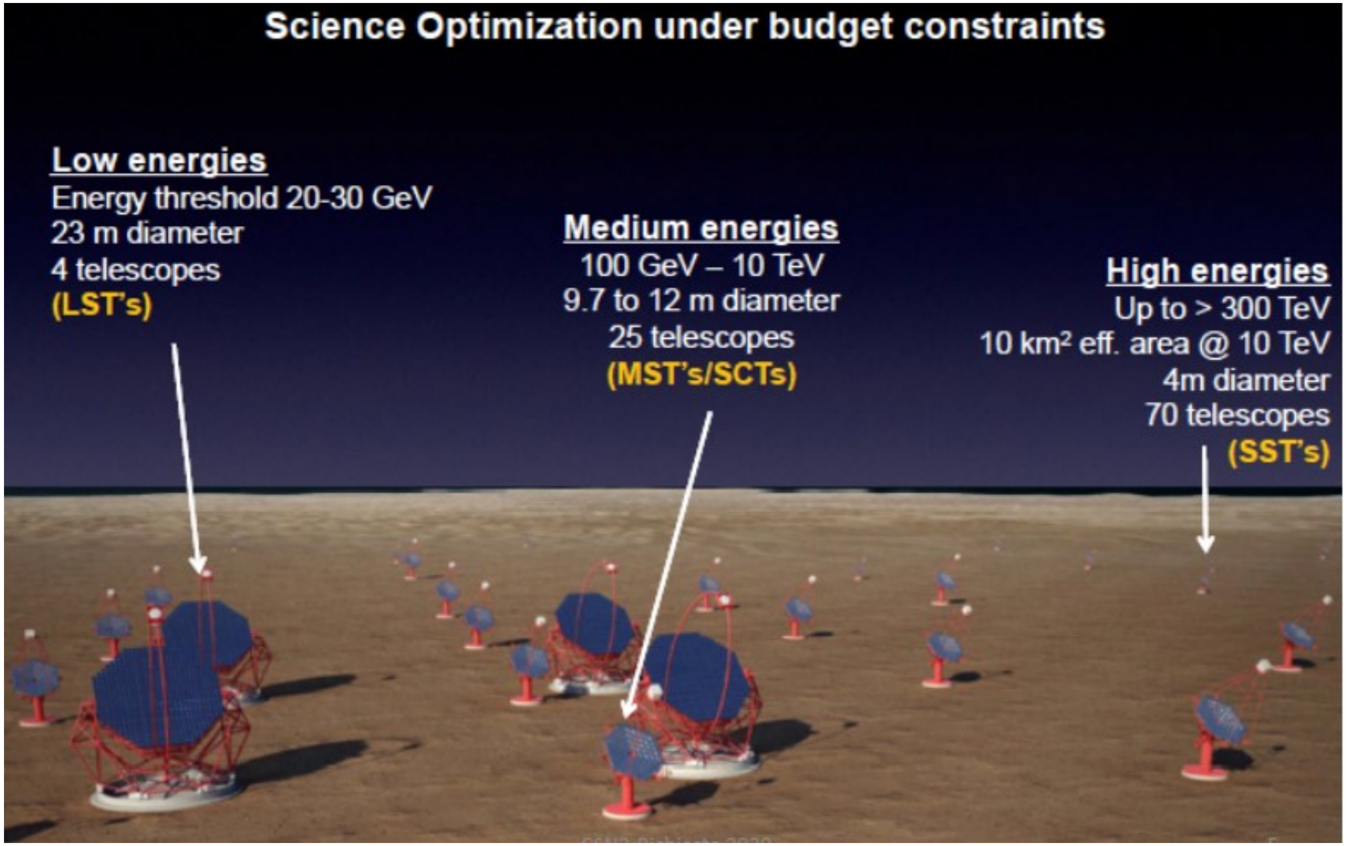
☛ More telescopes !



Simulation:
Superimposed images from 8 cameras

CTA Consortium

CTA Design


Science Optimization under budget constraints
Low energies
Energy threshold 20-30 GeV
23 m diameter
4 telescopes
(LST's)
Medium energies
100 GeV – 10 TeV
9.7 to 12 m diameter
25 telescopes
(MST's/SCTs)
High energies
Up to > 300 TeV
10 km² eff. area @ 10 TeV
4m diameter
70 telescopes
(SST's)

CLUE (Cherenkov Light Ultraviolet Experiment)

INFN PISA
ISTITUTO NAZIONALE DI FISICA NUCLEARE

Michele Giunta

MWPC detector

Aluminium mirror

- Site: La Palma (Canarian Islands), 2200 m a.s.l.
- 9 mirrors F1 1.8 m diameter, 45 m spaced.
- Experiment sensible to UV light: detects the Cherenkov photons produced by the charged components of VHE showers in the lower part of atmosphere, near the observation level.
  - Advantage: no NSB.
  - Disadvantage: not many photons.
- On focal planes there are MWPC chambers with TMAE as photoconverter gas and with quartz window.

CLUE

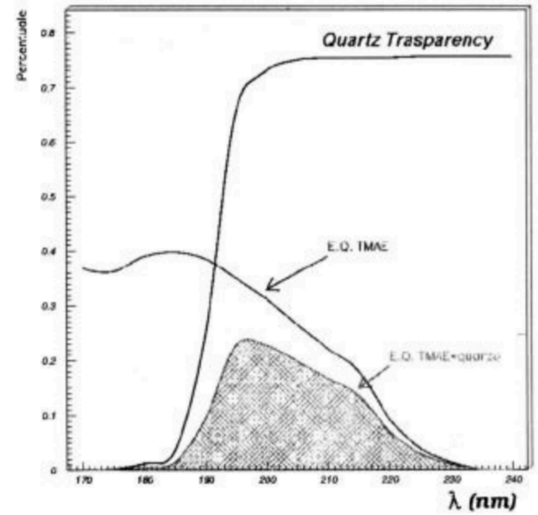


Figure 1: *Quantum efficiency of TMAE and quartz trasmittance.*

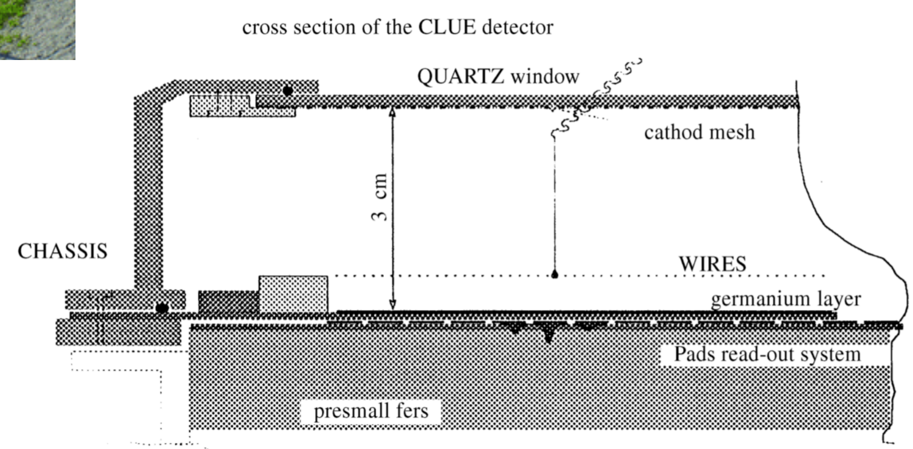
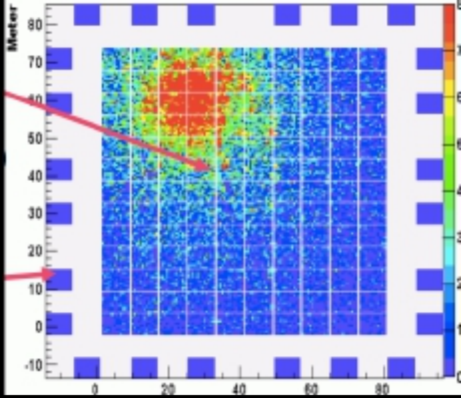


Fig. 1. Cross section of the last MWPC used in the CLUE experiment.

The idea was to detect UV Cherenkov Light form CR showers in atmosphere

Personal contribution:
Built and tested the MWPC
Installed The telecopes in La Palma
DAQ and data analysis

Tibet ASγ and ARGO

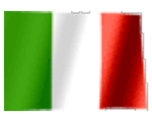


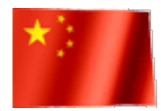
- Tibet air-shower array
  - High altitude – 4300 m a.s.l.
- Muon detector expansion underway for ASγ
- ARGO-YBJ: Resistive Plate Chamber Carpet
  - ~100 m x ~100 m , ~1 TeV threshold for gammas
  - Interesting results from 5 year northern sky survey

The ARGO-YBJ experiment

Collaboration Institutes:

- ✓ Chinese Academy of Science (CAS)
- ✓ Istituto Nazionale di Fisica Nucleare (INFN)





INFN and Dpt. di Fisica e Ing. Dell'Innovazione Università, Lecce
INFN and Dpt. di Fisica Universita', Napoli
INFN and Dpt. di Fisica Universita', Pavia
INFN and Dpt di Fisica Università "Roma Tre", Roma
INFN and Dpt. di Fisica Univesità "Tor Vergata", Roma
INAF/IFSI and INFN, Torino
INAF/IASF, Palermo and INFN, Catania

IHEP, Beijing
Shandong University, Jinan
South West Jiaotong University, Chengdu
Tibet University, Lhasa
Yunnan University, Kunming
Hebei Normal University, Shijiazhuang

The basic concepts

…for an unconventional air shower detector

- *HIGH ALTITUDE SITE* (YBJ - Tibet, 4300 m a.s.l, ~ 600 g/cm²)

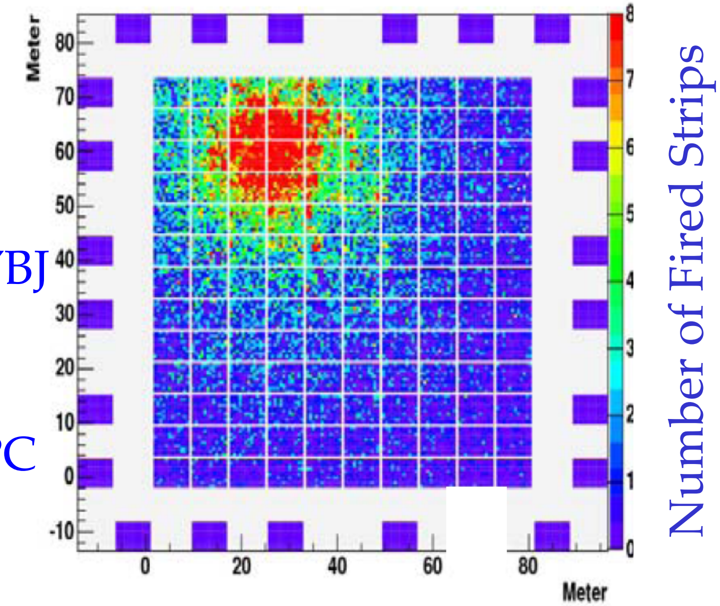
- *FULL COVERAGE* (RPC technology, 92% covering factor)

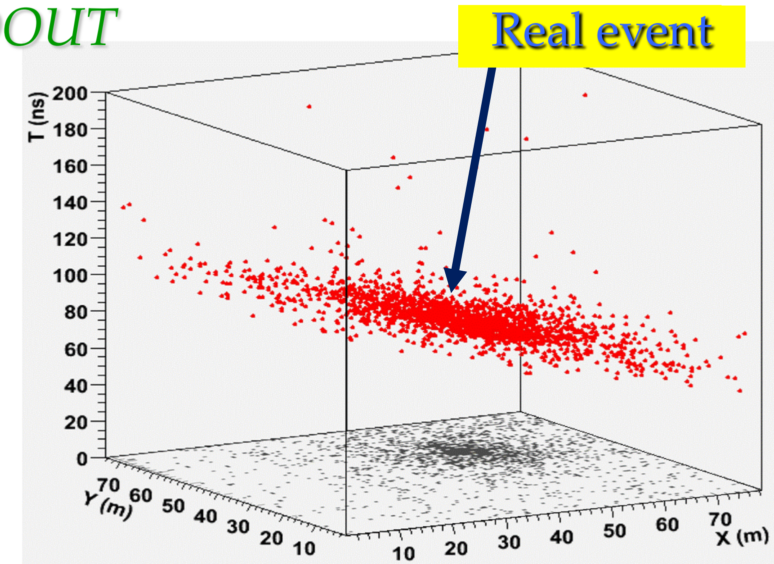
- *HIGH SEGMENTATION OF THE READOUT* (small space-time pixels)

  Space pixels: 146,880 strips (7×62 cm²)
  Time pixels: 18,360 pads (56×62 cm²)

… in order to:

- image the shower front
- get an energy threshold of a few hundreds of GeV





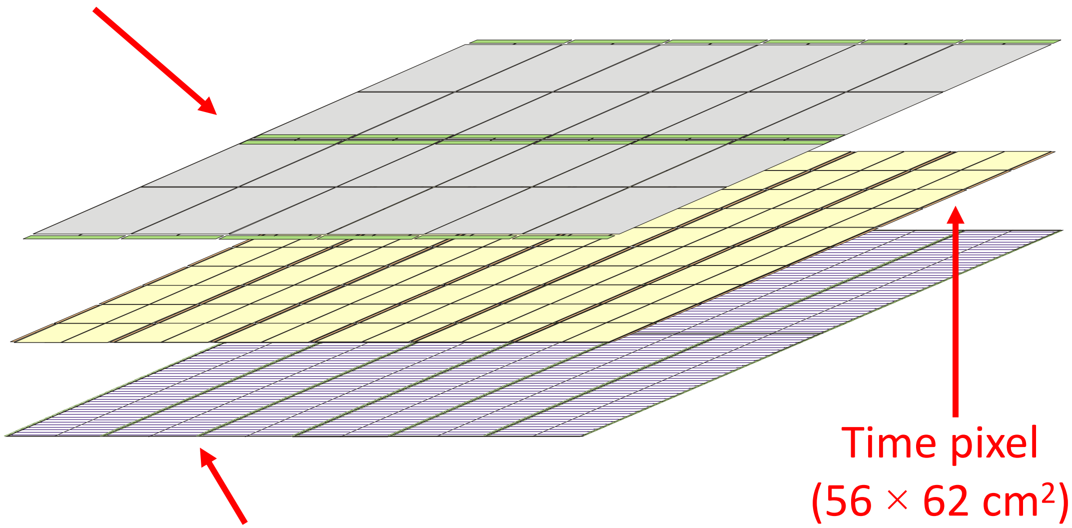
The basic concepts

…extending the dynamical range

- *ANALOG READ-OUT* → *PeV* (3672 1.40 × 1.25 m² "big pads")

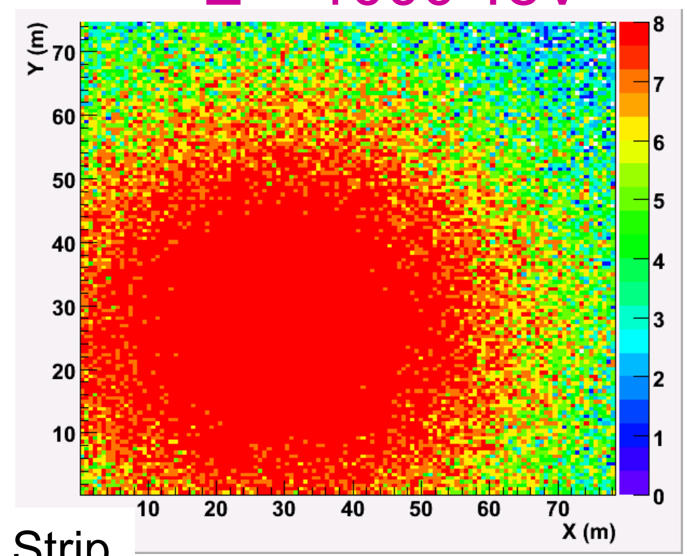
E ~ 1000 TeV

Big Pad for charge read-out

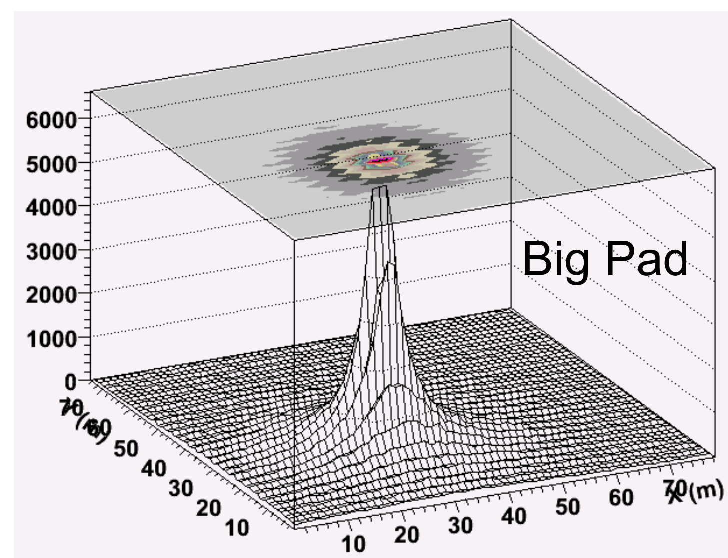


Time pixel
(56 × 62 cm²)
#18360

Space (digital) pixel
(6.7 × 62 cm²)
#146880

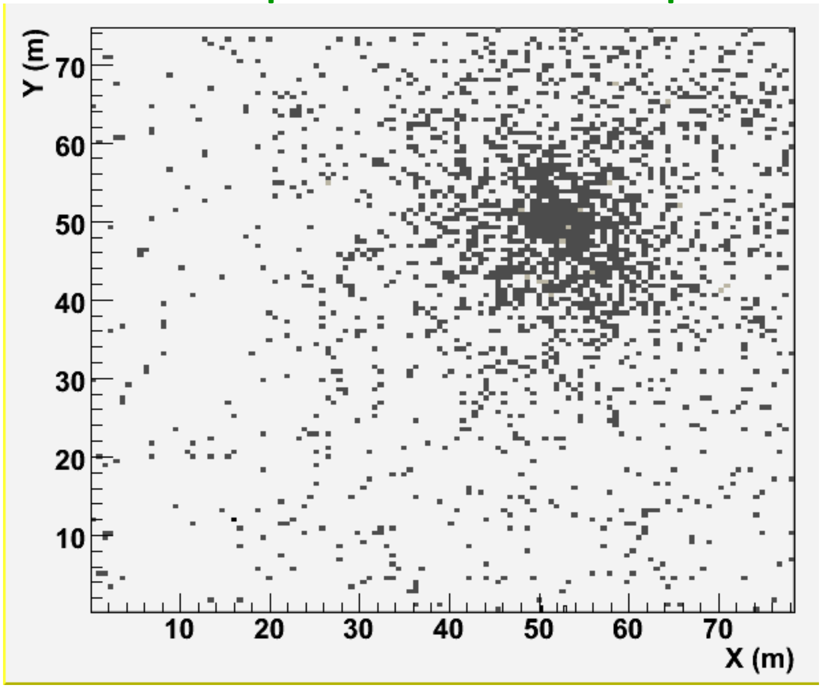


Strip

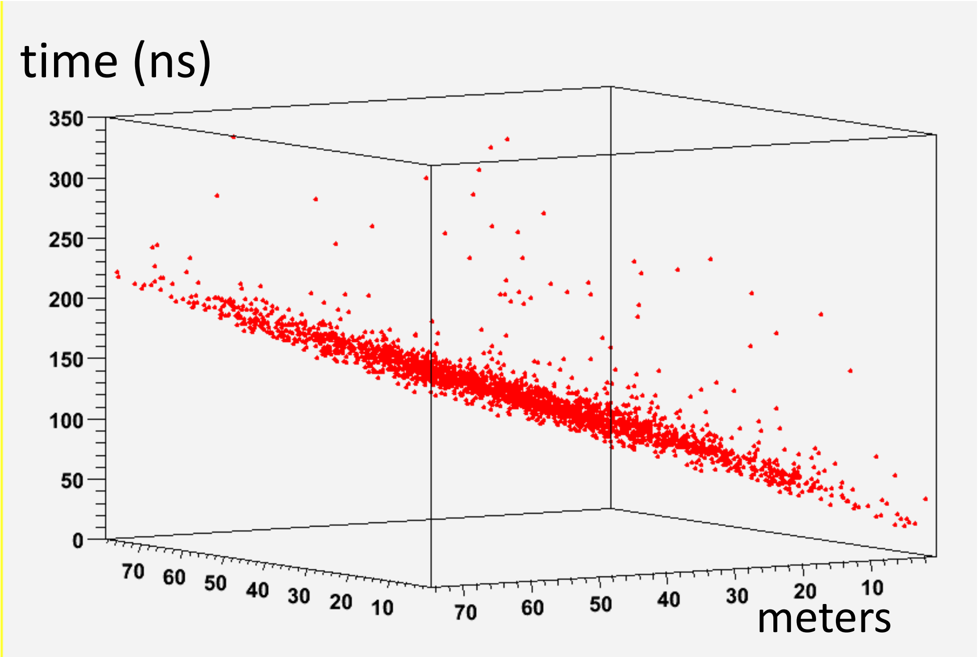


Shower reconstruction

Fired pads on the carpet



Arrival time vs position



Arrival direction measurement:

- Core reconstruction: Maximum Likelihood Method applied to the lateral density profile of the shower
- Fit of the shower front with a conical shape

ARGO-YBJ: a multi purpose experiment

- Sky survey $-20° \leq \delta \leq 80°$ above 300 GeV (γ-sources)
- High exposure for flaring activity (γ-sources, GRBs, solar flares)
- CR physics 1 TeV → 10^4 TeV
  - (p + He) spectrum at low energies
  - Knee region
  - p-air and p-p cross sections
  - Anisotropies
  - Multicore events
- CR $\bar{p}/p$ flux ratio at TeV energies
- Solar and heliospheric physics

Physics with EAS

Gamma-ray astronomy

- large field of view (~2 sr)
- duty cycle ∼100%
- energy threshold: few hundreds of GeV .

Cosmic ray physics

- Proton-air cross section measurement
- Anti-p /p ratio at energy ≈ TeV with the Moon shadow
- Spectrum and composition up to ≈ 10^3 TeV
- Anisotropy
- Sun shadow studies
- Atmospheric effects on showers (thunderstorms)

Scaler data

Countings of each cluster recorded every 0.5 s

for 4 levels of coincidence: $n \geq 1, 2, 3, 4$

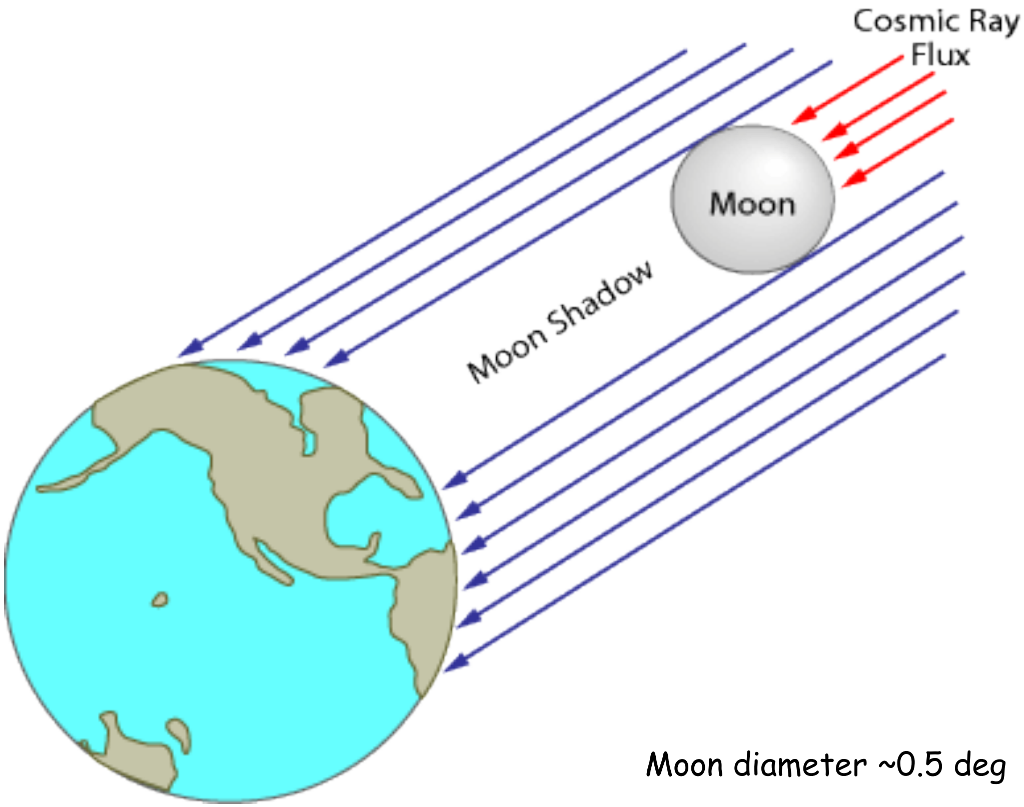
NO event reconstruction - NO primary direction

Physics: study of transient phenomena

- Gamma Ray Bursts in the 1-100 GeV energy range
- Sun and Heliosphere physics (solar flares, GLE…)
- Atmospheric effects on cosmic rays (thunderstorm)
- Environemental studies (Radon monitor)

AND detector monitoring

The Moon shadow

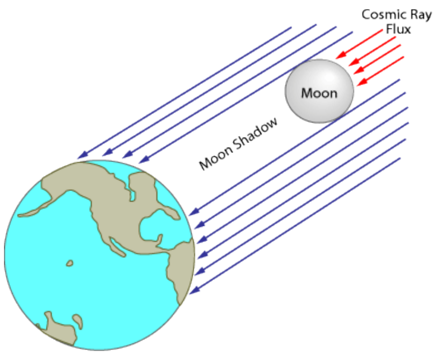


Moon diameter ~0.5 deg

Deficit of cosmic rays in the Moon direction

The Moon shadow

An important tool to check the detector performances



- Size of the deficit $\Rightarrow$ angular resolution
- Position $\Rightarrow$ pointing accuracy
- West displacement $\Rightarrow$ Energy calibration

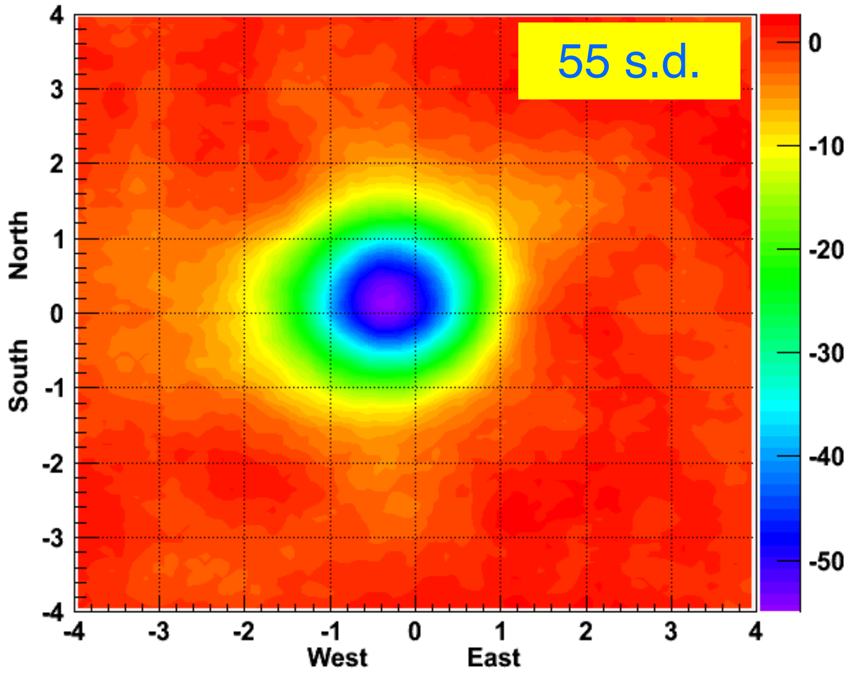
Geomagnetic bending $\approx$ 1.57° Z / E (TeV)

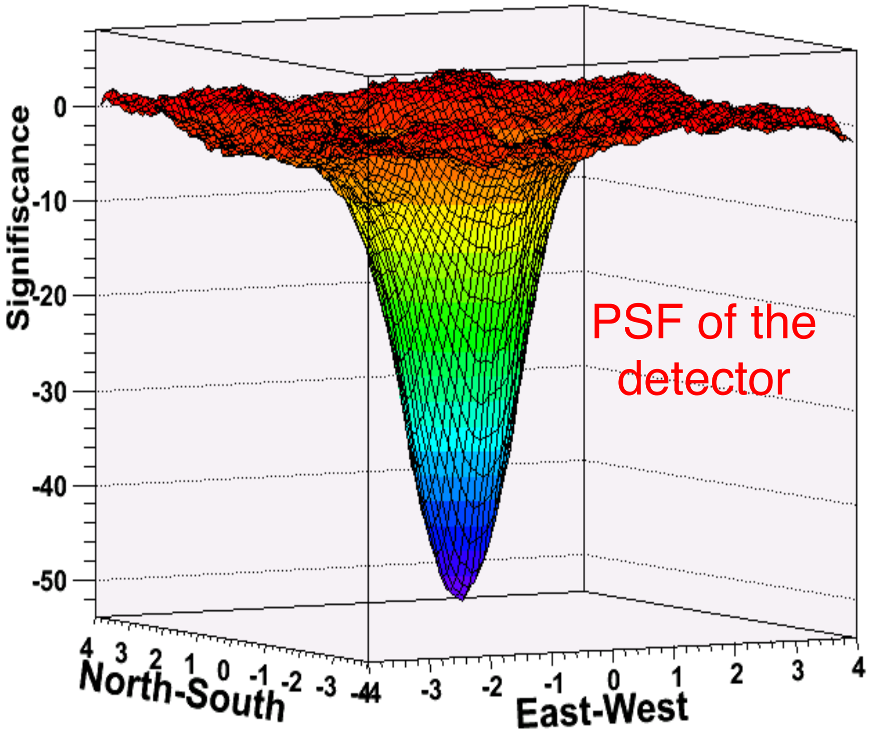
Physics: antiproton / proton ratio in cosmic rays (P.Camarri talk)

The Moon shadow

Data 2006 - 2009

3200 hours on-source



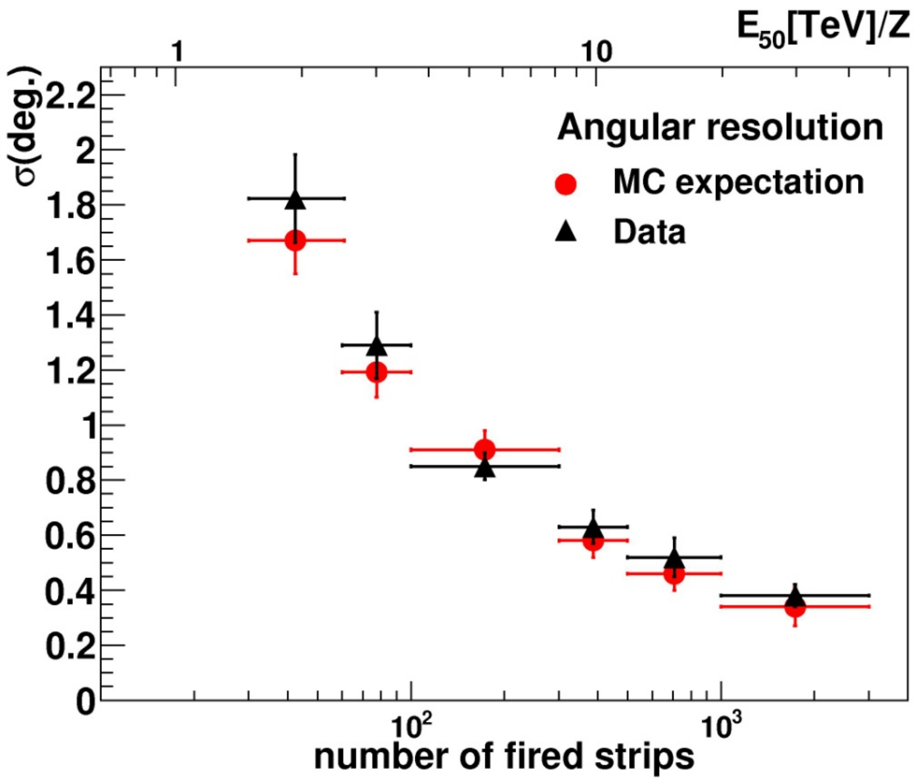


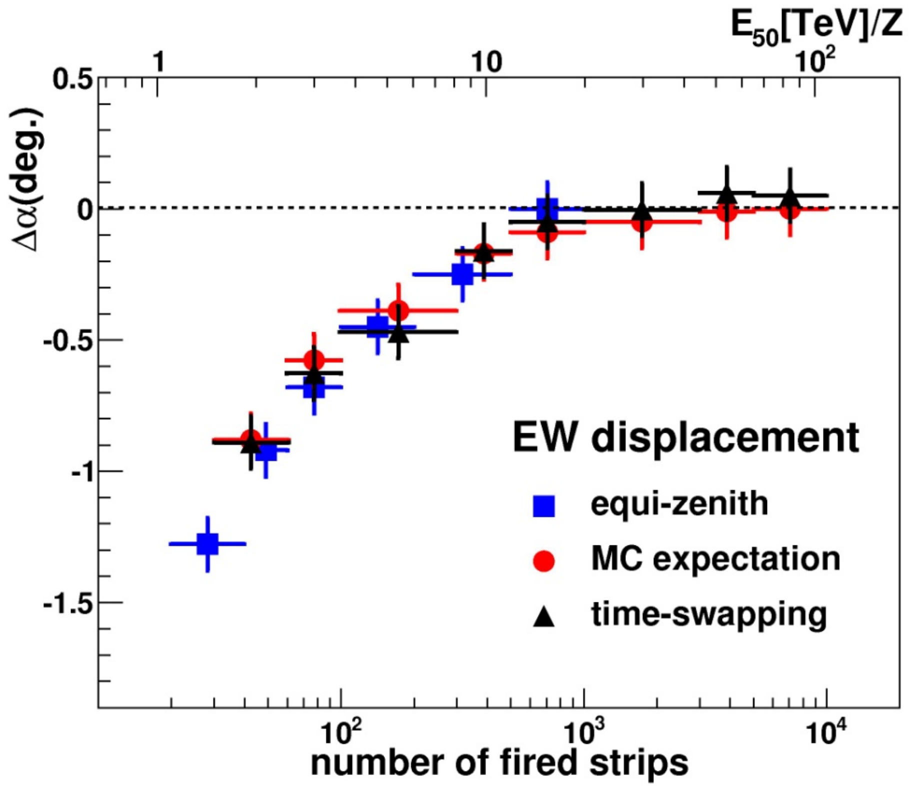
$N_{hit} > 100$

≈ 10 standard deviations /month

Angular Resolution

West displacement of the Moon shadow caused by the Geomagnetic field





Gamma Ray Astronomy

- Blazar Mrk421: 3 years of monitoring
- Galactic source MGRO J1908+06 : puzzling high flux
- Crab Nebula: flare in September 2010

NEW

- GRBs at GeV energies

Gamma ray astronomy

$N_{hit} > 40$ Very small showers !

$E_{med} \approx 1$ TeV for a spectrum slope 2.6

No gamma/hadron discrimination

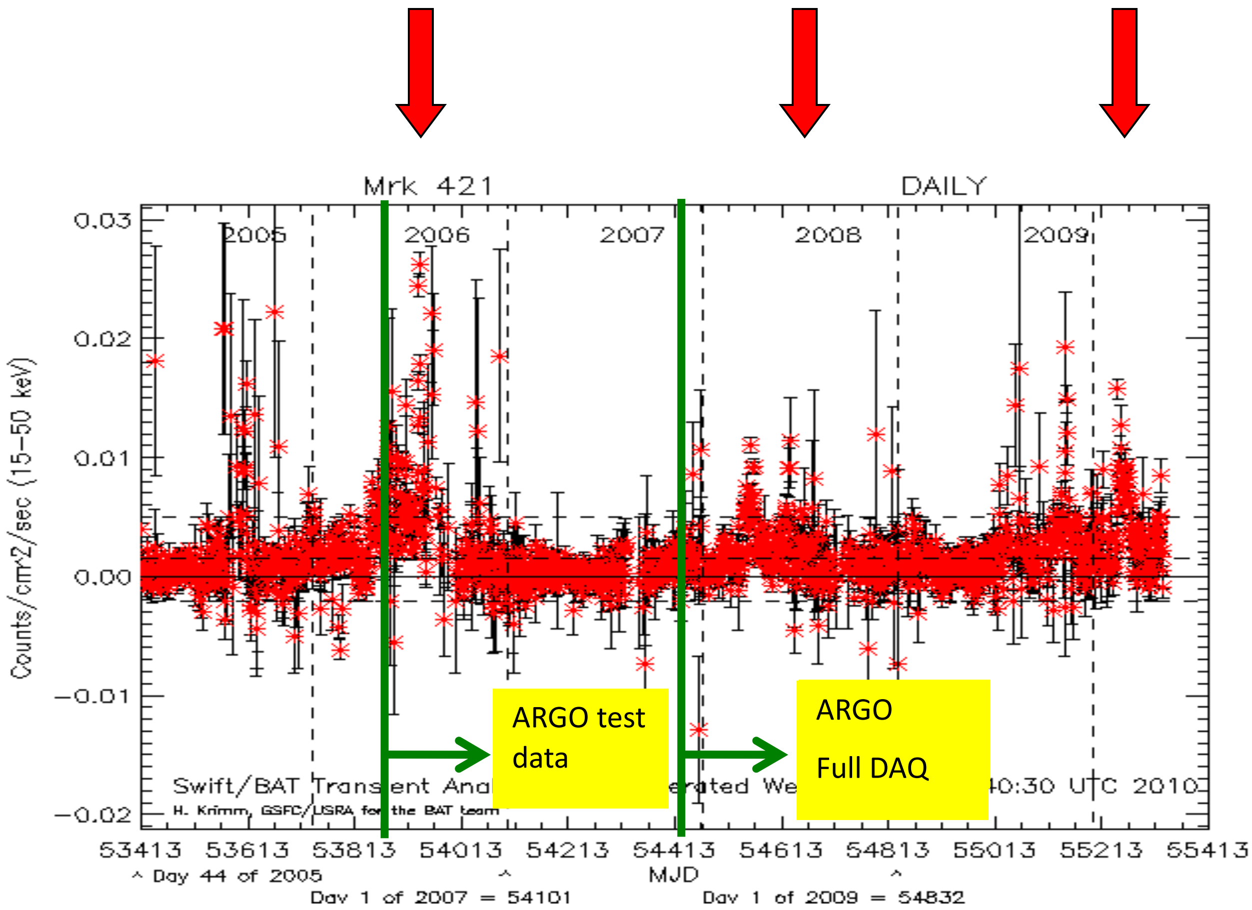
Cosmic ray background determination:

1) Time swapping method
2) Equi-zenith method

Mrk421
3 years of monitoring

Mrk421 flaring activity

FLARES July 2006 June 2008 Feb 2010



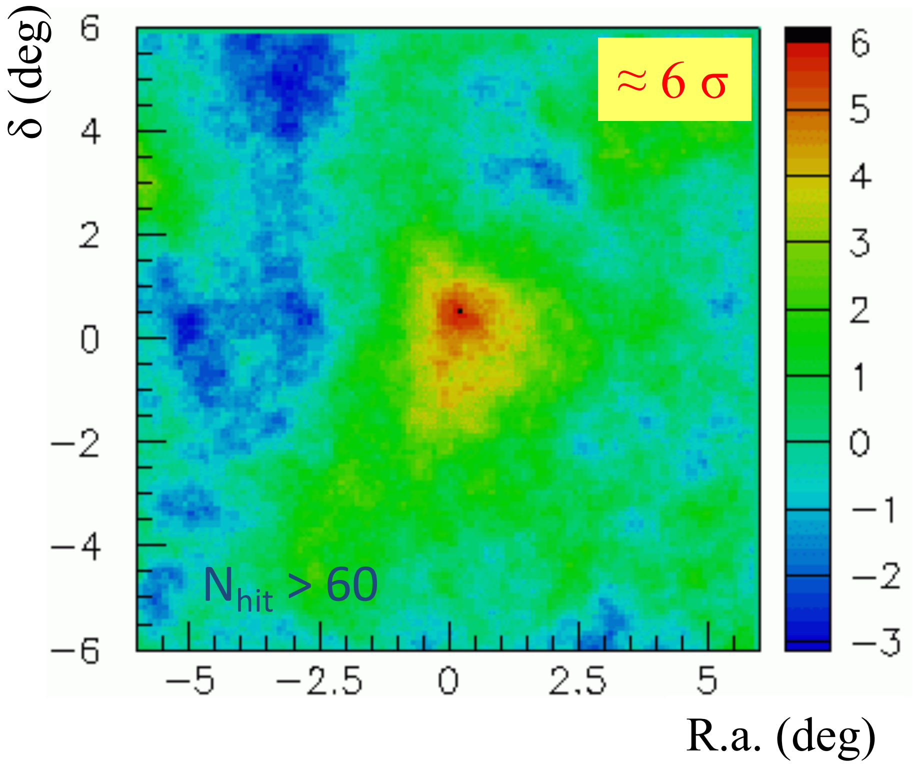
SWIFT

X-rays

(15-50 keV)

Mrk 421
the first source observed by ARGO

July 2006 flare



ARGO Test Data

2006 days 187-245 (110 hours)

Flux ≈ 3-4 Crab

NO Cerenkov measurements at that time

Mrk421
June 2008 flare
from optical to TeV energies

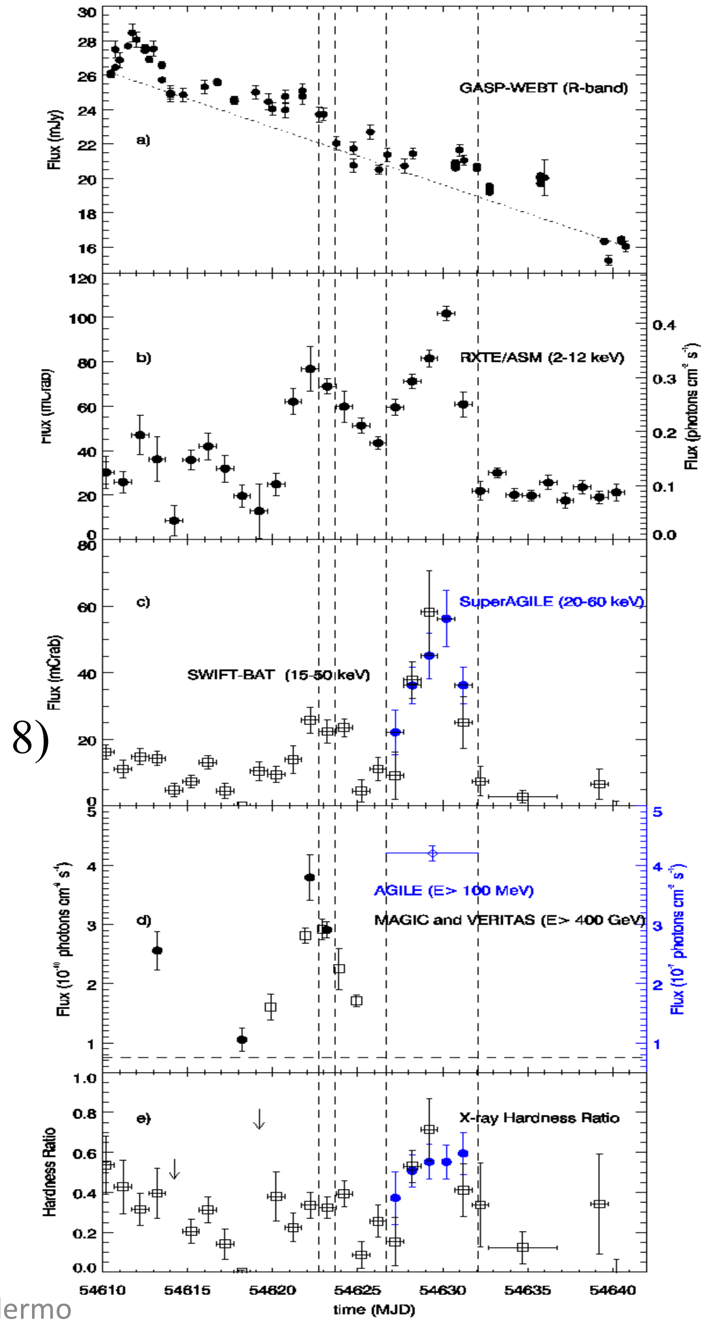
data from:

- GASP-WEBT (R-band)
- Rossi RXTE/ASM (2-12 keV)
- Swift/BAT (15-50 keV)
- SWIFT (UVOT & XRT; June 12-13)
- AGILE (E > 100 MeV; June 9-15)
- MAGIC and VERITAS (E> 400 GeV; May 27 - June 8)

2 flaring episodes: June 3-8 and June 9-15

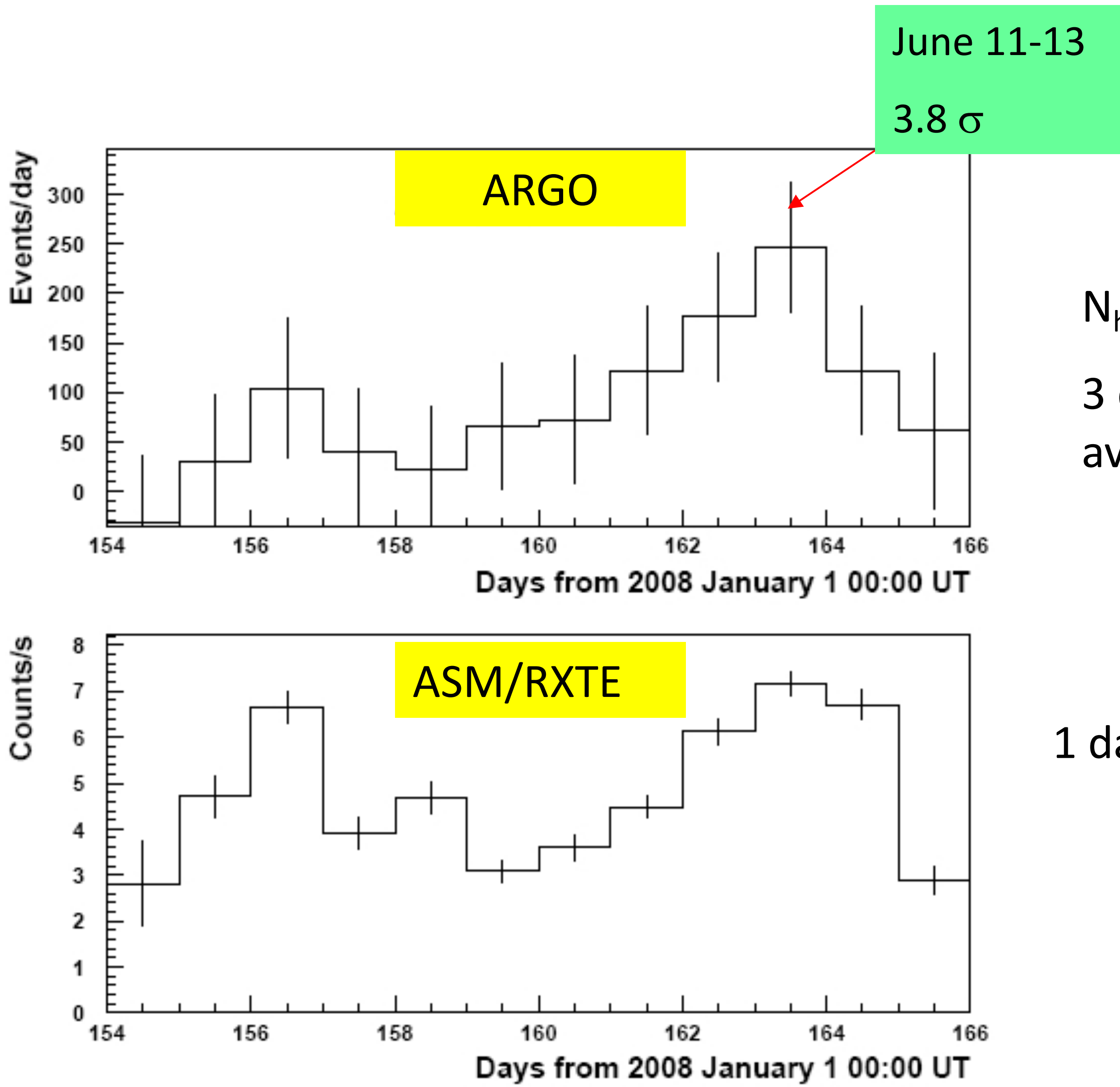
No Cherenkov data after June 8

the moonlight hampered the Cherenkov telescopes measurements



Donnarumma et al. (2009)

Mrk 421 - June 2008 flare

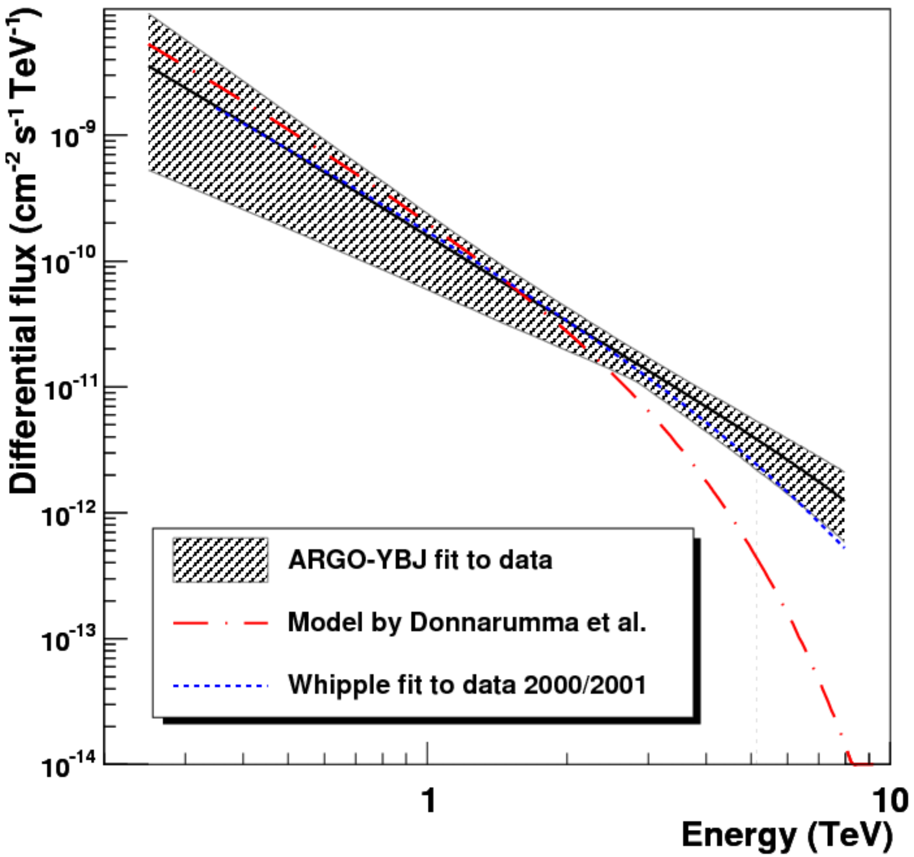


$N_{hit} > 100$

3 days average

1 day average

Mrk421 11-13 June 2008 flare



The spectrum slope is consistent with that measured by Whipple in 2000/2001 observing a similar flare

Flux (E > 1 TeV) ~ 6 Crab

G. Aielli et al. – ApJL 714 (2010) L208

Power law spectrum + EBL absorption :

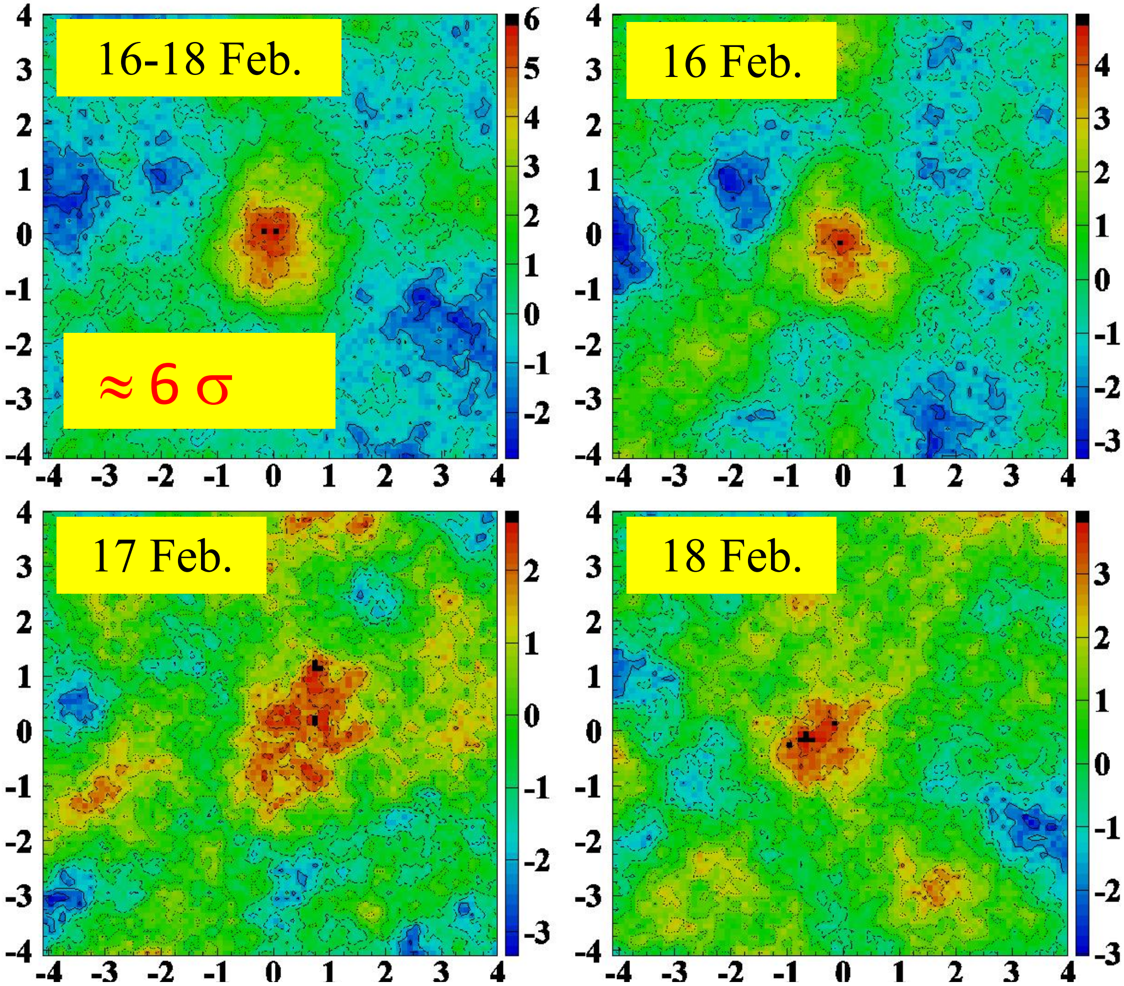
$$dN/dE = (3.2 \pm 1.0) \cdot 10^{-11} \quad (E/2.5)^{-2.1 \pm 0.7} e^{-\tau(E)} \text{ ev cm}^{-2} \text{ s}^{-1} \text{ TeV}^{-1}$$

Mrk421 16-18 Feb 2010

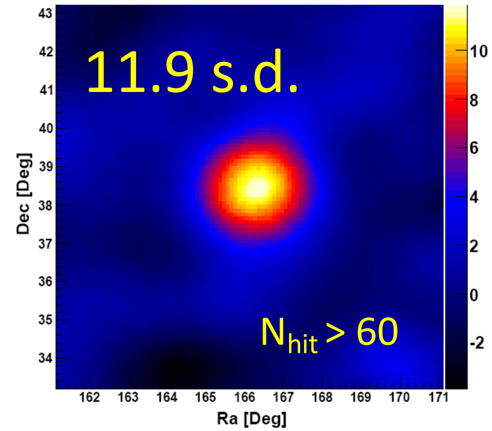
- ARGO observed a strong flare on 16-18 Feb. at 6 s.d.
- Flux > 3 Crab

Peak flux (16 Feb) > 10 Crab

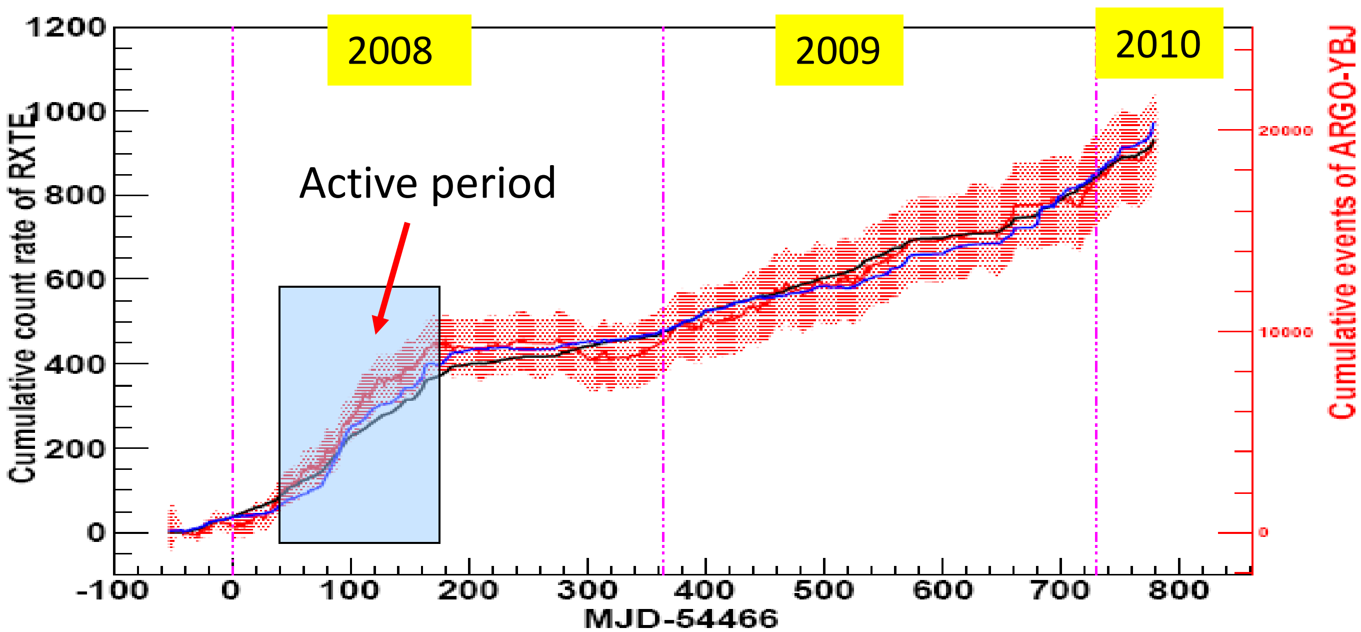
- For the first time an EAS-array observed a TeV flare at 4-5σ on a daily basis.
- VERITAS reported similar observation in Atel #2443.



Mrk421 - Correlation with X-rays



Integral counting rate



TeV γ rays ARGO

X- rays 2-12 KeV RXTE/AMS

X –rays 15-30 KeV SWIFT/BAT

Data sample:

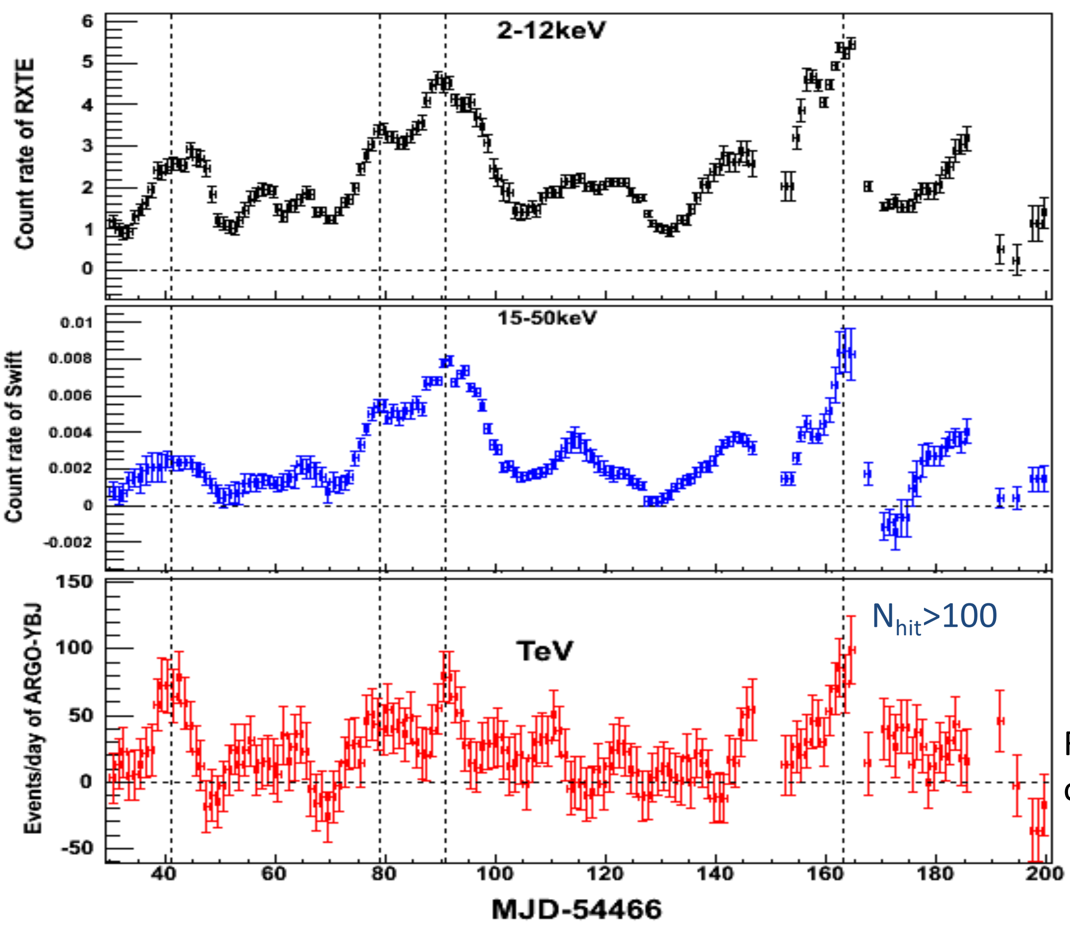
- Nov 2007 – Feb 2010
- effective time: 676 days

Ligth curve during the 2008 active period

RXTE

SWIFT

ARGO

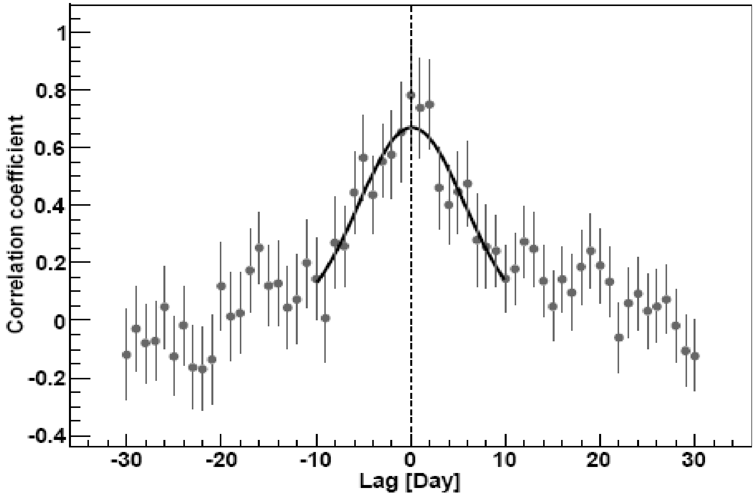


Daily counting rate

Running average on 5 days

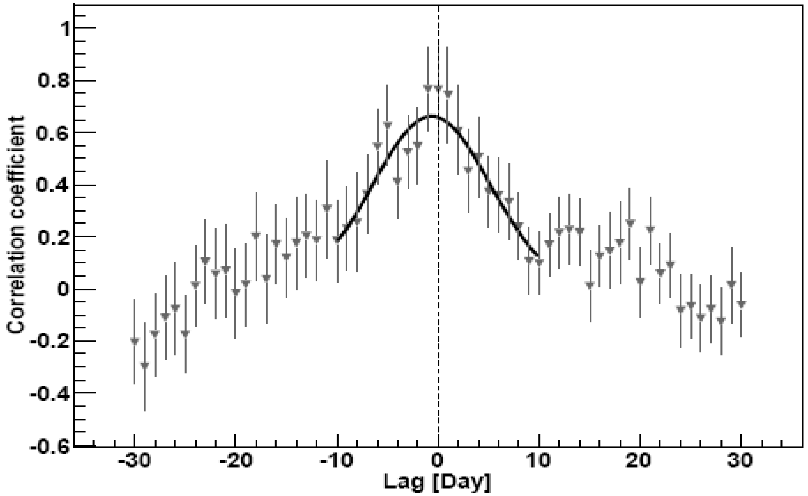
Correlation between X-rays and gamma rays

Correlation coefficient vs. time lag



RXTE & ARGO

Time lag = 0.11 ± 0.55 days

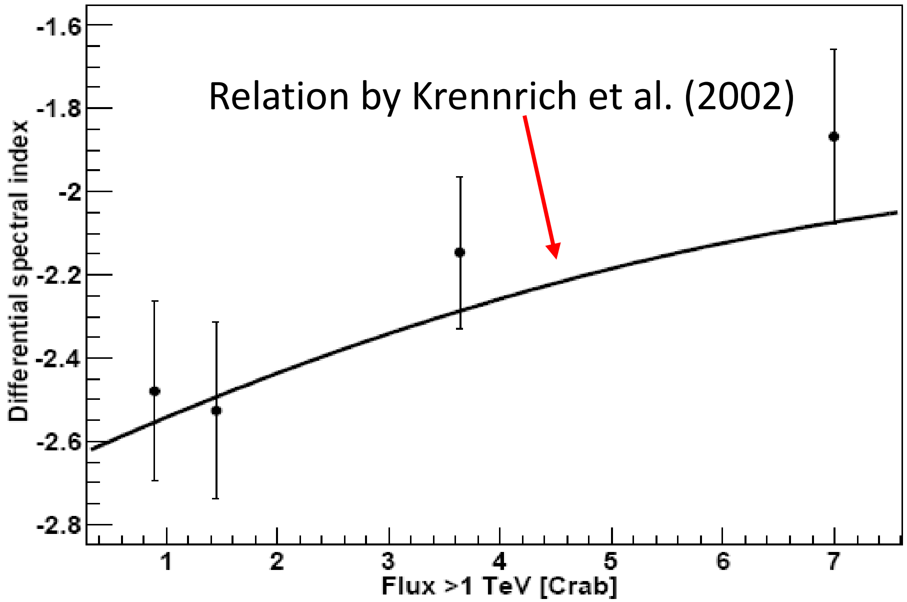


Swift & ARGO

Time lag = -0.65 ± 0.61 days

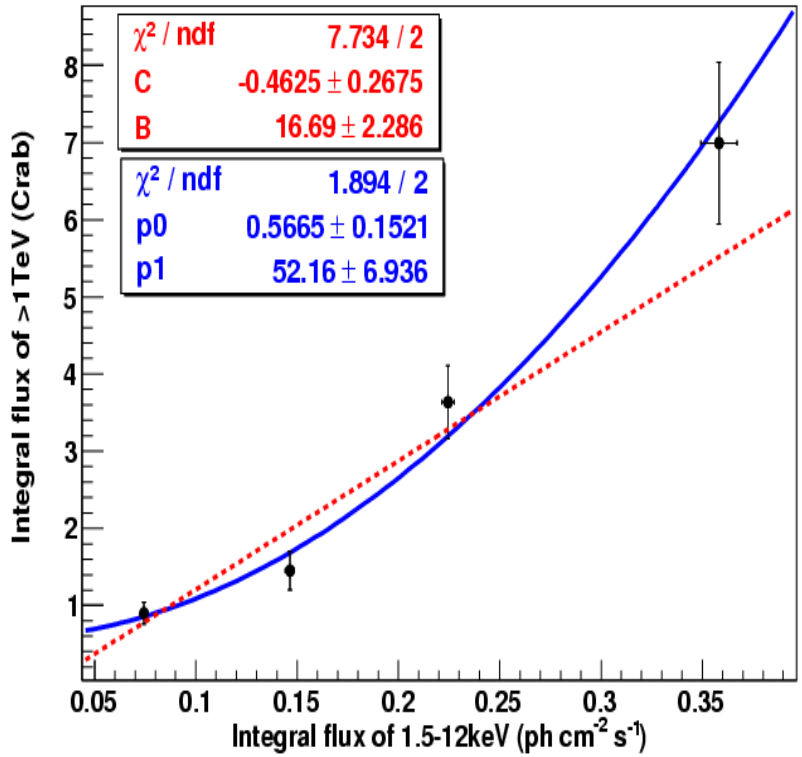
General spectral features

Spectral index vs. flux



The TeV spectrum hardens increasing the flux

TeV flux vs. X-ray flux



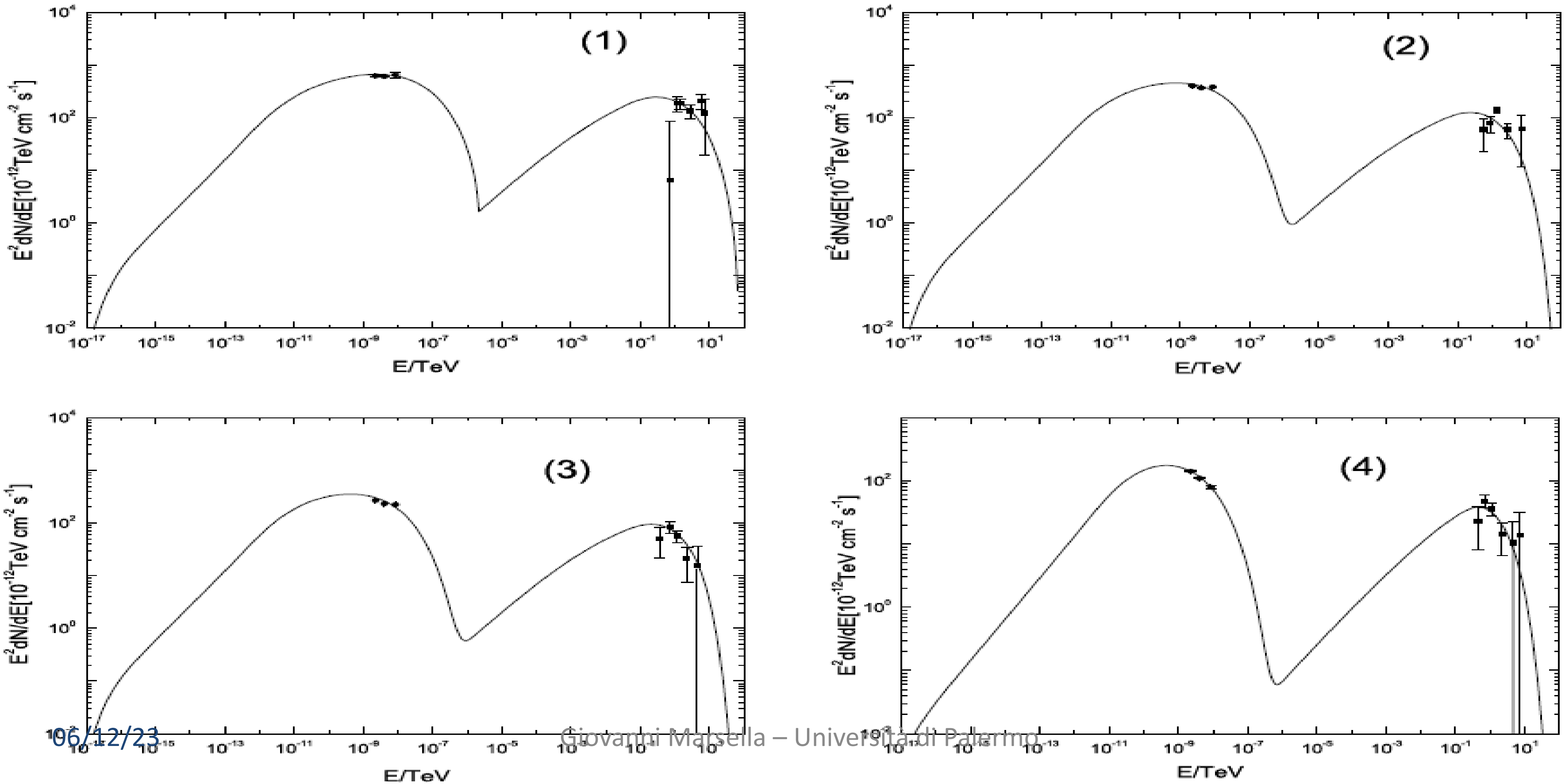
The relation between TeV and X-ray fluxes seems to be quadratic

Spectral Modeling

One-zone SSC model

(Mastichiadis & Kirk,1997, Yang et al., 2008)

flux level	γ_{max}	L_e	B (G)	R (cm)	δ	α
1	2×10^6	1.4×10^{-5}	0.15	5×10^{16}	15	1.7
2	1×10^6	1×10^{-5}	0.15	5×10^{16}	15	1.7
3	7×10^5	1×10^{-5}	0.15	5×10^{16}	15	1.7
4	7×10^5	6×10^{-6}	0.08	5×10^{16}	16	1.7



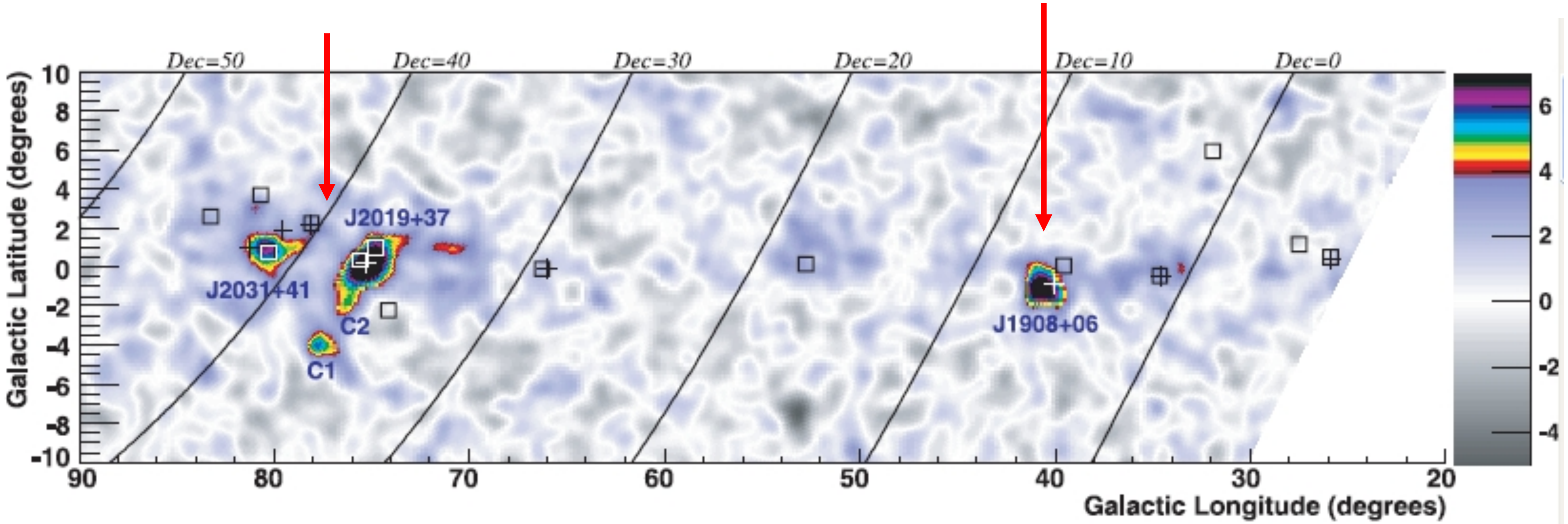
A puzzling source

MGRO J1908+06

MILAGRO galactic plane survey

Cygnus region

MGRO J1908+06



2000-2006 data

Abdo et al., 2007

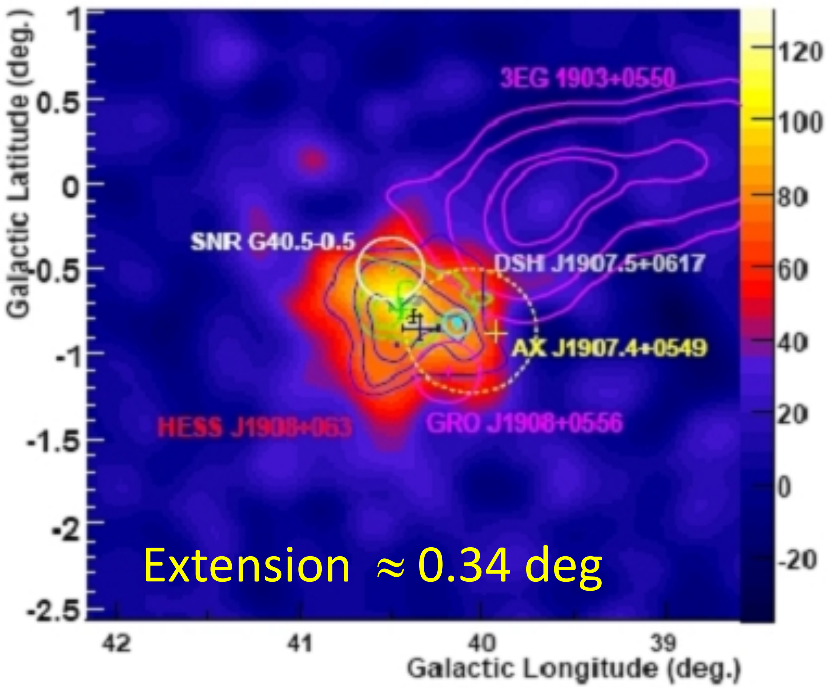
Median energy ≈ 20 TeV

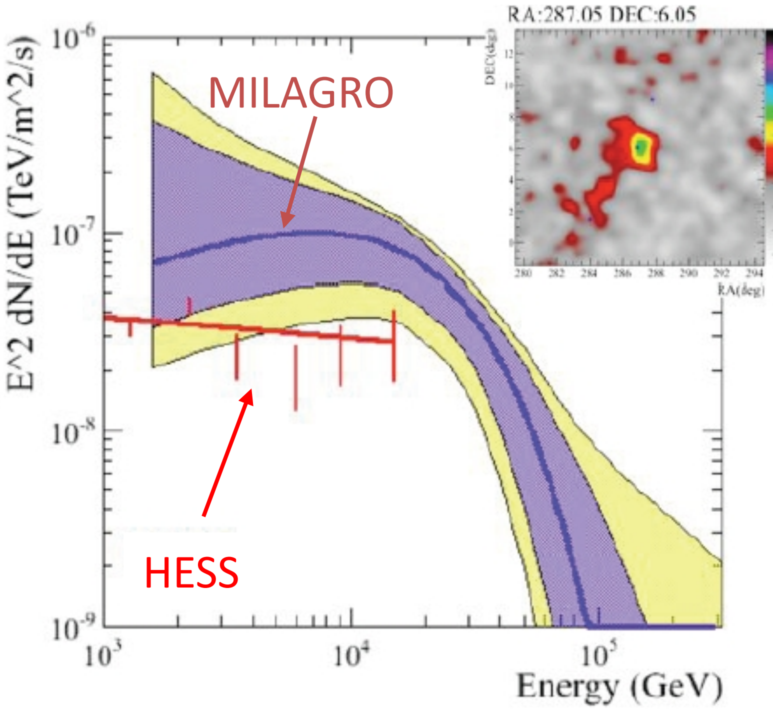
Extended source: extension < 2.6 deg

Flux ≈ 80% Crab

MGRO J1908+06
confirmed by HESS (2009)

Inside the nebula FERMI detected a pulsar with period 106.6 ms





HESS spectrum:

dN/dE = 4.14 10^{-12} $E^{-2.1}$ sec^{-1} cm^{-2} TeV^{-1}

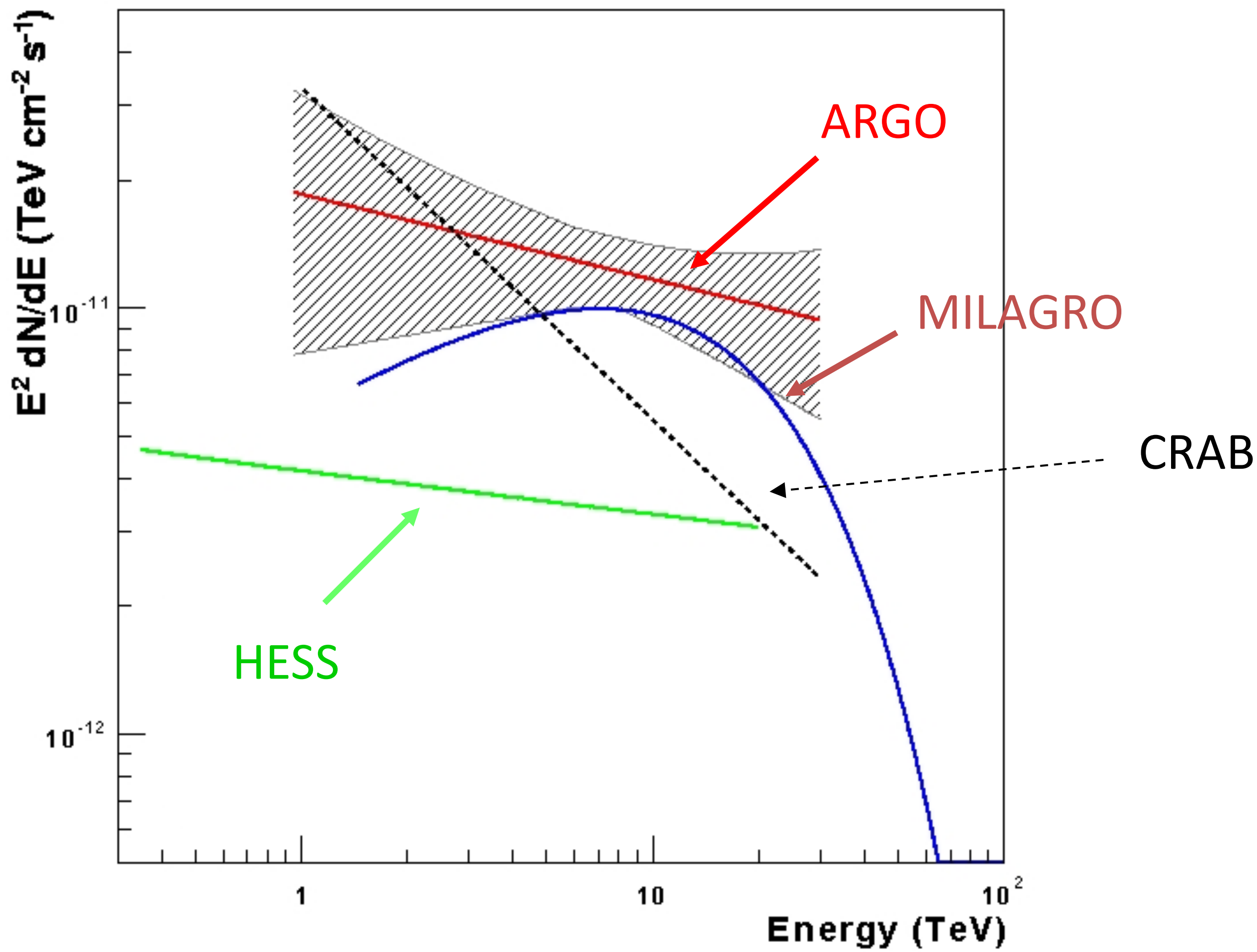
(Aharonian et al., 2009)

Milagro spectrum:

dN/dE = 6.2 10^{-12} $E^{-1.5}$ exp(-E/14.1) sec^{-1} cm^{-2} TeV^{-1}

(Smith et al., 2009)

Energy spectrum



Assumed a power law spectrum

$$dN/dE = (3.6 \pm 0.8)\ 10^{-13}\ (E/\ 6\ \text{TeV})^{-2.2 \pm 0.3}\ \text{ph}\ \ \text{sec}^{-1}\ \text{cm}^{-2}\ \text{TeV}^{-1}$$

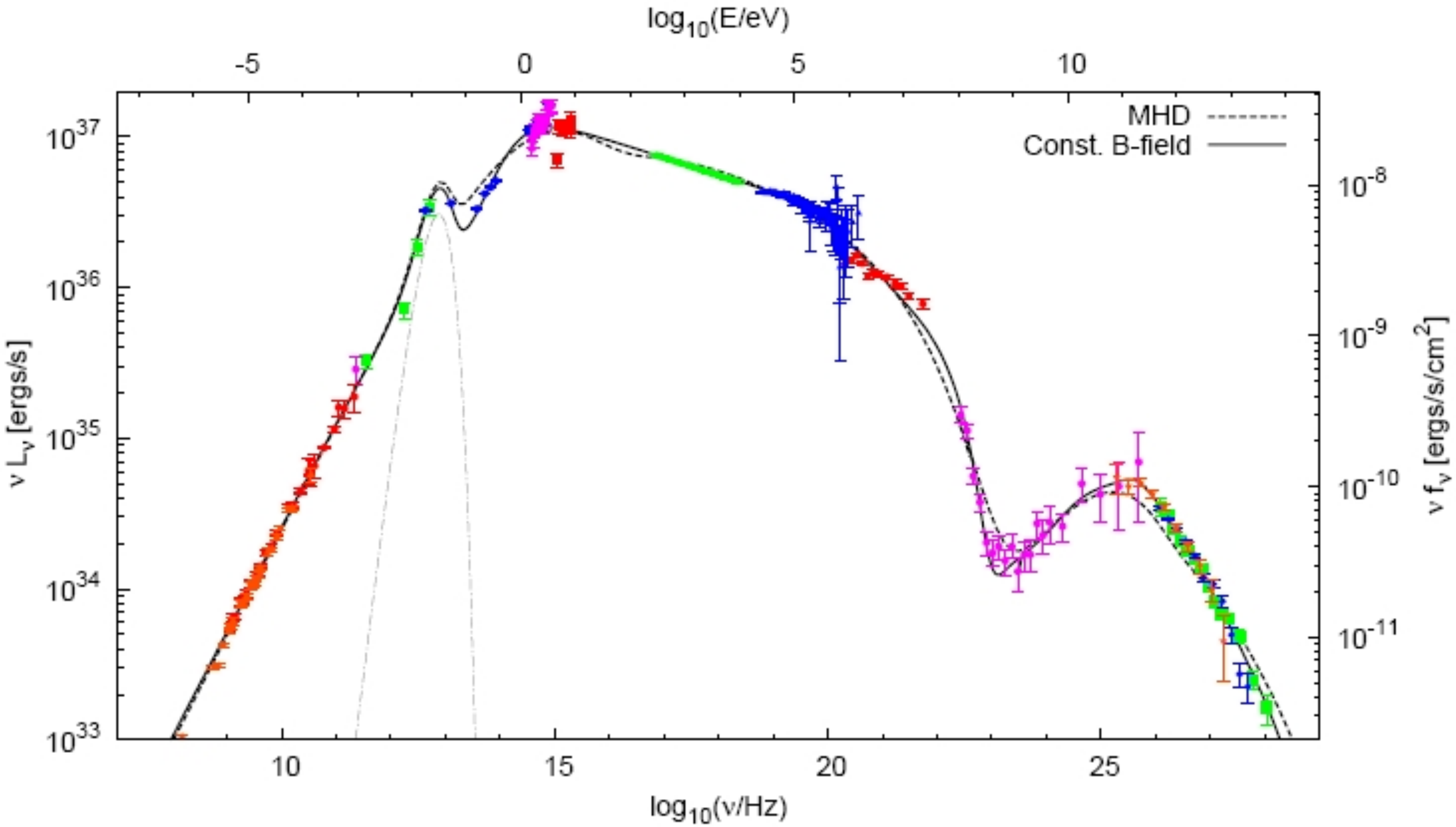
How to intepret this result ?

1) ARGO and Milagro integrate over a larger solid angle and detect something more than HESS
2) The source is variable

Crab Nebula

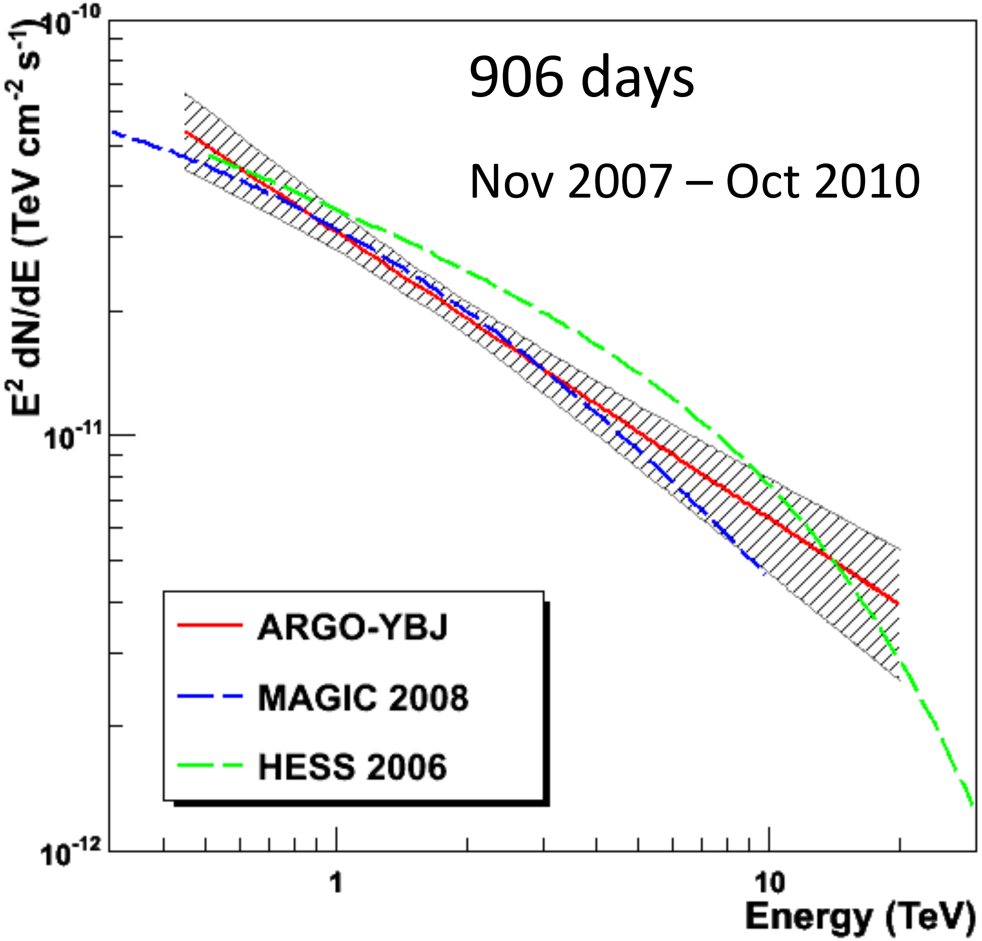
still a standard candle ?

Multiwavelenght Crab Nebula SED



Meyer, Horns, Zechlin 2010

Crab Nebula



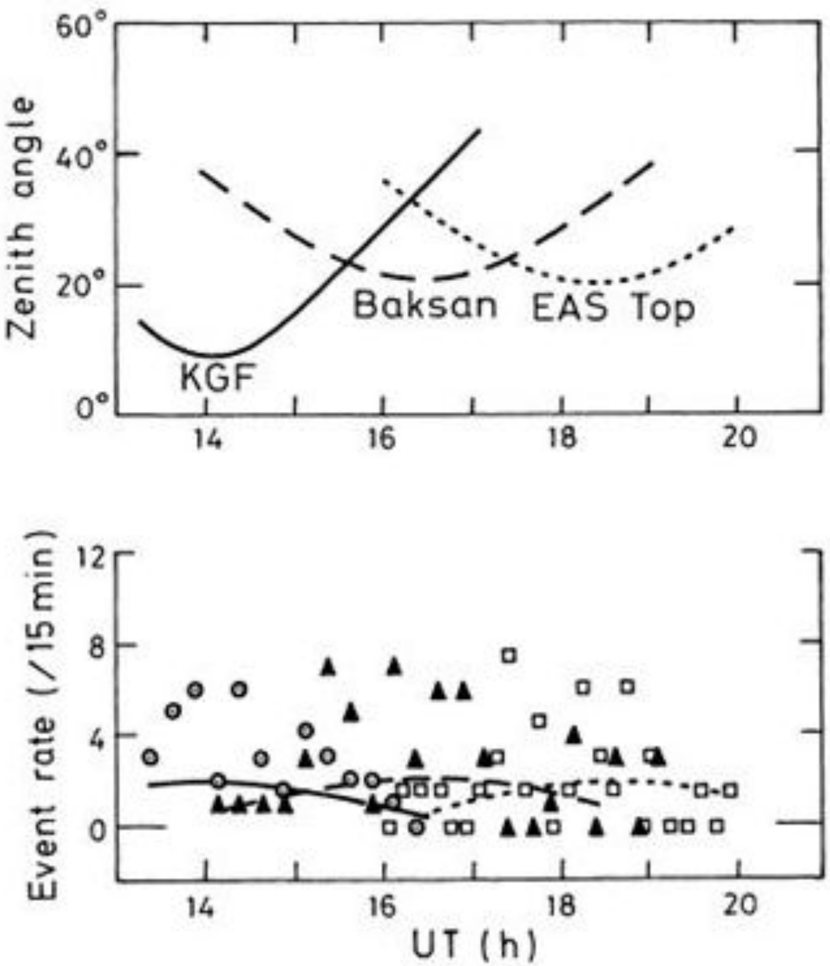
ARGO observes the Crab Nebula for ≈ 5 hours/day in average

≈ 4 σ in 750 h

$$dN/dE = 3.1 \pm 0.3 \;\; 10^{-11} \quad E^{-2.7 \pm 0.14} \;\; \text{ev cm}^{-2}\, \text{s}^{-1}\, \text{TeV}^{-1}$$

Crab Nebula flare at 100 TeV ?

23 February 1989



- KGF (India) 3.4 σ
- Baksan (USSR) 3-4 σ
- EASTOP (Italy) 2.3 σ

chance probability ≈ 10^{-5} - 10^{-7}

KGF flux (> 100 TeV) =

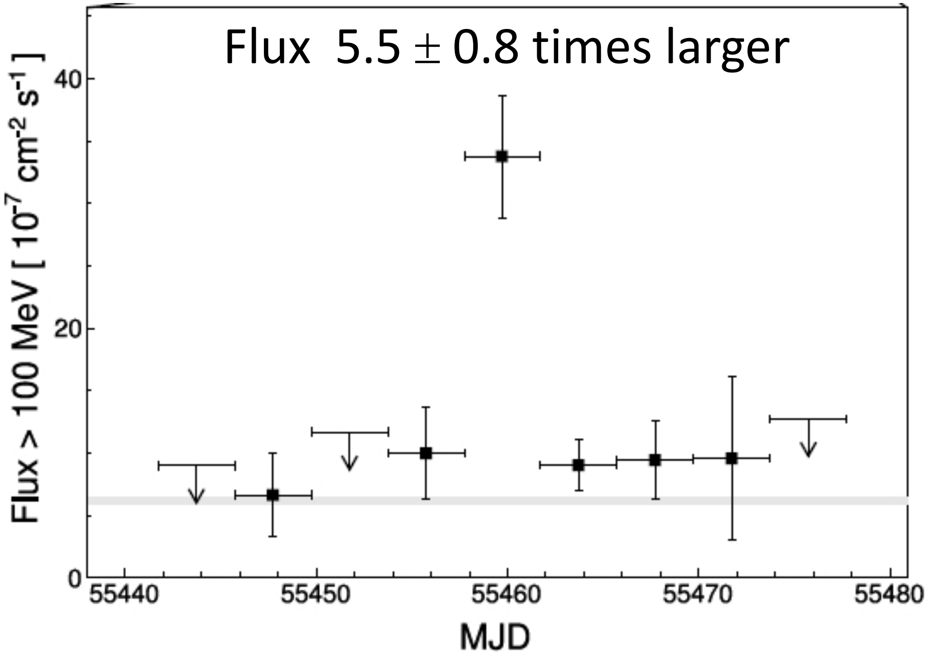
1.3 ±0.4 10^{-11} ev cm^{-2} s^{-1} !!!!

Flare duration ≈ 7 h

Flare on September 19th

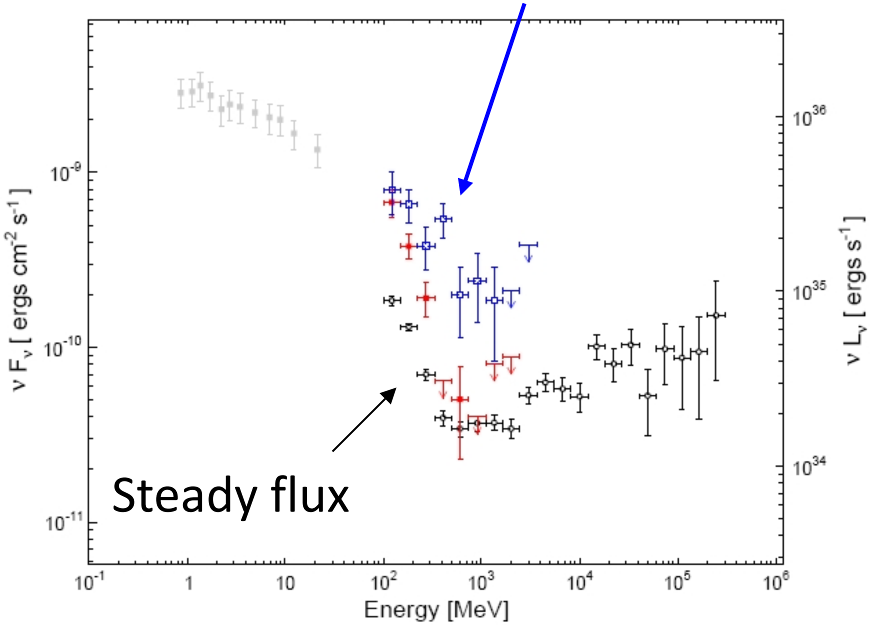
Detected by AGILE	duration 2-3 days	4.8 σ	(ATel #2855)
Confirmed by Fermi	duration 4 days	> 10 σ	(ATel #2861)

Fermi Light Curve E >100 MeV



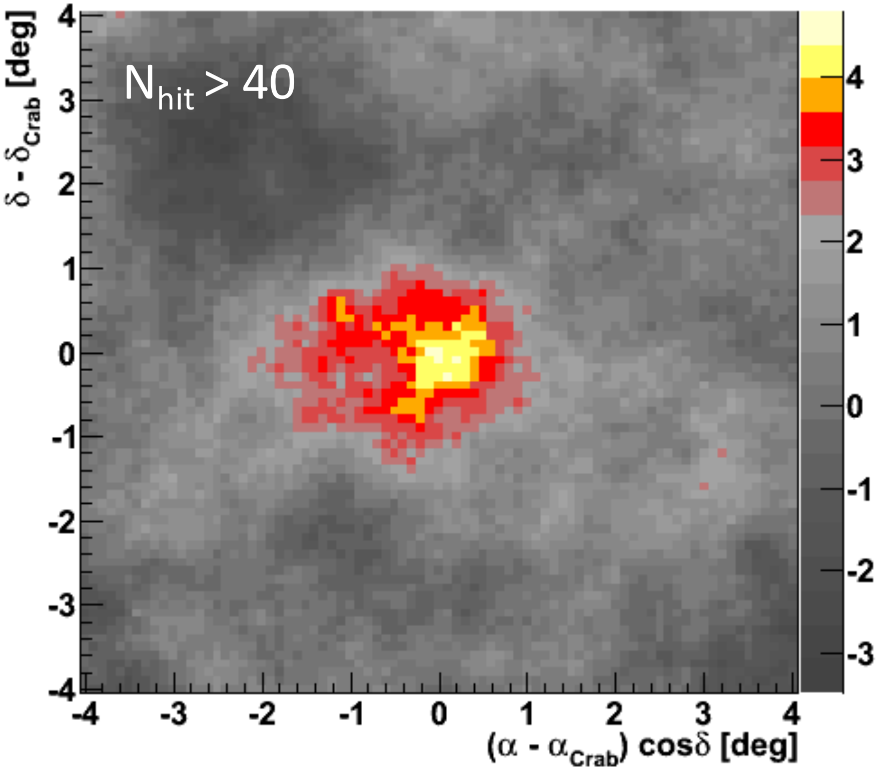
Abdo et al. 2010

Fermi SED



Fermi flare spectrum $\propto E^{-2.7 \pm 0.2}$

Crab Nebula 19-26 September



8 days

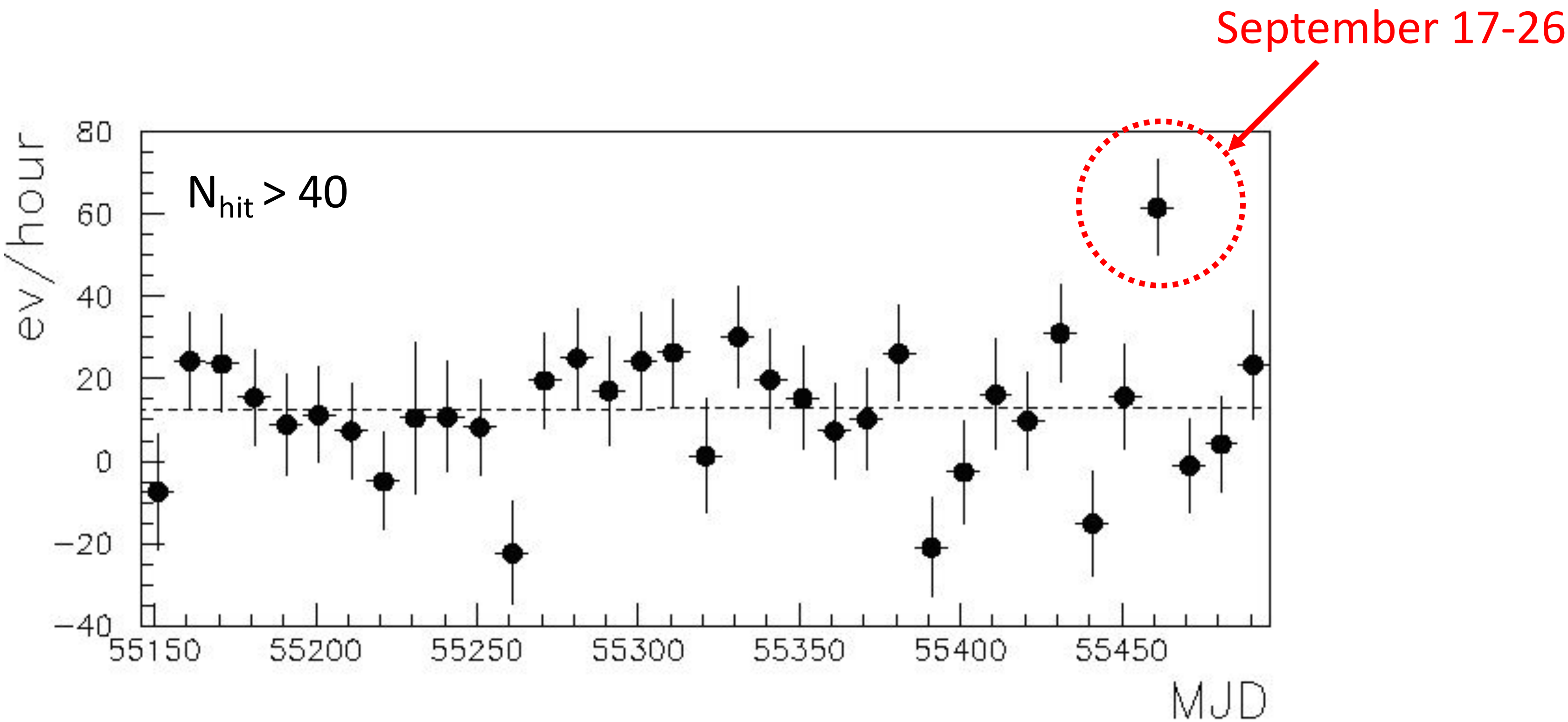
46 observation hours

Significance 4.8 σ

Expected 1.0 σ from steady flux

Chance probability: $p = 6.6 \; 10^{-5}$

Crab light curve - 10 days bin



In 10 days: 61 ± 11 ev/h

Significance 5.4 σ (expected 1.1σ)

Chance probability $p = 7.6\ 10^{-6}$

Observation by Cherenkov telescopes

Magic 58 min on Sept. 20 (ATel #2967)

Veritas 6×20 min on Sept 17-20 (ATel #2968)

No flux enhancement observed

After Sept 20 no Cherenkov observations because of the Moon

These observations do not overlap ARGO measurements due to the different longitudes of the 3 detectors

2 ways to intepret the results

1) The ARGO excess is an unlucky fluctuation with a chance probability $p = 6.6\ 10^{-5}$

2) The temporal structure of the flare is very complex

In case 2, there is job for theorists….

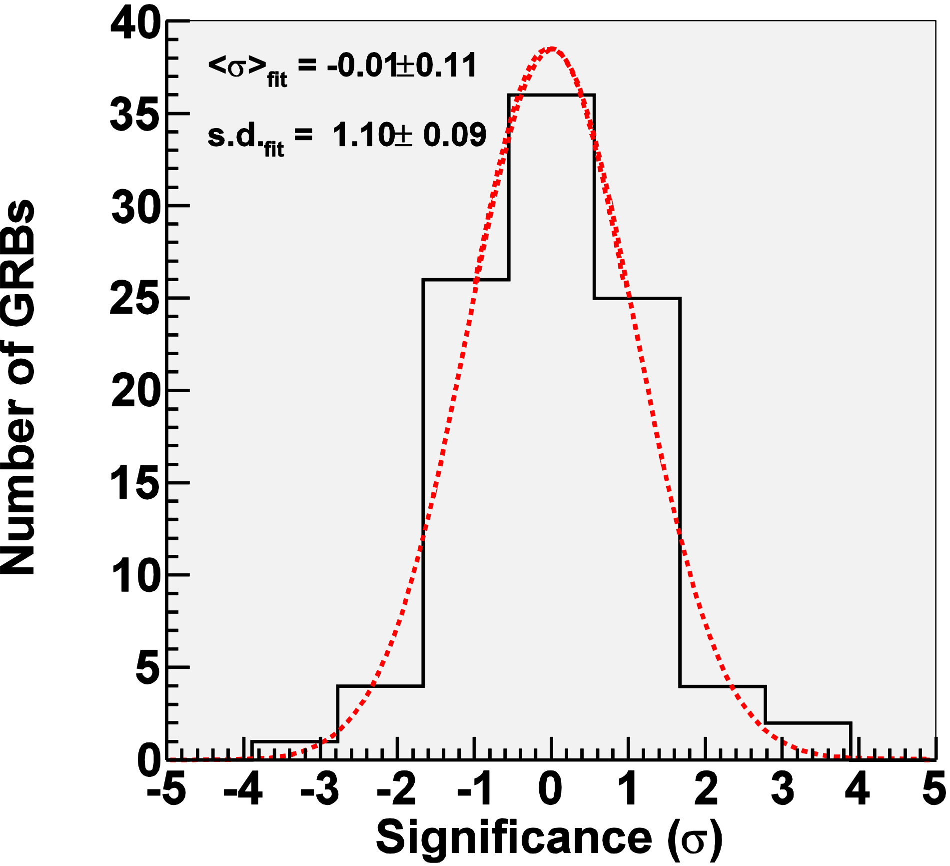
GRBs

at E $\approx$ 1-100 GeV

GRB Sample
Dec 2004 – Oct 2010

- GRBs analyzed ($\theta<45°$): 98 (Swift & Fermi)
- With known redshift: 16
- Long duration GRBs (> 2s): 87
- Short duration GRBs (≤ 2s): 11

Significance distribution



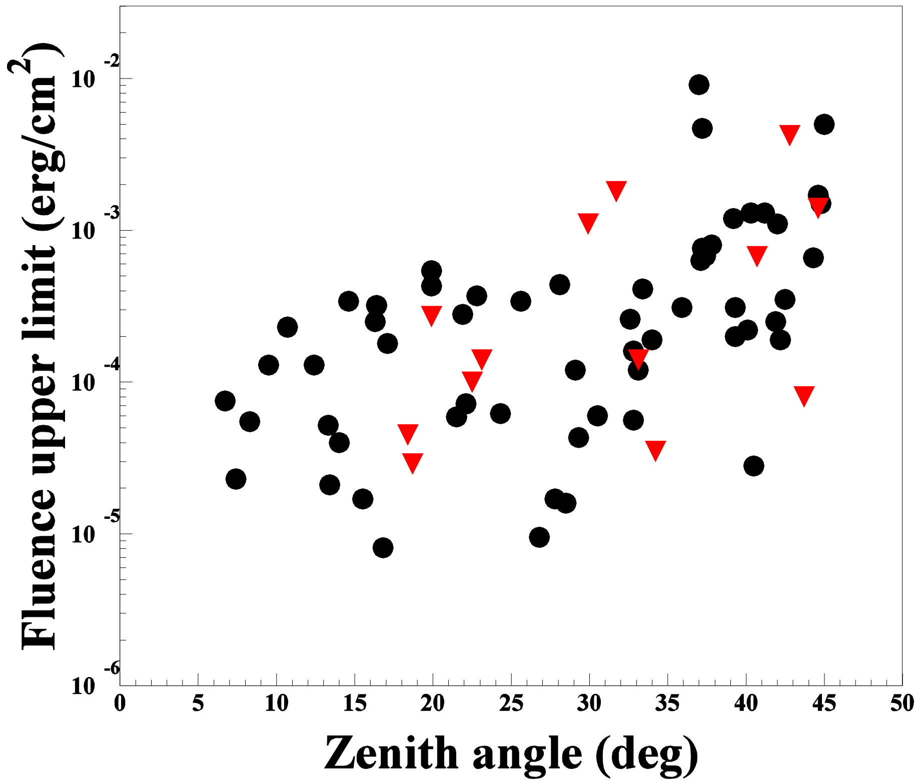
mean σ = -0.01±0.11

r.m.s = 1.1±0.09

σ_{max}=3.52 s.d.

2.2% chance probability

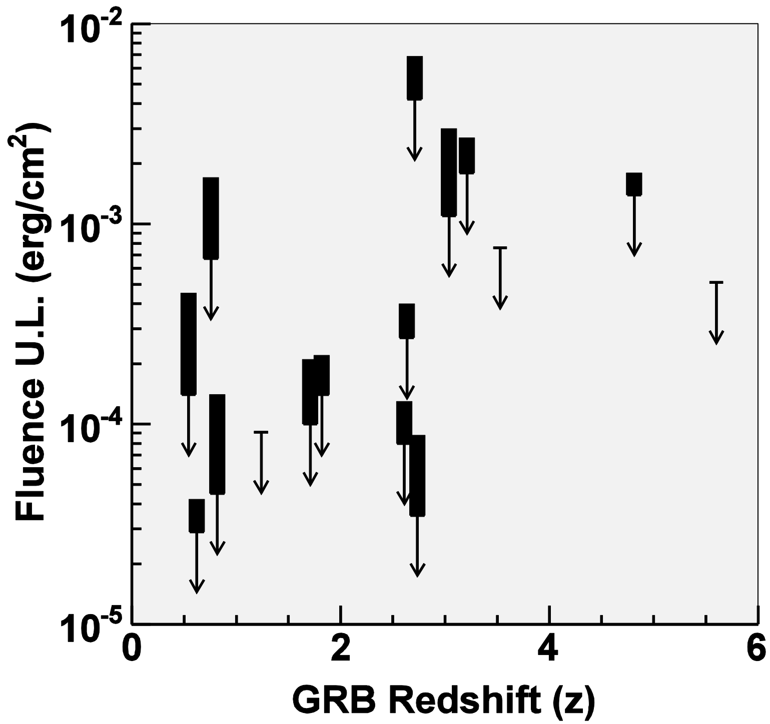
Fluence Upper Limits in the 1–100 GeV range



Fluence upper limits (99% c.l.) obtained extrapolating the power law spectra measured by satellites

Red triangles: GRBs with known z
or z = 1 is assumed to consider extragalactic absorption (Kneiske et al. 2004)

Fluence upper limits in the 1–100 GeV range for GRBs with known redshift



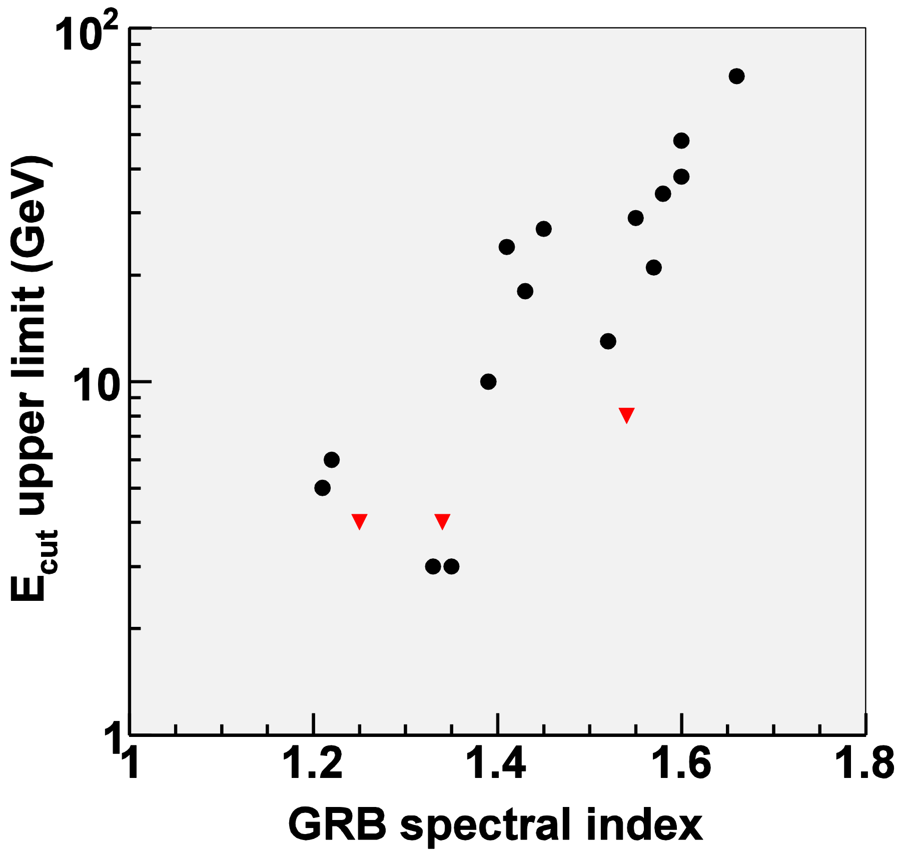
99% c.l.

Assumption: power law spectra with indexes ranging from the value measured by satellites to 2.5

(only this latter case is considered for Cutoff Power Law spectra)

Upper limits to the cutoff energy

99% c.l.



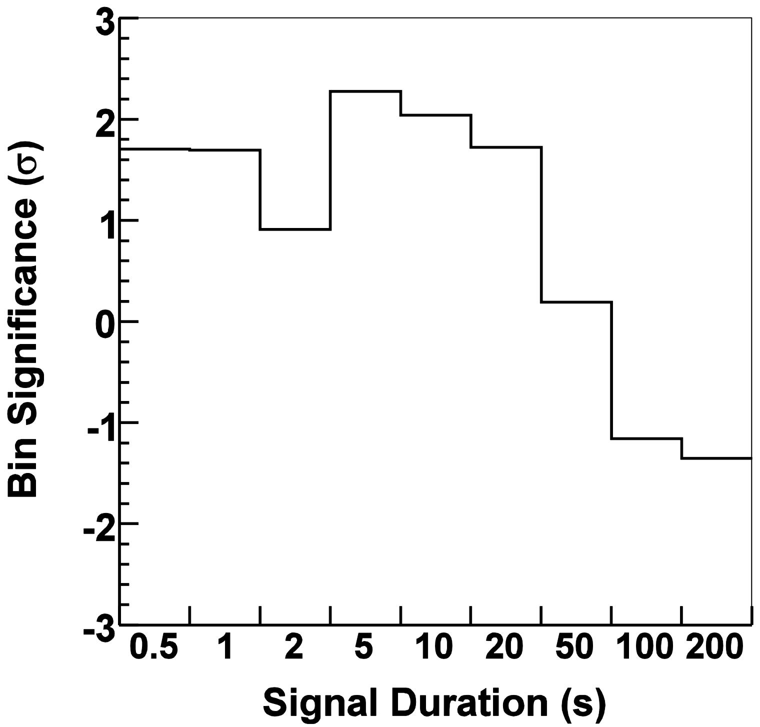
Assumption: power law spectra with the same index measured by satellites, up to E_{cut}

red triangles: GRBs with known redshift

GRBs stacked in time

The data of the first Δt seconds for all the GRBs have been added

Δt = 0.5, 1, 2, 5, 10, 20, 50, 100, 200



no evidence of emission for any Δt

Total significance: -0.68 σ

(taking into account that the 9 bins are non independent)

Results

ARGO has been taking data since Dec 2007 with duty cycle > 90%

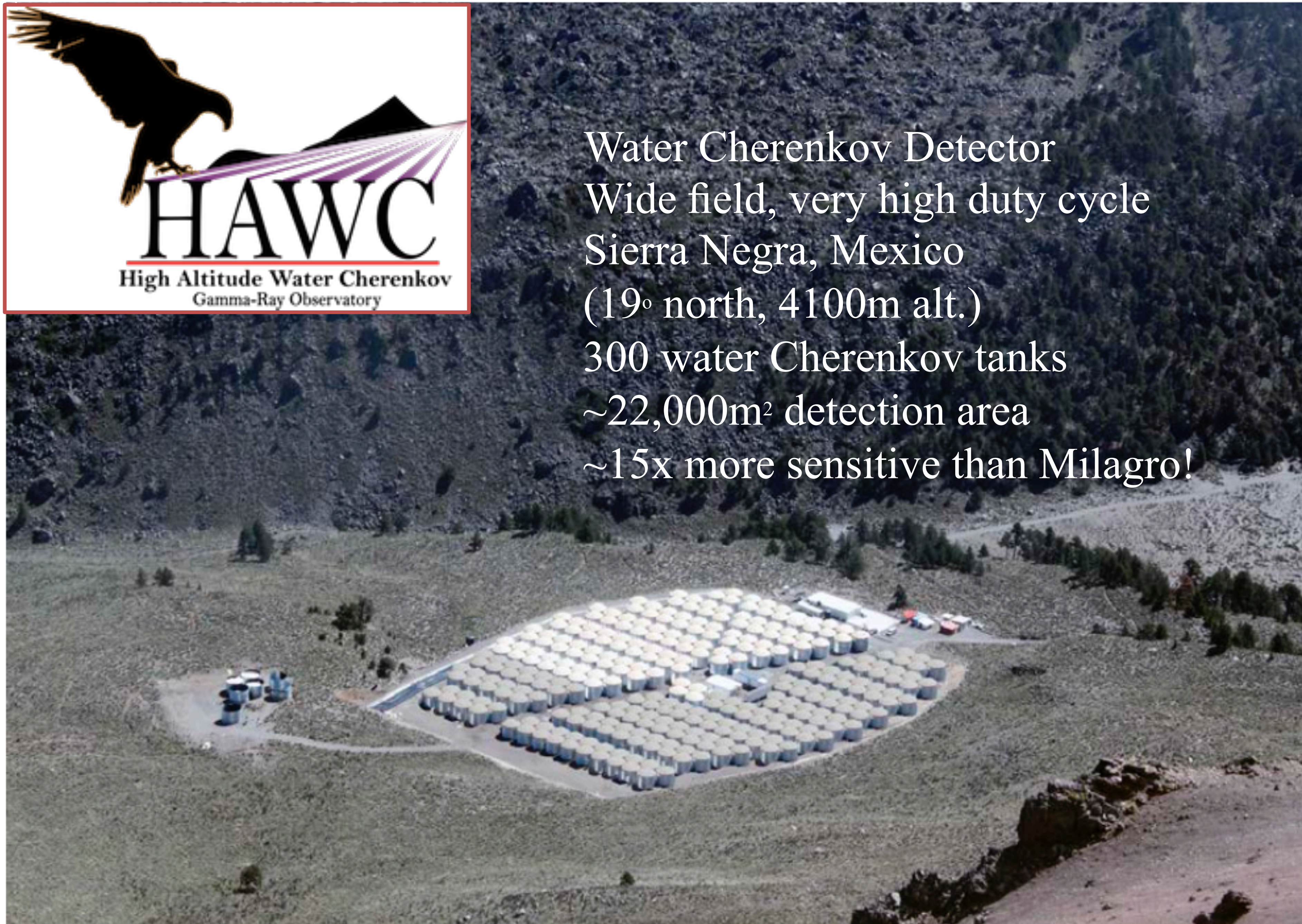
- Crab Nebula : spectrum in agreement with other experiments
  possible flare detected in coincidence with Agile & Fermi

- Mrk421 : - continuously monitored
  - VHE flux correlated with X-rays
  - observed flares in 2006, 2008, 2010
  - flare in Febuary 2010 detected in only one day

- MGRO J1908+06 : measured extension and spectrum
  - observed flux larger than HESS one

GRBs: upper limits obtained for 98 events at energy 1-100 GeV

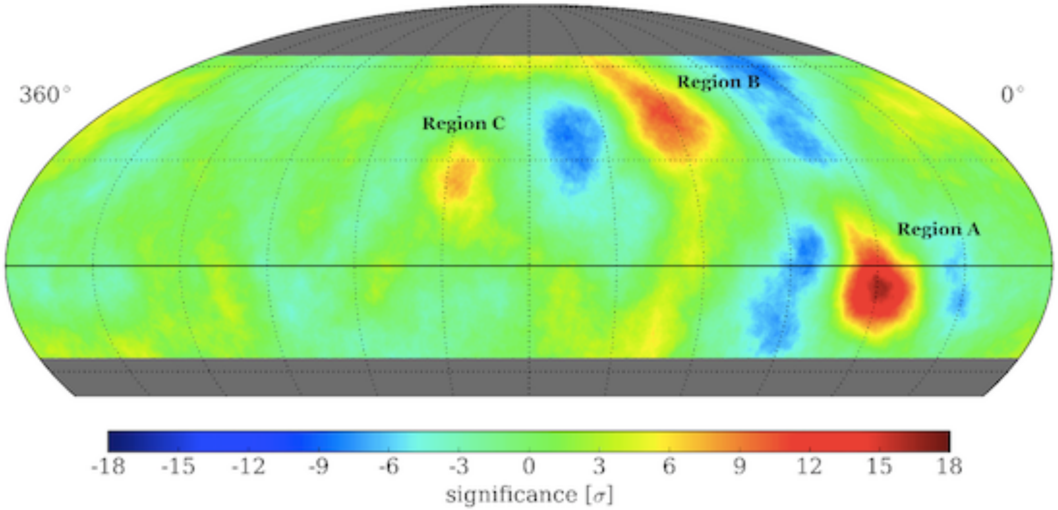
- Studies to increase the sensitivity are in progress
- Sky survey going on


HAWC
High Altitude Water Cherenkov
Gamma-Ray Observatory
Water Cherenkov Detector
Wide field, very high duty cycle
Sierra Negra, Mexico
(19° north, 4100m alt.)
300 water Cherenkov tanks
~22,000m² detection area
~15x more sensitive than Milagro!

HAWC

- Instrument completion end 2014
- Physics already started:
  - Moon shadow and CR anisotropy
  - Narrow miss with GRB 130427A (z=0.34)

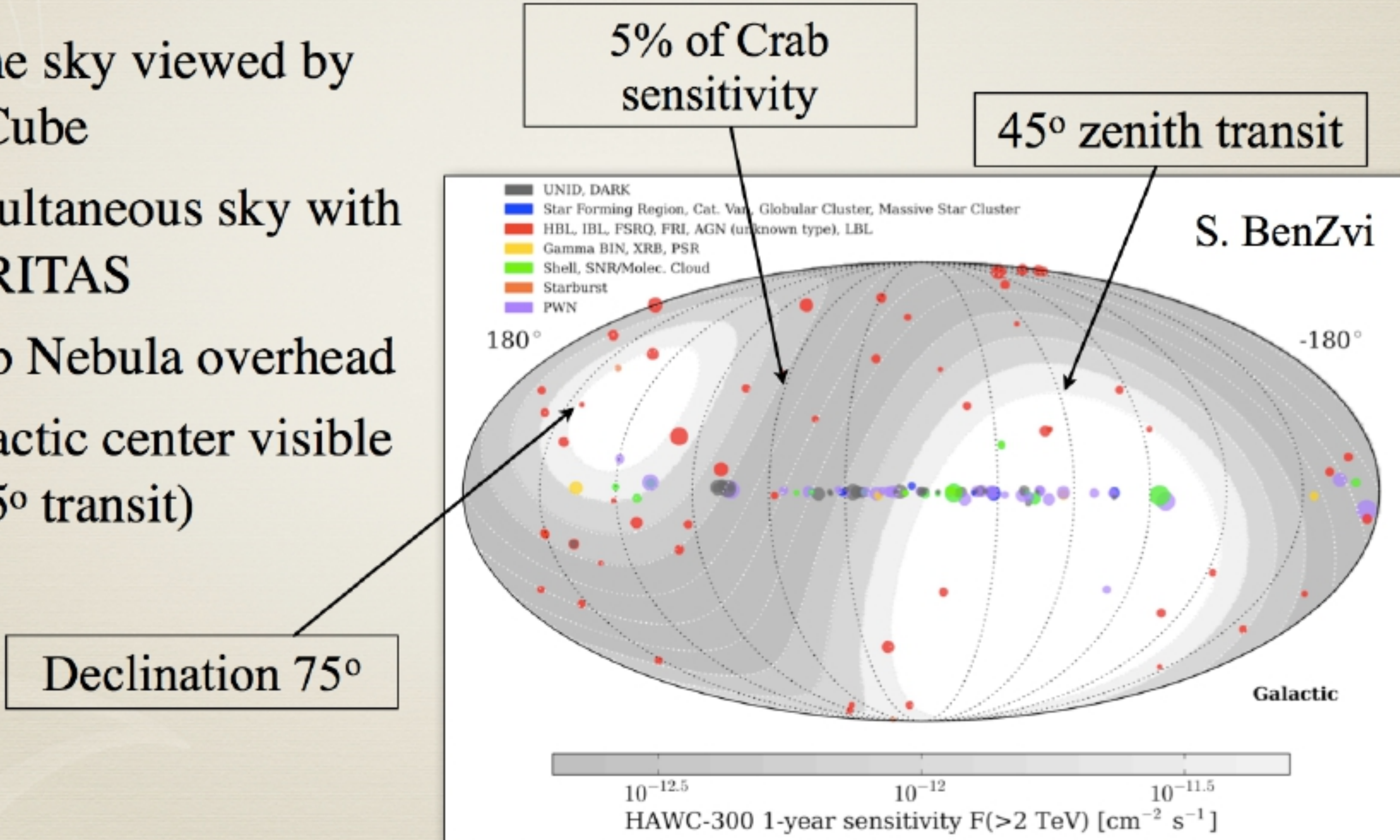
X01, the 300th HAWC tank to be deployed at Sierra Negra, is completed on Dec. 15, 2014 (see breaking news).



Celestial coordinates of small-scale cosmic-ray hot spots observed with the first 9 months of data from HAWC. From arXiv:1408.4805 [astro-ph].

HAWC Sky Coverage

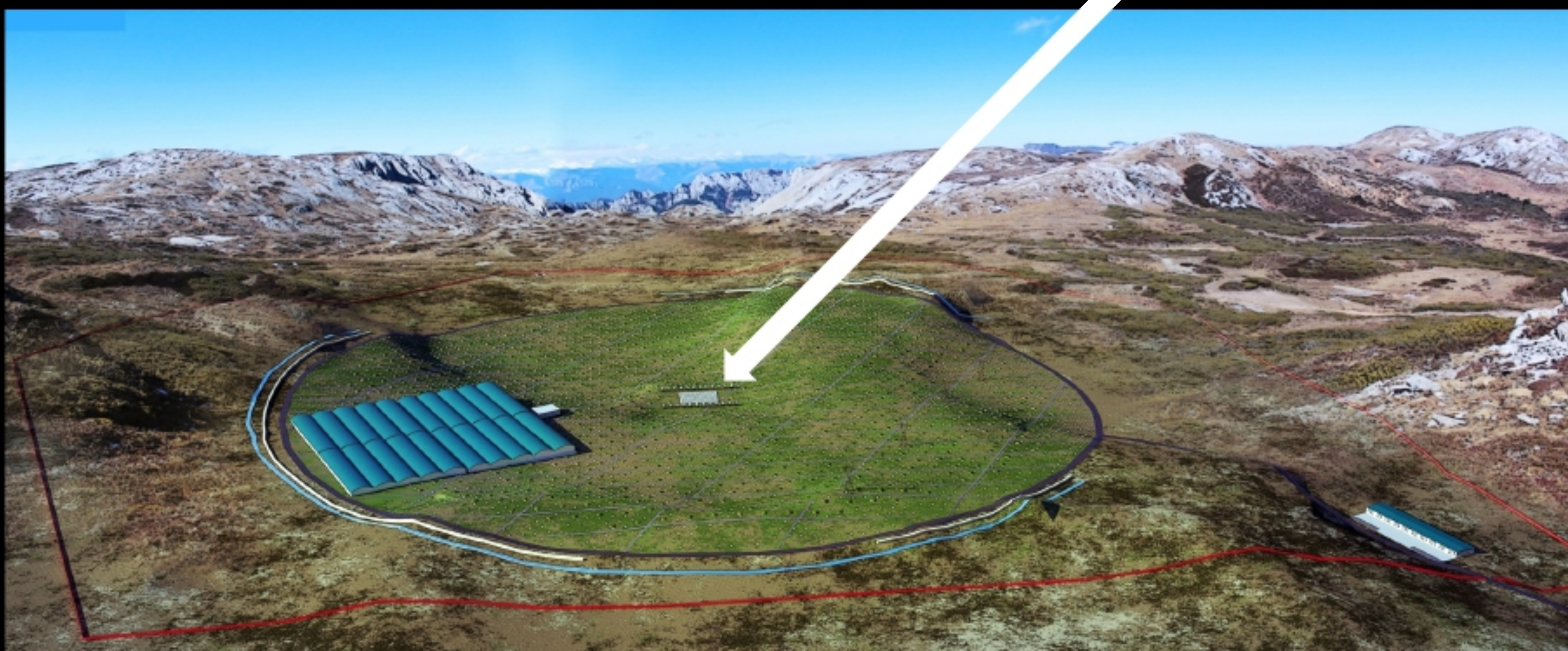
- Same sky viewed by IceCube
- Simultaneous sky with VERITAS
- Crab Nebula overhead
- Galactic center visible (~45º transit)



LHAASO

Gamma-ray surveys &
Cosmic ray studies

90k m_2 Water Cherenkov dets
1 km_2 Surface EAS detector array
++



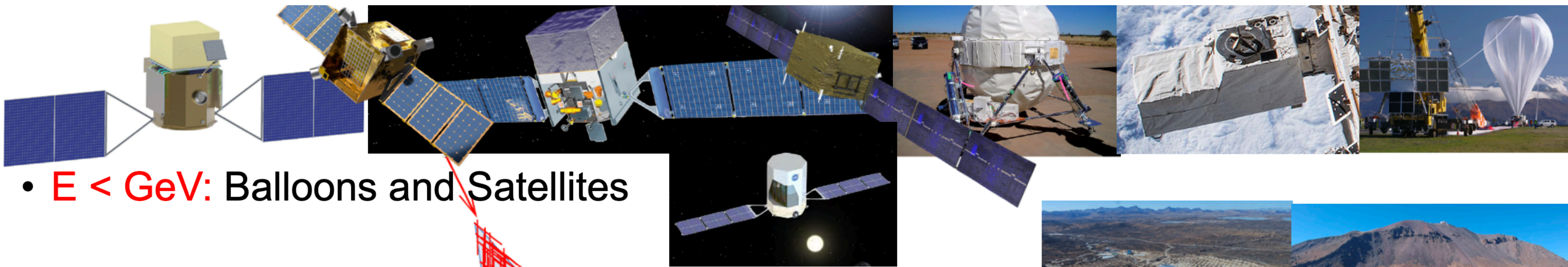
LHAASO

- Phase-0: Large Area Water Cherenkov Array (LAWCA)
  - YangBaJing, Tibet: around the ARGO detector
  - Completion end 2014
  - HAWC-like, but with access to somewhat lower energies
- Phase-1
  - Final site: Shangri-La
    - 4.3 km altitude
  - Sensitivity?
    - Will depend on background rejection power achieved in practice, but will be a **very** powerful instrument

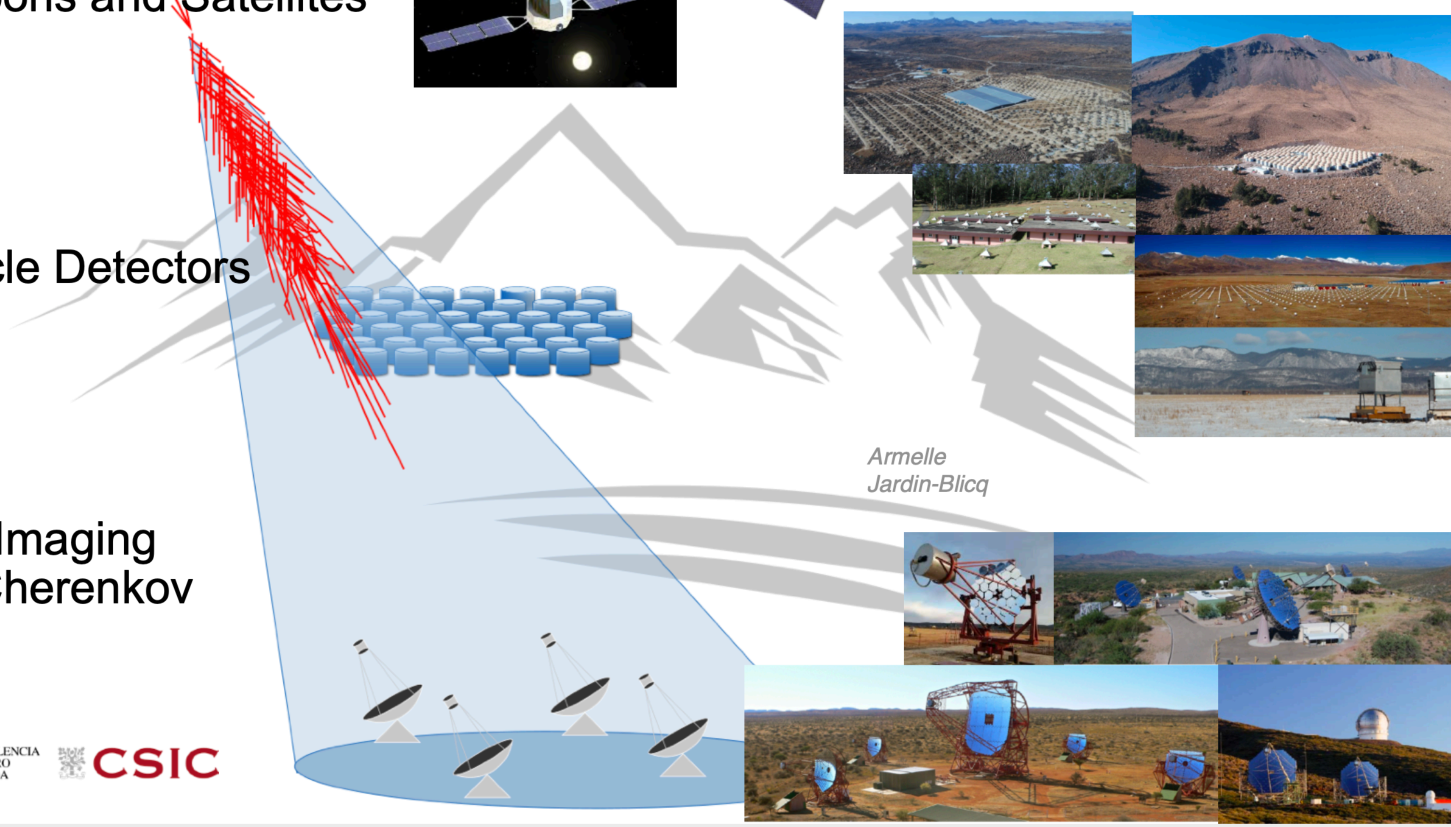
- Current and Future

(thanks To Ruben Lopez Coto, ICRC Gamma Rapporteur Talk)

Current and Future Instruments



- E < GeV: Balloons and Satellites
- E > TeV: Particle Detectors
- E ~ GeV-TeV: Imaging Atmospheric Cherenkov Telescopes



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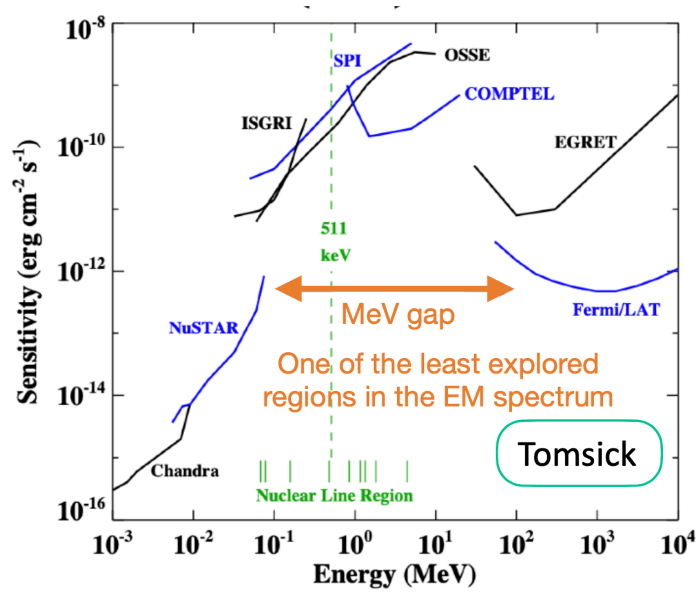
Present and Future Experiments: MeV

Positron annihilation, nuclear lines, polarization

- **COSI** Compton small explorer satellite (2027) [Tomsick]
  - previous balloon flights [Karwin]
- **ComPair** balloon prototype for AMEGO [Valverde].
- **AMEGO-X** medium explorer satellite [Karwin].
  - “AstroPix" [Dmytriiev] and payload tests [Uchikata]
- **GECCO** Compton telescope with Coded Aperture Mask [Moiseev].
  - Detector [Vigliano, Sasaki] and Science [Bottacini]
- **SMILE-2** balloon [Ikeda]
- **GRAMS**: gamma rays+antimatter balloon and future satellite [Aramaki]
  - Detector **[LeyVa]** and simulations **[Tsuji]**
- **miniSGD** a proof-of-concept balloon experiment [Okuma]
- **HEPD-02**: payload of CSES [Lega]
  - EM phenomena associated with geophysical processes and GRBs
- **XRPix** [Hashizume]



R. López-Coto, ICRC 2023, Nagoya, 03/08/23

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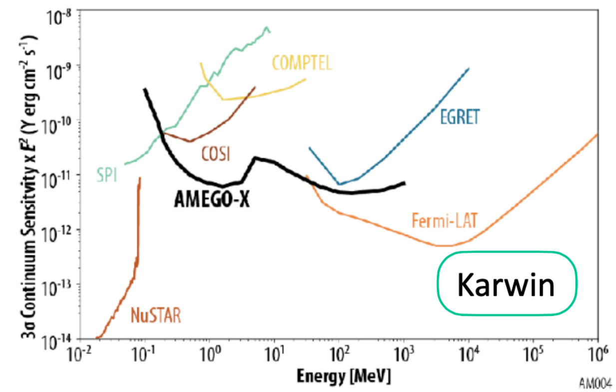

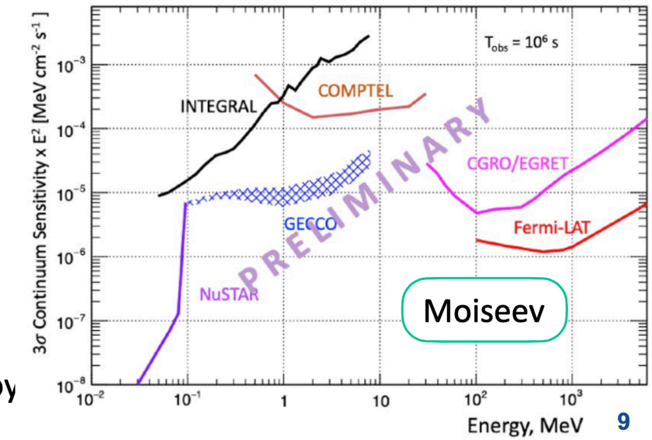

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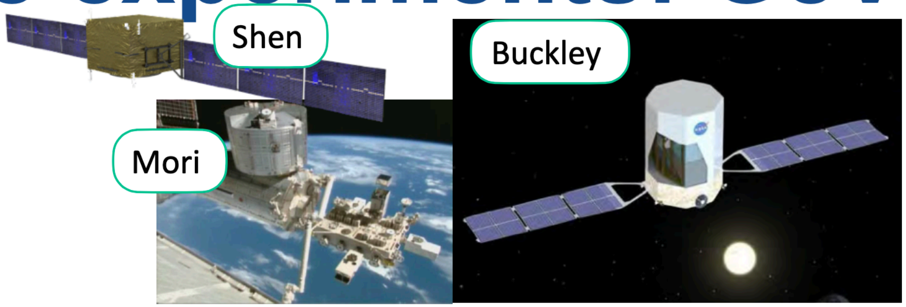
Present and future experiments: GeV

point sources, large scale emission



- ***Fermi*-LAT** Polarimetry [Laviron]
- **CALET** satellite at the ISS [Mori]
- **DAMPE** satellite [Shen]
- **GRAINE** Balloon with emulsion film => last flight in 2023 [Takahashi]
  - Several Technical developments [810, 811, 825, 829, 832, 883, 901, 915, 933]
- **ADAPT** balloon with a final goal of a super-*Fermi* satellite [Buckley].
  - Electronics [Sudvarg], simulations [Chen, Sudvarg]
- **HERD** proposed satellite for the CSS [Lucchetta]
- **VLAST** proposed satellite [Zhang]

Present and Future Experiments: GeV

-

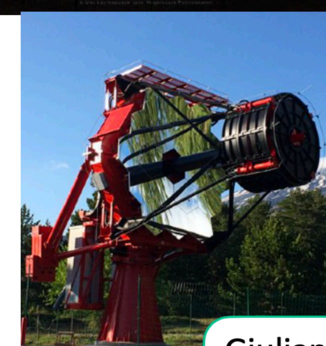
morphology, point sources, spectral precision

- **MAGIC**: 20 years - 200 papers [Paneque]

- The **ASTRI Mini-Array** project [Giuliani]
  - ASTRI-HORN Crab Nebula [Lombardi], different NSB [Saturni], data processing [Lombardi], new observing season for ASTRI-Horn [Iovenitti], mirrors [Leto], event builder [Germani], calibration [Mineo, Contino, Mollica], follow-up observations [Giuliani], transient prospects [Carosi]

- **HADAR** refracting atmospheric Cherenkov telescope [Qian]

Paneque



Giuliani

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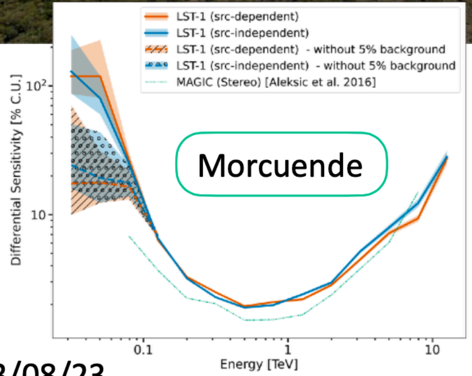
Present and future experiments: TeV

The Cherenkov Telescope Array Observatory

- **Large-Sized Telescope** first scientific results [Mazin]
  - Performance of LST1 [Morcuende] => meeting expectations
  - Joint performance with MAGIC [Di Pierro], Real Time Analysis [Caroff]
- **Medium-Sized Telescope** [Bradascio]
  - Mirrors [Niemiec], NectarCAM [Rueda] and its calibration [Patel]
- **Schwarzschild-Couder Telescope** [Kieda]
  - Electronics [Di Venere], optics [Shang]
- **Small-Sized Telescope** [Trois]
  - Camera [Depaoli], mirror area [Okumura], commissioning data [Tavernier], performance of the two SST-1M telescope prototypes [Jurysek]
- **CTA+** [Antonelli]



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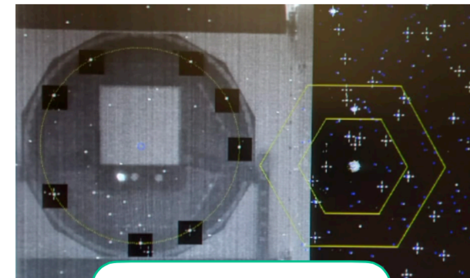
New developments: TeV

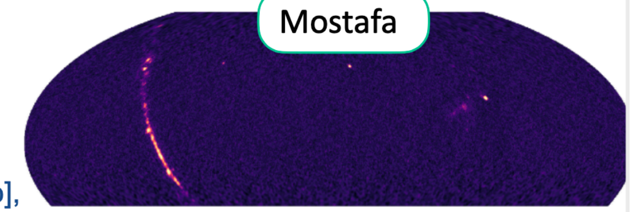


- **Stellar intensity interferometry**
  - VERITAS [Kieda] and MAGIC [Jiménez-Martínez]
- **Divergent pointing:** increasing IACT field of view [Donini]
- **HaST**: MAGIC+LST1 hardware trigger [Baxter]
- **LACT**: Array of imaging atmospheric Cherenkov Telescopes for LHAASO [Zhang]
  - Simulations [Zhang], mirrors [Li]
- **SiPM cameras for LSTs** [Heller]
  - Detector development and simulations [Saito, Loporchio, Okumura]

<u>Present</u> and future experiments: PeV

PeVatrons, extended emission

- **HAWC** [Mostafa]
- **LHAASO** status WCDA [Gao] and development of the detector [Zha, Zhang, Yao]
- **Tibet AS-γ** [Kato]
    - TASG J1844-038 up to sub-PeV energies
- **GRAPES-3** gamma-rays above 50 TeV [Pattanaik] and [Pant]
- **TAIGA-IACT** telescopes for Multi-Messenger observations [Ravdandorj]
    - Software methods [Elshoukrofy]
- ALPACA [Subieta Vasquez]
    - performance [Yokoe] detector [Kawashima, Anzorena] and Mega-ALPACA upgrade [Sako]
- SWGO [Conceiçao]
    - Detector [Zhang, Quispe Mamani, Goksu, Sandoval, Bellido, Nellen, Pihet, Otiniano], Simulations [Chiavassa], Reconstruction [Lang, Leitl, Nellen, Conceição], Site [Santander], Physics [Ren], Alternative RPCs [Di Sciascio].
- PANOSETI: Pulsed optical signal detector that can also be used for PeV Gamma-ray Astronomy [Korzoun]



3HWC Catalog

Present and future experiments: PeV

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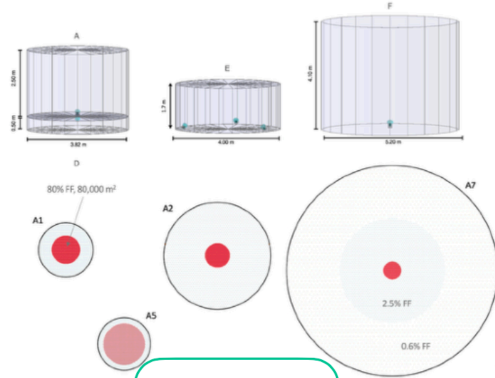
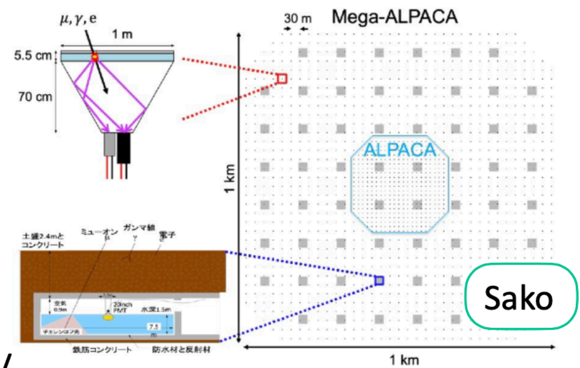
  - Detector [Zhang, Quispe Mamani, Goksu, Sandoval, Bellido, Nellen, Pihet, Otiniano], Simulations [Chiavassa], Reconstruction [Lang, Leitl, Nellen, Conceição], Site [Santander], Physics [Ren], Alternative RPCs [Di Sciascio].
- **PANOSETI**: Pulsed optical signal detector that can also be used for PeV Gamma-ray Astronomy [Korzoun]

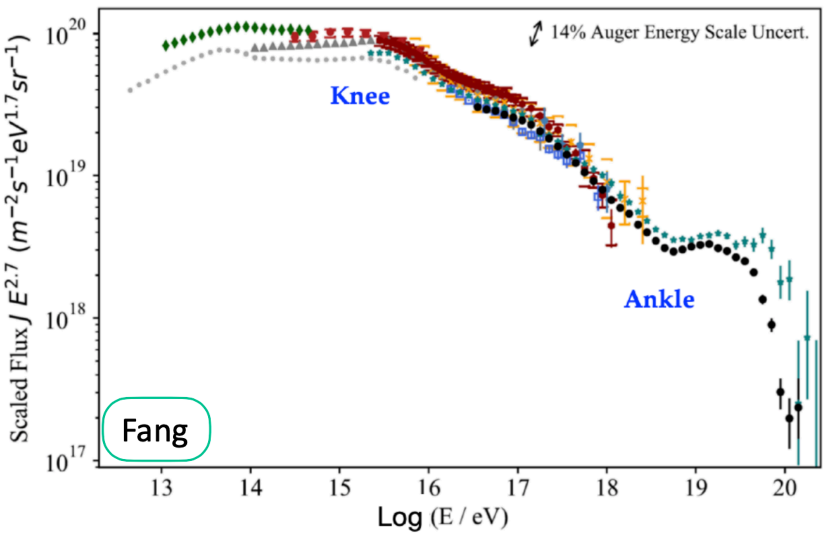


Conceiçao

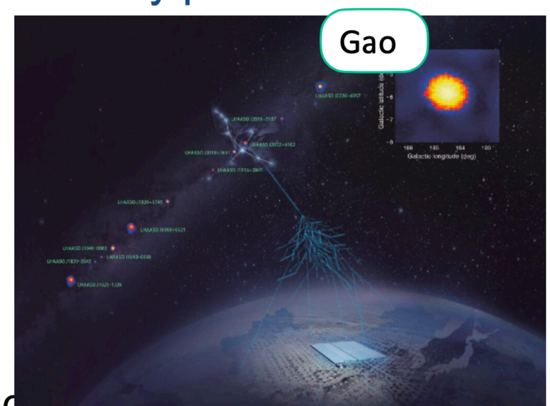


Sako

PeVatrons in the Galaxy



- Zoo of different sources modeled to accelerate particles up to PeV [Fang]
- Measurements of gamma rays beyond PeV imply that these sources must be accelerating them [Wu]
  - Are they protons or electrons?



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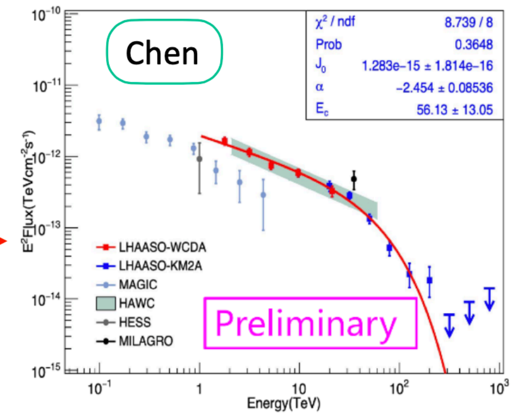
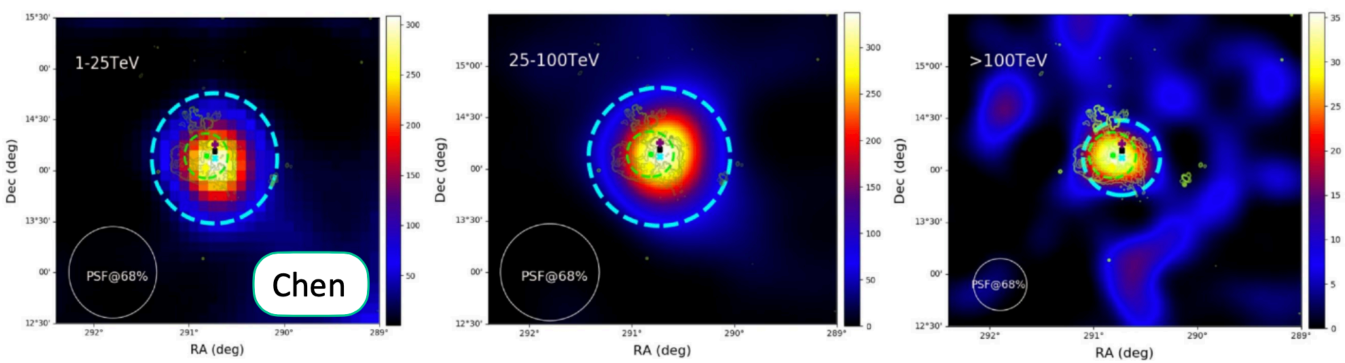
R. López-Coto, I

PeV acceleration?

Supernova Remnants

- **W51C** measured by LHAASO up to 300 TeV [Chen]
  - still favoring hadronic models (with cut-off at 400 TeV) to explain the emission





PeV acceleration?
Supernova Remnants

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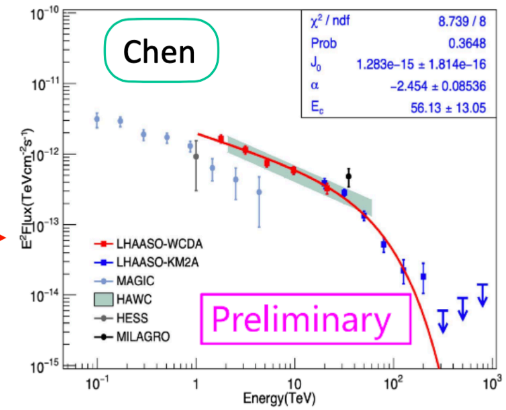

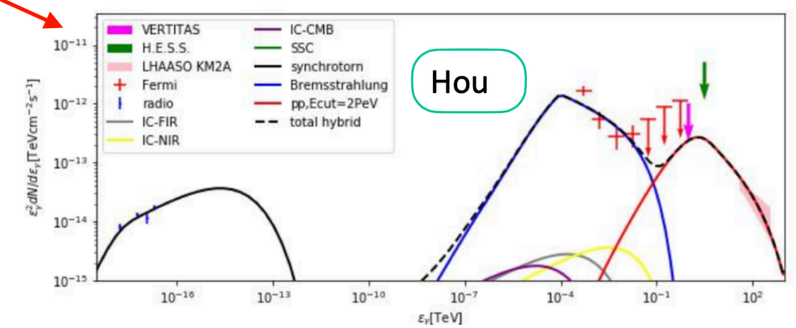

PeV acceleration?
Supernova Remnants

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  - still favoring hadronic models (with cut-off at 400 GeV) explain the emission
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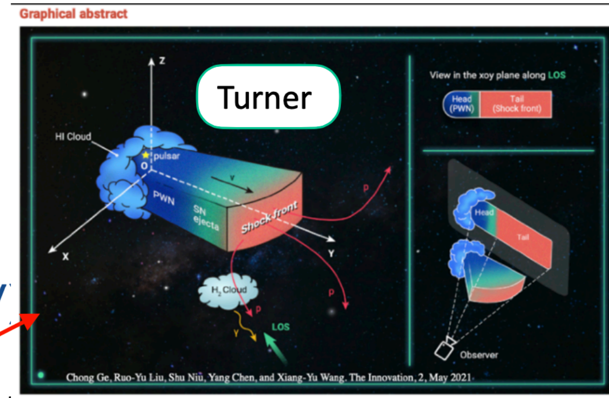
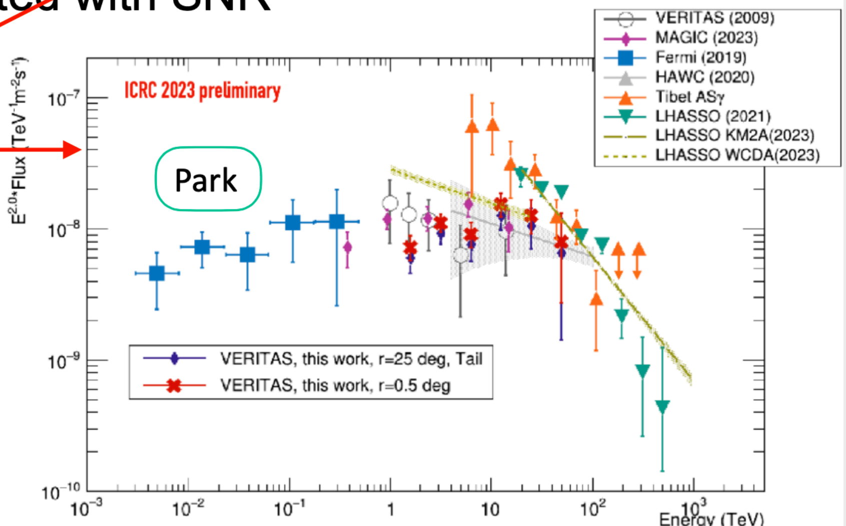
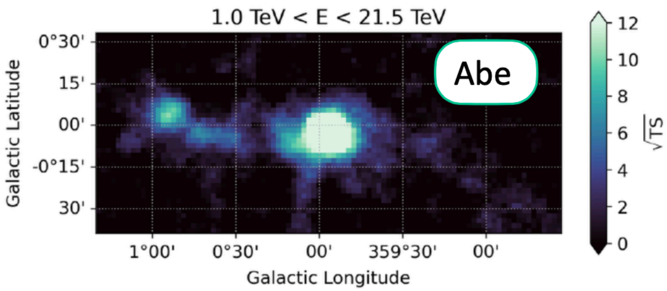
- **SNR G106.3+2.7** (Boomerang)
  - HAWC [Turner], VERITAS [Park], MAGIC [Strzys]
    - Spectrum up to 500 TeV. Origin unclear
  - X-ray modeling [Liang]
  - predictions for ASTRI Mini-Array [Cardillo]

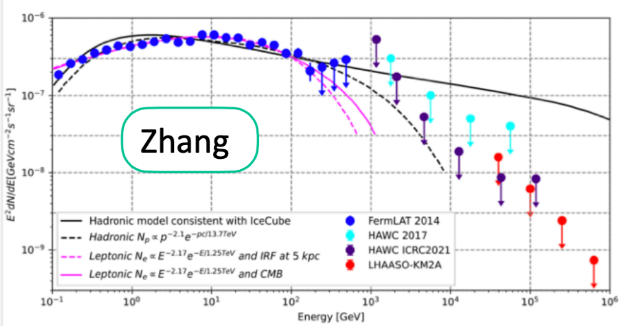




R. López-Coto, ICF

PeV acceleration?
Galactic Center





- Revisiting the Galactic Center observations with LST-1 and MAGIC [Abe]
- 3D modeling of the gamma-ray emission [Dörner]
- Dark matter origin?
  - The Galactic center “excess” with DAMPE [Shen]
  - VERITAS Dark Matter search in the Galactic Center Halo [Ryan]
- North Fermi Bubble upper lim SO-KM2A [Zhang]

We are working on it

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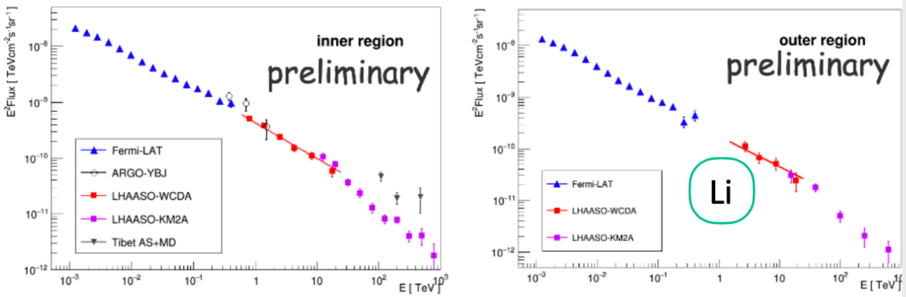
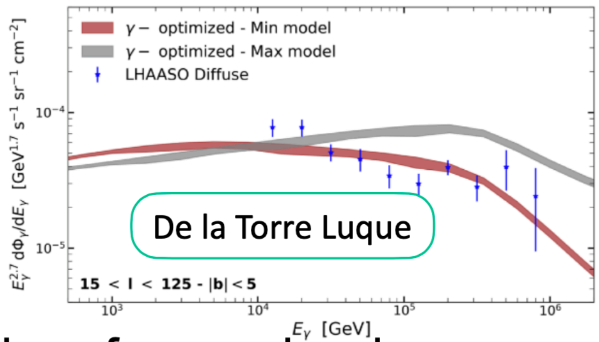
Diffuse Emission

- LHAASO measurement
  - Diffuse gamma-ray measurements by LHAASO claimed to be difficult to be explained with only CR propagation [Li, Zhang]
    - Depending on the parameters of the propagation, the emission from the CR sea or with the contribution from sources may be the answer [De la Torre Luque, Kaci, Semikoz, Stall, Zhang, Abounnasr]
    - Contribution from Stellar clusters [Menchiari, Wang]
    - or even PWNe [Villante]





- Cosmic-ray measurements using gamma-ray observations from molecular clouds [Peron, Kamal Youssef]

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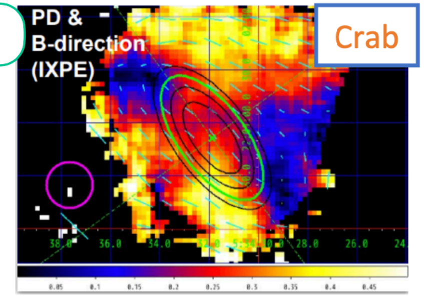
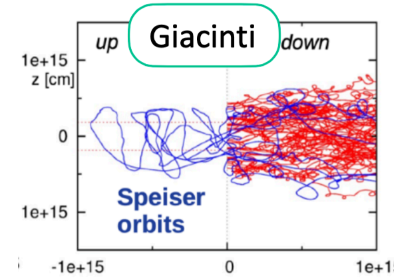
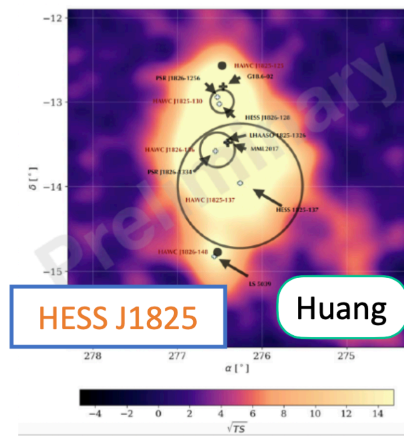
PeV acceleration
Pulsar Wind Nebulae







- **Crab Nebula**
  - X-ray polarization by IXPE [Mizuno]
  - e^- or e^+ acceleration depending on pulsar polarity up to E > PeV [Giacinti]
  - GeV flares not driven by a single mechanism [Tsirou]
  - Possibility of hadronic contribution to the VHE gamma-ray spectra? [Spencer]
- **HESS J1825:**
  - LHAASO [You] and HAWC [Huang] view of the source:
    - Measured above 200 TeV showing an extended morphology
- Magnetar Wind Nebula around **Swift J1834.9-0846** [Li]
  - claimed to be the first magnetar wind nebula powered by the internal magnetar energy of the central source
- **HAWC J2031+415:** HAWC morphological studies do not show any energy-dependence [Herzog]
  - More data are needed to support the PWN scenario

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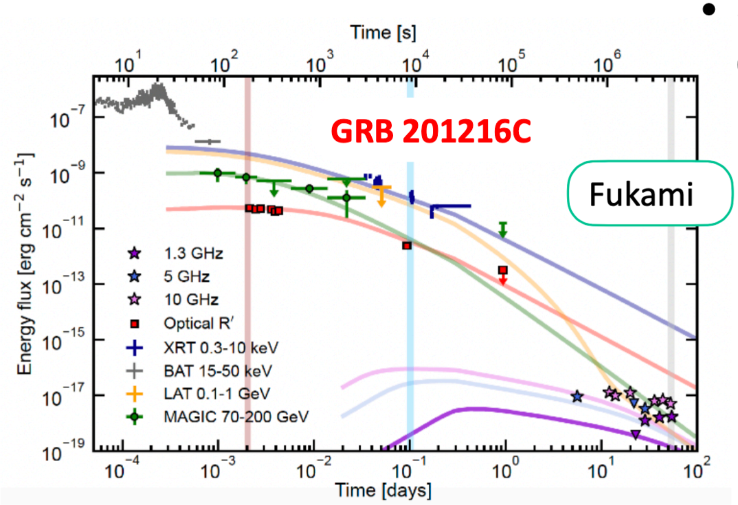
GRBs

- A lot of interesting results in the past from the sub-GeV band
  - We didn't have any at TeV energies (why? answer: [Ashkar]), now we have several!



- So far 5 GRBs have been detected at very high energy (VHE, > 50 GeV) gamma rays.
  - GRB 180720B (H.E.S.S.), GRB 190114C (MAGIC), GRB 190829A (H.E.S.S.), GRB 201216C (MAGIC), GRB 221009A (LHAASO)
  - All long GRBs (duration T90 > 2 sec)
    - detection of the afterglow emission
  - SSC by relativistic electrons in the forward shock as an explanation for the VHE emission

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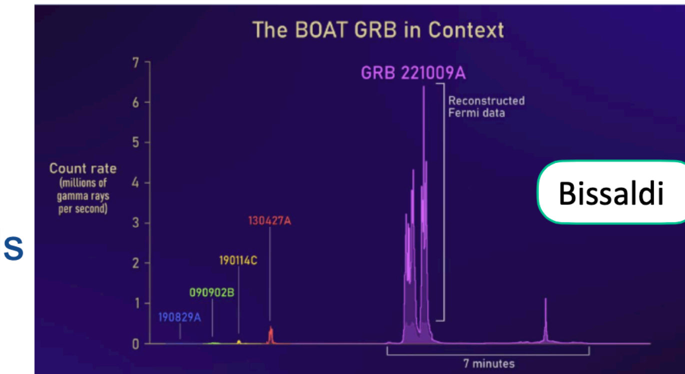
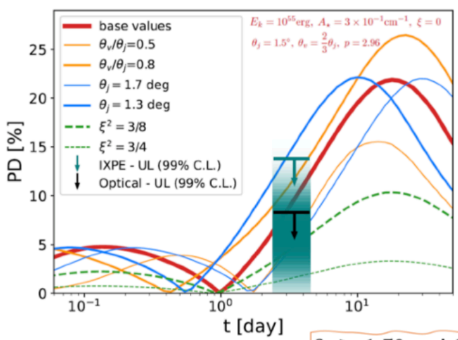
The BOAT: GRB 221009A

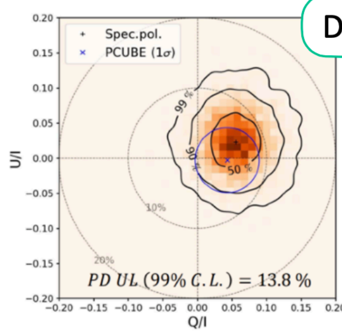
X-rays

- Brightest of all times GRB located at z = 0.151
- IXPE did not measure any polarization [Di Lalla]
  - Random magnetic fields or Compton drag models with a viewing angle close to the jet edge disfavored from IXPE afterglow observation
  - Synchrotron emission in an ordered, toroidal magnetic field configuration



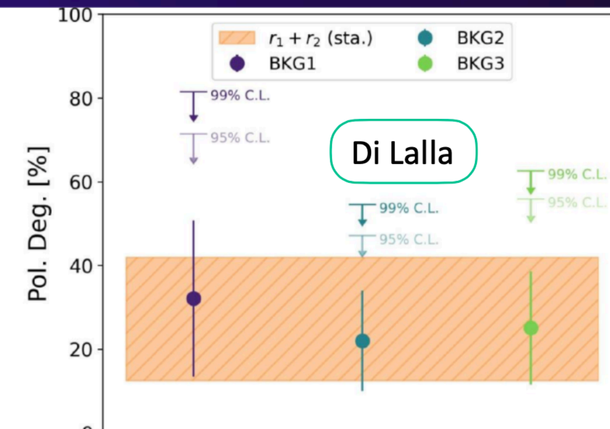
Bissaldi





Di Lalla

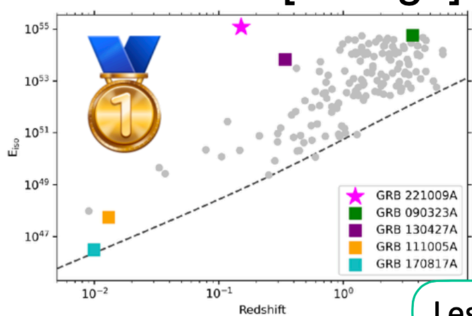
$\theta_j \gtrsim 1.5°$ and $\theta_v/\theta_j \lesssim 2/3$

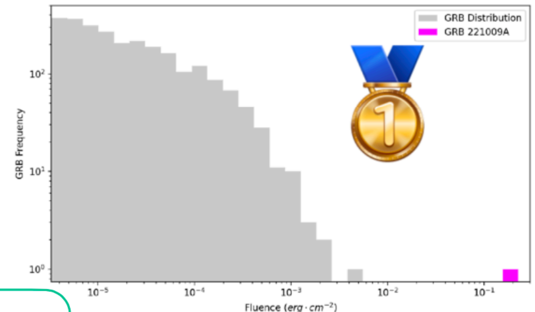


Di Lalla

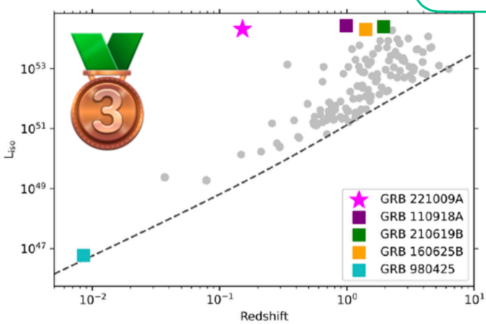
The BOAT: GRB 221009A
Gamma rays

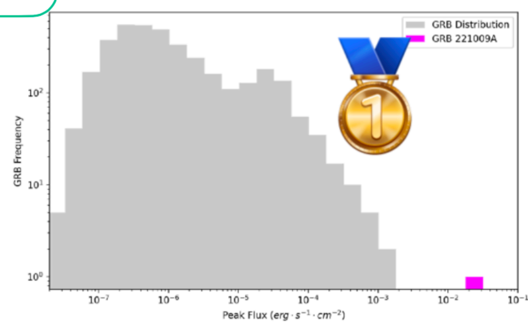
- *Fermi*-GBM [Lesage]



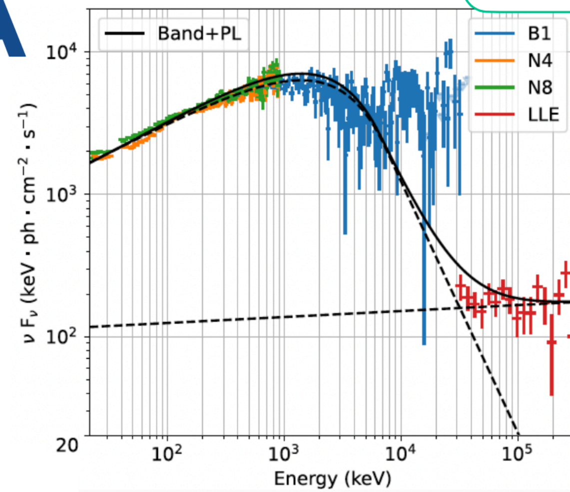


Lesage





Lesage



- The one with the highest isotropic energy
- the highest fluence
- the highest peak flux
- the 3rd highest isotropic intrinsic luminosity

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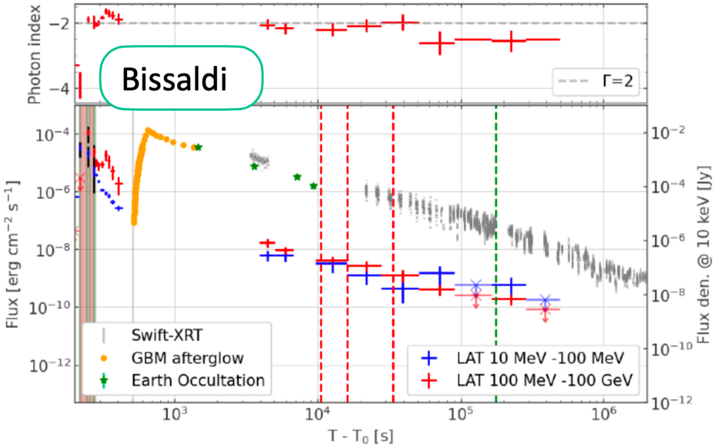
The BOAT: GRB 221009A

Gamma rays

- *Fermi*-LAT [Bissaldi]
  - Record breaking also in terms of longest GeV afterglow and highest photon energy (up to 400 GeV).



The BOAT: GRB 221009A

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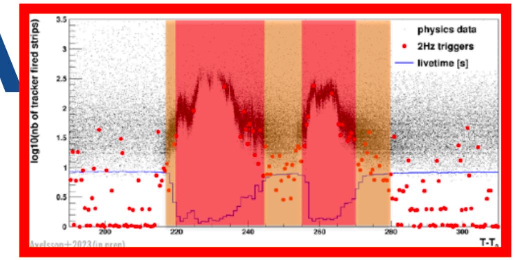

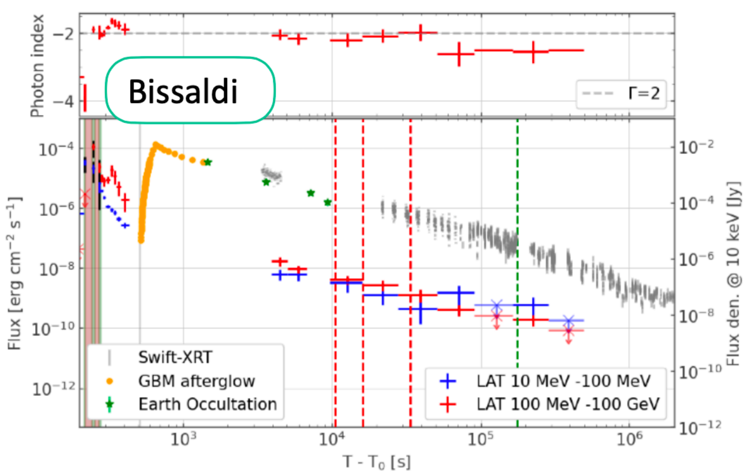

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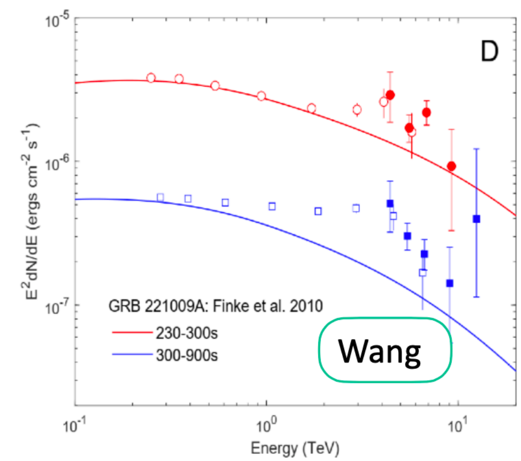
The BOAT: GRB 221009A
TeV gamma rays

- LHAASO detected photons up to 13 TeV from the afterglow [Wang]
  - Most stringent limits on the prompt TeV emission (emission detected only 230 s after the alert)
    - no SSC or too high absorption?
  - Data above 3 TeV hints to an additional component
    - can GRBs produce UHECRs? strong constraints from other GRBs [Zhang]
  - Difficult to explain ≳ 10 TeV leptonic emission due to SSC [Das]
- No IACT detection [Mbarubucyeye]
- Limits derived:
  - intergalactic magnetic field $>10^{-18}$ G [Huang] or 4×10^{-17} G [Xia]
  - even dark matter! [González]



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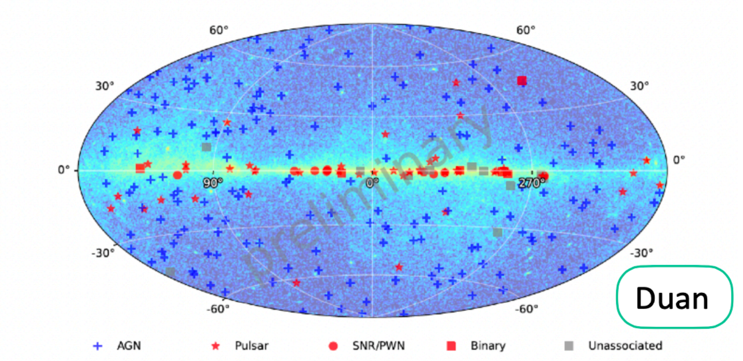
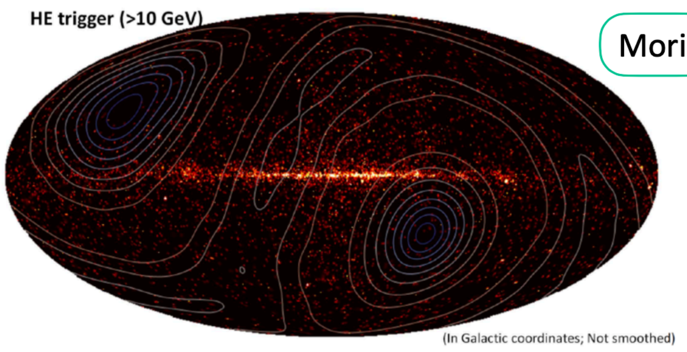
Surveys

- INTEGRAL, COMPTEL and *Fermi*-LAT [Orlando]
- DAMPE [Duan]: 248 sources
  CALET [Mori]: Improved gamma reco.
- H.E.S.S. [Remi]: 2nd H.E.S.S. Galactic Plane Survey catalogue
- HAWC: 2nd Ultra-high-energy catalog [Harding]
- LHAASO [Gao]: 12 UHE sources
  - E <25 TeV [Hu]: 69 sources
  - E >25 TeV [Xi]: 75 sources



Duan

Mori

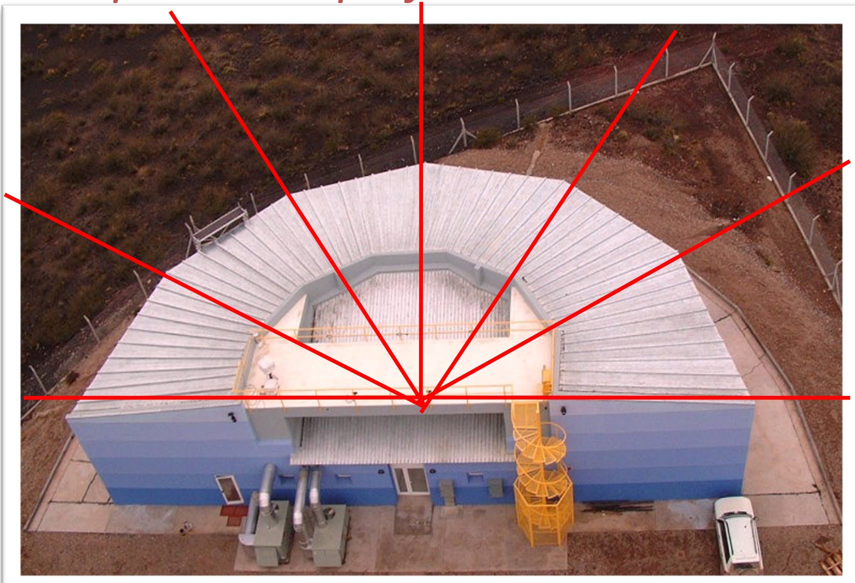


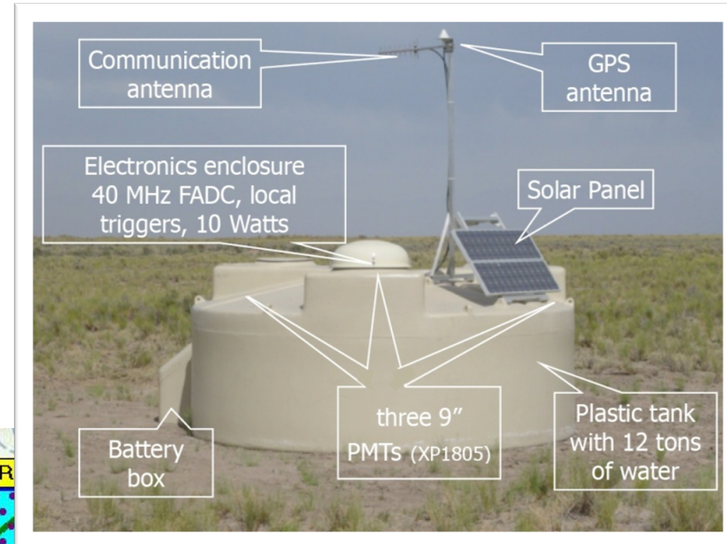
Thanks

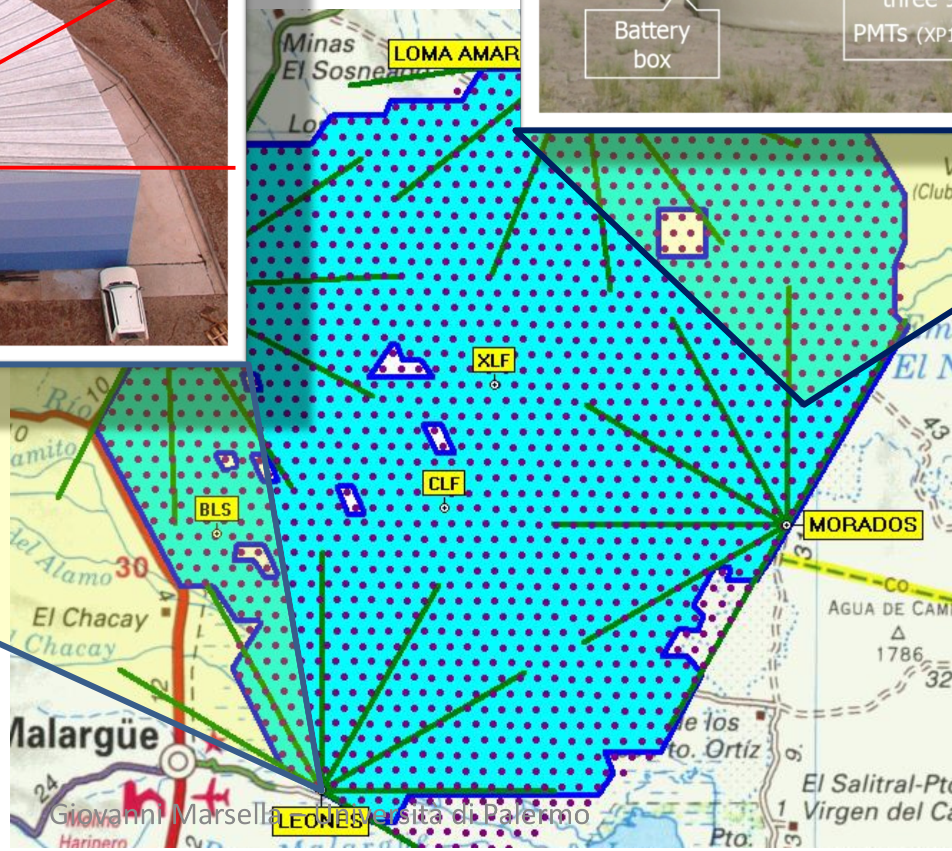
The Pierre Auger Observatory

Rivelatore di Superficie

1661 rivelatori Cherenkov a distanza di 1.5 km per una superficie totale di 3000 km^2





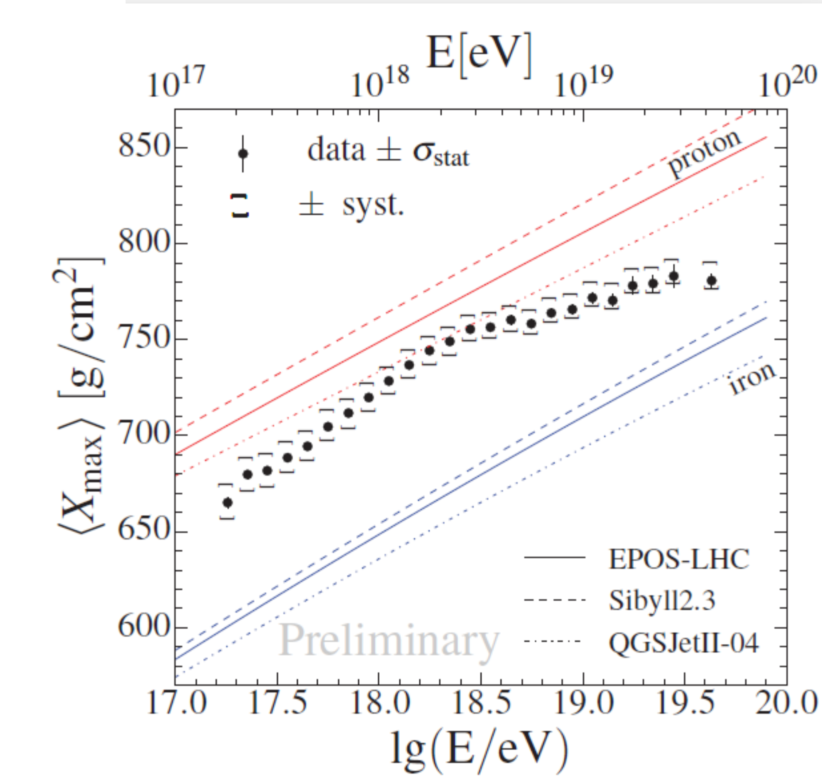


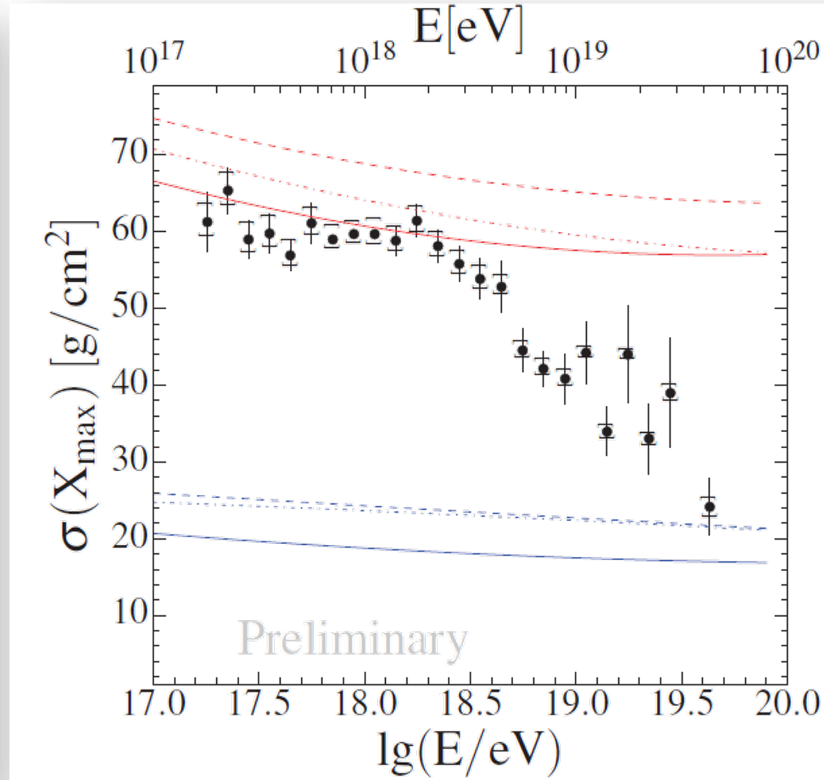
Rivelatore di Fluorescenza

24 telescopi, in quattro edifici ognuno con FOV 30° x 30°

Mass Composition.

Proceedings: UHECR 2018





Andamento di X_{max} misurato confrontato con MonteCarlo basati su diversi modelli di interazione

Andamento di RMS(X_{max}) misurato confrontato con MonteCarlo basati su diversi modelli di interazione

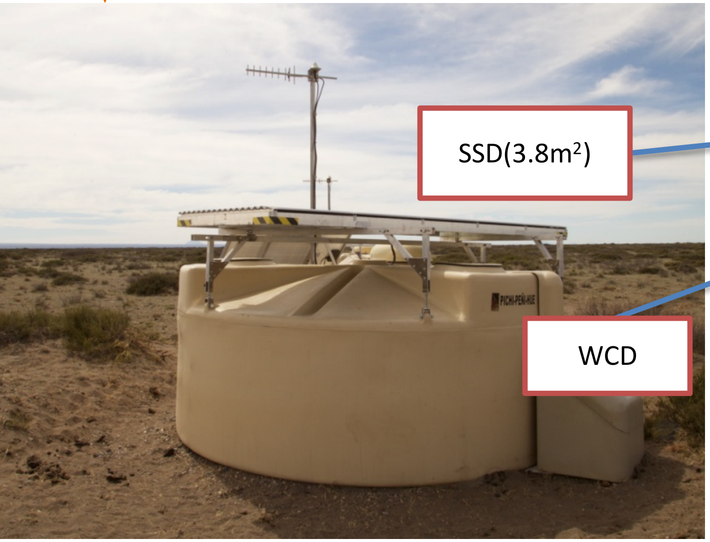
From Auger to AugerPRIME

Extension of operation of the Pierre Auger Observatory.

(MOUs have been signed in Nov 2015)

Main improvements:

1. A new detector above each of the existing water-Cherenkov detectors (WCD)
2. A new electronics for the SD and the extension of the dynamic range (smallPMT)
3. Extended FD operation
4. Underground Muon Detector with AMIGA to have a direct muon measurement
5. Radio antenna on every SD station.

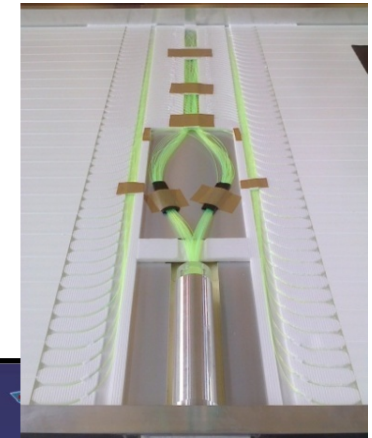


100% duty cycle

Complementarity of particle response used to discriminate electromagnetic and muonic components of air showers

SSD:The detector

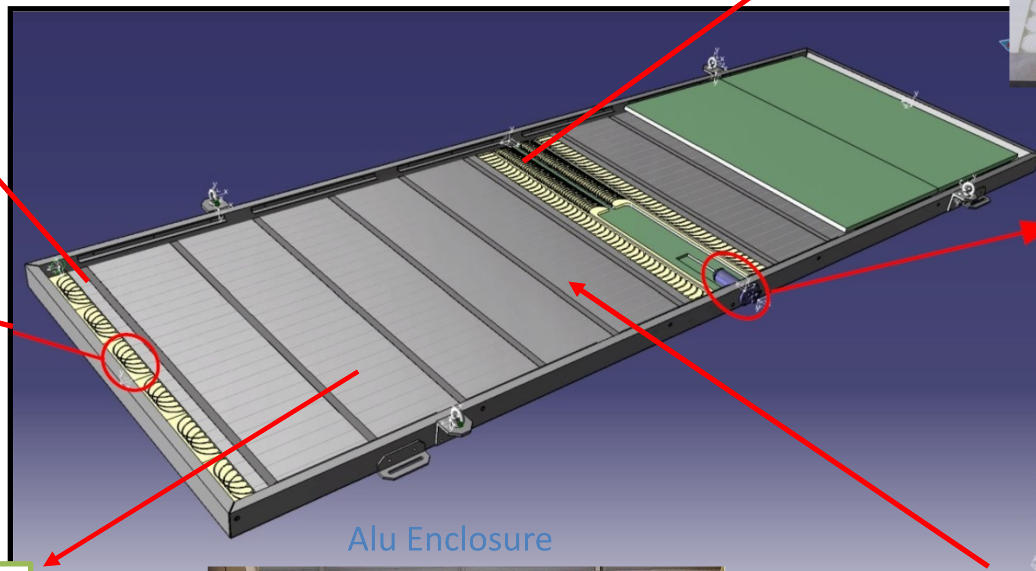
WLS fibers+routers



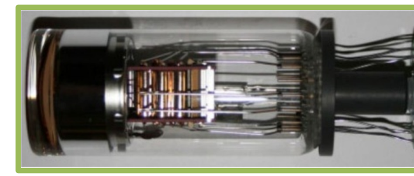
Extruded Scintillator bars with 2 holes

1cm

5cm

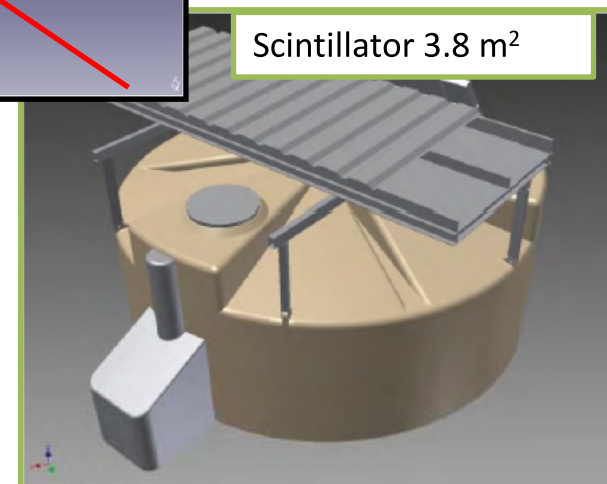


WLS fibers+routers



PMT

Scintillator 3.8 m^2



Extruded scintillator bars 160cm long