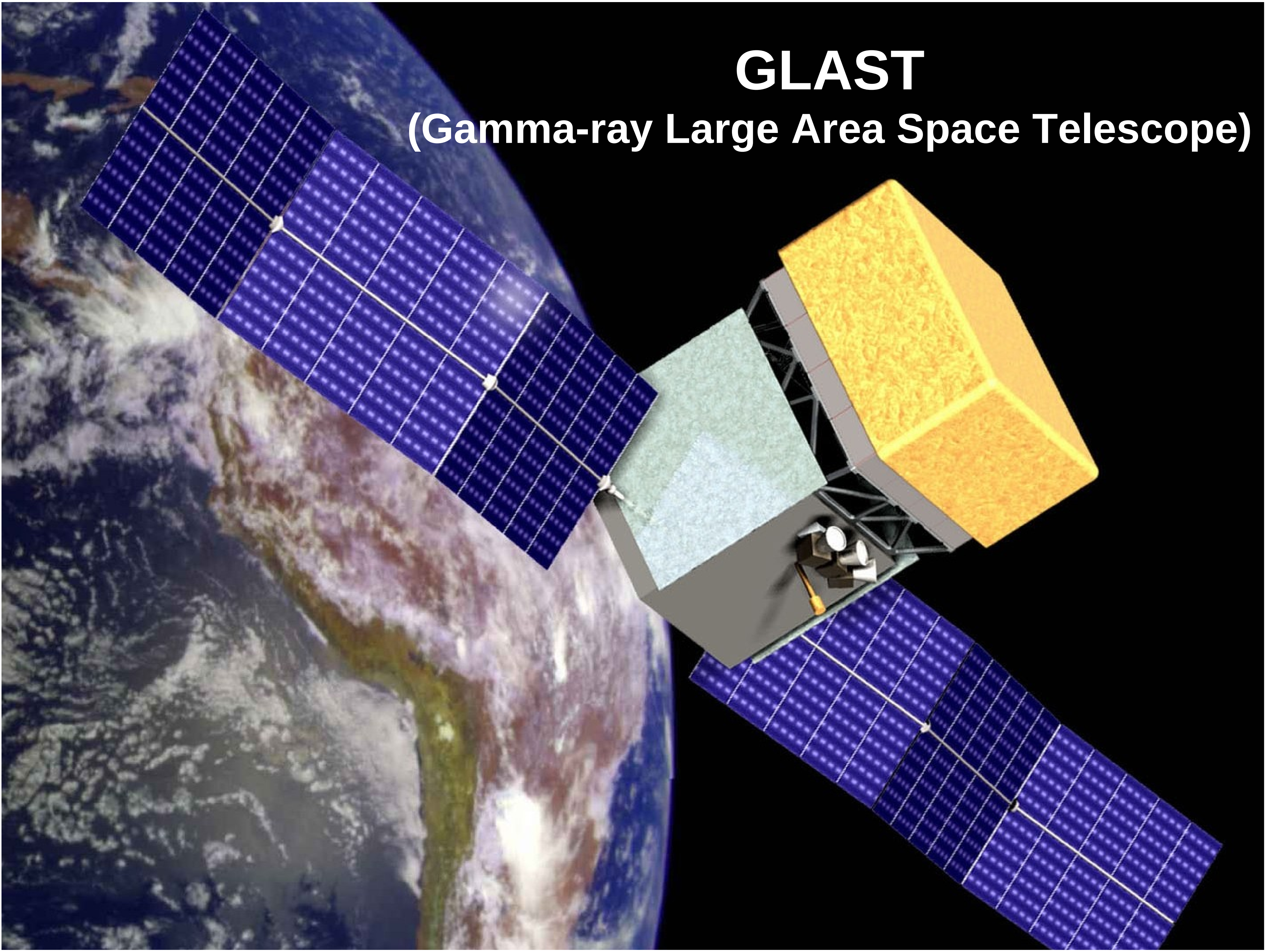
Exploring the Universe with High-Energy γ–rays

Benoît Lott , SLAC/CENBG

Specifity of high-energy gamma-ray astronomy

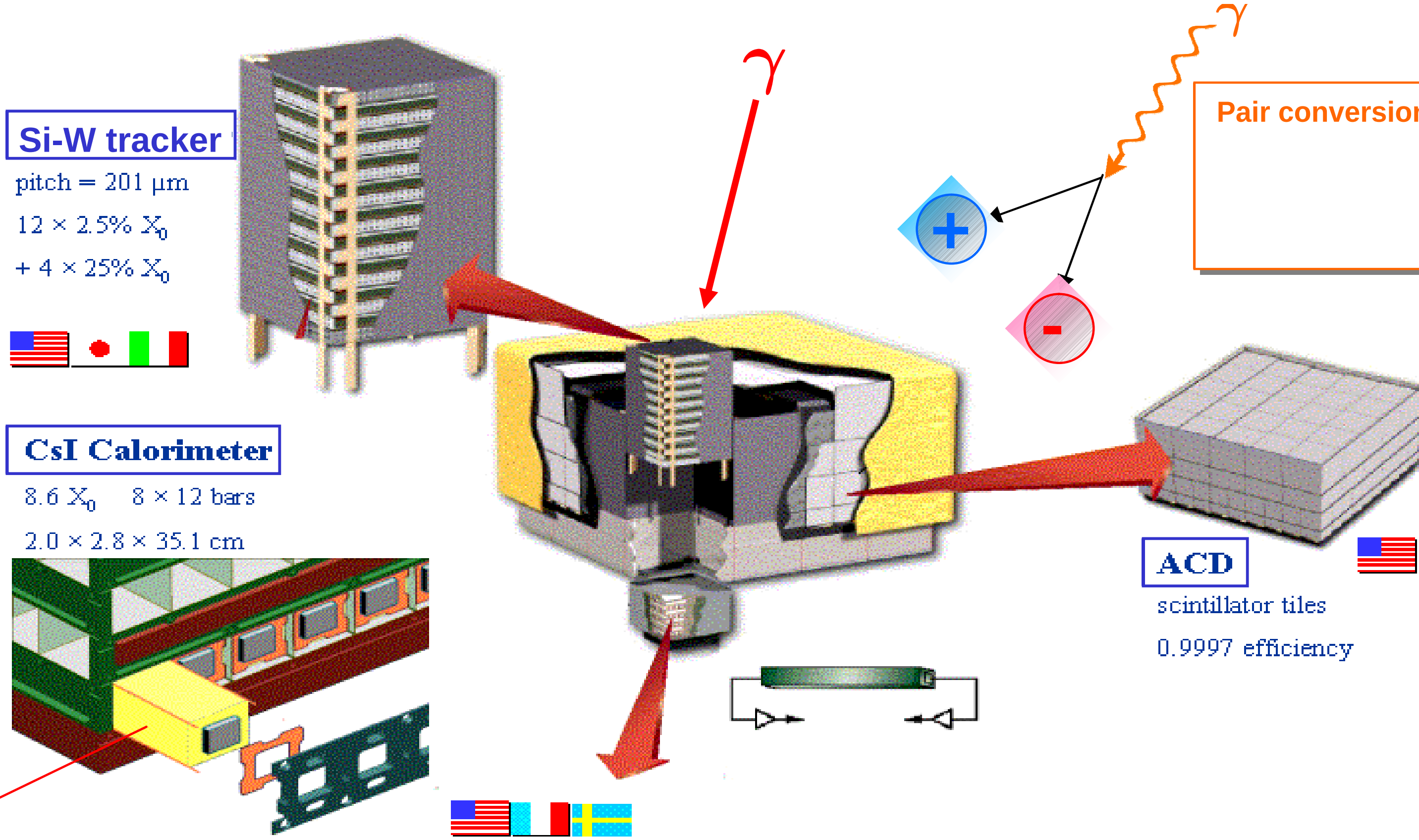
Extented domain: 30 keV-30 TeV 9 orders of magnitude
high-energy γ– rays: E>30 MeV

Instrumental specificities

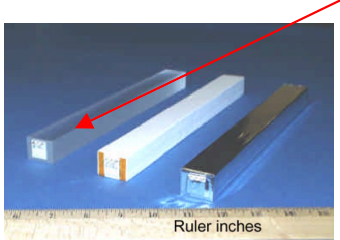

GLAST
(Gamma-ray Large Area Space Telescope)

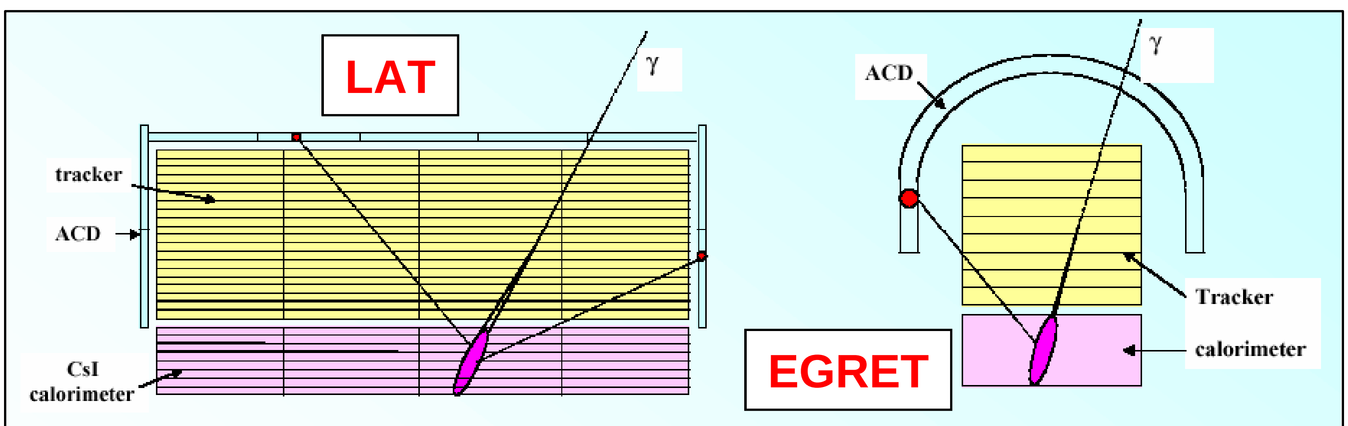
LAT (Large Area Telescope)

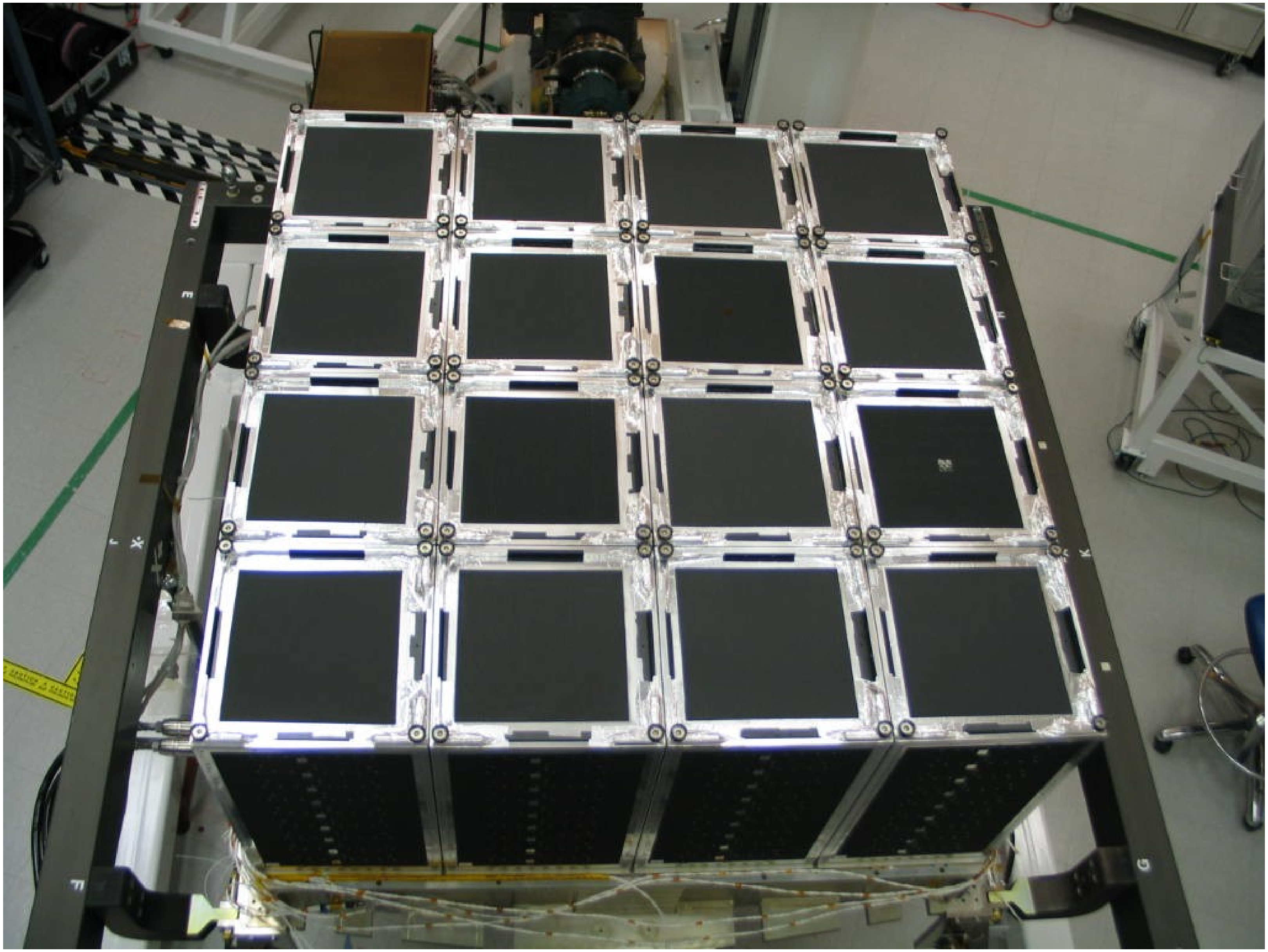
30 MeV-300 GeV

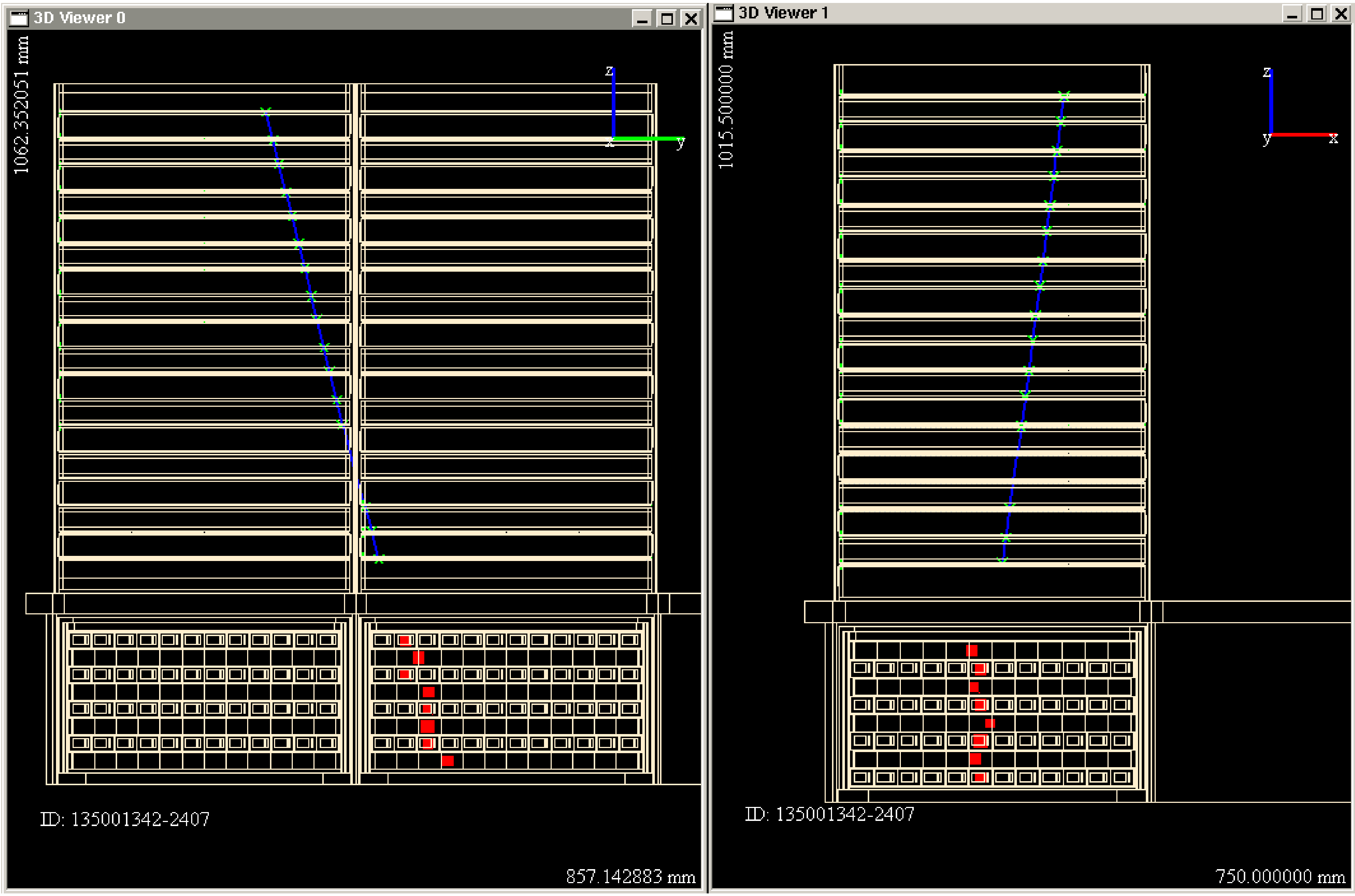


Pair conversion telescope
16 towers
- Veto
- Tracker
- Calorimeter








3D Viewer 0
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3D Viewer 1
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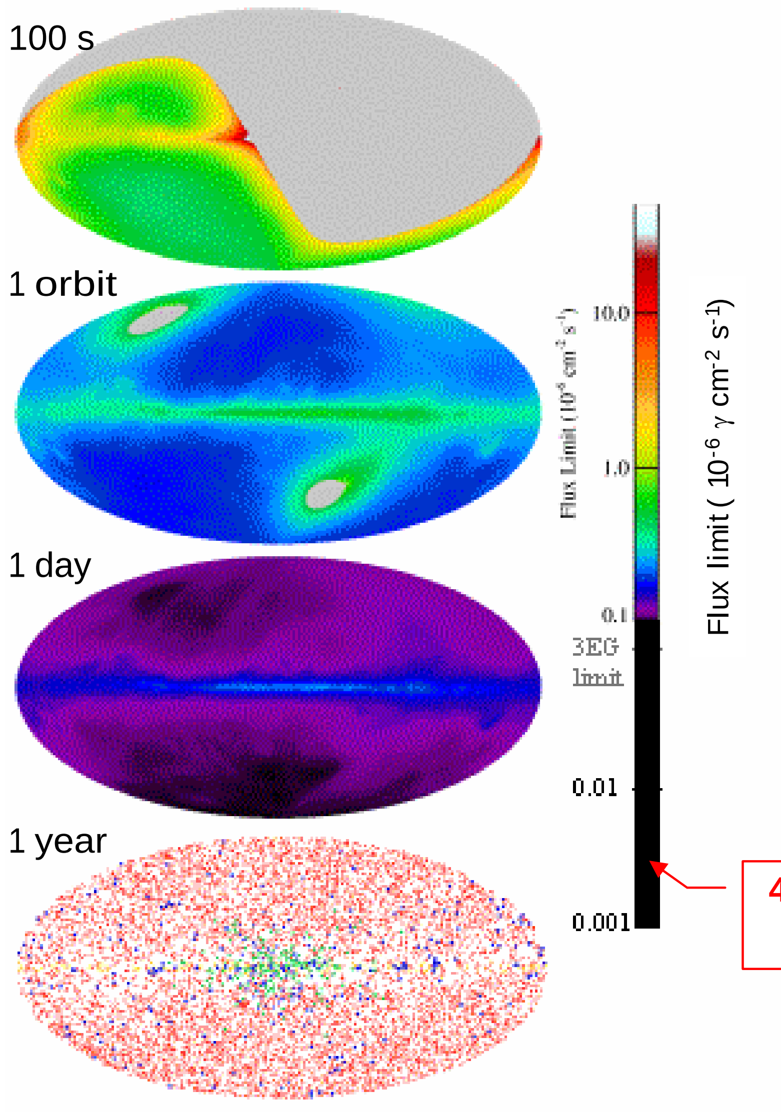
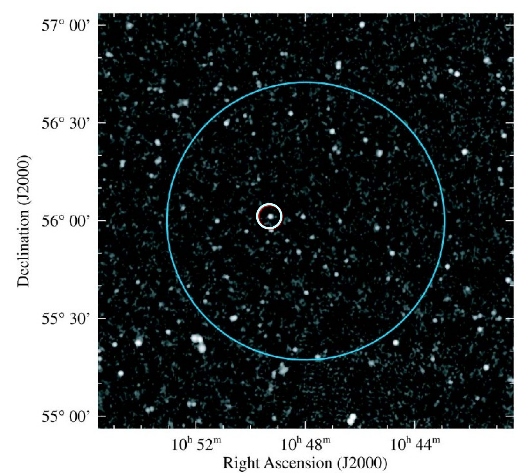
The LAT performance



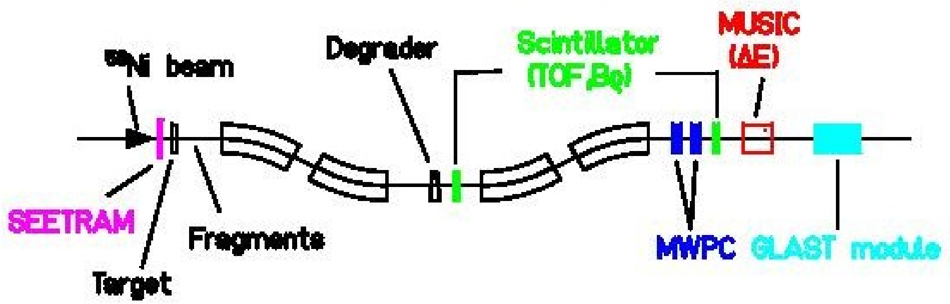
4 10^{-9} γ cm^{-2} s^{-1} for 1 year

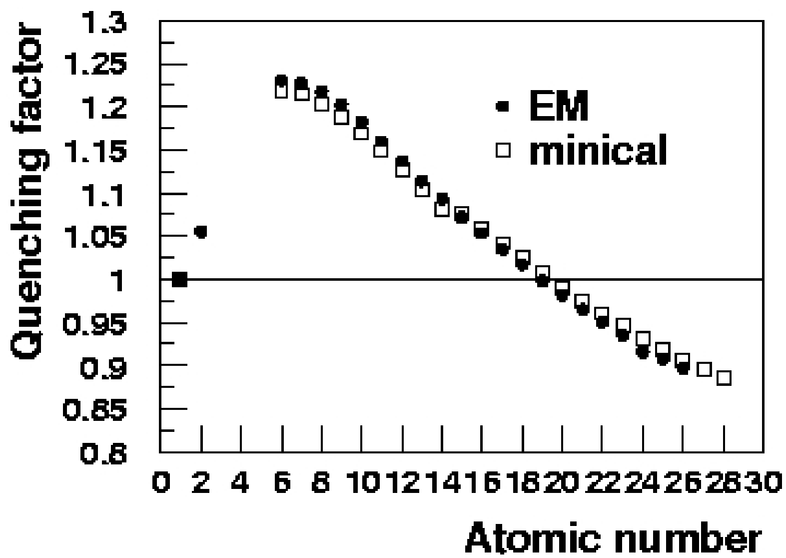
	EGRET	GLAST
Detector technology	Spark chambers+ NaI calorimeter	Si-strips+ CsI calorimeter
Energy range	20 MeV-30 GeV	20 MeV-300 GeV
Energy resolution	10%	10%
Effective area	1500 cm^2	8000 cm^2
Deadtime per photon	100 ms	20μs
Field of view	0.5 sr	2.4 sr
Angular resolution (PSD)	5.8° at 100 MeV	3° at 100 MeV 0.2° > 10 GeV
Source location determination	5'-30'	30''-5'
Sensitivity (>100 MeV)	10^{-7} cm^{-2}s^{-1}	4 10^{-9} cm^{-2}s^{-1}
Power	160 W	650W
Orbit	350 km/ 28.5°	550 km/ 28.5°
Mass	1810 kg	3000 kg
Lifetime	1991-2000	2007-2012 (17)



Response of the LAT calorimeter to:

relativistic heavy ions (FRS/GSI)

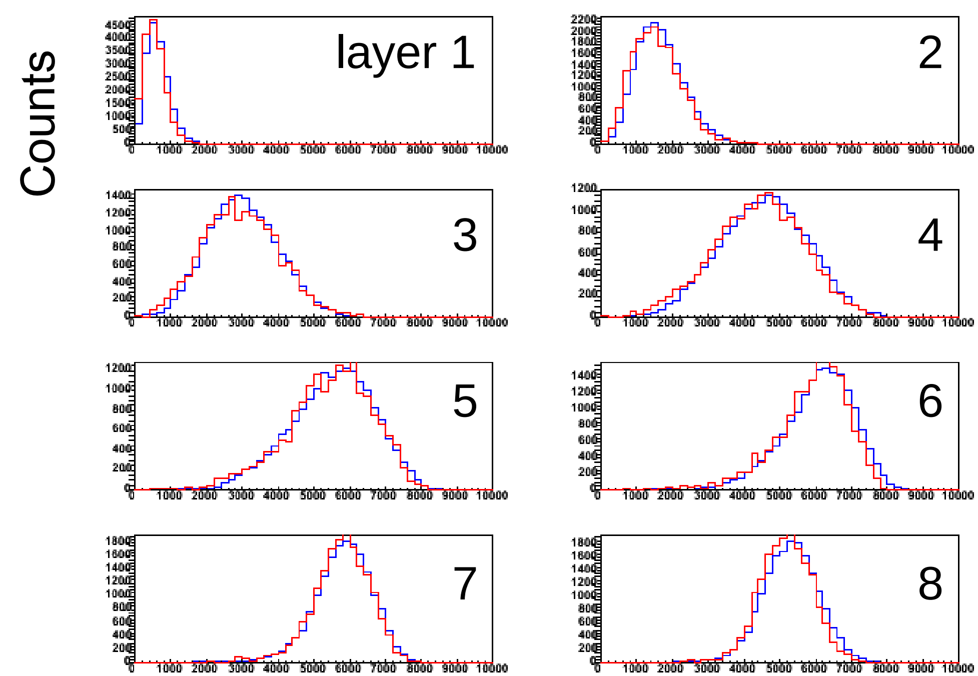




Quenching factor = k L_{meas}/E_{calc}

electromagnetic showers (CERN-SPS)

80 GeV e^+ 1.5 X_0

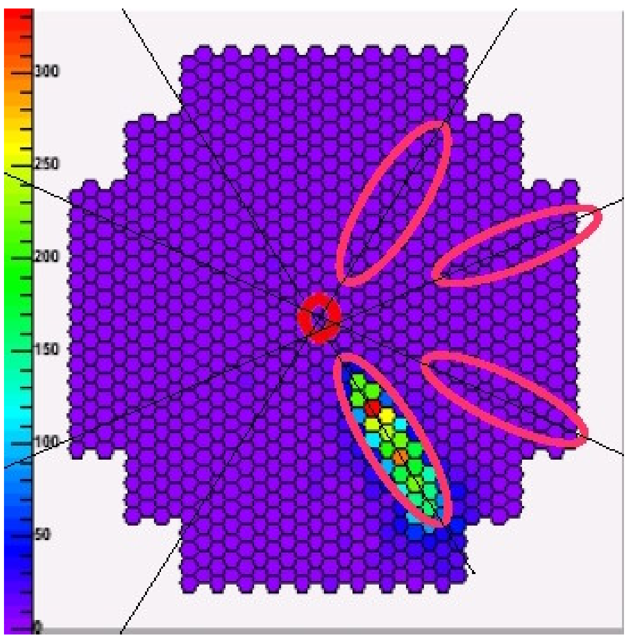


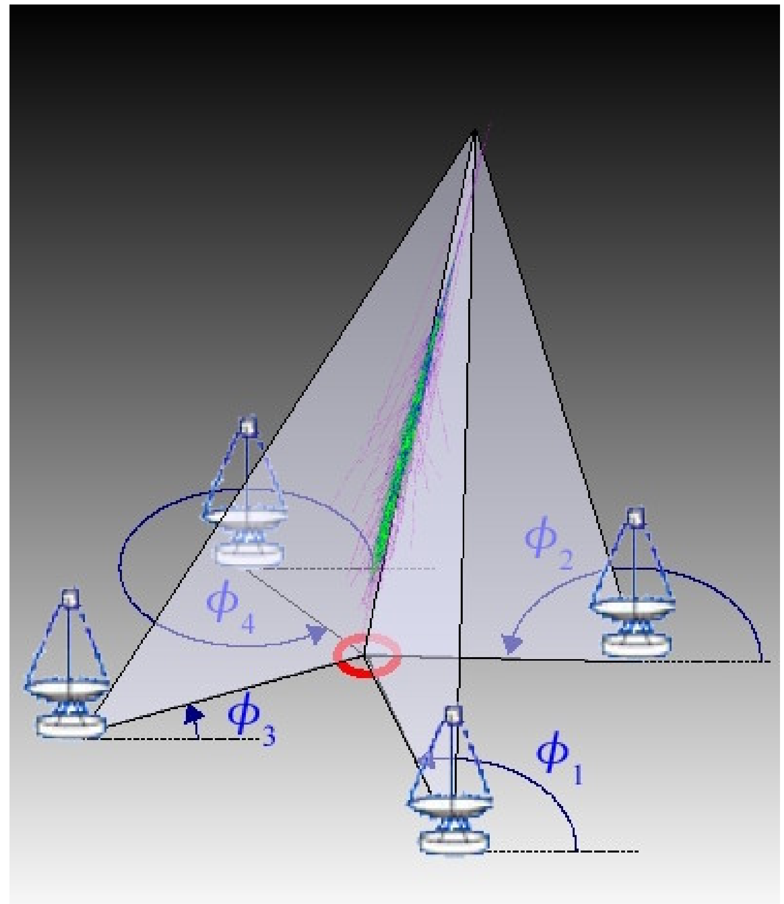
blue: data red: Geant4

deposited energy (MeV)

HESS

- in operation in Namibia since 2004
- main partners are Germany and France
- energy threshold: 100 GeV





A little history

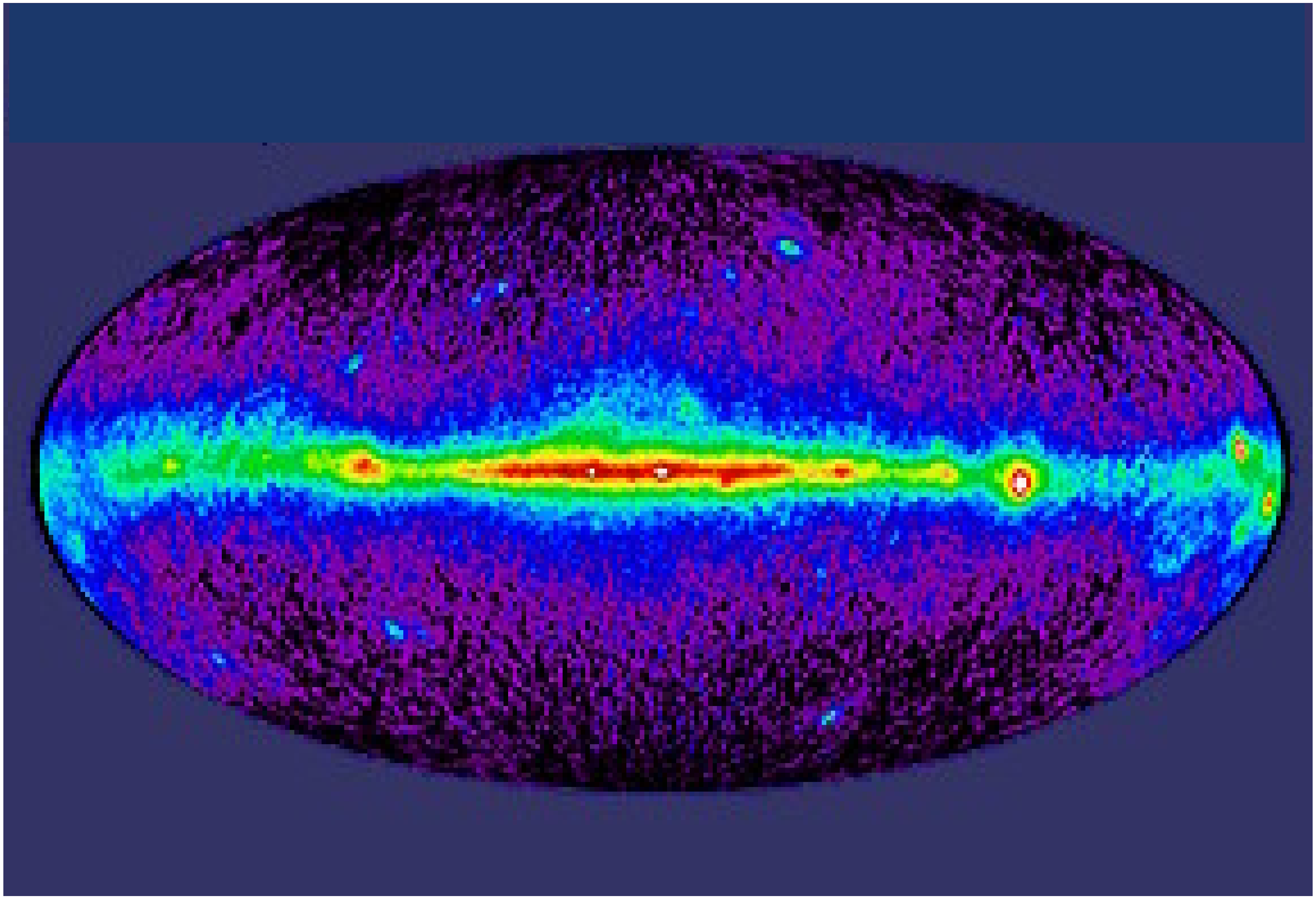
Space

Year	Mission	A_{eff} (cm^2)	Energy range	Life time	Detection
1967	OSO3	4	>50 MeV	15 months	Diffuse Emission
1972	SAS2	540	20 MeV-1 GeV	7 months	Crab,Vela, Geminga
1975	COSB	50	30 MeV-5 GeV	7 years	25 sources 3C273
1991	EGRET	1500	30 MeV-10 GeV	9 years	271 sources
2007	GLAST	10000	30 MeV-300 GeV	5(10) years	9000 sources?

Ground

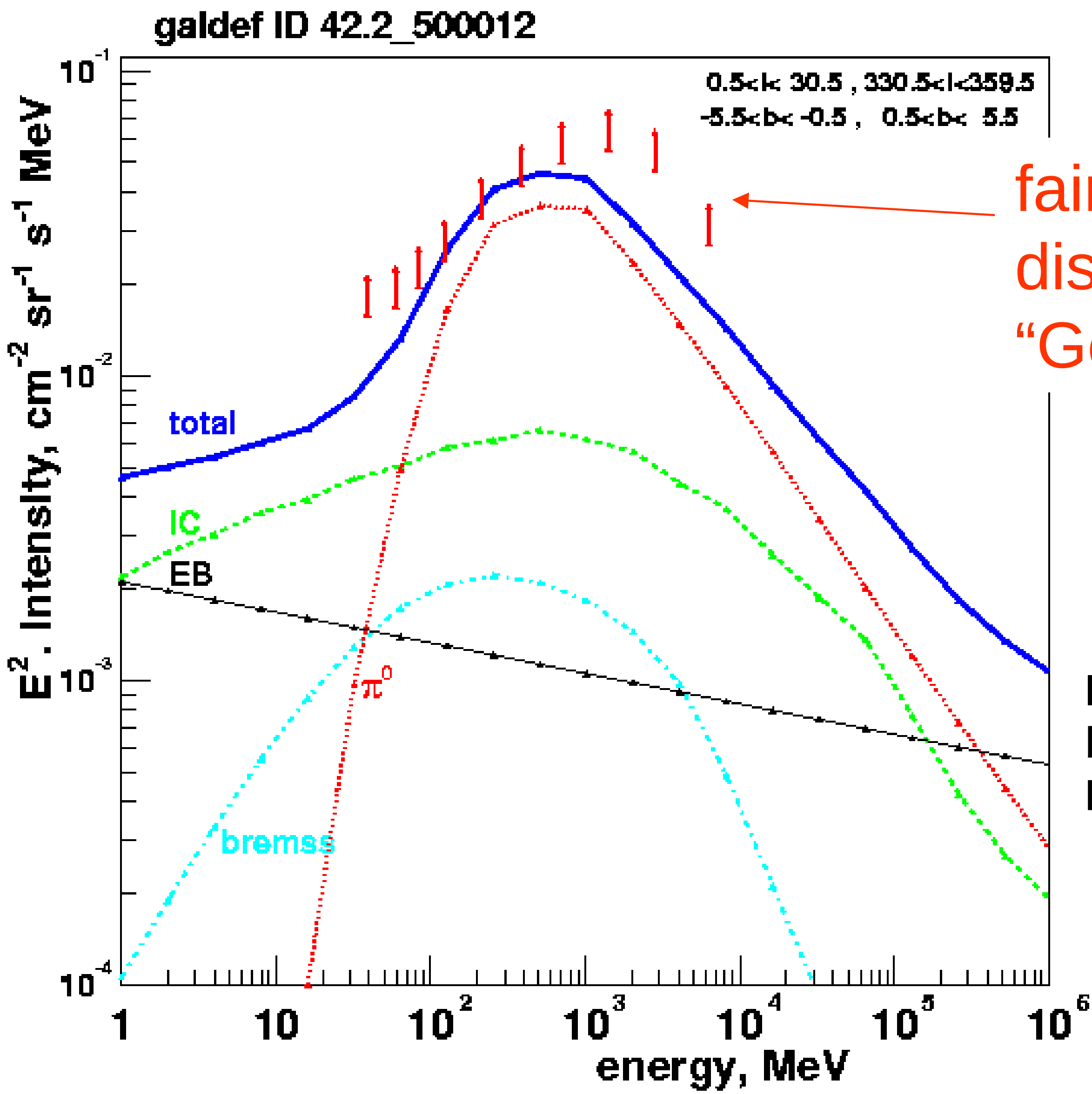
Year	Telescope	Threshold Energy	Detection
1989	Whipple	250 GeV	Crab
1992	Whipple	250 GeV	Mkn421
1995	Whipple	250 GeV	Mkn501
2002	Whipple CAT	250 GeV	1ES 1426+428 1ES 1959+650
2004-6	HESS	100 GeV	>30 sources

The high-energy gamma-ray sky



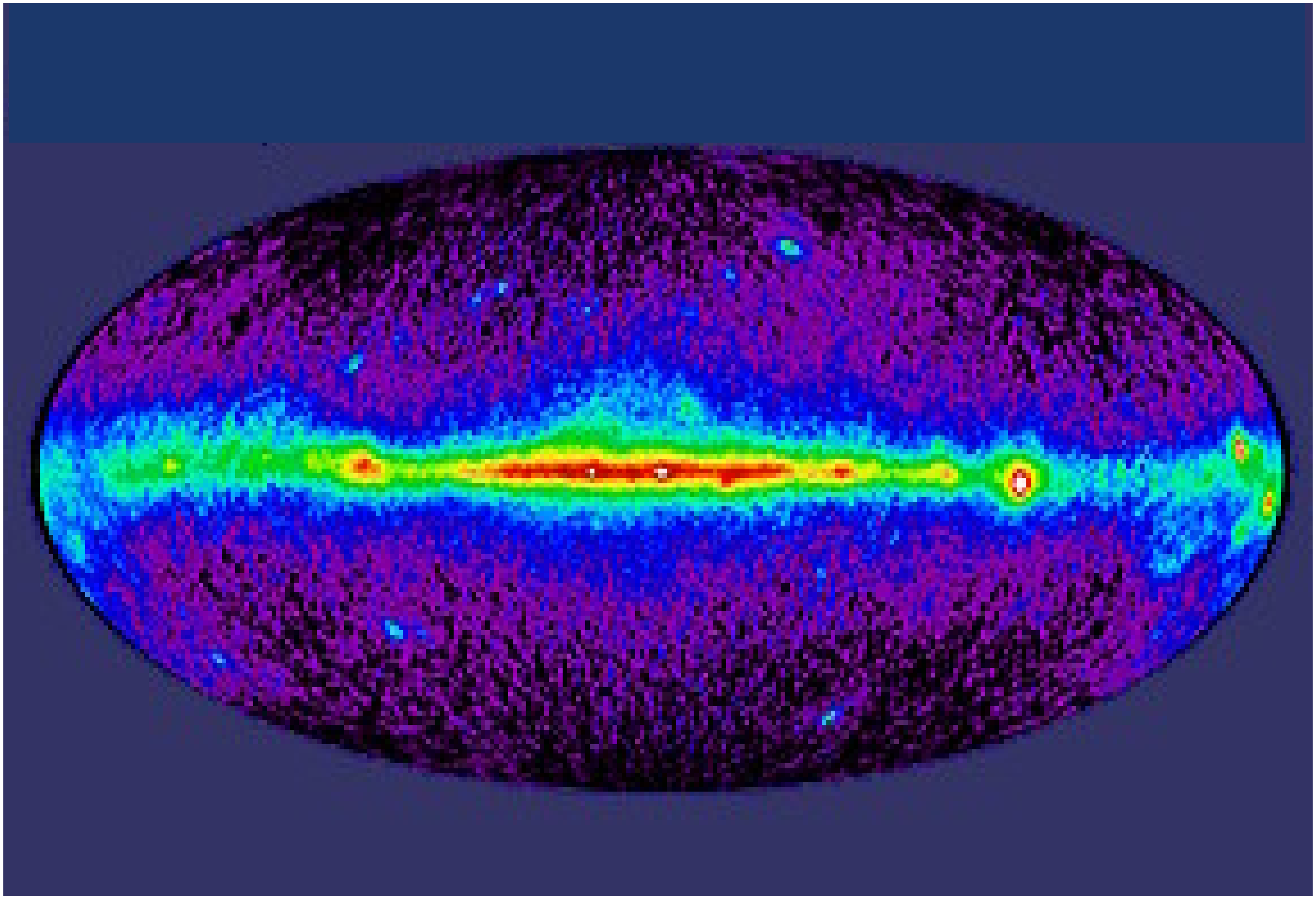
EGRET sky map for E>100 MeV (Seth Digel)
60% of photons from Galactic Diffuse Emission
30% of photons from Extragalactic Diffuse Emission (isotropic)

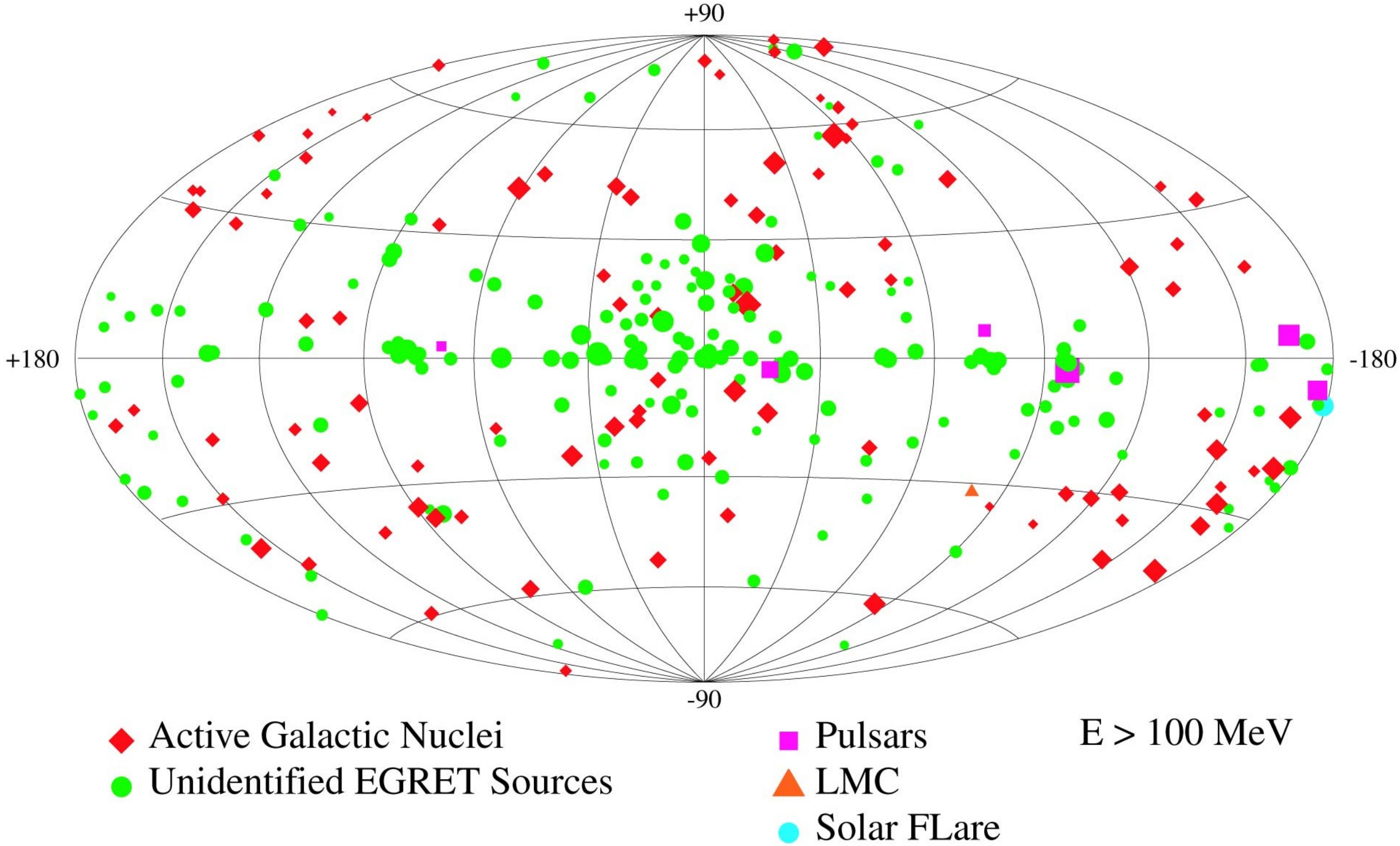
Galactic Diffuse Emission



fairly large discrepancy: "GeV-excess problem"

IC: Inverse Compton
bremss: bremsstrahlung
EB:Extagalactic background

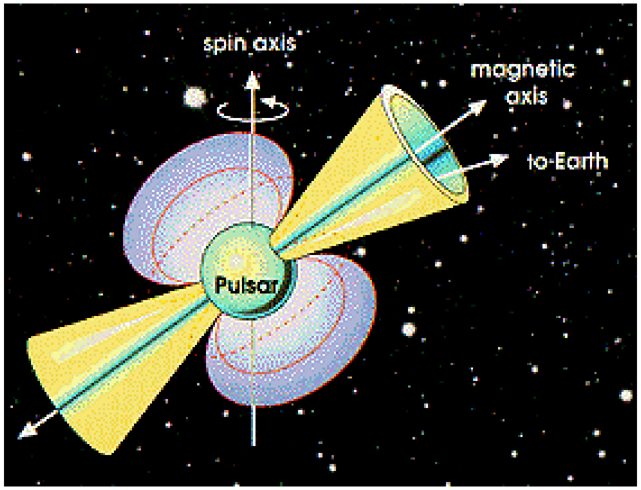


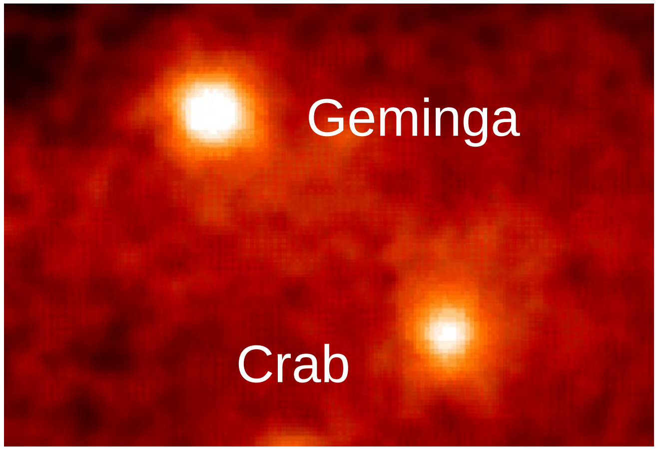


3rd EGRET Catalog: 271 sources

170 unindentified!

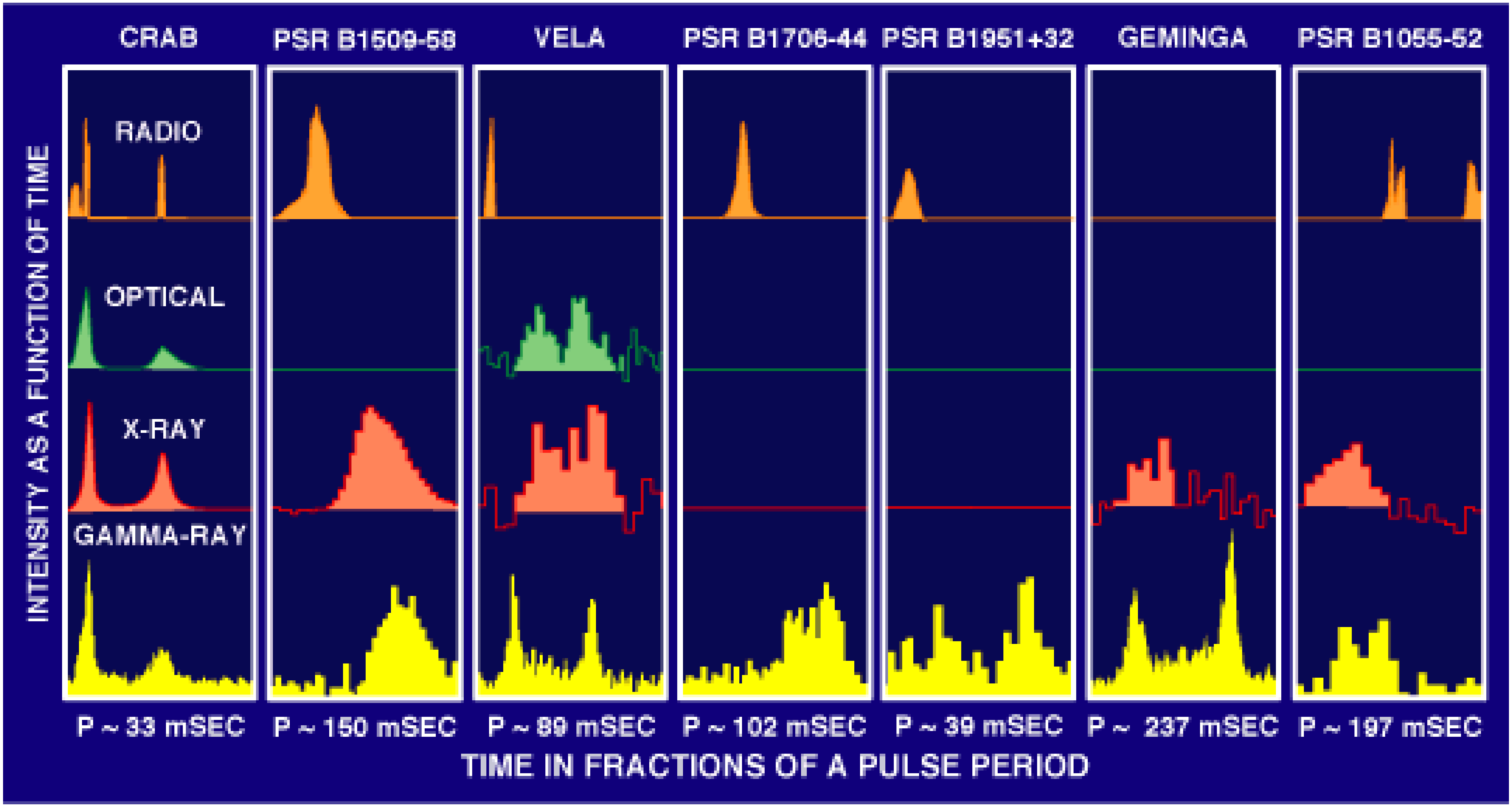
Pulsars



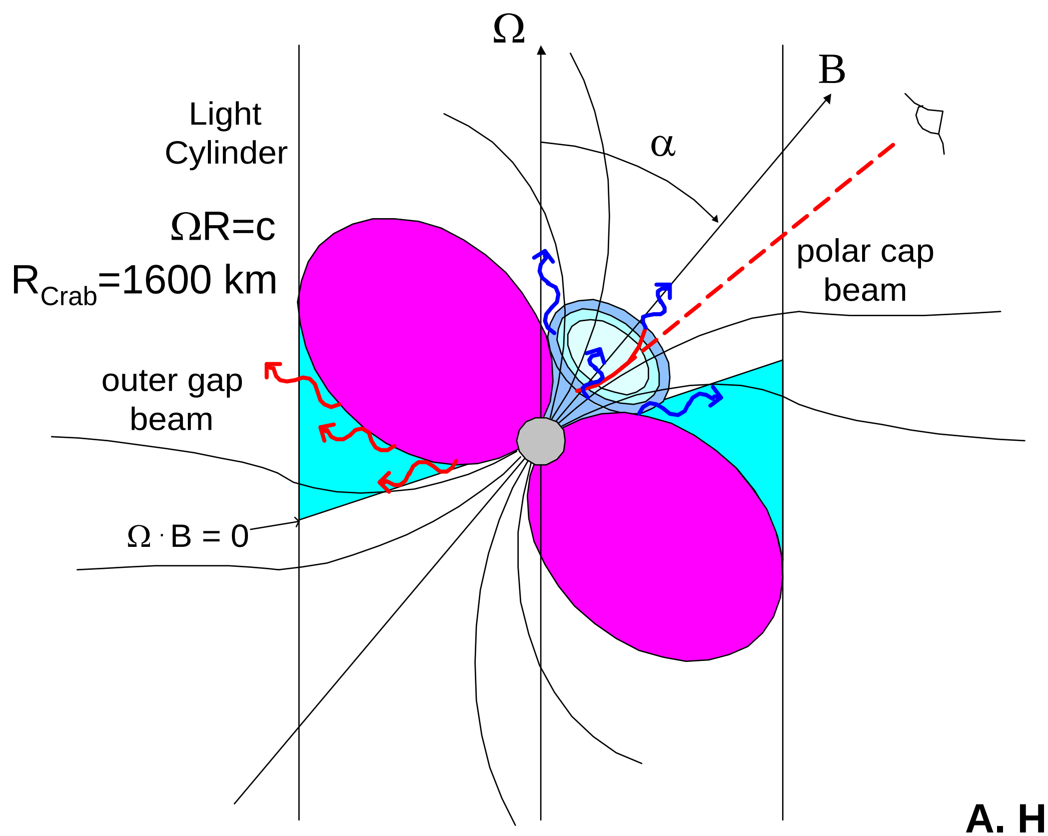


«Galactic anticenter» EGRET

Pulsar phasograms



Polar-cap and outer-gap emissions



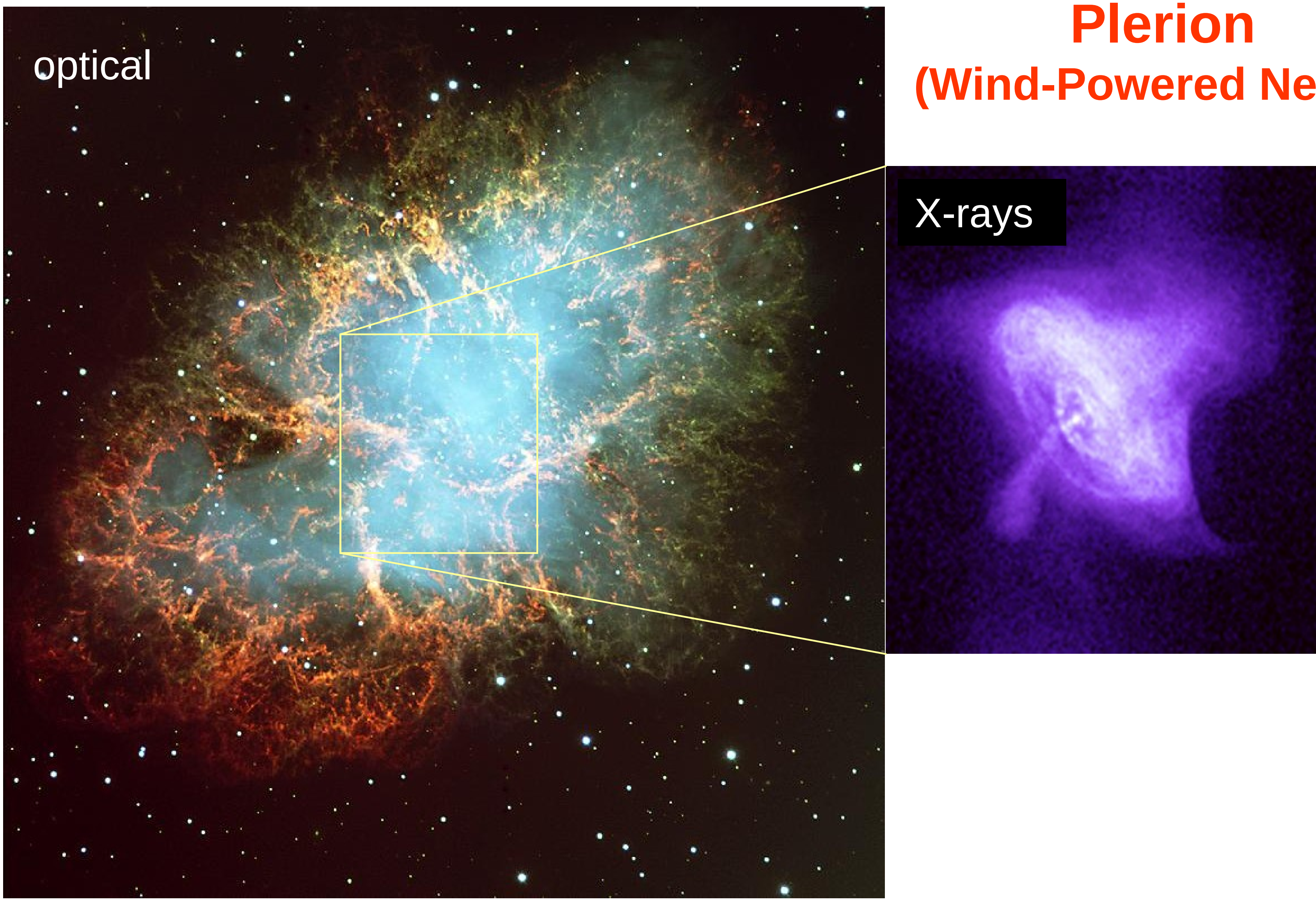
A. Harding

Radio: coherent emission

High-energy emission: two competing classes of models assuming different locations of the accelerating cavity within the magnetosphere

- polar cap (small Ω_{em})
- outer gap (large Ω_{em})

Plerion
(Wind-Powered Nebula)



Explosion on July 4, 1054   distance: 6.3 10^3 light years

T_{pulsar}= 33 ms

First-order Fermi process

Supernova Remnants (SNRs)

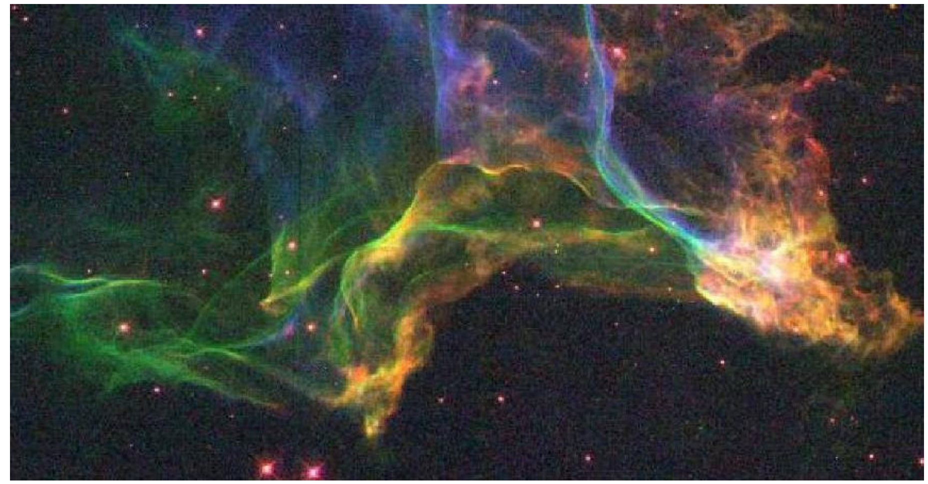
Some are « shell » SNRs (no active nebula)
known acceleration sites of electrons

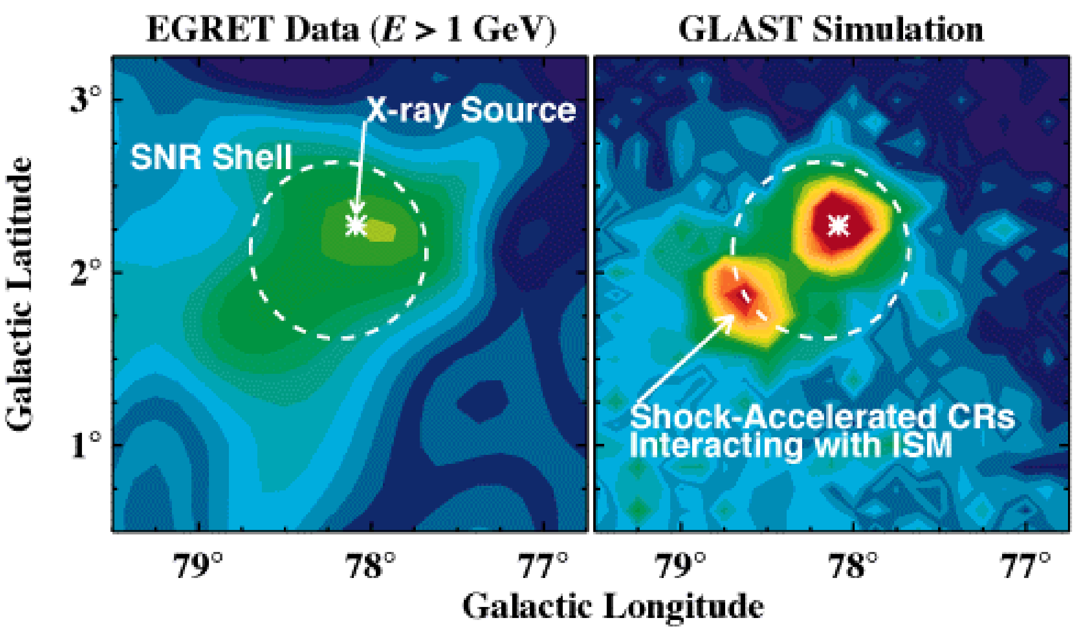
Example: Gamma Cygni

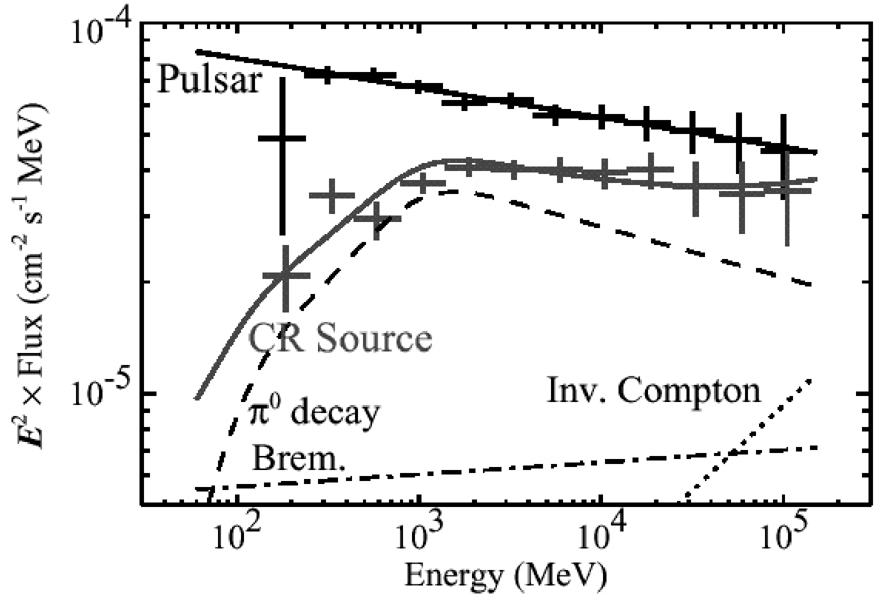
EGRET: several sources compatible with SNRs but:

- persistent location problems
- absence of clear π^0 peaks

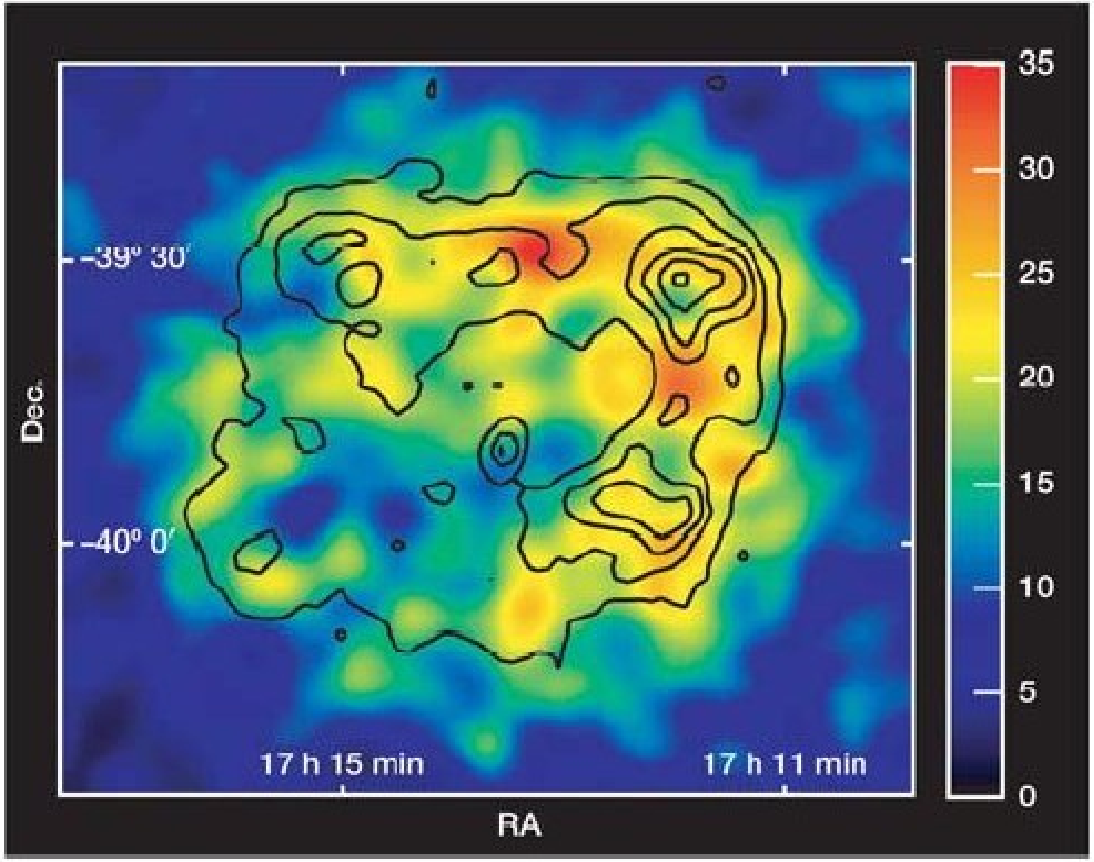
Cygnus loop, HST







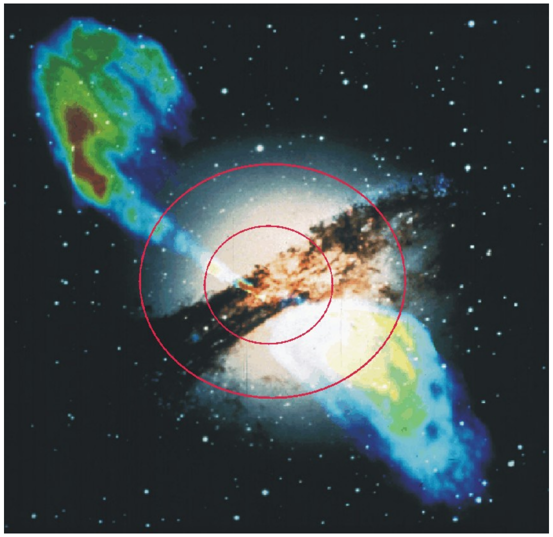
Supernova Remnant RX J1713.7-3946 (HESS, E>800 GeV)



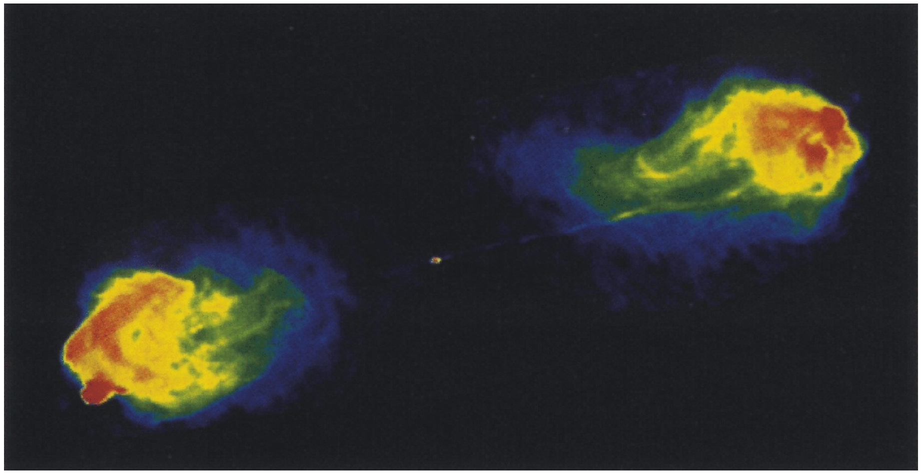
Supernova remnants shine at TeV energy, but whether this emission is due to π^0 decays remains unclear. GLAST will help sort out this issue.

Active Galaxy Nuclei (AGNs) - Blazars

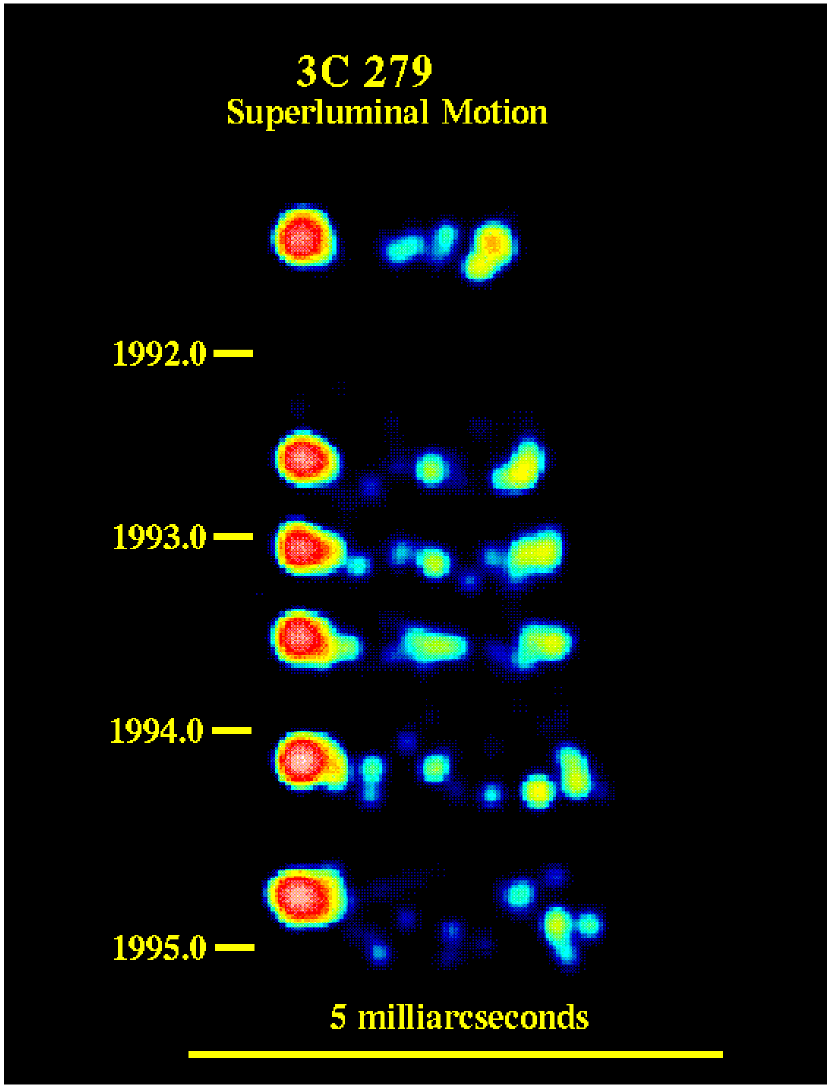
A few % of all galaxies are "active", $L_{nucleus} > L_{star}$
95% are radio-quiet:"Seyfert"
5% are radio-loud: "quasars" or "blazars"



1 $M_{\odot}$ ~10^{54} erg

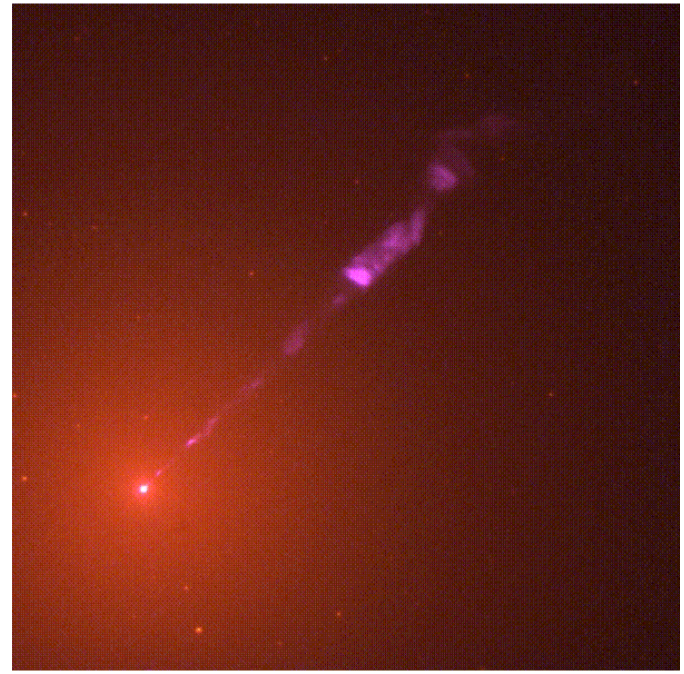


Superluminal motion



VLBI observation: v_{app}=4 c!

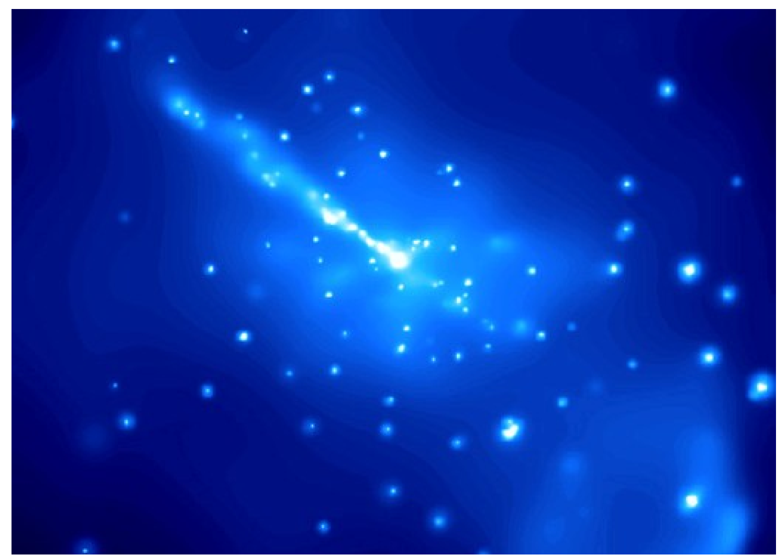
Jets in AGNs



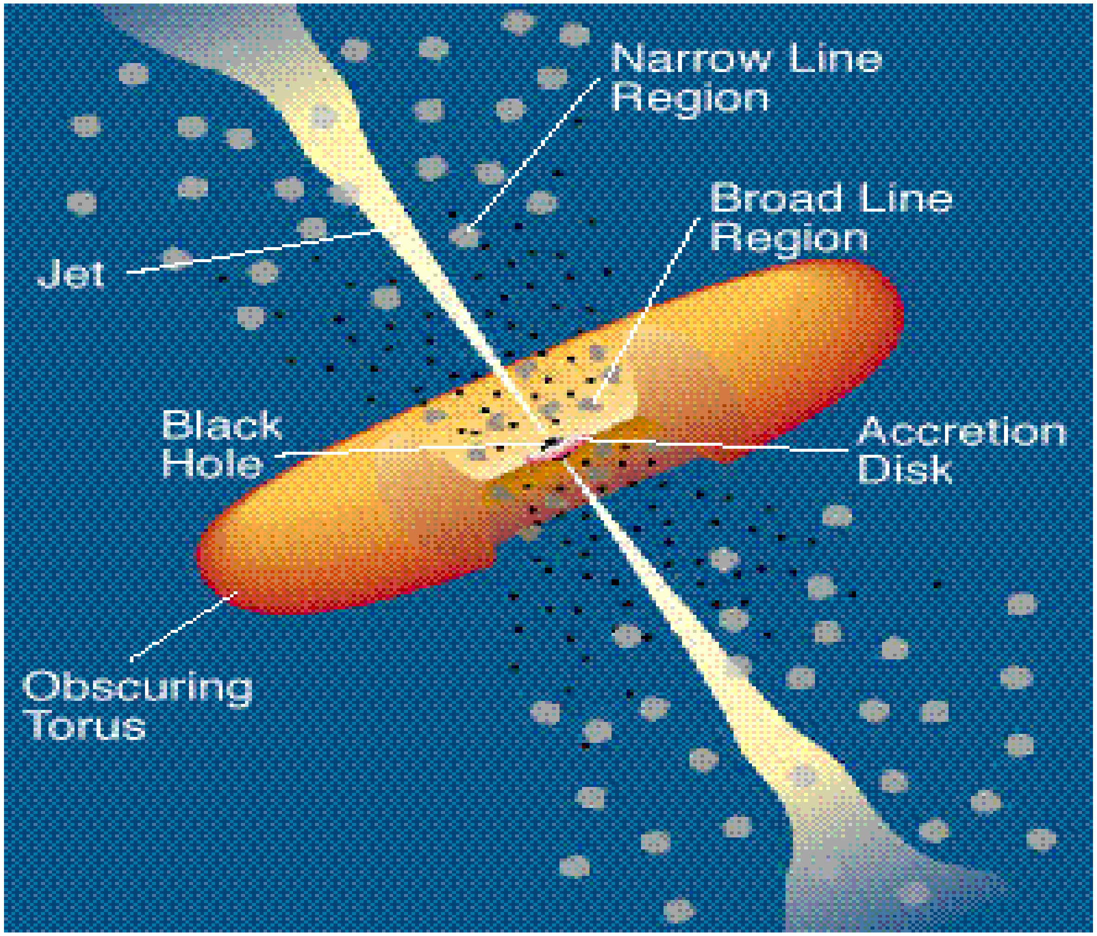
Problem: Compact sources, high luminosity

High **optical thickness** for pair production

$$\tau = \frac{\sigma_T}{5}\frac{L_{\gamma/x}}{4\pi R m_e c^3}$$



Blazar morphology

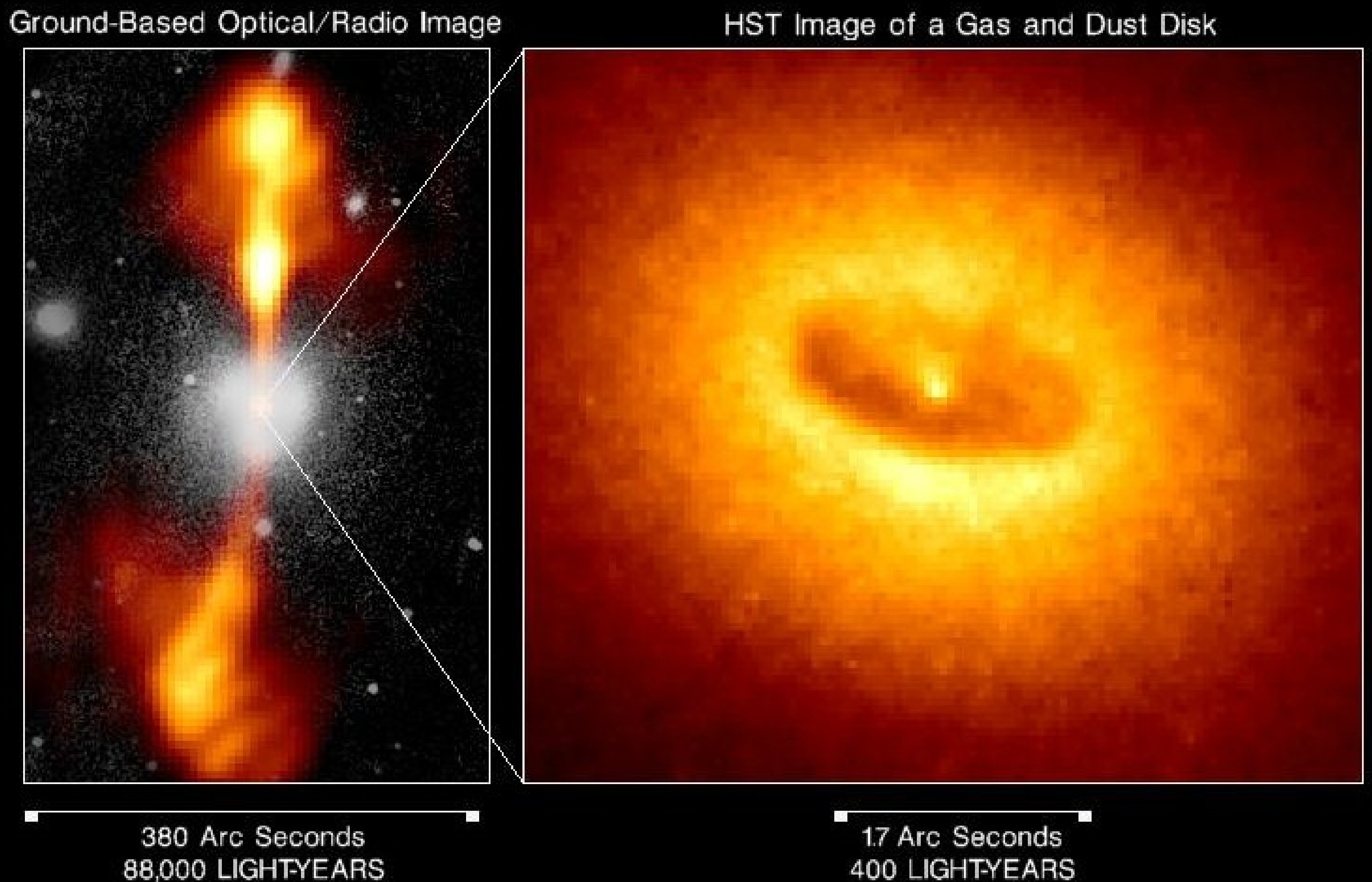


Courtesy of C.M. Urry and P. Padovani.

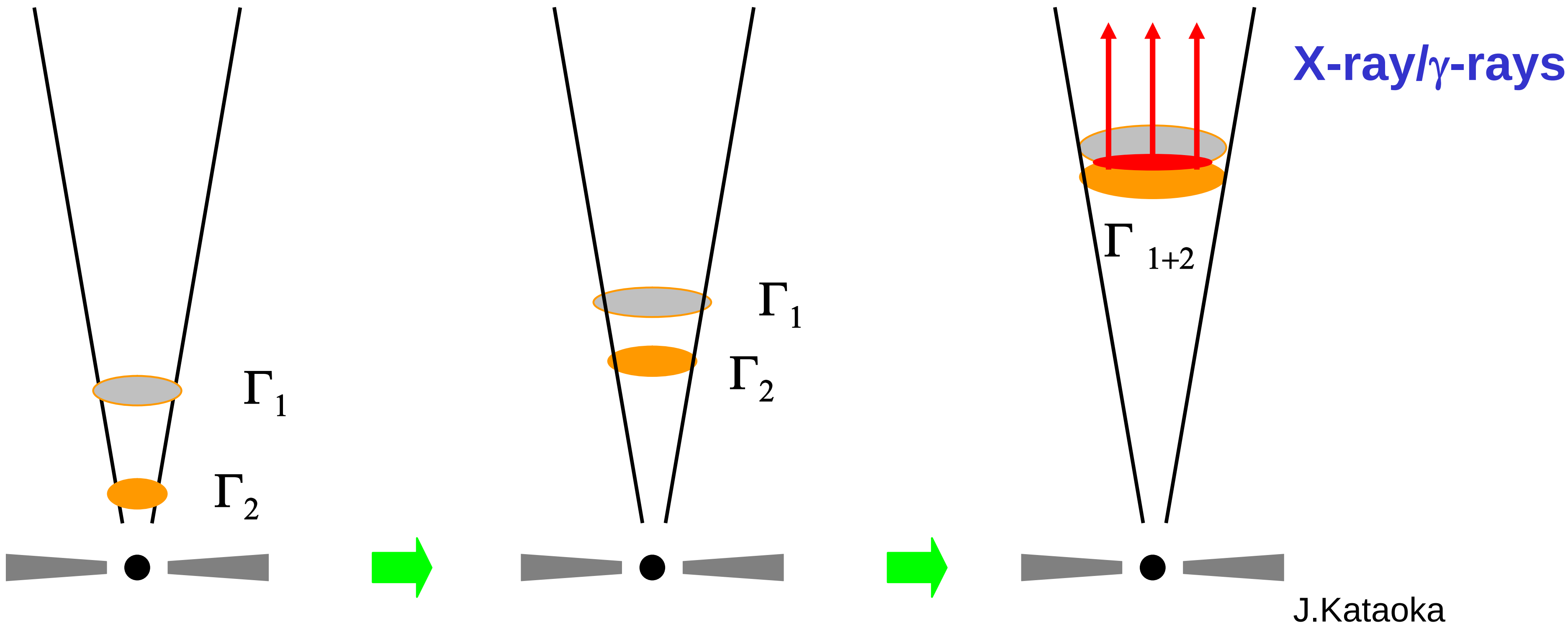
Core of Galaxy NGC 4261

Hubble Space Telescope

Wide Field / Planetary Camera



How to explain rapid variability



Modulation of relativistic flows - faster shell (Γ_1) catches up with the slower one (Γ_2)

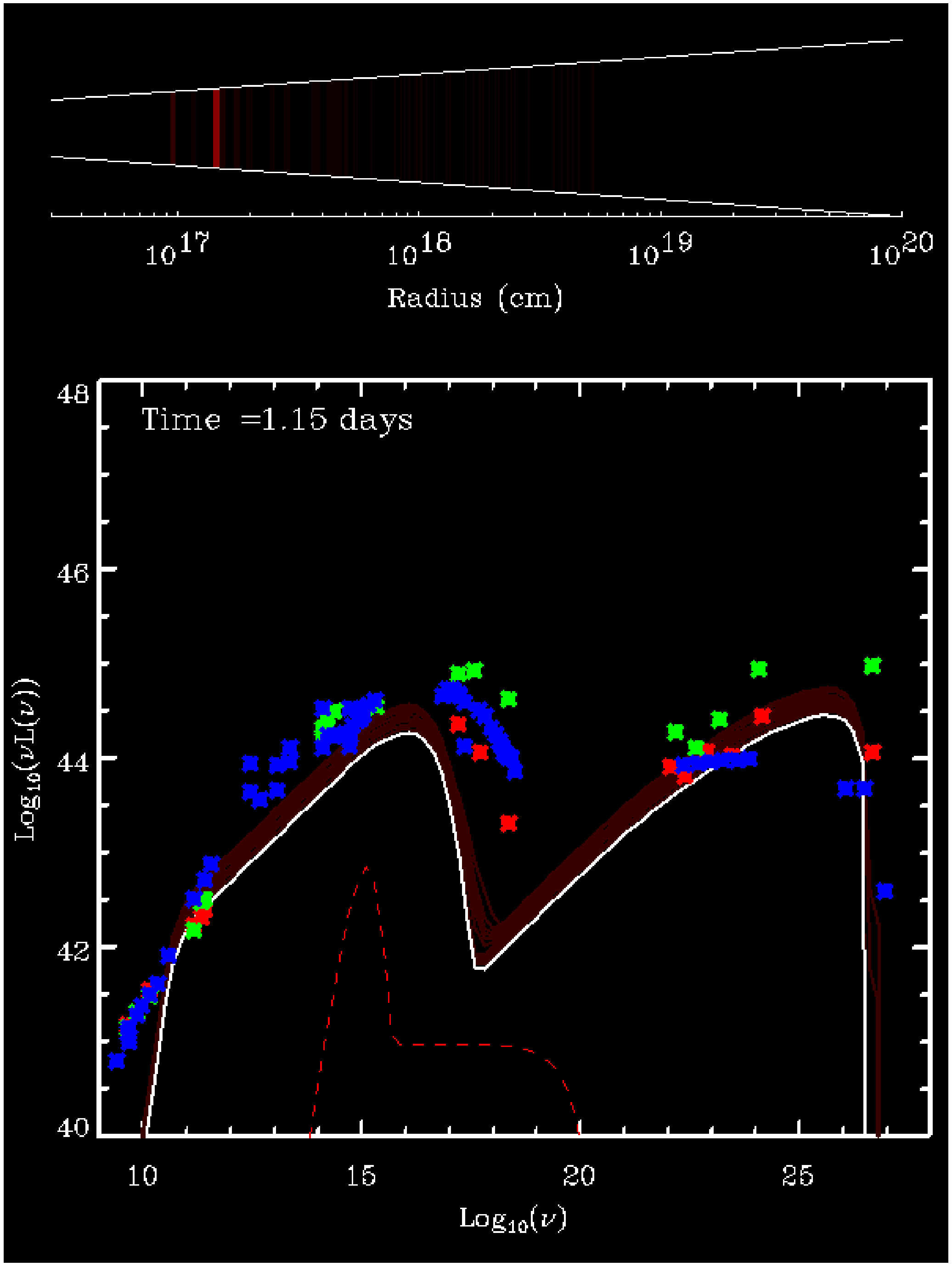
e^-e^+ (and possibly smaller fraction of p) are accelerated in the shock, and emit Synchrotron/ Inverse Compton radiation.

Blazar Spectral Energy Distributions

Spectra exhibit two humps, corresponding to synchrotron emission and IC scattering

Emission over 17 decades in energy!

Variability studies provide a wealth of information
time lags between bands →
acceleration/cooling competition



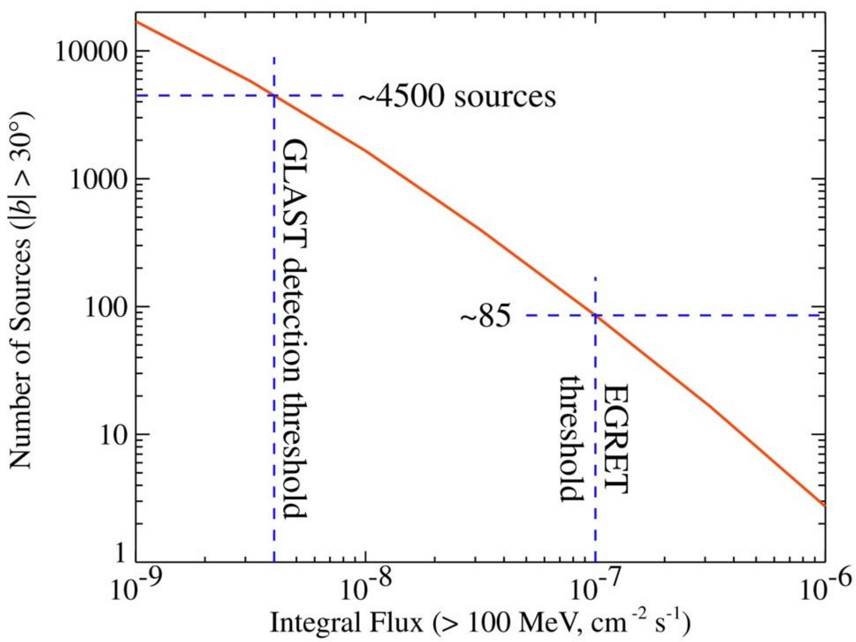
Spada et al. Mrk421

Open issues about blazars

- mechanism of extraction of energy from the BH and production of jet
- mechanism and sites of particle acceleration
- identification of the physical parameters driving the observational properties (LBL vs HBL): accretion rate?
- environment inducing the high-energy component Synchrotron Self-Compton vs External Compton
- Jet contents (leptonic or hadronic)
- luminosity function

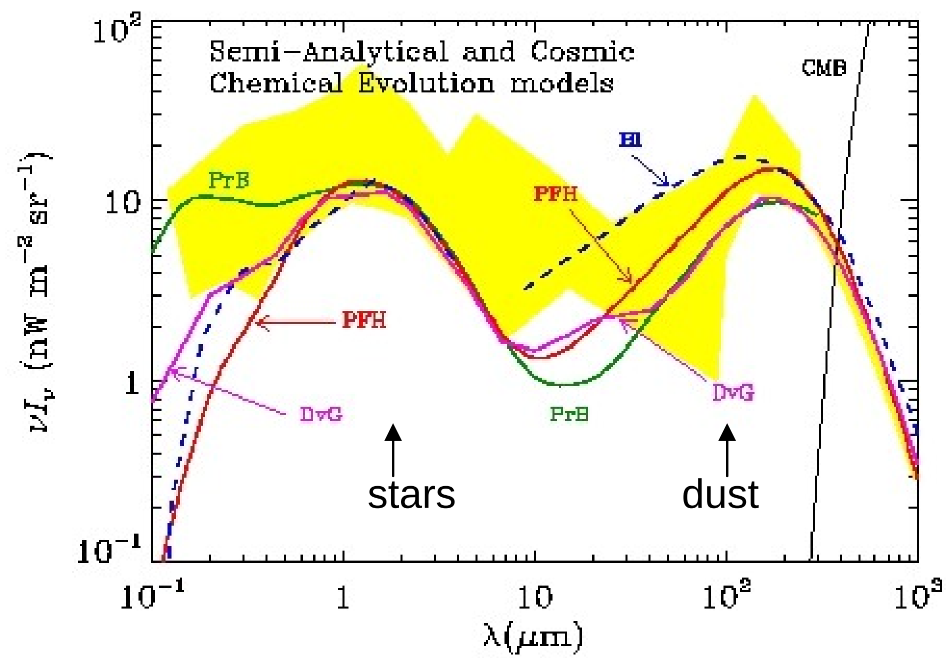
EGRET: 100 Blazars (0.03< z <2.3)

GLAST: > 4000 Blazars



Extragalactic Background Light

Hubble Deep Sky Survey



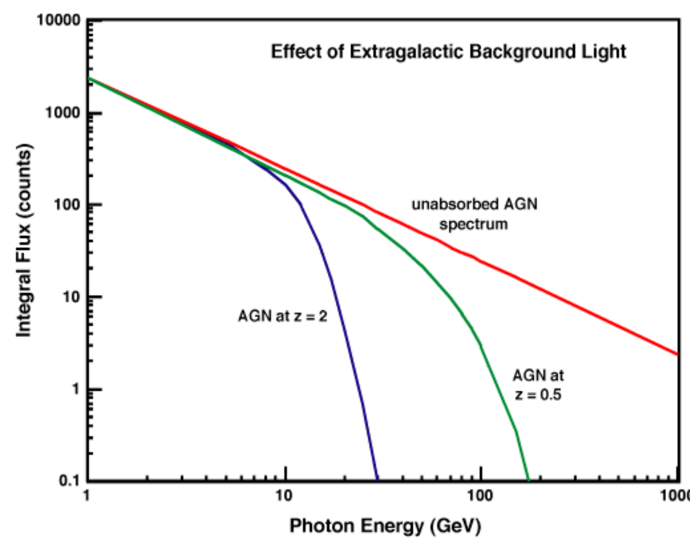
Direct measurement difficult due to large foreground components

$$\gamma + \nu_{IR} \rightarrow e^{+}e^{-}$$

$$\text{threshold:} \quad eE\,(1+z)^2(1-\cos\theta) > 2(m_e c^2)^2$$

$$e_{eV} = \frac{500\text{GeV}}{E_{GeV}(1+z)^2} \quad \text{or} \quad \lambda_{\mu m} = 1.2\frac{E_{GeV}(1+z)^2}{500\text{GeV}}$$

$$F_\nu^{obs} = F_\nu^0 \exp(-t(\nu, z))$$

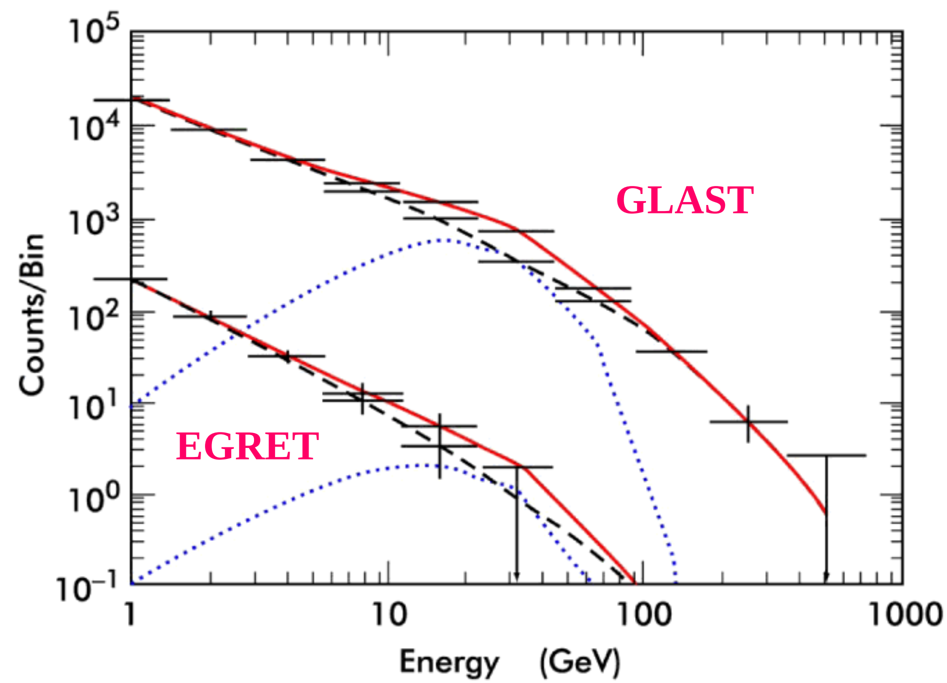


E. Bloom

Astroparticle Physics

Extragalactic Diffuse Background

Comes from non-resolved AGNs but a component could correspond to the decay of relic particles e.g. WIMPS



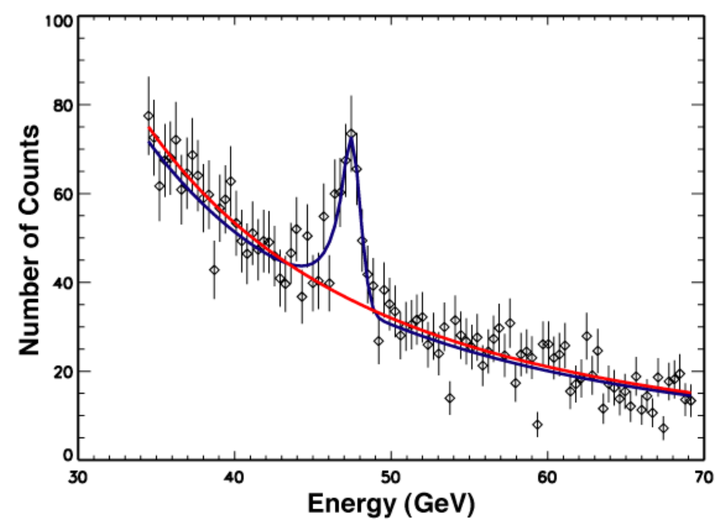
Stable supersymmetric candidate neutralino with 50 GeV < M_χ < 100 GeV

$\chi\chi \rightarrow \gamma X$ or $\chi\chi \rightarrow \gamma\gamma$

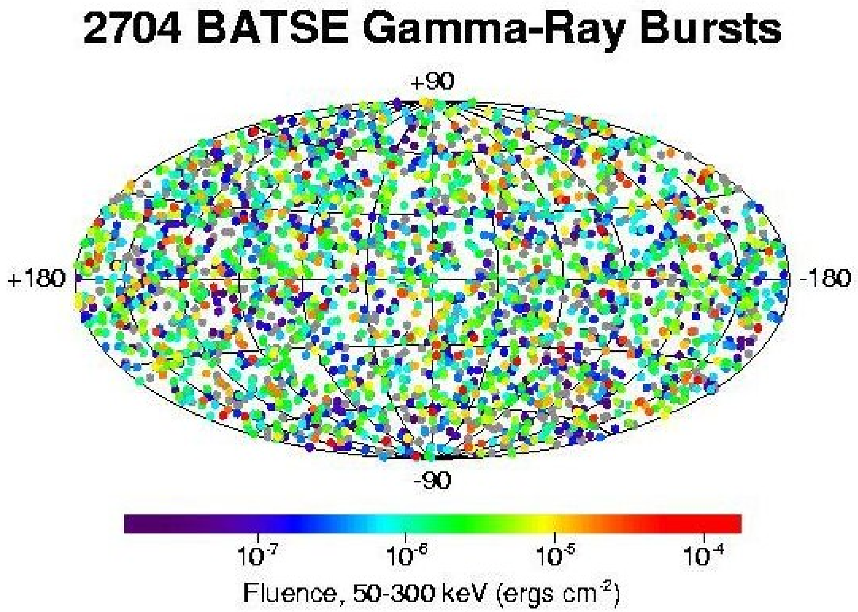
The large number of blazars detected by GLAST will enable to pin down the (non-accounted for) contribution.

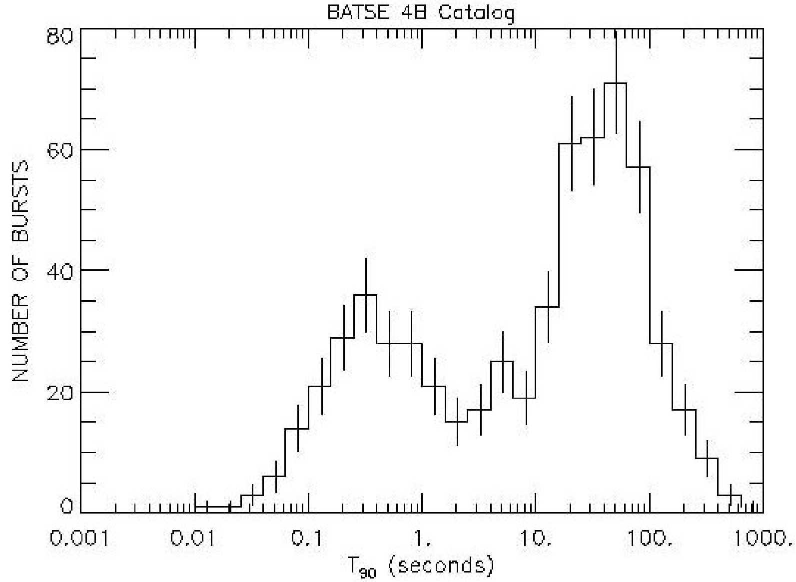
Galaxy center

Presence of a line at $E_\gamma = M_\chi$?

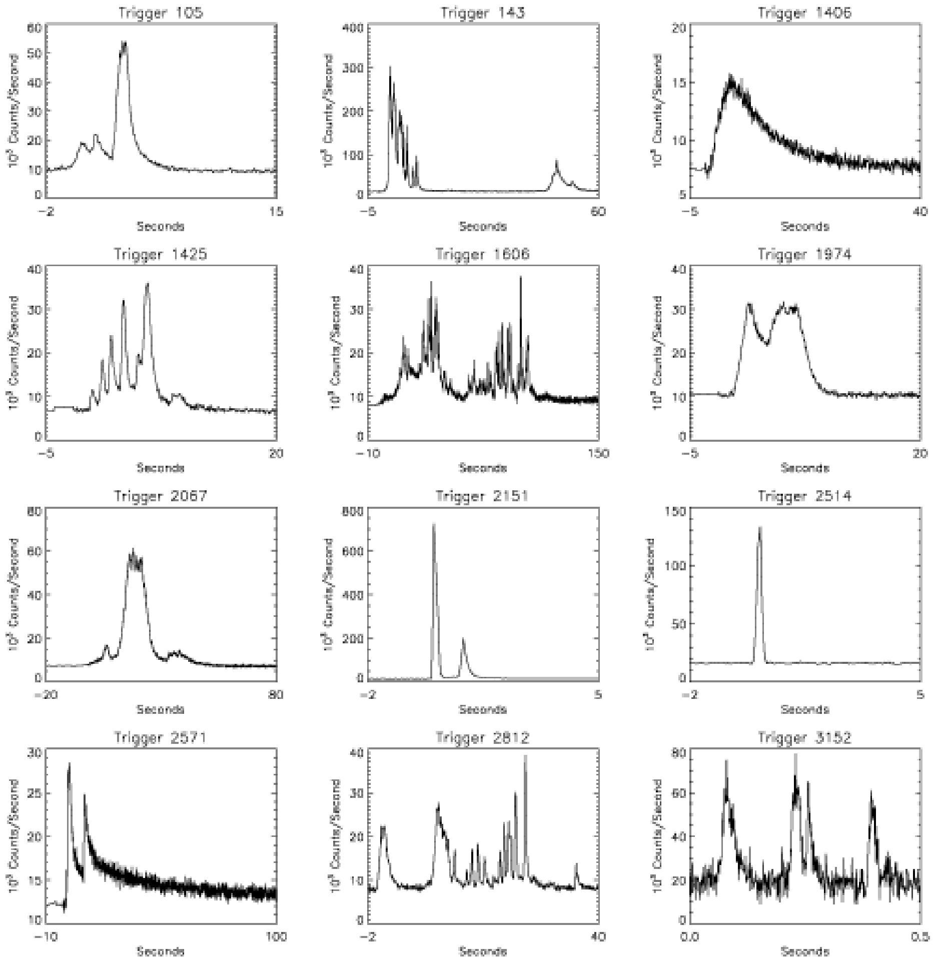


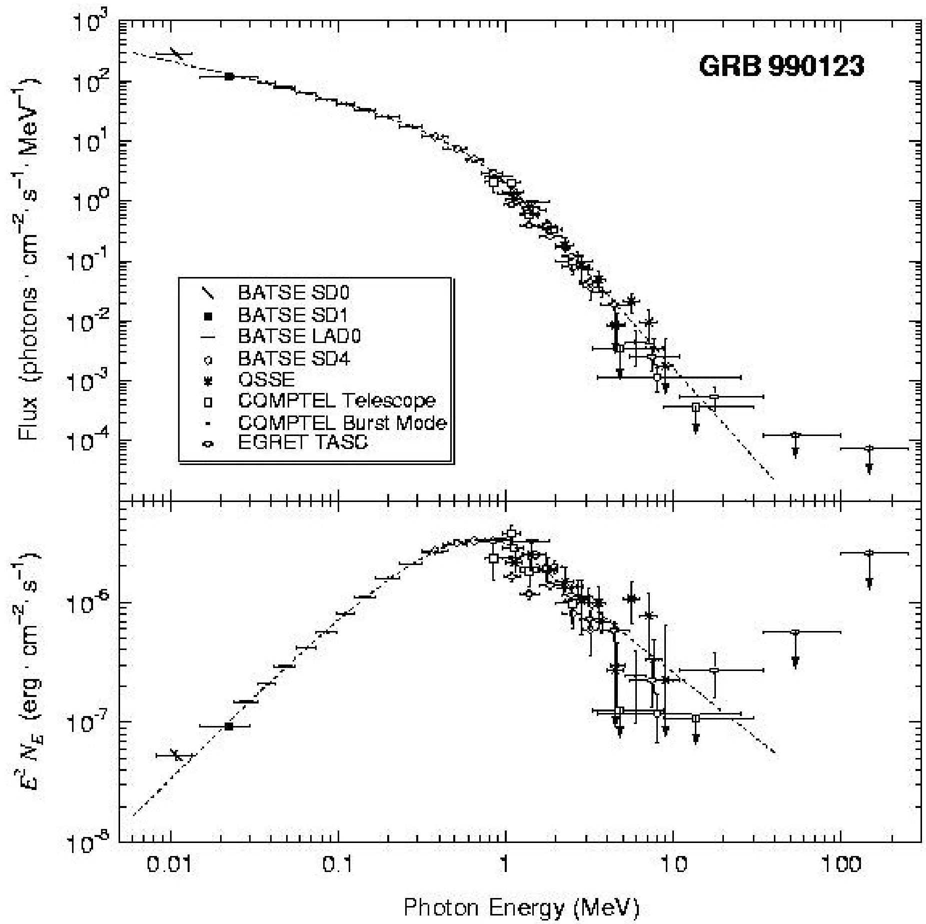
Gamma-Ray Bursts (GRBs)





Light curves and energy spectra





Great variety of light curves!

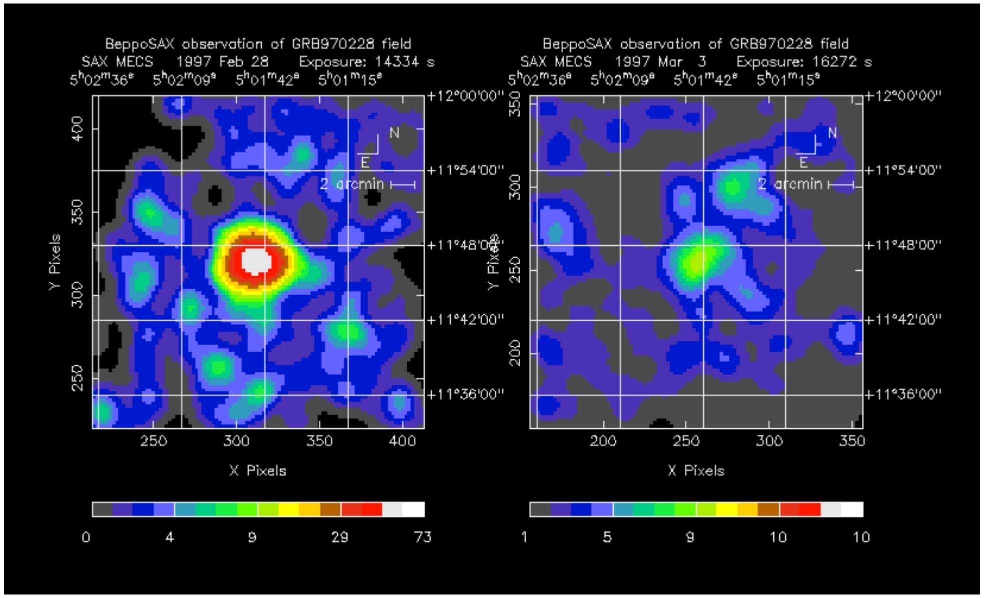
Band et al.:

$$N(E) \propto \begin{cases} E^{\alpha}\, e^{-E/E_p} & \text{for } E < E_p \\ E^{\beta} & \text{for } E > E_p \end{cases}$$

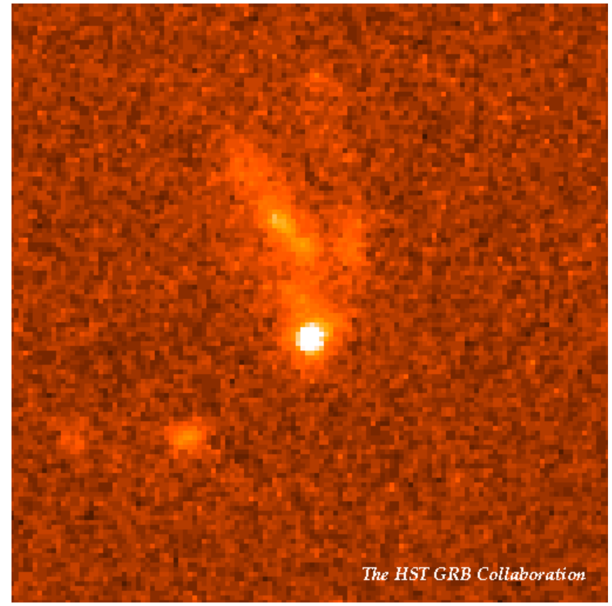
$$-1.0 \le \alpha \le -0.5 \qquad 100\,\mathrm{keV} \le E_p \le 200\,\mathrm{keV}$$

$$-3.0 \le \beta \le -2.0$$

Long GRBs' counterparts (afterglow)

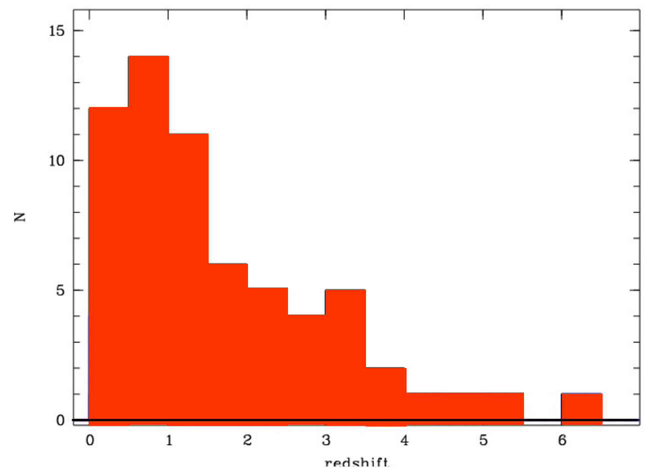


X-rays (Beppo-Sax)



Optical (HST)

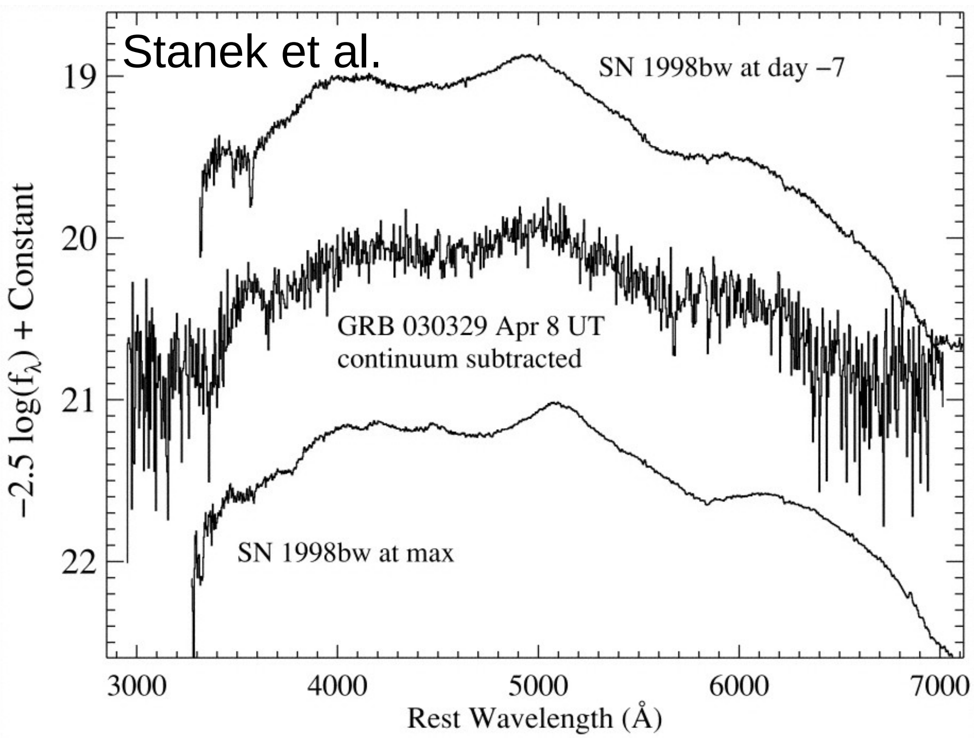
Finding the optical counteract enables the distance to be inferred (emission or absorption lines) and thus the absolute luminosity to be determined.



redshift

Progenitors

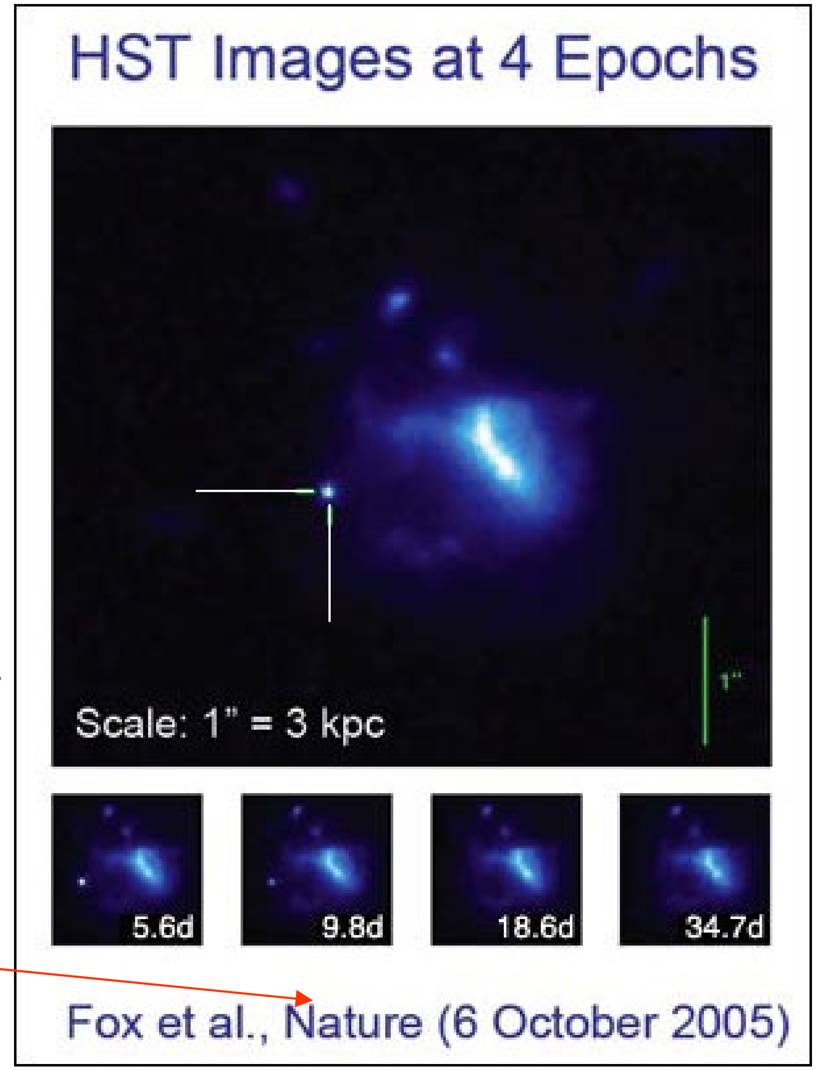
(disentangled by positions in host galaxies, light curve)



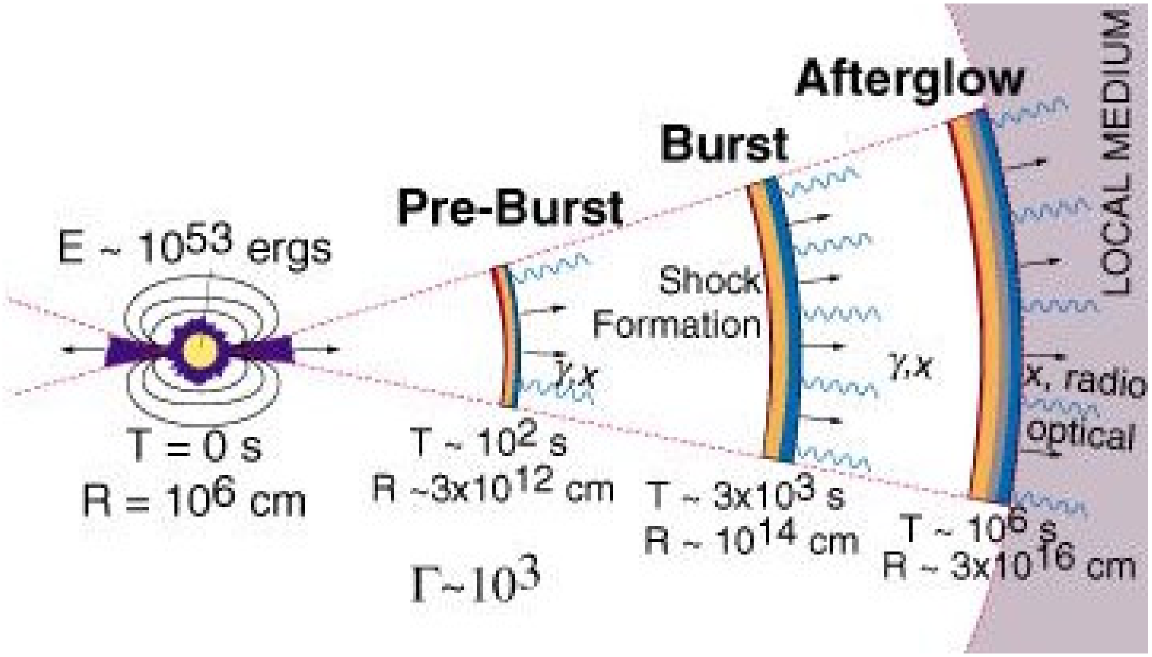
Long bursts: collapse of a massive star: hypernova

Short bursts:
coalescence of compact objects
(neutron stars, BH)

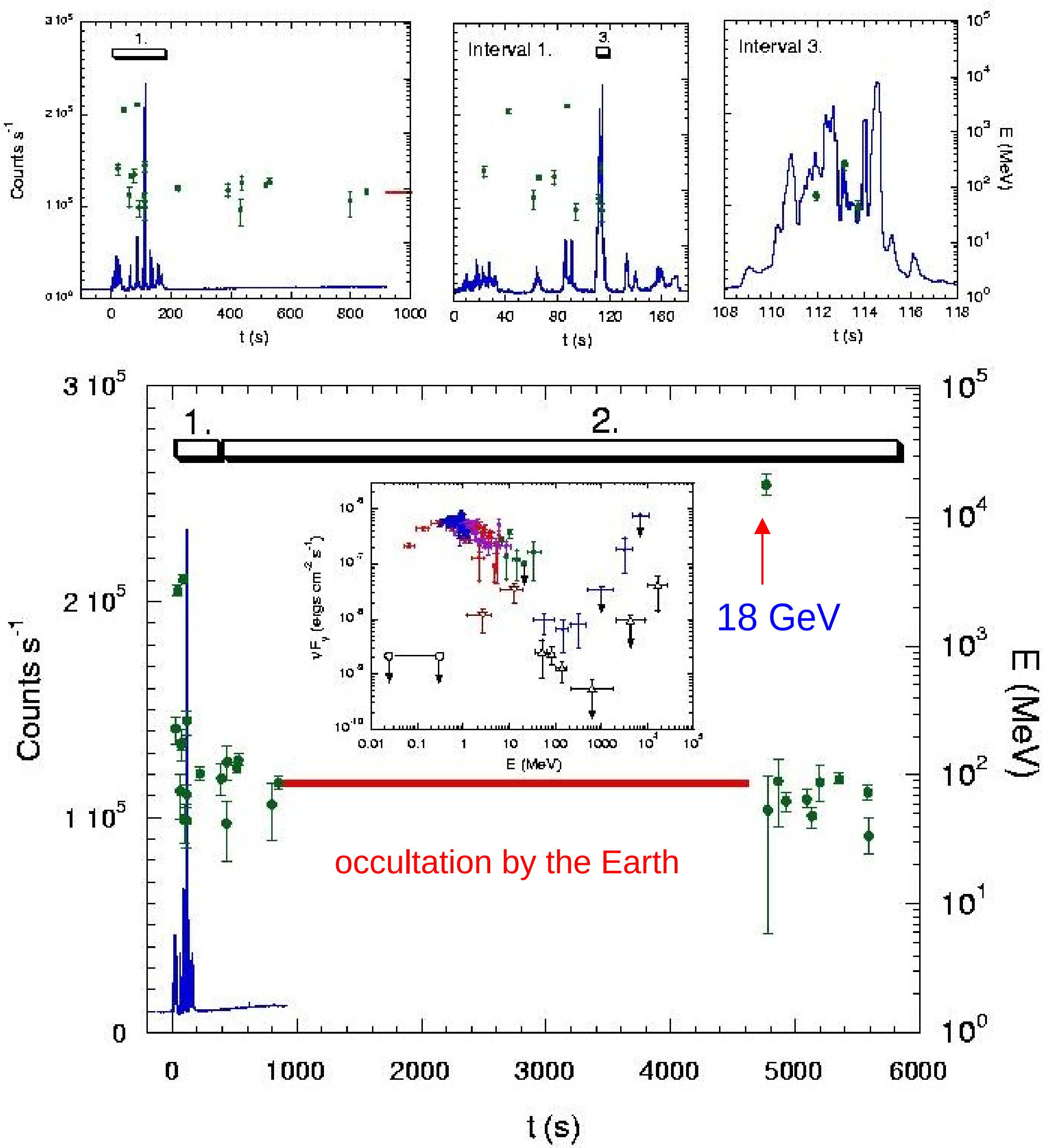
Breaking news!
(HETE,Swift)



The Fireball Model

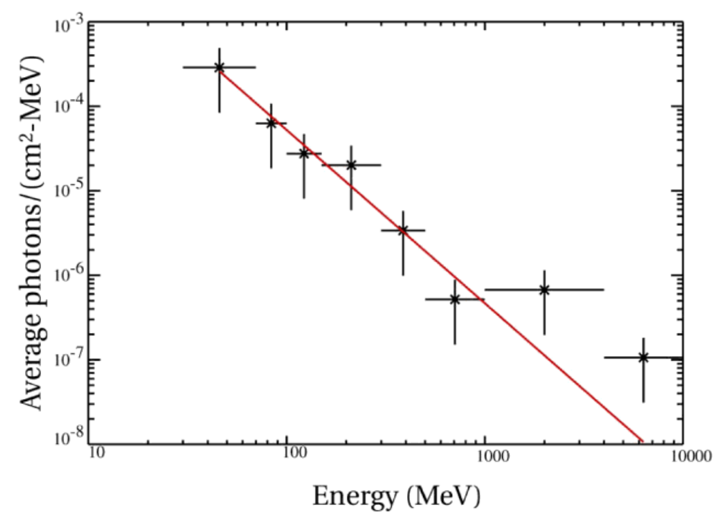


GRBs as seen by EGRET



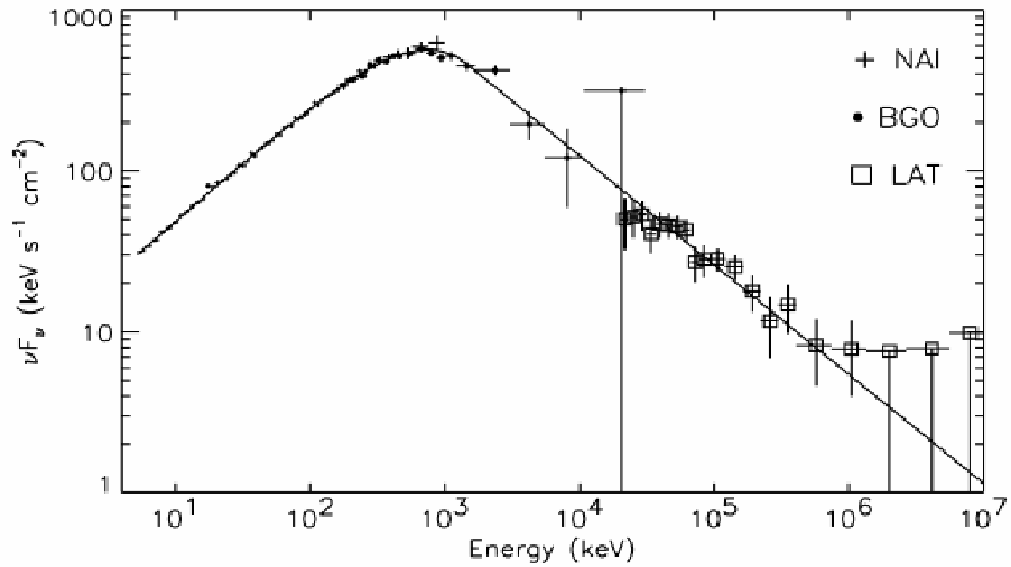
30 (long) GRBs including 4 with E>100 MeV

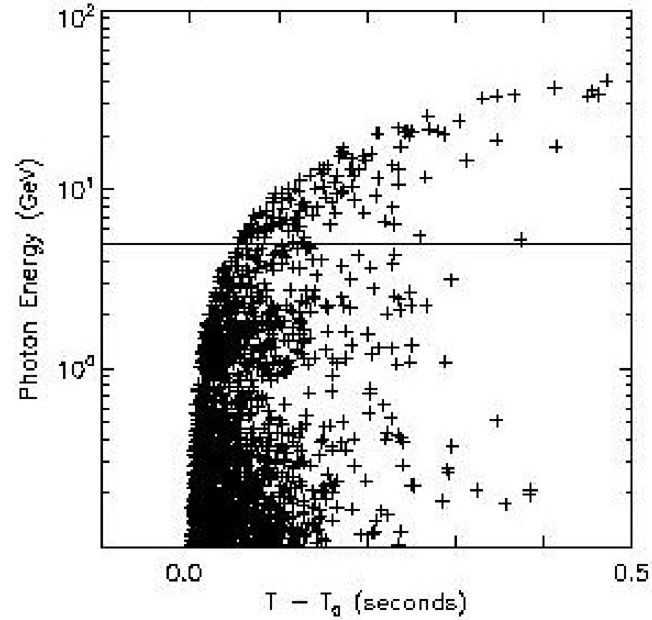
EGRET hampered by long dead time (100ms)



Energy spectrum for EGRET's 4 high-energy GRBs

Studying GRBs with GLAST





LAT+GRM: coverage from 20 keV to 300 GeV
200 GRBs per year!
Strong contraint on Γ via the highest energy measured

Test of Quantum Gravity
$v \sim c\,(1-\xi\, E_\gamma / E_{QG})$ $E_{QG} \sim 10^{19}$GeV

Other programs:
all other wavelengths (HETE2, SWIFT, ECLAIR, TAROT…)
« neutrinos bursts »: probe hadronic interactions
Ultra High Energy Cosmic Rays? GRBs may solve the « energetics + E_{loss} » problem
gravitational waves: coalescence of binary stars

Other new windows on the High-Energy Universe

Neut

Ul

..)

Happy Birthday, John!