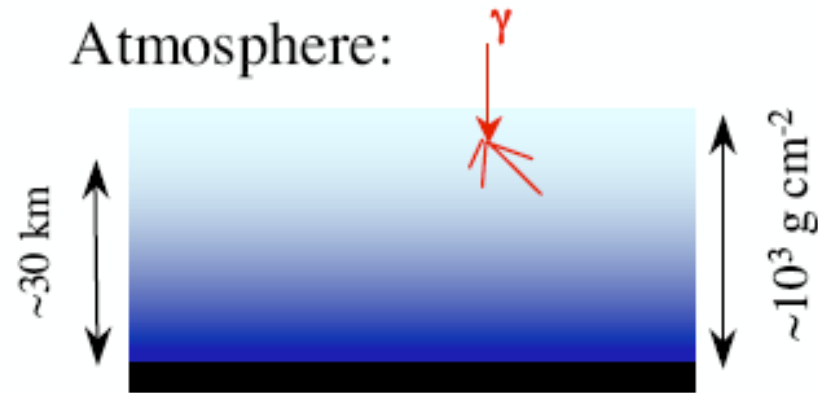


Some more on Gamma-Astronomy: Why on satellites?



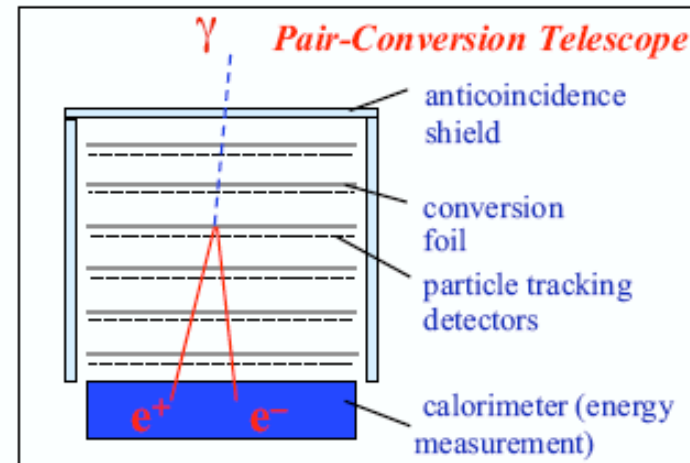
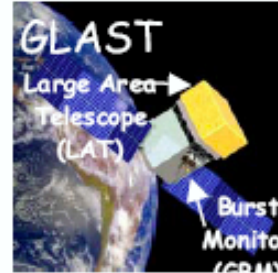
For $E_\gamma < \sim 100$ GeV, must detect above atmosphere (balloons, satellites)

For $E_\gamma > \sim 100$ GeV, information from showers penetrates to the ground (Cerenkov, air showers)

Summary of techniques

- **Space-based:**

- use pair-conversion technique



- **Ground-Based:**

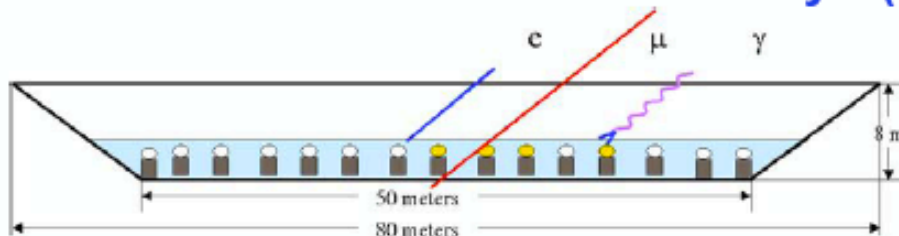
- Airshower Cerenkov Telescopes (ACTs)



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



- Extensive Air Shower Arrays (EAS)



Directly detect particles from the showers induced in the atmosphere. Example: MILAGRO

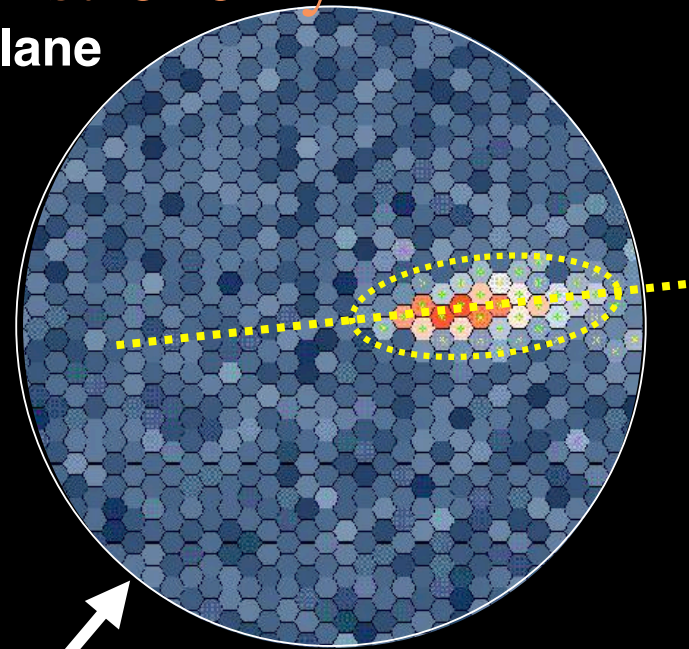
Ground-based Gamma-Astronomy

Focal Plane

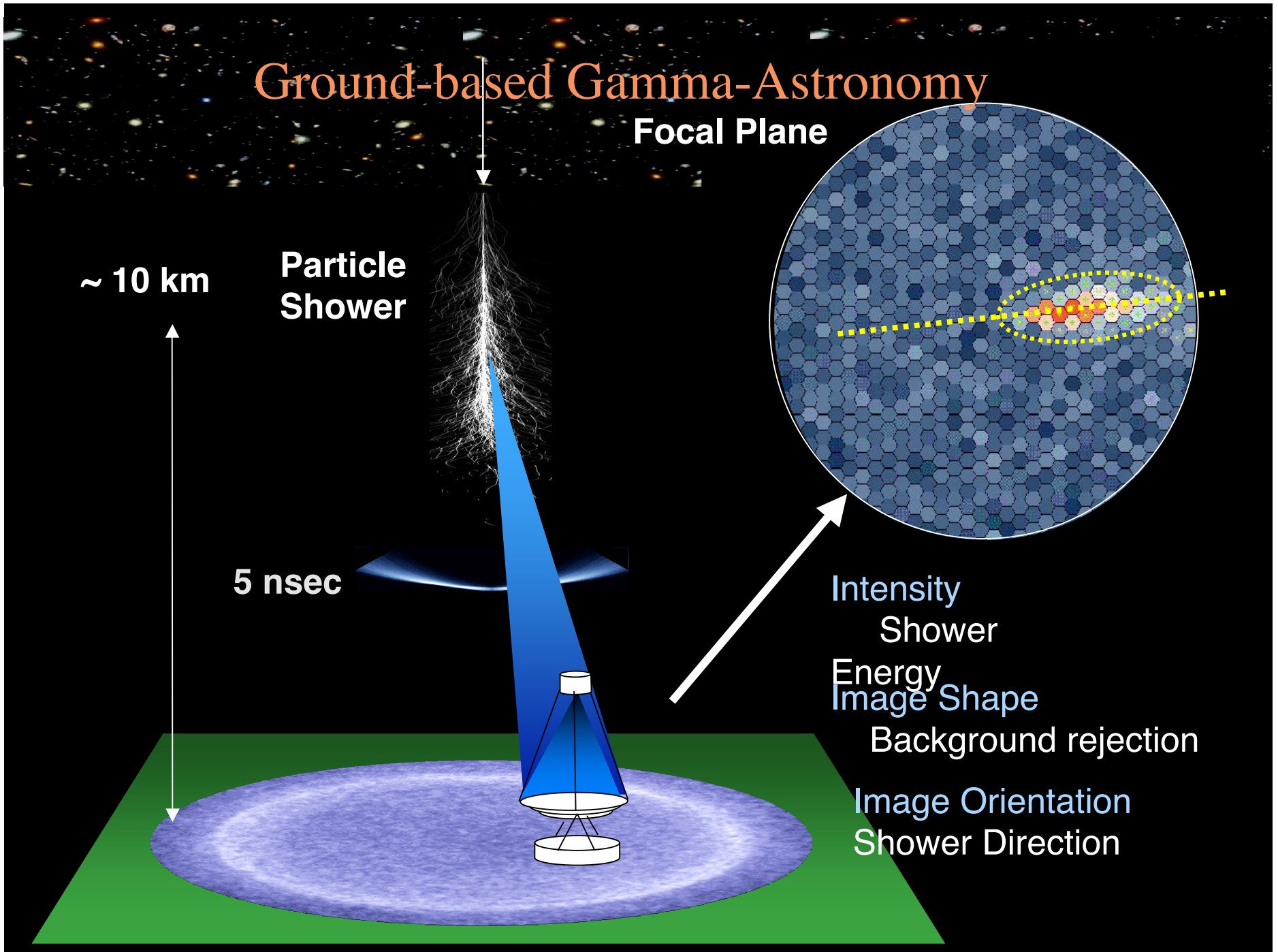
~ 10 km

Particle Shower

5 nsec



Intensity Shower
Energy Image Shape
Background rejection
Image Orientation
Shower Direction



stereoscopic approach

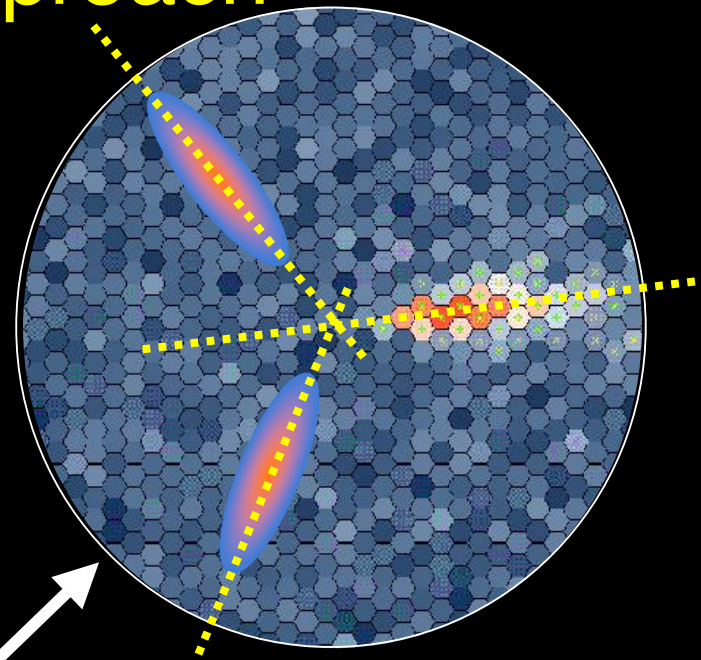
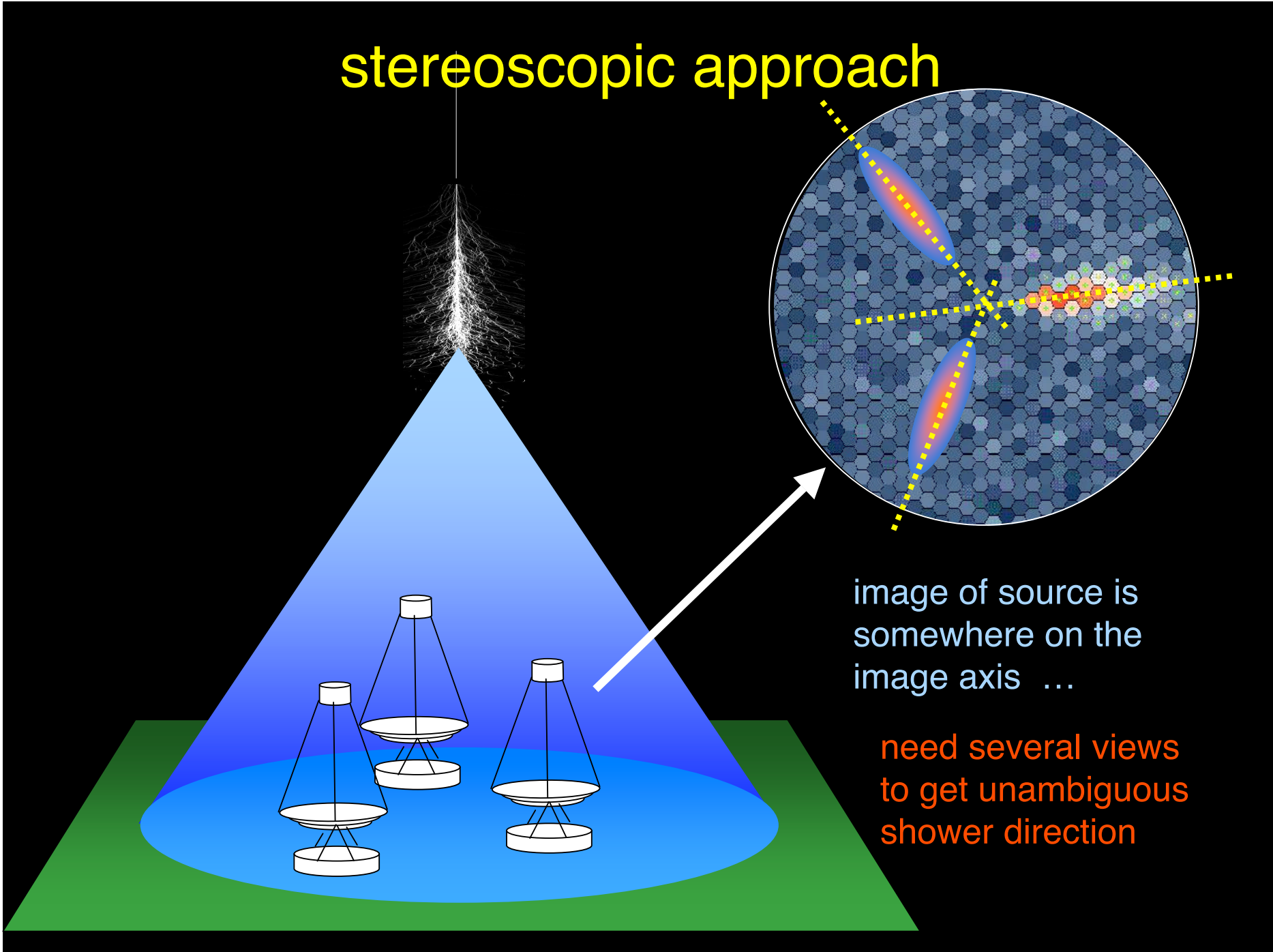
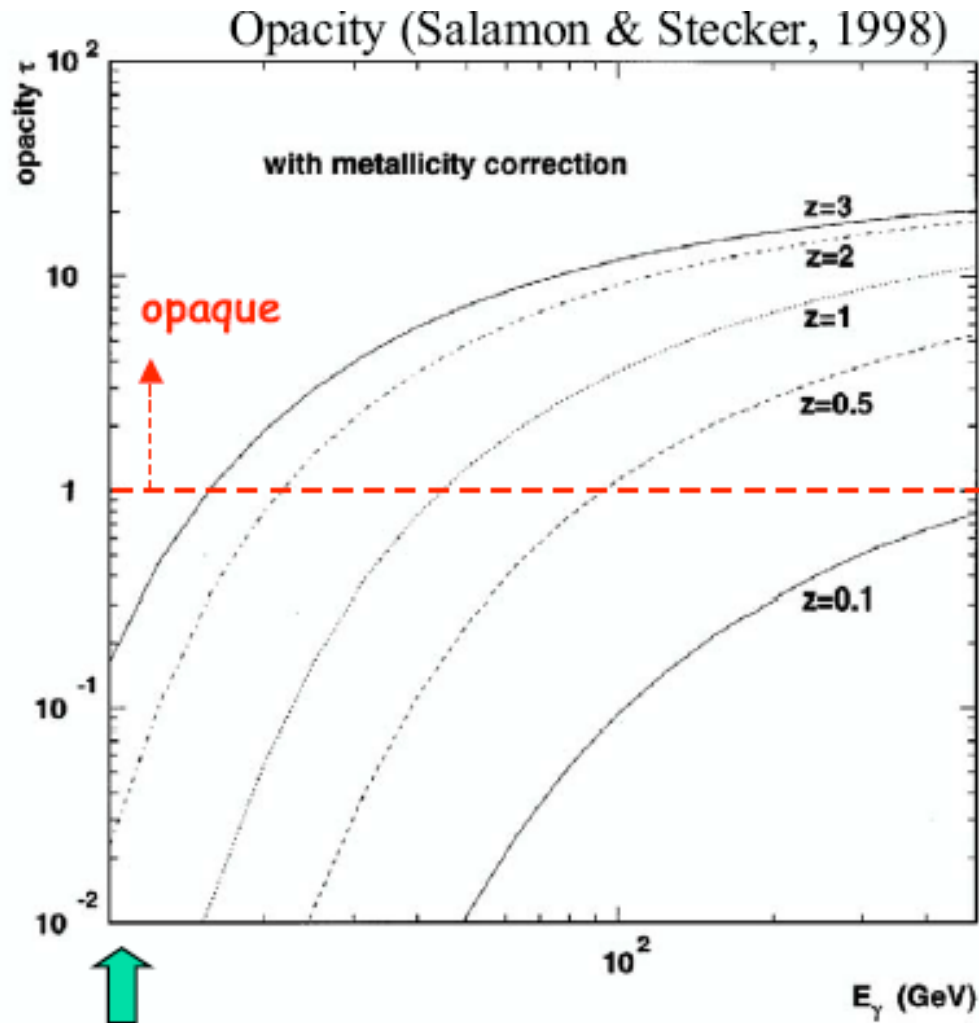


image of source is
somewhere on the
image axis ...

need several views
to get unambiguous
shower direction



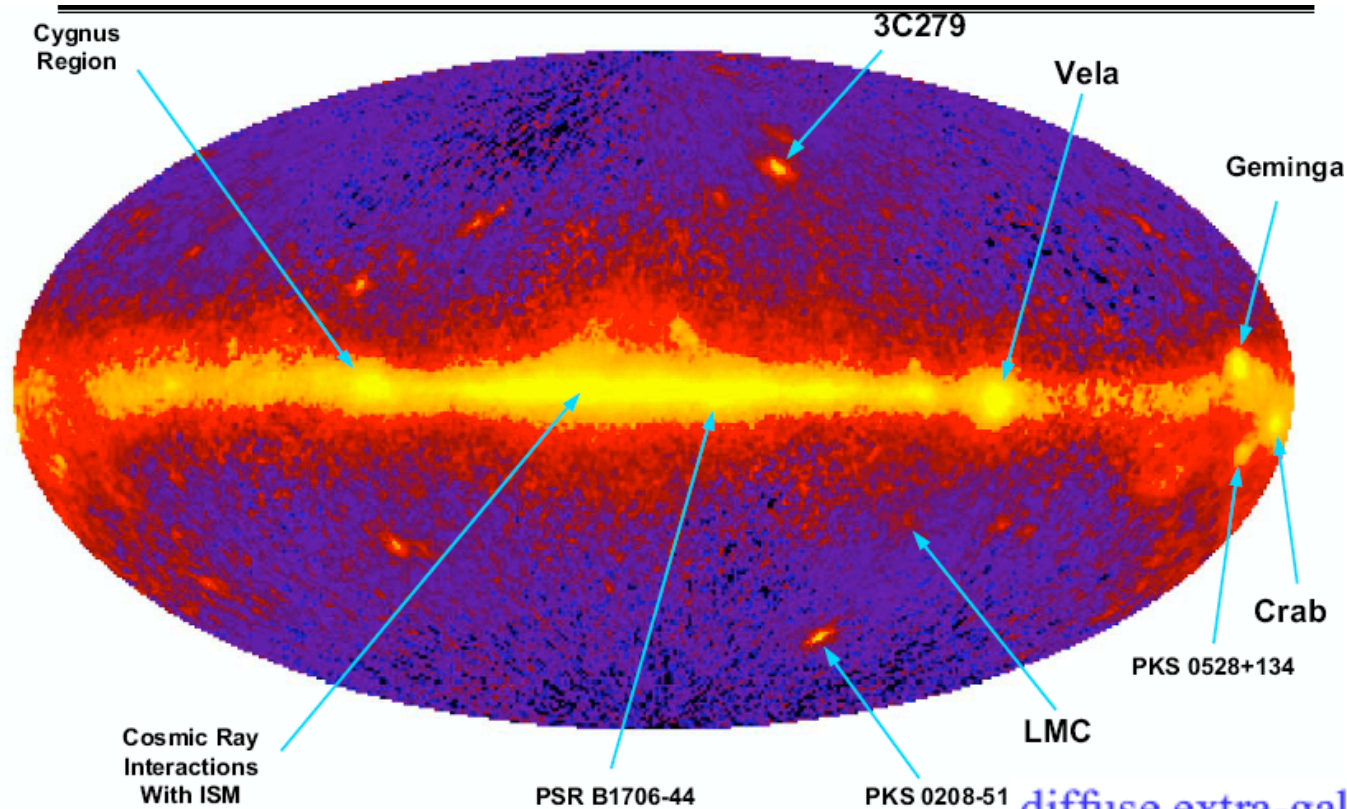
Attenuation of photons



No significant attenuation below ~ 10 GeV.

- Photons with $E > 10$ GeV are attenuated by optical-IR extragalactic background light (EBL)
- Only $e^{-\tau}$ of the source flux reaches us
- Important investigation for GLAST

The gamma-ray sky



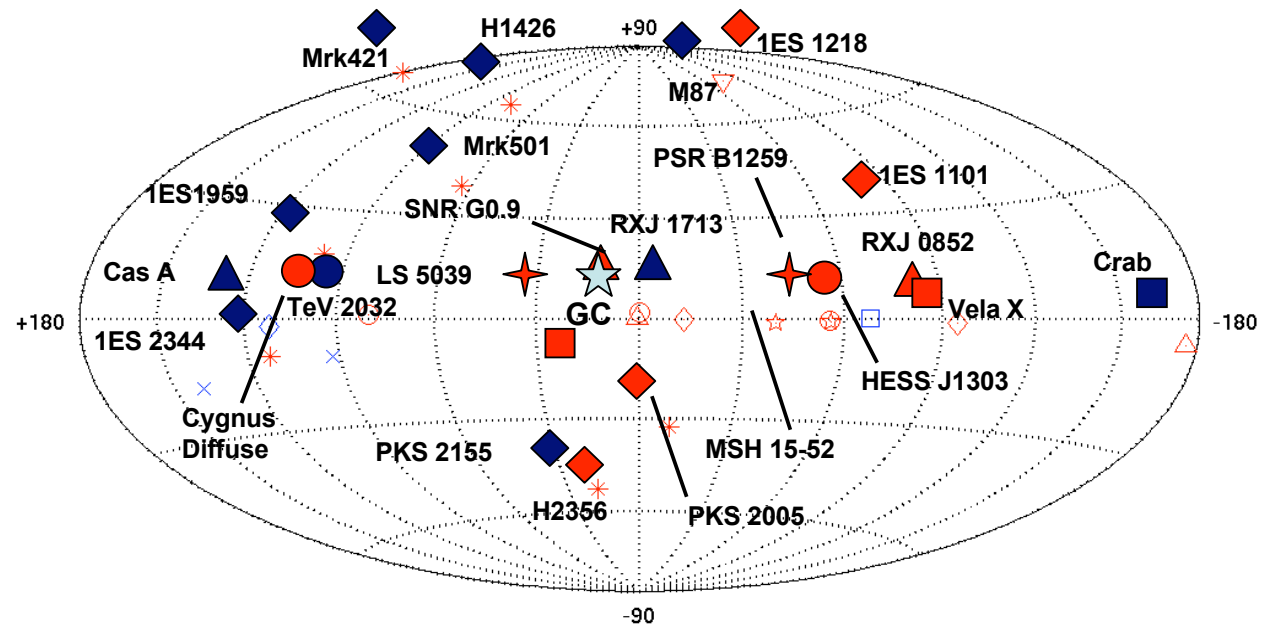
diffuse extra-galactic background
(flux $\sim 1.5 \times 10^{-5} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$)

galactic diffuse (flux $\sim O(100)$ times larger)

high latitude (extra-galactic) point sources (typical flux from EGRET sources $O(10^{-7} - 10^{-6}) \text{ cm}^{-2} \text{ s}^{-1}$)

The VHE Sky – today

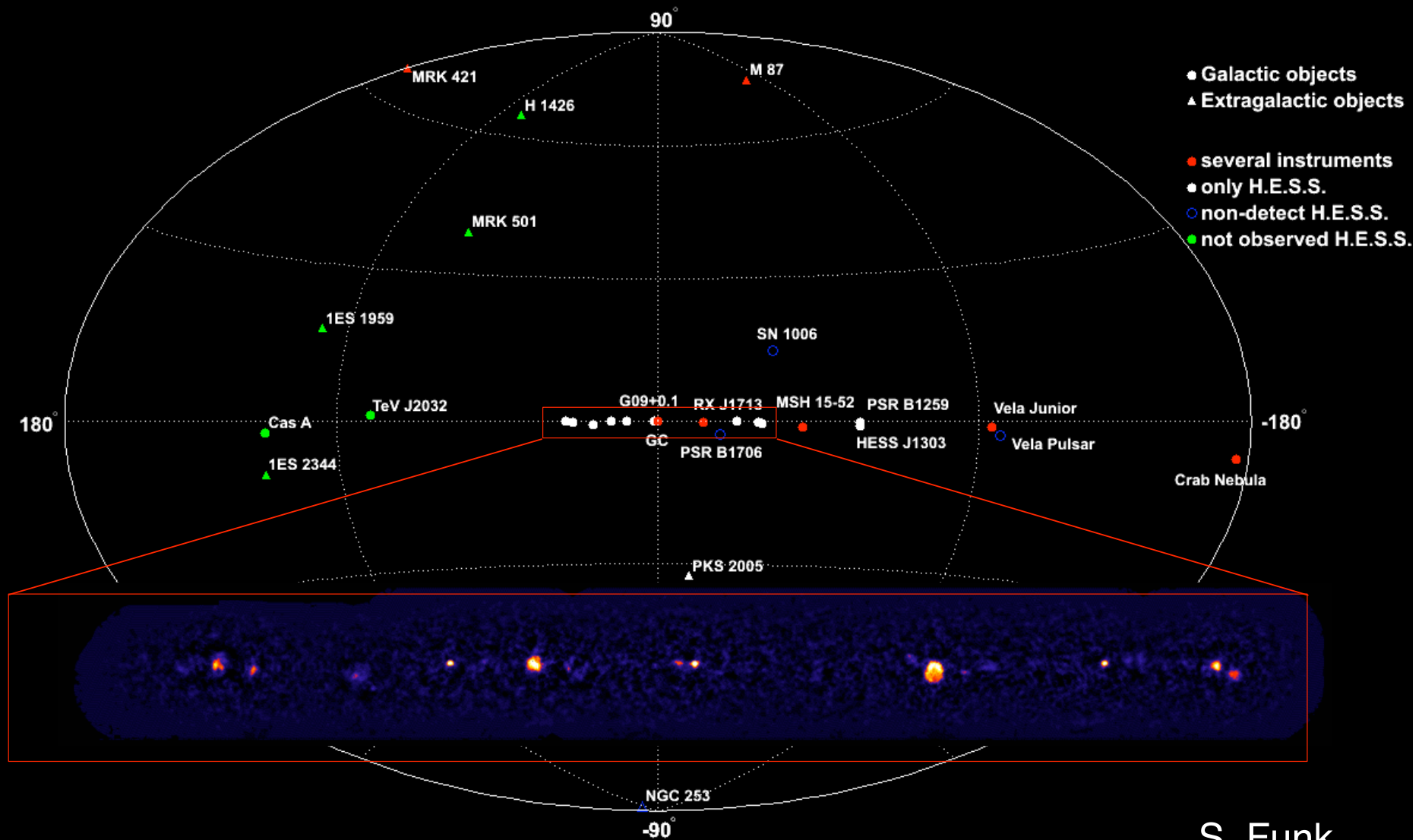
11 Galactic, 11 Extragalactic, GC, plus 15 unidentified
not many sources ... but at least 7 source populations !



- | | | |
|-----------------|-------------|-------------------|
| ■ Pulsar Nebula | ◆ AGN | ★ gal. compact |
| ▲ SNR | ● gal. unid | ★ Galactic Center |

H.E.S.S. survey of the central region of the Galactic Plane

15 more (yet unidentified) sources



S. Funk

<http://www.icrr.u-tokyo.ac.jp/~morim/TeV-catalog.htm>

TeV Source Catalog

Name	RA	Decl	GL	GB	Claim	Comment	No.	
NGC 253	11.888	-25.2882	97.369	-87.964	C2, ~H	Starburst Gal., z=0.00080	1	
3C66A	35.66505	43.0355	140.143	-16.767	Cr	QSO, z=0.444	2	
PSR0531+21	83.63288	22.01446	184.557	-5.785	Many	Crab pulsar/nebula	3	
PSR0833-45	128.8359	-45.1766	263.552	-2.787	C1, ~H	Vela pulsar	4	
RXJ0852.0-4622		132.2458	-45.6333	265.385	-1.181	C2, H	SNR, G266.6-1.2, Vela Jr.	5
Mkn 421	166.1138	38.20883	179.832	65.031	Many	XBL, z=0.031	6	
Cen X-3	170.3132	-60.6233	292.09	0.336	D	X-ray binary	7	
M87	187.7059	12.39112	283.778	74.491	H	Radio galaxy, z=0.00436	8	
PSR1259-63/SS2883		195.6987	-63.8357	304.184	-0.992	H	PSR/Be binary	9
HESS J1303-631		195.7642	-63.1986	304.241	-0.356	H	UnID	10
H1426+428	217.1354	42.67361	77.49	64.899	Many	XBL, z=0.129	11	
SN1006	225.5919	-41.8962	327.514	14.642	C1, ~H	SNR, G327.6+14.6	12	
MSH15-52	228.5292	-59.1575	320.330	-1.192	C1, H	SNR, G320.4-1.2, HESS J1514-591	13	
HESS J1614-518		243.5679	-51.8442	331.497	-0.594	H		14
HESS J1616-508		244.1033	-50.8964	332.394	-0.140	H	PSR J1617-5055?	15
HESS J1640-465		250.1829	-46.5319	338.317	-0.021	H	G338.3-0.0?	16
Mkn 501	253.4672	39.76004	63.6	38.859	Many	XBL, z=0.034	17	
PSR1706-44	257.426	-44.4825	343.1	-2.683	C1, ~H	3EGJ1710-4439	18	
RXJ1713.7-3946		258.425	-39.7667	347.346	-0.498	C1, C2, H	SNR, G347.3-0.5	19
Sgr A*	266.4169	-29.0078	359.944	-0.046	C2, W, H	Gal.C.[Rogers et al.1994 ApJ434L59]	20	
G0.9+0.1	266.8467	-28.1517	0.872	0.076	H	SNR	21	
HESS J1804-216		271.1329	-21.6919	8.408	-0.027	H	G8.7-0.1 / W30?	22
HESS J1813-178		273.4079	-17.8428	12.813	-0.034	H	SNR AX J1813-178/AGPS273.4-17.8	
HESS J1825-137		276.5150	-13.7633	17.820	-0.743	H	G18.0-0.7 ?	24
HESS J1826-148		276.5626	-14.8783	16.882	-1.289	H	LS 5039	25
HESS J1834-087		278.7104	-8.7533	23.258	-0.329	H	G23.3-0.3 / W41 ?	26
HESS J1837-069		279.4279	-6.9275	25.206	-0.121	H	G25.5+0.0 ?	27
1ES1959+650		299.9994	65.14852	98.003	17.67	U, W, HC	XBL, z=0.048	28
PKS2005-489	302.3721	-48.8219	350.386	-32.611	H	XBL, z=0.071	29	
TeV J2032+4130		308.0292	41.50833	80.254	1.074	HC	UnID: Cyg OB2?	30
PKS2155-304	329.7169	-30.2256	17.73	-52.246	D, H	XBL, z=0.117	31	
Cas A	350.8529	58.8154	111.736	-2.13	HC	SNR, G111.7-2.1	32	
BL Lac	330.6807	42.27779	92.59	-10.441	Cr	z=0.0686	33	
1ES2344+514		356.7702	51.70497	112.891	-9.908	W	XBL, z=0.044	34

Claim: W: Whipple, C1: CANGAROO-I, C2: CANGAROO-II, D: Durham, Cr: Crimea, HC: HEGRA CT, H: H.E.S.S., ~H: H.E.S.S. upper limit

TeV γ ray source populations

Extended Galactic Objects

- Shell Type SNRs
- Giant Molecular Clouds (star formation regions)
- Pulsar Wind Nebulae plerions

Compact Galactic Sources

- Binary pulsar PRB 1259-63
- LS5039 - a Microquasar

Galactic Center

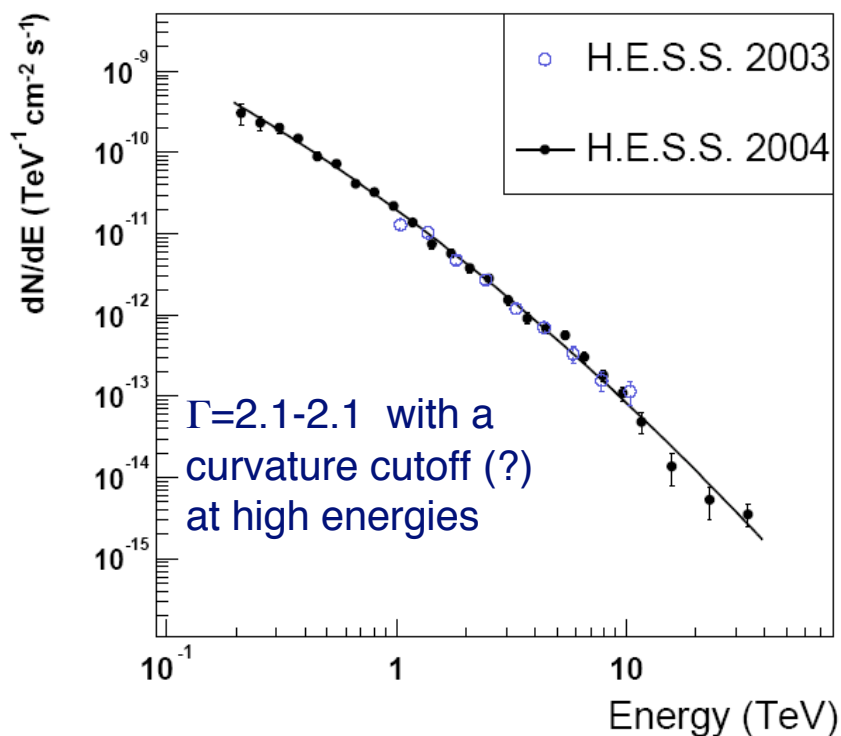
Review on Galactic sources Bednarek, Burgio, TM,
<http://arxiv.org/pdf/astro-ph/0404534>

Extragalactic objects

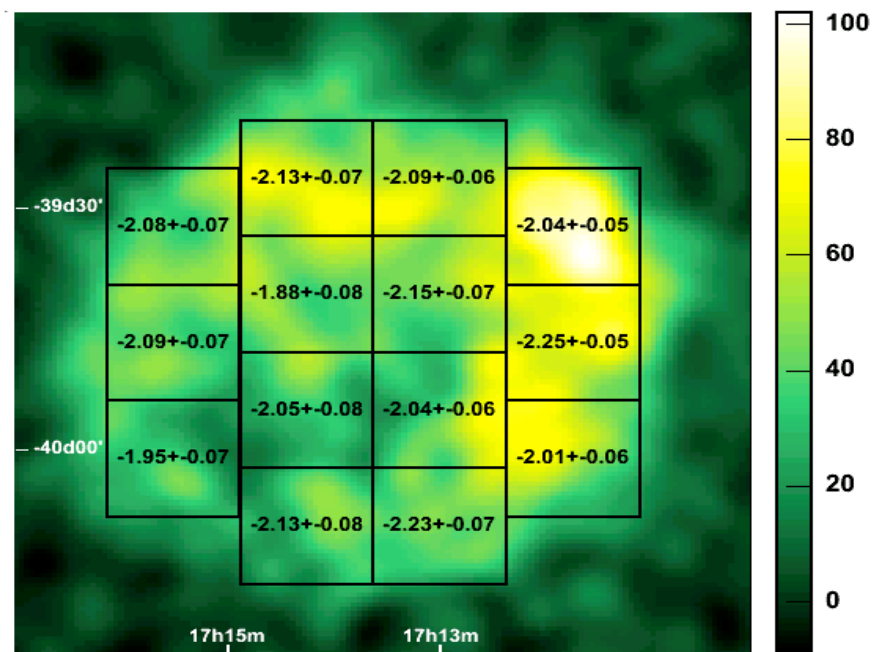
- M87 - a radiogalaxy
- TeV Blazars - with redshift from 0.03 to 0.18
- and a large number of yet unidentified TeV sources ...

RXJ1713.7-3946 is a TeV source !

energy spectrum and morphology

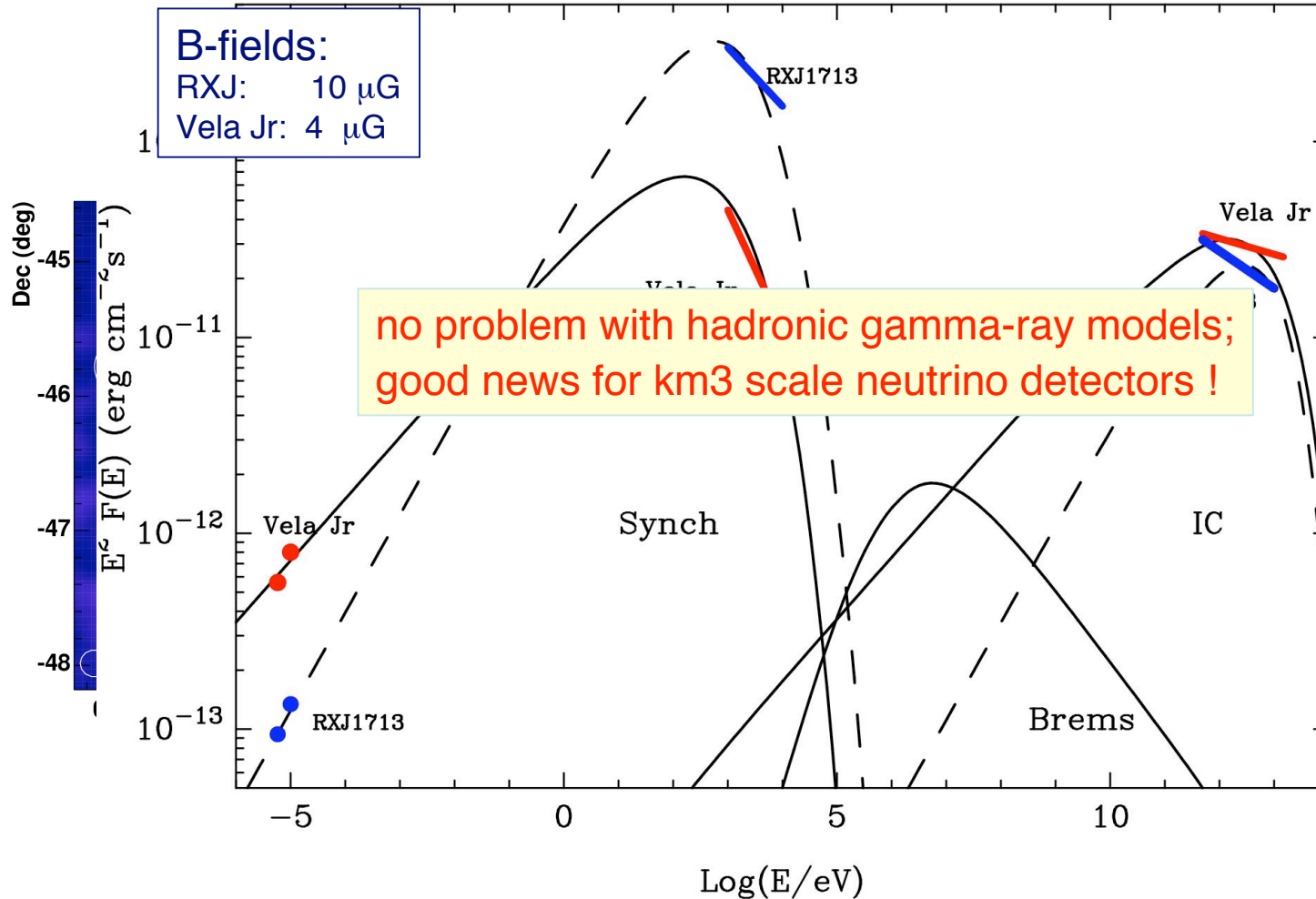


$\Gamma=2.1-2.2$ -evidence of acceleration of protons ?



no significant spectral variation
if a coordinate-independent single power law
 from 100 GeV to 10 TeV
 difficult to explain by IC

Vela Junior (a 2° diameter remnant)



IC origin ? – very small B-field, $B < 10 \mu\text{G}$, and
 very large $E_{\text{max}} > 100 \text{ TeV}$

two assumptions hardly can co-exists within standard acceleration models

Crab unit

- This is a unit of X-ray intensity evaluated at 5.2 keV, or over a band pass from 2 - 11 keV. If an X-ray source has the same type of spectrum as the Crab Nebula between 2 - 11 keV, we can compare them according to their brightness in Crab units. Numerically, 1 Crab equals 1060 microJanskys, and 1 microJansky = 0.242×10^{-11} ergs cm^{-2} sec^{-1} keV^{-1} or 1.51×10^{-3} keV cm^{-2} sec^{-1} keV^{-1} .

Example, at 2-11 keV, the star Algol produces 9 microJanskys or $9/1060 = 0.0085$ Crabs, assuming Algol's spectrum has the same shape as the Crab nebula between 2 - 11 keV.

- <http://www.icrr.u-tokyo.ac.jp/~morim/CrabUnit.html>

Ref: Crab flux: Aharonian et al., ApJ 614, 897 (2004)

$[2.83E-11 * (E/\text{TeV})^{(-2.62)} / \text{cm}^2 / \text{s} / \text{TeV}]$

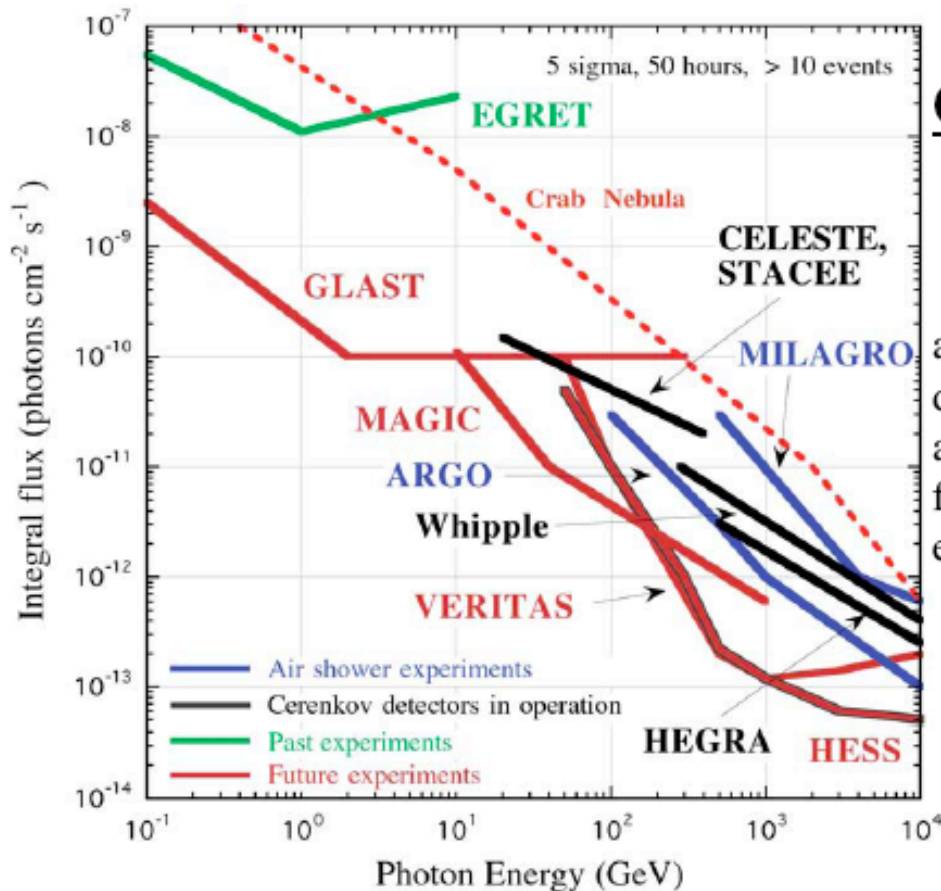
- SourceDiff. Index 2.62
- Energy threshold (GeV) 500
- Integral flux (Crab unit)

HESS Catalogue

http://www.mpi-hd.mpg.de/hfm/HESS/public/HESS_catalog.htm

Source identifier	Source coordinates (J2000)		Flux	Size	Counterpart / other names	Reference
	Ra	Dec	(Crab units)	(arcmin)		
HESS J0852-463	8h52m	46d20'	~100%	~40	RX J0852-4622 (Vela Jr)	A&A 437 (2005) L7
HESS J1104-382	11h04m27.6s	38d12' 54"	~300%	not extended	Mkn 421	A&A 437 (2005) 95
HESS J1302-638	13h02m49.3s	-63d49' 53"	up to ~10%	not extended	PSR B1259-63	A&A 442 (2005) 1
HESS J1303-631	13h03m0.4s	-63d11' 55"	~17%	~10	--	A&A 439 (2005) 1013
HESS J1514-591	15h14m7s	-59d9' 27"	~15%	~6x2	MSH 15-52 / PSR B1509-58	A&A 435 (2005) L17
HESS J1614-518	16h14m19.0s	-51d49' 7"	~25%	~12	-- Science307(2005)1938 * ApJ 636 (2006)777	
HESS J1616-508	16h16m23.6s	-50d53' 57"	~19%	~8	PSR J1617-5055 ?	Science307(2005)193
HESS J1632-478	16h32m8.6s	-47d49' 24"	~12%	8	IGR J16320-4751, AX J163252-4746 ?	ApJ636(2006) 777
HESS J1634-472	16h34m57.2s	-47d16' 2"	~6%	~7	IGR J16358-4726, G337.2+0.1 ?	ApJ 636 (2006) 777
HESS J1640-465	16h40m44.2s	-46d31' 44"	~9%	~2	G338.3-0.0 ? 3EG J1639-4702 ?	Science307(2005) 193
HESS J1702-420	17h2m44.6s	-42d4' 22"	~7%	~5	--	ApJ 636 (2006) 777
HESS J1708-410	17h8m14.3s	-41d4' 57"	~4%	~3	--	ApJ 636 (2006) 777
HESS J1713-381	17h13m58.0s	-38d11' 43"	~2%	~4	G348.7+0.3 ?	ApJ 636 (2006) 777
HESS J1713-397	17h13m	-39d45'	~66%	~15	RXJ 1713.7-3946, G347.3-0.5	Nature 432 (2004) 75
HESS J1745-290	17h45m41.3s	-29d0' 22"	~5%	< 3	Sgr A* / Sgr A East ?	A&A 425 (2004) L13
HESS J1745-303	17h45m2.2s	-30d22'	14" ~5%	~9	3EG J1744-3011 ?	ApJ 636 (2006) 777
HESS J1747-281	17h47m23.2s	-28d9' 6"	~2%	<1.3	G0.9+0.1	A&A 432 (2005) L25
HESS J1804-216	18h4m31.6s	-21d42' 3"	~25%	12	G8.7-0.1, PSR J1803-2137 ?	Science 307 (2005) 1938
HESS J1813-178	18h13m36.6s	-17d50' 35"	~6%	~2	G12.82-0.02, AX J1813-178 ?	Science 307 (2005) 1938
HESS J1825-137	18h26m3.0s	-13d45' 44"	~17%	~10	PSR J1826-1334 / 3EG J1826-1302 ?	Science 307 (2005) 1938
HESS J1826-148	18h26m15s	-14d49' 30"	~3%	not extended	LS 5039	Science 309 (2005) 746
HESS J1834-087	18h34m46.5s	-8d45' 52"	~8%	~5	G23.3-0.3 / W41 ?	Science 307 (2005) 1938
HESS J1837-069	18h37m37.4s	-6d56' 42"	~13%	~5	G25.5+0.0, AX J1838-0655 ?	Science 307 (2005) 1938
HESS J2009-488	20h9m29.3s	-48d49' 19"	~2.5%	not extended	PKS 2005-489	A&A 436 (2005) L17
HESS J2158-302	21h58m52.7s	-30d13'	18" up to 50%	not extended	PKS 2155-304 * A&A 430 (2005) 865	

Status of the γ -astronomy field



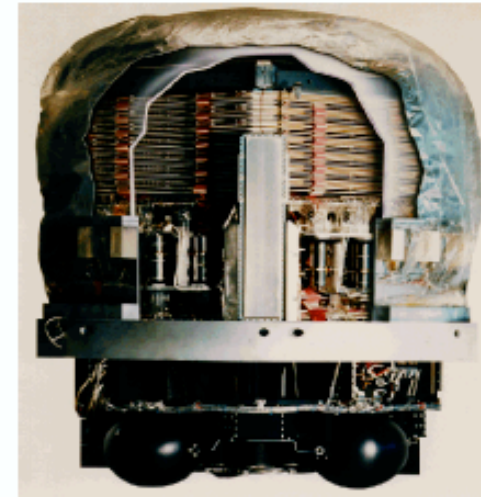
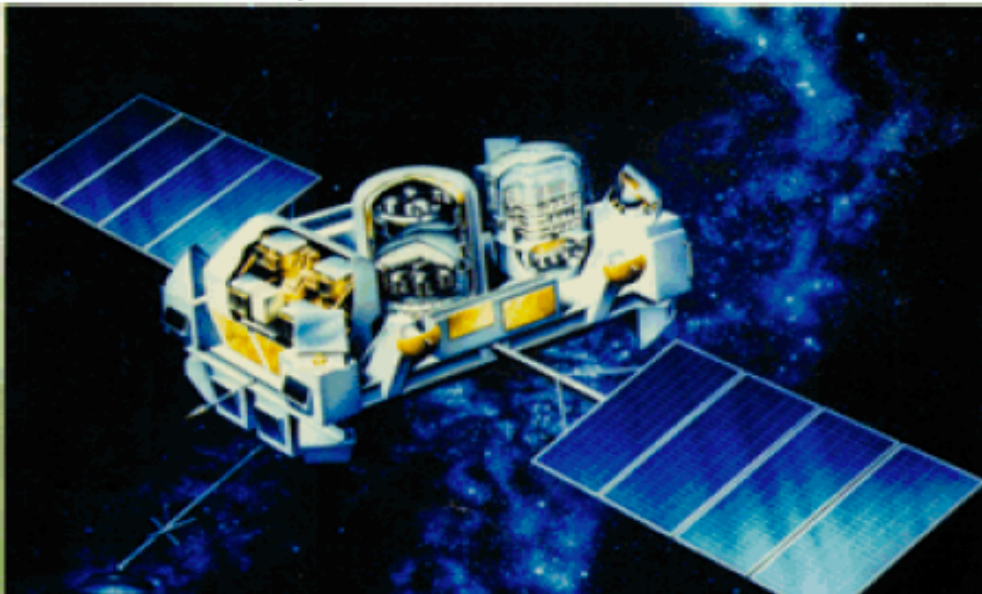
Complementary capabilities

	<u>ground-based</u>	<u>space-based</u>
	<u>ACT</u>	<u>EAS</u>
	<u>Pair</u>	
angular resolution	good	good
duty cycle	low	high
area	large	small
field of view	small	large+can reorient
energy resolution	good	fair
		good, w/ smaller systematic uncertainties

The next-generation ground-based and space-based experiments are well matched.

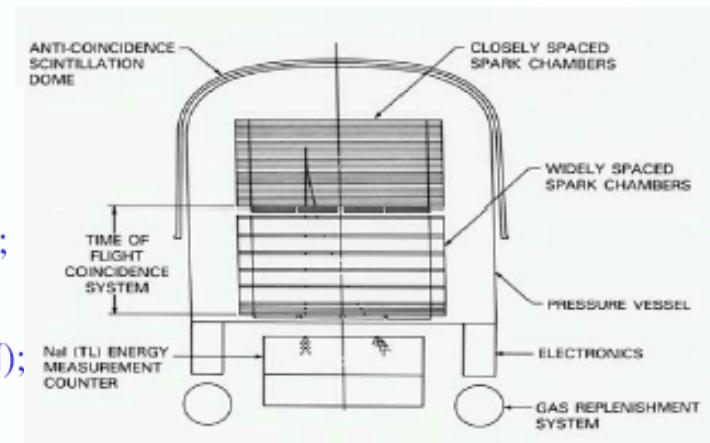
Previous missions: BATSE and EGRET on CGRO

The high energy gamma ray detector on the Compton Gamma Ray Observatory (20 MeV - ~20 GeV)



EGRET (1990's) established field:

- ★ increased number of ID'd sources by large factor;
- ★ broadband measurements covering energy range ~20 MeV - ~20 GeV;
- ★ discovered many still-unidentified sources;
- ★ discovered surprisingly large number of Active Galactic Nuclei (AGN);
- ★ discovered multi-GeV emissions from gamma-ray bursts (GRBs);
- ★ discovered GeV emissions from the sun

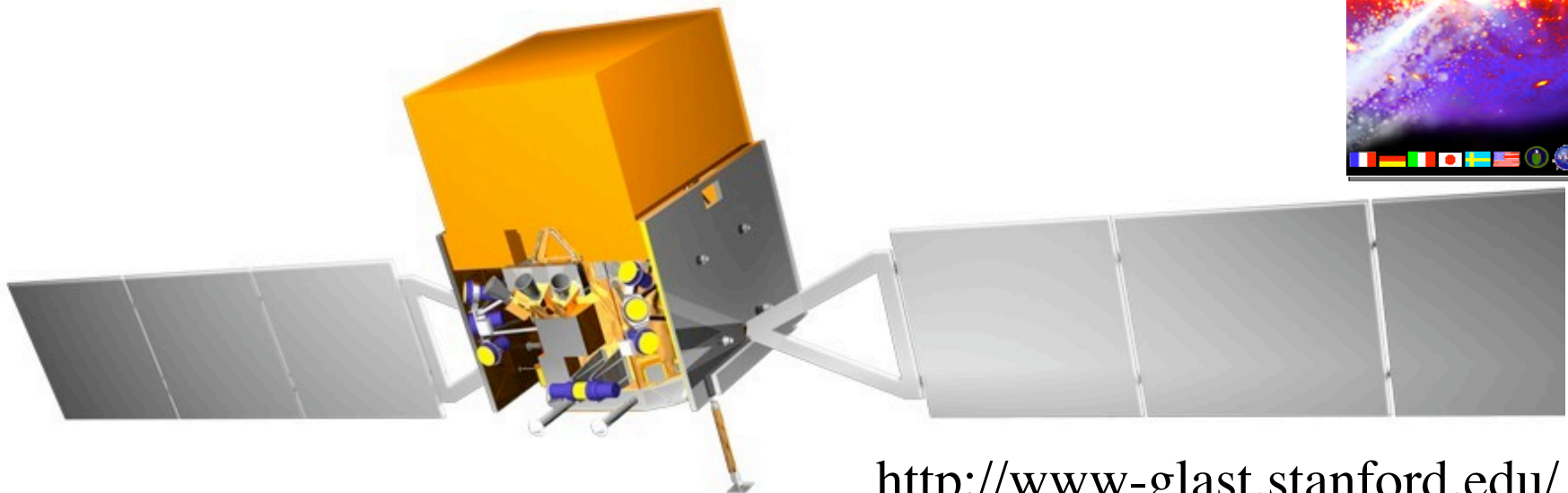


GLAST: Gamma Ray Large Area Space Telescope

Launch in late 2007.

- Main instrument: LAT (Large Area Telescope) sensitive to gamma rays between 20 MeV-300 GeV
- GBM (GLAST Burst Monitor) X-rays and γ -rays between 5 keV-25MeV

Mission duration > 5 yrs

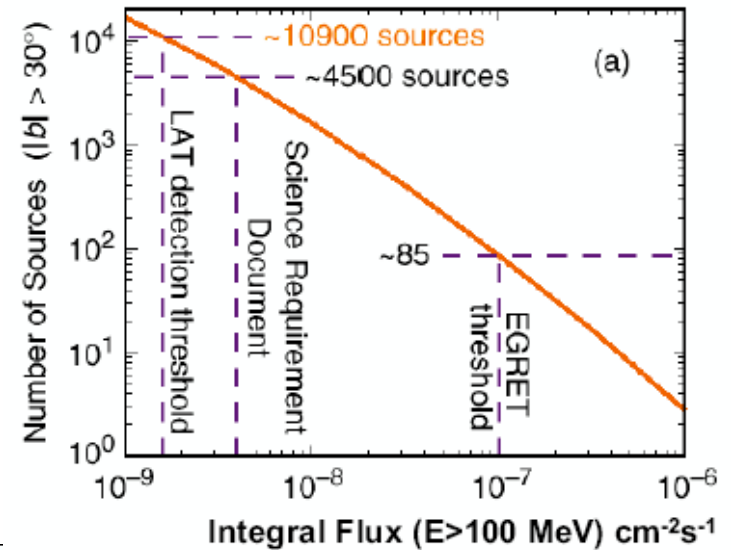


<http://www-glast.stanford.edu/>

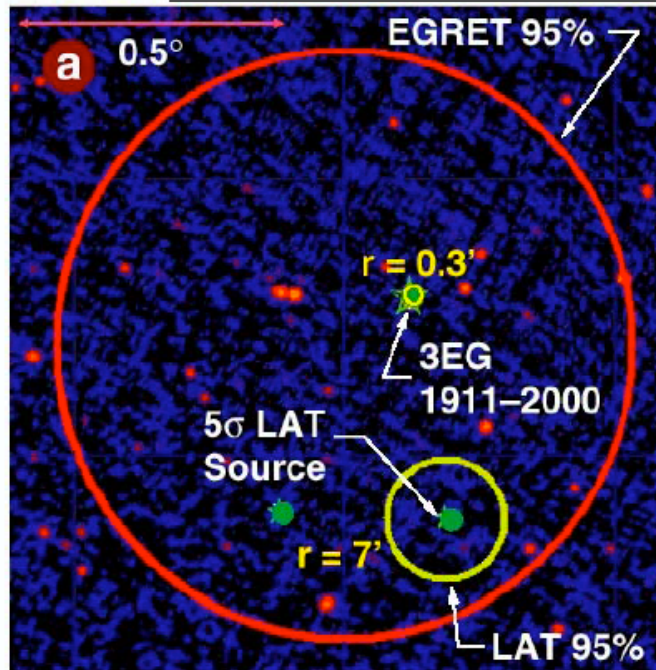
Advancing with GLAST

- Huge FOV ($\sim 20\%$ of sky)
- Broadband (4 decades in energy, including unexplored region > 10 GeV)
- Unprecedented PSF for gamma rays (factor > 3 better than EGRET for $E > 1$ GeV)
- Large effective area (factor > 4 better than EGRET)
- **Results in factor $> 30-100$ improvement in sensitivity**

EGRET/GLAST



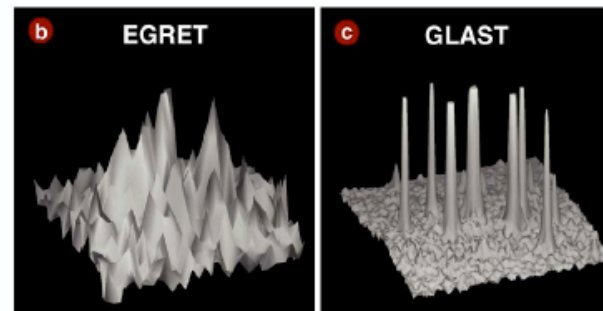
172 of the 271 sources in the EGRET 3rd catalog are “unidentified”



- Rosat or Einstein X-ray Source
- 1.4 GHz VLA Radio Source

EGRET source position error circles are $\sim 0.5^\circ$, resulting in counterpart confusion.

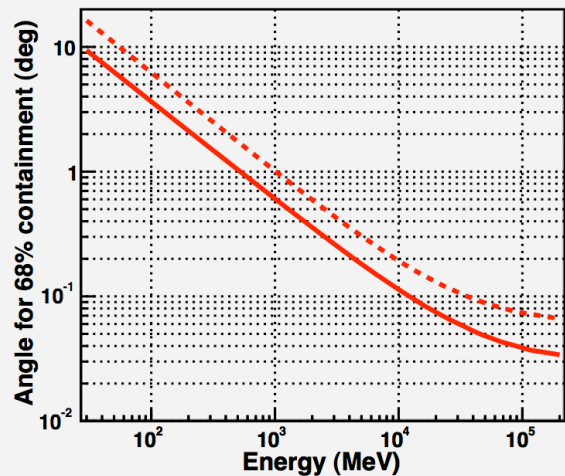
GLAST will provide much more accurate positions, with ~ 30 arcsec - ~ 5 arcmin localizations, depending on brightness.



Cygnus region (15x15 deg)

Definitions

Angular Resolution vs. True Energy at Normal Incidence

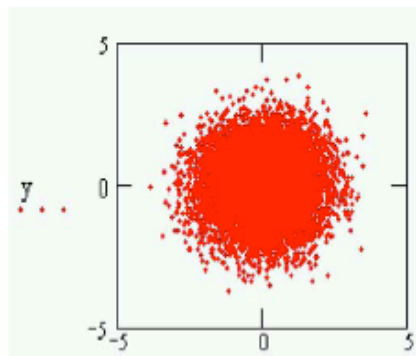
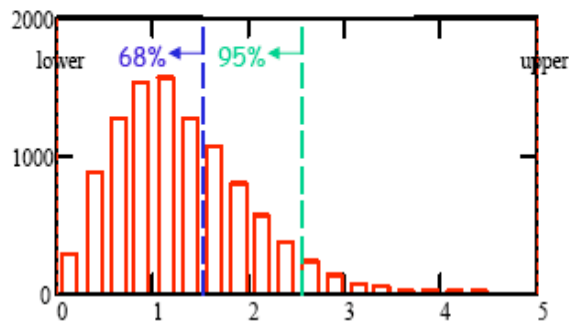


Effective area

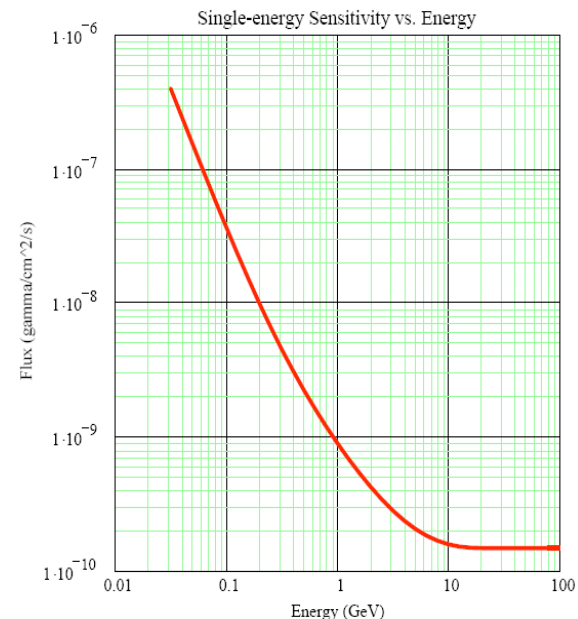
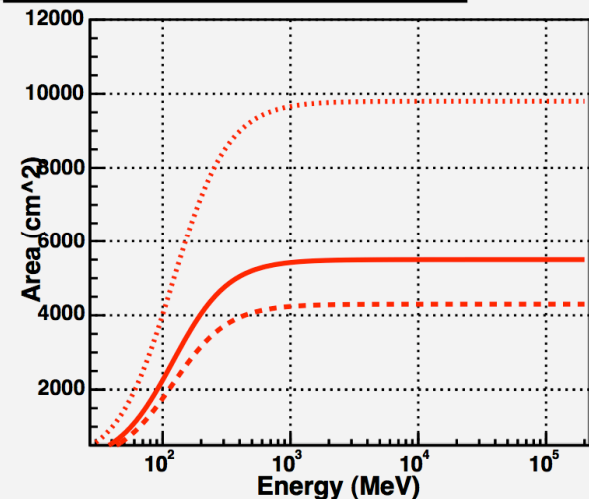
(total geometric acceptance) • (conversion probability) • (all detector and reconstruction efficiencies). Real rate of detecting a signal is (flux) • A_{eff}

Point Spread Function (PSF)

Angular resolution of instrument, after all detector and reconstruction algorithm effects. The 2-dimensional 68% containment is the equivalent of $\sim 1.5\sigma$ (1-dimensional error) if purely Gaussian response. The non-Gaussian tail is characterized by the 95% containment, which would be 1.6 times the 68% containment for a perfect Gaussian response.

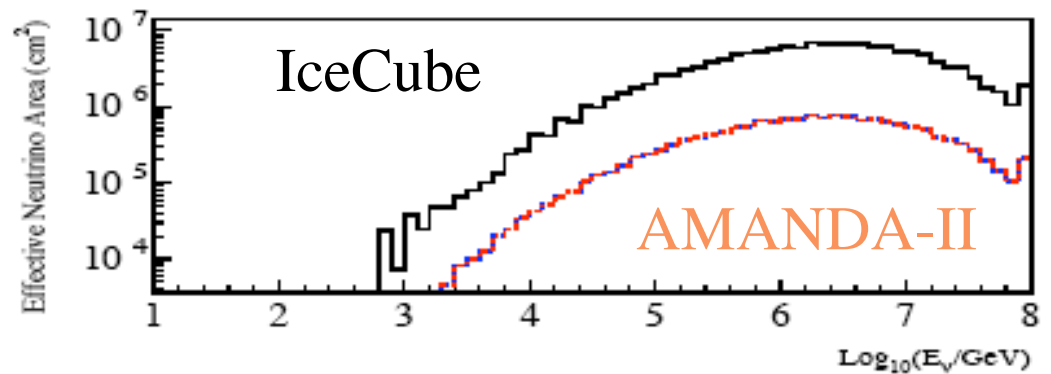


On-Axis Effective Area vs. True Energy



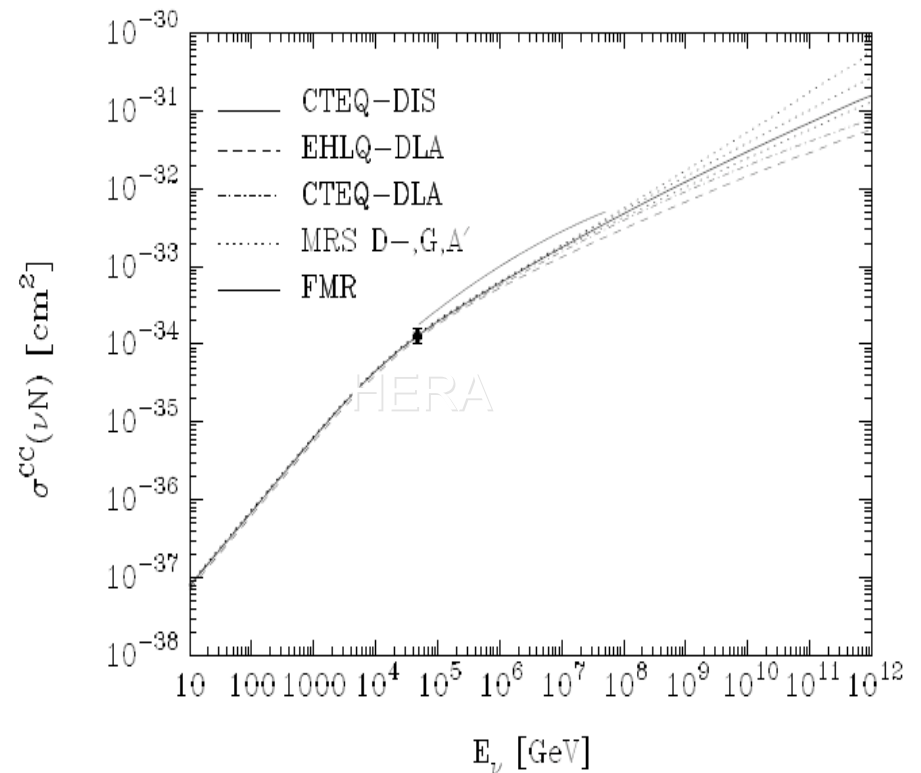
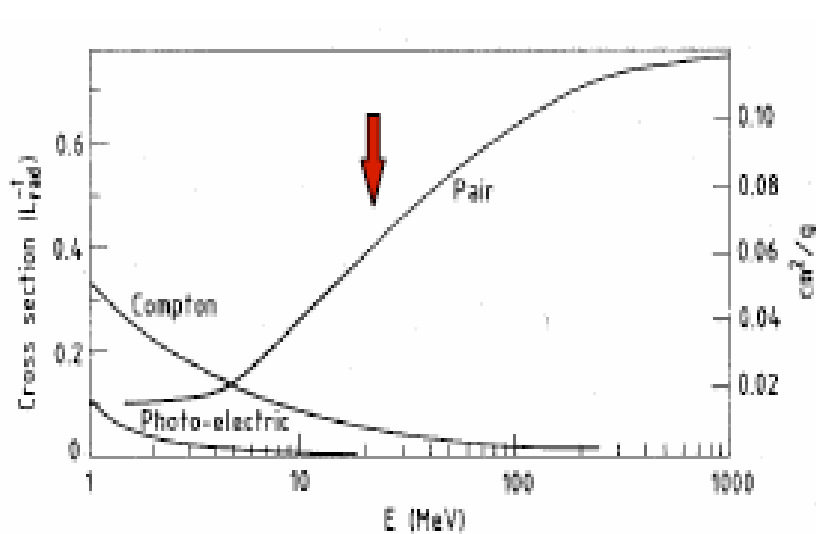
Scientific requirements

Parameter	SRD Value
Peak Effective Area (in range 1-10 GeV)	>8000 cm ²
Energy Resolution 100 MeV on-axis	<10%
Energy Resolution 10 GeV on-axis	<10%
Energy Resolution 10-300 GeV on-axis	<20%
Energy Resolution 10-300 GeV off-axis (>60°)	<6%
PSF 68% 100 MeV on-axis	<3.5°
PSF 68% 10 GeV on-axis	<0.15°
PSF 95/68 ratio	<3
PSF 55°/normal ratio	<1.7
Field of View	>2sr
Background rejection (E>100 MeV)	<10% diffuse
Point Source Sensitivity(>100MeV)	<6x10 ⁻⁹ cm ⁻² s ⁻¹
Source Location Determination	<0.5 arcmin
GRB localization	<10 arcmin



Experimental technique

- Measure direction, energy and arrival time of high energy photons (20 MeV-300 GeV)
- Dominated by pair production: clear signature for background rejection
- Background of CR is about 10^4 larger than γ signal

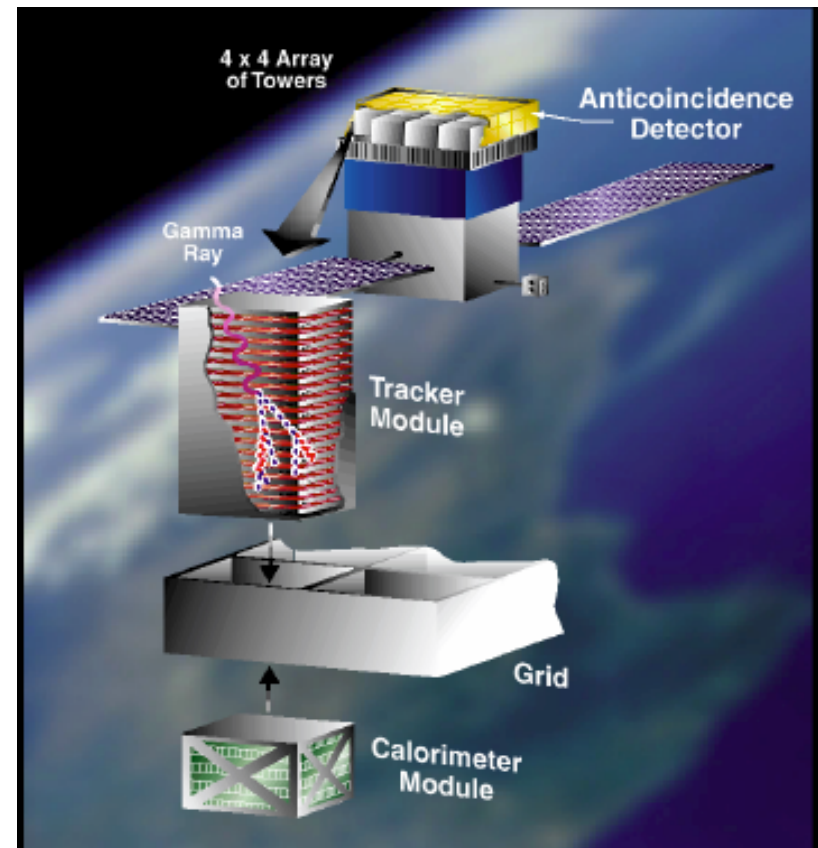
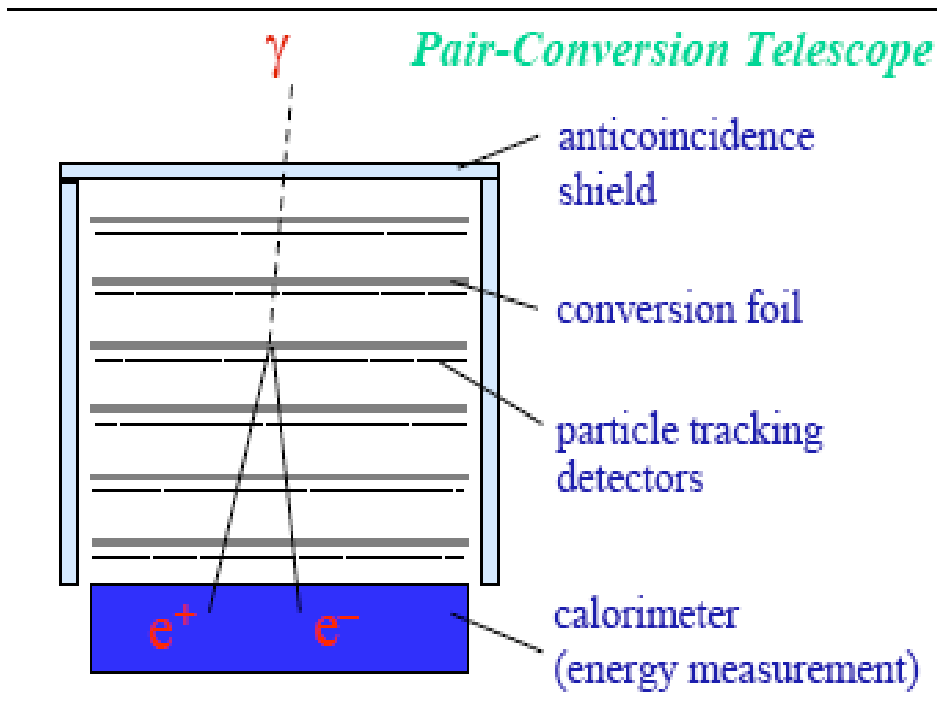


Neutrini are much harder to detect than photons!

LAT: the main detector

Pair conversion detector built with:

- plastic anticoincidence shield,
- segmented CsI em calorimeter
- the largest Si strip tracker with slabs of tungsten converter ever built. 4 x 4 identical towers surrounded by an anticoincidence (ACD) to identify charged CRs



Instrument Design

- limitations on angular resolution (PSF)

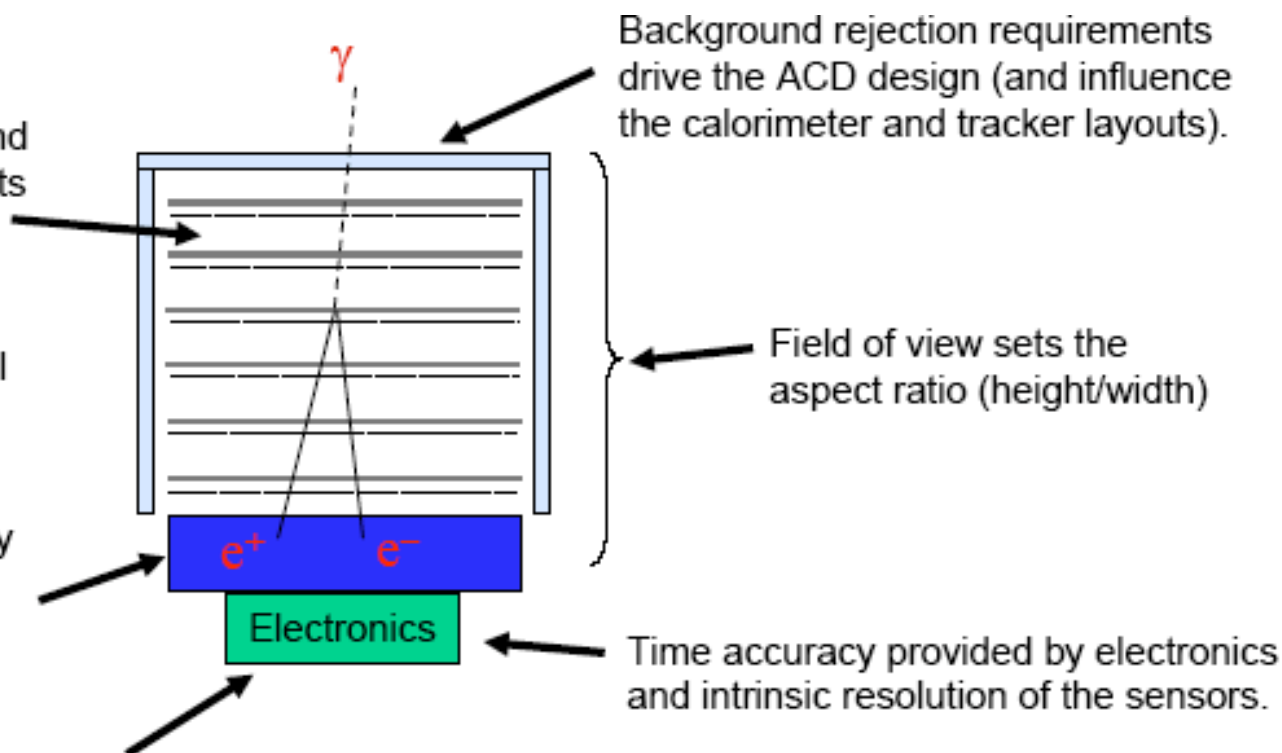
low E: multiple scattering => many thin layers

high E: hit precision & lever arm

Effective area and PSF requirements drive the converter thicknesses and layout. PSF requirements also drive the sensor performance, layer spacings, and drive the design of the mechanical supports.

Energy range and energy resolution requirements bound the thickness of calorimeter

On-board transient detection requirements, and on-board background rejection to meet telemetry requirements, are relevant to the electronics, processing, flight software, and trigger design.

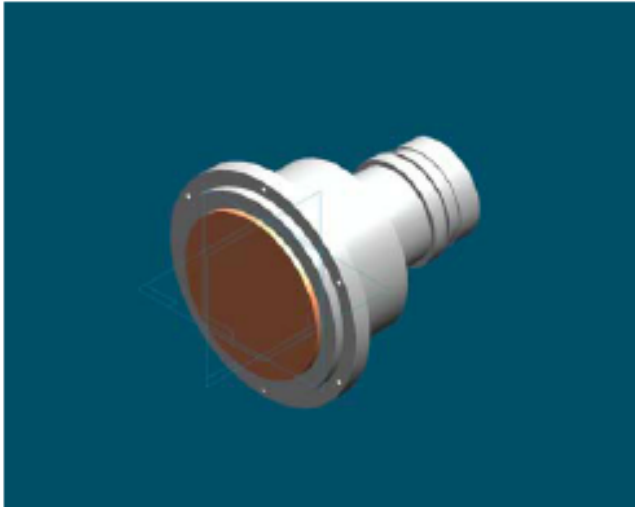


Instrument life has an impact on detector technology choices.

Derived requirements (source location determination and point source sensitivity) are a result of the overall system performance.

GBM

12 Sodium Iodide (NaI) Scintillation Detectors



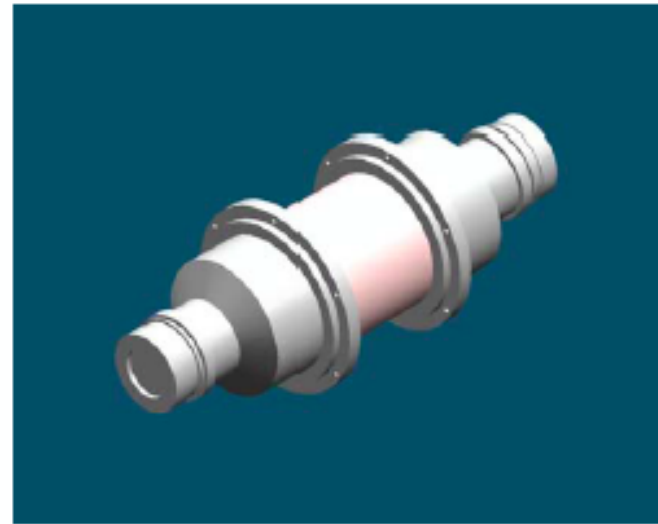
Characteristics

- 5-inch diameter, 0.5-inch thick
- One 5-inch diameter PMT per Det.
- Placement to maximize FoV
- Thin beryllium entrance window
- Energy range: ~5 keV to 1 MeV

Major Purposes

- Provide low-energy spectral coverage in the typical GRB energy regime over a wide FoV
- Provide rough burst locations over a wide FoV

2 Bismuth Germanate (BGO) Scintillation Detectors



Characteristics

- 5-inch diameter, 5-inch thick
- High-Z, high-density
- Two 5-inch diameter PMTs per Det.
- Energy range: ~150 keV to 30 MeV

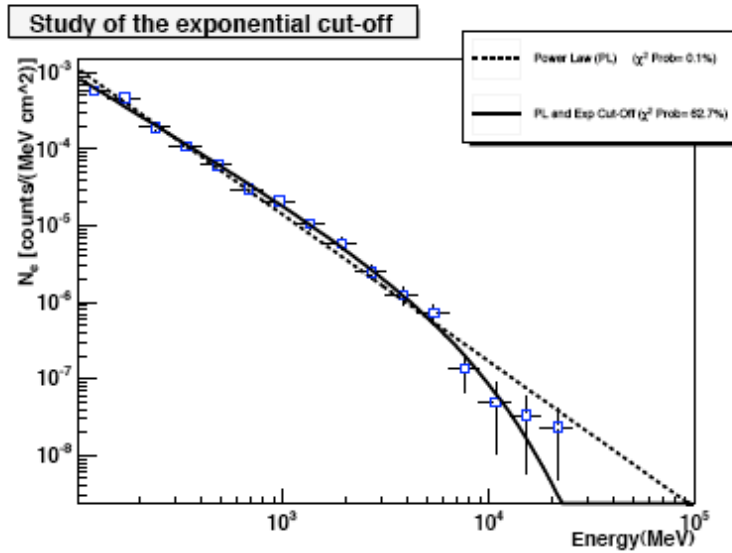
Major Purpose

- Provide high-energy spectral coverage to overlap LAT range over a wide FoV

Constraints to Design

- Mass < 3000 kg (restricts calorimeter depth)
- Lateral dimensions < 1.8 m (restricts the geometric area)
- Power < 650 W (restricts number of readout channels and onboard CPU)
- Telemetry bandwidth < 300 kbps (kbits per s) (sets the required level of onboard background rejection and data volume per event)
- Launch loads and other environmental constraints

Sensitivity to GRBs



Reconstruction of spectra; real cut-off at 4.5 GeV, reconstructed at 5.5 ± 1.5 GeV

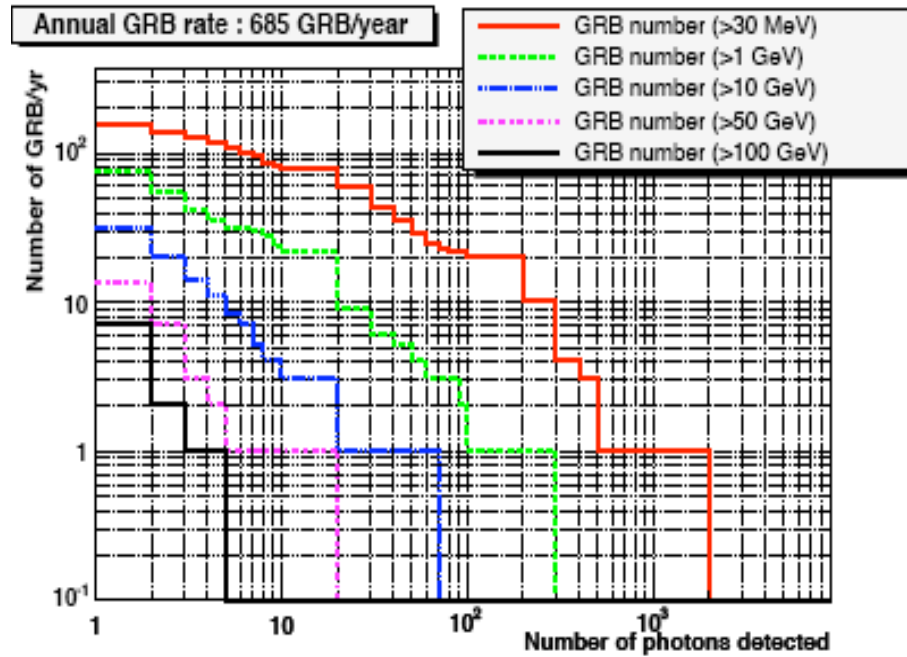


FIGURE 3. Model-dependent LAT GRB sensitivity assuming a mean burst rate of 650 bursts/yr, including the effect of the EBL absorption. Different curves refer to different energy thresholds.

Alerts for GRBs

For 5 yrs GLAST will scan uniformly the full sky in 3 hrs (scanning mode)

GBM and LAT will trigger independently on GRBs, GBM on a rapid increase of counts and LAT considering spatial and temporal clustering of counts

GBM will detect 200 bursts/yr of which more than 60 will fall in LAT FoV
Alerts will be sent to ground with a satellite communication system within 10 s
The initial on-board GBM localization accuracy is about 15 degrees within 1.8 s that can be used by LAT. Updates come later and reduce the GBM localization error box up to about 5 degrees for a bright burst while the **LAT can provide accuracy up to tens of arcminutes (1 arcmin = 0.01666 deg)** depending on burst intensity

About 20/yr SWIFT detected GRBs will be in LAT FoV