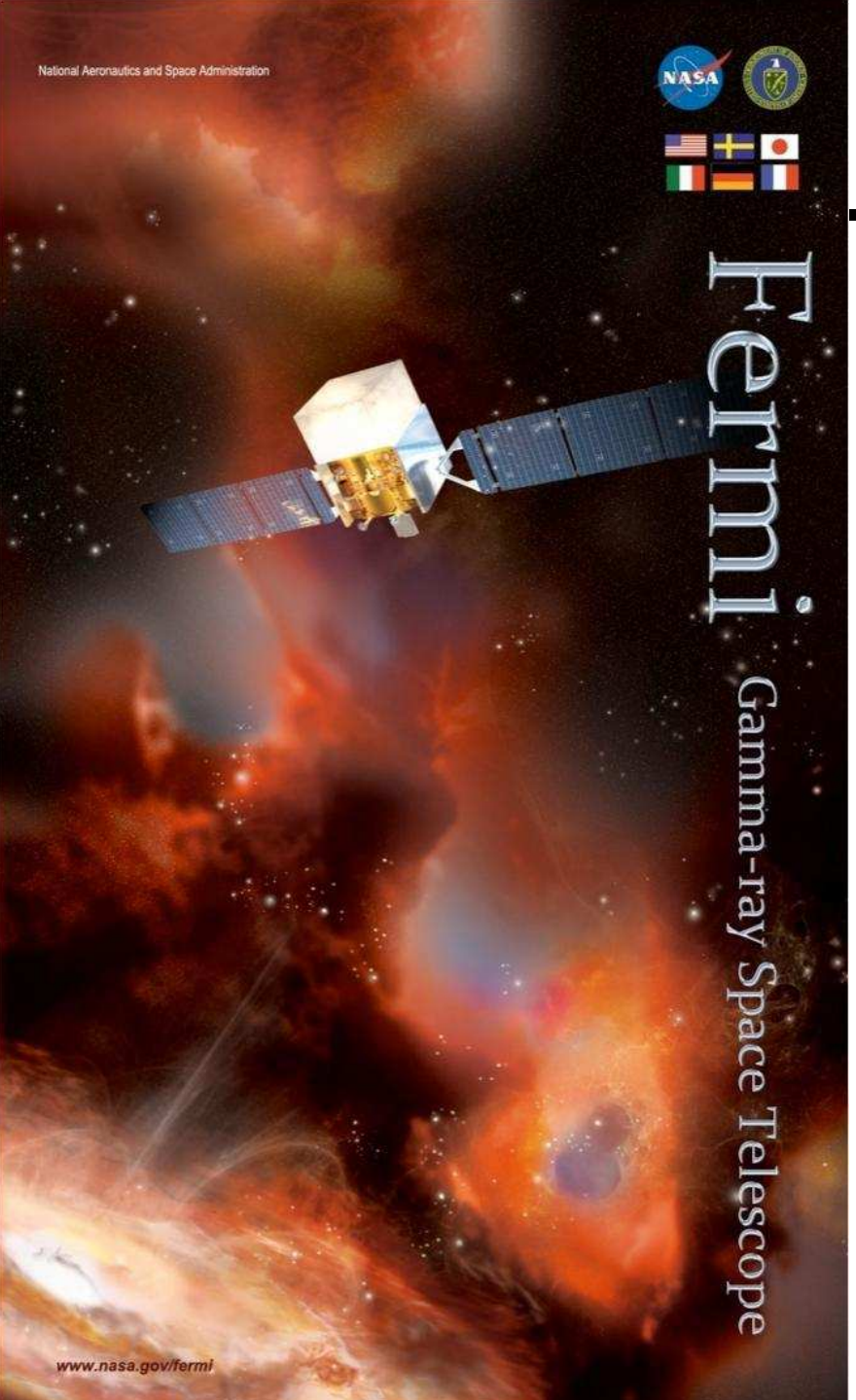

Fermi Analysis

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lott@cenbg.in2p3.fr

Outline

The Fermi Large Area Telescope (LAT)

Highlights

Performance

LAT data

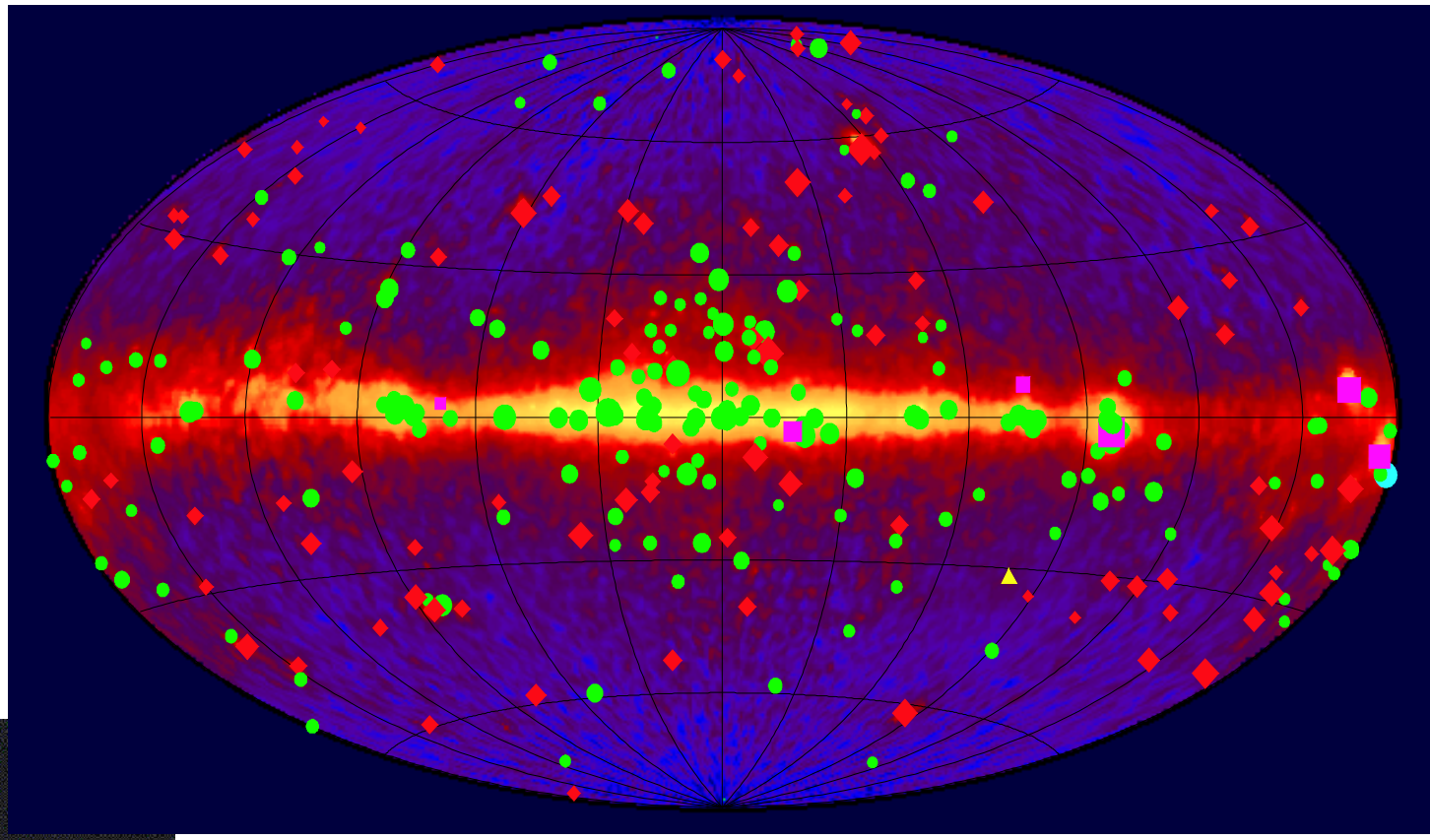
Standard analysis

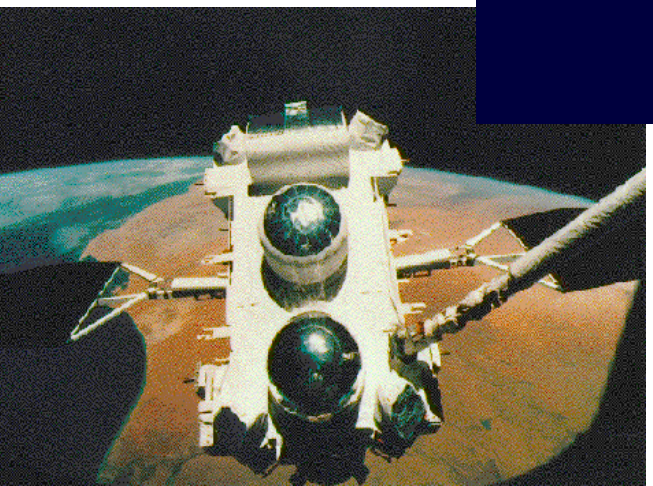
Compton Observatory / EGRET legacy

April 5, 1991 – June 4, 2000

3rd EGRET catalog
271 sources

- **AGN – blazars (70)**
- **unidentified**
- **Pulsars (7)**
- **LMC**

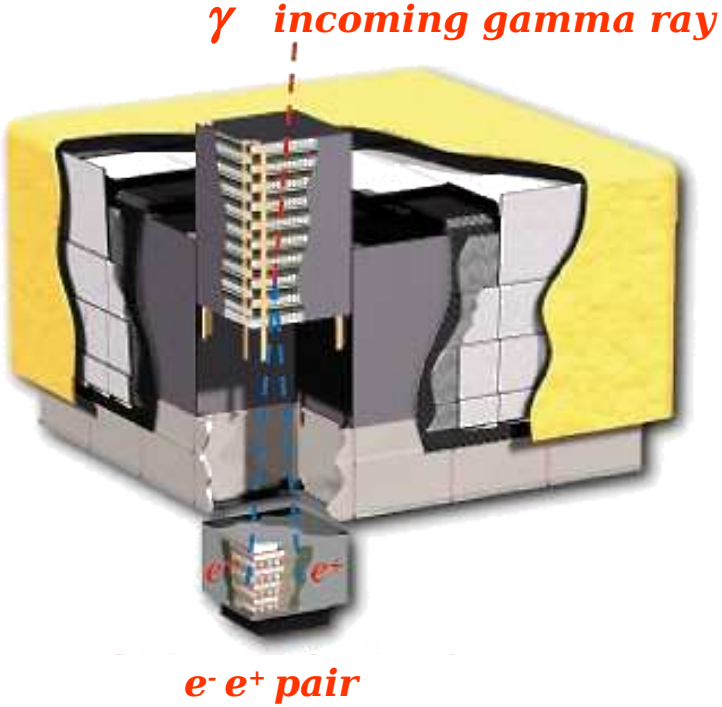


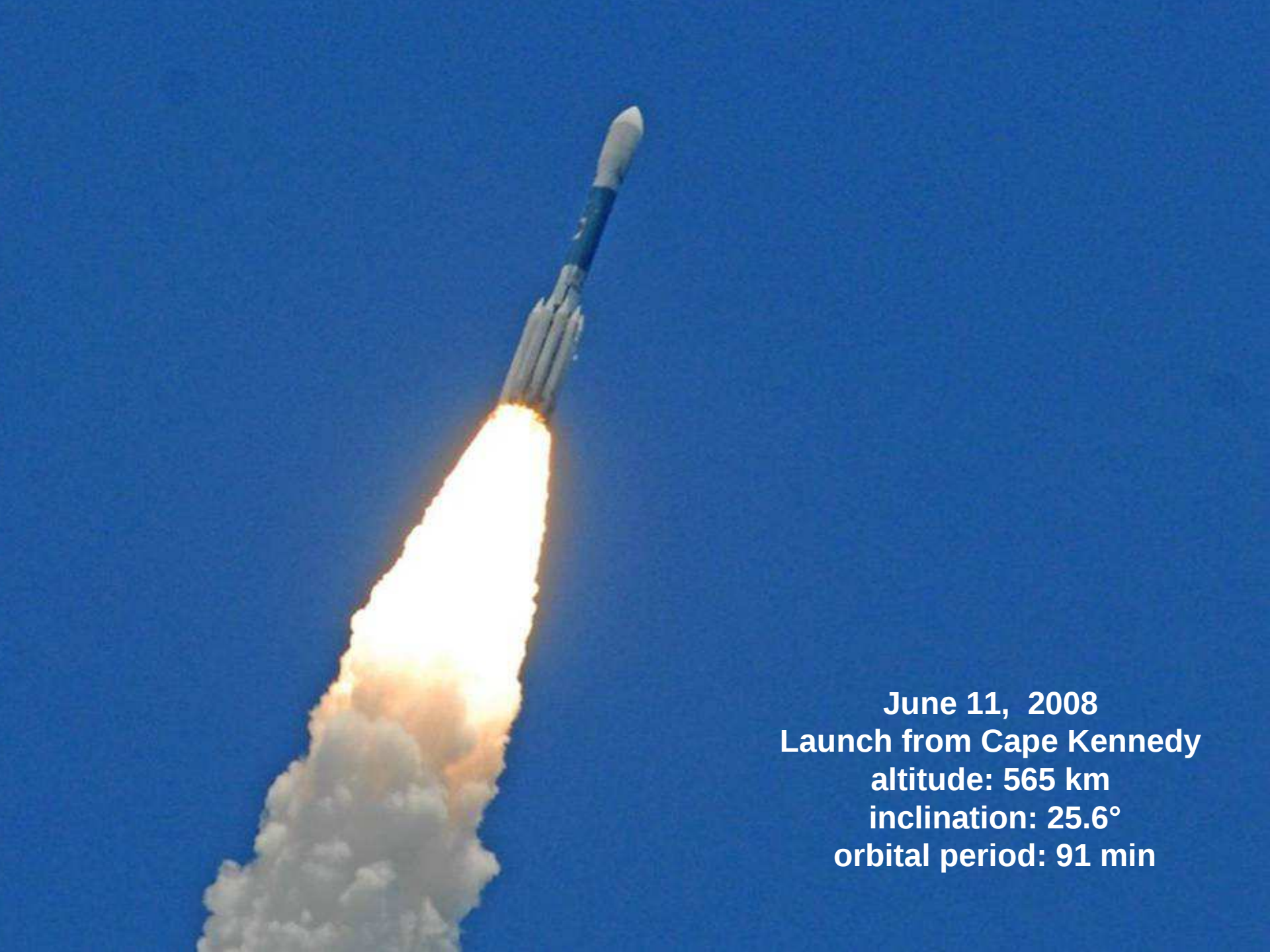


X25 lower sensitivity than Fermi LAT

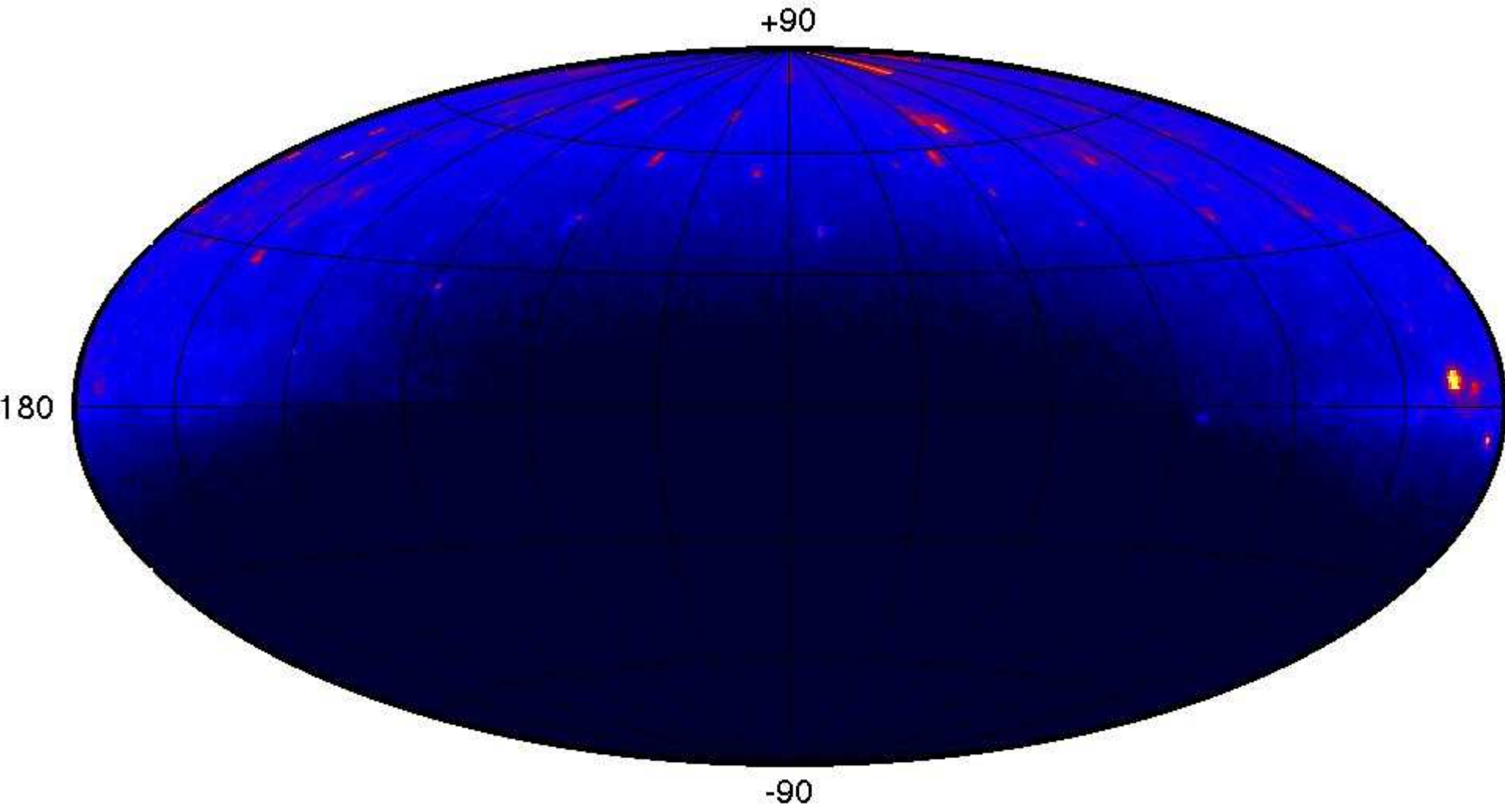
The Large Area Telescope on board the Fermi satellite

(launch: June 11, 2008)





June 11, 2008
Launch from Cape Kennedy
altitude: 565 km
inclination: 25.6°
orbital period: 91 min

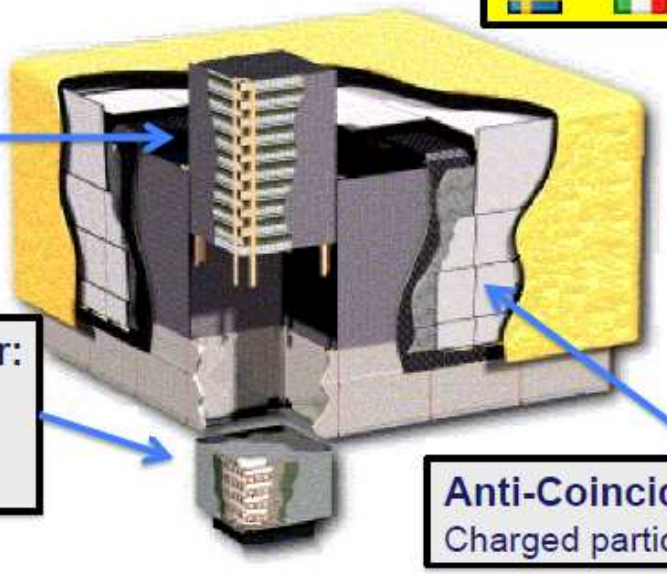

+90
180
-90

The Fermi LAT

Public Data Release:
All γ-ray data made public within 24 hours (usually less)

Fermi LAT Collaboration:
~400 Scientific Members, NASA / DOE & International Contributions

Si-Strip Tracker:
convert $\gamma \rightarrow e^+e^-$
reconstruct γ direction
EM v. hadron separation



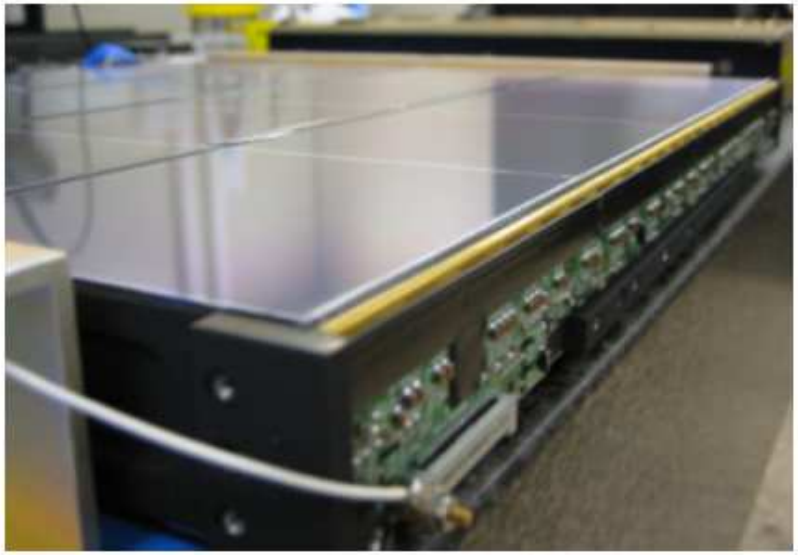
Hodoscopic CsI Calorimeter:
measure γ energy
image EM shower
EM v. hadron separation

Anti-Coincidence Detector:
Charged particle separation

Sky Survey:
With 2.5 sr Field-of-view LAT sees whole sky every 3 hours

Trigger and Filter:
Reduce data rate from ~10kHz to 300-500 HZ

Tracker

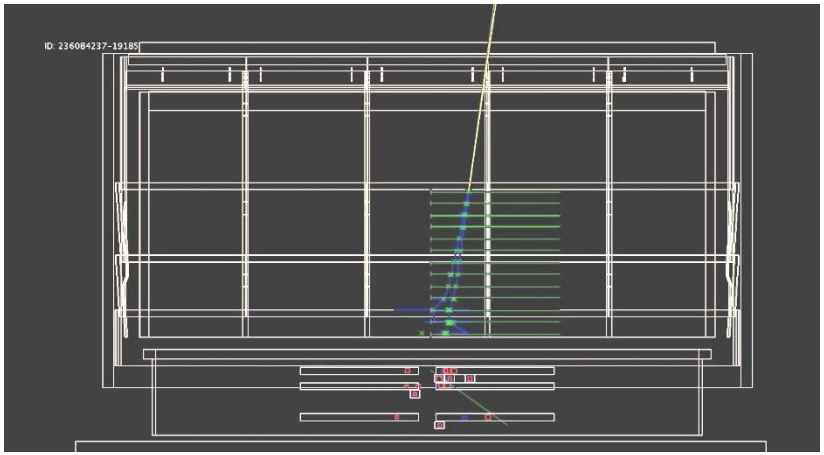


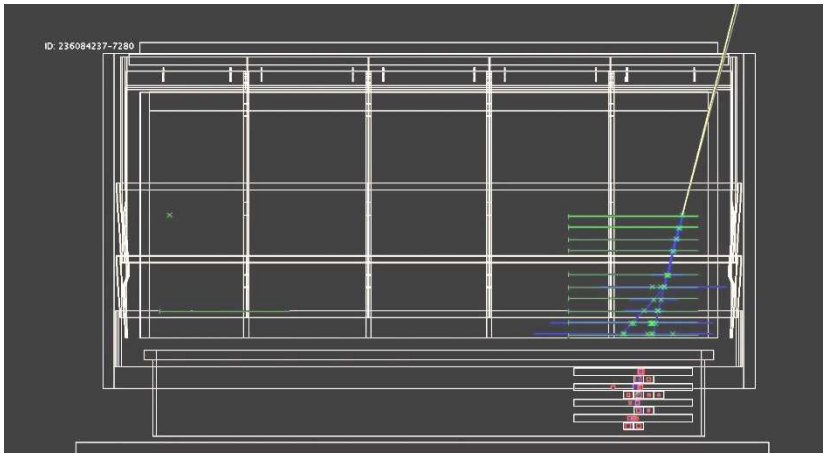
18 bi-layers, (x,y planes)

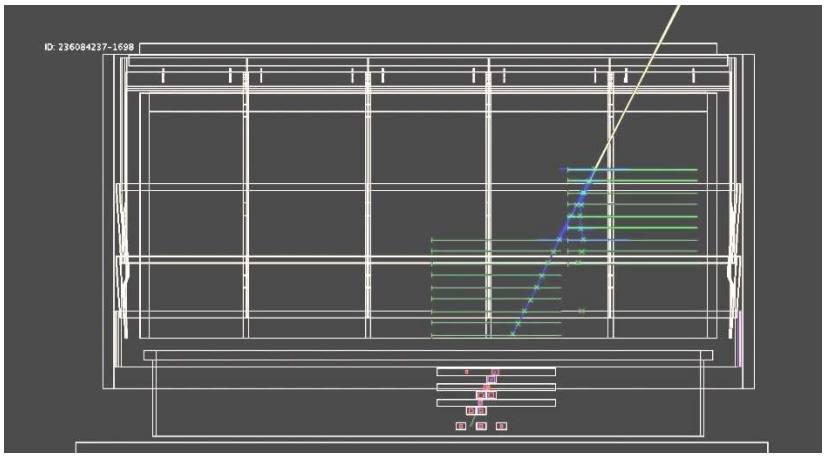
12 Layers thin (0.03 X_0) Tungsten
4 Layers thick (0.12 X_0) Tungsten
2 Layers no Tungsten

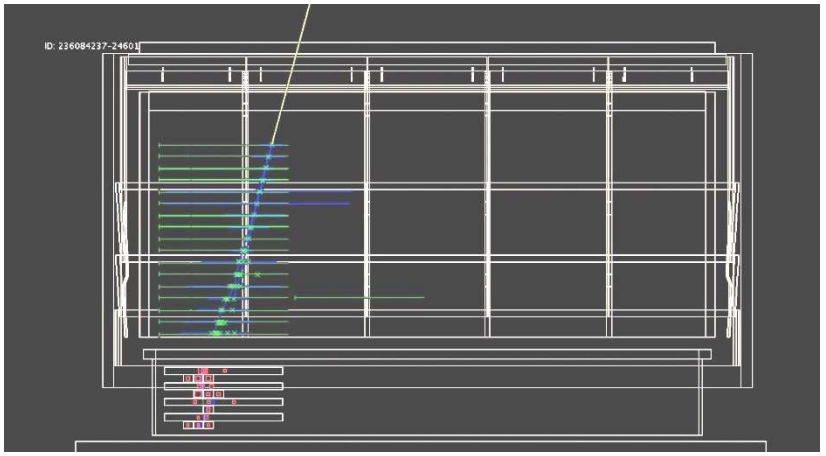
Thickness: 400μm, Pitch 256 μm
Point Resolution ~ pitch / sqrt(12)

Photons gamma dans le LAT









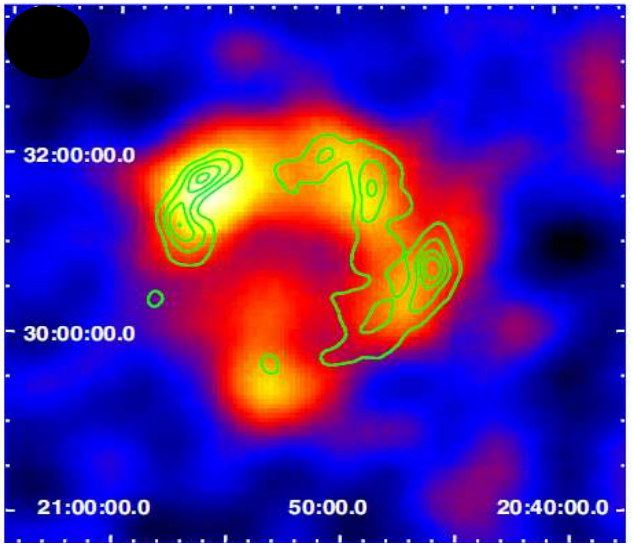
Les croix vertes indiquent les positions détectées des particules chargées, les lignes bleues indiquent les trajectoires reconstruites à partir des traces, et la ligne jaune montre la direction estimée du photon gamma. Les croix rouges indiquent les dépôts d'énergie détectés dans le calorimètre.

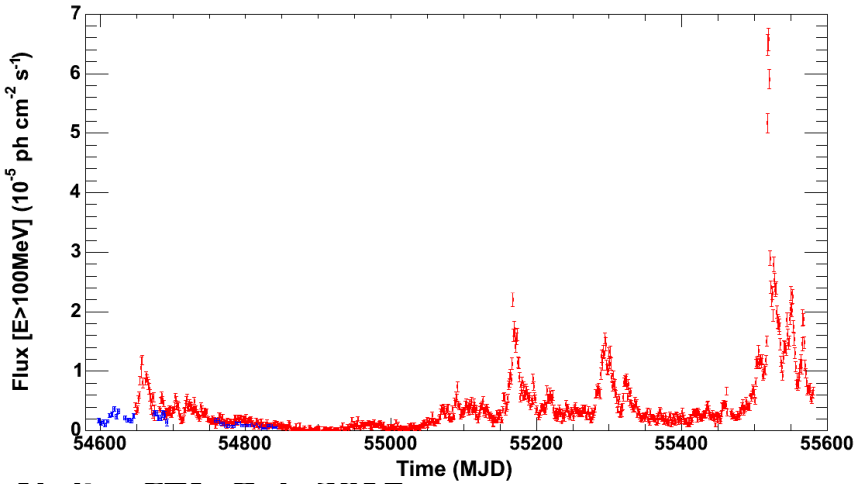
Novel features

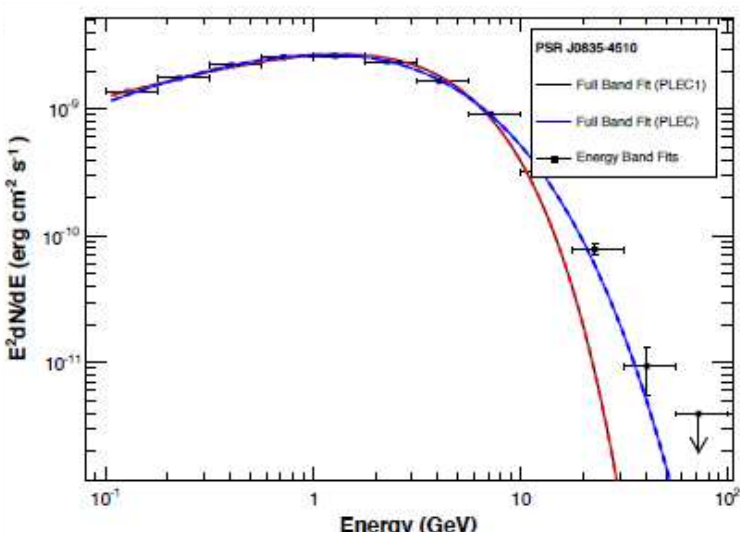
The Fermi-LAT allows for unprecedented studies about

- **morphology**
- **spectra**
- **variability**

in the GeV band



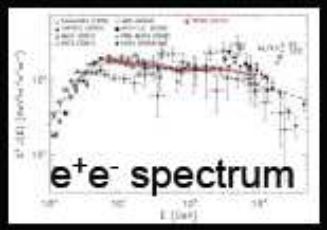




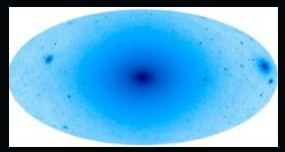
Fermi highlights and discoveries

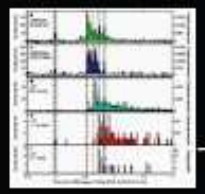
Fermi Highlights and Discoveries

Fermi Gamma-ray Space Telescope

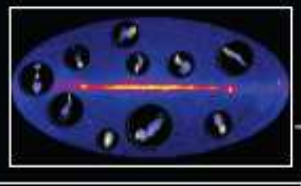


GC excess

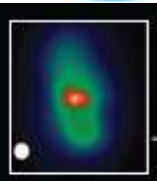




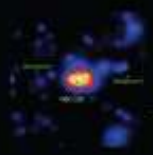
GRBs



Blazars

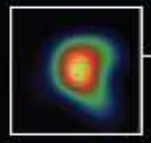


Radio Galaxies



Starburst Galaxies

LMC & SMC

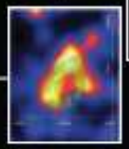


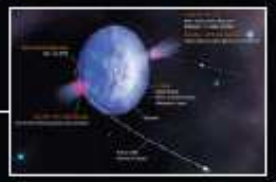
Globular Clusters

Fermi Bubbles

Nova

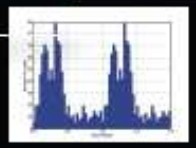
SNRs & PWN





γ-ray Binaries

Pulsars: isolated, binaries, & MSPs



Sun: flares & CR interactions

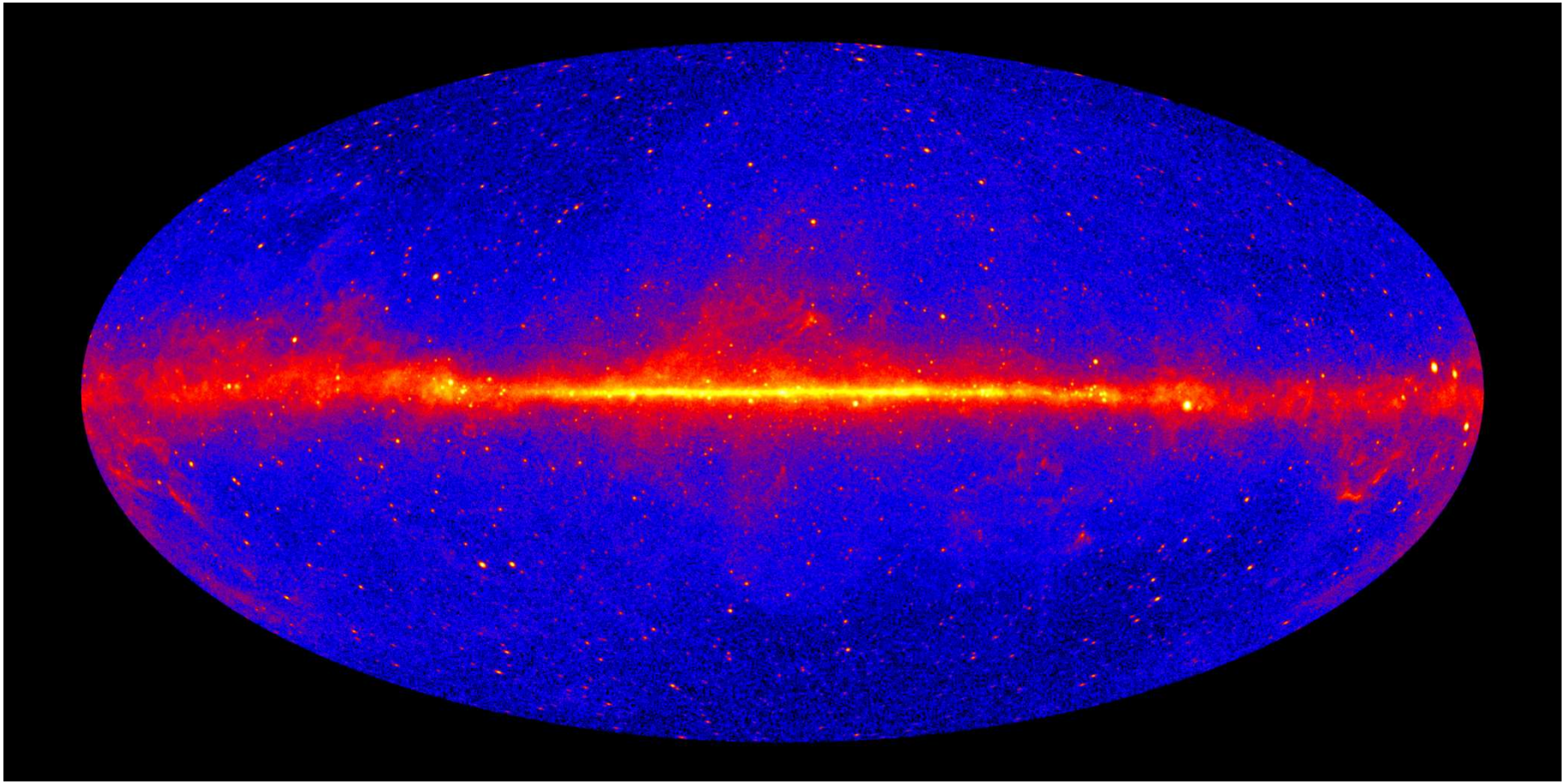
Terrestrial γ-ray Flashes

Unidentified Sources
(992/3031)

Extragalactic

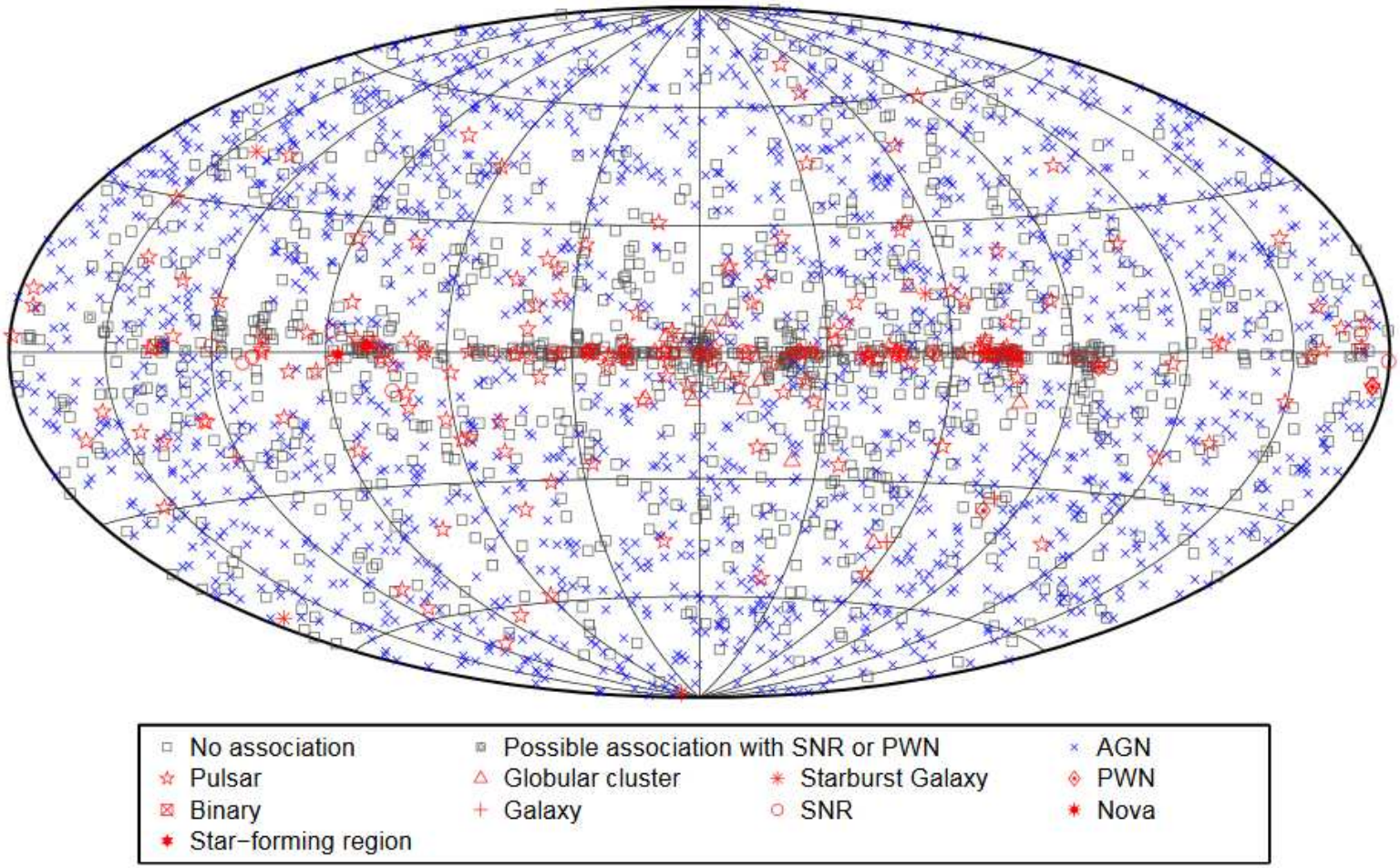
Galactic

9-year sky map



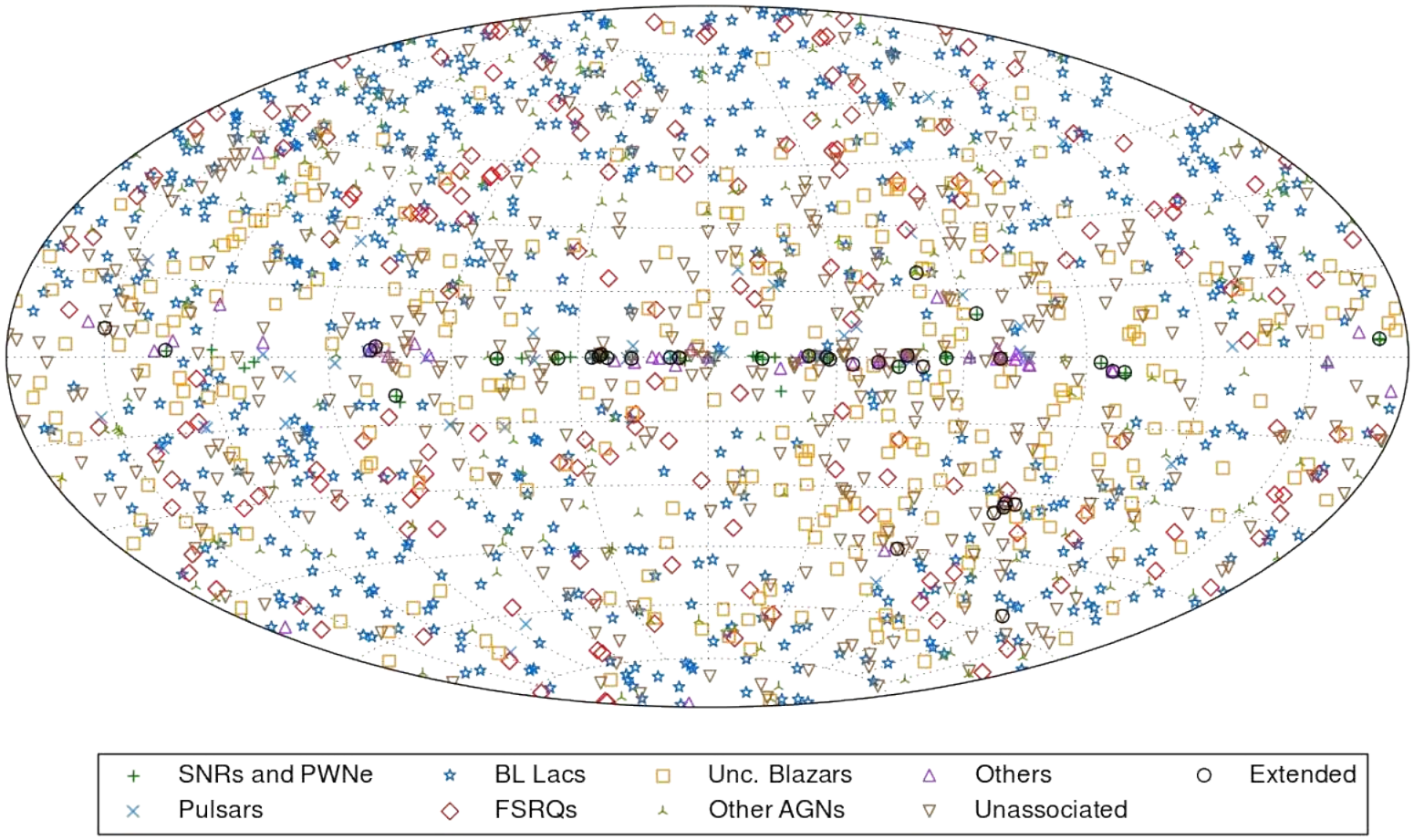
E>1 GeV

3FGL (E>100 MeV)



4 years of data, 3031 sources

3FHL (E> 10 GeV)

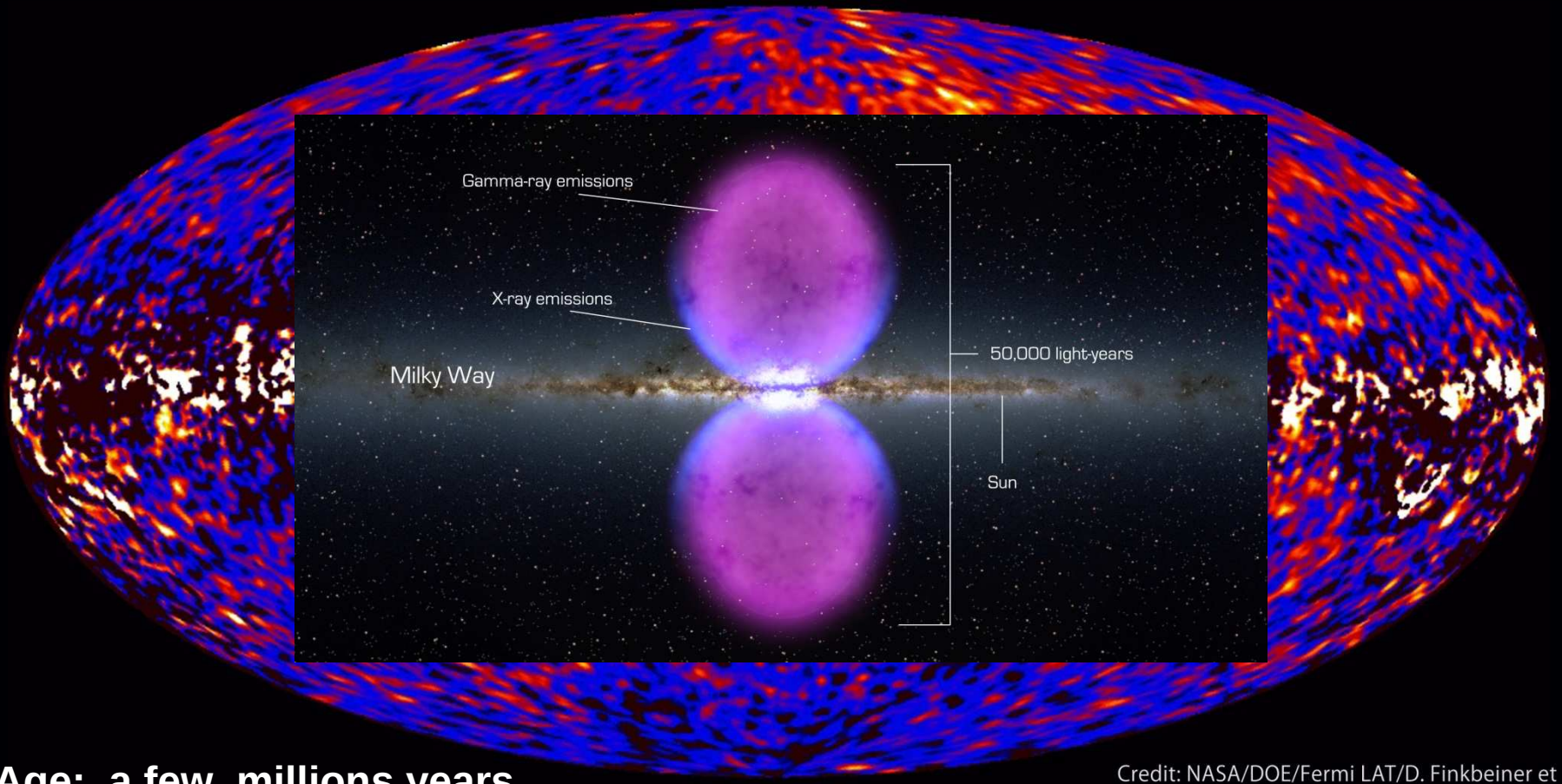


7 years of data, 1556 sources

Source catalogs

Catalog	Energy Range (GeV)	Data Interval (m)	Sources	Unasso-ciated	Event Selection	Release Date
0FGL	0.2-100	3	205	37 (18%)	P6V1 DIFFUSE	Feb. 2009
1FGL	0.1-100	11	1451	630 (43%)	P6V3 DIFFUSE	Feb. 2010
2FGL	0.1-100	24	1873	649 (35%)	P7V6 SOURCE	Aug. 2011
1FHL	10-500	36	511	65 (13%)	P7V6 CLEAN	Jun. 2013
3FGL	0.1-300	48	3031	992 (33%)	P7V15 SOURCE	Jan. 2015
2FHL	50-2000	80	360	48 (14%)	P8 SOURCE	Aug. 2015
3FHL	10-2000	84	1556	176 (11%)	P8 SOURCE	Mar. 2017
4FGL	*0.1-1000*	*96*	*~7500*	*~2500(30%)?*	*P8 SOURCE*	*Jan. 2018?*

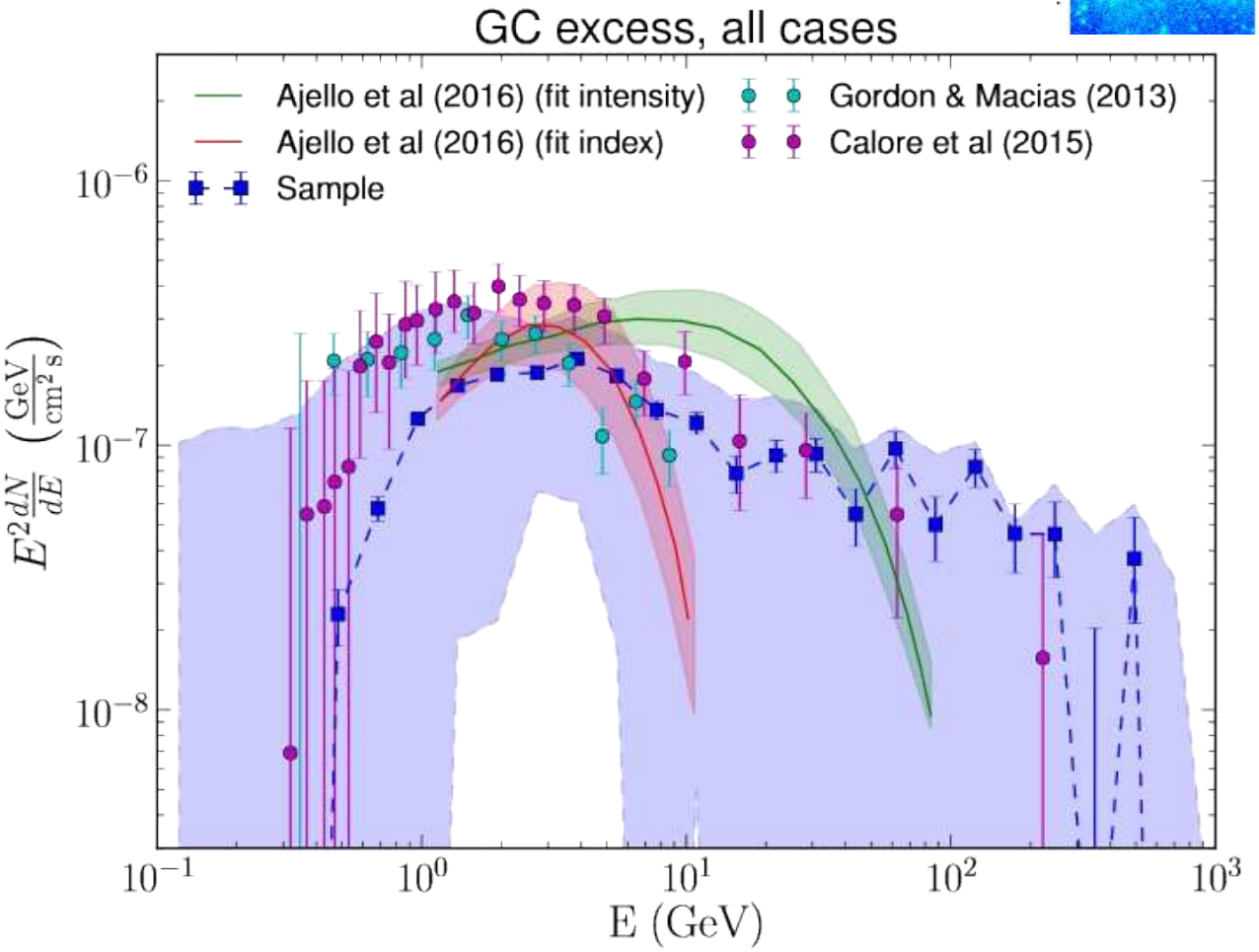
Fermi data reveal giant gamma-ray bubbles



Credit: NASA/DOE/Fermi LAT/D. Finkbeiner et al.

Age: a few millions years
Remnant of a jet ?
Intense episod of star formation?
Fusion of a secondary black hole?

Excess around Galactic Center



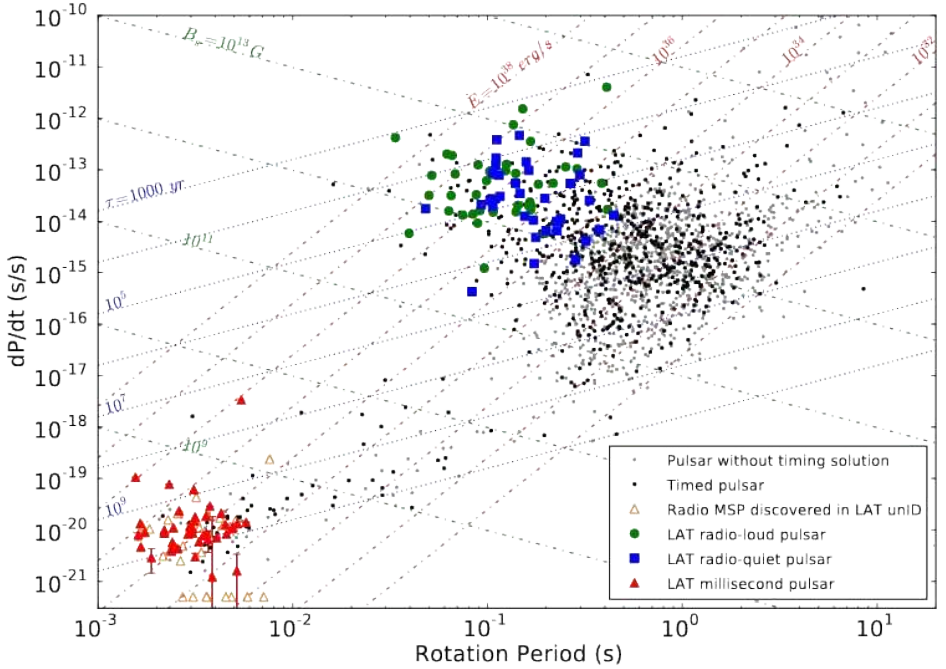
Fluctuation analysis favors the presence of a large population of unresolved sources (e.g., MSPs) Bartels+16

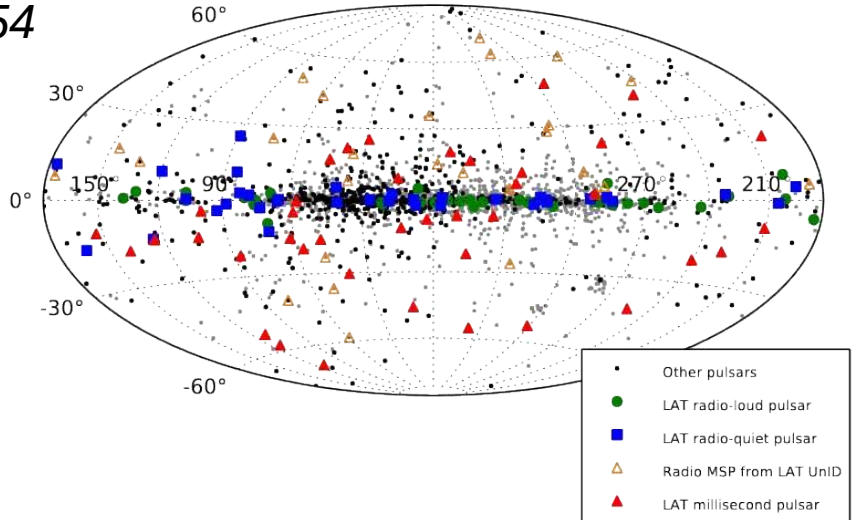
Ackermann+17

Pulsars

Summary Statistics

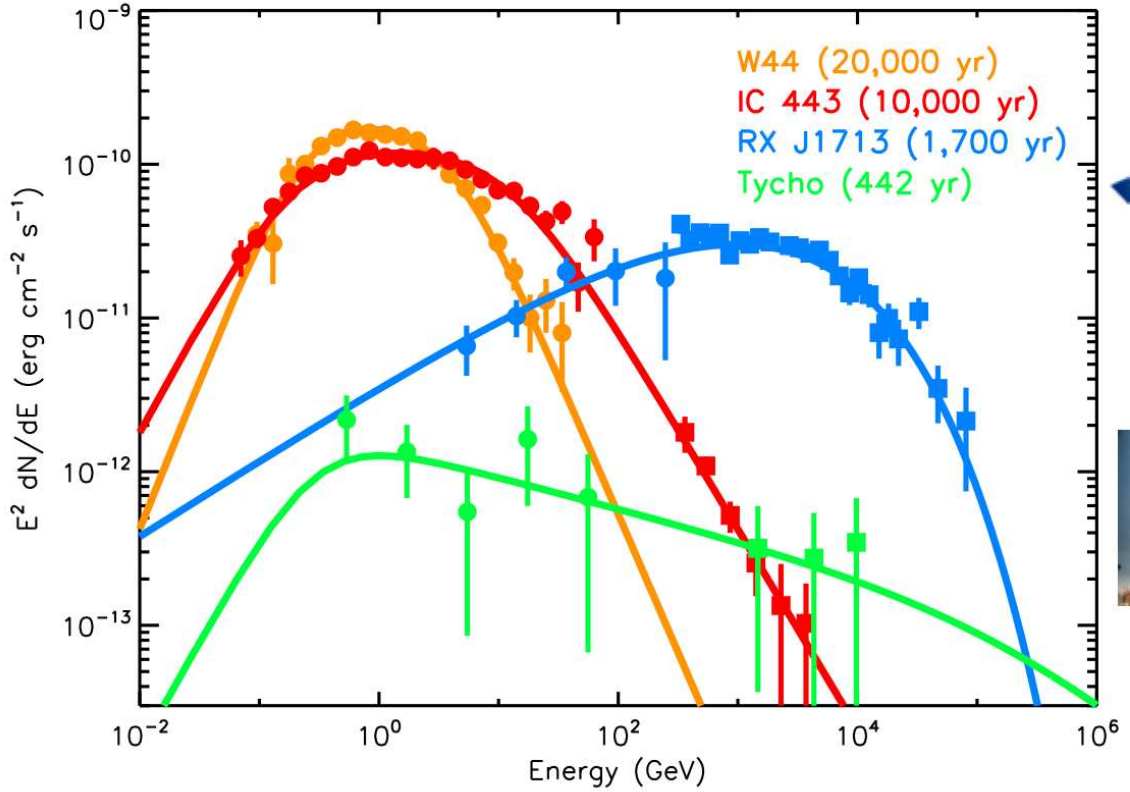
Total number of pulsars: 205
Young, radio selected : 53
Young, gamma selected : 54
Young, X-ray selected : 5
Total number young PSRs : 112
MSP, radio selected : 92
MSP, gamma selected : 1
Total number of MSPs : 93
Total number of binaries : 73
Found in radio searches of LAT sources : 54
EGRET/COMPTEL pulsars: 7





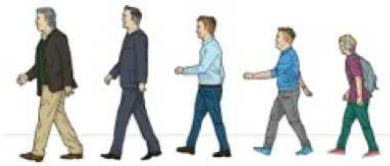
Shell SNRs

denser target



+

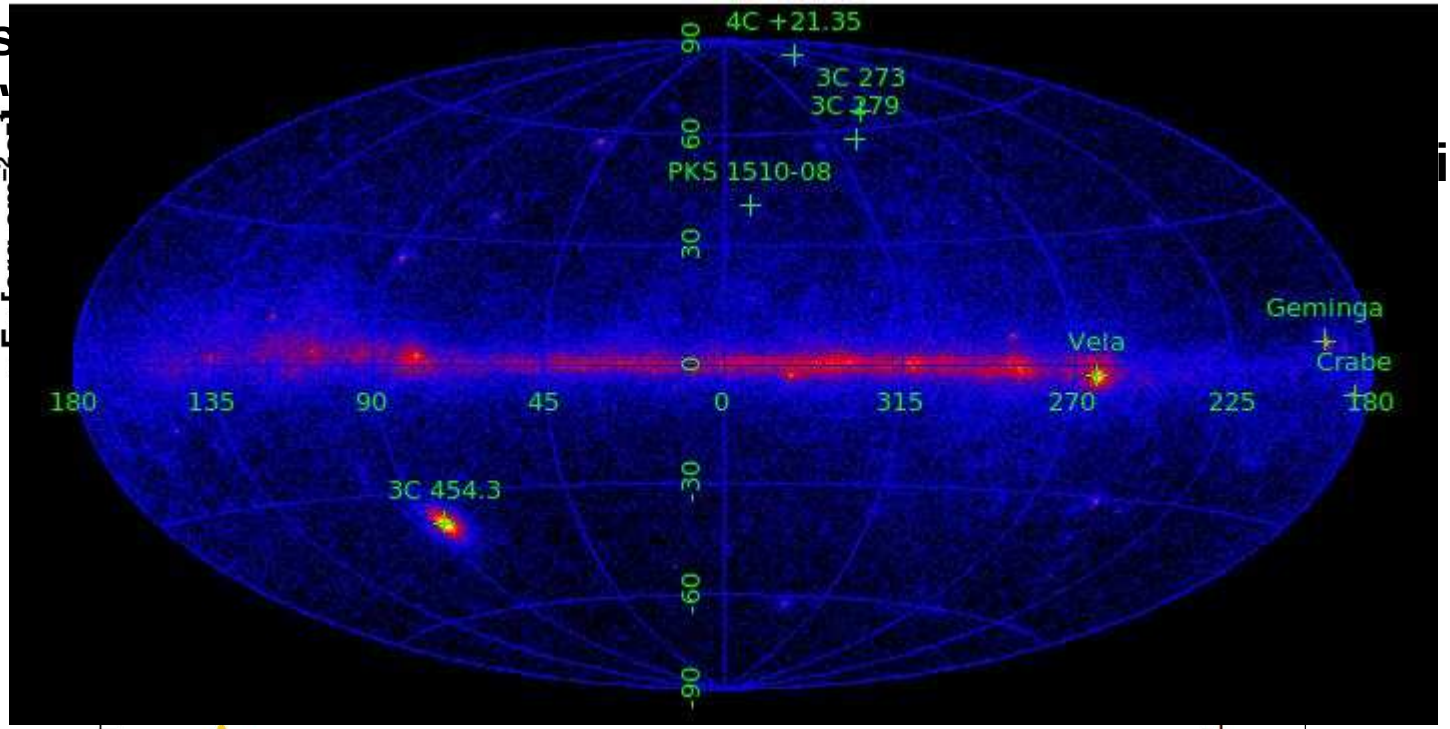
old young

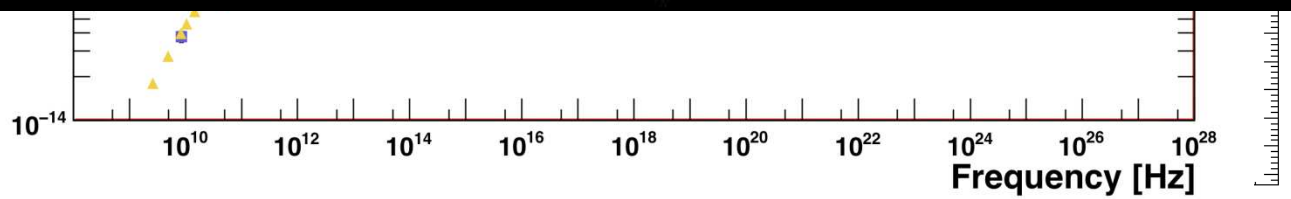


Hewitt14

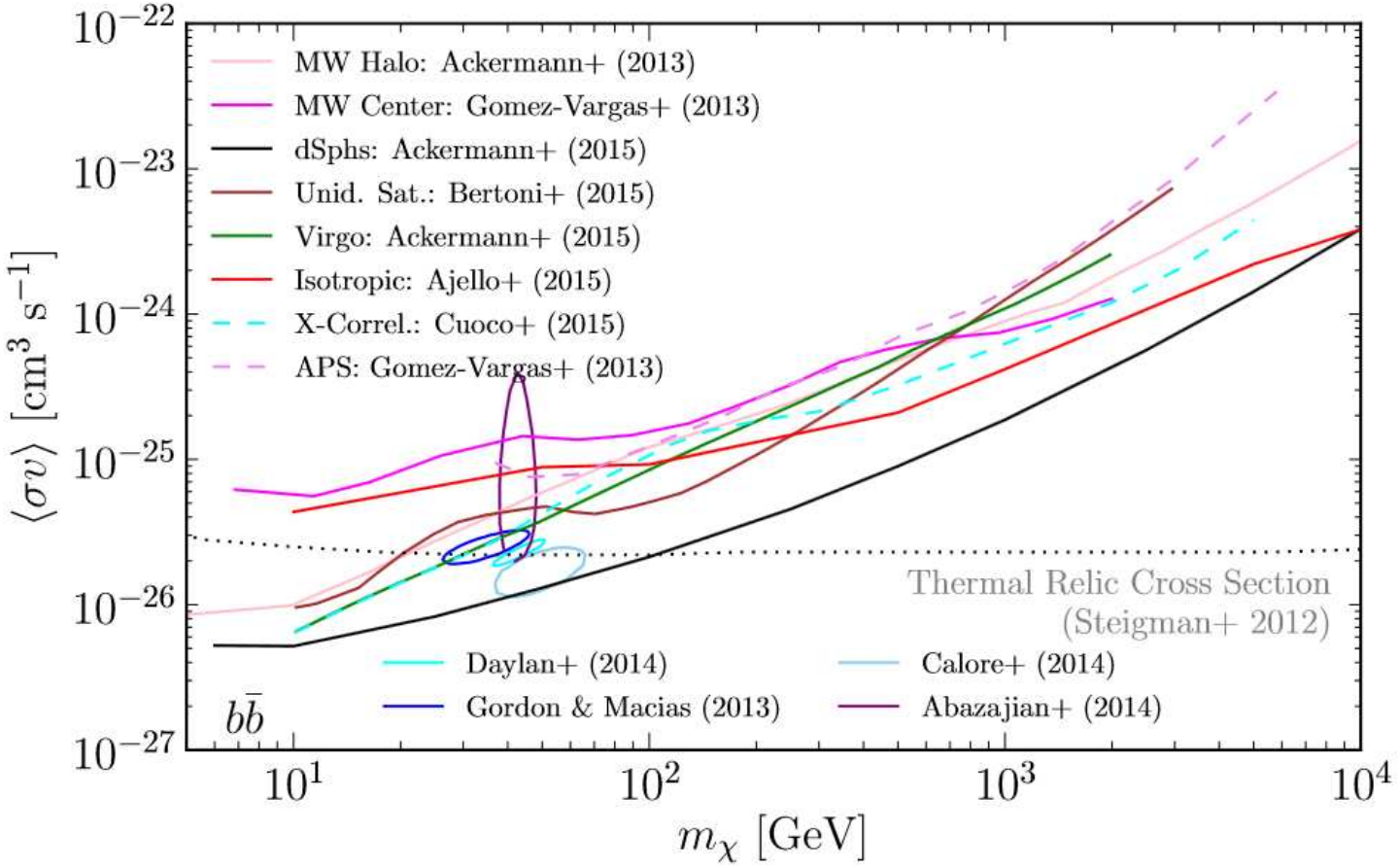
Highlights of AGN results

- Over 1600 de rs.
- Pos
  be
- Lu isk
  vs
- C
- va
- ur
- Sp
  el
- R
- Pl
- Po





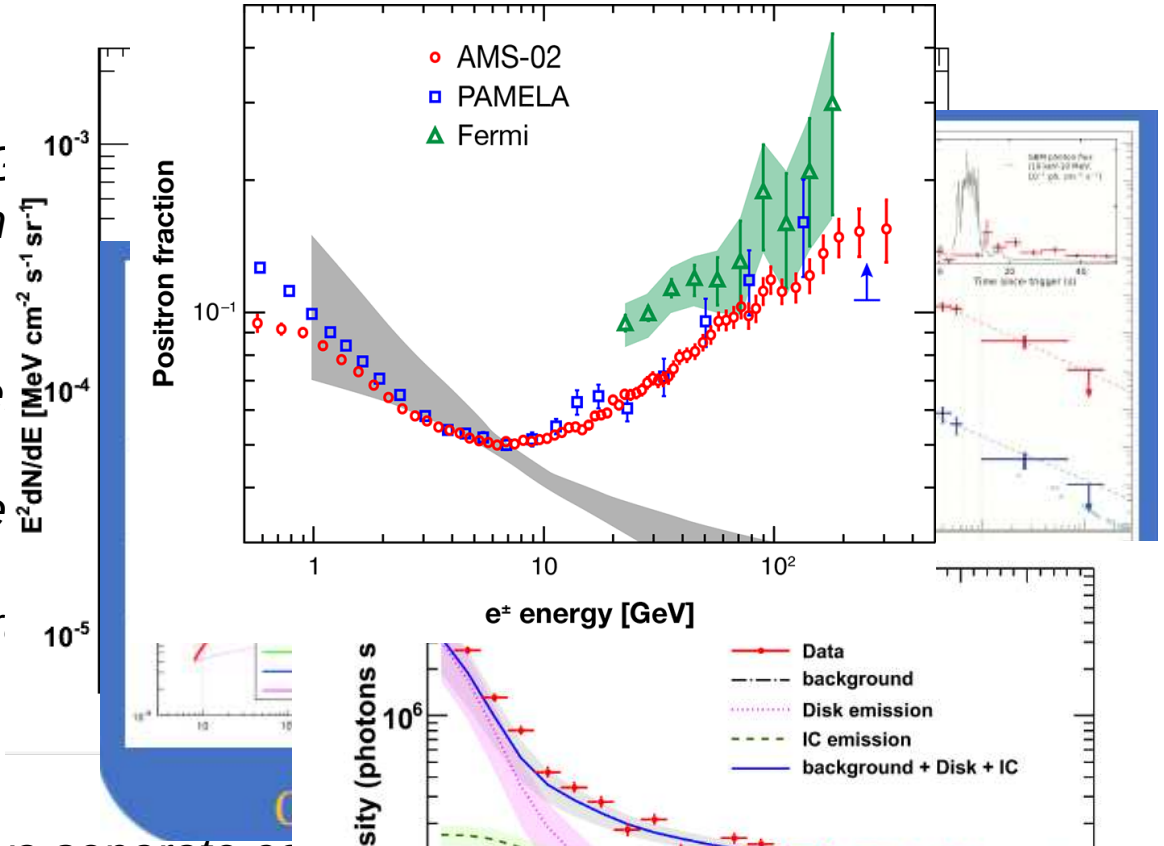
Search for dark matter



Charles, E. et al. 2016, Phys. Rep., 636, 1

More highlights

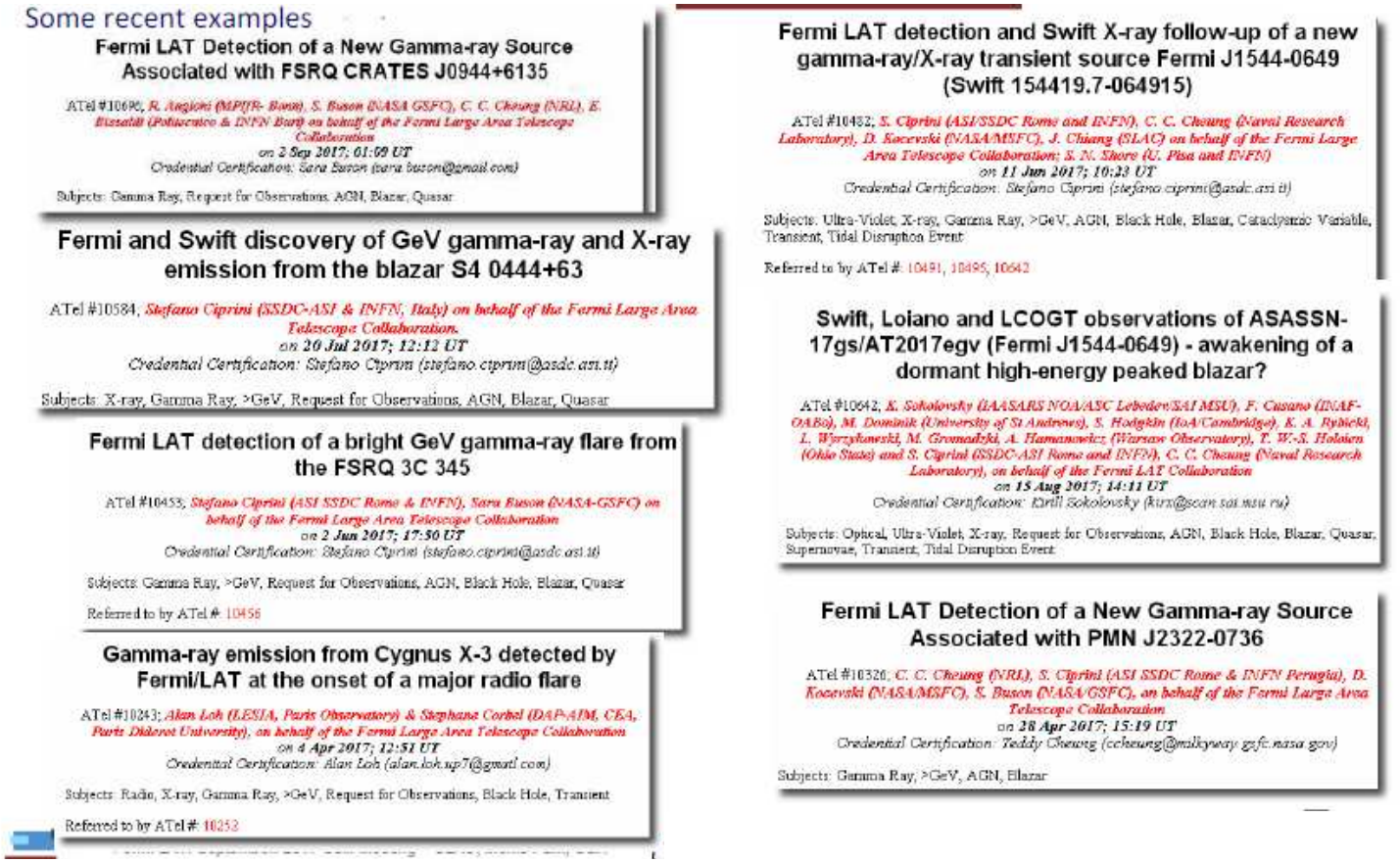
- ***Diffuse emission***
  - *Fermi bubbles*
  - *Extragalactic G*
  - *CRE spectrum*
- ***GRBs***
  - *~150 LAT eve*
  - *afterglow*
  - *detection of ve*
  - *time delays*
  - *multiple spectr*
  - *constraints on*
- ***Solar physics***
  - *Detection of two separate co*
  - *Detection of three behind-th*
  - *2012 March 7 flare: localizat*



Search for Transients

continuous sky survey

- ***>400 ATels***
- ***Flare Advocates***
- ***FAVA***



Fermi Gamma-ray Space Telescope

Performance

Event classes/types

https://fermi.gsfc.nasa.gov/ssc/data/analysis/LAT_essentials.html
https://fermi.gsfc.nasa.gov/ssc/data/analysis/documentation/Cicerone/

Tradeoff between statistics and residual-background contamination

P8R2 IRF name	Event Class (evclass)	Class Hierarchy	Photon File	Extended File
P8R2_ULTRACLEANVETO_V6	1024	Standard	X	X
P8R2_ULTRACLEAN_V6	512	Standard	X	X
P8R2_CLEAN_V6	256	Standard	X	X
P8R2_SOURCE_V6	128	Standard	X	X
P8R2_TRANSIENT010_V6	64	Standard		X
P8R2_TRANSIENT020_V6	16	Standard		X
P8R2_TRANSIENT010E_V6	64	Extended		X
P8R2_TRANSIENT020E_V6	8	Extended		X
P8R2_TRANSIENT015S_V6	65536	No-ACD		X

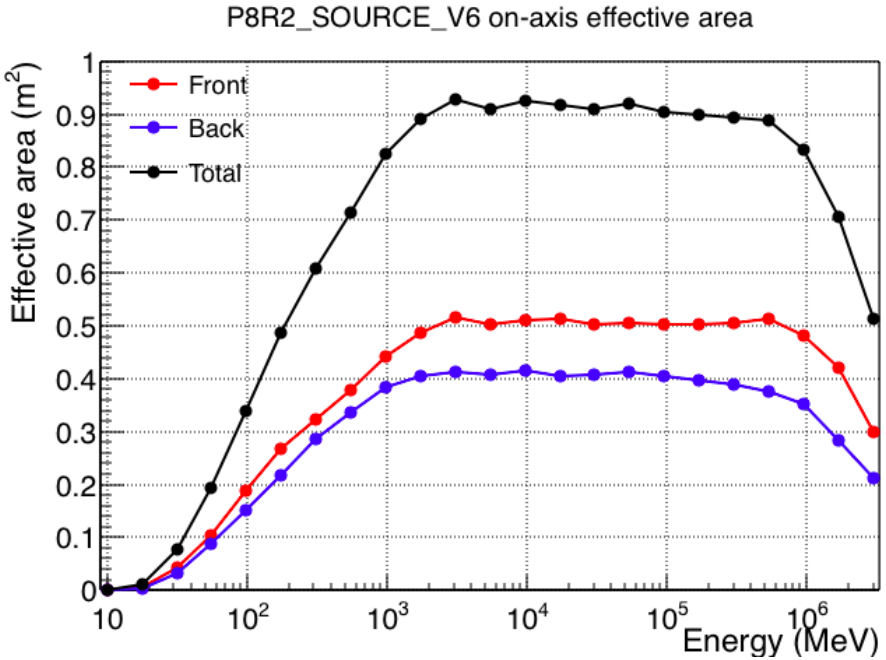
Different partitions of data according to:

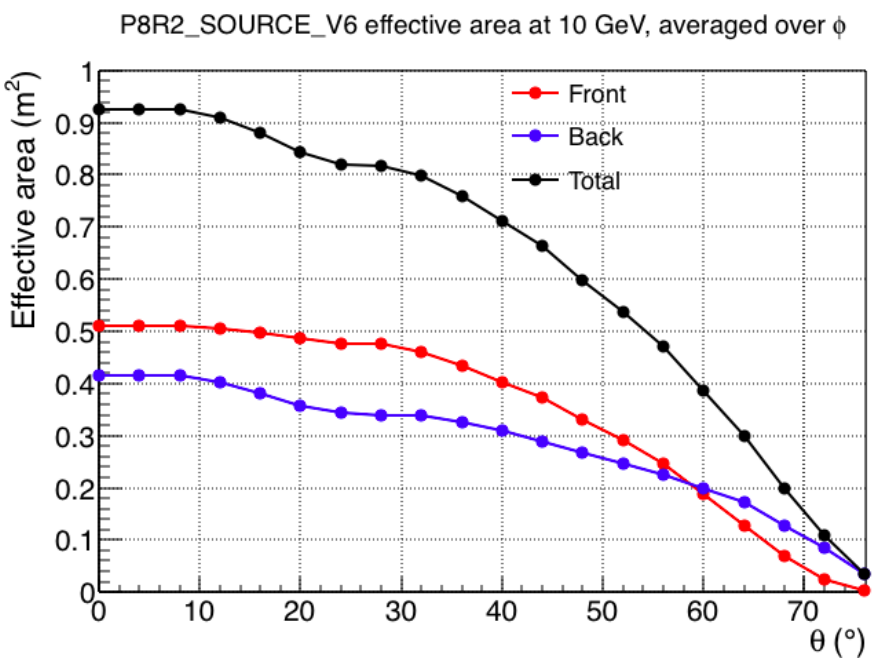
- *conversion type*
- *PSF*
- *energy dispersion*

P8R2 Event Type Name	Event Type Partition	Event Type Value (evtype)
FRONT	Conversion Type	1
BACK	Conversion Type	2
PSF0	PSF	4
PSF1	PSF	8
PSF2	PSF	16
PSF3	PSF	32
EDISP0	EDISP	64
EDISP1	EDISP	128
EDISP2	EDISP	256
EDISP3	EDISP	512

Effective area (Aeff)

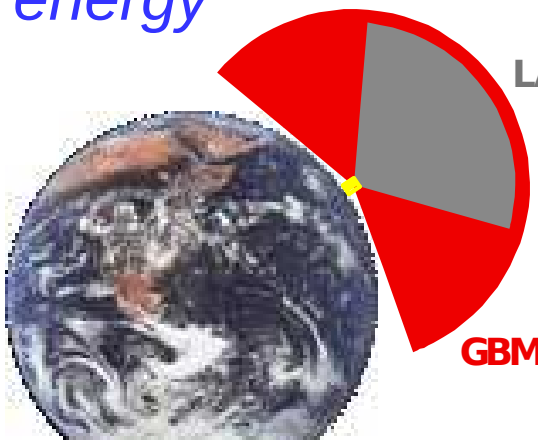
http://www.slac.stanford.edu/exp/glast/groups/canda/lat_Performance.htm



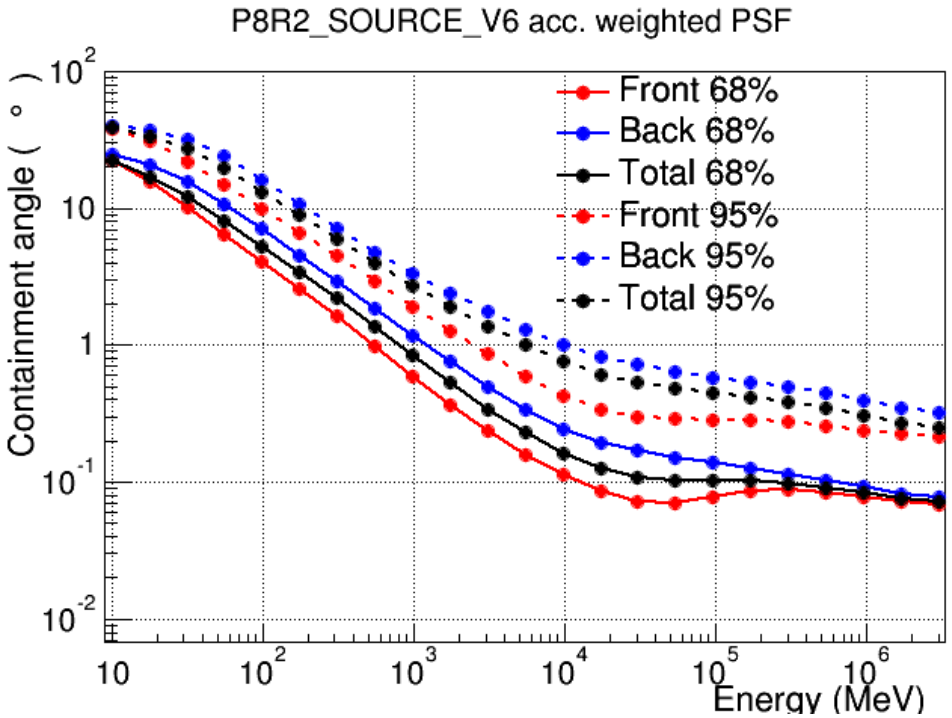


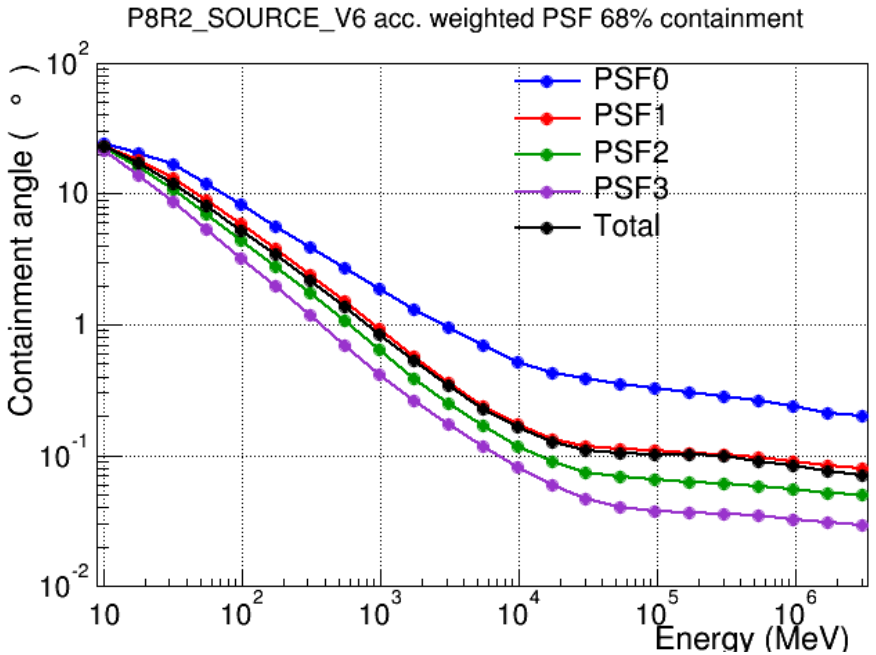
Aeff vs energy

Aeff vs incidence angle



Point Spread Function (PSF)

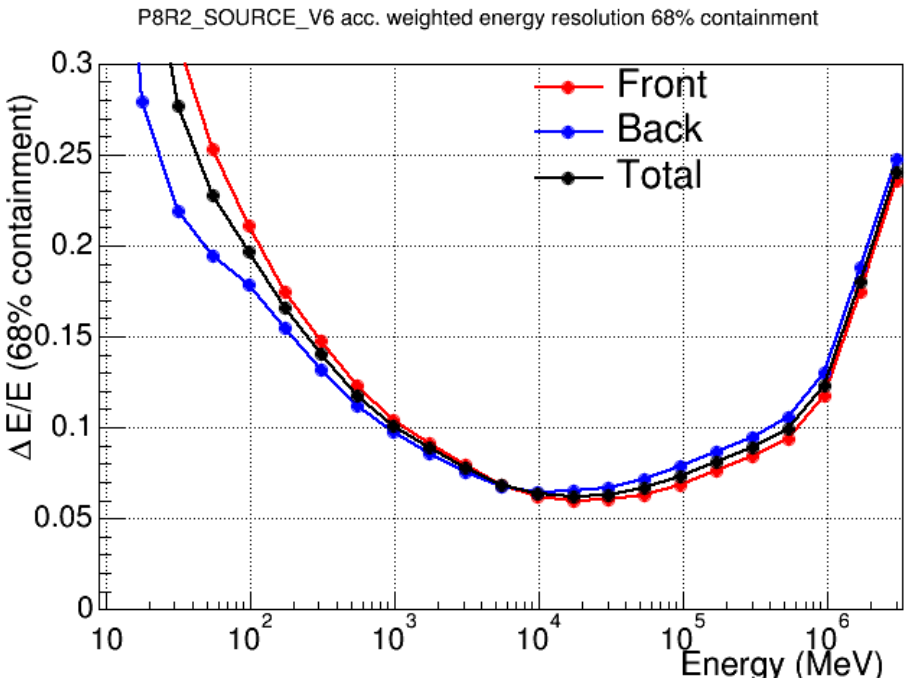


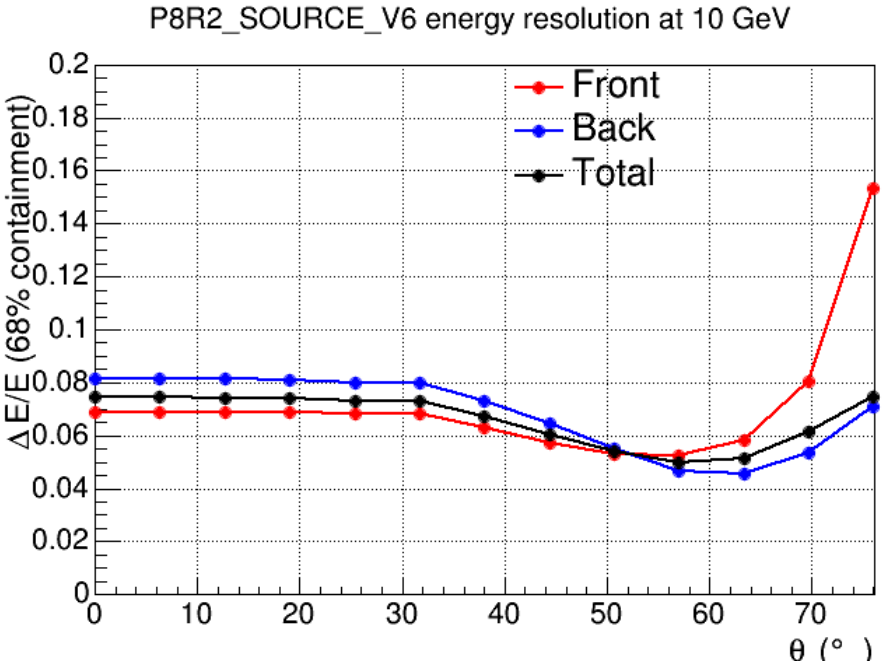


PSF vs Energy

PSF vs incidence angle

Energy resolution





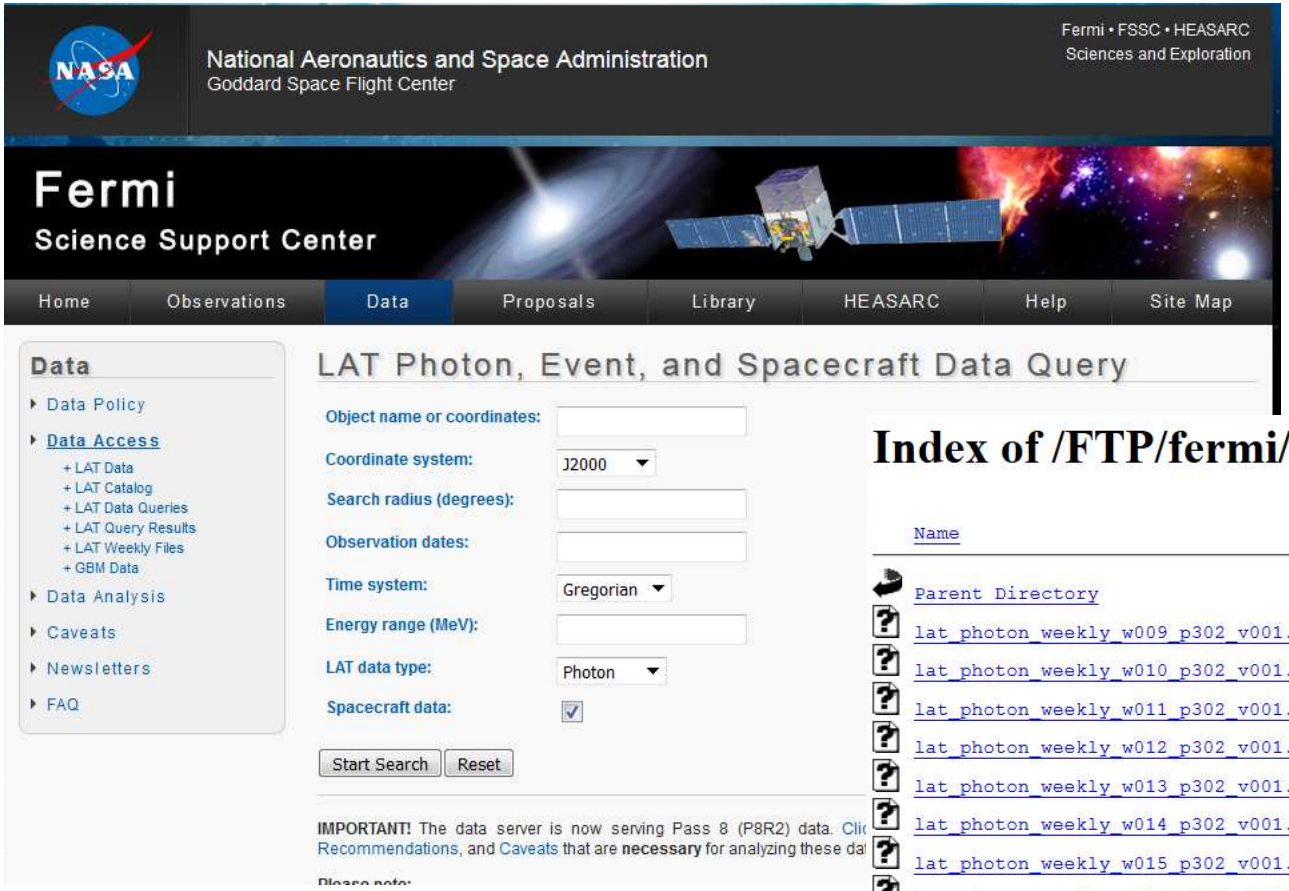
ΔE/E vs Energy

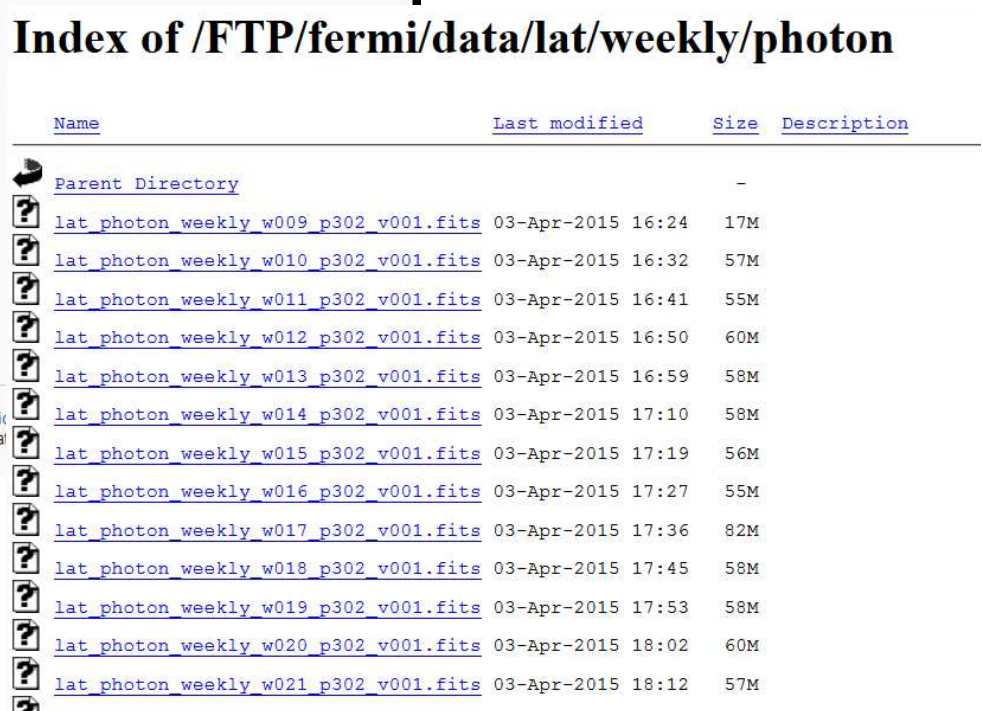
ΔE/E vs Incidence angle

LAT data

Downloading data

https://fermi.gsfc.nasa.gov/cgi-bin/ssc/LAT/LATDataQuery.cgi





Data cuts

Cut on zenith angle to reduce earth-limb background

Event Selection Recommendations (P8R2)

Analysis Type	Minimum Energy (emin)	Maximum Energy (emax)	Max Zenith Angle (zmax)	Event Class (evclass)	IRF Name
Galactic Point Source Analysis	100 (MeV)	500000 (MeV)	90 (degrees)	128	P8R2_SOURCE_V6
Off-plane Point Source Analysis	100 (MeV)	500000 (MeV)	90 (degrees)	128	P8R2_SOURCE_V6
Burst and Transient Analysis (<200s)	100 (MeV)	500000 (MeV)	100 (degrees)	16	P8R2_TRANSIENT020_V6
Galactic Diffuse Analysis	100 (MeV)	500000 (MeV)	90 (degrees)	128	P8R2_SOURCE_V6
Extra-Galactic Diffuse Analysis	100 (MeV)	500000 (MeV)	90 (degrees)	1024	P8R2_ULTRACLEANVETO_V6
Impulsive Solar Flare Analysis	100 (MeV)	500000 (MeV)	100 (degrees)	65536	P8R2_TRANSIENT015S_V6

Time Selection Recommendations

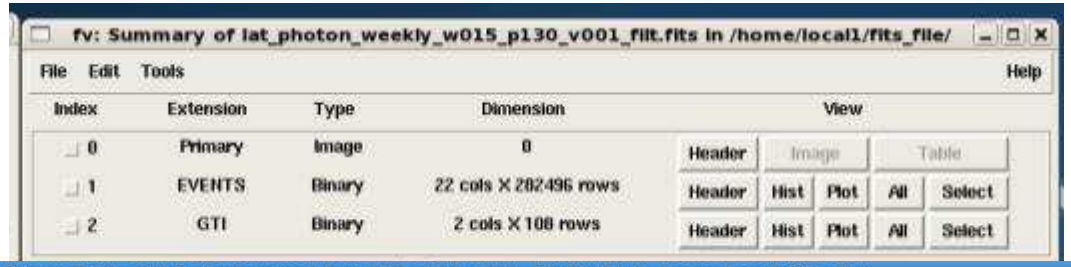
Analysis Type	ROI-Based Zenith Angle Cut (roicut)	Relational Filter Expression (filter)
Galactic Point Source Analysis	no	(DATA_QUAL>0)&&(LAT_CONFIG==1)
Off-plane Point Source Analysis	no	(DATA_QUAL>0)&&(LAT_CONFIG==1)
Burst and Transient Analysis	yes	(DATA_QUAL>0)&&(LAT_CONFIG==1)
Galactic Diffuse Analysis	no	(DATA_QUAL>0)&&(LAT_CONFIG==1)
Extra-Galactic Diffuse Analysis	no	(DATA_QUAL>0)&&(LAT_CONFIG==1)
Burst and Transient Analysis	yes	(DATA_QUAL>0||DATA_QUAL==-1)&&(LAT_CONFIG==1)

The Fermi-LAT data

Explore a weekly data file with the command fv (fits viewer)

- fv lat_photon_weekly_wxxx_p302_v001.fits

GTI: good time intervals



fv: Binary Table of lat_photon_weekly_w387_p302_v001_filt.fits[1] in /home/local1/fits_file/

File Edit Tools

Select All Invert	ENERGY E MeV Modify	RA E deg Modify	DEC E deg Modify	L E deg Modify	B E deg Modify	THETA E deg Modify	PHI E deg Modify	ZENITH_ANGLE E deg Modify	EARTH_AZIMUTH_ANGLE E deg Modify	TIME D s Modify
1	1.271360E+02	5.159875E+01	1.162258E+01	1.722078E+02	-3.602166E+01	1.971371E+01	2.266024E+02	3.285338E+01	3.244904E+02	4.677738951917E+08
2	1.573089E+02	5.680057E+01	6.685381E+01	1.389937E+02	9.635592E+00	3.552819E+01	4.544296E+01	8.284359E+01	3.545354E+02	4.677739008507E+08
3	1.695578E+03	7.843346E+01	3.965472E+01	1.674409E+02	4.382762E-01	2.255245E+01	3.470521E+02	5.540842E+01	7.098304E+00	4.677739030041E+08
4	9.674276E+02	4.965982E+01	3.994494E+01	1.512769E+02	-1.468975E+01	8.774882E+00	6.334771E+01	5.865550E+01	3.409695E+02	4.677739049480E+08
5	3.281965E+02	8.952564E+01	3.612177E+01	1.751360E+02	5.912612E+00	3.078979E+01	3.374878E+02	5.420893E+01	1.835685E+01	4.677739070787E+08
6	7.772005E+02	7.212161E+01	6.166676E+01	1.474597E+02	1.068874E+01	3.266009E+01	3.175640E+01	7.685814E+01	4.763033E-01	4.677739079864E+08
7	8.472022E+02	8.514504E+01	9.370120E+00	1.962426E+02	-1.112456E+01	3.731439E+01	2.894615E+02	2.809679E+01	3.013582E+01	4.677739102076E+08
8	1.405282E+02	7.420302E+01	2.288157E+01	1.788253E+02	-1.246904E+01	2.070964E+01	2.992690E+02	3.796863E+01	3.841174E+00	4.677739161209E+08
9	5.509283E+03	5.379588E+01	5.213021E+01	1.466845E+02	-3.024499E+00	2.044386E+01	4.795040E+01	6.888545E+01	3.483255E+02	4.677739172008E+08
10	6.077189E+02	7.858049E+01	1.016610E+01	1.920876E+02	-1.624311E+01	3.191987E+01	2.824131E+02	2.604097E+01	1.552682E+01	4.677739175089E+08
11	2.225864E+02	9.098786E+00	1.623577E+01	1.176853E+02	-4.648264E+01	4.292139E+01	1.499772E+02	6.946249E+01	2.941005E+02	4.677739222665E+08
12	7.667927E+02	8.480399E+01	3.681464E+01	1.725911E+02	3.004245E+00	2.636329E+01	3.391500E+02	5.305603E+01	1.279193E+01	4.677739226259E+08
13	8.353046E+02	9.168973E+01	-3.012069E+00	2.105100E+02	-1.131034E+01	5.036011E+01	2.830357E+02	2.270643E+01	6.045962E+01	4.677739226964E+08
14	9.223093E+02	7.733179E+01	2.966288E+00	1.978832E+02	-2.106479E+01	3.659081E+01	2.723547E+02	1.853242E+01	1.662431E+01	4.677739238359E+08
15	2.455558E+02	9.984896E+01	3.021271E+01	1.844327E+02	1.089841E+01	3.954520E+01	3.298105E+02	5.235728E+01	3.051429E+01	4.677739240784E+08
16	1.034272E+02	7.886540E+01	3.085065E+01	1.748058E+02	-4.408450E+00	2.166403E+01	3.237120E+02	4.607558E+01	7.911556E+00	4.677739259243E+08
17	1.528603E+02	9.732709E+01	1.112144E+01	2.005282E+02	2.158772E-01	4.529121E+01	3.024665E+02	3.580197E+01	4.511086E+01	4.677739277063E+08
18	1.309305E+02	4.218644E+01	6.013853E+01	1.370480E+02	5.218704E-01	2.923808E+01	6.142661E+01	7.870087E+01	3.451663E+02	4.677739297451E+08
19	1.377829E+02	4.239448E+01	1.752457E+01	1.589619E+02	-3.694826E+01	1.769841E+01	1.917520E+02	4.385422E+01	3.161351E+02	4.677739323600E+08
20	1.854340E+02	1.363964E+01	6.257446E+01	1.232917E+02	-2.950570E-01	3.977779E+01	7.766737E+01	8.969711E+01	3.367131E+02	4.677739347035E+08

The spacecraft data

fv lat_spacecraft_weekly_wxxxx_p202_v001.fits

fv: Summary of lat_spacecraft_weekly_w015_p202_v001.fits in /home/local1/fits_file_sat

File Edit Tools Help

Index	Extension	Type	Dimension	View
0	Primary	Image	0	Header Image Table
1	SC_DATA	Binary	30 cols X 17102 rows	Header Hist Plot All Select

fv: Binary Table of lat_spacecraft_weekly_w015_p202_v001.fits[1] in /home/local1/fits_file_sat/

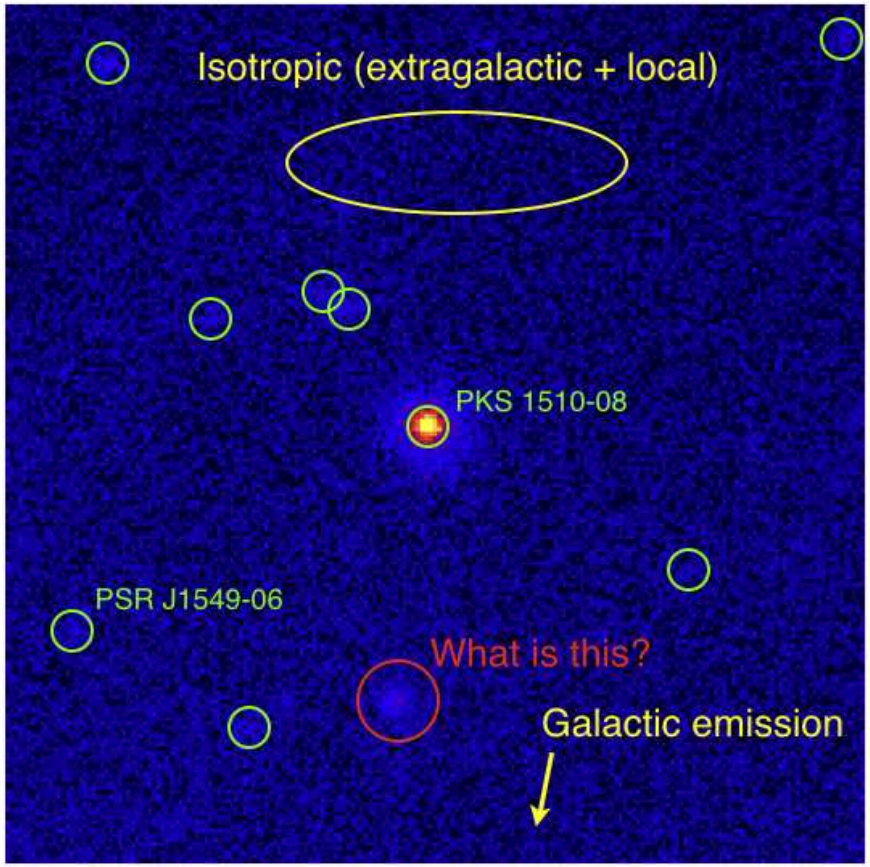
File Edit Tools

Select	START	STOP	SC_POSITION	LAT_GEO	LON_GEO	RAD_GEO	RA_ZENITH	DEC_ZENITH	B_MCILWAIN	L_MCILWAIN	GEOMAG_LAT
All	D	D	3E	E	E	D	E	E	E	E	E
Invert	s	s	m	deg	deg	m	deg	deg	Gauss	Earth_Radii	deg
	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify
1	2.427857869865E+08	2.427858166000E+08	Plot	-1.990907E+01	2.247747E+01	5.645522826428E+05	2.032747E+01	-1.977579E+01	2.385341E+00	1.448905E+00	3.382224E+01
2	2.427858166000E+08	2.427858466000E+08	Plot	-1.936498E+01	2.423490E+01	5.644139690017E+05	2.220862E+01	-1.923535E+01	2.308847E+00	1.430768E+00	3.327805E+01
3	2.427858466000E+08	2.427858766000E+08	Plot	-1.879419E+01	2.600236E+01	5.642632476559E+05	2.410142E+01	-1.866837E+01	2.230679E+00	1.411781E+00	3.268835E+01
4	2.427858766000E+08	2.427859066000E+08	Plot	-1.820441E+01	2.775689E+01	5.641031864036E+05	2.598130E+01	-1.808254E+01	2.151622E+00	1.392313E+00	3.206092E+01
5	2.427859066000E+08	2.427859366000E+08	Plot	-1.759642E+01	2.949864E+01	5.639359926110E+05	2.784839E+01	-1.747862E+01	2.074365E+00	1.372034E+00	3.138092E+01
6	2.427859366000E+08	2.427859666000E+08	Plot	-1.697097E+01	3.122778E+01	5.637608188173E+05	2.970287E+01	-1.685736E+01	1.999152E+00	1.351997E+00	3.068039E+01
7	2.427859666000E+08	2.427859966000E+08	Plot	-1.632885E+01	3.294453E+01	5.635797693304E+05	3.154497E+01	-1.621954E+01	1.925457E+00	1.331926E+00	2.994753E+01
8	2.427859966000E+08	2.427860266000E+08	Plot	-1.567083E+01	3.464919E+01	5.633934075831E+05	3.337497E+01	-1.556592E+01	1.854294E+00	1.311962E+00	2.918492E+01
9	2.427860266000E+08	2.427860566000E+08	Plot	-1.499767E+01	3.634205E+01	5.632046538888E+05	3.519316E+01	-1.489727E+01	1.786114E+00	1.292233E+00	2.839504E+01
10	2.427860566000E+08	2.427860866000E+08	Plot	-1.431015E+01	3.802348E+01	5.630122363429E+05	3.699994E+01	-1.421435E+01	1.720410E+00	1.272895E+00	2.758228E+01
11	2.427860866000E+08	2.427861166000E+08	Plot	-1.360904E+01	3.969387E+01	5.628170811632E+05	3.879568E+01	-1.351793E+01	1.660880E+00	1.253993E+00	2.674704E+01
12	2.427861166000E+08	2.427861466000E+08	Plot	-1.289511E+01	4.135367E+01	5.626228065841E+05	4.058081E+01	-1.280878E+01	1.602668E+00	1.235614E+00	2.589197E+01
13	2.427861466000E+08	2.427861766000E+08	Plot	-1.216913E+01	4.300333E+01	5.624288435352E+05	4.235581E+01	-1.208767E+01	1.548178E+00	1.217830E+00	2.501953E+01
14	2.427861766000E+08	2.427862066000E+08	Plot	-1.143186E+01	4.464334E+01	5.622344581762E+05	4.412117E+01	-1.135533E+01	1.497340E+00	1.200696E+00	2.413197E+01
15	2.427862066000E+08	2.427862366000E+08	Plot	-1.068404E+01	4.627421E+01	5.620400710153E+05	4.587738E+01	-1.061251E+01	1.448916E+00	1.184260E+00	2.323171E+01
16	2.427862366000E+08	2.427862666000E+08	Plot	-9.926421E+00	4.789650E+01	5.618466261620E+05	4.762501E+01	-9.859968E+00	1.406003E+00	1.168557E+00	2.232094E+01
17	2.427862666000E+08	2.427862966000E+08	Plot	-9.159789E+00	4.951076E+01	5.616578364172E+05	4.936462E+01	-9.098469E+00	1.365149E+00	1.153611E+00	2.140183E+01
18	2.427862966000E+08	2.427863266000E+08	Plot	-8.384860E+00	5.111759E+01	5.614722778054E+05	5.109679E+01	-8.328728E+00	1.327309E+00	1.139436E+00	2.047618E+01
19	2.427863266000E+08	2.427863566000E+08	Plot	-7.602385E+00	5.271758E+01	5.612908424451E+05	5.282212E+01	-7.551490E+00	1.292099E+00	1.126058E+00	1.954723E+01
20	2.427863566000E+08	2.427863866000E+08	Plot	-6.813104E+00	5.431137E+01	5.611073092280E+05	5.454125E+01	-6.767493E+00	1.259637E+00	1.113490E+00	1.861778E+01

Data analysis

Inspecting the ROI

Many (overlapping) sources in the ROI
→ maximum likelihood!



1GeV - 10GeV

Detected sources are listed in the 3FGL Catalog:
http://fermi.gsfc.nasa.gov/ssc/data/access/lat/4yr_catalog/

Likelihood analysis: basics

The source model is considered as:

$$S(E,\hat{p},t) = \sum_i s_i(E,t)\delta(\hat{p}-\hat{p}_i) + S_G(E,\hat{p}) + S_{\rm eg}(E,\hat{p}) + \sum_l S_l(E,\hat{p},t),$$

Point Sources | Galactic & EG Diffuse Sources | Other Sources

This model is folded with the Instrument Response Functions (IRFs) to obtain the predicted counts in the measured quantity space (E',p',t'):

$$M(E',\hat{p}',t) = \int_{\rm SR} dE d\hat{p} R(E',\hat{p}',t;E,\hat{p}) S(E,\hat{p},t)$$

where

$$R(E',\hat{p}';E,\hat{p},t) = A(E,\hat{p},\vec{L}(t)) D(E';E,\hat{p},\vec{L}(t)) P(\hat{p}';E,\hat{p},\vec{L}(t))$$

is the combined IRF. $L(t)$ *is the orientation vector of the spacecraft. The integral is performed over the Source Region, i.e. the sky region encompassing all sources contributing to the Region-of – Interest (ROI). In the standard analysis, only steady sources are considered*

$$S(E,\hat{p},t) \rightarrow S(E,\hat{p})$$

Likelihood analysis: basics

The function to maximize is:

$$\log \mathcal{L} = \sum_j \log M(E'_j, \hat{p}'_j, t_j) - N_{\rm pred}$$

where the sum is performed over photons in the ROI. The predicted number of counts is:

$$N_{\rm pred} = \int_{\rm ROI} dE' d\hat{p}' \, dt M(E', \hat{p}', t)$$

To save CPU time, a model-independent quantity, « exposure map (cube)» is precomputed:

$$\varepsilon(E, \hat{p}) \equiv \int_{\rm ROI} dE' \, d\hat{p}' \, dt \, R(E', \hat{p}', t; E, \hat{p})$$

Then

$$N_{\rm pred} = \int_{\rm SR} dE d\hat{p} \, S(E, \hat{p}) \, \varepsilon(E, \hat{p})$$

Diffuse-emission models

- *Galactic diffuse model:*

gll_iem_v06.fits

model adjusted to data

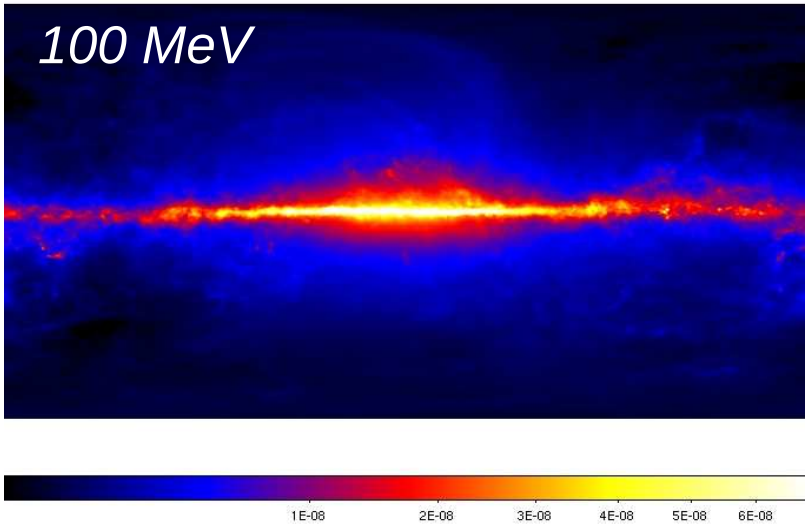
- *Extragalactic diffuse model*

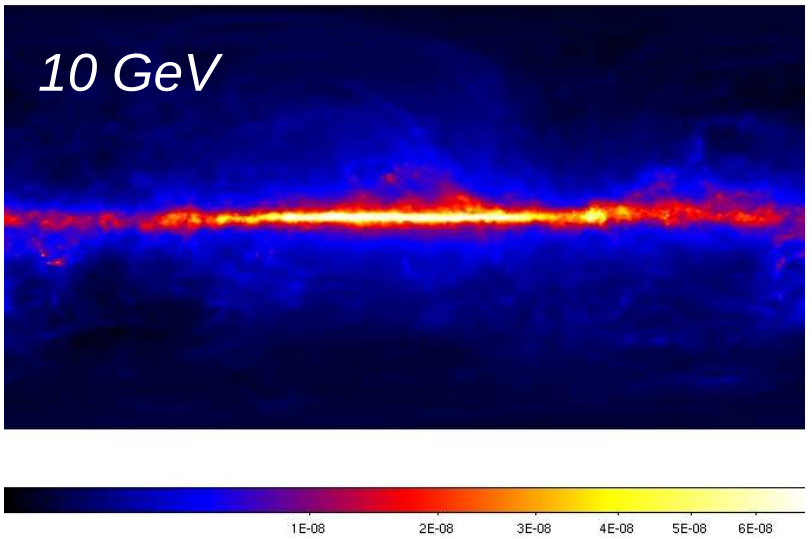
actually sum of true gamma-ray extragalactic diffuse+ instrumental background

Ex:

iso_P8R2_SOURCE_V6_v06.txt

34.171 2.52894e-06 2.02085e-09
44.3332 1.2486e-06 6.37177e-10
57.5177 6.14648e-07 4.13763e-10
74.6231 3.09835e-07 2.20674e-10
96.8155 1.58407e-07 1.36949e-10
125.608 9.04064e-08 8.11021e-11
162.963 5.44142e-08 5.50435e-11
211.427 2.96885e-08 3.16824e-11
274.305 1.579e-08 2.14466e-11
355.881 8.43735e-09 1.23411e-11
461.718 4.44418e-09 8.65201e-12
599.03 2.29861e-09 4.88778e-12
.....





xml model file

Include two diffise emission models
(galactic and isotropic)
+ point sources

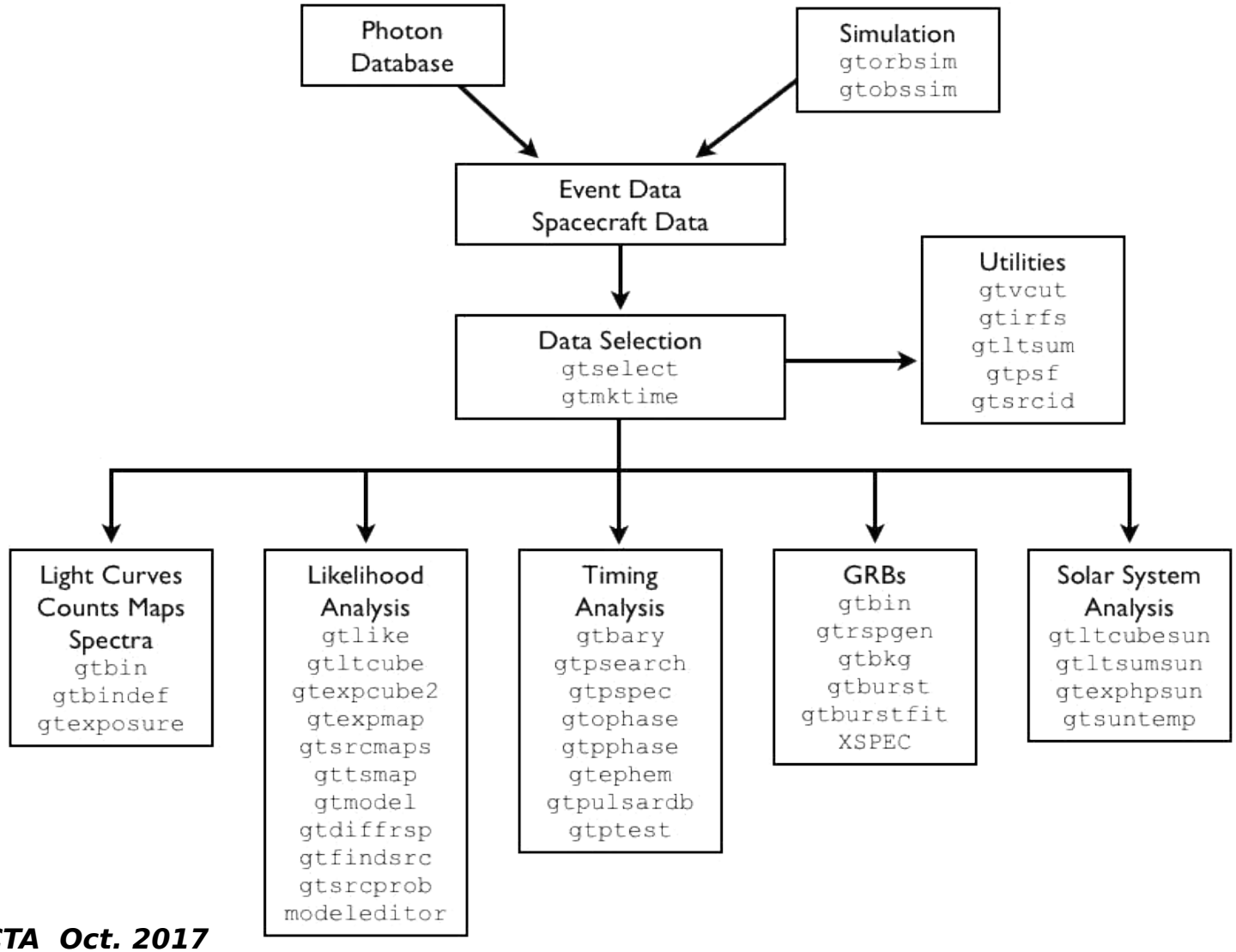
Variety of spectral shapes:

- *Power law*
- *Log parabola*
- *Power law + exponential cutoff*

….

```
<?xml version="1.0" ?>
<source_library title="source library">
<!-- Diffuse Sources -->
<source name="GAL_v02" type="DiffuseSource">
        <spectrum type="PowerLaw">
                <parameter free="1" max="10" min="0" name="Prefactor"
                 scale="1" value="1.22"/>
                <parameter free="0" max="1" min="-1" name="Index" scale="1.0" value="0"/>
                <parameter free="0" max="2e2" min="5e1" name="Scale" scale="1.0" value="1e2"/>
        </spectrum>
        <spatialModel file="gll_iem_v02.fit" type="MapCubeFunction">
                <parameter free="0" max="1e3" min="1e-3" name="Normalization" scale="1.0" value="1.0"/>
        </spatialModel>
</source>
<source name="EG_v02" type="DiffuseSource">
        <spectrum type="FileFunction" file="isotropic_iem_v02.txt">
                <parameter free="1" max="10" min="1e-2" name="Normalization" scale="1" value="1"/>
        </spectrum>
        <spatialModel type="ConstantValue">
                <parameter free="0" max="10.0" min="0.0" name="Value" scale="1.0" value="1.0"/>
        </spatialModel>
</source>
<!-- Target Sources -->
<source name="_3c454" type="PointSource">
   <spectrum type="PowerLaw2">
      <parameter free="1" max="10000" min="0.0001" name="Integral" scale="1e-07" value="15.6325" />
      <parameter free="1" max="5" min="1" name="Index" scale="-1" value="2.507" />
      <parameter free="0" max="500000" min="30" name="LowerLimit" scale="1" value="100" />
      <parameter free="0" max="500000" min="30" name="UpperLimit" scale="1" value="300000" />
    </spectrum>
    <spatialModel type="SkyDirFunction">
      <parameter free="0" max="360" min="-360" name="RA" scale="1" value="343.490616" />
      <parameter free="0" max="90" min="-90" name="DEC" scale="1" value="16.148211" />
    </spatialModel>
  </source>
<!-- Target Sources -->
<source name="Field1" type="PointSource">
   <spectrum type="PowerLaw2">
      <parameter free="1" max="10000" min="0.0001" name="Integral" scale="1e-07" value="1.58" />
      <parameter free="1" max="5" min="1" name="Index" scale="-1" value="2.32" />
      <parameter free="0" max="500000" min="30" name="LowerLimit" scale="1" value="100" />
      <parameter free="0" max="500000" min="30" name="UpperLimit" scale="1" value="300000" />
    </spectrum>
……
</source>
</source_library>
```

Science Tools



Science Tools

General:

gtselect	Performs selection cuts on event data files.
gtbin	Bins GBM or LAT event lists in time, energy, and/or space to produce light-curves, spectra, count cubes or count maps, respectively.
gtbkg	Creates a background spectrum file (PHA1 format).
gtexpcube2	Generates an exposure map, or a set of exposure maps for different energies, from a livetime cube written by gtltcube.
gtexposure	Given a counts light curve prepared using gtbin for a specific location on the sky, this tool computes the exposure (cm2-s) associated with each time bin,allowing for a light curve in photons/s to be computed.
gtirfs	Give the list of possible irfs
gtltcube	Calculates integrated livetime as a function of sky position and off-axis angle.
gtltsum	Adds together livetime cubes produced by gtltcube.
gtmktime	Create Good Time Intervals (GTIs) based on selections made using the spacecraft data file variables.
gtpsf	Calculates the effective point spread function, as a function of energy at a given source location, averaged over an observation.
gtvcut	This tool displays a summary of the Data Sub-Space keywords.

Likelihood:

gtdiffrsp	Calculates the integral over solid angle of a diffuse source model convolved with the instrumental response function
gtexpmap	Calculates exposure maps for unbinned likelihood analysis.
gtfindsrc	Optimizes a point source location using the likelihood test-statistic.
gtlike	Performs unbinned or binned likelihood analysis of LAT data.
gtltcube	Calculates integrated livetime as a function of sky position and off-axis angle.
gtmodel	Creates a model counts map based on a binned likelihood fit.
gtsrcmaps	Convolves source model components with instrument response.
gtsrcprob	Computes source component probabilities for event data.
gttsmap	Calculates test-statistic map for source localization and detection.
modeleditor	Create model files for use as input to the Fermi likelihood estimation program.

Source Identification:

gtsrcid	Creates a counterpart candidate catalog by correlating the objects from a list of detected sources with the objects of an existing source catalog, such as the 3EG catalog.

Gamma-ray Burst Analysis:

gtbin	Bins GBM or LAT event lists in time, energy, and/or space to produce light-curves, spectra, count cubes or count maps, respectively.
gtbindef	Generate an energy or time bin definition (FITS) file to be used with gtbin.
gtrspgen	CCreates a "Detector Response Matrix" (DRM or RSP) FITS file from the multi-dimensional response functions.
gtburstfit	Analyzes burst light curves by applying a Bayesian algorithm to determine the optimum set of blocks to follow the burst profile shape, then optionally fitting a model to the data using the Bayesian Block definitions to determine the number of model components and initial values for the model parameters.

Pulsar Analysis:

gtpsearch	Searches for pulsations at frequencies near to a known, guessed or estimated reference frequency.
gtpspec	Searches for pulsations in wide frequency range using the Discrete Fast Fourier Transfer (FFT) technique.
gtptest	Applies statistical tests to a series of pulse phase values stored in given event file(s).
gtpphase	Computes a pulse phase for each event in input event file(s), and writes it to a FITS column in the file(s).
gtophase	Computes an orbital phase for each event in input event file(s), and writes it to a FITS column in the file(s).
gtephem	Computes and displays a pulsar's frequency ephemeris for a given pulsar and instant of time.
gtpulsardb	CCreates, filters, and/or combines pulsar ephemerides database files.
gtbary	Performs barycentric or geocentric corrections to photon arrival times.

Solar System Sources:

gtltcubesun	Calculates integrated livetime as a function of sky position, instrument angle and distance from a solar system body (sun or moon).
gtltsumsun	Adds together livetime cubes produced by gtltcubesun.
gtexphpsun	It calculates the exposure for different energies as a function of distance from the Sun or Moon using the livetime cube generated by gtltcubesun. The map is used by gtsuntemp to calculate the exposure weighted average intensity of the Sun or the Moon.
gtsuntemp	Generates the average intensity skymaps as a function of energy for the Sun or the Moon. The output fits file can be used in likelihood analysis in a similar fashion as the diffuse emission model.

Observation Simulation:

gtobssim	Generate photon events from astrophysical sources and process those photons according to the specified instrument response functions.
gtorbsim	Generate spacecraft orbit and attitude data for a variety of pointing or survey mode strategies.
modeleditor	Create model files for use as input to the Fermi likelihood estimation program.

Analysis flow

Binned analysis is favored for long periods (faster to run).

Unbinned analysis is more accurate (short periods)

Mixing the two is possible (combined likelihood).

TS=-2 (log L- log L_0)

Binned (sum over bins in space and energy)

1. Create model
2. Extract data (gtselect/gtmktime)
3. Bin data into counts cube (gtbin)
4. Compute observation profile (gtltcube)
5. Compute exposure cube (gtexpcube2)
6. Produce source maps (gtsrcmaps)
7. Do MLE and compute TS (gtlike)

Unbinned (sum over photons)

1. Create model
2. Extract data (gtselect/gtmktime)
3. *Compute diffuse response (gtdiffrsp)*
4. Compute observation profile (gtltcube)
5. Compute diffuse exp. Maps (gtexpmap)
6. Do MLE and compute TS (gtlike)

Details of the methods can be found in http://fermi.gsfc.nasa.gov/ssc/data/analysis/documentation/Cicerone

Example of event selection

```
prompt> gtselect evclass=128 evtype=3
Input FT1 file: @events.txt
Output FT1 file[: 3C279_region_filtered.fits
RA for new search center (degrees) (0:360) : 193.98
Dec for new search center (degrees) (-90:90) : -5.82
radius of new search region (degrees) (0:180) : 20
start time (MET in s) (0:) : 311731200
end time (MET in s) (0:)  :311990400
lower energy limit (MeV) (0:) :100
upper energy limit (MeV) (0:) [:500000
maximum zenith angle value (degrees) (0:180) : 90
Done
prompt>
```

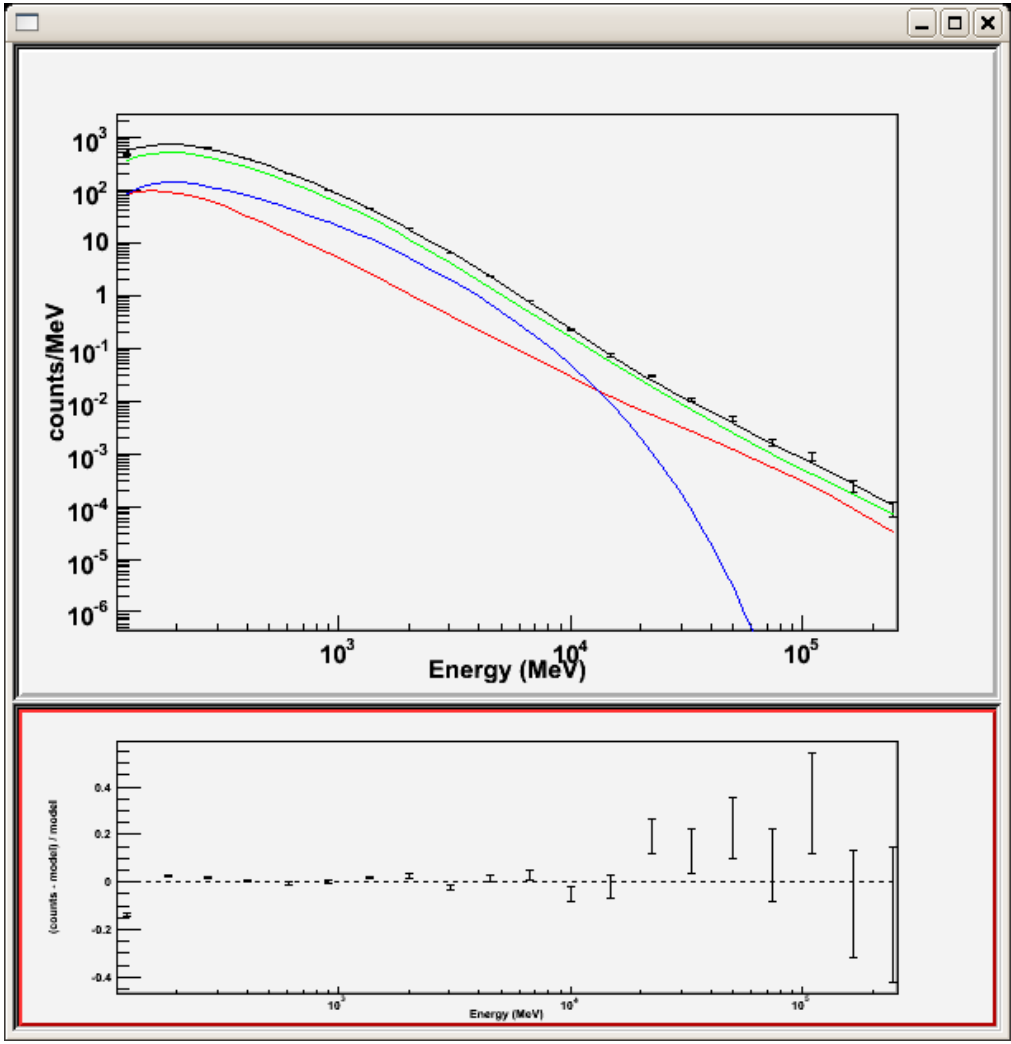
```
MIGRAD MINIMIZATION HAS CONVERGED.

MIGRAD WILL VERIFY CONVERGENCE AND ERROR MATRIX.

FCN=   325758.9      FROM MIGRAD     STATUS=CONVERGED     175 CALLS      176 TOTAL
                     EDM=    .26E-04     STRATEGY= 1      ERROR MATRIX ACCURATE

  EXT PARAMETER                                   STEP         FIRST
  NO.   NAME        VALUE            ERROR          SIZE      DERIVATIVE
   1  Normalizat   .61151          .31584E-01    .70564E-01     .33466
   2  Integral     1.5789          .13091        .84476E-02    -.40981
   3  Index        2.3207          .57567E-01    .32813        -.12866E-01
   4  Integral     .43409          .92339E-01    .10990E-01     .50641
   5  Index        2.2117          .11439        .50000        -.18973E-01
   6  Integral     1.5853          .18111        .84133E-02    -.66377E-01
   7  Index        3.1538          .11154        .50000        -.31552E-01
   8  Prefactor    1.2937          .29627E-01    .34174E-01     .22873
   9  Integral     15.650          .32651        .25325E-02    -4.1985
  10  Index        2.5079          .19465E-01    .10779         .34593
                               ERR DEF=   .500
 **********
 **    6 **HESSE
 **********

FCN=   325758.9      FROM HESSE      STATUS=OK            102 CALLS      278 TOTAL
                     EDM=    .36E-04     STRATEGY= 1      ERROR MATRIX ACCURATE

  EXT PARAMETER                                       INTERNAL      INTERNAL
  NO.   NAME        VALUE            ERROR          STEP SIZE       VALUE
   1  Normalizat   .61151          .45414E-01    .31227E-03    -1.0750
   2  Integral     1.5789          .15452        .48950E-04    -1.5457
   3  Index        2.3207          .68392E-01    .14478E-02    -.34657
   4  Integral     .43409          .11134        .60392E-03    -1.5576
   5  Index        2.2117          .13803        .27075E-01    -.40513
   6  Integral     1.5853          .20780        .74058E-04    -1.5456
   7  Index        3.1538          .14838        .29372E-01     .76991E-01
   8  Prefactor    1.2937          .42609E-01    .21076E-03    -.83494
   9  Integral     15.650          .34443        .38621E-04    -1.4917
  10  Index        2.5079          .20544E-01    .47616E-03    -.24859
                               ERR DEF=   .500
Final values:
  Normalizat = 0.611512
  Integral   = 1.5789
  Index      = 2.32065
  Integral   = 0.434088
  Index      = 2.21172
  Integral   = 1.58531
  Index      = 3.15383
  Prefactor  = 1.29372
  Integral   = 15.65
  Index      = 2.50793
Minuit fit quality: 3   estimated distance: 3.5555e-05
Minuit parameter uncertainties:
  1  0.0454168
  2  0.15452
  3  0.068407
  4  0.111335
  5  0.138158
  6  0.207796
  7  0.148518
  8  0.0426102
  9  0.344429
  10  0.020544
Computing TS values for each source (6 total)
......!
```

```
Field3:
Integral: 1.58531 +/- 0.207796
Index: 3.15383 +/- 0.148518
LowerLimit: 100
UpperLimit: 300000
Npred: 313.794
ROI distance: 10.5547
TS value: 136.841

GAL_v02:
Prefactor: 1.29372 +/- 0.0426102
Index: 0
Scale: 100
Npred: 16057

_3c454:
Integral: 15.65 +/- 0.344429
Index: 2.50793 +/- 0.020544
LowerLimit: 100
UpperLimit: 300000
Npred: 4527.45
ROI distance: 0
TS value: 10657.7
WARNING: Fit may be bad in range [100, 222.696] (MeV)

Total number of observed counts: 28719
Total number of model events: 28719

-log(Likelihood): 325758.9218

Elapsed CPU time: 85.62
/COSPAR < 121 >
```

Checking the fit quality (1)

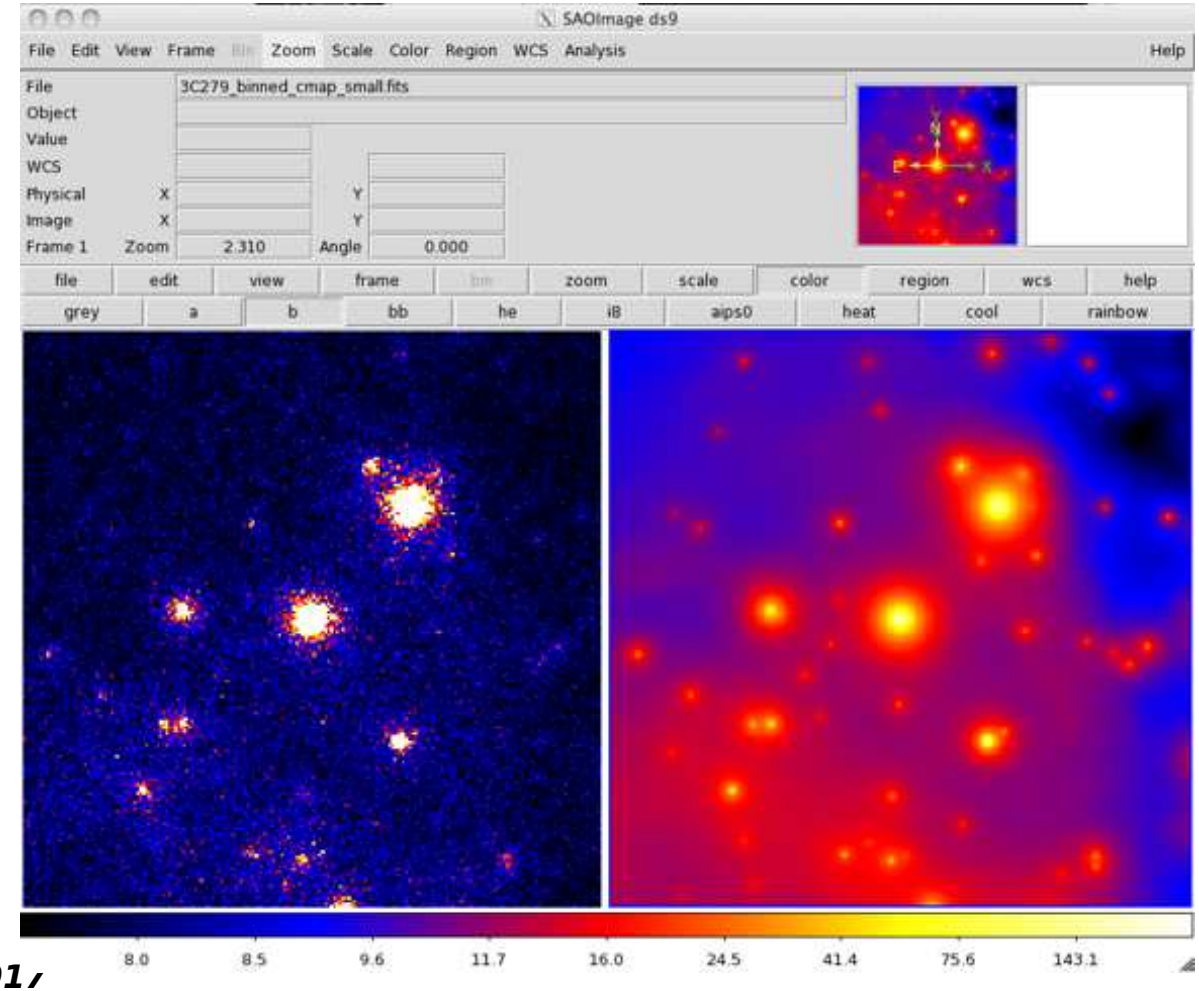
> *gtlike plot=yes*

Counts vs model predictions and residues for the whole ROI



Checking the fit quality (2)

gtmodel creates a model map to be compared to the data, yielding spatial residues .



Prospects

All ressources are available at the Fermi Science Support Center (FSSC).

Fermi will be operating till 2019, and possibly beyond. The GBM will continue detecting short GRBs, having potential GW counterparts.

Summer schools devoted to the Fermi data analysis are organized on a regular basis by NASA (ex. Lewes, Delaware).

Fermi Gamma-ray Space Telescope

Merci!