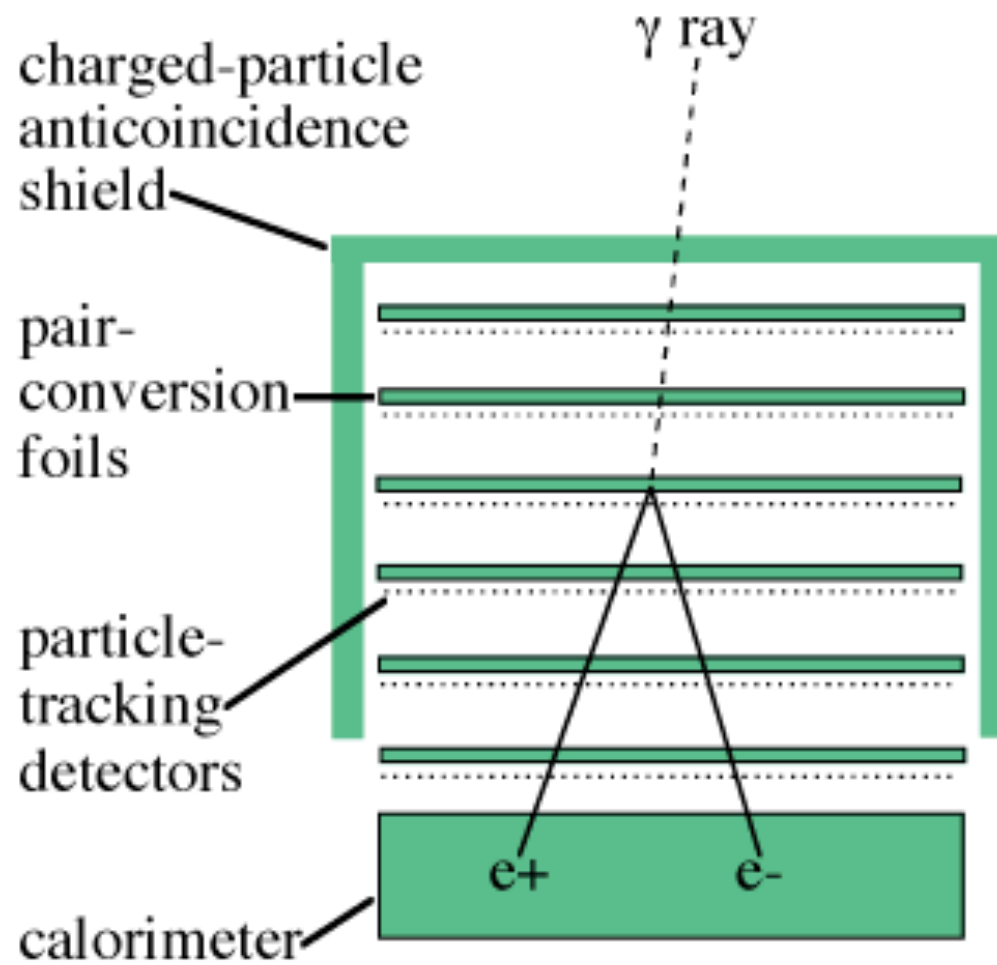


Astrofisica Nucleare e Subnucleare
GeV Astrophysics IV

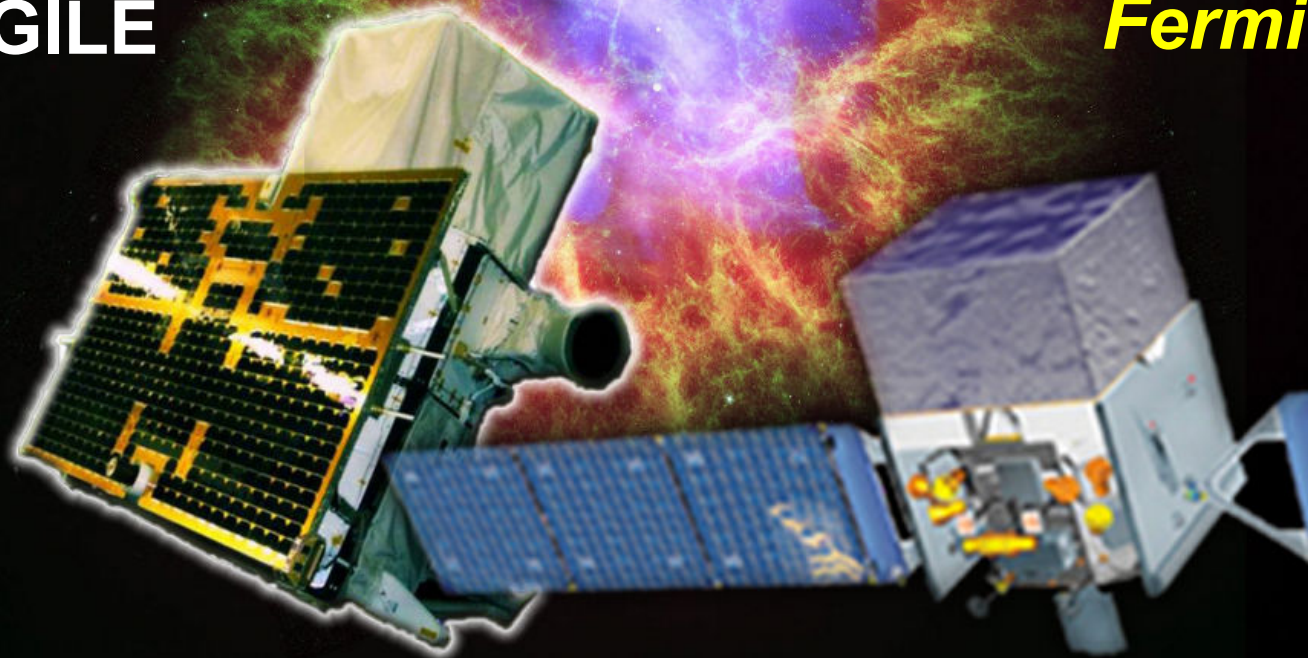
Detector Project



Gamma-ray astrophysics above 100 MeV

AGILE

Fermi



Picture of the day, Feb. 28, 2011, NASA-HEASARC®

CALET?

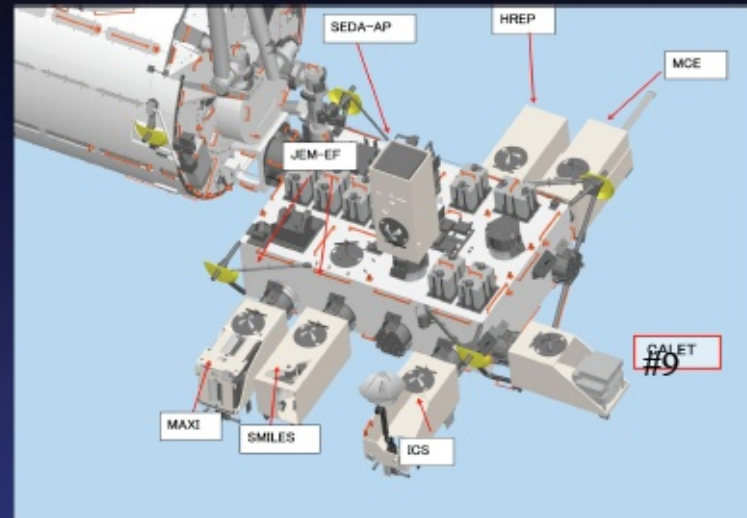
CALorimetric Electron Telescope (CALET)

P. S. Marrocchesi for the CALET Collaboration – RICAP11 – 2011 May 26

- **Instrument:**
High Energy Electron and Gamma-Ray Telescope
- **Carrier:**
HTV: H-IIA Transfer Vehicle
- **Attach Point on the JEM-EF: #9**
for heavy (< 2000 kg) payloads
- **Nominal Orbit:**
407 km, 51.6° inclination
- **Launch plan:**
FY 2013
- **Life Time:**
≥ 5 years



Firenze
Pisa
Siena
Roma Tor Vergata



1 GeV ~ 20 TeV for electrons

20 MeV ~ TeV for gamma-rays

Weight: 500 kg

GF (fiducial volume): ~ 0.12 m²sr

Power Consumption: 640 W

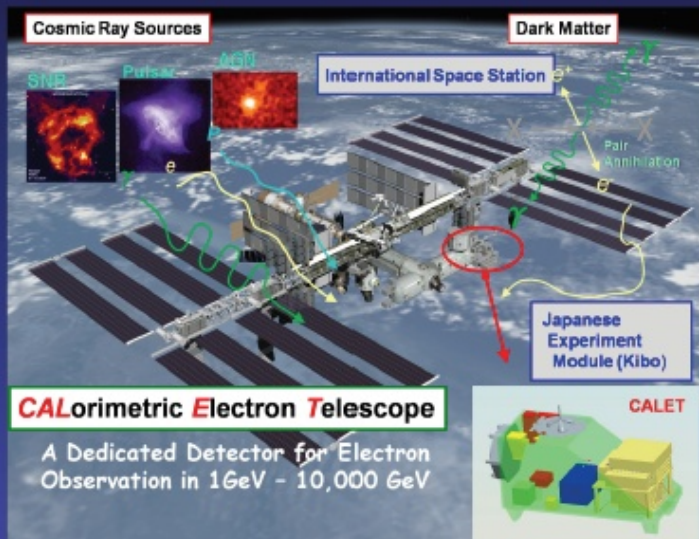
Data Rate: 300 kbps

CALET?

CALET Overview

Observation

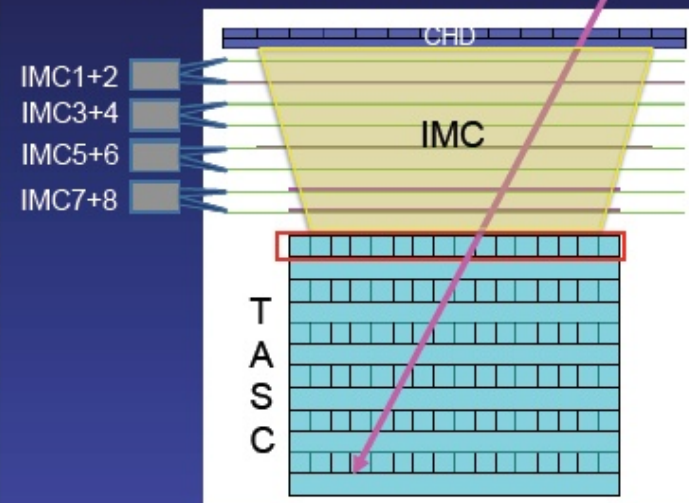
- **Electrons** : 1 GeV - 10 TeV
- **Gamma-rays** : 10 GeV-10 TeV (GRB > 1 GeV)
+ Gamma-ray Bursts : 7 keV-20 MeV
- **Protons, Heavy Nuclei**:
several 10 GeV- 1000 TeV (per particle)
- **Solar Particles and Modulated Particles**
in Solar System: 1 GeV-10 GeV (Electrons)



Instrument

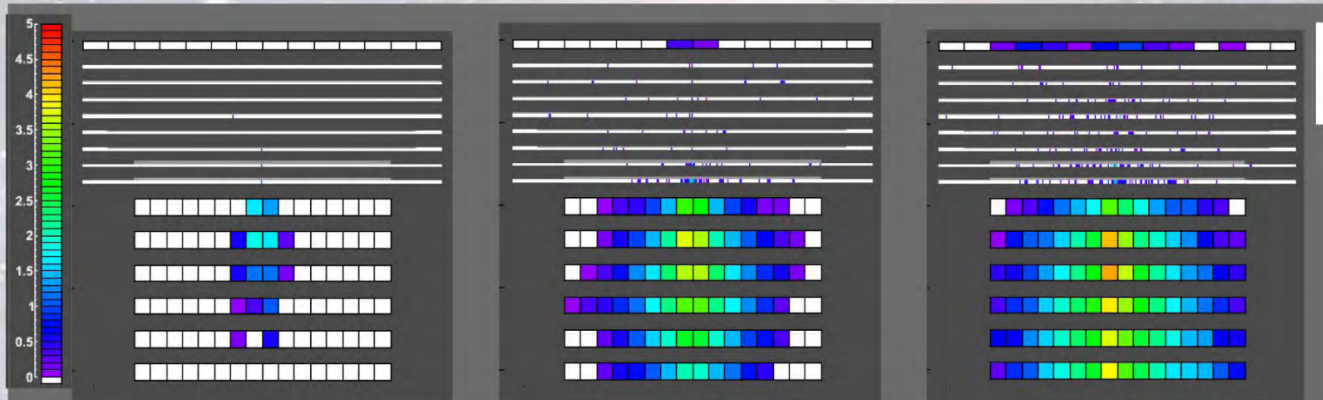
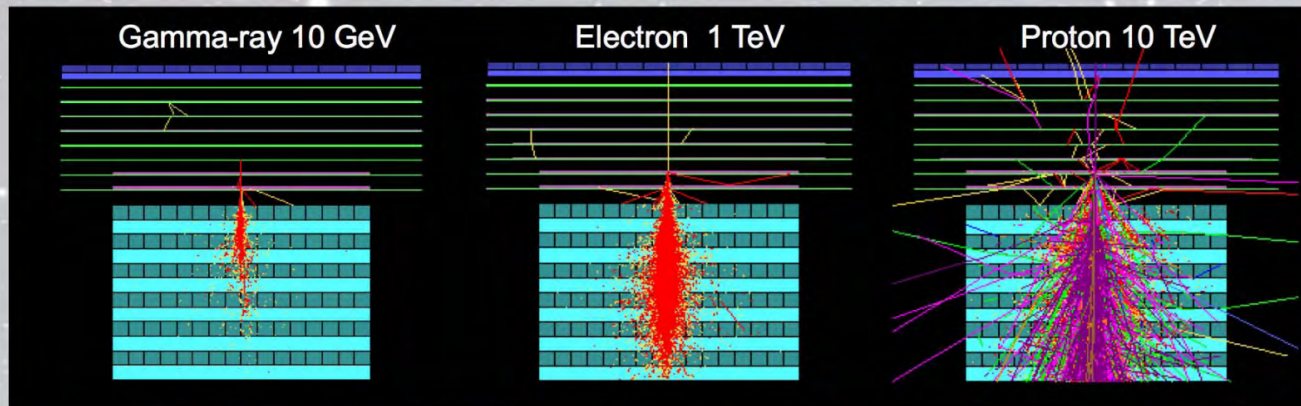
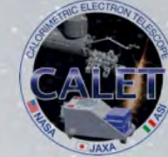
High Energy Electron and Gamma-Ray Telescope:

- **CHARGE DETECTOR (CHD)**
(Charge Measurement in $Z=1-40$)
- **IMAGING CALORIMETER (IMC)**
(Particle ID, Direction)
Total Thickness of Tungsten (W): $3 X_0$ $0.11 \lambda_T$
Layer Number of Scifi Belts: 8 Layers $\times 2(X,Y)$
- **TOTAL ABSORPTION CALORIMETER (TASC)**
(Energy Measurement, Particle ID)
PWO $20\text{mm} \times 20\text{mm} \times 320\text{mm}$
Total Depth of PWO: $27 X_0$ (24cm) , $1.35 \lambda_T$



CALET

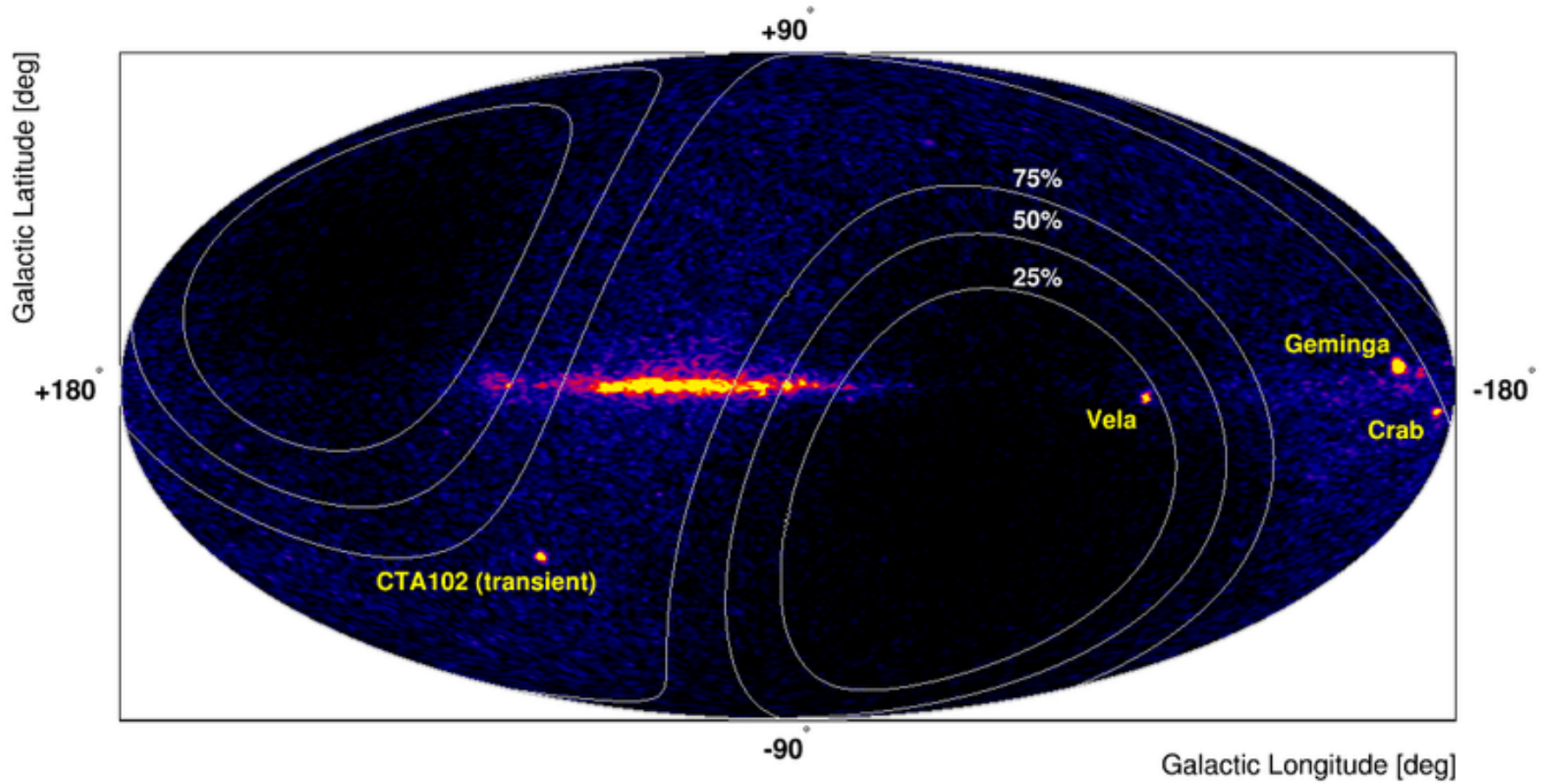
CALET/CAL Shower Imaging Capability (Simulation)



In Detector Space

- Proton rejection power $> 10^5$ can be achieved with the IMC and TASC shower imaging capability.
- Charge of incident particle is determined to $\Delta Z = 0.15 - 0.3$ with the CHD.

CALET gamma-sky



Gamma-400?

AC - anticoincidence detectors

C - multilayer converter

C1- C6 6 x 0,14Xo W

CD1 - CD6 6 x Si (x,y) strip
detectors (pitch 0.1 mm)

CD7 - CD8 Si (x,y) strip
detectors (pitch 0.1 mm)

S1, S2 - TOF detectors

TRD - transition radiation detectors

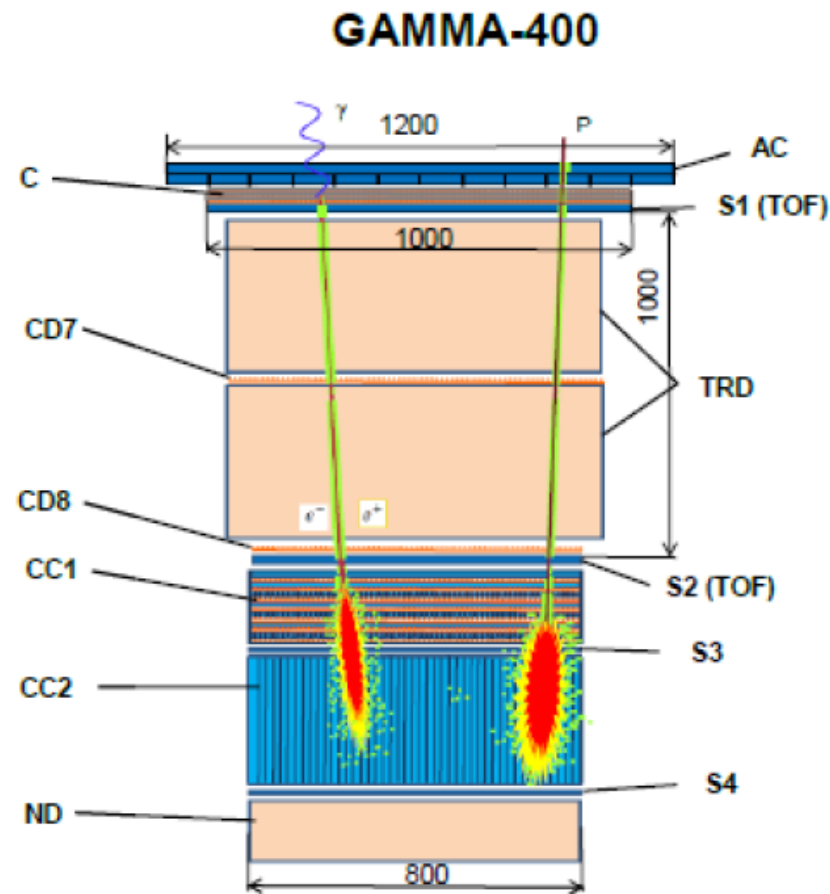
CC1 - imaging calorimeter (9Xo)

10 layers BGO + Si (x, y) strip
detectors (pitch 0.5 mm)

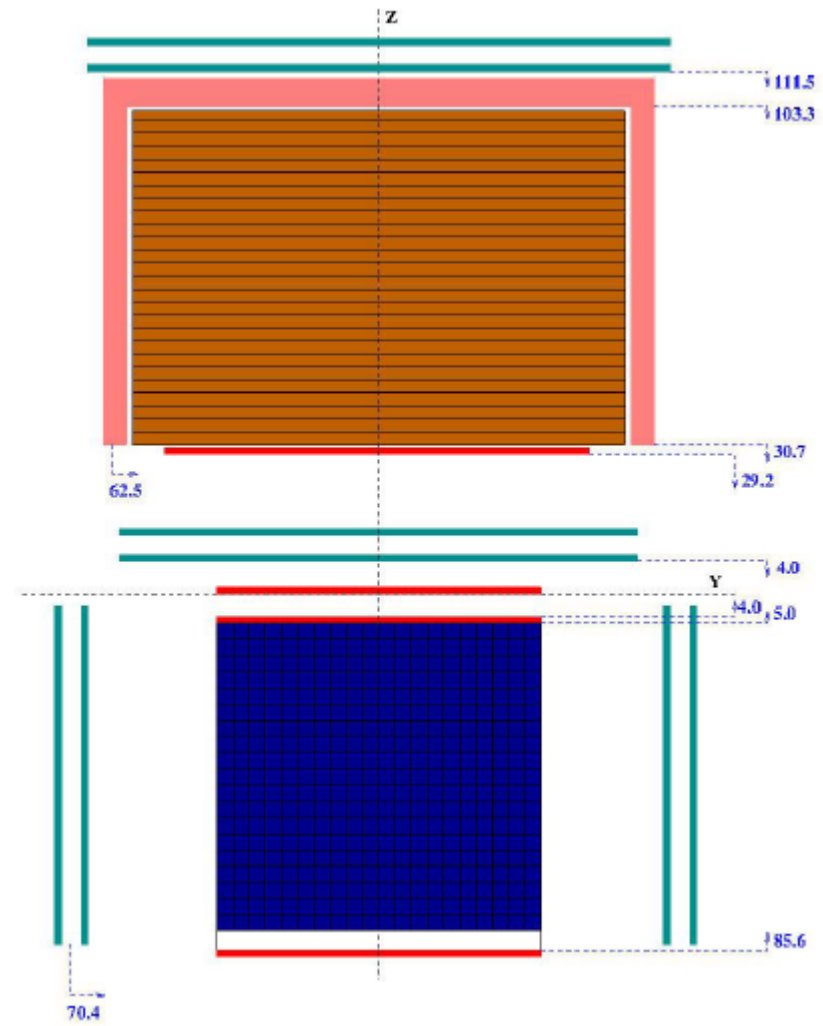
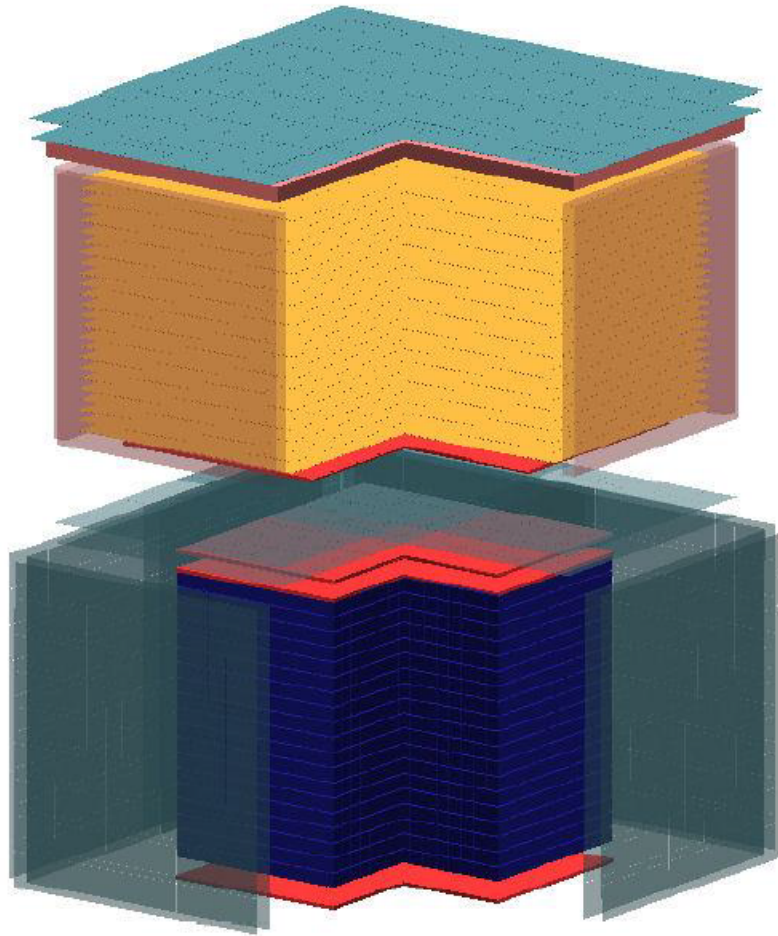
CC2 - BGO imaging calorimeter
(21.5Xo)

S3, S4 - scintillator detectors

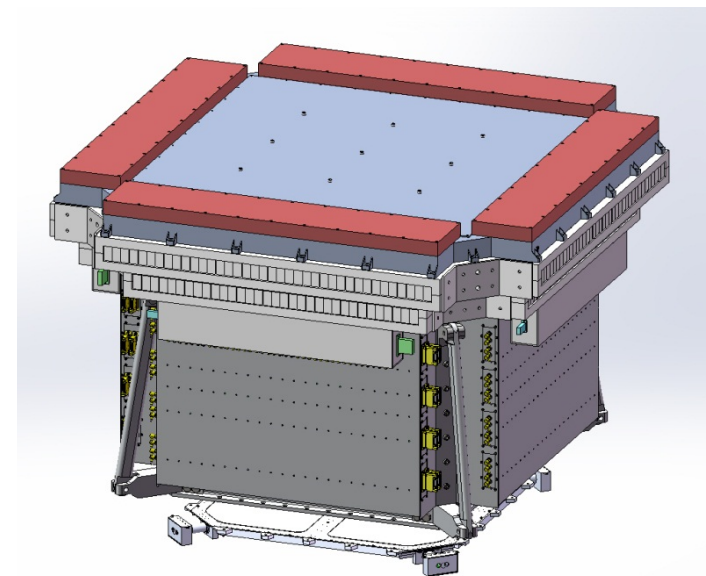
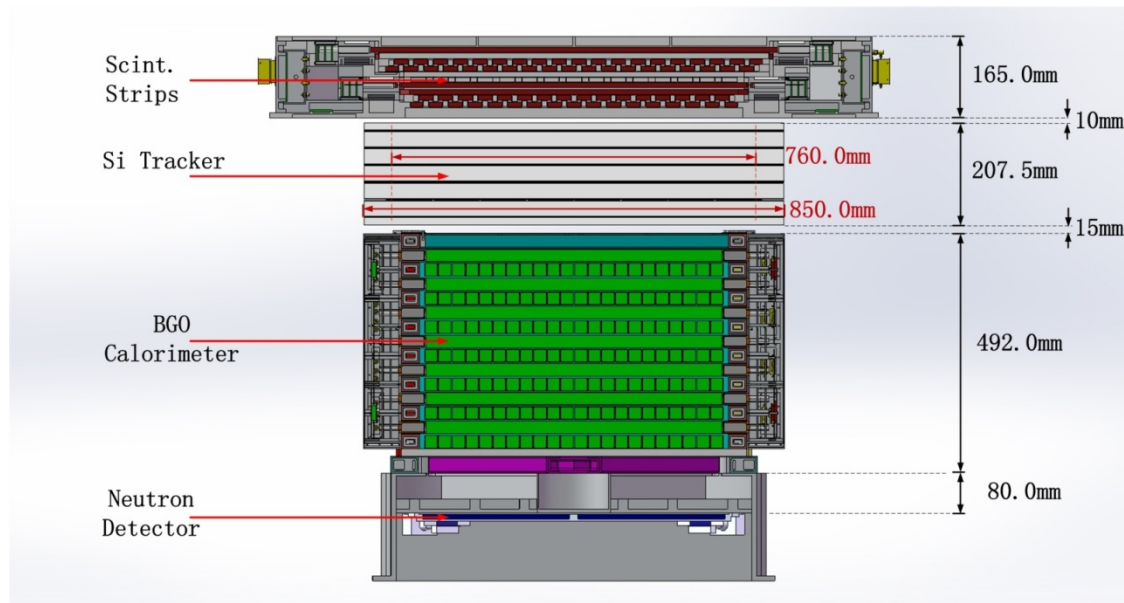
ND - neutron detectors



Gamma400



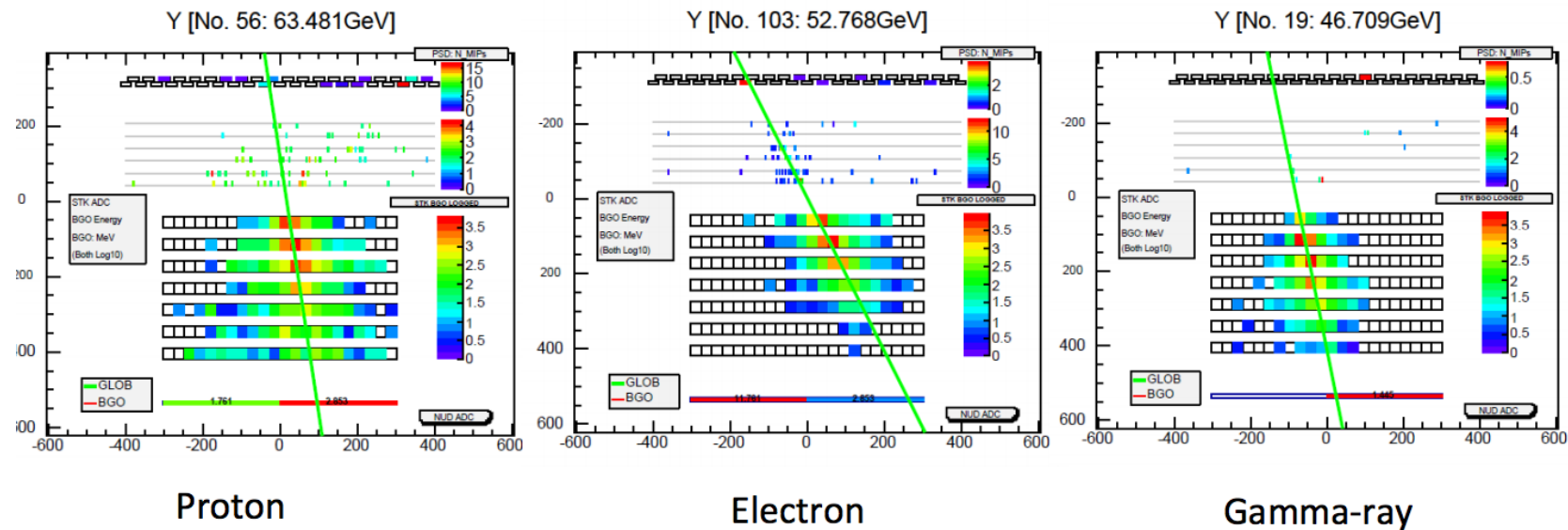
DAMPE



The detector is consisted of 4 parts:
Top scintillators (charge measurement)
Si tracker (5 layers)
BGO calorimeter
Neutron detector

DAMPE Gamma results

DAMPE γ -ray Selection: Different Events



- $e(\gamma)/p$ separation: BGO shower pattern
- e/γ separation: PSD and STK charge measurement

DAMPE Gamma results

DAMPE γ -ray Sky Map (Counts)

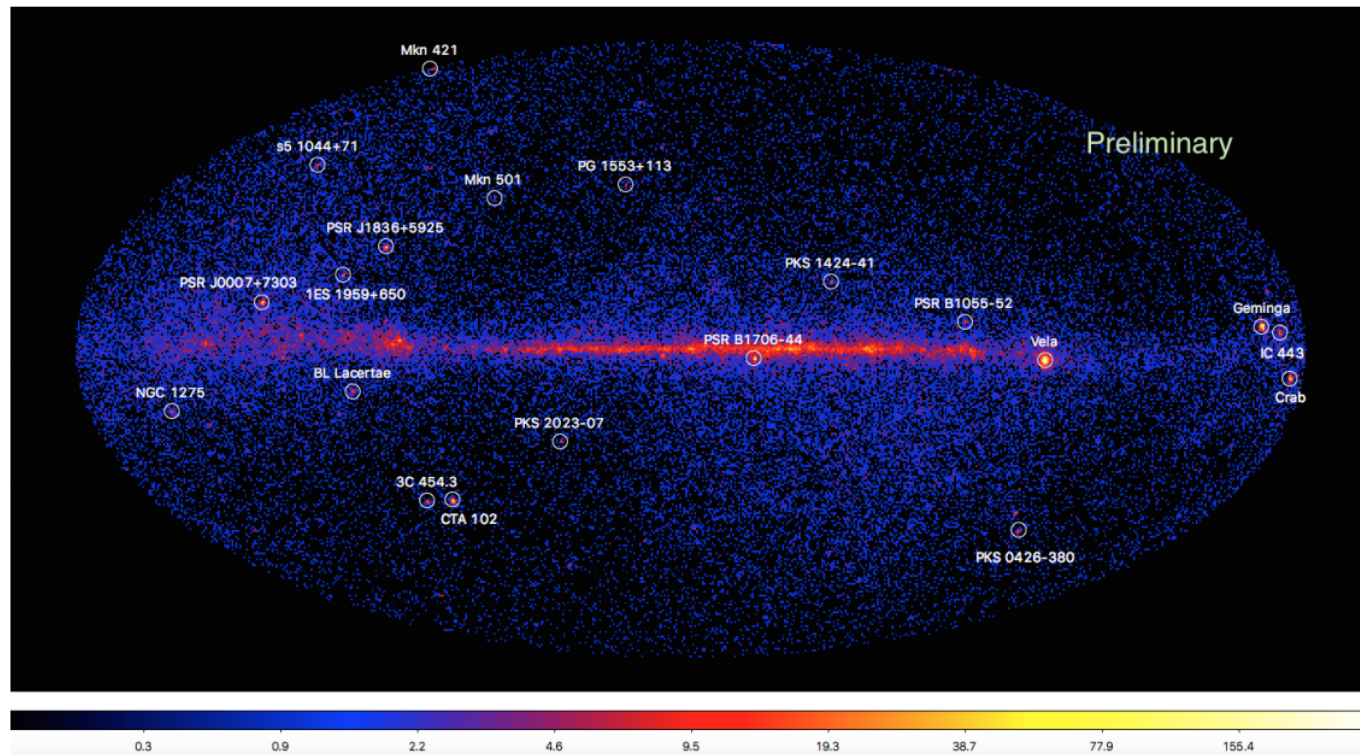
➤ 510 days

➤ $E > 2$ GeV

➤ 90,000
events

➤ $0.5^\circ \times 0.5^\circ$
pexel

➤ Mollweide
projection



HERD



Baseline Design: $\sim 2 T$, $\sim 2 KW$

Charge detector: Si+PIN.

Top: $2 \times (70 \times 70 \times (1 \text{ cm} \times 1 \text{ cm} \times 500 \mu\text{m}))$;

Sides: $4 \times (2 \times (70 \times 40 \times (1 \text{ cm} \times 1 \text{ cm} \times 500 \mu\text{m})))$

Shower Tracker:

W: $4X_0$; $10 \times 3.5 \text{ mm} +$

$2 \times 17.5 \text{ mm} + 2 \times 35 \text{ mm}$

Scin. Fibers:

$14 \times (2 \times (700 \times (1 \times 1 \times 700 \text{ mm}^3)))$

Nucleon Tracker: scin. fibers

$400 \times (1 \times 1 \times 700 \text{ mm}^3) +$

$700 \times (1 \times 1 \times 400 \text{ mm}^3)$

ECAL: $16X_0 = 0.7X_{NIL}$

$3 \times (2 \times (25 \times 25 \times 700 \text{ mm}^3))$

W+ CsI(Na) + Fiber + ICCD

HCAL

HCAL: W: $20 \times 3.5 \text{ mm} (0.8X_{NIL})$

CsI: $20 \times (2.5 \text{ cm} \times 2.5 \text{ cm} \times 0.2 \text{ cm})$

Neutron detector: B-doped plastic scintillator for delayed signals. Enhanced e/p discrimination. (TBD)

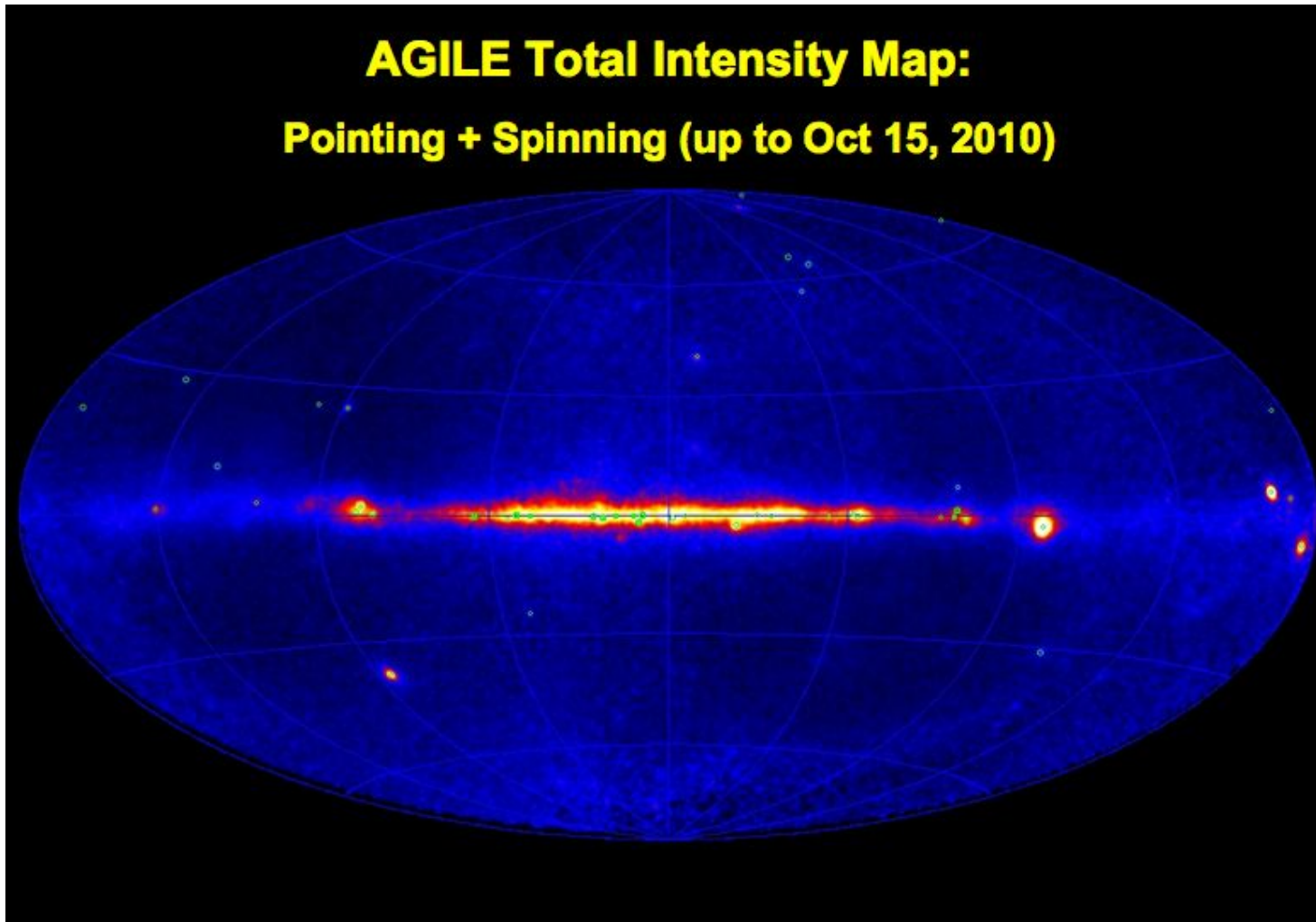


中国科学院空间科学与应用总体部

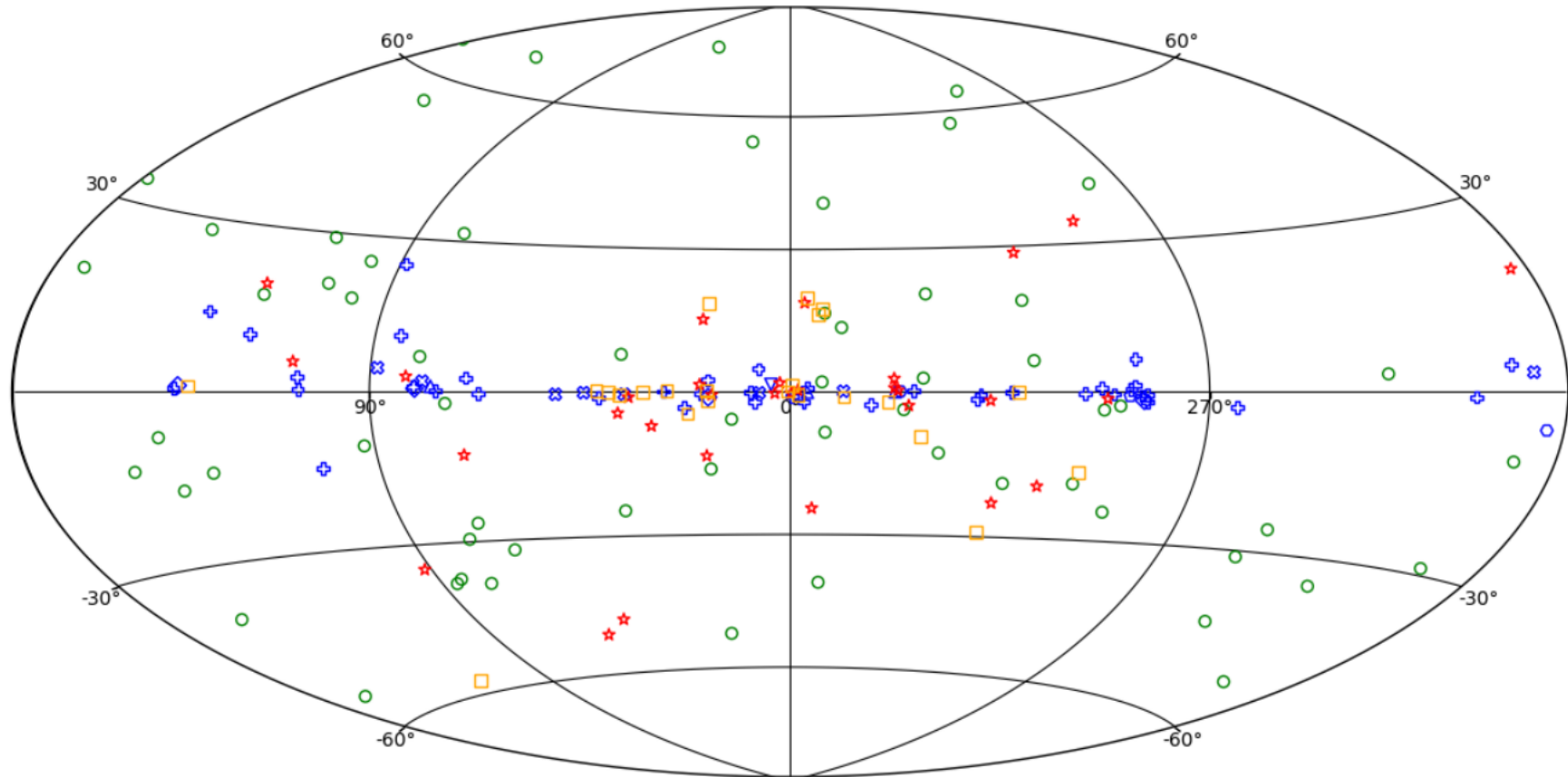
GENERAL ESTABLISHMENT OF SPACE SCIENCE AND APPLICATION
CHINESE ACADEMY OF SCIENCES

AGILE

The AGILE sky

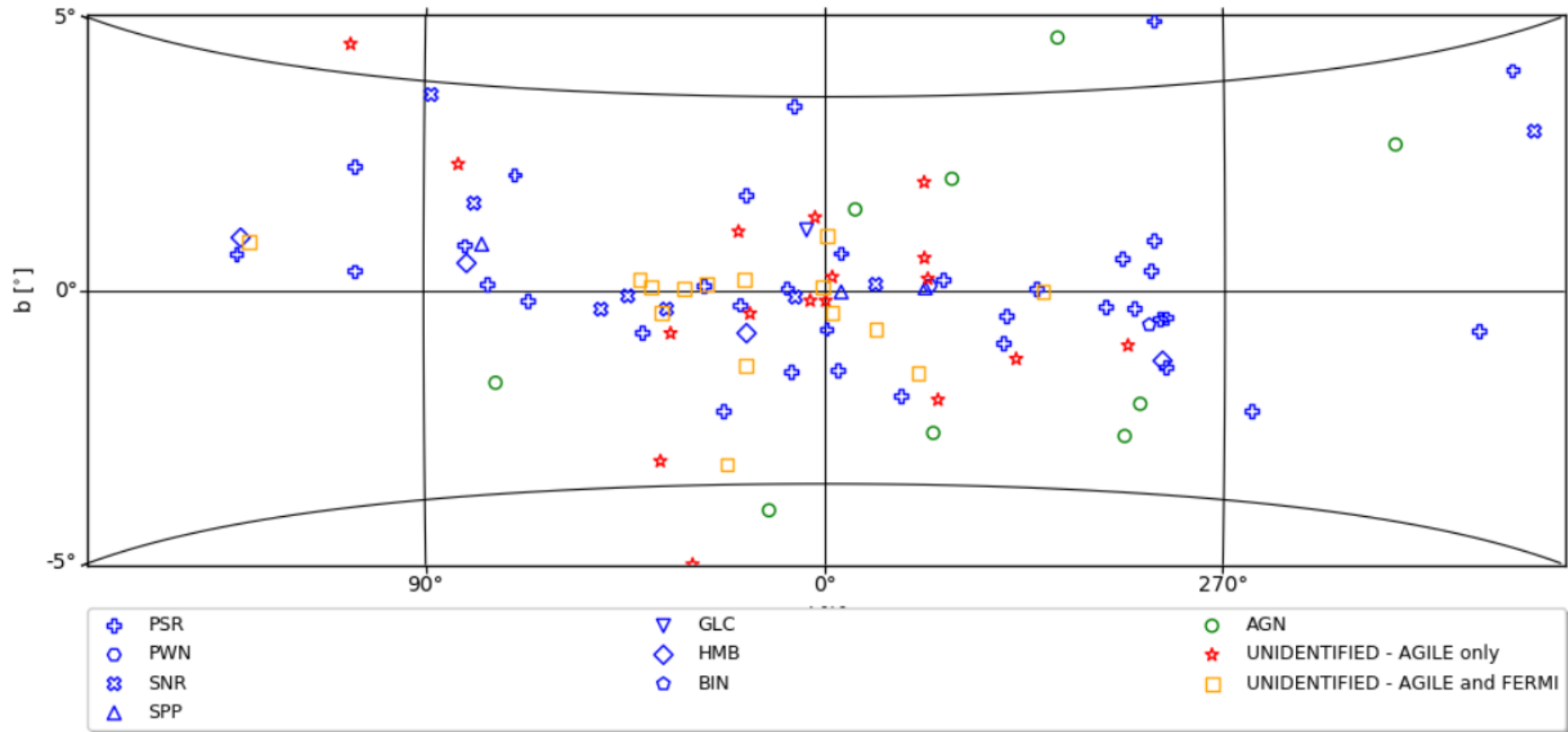


AGILE sources



Bulgarelli et al. 2019

AGILE sources



Bulgarelli et al. 2019

Where to find data?



The screenshot shows the top section of the SSDC website. At the top left is the SSDC logo with the tagline "Space Science Data Center". In the center, the text "Space Science Data Center" is displayed in a large, orange, sans-serif font. To the right is the ASI logo (Agenzia Spaziale Italiana). Below the header is a navigation menu with links: Home, About SSDC, News and Communication, Quick Look, Missions, Multimission Archive, Catalogs, Tools, Links, Bibliographic services, Helpdesk, and Privacy. Below the navigation menu is a banner for the AGILE Science Data Center, featuring an image of the AGILE satellite and the text "AGILE Science Data Center". At the bottom of the banner is another navigation menu with links: AGILE Home, About AGILE, ASI HQ AGILE, AGILE News, AGILE Data Archive, Public Software, AGILE Pointings, AGILE Catalogs, Restricted Area, Guest Observer Program, User Feedback Form, AGILE Workshops, and Agile Helpdesk.

Welcome to the AGILE Data Center Home Page at SSDC

These pages provide updated information and services in support to the general scientific community for the mission AGILE, which is a small Scientific Mission of the Italian Space Agency (ASI) with participation of INFN, IASF/INAF and CIFS .

AGILE is devoted to gamma-ray astrophysics and it is a first and unique combination of a gamma-ray (AGILE-GRID) and a hard X-ray (SuperAGILE) instrument, for the simultaneous detection and imaging of photons in the 30 MeV - 50 GeV and in the 18 - 60 keV energy ranges. After more than 13 years of operations, AGILE is working nominally, providing valuable data and important scientific results.

AGILE operations:

Launch date 23 April, 2007

Planned Nominal Phase: 2 + 2 extended years

Elapsed: 13 years in orbit completed on 23 April, 2020

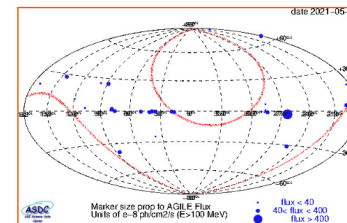
Current Extended Phase: ASI extended AGILE operations up to 31 May, 2022

The AGILE Mission Board (AMB) has executive power overseeing all the scientific matters of the AGILE Mission and is composed of:

- AGILE Principal Investigator: Marco Tavani, INAF Rome (Chair)
- ASI Project Scientist: Paolo Giommi, ASI
- ASI Mission Director: Fabio D'Amico, ASI
(Former ASI Mission Directors: Luca Salotti, up to September 20, 2010 and Giovanni Valentini up to January 22, 2015)
- AGILE Co-Principal Investigator: Guido Barbiellini, INFN Trieste
- 1 ASI representative: Elisabetta Tommasi di Vignano
(Former ASI representative: Sergio Colafrancesco up to June, 2010)
- INAF Project Scientist: Carlotta Pittori (from November 10, 2020)

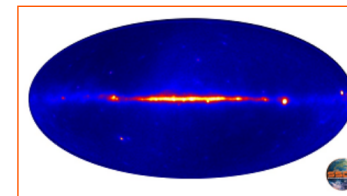
AGILE current spinning sky view

(Click here for previous pointing details)



[Click here to access the AGILE Spinning FOV plotter](#)

[Click here to access the AGILE Real Data FOV Plotter](#)



AGILE total intensity map up to Sep. 30, 2017.

<https://agile.ssdsc.asi.it/>

Conclusions

- AGILE crucial contributions to testing particle acceleration theories, plasma instabilities in the Universe and on the Earth !
 - Big surprise: discovery of gamma-ray flares from the Crab Nebula: 2012 Bruno Rossi Prize
 - Origin of cosmic rays, SNR W44, first direct evidence of neutral pion emission
 - Relativistic jets in microquasars and blazars
 - Gamma-ray emission up to 100 MeV from Terrestrial Gamma-Ray Flashes

AGILE

Data Analysis Tutorial

AGILE data analysis



Tutorial for the AGILE-LV3 online analysis

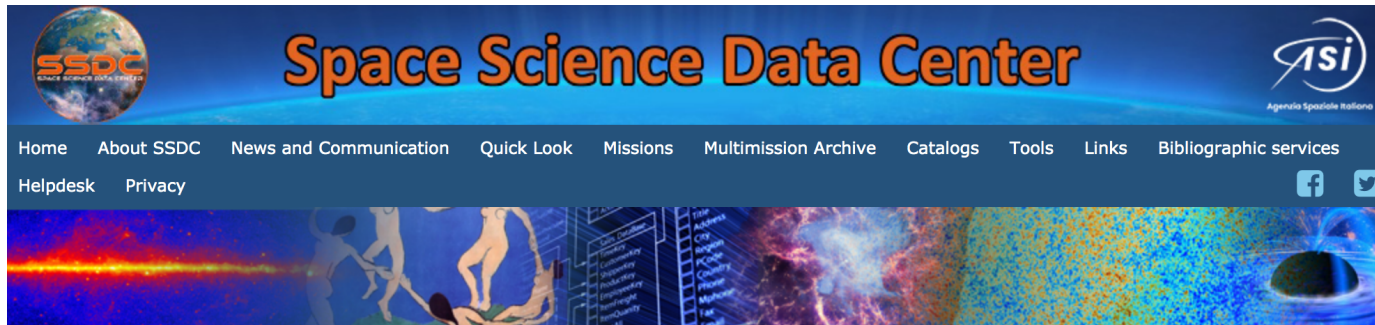
June 2018

1. Introduction

The gamma-ray satellite AGILE, launched in April 2007, is dedicated to the observation of astrophysical sources of photons with energy $E > 100$ MeV. The main detector of the satellite is the Gamma Ray Imaging Detector (GRID), sensitive to photon energies between 30 MeV and 50 GeV. The GRID is composed by the tungsten-silicon tracker for converting photons to e^+/e^- pairs, by a iodine-cesium crystals mini-calorimeter (MCAL) and by an anti-coincidence shield for suppressing the cosmic ray background. The scientific payload of the satellite is completed by coded mask X-ray detector, SuperAGILE, and the mini-calorimeter, which can operate independently of the GRID and reveal transient events of photons and charged particles in the rank of energy 300 KeV - 100 MeV. The AGILE mission operations, nominally scheduled for two years, have currently been extended beyond the 11th year.

After the first two years of observations in the so-called "Ponting Mode", in November 2009, due to a broken stabilization wheel, the satellite has been placed in "Spinning" observation mode. At present, the satellite rotates around the boresight axis (perpendicular to the solar panels), making one complete rotation in about 6 min.

AGILE data analysis



Multi-Mission Interactive Archive

Mission Selected
AGILE-LV3

AGILE-LV3 Tutorials:

- [Tutorial LV3.pdf](#)
- [video 1](#), [video 2](#)

[AGILE Software Manual](#)

[WARNINGS and PLANNED UPDATES](#)

AGILE-LV3 Processing Archive

- New** LV3 processing archive and analysis (B-SCI 25, IRFs: H0025)
- Old LV3 processing archive and analysis (B-SCI 21, IRFs: I0023)

Enter source name or coordinates: RA, DEC L, B Lon, Lat
(e.g. CYGX-1 or 19 58 21.7, +35 12 05.8 or 299.590333, 35.201611 or 71.334960, 3.066917)

Name Resolver: SSDC Name Server SIMBAD NED

Start Date: (dd-mm-yyyy) End Date: (dd-mm-yyyy)

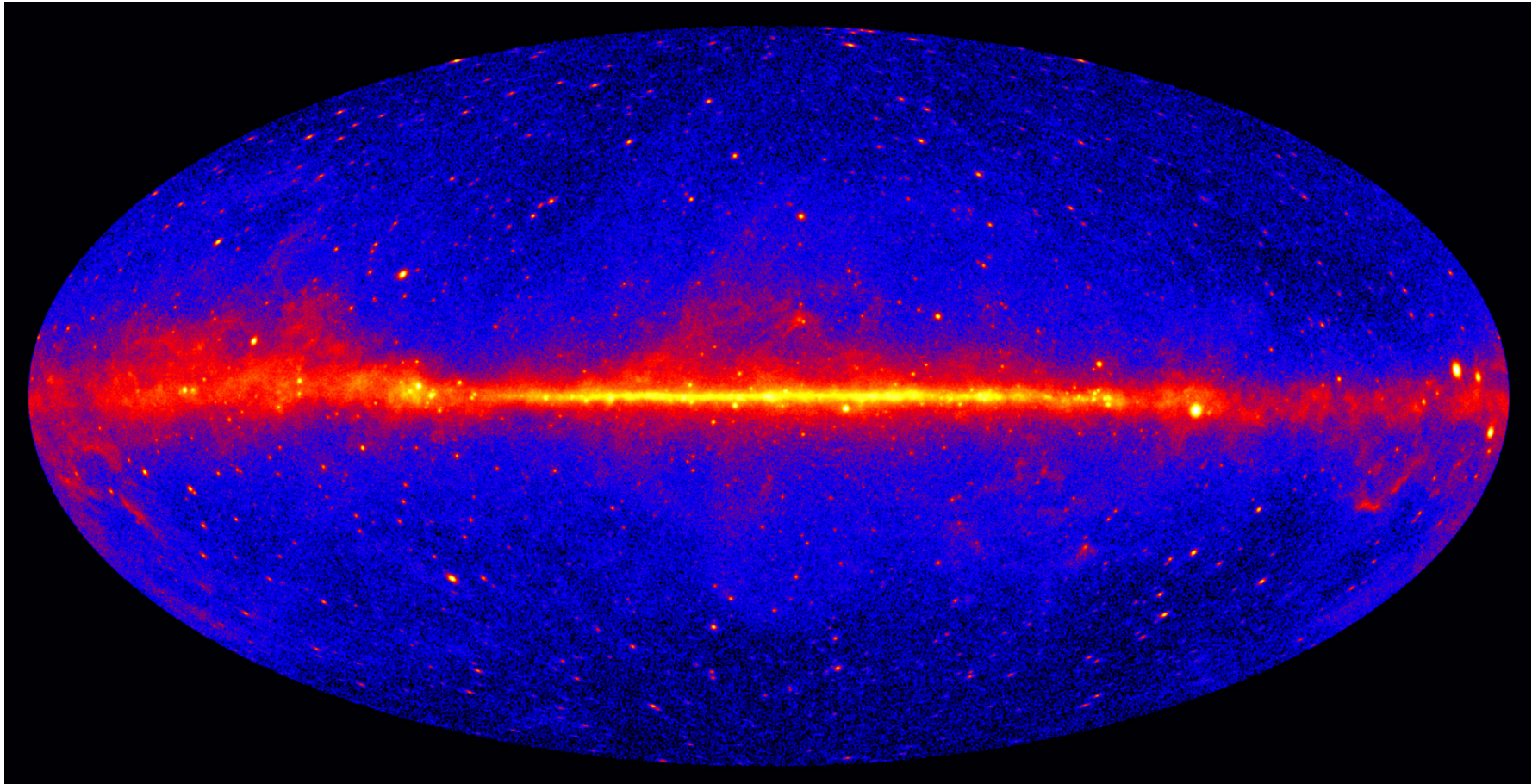
Duration: Day(s) Min EXP: (cm² s sr)

Max lines retrieved: Equinox: 2000 1950

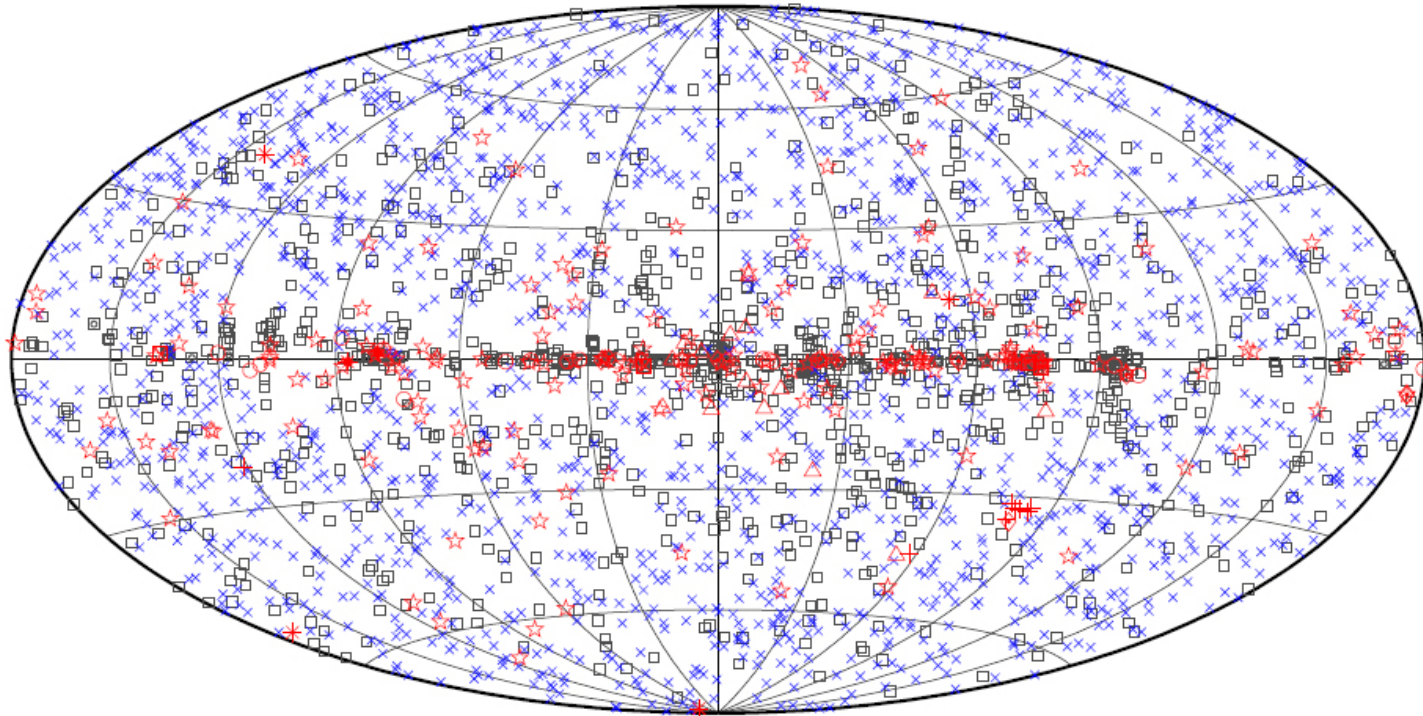
Submit

Fermi LAT

The GeV sky

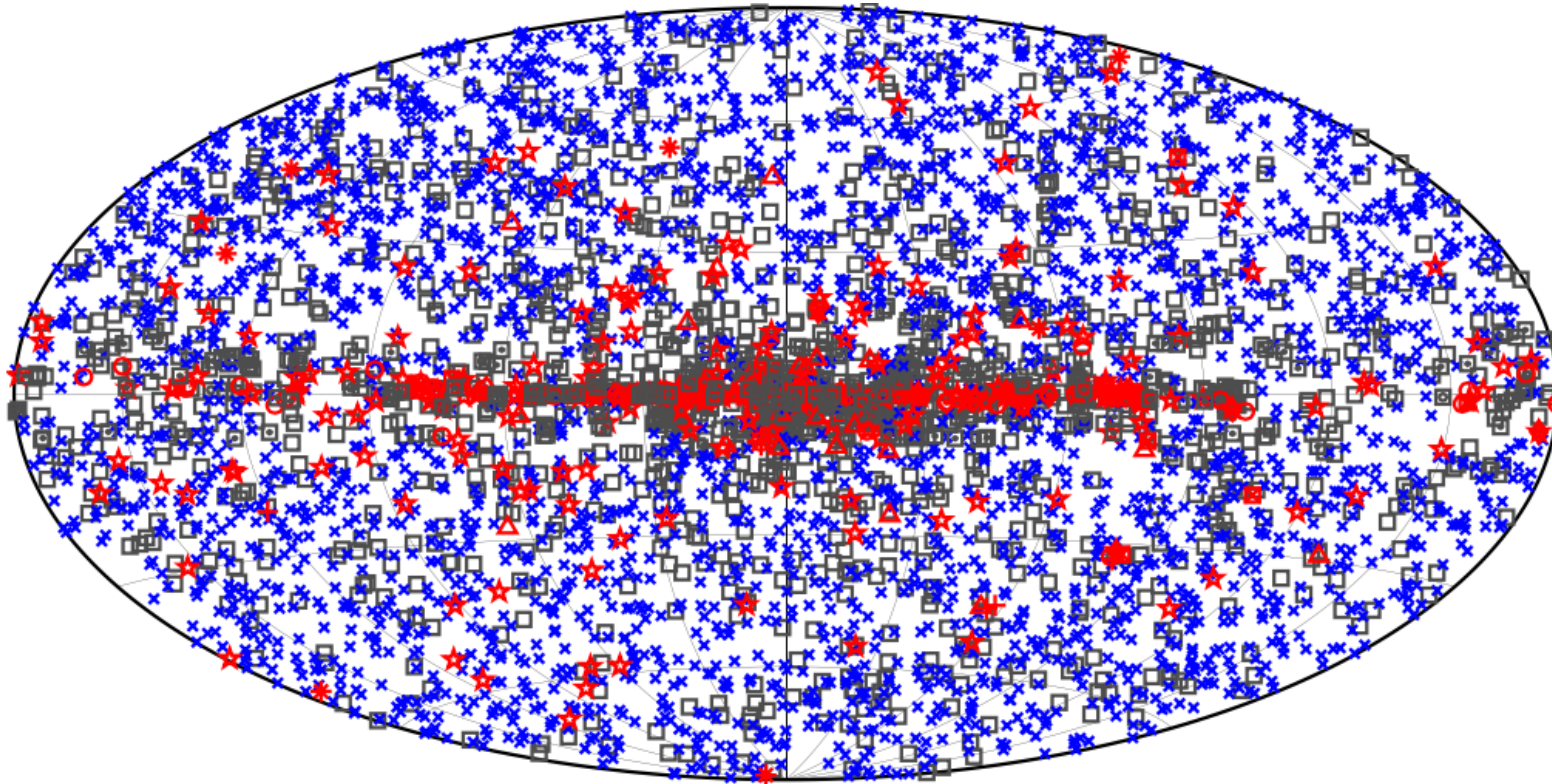


3FGL catalog – 3033 sources



□ No association	▣ Possible association with SNR or PWN	× AGN
☆ Pulsar	△ Globular cluster	✱ Starburst Galaxy
⊠ Binary	+ Galaxy	◇ PWN
★ Star-forming region	○ SNR	★ Nova

4FGL catalog

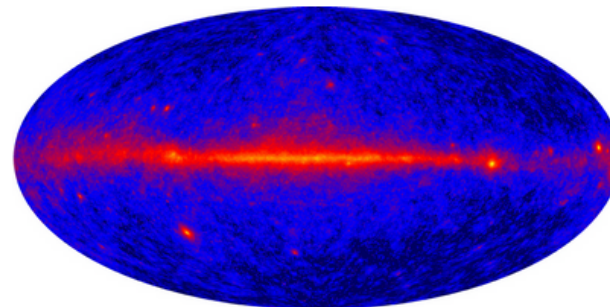


□ No association	■ Possible association with SNR or PWN	× AGN
★ Pulsar	▲ Globular cluster	* Starburst Galaxy
■ Binary	+ Galaxy	◇ PWN
★ Star-forming region	□ Unclassified source	⊙ SNR
		⊛ Nova

Where to find data?

The screenshot shows the top section of the Fermi Science Support Center website. On the left is the NASA logo and the text "GODDARD SPACE FLIGHT CENTER". In the center, there are three links: "+ NASA Homepage", "+ GSFC Homepage", and "+ Fermi Homepage". On the right is a search bar with the text "SEARCH Fermi:" above it, a "Search" input field, and a "+ GO" button. Below this is a banner image featuring the Fermi satellite and a colorful galaxy. At the bottom of the banner is a navigation menu with the following items: HOME, OBSERVATIONS, DATA, PROPOSALS, LIBRARY, HEASARC, HELP, and SITE MAP.

The Fermi Science Support Center (FSSC) runs the guest investigator program, creates and maintains the mission time line, provides analysis tools for the scientific community, and archives and serves the Fermi data. This web site is the portal to Fermi for all guest investigators.



This all-sky view from Fermi reveals bright emission in the plane of the Milky Way (center), bright pulsars and super-massive black holes.

Credit: NASA/DOE/International LAT Team

Look into the "Resources" section for finding schedules, publications, useful links etc. The "Proposals" section is where you will be able to find the relevant information and tools to prepare and submit proposals for guest investigator projects. At "Data" you will be able to access the Fermi databases and find the software to analyse them. Address all questions and requests to the helpdesk in "Help".

Quicklist

- [2011 Fermi Symposium](#)
- [Fermi Sky Blog](#)

<http://fermi.gsfc.nasa.gov/ssc/>

News

April 29, 2011

Fermi Cycle 4: List of Approved Guest Investigations

The phase-1 selection process for the Fermi Gamma-Ray Space Telescope Cycle-4 Guest Investigator Program has been completed. A total of 213 proposals were received in response to the cycle-4 NRA and 85 have been selected by NASA Headquarters on the basis of scientific peer-review evaluation completed in early April. A list of the titles and abstracts of the selected programs is available [here](#)

Mar 30, 2011

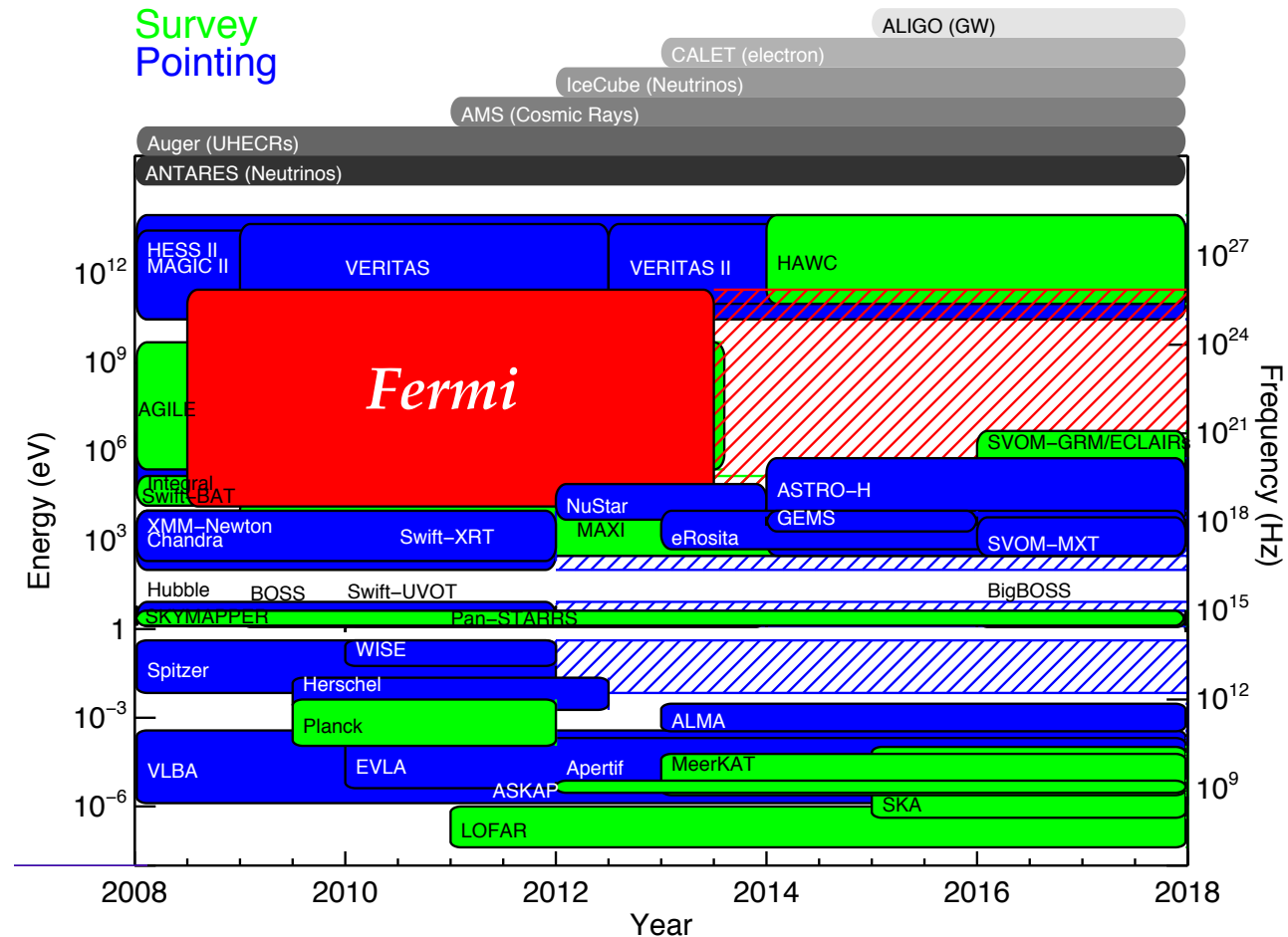
TOO for Cyg X-3

A 500 ks TOO pointed mode observation for Cyg X-3 was requested and initiated on Friday, March 25th in response to an increase in gamma-ray activity from the source (ATel 3233). The TOO was terminated manually Monday, March 28th. Stay informed by subscribing to the Fermi-News mailing list.

+ [Sign up for Fermi-News](#)

Synergies with Other Observatories

- *Fermi* covers a huge interval of the EM spectrum
 - Crucial and unique spectral coverage
- Complement the large number of upcoming new survey instruments from VHE to radio wavebands
 - At the dawn of time domain astrophysics



GRB science

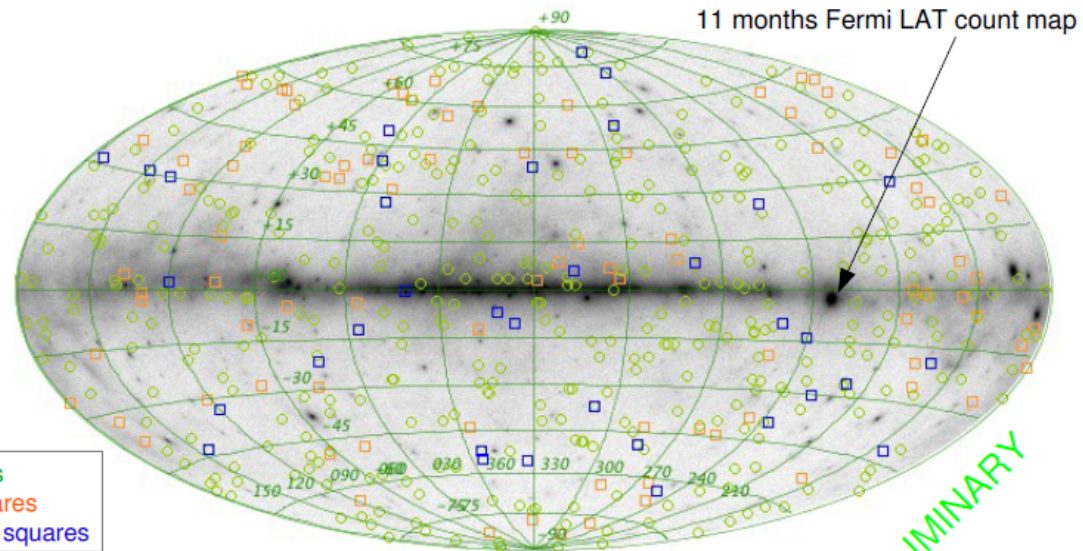


Fermi GRB detection statistics



GBM 2-year catalog
LAT 3-year catalog

GBM LGRB: green circles
GBM SGRB: orange squares
LAT detections (35): blue squares

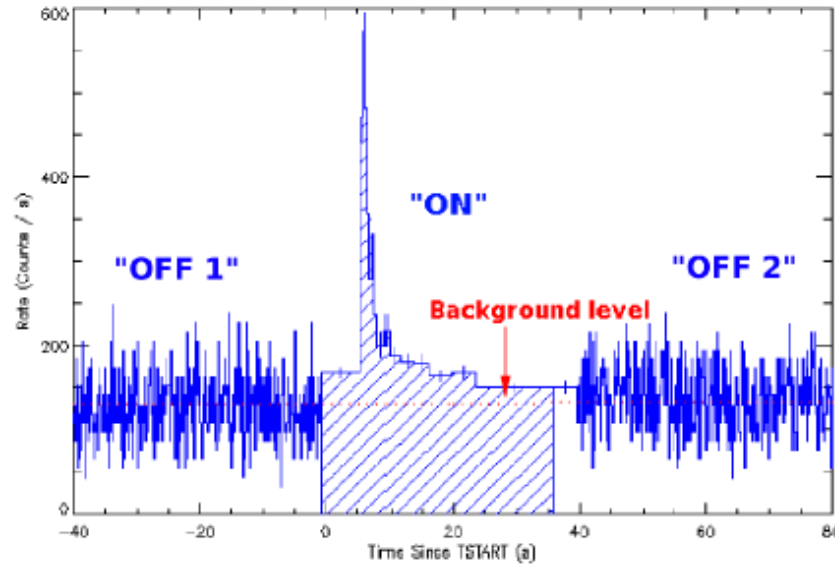


PRELIMINARY

- The GBM detects ~250 GRBs / year, ~half in the LAT FoV
- The LAT detected 35 GRBs in 3 years (30 long, 5 short), including 7 “LLE-only” GRBs
 - ~Half with more accurate follow-up localisations by Swift and ground-based observatories (GROND, Gemini-S, Gemini-N, VLT)
 - 9 redshift measurements, from $z=0.74$ (GRB 090328) to $z=4.35$ (GRB 080916C)

LLE data

arXiv:1002.2617

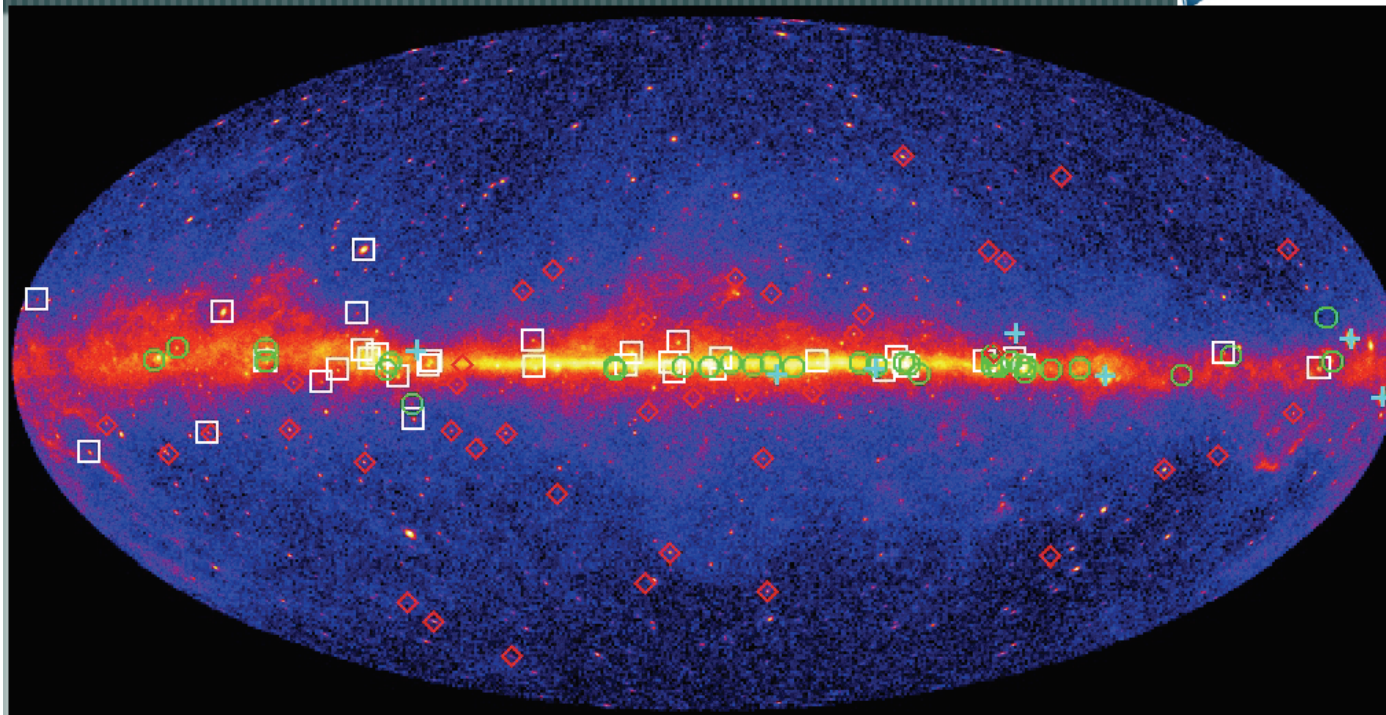


- The LAT Low Energy analysis (LLE) is a new type of analysis developed by the Fermi-LAT and Fermi-GBM teams for increasing the effective area of the Large Area Telescope at low energy, and it is suitable for studying transient phenomena, such as Gamma-Ray Bursts and Solar Flares. The LLE analysis filters event data with a very loose event selection, requiring only minimal information, such as the existence of a reconstructed direction.

http://fermi.gsfc.nasa.gov/ssc/data/analysis/LAT_caveats.html

Pulsar Science

117 Gamma-Ray Pulsars



Shown above are the gamma-ray pulsars detected with the LAT superimposed on the 3 year, front-converting, ≥ 1 GeV sky map: CGRO PSRs(+), young radio-selected (\circ), young gamma-selected(\square), and MSPs(\diamond).

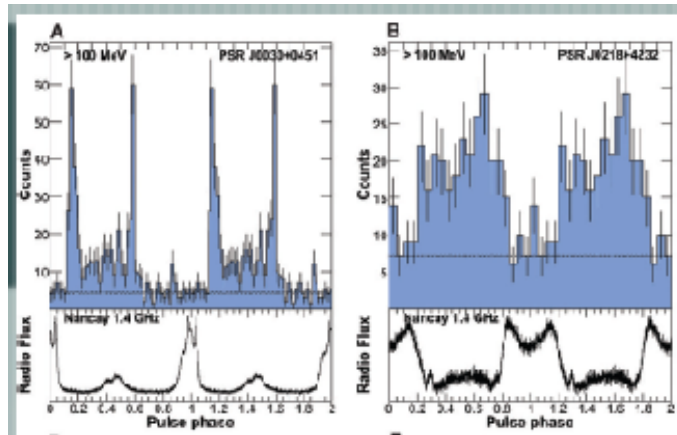
Ray : Fermi Summer School 2012

Periodic Analysis (eg. Pulsars)

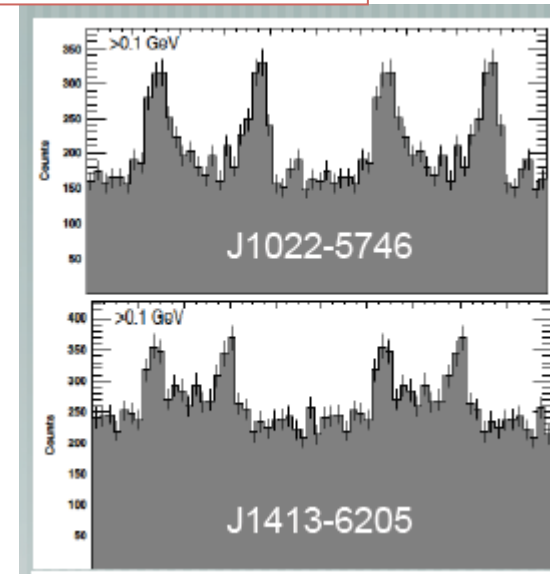
- Folding with known ephemeridis
- Blind searches
- Radio follow up on Fermi LAT sources



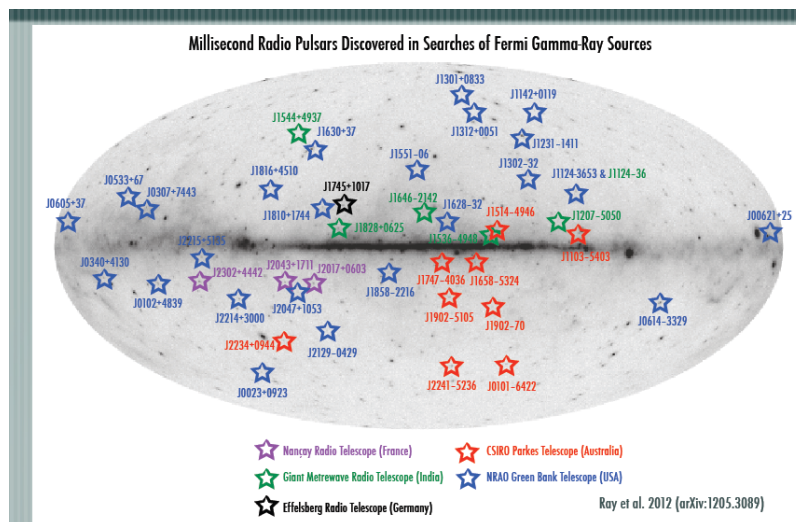
Atwood et al. 2006 Credit: M. Ziegler



Abdo et al. 2009

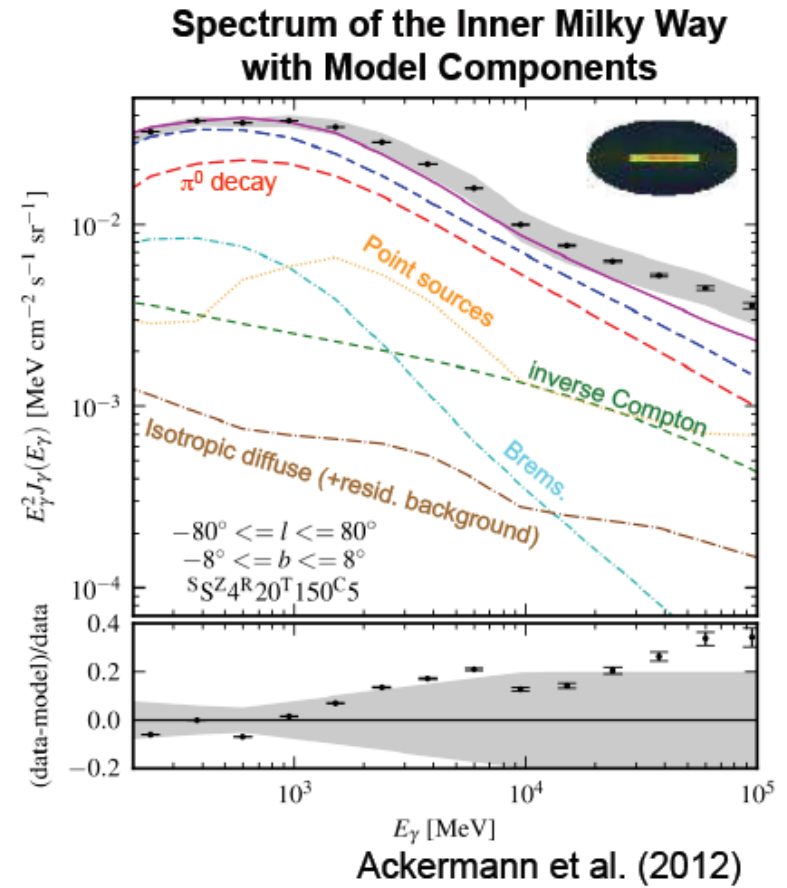
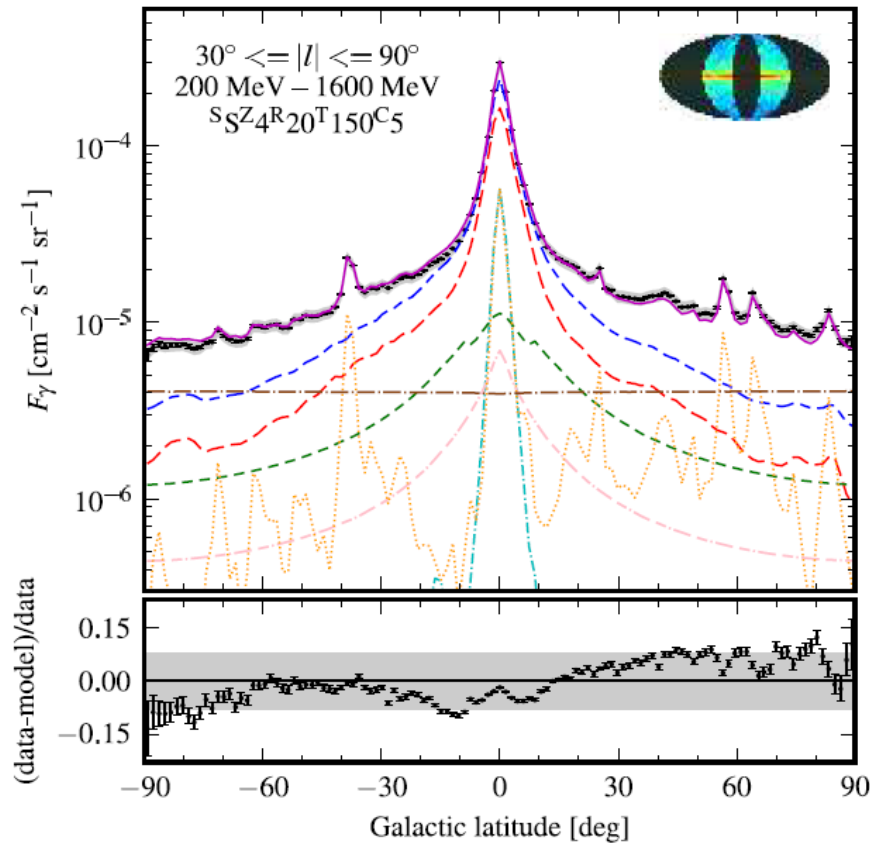


Saz Parkinson et al. 2010



Ray : Fermi Summer School 2011/12

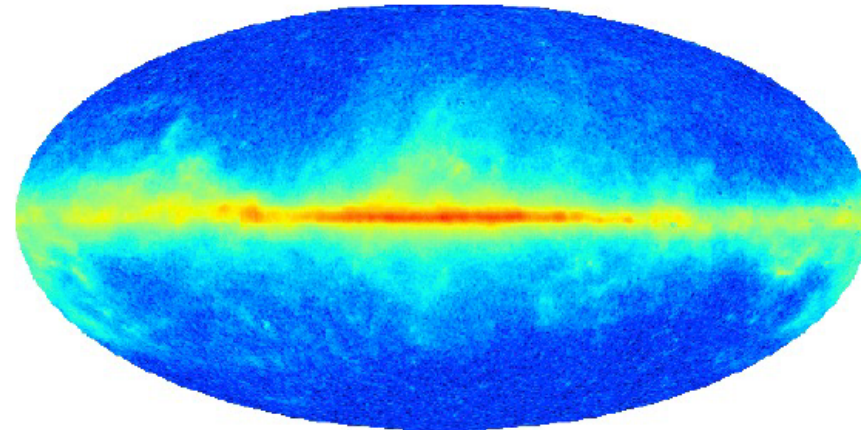
The Diffuse emission



Diffuse Analysis

- Cosmic rays
- Interstellar gas (molecular, atomic, ionized)
- Interstellar radiation field

LAT counts minus sources and isotropic above 300 MeV



0  3 *scale: log(counts)*

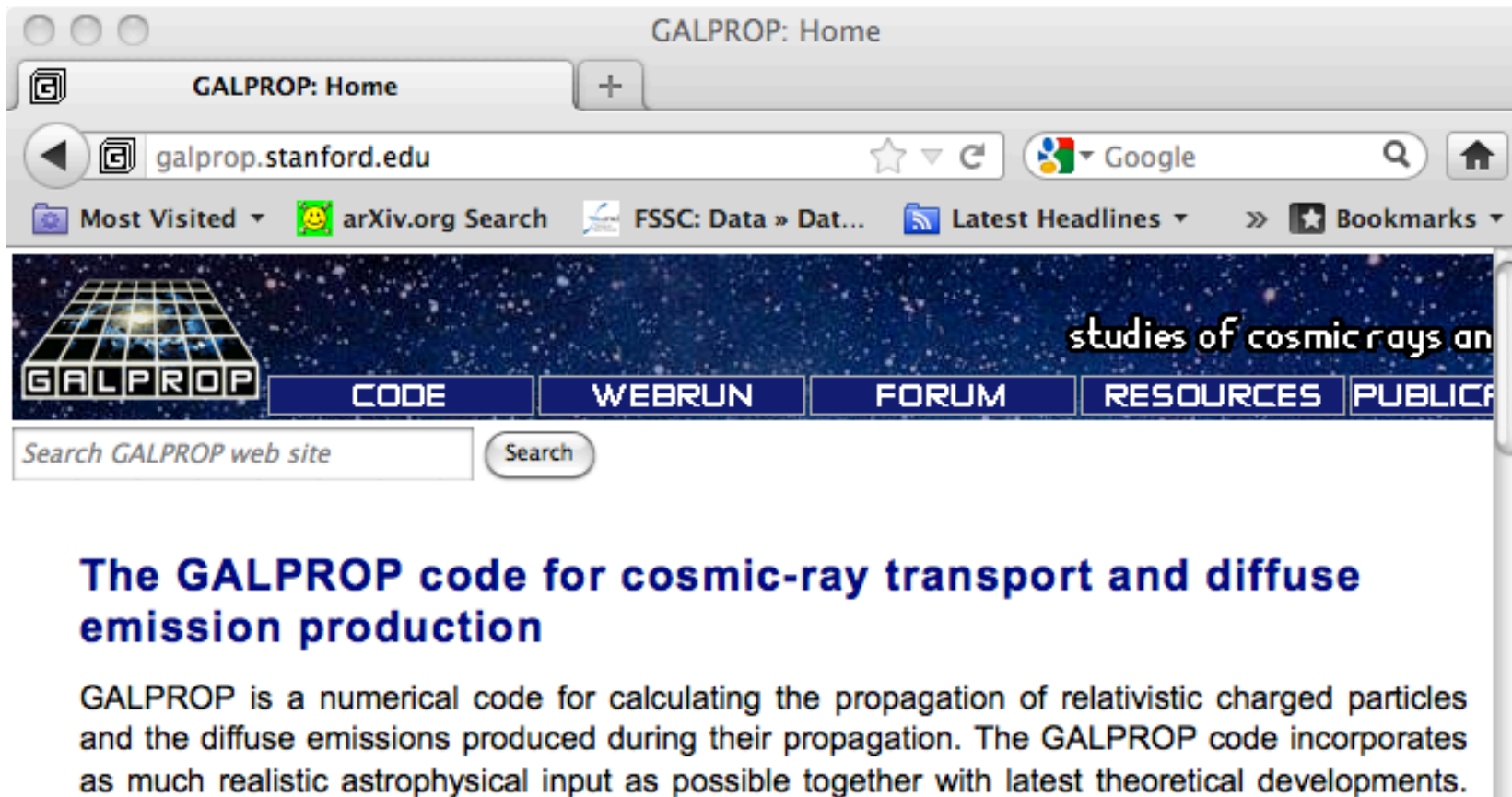


The GALPROP code for cosmic-ray transport and diffuse emission production

GALPROP is a numerical code for calculating the propagation of relativistic charged particles and the diffuse emissions produced during their propagation. The GALPROP code incorporates as much realistic astrophysical input as possible together with latest theoretical developments.

Casandjian: Fermi Symposium 2011
Digel: Fermi Summer school 2012

GalProp



The screenshot shows a web browser window titled "GALPROP: Home" with the address bar displaying "galprop.stanford.edu". The browser interface includes a search bar with the Google logo and a home button. Below the address bar, there are several bookmarked sites: "Most Visited", "arXiv.org Search", "FSSC: Data » Dat...", "Latest Headlines", and "Bookmarks". The main content area features a dark blue header with a grid pattern and the text "studies of cosmic rays an". Below the header, there are navigation buttons for "GALPROP", "CODE", "WEBRUN", "FORUM", "RESOURCES", and "PUBLICA". A search bar with the text "Search GALPROP web site" and a "Search" button is located below the navigation buttons.

The GALPROP code for cosmic-ray transport and diffuse emission production

GALPROP is a numerical code for calculating the propagation of relativistic charged particles and the diffuse emissions produced during their propagation. The GALPROP code incorporates as much realistic astrophysical input as possible together with latest theoretical developments.

GalProp

galprop.stanford.edu
studies of cosmic rays and galactic diffuse gamma-ray emission
GALPROP

CODE WEBRUN FORUM RESOURCES PUBLICATIONS CONTACTS BUGS?

Search
Logout [franzlongo]

GALPROP version: 54
[click to change](#)
Enter the desired GALPROP v. 54 parameters and click 'Submit' at the bottom of the form ↓

WebRun Help

Citing GALPROP

Configure & Submit

Monitor Queue

Download Results

Exchange Runs

Configure & Submit

Help: Configure & Submit

First-time User Mode

Advanced User Mode

Batch Runs

Monitor Queue

Download Results

Heliospheric modulation with HelMod

Exchange Runs

Please remember to

Common
click text to hide, drag to move

Import configuration from:

Common Parameters

Name	Value
Title	Untitled WebR
n_spatial_dimensions	2

Energetic and Spatial Grids

Name	Value
r_min	0.0
r_max	25.0
dr	1.0
z_min	-04.0
z_max	+04.0
dz	0.2

CR Propagation

Name	Value
D0_xx	6.10e28
D_rigid_br	4.0e3
D_g_1	0.33
D_g_2	0.33
diff_reacc	1
v_Alfven	30.0
convection	0
cross_section_option	012

mission

Abundances

WebRun Help

The WebRun service allows you to use the GALPROP server to run GALPROP calculations with physical parameters of your choice and download the output (FITS files with particle spectra and radiation maps) from this web site. There are 4 sections in the WebRun service accessible through the sidebar menu: **Configure & Submit**, **Monitor Queue**, **Download Results** and **Plot Figures**. You can also choose the version of the GALPROP code that will be used to run your jobs by clicking the button at the top of the sidebar menu.

1. Choosing the GALPROP version

You can choose an old version 50 for compatibility with calculations you may have already run with this publicly available code. You can chose a newer version 54 for faster and more stable runs and to have more configuration options. It is possible to migrate configuration files from one version to another: see the help page for Download Results.
2. Configure & Submit

Here you can specify the parameters you wish to use and submit the calculation (=job, =run) for execution. Your configuration will only be accepted if the parameters pass certain checks (i.e., get validated). The last configuration you entered is saved, and the next time you use the service, you will see the form with the last used parameters. You can also reset the parameters to default and use pre-defined configurations as well as retrieve the parameters from your previous runs.
3. Monitor Queue

In this section you can see the running output of your current calculation. You can only execute one calculation at a time, but if you submit additional calculations while one is running, they will be queued (i.e., batch runs are allowed), and you can watch and manage your queue from the 'Monitor Queue' section.
4. Download Results

The results you obtain will be saved, along with the configuration file that was used to obtain them. You can download your results (FITS files with particle spectra and radiation maps, if produced) from this section as tar files (results_*.tar.gz). You can also retrieve a configuration from a completed run and re-use it with slight modifications (e.g., to do a parameter search).

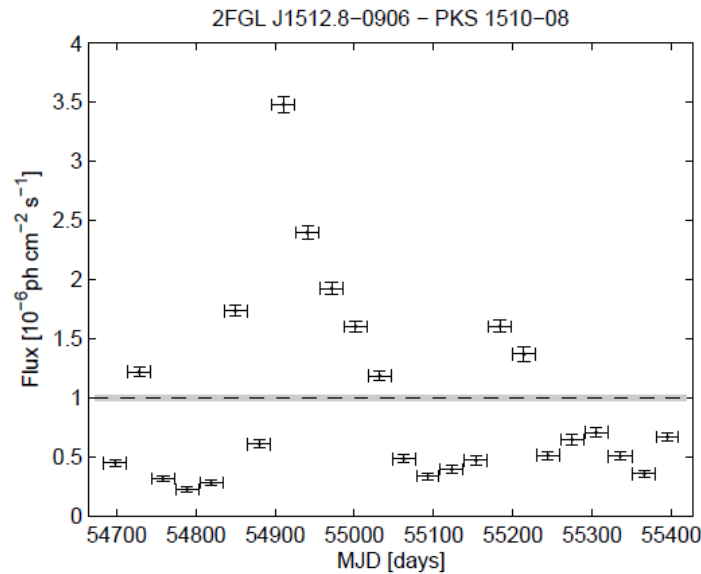
Please Cite GALPROP

Please take a minute to read the help section 'Citing GALPROP' (see the sidebar menu under 'WebRun Help') to find out how to use the results obtained with GALPROP and the WebRun service in your publications.

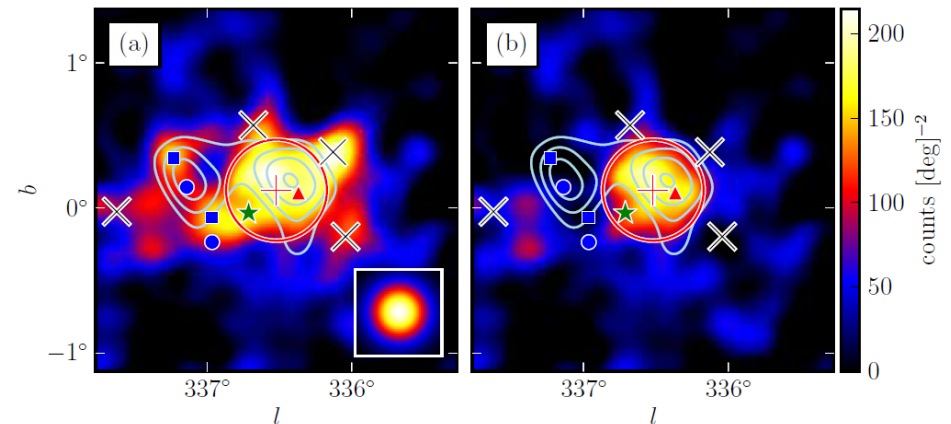
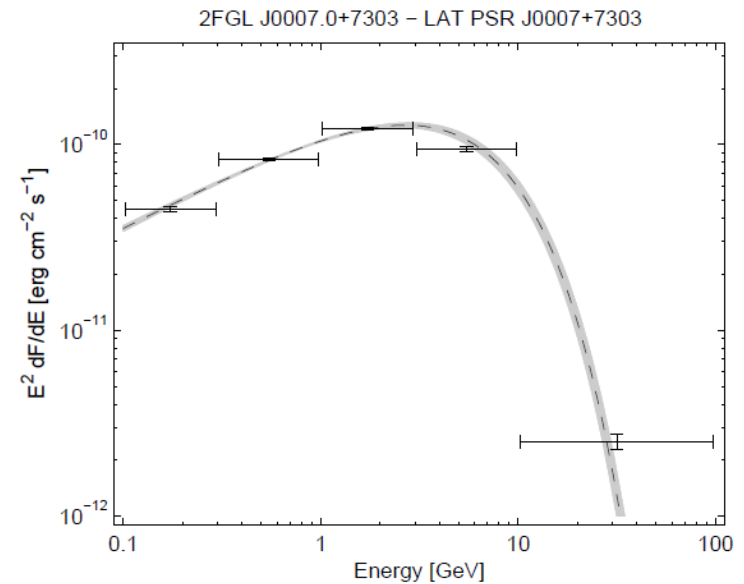
Options for determining isotopic production cross sections. Experimental data (table or fit) are used whenever available. Otherwise, for cross_section_options=012, the code of Webber et al. 93 is used (re-normalized if data exist), and for cross_section_option=022, the code of TS'00 is used (re-normalized if data exist).

Source Analysis

- Source detections algorithms
- Spectral analysis
- Association studies
- Variability studies
- Source extension



Abdo et al. 2011, Nolan et al. 2012



Lande et al. 2012

The Large Area Telescope

- The LAT is a particle physics detector we've shot into space
 - We analyze individual events (one photon at a time) with high energy physics techniques to get photon sample
 - Lots of hard work to get (RA,DEC,E) behind the curtain
- Huge variations in response to different types of events
 - Bandpass = 4-5 decades in energy ($< 20\text{MeV}$ to $> 300\text{ GeV}$)
 - Field of View = 2.4 sr (some response up to 70° off-axis)
- Several High Energy Astrophysics topics explored by the LAT

Fermi LAT Data Analysis Tutorial

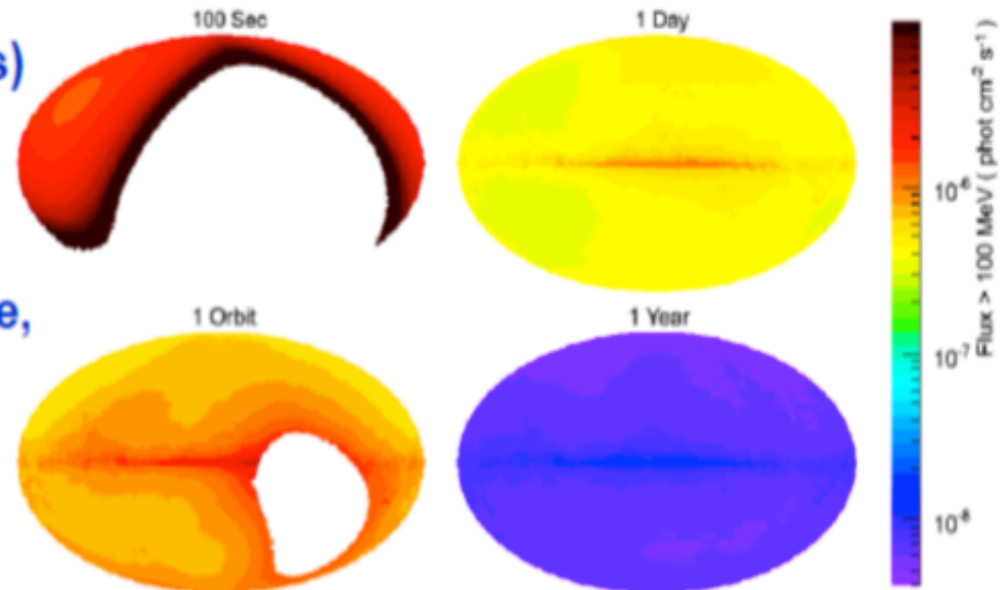
Tutorial

- Overview of the Fermi Large Area Telescope
 - **LAT data**
- **Fermi Science Tools**
 - **General Introduction**
- **Maximum Likelihood Overview**
 - **Source modeling**
- One study case:
 - **3c454.3: likelihood tutorial**
- **gtburst HE Analysis of GRBs**

Operating Mode

□ Primary observing mode is Sky Survey

- Full sky every 2 orbits (3 hours)
- Uniform exposure, with each region viewed for ~30 minutes every 2 orbits
- Best serves majority of science, facilitates multiwavelength observation planning
- Exposure intervals commensurate with typical instrument integration times for sources
- EGRET sensitivity reached in days



What do you need for the analysis

- Data ...of course!
 - LAT detected events
 - Spacecraft related stuff
 - Extras (Backgrounds , catalog sources, timing..)
- Fermi Science Tools
 - <http://fermi.gsfc.nasa.gov/ssc/data/analysis/software/>
- Other ancillary tools
 - ftools, HEASOFT, DS9 etc..
 - <http://heasarc.gsfc.nasa.gov/docs/software.html>
- Lots and lots of scripts!
 - Fermi tools are already scriptable
 - You can also use your favourite scripting language ... but ..
 - Science Tools can be imported as Python modules!

LAT DATA ARE PUBLIC!!

LAT data analysis references



Fermi Data Analysis: starting points

Fermi Science Support Center: <http://fermi.gsfc.nasa.gov/ssc/>

Fermi Newsletters: <http://fermi.gsfc.nasa.gov/ssc/resources/newsletter/>

Fermi Data Access: <http://fermi.gsfc.nasa.gov/cgi-bin/ssc/LAT/LATDataQuery.cgi>

Fermi Science Tools Reference Manual:
<http://fermi.gsfc.nasa.gov/ssc/data/analysis/scitools/references.html>

Fermi Analysis Threads:
<http://fermi.gsfc.nasa.gov/ssc/data/analysis/scitools/>
<http://fermi.gsfc.nasa.gov/ssc/data/analysis/documentation/Cicerone/>

Fermi - LAT Likelihood Algorithm description
http://fermi.gsfc.nasa.gov/ssc/data/analysis/documentation/Cicerone/Cicerone_Likelihood/

Cash W. 1979, ApJ 228, 939

Mattox J. R. et al 1996, ApJ 461, 396

Protassov et al. 2002, ApJ 57, 545

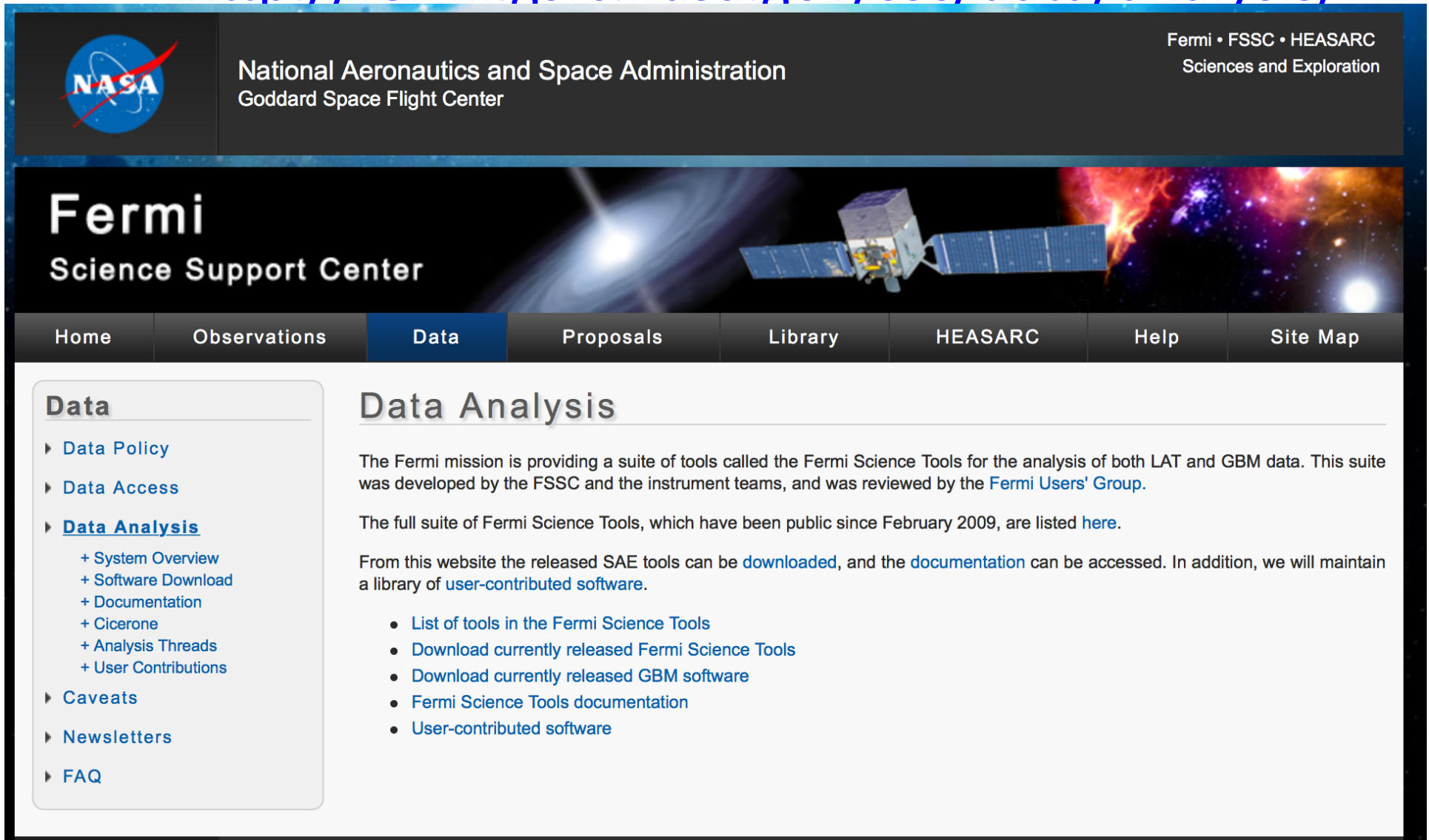
LAT Performance Page: http://www-glast.slac.stanford.edu/software/IS/glast_lat_performance.htm

The Large Area Telescope on the Fermi Gamma-Ray Space Telescope Mission, W.B. Atwood, et. al., ApJ, 2009, 695, 1071.

The On-orbit Calibrations for the Fermi Large Area Telescope, A.A. Abdo, et al. arXiv:0904.2226v1

How to access LAT Data

- <http://fermi.gsfc.nasa.gov/ssc/data/analysis/>



The screenshot shows the Fermi Science Support Center website. At the top left is the NASA logo. To its right, the text reads "National Aeronautics and Space Administration" and "Goddard Space Flight Center". In the top right corner, it says "Fermi • FSSC • HEASARC" and "Sciences and Exploration". Below this is a banner image of the Fermi satellite in space. A navigation menu is located below the banner, with "Data" highlighted. The main content area is titled "Data Analysis" and contains text about the Fermi Science Tools, a link to a list of tools, and a list of user-contributed software.

NASA
National Aeronautics and Space Administration
Goddard Space Flight Center

Fermi • FSSC • HEASARC
Sciences and Exploration

Fermi Science Support Center

Home Observations **Data** Proposals Library HEASARC Help Site Map

Data

- ▶ [Data Policy](#)
- ▶ [Data Access](#)
- ▶ [Data Analysis](#)
 - + [System Overview](#)
 - + [Software Download](#)
 - + [Documentation](#)
 - + [Cicerone](#)
 - + [Analysis Threads](#)
 - + [User Contributions](#)
- ▶ [Caveats](#)
- ▶ [Newsletters](#)
- ▶ [FAQ](#)

Data Analysis

The Fermi mission is providing a suite of tools called the Fermi Science Tools for the analysis of both LAT and GBM data. This suite was developed by the FSSC and the instrument teams, and was reviewed by the [Fermi Users' Group](#).

The full suite of Fermi Science Tools, which have been public since February 2009, are listed [here](#).

From this website the released SAE tools can be [downloaded](#), and the [documentation](#) can be accessed. In addition, we will maintain a library of [user-contributed software](#).

- [List of tools in the Fermi Science Tools](#)
- [Download currently released Fermi Science Tools](#)
- [Download currently released GBM software](#)
- [Fermi Science Tools documentation](#)
- [User-contributed software](#)

LAT Data

- LAT data products can be downloaded by the FSSC website
 - **LAT Data server** <http://fermi.gsfc.nasa.gov/cgi-bin/ssc/LAT/LATDataQuery.cgi>
 - **Archive of weekly files**
 - <https://heasarc.gsfc.nasa.gov/FTP/fermi/data/lat/weekly/photon/>
- Two main data products (stored in FITS format)
 - **Events file (FT1)**
 - **i. e. “what the LAT sees”**
 - (photons, their energy, coordinates, time, event classes etc..)
 - **Spacecraft files (FT2)**
 - **i. e. “where the LAT is”**
 - (position, angles..)



FT1: photons, photons...

Summary of L1307190816225D42602B76_PH01.fits in D:/download/Sesto/cta1photon/

Index	Extension	Type	Dimension	View
0	Primary	Image	0	Header Image Table
1	EVENTS	Binary	22 cols X 172002 rows	Header Hist Plot All Select
2	GTI	Binary	2 cols X 1623 rows	Header Hist Plot All Select

Binary Table of L1307190816225D42602B76_PH01.fits[1] in D:/download/Sesto/cta1photon/

Select	ENERGY	RA	DEC	L	B	THETA
All	E	E	E	E	E	E
Invert	MeV	deg	deg	deg	deg	deg
1	2.336191E+003	3.356806E+002	8.163372E+001	1.175507E+002	2.036243E+001	4.115981E+001
2	2.887859E+002	3.380240E+002	8.752237E+001	1.213699E+002	2.508607E+001	4.264727E+001
3	1.225226E+003	3.883369E+002	8.072034E+001	1.204938E+002	1.812485E+001	3.609352E+001
4	4.534384E+003	3.088722E+002	8.240852E+001	1.154877E+002	2.360458E+001	4.293106E+001
5	4.019389E+002	3.552110E+002	8.628517E+001	1.216945E+002	2.355435E+001	7.299443E+001
6	2.382755E+002	3.180323E+002	8.210764E+001	1.159586E+002	2.241227E+001	7.694953E+001
7	1.264944E+002	3.255829E+002	8.287437E+001	1.172845E+002	2.218270E+001	7.469367E+001
8	1.547845E+002	3.234117E+002	8.472955E+001	1.185430E+002	2.363485E+001	7.346131E+001
9	1.454238E+002	3.474094E+002	8.746054E+001	1.217301E+002	2.493102E+001	5.835028E+001
10	3.449312E+002	3.310049E+002	8.453091E+001	1.189708E+002	2.299933E+001	5.160154E+001
11	5.811864E+002	3.575490E+002	7.964534E+001	1.200859E+002	1.711370E+001	2.970138E+001
12	2.344030E+002	3.502021E+002	8.416479E+001	1.205161E+002	2.172313E+001	3.792418E+001
13	5.823864E+002	3.126542E+002	8.261592E+001	1.159879E+002	2.328888E+001	5.608511E+001
14	1.448622E+003	3.584331E+002	8.189178E+001	1.207991E+002	1.926012E+001	4.726143E+001
15	3.600245E+002	3.483517E+002	8.227232E+001	1.195281E+002	2.005690E+001	3.439582E+001
16	1.747731E+003	3.294199E+002	8.365910E+001	1.182192E+002	2.244669E+001	3.296274E+001
17	1.688157E+002	3.483332E+002	8.084929E+001	1.189347E+002	1.874854E+001	3.663948E+001
18	3.378409E+002	3.136788E+002	8.375113E+001	1.170663E+002	2.380627E+001	5.706439E+001

Events

Table Info of L13071908162...

Total Columns: 22
Total Rows: 172002

Selected columns for display

- ENERGY
- RA
- DEC
- L
- B
- THETA
- PHI
- ZENITH_ANGLE
- EARTH_AZIMUTH_ANGLE
- TIME
- EVENT_ID
- RUN_ID
- RECON_VERSION
- CALIB_VERSION
- EVENT_CLASS
- CONVERSION_TYPE
- LIVETIME
- DIFRSP0
- DIFRSP1
- DIFRSP2
- DIFRSP3
- DIFRSP4

Display Table
Select All
Clear All
Cancel
Help

Binary Table of L1307190816225D42602B76_P...

Select START STOP

All D s

Invert Modify Modify

1	2.530705209249E+008	2.530762370846E+008
2	2.530762499232E+008	2.530819660843E+008
3	2.530819789232E+008	2.53084660841E+008
4	2.530855789267E+008	2.530904400850E+008
5	2.53091889232E+008	2.530963210855E+008
6	2.530979839214E+008	2.531022110850E+008
7	2.531040179214E+008	2.531081320847E+008
8	2.531100139199E+008	2.531143880845E+008
9	2.531159969215E+008	2.531205430862E+008
10	2.531219739250E+008	2.531266340844E+008
11	2.531279449252E+008	2.531327030917E+008
12	2.531337379250E+008	2.531387810841E+008
13	2.531390149267E+008	2.531449860918E+008
14	2.531449989233E+008	2.531507160843E+008
15	2.531507289250E+008	2.531564450855E+008
16	2.531564579233E+008	2.531621740877E+008
17	2.531621869233E+008	2.531679030844E+008

Good Time Intervals (GTIs)



FT2: where is Fermi ?

fv: Summary of L1307190816225D42602876_SC00.fits in D:/download/Sesto/cta1photon/

Index	Extension	Type	Dimension	View
0	Primary	Image	0	Header Image Table
1	SC_DATA	Binary	29 cols X 886906 rows	Header Hist Plot All Select



fv: Binary Table of L1307190816225D42602876_SC00.fits[1] in D:/download/Sesto/cta1photon/

Select	START	STOP	SC_POSITION	LAT_GEO	LON_GEO	RAD_GEO
<input checked="" type="checkbox"/> All	D	D	3E	E	E	D
<input type="checkbox"/> Invert	s	s	m	deg	deg	m
	Modify	Modify	Modify	Modify	Modify	Modify
1	2.395612776000E+008	2.395613076000E+008	Plot	6.592855E+000	1.288651E+002	5.504893679991E+005
2	2.395613076000E+008	2.395613376000E+008	Plot	7.383996E+000	1.304637E+002	5.501927909688E+005
3	2.395613376000E+008	2.395613676000E+008	Plot	8.168575E+000	1.320687E+002	5.499135114643E+005
4	2.395613676000E+008	2.395613976000E+008	Plot	8.945851E+000	1.336805E+002	5.496488803954E+005
5	2.395613976000E+008	2.395614276000E+008	Plot	9.715078E+000	1.352999E+002	5.494012096987E+005
6	2.395614276000E+008	2.395614576000E+008	Plot	1.047550E+001	1.369274E+002	5.491686522950E+005
7	2.395614576000E+008	2.395614876000E+008	Plot	1.122635E+001	1.385636E+002	5.489517414953E+005
8	2.395614876000E+008	2.395615176000E+008	Plot	1.196685E+001	1.402090E+002	5.487538278698E+005
9	2.395615176000E+008	2.395615476000E+008	Plot	1.269626E+001	1.418642E+002	5.485701226070E+005
10	2.395615476000E+008	2.395615776000E+008	Plot	1.341378E+001	1.435296E+002	5.483998366015E+005
11	2.395615776000E+008	2.395616076000E+008	Plot	1.411865E+001	1.452058E+002	5.482435574869E+005
12	2.395616076000E+008	2.395616376000E+008	Plot	1.481007E+001	1.468931E+002	5.481000357595E+005
13	2.395616376000E+008	2.395616676000E+008	Plot	1.548726E+001	1.485919E+002	5.479706011147E+005

fv: Table Info of L13071908162...

Total Columns: 29
Total Rows : 886906

Selected columns for display

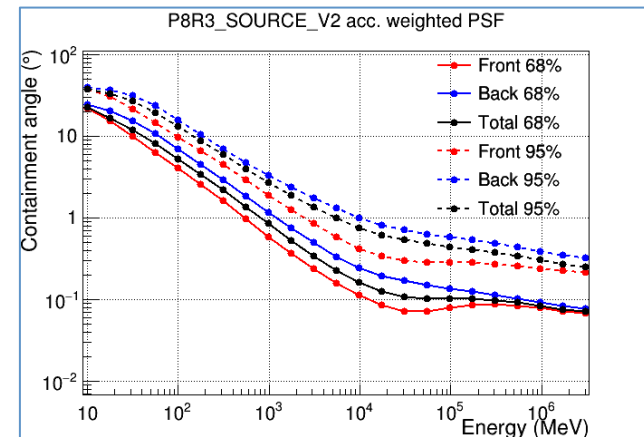
- START
- STOP
- SC_POSITION
- LAT_GEO
- LON_GEO
- RAD_GEO
- RA_ZENITH
- DEC_ZENITH
- B_MCILWAIN
- L_MCILWAIN
- GEOMAG_LAT
- IN_SAA
- RA_SCZ
- DEC_SCZ
- RA_SCX
- DEC_SCX
- RA_NPOLE
- DEC_NPOLE
- ROCK_ANGLE
- LAT_MODE
- LAT_CONFIG
- DATA_QUAL
- LIVETIME

Display Table
Select All
Clear All
Cancel
Help

spacecraft Data

Extras - IRFs

- LAT Instrument Response Functions (IRFs)
 - Point Spread Function (PSF)
 - Effective Area
 - Energy Resolution
- Highly dependent on energy and arrival direction of incident photon
- Fundamental for analysis!!



- http://www.slac.stanford.edu/exp/glast/groups/canda/lat_Performance.htm
- https://fermi.gsfc.nasa.gov/ssc/data/analysis/documentation/Cicerone/Cicerone_LAT_IRFs/IRF_overview.html

Extras

- Diffuse models (.txt & FITS files)
 - To correctly take into accounts the galactic and extagalactic backgrounds
 - <http://fermi.gsfc.nasa.gov/ssc/data/access/lat/BackgroundModels.html>
- Source Catalogs (4FGL, 3FHL, PSRs, GRB, SNR ...)
- Region of Interest model definition (stored in XML files)
 - More on this later ...
- Choose the proper combination of
 - event classes based on the probability of being a photon and background level
 - TRANSIENT (for very short events)
 - SOURCE (suggested for source analysis)
 - CLEAN and ULTRACLEAN (lowest particle contamination – for diffuse sources analysis)
 - Event types based on conversion point or PSF or Energy reconstruction

LAT background models

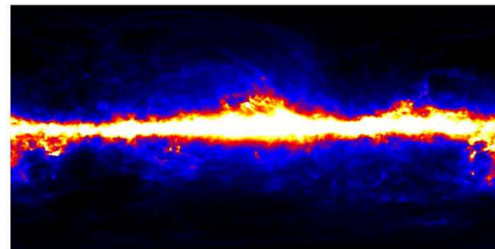


Extras 2 : Diffuse Models

Galactic diffuse model	gll_iem_v02.fit
Isotropic spectral template (all)	isotropic_iem_v02.txt
Isotropic spectral template (front)	isotropic_iem_front_v02.txt
Isotropic spectral template (back)	isotropic_iem_back_v02.txt
Detailed description	Model Description

Summary of gll_iem_v02.fit in /Users/ginotosti/TUTORIAL/

Index	Extension	Type	Dimension	View
<input type="checkbox"/> 0	Primary	Image	720 X 360 X 30	Header Image Table
<input type="checkbox"/> 1	ENERGIES	Binary	1 cols X 30 rows	Header Hist Plot All Select



39.3884	6.57144e-07	4.6946e-08
64.0414	4.09665e-07	5.72124e-09
104.125	1.72000e-07	8.35794e-10
169.296	6.60007e-08	2.15325e-10
275.257	2.24126e-08	7.58059e-11
447.539	7.21114e-09	2.95711e-11
727.651	2.20758e-09	1.16796e-11
1183.08	7.20365e-10	4.68072e-12
1923.57	2.35566e-10	1.93256e-12
3127.52	7.36933e-11	8.02165e-13
5085.02	2.75583e-11	3.52098e-13
8267.71	8.41675e-12	1.44008e-13
13442.4	2.61572e-12	6.04568e-14
21856	9.93124e-13	2.77996e-14
35535.5	4.07167e-13	1.32929e-14
57777	1.48419e-13	6.31664e-15
93939.4	6.49806e-14	3.22598e-15
152736	2.13205e-14	1.49108e-15
248332	6.498e-15	4.85176e-16
403761	2.1144e-15	2.60915e-16

<http://fermi.gsfc.nasa.gov/ssc/data/access/lat/BackgroundModels.html>

LAT background models

LAT Background Models

Many analyses of LAT data require models of Galactic diffuse and isotropic emission. Detailed discussion of how the latest Galactic diffuse emission model (available from this Web page) has been developed, and important caveats on its use, is available [here](#). Please refer to the [binned](#) or [unbinned](#) likelihood analysis tutorials for some examples of how to incorporate these models into your own Fermi data analysis. Here is a list of IRFs and diffuse models to be used with the various data sets. We have provided the model files for you to download. However, the files for the most recent data release are included in the Fermitools installation (in the \$(FERMI_DIR)/refdata/fermi/galdiffuse/ directory). As a result, it is unlikely that you will need to download each file separately.

For Pass 8, each event class and event type combination has a dedicated IRF and isotropic model. Only a subset are shown here, as examples.

Galactic interstellar emission model	Event Selection/ IRF Name	Isotropic spectral template
gll_iem_v07.fits (see below for P8R3 usage notes)	Pass 8 Source (front+back, allPSF, allEDISP) P8R3_SOURCE_V3	iso_P8R3_SOURCE_V3_v1.txt
	Pass 8 Source (front only) P8R3_SOURCE_V3::FRONT	iso_P8R3_SOURCE_V3_FRONT_v1.txt
	Pass 8 Source (back only) P8R3_SOURCE_V3::BACK	iso_P8R3_SOURCE_V3_BACK_v1.txt
	Pass 8 Clean (front+back, allPSF, allEDISP) P8R3_CLEAN_V3	iso_P8R3_CLEAN_V3_v1.txt
	Pass 8 Clean (PSF0) P8R3_CLEAN_V3::PSF0	iso_P8R3_CLEAN_V3_PSF0_v1.txt
	Pass 8 Clean (PSF1) P8R3_CLEAN_V3::PSF1	iso_P8R3_CLEAN_V3_PSF1_v1.txt
	Pass 8 Clean (PSF2) P8R3_CLEAN_V3::PSF2	iso_P8R3_CLEAN_V3_PSF2_v1.txt
	Pass 8 Clean (PSF3) P8R3_CLEAN_V3::PSF3	iso_P8R3_CLEAN_V3_PSF3_v1.txt
	Pass 8 Ultraclean (front+back, allPSF, allEDISP) P8R3_ULTRACLEAN_V3	iso_P8R3_ULTRACLEAN_V3_v1.txt

<https://fermi.gsfc.nasa.gov/ssc/data/access/lat/BackgroundModels.html>

LAT catalogs

- LAT catalogs and associated products (high-level products only)
 - LAT Source Catalog
 - [LAT 10-year Source Catalog \(4FGL-DR2\)](#)
 - [LAT 8-year Source Catalog \(4FGL\)](#)
 - [Preliminary LAT 8-year Source List \(FL8Y\)](#)
 - [LAT 4-year Source Catalog \(3FGL\)](#)
 - [LAT 2-year Source Catalog \(2FGL\)](#)
 - [LAT 1-year Source Catalog \(1FGL\)](#)
 - [LAT 3-month Bright Source List \(0FGL\)](#)
 - Aperture Photometry Light Curves
 - [Aperture Photometry Light Curves for LAT 10-year Catalog Sources \(Updated Weekly\)](#)
 - [Flaring Sources in the LAT 10-year Aperture Photometry Light Curves \(Updated Weekly\)](#)
 - [Aperture Photometry Light Curves for LAT 4-year Catalog Sources](#)
 - [Flaring Sources in the LAT 4-year Aperture Photometry Light Curves](#)
 - [Aperture Photometry Light Curves for the LAT 2-year Source Catalog](#)
 - [Flaring Sources in the LAT 2-year Aperture Photometry Lightcurves](#)
 - LAT High Energy Source Catalog
 - [LAT Third High Energy Source Catalog \(3FHL\)](#)
 - [LAT Second High-Energy Source Catalog \(2FHL\)](#)
 - [LAT First High-Energy Source Catalog \(1FHL\)](#)
 - [The Fourth Catalog of Active Galactic Nuclei -- Data Release 2 \(4LAC-DR2\)](#)
 - [The Fourth Catalog of Active Galactic Nuclei \(4LAC\)](#)
 - [LAT Monitored Source List Light Curves](#)
 - [LAT GRB Catalog](#)
 - [Extended Sources in the Galactic Plane \(FGES\)](#)
 - [Second Fermi All-sky Variability Analysis Catalog \(2FAV\)](#)
 - [1st Fermi-LAT SNR Catalog](#)
 - [LAT 3-year Catalog of Gamma-ray Pulsars](#)

<https://fermi.gsfc.nasa.gov/ssc/data/access/>

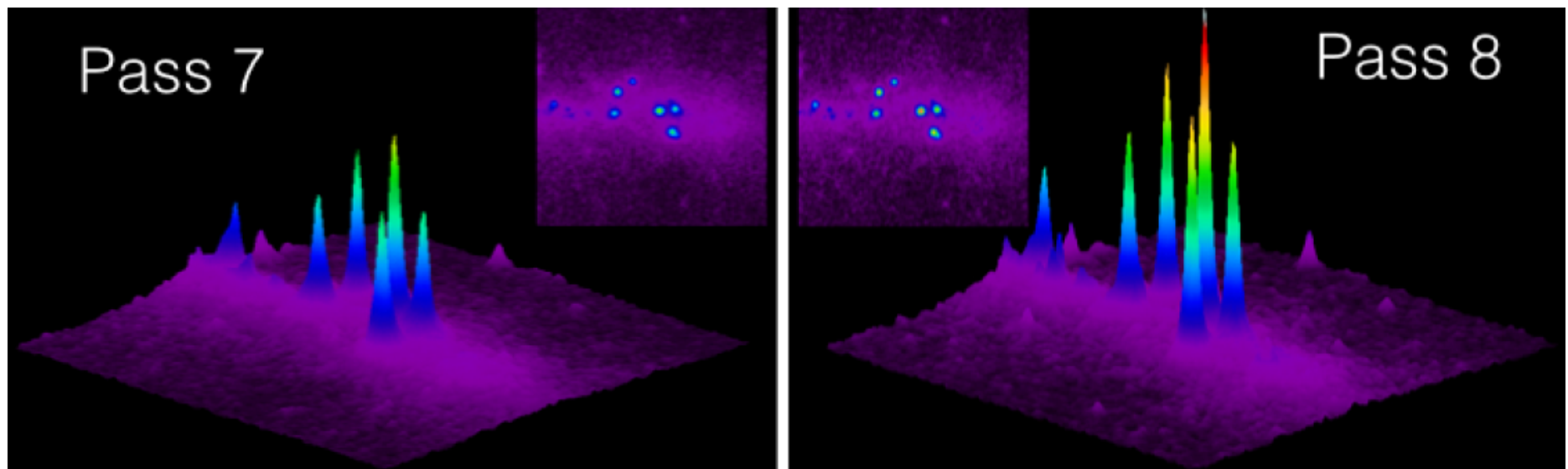
PASS8 DATA

Pass 8: Toward the Full Realization of the Fermi-LAT Scientific Potential

W. Atwood, A. Albert, L. Baldini, M. Tinivella, J. Bregeon, M. Pesce-Rollins, C. Sgrò, P. Bruel, E. Charles, A. Drlica-Wagner, A. Franckowiak, T. Jogler, L. Rochester, T. Usher, M. Wood, J. Cohen-Tanugi, S. Zimmer for the Fermi-LAT Collaboration

- Event reconstruction re-thought, re-coded from bottom to top.
- Performs significantly better.
- Data public since 2015.
- Several pulsars have popped into view.

Figure from 2016 NASA Senior Review.



New Pass8 data

Fermi Science Support Center

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Data

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Using LAT's New Pass 8 Data

The FSSC is now serving Pass 8 LAT data for analysis. The new version of LAT data provides a number of improvements over the reprocessed Pass 7 data, and is considered the best dataset for all types of LAT analysis. As of the release date (June 24, 2015) reprocessed Pass 7 data is no longer being served. However, existing Pass 7 reprocessed data has been archived and is available from the FSSC's [FTP server](#).

Pass 8 provides a full reprocessing of the entire mission dataset, including improved event reconstruction, a wider energy range, better energy measurements, and significantly increased effective area. In addition, the events have been evaluated for their measurement quality in both position and energy. This allows the user to select a subset of the events if appropriate to improve analysis results. To support the use of these data selections, there have been some structural changes to the *Fermi* Science Tools.

Here we discuss the changes to the data and tools, and how they affect your analysis.

Pass 8 Bottom Line



- Pass 8 contains a lot of changes, and the rest of this page may seem overwhelming. If you just want to get started doing a standard LAT analysis, here's the bottom line:
- Recommended event class for source analysis is "P8 Source" class (*evclass*=128).
- Add *evtype* parameter to your *gtselect* call (*convtype* parameter is deprecated). Recommended event type for source analysis is "FRONT+BACK" (*evtype*=3).
- Recommended zenith angle cut to eliminate Earth limb events ("*zmax*") is 90 degrees for events at 100 MeV and above.
- Recommended source list for analysis is the [3FGL Catalog](#). A python script is available at the [User-Contributed Tools](#) page that creates XML model files using the 3FGL catalog FITS file.

http://fermi.gsfc.nasa.gov/ssc/data/analysis/documentation/Pass8_usage.html

Pass 8 introduction

What does Pass mean?

- Each pass corresponds to a version of the Fermi LAT data
- It implies a whole package:
 - Instrument simulation
 - Reconstruction code
 - Event selection
 - Instrument Response Functions (IRFs)
 - Systematic uncertainties
 - Isotropic template (which includes the cosmic-ray residual background)
 - And sometimes more (Galactic diffuse model, Earth limb template, Sun+Moon template)
- It's only when we have validated the whole package that we can release it to the public.

Pass8 introduction

From Pass 6 to Pass 8

- Pass 6 (launch time)
 - Pass 6 reconstruction
 - Pass 6 selection
 - Based on pre-launch instrument simulation
 - First data revealed the issue of out-of-time pile-up (aka ghosts)
 - **New: instrument simulation with ghosts -> correct IRFs**
- Pass 7
 - Pass 6 reconstruction
 - **New: Pass 7 selection optimized with simulations with ghosts**
- Pass 8
 - **New: improved instrument simulation**
 - **New: Pass 8 reconstruction, as ghost-proof as possible**
 - **New: Pass 8 selection**

Pass8 Introduction

Pass 8 improvements

- Ghost handling
 - Tracker: ignoring ghost hits
 - ACD: partial deghosting
 - Calorimeter: clustering and cluster classification
- Improved direction measurement
 - Tree-based track finder
- Improved energy measurement
 - Extension of the energy range: from ~ 10 MeV to ~ 3 TeV
- Improved track/ACD matching information
 - Using the uncertainty of the tracker direction
- Improved event selection
 - Using the ROOT TMVA package (tmva.sourceforge.net)
- Additional sub-classes of events

Event classes

Standard Hierarchy for LAT Event Classes				
Event Class	evclass	Photon File	Extended File	Description
P8R3_TRANSIENT020	16		X	Transient event class with background rate equal to two times the A10 IGRB reference spectrum.
P8R3_TRANSIENT010	64		X	Transient event class with background rate equal to one times the A10 IGRB reference spectrum.
P8R3_SOURCE	128	X	X	This event class has a residual background rate that is comparable to P7REP_SOURCE. This is the recommended class for most analyses and provides good sensitivity for analysis of point sources and moderately extended sources.
P8R3_CLEAN	256	X	X	This class is identical to SOURCE below 3 GeV. Above 3 GeV it has a 1.3-2 times lower background rate than SOURCE and is slightly more sensitive to hard spectrum sources at high galactic latitudes.
P8R3_ULTRACLEAN	512	X	X	This class has a background rate very similar to ULTRACLEANVETO.
P8R3_ULTRACLEANVETO	1024	X	X	This is the cleanest Pass 8 event class. Its background rate is 15-20% lower than the background rate of SOURCE class below 10 GeV, and 50% lower at 200 GeV. This class is recommended to check for CR-induced systematics as well as for studies of diffuse emission that require low levels of CR contamination.
P8R3_SOURCEVETO	2048	X	X	This class has the same background rate than the SOURCE class background rate up to 10 GeV but, above 50 GeV, its background rate is the same as the ULTRACLEANVETO one while having 15% more acceptance.

Event classes

Extended Hierarchy				
Event Class	evclass	Photon File	Extended File	Description
P8R3_TRANSIENT020E	8		X	Extended version of the P8R3_TRANSIENT020 event class with a less restrictive fiducial cut on projected track length through the Calorimeter.
P8R3_TRANSIENT010E	32		X	Extended version of the P8R3_TRANSIENT010 event class with a less restrictive fiducial cut on projected track length through the Calorimeter.
NON-ACD Hierarchy				
Event Class	evclass	Photon File	Extended File	Description
P8R3_TRANSIENT015S	65536		X	Transient event class designed for analysis of prompt solar flares in which pileup activity may be present. This class has a background rate equal to 1.5 times the A10 reference spectrum.

Event types

Conversion Type Partition		
Event Type	evtype	Description
FRONT	1	Events converting in the Front-section of the Tracker. Equivalent to convtype=0.
BACK	2	Events converting in the Back-section of the Tracker. Equivalent to convtype=1.
PSF Type Partition		
Event Type	evtype	Description
PSF0	4	First (worst) quartile in the quality of the reconstructed direction.
PSF1	8	Second quartile in the quality of the reconstructed direction.
PSF2	16	Third quartile in the quality of the reconstructed direction.
PSF3	32	Fourth (best) quartile in the quality of the reconstructed direction.
EDISP Type Partition		
Event Type	evtype	Description
EDISP0	64	First (worst) quartile in the quality of the reconstructed energy.
EDISP1	128	Second quartile in the quality of the reconstructed energy.
EDISP2	256	Third quartile in the quality of the reconstructed energy.
EDISP3	512	Fourth (best) quartile in the quality of the reconstructed energy.

Recommendations

Event Selection Recommendations (P8R3)

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	P8R3_SOURCE_V2
Off-plane Point Source Analysis	100 (MeV)	500000 (MeV)	90 (degrees)	128	P8R3_SOURCE_V2
Burst and Transient Analysis (<200s)	100 (MeV)	500000 (MeV)	100 (degrees)	16	P8R3_TRANSIENT020_V2
Galactic Diffuse Analysis	100 (MeV)	500000 (MeV)	90 (degrees)	128	P8R3_SOURCE_V2
Extra-Galactic Diffuse Analysis	100 (MeV)	500000 (MeV)	90 (degrees)	1024	P8R3_ULTRACLEANVETO_V2 or P8R3_SOURCEVETO_V2 (when interested in E>1 GeV energy range)
Impulsive Solar Flare Analysis	100 (MeV)	500000 (MeV)	100 (degrees)	65536	P8R3_TRANSIENT015S_V2

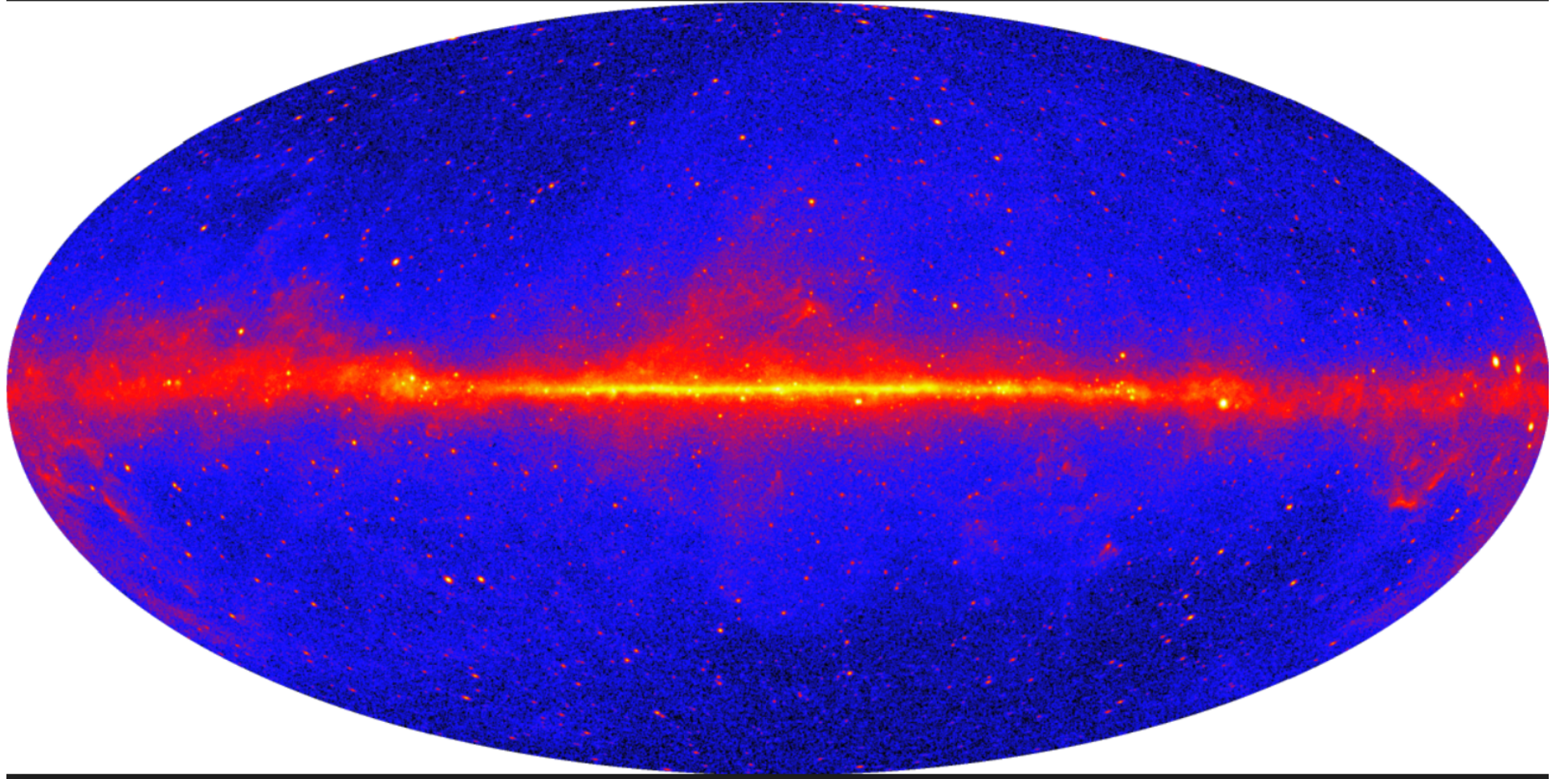
Recommendations

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)

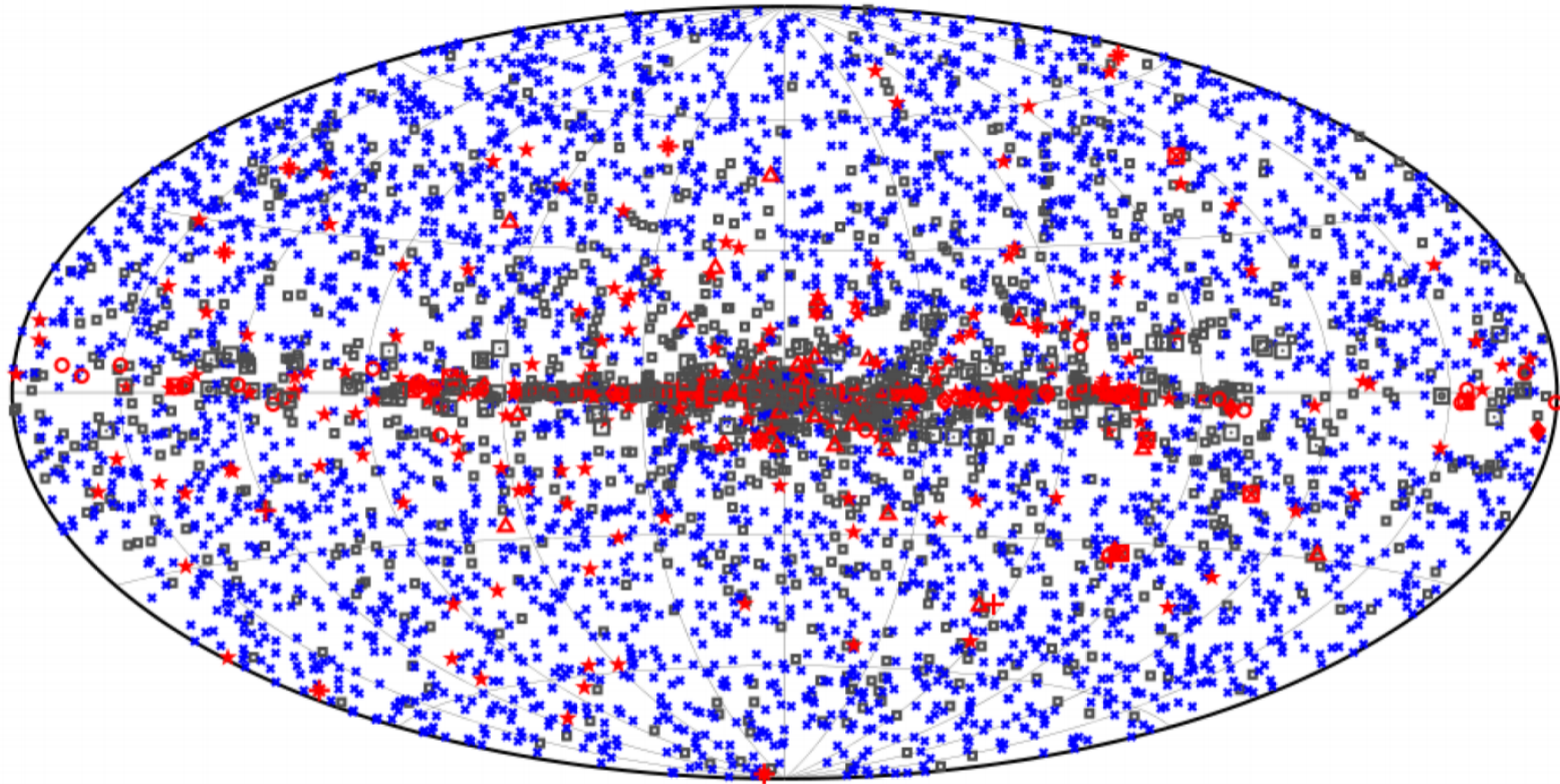
IMPORTANT: For analyses where an ROI-based zenith cut is NOT performed, an exposure correction must be made using the "zmax" option in the [gtlucube](#) tool.

LAT sky



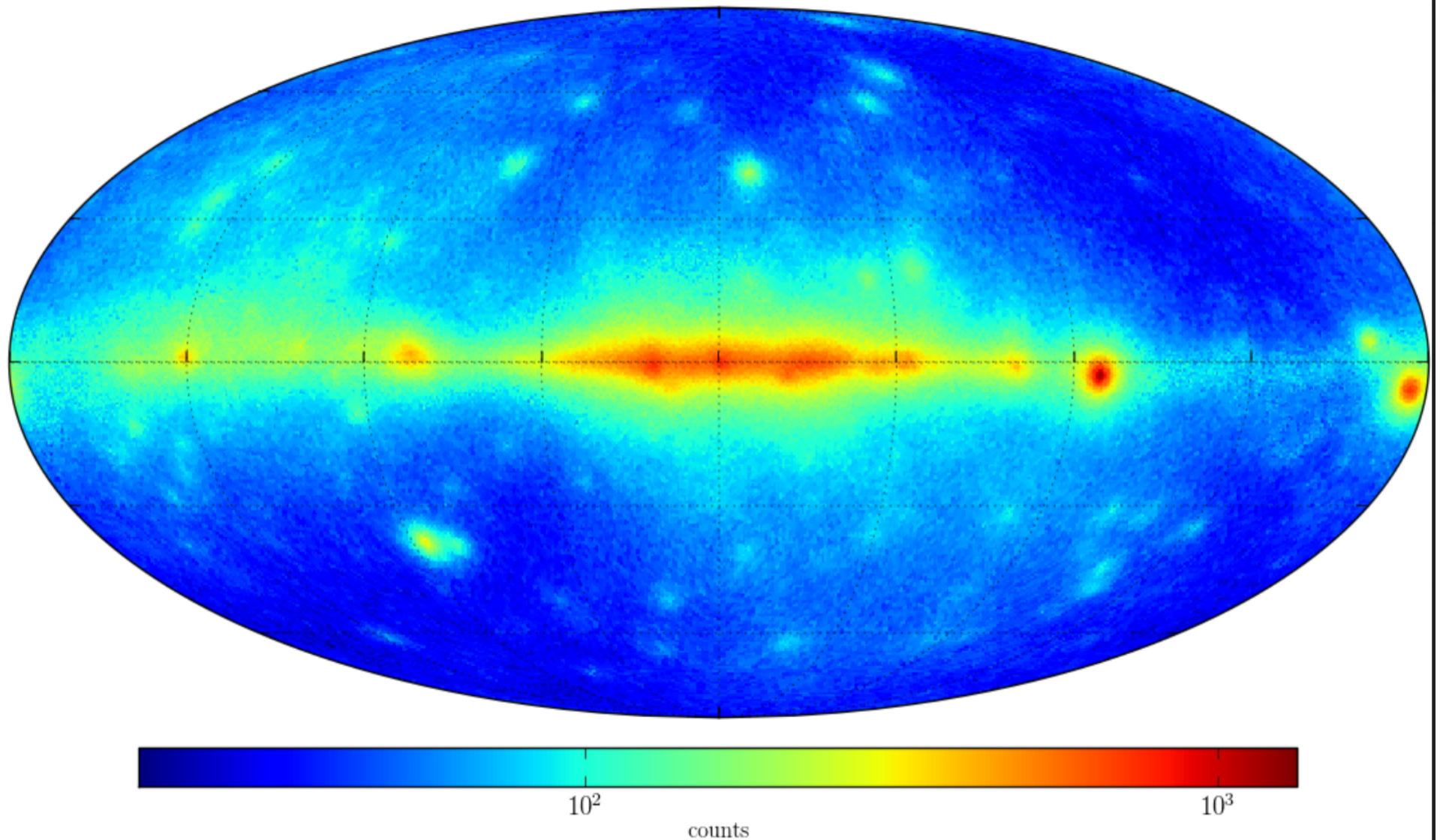
LAT 4FGL catalog

Abdollahi et al 2020

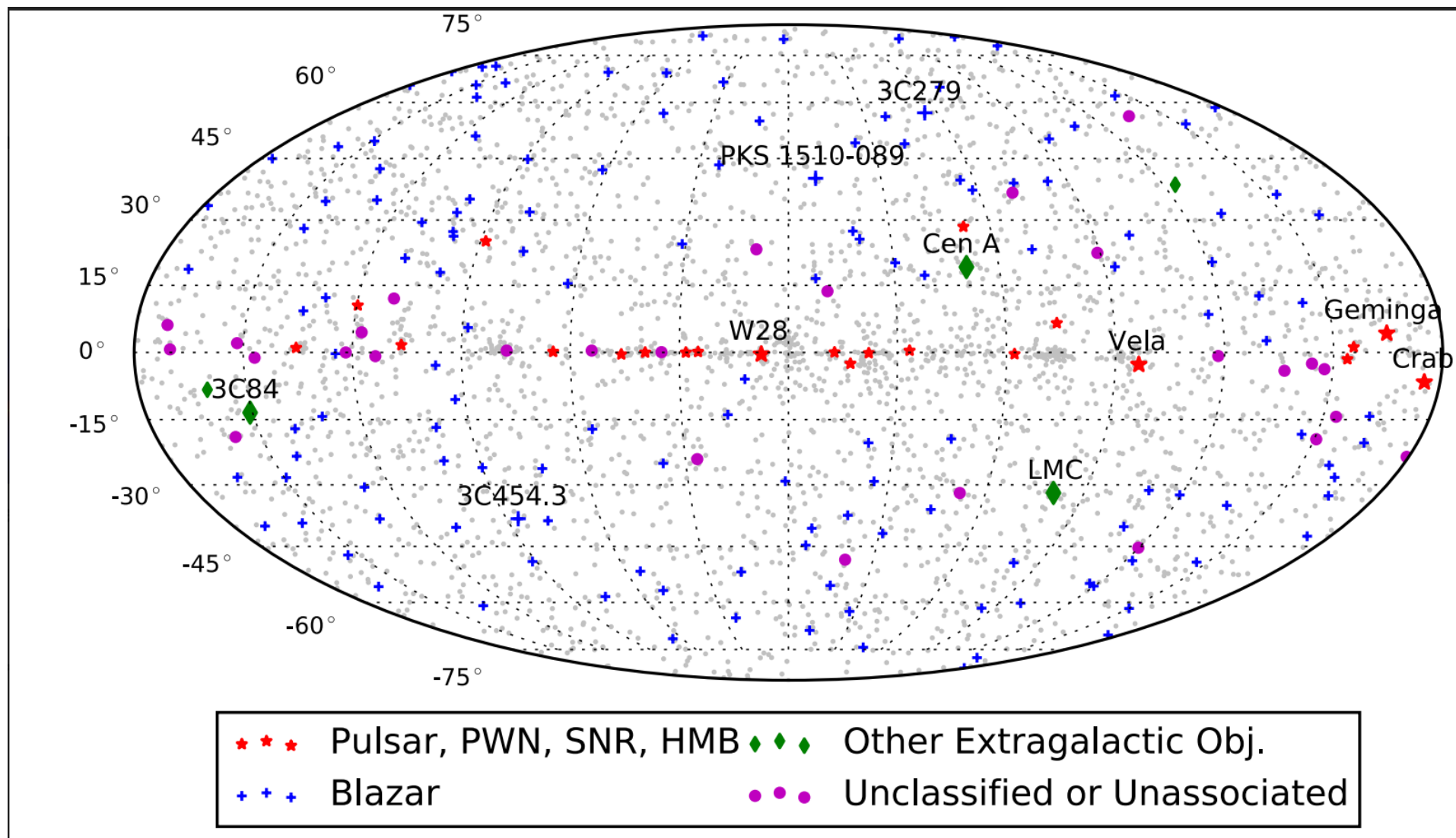


□ No association	▣ Possible association with SNR or PWN	★ AGN
★ Pulsar	△ Globular cluster	★ Starburst Galaxy
▣ Binary	+ Galaxy	◇ PWN
★ Star-forming region	□ Unclassified source	★ Nova
	○ SNR	

LAT – Low Energy (30 – 100 MeV) sky

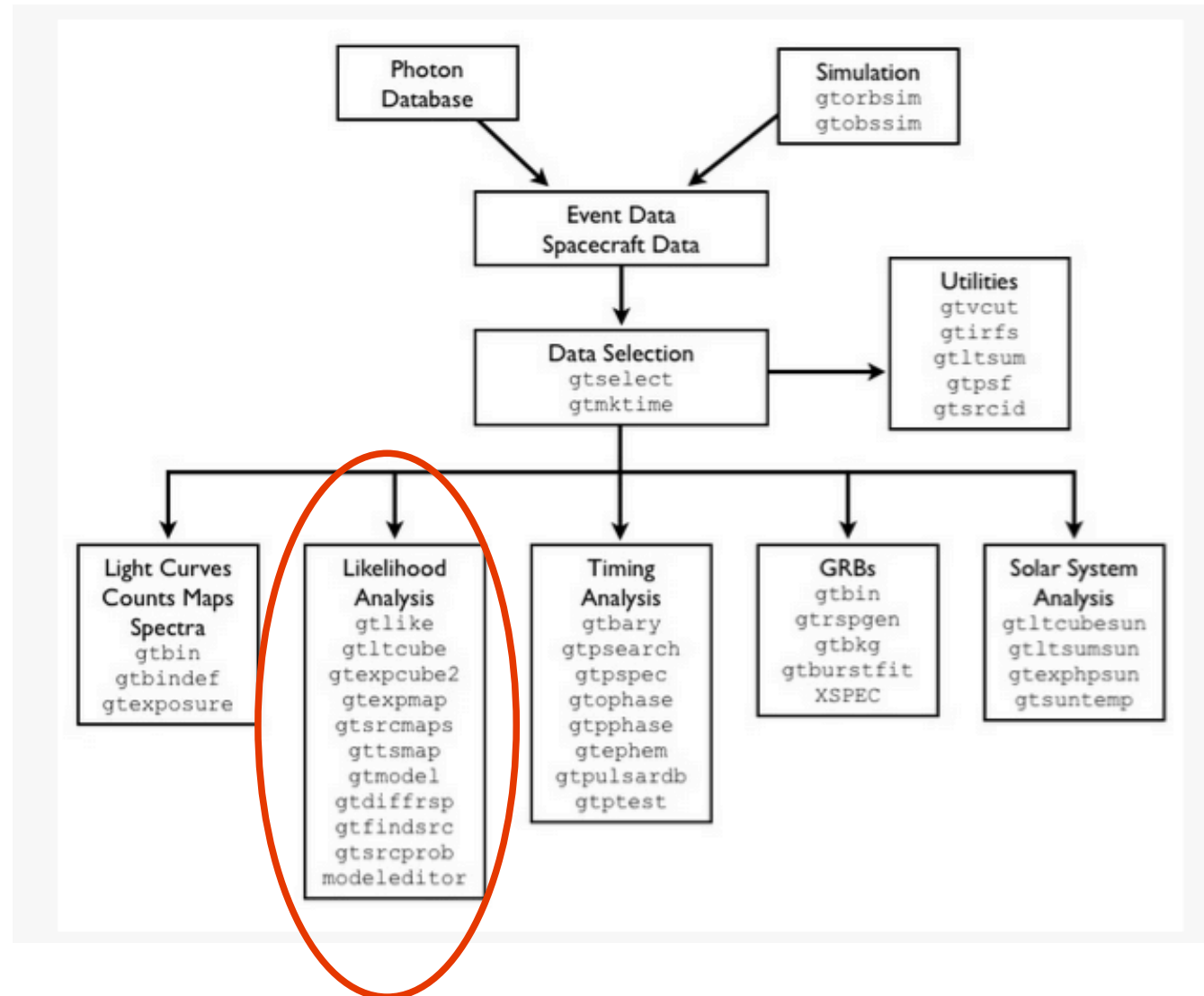


LAT – 1FLE catalog

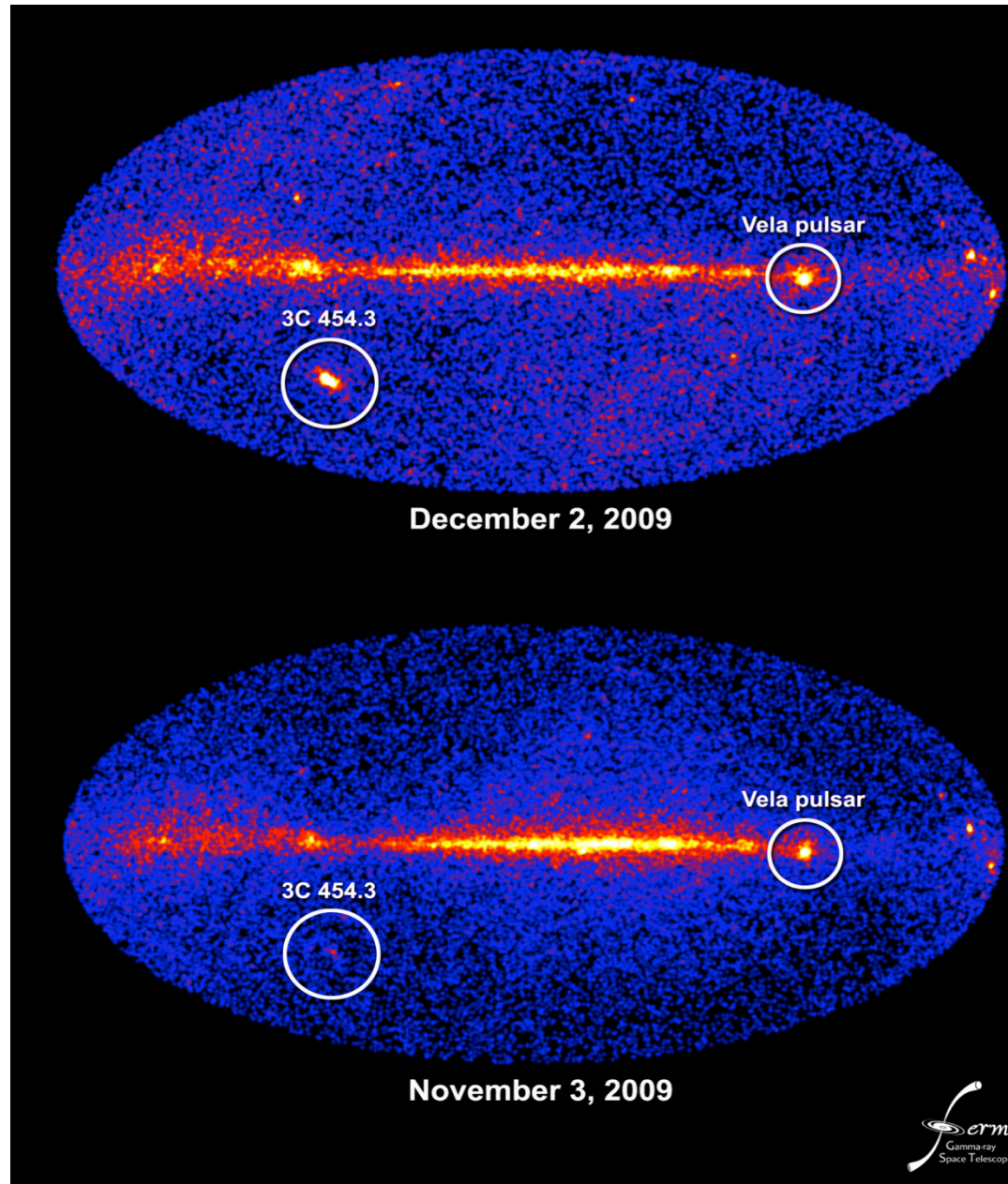


Explore LAT data

Overview of Fermi Science Tools



Blazar one of ... 3c454.3's record flares!



How to download data

- <http://fermi.gsfc.nasa.gov/cgi-bin/ssc/LAT/>

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LAT Photon, Event, and Spacecraft Data Query

June 3, 2014: The data server is now loaded with reprocessed Pass7 photon data. This update is to the diffuse columns of the photon data only See the [caveats page](#) for more information.

NOTE: For queries encompassing the whole sky (or close to it), please use the pre-generated [Weekly All-Sky Files](#) available through [HEASARC Browse](#).

NOTE: Additional selections must be applied to data downloaded from the data server prior to use in a data analysis. See [recommended data selections](#) and [LAT caveats](#) for more details.

The photon database currently holds 385684180 photons, collected between 2008-08-04T15:43:37 UTC and 2014-09-04T12:16:03 UTC (Mission Elapsed Time (MET) 239557417 to 431525763 seconds).

The event database currently holds 2382326033 events, collected between 2008-08-04T15:43:37 UTC and 2014-09-04T13:36:18 UTC (Mission Elapsed Time (MET) 239557417 to 431530578 seconds).

Use [xTime](#) to convert between MET and other time systems.

Object name or coordinates:

Coordinate system:

Search radius (degrees):

Observation dates:

Time system:

Energy range (MeV):

LAT data type:

Spacecraft data:

The week of the giant outburst!!

→ Download both spacecraft and photon data ←
Take note of the start and stop MET
follow the link

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Your search criteria were:

Equatorial coordinates (degrees)	(343.491,16.1482)
Time range (MET)	(281318400,281923200)
Time range (Gregorian)	(2009-12-01 00:00:00,2009-12-08 00:00:00)
Energy range (MeV)	(100,300)
Search radius (degrees)	15

The state of your query is 2 (Query complete)

<u>Server</u>	<u>Position in Queue</u>	<u>Estimated Time Remaining (sec)</u>
Photon Server	Query complete	N/A
Spacecraft Server	Query complete	N/A

The filenames of the result files consist of the query ID string with an identifier appended to indicate which database the file came from. The identifiers are of the form: `_DDNN` where DD indicates the database and NN is the file number. The file number will generally be '00' unless the query resulted in a large data volume. In that case the data is broken up into multiple files. The values of the database field are:

- PH - Photon Database
- SC - Spacecraft Pointing, Livetime, and History Database
- EV - Extended Database

In the event that you do not see any files with the data type you requested listed below, you should try resubmitting your query as there may have been a problem.

<u>Filename</u>	<u>Number of Entries</u>	<u>Size (MB)</u>	<u>Status</u>
L14090420274034A4AC2B81_PH00.fits	3372	0.33	Available
L14090420274034A4AC2B81_SC00.fits	17120	2.52	Available

If you would like to download the files via wget, simply copy the following commands and paste them into a terminal window. The files will be downloaded to the current directory in the terminal window.

```
wget http://fermi.gsfc.nasa.gov/FTP/fermi/data/lat/queries/L14090420274034A4AC2B81_PH00.fits  
wget http://fermi.gsfc.nasa.gov/FTP/fermi/data/lat/queries/L14090420274034A4AC2B81_SC00.fits
```

gtselect (select data)

- `[/home/]$ gtselect evclass=128 evtype=3`
- Input FT1 file[photon.fits]
- Output FT1 file[filtered.fits]
- RA for new search center (degrees) (0:360) [343.494812]
- Dec for new search center (degrees) (-90:90) [16.1495]
- radius of new search region (degrees) (0:180) [10]
- start time (MET in s) (0:) [281318400]
- end time (MET in s) (0:) [281923200]
- lower energy limit (MeV) (0:) [100]
- upper energy limit (MeV) (0:) [500000]
- maximum zenith angle value (degrees) (0:180) [90]
- `> gtselect evclass=128 evtype=3 infile=ph.fits outfile=filter_... \`
- `ra=343.49 dec=16.15 rad=15 tmin=281318400 tmax=281923200 \`
- `emin=100 emax=500000 zmax=90`
- Note: all analysis steps are scriptable via explicit assign parameters on command-line. Look at the manual for details.

Events with a high prob. to be gammas

Setting the max ZA, filter gammas from albedo events (gamma from the Earth that can be a significant source of background)

gtmktime (cut the bad time intervals)

- [/home/]\$ `gtmktime`
- Spacecraft data file[spacecraft.fits]
- Filter expression[(DATA_QUAL>0)&&(LAT_CONFIG==1)]
- Apply ROI-based zenith angle cut[no]
- Event data file[filtered.fits]
- Output event file name[filtered_gti.fits]

Filter out events collected while passing in SAA and other low-quality events

Use ZA to filter only proper GTIs

gtbin (Counts Map)

- [/home]\$ `gtbin`
- Type of output file (CCUBE|CMAP|LC|PHA1|PHA2|HEALPIX) [CMAP]
- Event data file name[filtered_gti.fits]
- Output file name[cmap.fits]
- Spacecraft data file name[spacecraft.fits]
- Size of the X axis in pixels[120]
- Size of the Y axis in pixels[120]
- Image scale (in degrees/pixel)[0.25]
- Coordinate system (CEL - celestial, GAL -galactic) (CEL|GAL) [CEL]
- First coordinate of image center in degrees (RA or galactic l)[343.494812]
- Second coordinate of image center in degrees (DEC or galactic b) [16.1495]
- Rotation angle of image axis, in degrees[0]
- Projection method e.g. AIT|ARC|CAR|GLS|MER|NCP|SIN|STG|TAN:[AIT]

Look at the counts map

Use DS9 to look at the counts map of your ROI and check for close-by sources
> ds9 CMAP.fits &

The image shows the DS9 software interface. At the top, there is a menu bar with buttons for 'zoom', 'scale', 'color', 'region', 'wcs', and 'help'. Below this is a secondary menu bar with buttons for 'none', 'delete', 'list', 'load', and 'save'. To the right of the 'region' button, there are two blue arrows pointing to the text 'Click on region' and 'Click on load'. The main window displays a large circular counts map with a dark background and numerous small green and red dots representing sources. Several sources are labeled with their names, such as '1FGL J1549.3+0235', '1FGL J1505.0+0328', and '24M1753.1'. On the left side, there is a file selection dialog box. The 'Filter' field contains '/data/glast/analysis/sara/allsky/*.reg'. The 'Directory' field is empty. The 'Files' list contains several files, with 'gll_psc24month_v2.reg' circled in blue. The 'Selection' field contains '/data/glast/analysis/sara/allsky/old_cat/gll_psc24month_v2.'. Below the dialog box, there are three buttons: 'OK', 'Filter', and 'Cancel'. A blue arrow points from the 'Filter' button to the text 'These files can be downloaded from FSSC'.

Click on region
Click on load

Filter:
/data/glast/analysis/sara/allsky/*.reg

Directory:

Files:
gll_psc11month_v1b.reg
gll_psc11month_v4r4_flags.
gll_psc11month_v8_assoc.
gll_psc24month_v2.reg

Selection:
/data/glast/analysis/sara/allsky/old_cat/gll_psc24month_v2.

REG FITS All

OK Filter Cancel

These files can be downloaded from FSSC

gtbin (Light Curve)

Take care that just one source falls inside the gtselect'ed ROI
(and take out albedo and other low-quality gammas via gtmktime)

- [/home]\$ `gtbir`
- Type of output file (CCUBE | CMAP | LC | PHA1 | PHA2 | HEALPIX) [LC]
- Event data file name[filtered_gti_smallROI.fits] → **NB**
selected at 1 deg
- Output file name[LC.fits]
- Spacecraft data file name[sc.fits]
- Algorithm for defining time bins (FILE | LIN | SNR) [LIN]
- Start value for first time bin in MET[281318400]
- Stop value for last time bin in MET[281923200]
- Width of linearly uniform time bins in seconds[86400]

Light-curve: a quick-look

Use FitsView to look at the lightcurve:

> fv LC.fits & (rough estimate .. Not background subtracted)

Index	Extension	Type	Dimension	View		
<input type="checkbox"/> 0	Primary	Image	0	Header	Image	Table
<input type="checkbox"/> 1	RATE	Binary	4 cols X 60 rows	Header	Hist	Plot All Select
<input type="checkbox"/> 2	GTI	Binary	2 cols X 1174 rows	Header	Hist	Plot All Select

Select Plot Columns

Click on a column name then select the corresponding plot axis or error bar

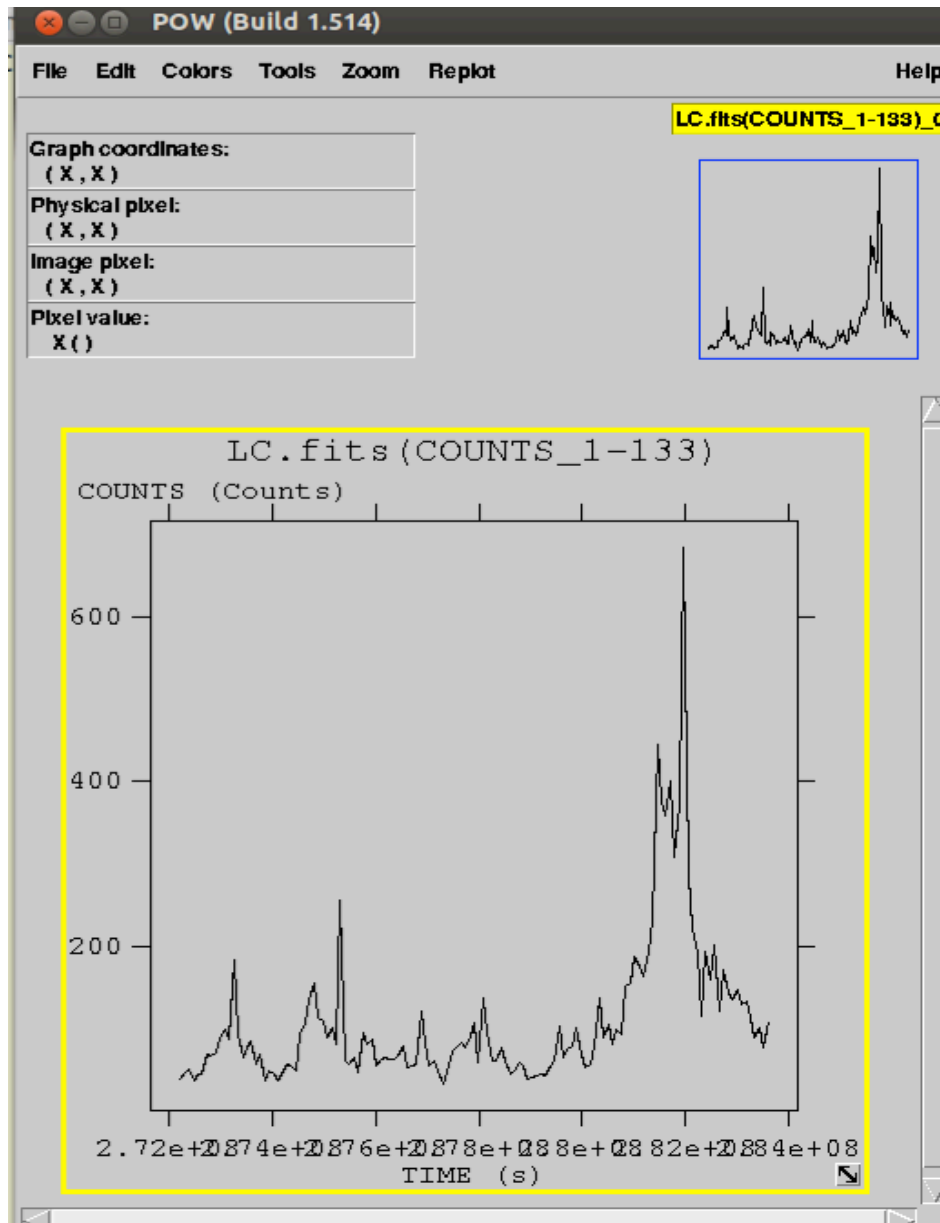
Axis	Column name or expression to plot
X	TIME
Y	COUNTS
X Error	
Y Error	ERROR
Rows:	

Use selected rows

Add my curve to current graph

Plot Clear Close Help

Light-curve: a quick-look



Rough estimate of light
curve
(background not
subtracted!)

gtbin – II (Light Curve)

- [/home]\$ `gtexposure`
- Light curve file[] `lc.fits`
- Spacecraft file[] `sc.fits`
- Response functions[`CALDB`]
- Source model XML file[`none`]
- Photon index for spectral weighting[`-2.1`]

Light-curve: calculate fluxes

Use FitsView to look at the lightcurve:

> fv LC.fits &

The screenshot shows two windows from the FitsView application. The top window, titled 'fv: Summary of lc.fits in /home/grb/GRBWorkdir/test3c454.3/', displays a table of fit components. The bottom window, titled 'fv: Binary Table of lc.fits[1] in /home/grb/GRBWorkdir/test3c454.3/', shows a detailed table of the light curve data. In both windows, the 'All' button in the 'View' section is highlighted with a red box.

Index	Extension	Type	Dimension	View
0	Primary	Image	0	Header Image Table
1	RATE	Binary	5 cols X 14 rows	Header Hist Plot All Select
2	GTI	Binary	2 cols X 108 rows	Header Hist Plot All Select

Select	TIME	TIMDEL	COUNTS	ERROR	EXPOSURE
D	D	J	E	E	E
s	s	Counts	cm**2 s		
<input checked="" type="checkbox"/> All					
Invert	Modify	Modify	Modify	Modify	Modify
1	2.813400000000E+08	4.320000000000E+04	499	2.233831E+01	3.357058E+07
2	2.813832000000E+08	4.320000000000E+04	562	2.370654E+01	2.934804E+07
3	2.814264000000E+08	4.320000000000E+04	786	2.803569E+01	3.361577E+07
4	2.814696000000E+08	4.320000000000E+04	804	2.835489E+01	2.940765E+07
5	2.815128000000E+08	4.320000000000E+04	789	2.808914E+01	3.383888E+07
6	2.815560000000E+08	4.320000000000E+04	642	2.533772E+01	2.968254E+07
7	2.815992000000E+08	4.320000000000E+04	704	2.653300E+01	3.394360E+07
8	2.816424000000E+08	4.320000000000E+04	678	2.603843E+01	2.950936E+07
9	2.816856000000E+08	4.320000000000E+04	870	2.949576E+01	3.397395E+07
10	2.817288000000E+08	4.320000000000E+04	581	2.410394E+01	3.093104E+07
11	2.817720000000E+08	4.320000000000E+04	631	2.511971E+01	3.316895E+07
12	2.818152000000E+08	4.320000000000E+04	609	2.467793E+01	3.036927E+07
13	2.818584000000E+08	4.320000000000E+04	712	2.668333E+01	3.331383E+07
14	2.819016000000E+08	4.320000000000E+04	695	2.636285E+01	3.292790E+07

Light-curve: calculate fluxes

Insert new column
Calculate rate
Calculate rate errors

The screenshot shows a software window titled "fv: Binary Table of lc.fits[1] in /home/grb/GRBWorkdir/test3c454.3/". The window contains a table with columns for TIME, TIMEDEL, COUNTS, ERROR, and EXPOSURE. The table has 14 rows of data. A dialog box titled "fv : add column info" is open in the foreground, allowing the user to define a new column. The dialog box has fields for Column Name, Column Format, Column Unit, Display Format, and Insert Before (set to "End of Table").

Select	TIME	TIMEDEL	COUNTS	ERROR	EXPOSURE
<input type="checkbox"/> All	D	D	J	E	E
<input type="checkbox"/> Invert	s	s	Counts		cm**2 s
	Modify	Modify	Modify	Modify	Modify
1	2.813400000000E+08	4.320000000000E+04	499	2.233831E+01	3.357058E+07
2	2.813832000000E+08	4.320000000000E+04	562	2.370654E+01	2.934804E+07
3	2.814264000000E+08	4.320000000000E+04	786	2.803569E+01	3.361577E+07
4	2.814696000000E+08	4.320000000000E+04	804	2.835489E+01	2.940765E+07
5	2.815128000000E+08	4.320000000000E+04	789	2.808914E+01	3.383888E+07
6	2.815560000000E+08	4.320000000000E+04	642	2.533772E+01	2.968254E+07
7	2.815992000000E+08	4.320000000000E+04			3.394360E+07
8	2.816424000000E+08	4.320000000000E+04			2.950936E+07
9	2.816856000000E+08	4.320000000000E+04			3.397395E+07
10	2.817288000000E+08	4.320000000000E+04			2.993104E+07
11	2.817720000000E+08	4.320000000000E+04			3.316895E+07
12	2.818152000000E+08	4.320000000000E+04			2.9036927E+07
13	2.818584000000E+08	4.320000000000E+04			3.331383E+07
14	2.819016000000E+08	4.320000000000E+04			2.92790E+07

fv : add column info

Column Name

Column Format ▼

Column Unit

Display Format

Insert Before End of Table ▼

OK Cancel

Light-curve: calculate fluxes

Insert new column
Calculate rate
Calculate rate errors

The screenshot shows two windows from a software application. The top window, titled "fv: Summary of lc.fits in /home/grb/GRBWorkdir/test3c454.3/", displays a table with columns: Index, Extension, Type, Dimension, and View. The bottom window, titled "fv: Binary Table of lc.fits[1] in /home/grb/GRBWorkdir/test3c454.3/", displays a detailed table with columns: TIME, TIMEDEL, COUNTS, ERROR, and EXPOSURE. The "Tools" menu in the bottom window is highlighted, and the "All" button in the top window's View column is also highlighted.

Index	Extension	Type	Dimension	View
0	Primary	Image	0	Header Image Table
1	RATE	Binary	5 cols X 14 rows	Header Hist Plot All Select
2	GTI	Binary	2 cols X 108 rows	Header Hist Plot All Select

	TIME	TIMEDEL	COUNTS	ERROR	EXPOSURE
Select	D	D	J	E	E
■ All	s	s	Counts		cm**2 s
Invert	Modify	Modify	Modify	Modify	Modify
1	2.813400000000E+08	4.320000000000E+04	499	2.233831E+01	3.357058E+07
2	2.813832000000E+08	4.320000000000E+04	562	2.370654E+01	2.934804E+07
3	2.814264000000E+08	4.320000000000E+04	786	2.803569E+01	3.361577E+07
4	2.814696000000E+08	4.320000000000E+04	804	2.835489E+01	2.940765E+07
5	2.815128000000E+08	4.320000000000E+04	789	2.808914E+01	3.383888E+07
6	2.815560000000E+08	4.320000000000E+04	642	2.533772E+01	2.968254E+07
7	2.815992000000E+08	4.320000000000E+04	704	2.653300E+01	3.394360E+07
8	2.816424000000E+08	4.320000000000E+04	678	2.603843E+01	2.950936E+07
9	2.816856000000E+08	4.320000000000E+04	870	2.949576E+01	3.397395E+07
10	2.817288000000E+08	4.320000000000E+04	581	2.410394E+01	3.093104E+07
11	2.817720000000E+08	4.320000000000E+04	631	2.511971E+01	3.316895E+07
12	2.818152000000E+08	4.320000000000E+04	609	2.467793E+01	3.036927E+07
13	2.818584000000E+08	4.320000000000E+04	712	2.668333E+01	3.331383E+07
14	2.819016000000E+08	4.320000000000E+04	695	2.636285E+01	3.292790E+07

Light-curve: calculate fluxes

Insert new column

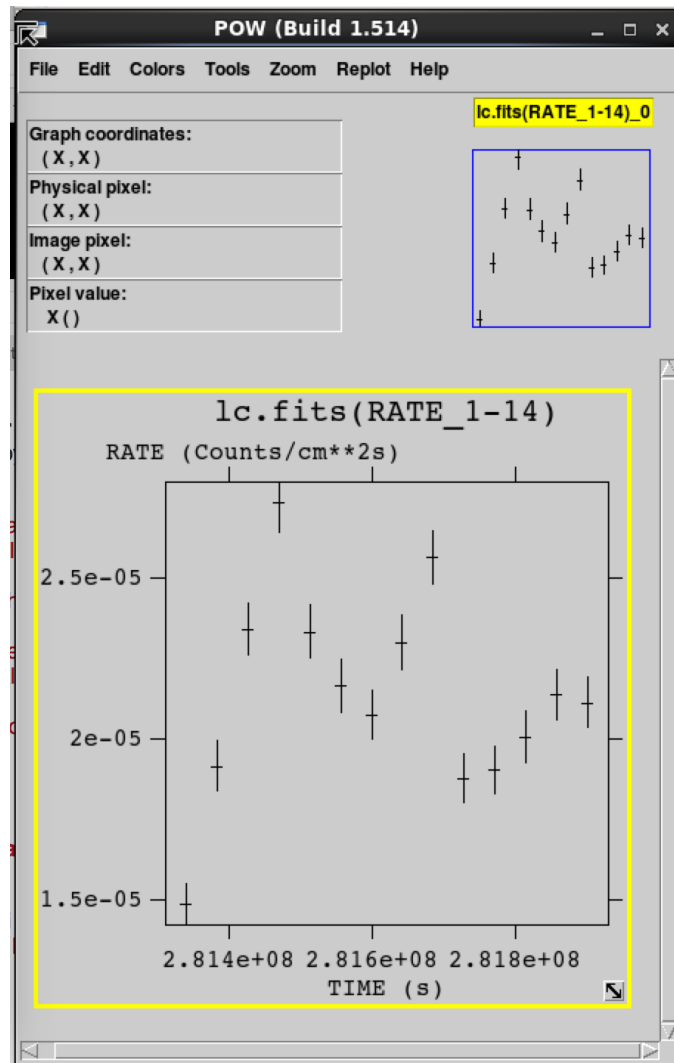
Calculate rate

Calculate rate errors

The screenshot shows a software interface for calculating fluxes. At the top, there are column headers: **TIME** (D), **TIMEDEL** (D), **COUNTS** (J), **ERROR** (E), **EXPOSURE** (E), and **RATE** (1E). Below these is a window titled "fv: Calculator" with a dropdown menu and an equals sign. The calculator window contains a grid of columns: TIME, TIMEDEL, COUNTS, ERROR, EXPOSURE, and RATE. Below the grid are buttons for "Calculate", "Close", and "Help". A checkbox labeled "Apply only to selected rows" is also present. To the right of the calculator window is a "Modify" button and a table with 10 rows of data, all showing 0.000000E+00 for the RATE column.

TIME	TIMEDEL	COUNTS	ERROR	EXPOSURE	RATE
					0.000000E+00
					0.000000E+00
					0.000000E+00
					0.000000E+00
					0.000000E+00
					0.000000E+00
					0.000000E+00
					0.000000E+00
					0.000000E+00
					0.000000E+00

Light curve



Analysis Tutorial - 2

Maximum Likelihood Overview

Perform the fit: the likelihood

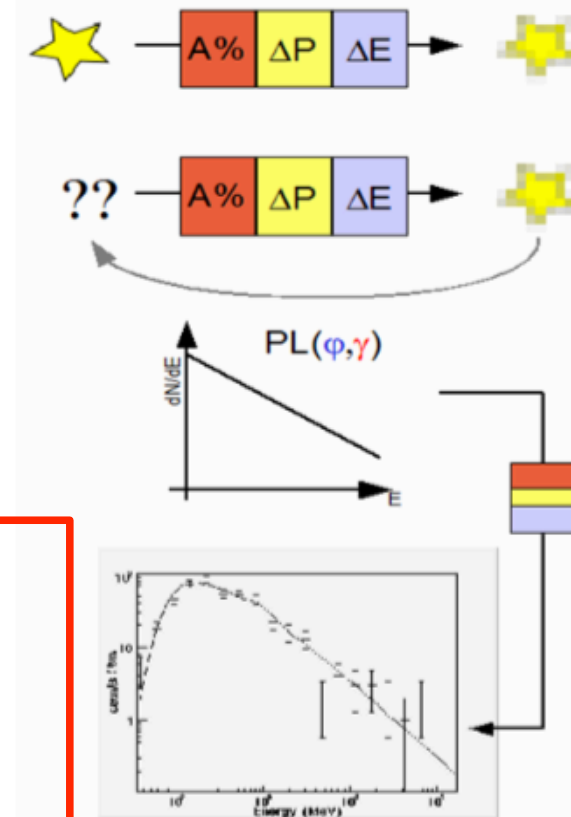
In high energy gamma rays it is never possible to really isolate a source because of limited statistics and strong and structured background.

Therefore statistical techniques have to be applied.

The most used method is the likelihood analysis based on the Poisson statistics.

The method requires to assume a model for the signal detected by the telescope.

- Assume a **model**
- Model **convolved** with Instrument response Function (IRF)
- Maximizing likelihood find the best set of parameters that reproduce the observed spectrum



Maximum likelihood technique

Given a set of observed data:

- Produce a model that accurately describes the data, including parameters that we wish to estimate
- derive the probability (density) for the data given the model (PDF)
- treat this as a function of the model parameters (likelihood function)
- maximize the likelihood with respect to the parameters - ML estimation.

Maximum likelihood ingredients

Data:

$$X = \{x_i\} = \{x_1, x_2, \dots, x_N\}$$

Model parameters:

$$\Theta = \{\theta_j\} = \{\theta_1, \theta_2, \dots, \theta_M\}$$

Likelihood:

$$\mathcal{L}(\Theta|X) = P(X|\Theta)$$

Conditional probability rule

for independent events:

$$P(A, B) = \underset{\text{CPR}}{P(A)} \underset{\text{Independence}}{P(B|A)} = P(A)P(B)$$

For independent data:

$$\begin{aligned} P(X|\Theta) &= P(\{x_i\}|\Theta) = P(x_1|\Theta)P(x_2, \dots, x_N|\Theta) = \dots \\ &= P(x_1|\Theta)P(x_2|\Theta) \dots P(x_N|\Theta) = \prod_i P(x_i|\Theta) \end{aligned}$$

$$\mathcal{L}(\Theta|X) = \prod_i P(x_i|\Theta)$$

\mathcal{L} is the product of the probability of observing the detected counts in each bin.

Maximum likelihood estimation

Parameters can be estimated by maximizing likelihood.

→ Easier to work with log-likelihood:

$$\ln \mathcal{L}(\Theta) = \ln \mathcal{L}(\Theta|X) = \sum_i \ln P(x_i|\Theta)$$

Estimates of $\{\hat{\theta}_k\}$ from solving simultaneous equations:

$$\left. \frac{\partial \ln \mathcal{L}}{\partial \theta_j} \right|_{\{\hat{\theta}_k\}} = 0$$

For one parameter, if we have:

$$\mathcal{L}(\theta) \sim e^{-\frac{(\theta - \hat{\theta})^2}{2\sigma_\theta^2}}$$

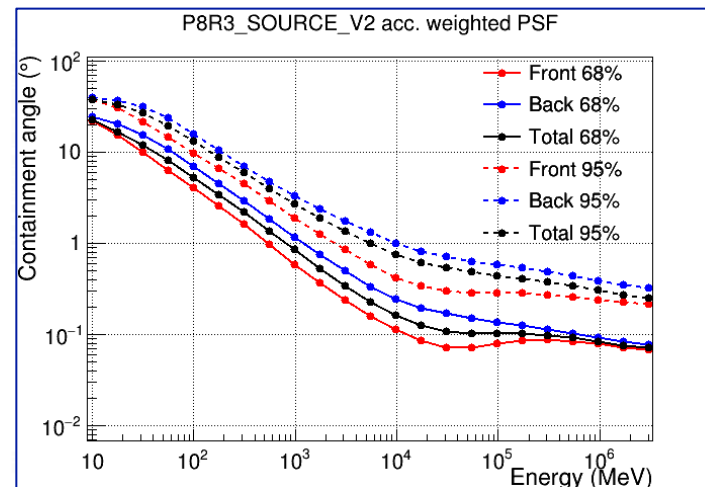
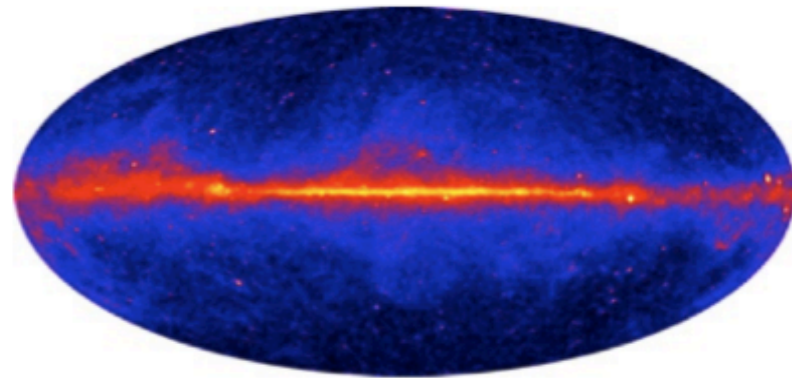
Gaussian approximation

then: $\left. \frac{\partial^2 \ln \mathcal{L}}{\partial \theta^2} \right|_{\hat{\theta}} = -\frac{1}{\sigma_\theta^2}$

so 2nd derivative is related to “errors”

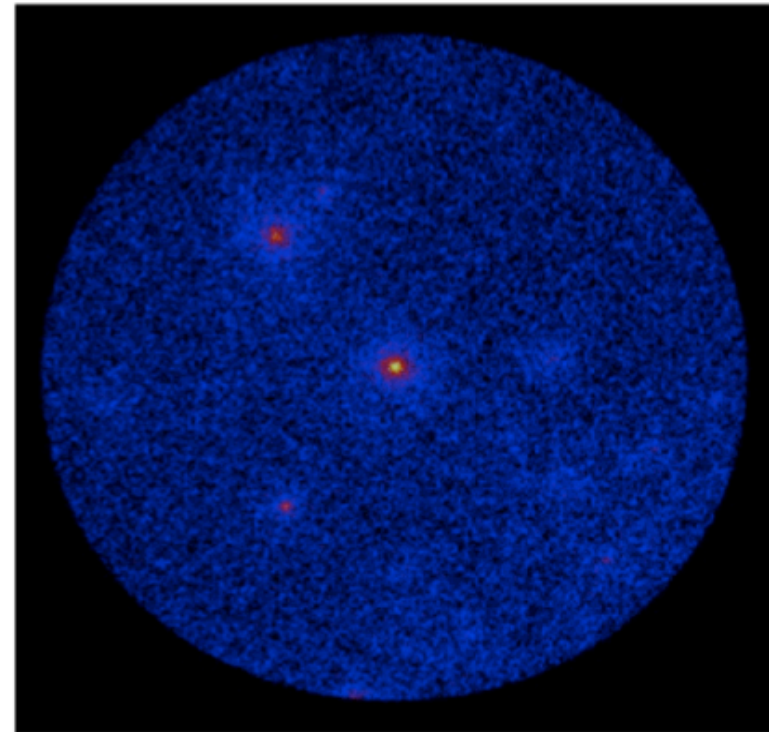
Why Model Fitting?

- We use the Likelihood method because the LAT data are limited by statistics, a bright diffuse background and a broad PSF.
- The model construction defines the questions we want to ask which means:
 - It will not answer a question you are not asking (ie. unknown parameters).
- The Likelihood will not tell you if a fit is 'good'. If the model does not represent your data well, the results will also not represent reality well.



The Challenge

- Gamma-ray data is a list of counts (photons) reconstructed in the detector.
- Qualitative exploration of the data suggests the presence of sources (spatial clustering).
- Quantitative analysis requires evaluating the significance of a 'model' of our region.

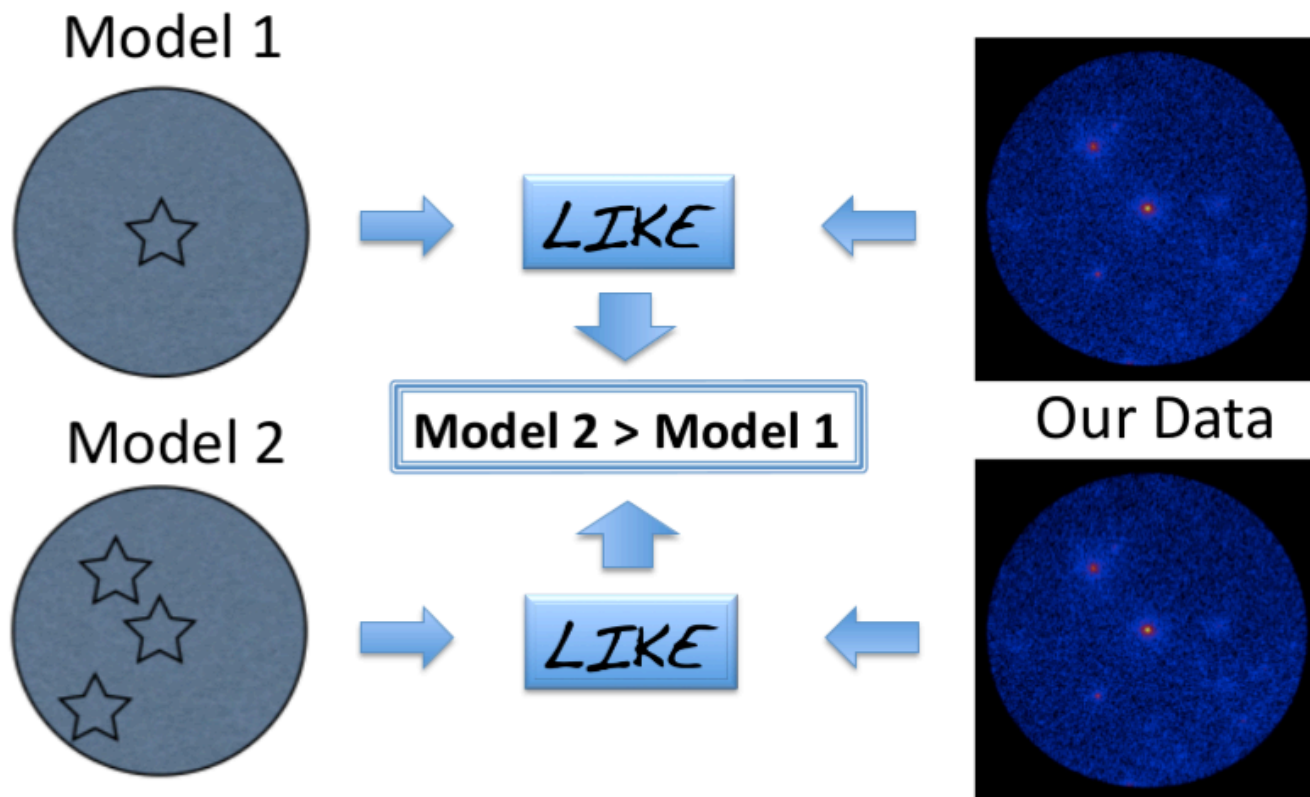


Count Map

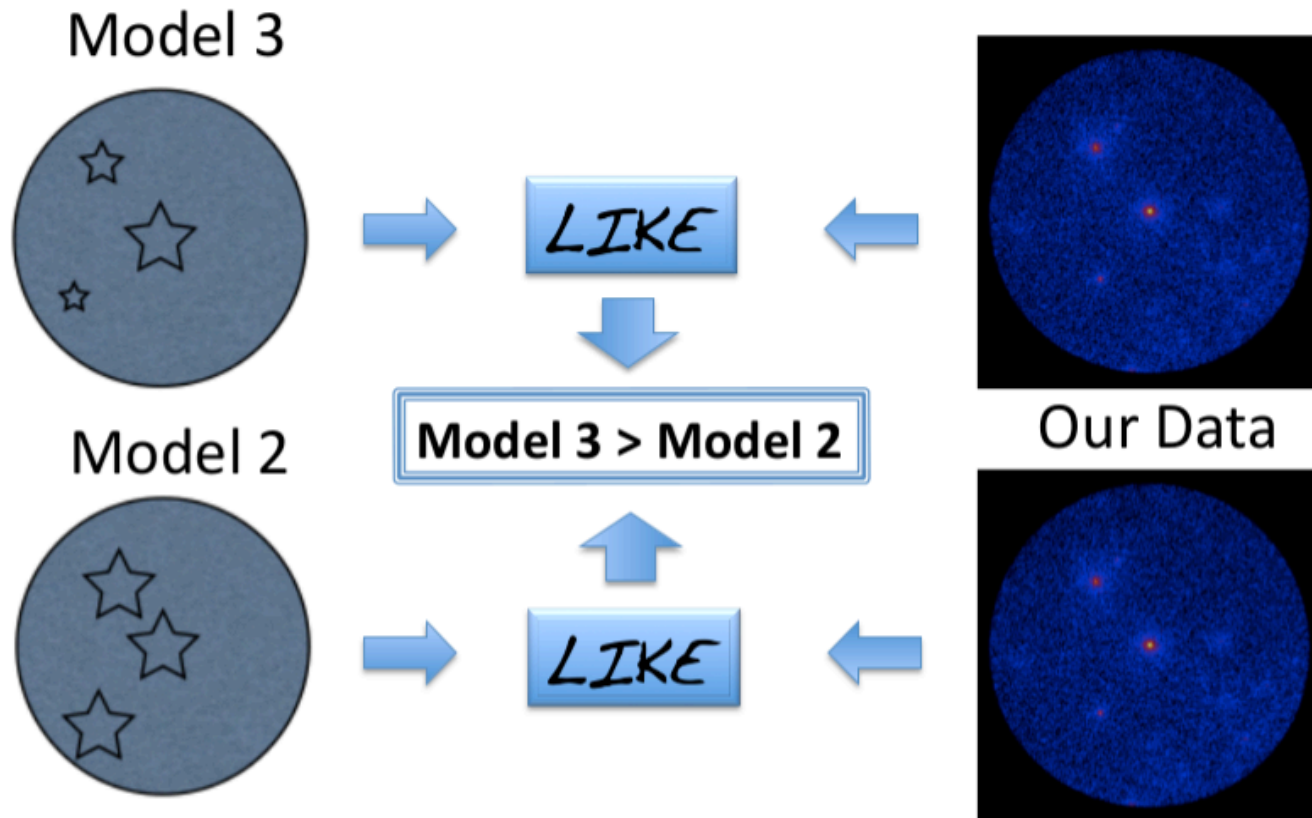
The Procedure

- Basically the initial '**model**' is a guess of the various parameters of the sources in our region:
 - location
 - spectral shape
 - flux
 - etc.
- The guess can be easier if you have a starting point like the 2FGL (3FGL).
- We quantify (using the Likelihood Method) the statistical significance of the model and vary the parameters to determine the most likely parameter values.

A Graphical Example



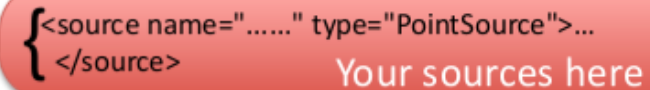
A Graphical Example



Describing the Source Model: the XML model

- Typical source entry for an assumed powerlaw spectrum

- `<!-- Point Sources -->`



```
{<source name="....." type="PointSource">...  
</source>
```

Your sources here

- `<source name="3c454.3" type="PointSource">`

- `<spectrum type="PowerLaw2">`

- `<!-- Source is in ROI center -->`

- `<parameter error="0.00" free="1" max="1000" min="1e-06" name="Integral" scale="1e-04" value="1.000"/>`

- `<parameter error="0.00" free="1" max="0" min="-5" name="Index" scale="1" value="-2.000"/>`

- `<parameter free="0" max="3e6" min="20" name="LowerLimit" scale="1" value="100."/>`

- `<parameter free="0" max="3e6" min="20" name="UpperLimit" scale="1" value="300000."/>`

- `</spectrum>`

- `<spatialModel type="SkyDirFunction">`

- `<parameter free="0" max="360.0" min="-360.0" name="RA" scale="1.0" value="343.494812"/>`

- `<parameter free="0" max="90" min="-90" name="DEC" scale="1.0" value="16.149500"/>`

- `</spatialModel>`

- `</source>`

XML model

- Test different models... power law * HE exponential cut-off
- `<source name="3c454.3" type="PointSource">`
- `<spectrum type="PLSuperExpCutoff">`
- `<parameter free="1" max="1000" min="1e-05" name="Prefactor" scale="1e-07" value="1"/>`
- `<parameter free="1" max="0" min="-5" name="Index1" scale="1" value="-1.7"/>`
- `<parameter free="0" max="1000" min="50" name="Scale" scale="1" value="200"/>`
- `<parameter free="1" max="30000" min="500" name="Cutoff" scale="1" value="3000"/>`
- `<parameter free="0" max="5" min="0" name="Index2" scale="1" value="1"/>`
- `</spectrum>`

- Look here for source model definition and XML model definitions:
- http://fermi.gsfc.nasa.gov/ssc/data/analysis/scitools/xml_model_defs.html
- http://fermi.gsfc.nasa.gov/ssc/data/analysis/scitools/source_models.html

- Useful python script to load 4FGL sources that belongs to your ROI in your XML file model ([make4FGLxml.py](#))
- <http://fermi.gsfc.nasa.gov/ssc/data/analysis/user/>
-

Describing the Source Model: the XML model

- Backgrounds

- `<!-- Diffuse Sources -->`
- `<source name="galactic_background" type="DiffuseSource">`
- `<spectrum type="PowerLaw">`
- `<parameter free="1" max="10" min="0" name="Prefactor" scale="1" value="1"/>`
- `<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_v07.fits" type="MapCubeFunction">`
- `<parameter free="0" max="1e3" min="1e-3" name="Normalization" scale="1.0" value="1.0"/>`
- `</spatialModel>`
- `</source>`
- `<source name="extragalactic_background" type="DiffuseSource">`
- `<spectrum file="iso_P8R3_SOURCE_V3_v1.txt" type="FileFunction">`
- `<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>`

Likelihood Analysis

- The likelihood \mathcal{L} is the probability of obtaining your data given an input model.
- In our case, the input model is the distribution of gamma-ray sources on the sky and includes their intensity and spectra.
- One will maximize \mathcal{L} to get the best match of the model to the data. Given a set of data, one can bin them in multidimensional (energy, sky pixels, ...) bins.
- \mathcal{L} is the product of the probabilities of observing the detected counts in each bin.

$$\mathcal{L} = \prod p_k$$

- Write \mathcal{L} as a function of the source model

The function to maximize is:

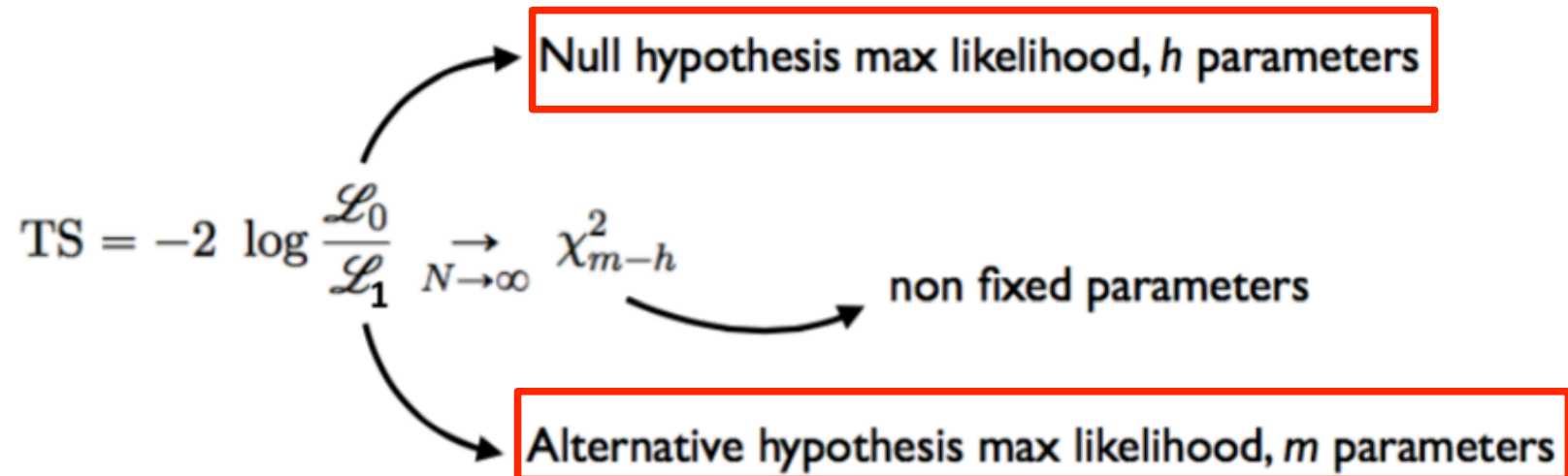
$$\log \mathcal{L} = \sum_j \log M(E'_j, \hat{p}'_j, t_j) - N_{\text{pred}}$$

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

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

- The source model is folded with the IRFs in order to obtain the predicted number of counts
- The IRFs can be decomposed into three functions: Effective Area (proj area of the detector * efficiency), Energy Dispersion, Point Spread Function
- Small number of counts in each bin --> Poisson distribution
- Bin size infinitesimally small
- Assume only steady source for standard analysis

Test Statistic



- In the limit of a large number of counts, Wilk's Theorem states that the TS for the null hypothesis is asymptotically distributed as χ_n^2 where n is the number of parameters characterizing the additional source.
- As a basic rule of thumb, the square root of the TS is approximately equal to the detection significance for a given source.

Summarizing

- Observed a photon from a location, at a time, with an energy.
- Assume a model:

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

- Calculate the probability of that photon being detected assuming our model:

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

- Calculate the total number of predicted counts assuming our model.

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

- Adjust the model until this is maximized:

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

- Calculate the TS:

$$\text{TS} = -2 \log \frac{\mathcal{L}_0}{\mathcal{L}_1} \xrightarrow{N \rightarrow \infty} \chi_{m-h}^2$$

Keep in mind that ..

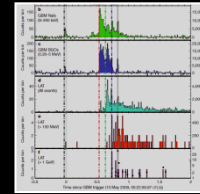
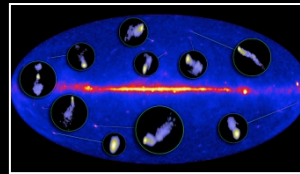
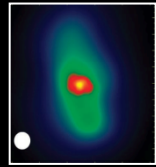
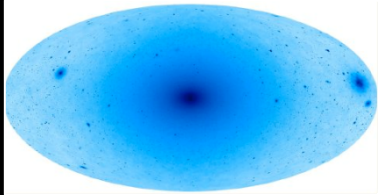
- Many variables may be calculated BEFORE selecting the models
- Very important to have a reliable model
- Absolute value of likelihood meaningless!
 - Likelihood function has no meaning itself, e.g., it is not a probability. Its usefulness comes from theorems such as the LRT.
- Comparison between model w/ and w/o source to reject null hypothesis = no source (TS large \rightarrow reject null hypothesis)

Astrofisica Nucleare e Subnucleare

Galactic GeV Sources

Fermi Highlights and Discoveries

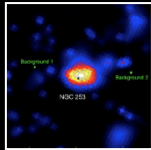
Dark Matter searches



GRBs

Blazars

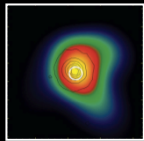
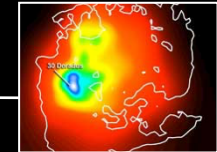
Radio Galaxies



Starburst Galaxies

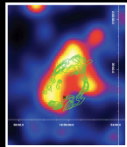
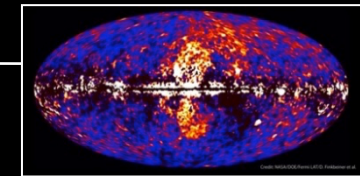
Extragalactic

LMC & SMC

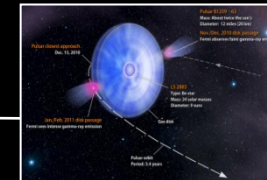


Globular Clusters

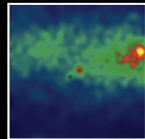
Fermi Bubbles



SNRs & PWN



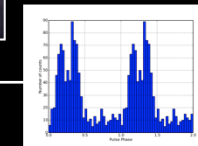
γ -ray Binaries



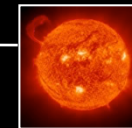
Novae

Galactic

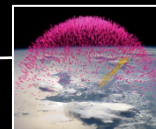
Pulsars: isolated, binaries, & MSPs



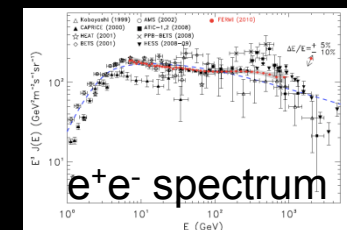
Sun: flares & CR interactions

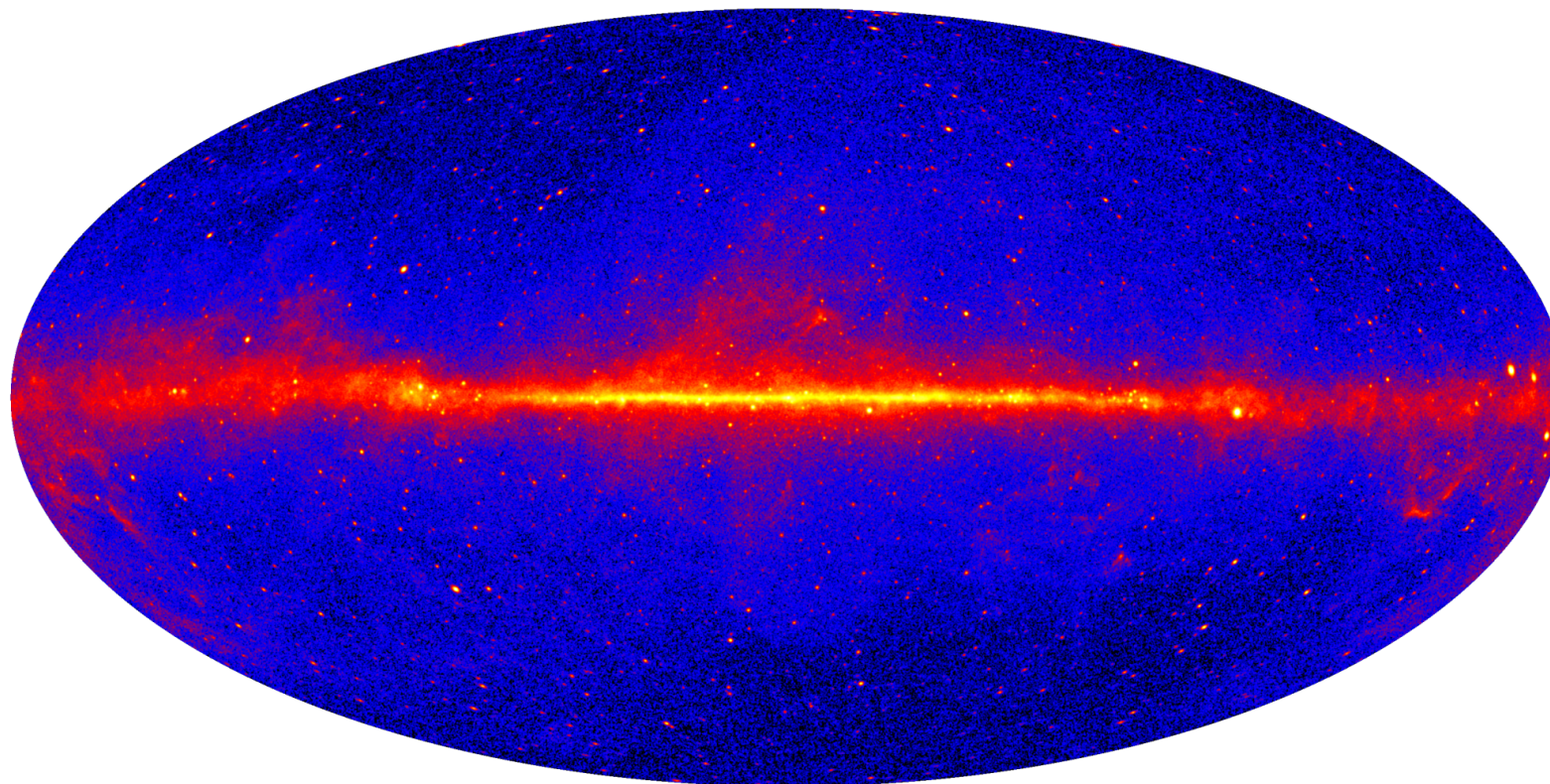
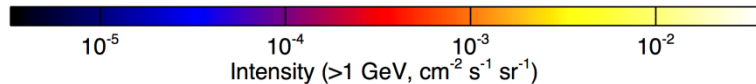


Terrestrial γ -ray Flashes



Unidentified Sources





84 months of data

>1 GeV. **Pass 8**, from August 4, 2008 through August 4, 2015.

LAT rocking angle <52° and zenith angle <100°.

Milky Way is gamma *bright*:

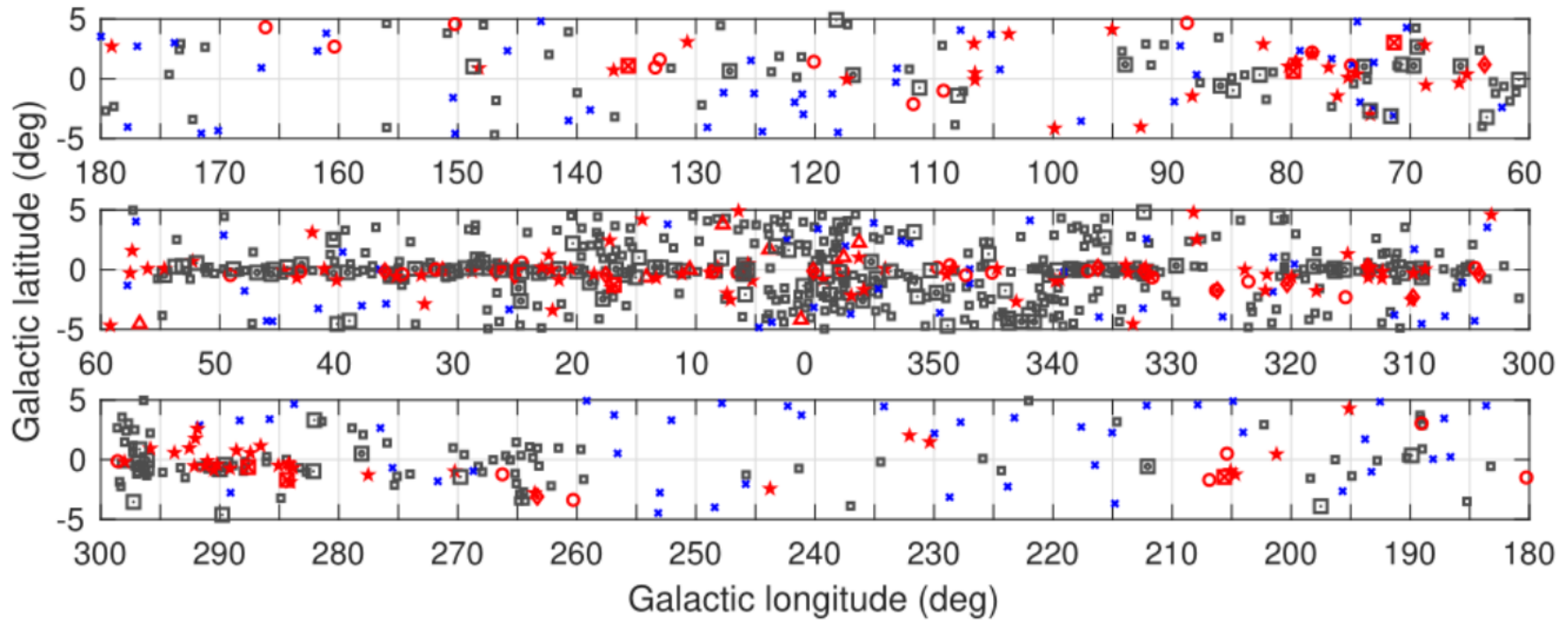
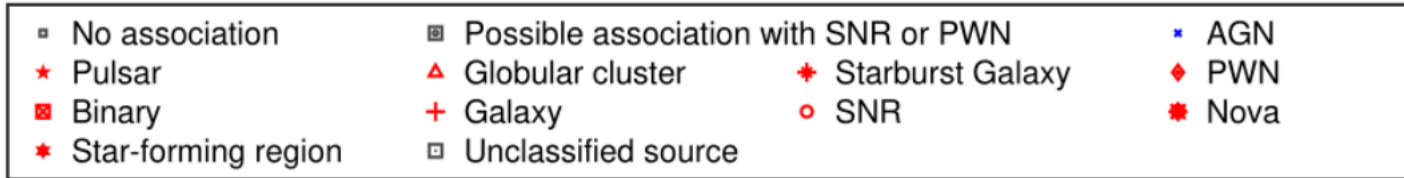
GeV and TeV cosmic rays (mostly protons) hit gas & dust to make pions,
 then $\pi^0 \rightarrow \gamma\gamma$ and $\pi^\pm \rightarrow \mu^\pm \nu \rightarrow e^\pm \nu \nu, e^\pm \rightarrow \gamma$'s.

Point sources in the plane are mostly pulsars.

Off the plane, mostly blazars (and some millisecond pulsars)

Smith 2016

Galactic GeV Sources



Unidentified Gamma-ray Sources

- Previous MeV-GeV energy gamma-ray missions left a legacy of “unidentified” sources (~2/3 of 3EG catalog)
 - Unidentified meant multiple possible candidates OR no plausible candidates (unassociated)
- LAT associations greatly aided by
 - Dramatically improved gamma-ray localization
 - Dedicated catalogs of potential gamma-ray counterparts
 - Multiwavelength searches
- LAT identifications from
 - Periodicity
 - Spatial morphology
 - Correlated variability with other observations

Spectral-Variability Classification

- Blazars and pulsars in the variability-spectral curvatur

