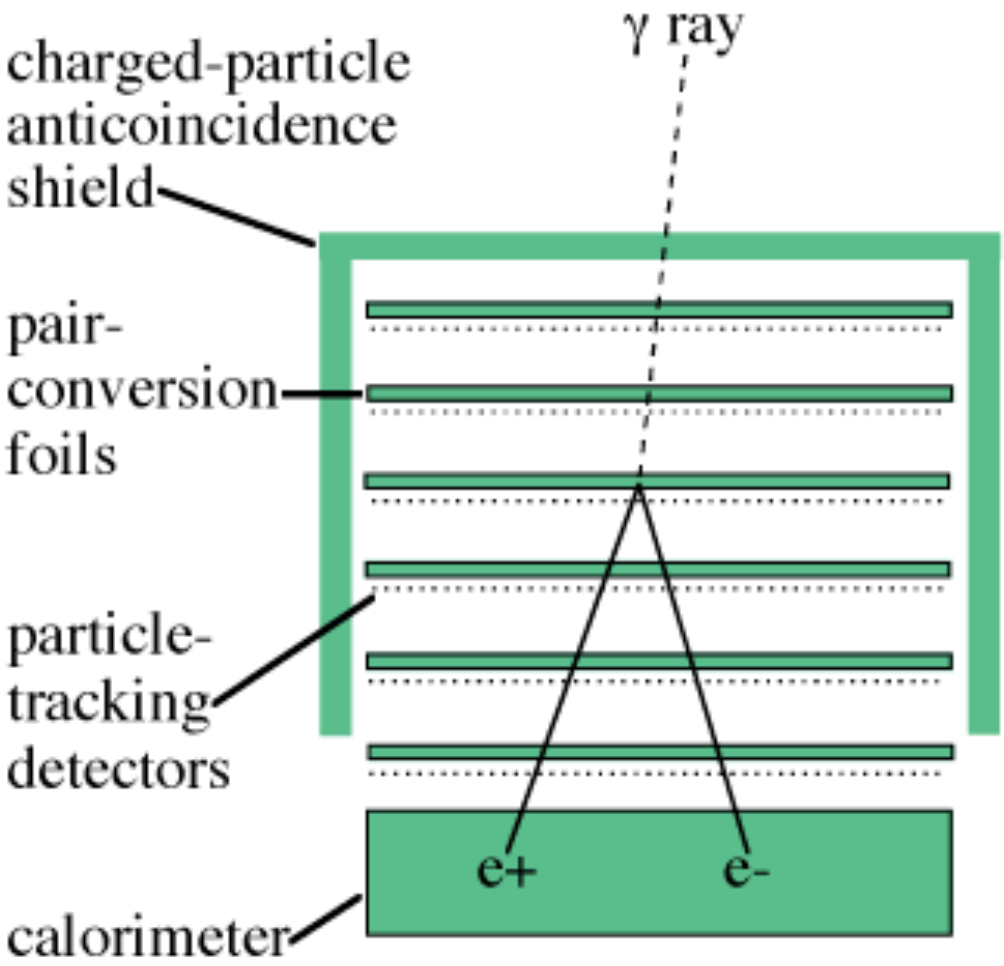
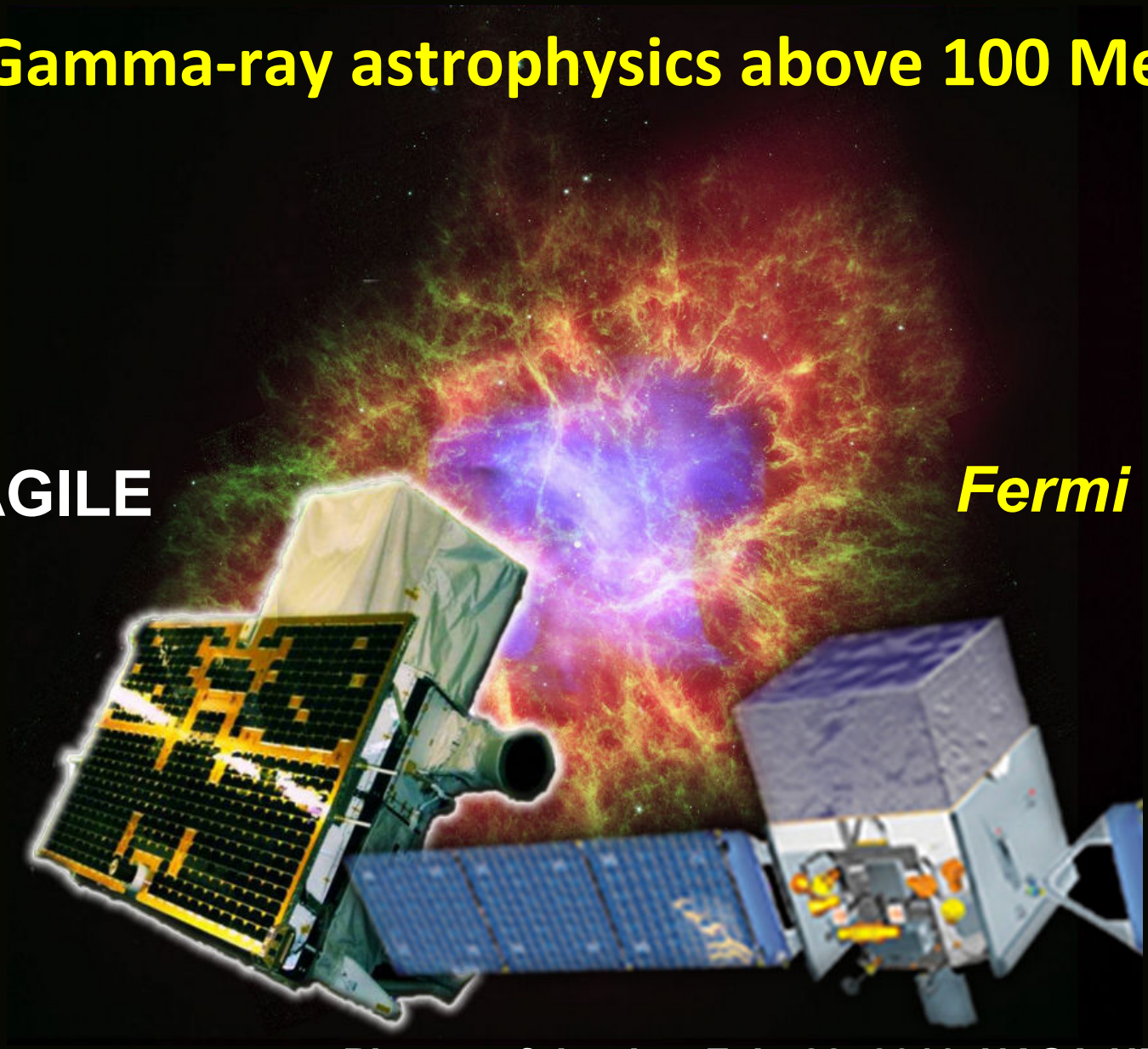
Astrofisica Nucleare e Subnucleare

GeV Astrophysics IV

Detector Project



Gamma-ray astrophysics above 100 MeV



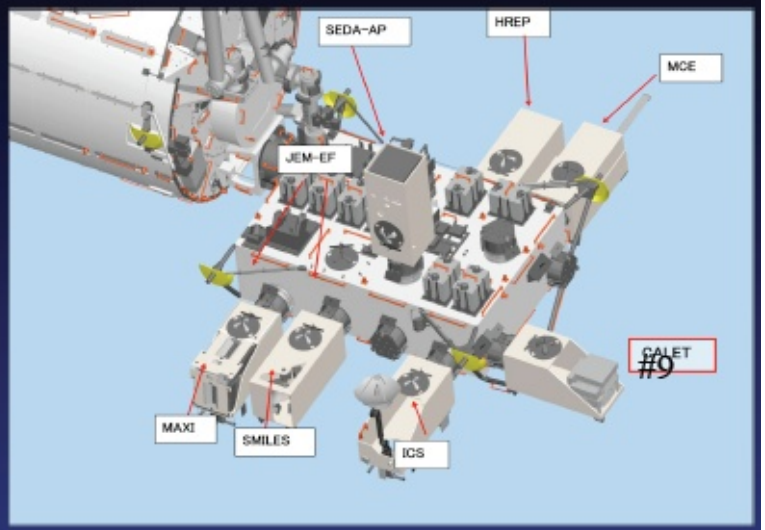
Picture of the day, Feb. 28, 2011, NASA-HEASARC

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



1 GeV ~ 20 TeV for electrons

20 MeV ~ TeV for gamma-rays

Weight: 500 kg

GF (fiducial volume): ~ 0.12 m^2sr

Power Consumption: 640 W

Data Rate: 300 kbps

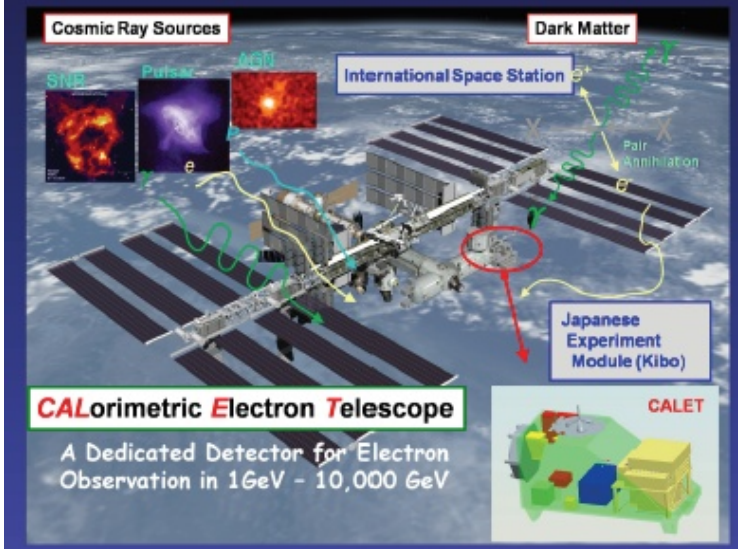
Firenze
Pisa
Siena
Roma Tor Vergata

CALET?

CALET Overview

Observation

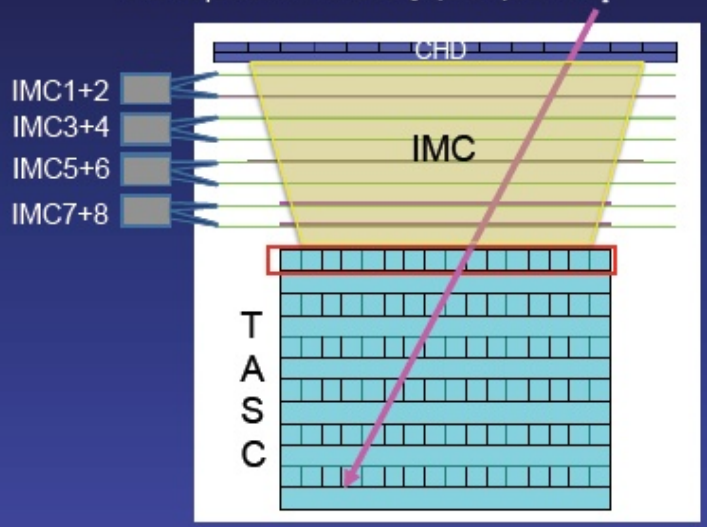
- **Electrons** : 1 GeV - 10 TeV
- **Gamma-rays** : 10 GeV-10 TeV (GRB > 1 GeV)
  + Gamma-ray Bursts : 7 keV-20 MeV
- **Protons, Heavy Nuclei**:
  several 10 GeV- 1000 TeV (per particle)
- **Solar Particles and Modulated Particles in Solar System**: 1 GeV-10 GeV (Electrons)



Instrument

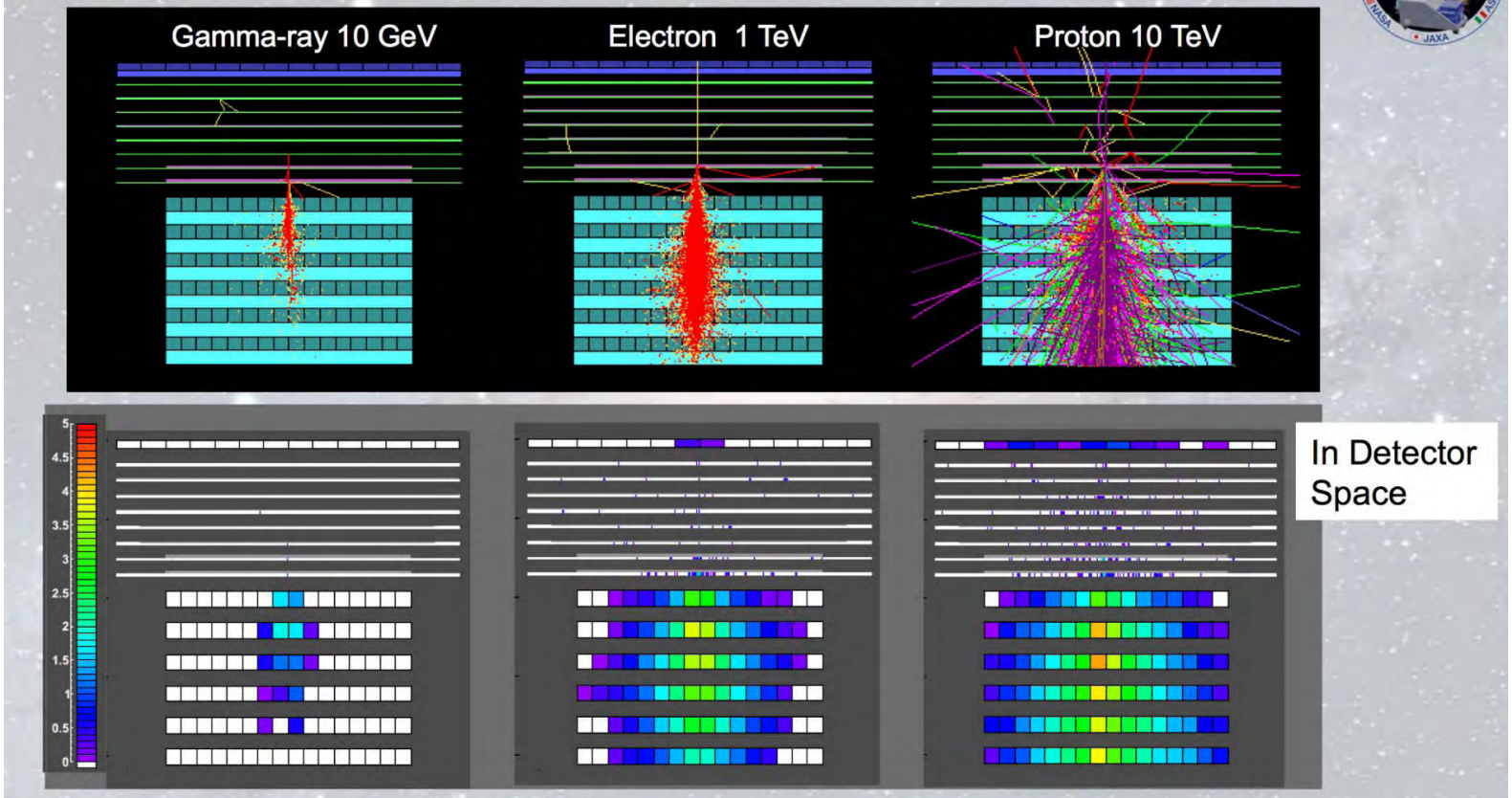
High Energy Electron and Gamma-Ray Telescope:

- 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 λ_I
  Layer Number of Scifi Belts: 8 Layers × 2(X,Y)
- Total Absorption Calorimeter (TASC)
  (Energy Measurement, Particle ID)
  PWO 20mm x 20mm x 320mm
  Total Depth of PWO: 27 X_0 (24cm) , 1.35 λ_I



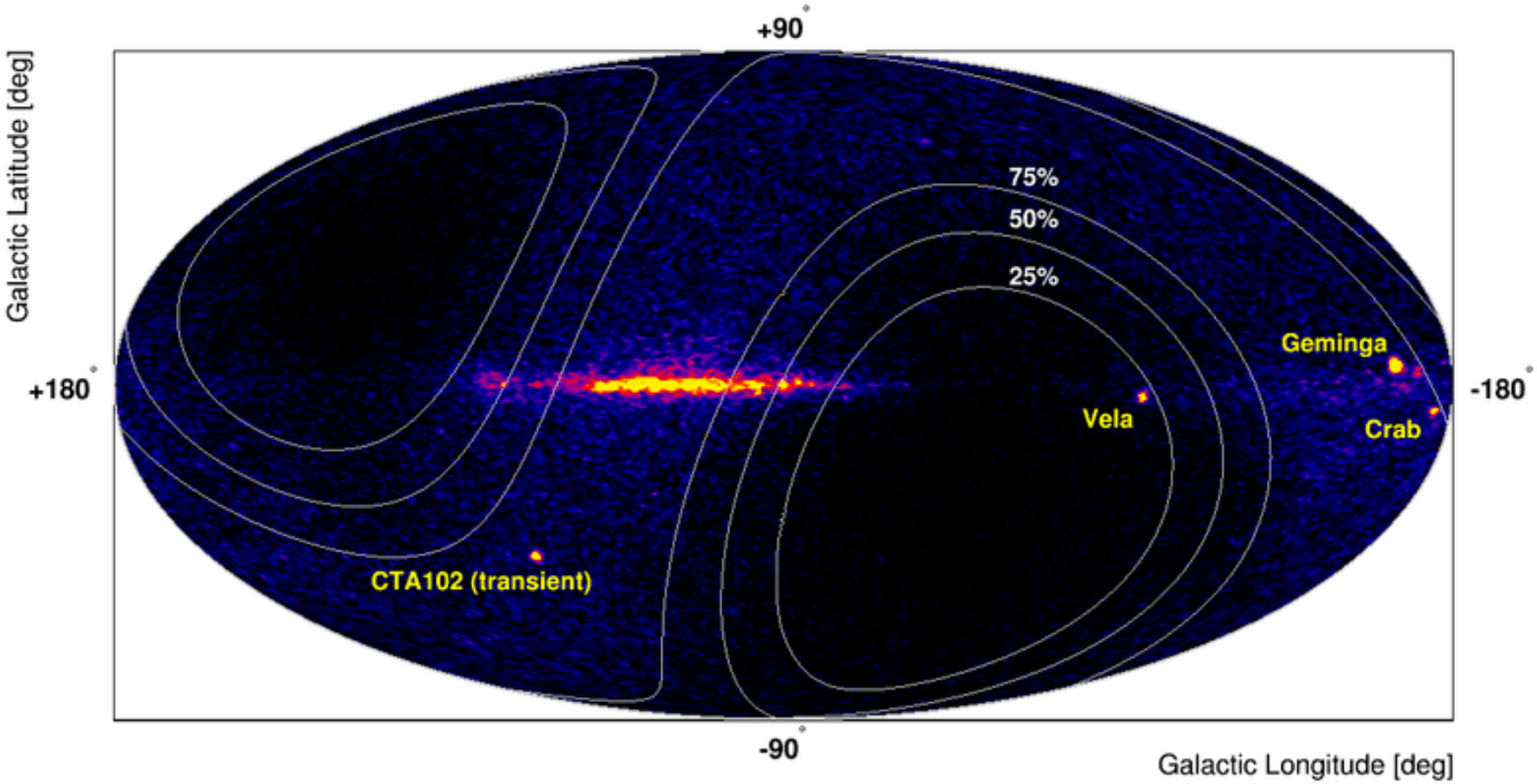
CALET

CALET/CAL Shower Imaging Capability (Simulation)



- 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

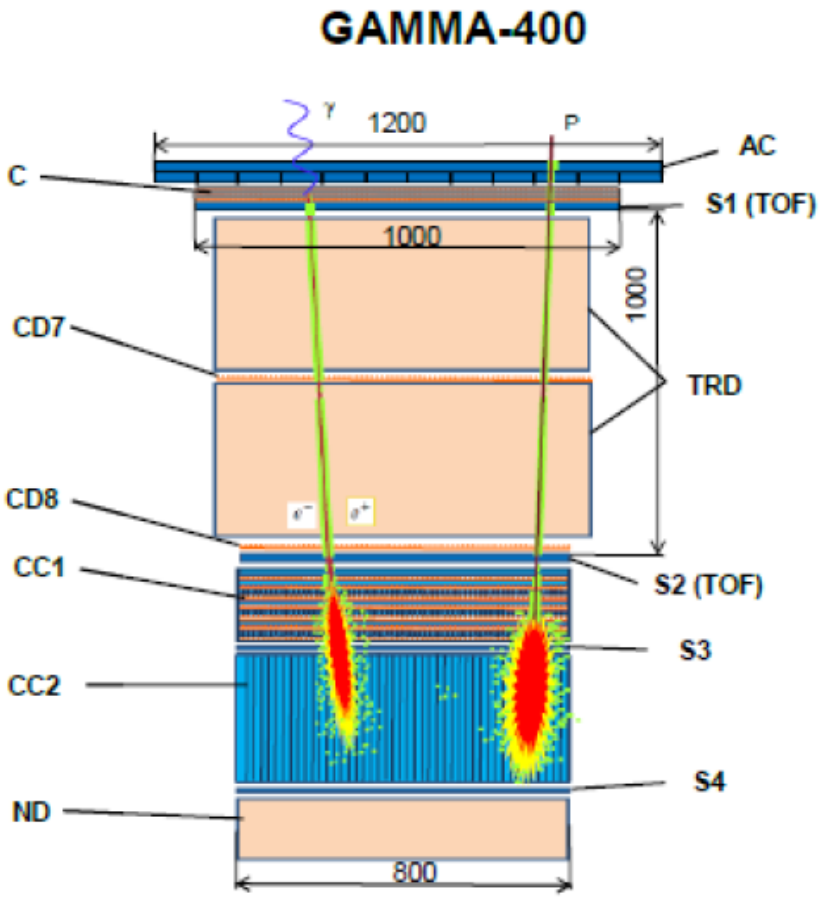
CC1 - imaging calorimeter (9Xo)

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

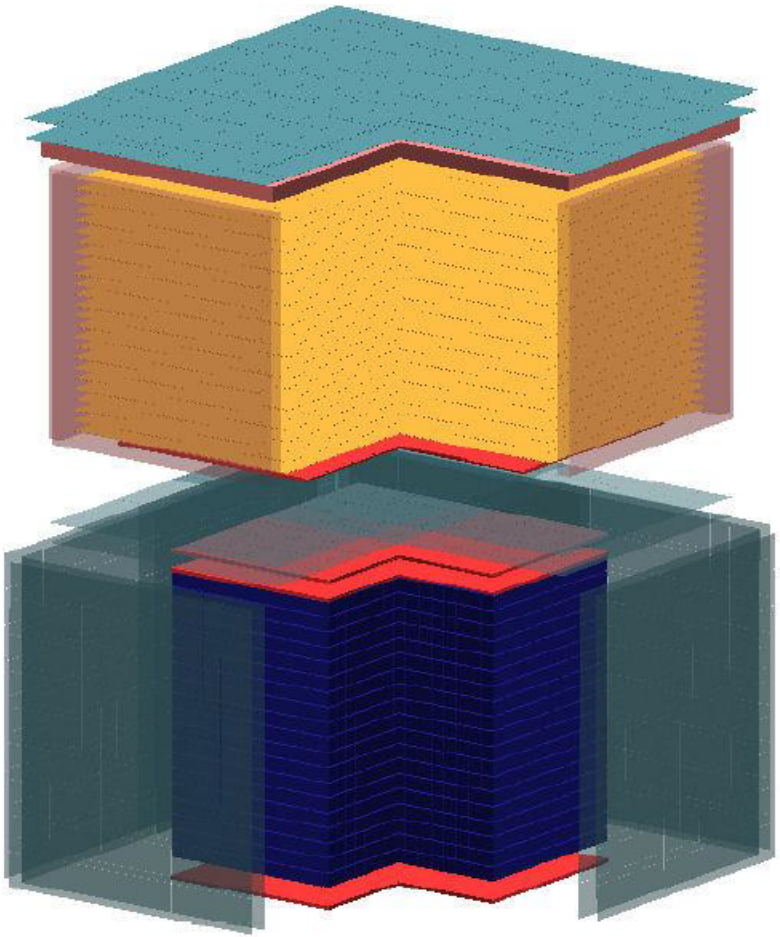
CC2 - BGO imaging calorimeter (21.5Xo)

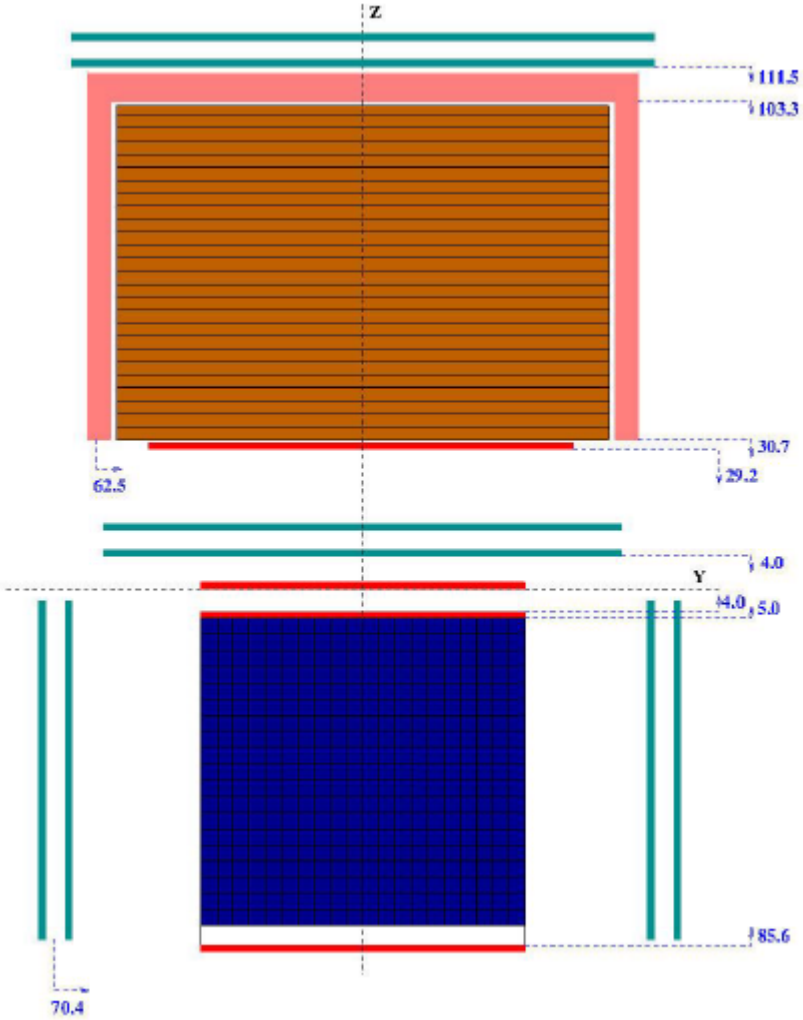
S3, S4 - scintillator detectors

ND - neutron detectors

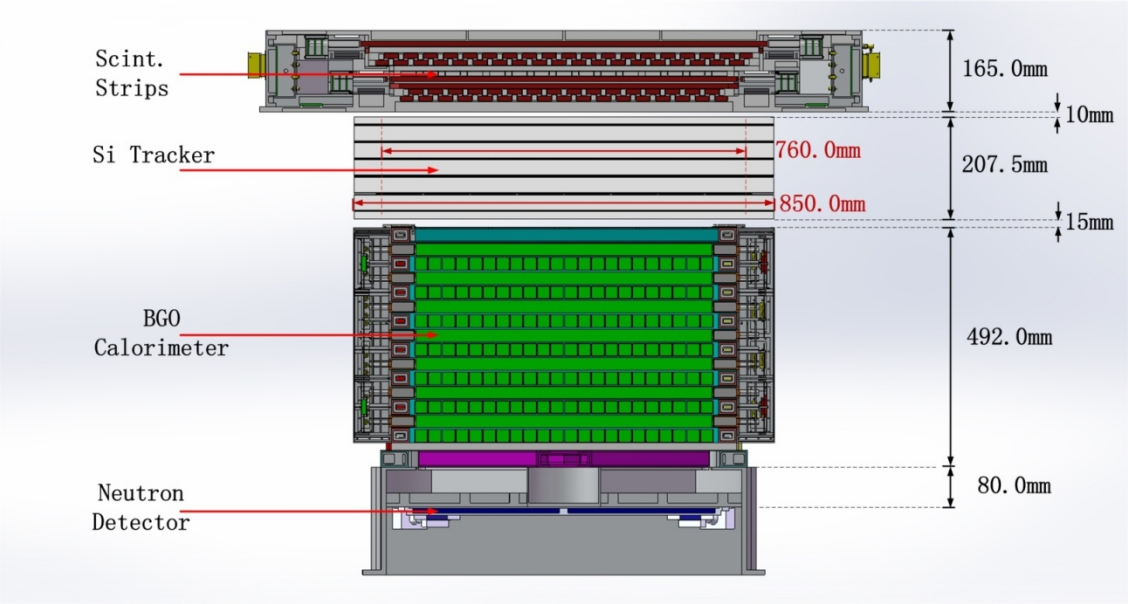


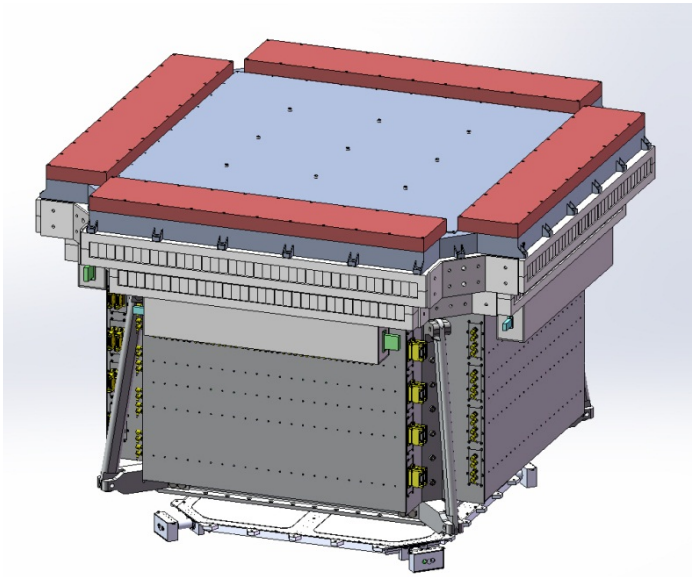
Gamma400





DAMPE

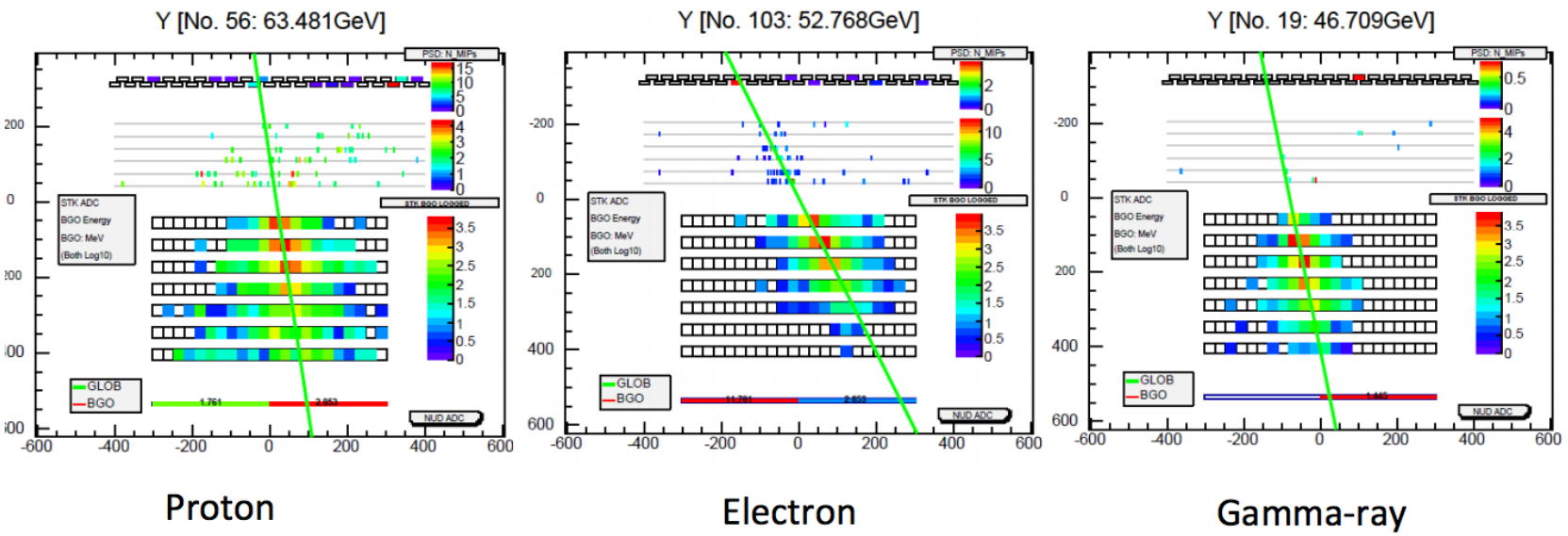




The detector is consisted of 4 parts:
Top scintillators (charge measurement)
Si tracker (5 layers)
BGO calorimeter
Neutron detector

DAMPE Gamma results

DAMPE γ-ray Selection: Different Events



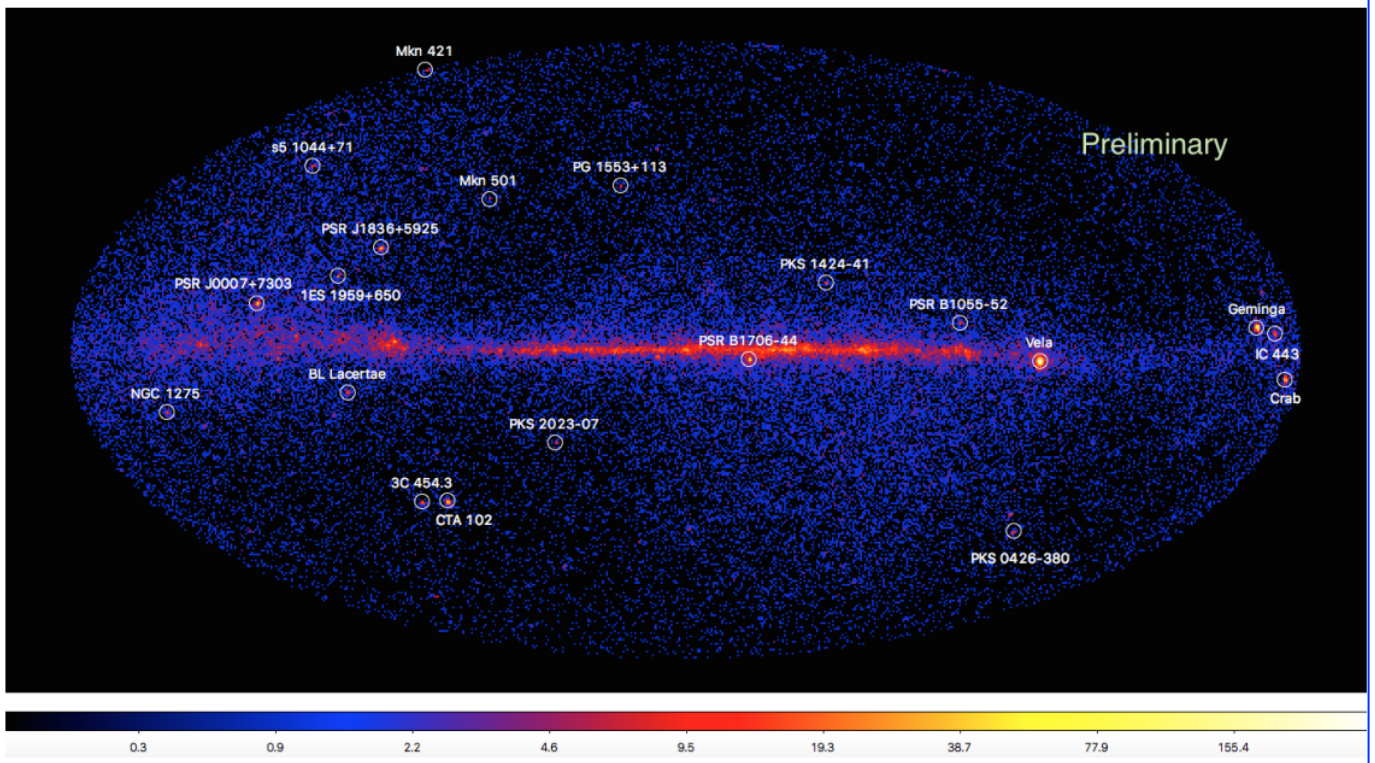
Proton Electron Gamma-ray

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

DAMPE Gamma results

DAMPE γ-ray Sky Map (Counts)

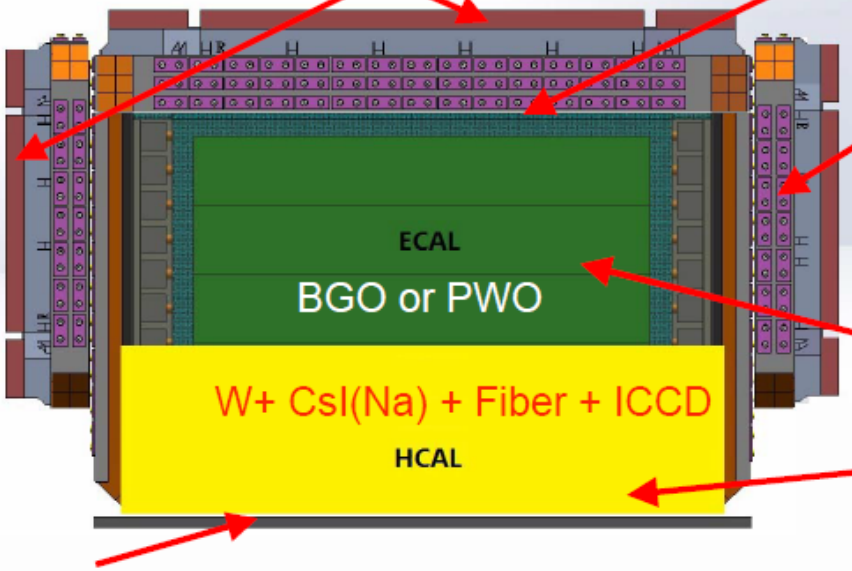
- 510 days
- E>2 GeV
- 90,000 events
- 0.5°×0.5° pexel
- Mollweide projection



HERD

Baseline Design: ~2 T, ~2 KW

Charge detector: Si+PIN.
Top: 2x(70x70x(1cm×1cm×500um));
Sides: 4x(2x(70x40x (1cm×1cm×500um)))



Shower Tracker:
W: $4X_0$; 10x3.5mm +
2x17.5mm + 2x35mm
Scin. Fibers:
14x(2x(700x(1x1x700mm^3)))

Nucleon Tracker: scin. fibers
400x(1x1x700mm^3)+
700x(1x1x400mm^3)

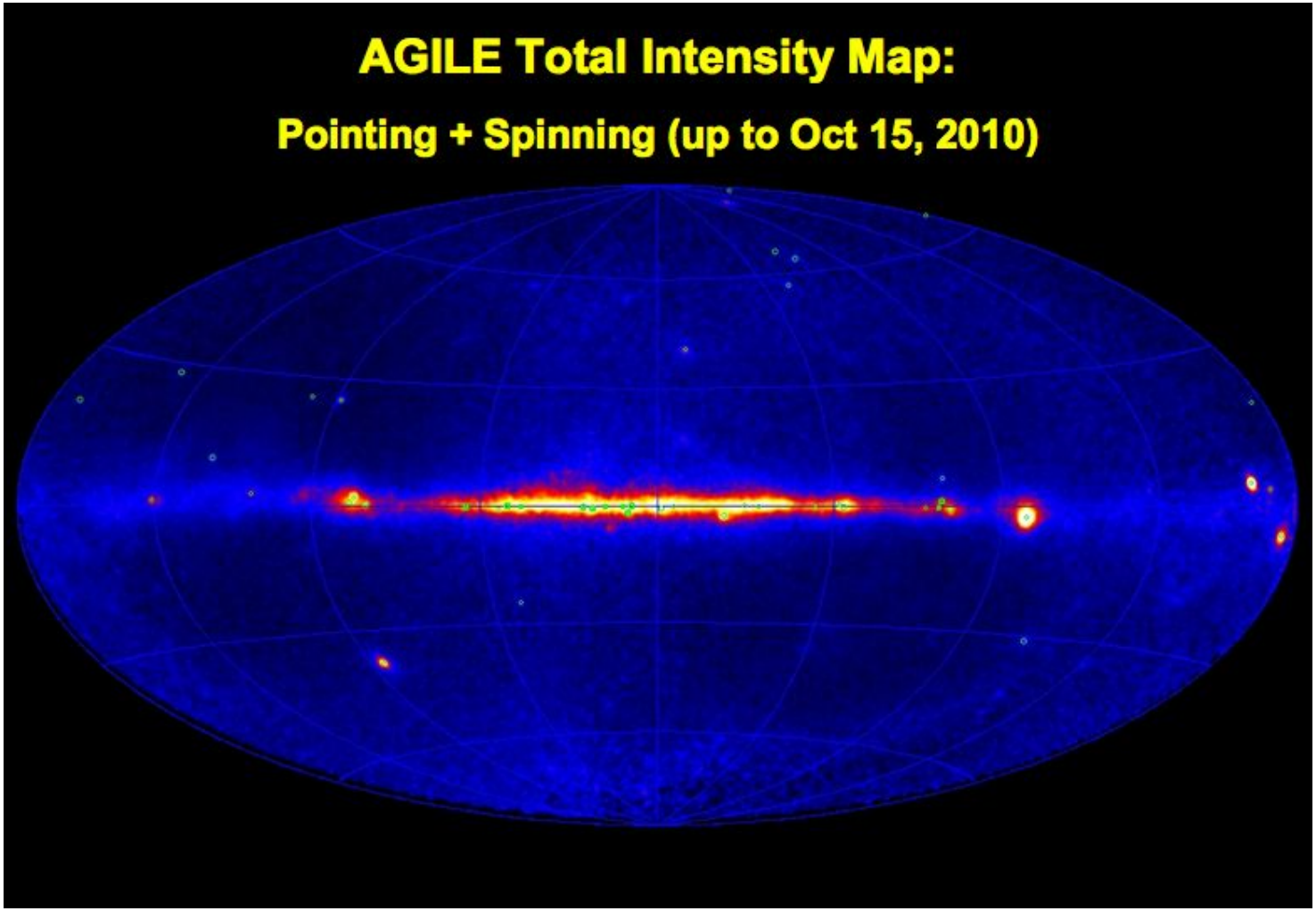
ECAL: $16X_0$=$0.7X_{NIL}$
3x(2x(25x25x700mm^3))

HCAL: W: 20x3.5mm ($0.8X_{NIL}$)
CsI: 20x(2.5cmx2.5cmx0.2cm)

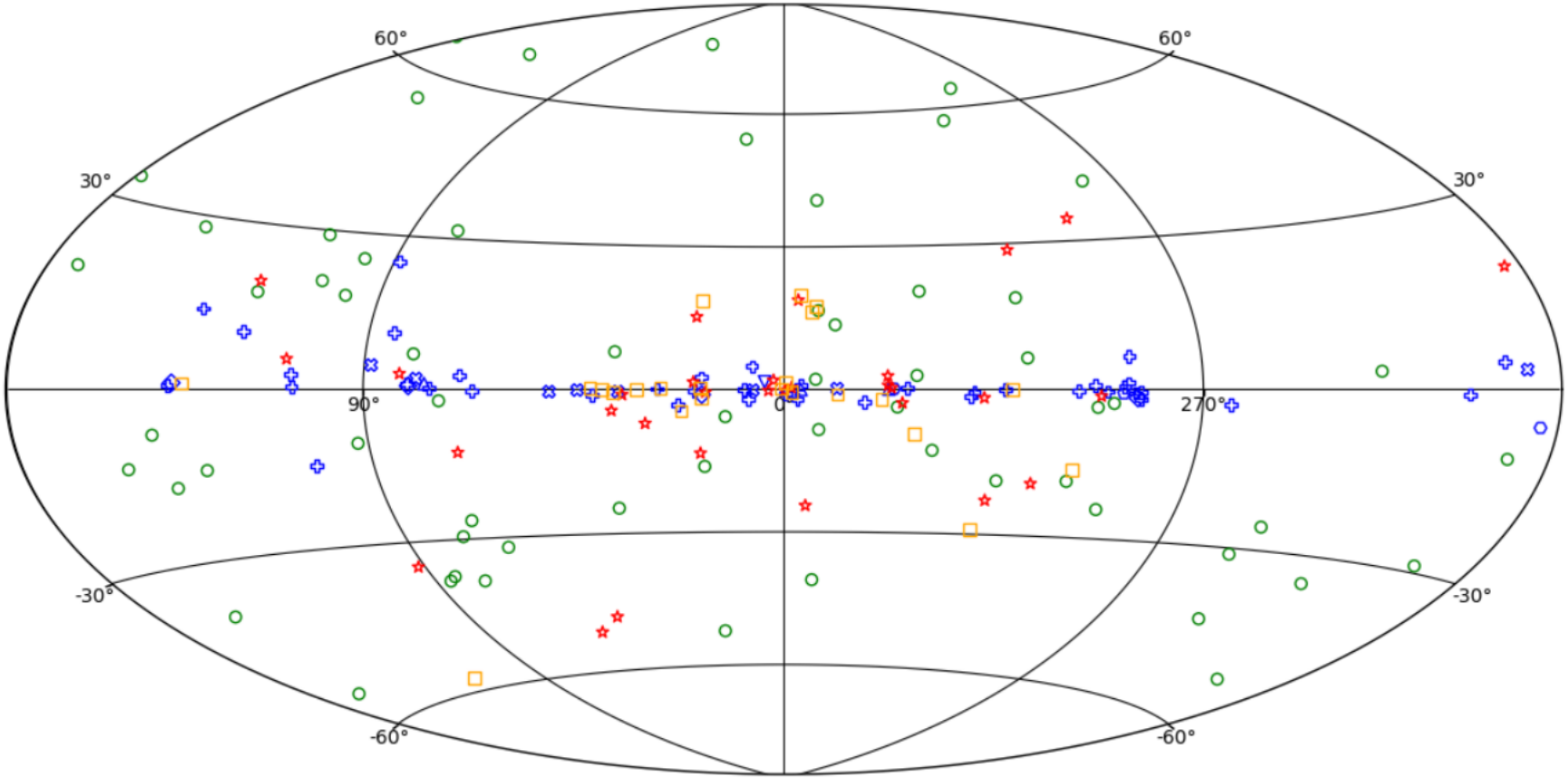
Neutron detector: B-doped plastic scintillator for delayed signals. Enhanced e/p discrimination. (TBD)

AGILE

The AGILE sky

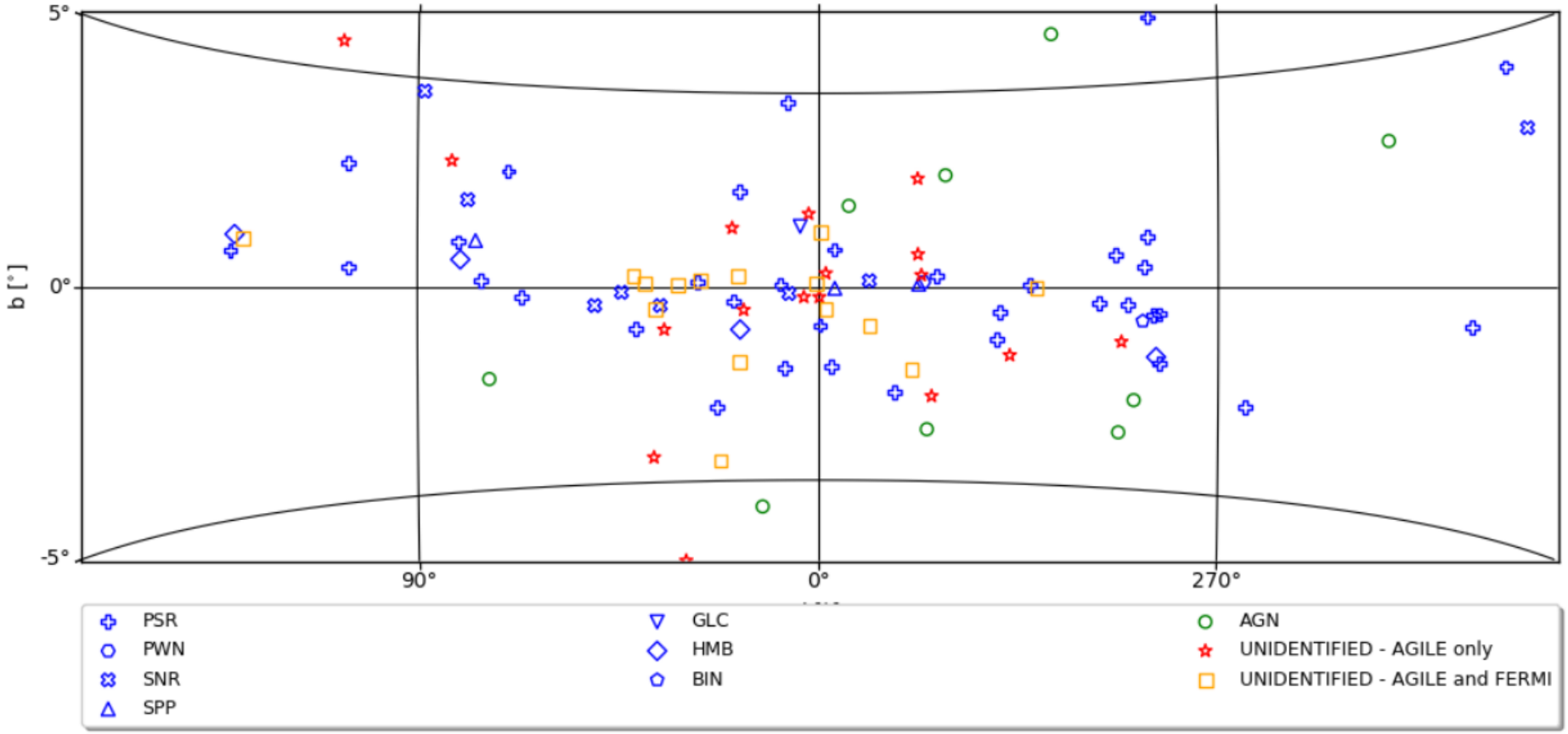


AGILE sources



Bulgarelli et al. 2019

AGILE sources



Bulgarelli et al. 2019

Where to find data?

Space Science Data Center

Home | About SSDC | News and Communication | Quick Look | Missions | Multimission Archive | Catalogs | Tools | Links | Bibliographic services | Helpdesk | Privacy

AGILE Science Data Center

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 | 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

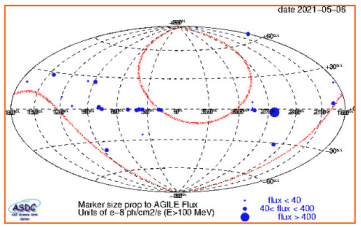
The AGILE Mission Board (AMB) has executive power overseeing all the scientific matters of the AGILE Mission and is composed of:

- 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)

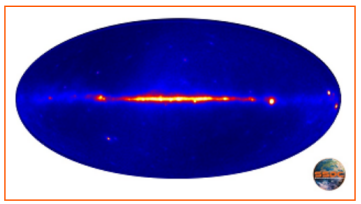
AGILE current spinning sky view

(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.ssdc.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 CREDITS

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: [x] SSDC Name Server [x] SIMBAD [x] NED

Start Date: 01-12-2007 (dd-mm-yyyy) **End Date:** 12-05-2021 (dd-mm-yyyy)

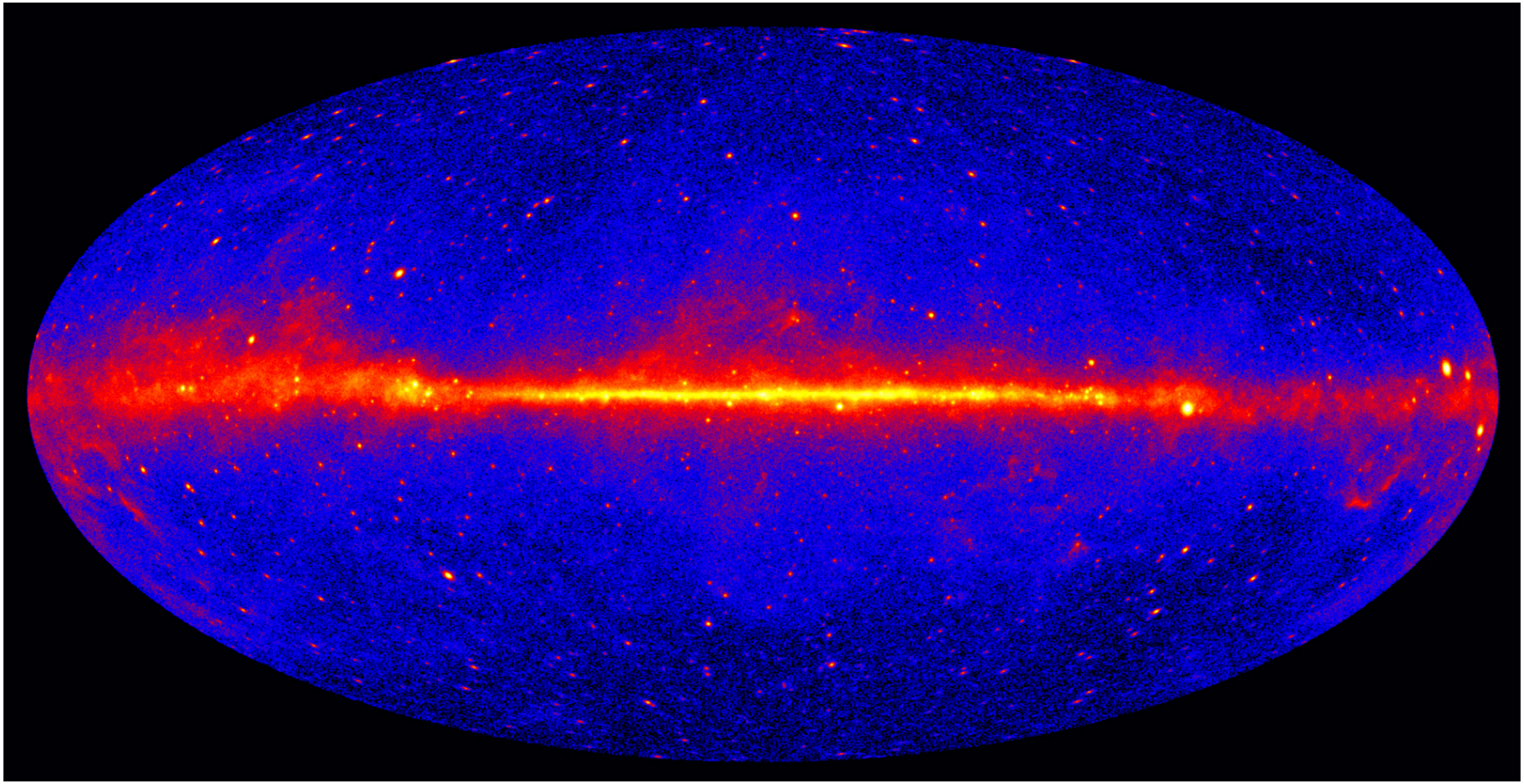
Duration: 28 Day(s) **Min EXP:** 80 (cm² s sr)

Max lines retrieved: 1000 **Equinox:** (●) 2000 ( ) 1950

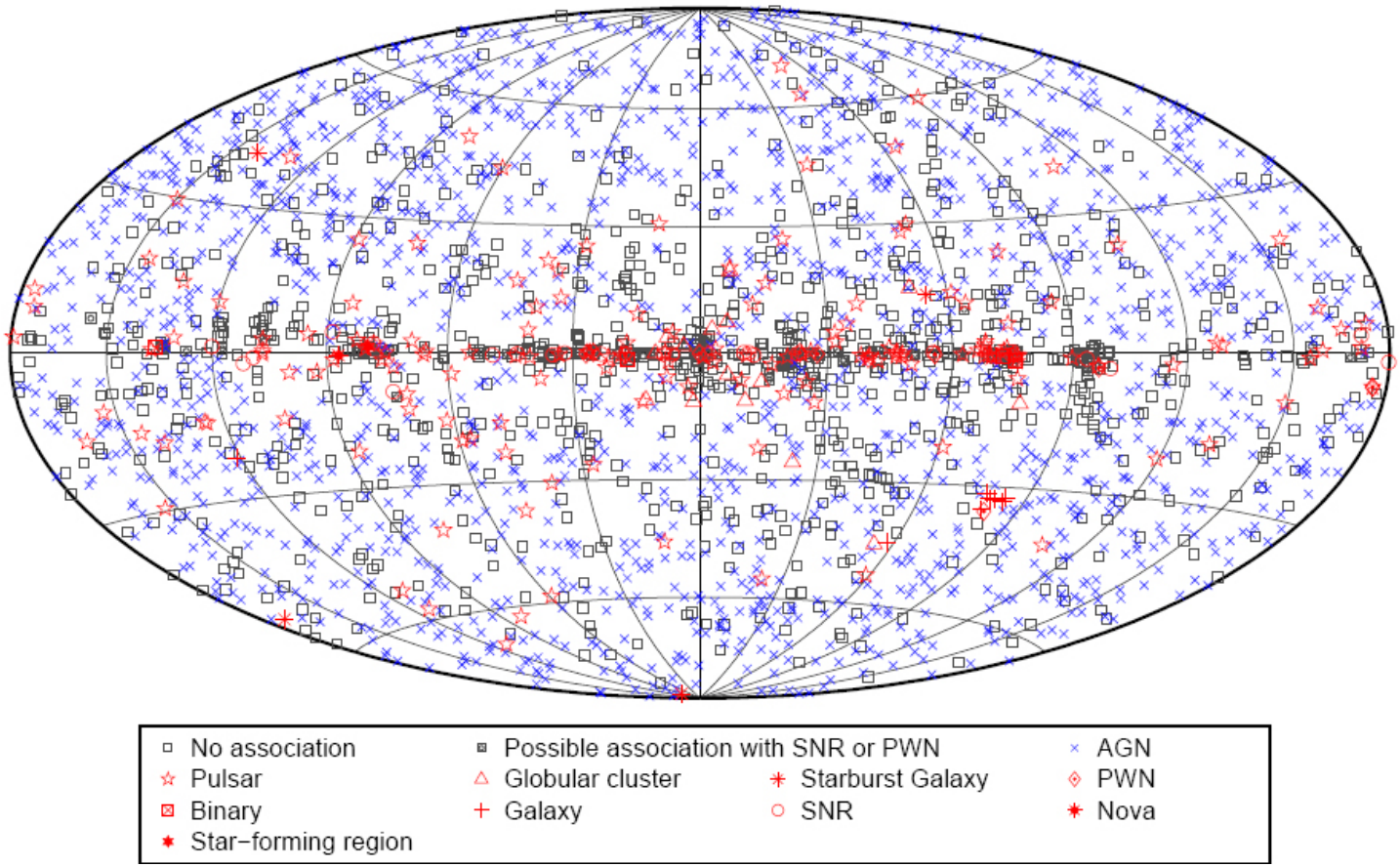
Submit

Fermi LAT

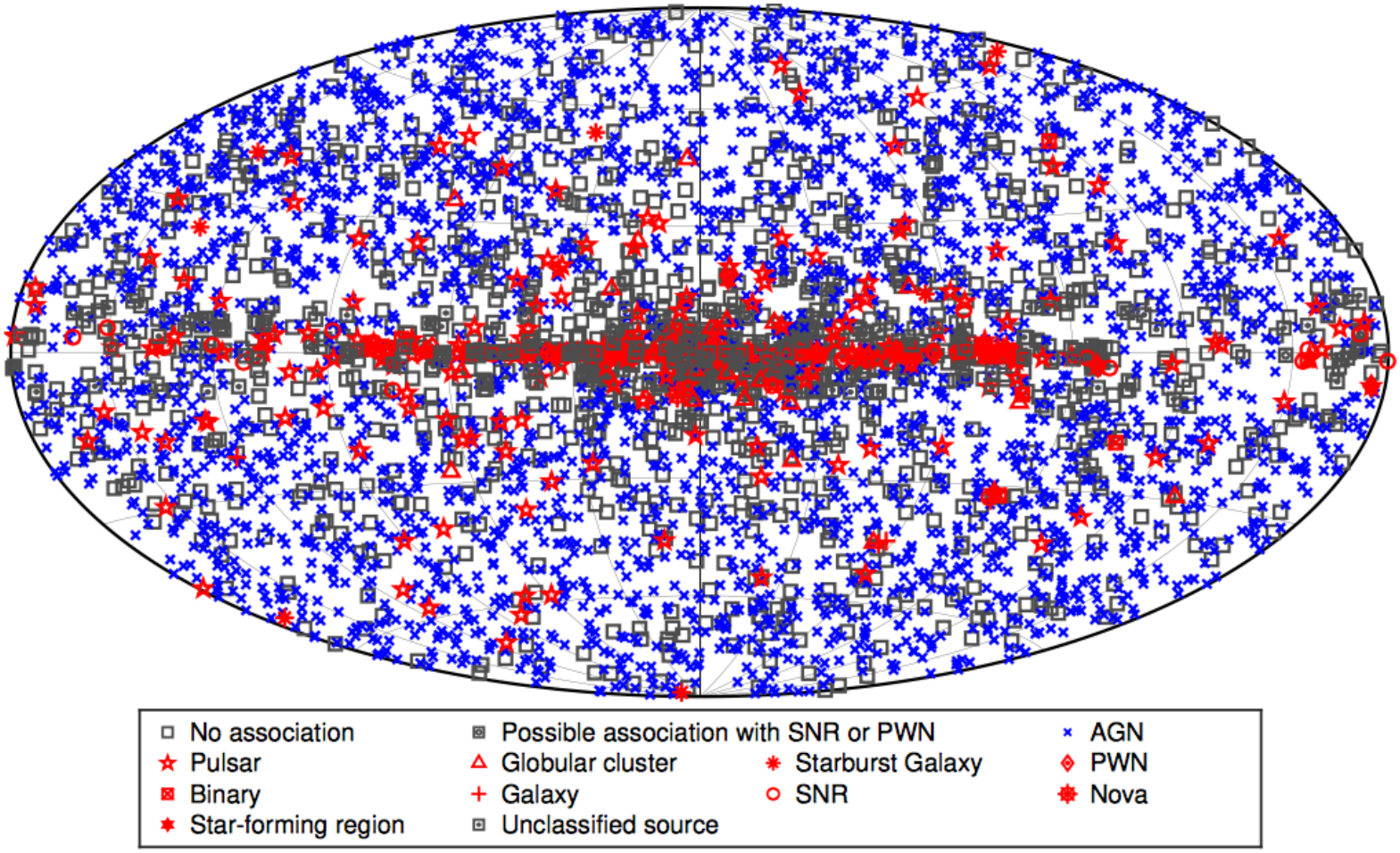
The GeV sky



3FGL catalog – 3033 sources



4FGL catalog



Abdollahi et al 2020

Where to find data?

GODDARD SPACE FLIGHT CENTER

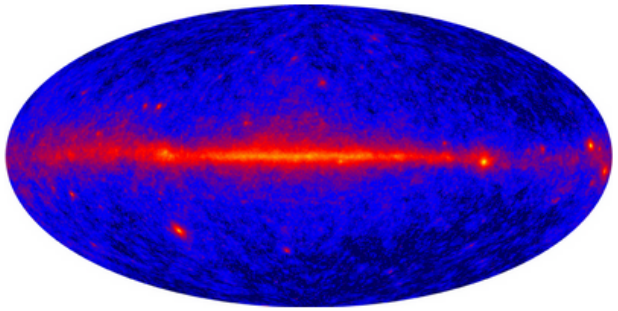
+ NASA Homepage
+ GSFC Homepage
+ Fermi Homepage

SEARCH Fermi: Search + GO

Fermi
Science Support Center

HOME | OBSERVATIONS | DATA | PROPOSALS | LIBRARY | HEASARC | HELP | 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/

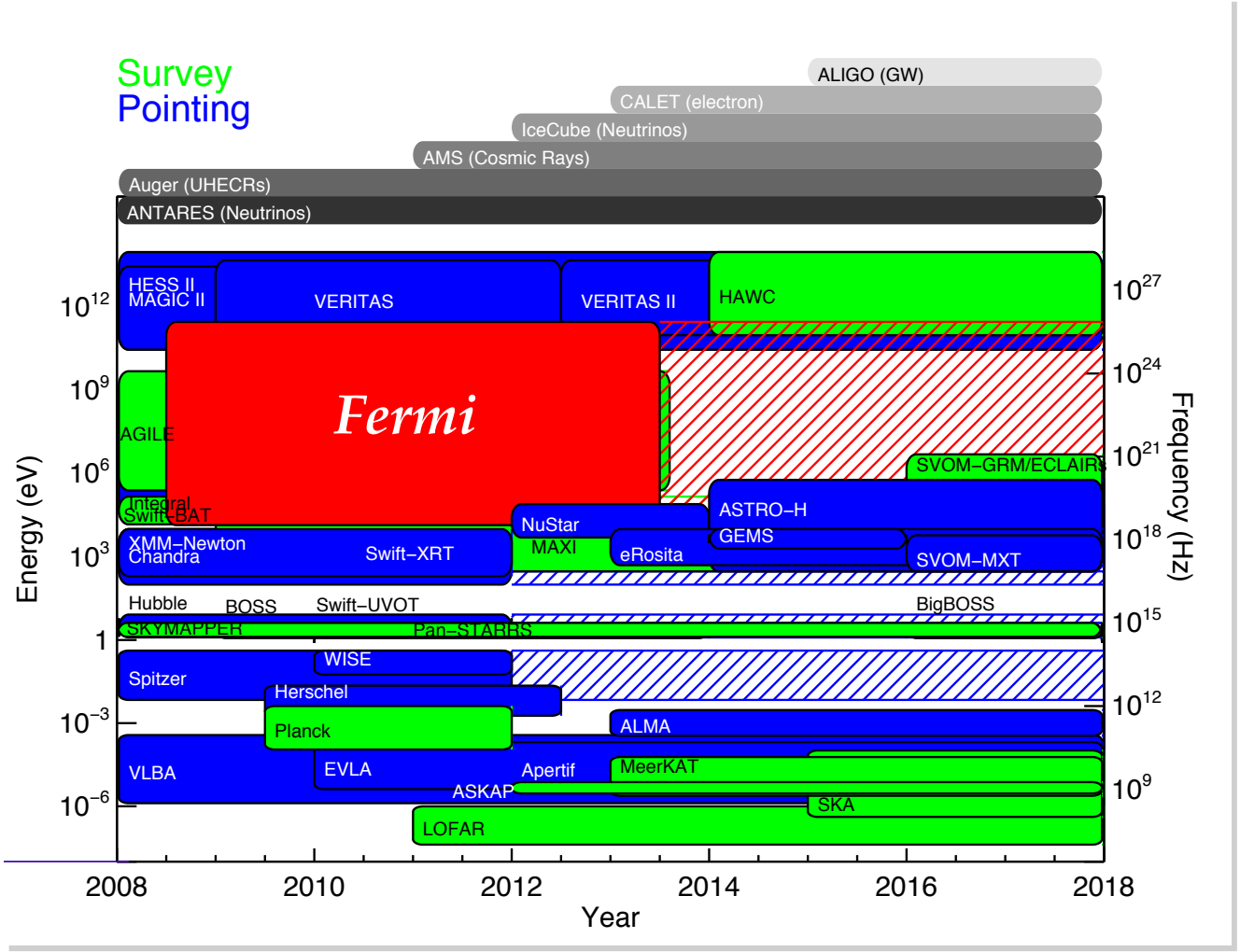
News

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

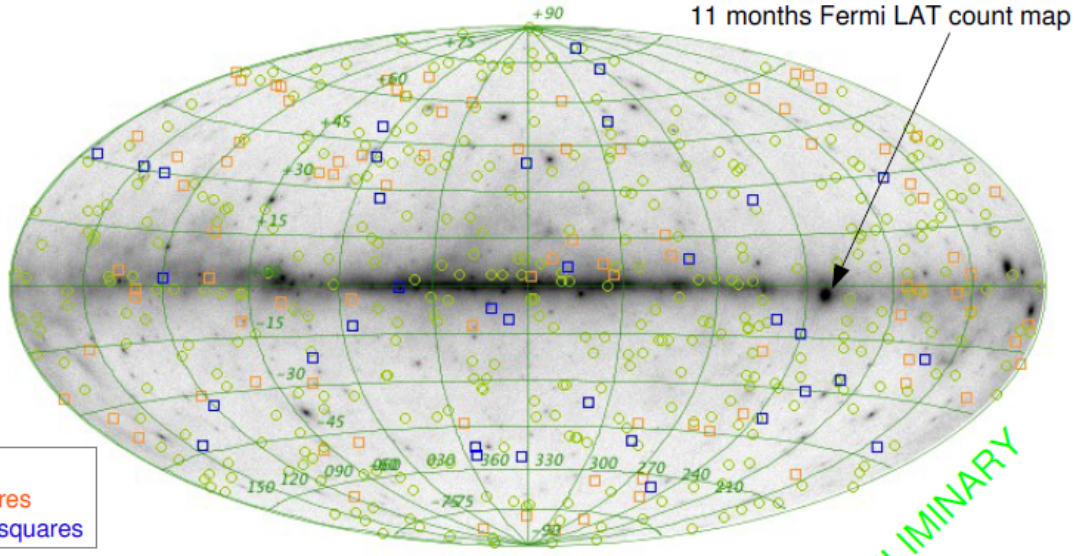
- *Fermi* covers a huge interval of the EM spectrum
  - Crucial and unique spectral coverage
- Complement the large number of upcoming new survey instruments from VHE to radio wavebands
  - At the dawn of time domain astrophysics



GRB science

Fermi GRB detection statistics

GBM 2-year catalog
LAT 3-year catalog

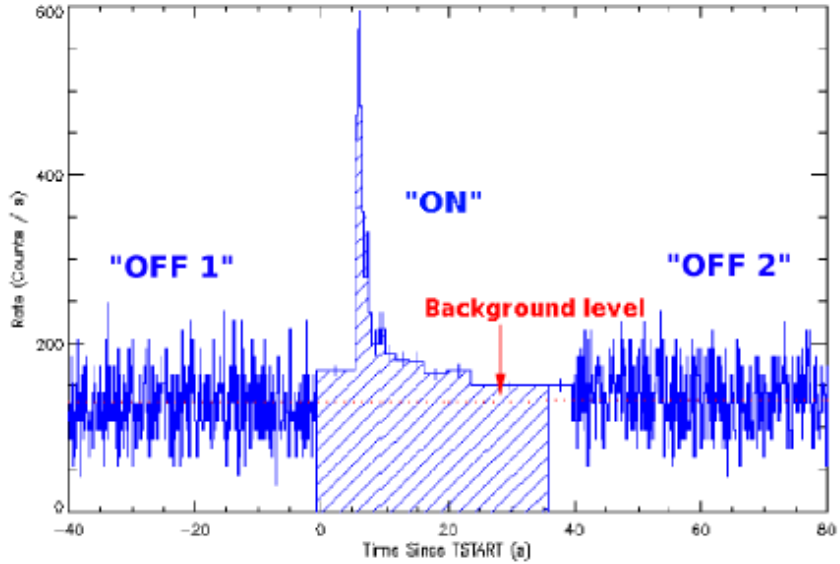


GBM LGRB: green circles
GBM SGRB: orange squares
LAT detections (35): blue squares

- 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

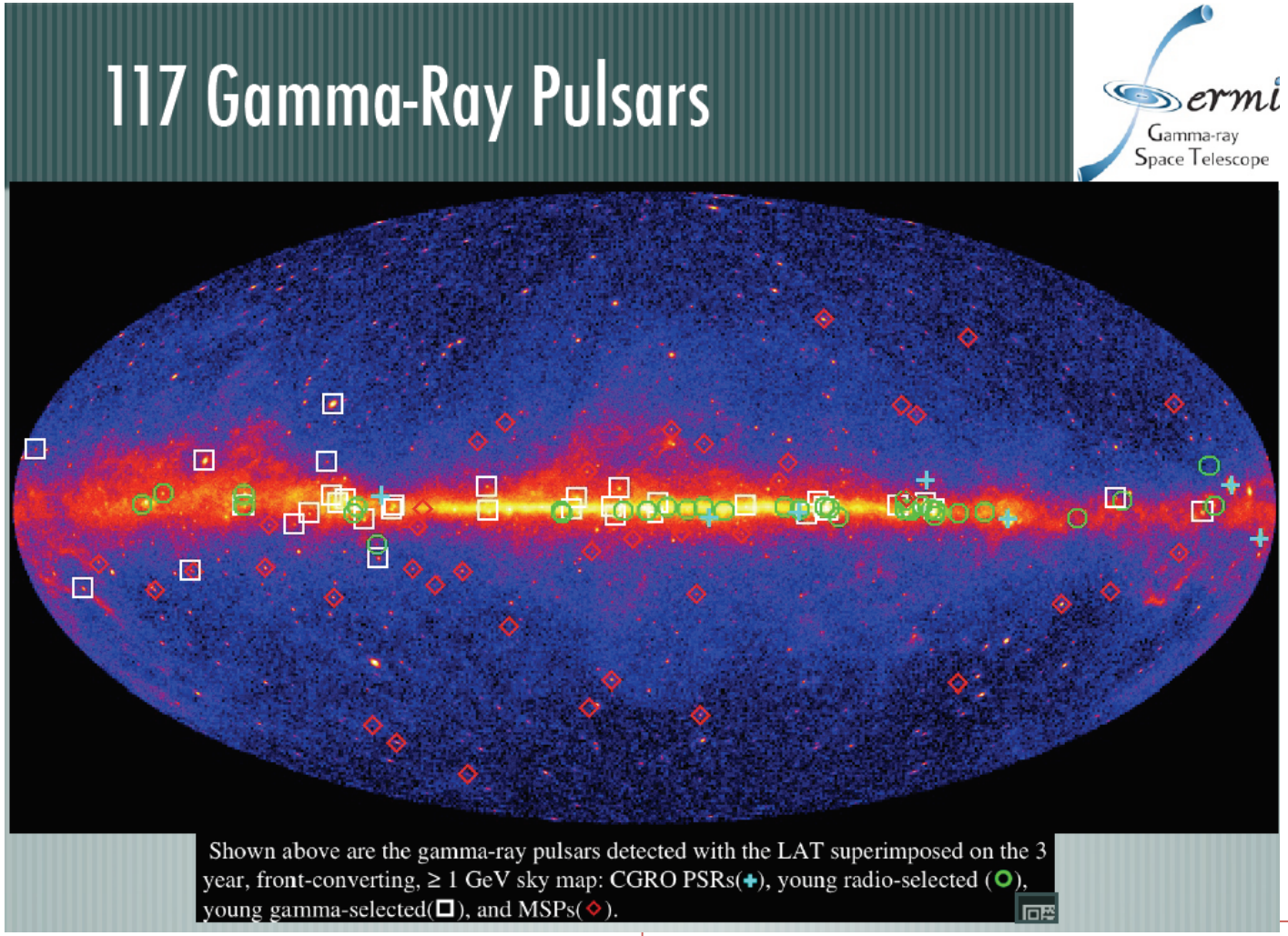
arXiv:1002.2617



- 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

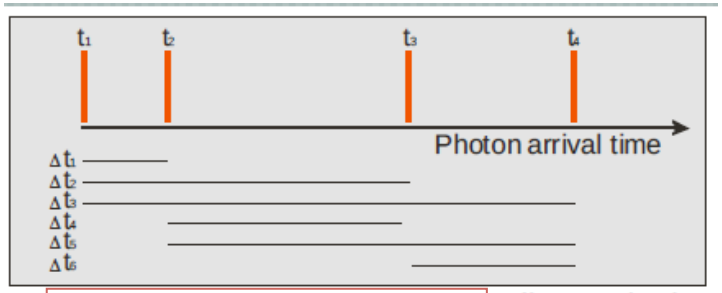
Pulsar Science



Ray : Fermi Summer School 2012

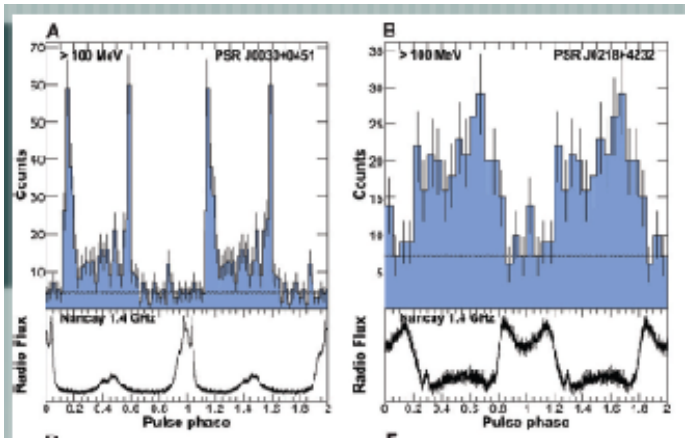
Periodic Analysis (eg. Pulsars)

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

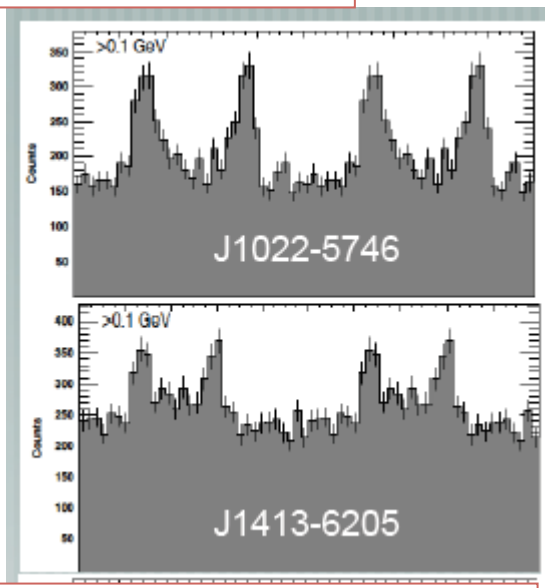


Credit: M. Ziegler

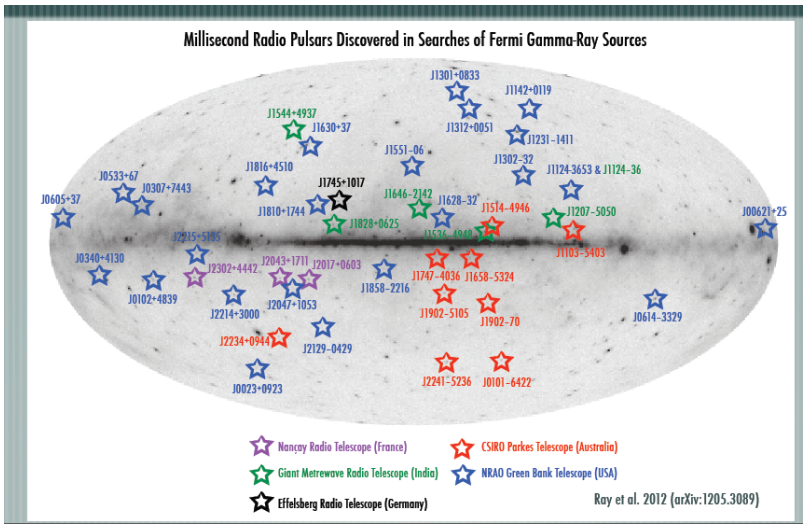
Atwood et al. 2006



Abdo et al. 2009

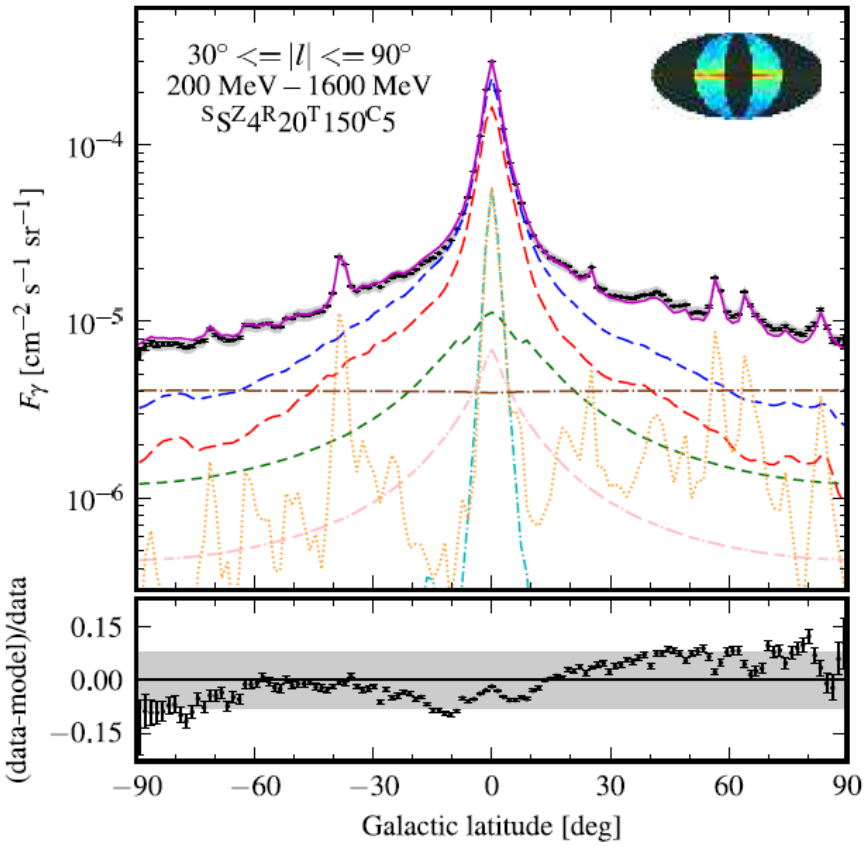


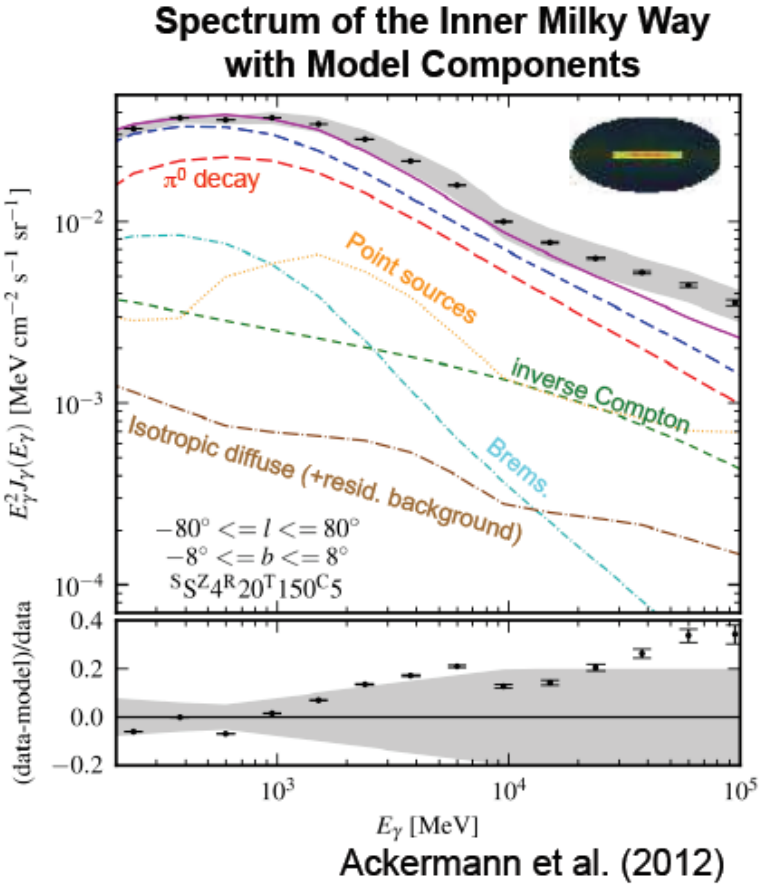
Saz Parkinson et al. 2010



Ray : Fermi Summer School 2011/12

The Diffuse emission

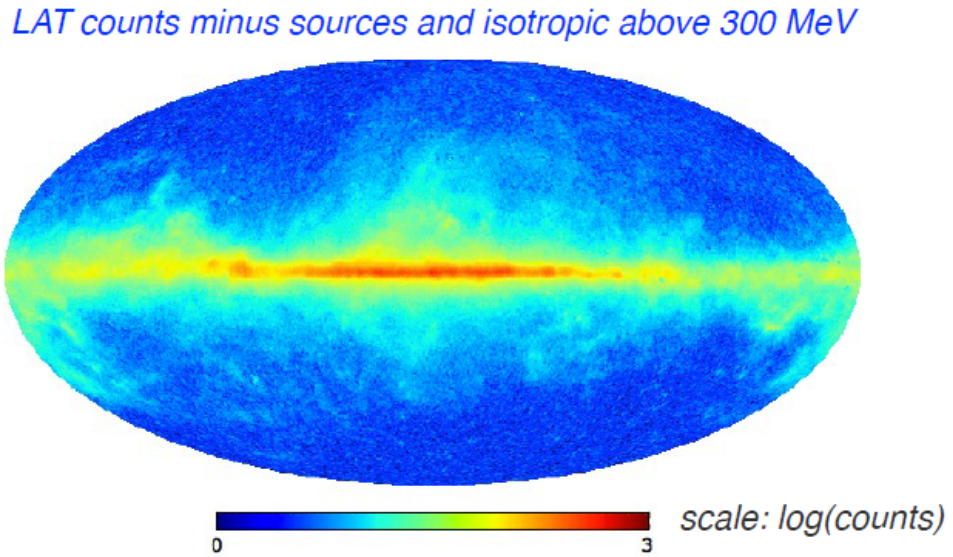


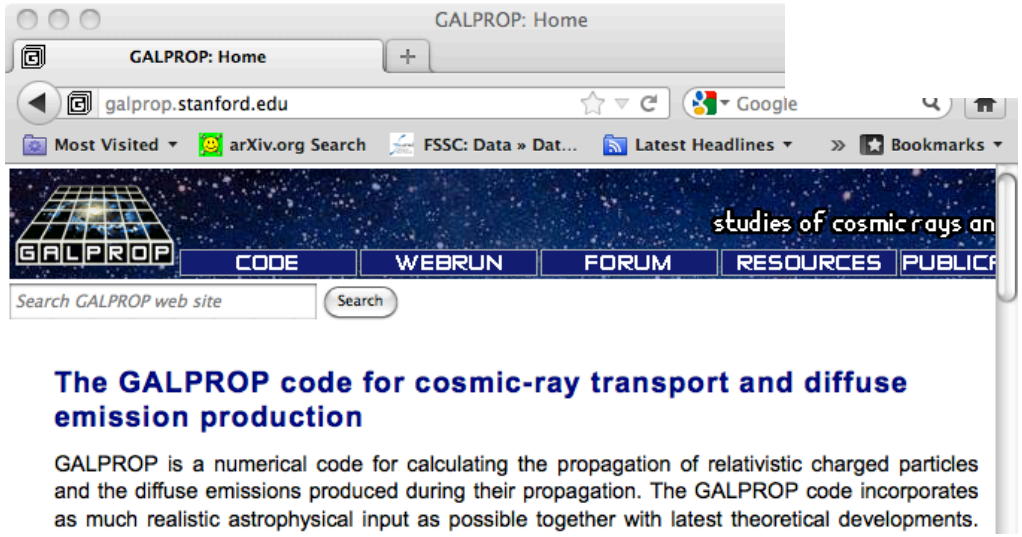


Ackermann et al. (2012)

Diffuse Analysis

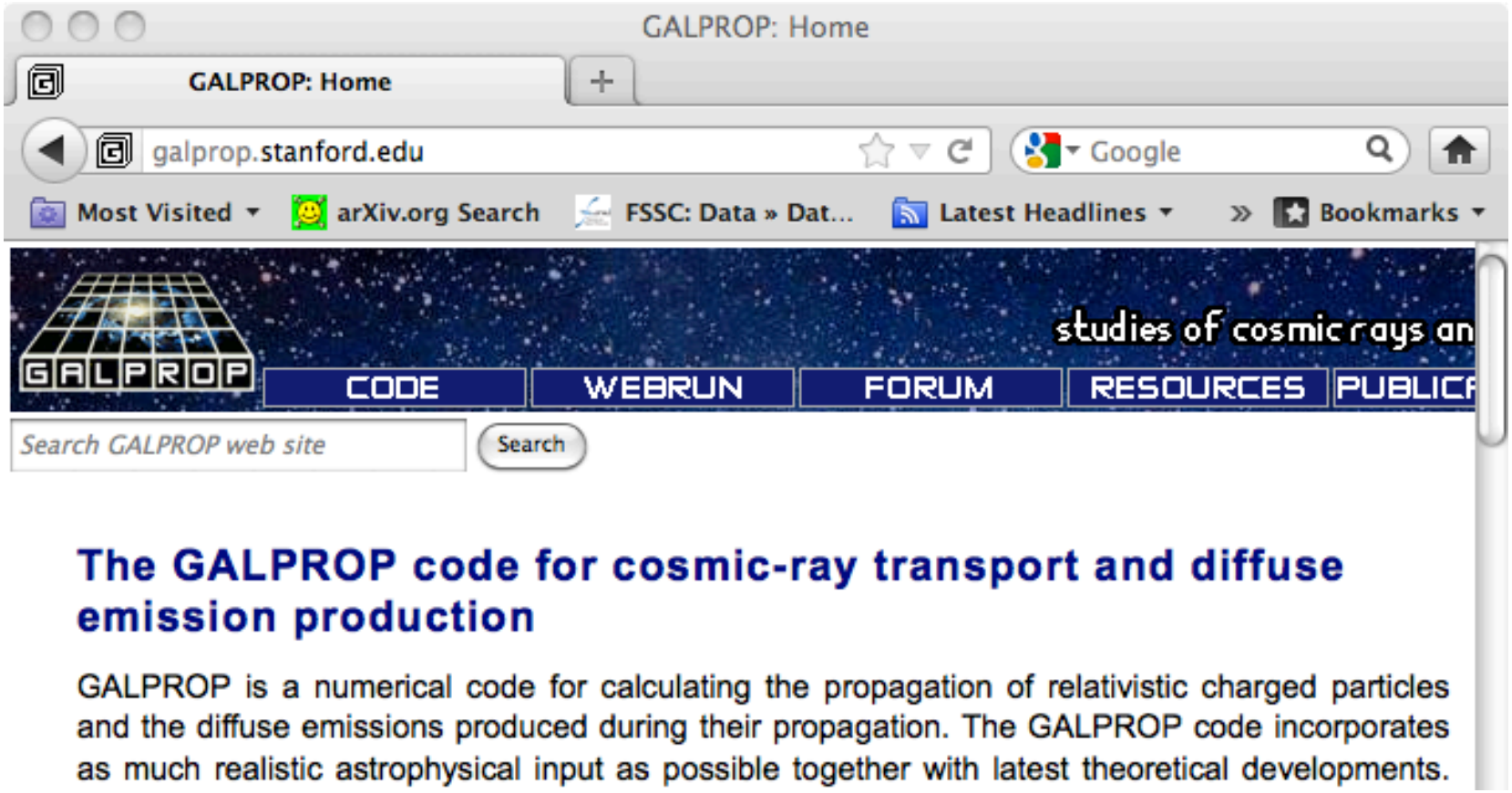
- Cosmic rays
- Interstellar gas (molecular, atomic, ionized)
- Interstellar radiation field



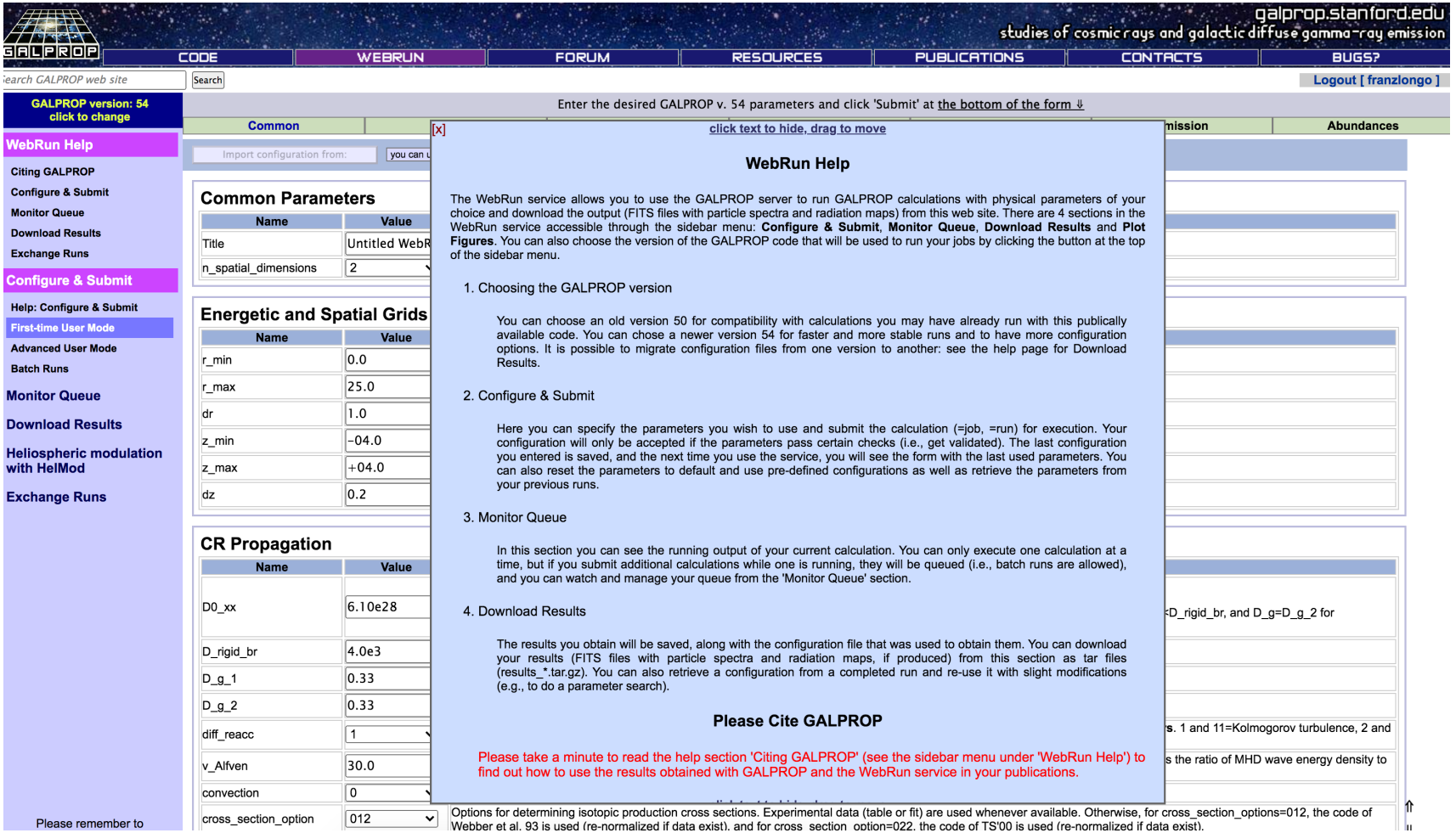


Casandjian: Fermi Symposium 2011
Digel: Fermi Summer school 2012

GalProp

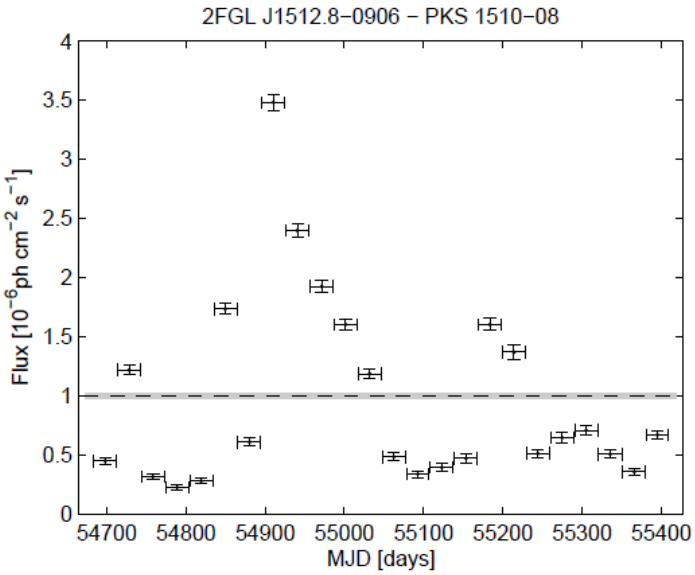

GALPROP: Home
GALPROP: Home
galprop.stanford.edu
Google
Most Visited
arXiv.org Search
FSSC: Data » Dat...
Latest Headlines
Bookmarks
GALPROP
studies of cosmic rays an
CODE
WEBRUN
FORUM
RESOURCES
PUBLICA
Search GALPROP web site
Search
The GALPROP code for cosmic-ray transport and diffuse emission production
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

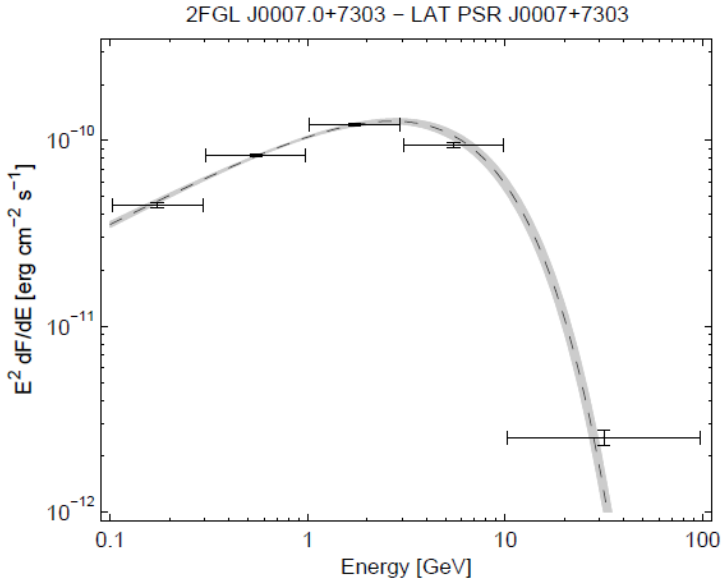

galprop.stanford.edu
studies of cosmic rays and galactic diffuse gamma-ray emission
GALPROP
CODE
WEBRUN
FORUM
RESOURCES
PUBLICATIONS
CONTACTS
BUGS?
Search
Logout [franzlongo]
GALPROP version: 54
click to change
Enter the desired GALPROP v. 54 parameters and click 'Submit' at the bottom of the form ⇓
Common
Abundances
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
Import configuration from:
Common Parameters
Name
Value
Title
Untitled WebR
n_spatial_dimensions
2
Energetic and Spatial Grids
r_min
0.0
r_max
25.0
dr
1.0
z_min
-04.0
z_max
+04.0
dz
0.2
CR Propagation
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
[x]
click text to hide, drag to move
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 publically 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).

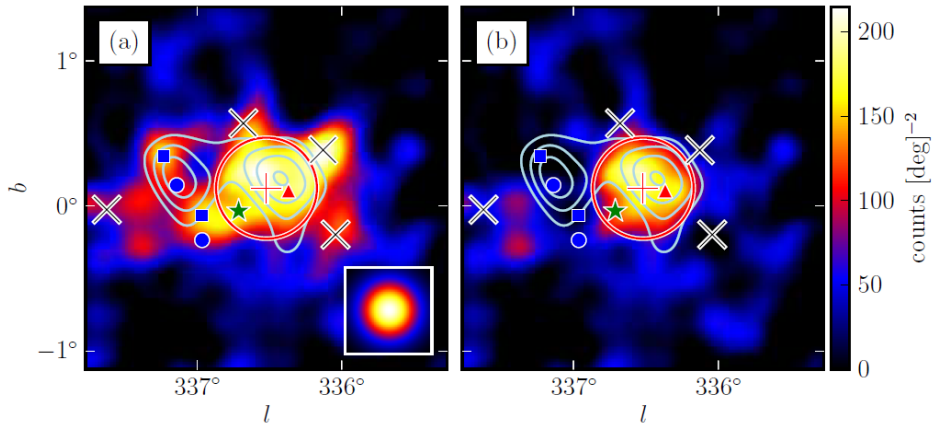
Source Analysis

- 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 (< 20MeV to > 300 GeV)
  - Field of View = 2.4 sr (some response up to 70° off-axis)
- Several High Energy Astrophysics topics explored by the LAT

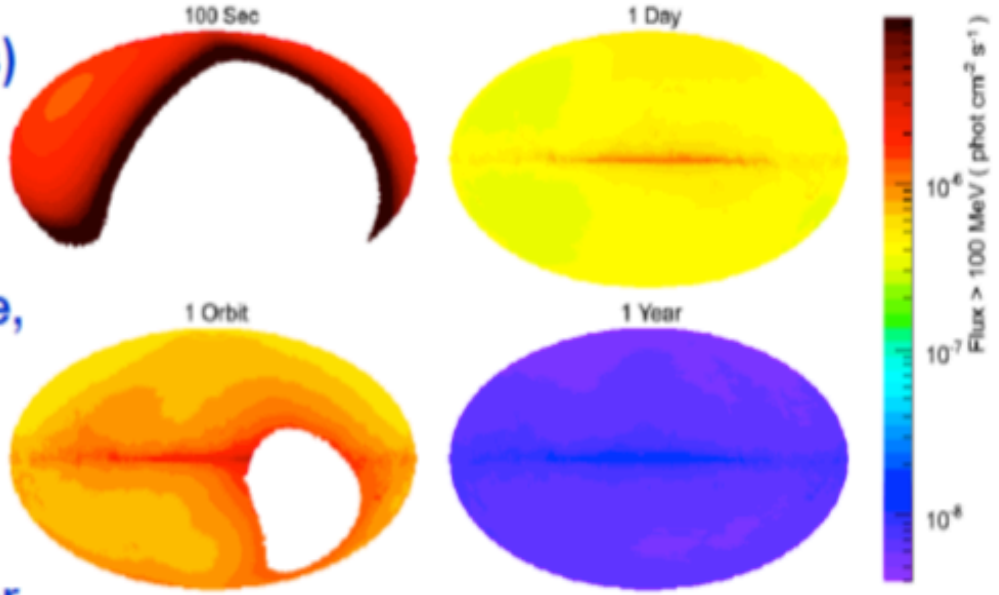
Fermi LAT
Data Analysis Tutorial

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..)

LAT DATA ARE PUBLIC!!

- 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 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

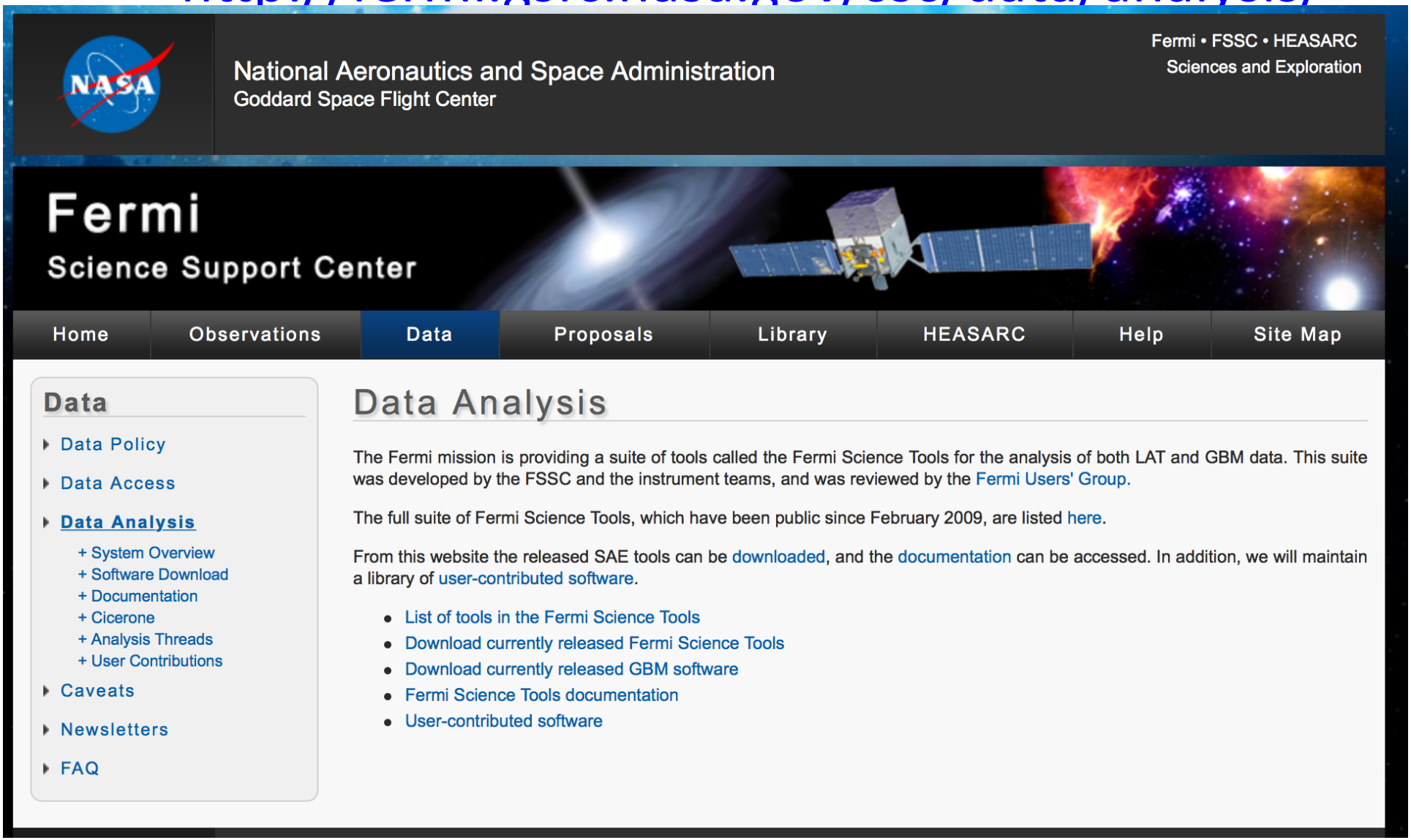
Fermi Analysis Threads:
http://fermi.gsfc.nasa.gov/ssc/data/analysis/scitools/
http://fermi.gsfc.nasa.gov/ssc/data/analysis/documentation/Cicerone/

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/



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"**

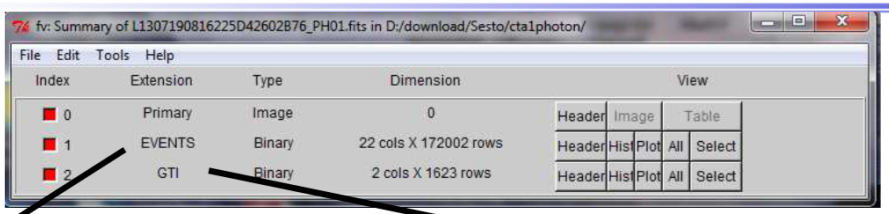
  – (photons, their energy, coordinates, time, event classes etc..)

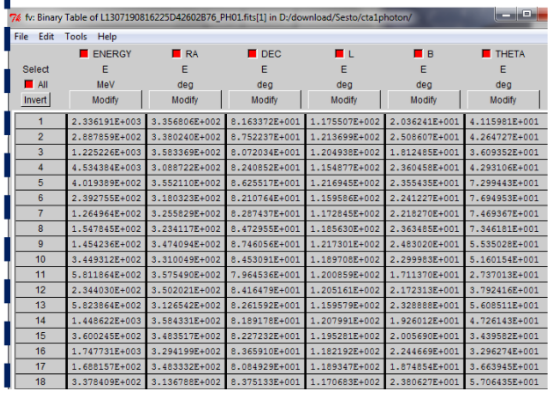
–**Spacecraft files (FT2)**

–**i. e. "where the LAT is"**

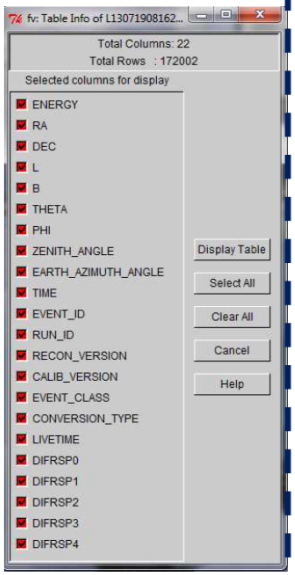
  – (position, angles..)

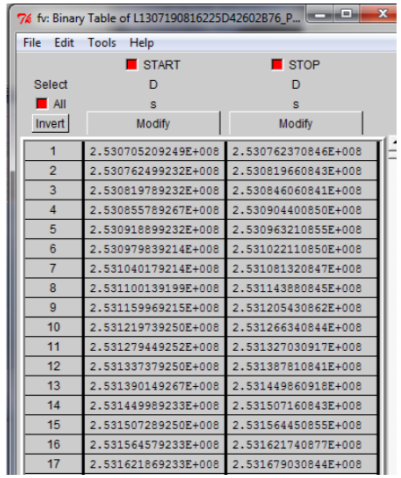
FT1: photons, photons…





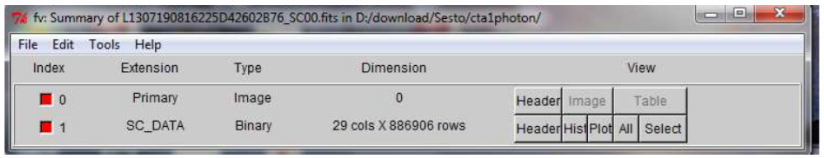
Events





Good Time Intervals (GTIs)

FT2: where is Fermi ?



spacecraft Data

Extras - IRFs

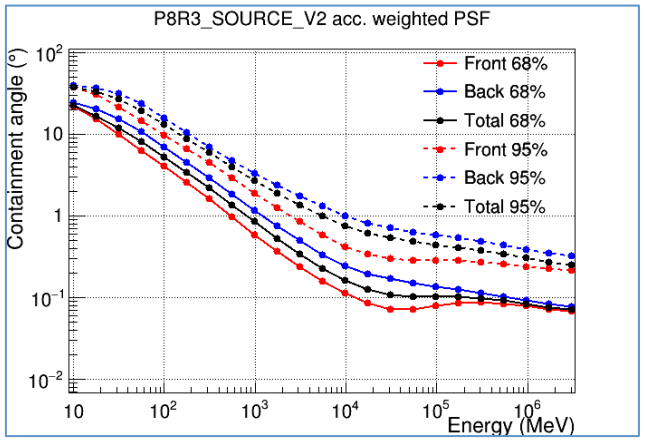
- LAT Instrument Response Functions (IRFs)

–**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

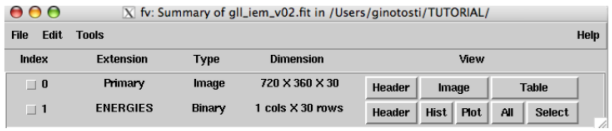
Extras

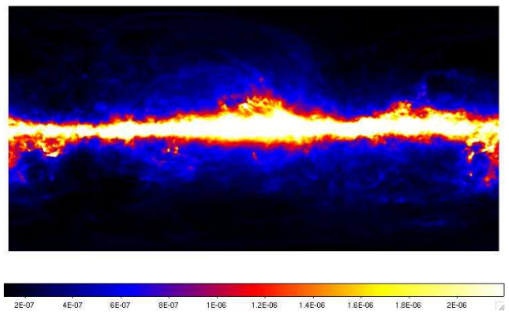
- Diffuse models (.txt & FITS files)
  - **To correctly take into accounts the galactic and extagalactic backgrounds**
  - http://fermi.gsfc.nasa.gov/ssc/data/access/lat/BackgroundModels.html
- Source Catalogs (4FGL, 3FHL, PSRs, GRB, SNR …)
- Region of Interest model definition (stored in XML files)
  - 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





```
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 theses 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/

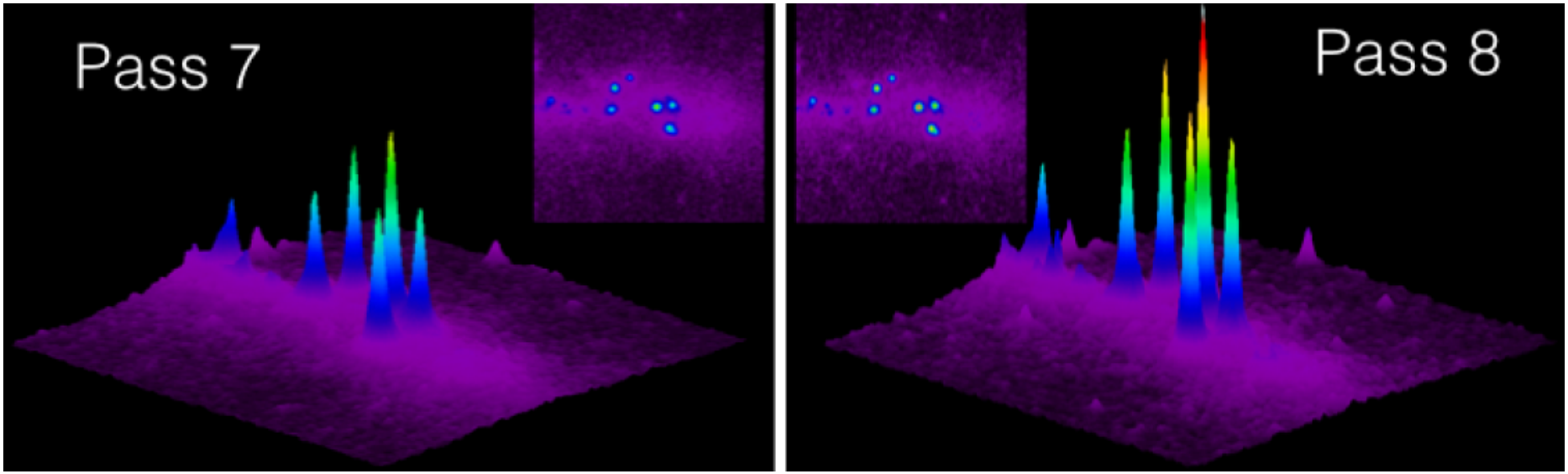
PASS8 DATA

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

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

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:
  - Intrument 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

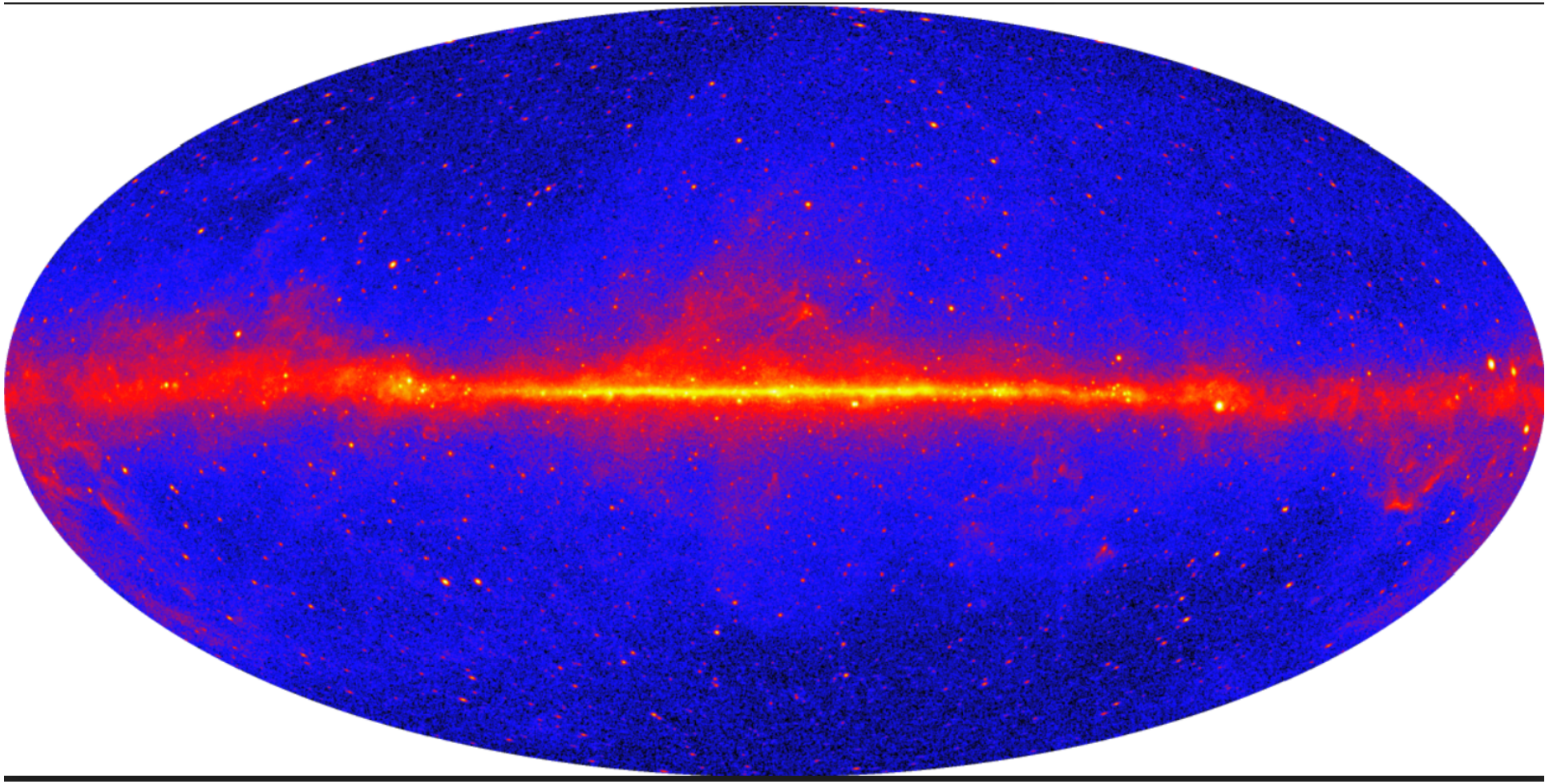
Recommendations

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)

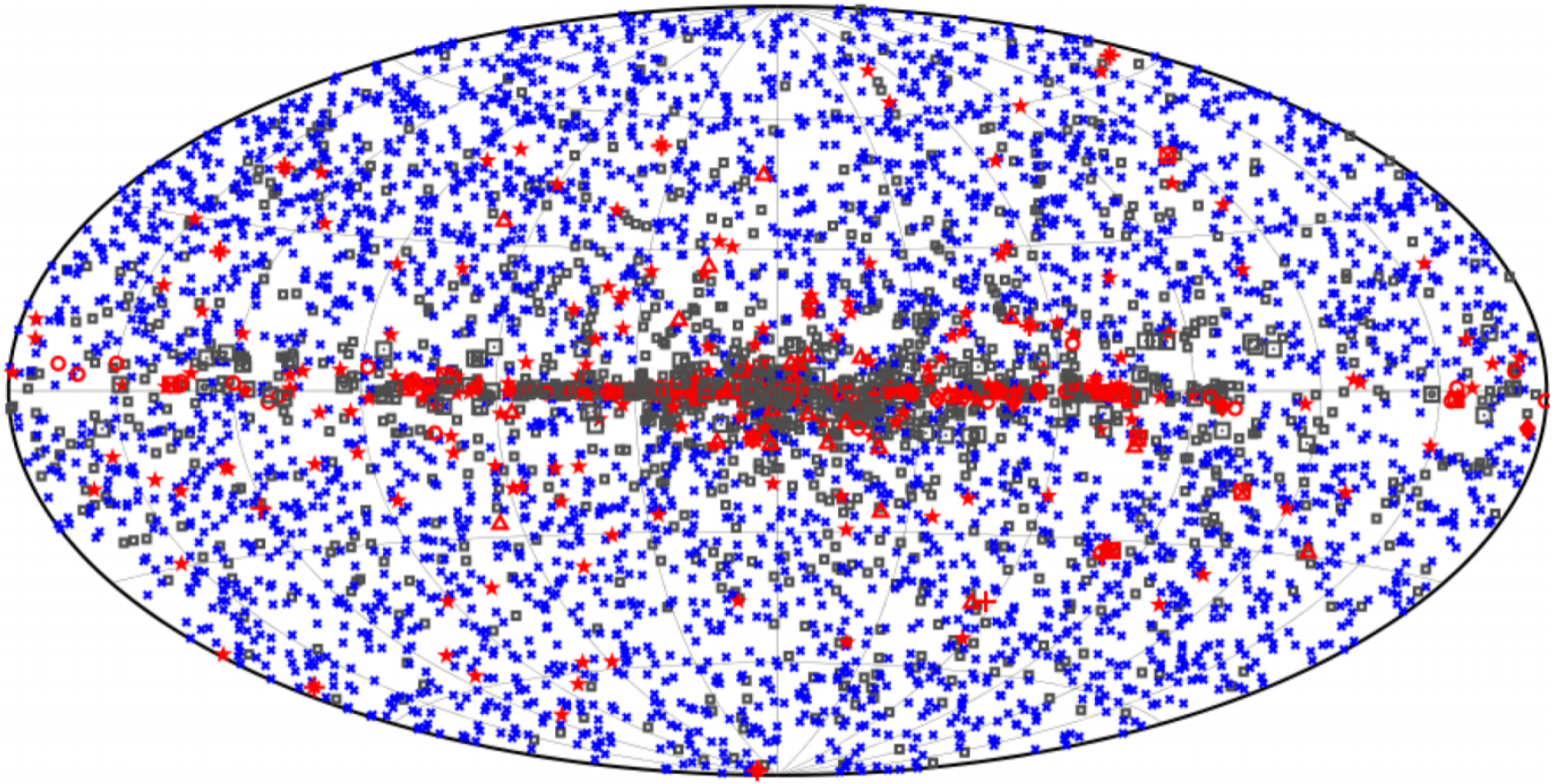
IMPORTANT: For analyses where an ROI-based zenith cut is NOT performed, an exposure correction must be made using the "zmax" option in the gtltcube tool.

LAT sky

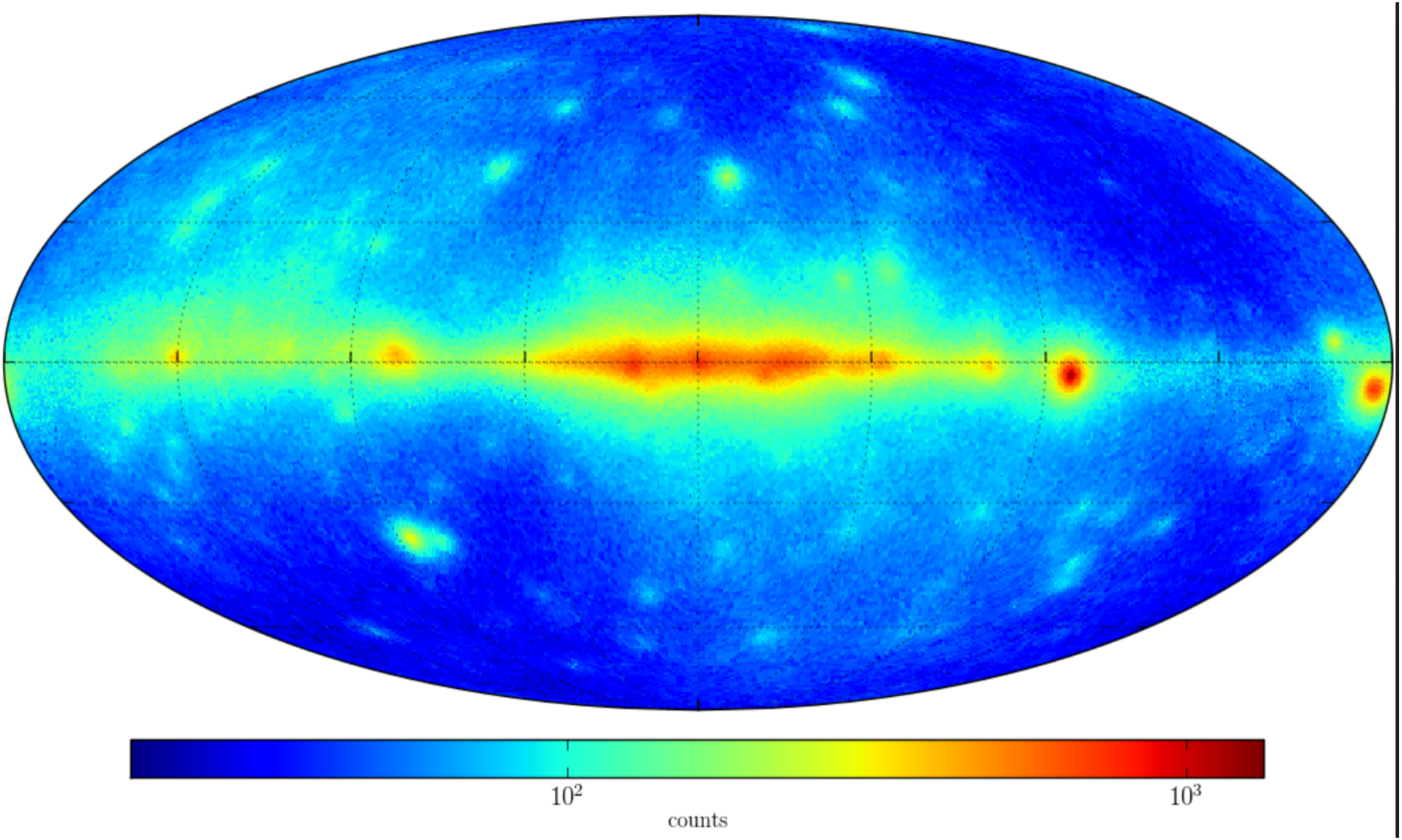


LAT 4FGL catalog

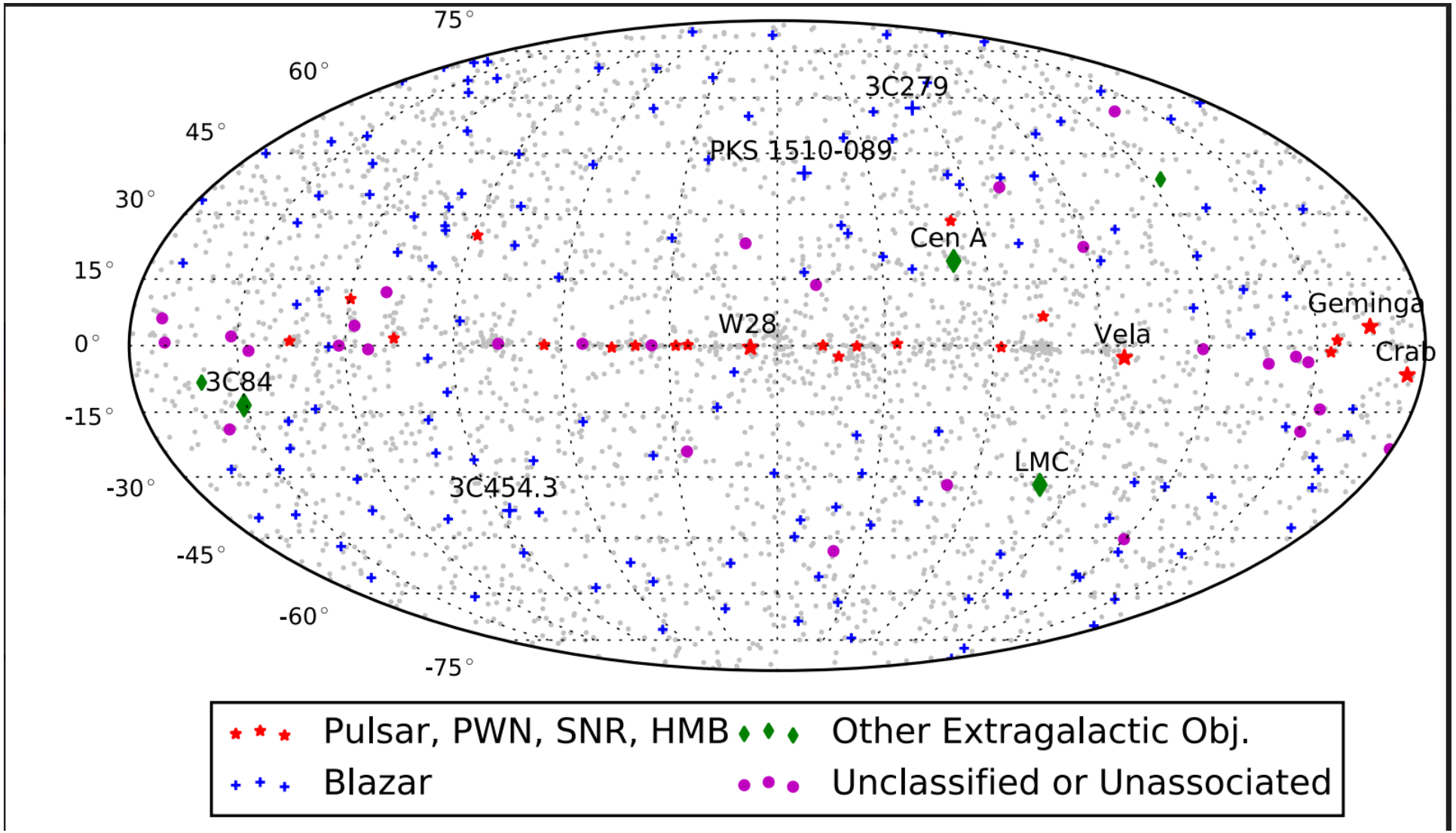
Abdollahi et al 2020



LAT – Low Energy (30 – 100 MeV) sky

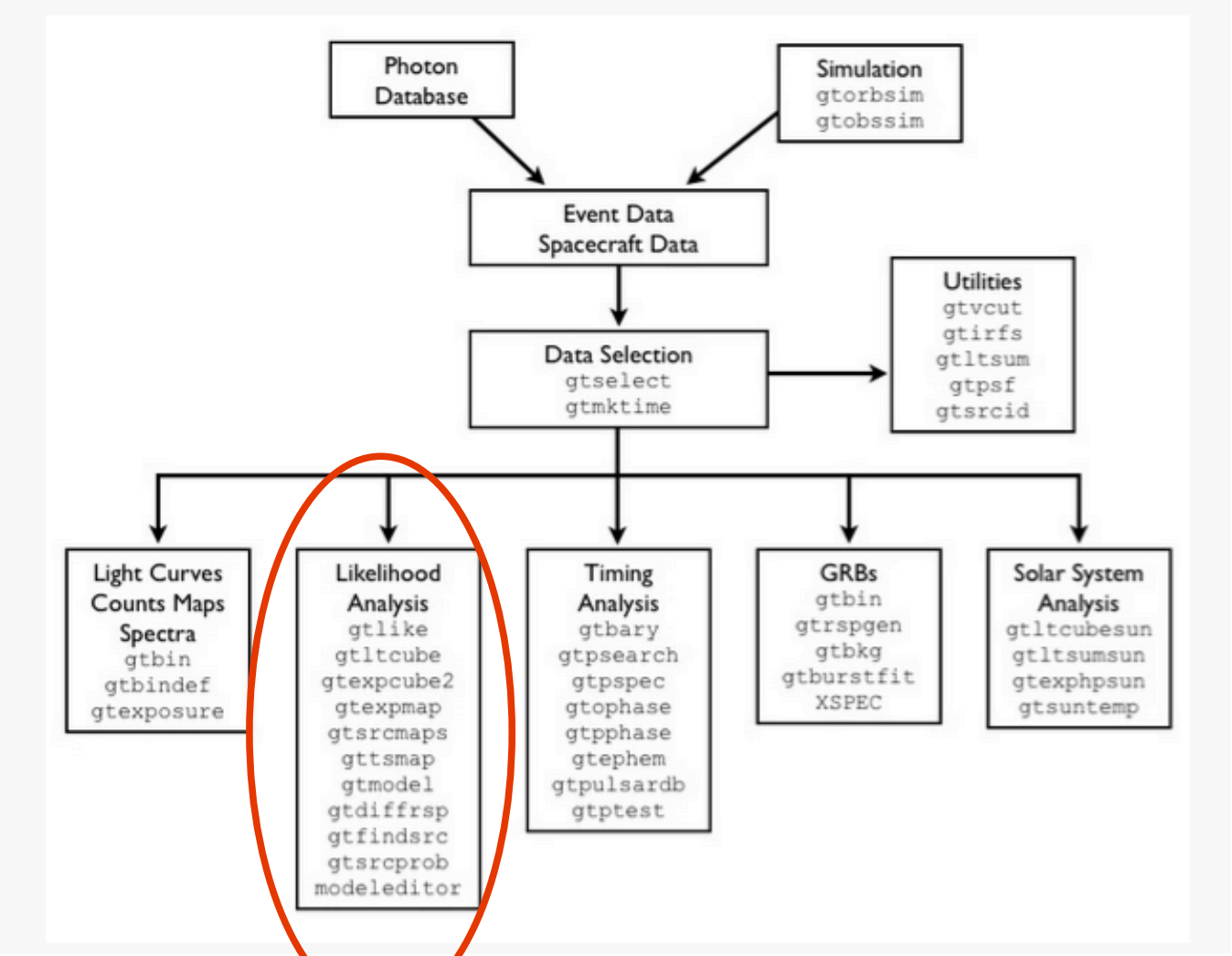


LAT – 1FLE catalog

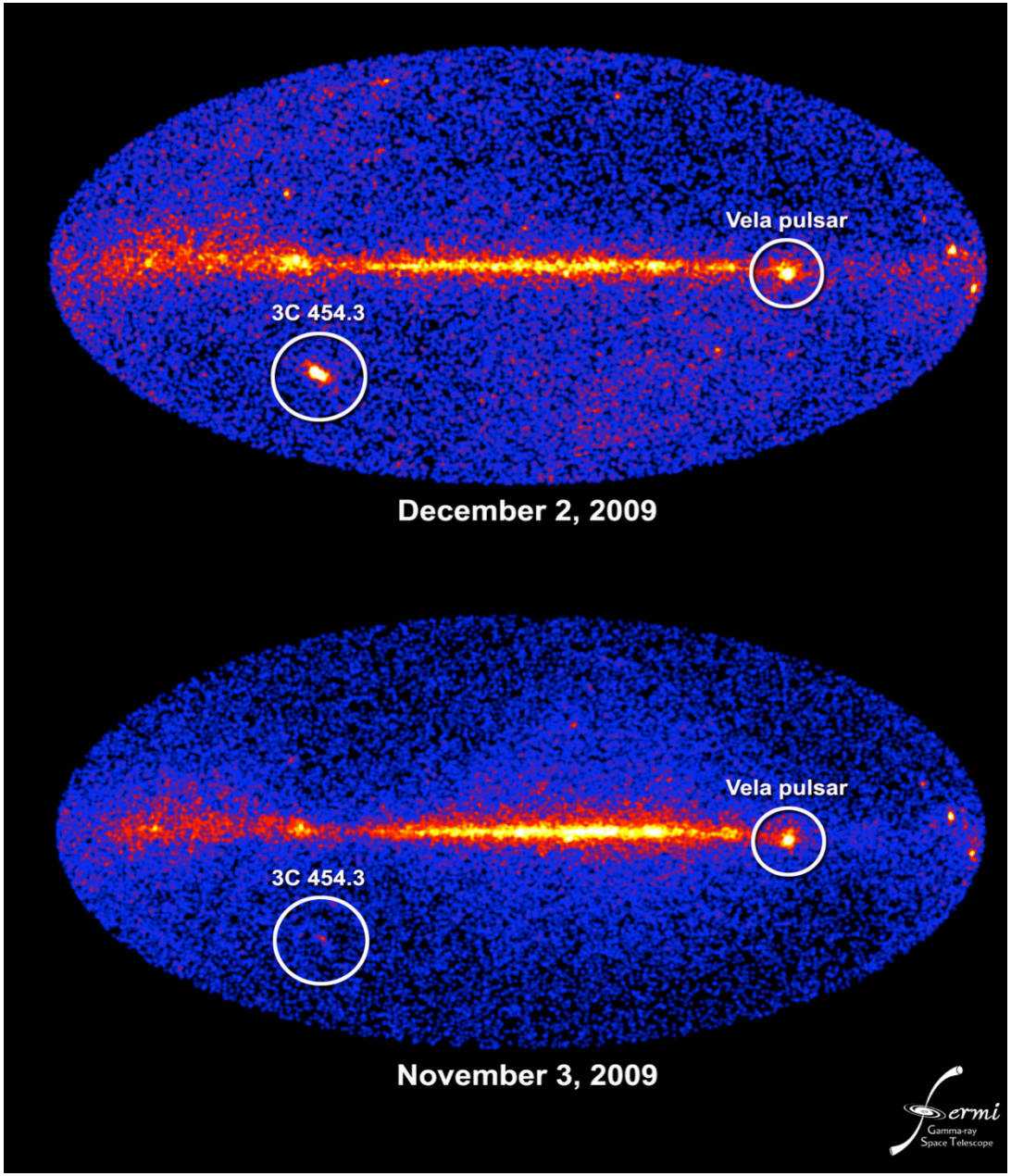


Explore LAT data

Overview of Fermi Science Tools

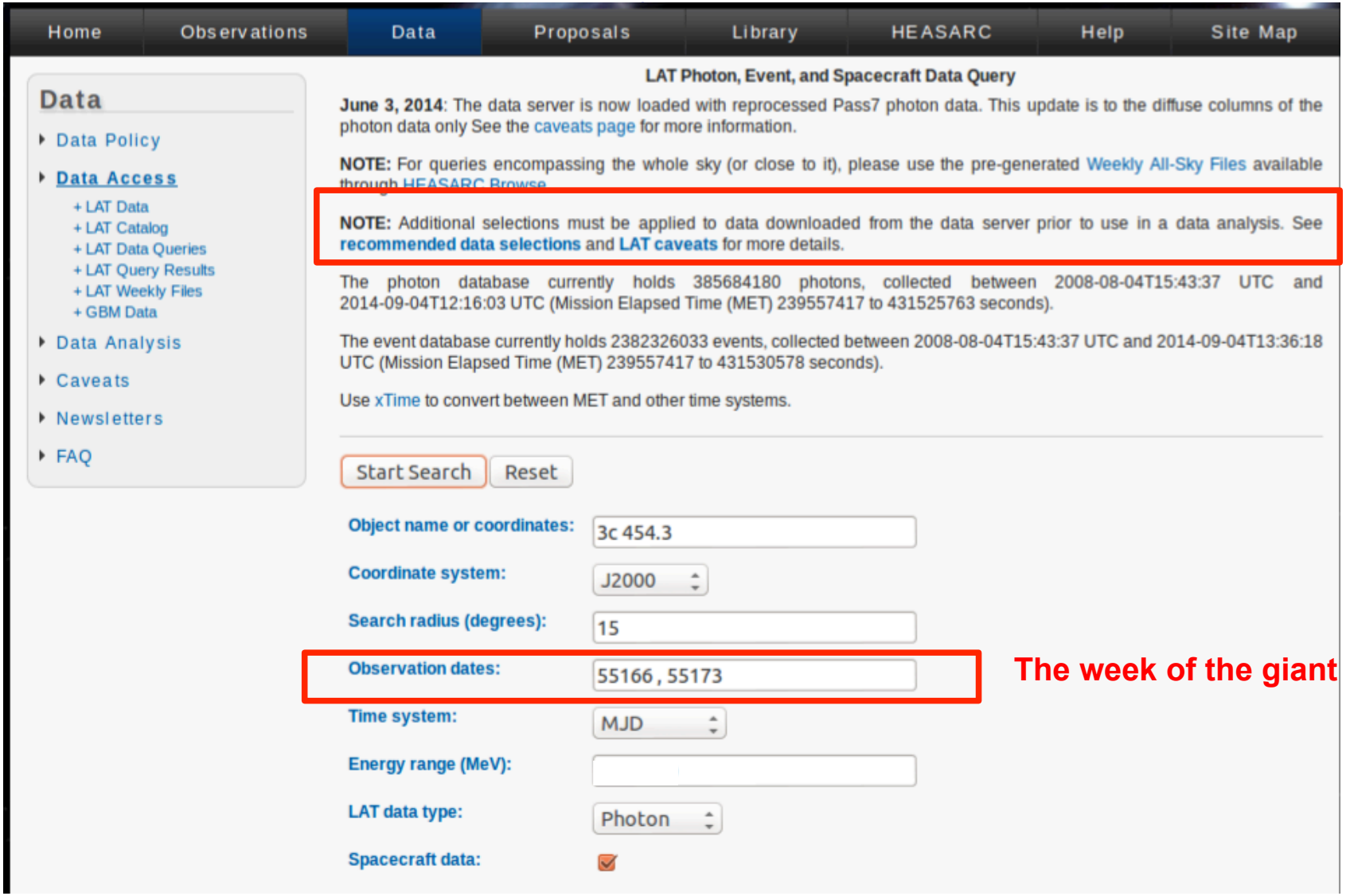


Blazar one of … 3c454.3's record flares!



How to download data

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



The week of the giant outburst!!

→ Download both spacecraft and photon data ←

Take note of the start and stop MET

follow the link

- Data Policy
- **Data Access**
  - + LAT Data
  - + LAT Catalog
  - + LAT Data Queries
  - + LAT Query Results
  - + LAT Weekly Files
  - + GBM Data
- Data Analysis
- Caveats
- Newsletters
- FAQ

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)

Server	Position in Queue	Estimated Time Remaining (sec)
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.

Filename	Number of Entries	Size (MB)	Status
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]

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)

- > 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.

gtmktime (cut the bad time intervals)

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

- [/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]

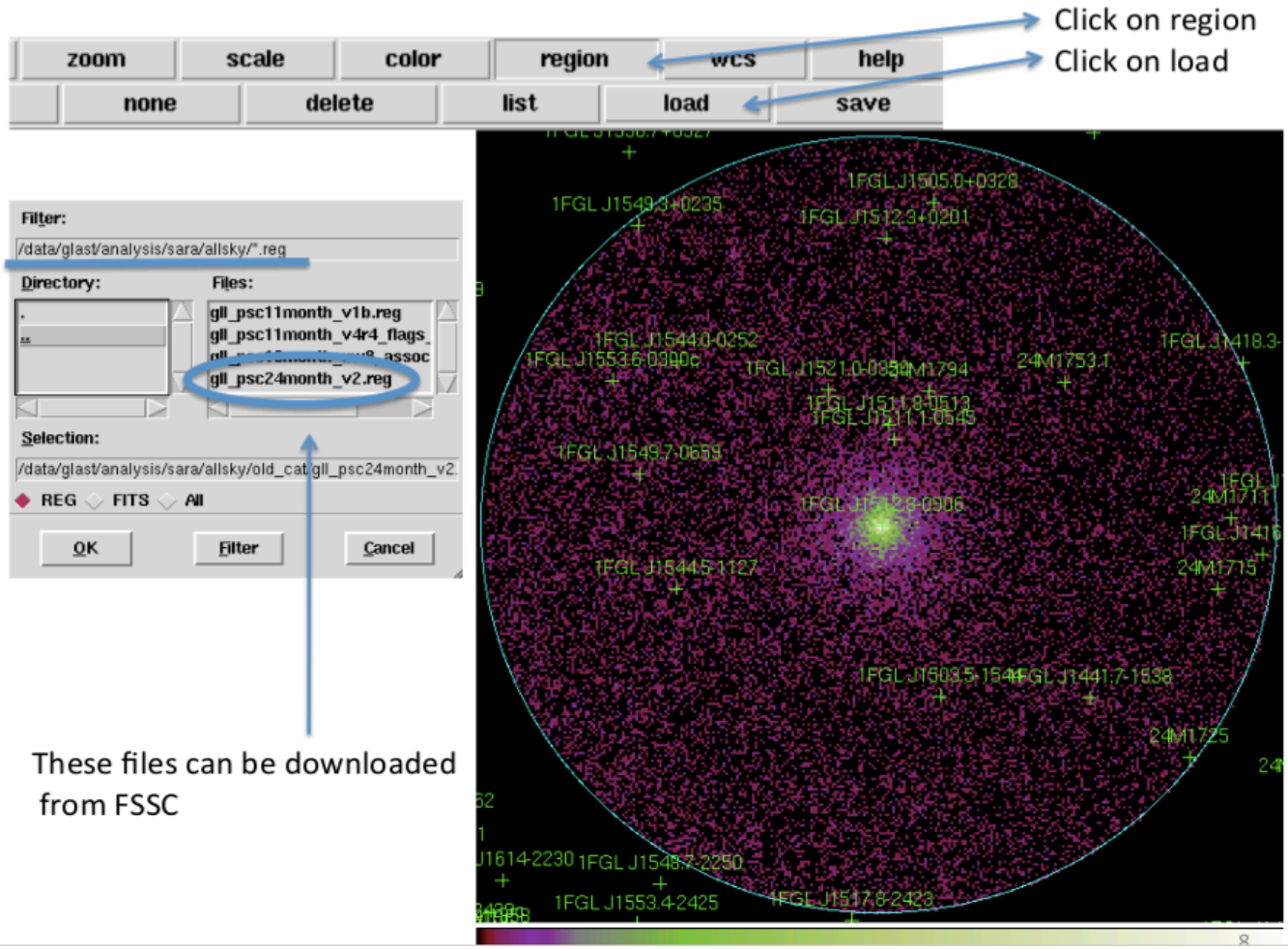
Use ZA to filter only proper GTIs

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 &



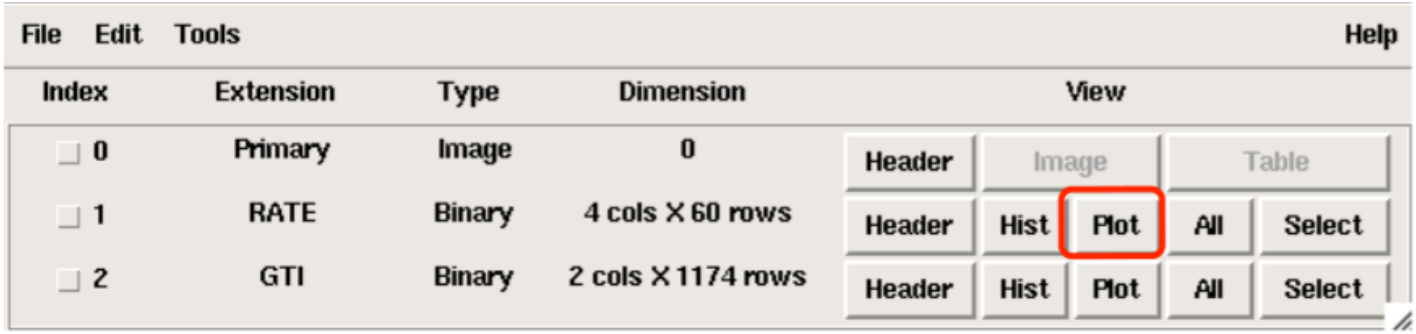
gtbin (Light Curve)

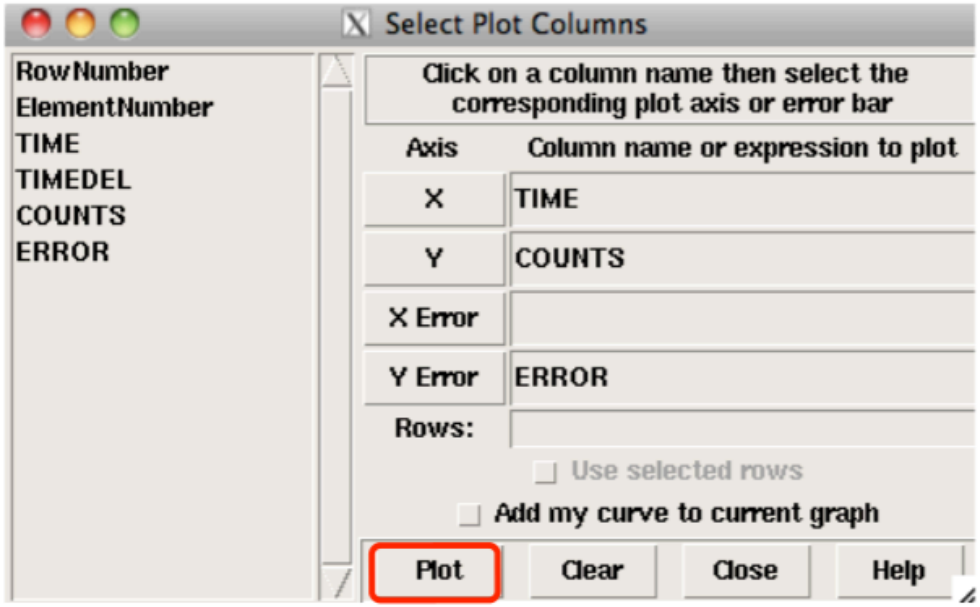
Take care that just one source falls inside the gtselect'ed ROI
(and take out albedo and other low-quality gammas via gtmktime)

- [/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]

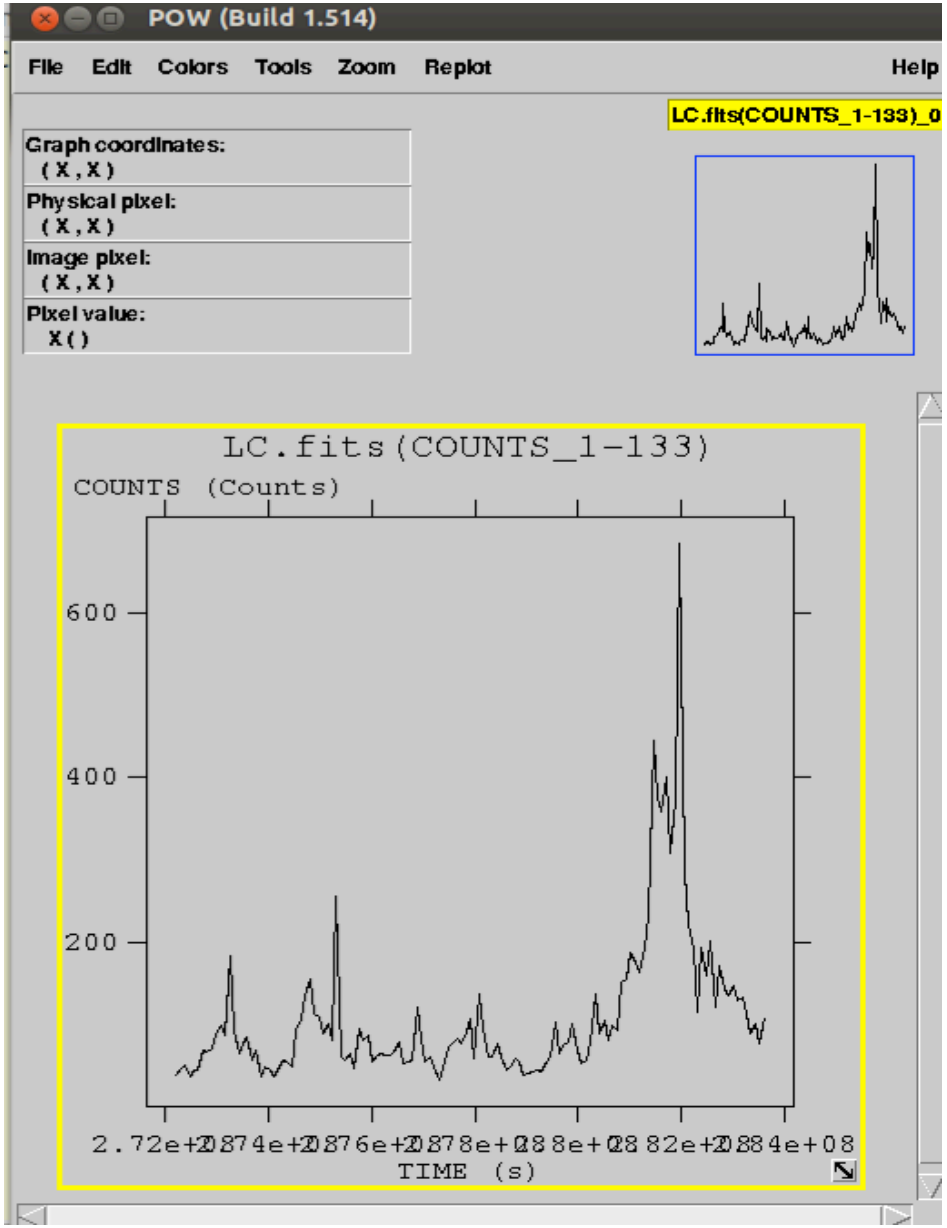
Light-curve: a quick-look

Use FitsView to look at the lightcurve:
> fv LC.fits & (rough estimate .. Not background subtracted)





Light-curve: a quick-look



Rough estimate of light curve
(background not subtracted!)

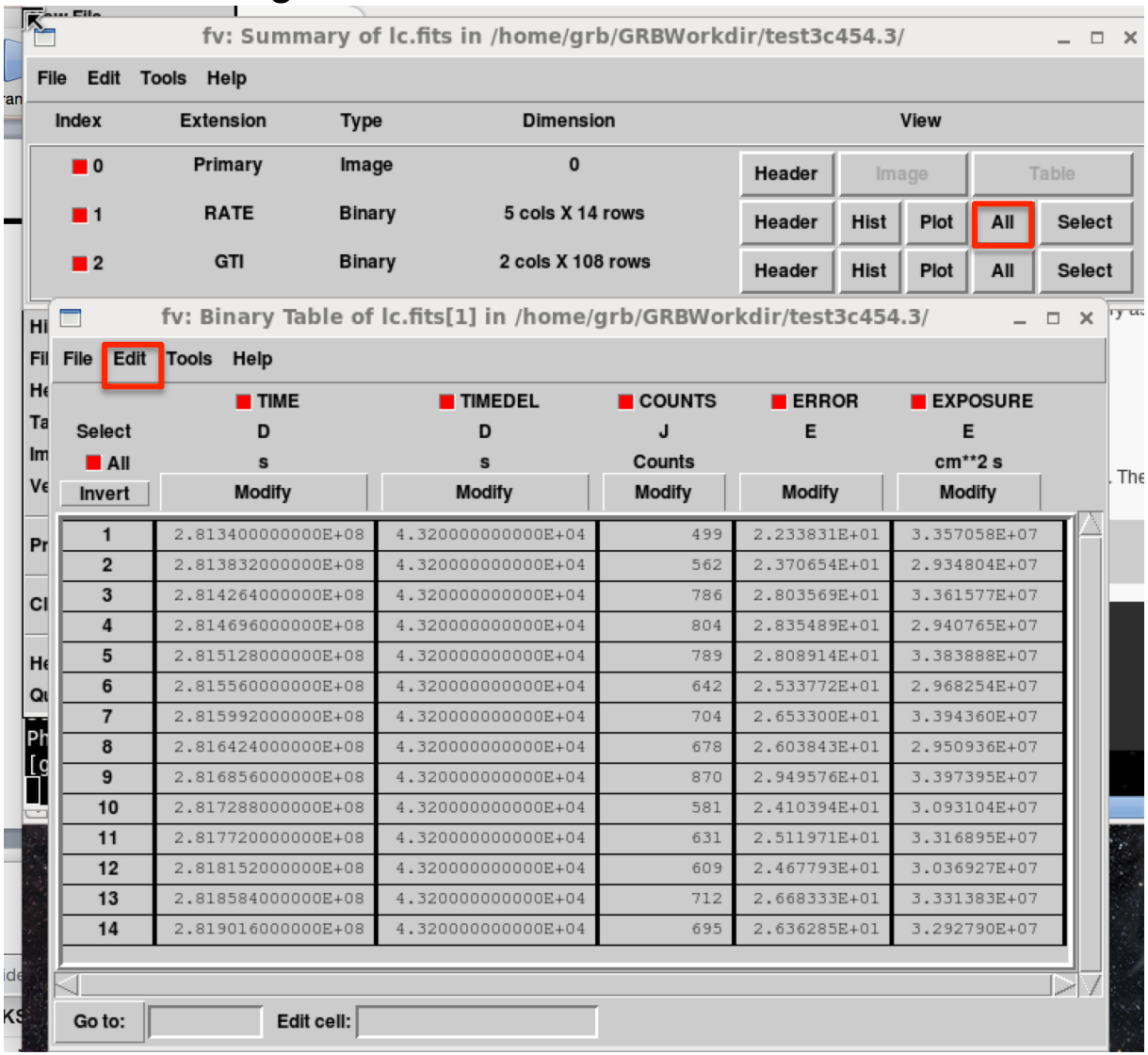
gtbin – II (Light Curve)

- [/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

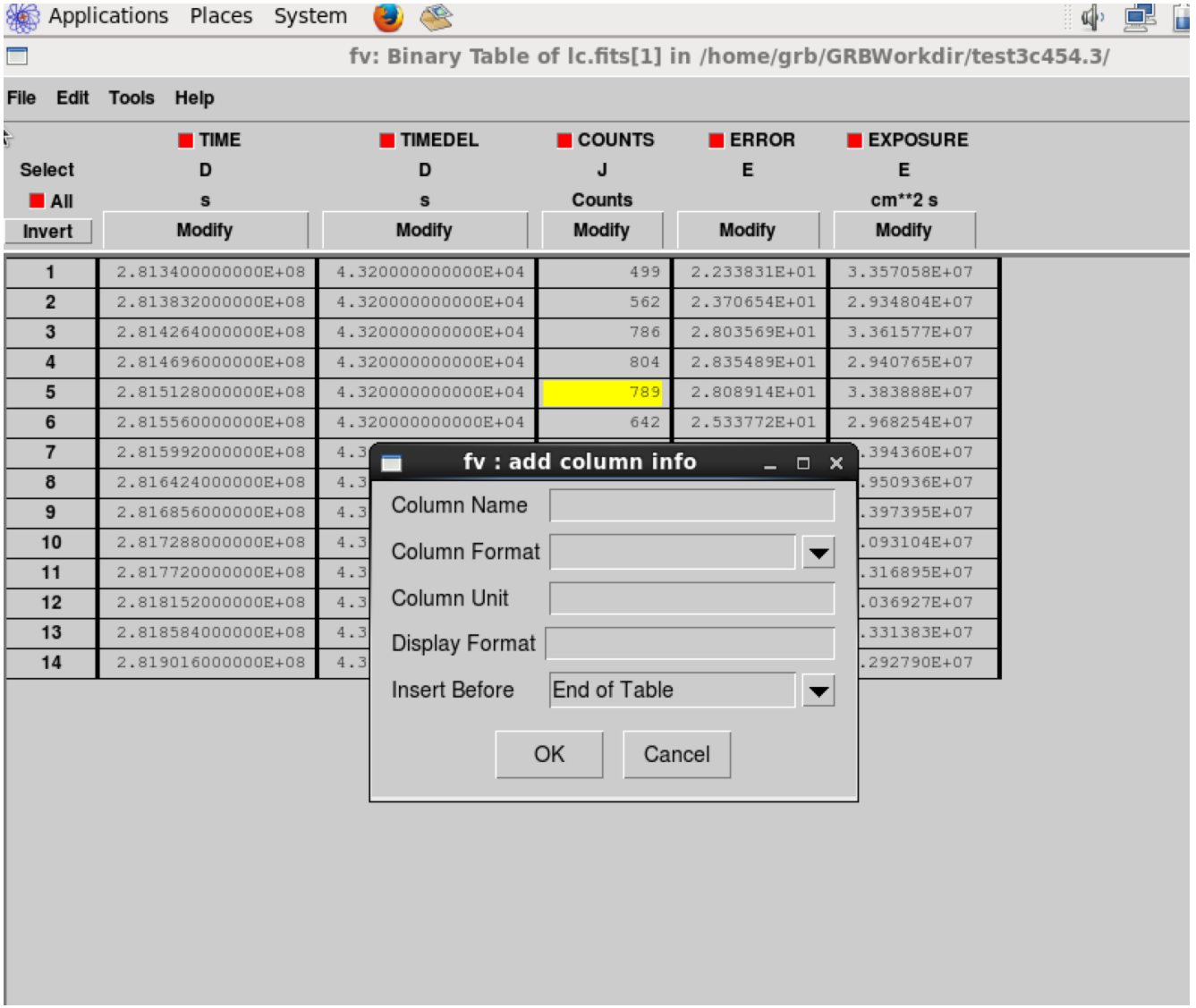
Use FitsView to look at the lightcurve:

> fv LC.fits &



Light-curve: calculate fluxes

Insert new column
Calculate rate
Calculate rate errors

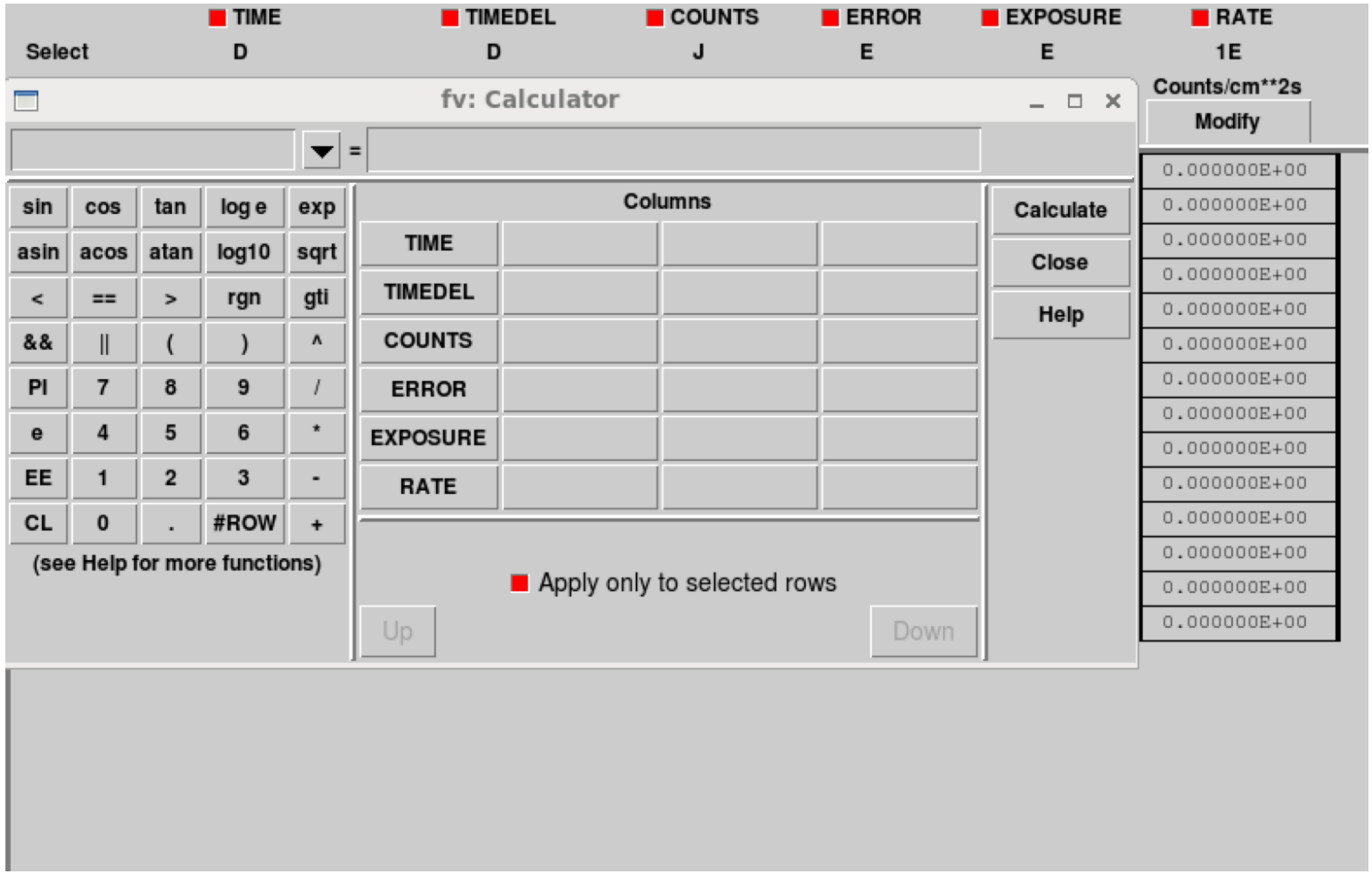


Light-curve: calculate fluxes

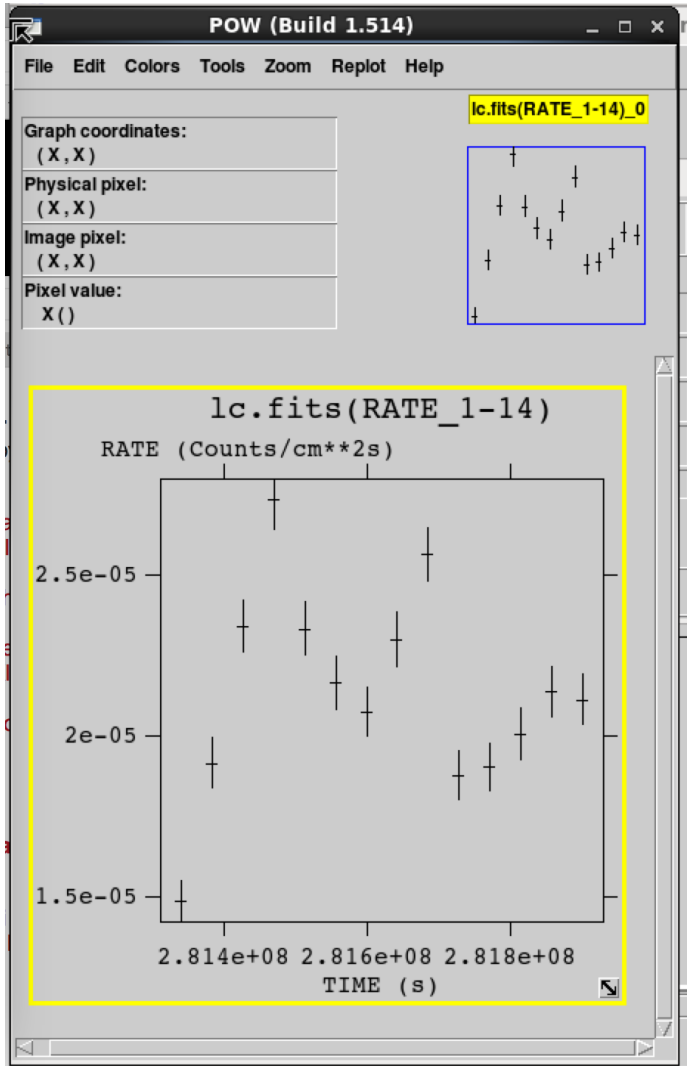
Insert new column
Calculate rate
Calculate rate errors

Light-curve: calculate fluxes

Insert new column
Calculate rate
Calculate rate errors



Light curve

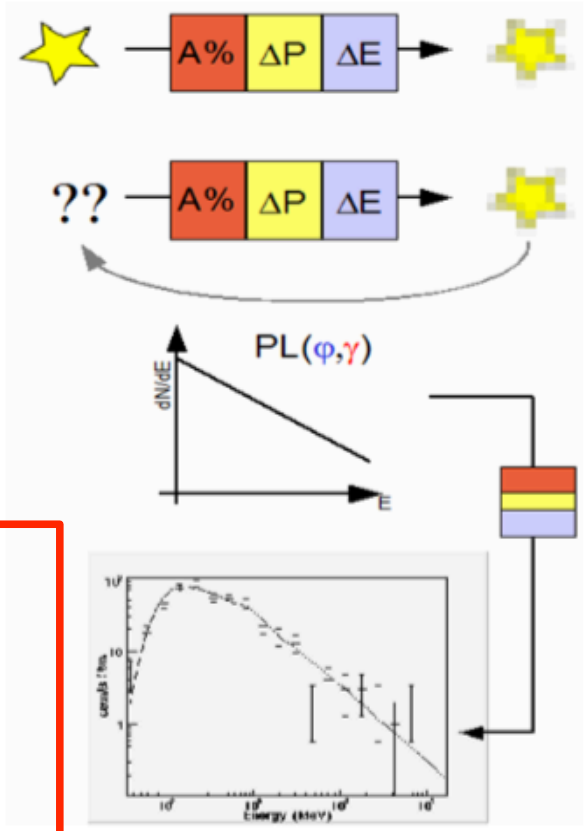

POW (Build 1.514)
File Edit Colors Tools Zoom Replot Help
lc.fits(RATE_1-14)_0
Graph coordinates:
(X,X)
Physical pixel:
(X,X)
Image pixel:
(X,X)
Pixel value:
X()
lc.fits(RATE_1-14)
RATE (Counts/cm**2s)
2.5e-05
2e-05
1.5e-05
2.814e+08 2.816e+08 2.818e+08
TIME (s)

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 responce 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: $X = \{x_i\} = \{x_1, x_2, ..., x_N\}$

Model parameters: $\Theta = \{\theta_j\} = \{\theta_1, \theta_2, ..., \theta_M\}$

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

Conditional probability rule for independent events:

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

For independent data:

$$P(X|\Theta) = P(\{x_i\}|\Theta) = P(x_1|\Theta)P(x_2, .., x_N|\Theta) = \cdots$$
$$= P(x_1|\Theta)P(x_2|\Theta)\cdots P(x_N|\Theta) = \prod_i P(x_i|\Theta)$$

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

$\mathcal{L}$ 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:

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

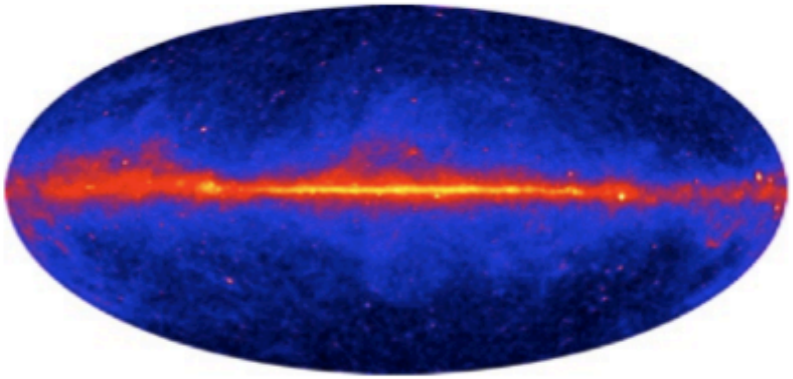
For one parameter, if we have: $\mathcal{L}(\theta) \sim e^{-\frac{(\theta-\hat{\theta})^2}{2\sigma_\theta^2}}$ **Gaussian approximation**

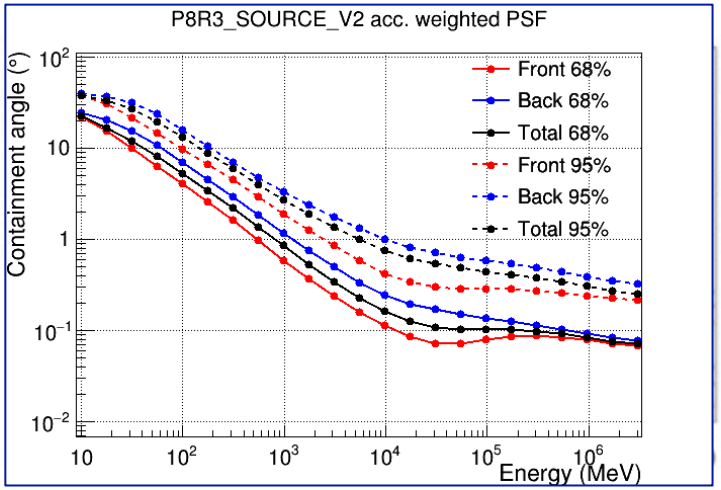
then: $$\left.\frac{\partial^2 \ln \mathcal{L}}{\partial \theta^2}\right|_{\hat{\theta}} = -\frac{1}{\sigma_\theta^2}$$

so 2nd derivative is related to "errors"

Why Model Fitting?

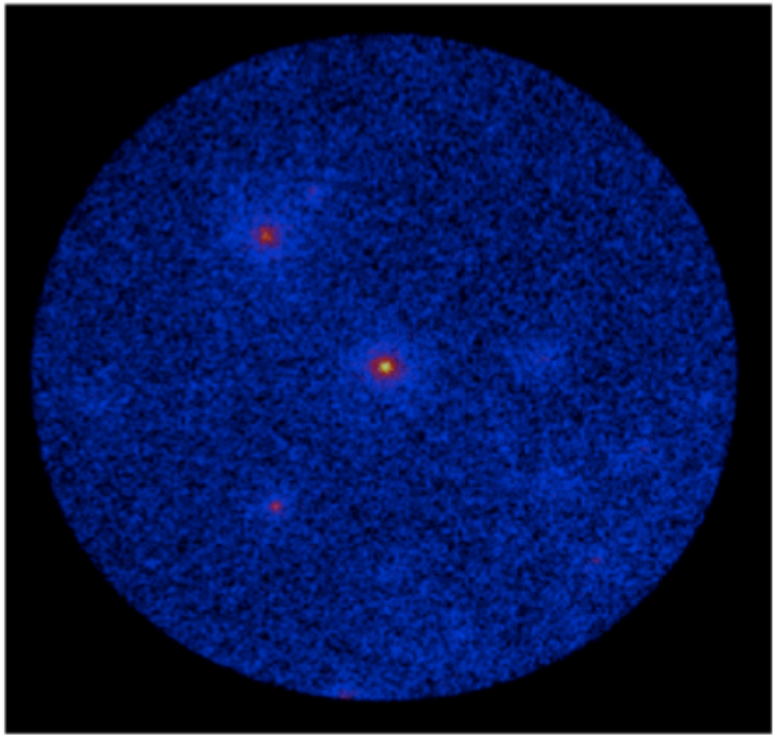
- We use the Likelihood method because the LAT data are limited by statistics, a bright diffuse background and a broad PSF.
- The model construction defines the questions we want to ask which means:
  - It will not answer a question you are not asking (ie. unknown parameters).
- The Likelihood will not 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.

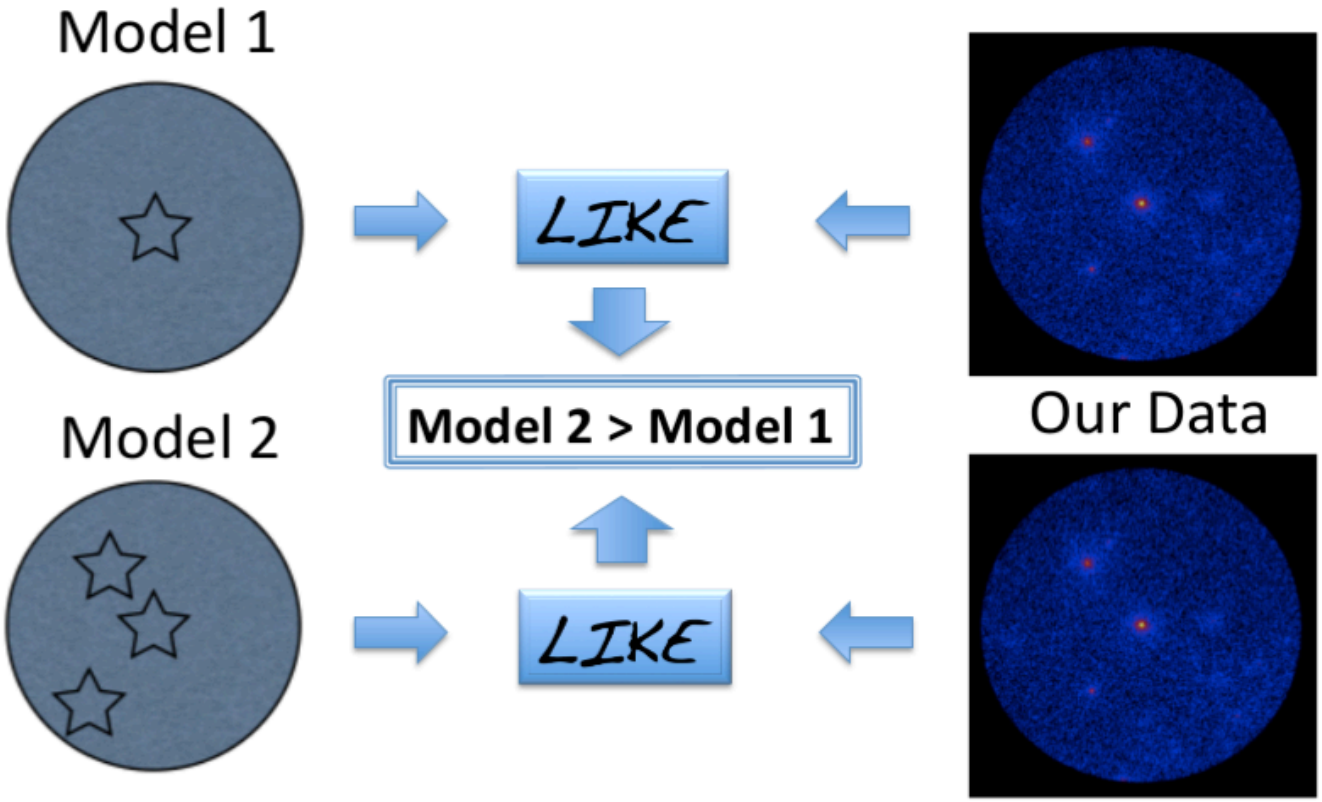


Count Map

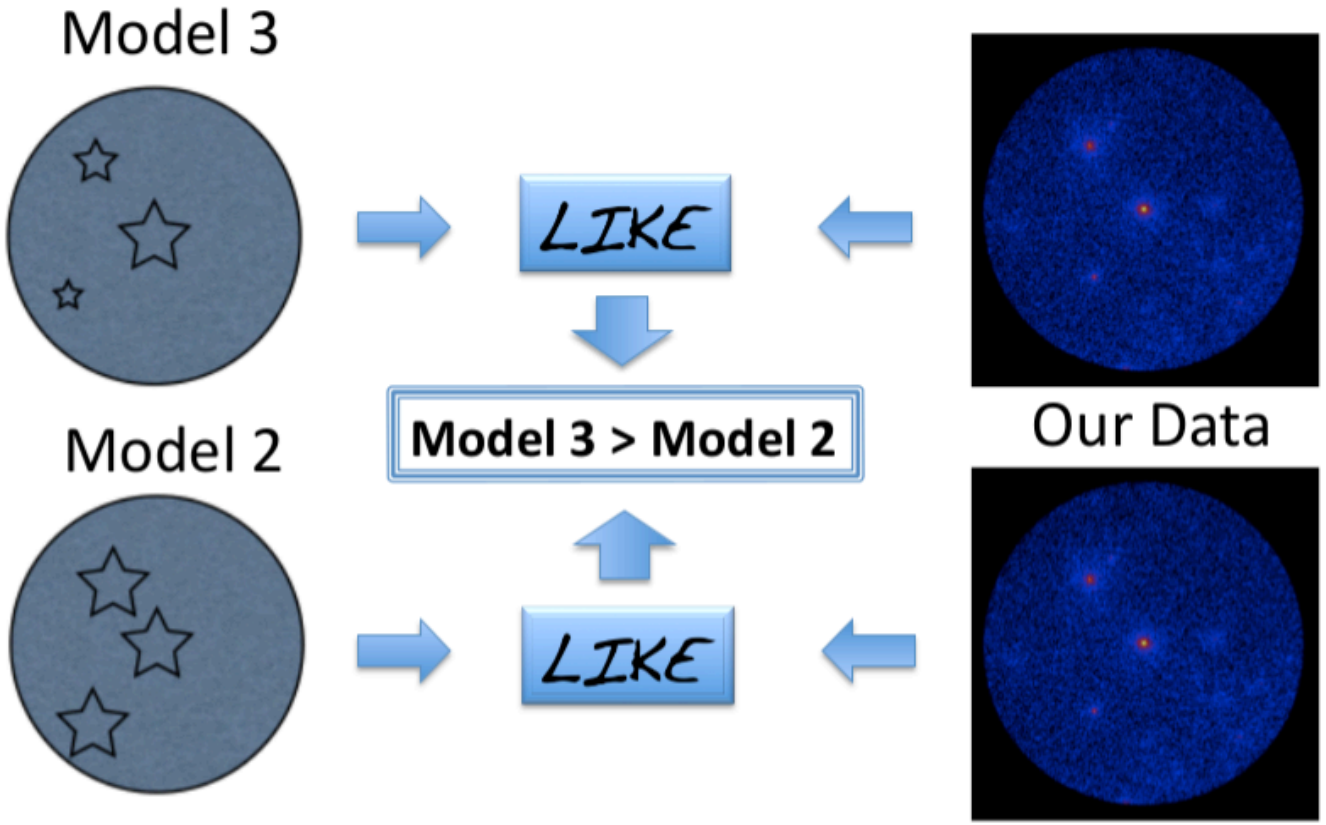
The Procedure

- 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

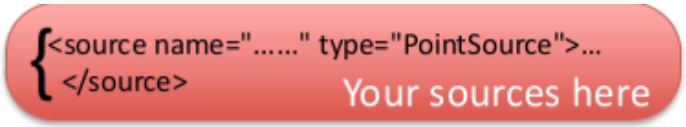


A Graphical Example



Describing the Source Model: the XML model

- Typical source entry for an assumed powerlaw spectrum



- <!-- Point Sources -->
- <source name="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.

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

- Write L as a function of the source model

The function to maximize is:

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

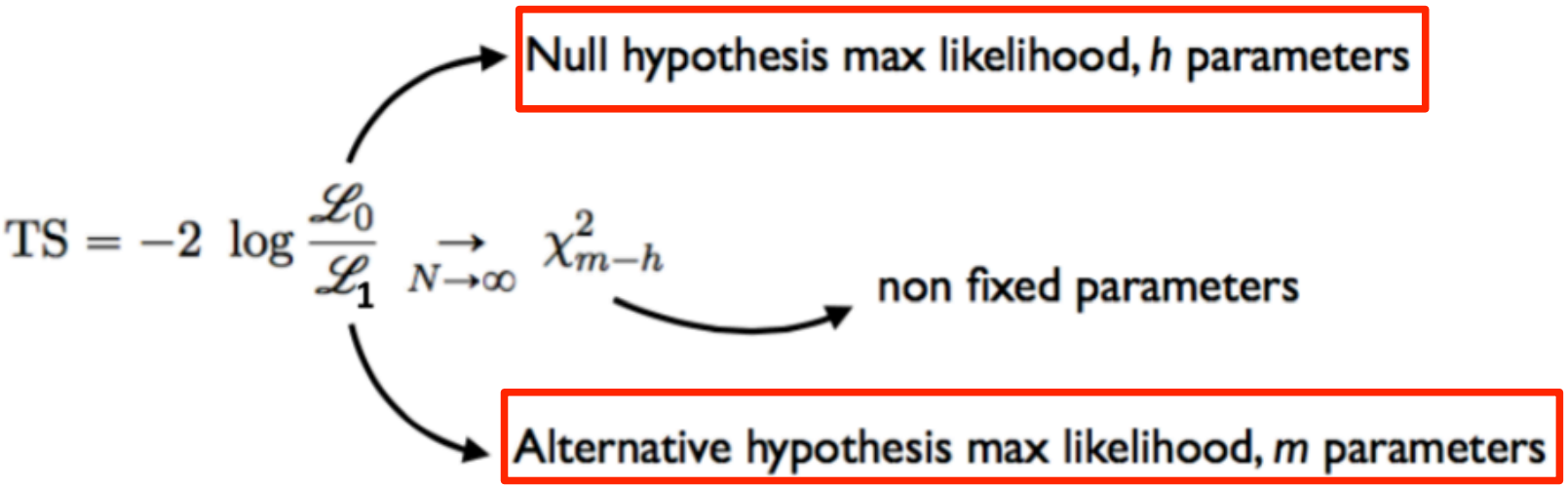
where the sum is performed over photons in the ROI. The predicted number of counts is

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

- The source model is folded with the IRFs in order to obtain the predicted number of counts
- The IRFs can be decomposed into three funtions: Effective Area (proj area of the detector * efficency), Energy Dispesion, Point Spread Function

- Small number of counts in each bin --> Poisson distribuiton
- 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^2_n 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:

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

Point Sources — Galactic & EG diffuse Sources — Other Sources

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

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

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

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

- Adjust the model until this is maximized:

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

- Calculate the TS:

$$\mathrm{TS} = -2\ \log \frac{\mathscr{L}_0}{\mathscr{L}_1} \underset{N\to\infty}{\to} \chi^2_{m-h}$$

Keep in mind that ..

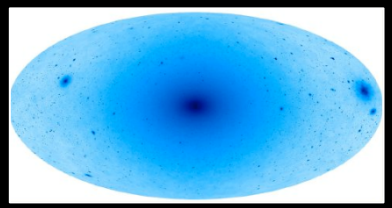
- Many variables may be calculated BEFORE selecting the models
- Very important to have a reliable model
- Absolute value of likelihood meaningless!
  - Likelihood function has no meaning itself, e.g., it is not a probability. Its usefulness comes from theorems such as the LRT.
- Comparison between model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

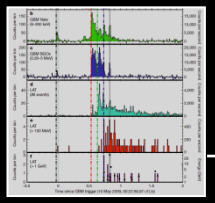
Astrofisica Nucleare e Subnucleare

Galactic GeV Sources

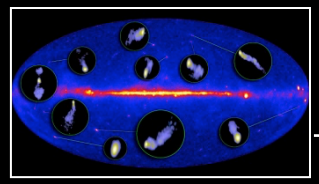
Fermi Highlights and Discoveries

Dark Matter searches

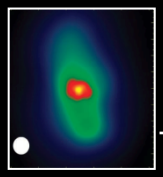




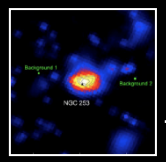
GRBs



Blazars

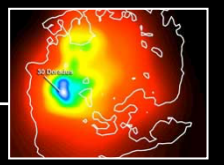


Radio Galaxies

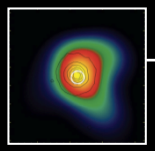


Starburst Galaxies

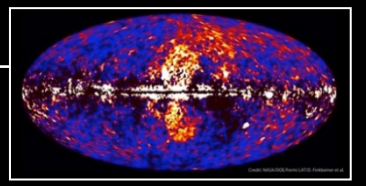
Extragalactic



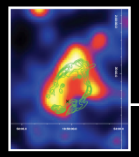
LMC & SMC



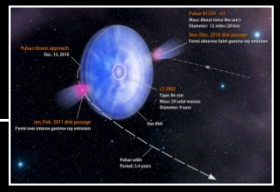
Globular Clusters



Fermi Bubbles

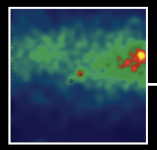


SNRs & PWN

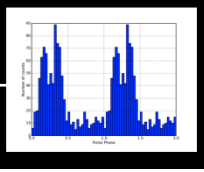


γ-ray Binaries

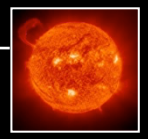
Galactic



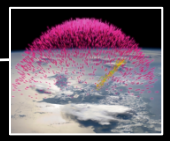
Novae



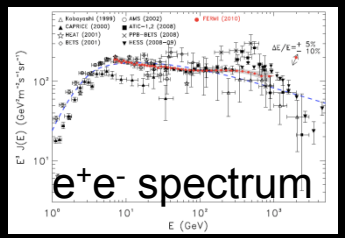
Pulsars: isolated, binaries, & MSPs



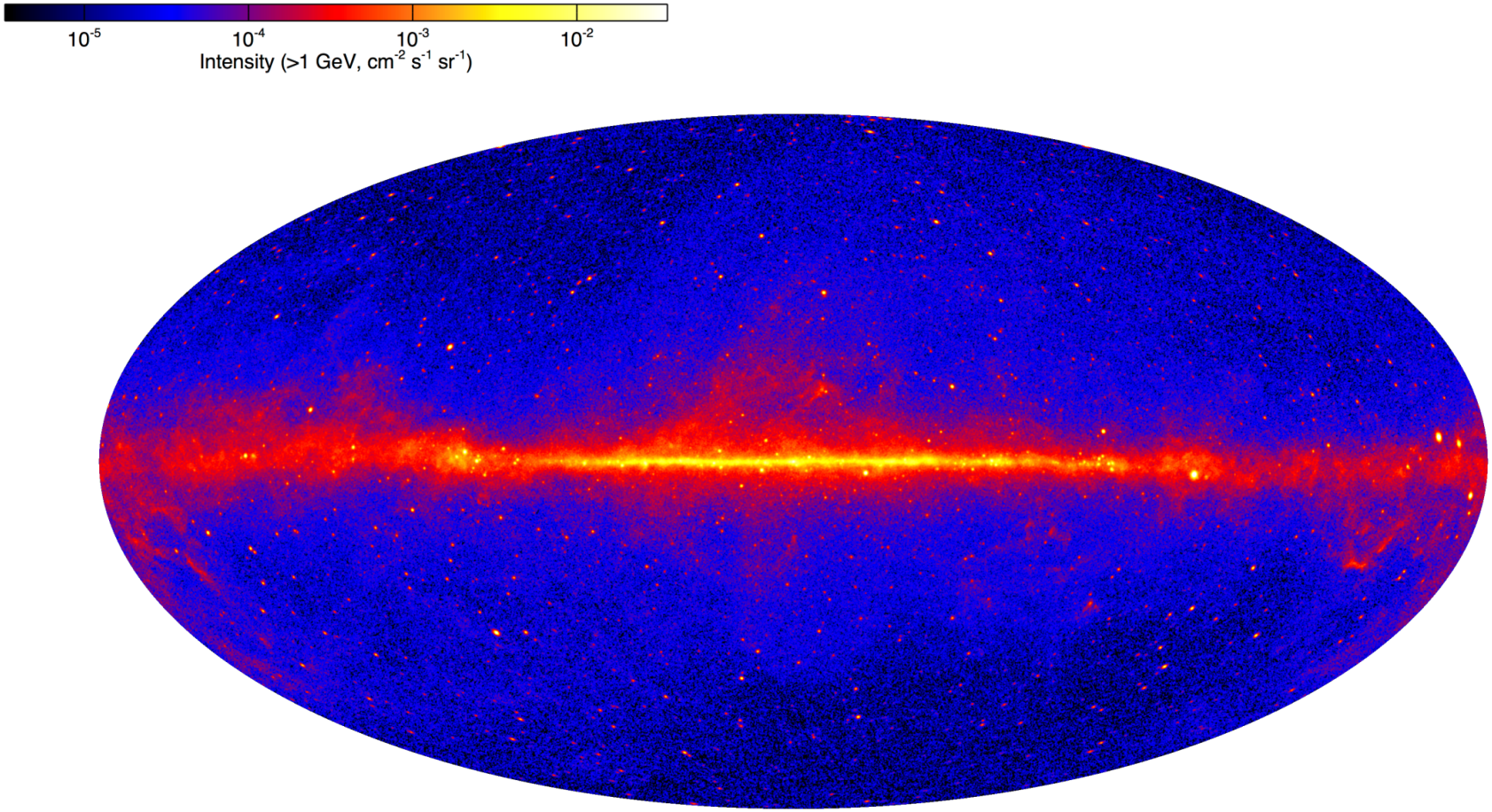
Sun: flares & CR interactions



Terrestrial γ-ray Flashes



Unidentified Sources



84 months of data

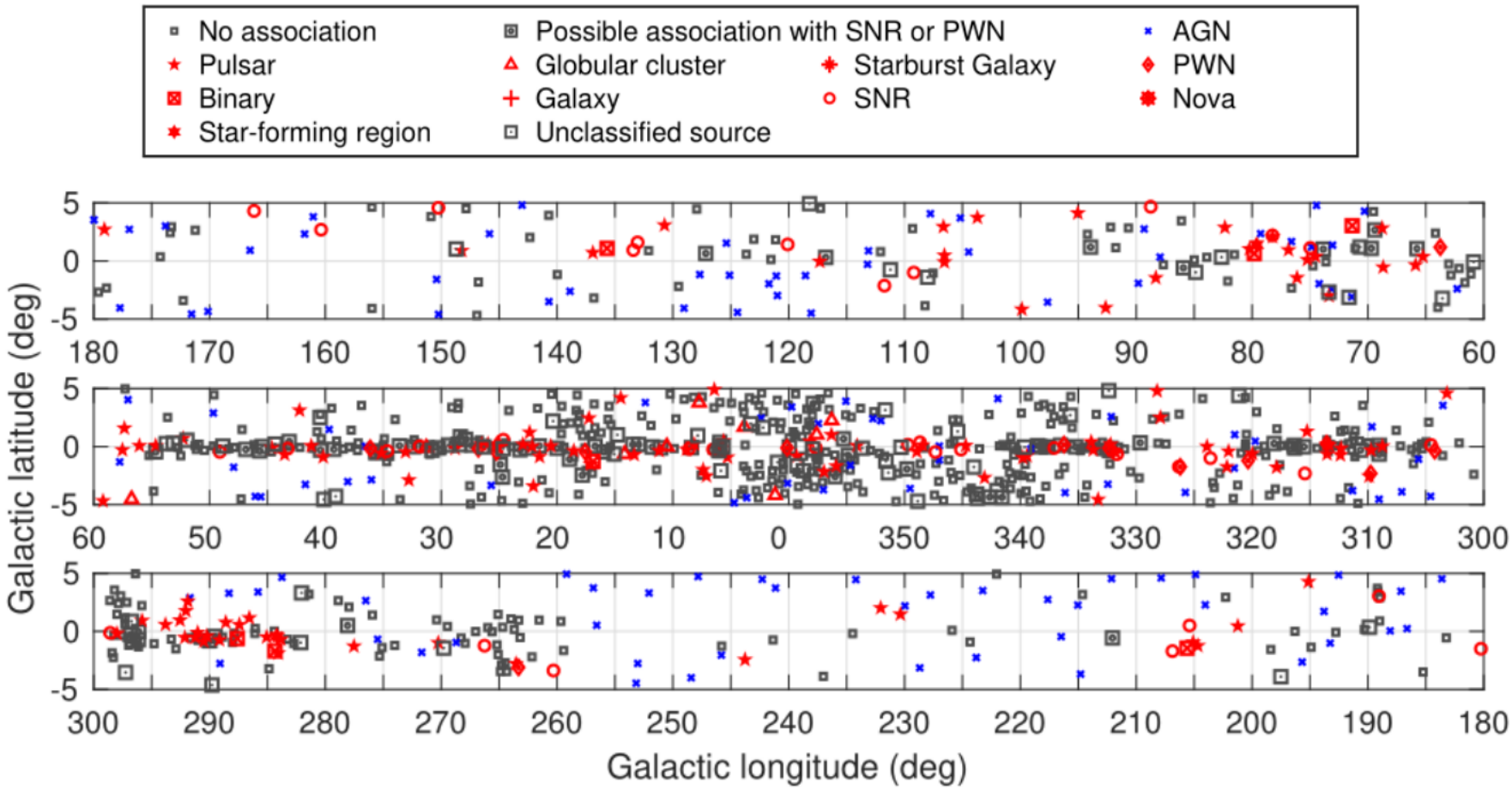
>1 GeV. Pass 8, from August 4, 2008 through August 4, 2015.
LAT rocking angle <52° and zenith angle <100°.

Milky Way is gamma *bright*:
GeV and TeV cosmic rays (mostly protons) hit gas & dust to make pions,
then $\pi^{\circ} \rightarrow \gamma\gamma$ 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



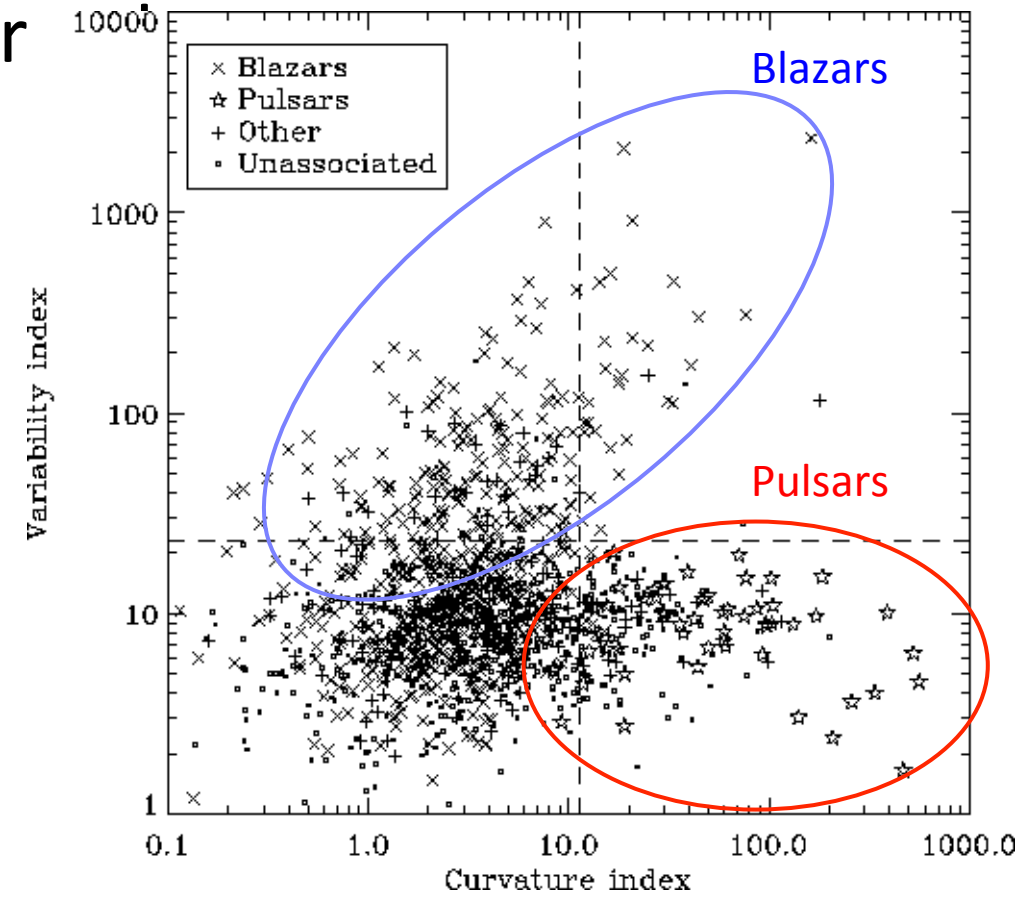
Unidentified Gamma-ray Sources

- 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

Hays 2010

Spectral-Variability Classification

- Blazars and pulsars in the variability-spectral curvatur



Hays 2010