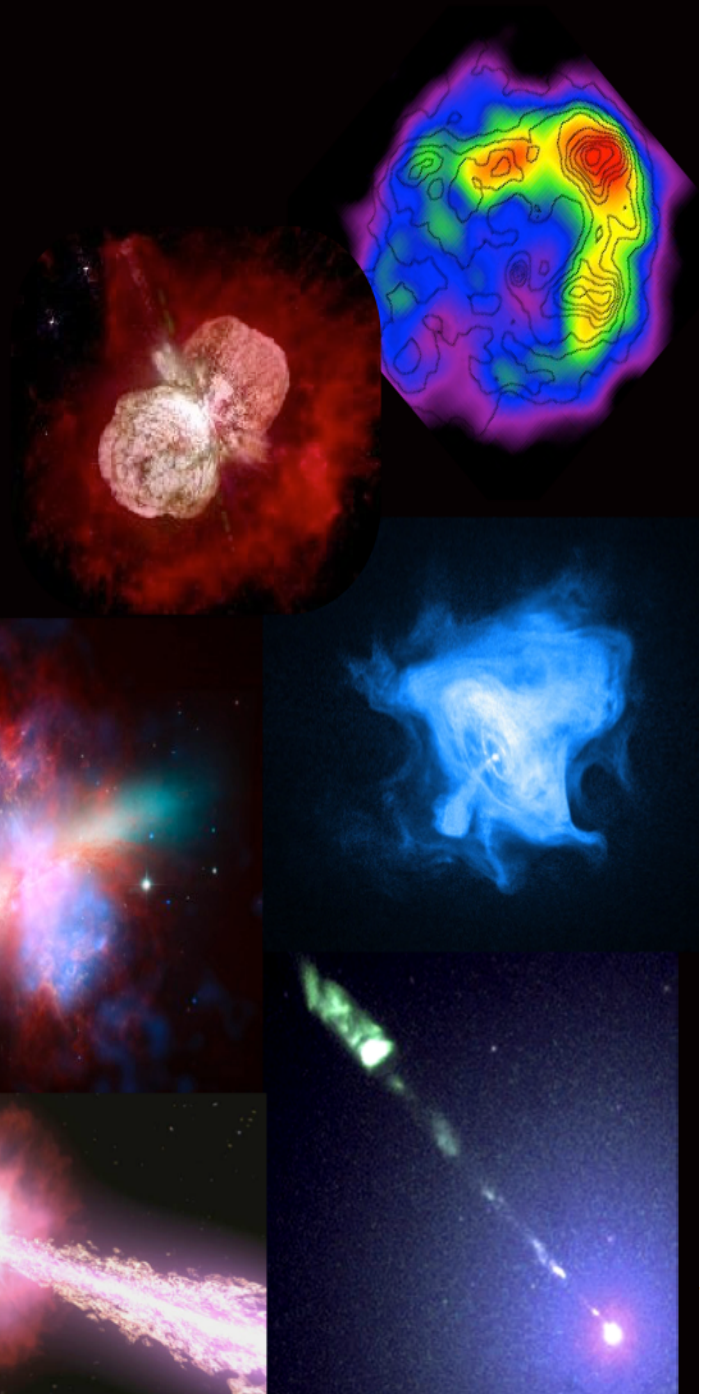
Astrofisica Nucleare e Subnucleare

UHECR

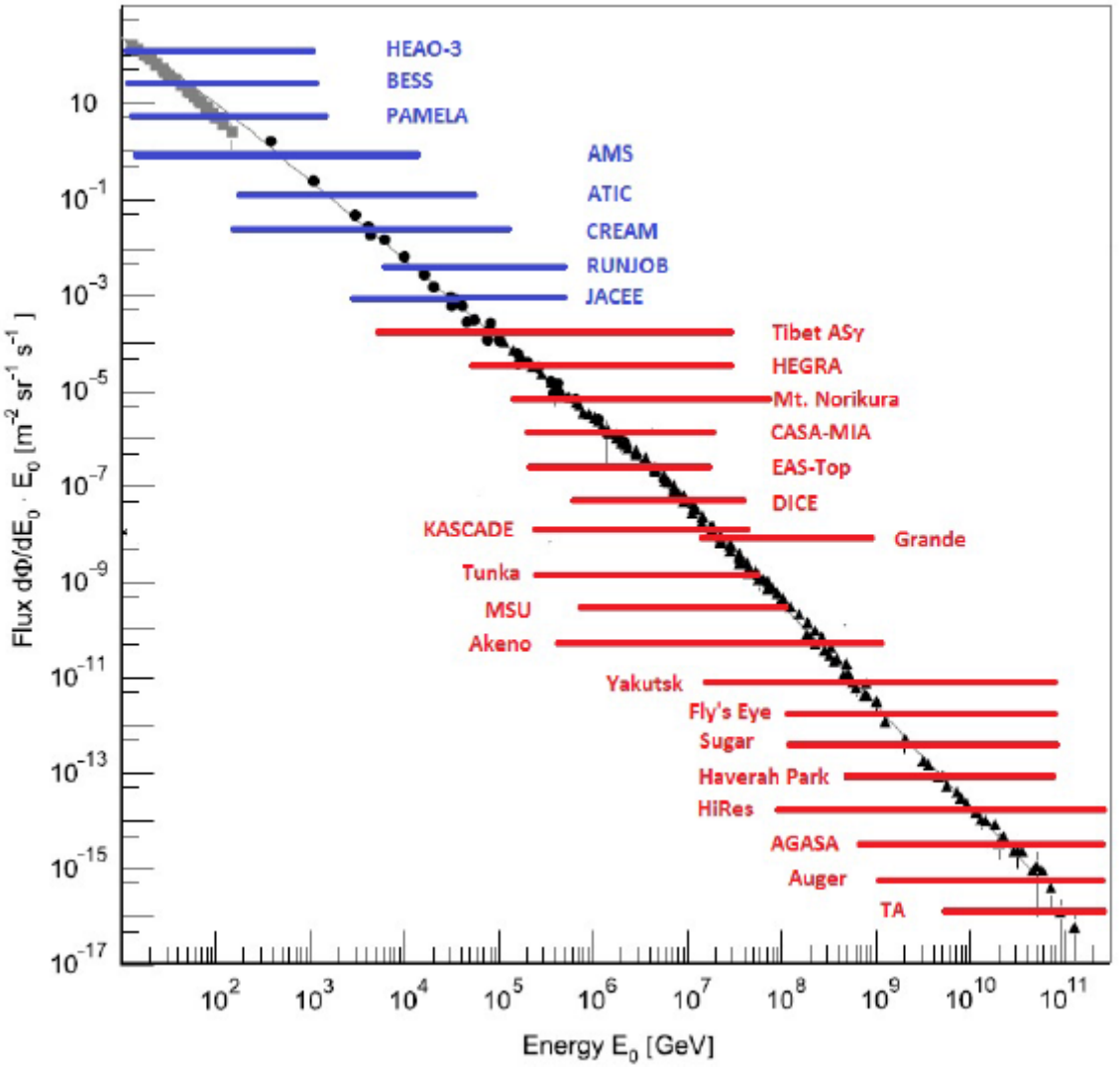
- Astonishing variety of TeV* emitters
  - Within the Milky Way
    - Supernova remnants
    - Bombarded molecular clouds
    - Stellar binaries - colliding wind & X-ray
    - Massive stellar clusters
    - Pulsars and pulsar wind nebulae
    - Supermassive black hole Sgr A*
  - Extragalactic
    - Starburst galaxies
    - MW satellites
    - Radio galaxies
    - Flat-spectrum radio quasars
    - 'BL Lac' objects
    - Gamma-ray bursts
- Acceleration to TeV energies is common, gamma-rays are an effective probe
  - Strongly complementary to sync. measurements

*0.05-50 TeV

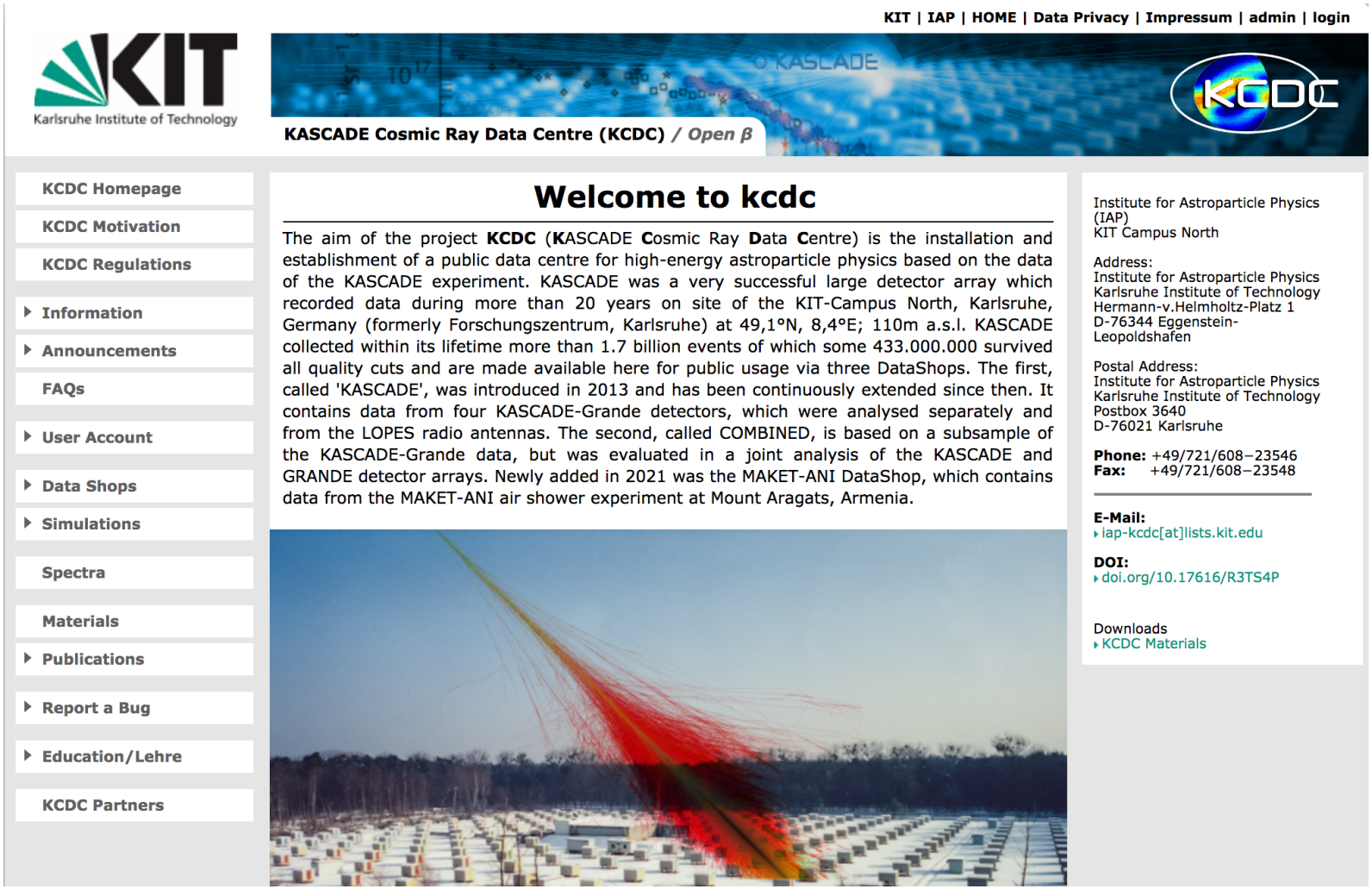


Metodi di misura dei raggi cosmici

Misure dirette
$E<10^{14}$ eV
Misure indirette,
$E>10^{14}$ eV



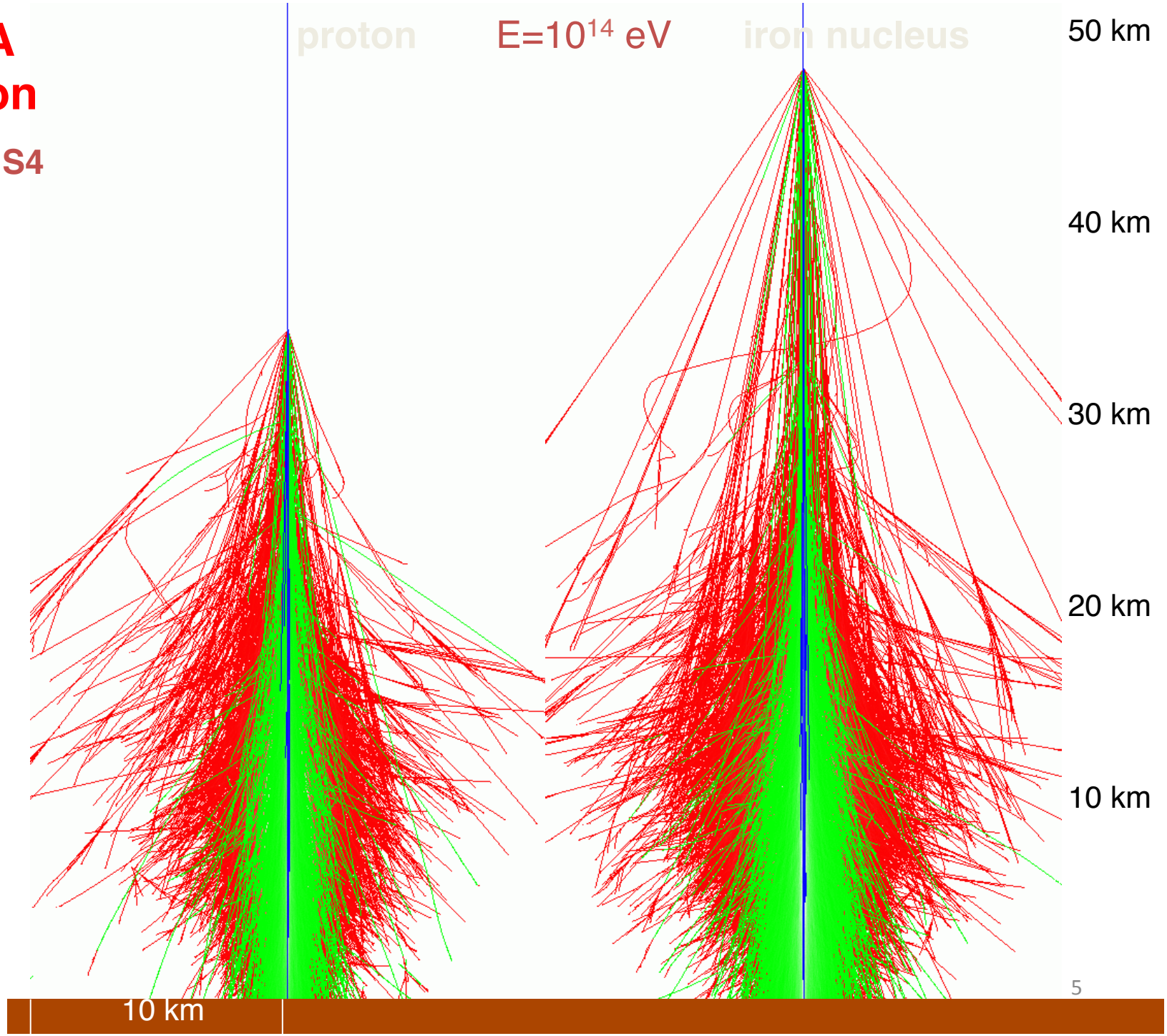
KASCADE



https://kcdc.ikp.kit.edu/

CORSIKA Simulation

QGSJET/EGS4

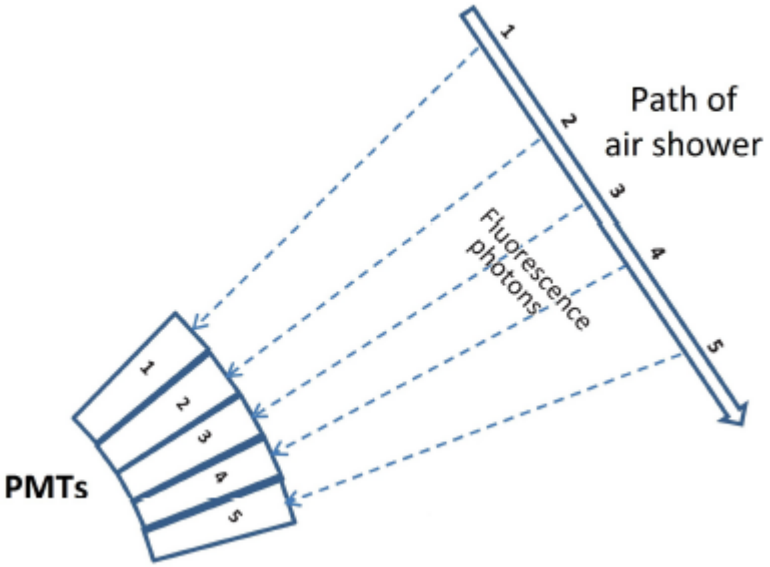


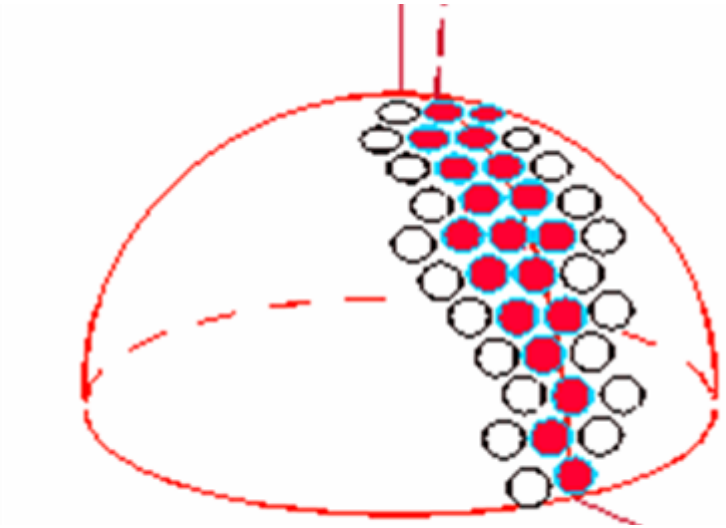
e/γ

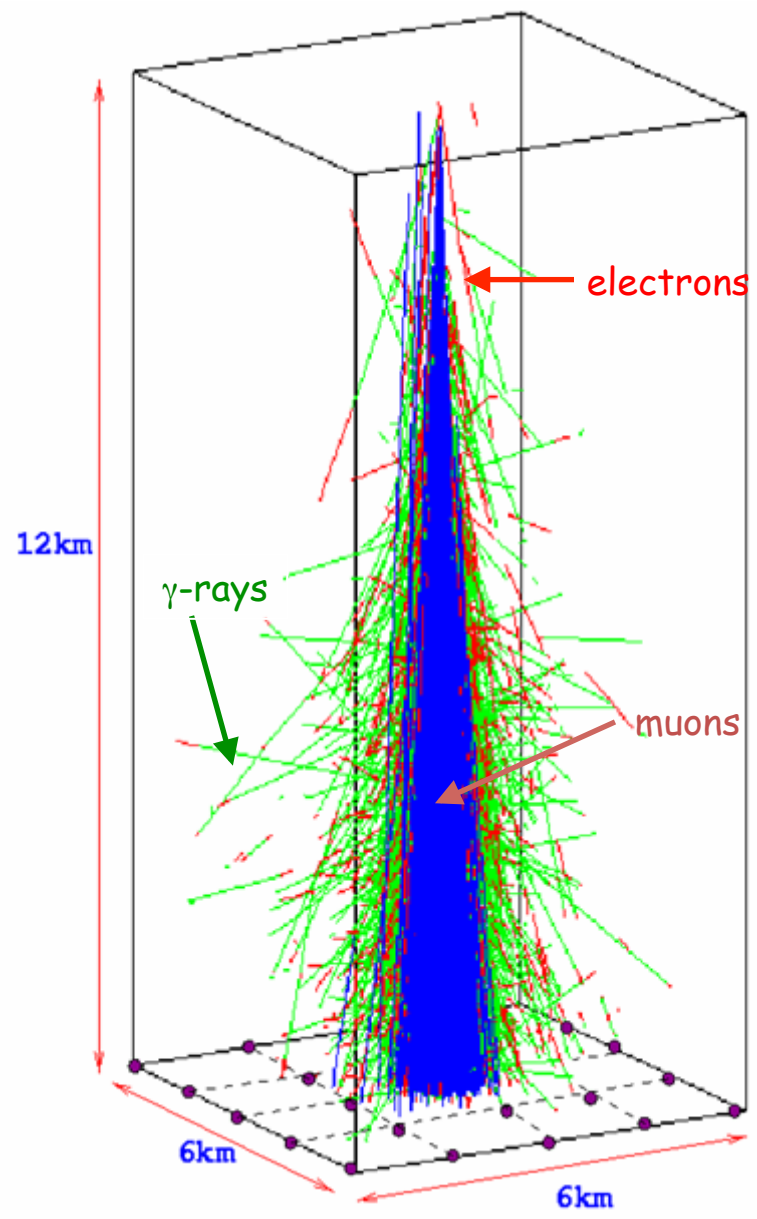
μ

h

Rivelatori di sciami di alta energia







AUGER: Un rivelatore ibrido

Rivelatore di sciami: 1600 taniche cilindriche (ciascuna di 10 m^2 ed alte 1.5 m) riempite di acqua, per rivelare gli sciami al suolo tramite la luce Cerenkov emessa dagli elettroni nell'acqua

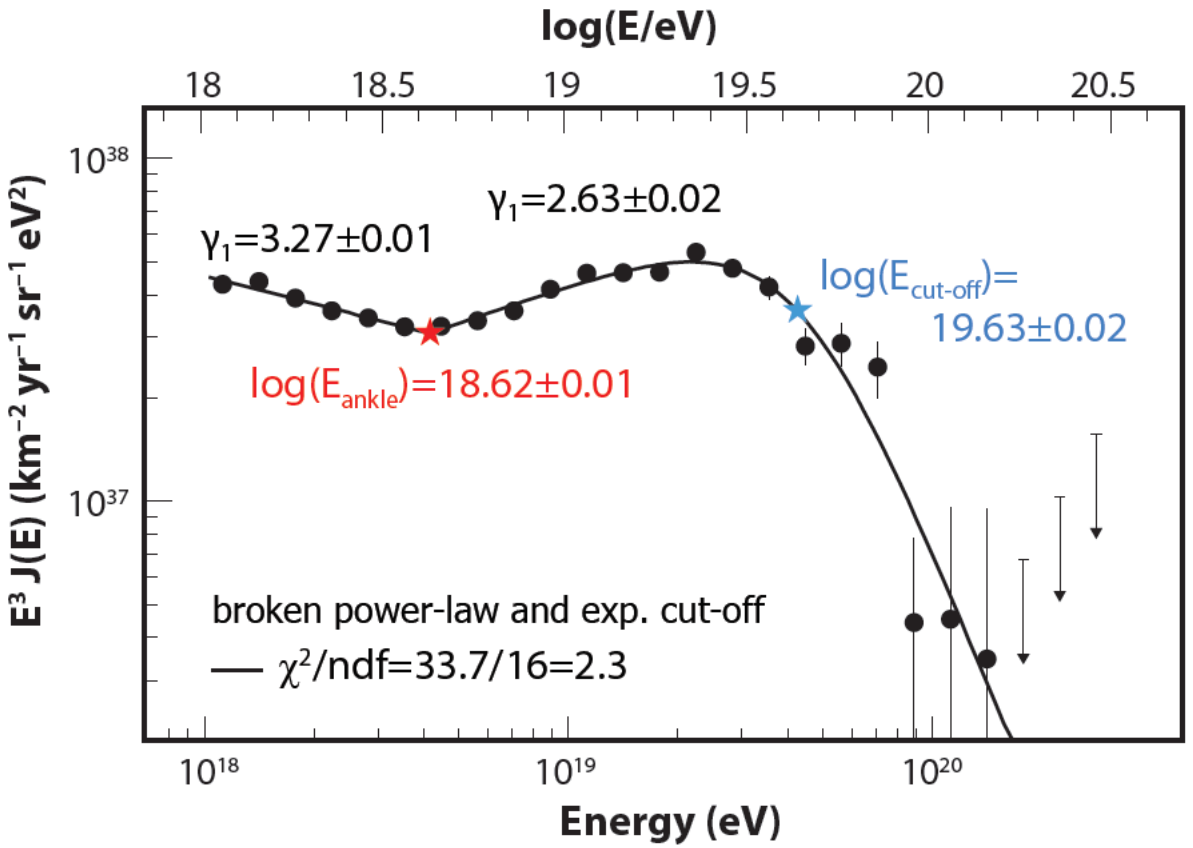
- Il rivelatore di sciami misura la distribuzione laterale e temporale dello sciame
- Distanza tra taniche: 1.5 km
- Area di forma esagonale, di 60×60 km^2
- Rivelatori di fluorescenza: 6 telescopi con ciascuno 4 "occhi" per determinare il profilo longitudinale dello sciame e l'altezza del suo massimo.

AUGER Energy spectrum

SD+Hybrid Combined Spectrum

#893: Salamida

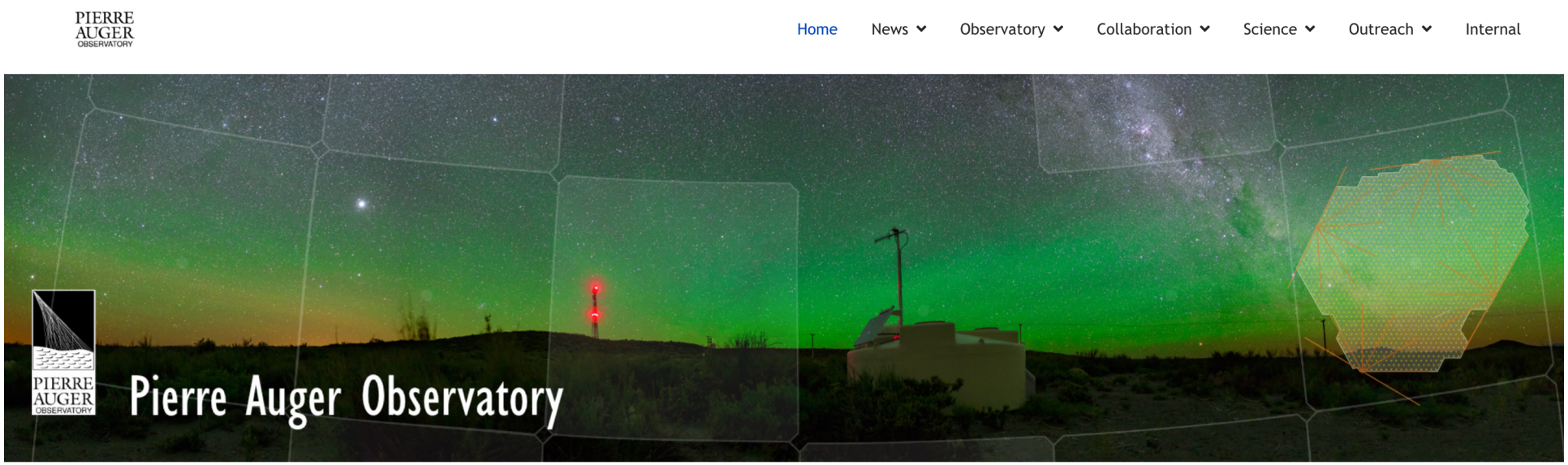
#724: Dembinsky



Exposure = 20905 km² sr yr (60% increase over PLB 685 (2010) 239)

Inclined showers add another 5300 km² sr yr (→ #724)

Auger



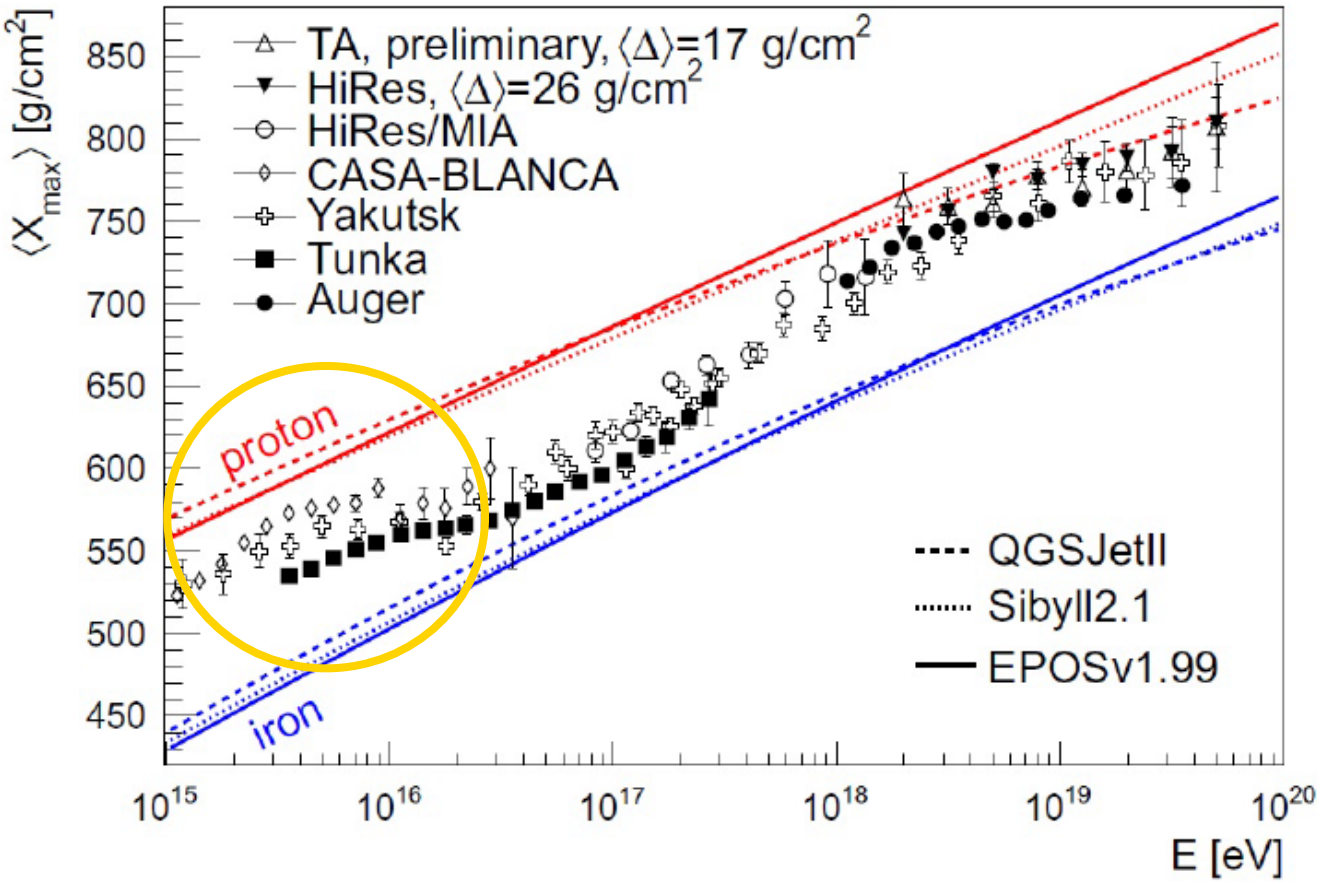
The Pierre Auger Collaboration wants to express all its closeness and solidarity to the people in Ukraine who are suffering the consequences of the war.

https://www.auger.org/

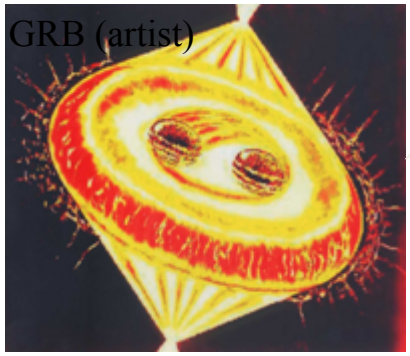
Composizione chimica dei RC nella regione degli EAS

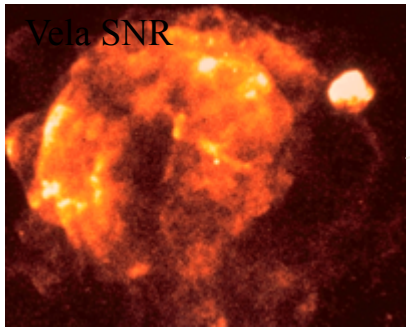
- Il modello del *leaky box* prevede un arricchimento di elementi pesanti nei RC sino al ginocchio.

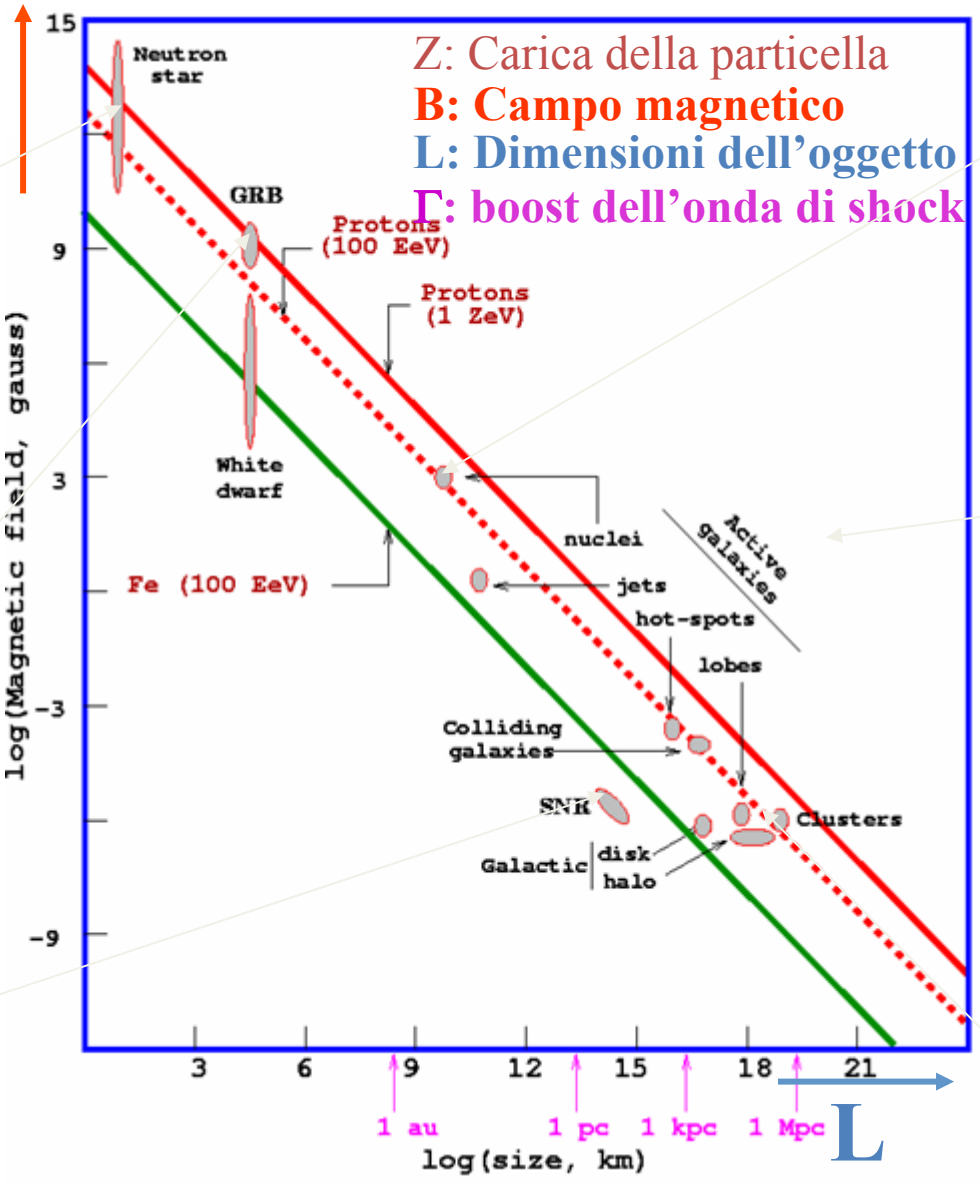
- Gli EAS possono misurare <A> con difficoltà.
- Le misure possono essere poi confrontate con *modelli estremi* (solo p o Fe) via MC

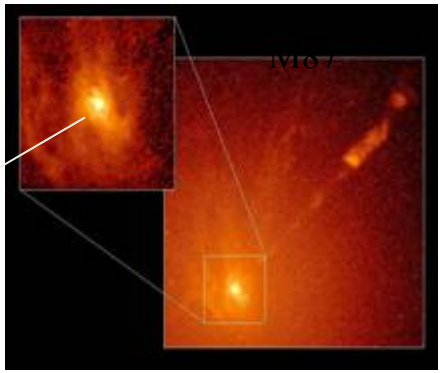


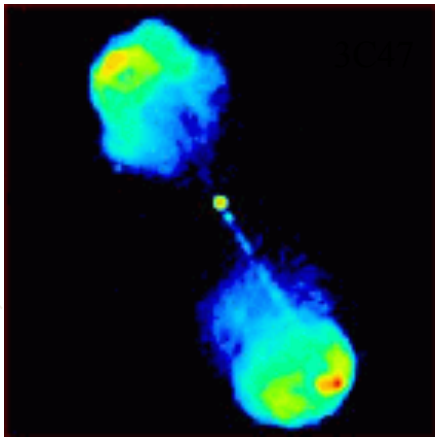
Possibili macchine acceleratrici







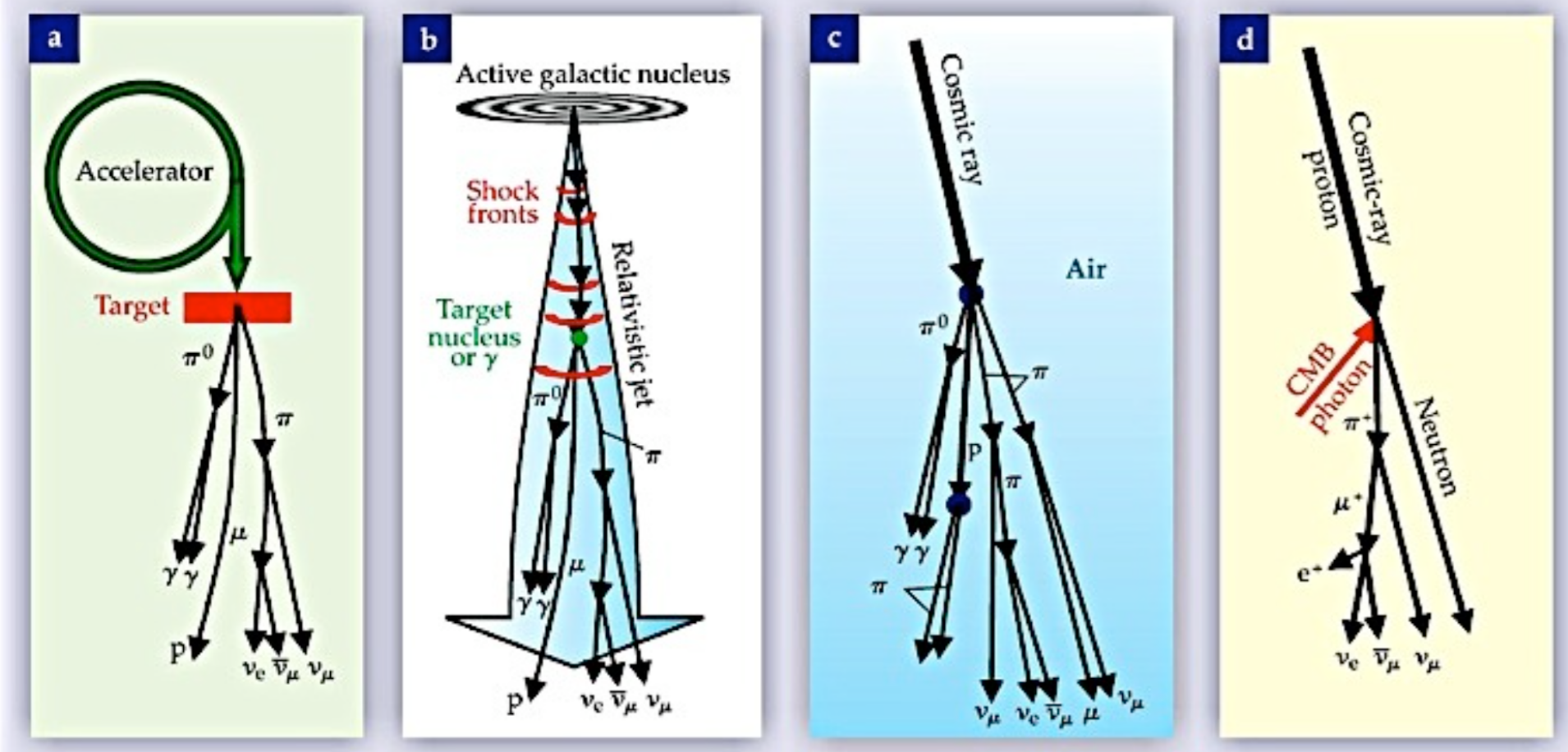




Astrofisica Nucleare e Subnucleare

Astrophysical Neutrinos

Summary of neutrino production modes



From Physics Today

THE ICECUBE NEUTRINO OBSERVATORY

Deployed in the deep glacial ice at the South Pole

5160 PMTs

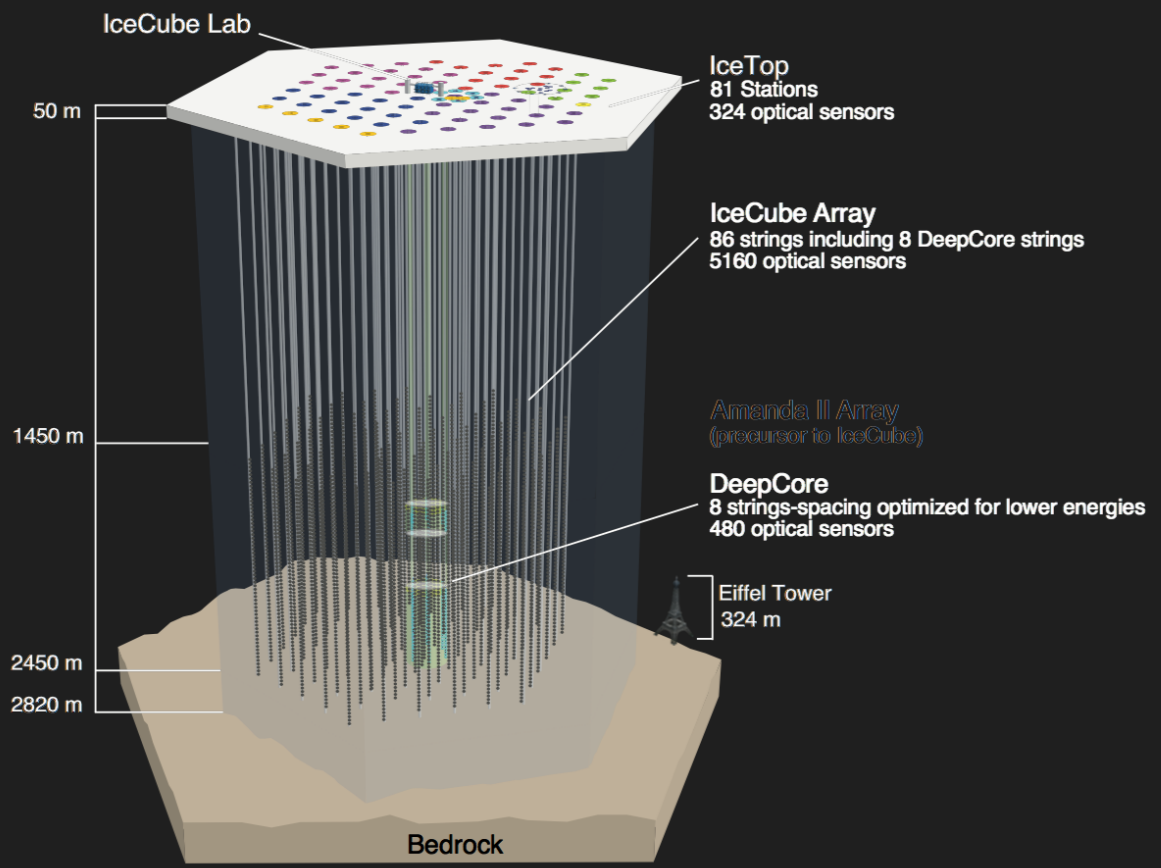
1 km^3 volume

86 strings

17 m vertical spacing

125 m string spacing

Completed **2010**

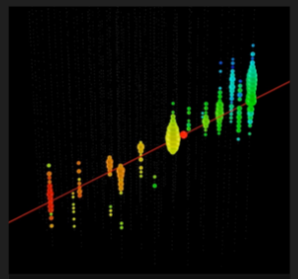


NEUTRINO EVENT SIGNATURES

Signatures of signal events

time

CC Muon Neutrino

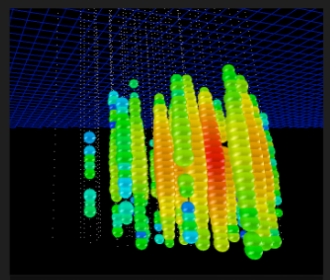


$$\nu_\mu + N \rightarrow \mu + X$$

track (data)

factor of ≈ 2 energy resolution
< 1° angular resolution at high energies

Neutral Current / Electron Neutrino



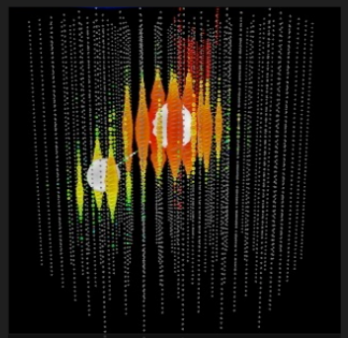
$$\nu_e + N \rightarrow e + X$$

$$\nu_x + N \rightarrow \nu_x + X$$

cascade (data)

≈ ±15% deposited energy resolution
≈ 10° angular resolution (in IceCube)
(at energies ≳ 100 TeV)

CC Tau Neutrino

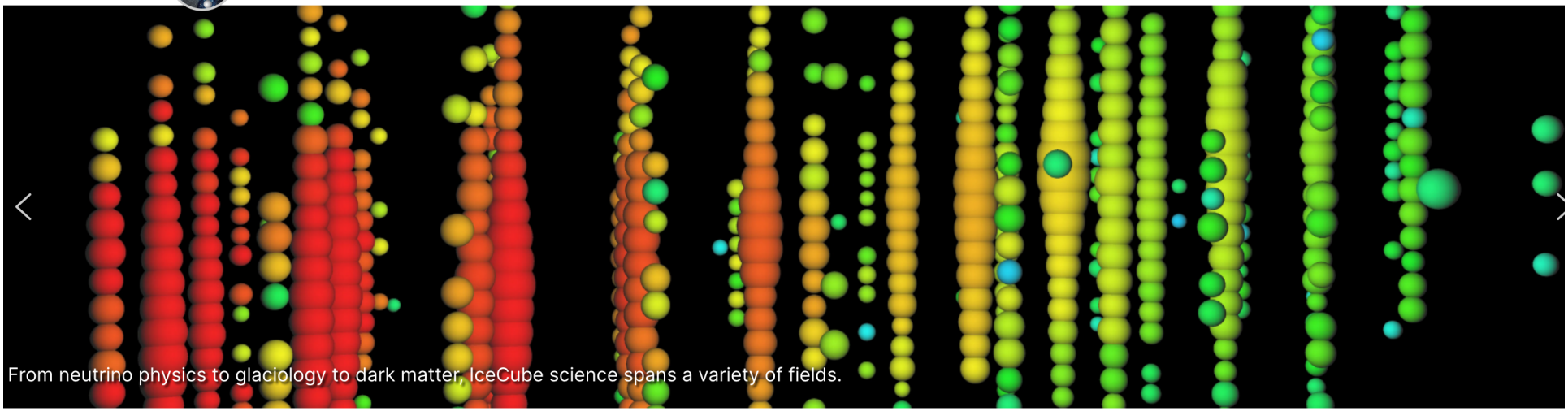


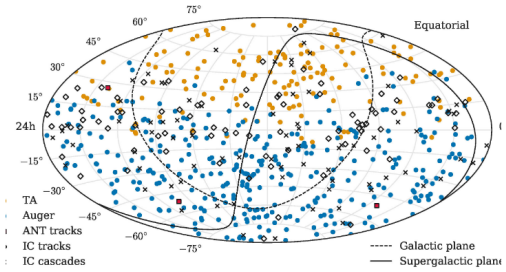
$$\nu_\tau + N \rightarrow \tau + X$$

"double-bang" (≳10PeV) and other signatures (simulation)

(not observed yet: τ decay length is 50 m/PeV)

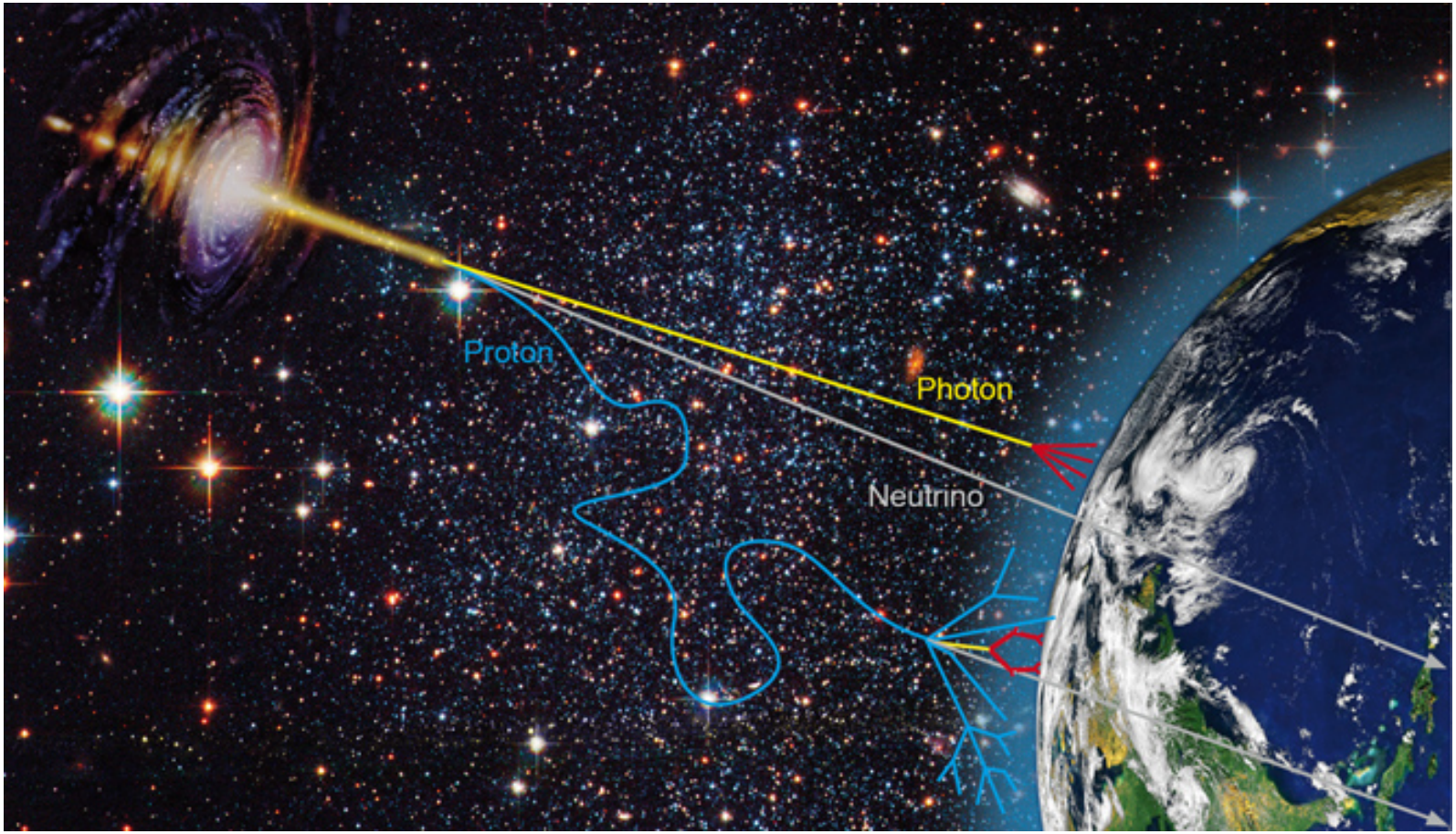
Icecube



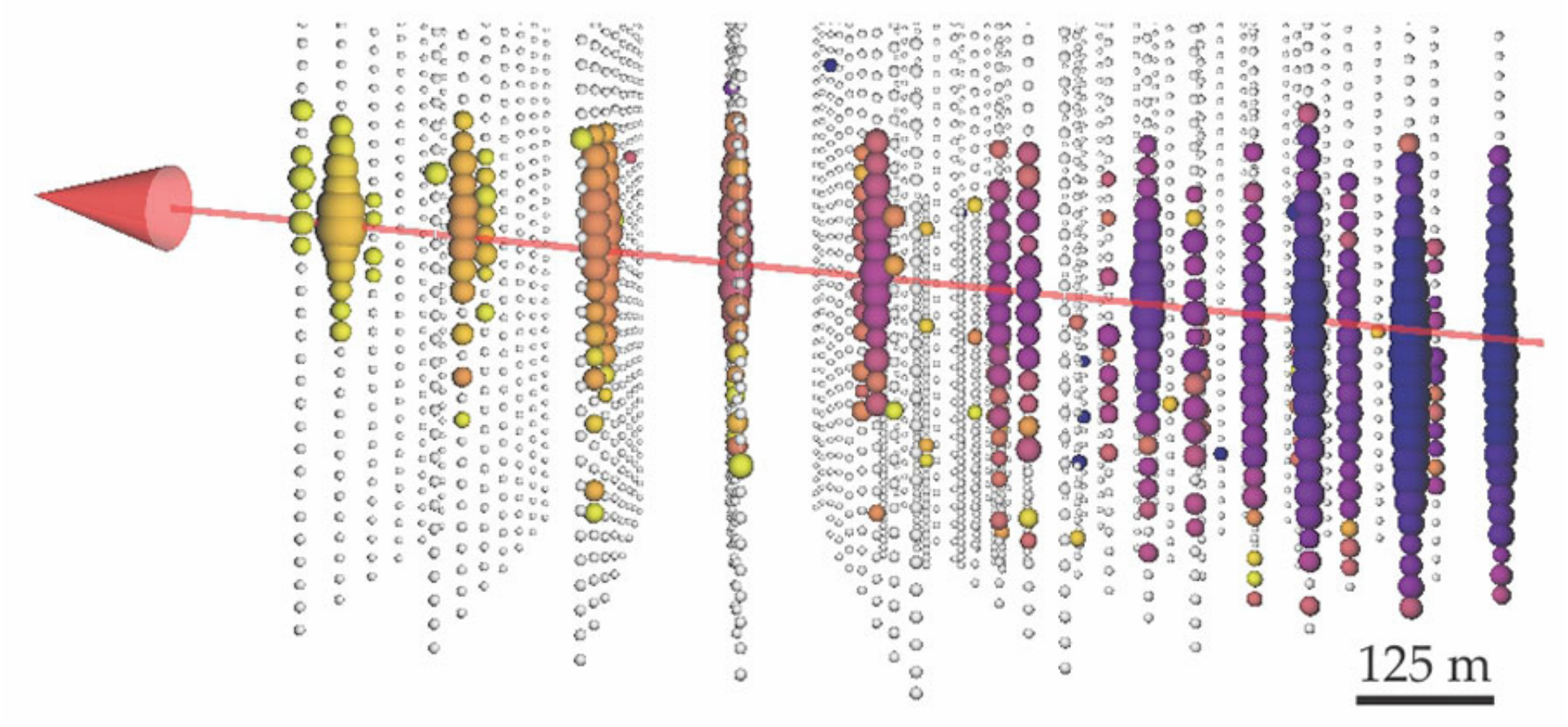


https://icecube.wisc.edu/

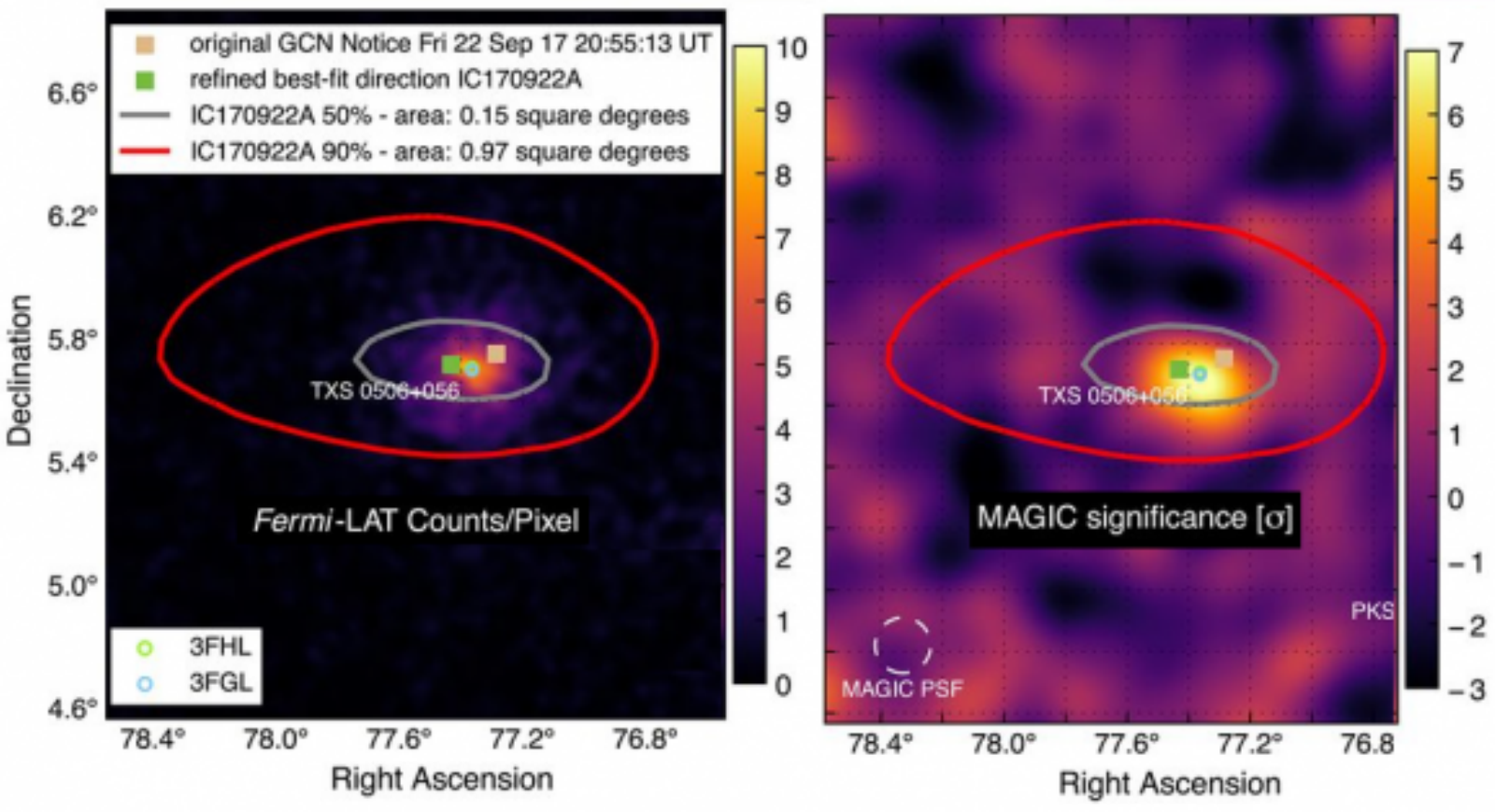
Astrophysical Neutrinos



“The” neutrino …

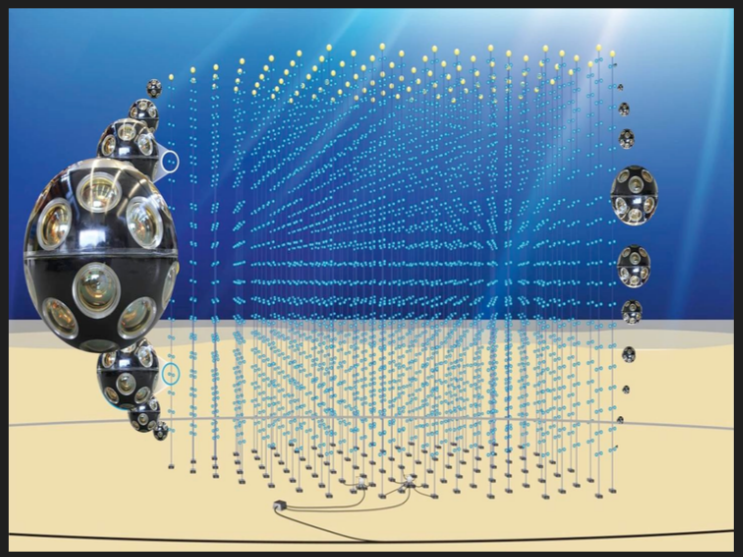


TXS 0506+056

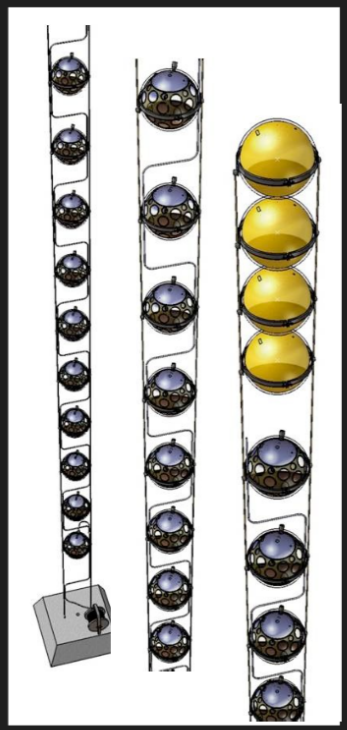

original GCN Notice Fri 22 Sep 17 20:55:13 UT
refined best-fit direction IC170922A
IC170922A 50% - area: 0.15 square degrees
IC170922A 90% - area: 0.97 square degrees
TXS 0506+056
Fermi-LAT Counts/Pixel
3FHL
3FGL
Declination
6.6°
6.2°
5.8°
5.4°
5.0°
4.6°
78.4°
78.0°
77.6°
77.2°
76.8°
Right Ascension
10
9
8
7
6
5
4
3
2
1
0
TXS 0506+056
MAGIC significance [σ]
MAGIC PSF
PKS
78.4°
78.0°
77.6°
77.2°
76.8
Right Ascension
7
6
5
4
3
2
1
0
−1
−2
−3

THE KM3NET NEUTRINO TELESCOPE

Multi-site installation in the Mediterranean Sea (France, Italy), instrumented in "building blocks", started construction



KM3NeT "building block"

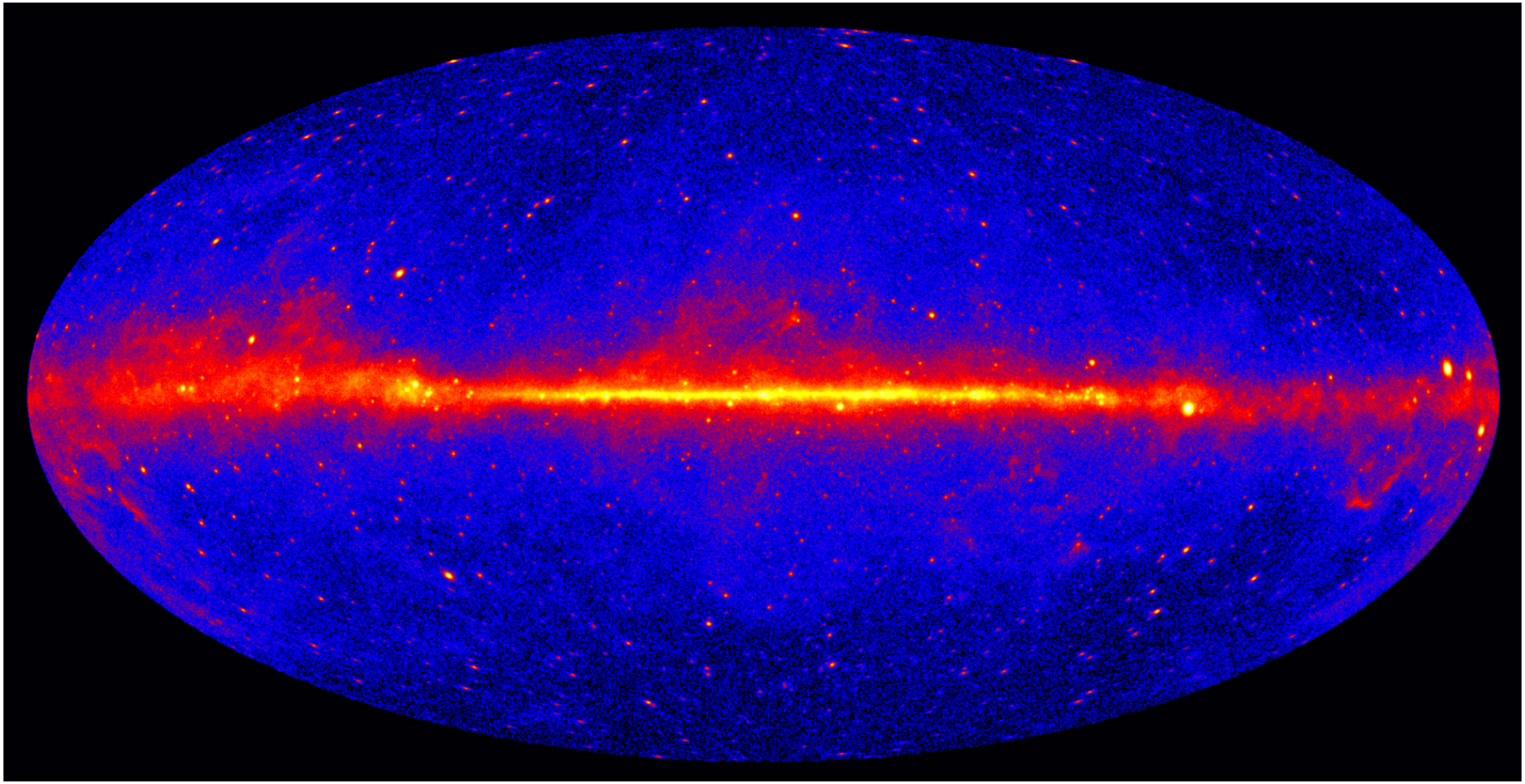


string with OMs

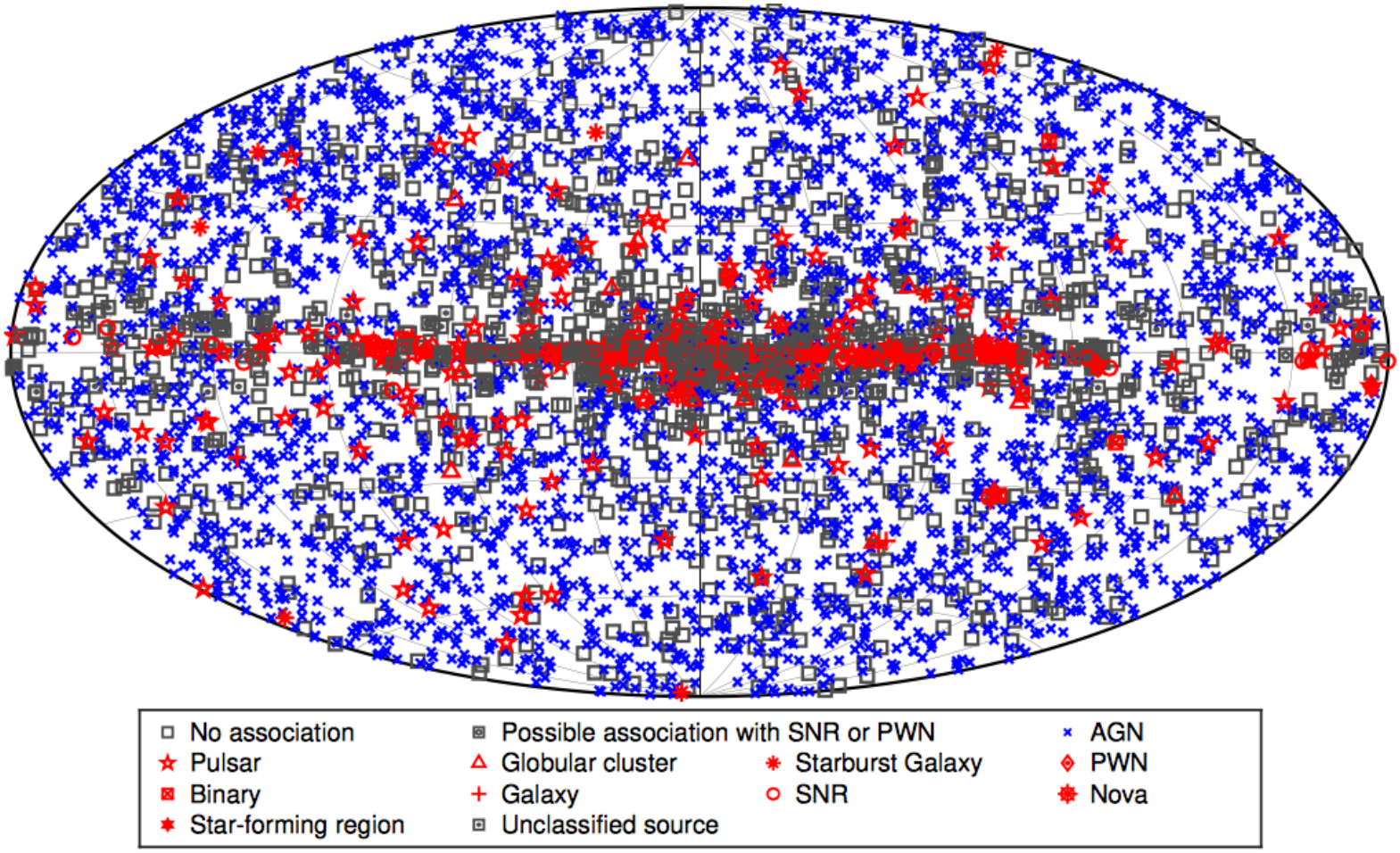
Multi-PMT digital optical module ("DOM")

Fermi LAT

The GeV sky



4FGL catalog



Abdollahi et al 2020

Where to find data?

GODDARD SPACE FLIGHT CENTER

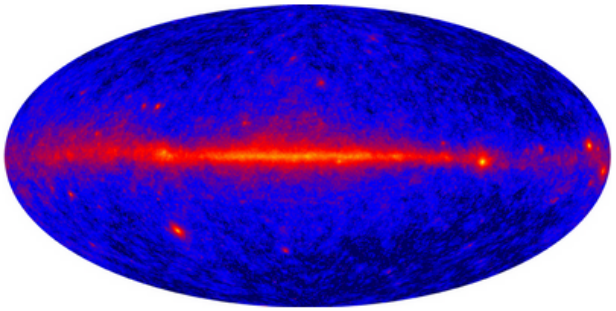
+ NASA Homepage
+ GSFC Homepage
+ Fermi Homepage

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

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**

What do you need for the analysis

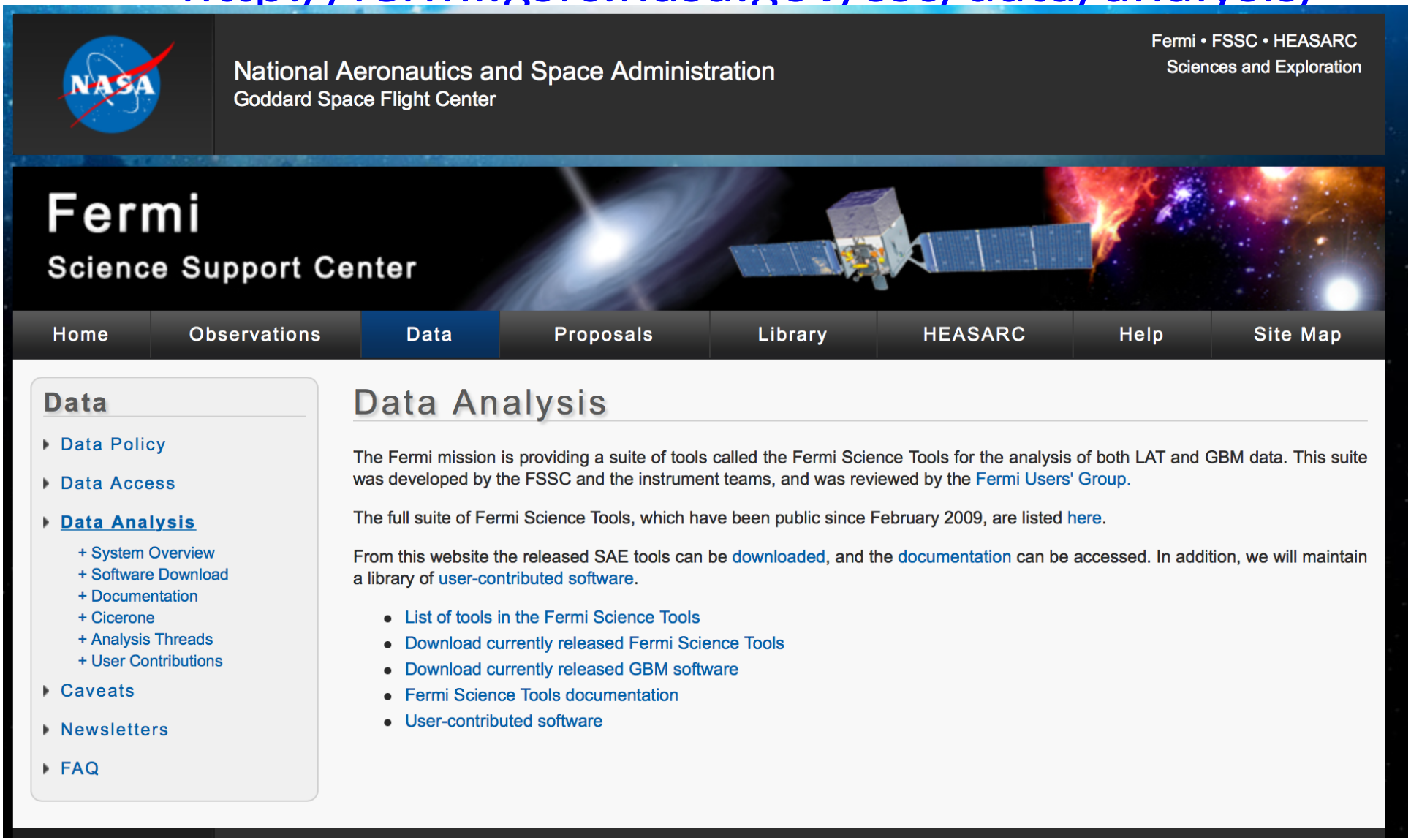
- Data ...of course!
  - LAT detected events
  - Spacecraft related stuff
  - Extras (Backgrounds , catalog sources, timing..)

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!

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"**

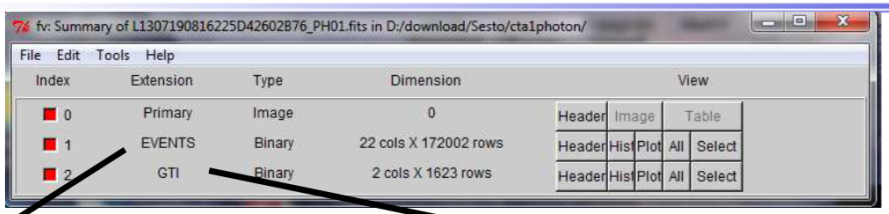
  – (photons, their energy, coordinates, time, event classes etc..)

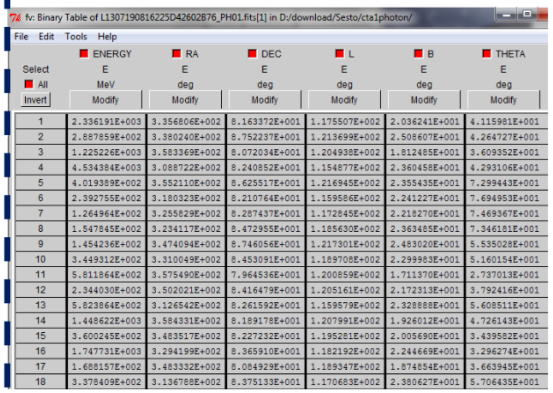
–**Spacecraft files (FT2)**

–**i. e. "where the LAT is"**

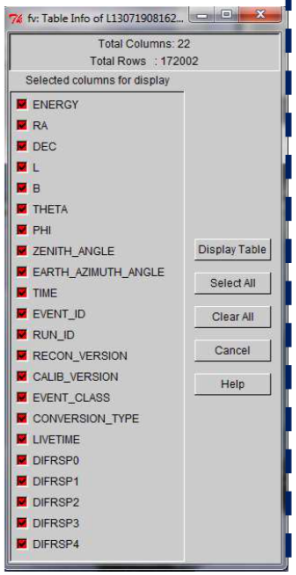
  – (position, angles..)

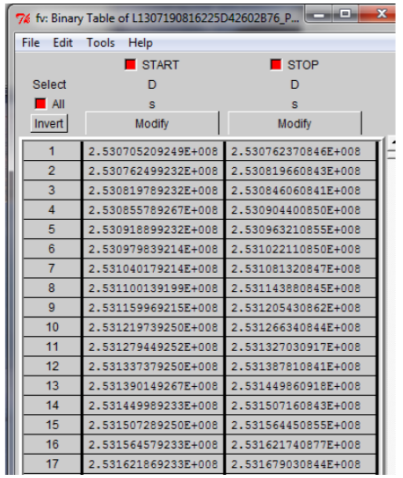
FT1: photons, photons…





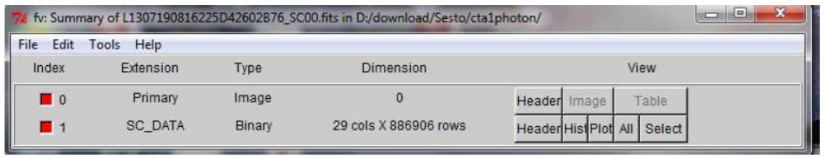
Events





Good Time Intervals (GTIs)

FT2: where is Fermi ?



spacecraft Data

Extras - IRFs

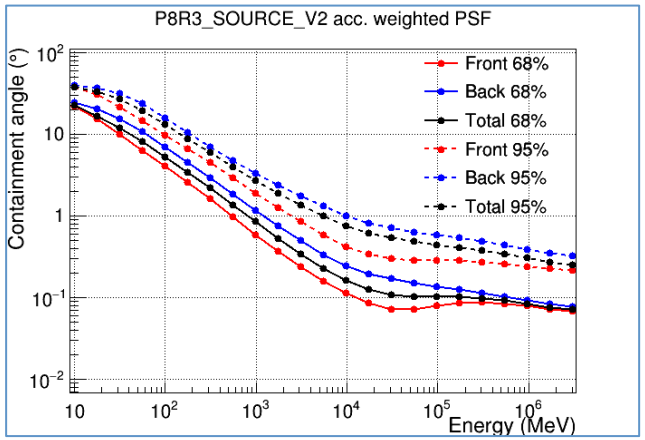
- LAT Instrument Response Functions (IRFs)

–**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

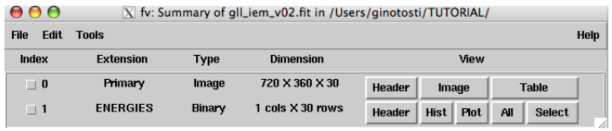
Extras

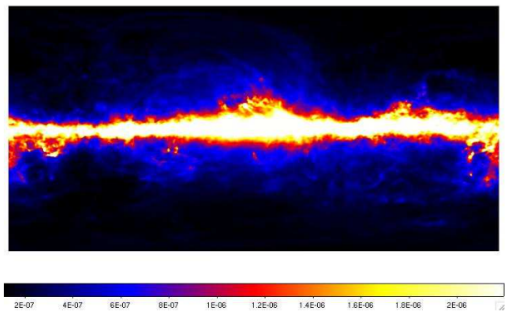
- Diffuse models (.txt & FITS files)
  - **To correctly take into accounts the galactic and extagalactic backgrounds**
  - http://fermi.gsfc.nasa.gov/ssc/data/access/lat/BackgroundModels.html
- Source Catalogs (4FGL, 3FHL, PSRs, GRB, SNR …)
- Region of Interest model definition (stored in XML files)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





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104.125 1.72000e-07 8.35794e-10
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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

PASS8 DATA

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

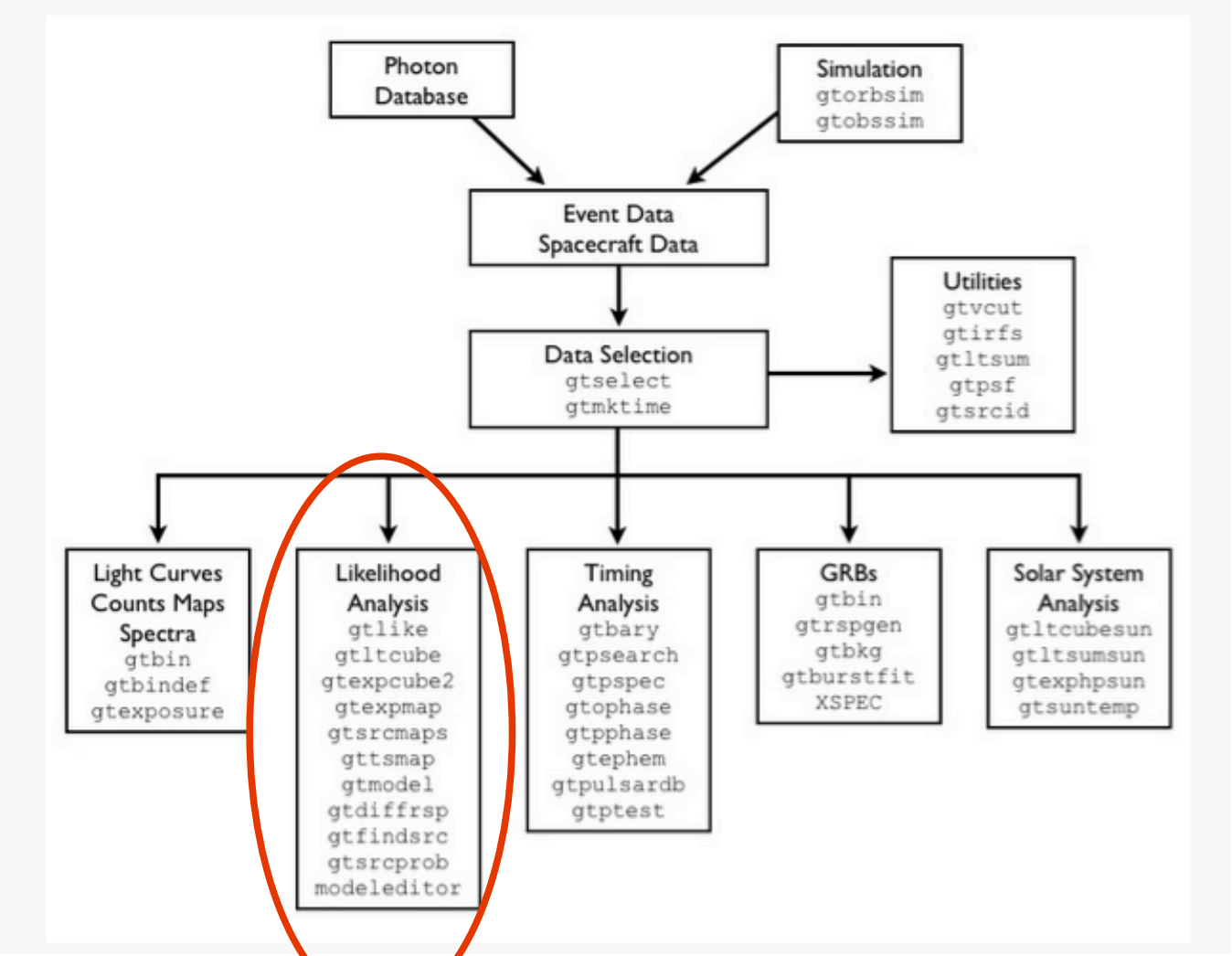
Time Selection Recommendations

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)

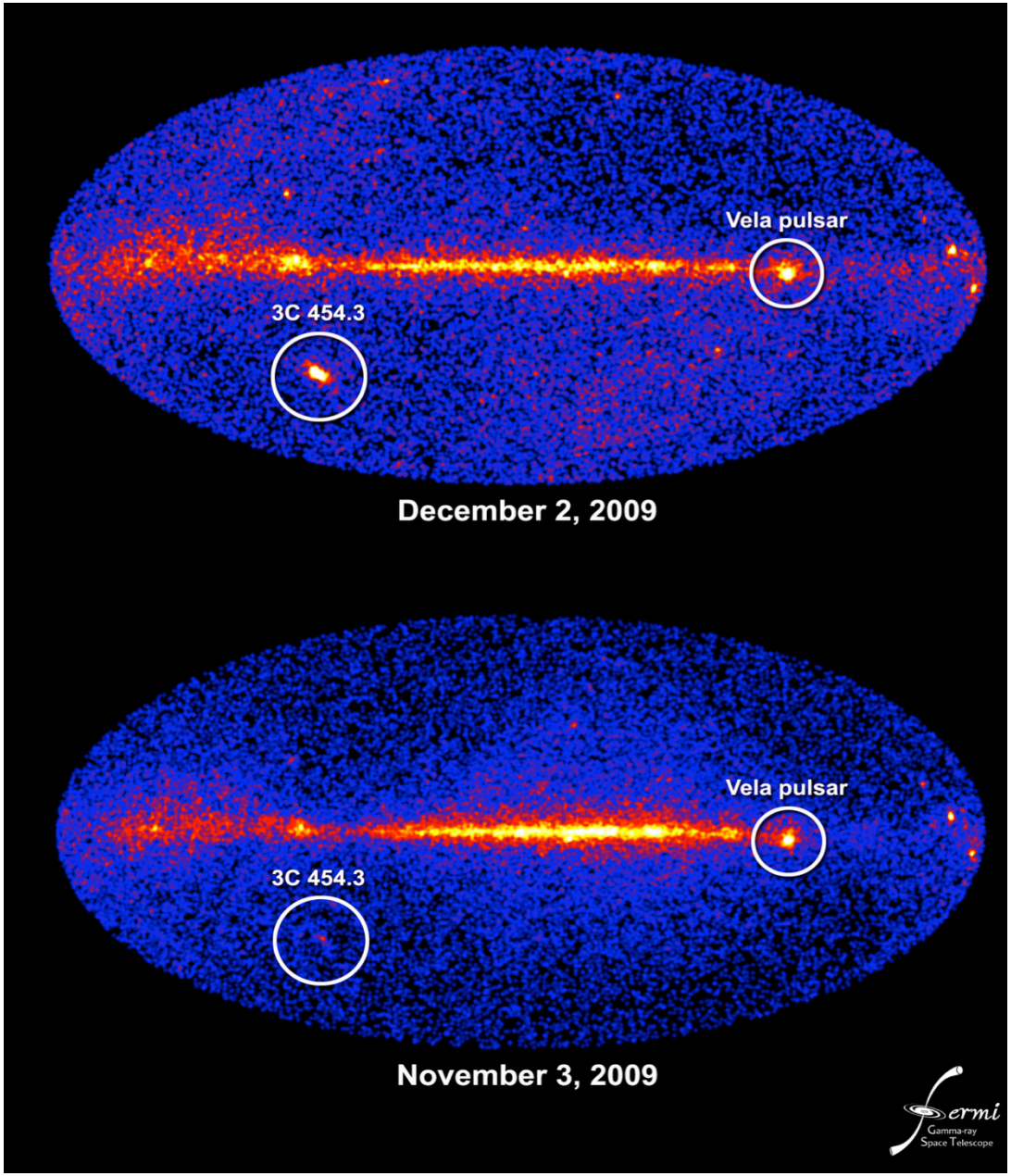
IMPORTANT: For analyses where an ROI-based zenith cut is NOT performed, an exposure correction must be made using the "zmax" option in the gtltcube tool.

Explore LAT data

Overview of Fermi Science Tools

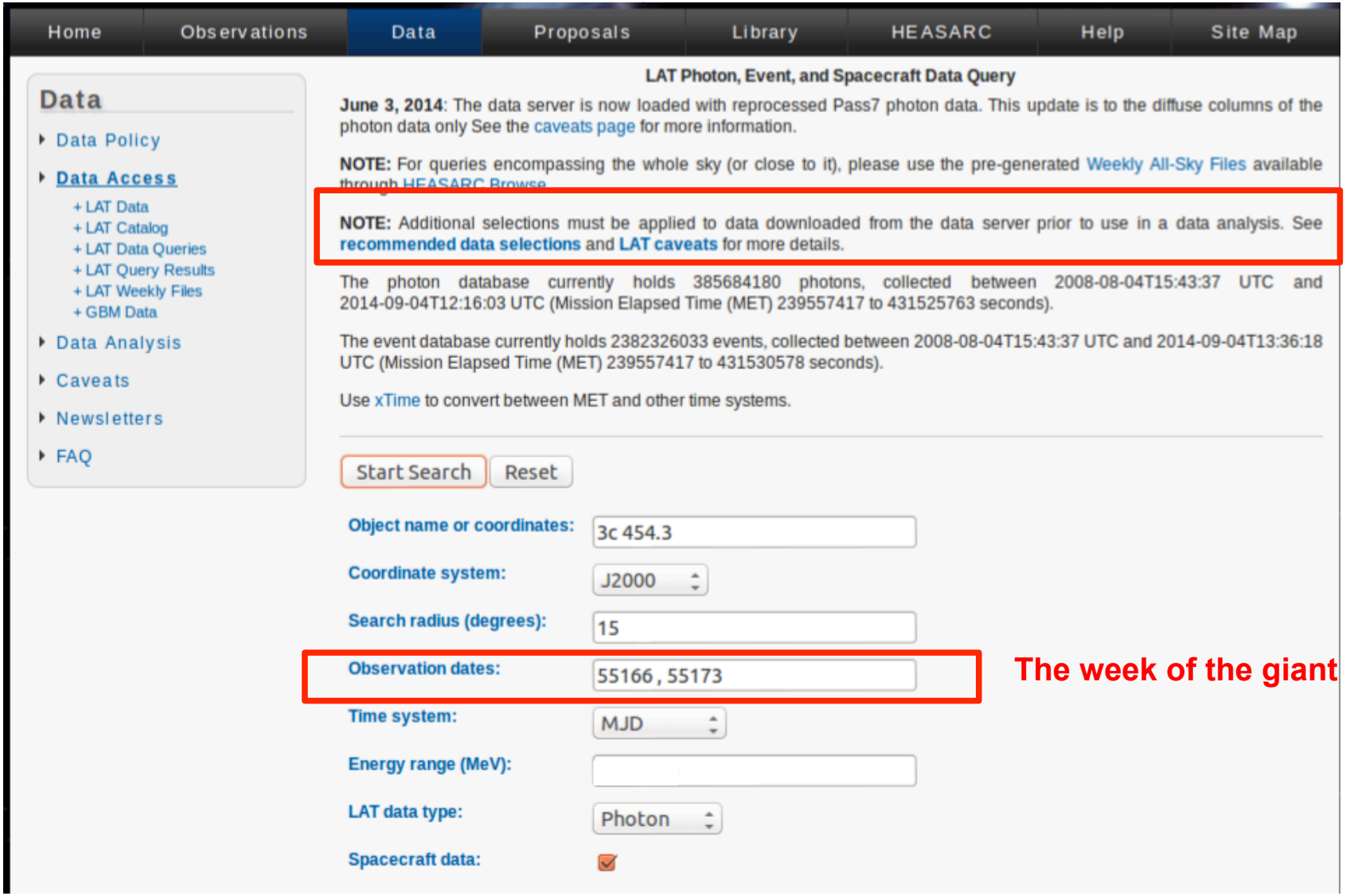


Blazar one of … 3c454.3's record flares!



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=filtered.fits \
- 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

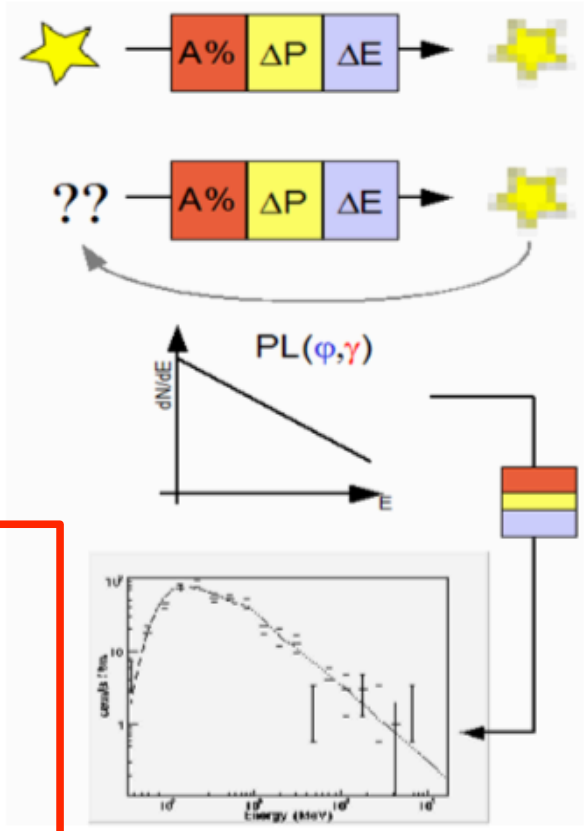
gtbin (Counts Map)

- [/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]

Maximum Likelihood Overview

Perform the fit: the likelihood

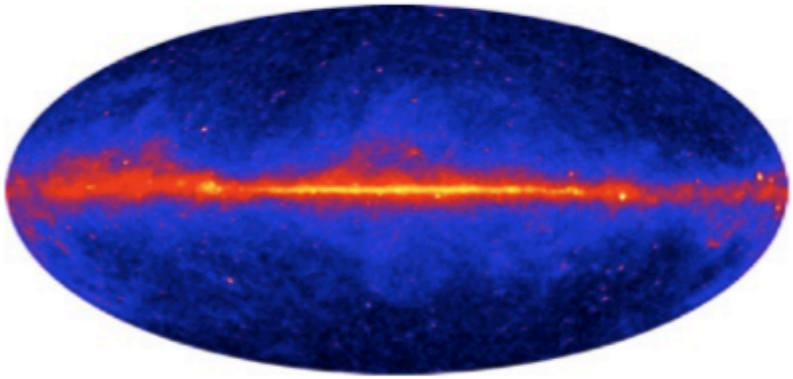
In high energy gamma rays it is never possible to really isolate a source because of limited statistics and strong and structured background.
Therefore statistical techniques have to be applied.
The most used method is the likelihood analysis based on the Poisson statistics.
The method requires to assume a model for the signal detected by the telescope.

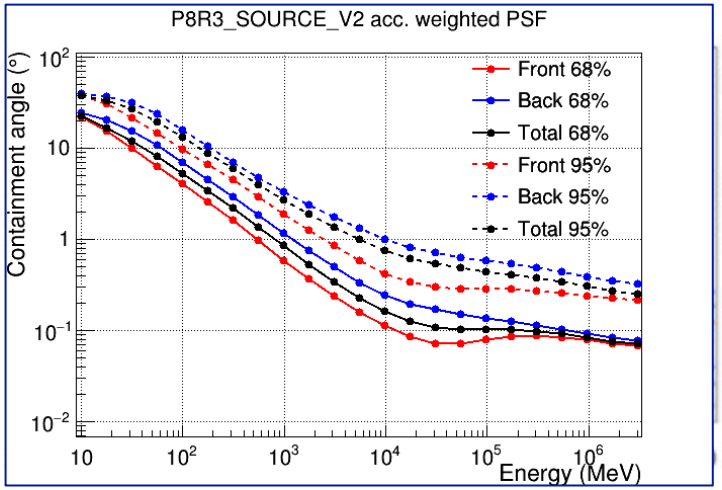


- Assume a **model**
- Model **convolved** with Instrument responce Function (IRF)
- Maximizing likelihood find the best set of parameters that reproduce the observed spectrum

Why Model Fitting?

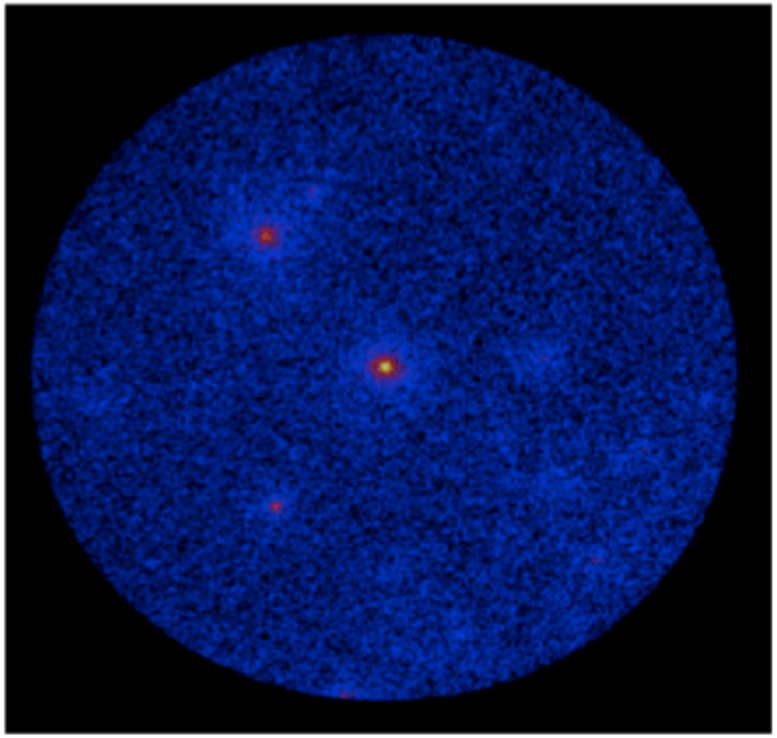
- We use the Likelihood method because the LAT data are limited by statistics, a bright diffuse background and a broad PSF.
- The model construction defines the questions we want to ask which means:
  - It will not answer a question you are not asking (ie. unknown parameters).
- The Likelihood will not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

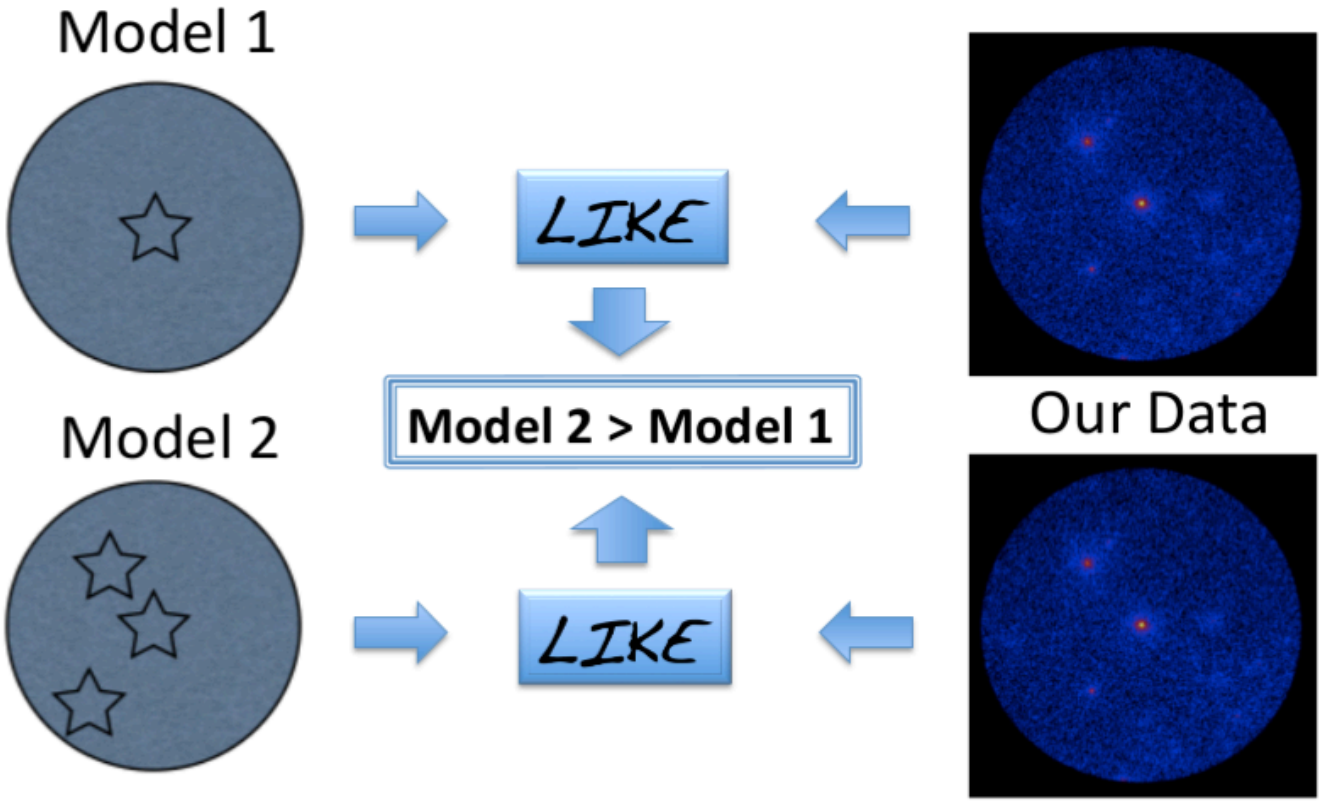


Count Map

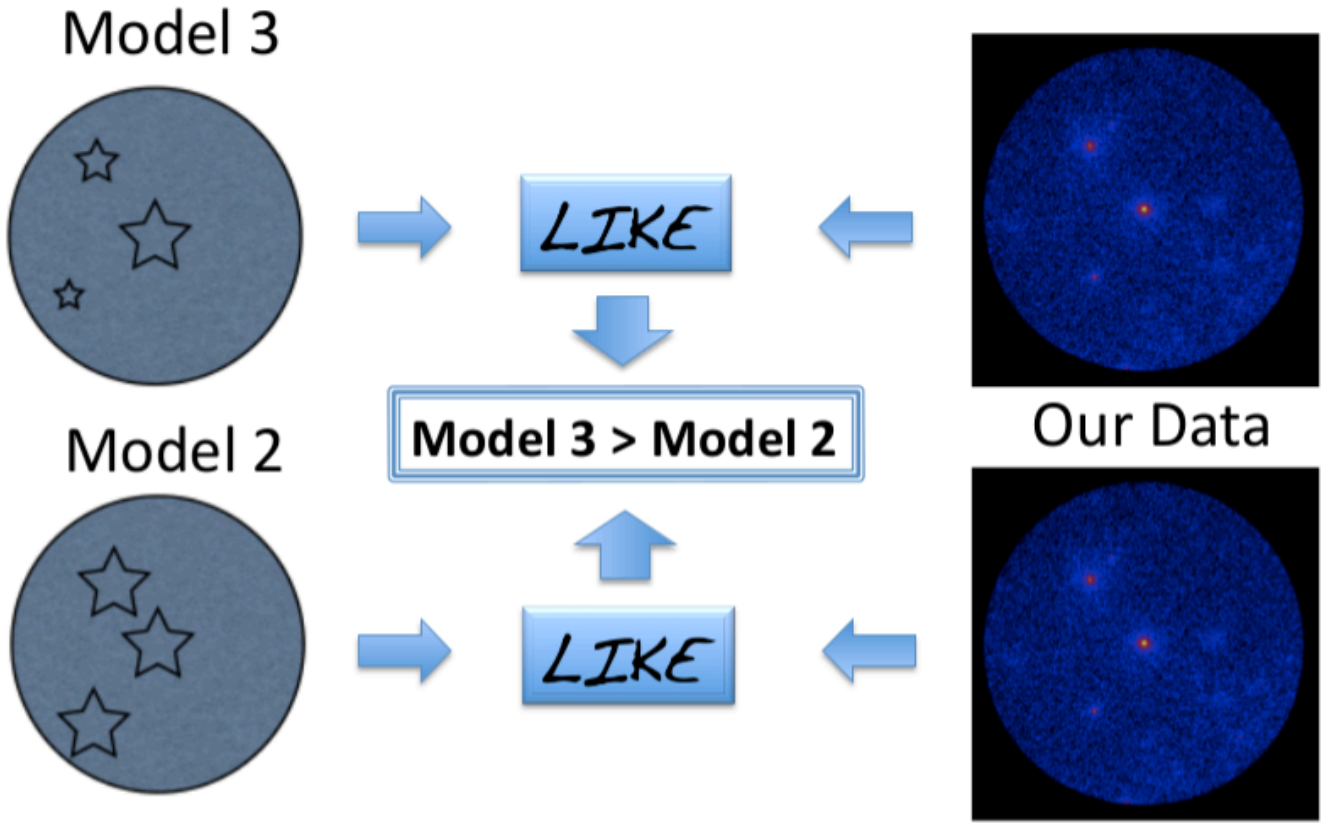
The Procedure

- 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

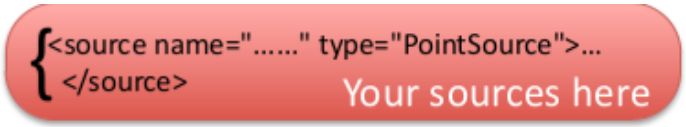


A Graphical Example



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 1st step: gtltcube

- [/home]$ gtltcube zmax=90
- Event data file[filtered_gti.fits]
- Spacecraft data file[sc.fits]
- Output file[ltCube.fits]
- Step size in cos(theta) (0.:1.) [0.025]
- Pixel size (degrees)[1]
- ……..

The “livetime cube” must be re-calculated when a new time-interval or a new ZA is selected

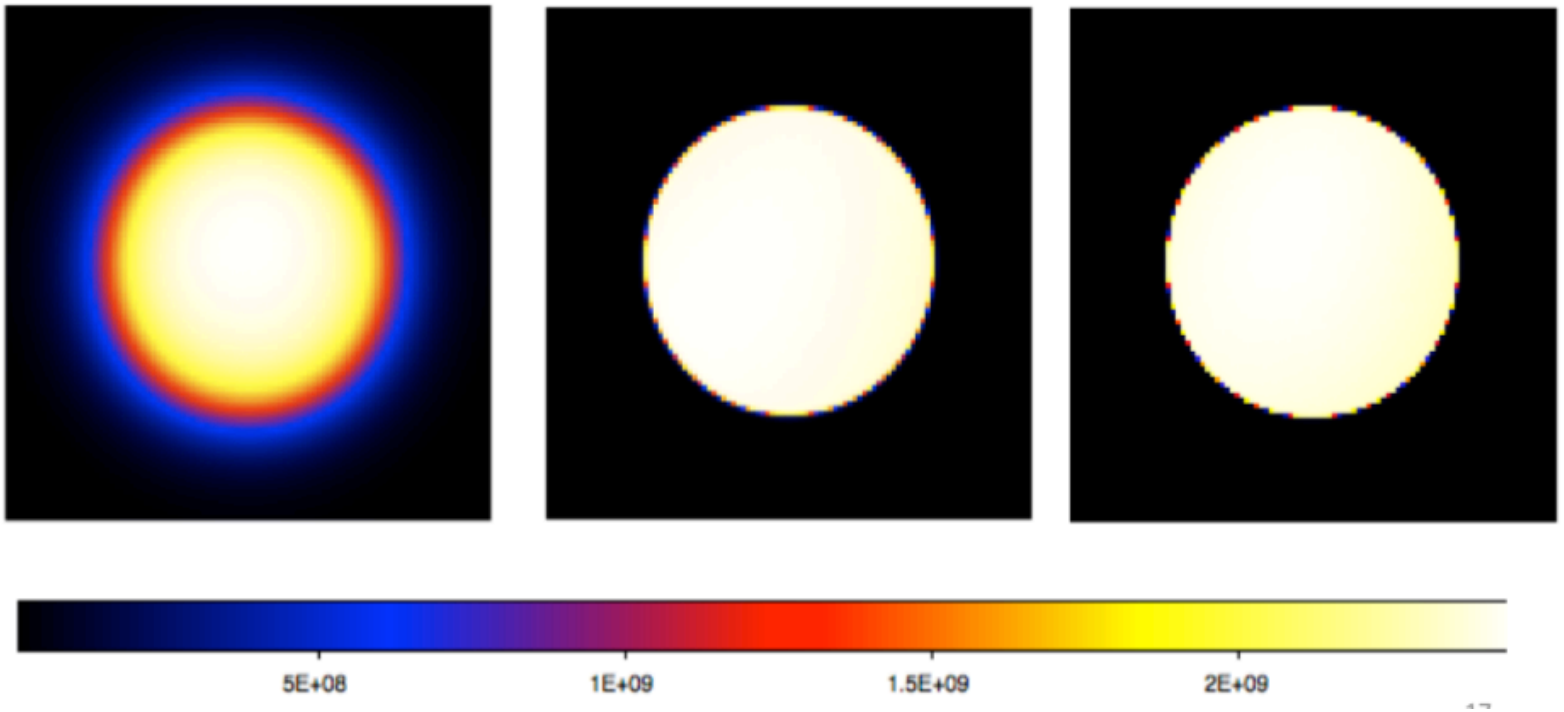
Likelihood 2nd step: gtexpmap

- [/home/]$ gtexpmap
- Event data file[filtered_gti.fits]
- Spacecraft data file[sc.fits]
- Exposure hypercube file[ltCube.fits]
- output file name[expMap.fits]
- Response functions[CALDB]
- Radius of the source region (in degrees)[30]
- Number of longitude points (2:1000) [120]
- Number of latitude points (2:1000) [120]
- Number of energies (2:100) [20]
- Computing the ExposureMap using ltCube.fits
- …

Add 15° to the ROI radius

gtexpmap

Quick check with DS9: fields must be homogenous



Likelihood 3rd step: the XML model

5. Create a source model XML file

The gtlike tool reads the source model from an XML file. The model file contains your best guess at the locations and spectral forms for the sources in your data. A source model can be created using the model editor tool, by using the user contributed tool **make3FGLxml.py** (available at the user-contributed tools page), or by editing the file directly within a text editor.

Here we cannot use the same source model that was used to analyze six months of data in the Unbinned Likelihood tutorial, as the 2-year data set contains many more significant sources and will not converge. Instead, we will use the 3FGL catalog to define our source model by running make3FGLxml.py. To run the script, you will need to download the current LAT catalog file and place it in your working directory:

```
prompt> make3FGLxml.py gll_psc_v16.fit 3C279_binned_gti.fits -o 3C279_input_model.xml
-G $FERMI_DIR/refdata/fermi/galdiffuse/gll_iem_v06.fits -g gll_iem_v06
-I $FERMI_DIR/refdata/fermi/galdiffuse/iso_P8R2_SOURCE_V6_v06.txt
-i iso_P8R2_SOURCE_V6_v06 -s 120 -p TRUE -v TRUE
This is make3FGLxml version 01r0.
The default diffuse model files and names are for pass 8
and assume you have v10r00p05 of the Fermi Science Tools or higher.
Creating file and adding sources from 3FGL
Added 312 point sources, note that any extended sources in ROI were modeled as point sources
because psForce option was set to True
prompt>
```

Note that we are using a high level of significance so that we only fit the brightest sources and we have forced the extended sources to be modeled as point sources. This only affects the lobes of Centarus A which are just outside the FOV.

It is also necessary to specify the entire path to location of the diffuse model on your system. The resulting XML model contains 312 sources. Clearly, the simple 4-source model we used for the 6-month Unbinned Likelihood analysis would have been too simplistic.

This XML file uses the spectral model from the 3FGL catalog analysis for each source. (The catalog file is available at the LAT 4-yr Catalog page.) However, that analysis used a subset of the available spectral models. A dedicated analysis of the region may indicate a different spectral model is preferred. For more details on the options available for your XML models, see:

- Descriptions of available Spectral and Spatial Models
- Examples of XML Model Definitions for Likelihood

Likelihood 3rd step

- python make4FGLxml.py gll_psc_v28.xml filtered_gti.fits -o 3C454.xml -r 5.0

Describing the Source Model: the XML model

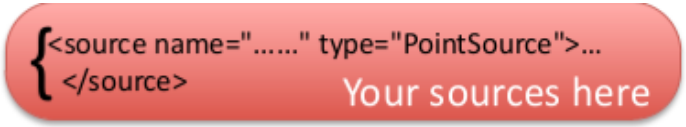
- Backgrounds
- <!-- Diffuse Sources -->
- <source name="galactic_background" type="DiffuseSource">
- <spectrum type="PowerLaw">
- <parameter free="1" max="10" min="0" name="Prefactor" scale="1" value="1"/>
- <parameter free="0" max="1" min="-1" name="Index" scale="1.0" value="0"/>
- <parameter free="0" 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 3rd step: 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_v06.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_P8R2_SOURCE_V6_v06.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>

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 2FGL sources that belongs to your ROI in your XML file model (make3FGLxml.py)
- http://fermi.gsfc.nasa.gov/ssc/data/analysis/user/
-

Diffuse response

- [/home/]$gtdiffrsp
- Event data file[]filtered_gti.fits
- Spacecraft data file[] sc.fits
- Source model file[] 3c454.3.xml
- Response functions to use[] CALDB

Finally... gtlike performing the actual fit

- [/home/]$ gtlike plot=no
- Statistic to use (BINNED|UNBINNED) [UNBINNED]
- Spacecraft file[sc.fits]
- Event file[filtered_gti.fits]
- Unbinned exposure map[expMap.fits]
- Exposure hypercube file[ltCube.fits]
- Source model file[../xml_models/_3c454.3_model_ROI15.xml]
- Response functions to use[CALDB]
- Optimizer (DRMNFB|NEWMINUIT|MINUIT|DRMNGB|LBFGS) [DRMNFB]

Typically use DRMNGB/DRMNFB to find a rough estimate of the likelihood maxima and refine later on with **MINUIT (or NEWMINUIT)**

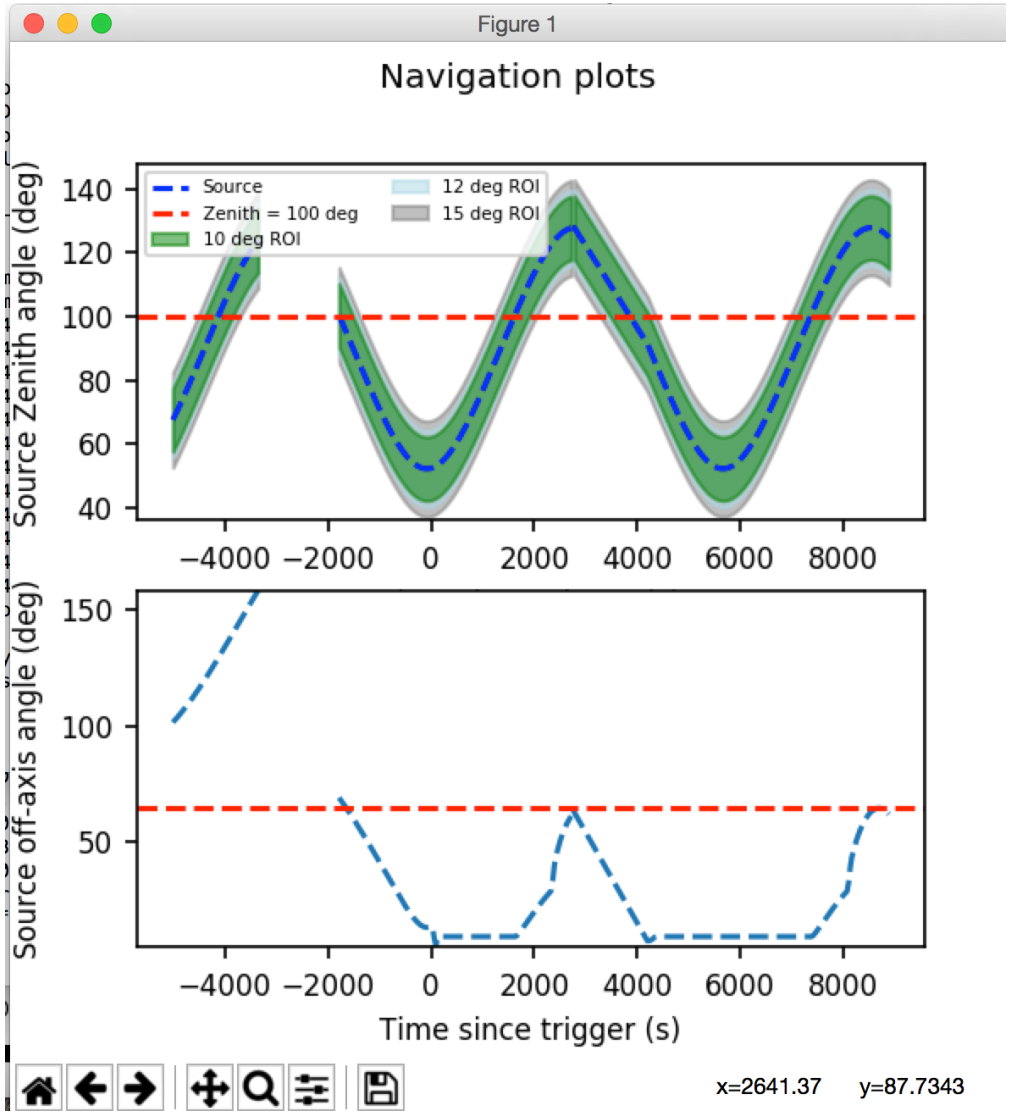
Likelihood output

- {'3c454.3': {'Integral': '0.146106 +/- 0.00271733',
- 'Index': '-2.29973 +/- 0.017189',
- 'LowerLimit': '100',
- 'UpperLimit': '300000',
- 'Npred': '4171.85',
- 'ROI distance': '0',
- 'TS value': '17548.4',
- 'Flux': '1.46192e-05 +/- 2.7178e-07',
- …
- extragalactic_background': {'Normalization': '1.20197 +/- 0.23541',
- 'Npred': '643.953',
- 'Flux': '0.000170707 +/- 3.34331e-05',
- },
- 'galactic_background': {'Prefactor': '0.739969 +/- 0.251827',
- 'Index': '0',
- 'Scale': '100',
- 'Npred': '357.929',
- 'Flux': '0.000215978 +/- 7.35023e-05',

gtlike creates two output files:
1) results.dat: fit results
2) counts_spectra.fits: the counts in a proper energy binning

gtburst overview

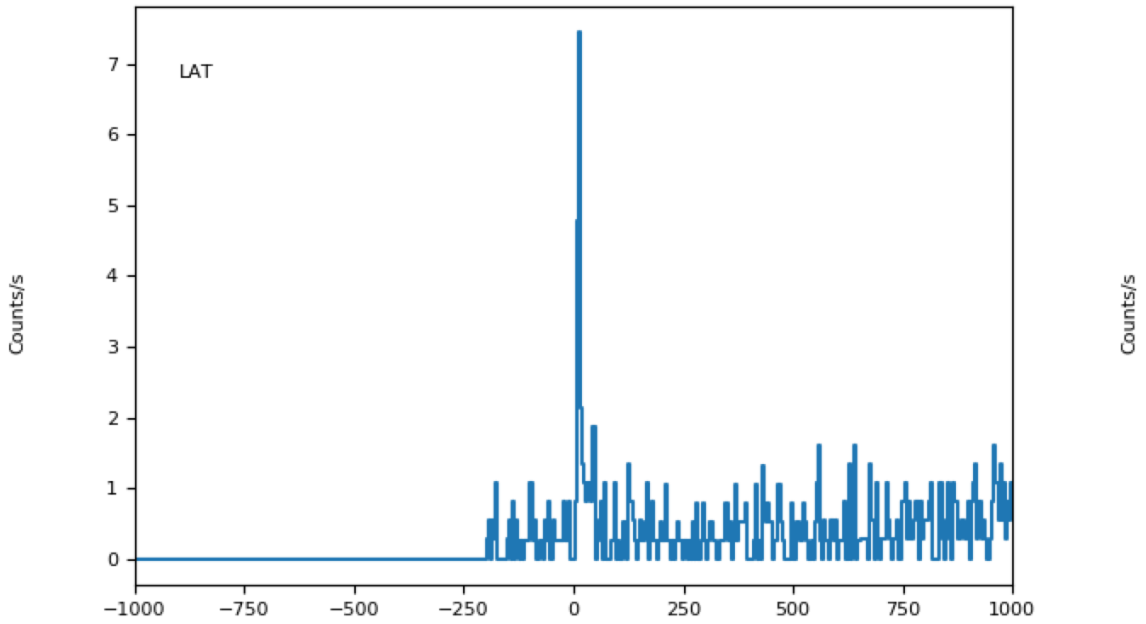
Check the “Navigation” plot



Likelihood with gtburst

Fermi bursts analysis GUI

Trigger name	bn160905471
R.A. (J2000)	162.245
Dec. (J2000)	-50.801
Trigger date (MET)	494767139.912



Detectors to display in the LC:

☑ LAT (16 deg)

Loaded datasets: LAT

You can zoom/pan the light curve using the toolbar at the bottom of the figure. For help on the use of the toolbar, see http://matplotlib.org/users/navigation_toolbar.html

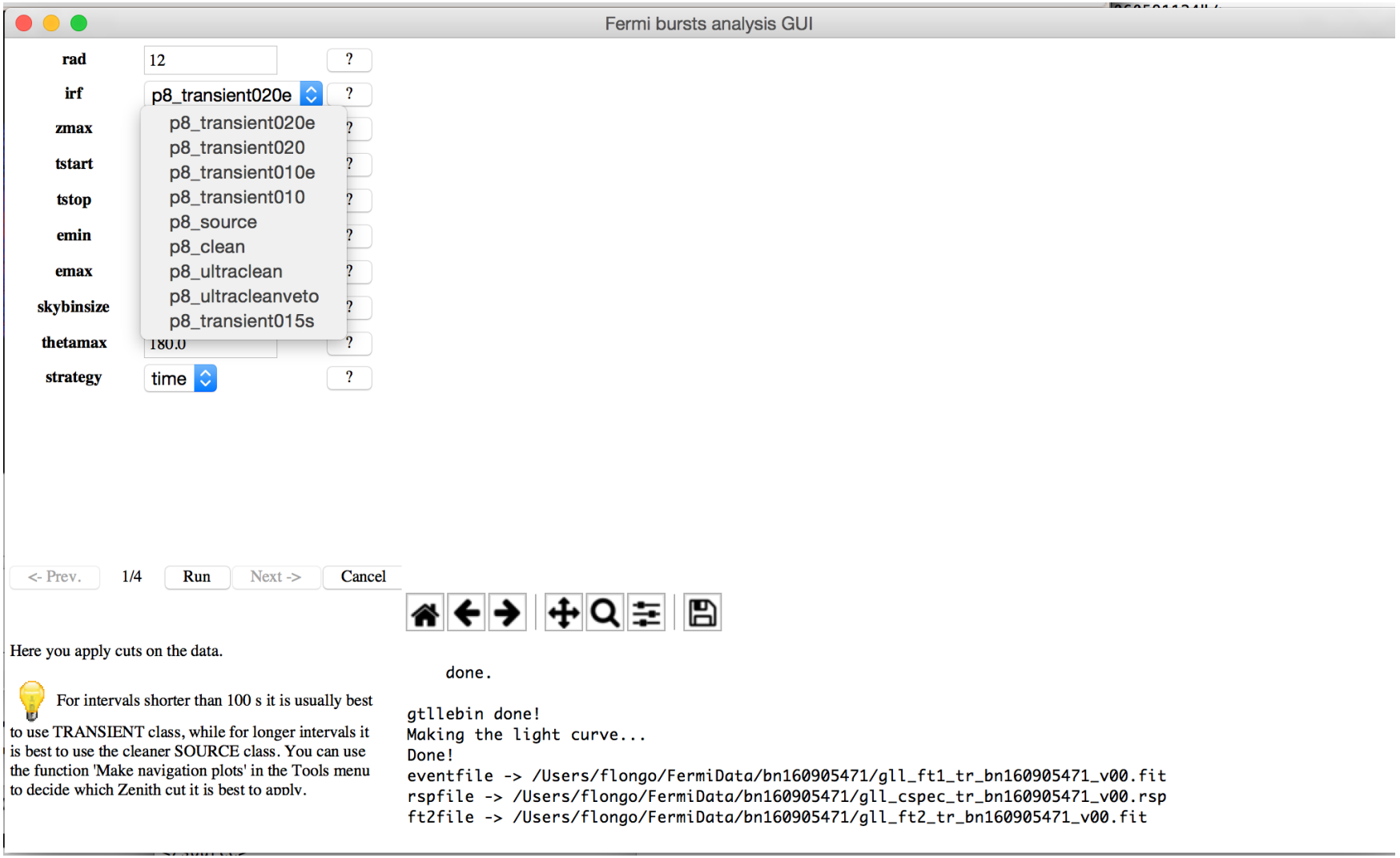
```
    done.

 *  Updating keywords in the headers of the CSPEC file...

    done.

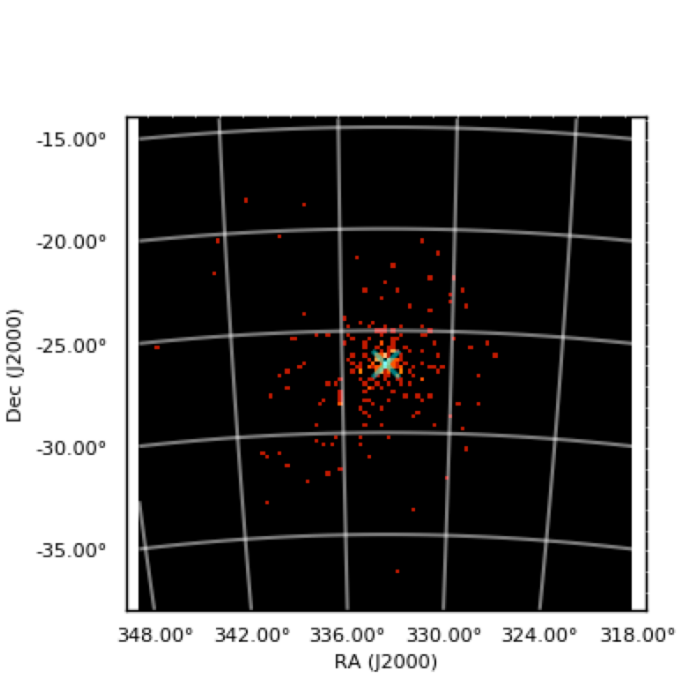
gtllebin done!
Making the light curve...
Done!
```

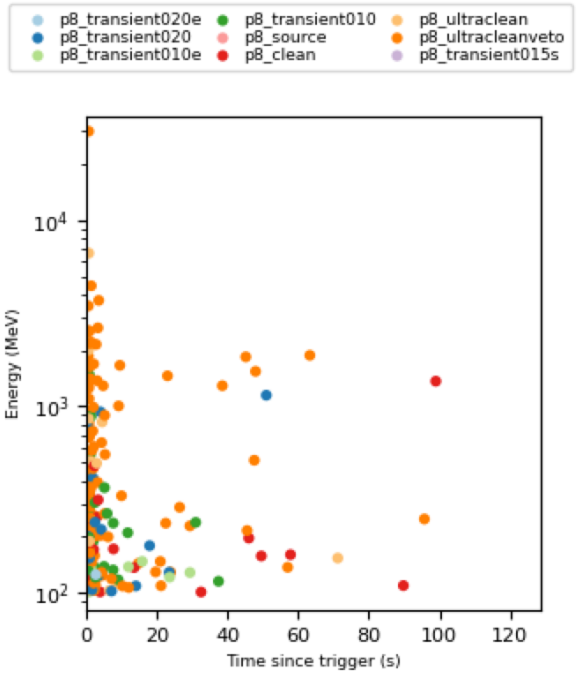
Select event class



See count map and list of photons

rad	12	?
irf	p8_transient020e	?
zmax	100	?
tstart	0	?
tstop	100	?
emin	100	?
emax	100000	?
skybinsize	0.2	?
thetamax	180.0	?
strategy	time	?





<- Prev. 1/4 Run Next -> Cancel

Here you apply cuts on the data.

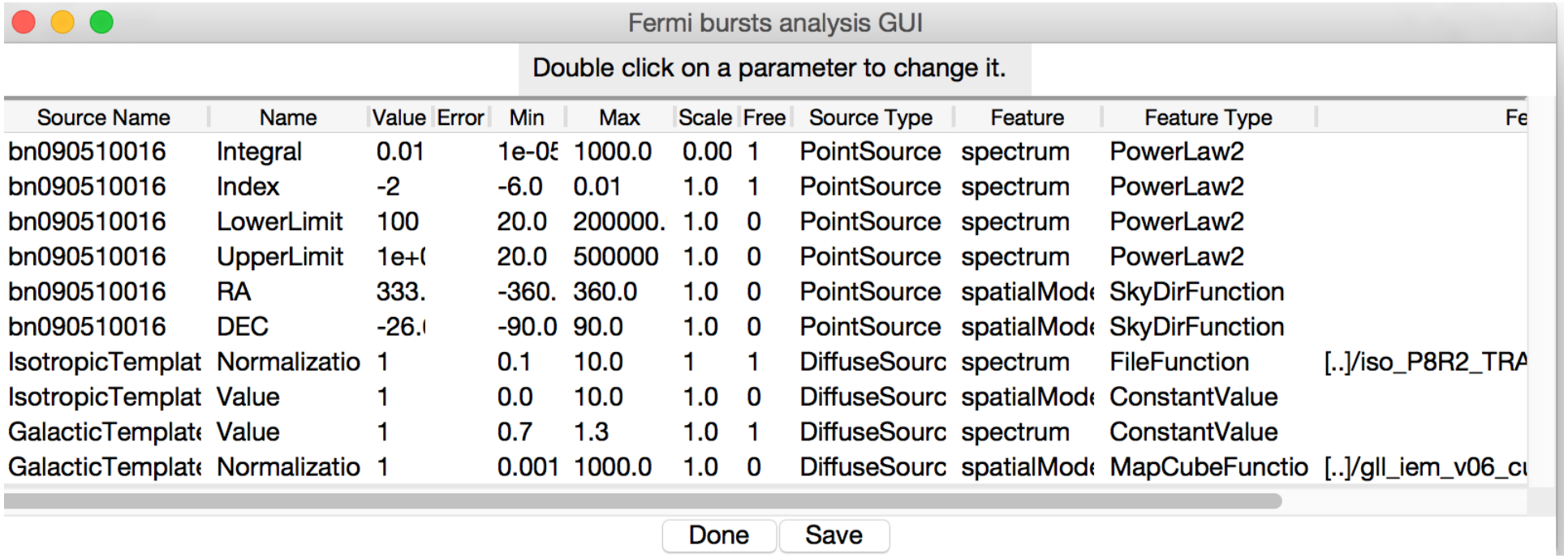
For intervals shorter than 100 s it is usually best to use TRANSIENT class, while for longer intervals it is best to use the cleaner SOURCE class. You can use the function 'Make navigation plots' in the Tools menu to decide which Zenith cut it is best to apply.

```
Class p8_transient010 only:                47
Class p8_source only:                      0
Class p8_clean only:                       32
Class p8_ultraclean only:                  19
Class p8_ultracleanveto only:              123
Class p8_transient015s only:               0

============================================================
```

Create XML model

Select the parameters of the model



Fit plots

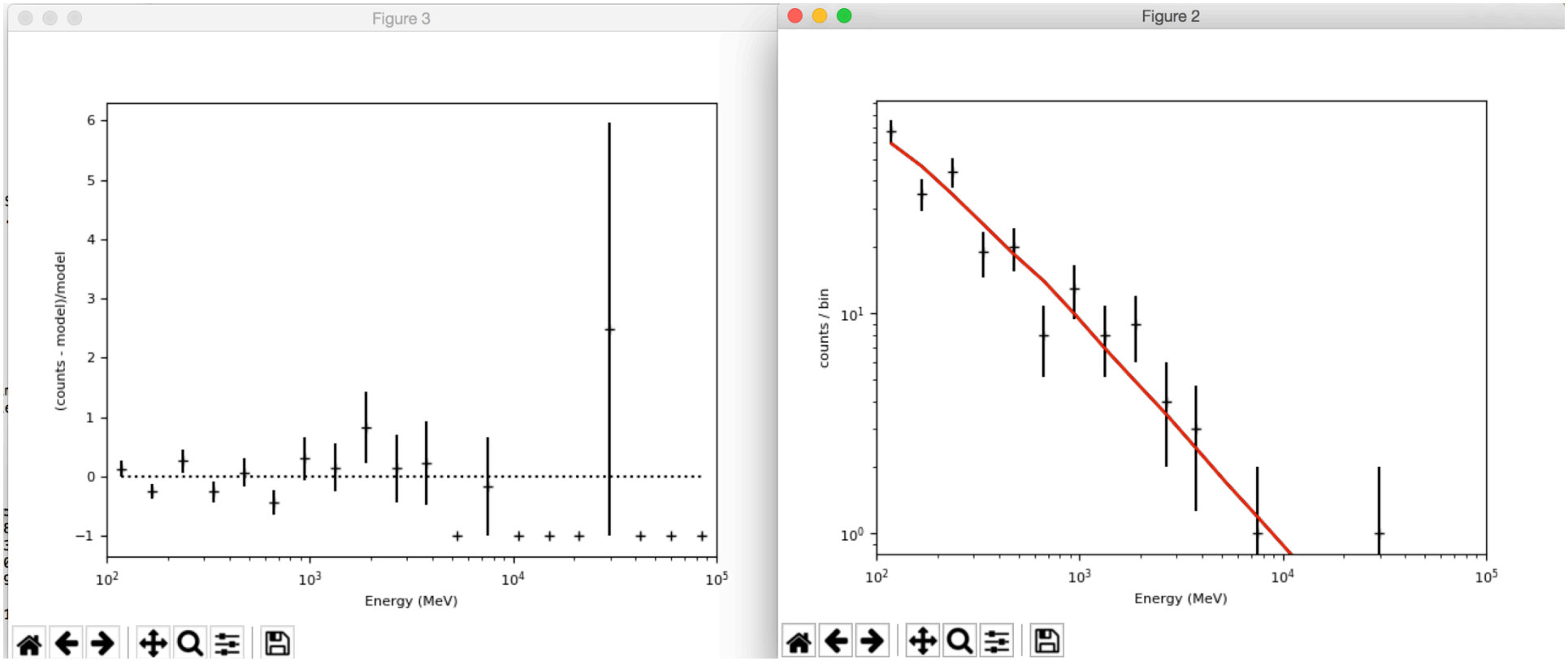


Figure 3
(counts - model)/model
Energy (MeV)
Figure 2
counts / bin
Energy (MeV)

Fit results

Likelihood results

Source name	Par. Name	Value	Error	Units	TS
GalacticTemplate					0
	Value	1	0.15	-	
	Energy flux	2.1e-07	3.14e-08	erg/cm2/s	
	Photon flux	0.000443	6.63e-05	ph./cm2/s	
IsotropicTemplate					1
	Normalization	0.426	1.32	-	
	Energy flux	4.75e-08	1.47e-07	erg/cm2/s	
	Photon flux	0.000134	0.000413	ph./cm2/s	
bn090510016					2056
	Integral	0.000363	2.31e-05	ph./cm2/s	
	Index	-2.03	0.0628	-	
	LowerLimit	100	n.a. (fixed)	MeV	
	UpperLimit	1e+05	n.a. (fixed)	MeV	
	Energy flux	1.33e-07	8.44e-09	erg/cm2/s	
	Photon flux	0.00033	2.2e-05	ph./cm2/s	

*** All fluxes and upper limits have been computed in the 100.0 - 1000.0 energy range.
*** Upper limits (if any) are computed assuming a photon index of -2.0, with the 95.0 % c.l.
Log(likelihood) = 769.199818608

New localization from gtfindsrc:

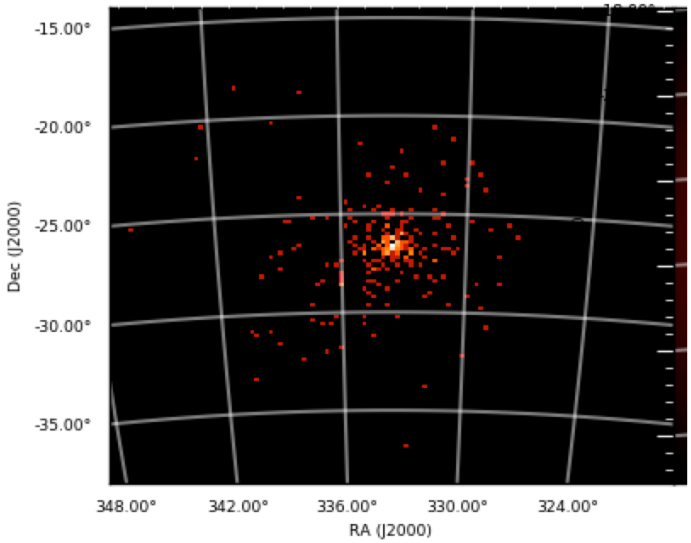
(R.A., Dec) = (333.567, -26.625)
68 % containment radius = 0.028
90 % containment radius = 0.040
Distance from initial position = 0.039

Results of the last likelihood analysis. Select 'close' from the file menu to close this window.

Fit results

Fermi bursts analysis GUI

tsmin	20	?
optimizeposition	yes	?
showmodelimage	yes	?
spectralfiles	yes	?
liketype	unbinned	?
clul	0.95	?
flemin	100	?
flemax	1000	?



<- Prev. 4/4 Run Finish! Cancel

Here you will perform a likelihood analysis on the data you selected in the first step, using the model you selected in the 2nd step.

The likelihood analysis should take between 5 and 10 minutes to complete.

```
90 % containment radius        =  0.040
Distance from initial position  =  0.039

NOTE: this new localization WILL NOT be used by default. If you judge it is a better localization than
the one you started with, update the coordinates yourself and re-run the likelihood


============================================================
```