High Energy Tutorial : Fermi-LAT

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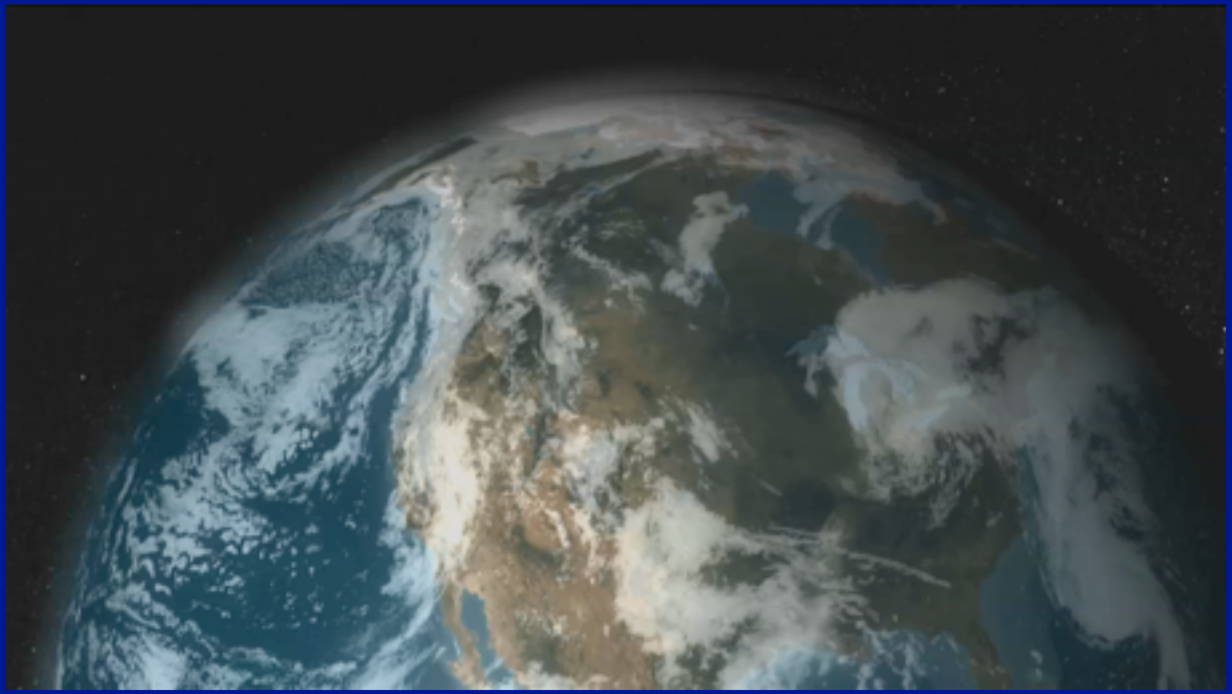
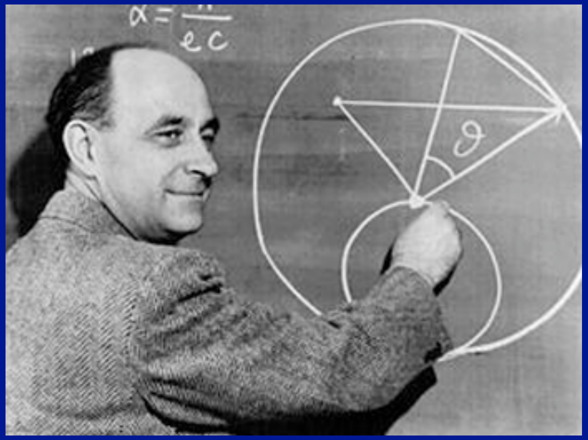
INAF-IASFBO



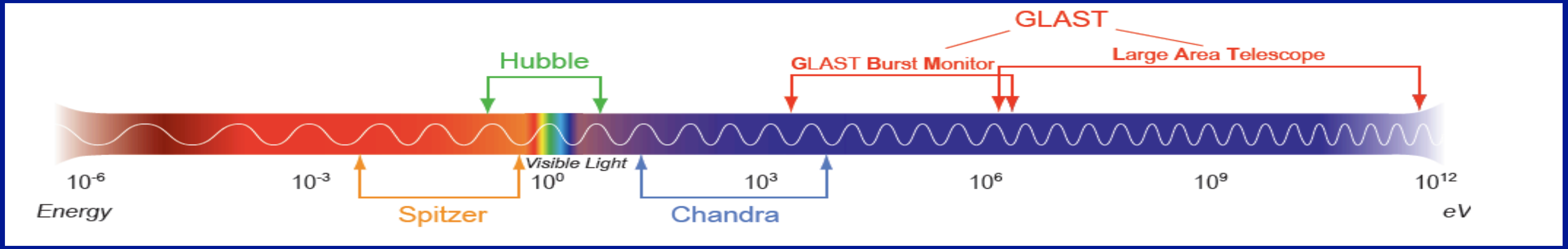
Lab X course, 2013 Bologna, Italy
in collaboration with the University of Bologna

Bologna, 27 November 2013



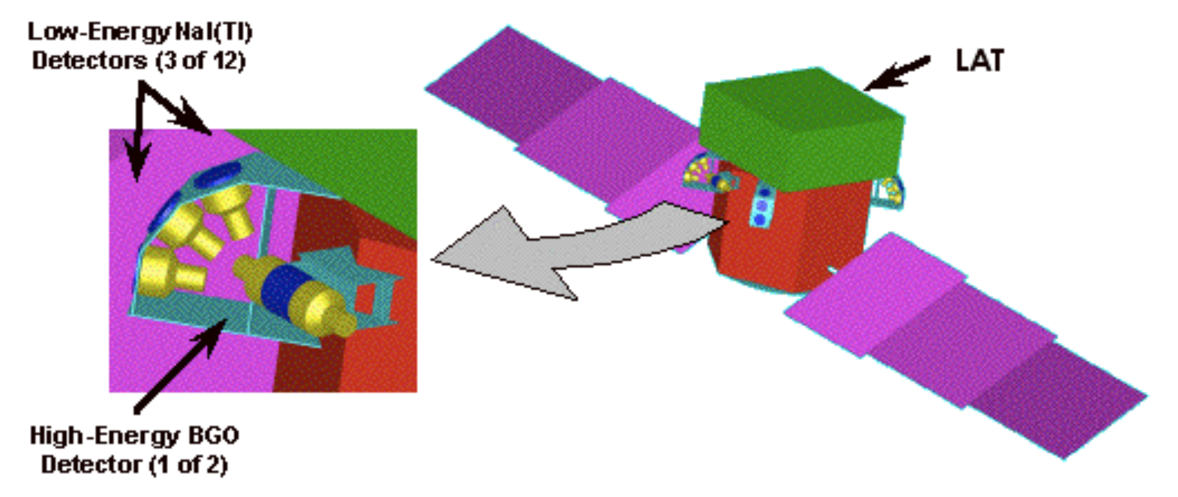
Fermi (GLAST) Gamma-ray Space Telescope

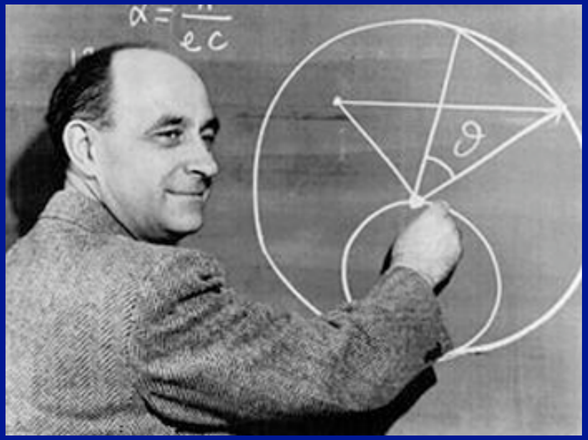
Launched on 11 June 2008



Fermi consists of two instruments:

1. the Large Area Telescope : LAT (20 Mev -300 GeV)
2. the Gamma-ray Burst Monitor : GBM (8 keV -40 MeV).





Fermi (GLAST) Gamma-ray Space Telescope

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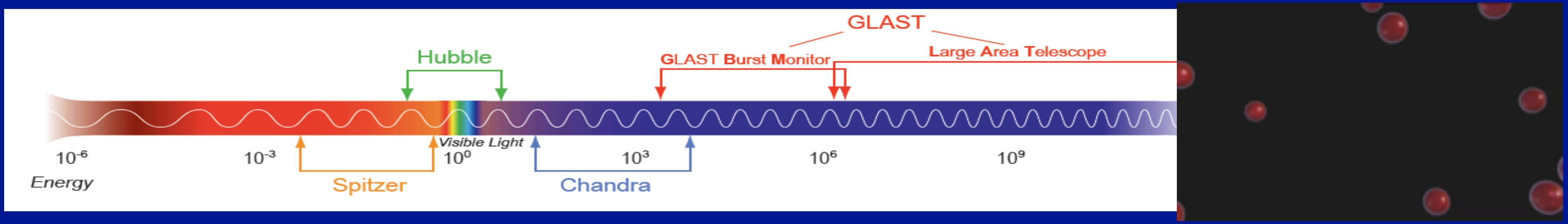

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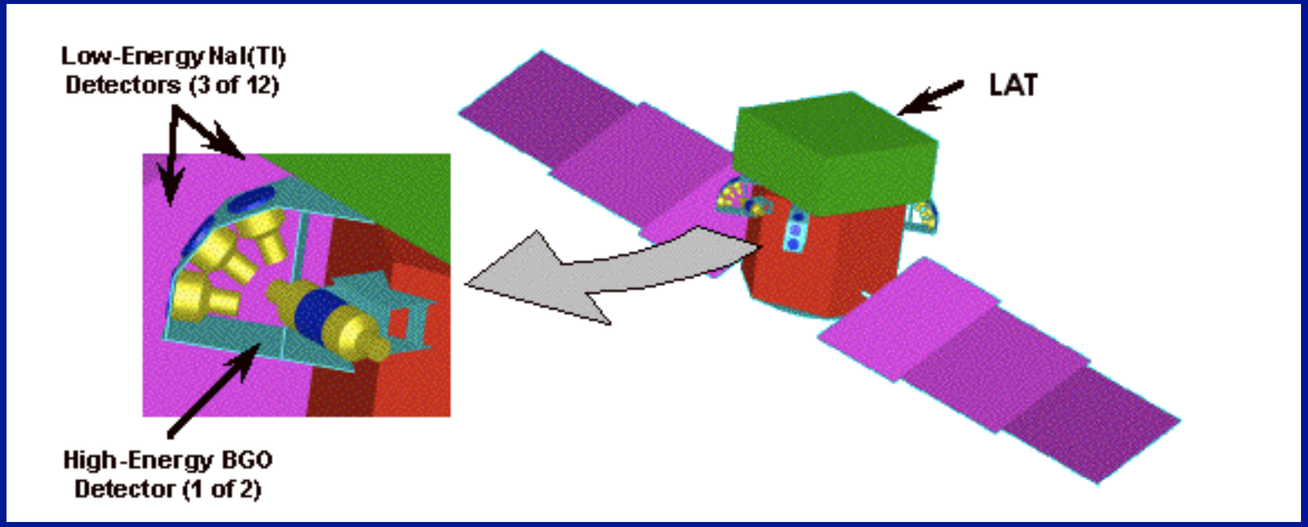
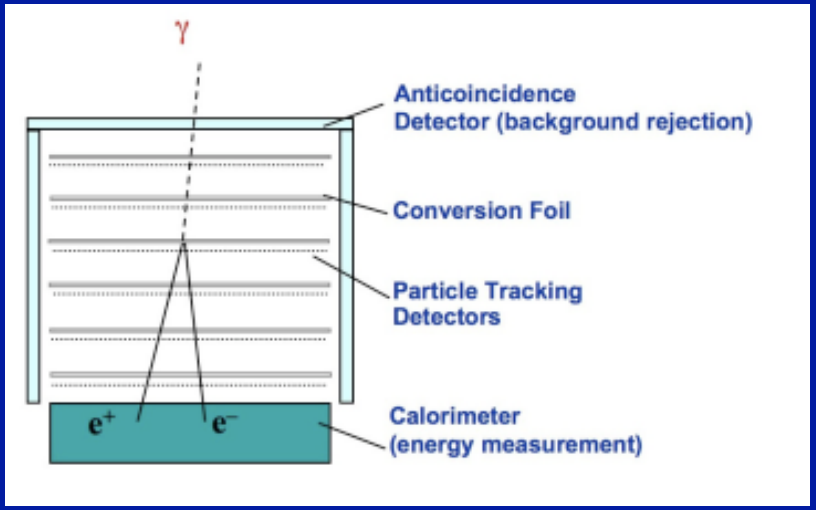


The LAT is an imaging high-energy gamma-ray telescope

The LAT is a pair-conversion telescope with a precision tracker and calorimeter



FOV =2.3 sr ~ 1/5 of the full sky

It scans the entire sky in about 3 hr

- On-axis effective area ≈ 1500 cm^2 **at** 100 MeV to ≈ 8000 cm^2 at E≥1 GeV
- Energy resolution better than 10% between ≈ 50 MeV and ≈ 50 GeV.
- Spatial resolution depends on the photon energy

$R_{68} \approx 3.5^\circ$ at $E \approx 100$ MeV

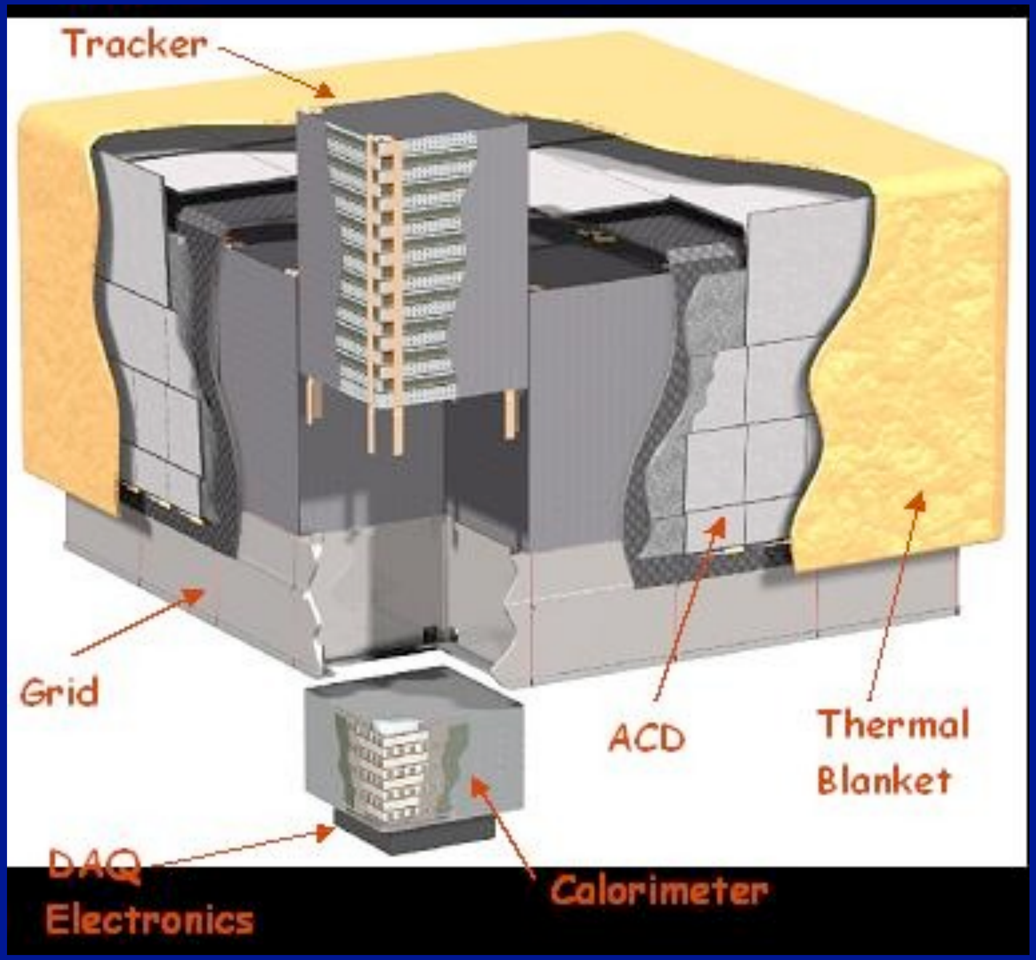
$R_{68} \approx 0.6^\circ$ at $E \approx 1$ GeV

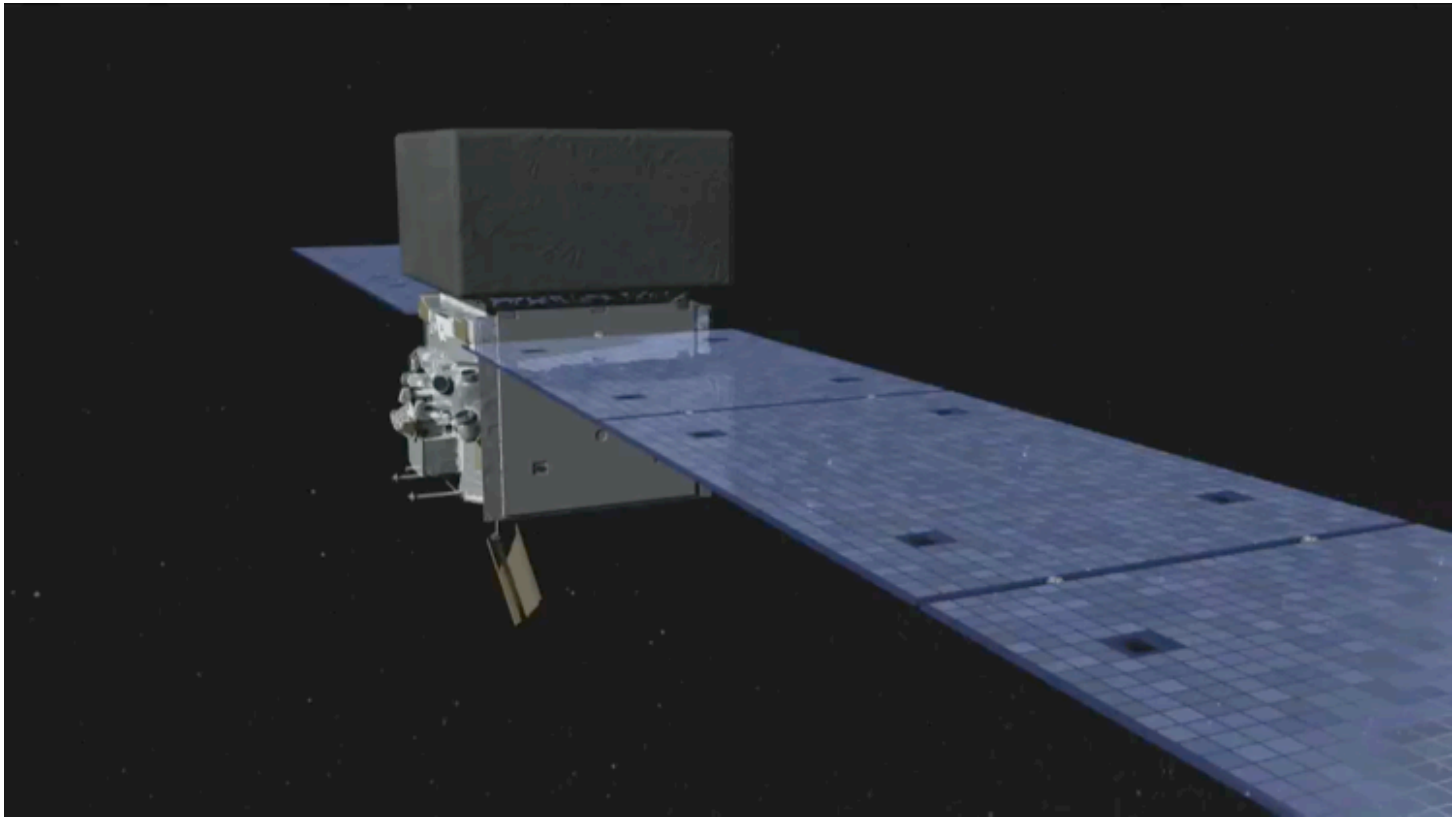
Ad energie dei fotoni superiori alla decina di MeV il processo principale è la **produzione di coppie**, un fenomeno in base al quale un raggio gamma interagendo con la materia è convertito in una coppia di particelle formata da un elettrone ed un positrone (l'antiparticella dell'elettrone, uguale all'elettrone ma con carica positiva). Conoscendo la traiettoria e l'energia delle due particelle "figlie" è possibile risalire all'energia ed alla direzione del raggio gamma iniziale (v. movie).

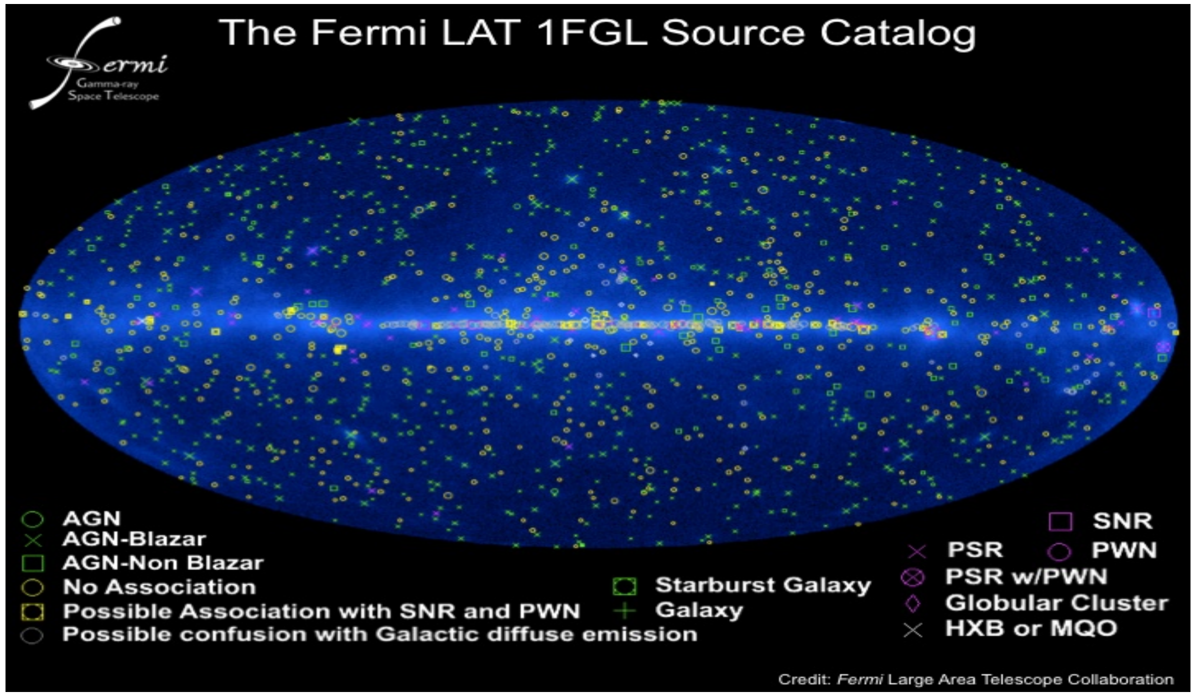
Lo strumento principale di GLAST, il Large Area Telescope (LAT) funziona sfruttando questo meccanismo. Il LAT ha una struttura modulare basata su 16 elementi identici chiamati "torri ". Ogni torre a sua volta è costituita da due sottosistemi: un **tracciatore** ad alta precisione ed un **calorimetro elettromagnetico**

Il tracciatore ("misuratore di traiettorie") è un complesso rivelatore basato sulle più moderne tecnologie a semiconduttore. Esso è costituito infatti da piani di rivelatori al silicio a microstrisce alternati a piani di convertitore per i gamma (tungsteno). Nel tracciatore si formano le tracce della coppia e^+e^-.
La costruzione dell'intero tracciatore è stata responsabilità della collaborazione italiana. Dalla componente pisana dell'INFN dipendeva in particolare la qualificazione dei sensori al silicio, l'ingegnerizzazione della costruzione, la definizione delle procedure di allineamento, di assemblaggio e di tutti i test elettricii, meccanici e funzionali necessari per l'accettazione delle varie componenti del tracciatore.

Al calorimetro è affidata la misura dell'energia dei prodotti dell'interazione del raggio gamma. Da questa misura è possibile risalire all'energia del gamma incidente. Questo strumento è strutturato in una matrice di cristalli di ioduro di cesio in modo tale da permettere di ricostruire lo sviluppo della perdita di energia che in esso avviene. Questa ulteriore informazione, integrata con quella proveniente dal tracciatore, permette di risalire alla direzione del gamma e quindi alla localizzazione in cielo della sorgente.



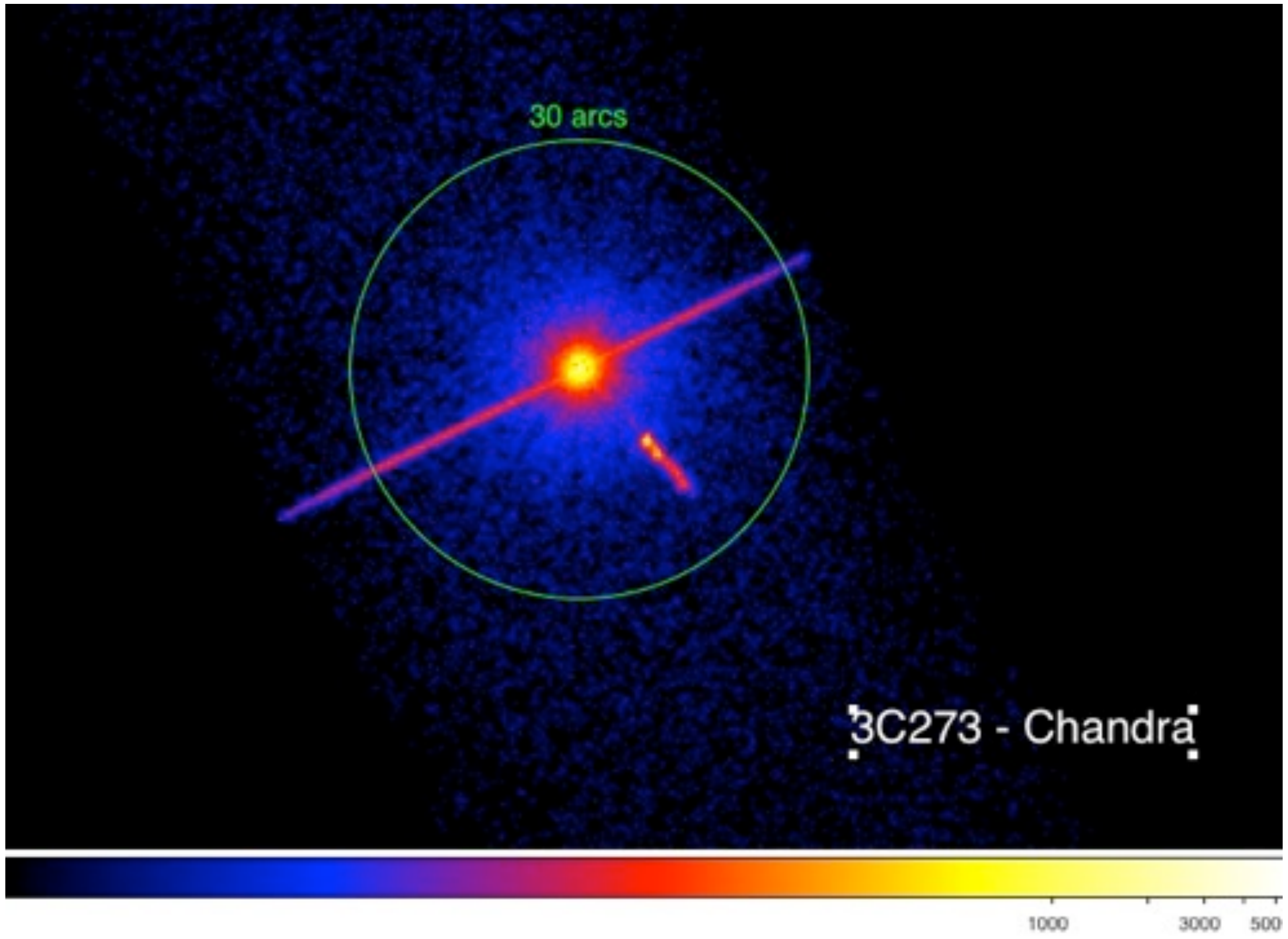


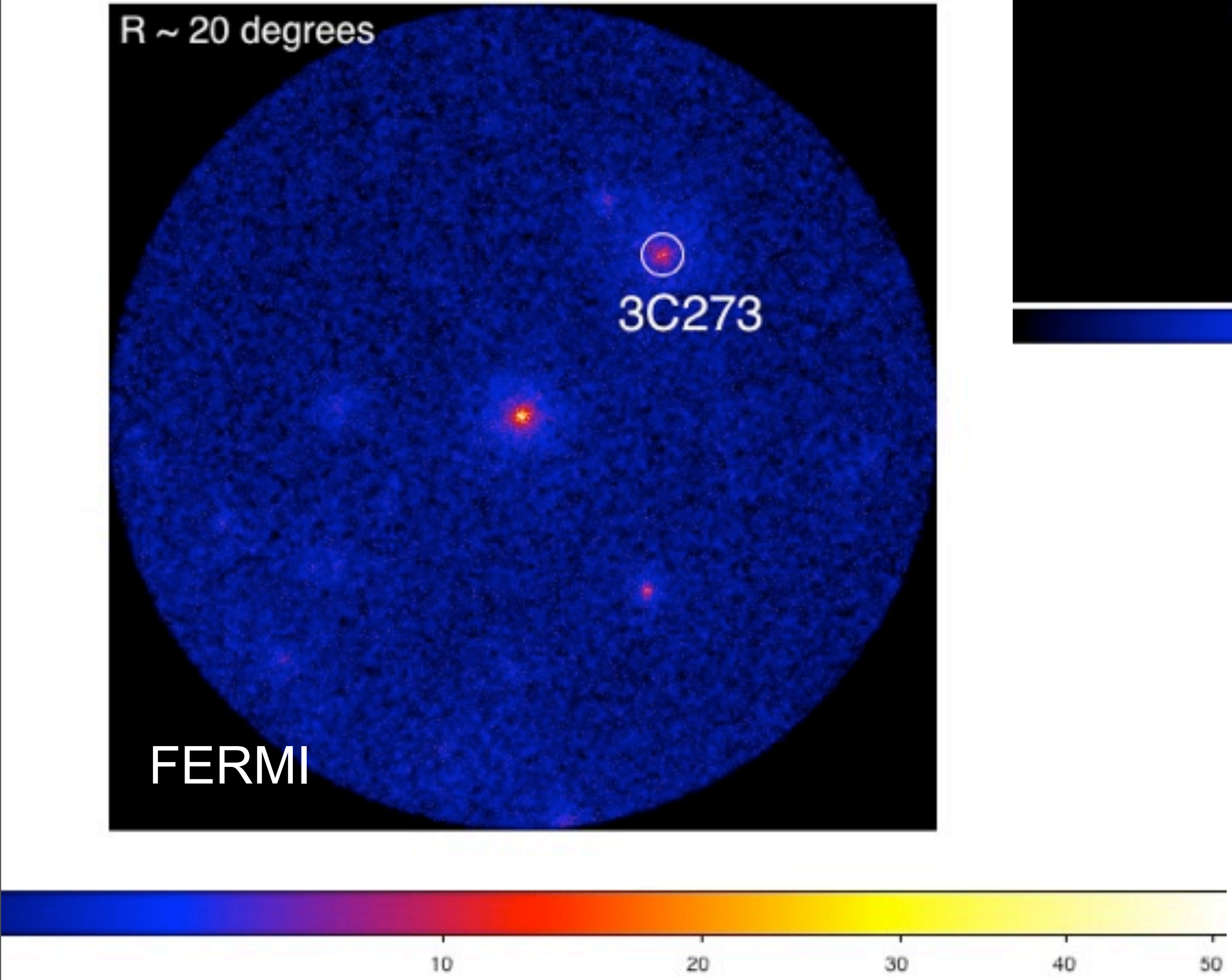

The Fermi LAT 1FGL Source Catalog

Credit: *Fermi* Large Area Telescope Collaboration

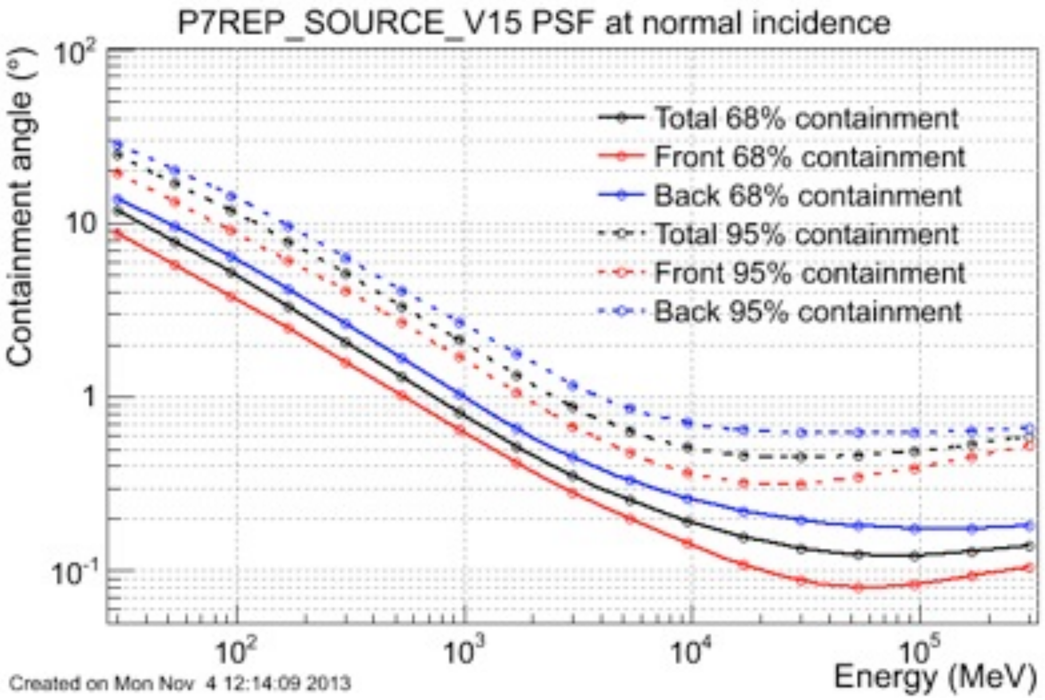
X-ray	Gamma-ray
File data File housekeeping	File data (ft1) File housekeeping (ft2)
Data cleaning	Data cleaning
Response matrix Background	Response matrix (Instrumental Response Function :IRF) Background
Prodotti: i) light curve; ii) count map (image); iii) spectrum.	Prodotti i) count maps; ii) spectrum; iii) light curve.
source spectrum bkg spectrum arf + rmf model XSPEC	Region of interest (ROI) ~ 15 degrees centered on the target Spectral model and position of all the sources in the Roi background IRF ==> Likelihood analysis

Count map

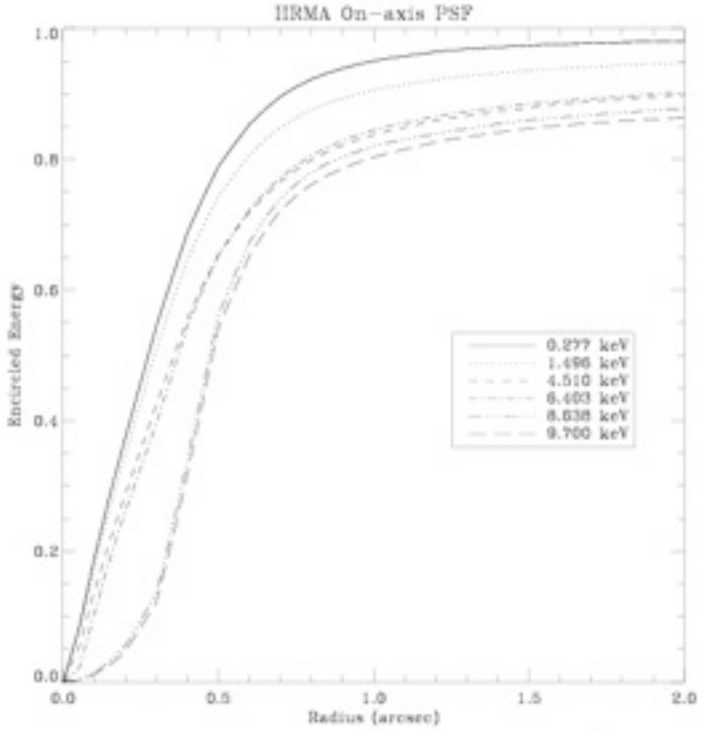

30 arcs
3C273 - Chandra
1000
3000
500


R ~ 20 degrees
3C273
FERMI
10
20
30
40
50

PSF

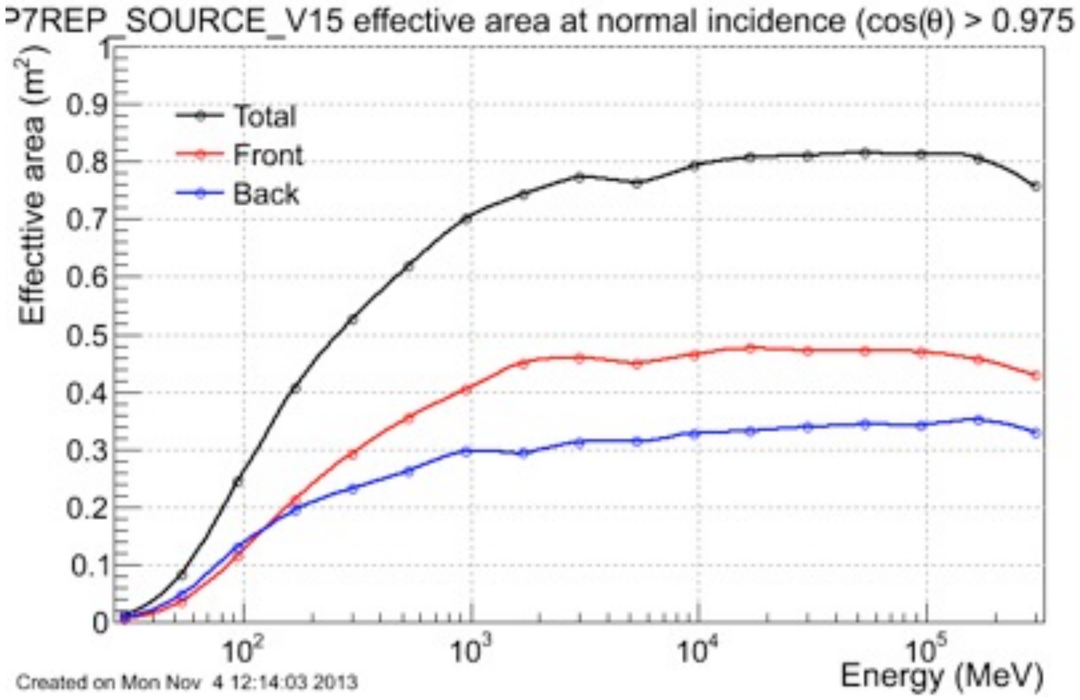


FERMI-LAT GAMMA

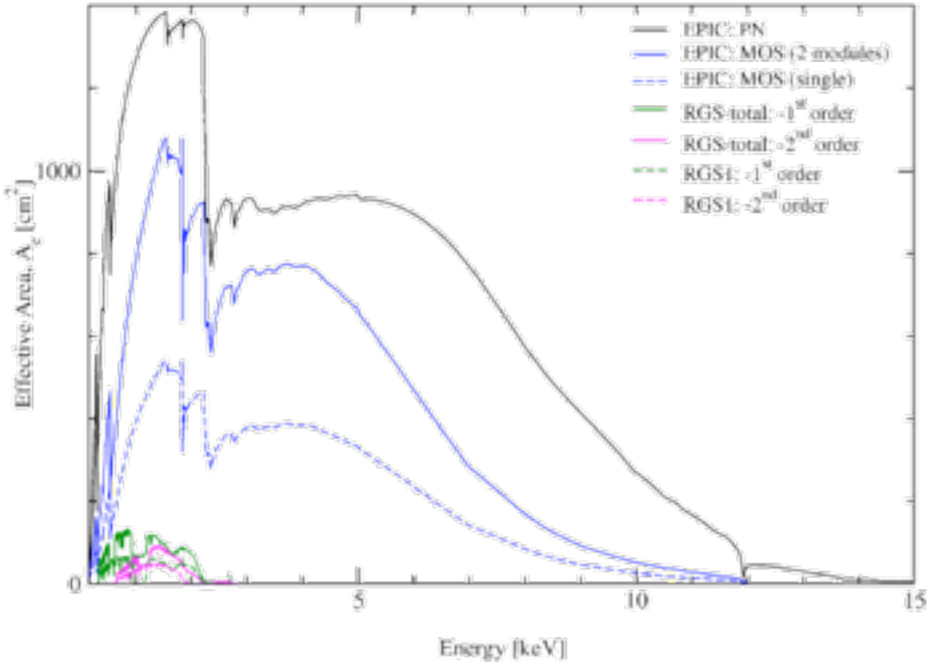


Chandra X_RAY

EFFECTIVE AREA



FERMI-LAT GAMMA



XMM-NEWTON

Because of the paucity of data, the large errors associated with detecting gamma-rays and a bright background, analysis and interpretation of the data require complex statistical techniques

We need a likelihood analysis

The likelihood *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 (+background).
- One will maximize *L* to get the best match of the model to the data.

The Test Statistic is defined as:

$TS=-2 \ln (L_{max,0}/L_{max,1})$

- Where $L_{max,0}$ is the maximum likelihood value for a model without an additional source (the 'null hypothesis') and $L_{max,1}$ is the maximum likelihood value for a model with the additional source at a specified location.

- As a basic rule of thumb, the square root of the TS is approximately equal to the detection significance for a given source. $TS \sim \sigma^2$

Pointlike Analysis of FERMI data

http://joshualande.com/coding/pointlike/

The pointlike analyis uses the python language.

Don’t Panic!!!

It is not required to know the python language. It is sufficient to understand the different steps within the file. py module provided by the Lab X staff) file => fermi.sh to set the environment

file => model.xml: model file

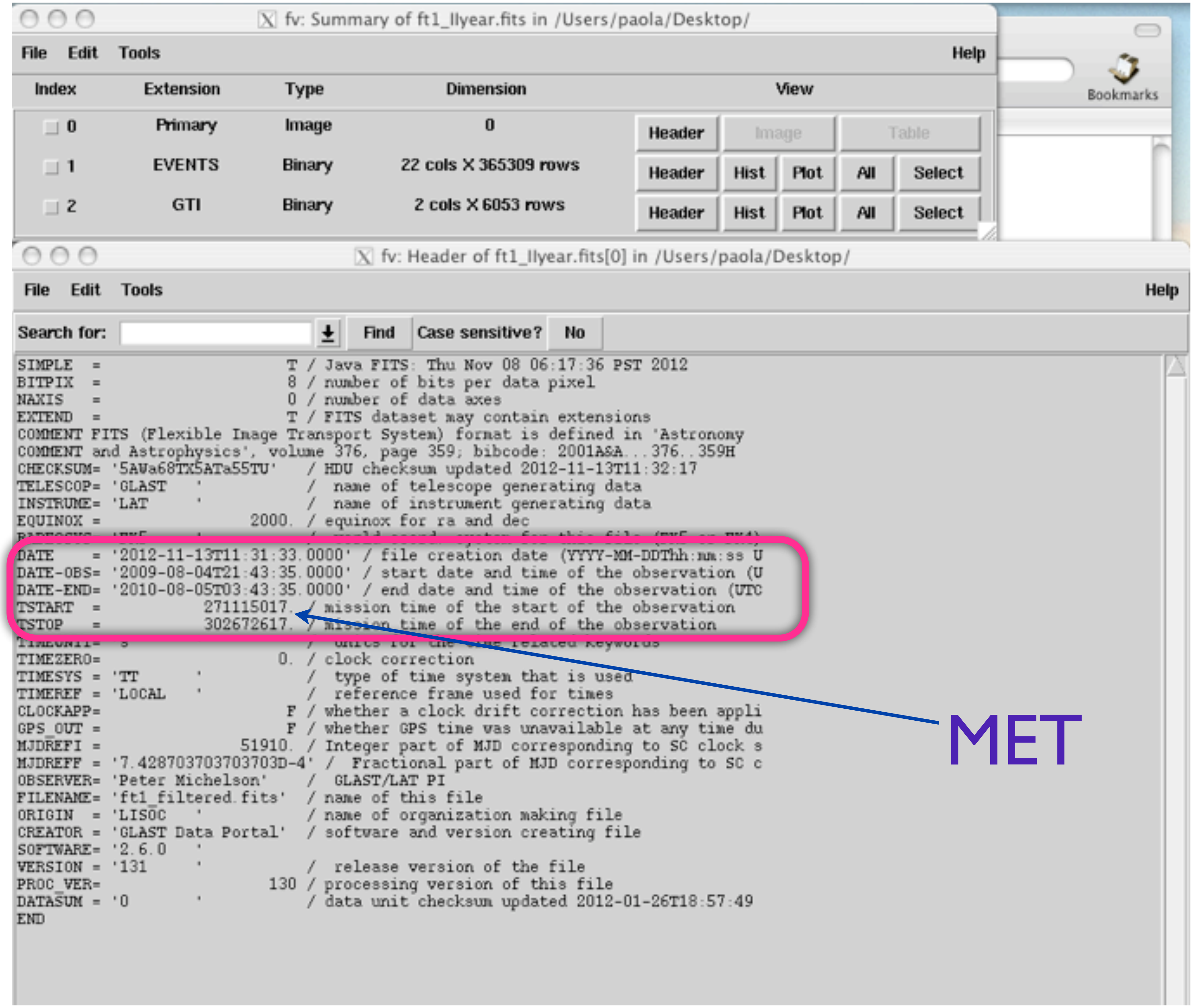
file => ft2.fits (housekeeping file)

file => analysis.py (command file)

file => ft1.fits (cleaned event file)

file => expCube.fits

The LAT instrument response functions are depend on the angle between the direction to a source and the instrument z-axis. (This angle is commonly referred to as the inclination or "off-axis angle".) The number of counts that are detected for a source of a given intensity thus depends on how long that source spends at various inclination angles over the course of an observation. The number of counts will also depend on the "livetime", i.e., the accumulated time during which the LAT is actively taking event data.

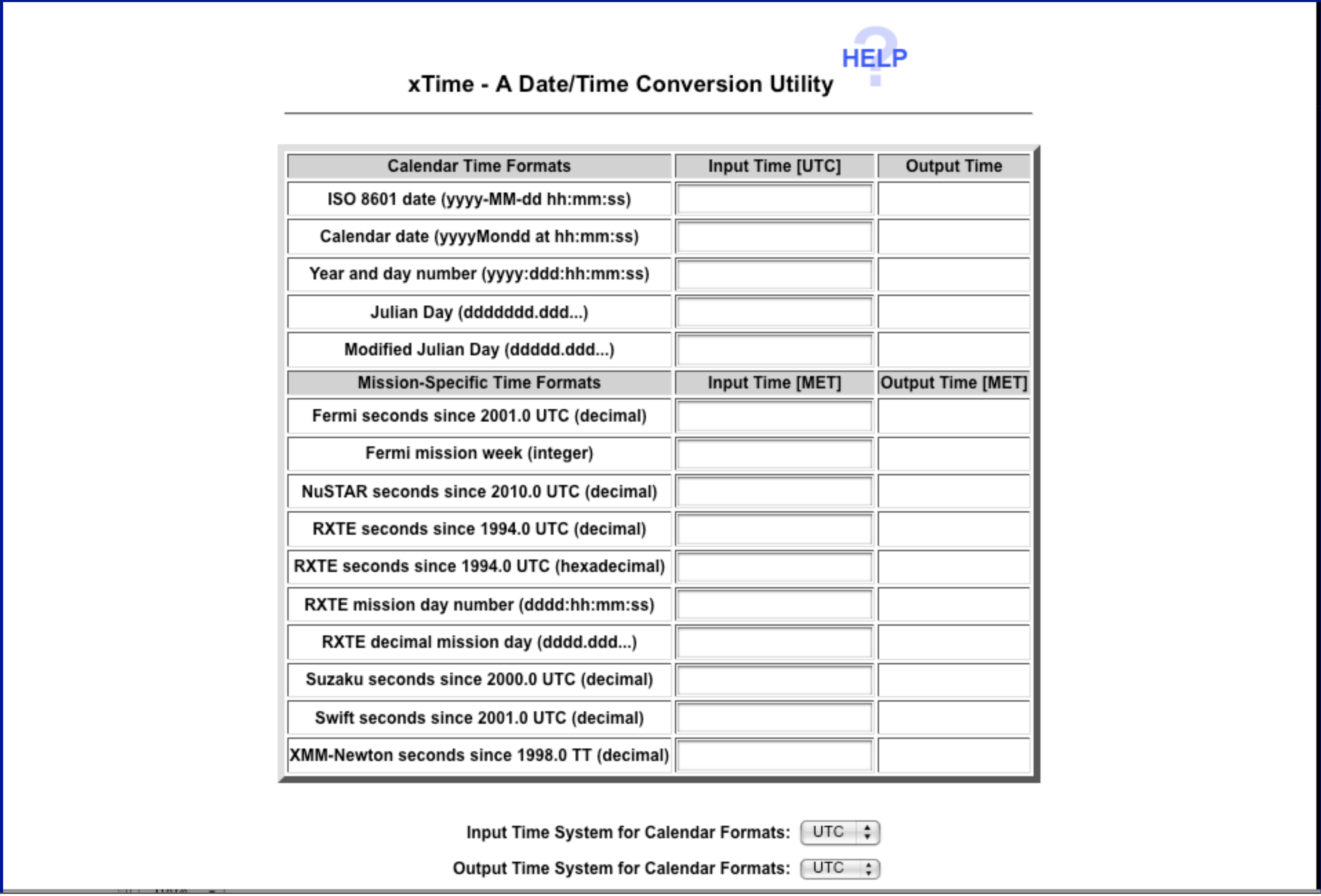


Index	Extension	Type	Dimension	View
☐ 0	Primary	Image	0	Header Image Table
☐ 1	EVENTS	Binary	22 cols X 365309 rows	Header Hist Plot All Select
☐ 2	GTI	Binary	2 cols X 6053 rows	Header Hist Plot All Select

```
SIMPLE  =                    T / Java FITS: Thu Nov 08 06:17:36 PST 2012
BITPIX  =                    8 / number of bits per data pixel
NAXIS   =                    0 / number of data axes
EXTEND  =                    T / FITS dataset may contain extensions
COMMENT FITS (Flexible Image Transport System) format is defined in 'Astronomy
COMMENT and Astrophysics', volume 376, page 359; bibcode: 2001A&A...376..359H
CHECKSUM= '5AWa68TX5ATa55TU'   / HDU checksum updated 2012-11-13T11:32:17
TELESCOP= 'GLAST   '           /  name of telescope generating data
INSTRUME= 'LAT     '           /  name of instrument generating data
EQUINOX =                2000. / equinox for ra and dec
RADECSYS= 'FK5     '           /  world coord. system for this file (FK5 or FK4)
DATE    = '2012-11-13T11:31:33.0000' / file creation date (YYYY-MM-DDThh:mm:ss U
DATE-OBS= '2009-08-04T21:43:35.0000' / start date and time of the observation (U
DATE-END= '2010-08-05T03:43:35.0000' / end date and time of the observation (UTC
TSTART  =           271115017. / mission time of the start of the observation
TSTOP   =           302672617. / mission time of the end of the observation
TIMEUNIT= 's       '           /  units for the time related keywords
TIMEZERO=                   0. / clock correction
TIMESYS = 'TT      '           /  type of time system that is used
TIMEREF = 'LOCAL   '           /  reference frame used for times
CLOCKAPP=                    F / whether a clock drift correction has been appli
GPS_OUT =                    F / whether GPS time was unavailable at any time du
MJDREFI =               51910. / Integer part of MJD corresponding to SC clock s
MJDREFF = '7.428703703703703D-4' /  Fractional part of MJD corresponding to SC c
OBSERVER= 'Peter Michelson'    /  GLAST/LAT PI
FILENAME= 'ft1_filtered.fits'  / name of this file
ORIGIN  = 'LISOC   '           / name of organization making file
CREATOR = 'GLAST Data Portal'  / software and version creating file
SOFTWARE= '2.6.0   '
VERSION = '131     '           /  release version of the file
PROC_VER=                  130 / processing version of this file
DATASUM = '0       '           / data unit checksum updated 2012-01-26T18:57:49
END
```

mission elapsed time (*MET*)
the number of seconds since the reference time of January 1, 2001, at 0h:0m:0s

http://heasarc.gsfc.nasa.gov/cgi-bin/Tools/xTime/xTime.pl



xTime - A Date/Time Conversion Utility

Calendar Time Formats	Input Time [UTC]	Output Time
ISO 8601 date (yyyy-MM-dd hh:mm:ss)		
Calendar date (yyyyMondd at hh:mm:ss)		
Year and day number (yyyy:ddd:hh:mm:ss)		
Julian Day (ddddddd.ddd...)		
Modified Julian Day (ddddd.ddd...)		
Mission-Specific Time Formats	**Input Time [MET]**	**Output Time [MET]**
Fermi seconds since 2001.0 UTC (decimal)		
Fermi mission week (integer)		
NuSTAR seconds since 2010.0 UTC (decimal)		
RXTE seconds since 1994.0 UTC (decimal)		
RXTE seconds since 1994.0 UTC (hexadecimal)		
RXTE mission day number (dddd:hh:mm:ss)		
RXTE decimal mission day (dddd.ddd...)		
Suzaku seconds since 2000.0 UTC (decimal)		
Swift seconds since 2001.0 UTC (decimal)		
XMM-Newton seconds since 1998.0 TT (decimal)		

Input Time System for Calendar Formats: UTC

Output Time System for Calendar Formats: UTC

Let's edit analysis.py and work on it

python file step by step

python file step by step

I - STEP

```
#!/usr/bin/env python

import os, sys

from uw.like.pointspec import DataSpecification
from uw.like import counts_plotter
from skymaps import SkyDir
from uw.like.pointspec import SpectralAnalysis
from uw.like import roi_plotting
from uw.like import roi_printing
from uw.like.roi_extended import ExtendedSource
from uw.like.SpatialModels import *
from uw.like.Models import *

fd = open('file.txt','w') # open the result file in write mode
```

put the name of the output file containing the results

```
old_stdout = sys.stdout
sys.stdout = fd
```

python file step by step

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fd = open('file.txt','w') # open the result file in write mode
```

put the name of the output file containing the results

```
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sys.stdout = fd
```

II - STEP

```
data_specification = DataSpecification(ft1files ="ft1.fits",ft2files = “../ft2.fits",ltcube    =
"expCube.fits", binfile  = " binned.fits")


exposure_center=SkyDir(RA,DEC,SkyDir.EQUATORIAL)
spectral_analysis = SpectralAnalysis(data_specification,binsperdec = 4,emin= 100
,emax=1e5, irf="P7SOURCE_V6", zenithcut=100, event_class=0, roi_dir=exposure_
center, maxROI=10, minROI= 10)

roi_center=SkyDir(RA, DEC,SkyDir.EQUATORIAL)
roi=spectral_analysis.roi_from_xml(roi_dir = roi_center, xmlfile = "../model.xml", fit_emin =
100, fit_emax = 1e5  )
```

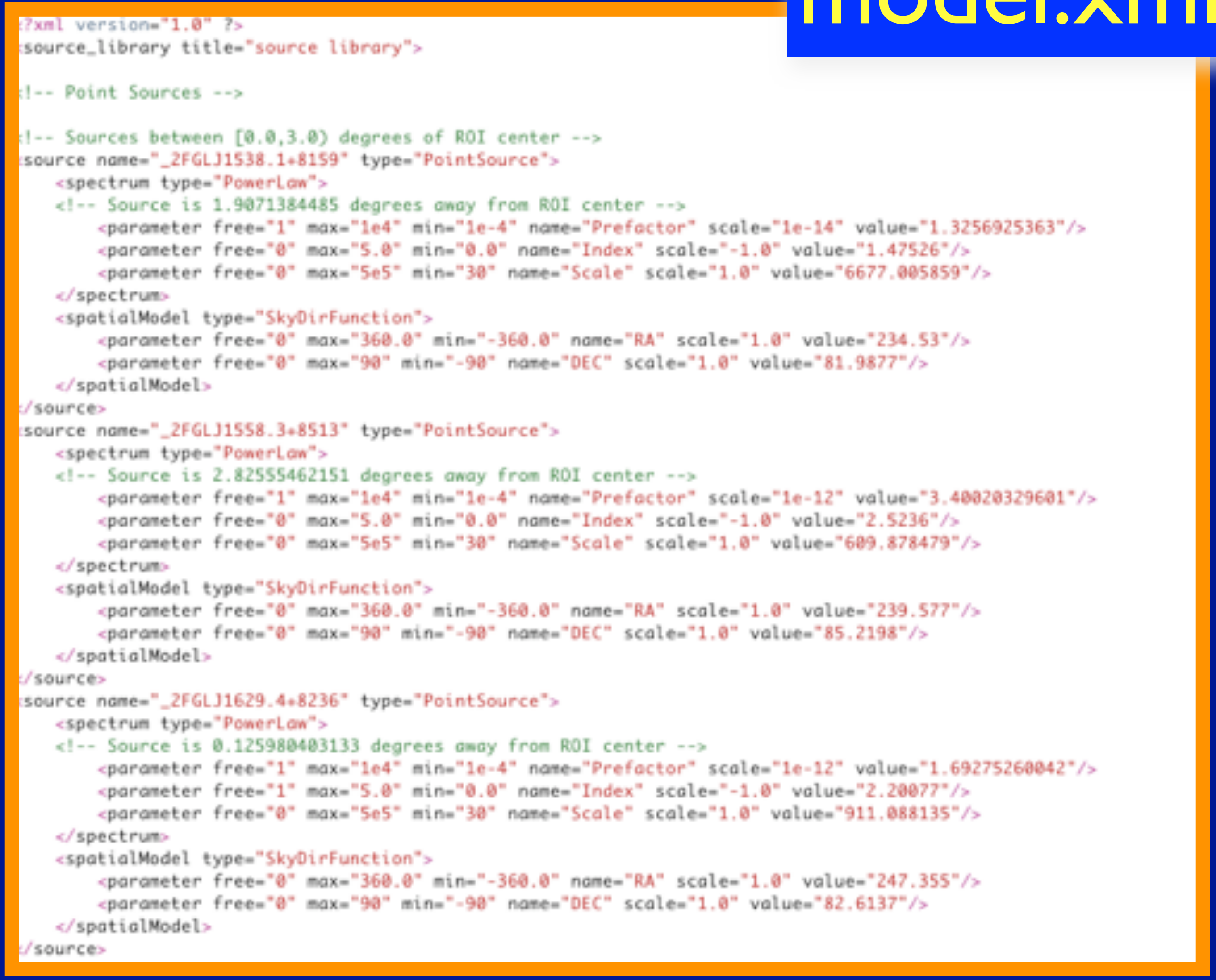
RA,DEC in degree: for NGC6251 =>247.355 , 82.6137

data_specification,binsperdec = 4 => number of bin per decade used to produce the spectrum

emin= 100 ,emax=1e5 energy range (MeV) chosen for the analysis in MeV

maxROI=10, minROI= 10   dimension f the ROI in degrees

model.xml



```
?xml version="1.0" ?>
source_library title="source library">

!-- Point Sources -->

!-- Sources between [0.0,3.0) degrees of ROI center -->
source name="_2FGLJ1538.1+8159" type="PointSource">
    <spectrum type="PowerLaw">
    <!-- Source is 1.9071384485 degrees away from ROI center -->
        <parameter free="1" max="1e4" min="1e-4" name="Prefactor" scale="1e-14" value="1.3256925363"/>
        <parameter free="0" max="5.0" min="0.0" name="Index" scale="-1.0" value="1.47526"/>
        <parameter free="0" max="5e5" min="30" name="Scale" scale="1.0" value="6677.005859"/>
    </spectrum>
    <spatialModel type="SkyDirFunction">
        <parameter free="0" max="360.0" min="-360.0" name="RA" scale="1.0" value="234.53"/>
        <parameter free="0" max="90" min="-90" name="DEC" scale="1.0" value="81.9877"/>
    </spatialModel>
/source>
source name="_2FGLJ1558.3+8513" type="PointSource">
    <spectrum type="PowerLaw">
    <!-- Source is 2.82555462151 degrees away from ROI center -->
        <parameter free="1" max="1e4" min="1e-4" name="Prefactor" scale="1e-12" value="3.40020329601"/>
        <parameter free="0" max="5.0" min="0.0" name="Index" scale="-1.0" value="2.5236"/>
        <parameter free="0" max="5e5" min="30" name="Scale" scale="1.0" value="609.878479"/>
    </spectrum>
    <spatialModel type="SkyDirFunction">
        <parameter free="0" max="360.0" min="-360.0" name="RA" scale="1.0" value="239.577"/>
        <parameter free="0" max="90" min="-90" name="DEC" scale="1.0" value="85.2198"/>
    </spatialModel>
/source>
source name="_2FGLJ1629.4+8236" type="PointSource">
    <spectrum type="PowerLaw">
    <!-- Source is 0.125980403133 degrees away from ROI center -->
        <parameter free="1" max="1e4" min="1e-4" name="Prefactor" scale="1e-12" value="1.69275260042"/>
        <parameter free="1" max="5.0" min="0.0" name="Index" scale="-1.0" value="2.20077"/>
        <parameter free="0" max="5e5" min="30" name="Scale" scale="1.0" value="911.088135"/>
    </spectrum>
    <spatialModel type="SkyDirFunction">
        <parameter free="0" max="360.0" min="-360.0" name="RA" scale="1.0" value="247.355"/>
        <parameter free="0" max="90" min="-90" name="DEC" scale="1.0" value="82.6137"/>
    </spatialModel>
/source>
```

Sources in the ROI

Power Law model

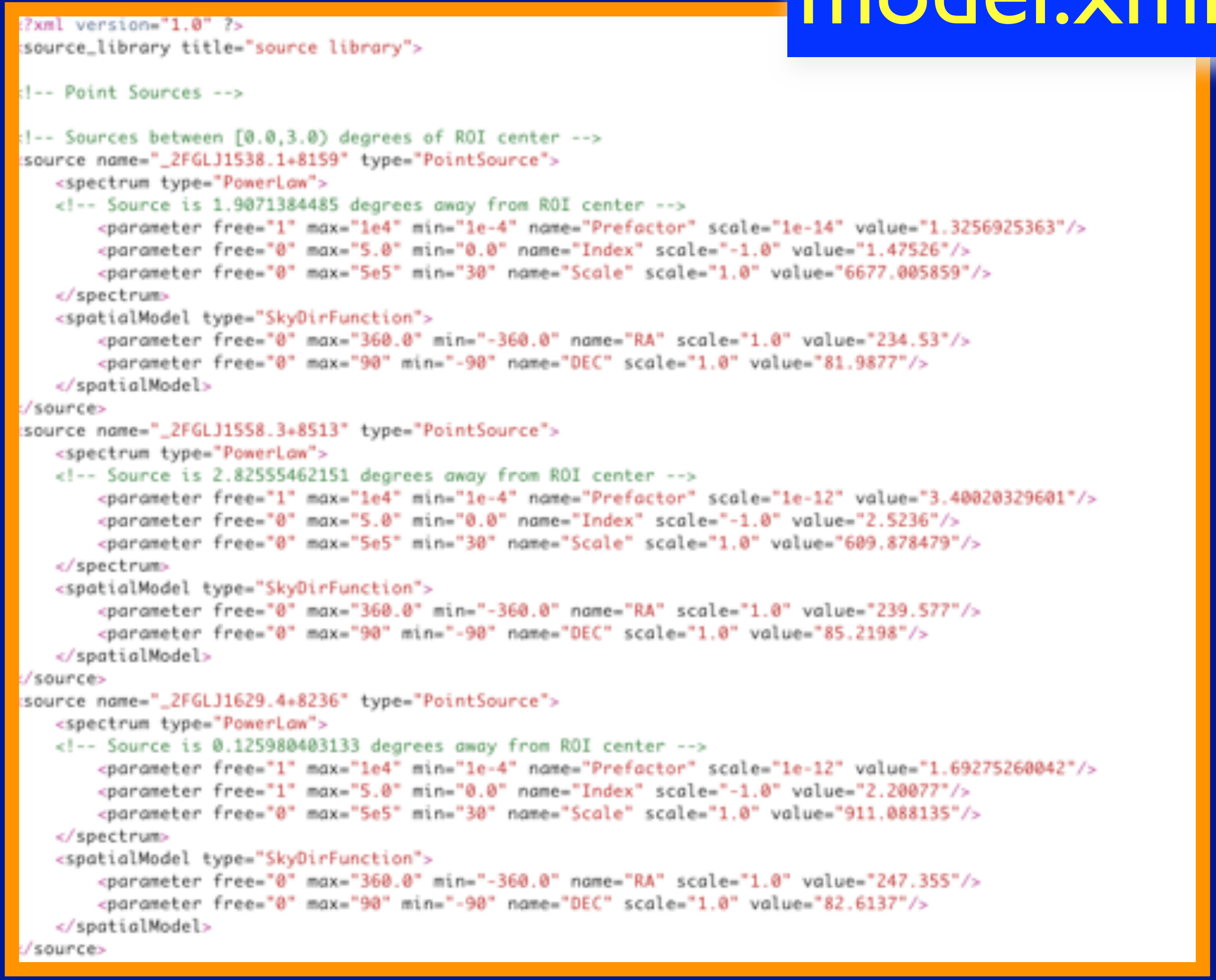
$$\frac{dN}{dE} = N_0(\frac{E}{E_0})^{-\Gamma}$$

N_0 = Prefactor

Gamma = Index

E_0= Scale in MeV

model.xml



```xml
<?xml version="1.0" ?>
<source_library title="source library">

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        <parameter free="0" max="5.0" min="0.0" name="Index" scale="-1.0" value="1.47526"/>
        <parameter free="0" max="5e5" min="30" name="Scale" scale="1.0" value="6677.005859"/>
    </spectrum>
    <spatialModel type="SkyDirFunction">
        <parameter free="0" max="360.0" min="-360.0" name="RA" scale="1.0" value="234.53"/>
        <parameter free="0" max="90" min="-90" name="DEC" scale="1.0" value="81.9877"/>
    </spatialModel>
</source>
<source name="_2FGLJ1558.3+8513" type="PointSource">
    <spectrum type="PowerLaw">
    <!-- Source is 2.82555462151 degrees away from ROI center -->
        <parameter free="1" max="1e4" min="1e-4" name="Prefactor" scale="1e-12" value="3.40020329601"/>
        <parameter free="0" max="5.0" min="0.0" name="Index" scale="-1.0" value="2.5236"/>
        <parameter free="0" max="5e5" min="30" name="Scale" scale="1.0" value="609.878479"/>
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    </spatialModel>
</source>
```

Sources in the ROI

Power Law model

$$\frac{dN}{dE} = N_0\left(\frac{E}{E_0}\right)^{-\Gamma}$$

N_0 = Prefactor

Gamma = Index

E_0= Scale in MeV

model.xml

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    <!-- Source is 2.82555462151 degrees away from ROI center -->
        <parameter free="1" max="1e4" min="1e-4" name="Prefactor" scale="1e-12" value="3.40020329601"/>
        <parameter free="0" max="5.0" min="0.0" name="Index" scale="-1.0" value="2.5236"/>
        <parameter free="0" max="5e5" min="30" name="Scale" scale="1.0" value="609.878479"/>
    </spectrum>
    <spatialModel type="SkyDirFunction">
        <parameter free="0" max="360.0" min="-360.0" name="RA" scale="1.0" value="239.577"/>
        <parameter free="0" max="90" min="-90" name="DEC" scale="1.0" value="85.2198"/>
    </spatialModel>
/source>
source name="_2FGLJ1629.4+8236" type="PointSource">
    <spectrum type="PowerLaw">
    <!-- Source is 0.125980403133 degrees away from ROI center -->
        <parameter free="1" max="1e4" min="1e-4" name="Prefactor" scale="1e-12" value="1.69275260042"/>
        <parameter free="1" max="5.0" min="0.0" name="Index" scale="-1.0" value="2.20077"/>
        <parameter free="0" max="5e5" min="30" name="Scale" scale="1.0" value="911.088135"/>
    </spectrum>
    <spatialModel type="SkyDirFunction">
        <parameter free="0" max="360.0" min="-360.0" name="RA" scale="1.0" value="247.355"/>
        <parameter free="0" max="90" min="-90" name="DEC" scale="1.0" value="82.6137"/>
    </spatialModel>
/source>
```

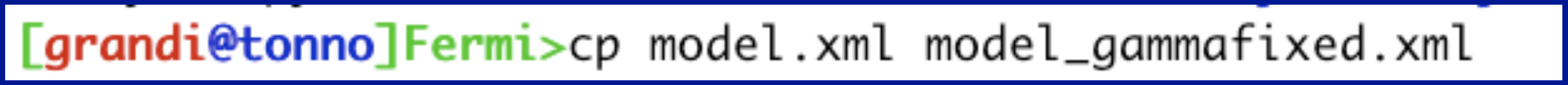
Sources in the ROI

```
<!-- Diffuse Sources -->
<source name="gal_2yearp7v6_v0" 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="/RossiFumi/prod/GLAST_EXT/redhat5-x86_64-64bit-gcc41/diffuseModels/v2r0/
ring_2year_P76_v0.fits" type="MapCubeFunction">
        <parameter free="0" max="1e3" min="1e-3" name="Normalization" scale="1.0" value="1.0"/>
    </spatialModel>
</source>
<source name="iso_p7v6source" type="DiffuseSource">
    <spectrum file="/RossiFumi/prod/GLAST_EXT/redhat5-x86_64-64bit-gcc41/diffuseModels/v2r0/
isotrop_2year_P76_source_v0.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>
</source_library>
```

Background

Fixing the spectral slopes

create a copy of model.xml



```
[grandi@tonno]Fermi>cp model.xml model_gammafixed.xml
```

edit model_gammafixed.xml and fix the spectral index of all the sources

```
<?xml version="1.0" ?>
<source_library title="source library">

<!-- Point Sources -->

<!-- Sources between [0.0,3.0) degrees of ROI center -->
<source name="_2FGLJ1538.1+8159" type="PointSource">
	<spectrum type="PowerLaw">
	<!-- Source is 1.9071384485 degrees away from ROI center -->
		<parameter free="1" max="1e4" min="1e-4" name="Prefactor" scale="1e-14" value="1.3256925363"/>
		<parameter free="1" max="5.0" min="0.0" name="Index" scale="-1.0" value="1.47526"/>
		<parameter free="0" max="5e5" min="30" name="Scale" scale="1.0" value="6677.005859"/>
	</spectrum>
	<spatialModel type="SkyDirFunction">
		<parameter free="0" max="360.0" min="-360.0" name="RA" scale="1.0" value="234.53"/>
		<parameter free="0" max="90" min="-90" name="DEC" scale="1.0" value="81.9877"/>
	</spatialModel>
</source>
<source name="_2FGLJ1558.3+8513" type="PointSource">
	<spectrum type="PowerLaw">
```

delete 1 and write 0

III- STEP

```
roi.fit(use_gradient=True)                        <= data fit

model=roi.get_model(which='_2FGLJ1629.4+8236')   <= Name of the source to be analyzed

flux=model.i_flux(emin=100,emax=100000)          <= emin, emax can be changed
print, flux                                      <= print the flux in the chosen energy band

ts=roi.TS(which="_2FGLJ1629.4+8236")
print ts                                         <= print the TS value
```

_2FGLJ1629.4+8236 is the gamma-ray counterpart of NGC6251
in the second Fermi-LAT catalog (2FGL) catalog

IV step

```
roi.plot_sed(which='_2FGLJ1629.4+8236',filename='pl.png',axis=(1e3,1e6,5e-8,1e-5))
```

produce a plot of the spectrum

```
roi.localize(which="_2FGLJ1629.4+8236", update=True)
roi.get_ellipse()
roi.print_ellipse()
```

search for the best position of the source in RA and DEC

`roi.toXML('pl.xml')` <= write the fitted model in the pl.xml file

V- STEP

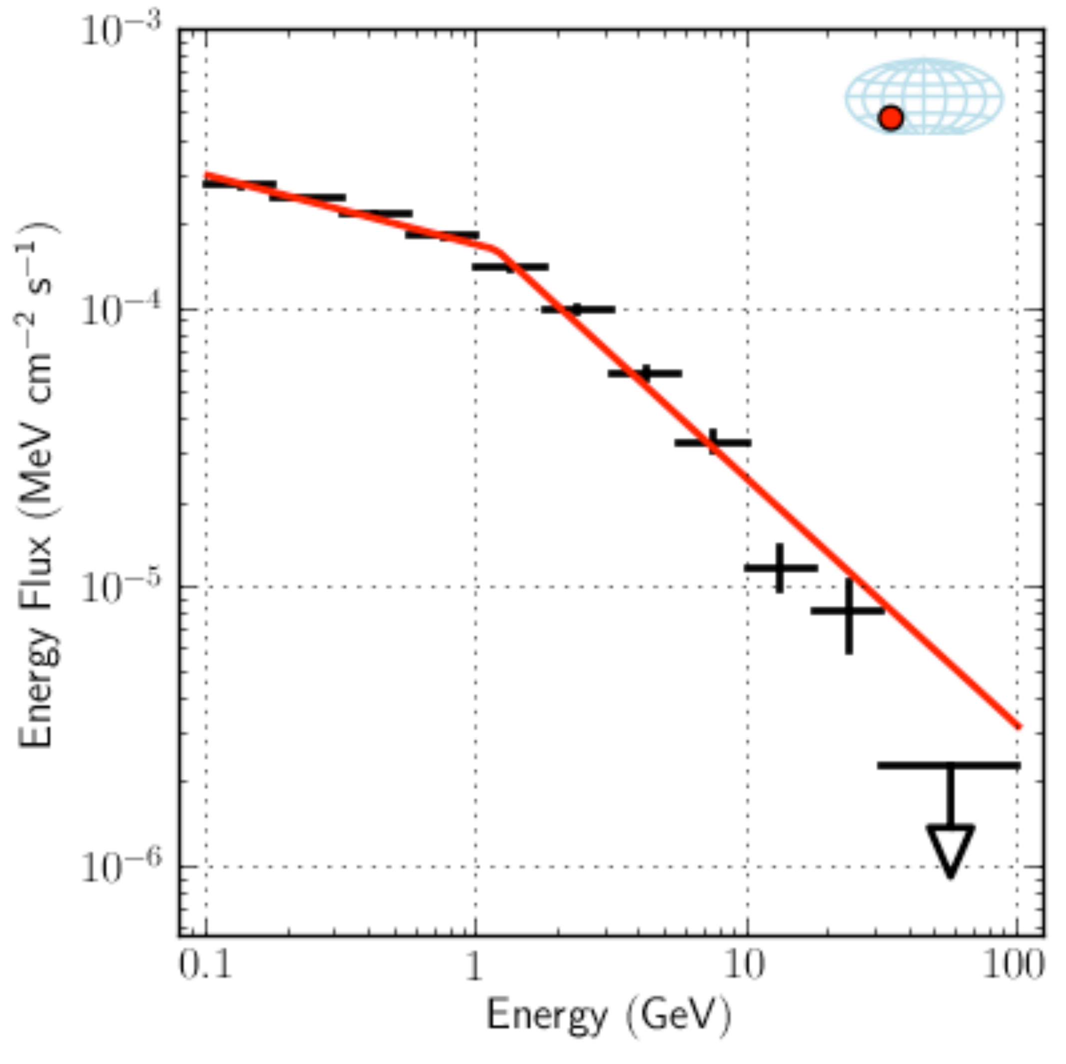
```
source=roi.get_source(which="_2FGLJ1629.4+8236")

roi.zero_source(which='_2FGLJ1629.4+8236')
roi.plot_tsmap(fitsfile='ts_map.fits', galactic=False)

roi.unzero_source(which='_2FGLJ1629.4+8236')
roi.plot_tsmap(fitsfile='ts_map_res.fits', galactic=False)
```

commands to produce
a TS map of the source and
a Residual TS map (the same sky region without the source)

I. OUTPUT: Spectrum



The fit results for all the sources in the ROI are in the file pl.txt

The new model is in the pl_I(II,III,IV)year.xml file

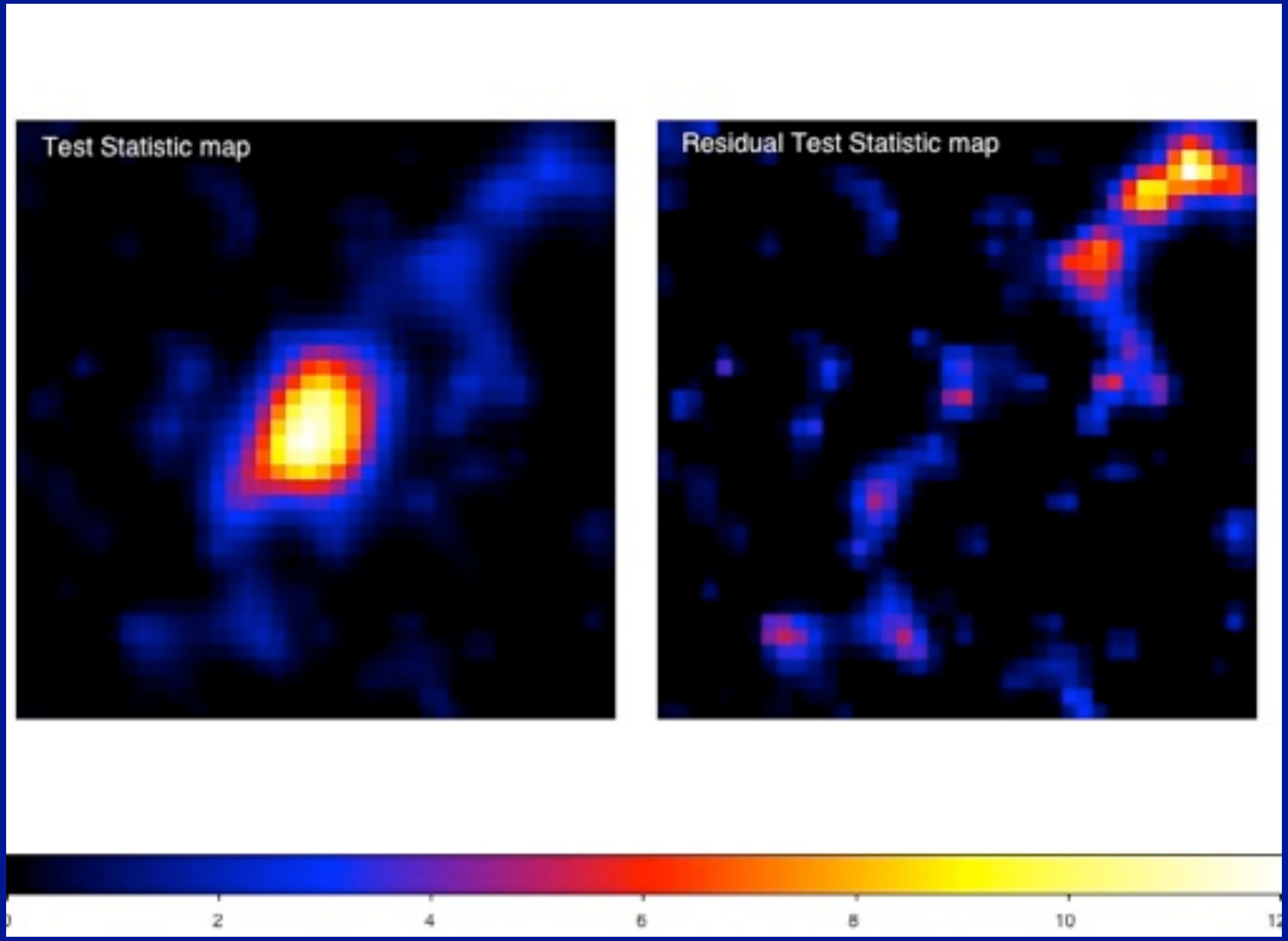
II. OUTPUT: Source position

This information is in the file.txt

```
      ra       dec         a     b         ang        qual
258.008 -39.635 0.061 0.031 25.5596 7.7114
```

The ellipse's major axis is a, minor axis is b, orientation angle is ang (measured east of celestial north), and elliptical fit quality is qual.

III. OUTPUT: TS map



In your directory you will find:

ssh -X gruppox@login01.iasfbo.inaf.it

file => fermi.sh to set the environment
file => model.xml: model file
file => ft2.fits (housekeeping file)
file => analysis.py (command file)

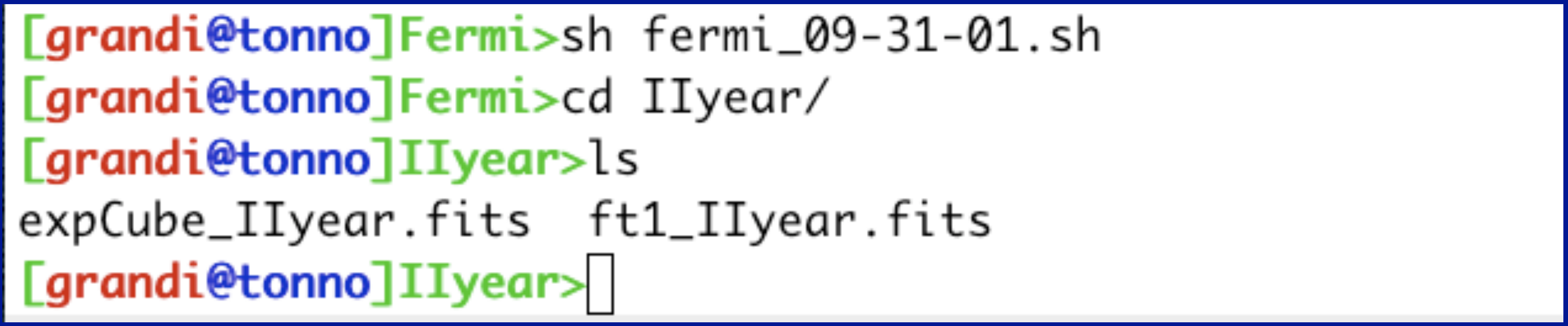
5 directories => Iyear , IIyear, IIIyear, IVyear, LC

```
[grandi@tonno]Fermi>ls
analysis.py          ft2.fits  IIyear  Iyear  model.xml
fermi_09-31-01.sh    IIIyear   IVyear  LC
[grandi@tonno]Fermi>
```

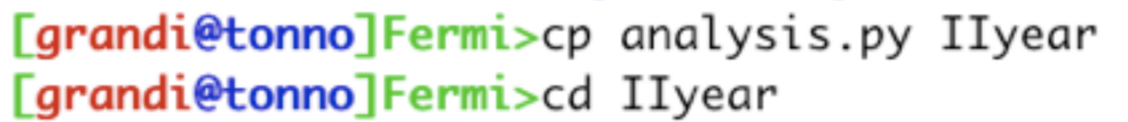
ssh -X gruppoG@login01.iasfbo.inaf.it

```
[grandi@tonno]Fermi>ls
analysis.py        ft2.fits  IIyear  Iyear  model.xml
fermi_09-31-01.sh  IIIyear   IVyear  LC
[grandi@tonno]Fermi>
```

The likelihood analysis of the target has to be repeated for each year

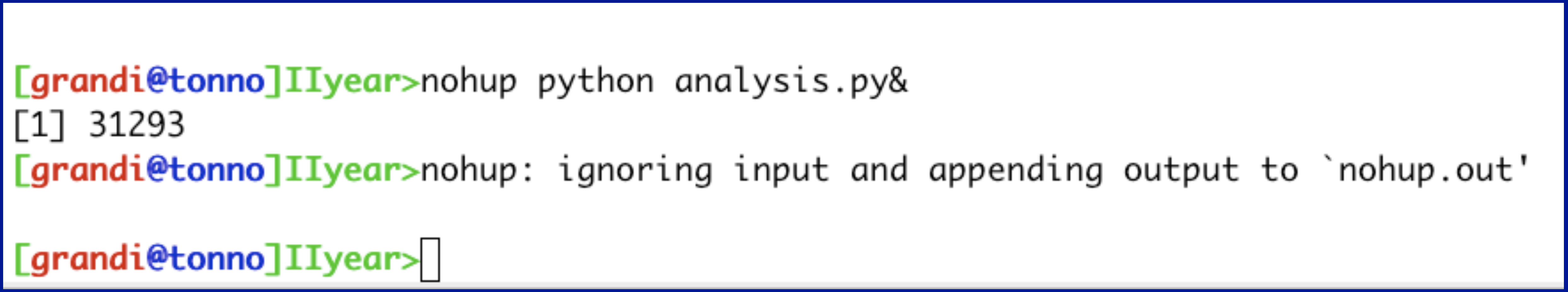


```
[grandi@tonno]Fermi>sh fermi_09-31-01.sh
[grandi@tonno]Fermi>cd IIyear/
[grandi@tonno]IIyear>ls
expCube_IIyear.fits  ft1_IIyear.fits
[grandi@tonno]IIyear>
```



```
[grandi@tonno]Fermi>cp analysis.py IIyear
[grandi@tonno]Fermi>cd IIyear
```

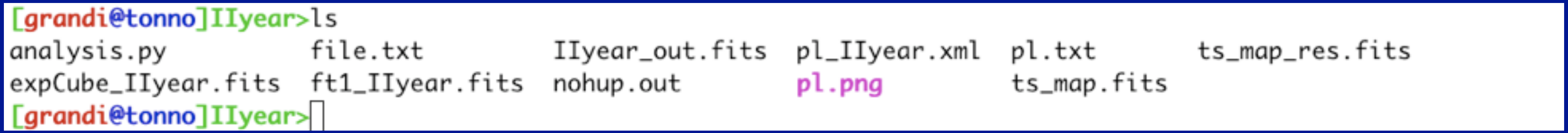
open analysis.py and work on it then run python.py ...



```
[grandi@tonno]IIyear>nohup python analysis.py&
[1] 31293
[grandi@tonno]IIyear>nohup: ignoring input and appending output to `nohup.out'

[grandi@tonno]IIyear>
```

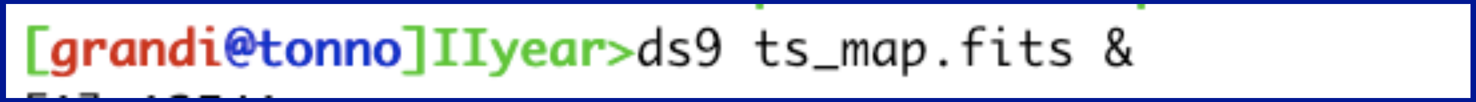
After a while you get the results



```
[grandi@tonno]IIyear>ls
analysis.py          file.txt          IIyear_out.fits  pl_IIyear.xml  pl.txt        ts_map_res.fits
expCube_IIyear.fits  ft1_IIyear.fits   nohup.out        pl.png         ts_map.fits
[grandi@tonno]IIyear>
```

```
[grandi@tonno]IIyear>gimp pl.png
```

to plot the spectrum

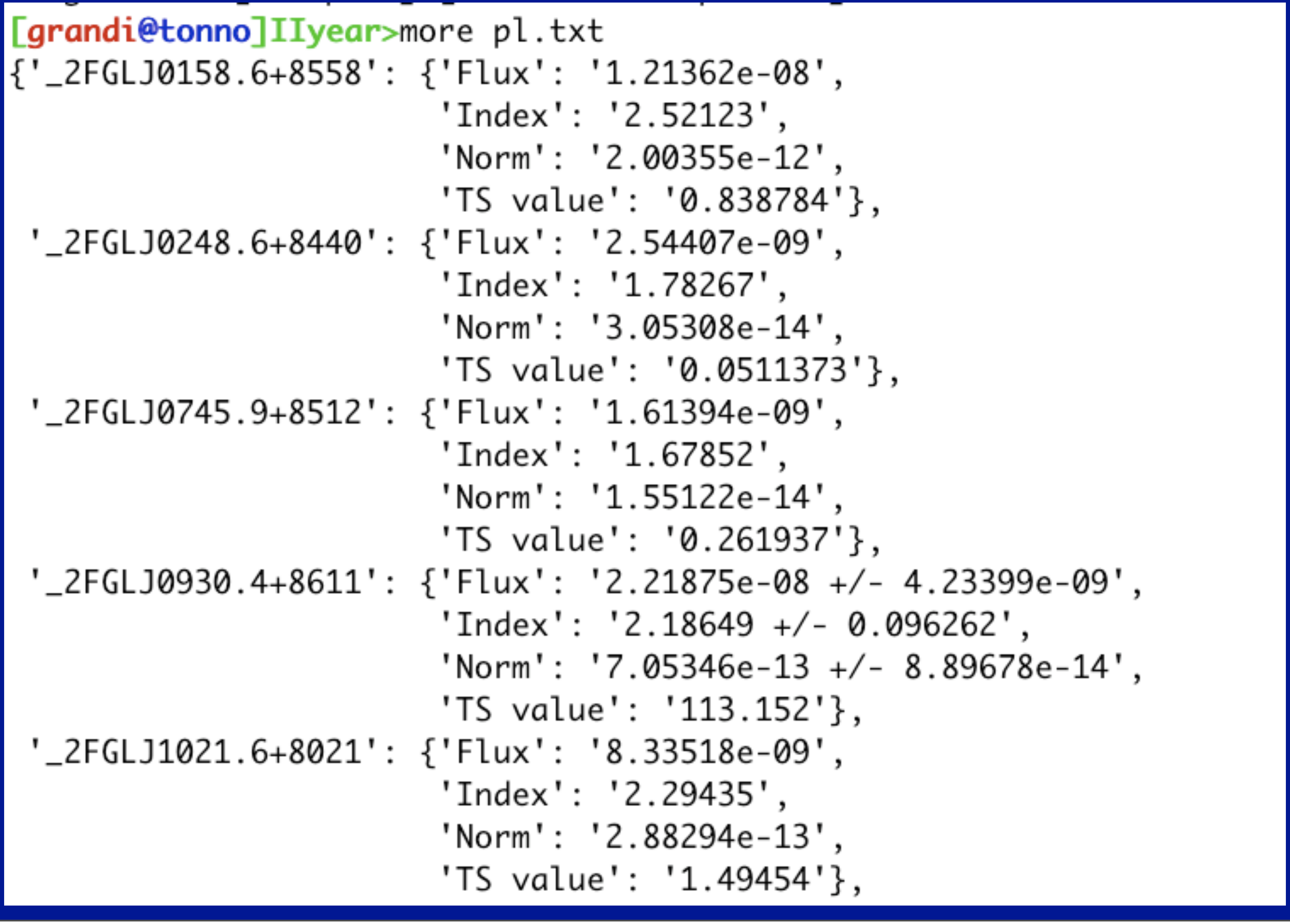


```
[grandi@tonno]IIyear>ds9 ts_map.fits &
```

to explore the TS image

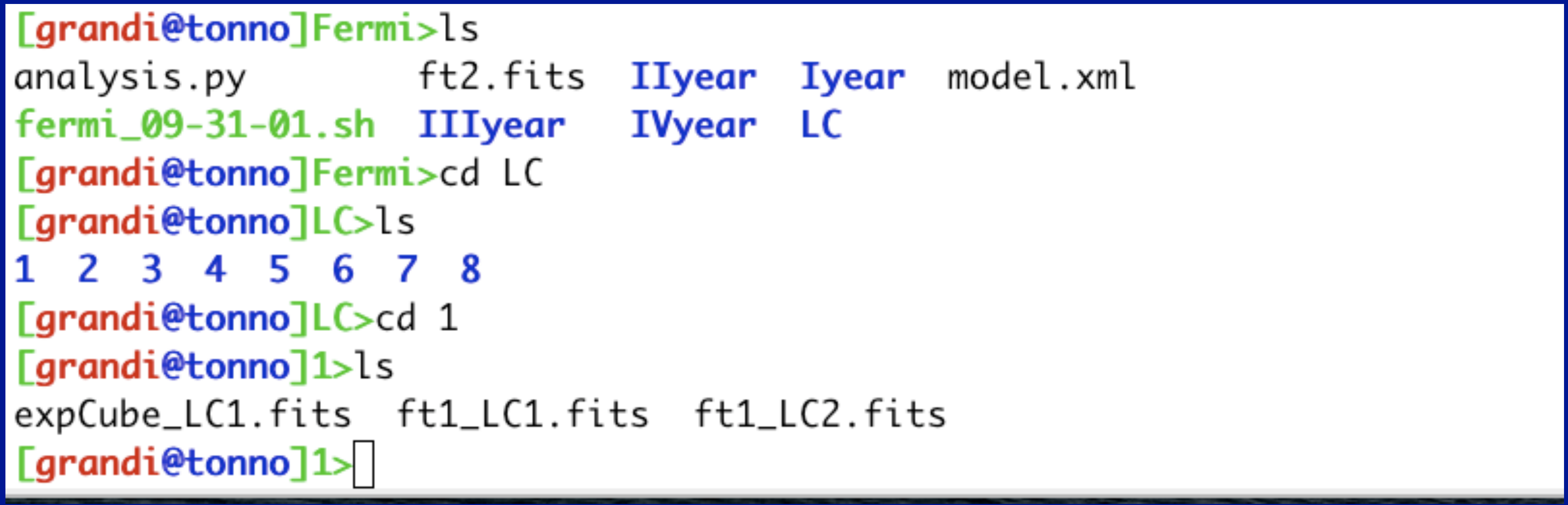
```
[grandi@tonno]Ilyear>more file.txt
Using gti from expCube_Ilyear.fits
loaded LivetimeCube expCube_Ilyear.fits
.....set Data theta cut at 66.4 deg
loading 1 FT1 file(s) ft1_Ilyear.fits...ft1_Ilyear.fits
selecting event_class 0
.....saving binfile Ilyear_out.fits for subsequent use
.....loading binfile Ilyear_out.fits ... found 24 bands, energies 100-100000 MeV
.....setting up point sources (31 in ROI)... done!
.....setting up diffuse/extended backgrounds for 24 bands...
.......... gal_2yearp7v6_v0 ...convolving band  6/24
 ...convolving band 12/24
 ...convolving band 18/24
 ...convolving band 24/24
.......... iso_p7v6source ...convolving band  6/24
 ...convolving band 12/24
 ...convolving band 18/24
 ...convolving band 24/24
.....performing likelihood maximization... Function value at minimum: -34273.364
Attempting to invert full hessian...
1.60634703985e-08   FLUX
103.636723875  TS
```

pl.txt contains the fit results of all the sources in the ROI



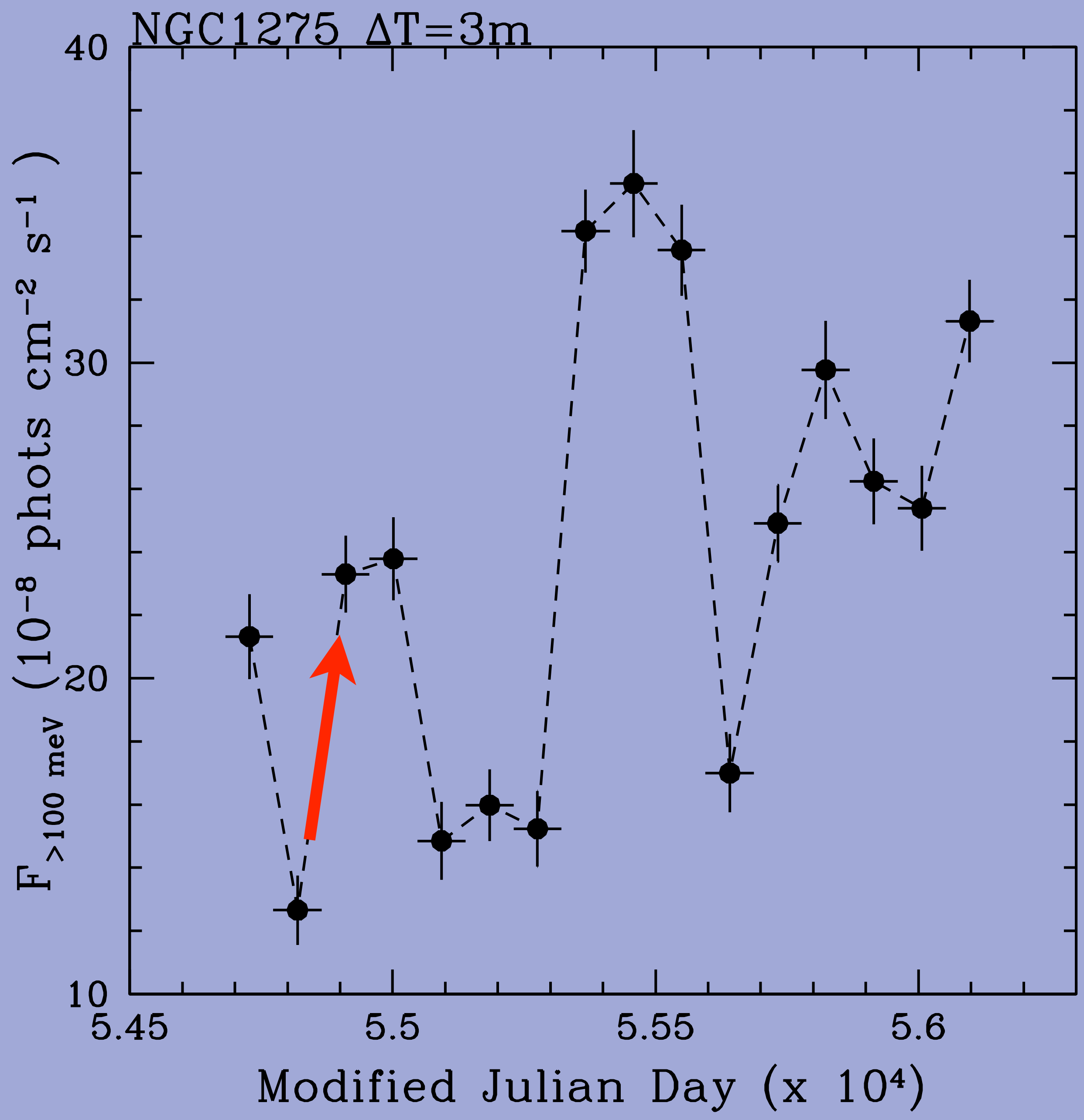
```
[grandi@tonno]IIyear>more pl.txt
{'_2FGLJ0158.6+8558': {'Flux': '1.21362e-08',
                       'Index': '2.52123',
                       'Norm': '2.00355e-12',
                       'TS value': '0.838784'},
 '_2FGLJ0248.6+8440': {'Flux': '2.54407e-09',
                       'Index': '1.78267',
                       'Norm': '3.05308e-14',
                       'TS value': '0.0511373'},
 '_2FGLJ0745.9+8512': {'Flux': '1.61394e-09',
                       'Index': '1.67852',
                       'Norm': '1.55122e-14',
                       'TS value': '0.261937'},
 '_2FGLJ0930.4+8611': {'Flux': '2.21875e-08 +/- 4.23399e-09',
                       'Index': '2.18649 +/- 0.096262',
                       'Norm': '7.05346e-13 +/- 8.89678e-14',
                       'TS value': '113.152'},
 '_2FGLJ1021.6+8021': {'Flux': '8.33518e-09',
                       'Index': '2.29435',
                       'Norm': '2.88294e-13',
                       'TS value': '1.49454'},
```

Light Curve bin time = 6 months



```
[grandi@tonno]Fermi>ls
analysis.py        ft2.fits   IIyear  Iyear  model.xml
fermi_09-31-01.sh  IIIyear    IVyear  LC
[grandi@tonno]Fermi>cd LC
[grandi@tonno]LC>ls
1  2  3  4  5  6  7  8
[grandi@tonno]LC>cd 1
[grandi@tonno]1>ls
expCube_LC1.fits  ft1_LC1.fits  ft1_LC2.fits
[grandi@tonno]1>
```

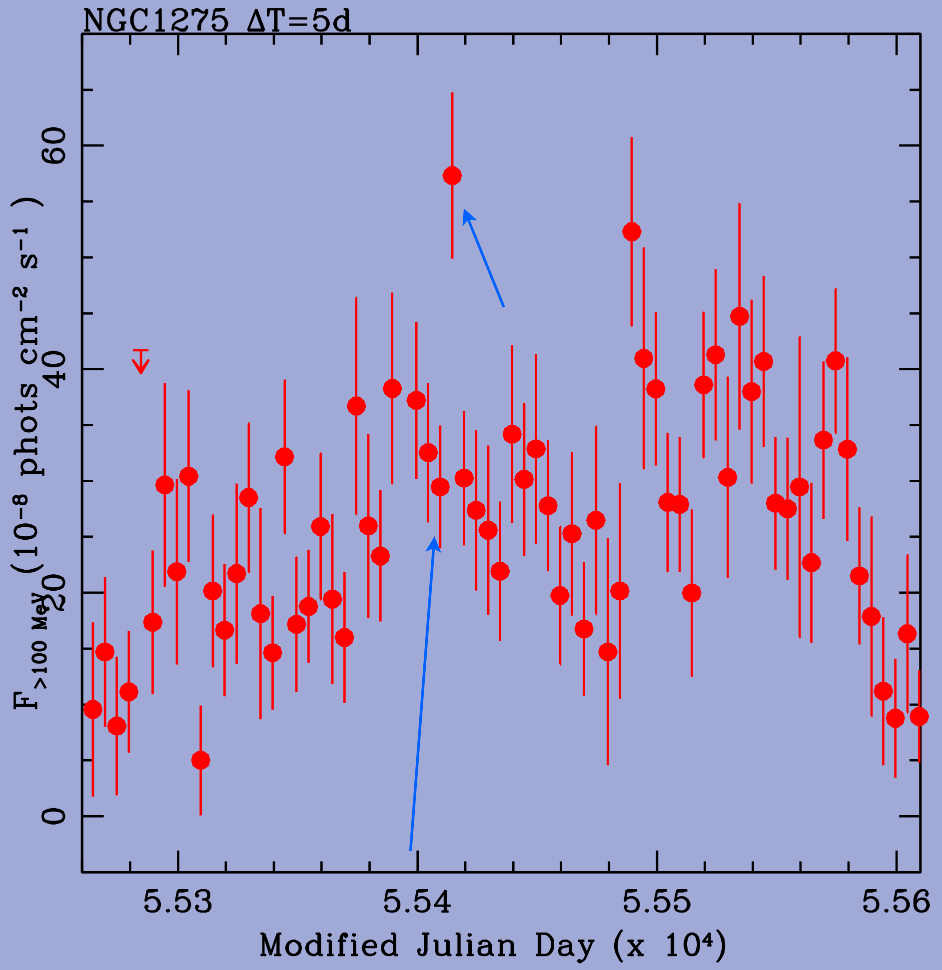
Copy the analysis.py file in each subdirectory (1,2,3,..) of the LC directory, fix the spectral slopes of each source and perform the analysis in each time interval copy the analysis.py file in each subdirectory (1,2,3,..) of the LC directory, fix the spectral slopes of each source and perform the analysis in each time interval



The source doubles its flux in about 6 months (Δ T) .

Un upper limit on the dimension of the emitting region is

$$R < c\,\Delta T\,\delta/(1+z)$$



The Doppler Factor $\delta(\beta, \theta)$ is the key parameter

$$\boxed{\delta = [\gamma(1 - \beta cos\theta)]^{-1}}$$

$$\left\{\begin{array}{l} \beta = v/c \text{ is the bulk velocity} \\ \gamma = \sqrt{(1 - \beta^2)} \text{ is the Lorentz factor} \\ \theta \text{ is the angle between the jet axis and the line of sight} \end{array}\right.$$

The Doppler factor relates intrinsic and observed flux for a moving source at relativistic speed $v = \beta$ c.

For an **intrinsic** power law spectrum: $F'(\nu') = K(\nu')^{-\alpha}$ the **observed** flux density is

$$F_\nu(\nu) = \delta^{3+\alpha} F'_{\nu'}(\nu)$$

$$\Delta t = \Delta t' / \delta$$