



Fermi LAT Data Exploration

Aous Abdo

< Aous.Abdo@nrl.navy.mil >

National Academy of Sciences &

Naval Research Laboratory

Washington DC



Overview

- ❖ In this part we will learn how to explore the LAT data:
 1. We will learn how to make counts maps with gtbin
 - Overlay 1FGL source catalogues
 2. Make light curves
 3. Obtain energy spectra
 4. Look at the exposure maps



Counts Maps

- ❖ Now that we have a file that is ready to be analyzed the first thing we will do is to look at the region that we extracted.
- ❖ This is a good practice in all types of analyses since it gives you an idea about sources in the region and how complex the region is.
- ❖ We will use the Science Tool `gtbin` to do this.



gtbin

- ❖ gtbin can be used with the LAT data to:
 - Make raw counts maps
 - Make quick-look light curve
 - Obtain spectra
- ❖ gtbin products should be considered as a first step and to get a rough idea about the source in question.
- ❖ This is true since gtbin does NOT take into account things like
 - Exposure correction
 - Instrument response



Counts Maps With gtbin

```
$ gtbin
This is gtbin version v2r2p3
Type of output file (CCUBE|CMAP|LC|PHA1|PHA2) [ ]CMAP
Event data file name [ ]FT1_gtmktime_sorted.fits
Output file name [ ]FT1_gtmktime_sorted_cmap.fits
Spacecraft data file name [ ]
Size of the X axis in pixels [ ]200
Size of the Y axis in pixels [ ]200
Image scale (in degrees/pixel) [ ]0.1
Coordinate system (CEL - celestial, GAL -galactic) (CEL|GAL) [ ]CEL
First coordinate of image center in degrees (RA or galactic l) [ ]1.7565
Second coordinate of image center in degrees (DEC or galactic b) [ ]73.05225
Rotation angle of image axis, in degrees [ ]0
Projection method e.g. AIT|ARC|CAR|GLS|MER|NCP|SIN|STG|TAN: [ ]AIT
```

we select cmap for counts maps

no spacecraft file is required

center of our cmap is the position of our source

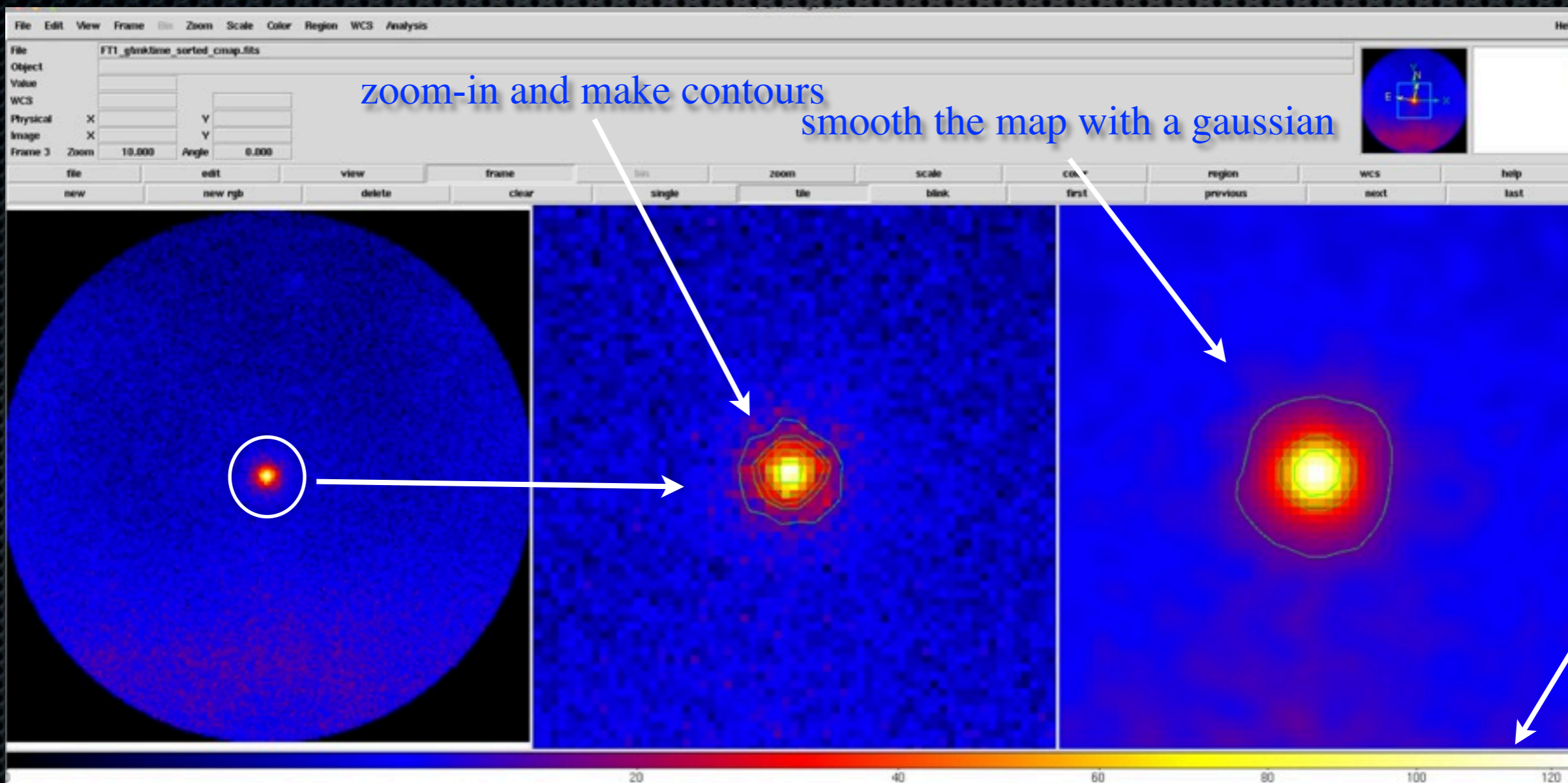
- ❖ size of the given axis in pixels = ROI diameter x Image scale
- ❖ We wanted to bin out image in 0.1 degrees/pixel so we selected $(2*10)/0.1 = 200$ for the sizes of our axes



Counts Maps With gtbin

- ❖ Now we use ds9 to view the counts map file

```
$ds9 -cmap b -scale sqrt FT1_gtmktime_sorted_cmap.fits
```





Overlaying 1FGL Sources



- ❖ One can overlay a number of catalogues on the counts map.
- ❖ We will overlay the 1FGL catalogue (`g11_psc_v02_ellipses.reg`) sources on our image.
- ❖ <http://fermi.gsfc.nasa.gov/ssc/data/access/lat/>

FSSC: Data » Data Access

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

Analysis Forum | Coord. | Data Catalog | Science Groups | Time | Workbook | CLAST

Problem loading page | Standards for High-L | gmsktime - Google Se | Download F | (Unlisted)

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Currently Available Data Products

The Fermi data released to the scientific community is governed by the [data policy](#). The released instrument data for the GBM, along with LAT source lists, can be accessed through the [Browse interface specific to Fermi](#). LAT photon data can be accessed through the LAT data server.

The FITS files can also be downloaded from the Fermi FTP site. The file version number is the 'xx' in the characters before the extension in each filename; you should keep track of the version numbers of files you analyze since the instrument teams may update them.

- LAT Photon and Extended Data
 - LAT Data Server
- LAT Data (high-level products only)
 - LAT Monitored Source List
 - LAT Monitored Source List Light Curves
 - LAT Pulsar Ephemerides
 - LAT Burst Catalog
 - **LAT 1-year Point Source Catalog**
 - LAT Bright Source List
 - LAT Background Models
- GBM Data
 - GBM Trigger Catalog
 - GBM Burst Catalog
 - GBM Daily Data

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Data

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LAT 1-year Point Source Catalog

The Fermi Gamma-ray Space Telescope (Fermi) Large Area Telescope (LAT) is a successor to EGRET, with greatly improved sensitivity, resolution, and energy range. This web page presents the first full catalog of LAT sources, based on the first eleven months of survey data. For a full explanation about the catalog and its construction see the [LAT 1-year Catalog Paper preprint](#).

The source designation is 1FGL JHHMM.m+DDMM(c) where the 1 refers to the first catalog (others are planned for years 2 and 5) and FGL represents Fermi Gamma-ray LAT. The optional "c" designator is explained in the caveats below.

LAT Catalog Data Products

The LAT 1-year Point Source Catalog is currently available as a FITS file and as an XML model file to be used for data analysis within the Fermi Science Tools. It has also been made available as a BROWSE table. Supporting tools and information have also been provided and are linked below.

It is important that all users of this catalog review the caveats listed below the catalog links. These describe the content of the catalog at a high level, as well as some cautions for the user.

- [LAT 1-year Point Source Catalog \(FITS format\)](#)
- [New LAT 1-year catalog DS9 region files \(crosses, ellipses\)](#)
- [LAT 1-year Point Source Catalog \(BROWSE table\)](#)
- [LAT 1-year Catalog Paper preprint](#)
- [LAT 1-year Catalog column descriptions](#)
- [XML Model File for LAT 1-year Catalog](#)
- [Python tool to convert FITS information to XML \(User contributed\)](#)

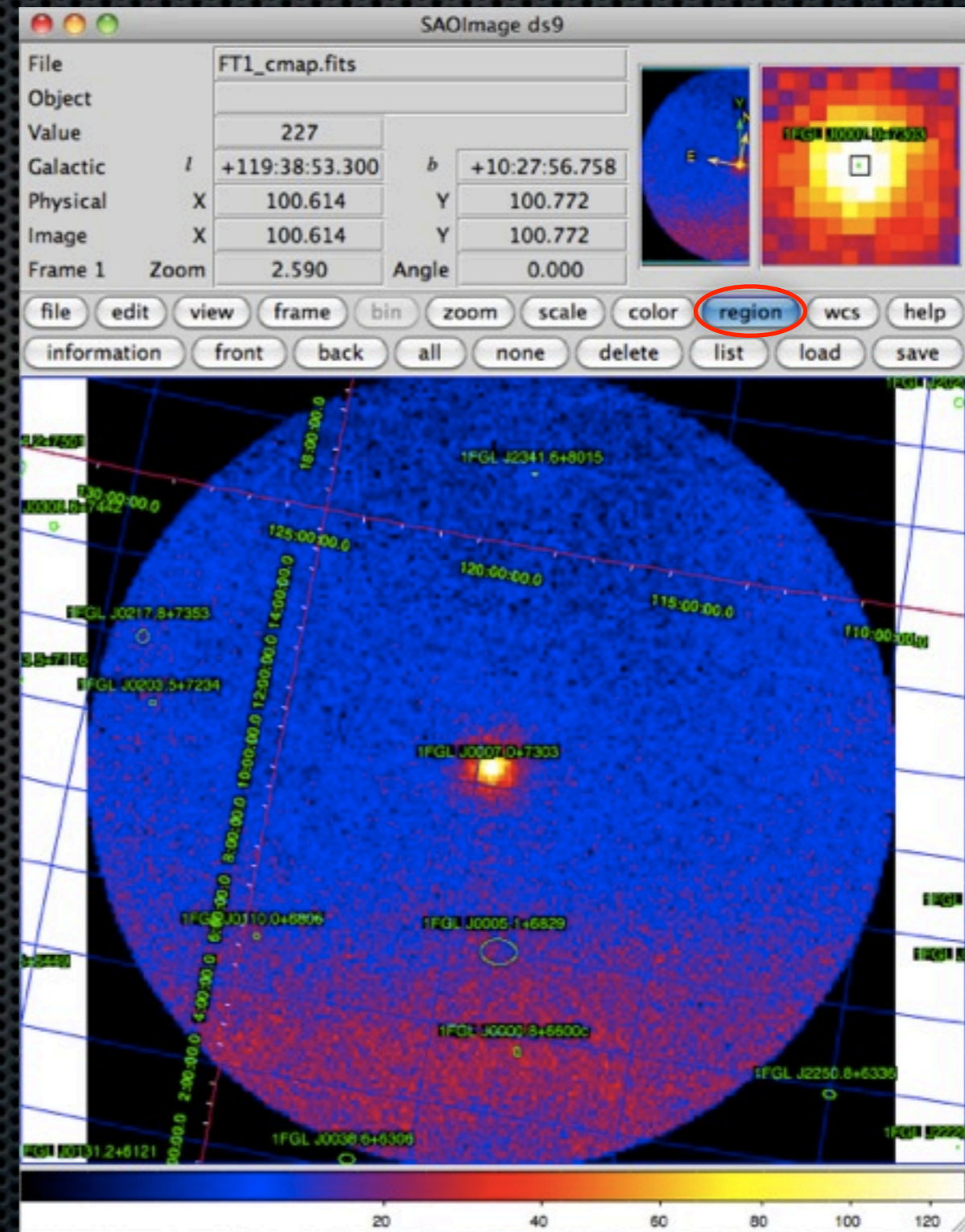
LAT Catalog Caveats

Some work on the analysis procedures for data from Fermi LAT is still in progress. In particular, we emphasize several caveats for use of this catalog:



Overlaying 1FGL Sources

- ❖ Not many sources in the ROI (~6 sources)
- ❖ Relatively uncomplicated region. Will be easier and faster to to run the likelihood analysis





Light Curves With gtbin

- ❖ We will make a quick light curve using gtbin.
- ❖ We will look at the light curve of the CTA1 pulsar during the last week of the observation file we downloaded.
- ❖ We will bin the data in 1-day time bins

select LC for light curves

```
$ gtbin
This is gtbin version ScienceTools-v9r15p2-fssc-20090806
Type of output file (CCUBE|CMAP|LC|PHA1|PHA2) [ ]LC
Event data file name[] FT1_gtmktime_292937396-293542196MET.fits
Output file name[]FT1_gtmktime_292937396-293542196MET_LC.fits
Spacecraft data file name[]L100422151847E0D2F37E30_SC00.fits
Algorithm for defining time bins (FILE|LIN|SNR) [ ]LIN
Start value for first time bin in MET[] 292937396
Stop value for last time bin in MET[]293542196
Width of linearly uniform time bins in seconds[]86400
```

linear time bins

seconds in 1 day



Light Curves With gtbin

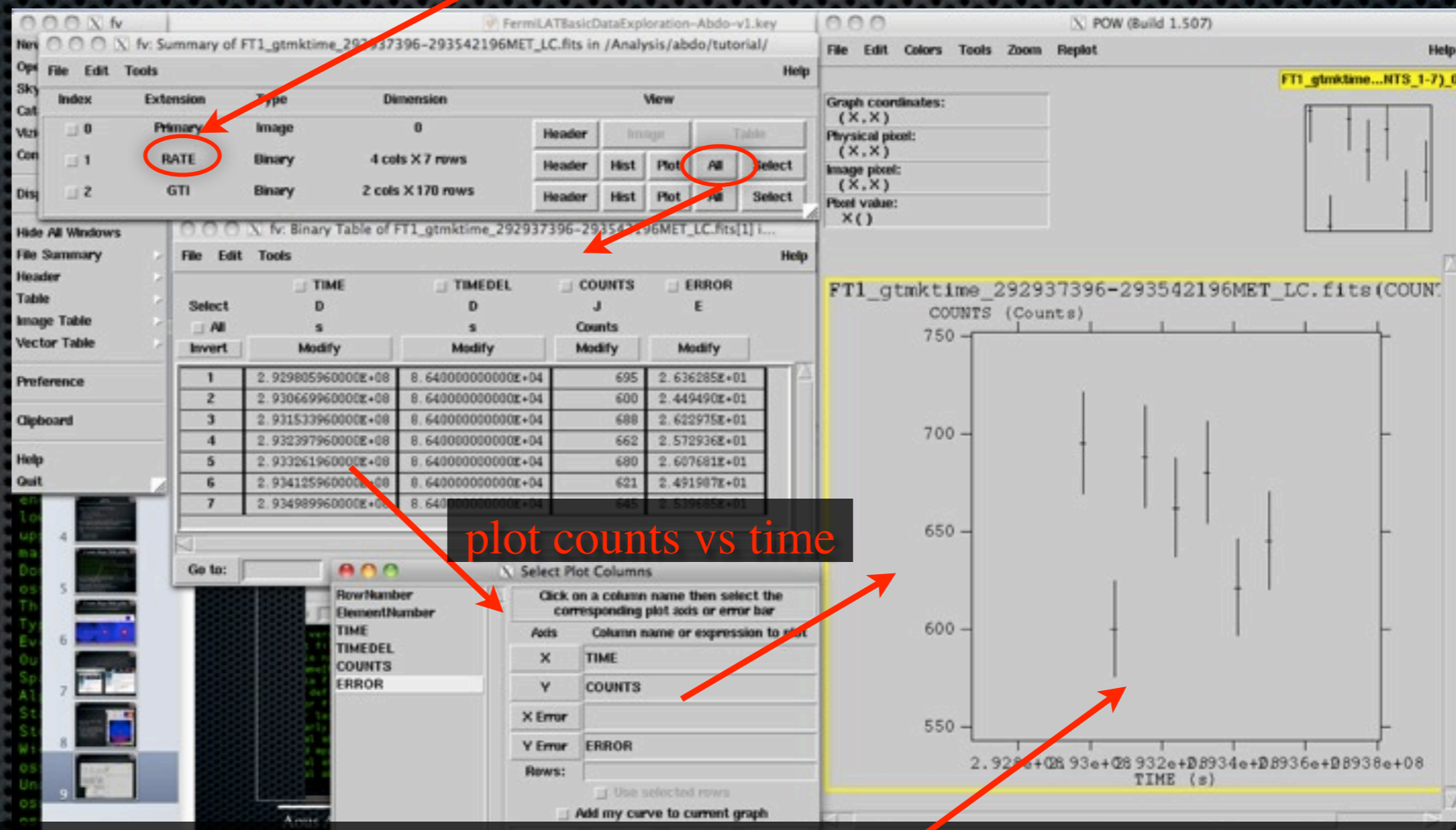
❖ The output file has the extension “RATE” which gives counts as a function of time

❖ To make a plot of the light curve click on the “All” button under the RATE extension

❖ TIME goes on the x-axis

❖ COUNTS on the y-axis

❖ And ERROR on the y-axis error



remember this does not have exposure correction and instrument response



Energy Spectra With gtbin



- ❖ We will look at the spectra of CTA1 using gtbin
- ❖ gtbin can produce:
 - Energy spectrum binned in energy (PHA1)
 - Energy spectra binned in energy for a series of time ranges (PHA2)

```
$ gtbin
This is gtbin version ScienceTools-v9r15p2-fssc-20090808
Type of output file (CCUBE|CMAP|LC|PHA1|PHA2) [LC] PHA1
Event data file name[FT1_gtmktime_292937396-293542196MET.fits]
Output file name[] FT1_gtmktime_292937396-293542196MET_PHA1.fits
Spacecraft data file name[L100422151847E0D2F37E30_SC00.fits]
Algorithm for defining energy bins (FILE|LIN|LOG) [LOG]
Start value for first energy bin in MeV[30] 100
Stop value for last energy bin in MeV[200000] 300000
Number of logarithmically uniform energy bins[0] 20
```

select PHA1

logarithmically-spaced
energy bins

number of energy bins



Energy Spectra with gtbin



- ❖ Output file:
- ❖ SPECTRUM extension:
 - ❖ CHANNEL : Energy bin number
 - ❖ COUNTS: # of photons in that bin
 - ❖ STAT_ERR: statistical error
- ❖ EBOUNDS extension:
 - ❖ Minimum and maximum energy for energy bin

The screenshot shows three windows from the FITS viewer. The top window displays the FITS file structure with the following table:

Index	Extension	Type	Dimension	View
<input type="checkbox"/> 0	Primary	Image	0	Header Image Table
<input type="checkbox"/> 1	SPECTRUM	Binary	3 cols X 20 rows	Header Hist Plot All Select
<input type="checkbox"/> 2	EBOUNDS	Binary	3 cols X 20 rows	Header Hist Plot All Select
<input type="checkbox"/> 3	GTI	Binary	2 cols X 170 rows	Header Hist Plot All Select

The middle window shows the SPECTRUM extension with the following table:

Select	CHANNEL	COUNTS	STAT_ERR
I	J	E	
<input type="checkbox"/> All		Counts	
Invert	Modify	Modify	Modify
1	1	320	1.788854E+01
2	2	748	2.734959E+01
3	3	941	3.067572E+01
4	4	808	2.842534E+01
5	5	592	2.433105E+01
6	6	471	2.170253E+01
7	7	293	1.711724E+01
8	8	216	1.469694E+01
9	9	98	9.899495E+00
10	10	54	7.348469E+00
11	11	24	4.898980E+00
12	12	13	3.605551E+00
13	13	5	2.397916E+00
14	14	4	2.179450E+00
15	15	1	1.322876E+00
16	16	2	1.658312E+00
17	17	1	1.322876E+00
18	18	0	8.660254E-01
19	19	0	8.660254E-01
20	20	0	8.660254E-01

The right window shows the EBOUNDS extension with the following table:

Select	CHANNEL	E_MIN	E_MAX
I	E	keV	keV
<input type="checkbox"/> All			
Invert	Modify	Modify	Modify
1	1	1.000000E+05	1.492300E+05
2	2	1.492300E+05	2.226958E+05
3	3	2.226958E+05	3.323290E+05
4	4	3.323290E+05	4.959344E+05
5	5	4.959344E+05	7.400828E+05
6	6	7.400828E+05	1.104425E+06
7	7	1.104425E+06	1.648134E+06
8	8	1.648134E+06	2.459510E+06
9	9	2.459510E+06	3.670325E+06
10	10	3.670325E+06	5.477226E+06
11	11	5.477226E+06	8.173662E+06
12	12	8.173662E+06	1.219755E+07
13	13	1.219755E+07	1.820241E+07
14	14	1.820241E+07	2.716345E+07
15	15	2.716345E+07	4.053600E+07
16	16	4.053600E+07	6.049187E+07
17	17	6.049187E+07	9.027200E+07
18	18	9.027200E+07	1.347129E+08
19	19	1.347129E+08	2.010320E+08
20	20	2.010320E+08	3.000000E+08



Energy Spectra with gtbin



❖ To make a plot of the energy spectrum use the plot button under the SPECTRUM extension

❖ CHANNEL goes on the x-axis

❖ COUNTS on the y

❖ And STAT_ERR on the y-axis error

The screenshot shows the 'Summary of FIT' window with the following table:

Index	Extension	Type	Dimension	View
<input type="checkbox"/> 0	Primary	Image	0	Header Image Table
<input type="checkbox"/> 1	SPECTRUM	Binary	3 cols X 20 rows	Header Hist Plot All Select
<input type="checkbox"/> 2	EBOUNDS	Binary	3 cols X 20 rows	Header Hist Plot All Select
<input type="checkbox"/> 3	GTI	Binary	2 cols X 170 rows	Header Hist Plot All Select

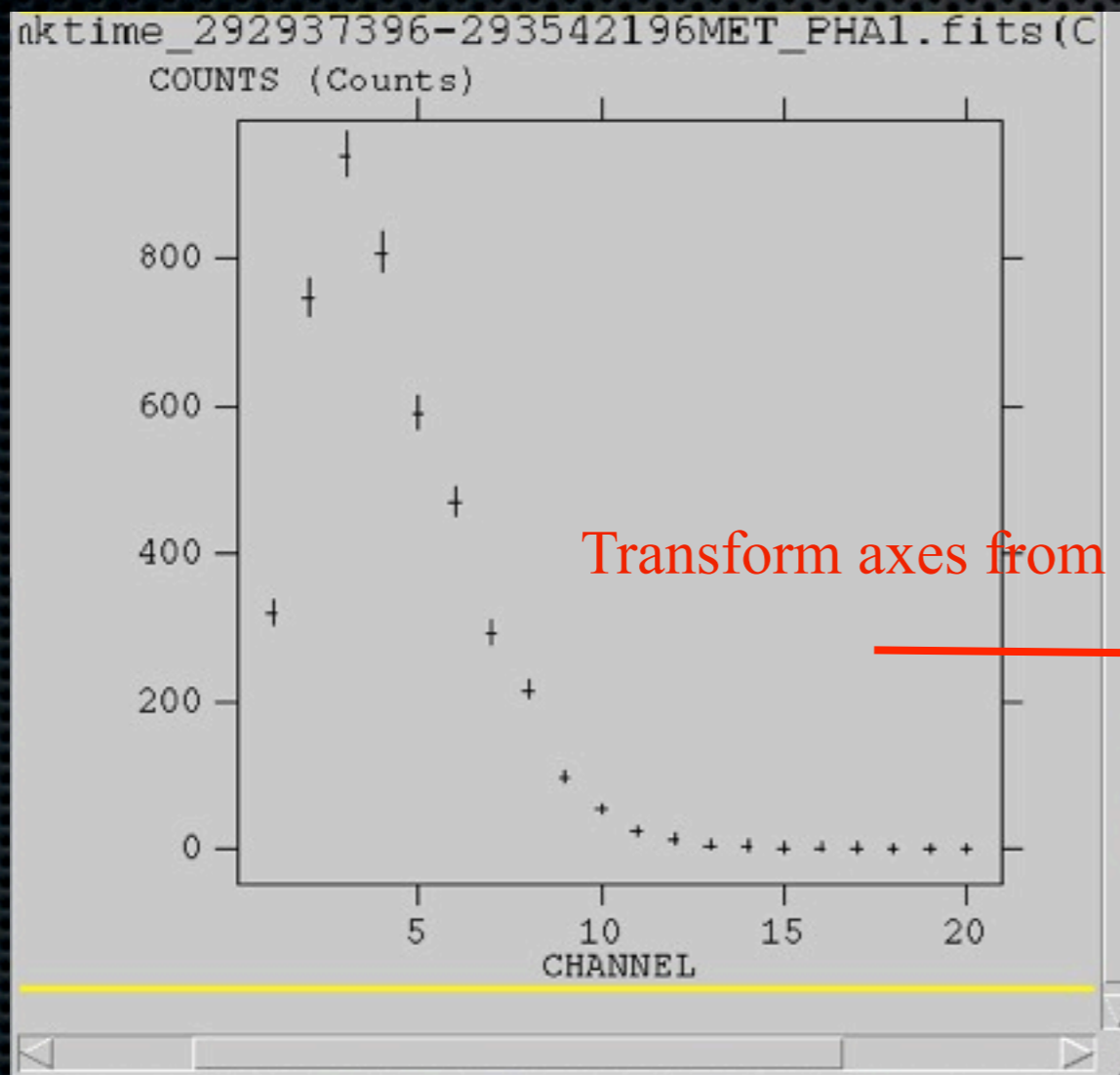
The 'Select Plot Columns' dialog box is open, showing the following configuration:

Axis	Column name or expression to plot
X	CHANNEL
Y	COUNTS
X Error	
Y Error	STAT_ERR
Rows:	

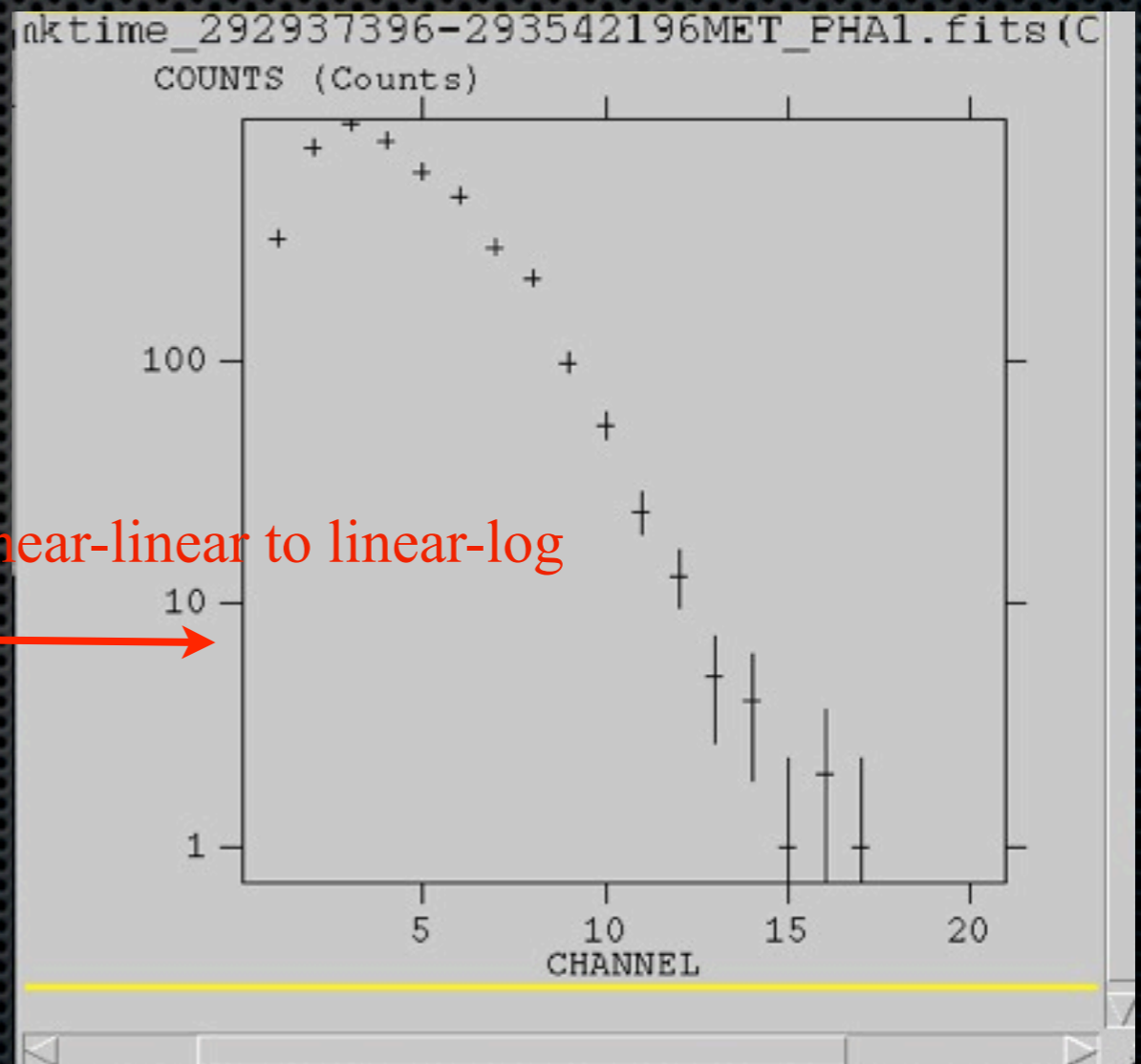
Buttons: **Plot** (circled), Clear, Close, Help



Energy Spectra with gtbin



Transform axes from linear-linear to linear-log



The spectrum measured takes into account all the sources in the 10 degree region.



Looking At The Exposure



- ❖ An exposure map simply shows how Fermi viewed the sky within some time interval.
- ❖ For this task we use:
 - gtlcube: This tool creates a livetime* cube, which is a HealPix table, covering the full sky, of the integrated livetime as a function of inclination with respect to the LAT z-axis.
 - gtexpcube: Generates exposure maps

*Livetime: The accumulated time during which the LAT is actively taking event data



gltcube

- ❖ gltcube takes a lot of time to run especially for long observations.
- ❖ We will thus look at the exposure for the last week of the observation file we downloaded. (One can use gltsum to add exposure cubes. More on this to come)

```
$ gltcube
Event data file[] FT1_gtmktime_292937396-293542196MET.fits
Spacecraft data file[] L100422151847E0D2F37E30_SC00.fits
Output file[] expCube_292937396-293542196MET.fits
Step size in cos(theta) (0.:1.) []0.025
Pixel size (degrees)[0.5] 1
Working on file
L100422151847E0D2F37E30_SC00.fits.....!
```



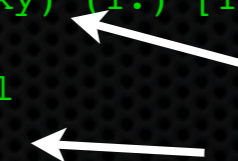

gtexpcube

```
$ gtexpcube
This is gtexpcube version N/A
Exposure cube input file name[expCube_292937396-293542196MET.fits]
FT1 events input file name[FT1_gtmktime_292937396-293542196MET.fits]
Count map input file name (NONE for manual input of map geometry)[None]
Exposure map output file name[exposure_292937396-293542196MET.fits]
Response function to use, e.g. HANDOFF, DC1F/DC1B, G25F/G25B, TestF/TestB[P6_V3_DIFFUSE]
Size of the X axis in pixels (leave at 1 for auto full sky (1:)) [1]
Size of the Y axis in pixels (leave at 1 to copy nxpix or auto full sky) (1:) [1]
Image scale (in degrees/pixel)[0.5]
Coordinate system (CEL - celestial, GAL -galactic) (CEL|GAL) [CEL] gal
First coordinate of image center in degrees (RA or galactic l)[] 0
Second coordinate of image center in degrees (DEC or galactic b)[] 0
Rotation angle of image axis, in degrees[0]
Projection method (AIT|ARC|CAR|ZEA|GLS|MER|NCP|SIN|STG|TAN) [AIT]
Start value for first energy bin[100]
Stop value for last energy bin[300000]
Number of logarithmically uniform energy bins[4]
How are energy layers computed from count map ebounds? (CENTER|EDGE) [CENTER]
Creating an Exposure object from file expCube_292937396-293542196MET.fits
Using Aeff(s)
Combining exposure from the response function(s), specified by "P6_V3_DIFFUSE":
    P6_V3_DIFFUSE::FRONT
    P6_V3_DIFFUSE::BACK
Cutoff used: 6.12303e-17
Creating an Image, will write to file exposure_292937396-293542196MET.fits
Generating layer 0 at energy 420.041 MeV  Aeff(0): 5305.39 cm^2
Generating layer 1 at energy 3108.65 MeV  Aeff(0): 7216.35 cm^2
Generating layer 2 at energy 23006.6 MeV  Aeff(0): 7986.31 cm^2
Generating layer 3 at energy 170268 MeV  Aeff(0): 7890.73 cm^2
```

IRFs: select
P6_V3_DIFFUSE



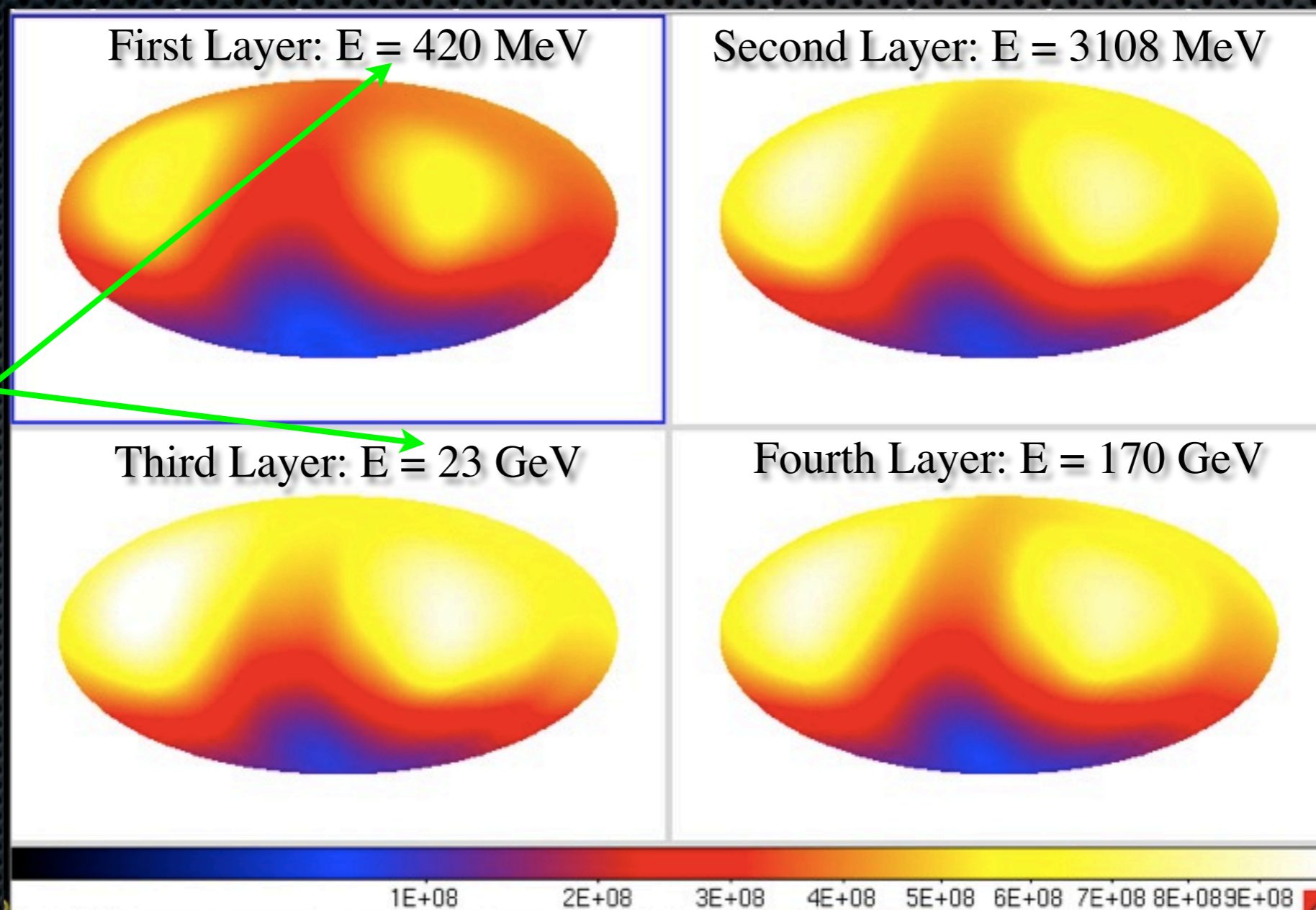
the whole sky in
Galactic coordinate



Exposure Maps

- ❖ gtxpmap produced four exposure maps for the energies shown.
- ❖ The units of these maps are $\text{cm}^2 \text{ s}$

Energies at which the exposure maps were calculated



In Galactic coordinates

Same color scale for all maps



Adding Exposure Cubes

- ❖ Generating exposure cubes with `gtlucube` can take a lot of time.
- ❖ To overcome this, we:
 - Split the event data file into smaller time bins. On the order of 4-7 days is fine.
 - run `gtlucube` on each of these files separately on the cluster to generate individual exposure cubes.
 - use `gtlsum` to add up all these cubes.
 - Note that `gtlucube` adds two files at a time so one would need to script the addition of large number of cubes.

```
$ gtlsum  
Livetime cube 1 or list of files[] expCube0.fits  
Livetime cube 2[none] expCube1.fits  
Output file [] : expCube.fits
```