Fermi LAT Data Exploration

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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 <u>NOT</u> 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

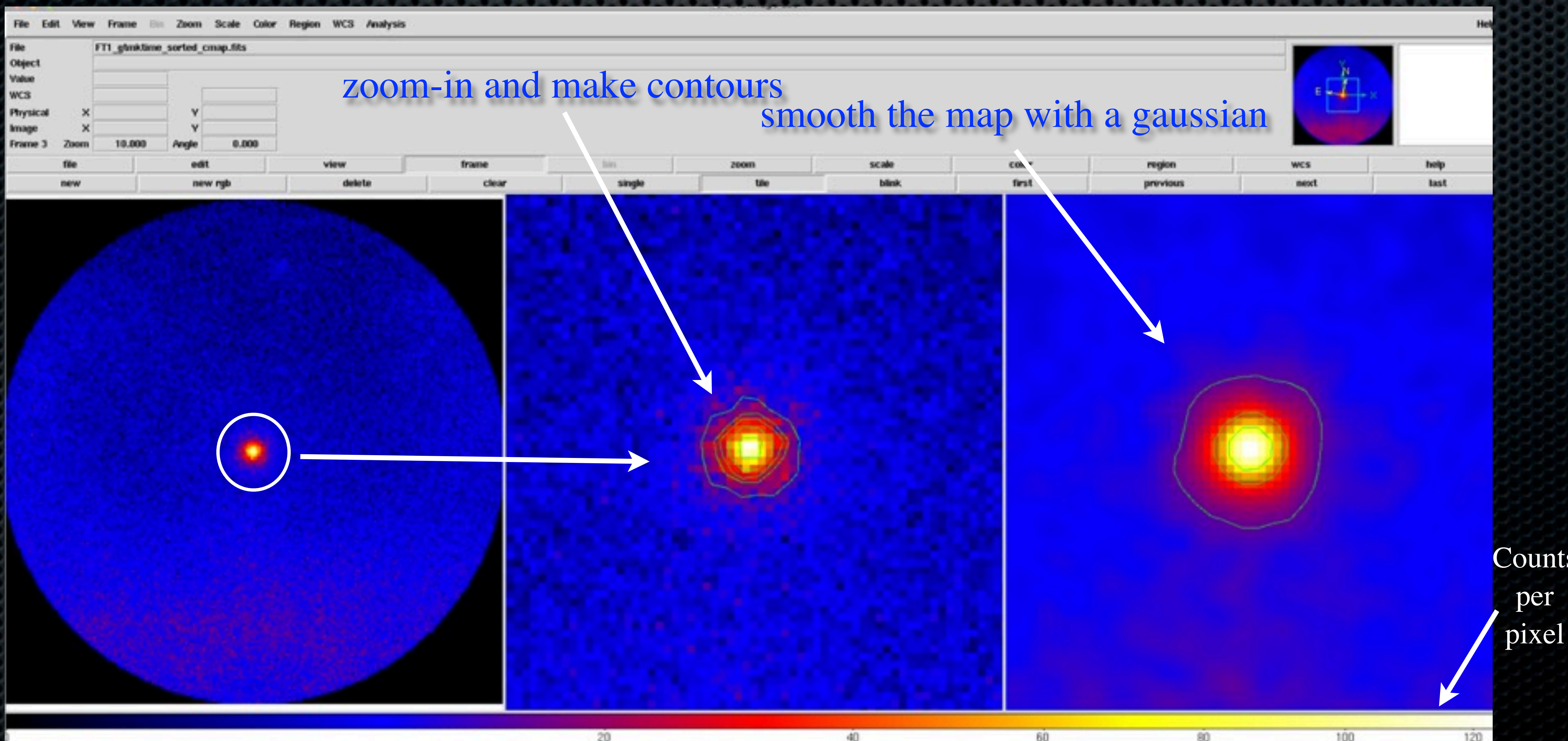
center of our cmap is the position of our source

- size of the given axis in pixels = ROI diamater 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

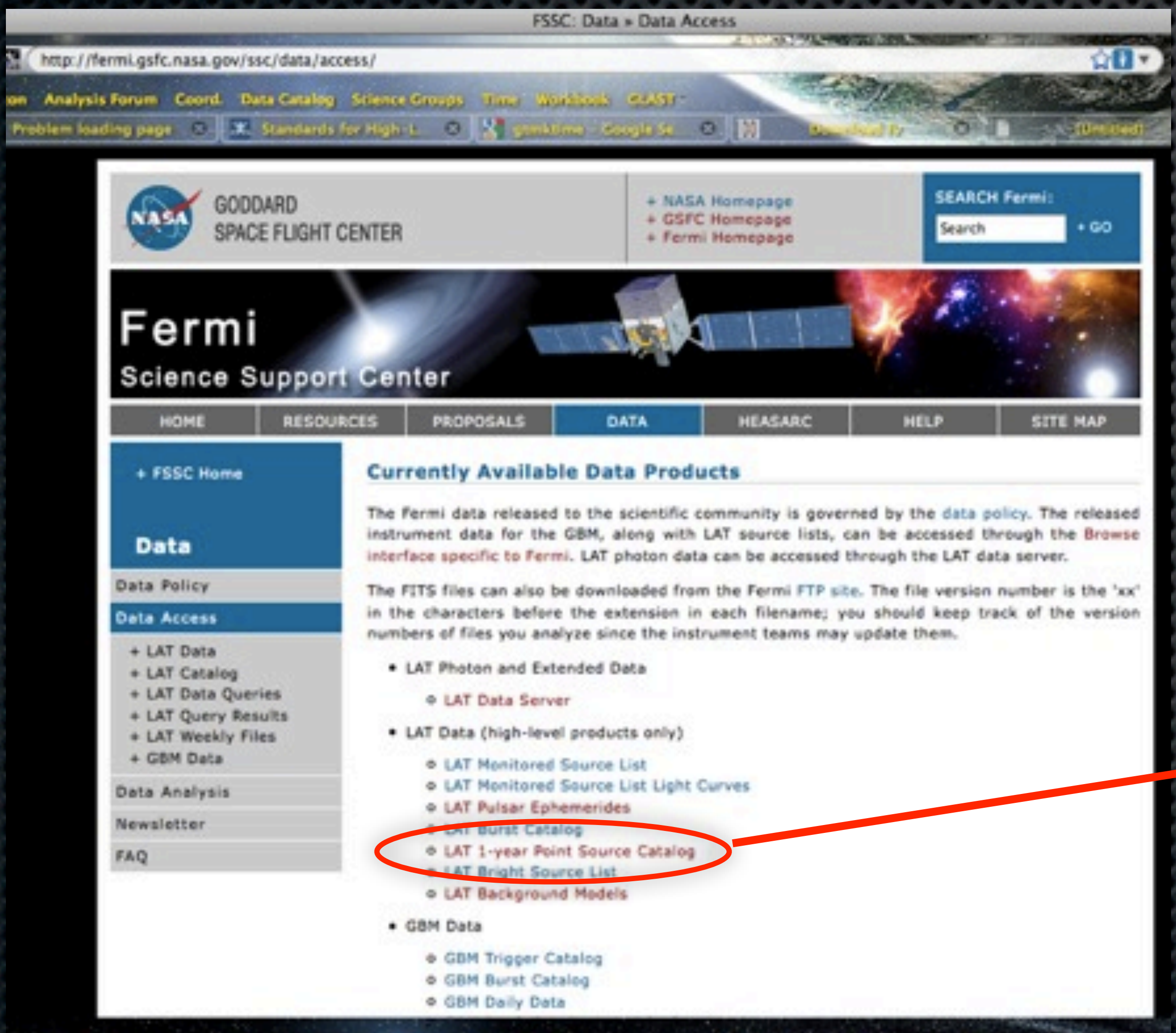
- Now we use ds9 to view the counts map file

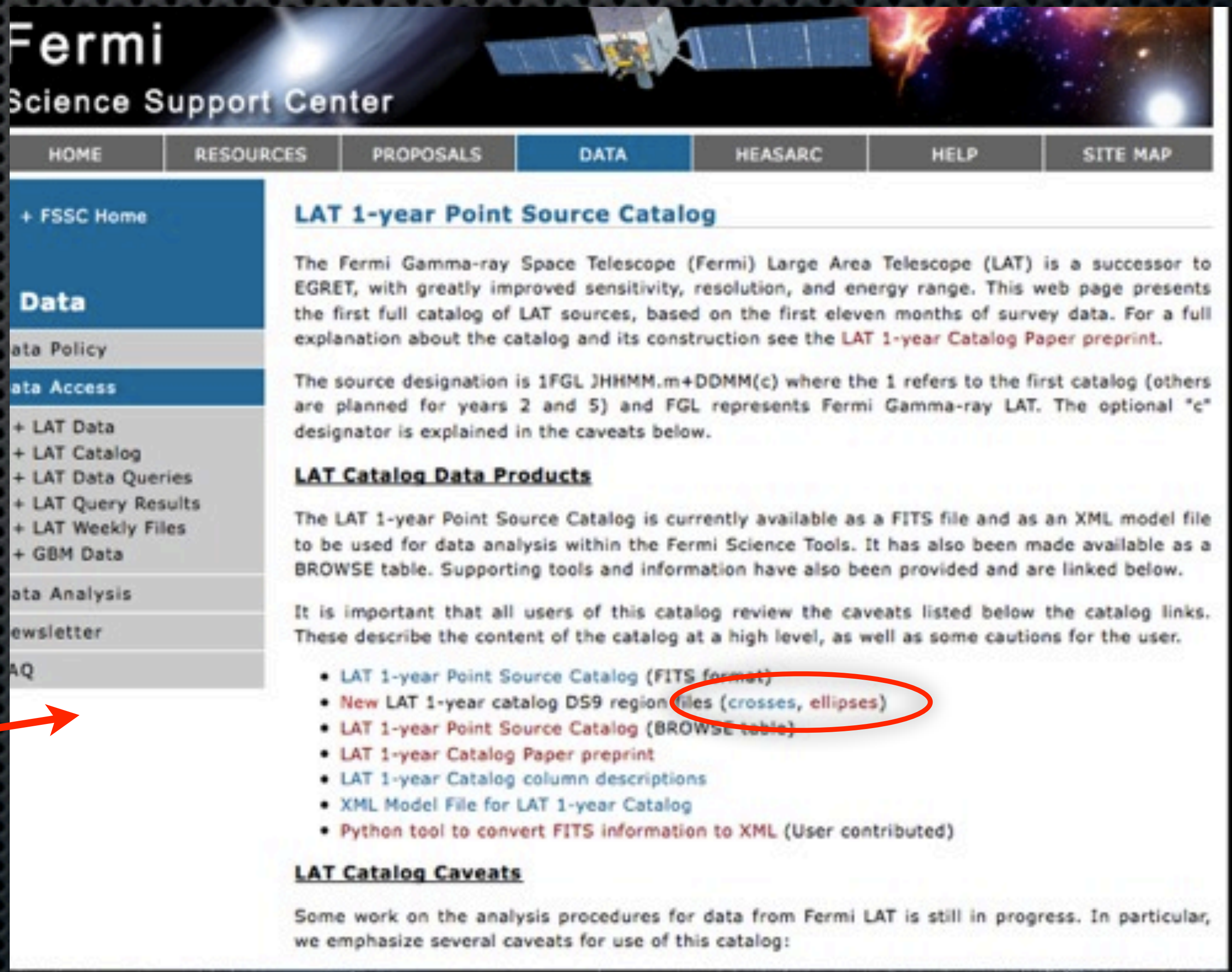
```
$ds9 -cmap b -scale sqrt FT1_gtmktime_sorted_cmap.fits
```



Overlaying 1FGL Sources

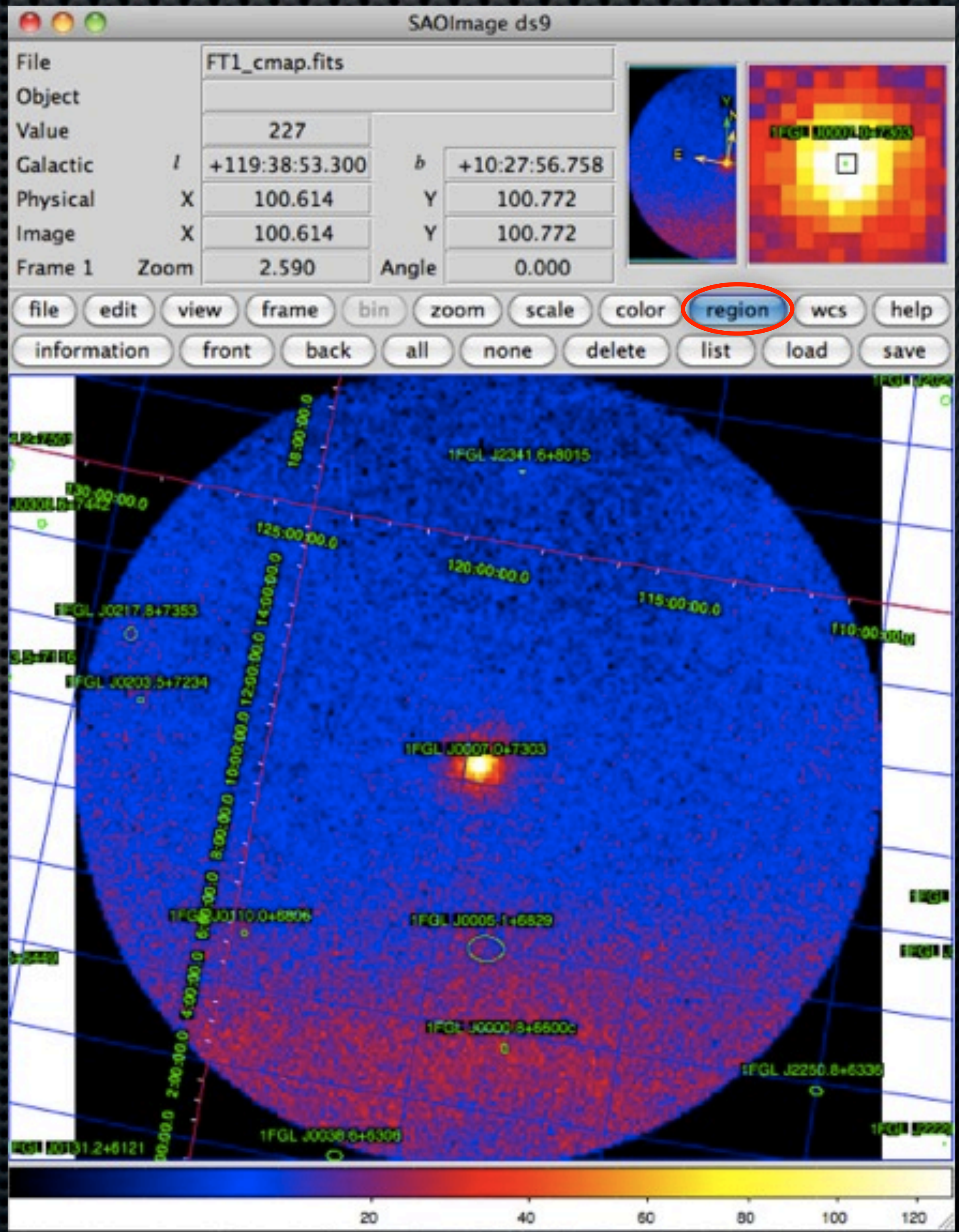
- One can overlay a number of catalogues on the counts map.
- We will overlay the 1FGL catalogue (`gll_psc_v02_ellipses.reg`) sources on our image.
- <http://fermi.gsfc.nasa.gov/ssc/data/access/lat/>





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-20090808
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

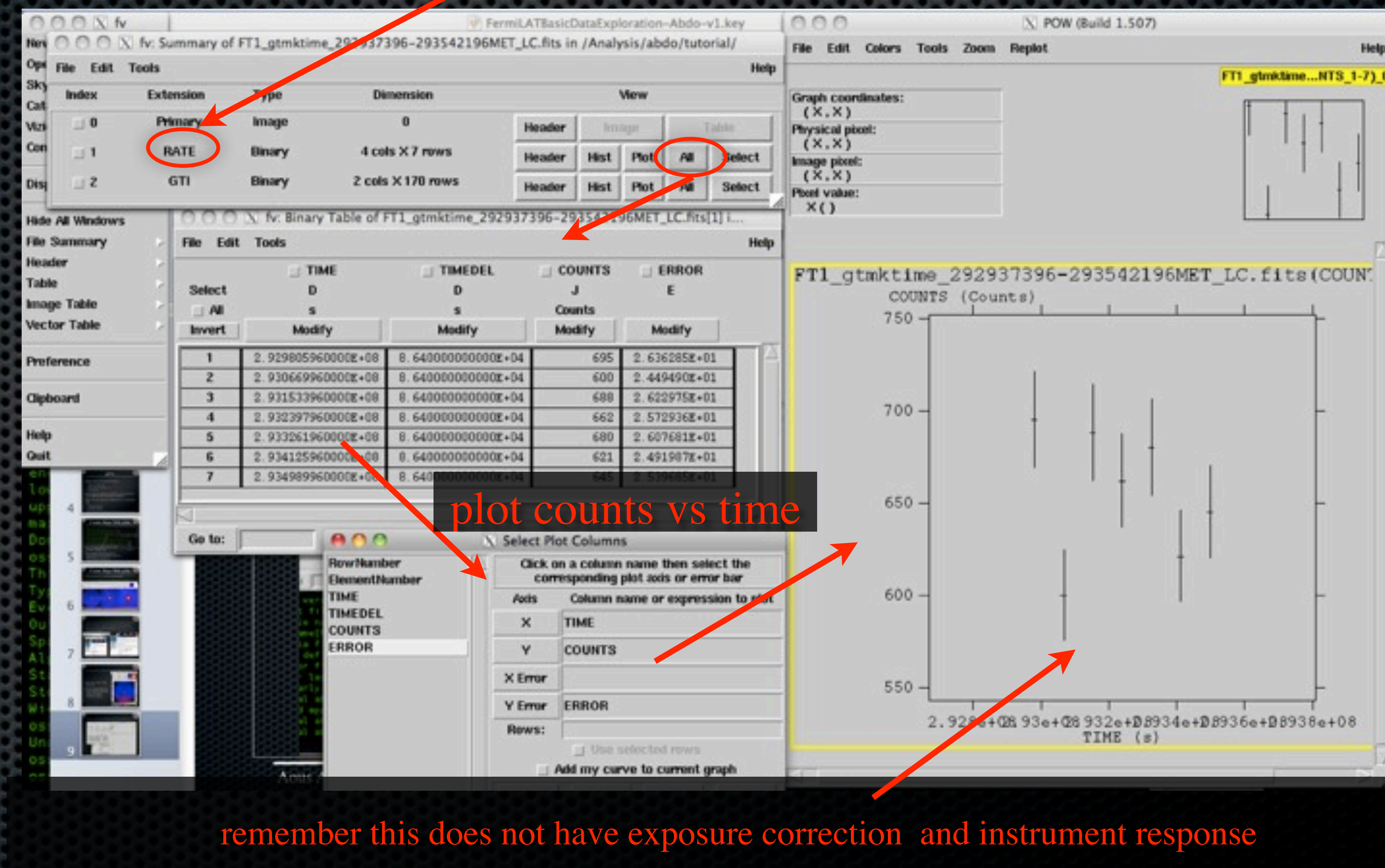
- The output file has the extension “RATE” which gives counts as a function of time

❖ 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

❖ And ERROR on the y-axis error



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)

select PHA1

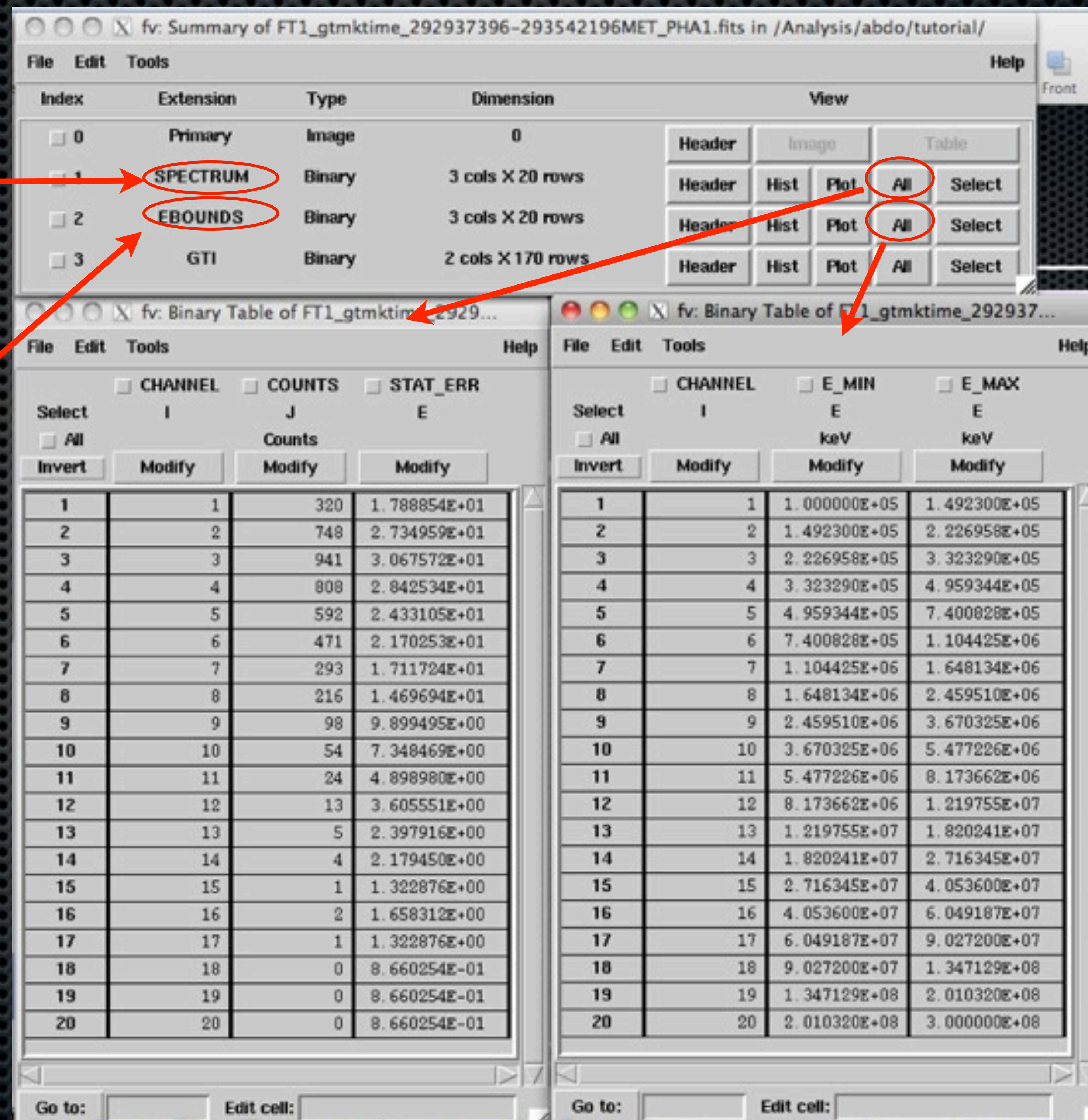
```
$ gtbin
This is gtbin version ScienceTools-v9r15p2-fssc-20090808
Type of output file (CCUBE|CMAP|LC|PHA1|PHA2) [LC] PHA1
Event data file name[FT1_gtmktime_292937396-293542196MET.fits]
Output file name[] FT1_gtmktime_292937396-293542196MET_PHA1.fits
Spacecraft data file name[L100422151847E0D2F37E30_SC00.fits]
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
```

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



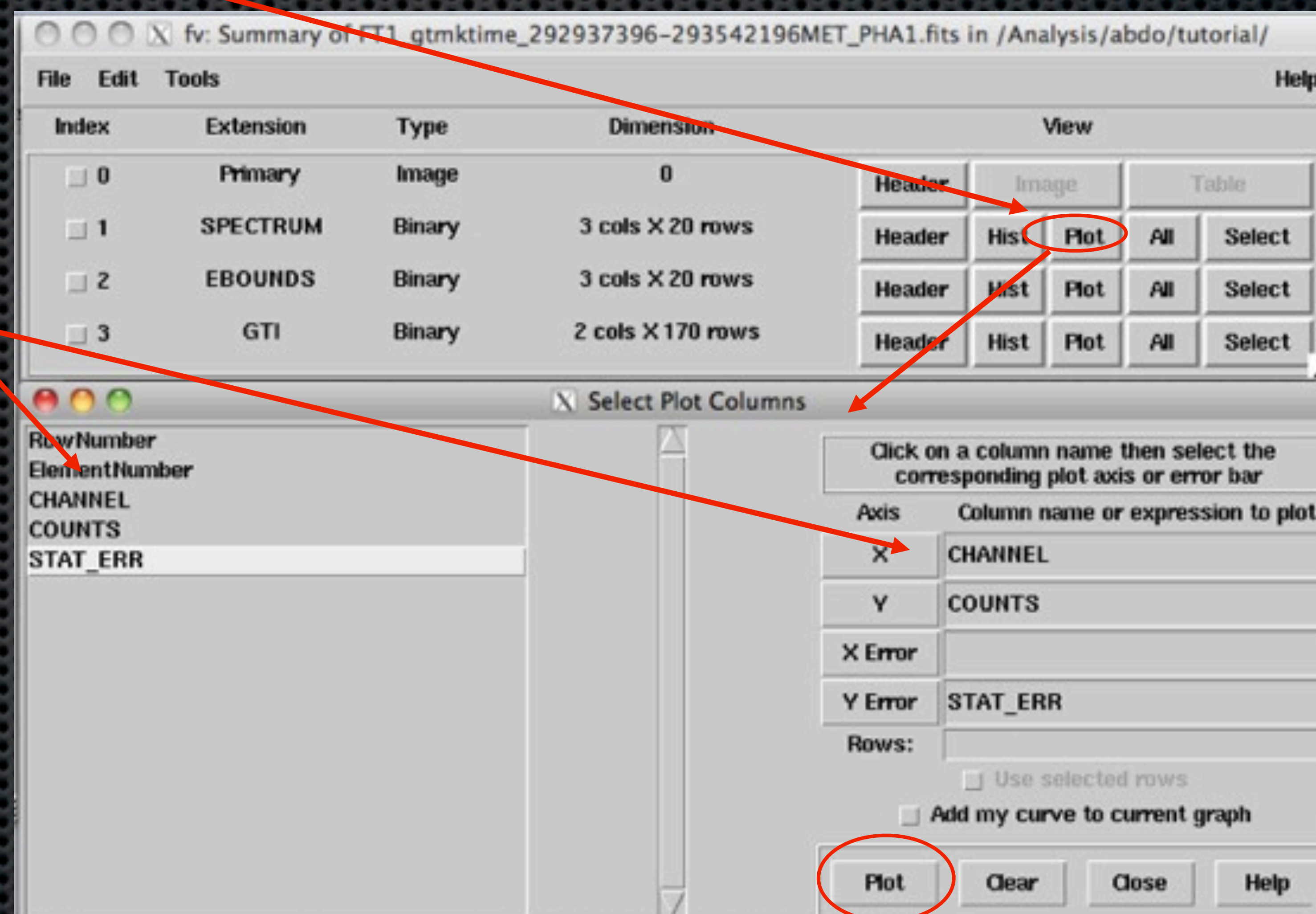
Index	Extension	Type	Dimension	View
0	Primary	Image	0	Header Image Table
1	SPECTRUM	Binary	3 cols X 20 rows	Header Hist Plot All Select
2	EBOUNDS	Binary	3 cols X 20 rows	Header Hist Plot All Select
3	GTI	Binary	2 cols X 170 rows	Header Hist Plot All Select

Select	CHANNEL (I)	COUNTS (J, Counts)	STAT_ERR (E)
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

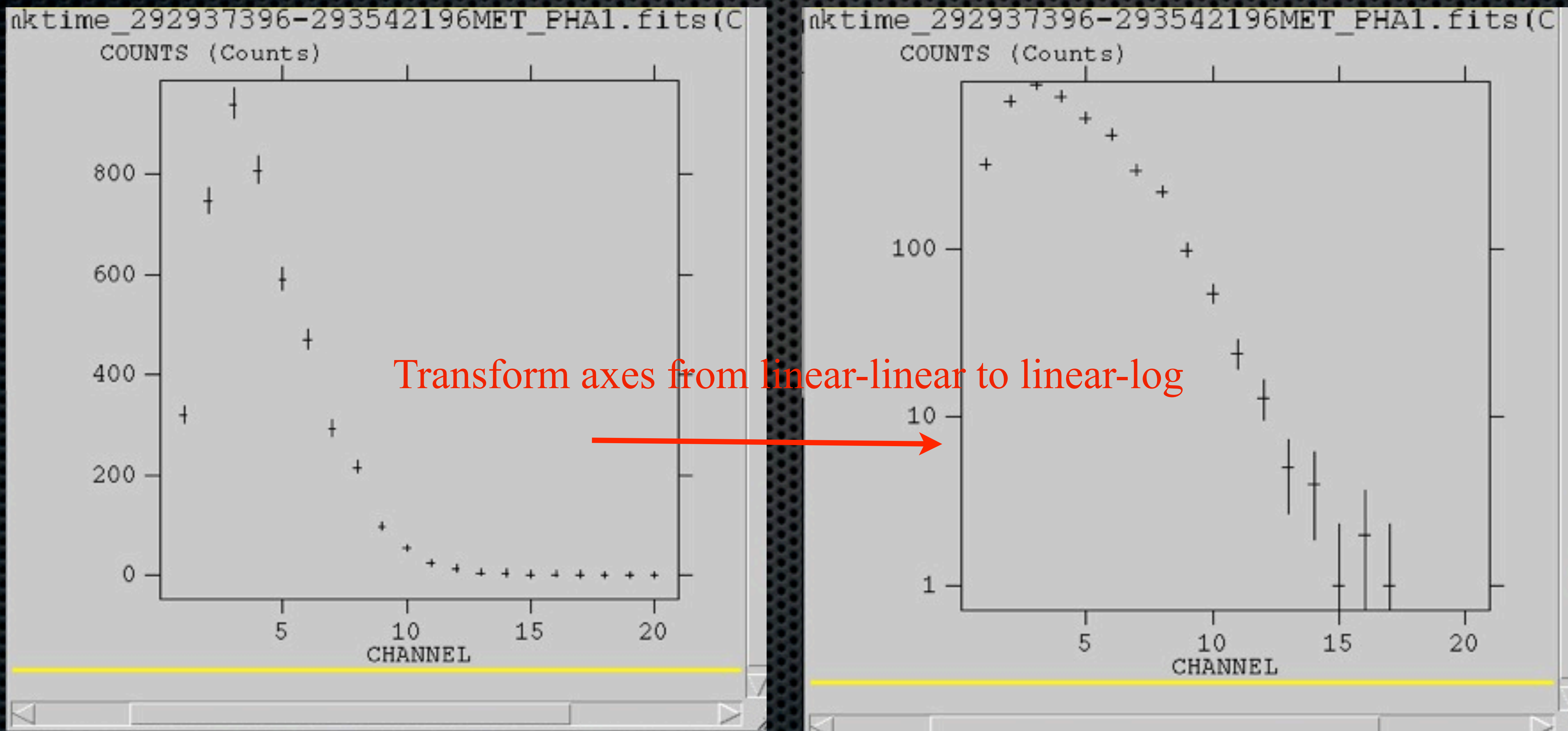
Select	CHANNEL (I)	E_MIN (E, keV)	E_MAX (E, keV)
1	1	1.000000E+05	1.492300E+05
2	2	1.492300E+05	2.226958E+05
3	3	2.226958E+05	3.323290E+05
4	4	3.323290E+05	4.959344E+05
5	5	4.959344E+05	7.400828E+05
6	6	7.400828E+05	1.104425E+06
7	7	1.104425E+06	1.648134E+06
8	8	1.648134E+06	2.459510E+06
9	9	2.459510E+06	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



Energy Spectra with gtbin



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:
    - gtltcube: 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

gtltcube

- gtltcube 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 gtltsum to add exposure cubes. More on this to come)

```
$ gtltcube
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
```

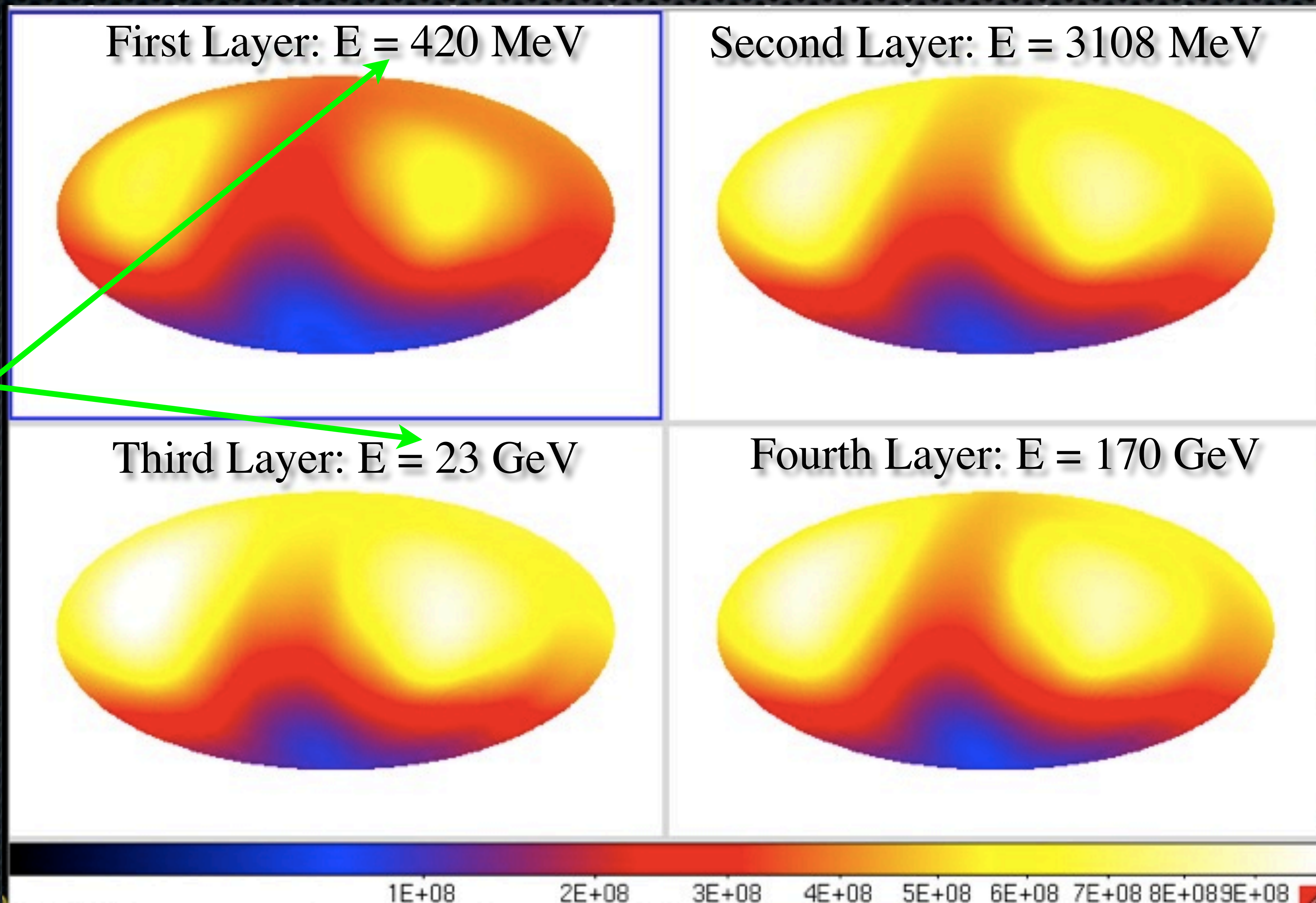
IRFs: select
P6_V3_DIFFUSE

the whole sky in
Galactic coordinate

Exposure Maps

- gtexpmap produced four exposure maps for the energies shown.
- The units of these maps are cm^2 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 gtltcube can take a lot of time.
- To over come this, we:
  - Split the event data file into smaller time bins. On the order of 4-7 days is fine.
  - run gtltcube on each of these files separately on the cluster to generated individual exposure cubes.
  - use gtltsum to add up all these cubes.
  - Note that gtltcube adds two files at a time so one would need to script the addition of large number of cubes.

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