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# **FSSC Science Tools**

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## **Source Analysis**



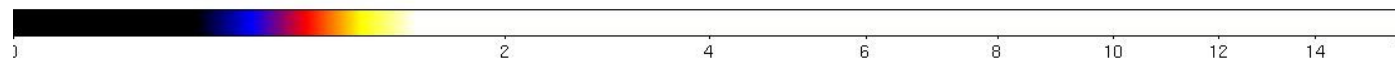
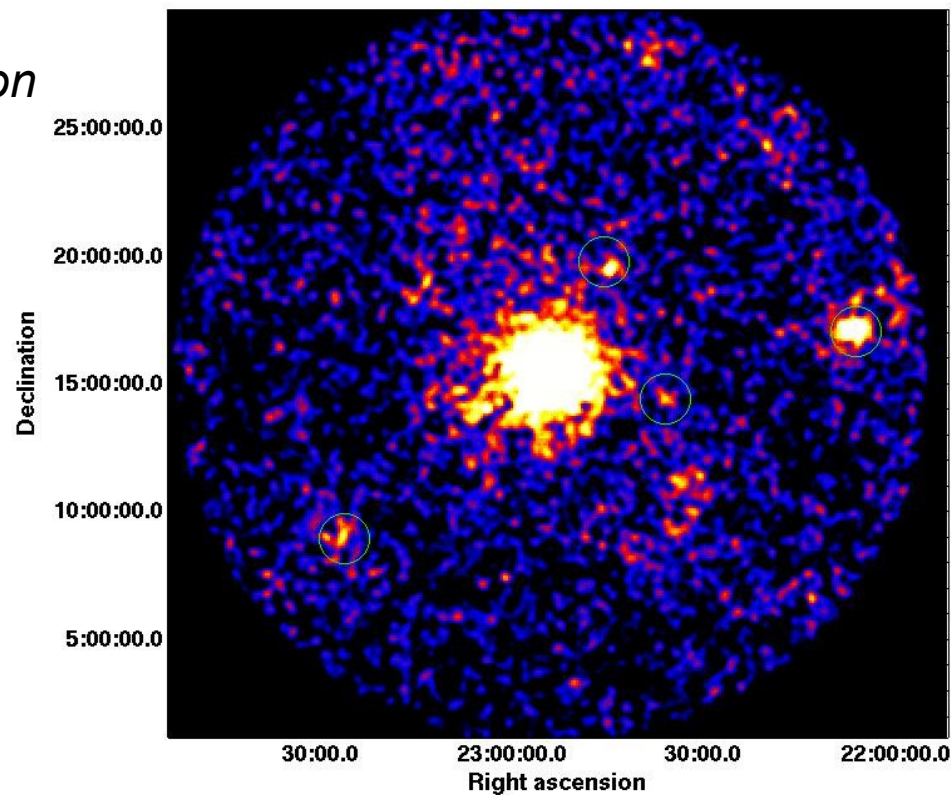
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# Science Tools: Documentation

- ▶ *Multi-Tier Documentation*
  - *Full set accompanies SW release*
    - *Fermi Mission Technical Handbook*
  - *Multiple levels:*
    - *Detailed analysis description ('Cicerone')*
    - *Individual tool descriptions (like fhhelp)*
    - *Analysis threads (cook book examples)*



► *3c454 region*





# Likelihood Analysis

- ▶ *Unbinned and binned modes are available. I'll describe unbinned analysis.*
- ▶ *Several tools are needed to define the model and prepare the data*
  - *modeeditor: GUI for preparing the xml model definition file*
  - *gtselect: applies region-of-interest cuts – sky acceptance cone, energy range (0.2 – 300 GeV), time range, zenith angles ( $< 105^\circ$ )*
  - *gtmktime: constructs good time intervals (GTIs) based on pointing information selections and zenith angle cuts*



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# Likelihood Analysis cont.

- *gtlrcube*: integrates LAT livetime as a function of sky position and off-axis angle
  - *gtexpmap*: computes RoI-specific exposure maps
  - *gtlike*: fits model parameters using maximum likelihood
- ▶ Details of the method can be found in <http://fermi.gsfc.nasa.gov/ssc/data/analysis/documentation/Cicerone>



# Likelihood Analysis cont.

► Using the modeeditor GUI:

Add sources  
(point-like or diffuse)  
using the drop down  
menu

ModelEditor (3c454\_srcmdl.xml)

File Edit Source Help

Title: source library

Source Name: \_3c454 Source Type: PointSource

Spectrum Type: PowerLaw2 File: Browse

name	value	scale	min	max	free
Integral	15.6325	1e-07	0.0001	10000.0	<input checked="" type="checkbox"/>
Index	2.507	-1.0	1.0	5.0	<input checked="" type="checkbox"/>
LowerLimit	100.0	1.0	30.0	500000.0	<input type="checkbox"/>
UpperLimit	300000.0	1.0	30.0	500000.0	<input type="checkbox"/>
					<input type="checkbox"/>
					<input type="checkbox"/>
					<input type="checkbox"/>

Spatial Model Type: SkyDirFunction File: Browse

name	value	scale	min	max	free
RA	343.490616	1.0	-360.0	360.0	<input type="checkbox"/>
DEC	16.148211	1.0	-90.0	90.0	<input type="checkbox"/>
					<input type="checkbox"/>
					<input type="checkbox"/>
					<input type="checkbox"/>
					<input type="checkbox"/>
					<input type="checkbox"/>



# Likelihood Analysis cont.

Edit source name,  
default f t parameters,  
bounds, scaling, etc.

The screenshot shows the ModelEditor interface for source '3c454'. The 'Spectrum Type' is 'PowerLaw2' and the 'Spatial Model Type' is 'SkyDirFunction'. The 'Integral' parameter table is as follows:

name	value	scale	min	max	free
Integral	15.6325	1e-07	0.0001	10000.0	<input checked="" type="checkbox"/>
Index	2.507	-1.0	1.0	5.0	<input checked="" type="checkbox"/>
LowerLimit	100.0	1.0	30.0	500000.0	<input type="checkbox"/>
UpperLimit	300000.0	1.0	30.0	500000.0	<input type="checkbox"/>

The 'Spatial Model Type' table is as follows:

name	value	scale	min	max	free
RA	343.490616	1.0	-360.0	360.0	<input type="checkbox"/>
DEC	16.148211	1.0	-90.0	90.0	<input type="checkbox"/>

If a model component  
requires a FITS image  
(e.g., Galactic diffuse,  
SNR), enter the  
f lename here



# Likelihood Analysis

▶ *gtmktime, gtltcube*

```
>gtmktime  
Spacecraft data file[3c454_SC00.fits]  
Filter expression[(IN_SAA!=T) && (DATA_QUAL!=1)]  
Apply ROI-based zenith angle cut[yes]  
Event data file[3c454_100_300000_evt01.fits]  
Output event file name[3c454_100_300000_evt02.fits]
```

This removes time intervals when the ROI is intersected by the zenith angle cut

```
>gtltcube  
Event data file[3c454_100_300000_evt02.fits]  
Spacecraft data file[3c454_SC00.fits]  
Output file[3c454_100_300000_ExpCube.fits]  
Step size in cos(theta) (0.:1.) [0.025]  
Pixel size (degrees)[1]
```





# Likelihood Analysis

► *gtexpmap*

```
>gtexpmap
The exposure maps generated by this tool are meant
to be used for *unbinned* likelihood analysis only.
Do not use them for binned analyses.
Event data file[3c454_100_300000_evt02.fits]
Spacecraft data file[3c454_SC00.fits]
Exposure hypercube file[3c454_100_300000_ExpCube.fits]
output file name[3c454_100_300000_ExpMap.fits]
Response functions[P6_V3_DIFFUSE]
Radius of the source region (in degrees)[25]
Number of longitude points (2:1000) [120]
Number of latitude points (2:1000) [120]
Number of energies (2:100) [20]
Computing the ExposureMap using 3c454_100_300000_ExpCube.fits
.....!
```



# Likelihood Analysis cont.

► *Finally, running gtlake:*

```
gtlike
Statistic to use (BINNED|UNBINNED) [UNBINNED]
Spacecraft file[3c454_SC00.fits]
Event file[3c454_100_300000_evt02.fits]
Unbinned exposure map[3c454_100_300000_ExpMap.fits]
Exposure hypercube file[3c454_100_300000_ExpCube.fits]
Source model file[3c454_srcmdl.xml]
Response functions to use[P6_V3_DIFFUSE]
Optimizer (DRMNFB|NEWMINUIT|MINUIT|DRMNGB|LBFGS) [minuit]
...
Computing TS values for each source (6 total)
.....!
```

This is the xml model file created using the modeleditor GUI



```
GAL_v02:
Prefactor: 1.29563 +/- 0.0426252
Index: 0
Scale: 100
Npred: 16076

_3c454:
Integral: 15.6539 +/- 0.34452
Index: 2.50803 +/- 0.0205473
LowerLimit: 100
UpperLimit: 300000
Npred: 4527.59
ROI distance: 0
TS value: 10656.9
WARNING: Fit may be bad in range [100, 222.696] (MeV)

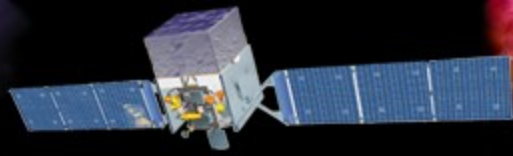
Total number of observed counts: 28719
Total number of model events: 28719

-log(Likelihood): 325751.9386

Writing fitted model to 3c454_outmdl.xml
```

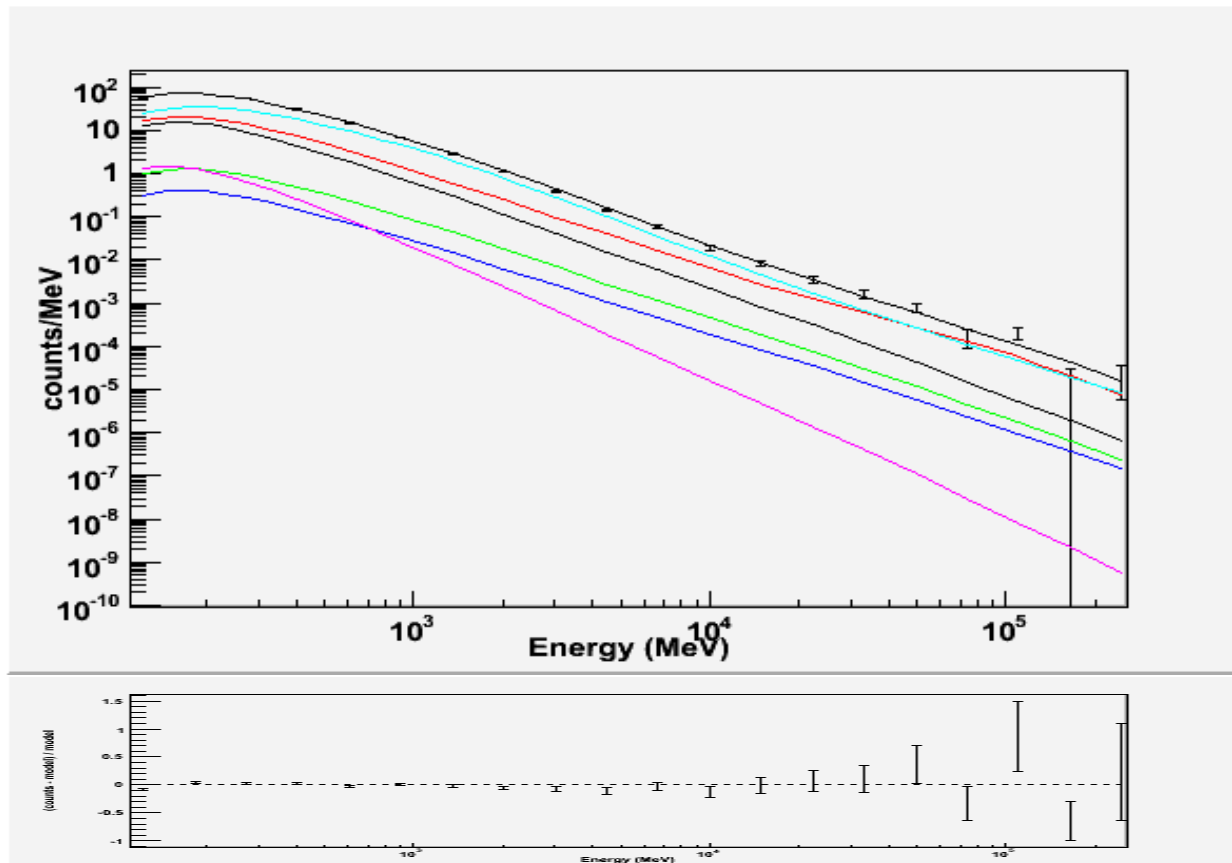
The Test Statistic (TS) is distributed as  $\chi^2$  for n dof. For a power law model TS = 25 is roughly  $5\sigma$

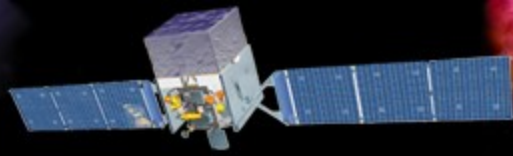
Warning messages based on Poisson probability of observed counts given the model prediction in these bands



# Likelihood Analysis cont.

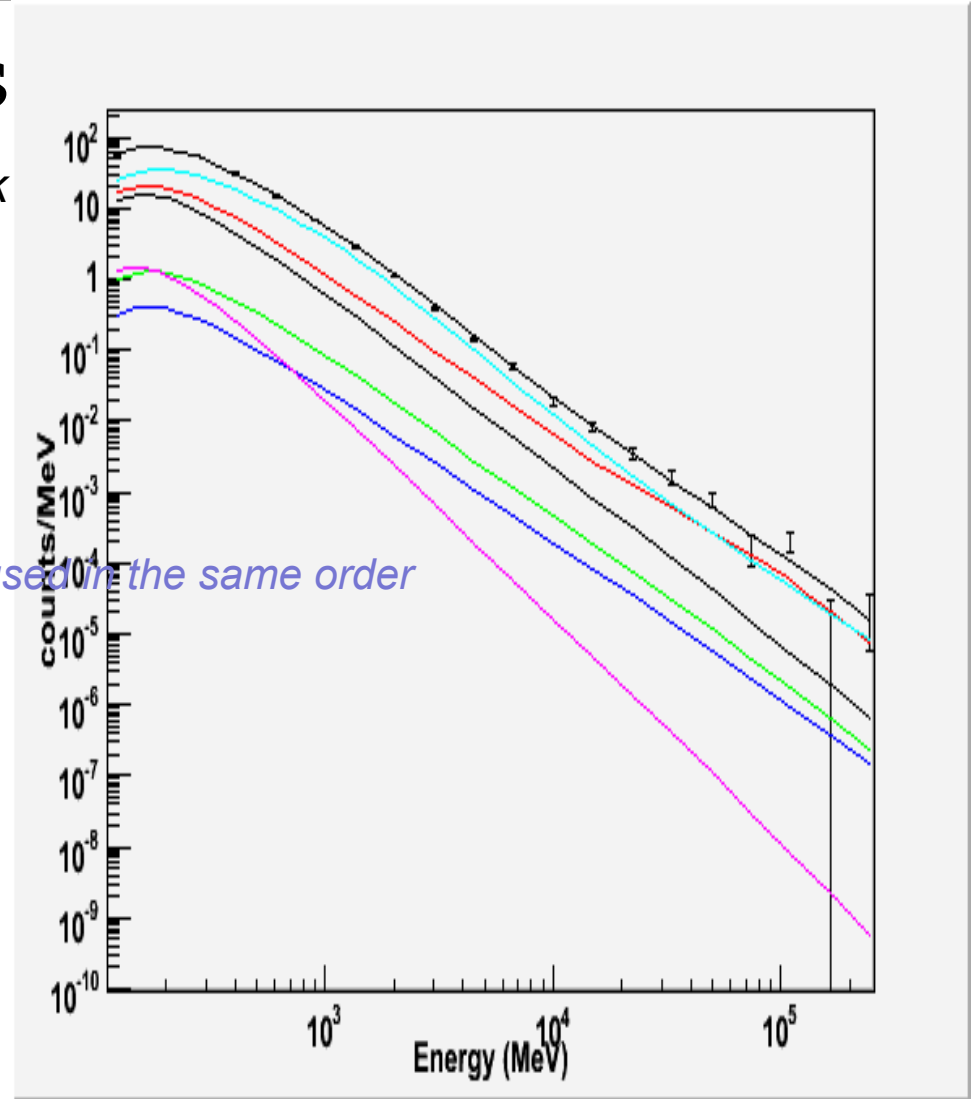
- Plot the results (*gtlike plot=yes*)

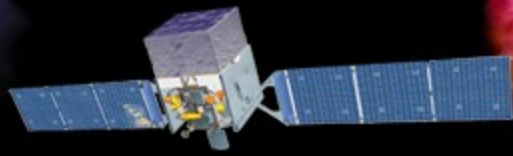




# Plot Colors

- ▶ *The summed model is black*
- ▶ *The first source is red*
- ▶ *the second, green*
- ▶ *the third, blue*
- ▶ *the fourth, magenta*
- ▶ *the fifth, cyan*
- *after this the colors are reused in the same order*





## Now from Python

- ▶ *setup FSSC science tools*
- ▶ *setup python & data files*

```
import glob
from UnbinnedAnalysis import *
my_obs = unbinnedAnalysis('3c454_100_300000_evt02.fits',
                           '3c454_SC00.fits',
                           expMap='3c454_100_300000_ExpMap.fits',
                           expCube='3c454_100_300000_ExpCube.fits',
                           irfs='P6_V3_DIFFUSE',
                           optimizer='MINUIT')
```



## Now from Python cont.

▶ *setup model*

```
>>> analysis = unbinnedAnalysis(my_obs, "3c454_srcmdl.xml")
>>> print analysis
Event file(s): ('3c454_100_300000_evt02.fits',)
Spacecraft file(s): ('3c454_SC00.fits',)
Exposure map: 3c454_100_300000_ExpMap.fits
Exposure cube: 3c454_100_300000_ExpCube.fits
IRFs: P6_V3_DIFFUSE
Source model file: 3c454_srcmdl.xml
Optimizer: MINUIT
```



## Now from Python cont.

▶ *setup model*

```
>>> analysis = unbinnedAnalysis(my_obs, "3c454_srcmdl.xml")
>>> print analysis
Event file(s): ('3c454_100_300000_evt02.fits',)
Spacecraft file(s): ('3c454_SC00.fits',)
Exposure map: 3c454_100_300000_ExpMap.fits
Exposure cube: 3c454_100_300000_ExpCube.fits
IRFs: P6_V3_DIFFUSE
Source model file: 3c454_srcmdl.xml
Optimizer: MINUIT
```





## Now from Python cont.

- ▶ *fit model (verbosity=0)*

```
>>> analysis.fit(verbosity=0)
325751.93858041393
```

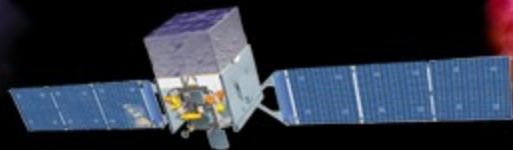
- ▶ *fit model (verbosity=1) Much more output*

```
>>> analysis.fit(verbosity=1)
*****
**      1 **SET PRINT      .000
*****
*****
**      2 **SET NOWARN
*****

PARAMETER DEFINITIONS:
   NO.   NAME                VALUE      STEP SIZE      LIMITS
   1 'Normalizat'          .60995      1.0000      .10000E-01  10.000
   2 'Integral'            1.5776      1.0000      .10000E-03  10000.
   3 'Index'                2.3203      1.0000      1.0000      5.0000

<skip output>

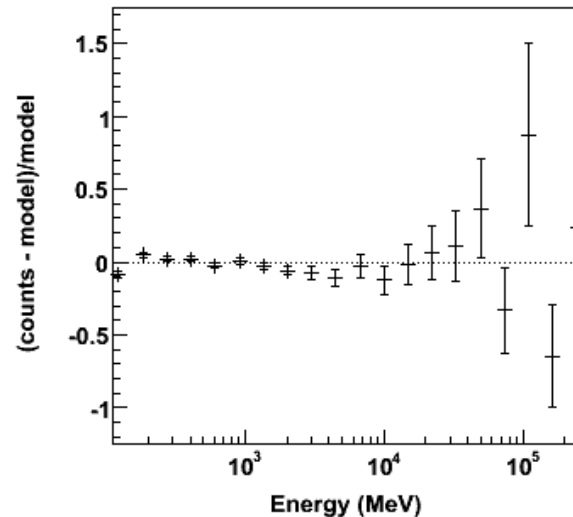
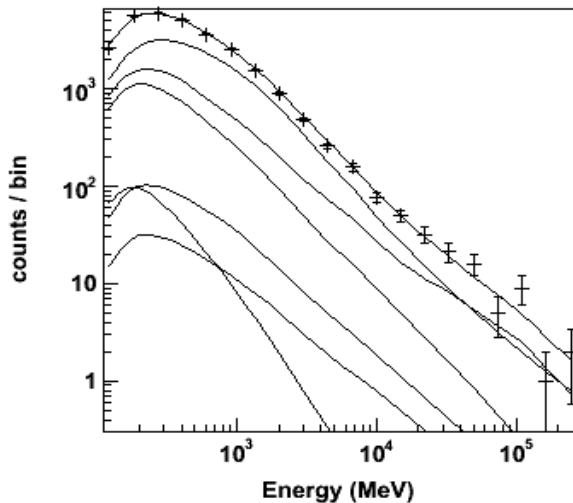
Minuit parameter uncertainties:
...
   8  0.0426301
   9  0.34453
  10  0.0205469
325751.93858041393
```



# Now from Python cont.

► *Plot fitted model*

```
>>> analysis.plot()  
>>> █
```





# Now from Python cont.

► *view model*

```
>>> analysis.model
EG_v02
  Spectrum: FileFunction
0   Normalization:  1.000e+00  0.000e+00  1.000e-02  1.000e+01 ( 1.000e+00)

<skip some models>

GAL_v02
  Spectrum: PowerLaw
13  Prefactor:  1.220e+00  0.000e+00  0.000e+00  1.000e+01 ( 1.000e+00)
14   Index:  0.000e+00  0.000e+00 -1.000e+00  1.000e+00 ( 1.000e+00) fixed
15   Scale:  1.000e+02  0.000e+00  5.000e+01  2.000e+02 ( 1.000e+00) fixed

_3c454
  Spectrum: PowerLaw2
16  Integral:  1.563e+01  0.000e+00  1.000e-04  1.000e+04 ( 1.000e-07)
17   Index:  2.507e+00  0.000e+00  1.000e+00  5.000e+00 (-1.000e+00)
18  LowerLimit:  1.000e+02  0.000e+00  3.000e+01  5.000e+05 ( 1.000e+00) fixed
19  UpperLimit:  3.000e+05  0.000e+00  3.000e+01  5.000e+05 ( 1.000e+00) fixed
```