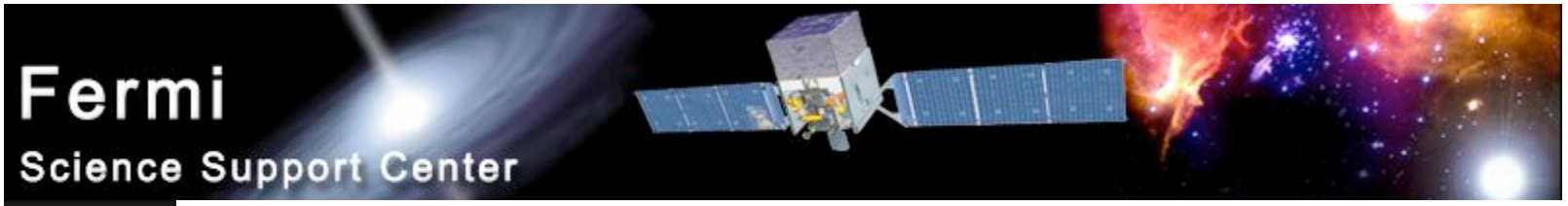
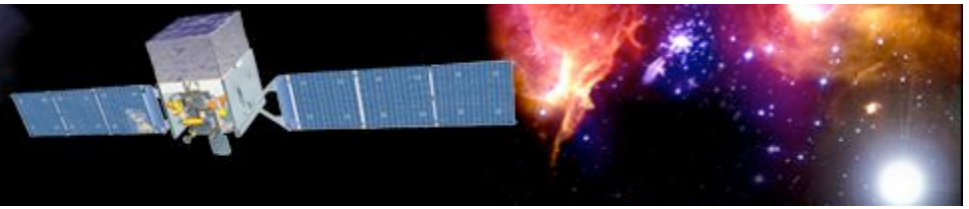


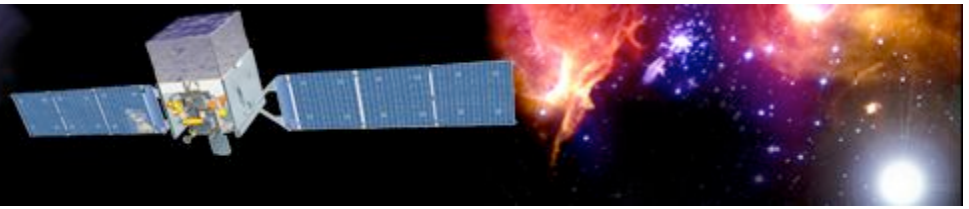
FSSC Science Tools

Analysis Examples



Science Tools Structure

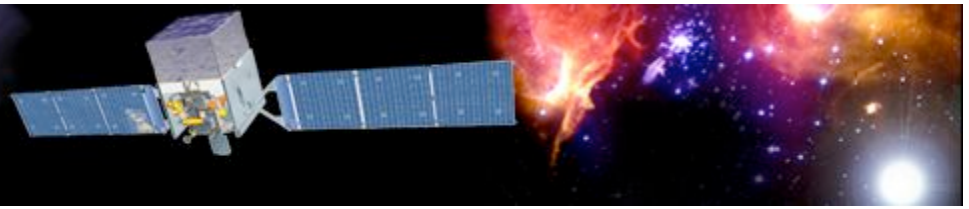
- *"Atomic" executables*
  - *Allows for divergent analysis without task repetition*
  - *Scriptable into more complex analysis chains*
- *Familiar file types*
  - *FITS data i/o*
  - *IRAF style param files*
  - *XML source models*
  - *Text-based supporting files*
- *Familiar toolsets*
  - *FV, DS9, XSPEC*



Parameter File Example

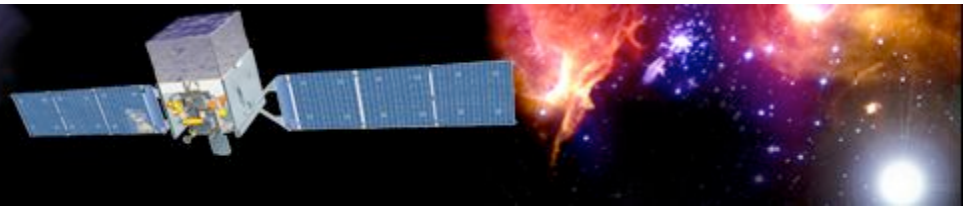
- *gtselect.par*

```
#
# $Header: /nfs/slac/g/glast/ground/cvs/dataSubselector/pfiles/
gtselect.par,v 1.13 2008/04/01 20:47:53 jchiang Exp $
#
infile,f,a,"Filtered_evt_00054_events.fits",,,"Input FT1 file"
outfile,f,a,"Filtered_evt_00054_events_cut.fits",,,"Output FT1 file"
ra,r,a,86.4,0,360,RA for new search center (degrees)
dec,r,a,28.9,-90,90,Dec for new search center (degrees)
rad,r,a,20,0,180,radius of new search region (degrees)
tmin,r,a,0,0,,start time (MET in s)
tmax,r,a,0,0,,end time (MET in s)
emin,r,a,30,0,,lower energy limit (MeV)
emax,r,a,200000,0,,upper energy limit (MeV)
evclsmin,i,h,0,0,10,"Minimum event class ID"
evclsmax,i,h,10,0,10,"Maximum event class ID"
convtype,i,h,-1,-1,1,"Conversion type (-1=both, 0=Front, 1=Back)"
zmax,r,h,180,0,180,maximum zenith angle value (degrees)
phasemin,r,h,0,0,1,minimum pulse phase
phasemax,r,h,1,0,1,maximum pulse phase

evtable,s,h,"EVENTS",,,"Event data extension"

chatter,i,h,2,0,4,Output verbosity
clobber,        b, h, yes, , , "Overwrite existing output files"
debug,          b, h, no, , , "Activate debugging mode"
gui,            b, h, no, , , "GUI mode activated"
mode,           s, h, "ql", , , "Mode of automatic parameters"
```



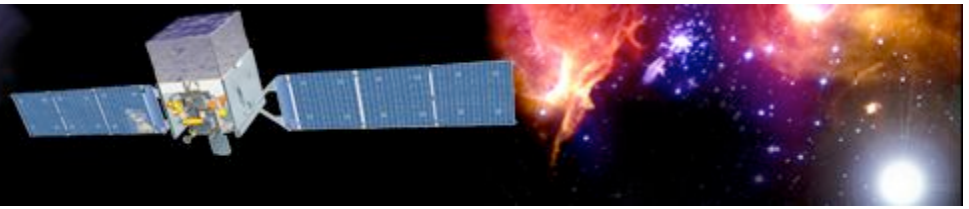
Science Tools Execution

- *Parameters input in three ways*
  - *Command line entry - useful for scripting*
    - *Allows modification of "hidden" parameters (likely not needed for standard analyses)*
  - *Last value stored in param file for next use*
  - *Interactive prompted entry*
    - *No access to hidden parameters*
- *Parameter input can be mixed*
  - *%gtselect*
  - *%gtselect clobber=no*
  - *%gtselect clobber=no, infile=events.fits, outfile=events_cut.fits, etc...*



Observation Simulation - 1

- *Simple example source model:*
  - *LSI +61 303, flux estimated from LAT monitored source page: http://fermi.gsfc.nasa.gov/ssc/data/access/lat/msl_lc*
    - *model as a constant source even though BSL paper shows that it varies*
  - *PKS 2155–304, high state*
  - *Galactic diffuse component*
  - *Isotropic extragalactic diffuse (EGRET measurement)*
- *Could also use Bright Source List to build model*
  - *http://fermi.gsfc.nasa.gov/ssc/data/access/lat/bright_src_list*
- *Perform a week-long simulation*



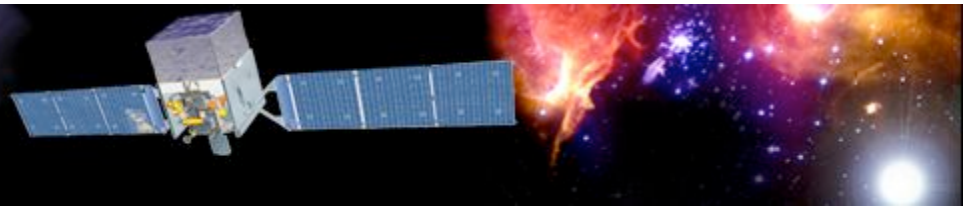
Observation Simulation - 2

- *Define a source model in xml:*

```
% cat gtobssim_model.xml
<source_library title="my LSI +60 303 model">
  <source name="GALPROP_diffuse">
    <spectrum escale="MeV">
      <SpectrumClass name="MapCube" params="12.59,
       $(FERMI_DIR)/refdata/fermi/galdiffuse/GP_gamma_v0r0p1.fits"/>
      <use_spectrum frame="galaxy"/>
    </spectrum>
  </source>
  <source name="Extragalactic_diffuse">
    <spectrum escale="MeV">
      <SpectrumClass name="Isotropic" params="10.7, 2.1, 20., 2e5"/>
      <use_spectrum frame="galaxy"/>
    </spectrum>
  </source>
  <source flux="0.041" name="LSI_p61_303">
    <spectrum escale="MeV">
      <particle name="gamma">
        <power_law emax="1000000.0" emin="20.0" gamma="2.1"/>
      </particle>
      <celestial_dir dec="61.2290" ra="40.1310"/>
```

A more recent version of the GALPROP model will be available from the FSSC site

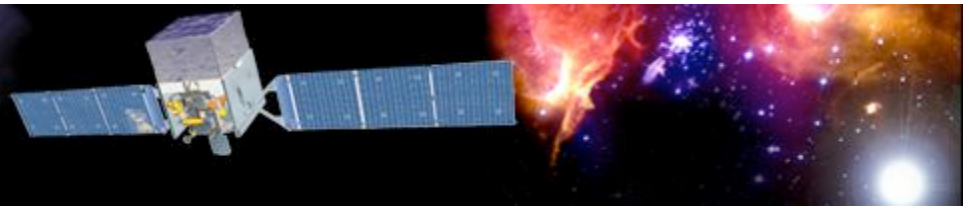
Flux units for the gtobssim models are ph m^{-2} s^{-1}



Observation Simulation - 3

```
    </spectrum>
  </source>
  <source flux="0.03" name="PKS_2155m304">
    <spectrum escale="MeV">
      <particle name="gamma">
        <power_law emax="1000000.0" emin="20.0" gamma="1.81"/>
      </particle>
      <celestial_dir dec="-30.226" ra="329.717"/>
    </spectrum>
  </source>
</source_library>
```

- *Other examples are distributed with the ScienceTools and can be found in* ***`${FERMI_DIR}/xml/fermi/observationSim`***
- *Models can be defined using the ModelEditor GUI*

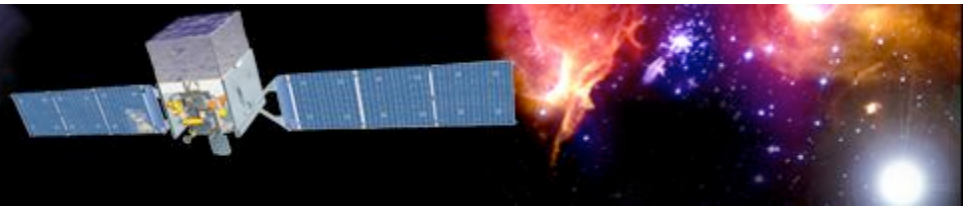


Observation Simulation - 4

- *Running gtobssim:*

```
% gtobssim
File of flux-style source definitions[none] xmlFiles.txt
File containing list of source names[source_names.txt]
Pointing history file[none]
Prefix for output files[test] LSI_sim
Simulation time (seconds)[86400] 604800
Simulation start date[2001-01-01 00:00:00] 2009-03-06 00:00:00
Apply acceptance cone?[no]
Response functions[] P6_V1_DIFFUSE
Random number seed[293049] 4909141
added source "GALPROP_diffuse"
added source "Extragalactic_diffuse"
added source "LSI_p61_303"
added source "PKS_2155m304"
Generating events for a simulation time of 604800 seconds....
```

The pointing history will be generated with idealized survey mode



- *Auxiliary files for gtobssim:*

Can include multiple xml files here →

```
% cat xmlFiles.txt
gtobssim_model.xml
```

Entries can be commented out with a "#" →

```
% cat source_names.txt
GALPROP_diffuse
Extragalactic_diffuse
LSI_p61_303
PKS_2155m304
```

- *Output files:*

```
% ls LSI_sim*
LSI_sim_events_0000.fits  LSI_sim_scData_0000.fits
LSI_sim_events_0001.fits  LSI_sim_srcIds.txt
```

Pointing file →

Event files →

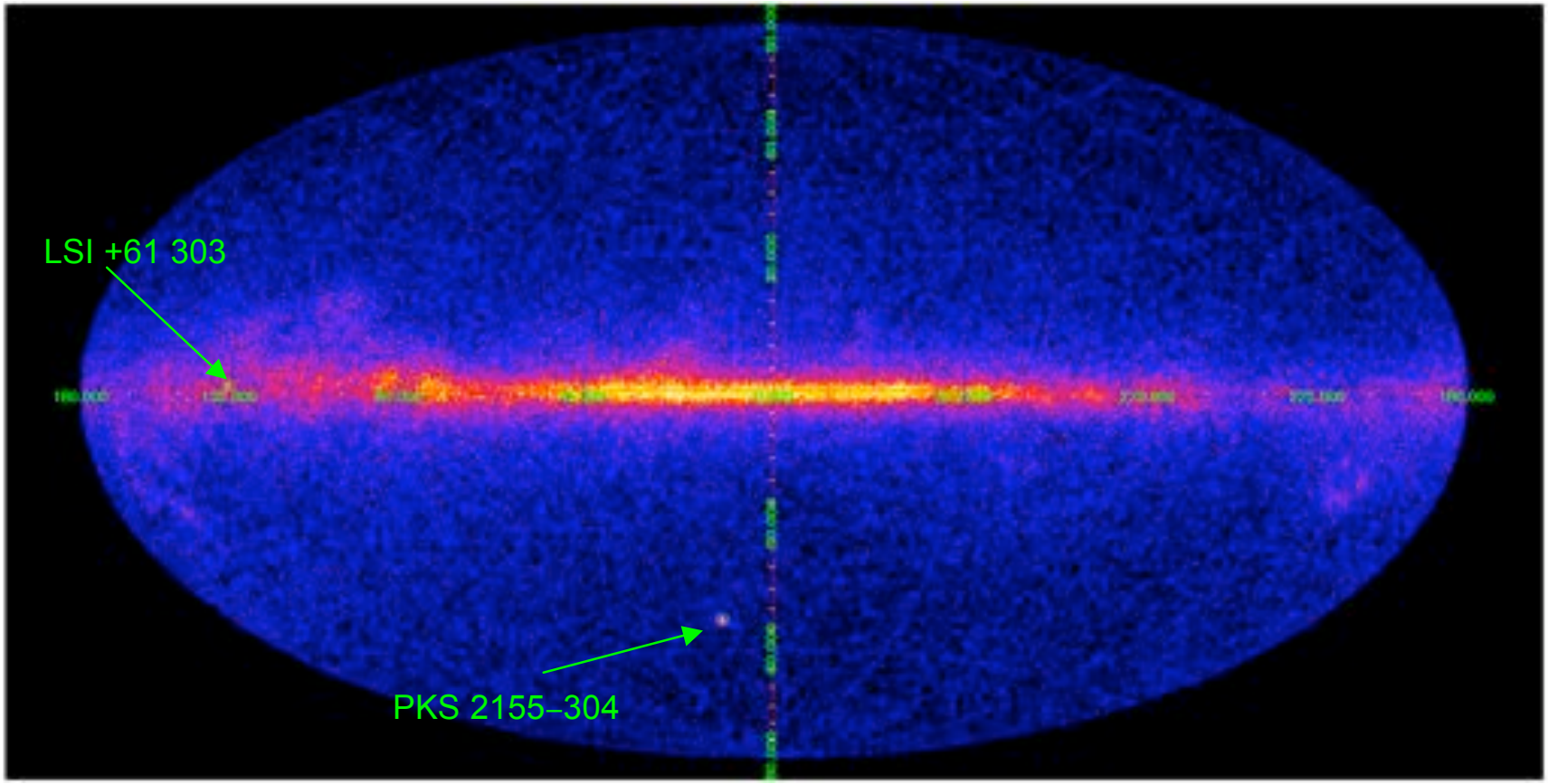
contains MC_SRC_ID mapping

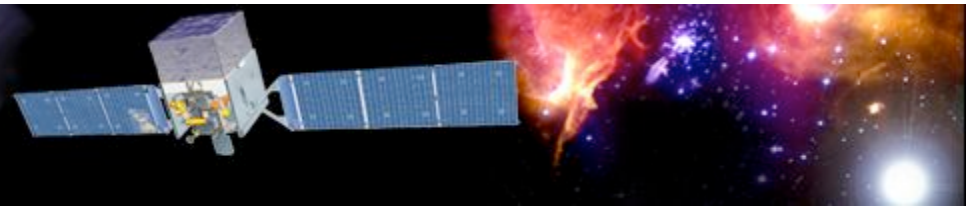
a list of event files as input to the tools →

```
% ls LSI_sim_events* > evfiles
```

Counts Maps - 1

- *All-sky map created with gtbin:*





Counts Maps - 2

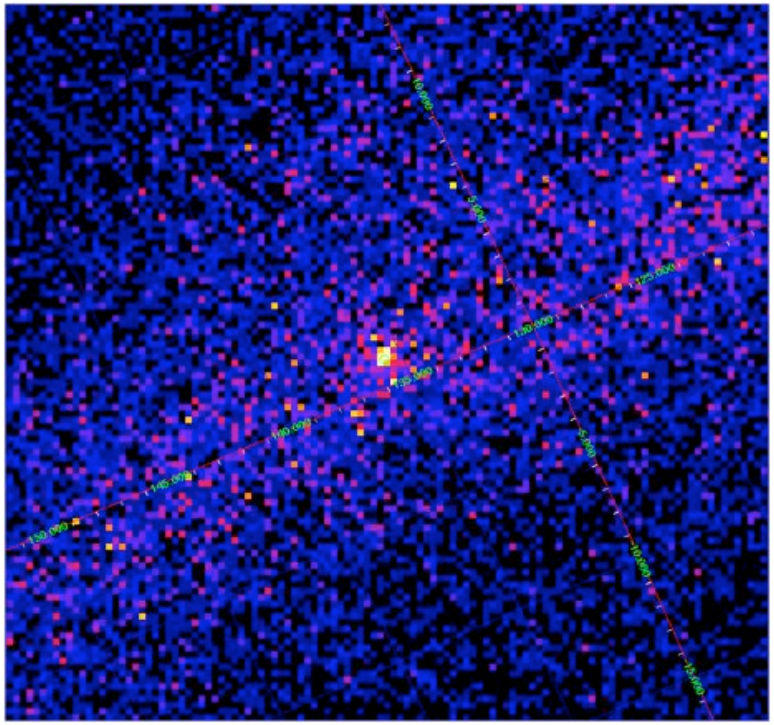
- *Counts maps with gtbin, all-sky map example:*

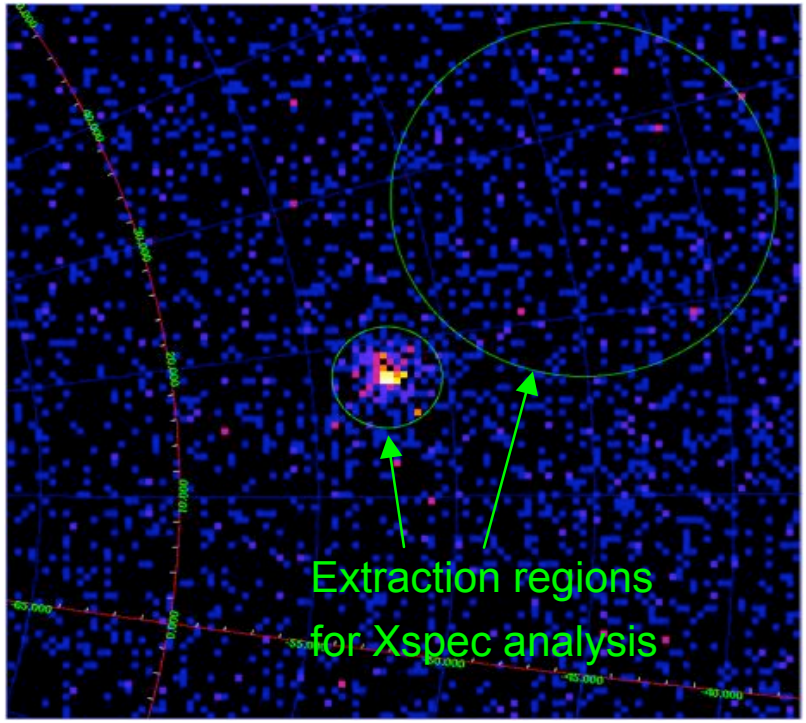
```
% gtbin
This is gtbin version ScienceTools-v9r8p2-fssc-20090206
Type of output file (CCUBE|CMAP|LC|PHA1|PHA2) [PHA2] cmap
Event data file name[] @evfiles
Output file name[] cmap_allsky.fits
Spacecraft data file name[NONE] LSI_sim_scData_0000.fits
Size of the X axis in pixels[] 720
Size of the Y axis in pixels[] 360
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 e.g. AIT|ARC|CAR|GLS|MER|NCP|SIN|STG|TAN:[AIT]
```

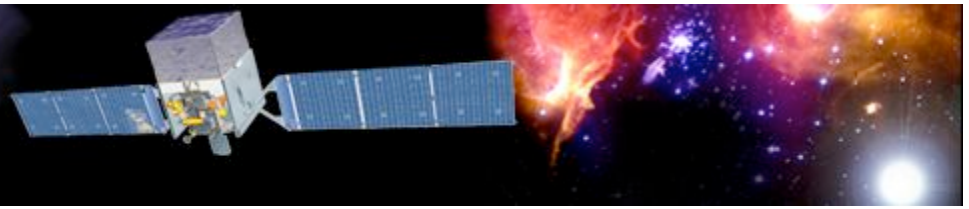
event file or
list of event files

Counts Maps - 3

- *LSI +61 303 and PKS 2155–304 regions:*

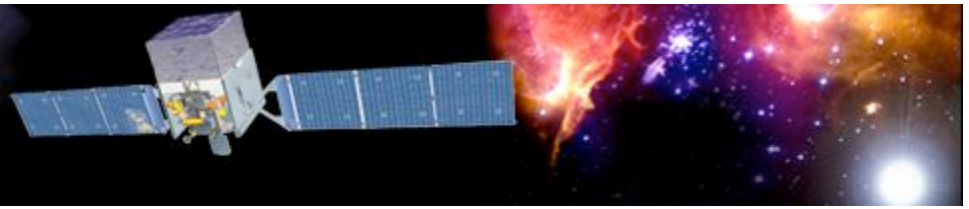






Likelihood Analysis - 1

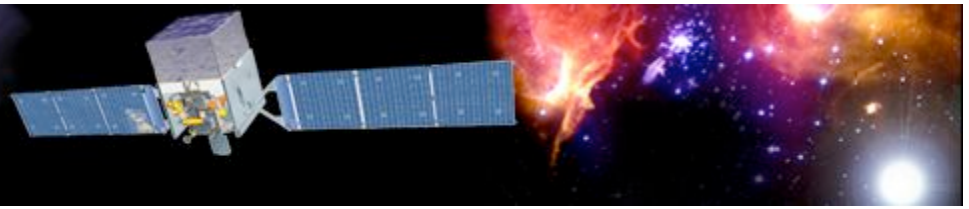
- *Unbinned and binned modes are available. I'll describe unbinned analysis.*
- *Several tools are needed to define the model and prepare the data*
  - *modeleditor: GUI for preparing the xml source model definition file*
  - *gtselect: applies region-of-interest cuts – sky acceptance cone, energy range (0.2 – 300 GeV), time range, zenith angles (<105°)*
  - *gtmktime: constructs good time intervals (GTIs) based on pointing information selections and zenith angle cuts*
  - *gtdiffrsp: pre-computes integrals over spatial distribution of diffuse sources and adds a column per source to the event file.*



Likelihood Analysis - 2

- *gtltcube: 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*



Source Model Example

```
<?xml version="1.0" ?>
<source_library title="source library">
  <source name="Source1" type="PointSource">
    <spectrum type="PowerLaw2">
      <parameter error="0.00" free="1" max="1000" min="1e-05" name="Integral" scale="1e-06" value="2.000"/>
      <parameter error="0.00" free="1" max="0" min="-5" name="Index" scale="1" value="-2.200"/>
      <parameter free="0" max="5e5" min="20" name="LowerLimit" scale="1" value="100.000000"/>
      <parameter free="0" max="3e5" min="20" name="UpperLimit" scale="1" value="30000.000000"/>
    </spectrum>
    <spatialModel type="SkyDirFunction">
      <parameter free="0" max="360" min="-360" name="RA" scale="1" value="304"/>
      <parameter free="0" max="90" min="-90" name="DEC" scale="1" value="37"/>
    </spatialModel>
  </source>
  <source name="Extragalactic Diffuse" type="DiffuseSource">
   <spectrum type="PowerLaw">
    <parameter error="0.289864" free="1" max="100.0" min="1e-05" name="Prefactor" scale="1e-07"
value="1.65213"/>
    <parameter free="0" max="-1.0" min="-3.5" name="Index" scale="1.0" value="-2.1"/>
    <parameter free="0" max="200.0" min="50.0" name="Scale" scale="1.0" value="100.0"/>
   </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>
```

Likelihood Analysis - 3

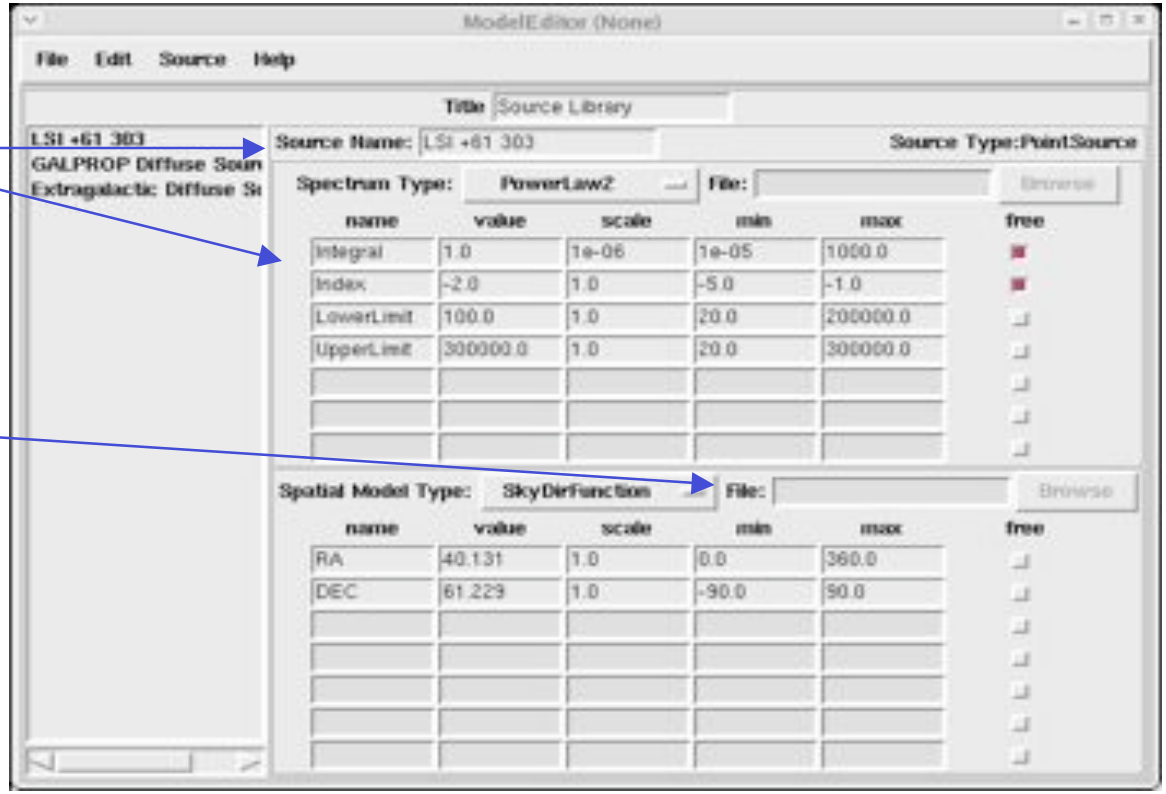
- *Using the ModelEditor GUI:*

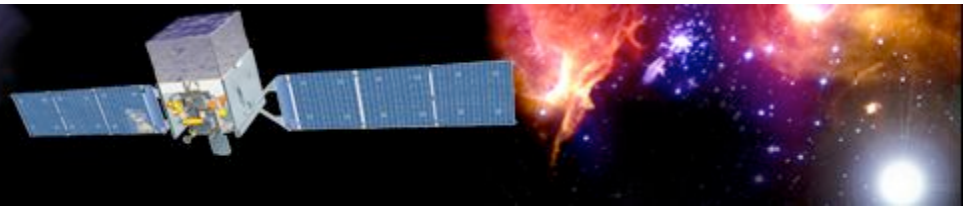
Add sources (point-like or diffuse) using the drop-down menu

Likelihood Analysis - 4

Edit source name, default fit parameters, bounds, scaling, etc.

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





Likelihood Analysis - 5

- *Extract the data in the RoI:*

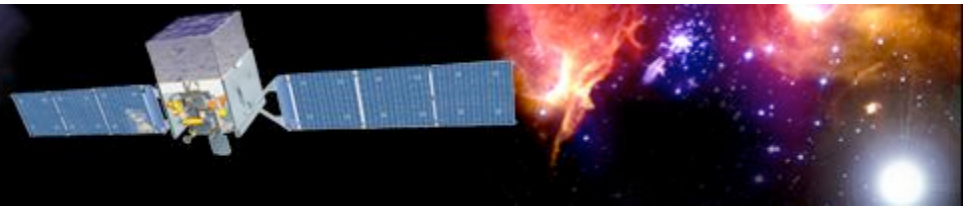
```
% gtselect
Input FT1 file[@evfiles]
Output FT1 file[lsi_filtered_3deg.fits] lsi_filtered.fits
RA for new search center (degrees) (0:360) [40.131]
Dec for new search center (degrees) (-90:90) [61.229]
radius of new search region (degrees) (0:180) [3] 10
start time (MET in s) (0:) [0]
end time (MET in s) (0:) [0]
lower energy limit (MeV) (0:) [200]
upper energy limit (MeV) (0:) [300000]
maximum zenith angle value (degrees) (0:180) [105]
Done.
```

Choose an acceptance cone large enough to characterize any sources that may overlap with target

These defaults mean "no time selection"

Effective area varies strongly below 200 MeV

Zenith angle cut to avoid Earth albedo photons. Important at low energies and for pointed mode.

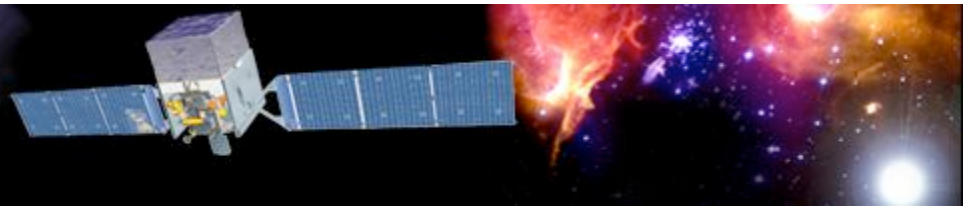


Likelihood Analysis - 6

- *gtmktime, gtltcube*

```
% gtmktime
Spacecraft data file[] LSI_sim_scData_0000.fits
Filter expression[IN_SAA!=T]
Apply ROI-based zenith angle cut[yes]
Event data file[] lsi_filtered.fits
Output event file name[] lsi_filtered_zmax_roi.fits

% gtltcube
Event data file[] lsi_filtered_zmax_roi.fits
Spacecraft data file[] LSI_sim_scData_0000.fits
Output file[expCube.fits]
Step size in cos(theta) (0.:1.) [0.025]
Pixel size (degrees)[1]
Working on file LSI_sim_scData_0000.fits
.....................!
```

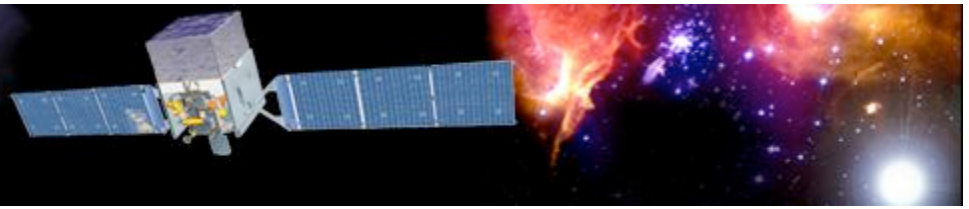
This removes time intervals when the RoI is intersected by the zenith angle cut



Likelihood Analysis - 7

- *gtexpmap*

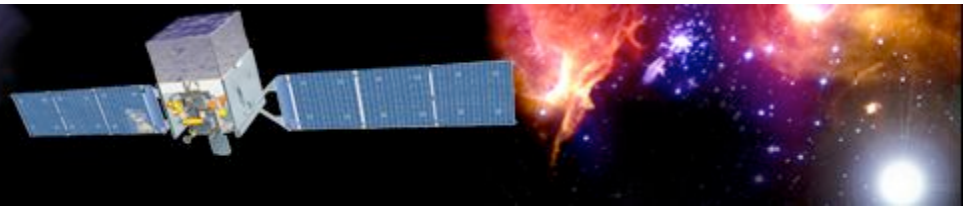
```
% gtexpmap
The exposure maps generated by this tool are meant
to be used for *unbinned* likelihood analysis only.
Do not use them for binned analyses.
Event data file[] lsi_filtered_zmax_roi.fits
Spacecraft data file[] LSI_sim_scData_0000.fits
Exposure hypercube file[] expCube.fits
output file name[] expMap.fits
Response functions[] P6_V1_DIFFUSE
Radius of the source region (in degrees)[30] 20
Number of longitude points (2:1000) [120]
Number of latitude points (2:1000) [120]
Number of energies (2:100) [20]
Computing the ExposureMap using expCube.fits
.....................!
```



Likelihood Analysis - 8

- *gtdiffrsp*

```
% gtdiffrsp
Event data file[] lsi_filtered_zmax_roi.fits
Spacecraft data file[] LSI_sim_scData_0000.fits
Source model file[] lsi_model.xml
Response functions to use[] P6_V1_DIFFUSE
adding source Extragalactic Diffuse
adding source GalProp Diffuse
Working on...
lsi_filtered_zmax_roi.fits.....................!
```

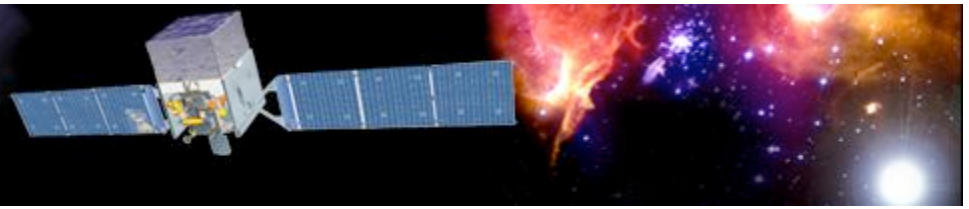


Likelihood Analysis - 9

- *Finally, running gtlike:*

```
% gtlike
Statistic to use (BINNED|UNBINNED) [UNBINNED]
Spacecraft file[none] LSI_sim_scData_0000.fits
Event file[none] lsi_filtered_zmax_roi.fits
Unbinned exposure map[none] expMap.fits
Exposure hypercube file[none] expCube.fits
Source model file[] lsi_model.xml
Response functions to use[] P6_V1_DIFFUSE
Optimizer (DRMNFB|NEWMINUIT|MINUIT|DRMNGB|LBFGS) [DRMNFB] NEWMINUIT

<... skip some output ...>

Computing TS values for each source (3 total)
...!

Extragalactic Diffuse:
Prefactor: 1.609157 +/- 1.0376564
Index: -2.1576144 +/- 0.21421358
Scale: 100
Npred: 392.94834
```

This is the xml model file created using the ModelEditor GUI



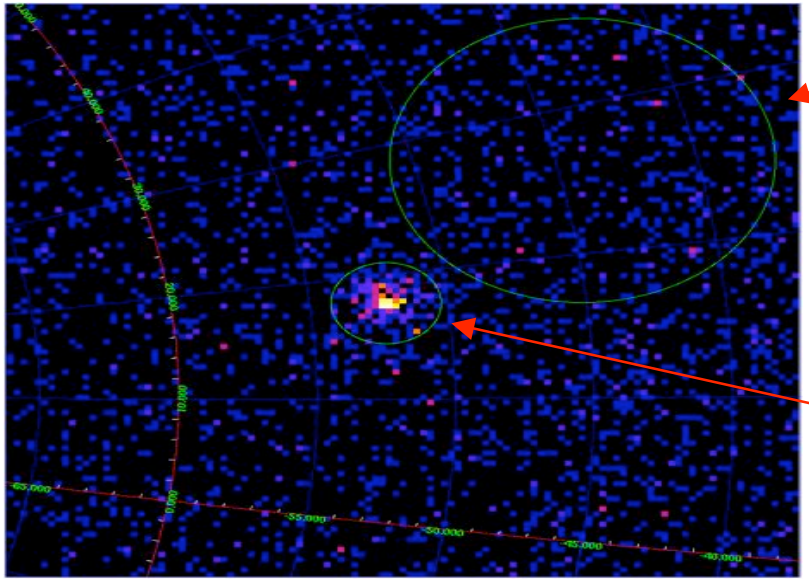
```
CalProp Diffuse:
Value: 0.99102047 +/- 0.041932682
Npred: 4577.3401

LSI +61 303:
Integral: 4.4176578 +/- 1.3154204
Index: -2.1117783 +/- 0.097404512
LowerLimit: 20
UpperLimit: 200000
Npred: 228.61496
ROI distance: 0
TS value: 306.72589
WARNING: Fit may be bad in range [399.052, 796.214] (MeV)
WARNING: Fit may be bad in range [2244.04, 3169.79] (MeV)

Total number of observed counts: 5207
Total number of model events: 5198.9034

-log(Likelihood): 52165.72877

Elapsed CPU time: 33.91
```

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

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

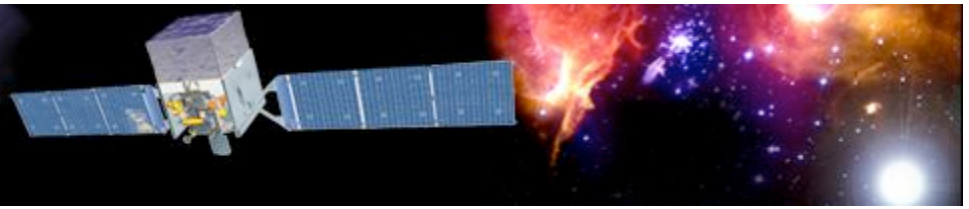
Xspec Analysis - 1

- *PKS 2155–304, an HBL, with b = –52.2° (so the diffuse component is fairly flat).*
- *Extract source and background regions using gtselect:*



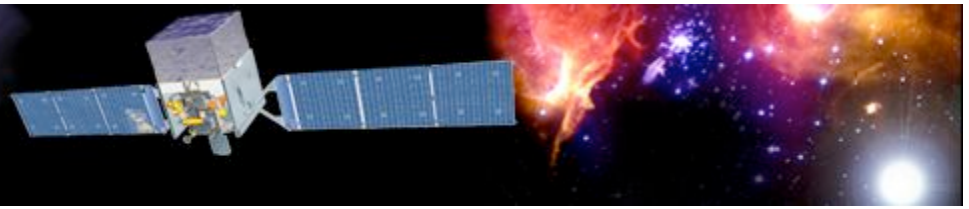
7° radius background region

2° radius source region



Xspec Analysis - 2

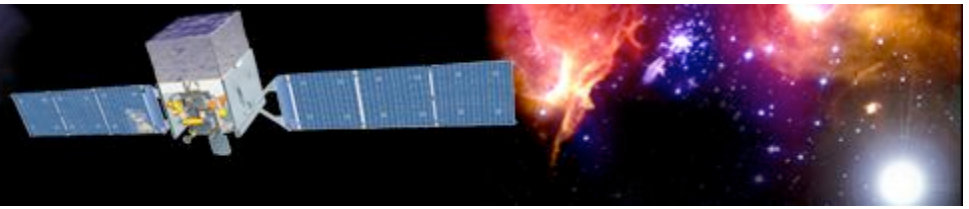
- *Run gtbin to create on-source and background pha files, gtrspgen to generate response matrix.*
- *Use grppha ftool to set background file and background file scaling (ratio of solid angles).*
- *Run Xspec as usual (statistic cstat).*



Xspec Analysis - 3

- *gtselect: 2 deg cone centered on PKS 2155–304*

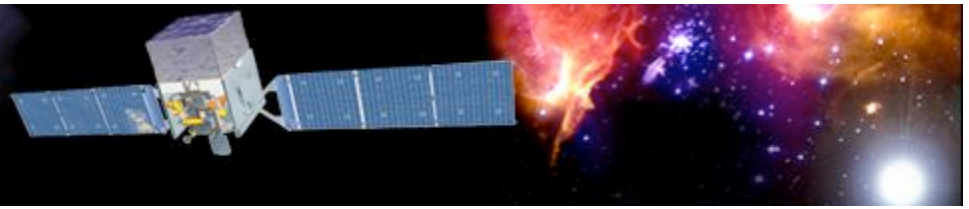
```
% gtselect
Input FT1 file[] @evfiles
Output FT1 file[] pks2155_filtered.fits
RA for new search center (degrees) (0:360) [0] 329.717
Dec for new search center (degrees) (-90:90) [0] -30.226
radius of new search region (degrees) (0:180) [180] 2
start time (MET in s) (0:) [0]
end time (MET in s) (0:) [0]
lower energy limit (MeV) (0:) [30] 200
upper energy limit (MeV) (0:) [300000]
maximum zenith angle value (degrees) (0:180) [180] 105
Done.
```



Xspec Analysis - 4

- *gtselect on background region:*

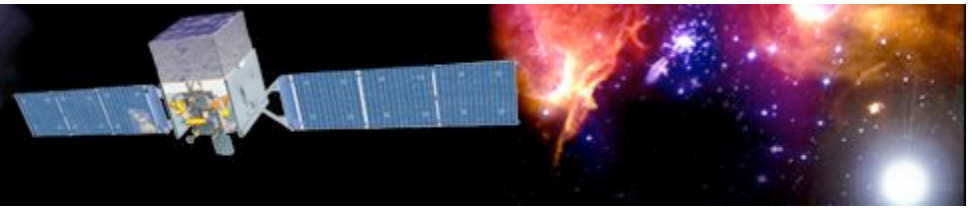
```
% gtselect
Input FT1 file[@evfiles]
Output FT1 file[pks2155_filtered.fits] pks2155_bg.fits
RA for new search center (degrees) (0:360) [329.717] 322
Dec for new search center (degrees) (-90:90) [-30.226] -23
radius of new search region (degrees) (0:180) [2] 7
start time (MET in s) (0:) [0]
end time (MET in s) (0:) [0]
lower energy limit (MeV) (0:) [200]
upper energy limit (MeV) (0:) [300000]
maximum zenith angle value (degrees) (0:180) [105]
Done.
```



Xspec Analysis - 5

- *gtbin to create pha file (same for source and bg)*

```
% gtbin
This is gtbin version v2r1p2
Type of output file (CCUBE|CMAP|LC|PHA1|PHA2) [PHA2] pha1
Event data file name[] pks2155_filtered.fits
Output file name[] pks2155.pha
Spacecraft data file name[NONE] LSI_sim_scData_0000.fits
Algorithm for defining energy bins (FILE|LIN|LOG) [LOG]
Start value for first energy bin in MeV[30] 200
Stop value for last energy bin in MeV[200000] 3e5
Number of logarithmically uniform energy bins[] 15
```



Xspec Analysis - 6

- *gtrspgen*

```
% gtrspgen
This is gtrspgen version HEAD
Response calculation method (GRB|PS) [GRB] ps
Spectrum file name[] pks2155.pha
Spacecraft data file name[] LSI_sim_scData_0000.fits
Output file name[] pks2155.rsp
Cutoff angle for binning SC pointings (degrees)[60.] 90
Size of bins for binning SC pointings (cos(theta))[.05]
Response function to use, Handoff|DC2|DC2A|DC2FA|DC2BA|DC2FB etc[Handoff] P6_V1_DIFF
Algorithm for defining true energy bins (FILE|LIN|LOG) [LOG]
Start value for first energy bin in MeV[30.] 20
Stop value for last energy bin in MeV[200000.] 5e5
Number of logarithmically uniform energy bins[100]
```

There is effective area at off-axis angles > 60°, so override default

Energy range should be larger than data selection