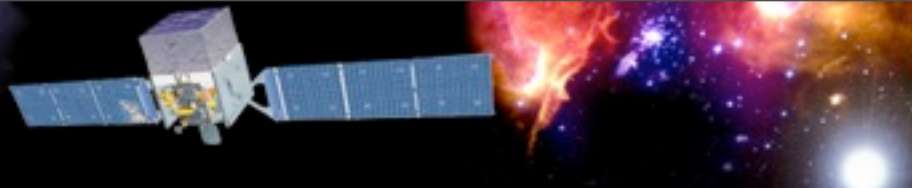


LAT Light Curve Analysis

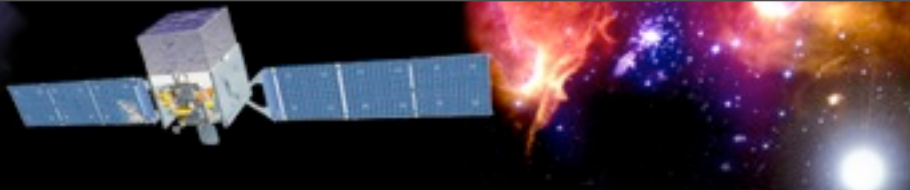
Robin Corbet
FSSC

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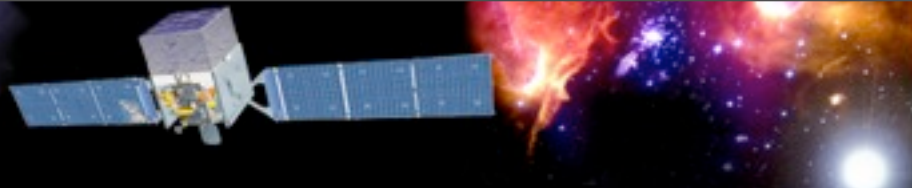
Photometry

- LAT light curves can be obtained in two basic ways:
 - Likelihood analysis
 - Aperture photometry
- Likelihood analysis has the potential for greater sensitivity. However, aperture photometry is easier, faster, and has the benefit of model independence.
- This presentation only deals with aperture photometry.



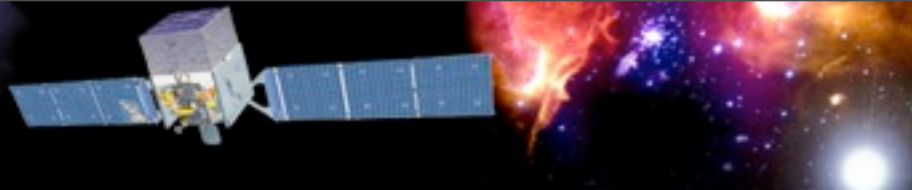
Tools Used

- Data server
- fkeypar/pget
- gtselect
- gtmktime
- gtbin
- gtexposure
- fdump + external data manipulation scripts



Steps

- It is recommended to use a script to chain together the tools.
 - `fkeypar` – determine file start and stop times
 - `gtselect` – filter data based on time, zenith limit, energy, position, and event class
 - `gtmktime` – create good time intervals
 - `gtbin` – make quasi-light curve (counts rather than rate)
 - `fdump` – export data
 - other tools – convert counts to rates, calculate errors



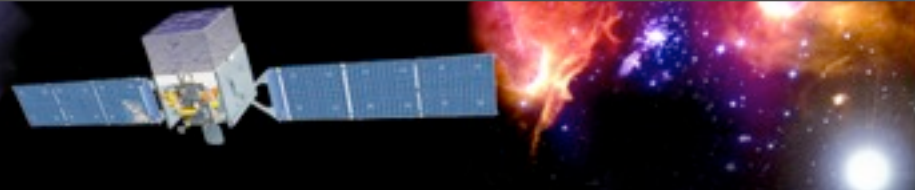
Get Photon File Start/Stop Times

```
$ fkeypar "L090923112502E0D2F37E71_PH00.fits[1]" TSTART
```

(photon start time = 266976000.)

```
$ fkeypar "L090923112502E0D2F37E71_PH00.fits[1]" TSTOP
```

(photon stop time = 275369897.)



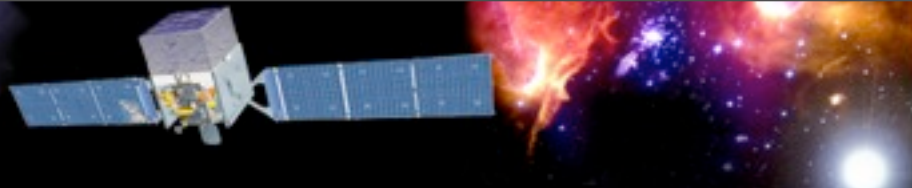
Filter the Photon File

```
$ gtselect zmax=105 emin=100 emax=200000 infile="L090923112502E0D2F37E71_PH00.fits"  
outfile=temp2_1DAY_3C454.3.fits ra=343.490616 dec=16.148211 rad=1 tmin=26697  
6000. tmax=275369897. evclsmin=3 evclsmax=10
```

Parameters specify:

- Energy range (100 to 200,000 MeV)
- Source coordinates
- 1 degree radius aperture
- start and stop times previously determined
(N.B. If you're going to barycenter then the min and max times should instead be slightly greater/less than the times in the spacecraft file.)
- evclsmin = 3 for DIFFUSE class (for simulated data use 0)

Writes to file: temp2_1DAY_3C454.3



Calculate GTIs

```
$ gtmktime scfile="L090923112502E0D2F37E71_SC00.fits" filter="(DATA_QUAL==1) &&  
(angsep(RA_ZENITH,DEC_ZENITH,343.490616,16.148211)+1<105) &&  
(angsep(343.490616,16.148211,RA_SCZ,DEC_SCZ)<180)" roicut=n  
evfile="temp2_1DAY_3C454.3" outfile="temp3_1DAY_3C454.3"
```

Parameters specify:

- Good data quality
- photons less than 105 degrees from zenith (+ 1 is because using a 1 degree aperture)
- photon locations less than 180 degrees center of field of view
- input file is output from gtselect

Writes to file: temp3_1DAY_3C454.3



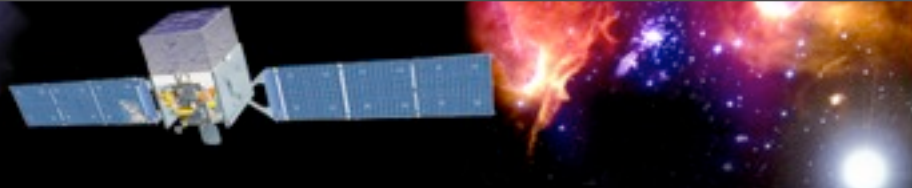
Extract a Light Curve

```
$ gtbin algorithm=LC evfile=temp3_1DAY_3C454.3.fits outfile=lc_1DAY_3C454.3.fits  
scfile=L090923112502E0D2F37E71_SC00.fits tbinalg=LIN tstart=266976000.  
tstop=275369897. dtime=86400
```

Parameters specify:

- Make a light curve (LC)
- Input file is output file from gtselect
- Spacecraft file
- Linear time bins
- Start and stop times again
- dtime = 86400: 1 day bins

Writes to file: lc_1DAY_3C454.3.fits



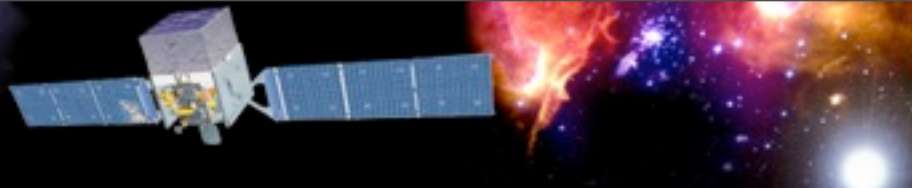
Calculate Exposures of Time Bins

```
$ gtexposure infile="lc_1DAY_3C454.3.fits" scfile="L090923112502E0D2F37E71_SC00.fits"  
irfs="P6_V3_DIFFUSE" srcmdl="none" specin=-2.1
```

Parameters specify:

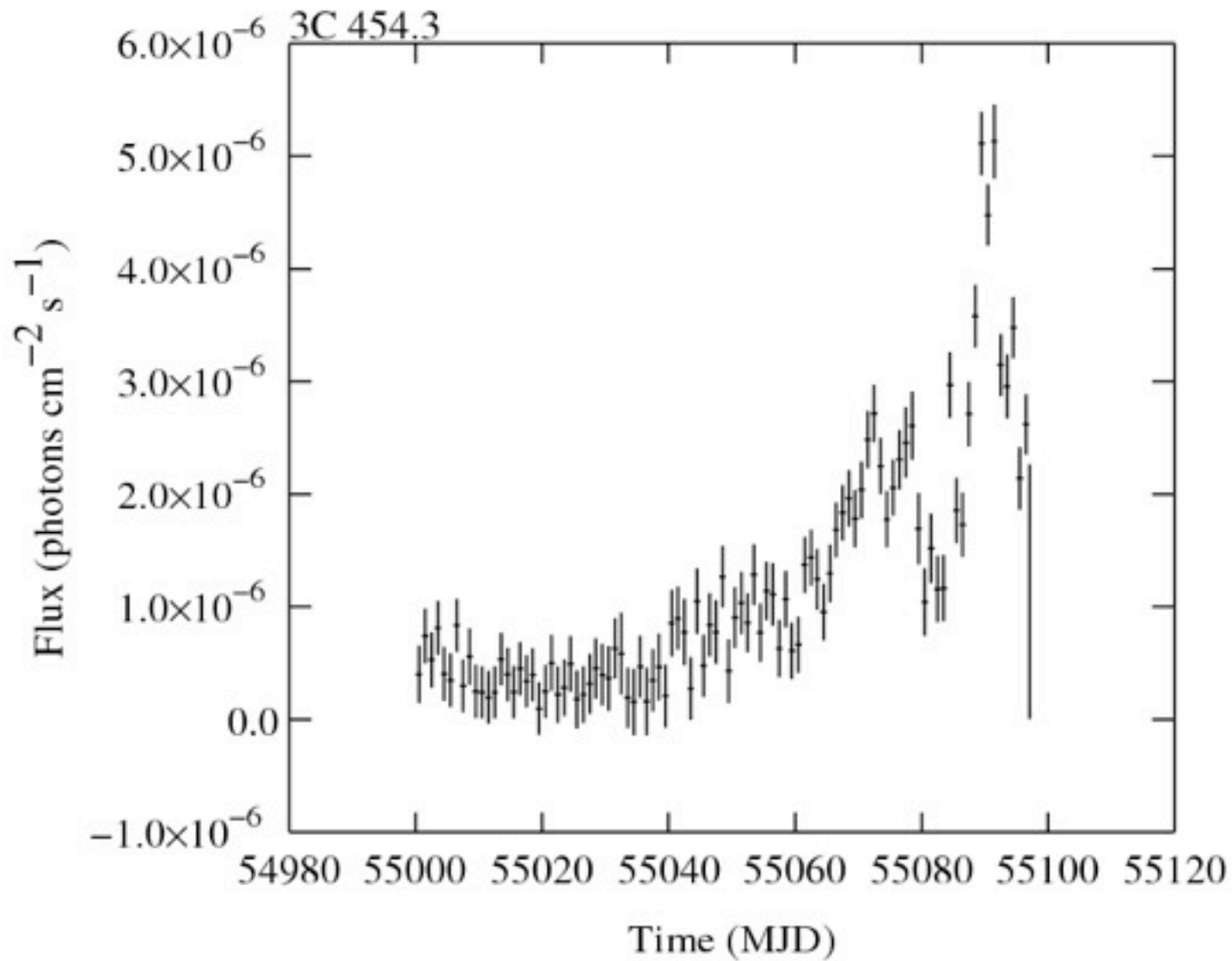
- Spacecraft file
- Instrument response functions (“irfs”). If, for example, SOURCE class rather than DIFFUSE was used in gtselect then use `irfs="P6_V3_SOURCE"`
- `srcmdl` – enables a more complex model than the default simple power law to be used in the exposure calculation.
- `specin` – photon spectral index for power-law spectrum. Note that the minus sign must be used.

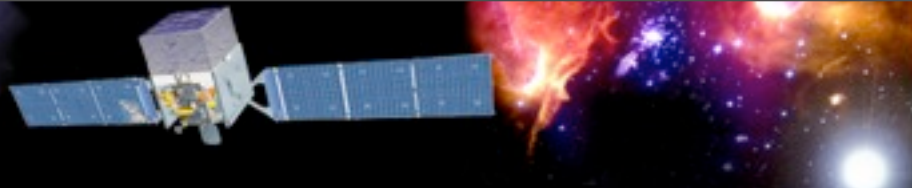
An EXPOSURE column is added to the input file: `lc_1DAY_3C454.3.fits`



The Output File

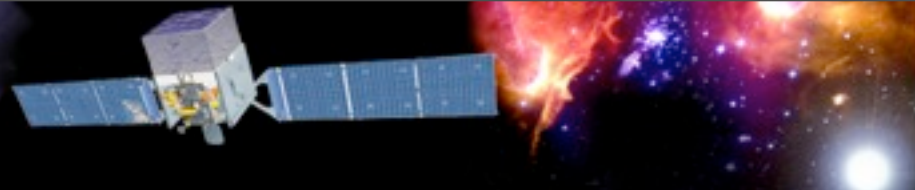
- The “final” file will contain Time (in MET), Bin width (s) number of counts in the bin, Error Exposure.
- To convert to rates use e.g. fv or other software to divide counts by exposure. (Also convert from MET to MJD.)
- Error bars in output file are $\sqrt{\text{counts}}$
 - For (e.g.) few counts this may be incorrect.
 - To do things correctly is more complicated (see supplemental material).





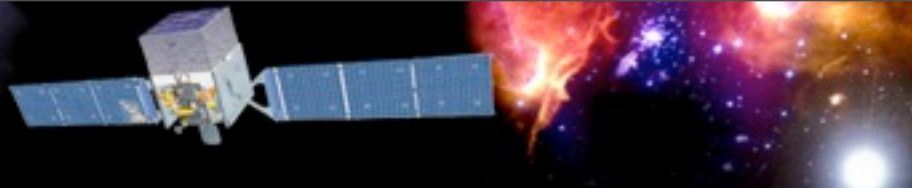
barycentering

- `gtbary` can also be used to barycenter light curves.
- `gtbary` must be done as the last step.
 - If you barycenter the photon file the exposure time calculations will be wrong!
- Spacecraft file must cover longer (not same) time range than photon file.
 - Use `gtselect` to trim down time range by tiny amount (e.g. 60 seconds)



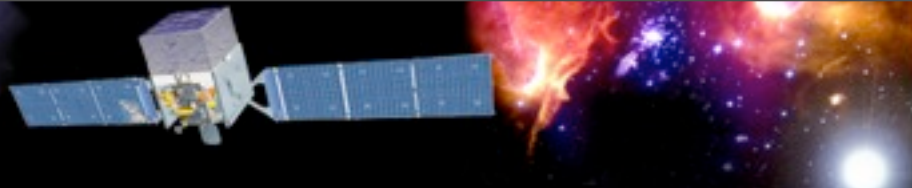
Supplemental Material:

Errors on Few and Zero Counts



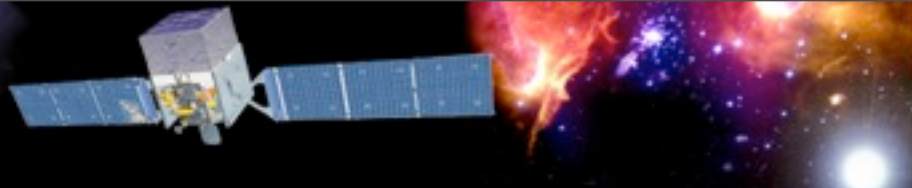
More Advanced Error Bar Treatment

- Dealing with error bars for small numbers of counts has been discussed in the astronomical literature by e.g.
 - Gehrels, 1986, ApJ, 303, 336
 - Kraft, Burrows, & Nousek, 1991, ApJ, 374, 344
- Useful review of concept of “coverage” by Heinrich in:
 - www-cdf.fnal.gov/publications/cdf6438_coverage.pdf



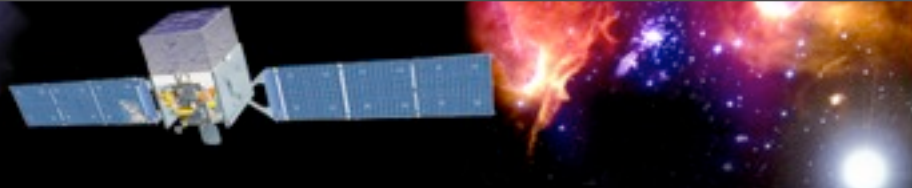
Simple Approach to Low-Count Errors

- Instead of taking errors as $N^{1/2}$, where N is the observed number of counts, look at the ends of the error bars.
 - i.e. what underlying “population” count rate would be consistent with the “sample” count rate?
 - $\sigma = \pm 0.5 + \text{sqrt}(N + 0.25)$
 - e.g. $0 \rightarrow 0, +1, -0$
 - $1 \rightarrow 1, +1.62, -0.62$
 - $2 \rightarrow 2, +2, -1$
- If needed, these errors can be “symmetrized”.



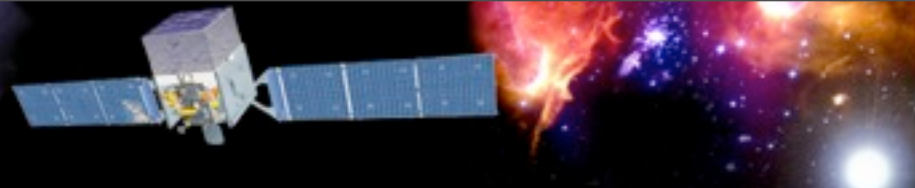
Count Errors vs. Exposure Errors

- For some purposes, errors based on observed counts are not correct.
- At low count rates there is considerable shot-noise.
- This gives Poisson variation in both count rate and error for time bins, even if the exposure is the same.
- An alternative is to use errors based on the exposure.



Exposure-Based Errors

- Calculate mean count rate.
- For each time bin, calculate the expected number of counts based on the exposure of that time bin.
- Take the square root of predicted number of counts.
- Divide by exposure to get rate.
- This gives an error based only on the “quality” of each time bin.



Comparison of Error Schemes: the Orbital Period of Cygnus X-3

