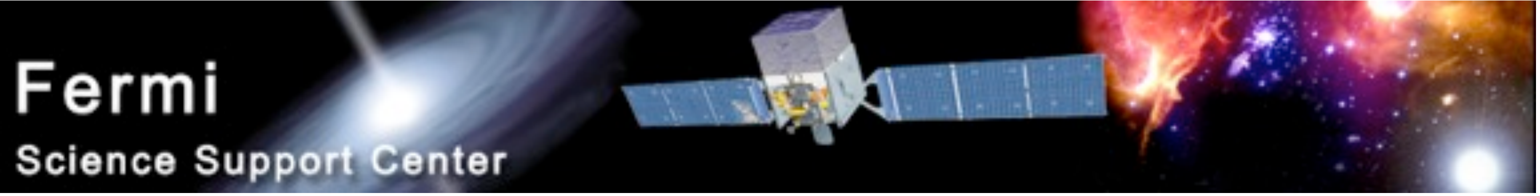

LAT Light Curve Analysis

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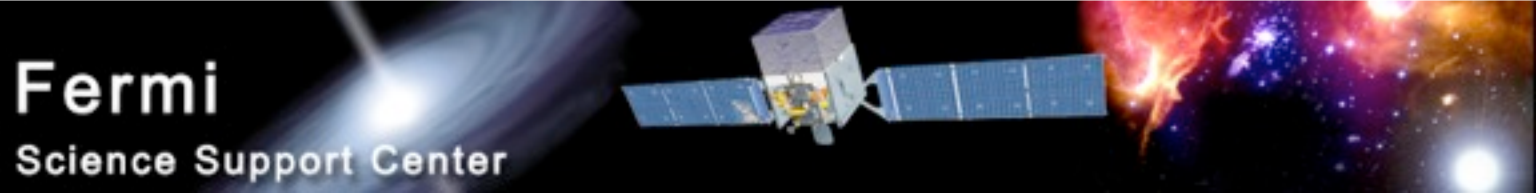
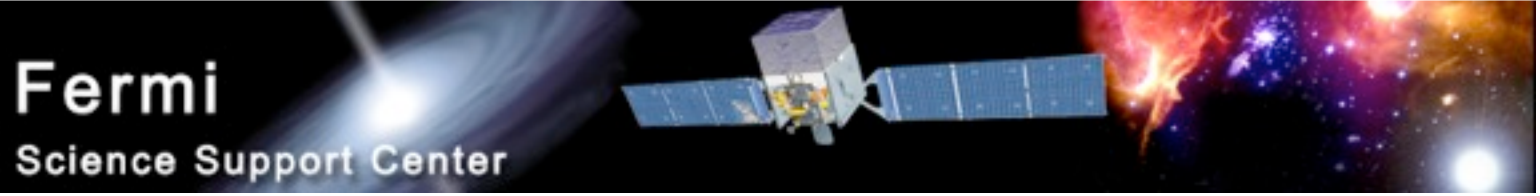


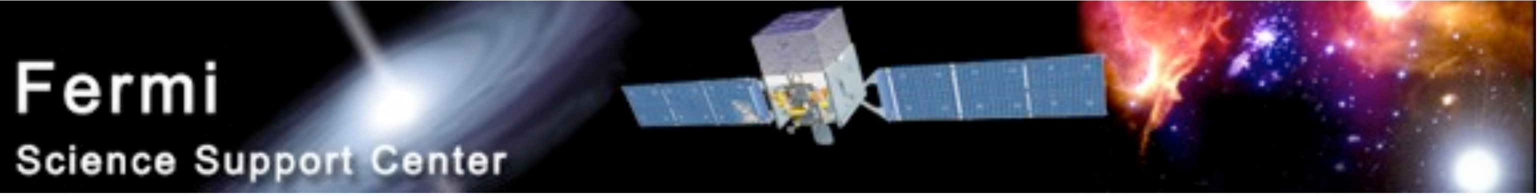
Photometry

- 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.



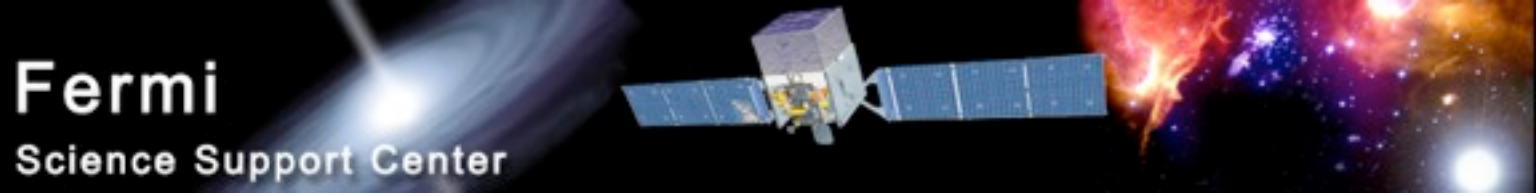
Tools Used

- 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



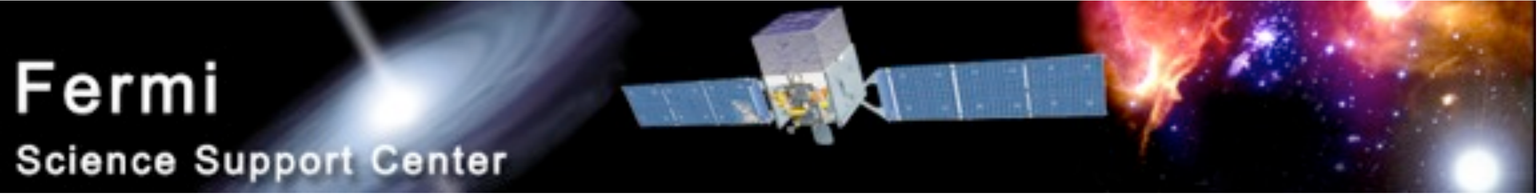
Get Photon File Start/Stop Times

$ fkeypar "L090923112502E0D2F37E71_PH00.fits[1]" TSTART

(photon start time = 266976000.)

$ fkeypar "L090923112502E0D2F37E71_PH00.fits[1]" TSTOP

(photon stop time = 275369897.)



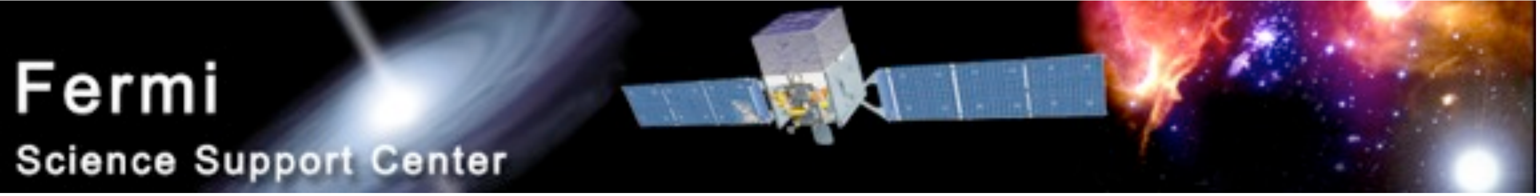
Filter the Photon File

$ 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=266976000. tmax=275369897. evclsmin=3 evclsmax=10

Parameters specify:
- Energy range (100 to 200,000 MeV)
- Input file is output file from gtmktime
- 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 <u>simulated</u> data use 0)

Writes to file: temp2_1DAY_3C454.3

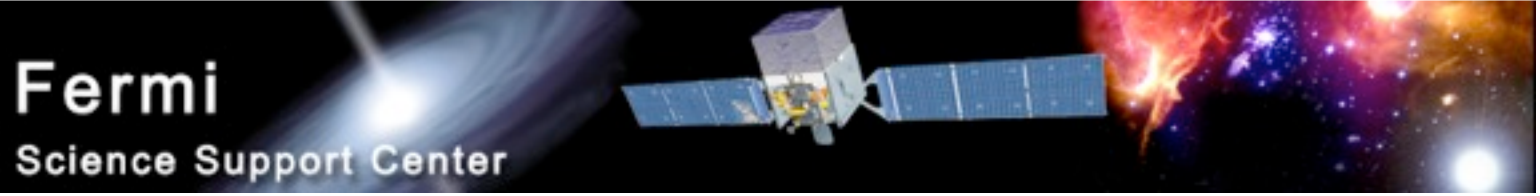


Calculate GTIs

$ gtmktime scfile="L090923112502E0D2F37E71_SC00.fits" filter="(IN_SAA!=T) && (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:
- Not in SAA
- 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

Writes to file: temp3_1DAY_3C454.3

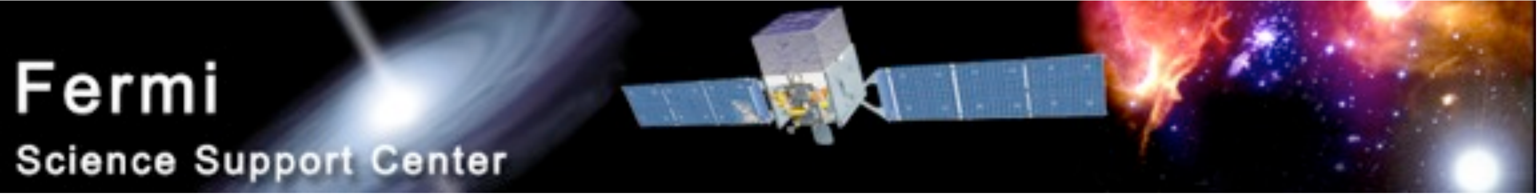


Extract a Light Curve

$ 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

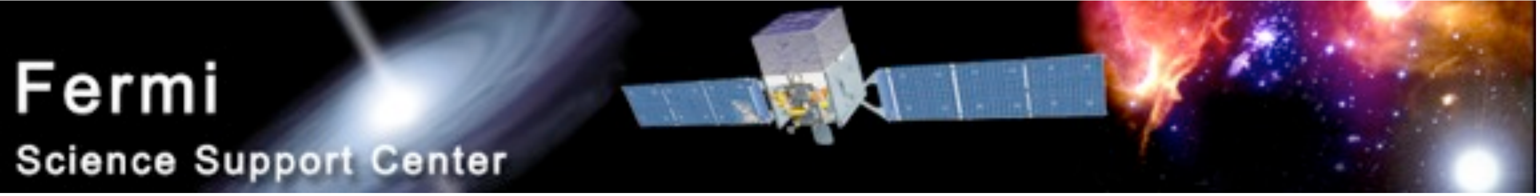


Calculate Exposures of Time Bins

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

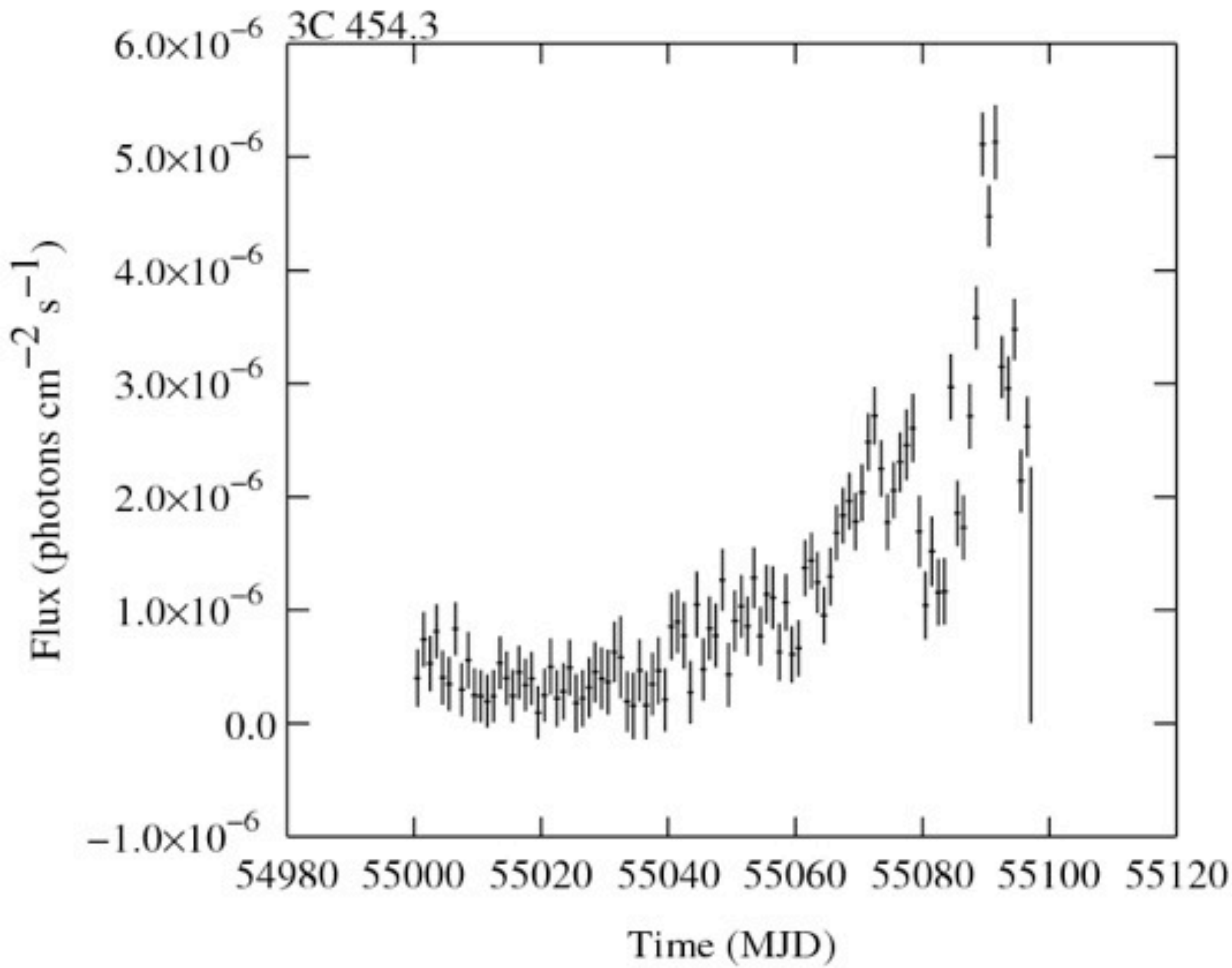
Parameters specify:
- Spacecraft file
- Instrument response functions (“irfs”). If, for example, SOURCE class rather than DIFFUSE was used in gtselect then use irfs="P6_V3_SOURCE”
- srcmdl – enables a more complex model than the default simple power law to be used in the exposure calculation.
- specin – 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



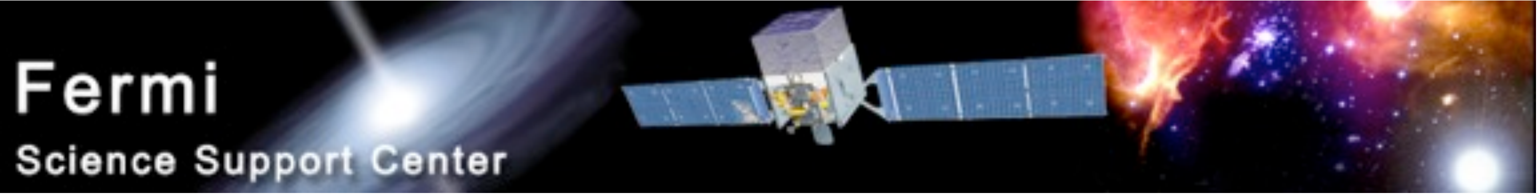
The Output File

- 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(counts)
  - For (e.g.) few counts this may be incorrect.
  - To do things correctly is more complicated (see supplemental material).


3C 454.3
6.0×10⁻⁶
5.0×10⁻⁶
4.0×10⁻⁶
3.0×10⁻⁶
2.0×10⁻⁶
1.0×10⁻⁶
0.0
−1.0×10⁻⁶
Flux (photons cm⁻² s⁻¹)
54980 55000 55020 55040 55060 55080 55100 55120
Time (MJD)

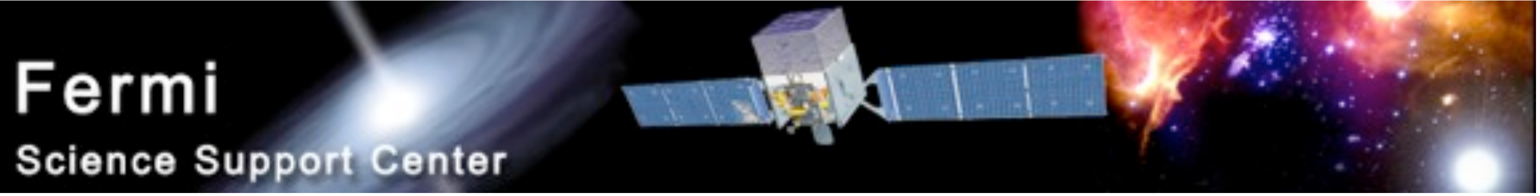
barycentering

- 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)



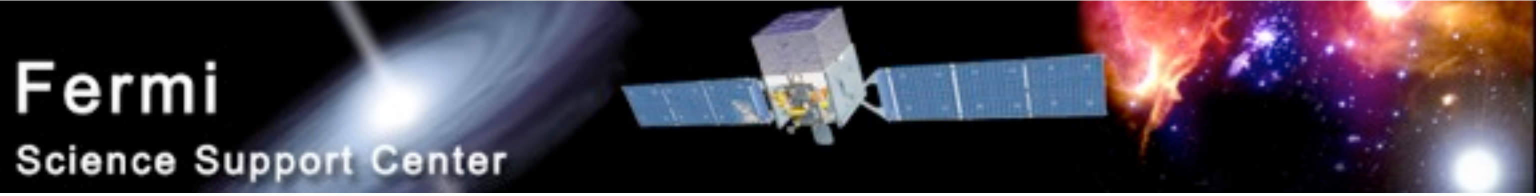
Supplemental Material:

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?
    - $\sigma = \pm 0.5 + \mathrm{sqrt}(N + 0.25)$
        - e.g. 0 → 0, +1, -0
        - 1 → 1, +1.62, -0.62
        - 2 → 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