Exposure Calculation for the LAT

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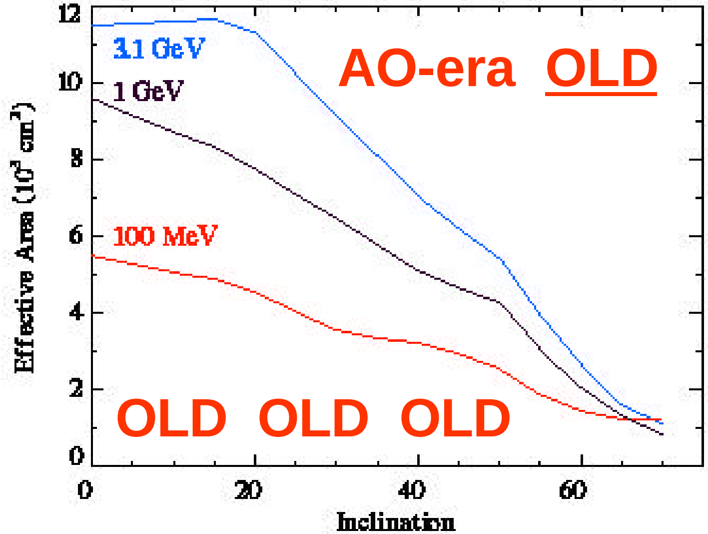
What is exposure?

- The problem:
  - What do we want? Calibrated Fluxes!
  - When do we want them? Right Now!
- The concept is that exposure is used to normalize the instrumental response
  - In application, exposure is used equivalently to convert physical models to ‘counts space’ where the fitting is performed
- Flux for a point source is measured in photons $cm^{-2}\ s^{-1}$ or $cm^{-2}\ s^{-1}\ MeV^{-1}$; for extended emission add sr^{-1}

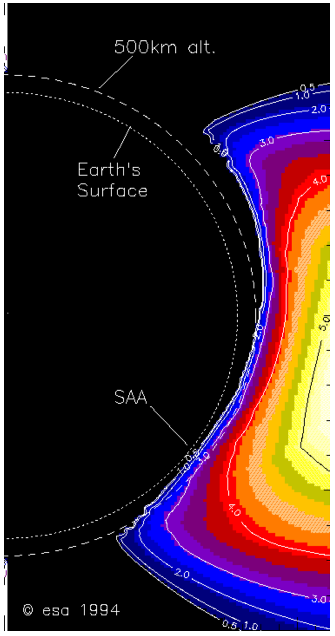
Area × Time factor

Complications

- Livetime is not 100%; minimum deadtime per trigger is ~5 μs, plus LAT will be off in the SAA
- Effective area depends on lots of parameters, like inclination, azimuth, energy, plane of conversion
- And because the PSF & Eng res depend on these parameters, too we can't just integrate over them but instead need to keep track of how exposure depends on them
- The LAT will generally be scanning and rolling during observations



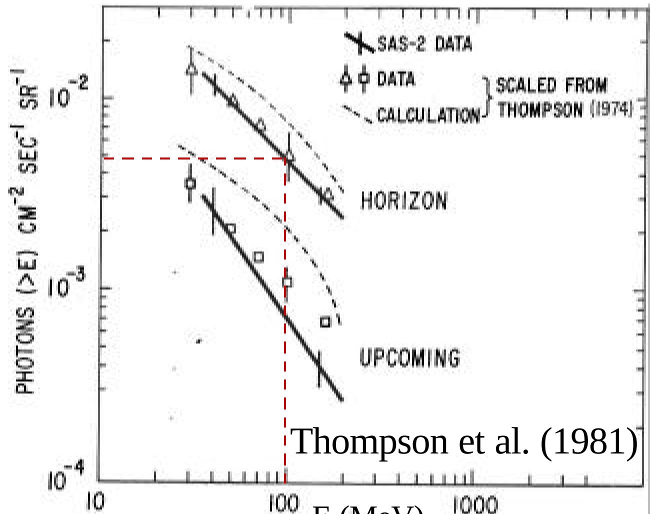
SAA in cross section



http://www.estec.esa.nl/wmwww/wma/rad_env.html

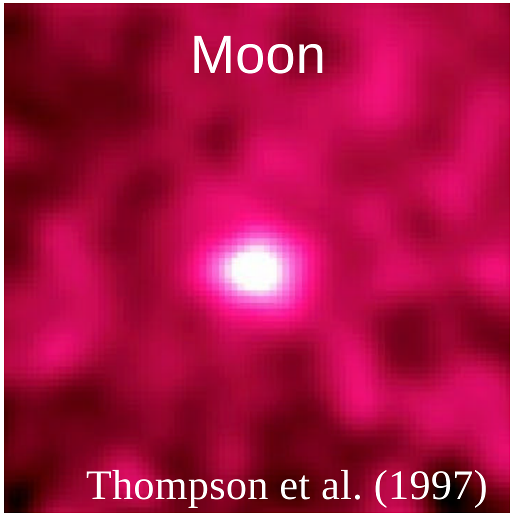
Complications 2

- We need to exclude the earth's limb (and the region of the sky occulted by the earth) from the analysis
- While we are at it, we should exclude the positions of the moon & sun (and Jupiter, too?) [unless we are trying to study them as sources]



Thompson et al. (1981)

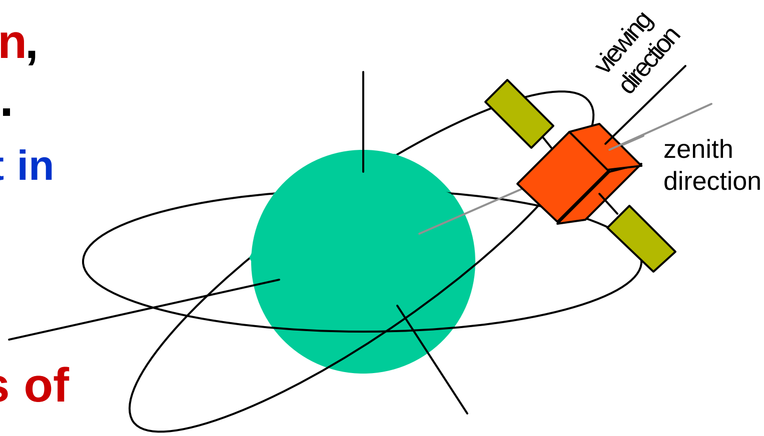
Flux: $(4.7 \pm 0.7) \times 10^{-7}$ cm^{-2} s^{-1} (>100 MeV) (image 40° × 40°)

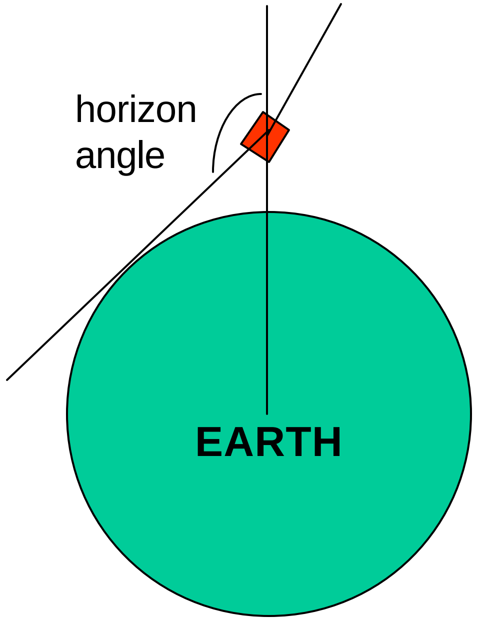


Thompson et al. (1997)

Complications 3

- Note that the cuts for the earth, sun, Moon, etc. necessarily will be fairly complicated.
  - In order to limit the loss of useful data, but in recognition of the significant energy and angle dependence of the PSF, the cuts will depend on energy and angle.
- Note that we will likely have several kinds of response function to juggle in high-level analyses of the same time range,
  - e.g., front vs. back converting or even CAL-only gamma rays.
  - Each set of response functions has a different corresponding set of zenith angle limits, which suggests that a single query of the LAT Level 1 database would require many calculations of exposure





How can exposure be calculated for the LAT?

- One consideration works in our favor: The effective area does not vary quickly on scales of even several degrees
  - This means that we can calculate exposures on a fairly coarse spatial grid, and can base them on a pointing/livetime mode database that itself has fairly coarse (corresponding to degree-scale angular bins)

Basic procedure for exposure calculation

- See tool U3
- *For any particular direction on the sky*, the exposure calculation for the LAT would go like this: [Make flow chart?]
  1. Using the entries of the pointing/livetime/mode history database for the time range of interest, for each timestamp, evaluate the inclination, azimuth, and zenith angle
  2. If it passes the zenith angle limit check and the limits on angular distance from the sun, moon, etc., then add the livetime for that interval to the current tally (think multidimensional histogram) for that inclination and azimuth (and energy, and plane of conversion)* HERE'S THE PROBLEM
  3. For the response functions that you are interested in (i.e., for those that apply to the gamma rays that you have selected for study), convert the livetime tally into exposures using the tabulation of the dependence of effective area on all of these parameters
  4. If you've got more than one kind of event in the analysis, go back and calculate the livetime tally again for the next kind of event
- These livetime tallys would be BIG.

Work around

- Accumulate livetime as a function of inclination, azimuth, AND zenith angle.
- Then apply the zenith angle limits later, while calculating the exposure
- Standard limits would generally be predefined for each set of response functions
- [What about sun, moon, etc.?]
- The ‘exposure’ calculated by U3 would be a livetime tally. Actual exposures would be calculated from this (by the tools that need exposure) by applying the zenith angle limits for integration and the effective area tabulations for each set of response functions of interest

Make it go fast

- **Exposure evaluations will involve a lot of calculations, especially for large exposure maps (e.g., a grid of ~10^4 positions on the sky) for a large time range (~10^6 time steps/year)**
- **A lot of the work is in trigonometry, evaluating all kinds of angular distances (from z-axis, from zenith, azimuth, sun, moon)**
- **Some time ago, Cathie Meetre (who was thinking about spatial access databases) realized that the same kinds of cells used to tessellate the sky could also be useful for exposure calculations.**
  - **The trick: discretize the coordinates (using spatial cells that are small compared to the angular scale over which the response functions vary significantly) and then once and for all calculate a giant lookup table.**
  - **For each spatial cell (approx ~10^4 2°×2° cells would cover the sky), tabulate the angular distance from every other cell.**

Make it go fast (2)

- **Then for any cell on the sky, the angular distances you need can be extracted quickly from the lookup table**
- **Much of the remaining work is in interpolating the response functions, which is not computationally intensive**

Open issues

- **For routine work can't we just ignore the (usually) shadow of the sun or the flux of the moon?**
  - **Related question from Tune Kamae: Isn't the ecliptic then a bright streak?**
  - **I think that the answer is no, that the ecliptic is not a detectable streak in the EGRET data. The intensity of the moon is diluted too much. Averaged over the 360° circumference of the ecliptic and the ~5° inclination of the moon's orbit with respect to the ecliptic, the increment to the diffuse intensity would be about 5×10^{-7} cm^{-2} s^{-1} sr^{-1} (>100 MeV). The average intensity EGRET measured on the sky is 5.7×10^{-5} cm^{-2} s^{-1} sr^{-1} (>100 MeV), and the average intensity for $|b| >$ 30° is 2.5×10^{-5} cm^{-2} s^{-1} sr^{-1} (>100 MeV)**
- **What if we actually want to calculate the exposure to the moon (or other moving source), or in instrument coordinates?**

Open issues 2

- **Exposures for very short intervals of time**
  - **Will be important only for GRBs**
  - **Then we will have to examine the livetime counter values in the events**
- **Point exposure tool (would it answer the ‘time series exposure’ question?)**
  - **Simpler than marginalizing a multidimensional exposure over all of its dimensions**