Application of HEALpix Pixelization to Gamma-ray Data

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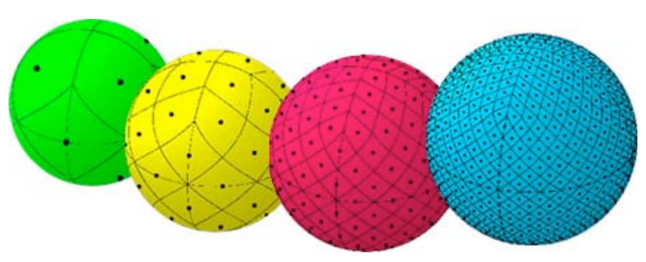
Abstract

The HEALpix scheme for tessellating the sky is a natural way to represent all-sky data that is naturally binned in sky coordinates, for example, WMAP. Gamma-ray data is collected and saved as individual photons, and usually analyzed as such. We present a summary data representation that is compact, saves energy information, and is consistent with the energy-dependent resolution. We take advantage of the equal-area, hierarchical characteristics of the HEALpix representation by relating pixel size to energy band. The data set is a sparse list of variable-size pixels, arranged to group regions of the sky. Thus numerous low-energy photons share pixels, while rare high-energy photons often are represented by single pixels. Of course, time variation is lost. We will show how this is used for generating sky pictures, efficiently finding and localizing point sources, and even construction WMAP-like angular power spectra.

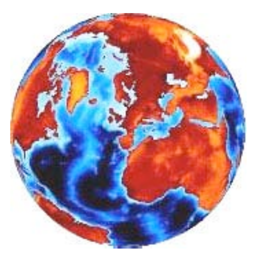
What is HEALpix?

See http://healpix.jpl.nasa.gov: This is a scheme for tessellating the sky into equal-area, quadrilateral pixels which are:
• Hierachical: different scales are nested: specified by a parameter n_{side}
• Equal-area: simplifies integration, weighting schemes

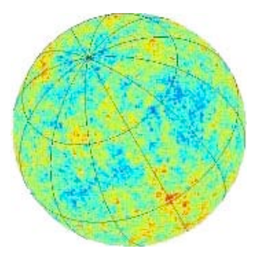
It is the way that WMAP presents its data, and has been adopted by other CMB missions, like Planck.



Showing grid refinement



Earth: ~3M pixels

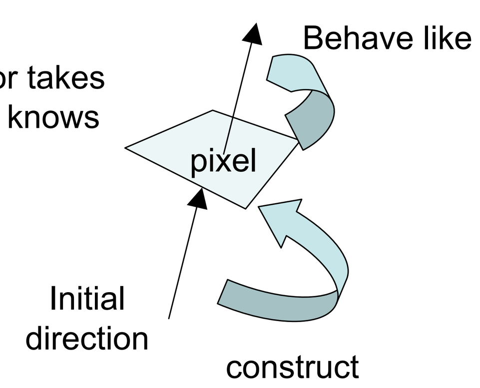


CMB data: ~12M pixels

It is also a very efficient way to express sky coordinates by single integers. For 32 bit integers, one can index ~800M pixels with separation of 0.5 arcmin, quite adequate for GLAST.

Utility routines for converting to and from spherical coordinates are available from JPL, and incorporated into the LAT science analysis software.

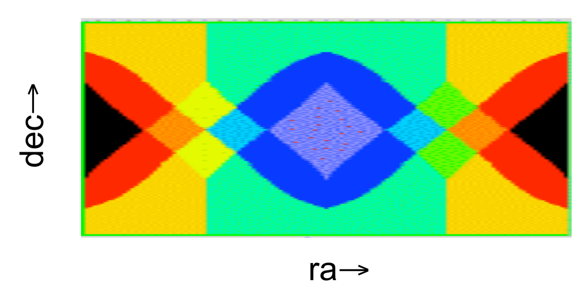
Define a C++ "Healpix" class to encapsulate the external code. The constructor takes a direction, represents itself by the index. A pixel behaves like a direction, and knows its
- direction
- area, or solid angle
- neighboring pixels (7 or 8)



Application to exposure calculations

This is a natural way to present any data that is distributed over the entire sphere. We use 1-degree pixels.

Exposure calculation is a 2-step process:
1. Create exposure cube: Integrate (or sum) over a history, generating the exposure as function of sky position (ra, dec) and angle to GLAST z-axis. (And maybe eventually phi). Save as intermediate file –this is very time-consuming process. The result is a table indexed by healpix index and θ bin, covering the full sky.
2. Use the exposure cube to perform a integral over effective area, a function of energy and θ , for desired sky positions.

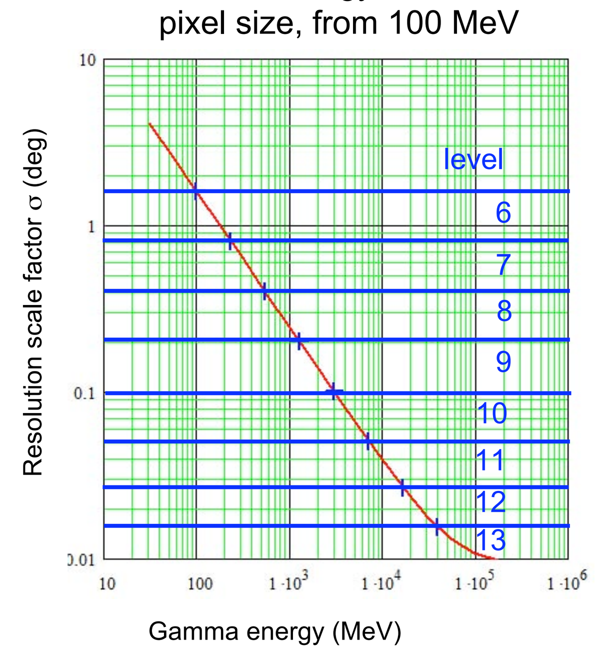


The "quilting block" example: showing the boundaries of 48 pixels (CAR projection) with on FOV function $F(\theta)=(\cos\theta -1)/2$ and a single point at (ra,dec)=(0,0)

Binning on the sky: multiscale images

- **The problem:** GLAST-LAT images the sky, but it is **not** an imaging device! Each photon has its own unique reconstructed direction and resolution, described by the point spread function, or PSF. LAT data spans three decades in energy, and the corresponding PSF depends very dramatically on energy, a result of multiple scattering, itself varying by two orders of magnitude. The dependence on angle is rather small.
- **A solution:** HealPixel objects: Bin the photons into HEALpix pixels, but use the hierarchical property to vary the size according the energy.
The HealPixel class is designed for this, adding one more piece of information to the Healpix class described above, namely the energy bin. The diagram shows the correspondence, appropriate for photons converting in the front, or thin converter section.There are 8 nested levels, from 100 MeV, by factors of 2.3, the last above 40 GeV.
The storage is sparse: unlike an image, only non-empty pixels are stored.

Relate energy bands to pixel size, from 100 MeV

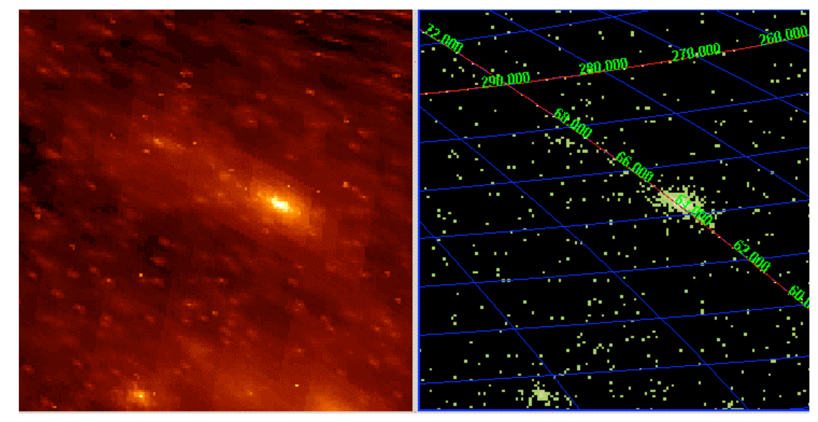


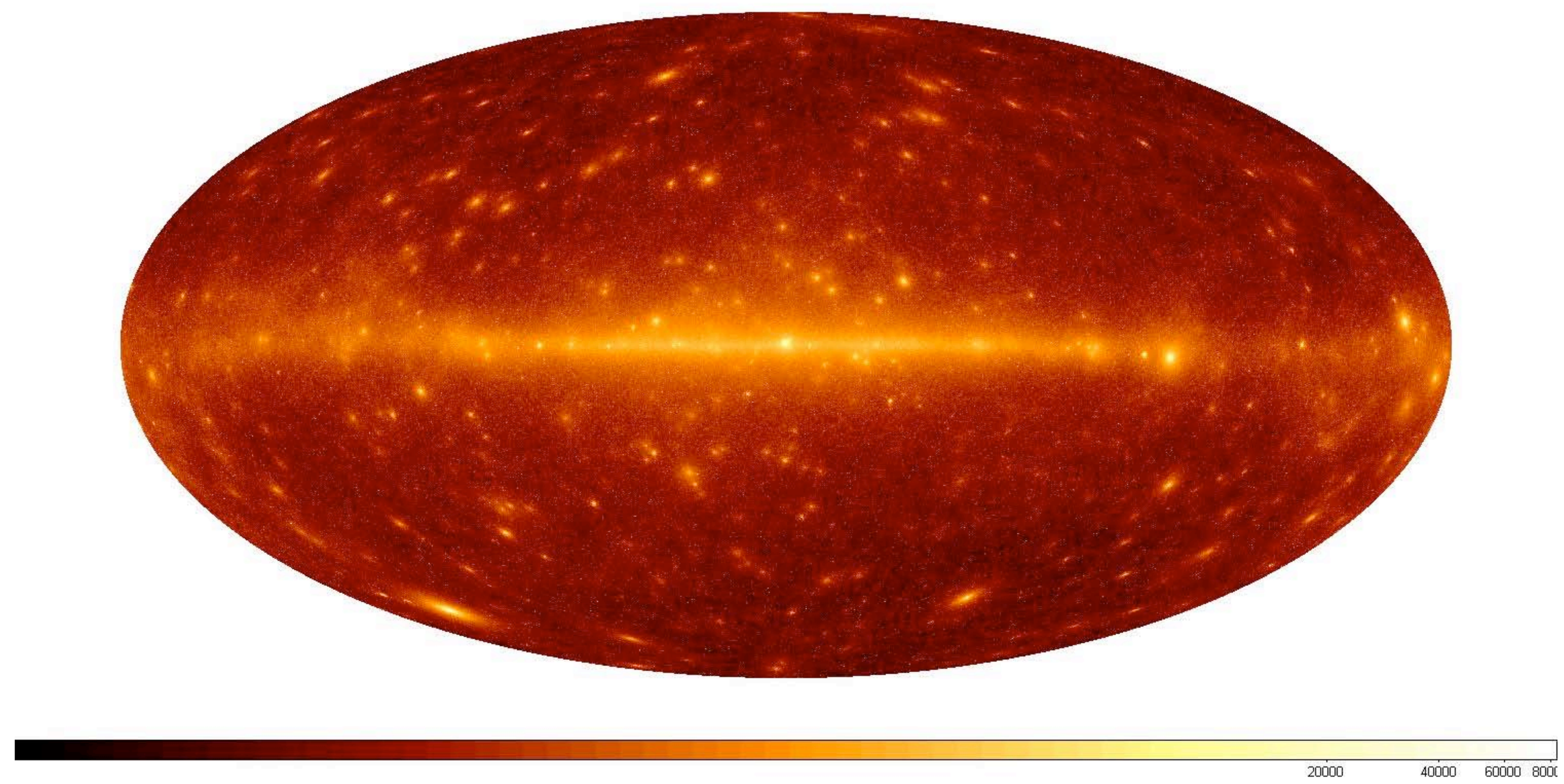
Images that emphasize point sources

Images can be very useful. Since high energy photons are more localized, and represented by smaller Healpixels, we express this by defining the **density**, photons/area, which is easily determined from the data base and the Healpix code.

At right: DC2 images of 3C273: density vs. all photons above 100 Mev

Below: the full sky, from a 1-year simulation





Finding and localizing Sources: the UW algorithm

The HealPixel database is efficient for storage, capable of storing all the data for the entire mission in memory. Selection of regions of the sky is easy and fast, due to the hierarchical indexing scheme.
After populating the Healpixel structure, the UW algorithm applies a series of tests to narrow down the likely source candidates:
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1. **Level 8 weighted pixel count**. All 786,432 level 8 pixles are examined to see if there are enough photons, including those in nested higher-level pixels, to be worth attempting a fit.
2. **Simple Likelihood fit**. Starting from each candidate location, a simplified maximum likelihood fit is performed. It assumes a model of a single point source on a uniform background. Only HealPixels from levels 8 and above are included in order to minimize false positives associated with the fact that the background is not uniform on larger scales. Each level is fit independently, but assumes a common location for the point source. The fit, including finding the best position, must converge. Than a threshold is applied to the total test statistic (TS.)
3. **Non-weighted count, with children**. Starting from each remaining candidate location, the algorithm determines the level 8 pixel in which it is included. A non-weighted count of photons is then taken for the enclosing level 8 pixel and its children. If the result is above a given threshold, the candidate is accepted.
4. **Prune neighbors**. This step eliminates candidates which overlap the error circles of candidates that have higher TS values. In addition, any candidate closer than 0.25 degrees to a stronger candidate (comparing TS values) is eliminated.
5. **Apply power law filter**. Finally, false positives are greatly reduced by fitting the spectra (the 8 separate bins) to a power law, and including that in the TS. (This step is under development)

Current status: very fast (39 min total for DC2) good efficiency and localization, but too many false positives.

Angular Power Spectra!

This is a WMAP-like analysis of the angular power spectrum, easily done with the HEALpix tools. This is photons only, but there are predictions for the distribution of blazars (astro-ph/06101155).