11-May-2009

Choosing the Number of Roll Bins for RHESSI Visibilities

G. J. Hurford

Each RHESSI visibility measures a single Fourier component of the x-ray source distribution. Whether a visibility is measured during a single rotation of the spacecraft or during multiple rotations, the measurement must necessarily average over a range of roll angles. This memo discusses the issue of how to choose the range of roll angles over which to average and the implications of the choice.

Background

RHESSI visibilities are calculated by first associating each time bin in the modulated light curve with two parameters, roll and phase, which, for a given choice of map center fully define the circumstances of the measurement. The association takes into account the aspect solution. Roll is the orientation of the grids relative to solar north. Phase is a measure of the position of the grids modulo their angular period. The peak of a modulation cycle for a source located at the map center corresponds to a phase of zero.

The roll and phase parameters effectively replace time as the independent variable for that time bin. For each roll bin, the data with various phases are then fitted to a sine-wave and the resulting fit parameters (after calibration) measure a single visibility. The number of phase bins (default 12) is sufficiently large to prevent excessive loss of s/n due to digitization. The issue at hand is the seemingly mundane one of how to choose the size or number of roll bins.

This RHESSI issue is analogous to choosing the averaging time in radio interferometry. "Visibility averaging" is discussed in section 6.4 of *Interferometry and Synthesis in Radio Astronomy,* by Thompson, Moran and Swenson.

Implications of Roll Bin Size

What are the implications of the choice of roll bin size?

First, we note that a finite roll bin is equivalent to averaging over a range of roll angles. (For example, using 32 roll bins per rotation corresponds to averaging over 11.25 degrees of rotation. For a source 30 arcseconds from map center, such averaging would smear it by ~6 arcseconds.) Note that sources are rotationally smeared about the *map center*, not *sun center*. Clearly we want to choose roll bins that are sufficiently small that this smearing is acceptably small. Note also that the deleterious effects can be minimized by choosing a map center close to the source components.

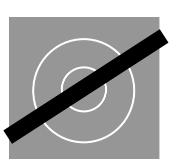
The effect of the rotational smearing is manifest in four ways: first, as a reduction in the amplitude of the observed visibility; second, as an apparent increase in the azimuthal size of reconstructed source components; third, in terms of the shape of the source component, and fourth, as a reduction in apparent peak (as opposed to spatially-integrated) intensity of a given source. (Note the relevance of these effects to studies of the relative size and flux of footpoints, for example.)

Note that while using more roll bins decreases the s/n in each visibility, this is fully compensated by having more visibilities to use as input to the mapping. As a result, to first order, the number of roll bins does not affect the *statistical* noise in the resulting maps. However, a larger number of roll bins provides more *uv* points for mapping and so tends to reduce sidelobes.

Limitations on the Number of Roll Bins

Although it would appear that more roll bins are better, there is an important constraint that prevents the number of roll bins from increasing arbitrarily, namely the requirement that a visibility measurement must integrate over at least ~one modulation cycle. This means that within each roll bin, data must be available over a range of phases. If this is not the case, then fitting the amplitude and phase and 'DC' component is unduly sensitive to systematic errors. At present this is implemented (*hsi_visibility_fit*) by requiring that the maximum phase gap between adjacent phase measurements be less than 2 radians (115 degrees). For example, phases sampled at 0, 90,180, 270 degrees would be ok; phases sampled at 0, 45, 90,180 degrees would not. Ed Schmahl has opined that this criteria is too conservative and has suggested an alternative based on the (pivot-element?) results of the least squares fitting algorithm.

In practice, this (necessary) requirement often results in missing visibility measurements, particularly during the slow segment of the modulation profile and for the coarse grids. Another perspective is that this requirement leads to a linear gap in coverage across the *uv* plane, shown schematically below.



In summary then, the tradeoff in the choice of the number of roll bins is between having sufficiently large number to avoid excessive degradation for sources displaced from the map center while having a sufficiently small number to enable reliable measurements in terms of the modulation cycles.

Note that, for a given subcollimator, the minimum number of roll bins is determined by the source extent (radius), whereas the maximum number of roll bins is determined by the offset between the spin axis and the source location.

Current Options for calculating the number of roll bins

There are several options currently in use for calculating the number of roll bins.

- Specify a fixed number (e.g. 32) of roll bins for each subcollimator. This was the original default, chosen for simplicity and to facilitate visibility comparisons at specific azimuth angles.

- Specify of the maximum source offset from map center (phase_radius) from which the minimum even number is automatically calculated and used, subject to upper and lower bounds. This chooses the smallest acceptable number of roll bins, $N_{min}(i)$.

- Use *hsi_vis_rollbin_nominal* to calculate the largest number, $N_{max}(i)$ of equal rollbins for a given source to rotation axis offset such that each roll bin contains at least on modulation cycle. (The problem occurs when $N_{min}(i) > N_{max}(i)$.)

- Use the 'Massone strategy' to maximize the number of calculated visibilities by 'trial and error'. (effective, but not very efficient)

Debatable assumptions associated with the tradeoff:

- Currently the recommended option is to use an even number of roll bins per rotation. The advantage of this is that some systematic errors in the calculation of the visibilities tend to cancel when conjugate visibilities are calculated. The alternative of using an odd number of roll bins has the advantage that about twice as many independent visibilities would be available, but with an increased risk of systematic errors.

- The strategy of using roll bins of equal azimuth range has the advantagesthat to first order, all visibilities have comparable statistical error. An alternate approach might tailor the roll bin width to the modulation frequency. This would have TBD effects on the imaging.

- The requirement that each time bin contributes to just one roll-phase bin results in statistical independence of all calculated visibilities. This is an important requirement for most visibility-based algorithms, but not all (e.g. uvsmooth). If this requirement were relaxed, the tradeoff issue is largely resolved.

- It might be possible to increase the number of independent visibilities by using a form of 'interleaved binning', whereby the association of successive time bins is toggled among overlapping roll bins.

- In cases where the number of roll bins were limited, a post-facto correction could be applied to the resulting smeared maps.

ISSUES FOR DISCUSSION:

- Should we relax the requirement that each count contribute to only one visibility? (Requires substantial recoding.)

- Should we default to an odd number of roll bins per rotation? (An easy improvement, but requires evaluation of typical systematic errors.)

- Should we provide option of unequal roll bin widths? (Requires evaluation of effect on imaging.)

- Should we implement interleaved roll bins? (Requires substantial recoding.)

- Should we retain present criteria for phase diversity, change its parameterization or adopt an alternate strategy such as suggested by EJS? (Might provide some relief, but requires evaluation.)

OTHER ISSUES

- The source of remaining systematic errors (such as the effect of time varying flux) should be evaluated.

- The calculation of visibilities and the demodulation corrections for light curves are closely intertwined. Improvements to both would be possible if a common 'engine' was used and this would also provide a natural way to extract visibilities for high-time resolution imaging. (Strategy would involve mapping current timebins into roll bins labeled with roll angles that increased monatonically instead of wrapping.)