Spectrum estimation for ASTROSAT CZTI using Bayesian inference

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X-ray sources are highly variable i.e., their spectrum changes irregularly with time. Thus, the study of the energy spectrum (intensity as function of wavelength) of these sources is of paramount importance. In direct imaging technique, we can estimate the source spectrum by considering the counts in the region illuminated by the source. However at high energies indirect imaging methods such as Coded Mask Imaging (CAM) are open used to help cover a large Field of View (FOV). In Coded Mask Imaging each source illuminates almost the whole detector. Hence, for indirect imaging we can not use conventional methods to estimate spectrum.

One proposed technique to estimate the source spectrum is Mask Weighting, which assumes that the source location is known. In Coded Mask Imaging, each photon is recorded as an individual event tagged with time, energy and position. We can assign weight w that a photon is contributed by the target source. Weight for each event can be calculated using, $w_t(i_k, j_k) = 2f(i_k, j_k) - 1$. Here f is the open fraction for the detector position (i_k, j_k) for lines of sight towards the target source.

We have simulated event files for ASTROSAT CZTI, and applied mask weighting technique to reconstruct the source spectrum. We found that, mask weighting is able to estimate the source spectrum for single source in the FOV but it fails to estimate the spectrum in presence of multiple sources of comparable strength in the FOV. In indirect imaging, detected photons can not be uniquely traced back to a specific source and hence, probabilistic methods such as Bayesian inference need to be implemented for the estimation of spectrum. We have developed a technique based on Bayesian inference which assumes a prior spectrum and uses the likelihood function to iterate on the prior to compute an estimated spectrum.

We used Cross-correlation and Richardson Lucy algorithms to find sources in the FOV. To compute prior spectrum, we divided energy range in small energy bands. For each energy band, then we computed intensity value by fitting the Detector Plane Histogram (DPH), which is an array of counts in each pixel, with the expected shadow pattern. Intensity values for a given source in multiple energy bands are considered as a prior spectrum for that source.

Next, we used the likelihood function defined below to update the probabilities,
Likelihood function:

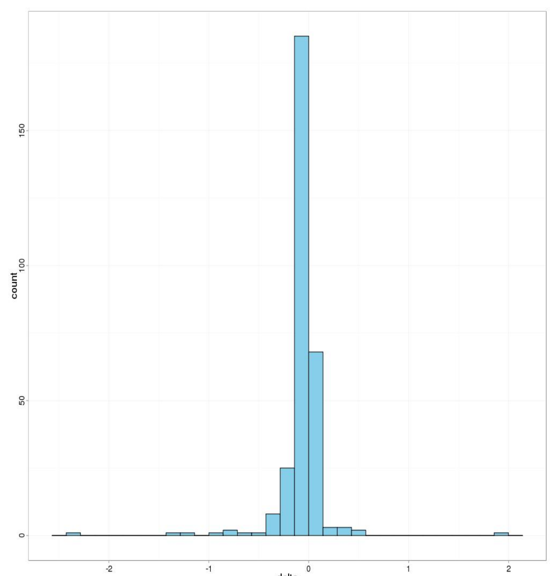
$$P_{ij} = \frac{F_{ij} * I_i(E_j)}{\sum_{i=1}^{N} F_{ij} * I_i(E_j)} \quad (1)$$

Computing posterior spectrum:

$$I_i(E_k) = \sum_{j}^{T} P_{ij}(|E_j - E_k| \leq \Delta E/2) \quad (2)$$

Here, N is number of sources in FOV, T is total number of events recorded, I_i is prior spectrum for source i, F_{ij} is the mask open fraction seen by the pixel corresponding to event j if this event is associated with source_i, P_{ij} is probability that event j is associated with source i, E_k are the bin centred energy values used in the spectrum and ΔE is width of each spectral bin.

We used the updated probabilities to compute new spectrum called posterior spectrum by binning the probabilities in each bin as in equation 2. Then we passed the posterior spectrum as a prior to refine $P_{i,j}$ as in equation 1 and repeated this procedure until the difference between the prior spectrum and posterior spectrum is less than a preset threshold.



We simulated realistic sky using BAT catalog for various pointings of the CZTI. We applied aforementioned technique on the simulated data. Shown is the histogram of difference between the simulated and estimated power law index of the sources reconstructed via this method.