More Parametrization of the Chandra Point Spread Function

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Introduction

A parametrization of the Chandra PSF as previously presented offers much of the power and accuracy of the complete optics model without the need to run lengthy raytraces. We have extended this work to:

- Parametrize a denser grid
- Produce ECF tables using the latest HRMA models
- Produce ECF tables for all nominal detector combinations
- Improve the method so that ECF tables may be done in a reasonable amount of time

Method Summary

For each point on our dense radial grid we:

- simulate a monoenergetic point source and generate approximately 1M rays using current values in the SAOtrace model
- apply a detector model (presented tables have been created using the HRC-I detector model and support for other detectors will follow)
- fit a series of elliptical regions to resulting incident photons
- repeat as needed to calculate confidence intervals on fit regions (error analysis below)
- tabulate the data as a parametrization of the PSF at that point

Error Analysis

At a rate of approximately 34 hours to run 1000 independent sets of 1 million rays, it would take approximately 15 machine years to run the complete error analysis on a 4000 point grid for one detector. Instead, we have used fewer rays for error analysis, used a bootstrap resampling technique with replacement to speed up the calculation of error, and we have performed this analysis only on a subset of the final grid.

Time required for possible simulation setups:

- 1k independent runs of 1M rays: 34 hr
- 1k independent runs 100k: 2 hr
- 1k "resamplings" of 100k of 1M rays: 10 min

The use of 1000 bootstrap sampled sets of 100k rays from a set of 1M rays is sufficient for our purposes, as the confidence intervals appear reasonable and the median values fall well within the confidence intervals of the 1000 independent runs of 1M rays (gold standard).

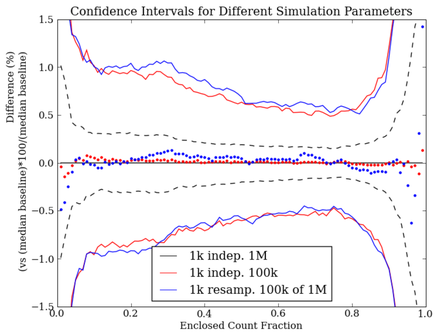

Figure 1. Evaluation of possible simulation setups relative to "gold standard" of 1k independent realizations of 1M rays. Dashed black lines are 95% confidence intervals on circular ECF radius from the "gold standard" run. Red dots represent median values for 1k independent runs of 100k rays. Corresponding red lines are the 95% confidence intervals on that set. Blue dots and lines are from 1k "resamplings" of 100k rays from a set of 1M rays. Notice blue and red dots are within dashed black lines. Circular ECF radius is used as a proxy for the ellipticals, as there are just too many degrees of freedom to plot effectively for the elliptical ECFs.

Process time was reduced further by running the resampling procedure for a subset of the ECF grid. As the error varies insignificantly for varying phi, we can generalize the error from a single value of phi for each theta.

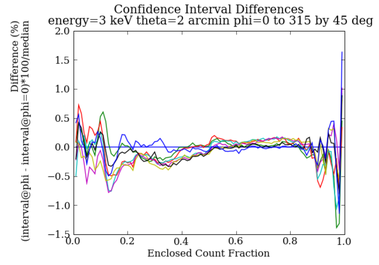

Figure 2. Percent difference in 95% confidence intervals for fixed theta and varying phi.

The confidence intervals are highly dependent on theta, and thus the error analysis is performed at all values of theta.

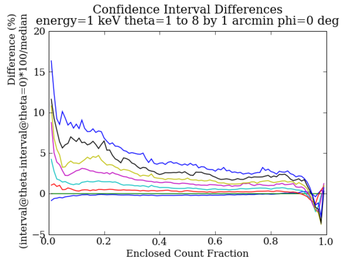

Figure 3. Percent difference in 95% confidence intervals on radius for fixed phi and varying theta showing much greater variation than for varying phi in Figure 2.

Results

Dense grid ECF tables for all of the the nominal detector combinations are forthcoming. These tables will increase analysis accuracy by reducing the need for interpolation.

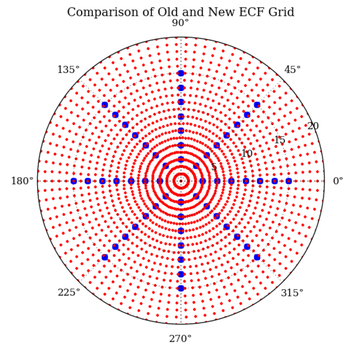

Figure 4. Parametrization points (theta, phi) of old and new ECF tables. Blue: Old, Red: New

A comparison of results from the new parametrization and the old tables demonstrates that:

- The new results are basically within the confidence intervals of the old ECF tables.
- The fundamentals of the SAOtrace model have changed little, but there is improved modeling of scattering. Therefore, as expected, differences between the old and new tables are greatest for higher energies.

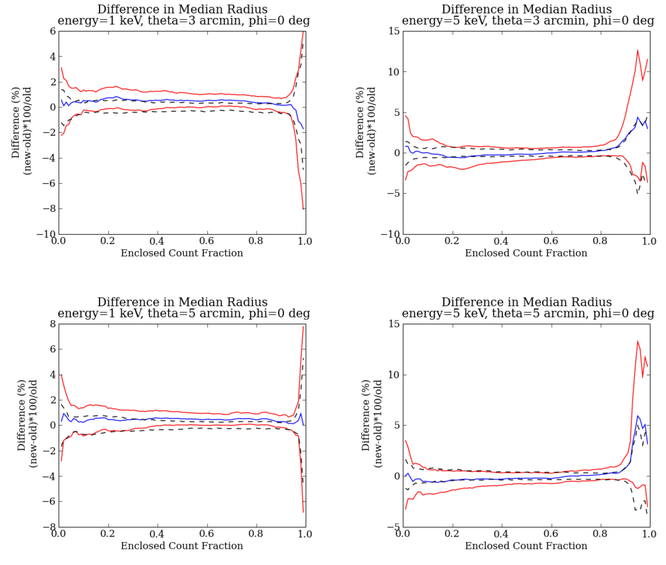

Figure 5. Percent difference in Median Radius (for circular ECFs) for several combinations of energy, theta, and phi. Black dashed lines=old ECF confidence intervals. Blue lines=new median value differences. Red lines=95% confidence intervals of the new data.