



## MEMORANDUM

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## 1 Introduction

The CXC Optics group is tasked with the characterization and calibration of Chandra's optics, and the dissemination of that knowledge.

The group's primary concern is to characterize the performance of Chandra's optics (the HRMA), which can be categorized as the on- and off-axis PSF, the on-axis effective area, off-axis vignetting, and focal plane geometric distortions. As the optical performance is tightly coupled to that of other telescope subsystems (such as the aspect control system and the detectors), the group expends a significant effort in understanding the detectors and subsystems. Characterization of the performance requires the development and testing of metrics for various aspects of performance; some of these (e.g., Enclosed Count Fraction ellipses) will be of use to the user community. In addition, it is necessary to monitor HRMA performance, and anticipate any problems or changes in the HRMA performance resulting from changes in the HRMA itself (e.g., off-nominal thermal control) or with the detectors or aspect.

## 2 Projects

### 2.1 On-Axis PSF

#### 2.1.1 PSF Core

We believe that we understand the core of the intermediate-energy PSF. The energy-dependent PSF core is not well known. Our initial attempt at quantifying it led to a significant discrepancy between the ACIS and HRC-I PSF at radii of  $\sim 2''$ - $10''$  (presented at the last CUC meeting) which is not yet resolved. We are investigating that effect by increasing the number of sources used to derive the ACIS PSF, in particular focusing on non-grating data.

Additionally, although we cull the data to prevent inclusion of pileup in our measurements, recent analysis by A. Vikhlinin of ACIS data indicates that pileup may be present in observations with lower count rates than were before realized. He has also determined additional criteria useful for its detection. We will be integrating these results in our work.

As the ACIS pixel size is significant compared to the scale of the PSF core, better modeling of the detection process is needed. We intend to incorporate a model of the ACIS detection into the raytrace. The spacecraft dither also needs to be modeled: dithering carries the PSF through pixels resulting in a broadening of the PSF, and no single location of the PSF relative to the pixel provides the appropriate broadening.

#### 2.1.2 PSF Core-Wings transition

This is particularly relevant for assessing source extent. There is significant overlap between this area and the PSF Core work discussed above.

As mentioned above, there is discrepancy between HRC-I and ACIS for radii  $\sim 2'' - 10''$ . Understanding this is also important for matching up to the PSF wings (normalized by the ACIS transfer streak spectrum).

### 2.1.3 PSF Wings

The first pass of the work has been done and a memo was recently released. Future work would include correcting for the effect of the spatially-varying ACIS contamination layer and characterizing the azimuthal variation of the wing profile. The wings observation was near the corner of ACIS-S3, so the absorption in the ACIS contamination layer could alter the slope and/or normalization of the wings, particularly for energies below  $\sim 2$  keV. These studies await the characterization of the spatial variation of the ACIS contamination layer.

## 2.2 On-Axis Effective Area

Our knowledge of the on-orbit  $A_{eff}$  is based mainly on fits to AGN spectra (primarily by Herman Marshall). Overall the models and data are consistent. There is, however, a discrepancy around the Ir  $M_V$  edge which leads to inconsistent data analysis.

In the short term we will apply an *ad hoc* correction to the effective area. The correction is being determined from an analysis of low-flux HETG data in order to avoid contamination by pileup (which can dramatically affect the appearance of the Ir edge).

Our initial analysis indicates that the discrepancy is consistent with the presence of a  $\sim 10 - 20$  Å hydrocarbon contaminant layer, believed to be present since before launch. There is no evidence for further post-launch contamination. The presence of such a layer would impact other aspects of performance, such as the off-axis effective area. If the addition of a contamination layer does not result in inconsistencies in other areas, we will add this to the model of the optics.

## 2.3 Off-Axis PSF

### 2.3.1 PSF Core

The level of calibration required for the off-axis PSF core depends upon the scientific needs of the observer. Much work can be carried out using a parametric description of the PSF. This is most useful for those who wish to perform object removal or detection (e.g., the Level 3 pipelines). We are about to release elliptical parameterizations of the PSF.

The study of serendipitous objects often leads to the case where several objects are within a few arcseconds of each other. Because of the asymmetries in the PSF, determining contamination by neighboring objects requires knowledge of the full 2D PSF. As part of our parameterization project we have also generated “wedge slices” which allow a crude estimate of the 2D asymmetries; these are yet to be calibrated against observational data.

Another method is to produce PSF’s derived from observational data to serve as templates (as well as providing inputs for updating the model). This work is in the planning stages.

### 2.3.2 PSF Core/Wings and PSF Wings

The core/wings transition becomes less relevant with increasing off-axis angle as the the quasi-specular core balloons out; almost all we see in the far off-axis PSF is the core. The wings of the PSF for far off-axis sources are very poorly known; there are no data, and the deficiencies of the scattering modeling make prediction unreliable.

## 2.4 Off-Axis Effective Area (Vignetting)

Measurements of the off-axis effective area were done with specially staged observations of G21.5 using both the ACIS-I and ACIS-S. Results (most recently presented at the 2003 Calibration Workshop) indicate that, averaged over  $\sim 0.5$  keV bands (our best current data), the models predict the vignetting to  $\sim 10\%$ . The models tend to overpredict the vignetting. We are now pursuing other data sets (in particular, calibration observations of galaxy clusters) to improve our resolution. We anticipate updating the model based upon these measurements.

## 2.5 Raytrace Model Components

### 2.5.1 Surface Scattering Model

Ping Zhao has developed a new algorithm for surface scattering, which we are in the process of implementing and testing.

### 2.5.2 Mirror Alignments

Our knowledge of the mirror alignments stems primarily from XRCF measurements. Errors in our knowledge lead to a misshapen modelled PSF, which has prevented application of deconvolution methods outside of the inner few arcminutes of the field of view. There is accumulating evidence that the alignment model needs to be refined, and enough high quality off-axis data (which are the most diagnostic) have become available. We are also generating new diagnostics (e.g., PSF centroid shifts as a function of source location) which promise to provide us with quantitative metrics for comparison of models to data.

### 2.5.3 Source and Telescope

The following additions to the raytrace source and telescope models are planned to support both more flexible use of ChaRT, as well as to improve our modelling of the PSF.

- the ability to use images as source maps
- simulations of telescope dither (using observed aspect data)

## 2.6 Infrastructure

The ramping down of programming and data specialist support staff in the Optics group dictates the need to finish items which will minimize effort and software maintenance for future modeling, data reduction, and analysis efforts. This includes

- Porting the raytrace suite to Linux. Our compute platform is shifting from Sun Sparc/Solaris to Linux/x86. This work will also allow us to release the raytrace suite to motivated outside users.
- Development of tools to automate calibration tasks using the constantly growing cache of archival data.

## 3 Products

### 3.1 Current/in-progress

- On-Axis PSF: fits to PSF wings
- Off-Axis PSF: Enclosed Count Fractions (ECF)
- On-Axis  $A_{eff}$ : tables of on-axis effective area from raytraces, scaled by an *ad hoc* correction to match the ground calibration measurements.
- HRMA vignetting map
- HRMA *User's Guide*

### 3.2 Planned

- *ad hoc* correction for Ir edge effective area discrepancy
- input for ChaRT upgrades (improvements to raygen)
- improved mirror conic parameters for MARX

## 4 Major Task Priorities

1. Port the simulations software to Linux
2. Implement the new scattering algorithm, and compare to measured PSF.
3. Implement *ad hoc* correction to  $A_{eff}$  to correct Ir edge discrepancies
4. Refine knowledge of on-axis ACIS PSF
5. Resolve the discrepancy between the on-axis HRC-I and ACIS PSF results in the  $2''$ - $10''$  range
6. Integration of the CCD response model into the raytrace to investigate the effects of pileup on the PSF.
7. Revise mirror alignment model to incorporate improved analyses of on-orbit and ground data
8. Generate detector and SIM position specific vignetting functions
9. Provide updated conic constants for MARX