An Overview of *Chandra*'s Optics

Diab Jerius
SAO

Chandra Calibration Workshop
6 November 2002

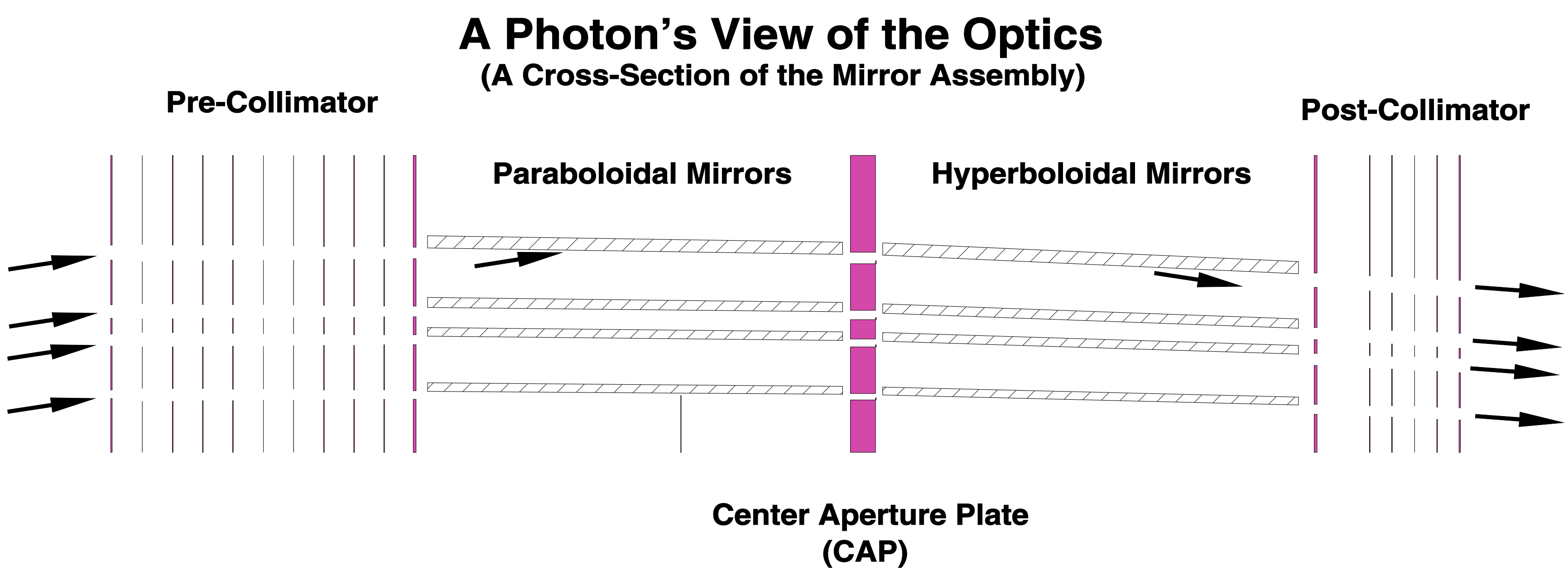
- What is the HRMA?
- Things of import to the Observer
- Which bits are calibrated?
- What happens to those bits?

Chandra's Optics

The *Chandra* X-Ray Observatory (CXO) mirrors (the High Resolution Mirror Assembly, or HRMA) were designed to produce images with better than one arc-second resolution, and to concentrate better than 85% of the energy at 0.277 keV within a $1''$ diameter. The optics were manufactured by Hughes-Danbury Optical Systems, and assembled with the support structures into the HRMA by Eastman Kodak.

- Wolter type I geometry (paired paraboloids and hyperboloids)
- 4 nested pairs of mirrors (shells), 838 mm long
- Radii range from ~ 320 mm to ~ 600 mm
- Ir coating on Cr coated Zerodur.
- PSF FWHM $\sim 0.5''$

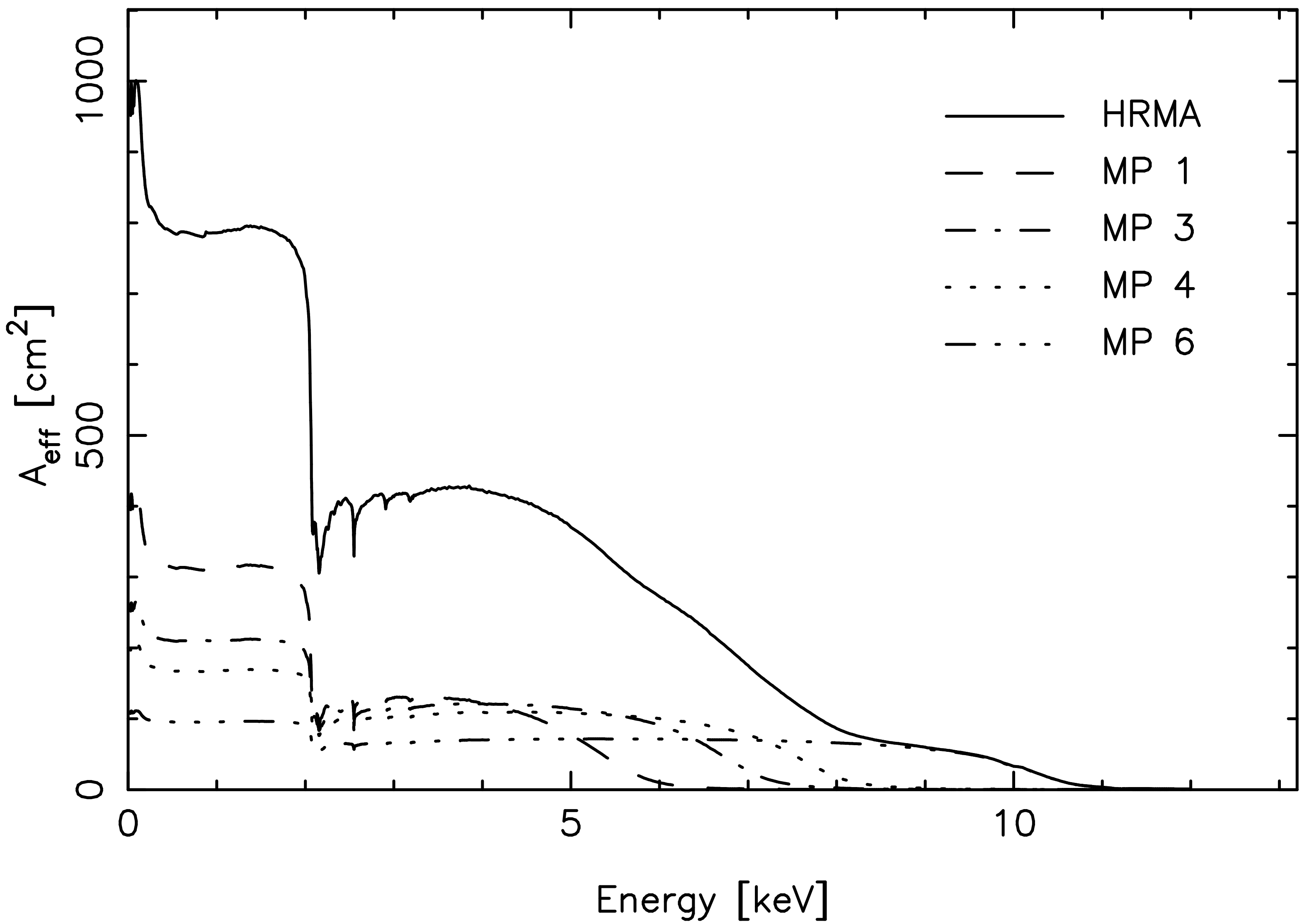
Schematic Cross-section of the HRMA



Characteristics of Import to the Observer

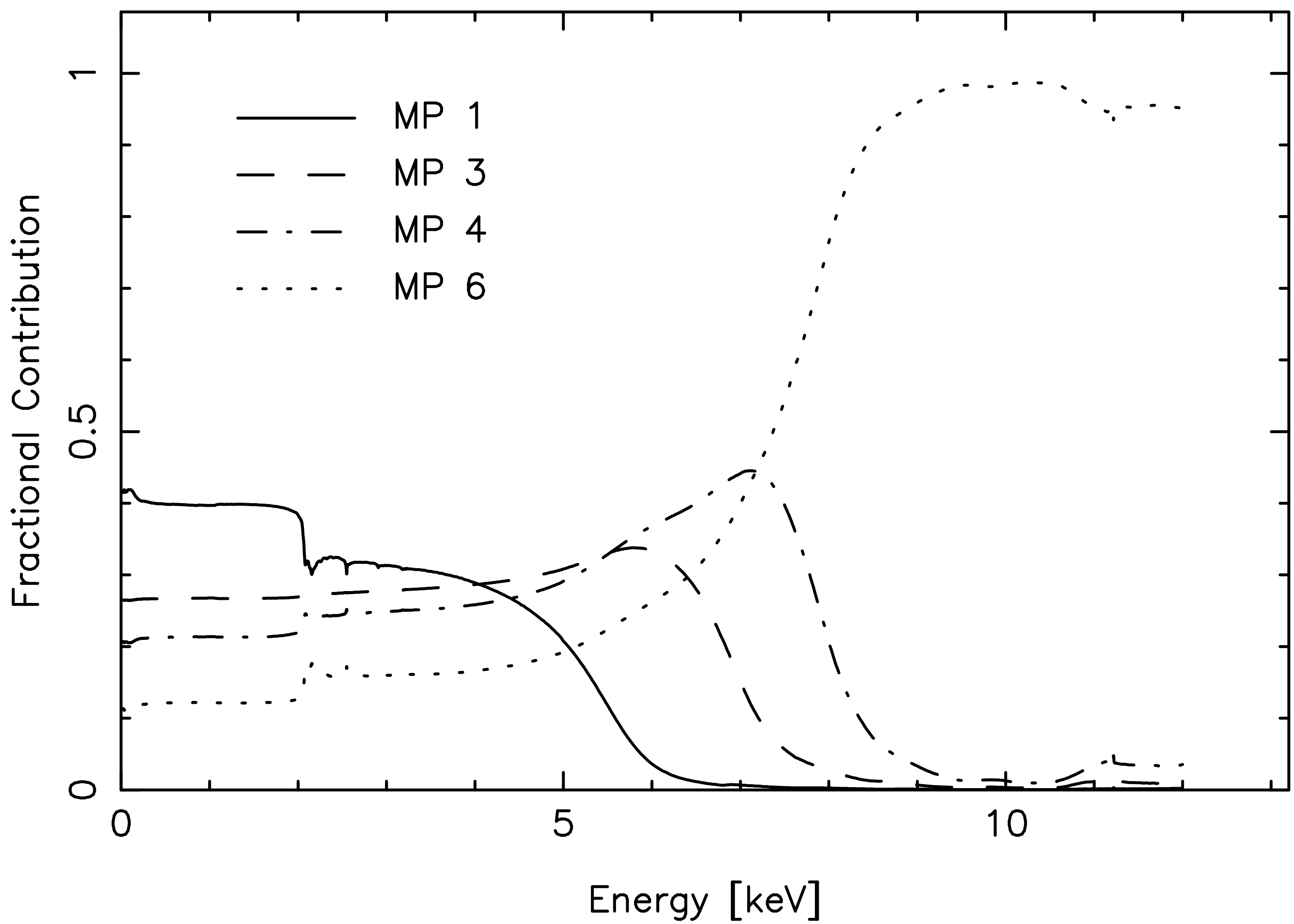
- focal length ~ 10 m ; plate scale $\sim 50\ \mu\text{m}/''$
- f/#'s vary from ~ 8.2 (Shell 1) to ~ 16.4 (Shell 6)
- Focal planes coincident on-axis; diverge off-axis
- Shells have different energy dependent throughputs (reflectivity is a strong function of the incident angle).
- Assembly errors produced misalignments which affect off-axis and shell 6 performance.
- Surface roughness scatters photons producing low level power law wings which are strongly energy dependent.

Spectral Response of the Mirror Shells

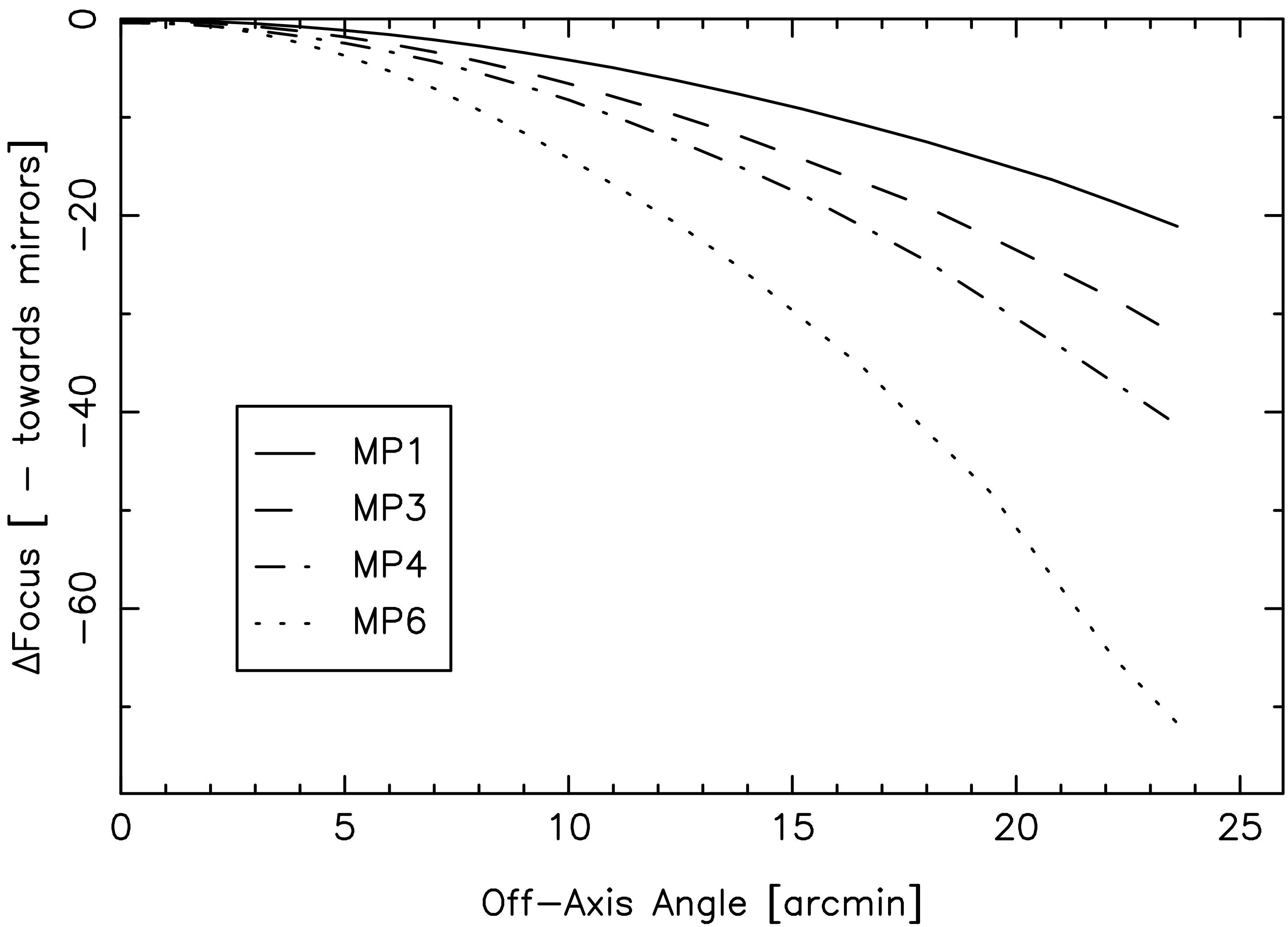


Spectral Response of the Mirror Shells

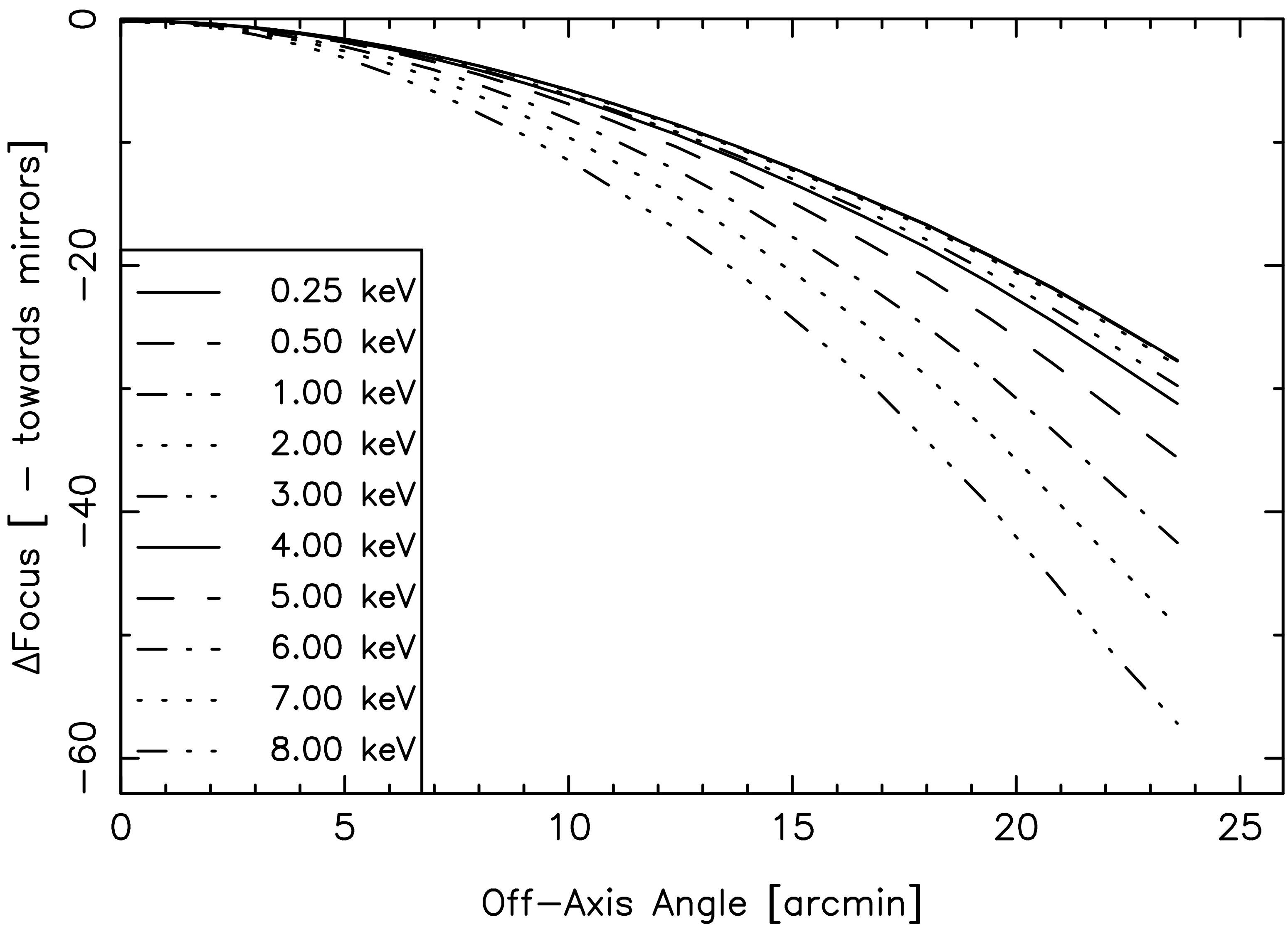
The contribution of each shell to the overall effective area of the telescope is energy dependent:



Divergence of the Shells' Focal Planes



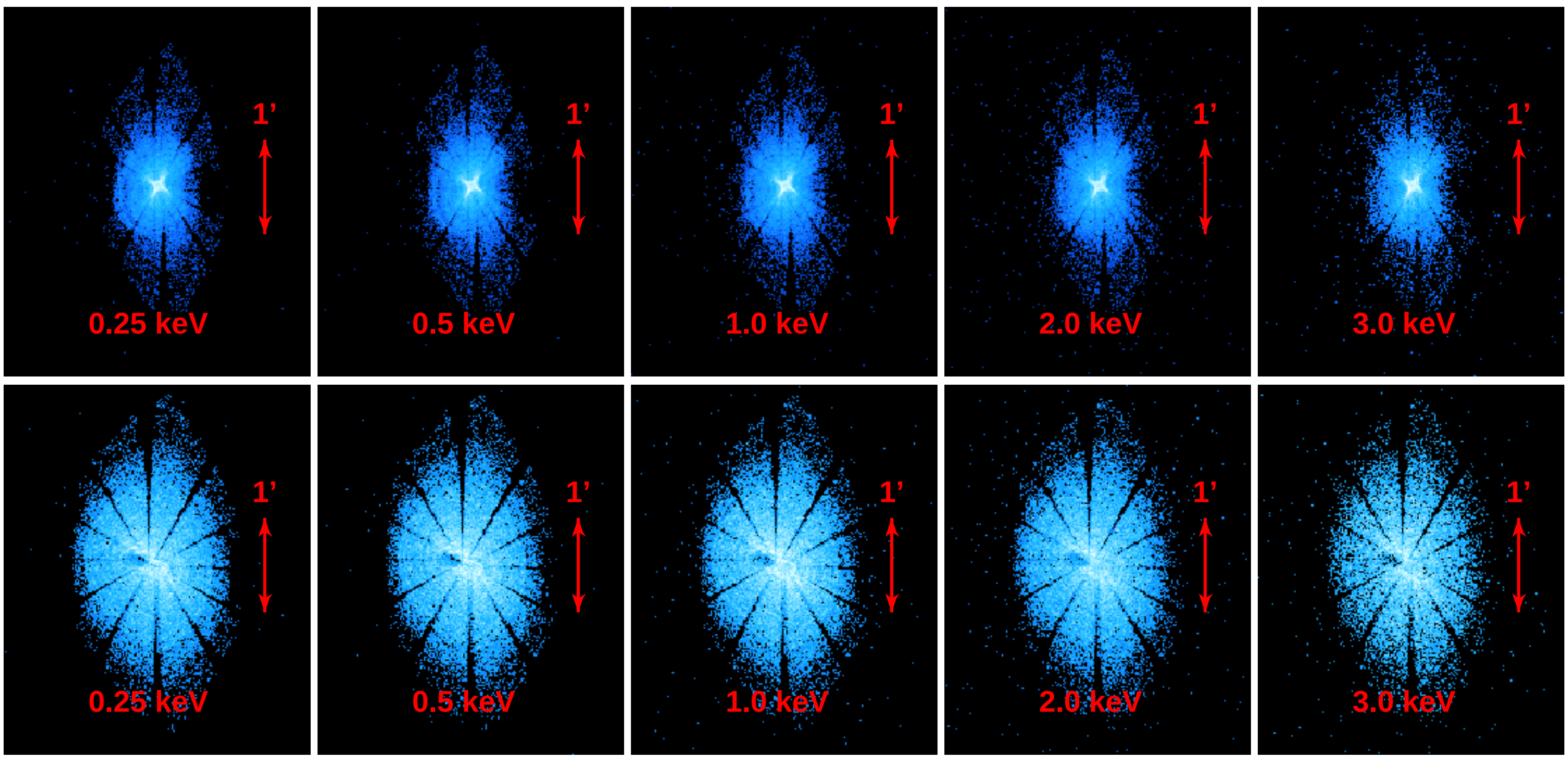
Energy dependence of HRMA Focal Plane



Effect of non-ideal detector/focal plane match

Simulation of monochromatic point sources 23.6′ off-axis
HRC-I 0.25 keV – 3.0 keV, (log stretch)

Ideal focal plane

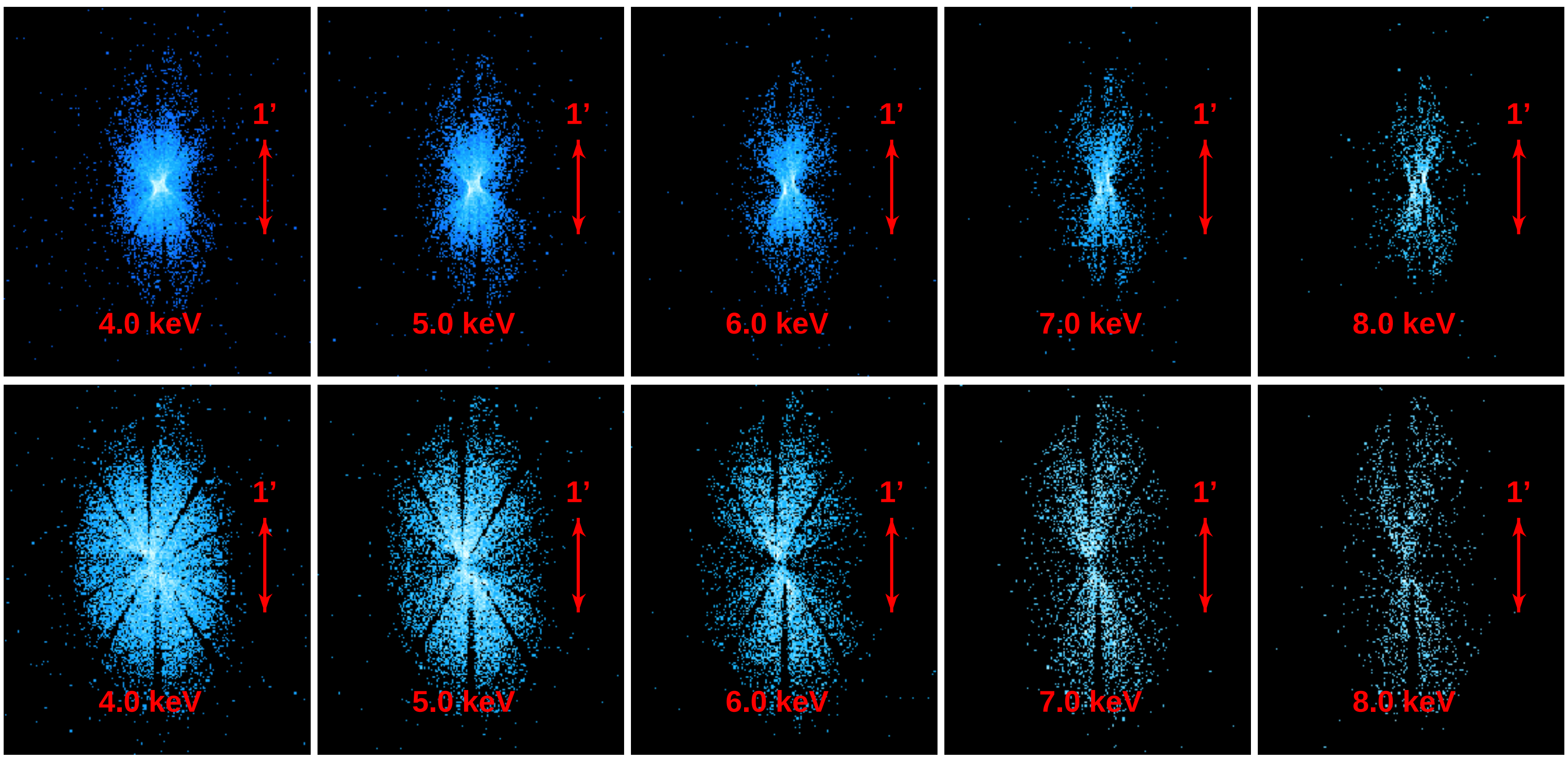


HRC-I focal plane

Effect of non-ideal detector/focal plane match

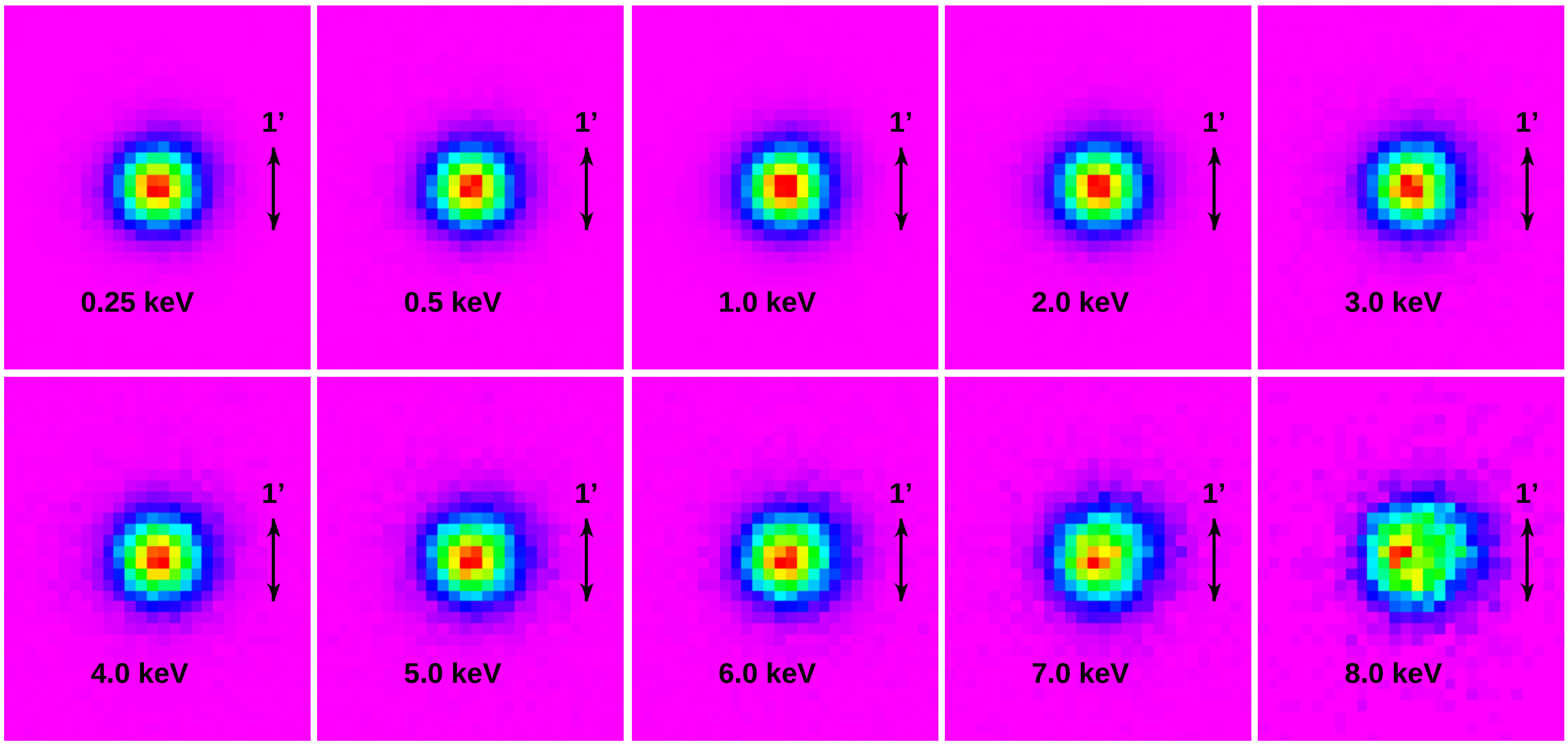
Simulation of monochromatic point sources 23.6′ off-axis
HRC-I 4.0 keV – 8.0 keV, (log stretch)

Ideal focal plane



HRC-I focal plane

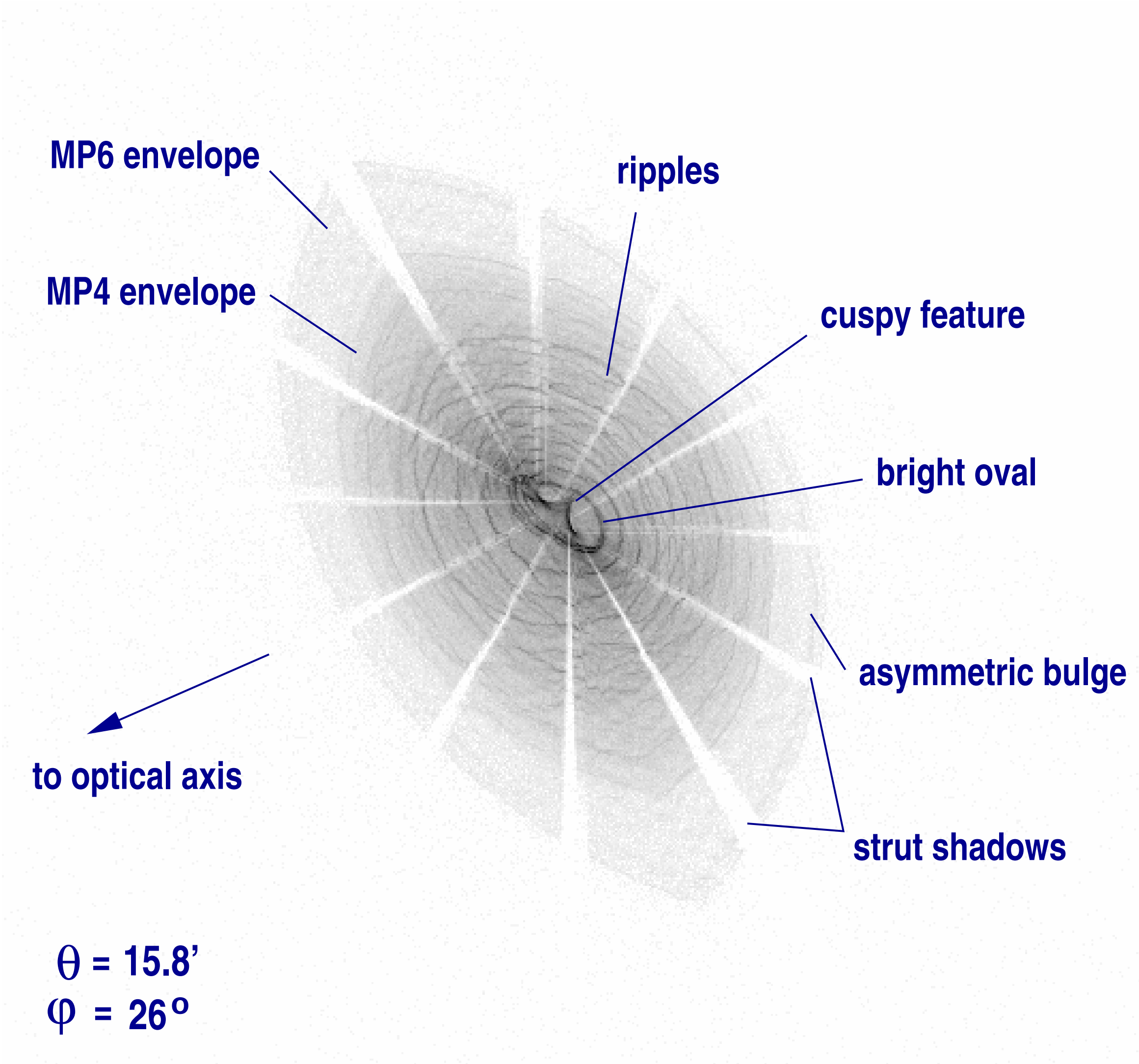
Alignment effects on on-axis PSF morphology



Simulated HRC-I observation, including aspect (linear stretch)

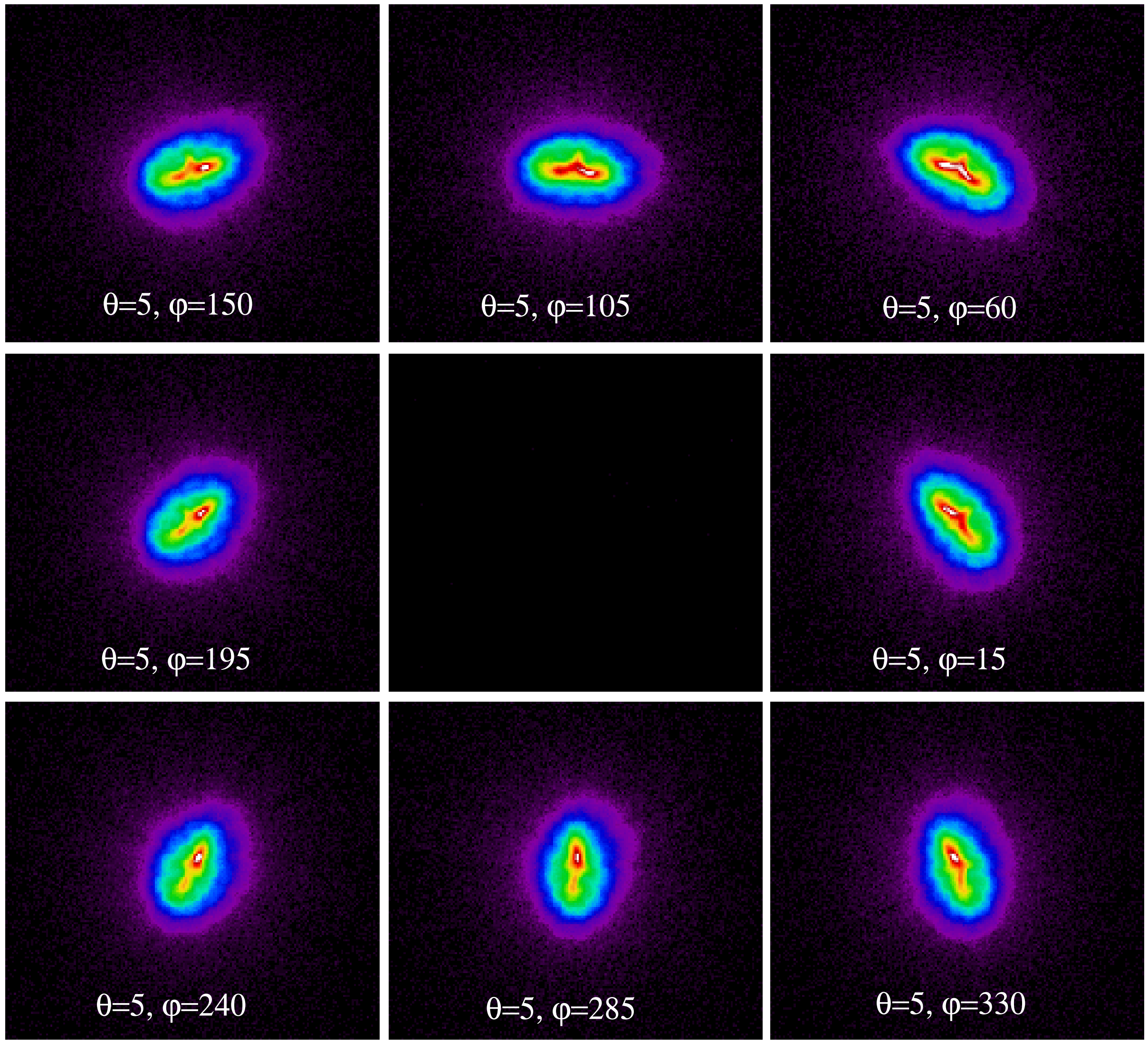
Alignment effects on off-axis PSF structure

Simulation, 15.8′ off axis



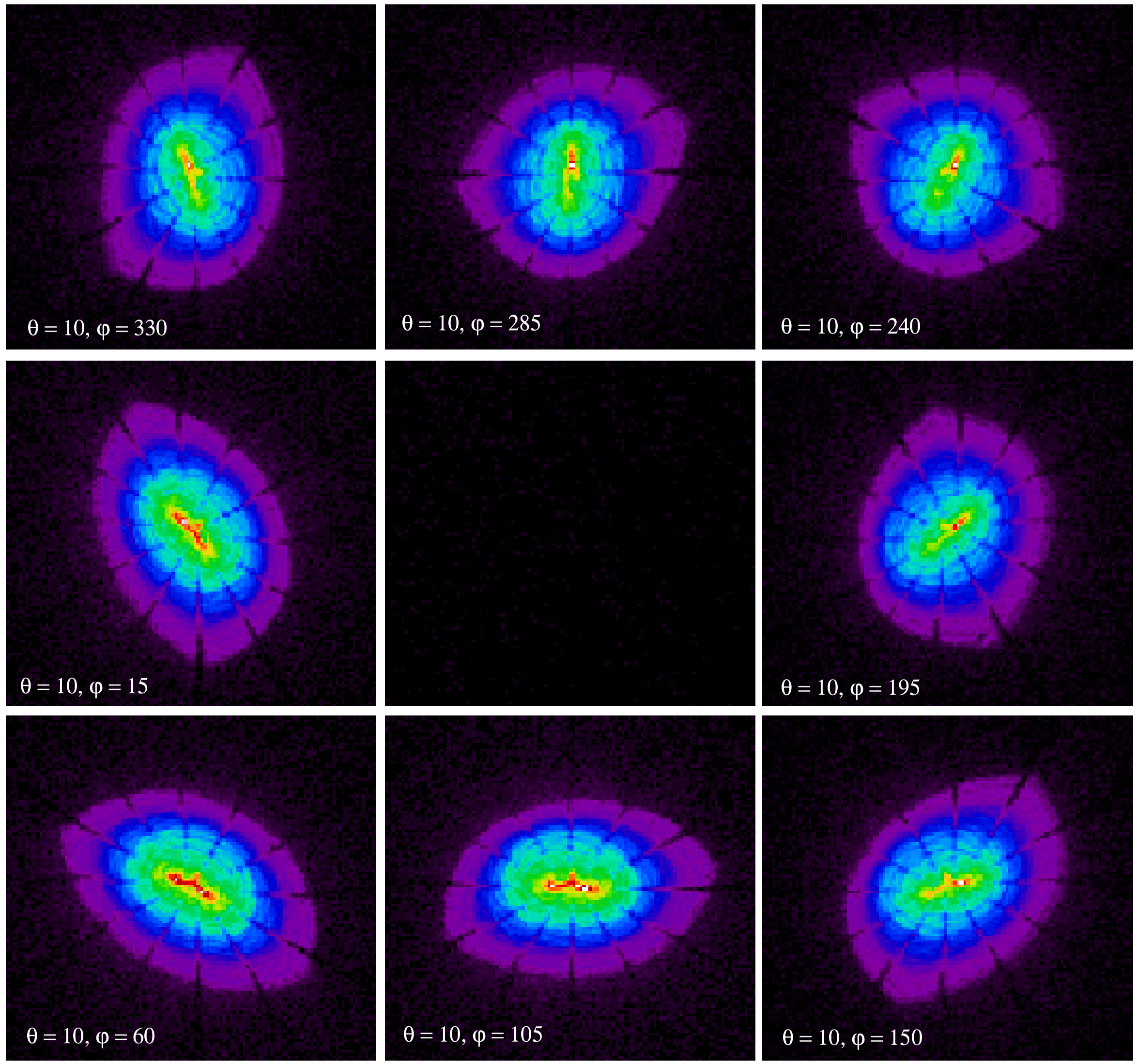
Alignment effects on off-axis PSF morphology

Simulation, 5′ off-axis, various azimuths



Alignment effects on off-axis PSF morphology

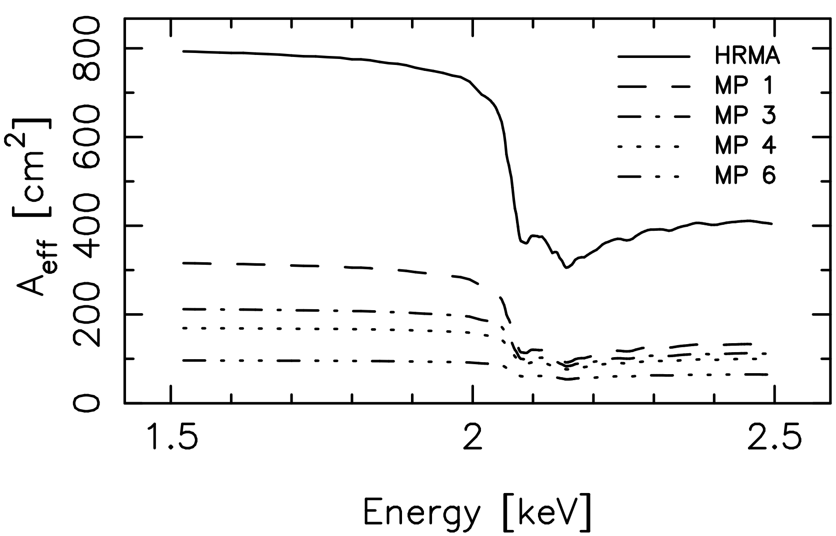
Simulation, 10′ off-axis, various azimuths



Things to Calibrate and How to do so

The HRMA performance can be divided into the following areas:

- Spectral response. Must use ACIS.
  - On-axis A_{eff}
    - Primary calibration done during ground calibration
    - On-orbit calibration tied closely to detector QE calibration.
    - Region most sensitive to calibration errors near 2 keV Ir edge; use power-law (e.g. AGN sources) with gratings.



Things to Calibrate and How to do so

- Spectral response (con't)
  - Off-axis vignetting
    - ∗ Compare on- & off- axis measurements of diffuse source (to avoid ACIS pileup effect). Difficult to determine at higher energies.
- PSF
  - 1D and 2D structure.
    - ∗ On-axis must use HRC due to ACIS pileup and pixel size; no spectral information.
  - Energy distribution
  - Scattering wings
    - ∗ Long ACIS observations of bright sources - Her X-1

Role of Simulations

What are we really calibrating? The *Chandra* Optics calibration program is designed to verify the performance of a *model* of the HRMA.

- It is impossible to completely characterize the on-orbit performance of the actual HRMA experimentally.
- The finite resources available for laboratory (i.e. pre-flight) calibration precluded a thorough determination of the optics' performance.

The design of the calibration effort was predicated upon knowledge of the optics' performance in key areas, derived from pre-flight calibration activities.

The result is that the mirror model serves as the ultimate predictor of the mirror's behavior; the pre-flight and on-orbit calibration measurements are designed to test and constrain that model. All HRMA data in the *Chandra* CALDB is derived from that semi-analytical model (SAOsac).