The HRMA User's Guide

T. J. Gaetz, D. Jerius

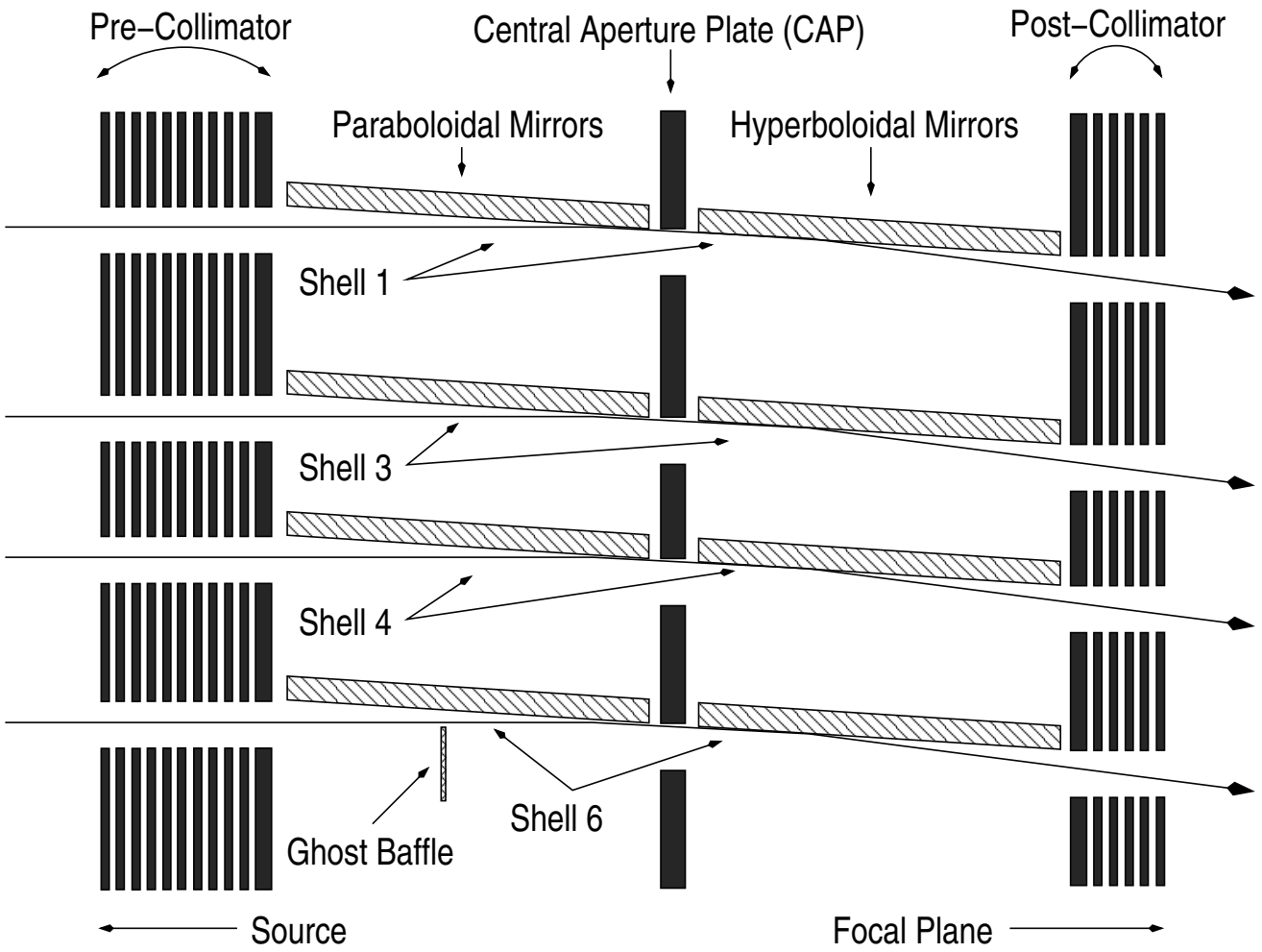

Chandra X-ray Center (SAO)

2004 October 26

HRMA General Properties

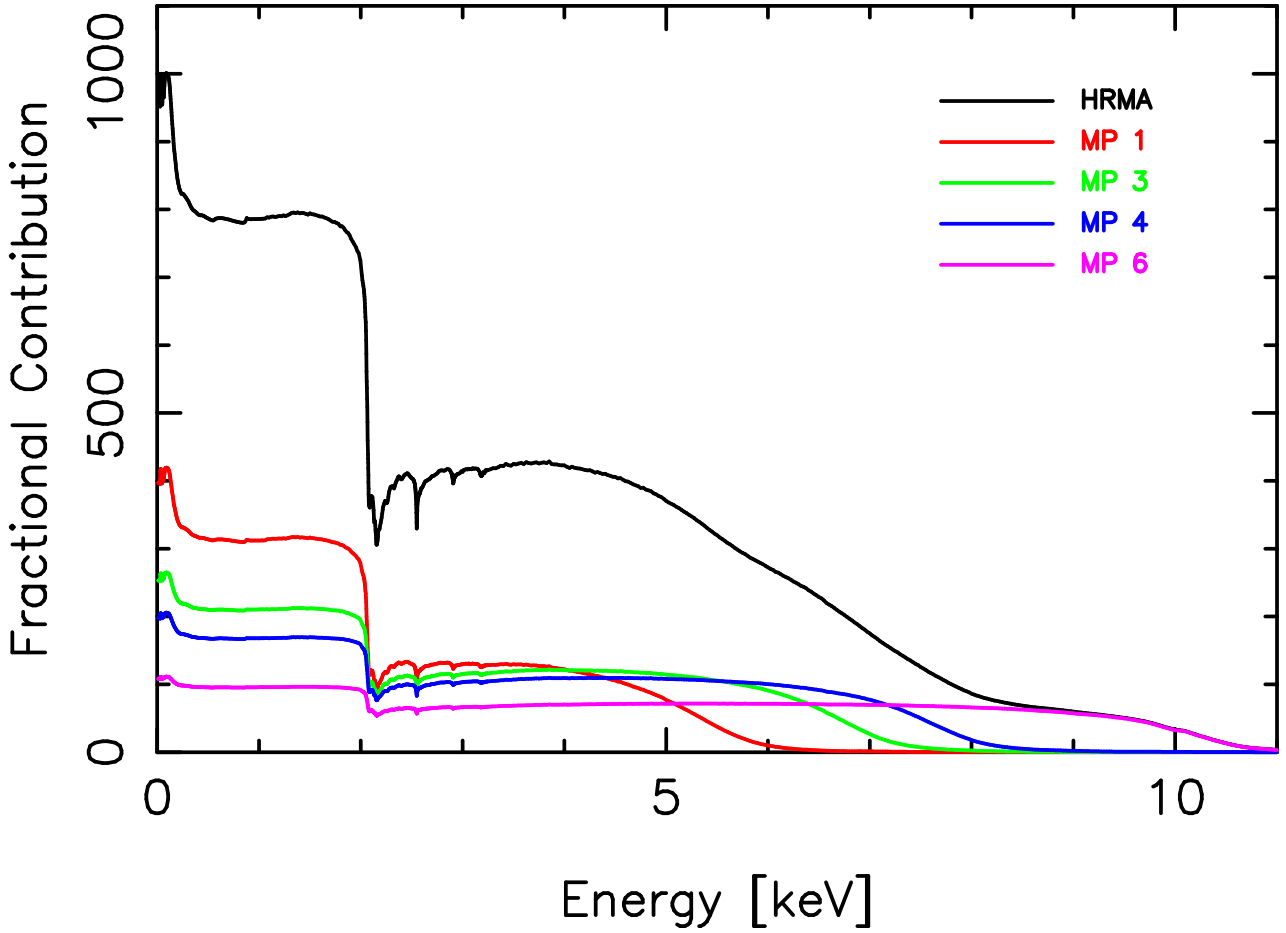
- *Chandra* X-ray mirrors: HRMA: "High Resolution mirror Assembly".
- 4 concentric Wolter-I telescopes
  - MP1, 3, 4, 6 (large $\Longleftrightarrow$ small); f-ratio: $\sim$8.4 $\Longleftrightarrow$ $\sim$15.7
- Effective area:
  - large drop at $\sim$2 keV (Ir edge)
  - Energy dependence: high energy dominated by smaller shells
- Focal plane curvature: individual shell focal planes curve toward mirrors
  - smallest shell $\rightarrow$ greatest curvature
- alignments and aberrations
  - lateral parfocalization: good!
  - axial parfocalization: $\sim$0.6 mm between MP1&MP6; MP3&MP4 in between.
  - dominant off-axis aberration: tangential stretching intrinsic to Wolter-I
  - significant "coma-free" decenter:
    minimal on-axis coma, but significant off-axis (θ, φ)-dependent aberrations.
    $\Rightarrow$ bright PSF substructure;
  - off-axis Wolter-I and "coma-free" decenter aberrations larger for smaller shells
  - tilt: $\sim 0.6''$ diameter tilt ring in MP6; non-uniform and offset!

Schematic of the HRMA



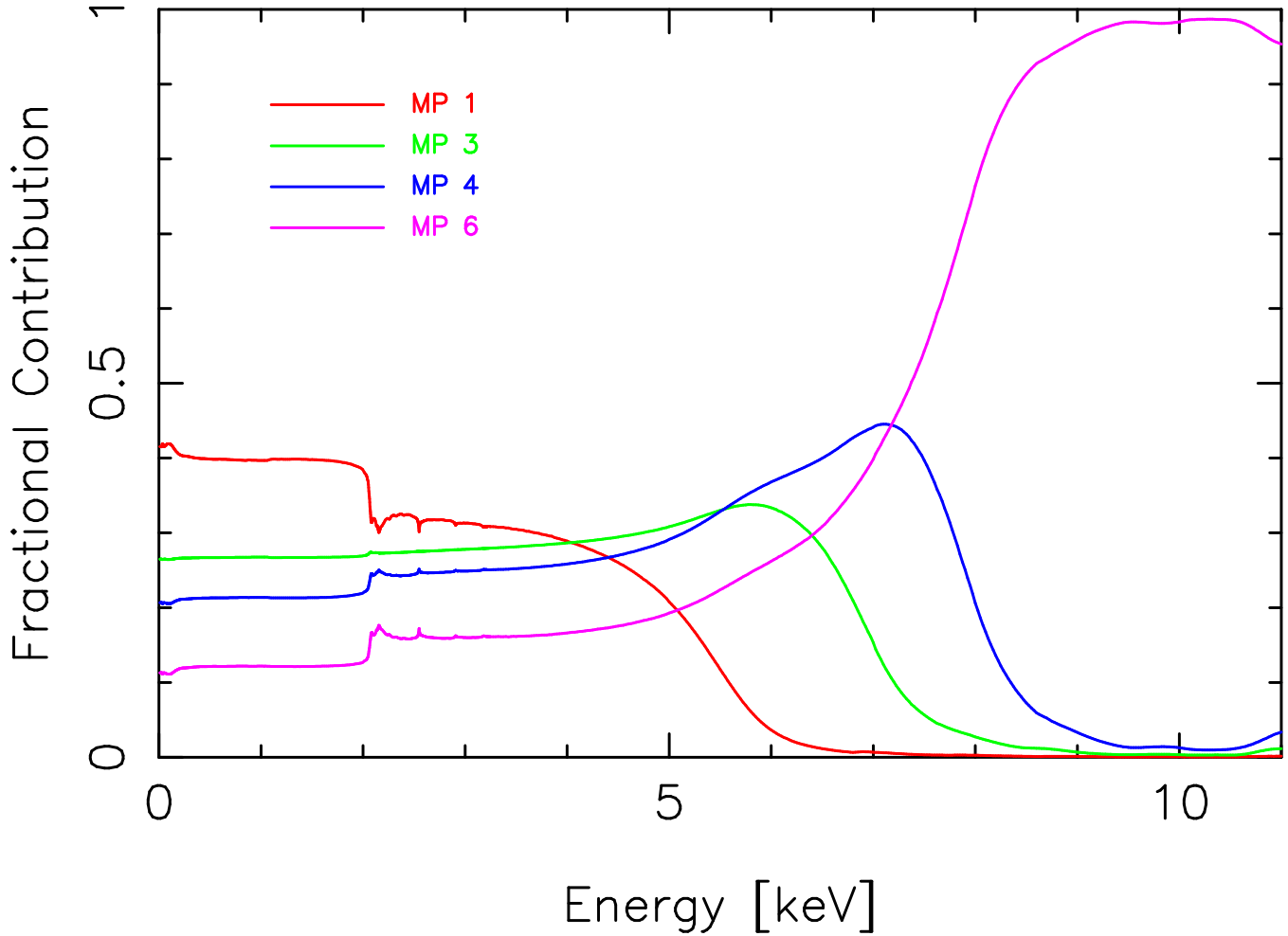
HRMA and Shell Effective Areas

- large drop at ∼2 keV (Ir edge)
- Energy dependence: high energy dominated by smaller shells



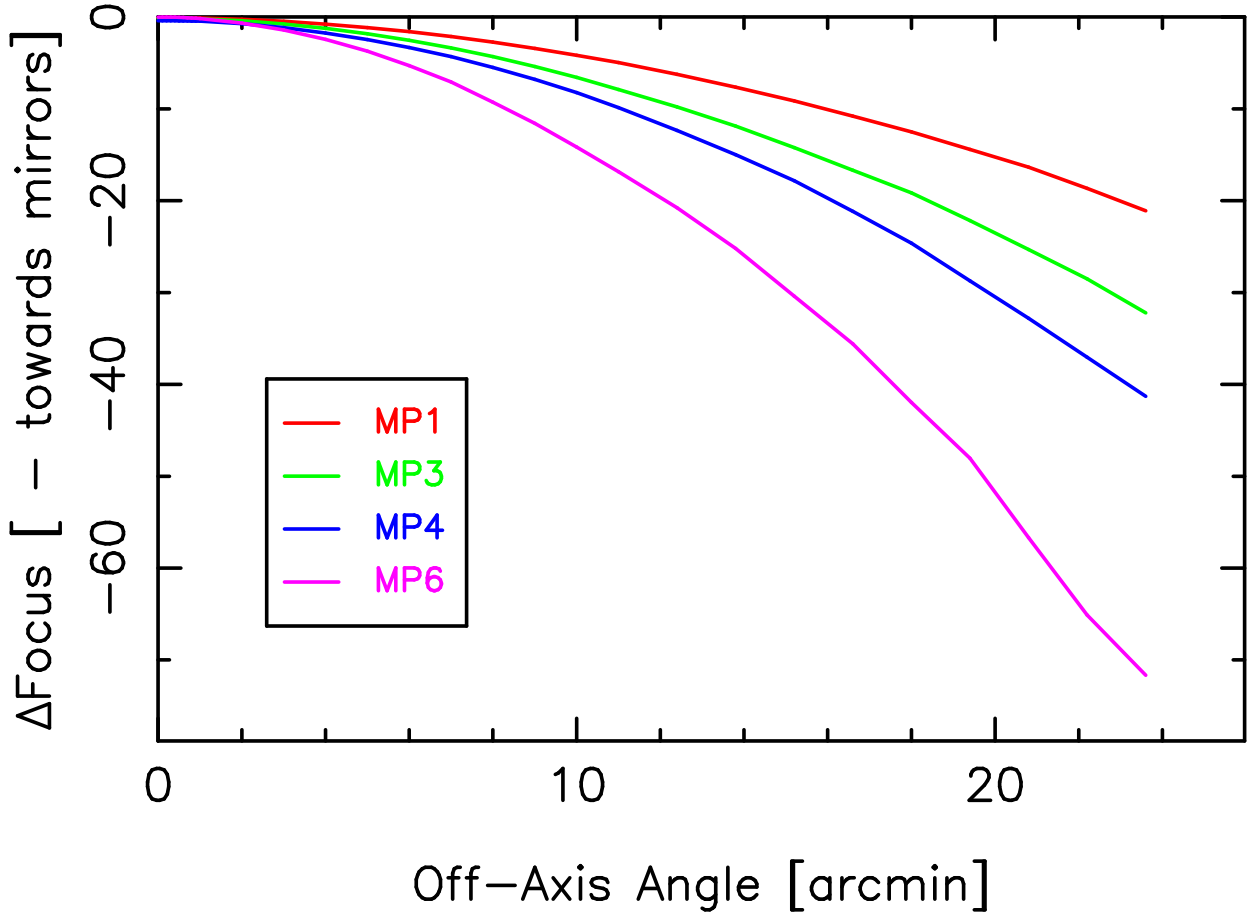
Shell Fractional Effective Area

MP6 dominates at high energies ($\gtrsim$7.5 keV)



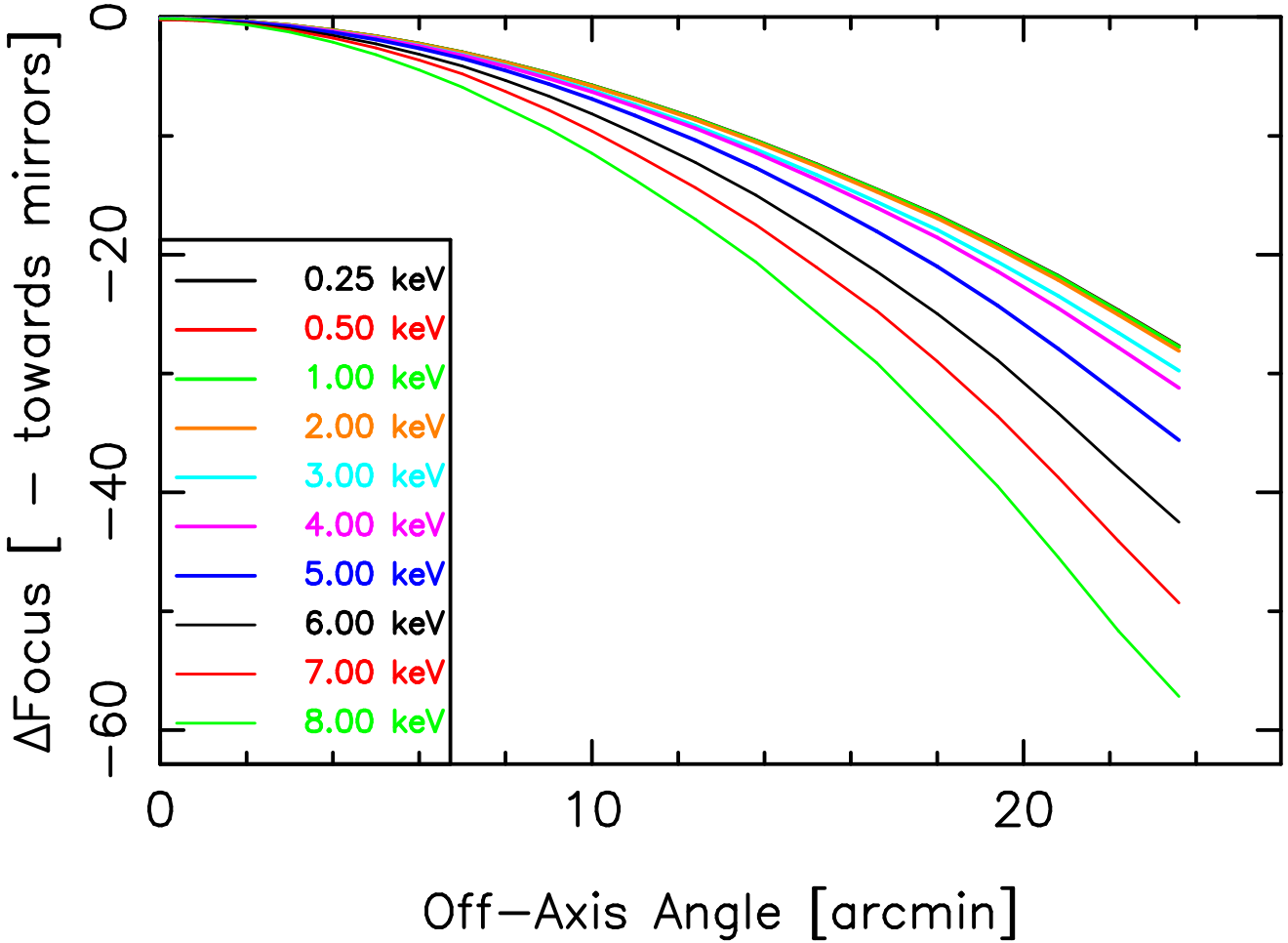
Focal Planes

- Individual shell focal planes curve toward mirrors;
  smallest shell ⇒ greatest curvature; divergent focal planes!



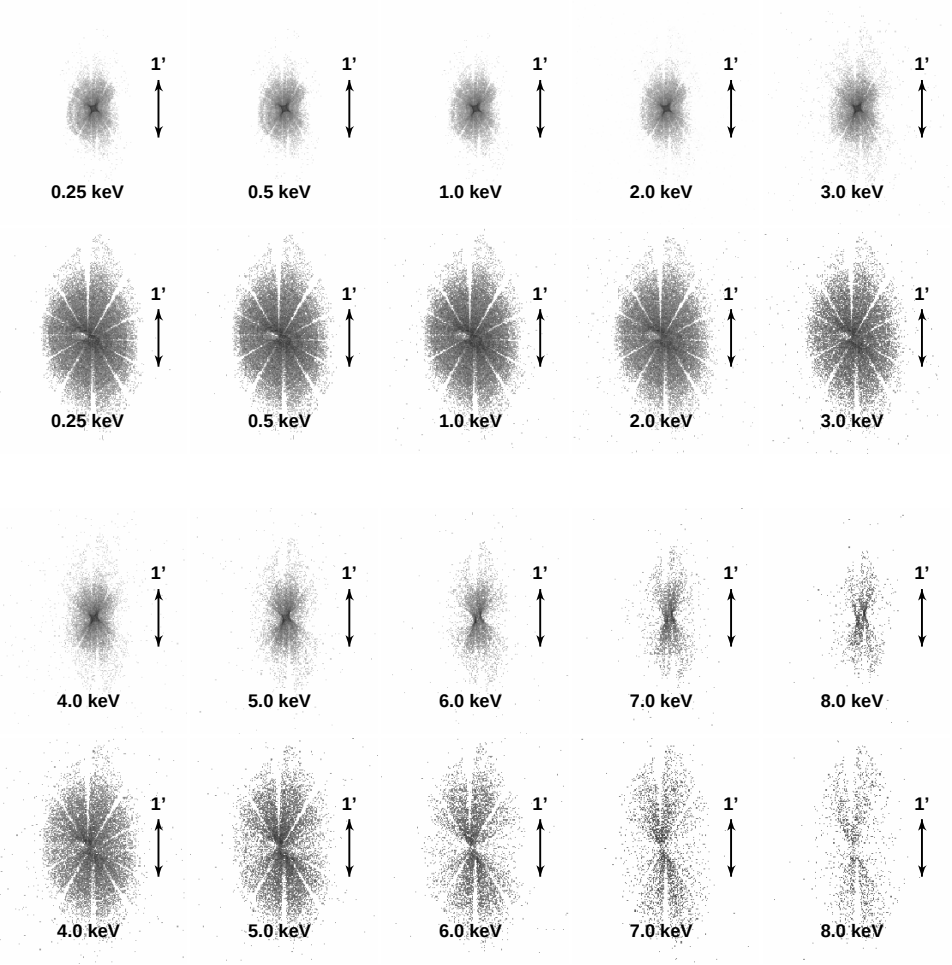
HRMA Focal Plane - Energy Dependence

- high energy dominated by smaller shells; increasing curvature as E increases



Ideal HRMA Focal Plane *vs.* HRC-I Focal Plane

23.6′ off-axis; log stretch



HRMA focal plane (0.25−3.0 keV)

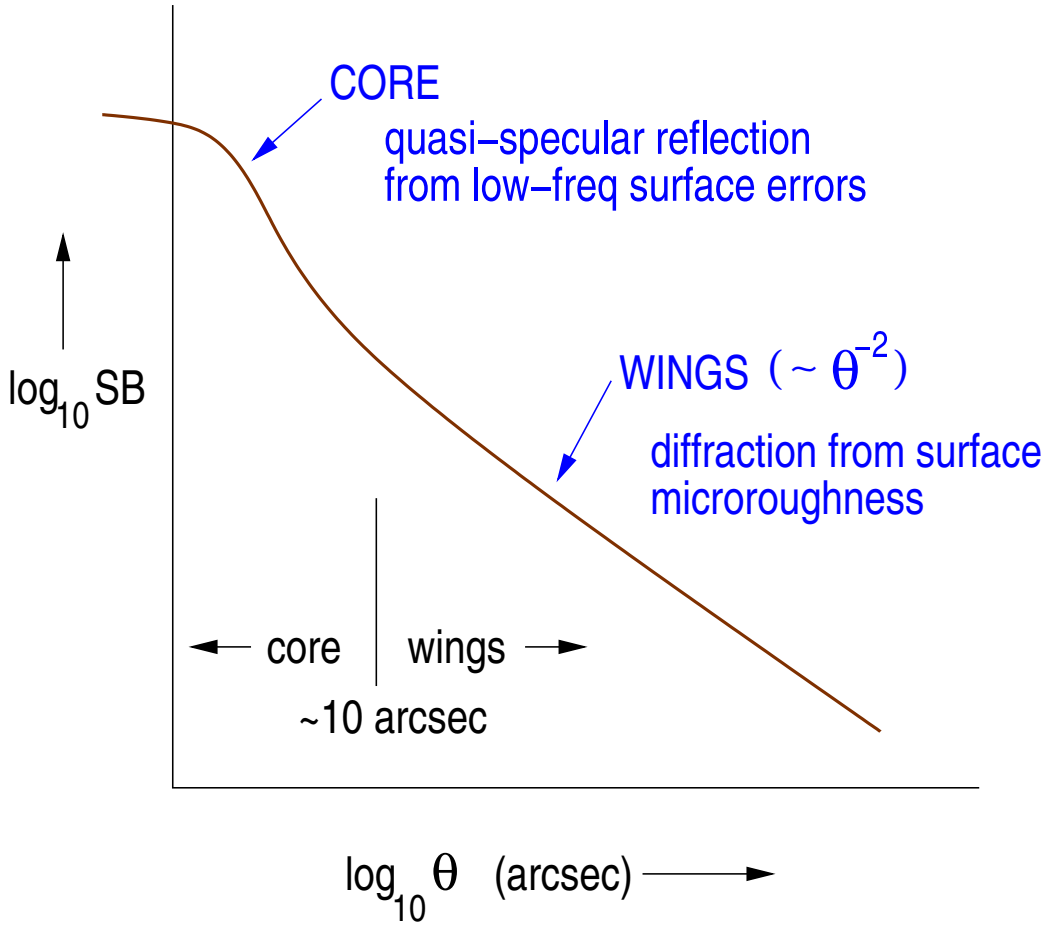
HRC focal plane (0.25−3.0 keV)

HRMA focal plane (4.0−8.0 keV)

HRC focal plane (4.0−8.0 keV)

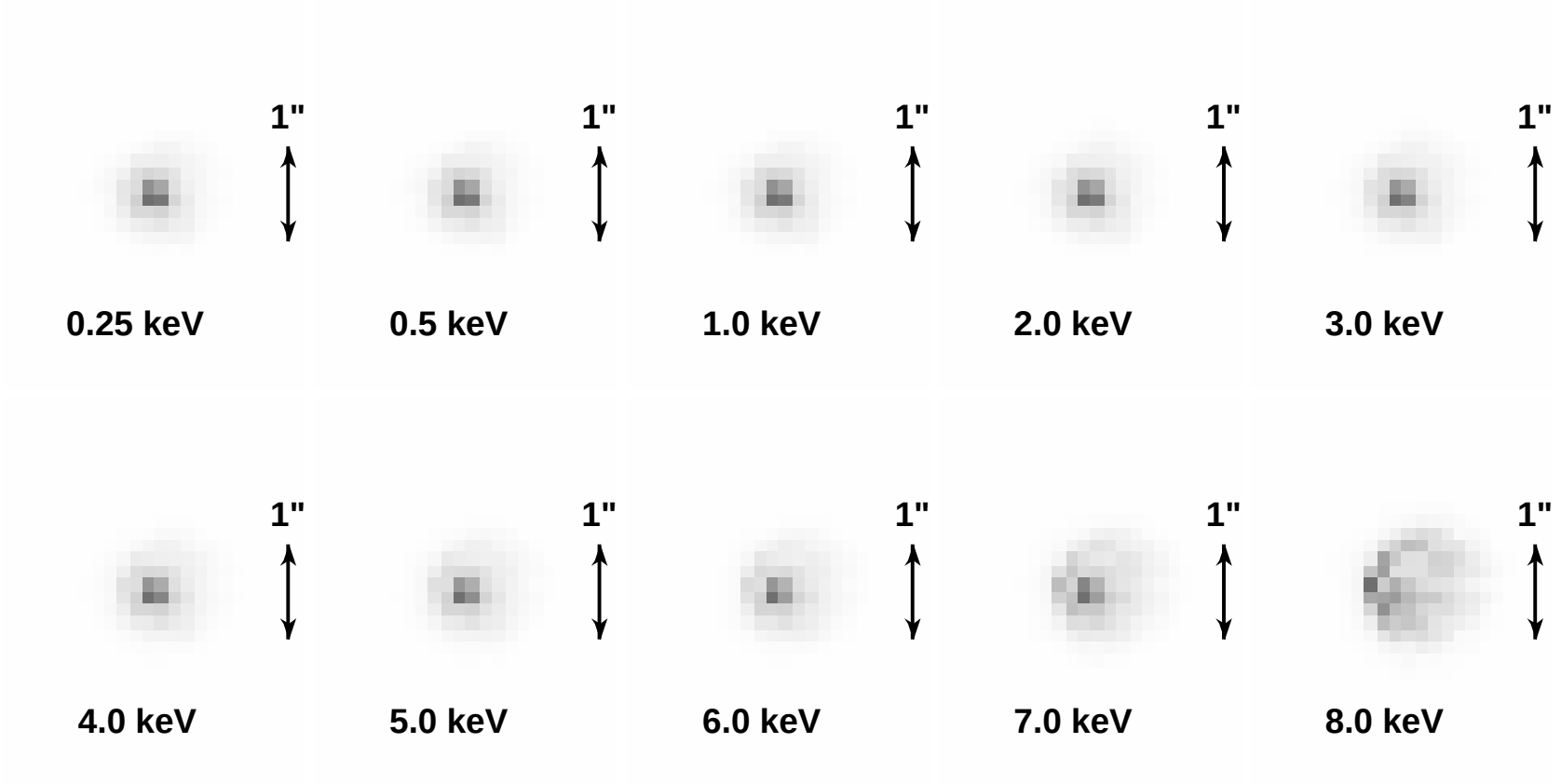
Anatomy of the On-Axis PSF: core/halo structure

- sharply peaked core: narrow; sub-arcsecond imaging ($\sim$0.5″ FWHM)
- wings: faint diffuse energy-dependent halo extending to large angles



On-Axis PSF Core *vs.* Energy

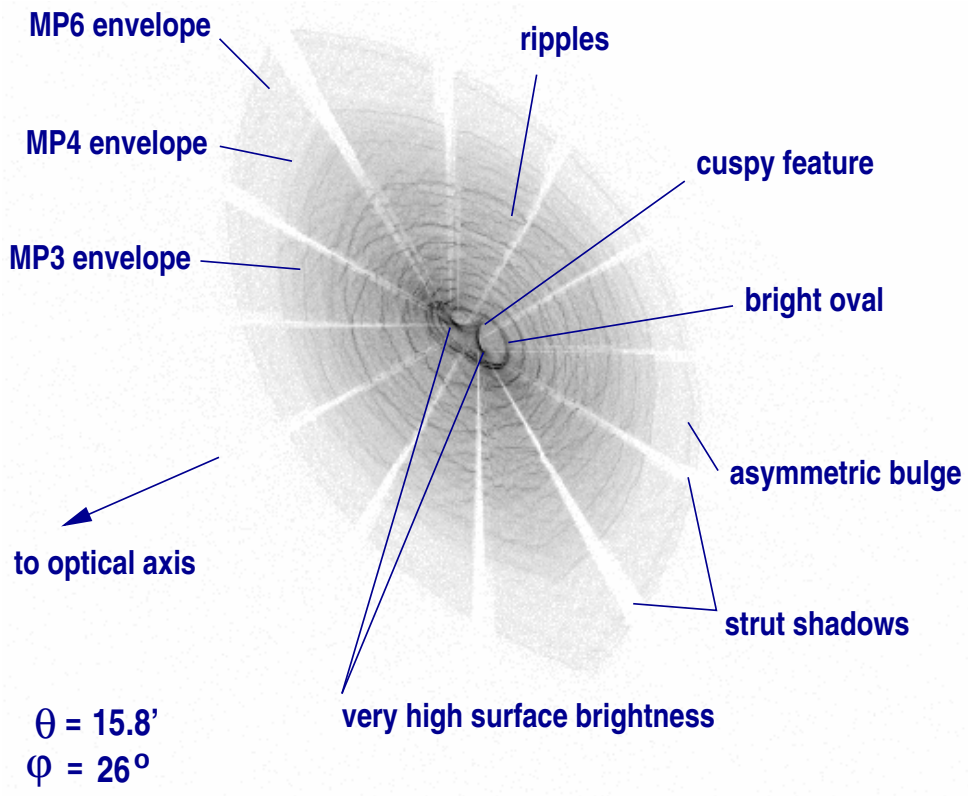
- structure: combination of surface figure + misalignments
- MP6 structure dominates at high energies; PSF "puffed out"



[simulated on-axis; HRC-I pixels; aspect blur included; linear stretch]

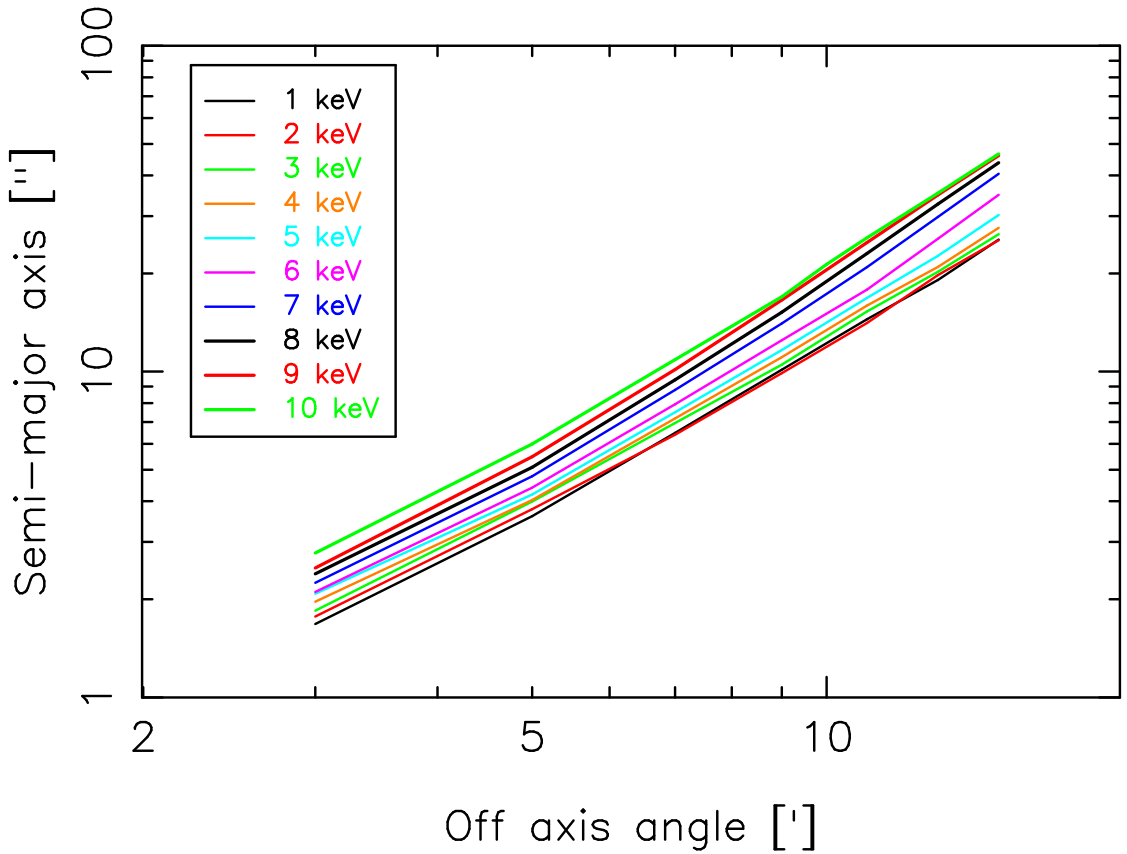
Anatomy of the Off-Axis PSF (simulation: $15.8'$ off-axis)

- dominant aberration: tangential stretching of PSF; "cat's eye"; varies $\propto \varphi$
- "coma-free" decenter misalignment
  $\Rightarrow$ very high surface-brightness caustic features and asymmetric bulge; vary $\propto \varphi/2$
- Extended envelope seen in deep off-axis images is PSF *core*

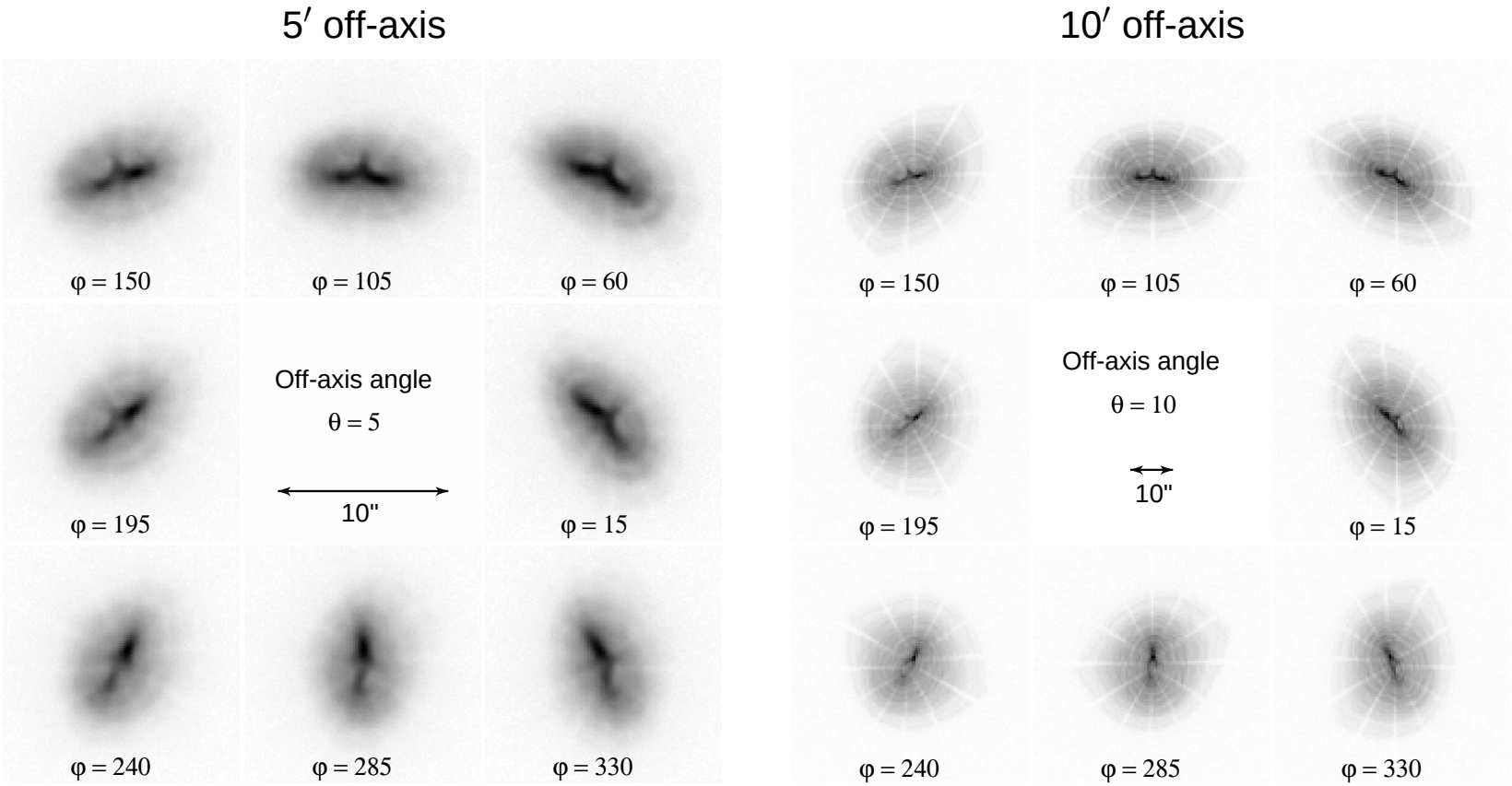


Off-Axis PSF Size

- PSF size
  - increases with energy
  - increase a bit less steeply than quadratically with θ



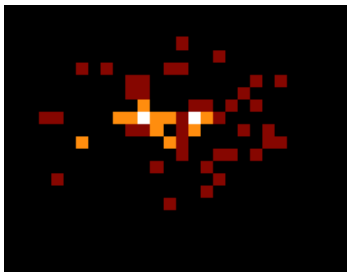
Off-Axis PSF (HRC-I focal plane)



- PSF shape varies systematically with *both* θ and φ
- grows with θ; variable stretching and elongation as $\varphi/2$ and φ

Off-Axis PSF Analysis Issues

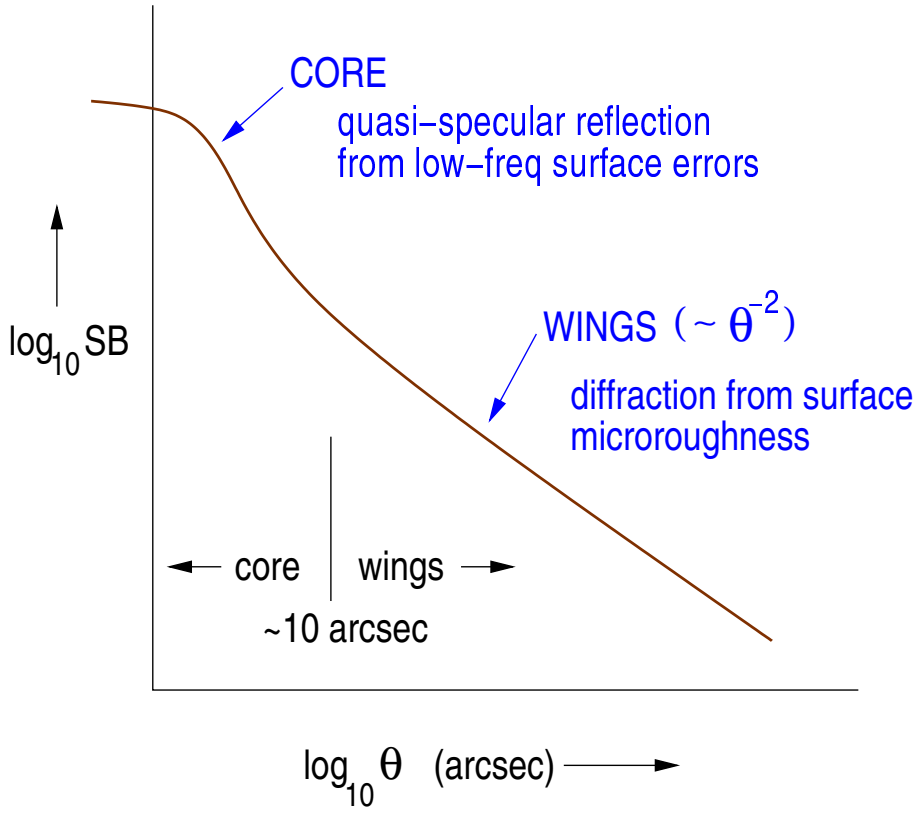
- off-axis PSF varies systematically with θ and φ
  - PSF size grows $\lesssim$ quadratically with θ
  - tangential elongation ($\propto \varphi$); bright PSF substructure varies $\propto \varphi/2$
    $\Rightarrow$ variable stretching and elongation with φ
  - Energy dependence: high energies dominated by smaller shells
    $\Rightarrow$ larger PSF, more extreme aberrations as E increases
- possible confusions:
  - mistake PSF aberration as source extent
  - low count statistics: Poisson fluctuations
    $\Rightarrow$ high surface brightness substructure can look like multiple sources.
- verify expected PSF using `ChaRT` to raytrace the optics, and `Marx` to apply detector pixelization.



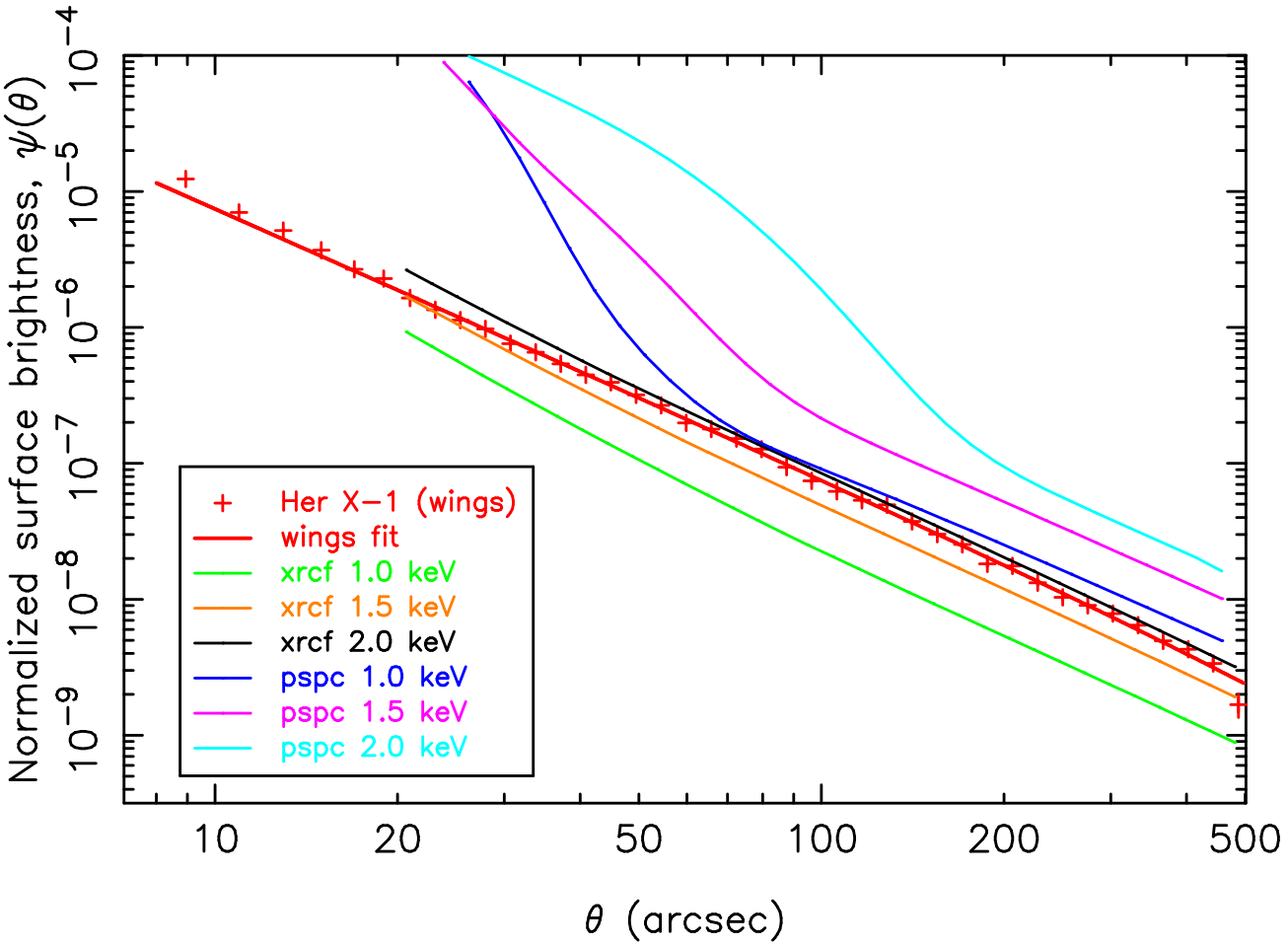
simulation: point source $6.9'$ off-axis; 67 counts; ACIS pixels; linear stretch.

PSF Wings

- The HRMA PSF has a faint halo extending to large angles
  - mirror scatter is E-dependent
  - scattered spectrum ⇒ harder with increasing angle from the source

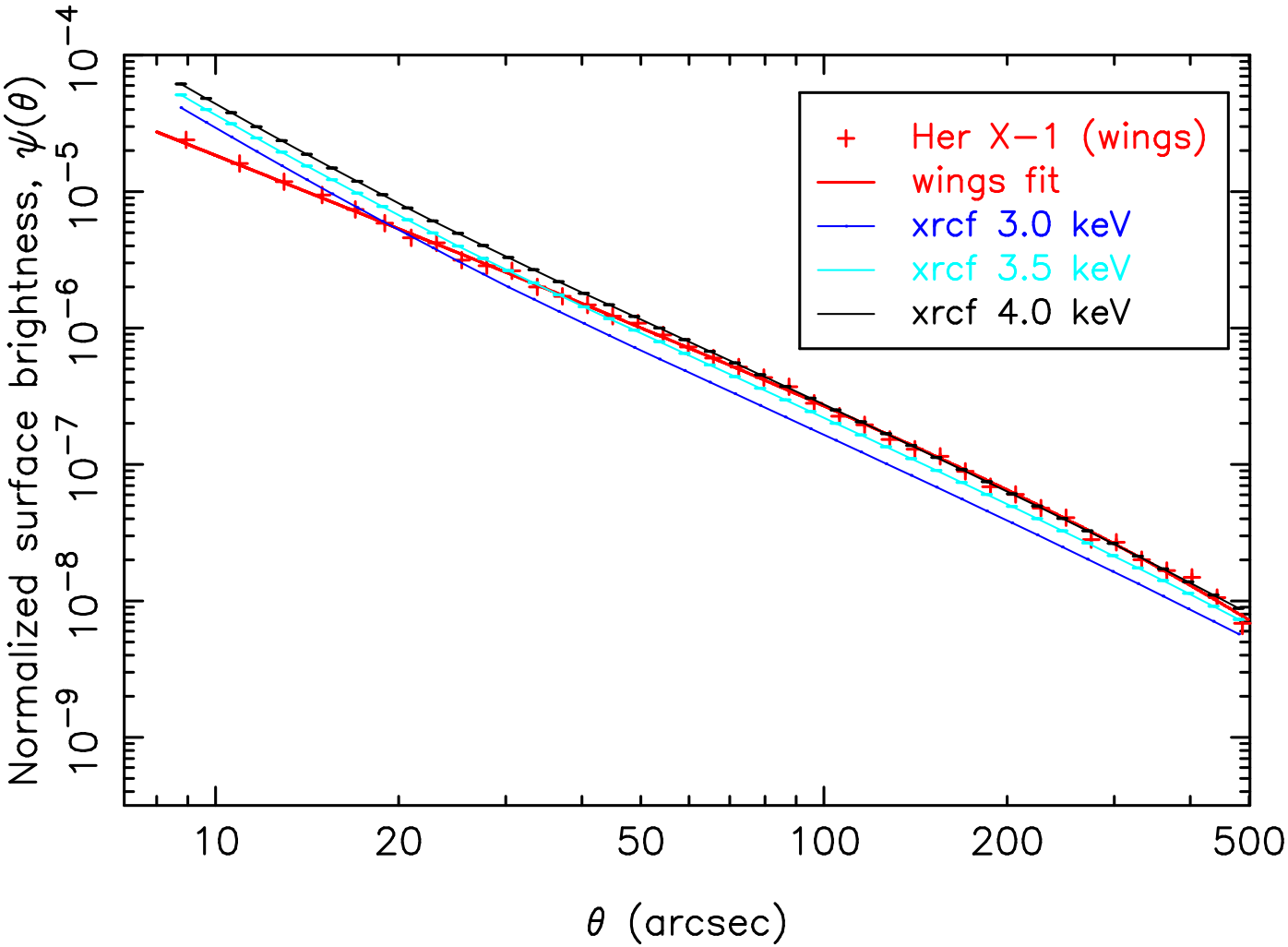


PSF wing profile - 1.0-2.0 keV



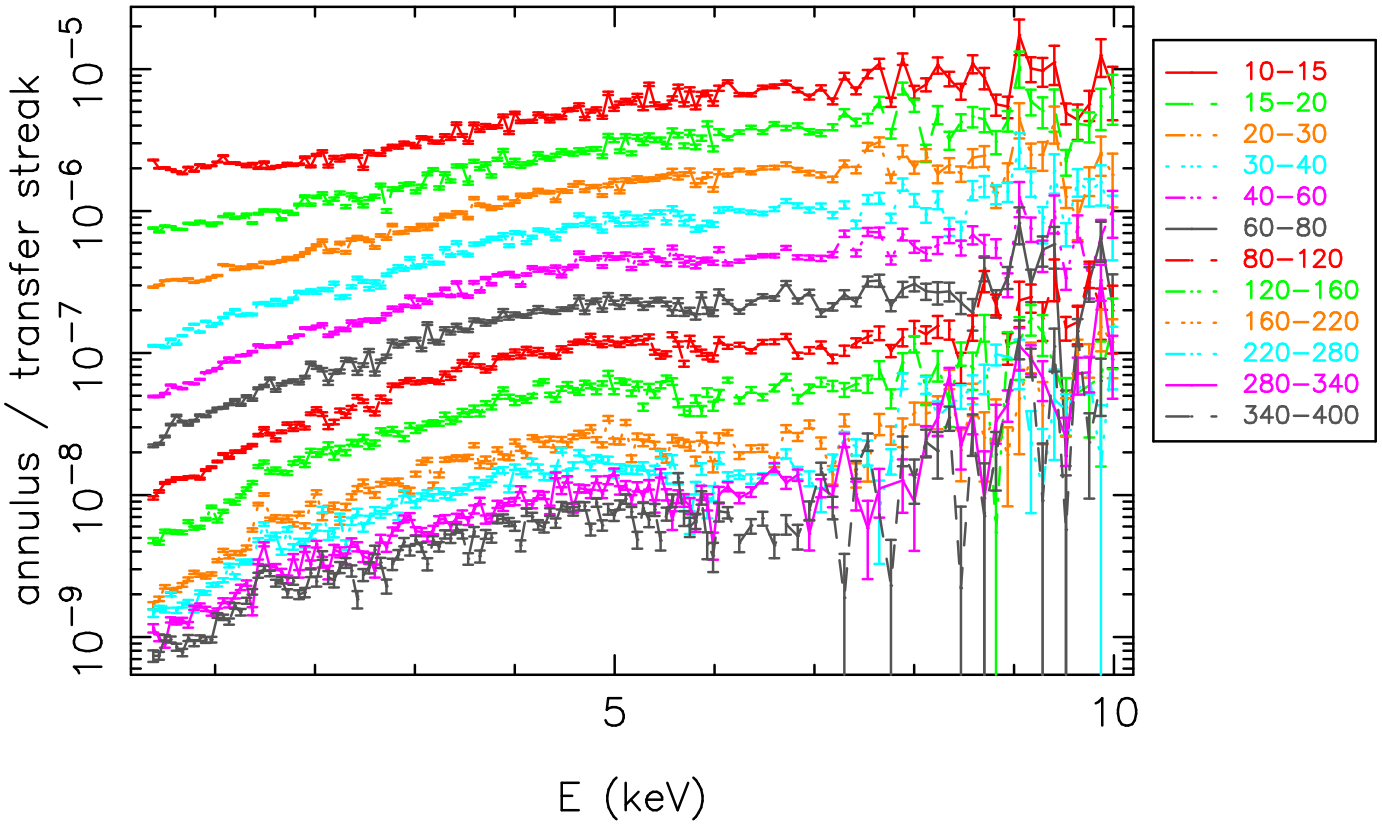
ROSAT PSPC fit: Boese 2000, A&Ap 141, 507

PSF wing profiles - 3.0-4.0 keV



PSF diffuse wing spectra

- diffuse mirror scattering strongly energy dependent
  $\Rightarrow$ hardening of diffuse scattering spectra with distance from source



Summary: Some PSF-related Analysis Issues

- On-axis PSF:
  - Core: increasing size with increasing energy (MP6 effect)
  - Wings: diffuse mirror scattering wings are energy dependent; diffuse scattered spectrum differs from that of the source
  - Shadows: mirror support struts & mirror support deformations
    $\Rightarrow$ 12-fold symmetry; could be mistaken for source structure.
- Off-axis PSF:
  - PSF size grows rapidly with off-axis angle
  - strongly asymmetrical aberrations; E-dependent
  - large range of surface brightness in off-axis PSF (core)
  - very bright PSF substructure; clumpy, could be mistaken for source structure
  - mirror support strut shadows could produce apparent source structure
- Single-reflection ghosts:
  - very bright sources far off-axis can produce faint ghost arcs;
    suppressed inside $\sim 14'$ $\Rightarrow$ mainly an issue for brightest sources
    and largest detectors (HRC-I, HRC-S, ACIS-S)