Calibration of the Chandra On-Axis PSF

Chandra User's Committee Presentation
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On-axis PSF

- PSF core ($\lesssim 90\%$ encircled energy)
  - low frequency mirror figure errors; misalignments
- PSF wings
  - scattering from mirror microroughness (high frequency errors)
  - low level (especially at low energies); requires bright source to see wings above background, leading to pile-up for ACIS detectors.

Calibration Aims

- Qualitative
  - PSF shape – "is my source extended?"
- Quantitative
  - PSF as "background"; need accurate subtraction, $e.g.$, extracting an X-ray dust scattering halo.
  - need: shape, absolute normalization, as function of E.

Ground Calibration (XRCF Wing Scans)

Wing Scan Data

- Surface brightness sampled with pinholes
  - $D_{ap} = 1, 4, 10, 20, 35$ mm diameter
  - up to 6 off-axis offsets $(\pm 1, \pm 2, \pm 3)$ D_{ap}; $(\theta \gtrsim 10'')$.
  - isolated quadrants of individual mirror pairs using shutters
  - HRMA tilted to approximate on-orbit graze angles
  - sampled selected mirror-pair quadrants at 0.277 , 1.49 , 4.51 , 5.41 , 6.4 , 8.08 keV

- mirror-pair/energy combinations (Mirror pair 1 is largest, 6 is smallest):
  - Mirror pair 1: 1.49 , 4.51 keV
  - Mirror pair 3: 1.49 , 4.51 , 5.41 , 6.4 keV
  - Mirror pair 4: 1.49 , 4.51 , 5.41 , 6.4 , 8.08 keV
  - Mirror pair 6: 0.277 , 1.49 , 4.51 , 5.41 , 6.4 , 8.08 keV

Ground Calibration (XRCF Wing Scans)

Analysis strategy:

- Evaluate and fit PSD's (surface roughness functions) for each mirror pair:
  - evaluate normalized mirror pair surface brightness profiles (for each energy)
  - combine surface brightness data from different energies to estimate the PSD (surface roughness function) *vs.* roughness spatial frequency for each mirror pair.
  - fit the PSD for each mirror pair
- Use individual mirror pair PSD fits to evaluate HRMA surface brightness profile; for a given energy :
  - evaluate the normalized surface brightness profile for the mirror pair
  - add the profiles, weighted by the fraction of total effective area.
- This procedure allows interpolation to different energies

Ground Calibration (XRCF Wing Scans)

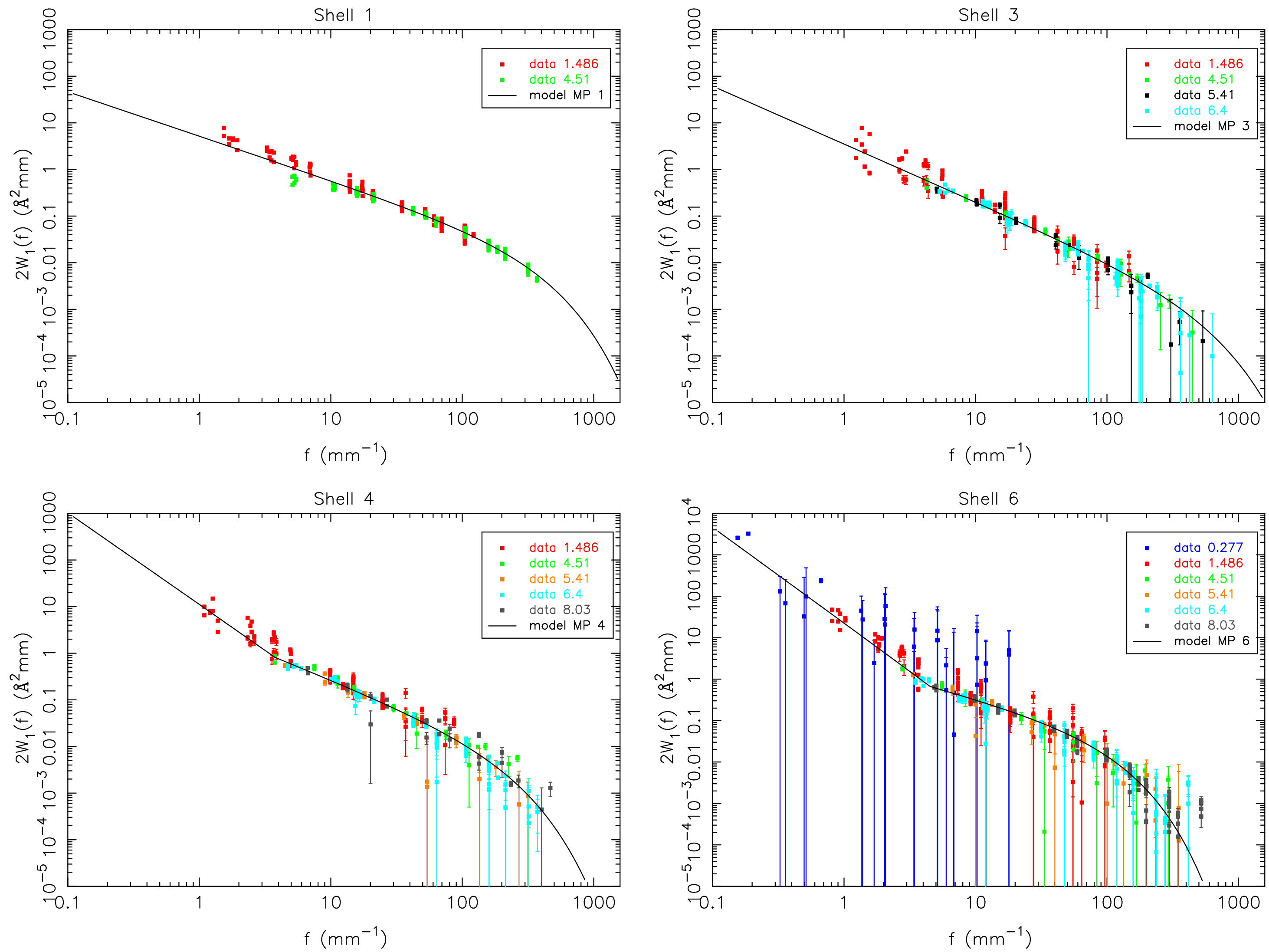

Figure 1: PSD ($2W_1$) data and fits for individual mirror pairs

Ground Calibration (XRCF Wing Scans)

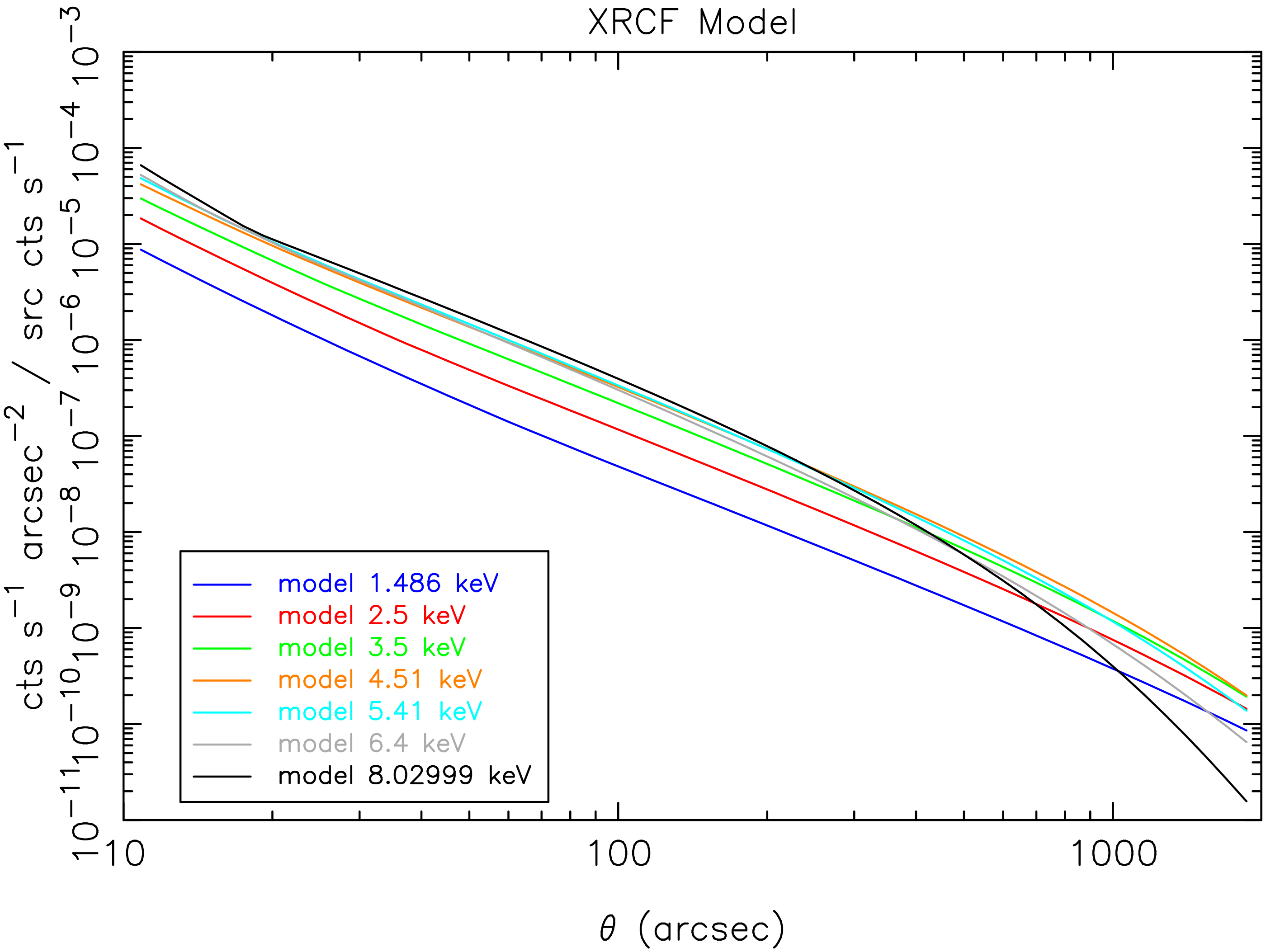

Figure 2: Model HRMA surface brightness profiles based on mirror pair PSD's

Ground Calibration (XRCF Wing Scans)

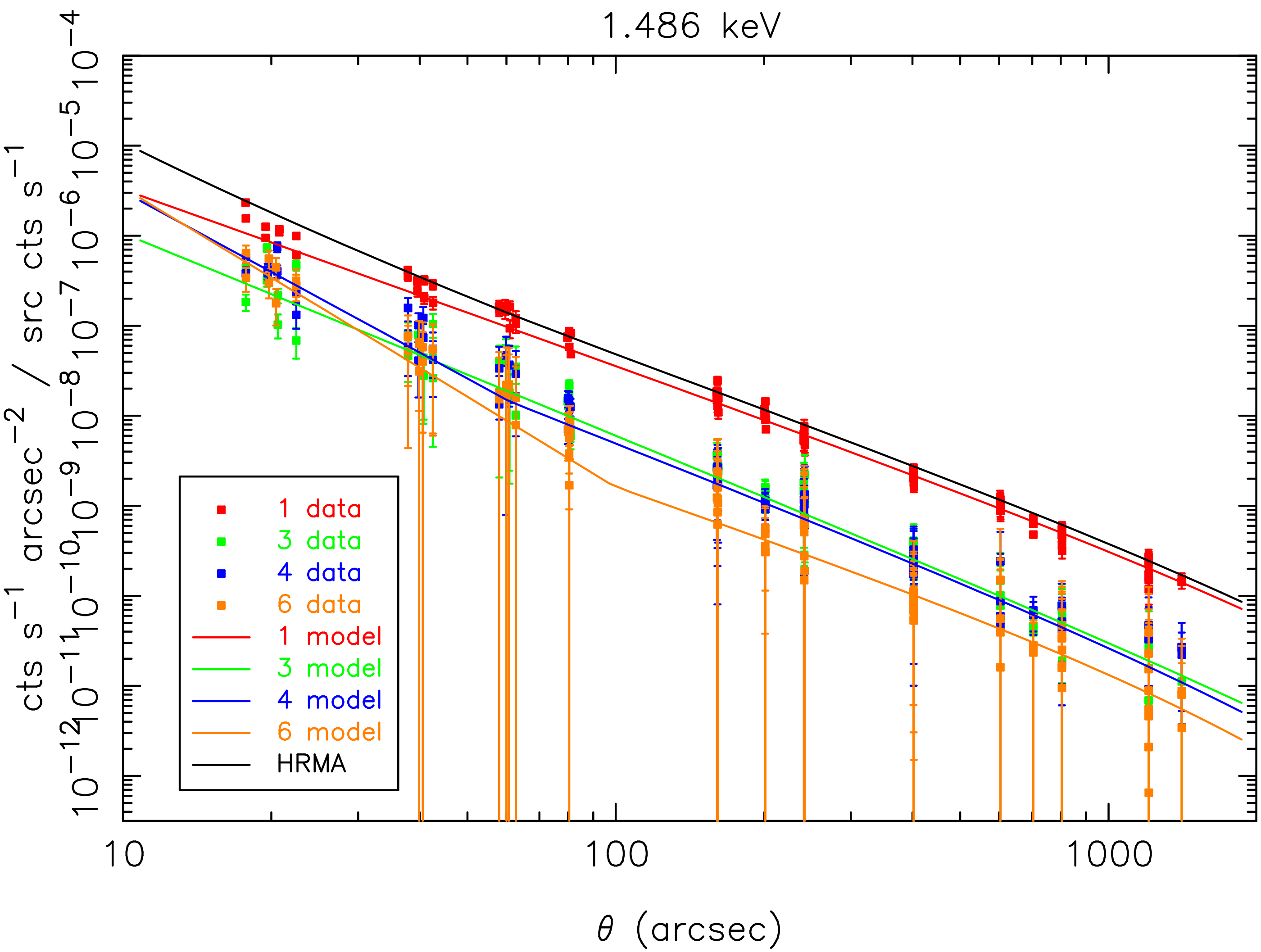

Figure 3: Modeled HRMA surface brightness profile *vs.* data (E = 1.486 keV)

Ground Calibration (XRCF Wing Scans)

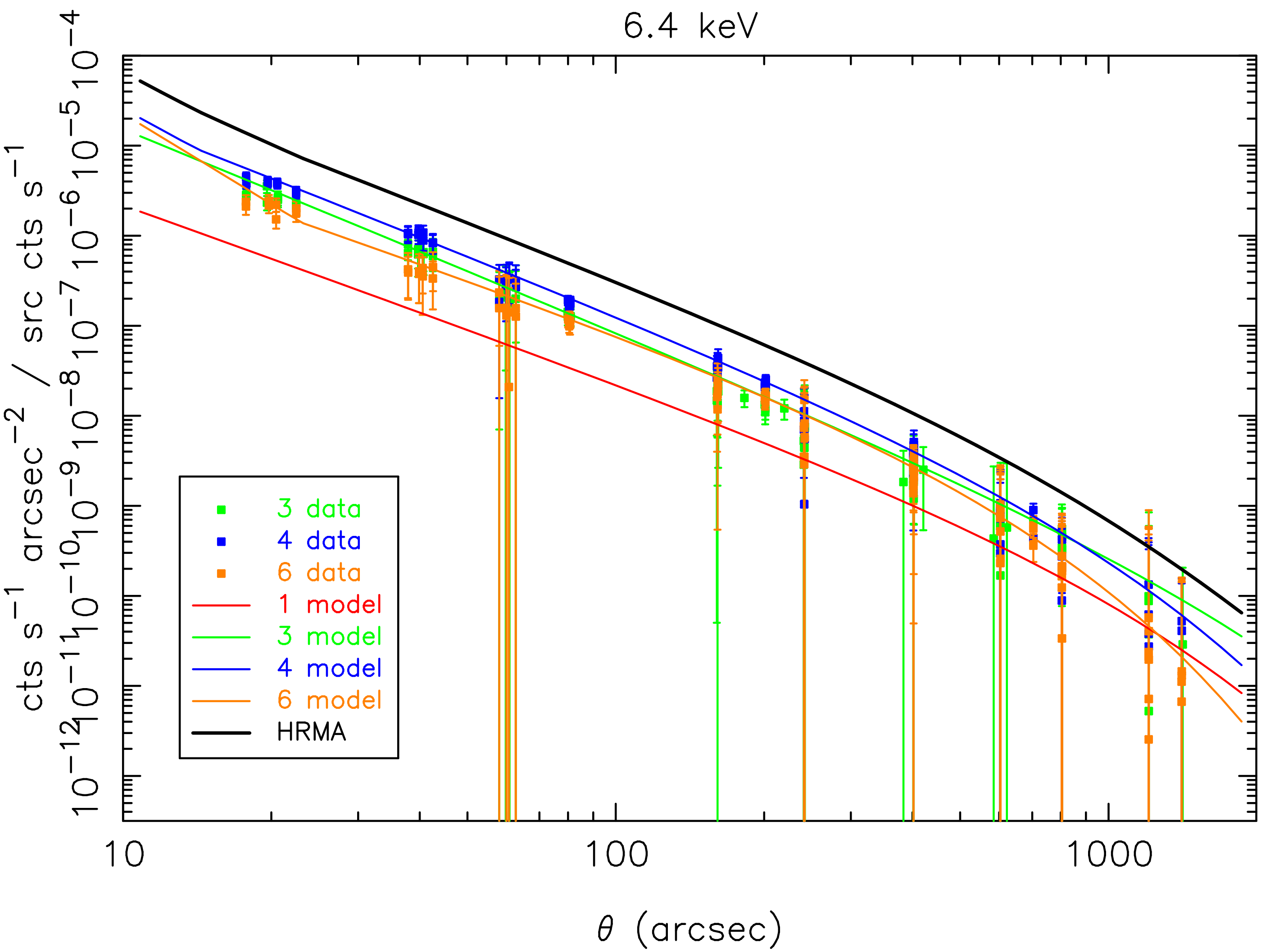

Figure 4: Modeled HRMA surface brightness profile *vs.* data (E = 6.4 keV)

On-Orbit Data

- obsid 01712: 3C273 on ACIS-S3
  - failed grating insertion
  - ~ 30 ks total, GTI ~ 15 ks
  - $N_{HI} = 1.69 \times 10^{20}$ cm^2 (Lockman & Savage 1995, *ApJS*, **97**, 1)

- obsid 01422: LMC X-1 on ACIS-I
  - ~ 4 ks total, GTI ~ 4 ks
  - $N_H \simeq 10^{22}$ cm^2; 2.9% dust X-ray halo reported (Predehl & Schmitt 1995, *A&A*, **293**, 889)
  - complex field, *e.g.* SNR 0540-6944 within a few arcmin (Williams *et al.* 2000, *ApJL*, **536**, L27)

- obsid 01385: AR Lac on HRC-I
  - ~ 19 ks total, GTI ~ 19 ks
  - $N_{HI} = (5.9 \pm 2.5) \times 10^{18}$ cm^2 (Rodonò *et al.* 1999, *A&A*, **346**, 811)

On-Orbit: 3C273

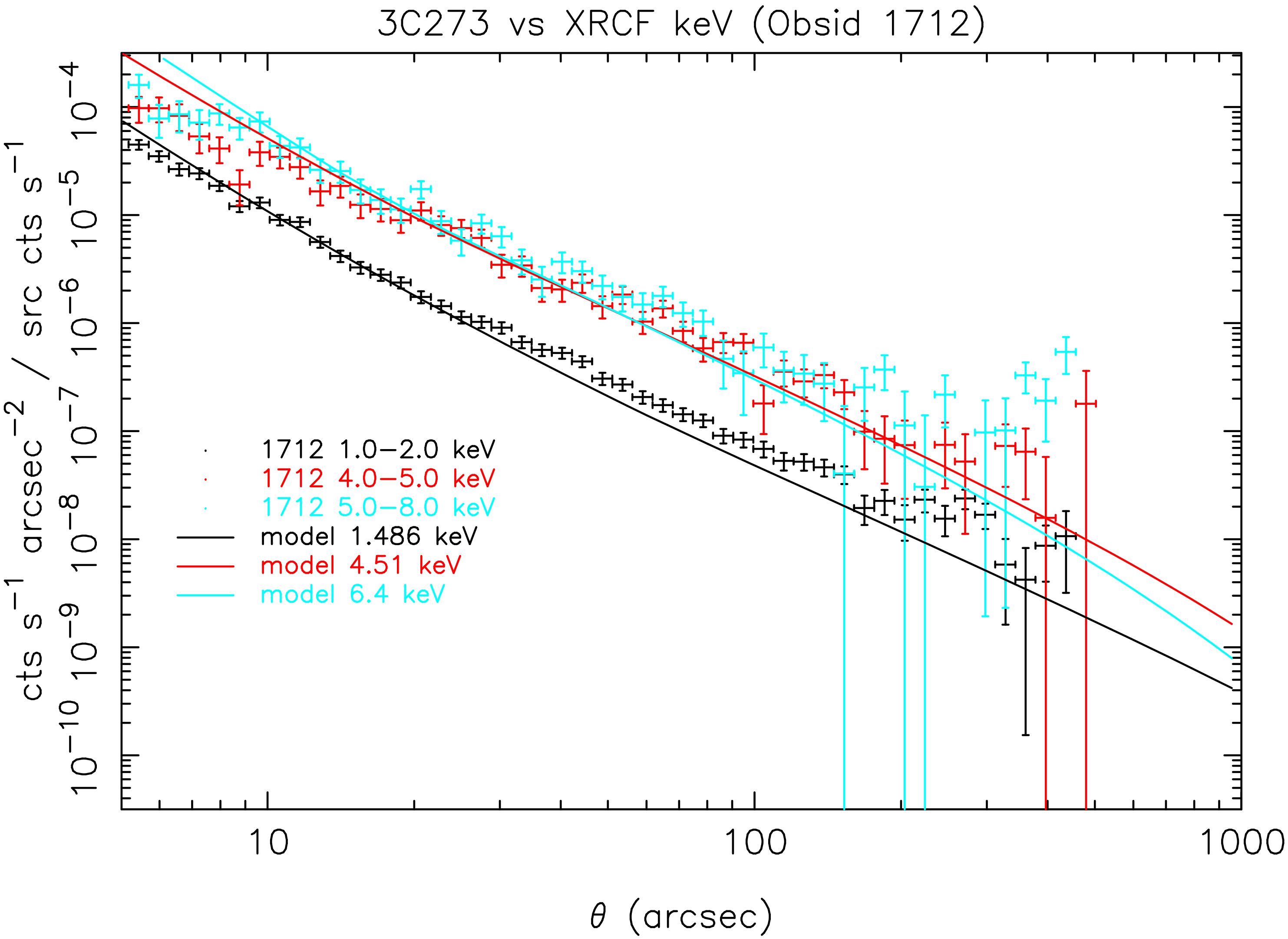

Figure 5: Surface brightness: 3C273 data (ACIS-S3) *vs.* HRMA model based on PSD's

On-Orbit: LMC X-1

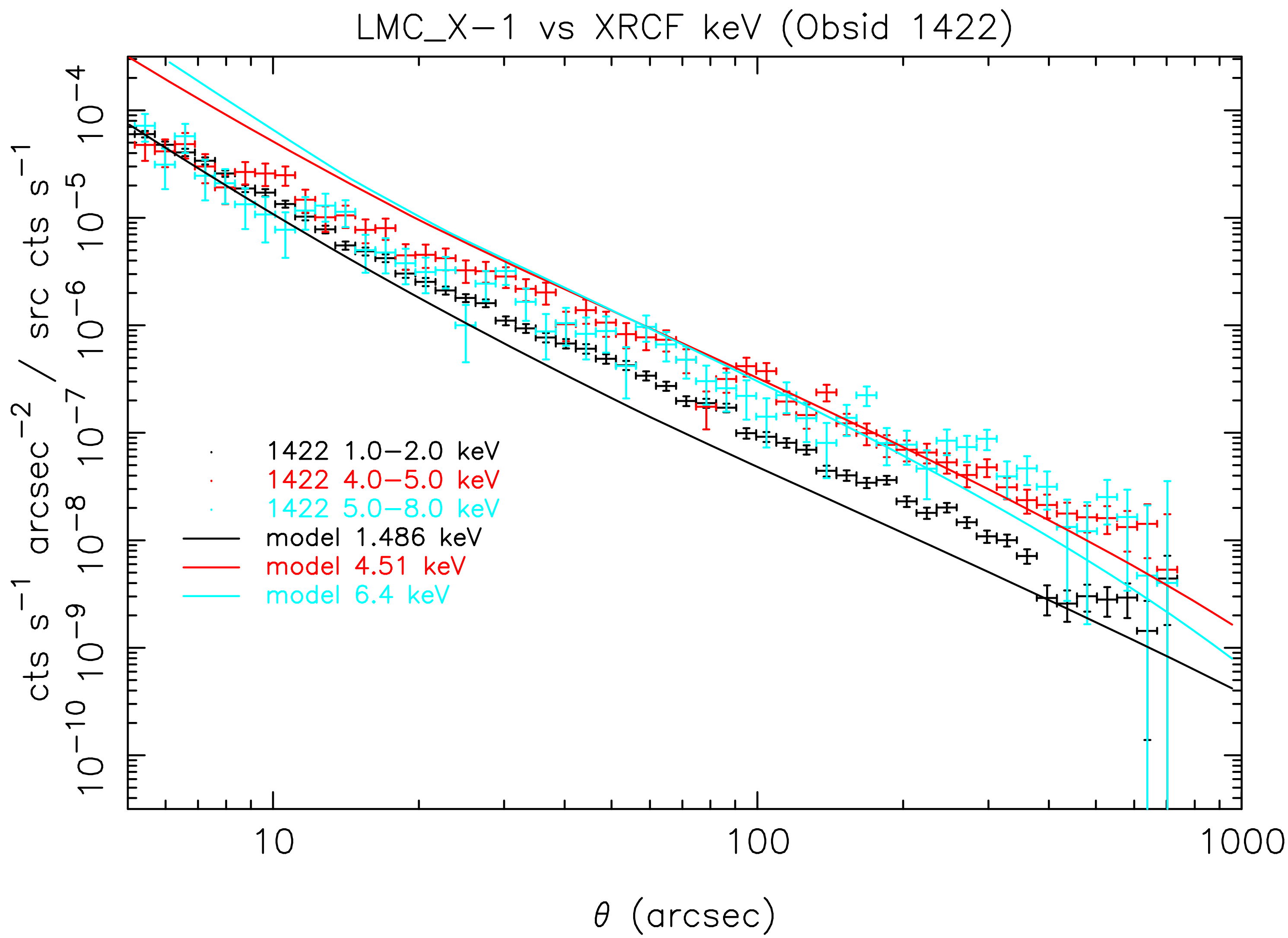

Figure 6: Surface brightness: LMC X-1 data (ACIS-I) *vs.* HRMA model based on PSD's

HRMA PSF – Core and Inner Wings

- AR Lac, Obsid 1385
- Note: systematic residual position offsets in HRC event position reconstruction
  - depends on where on the tile the X-ray landed;
  - adds several-pixel blur.
  - overview of some of the issues: M. Juda memo: http://hea-www.harvard.edu/ juda/memos/hrc_blur/hrc_blur.html
- apply an ad-hoc correction for residual HRC position errors:
  - assume AR Lac is a point source
  - aspect residuals are random in direction and uncorrelated.
  - For details of the correction, see the D. Jerius presentation at the Oct. 2001 Calibration Review: http://cxc.harvard.edu/cal/calreview/on-axis-psf.ps
- Good agreement between corrected data and raytrace simulation
- Caveats:
  - HRC has very little energy resolution
  - AR Lac is a fairly soft source; tests low energy PSF only

HRMA PSF – Core and Inner Wings

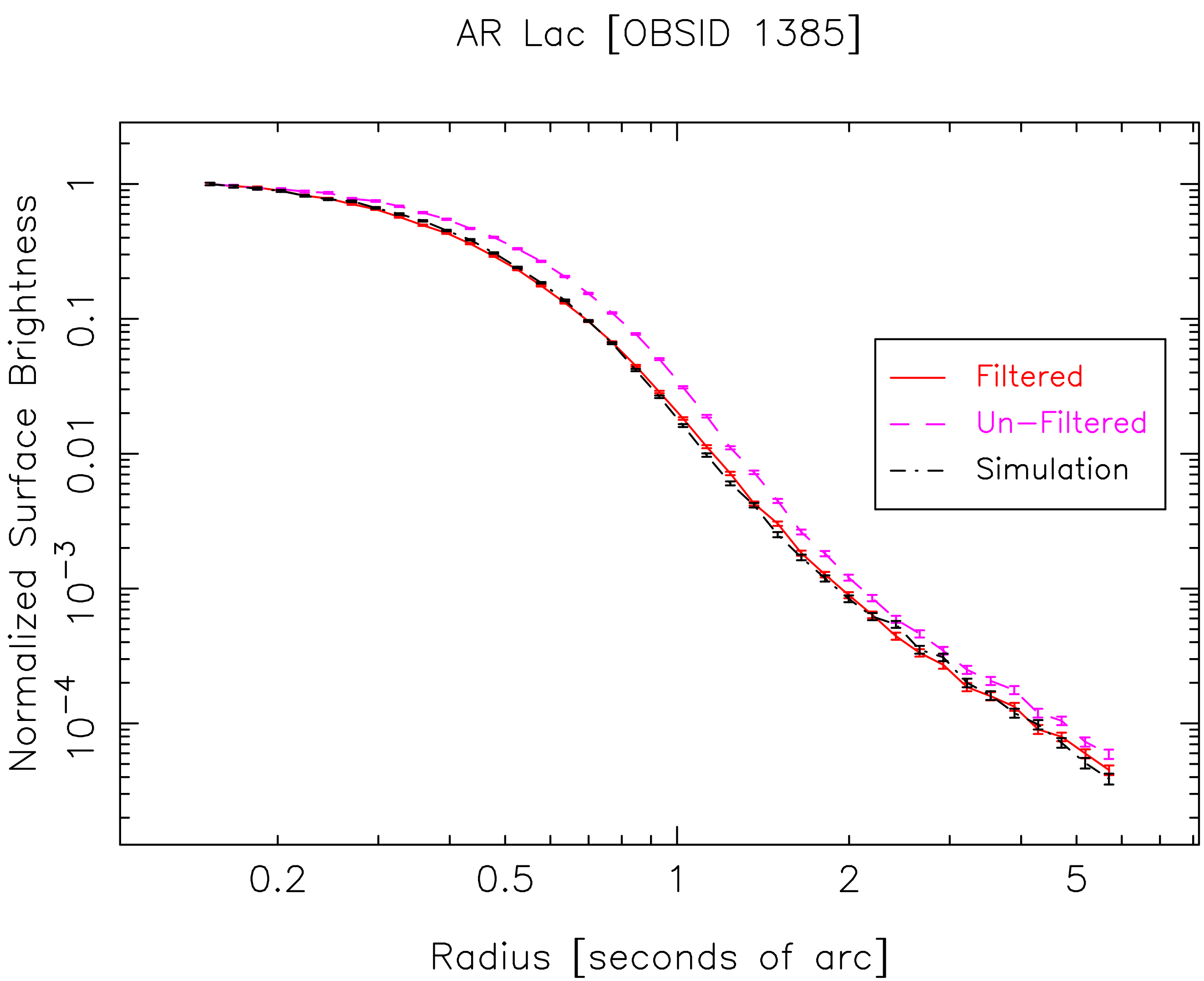

Figure 7: Core and inner wings based on massaged AR Lac HRC data

HRMA PSF – $E \sim 1.5$ keV

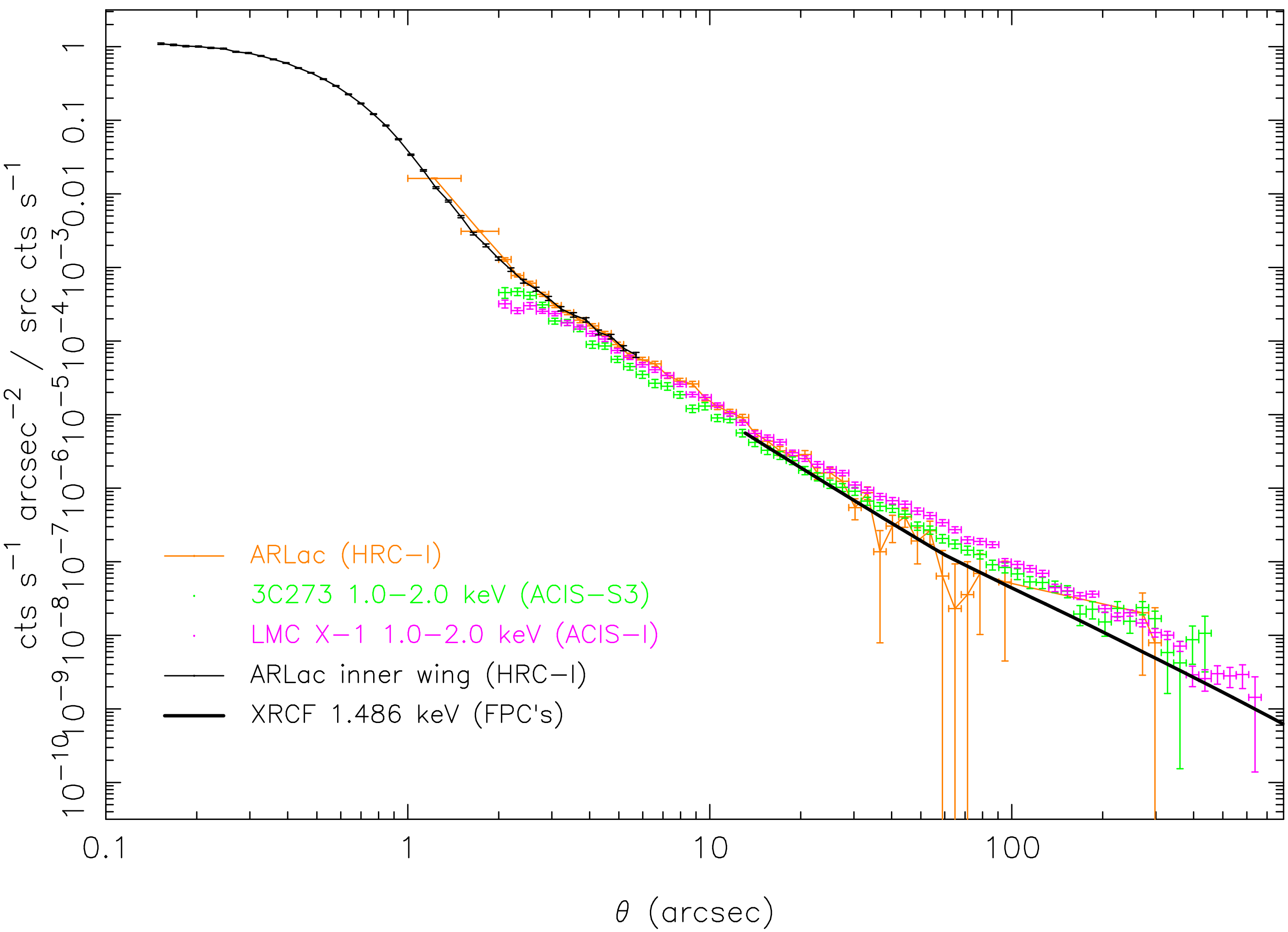

Figure 8: low energy surface brightness: $E \sim 1.5$ keV

HRMA PSF Wings - Issues

Issues

- normalization of wings
- need better statistics
- core-wing transition (as a function of energy)
  - core: $\lesssim$few arcsec
  - wings: $\gtrsim$10 arcsec
- ground calibration systematics
  - quad shutter correction; tilt of HRMA; illumination pattern

Plans

- planned calibration observation for wings, either:
  - 100 ks observation of 3C273 on ACIS-I, using `very faint` mode to further reduce background; $N_{HI} \approx 1.7 \times 10^{20}$ cm^2.
  - shorter observation of Her X-1 on ACIS-I, using `very faint` mode [revised; was: *graded mode*]; $N_H \approx 10^{20}$ cm^2
- far core/near wings
  - search for on-axis intermediate strength sources on ACIS (for energy resolution); less pile-up gets us closer to the core.

HRMA PSF - Some caveats

Ground Calibration Data (XRCF)

- Backing out ground calibration effects, *e.g.*
  - Illumination of the optics is different than on-orbit; this emphasizes the smoother middle portion of the optics $\Longrightarrow$ expect profiles to somewhat underestimate the wings.
  - Normalization of the data points: assumed an approximate correction for the effects of the quadrant shutters; assumed to be exactly a factor of 2, but could vary depending on off-axis distance and direction (scattering to smaller or larger angles from the optic surface).
- Longer term:
  - iterative refinement of scattering model for raytrace to improve agreement with models; this will allow the ground effects & systematics to be backed out more reliably.

Sky data (ACIS)

- Provides an upper limits on wings
  - astrophysical effects (*e.g.*, dust scattering halos) can broaden the PSF; need "clean" lines of sight.
- Systematics, *e.g.*:
  - Depression of inner regions by detector pile-up effects.
  - Background subtraction uncertainties; vignetted *vs.* unvignetted background.
  - Evaluation of source rate for absolute normalization.