Chandra Calibration: Plans, Status, Future

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HRMA Cal Summary

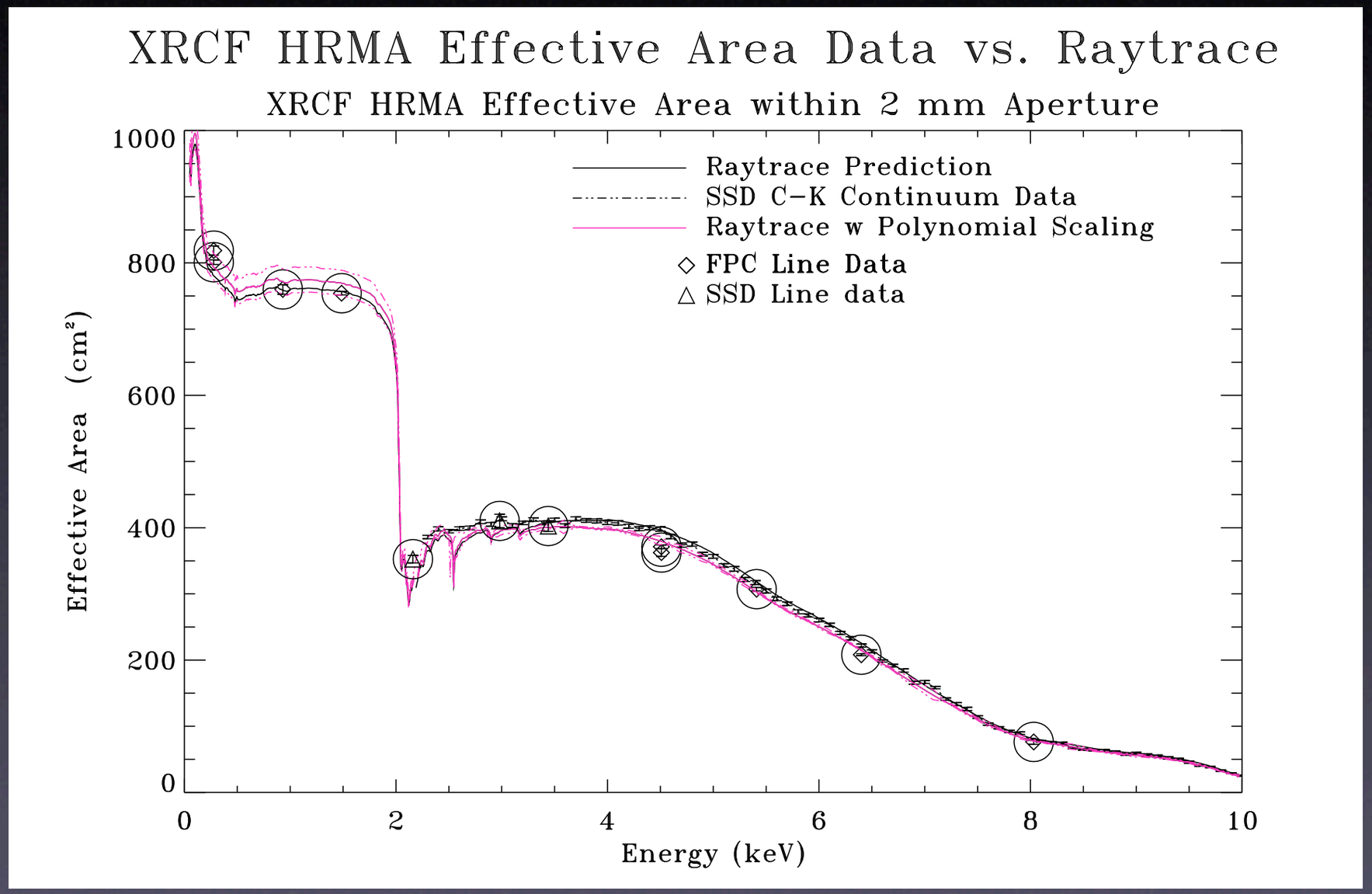
- Ground calibration
  - Reflectivity measurements on witness samples
  - Metrology of optical surfaces
  - Positioning feedback during assembly
  - High fidelity raytrace, modeling distortions
    - XRCF imaging and reflectivity measurements
      - Accounting for finite source size and distance
      - Testing each quadrant of each shell separately
      - Allowing for illumination differences to flight
- Flight verification
  - Imaging star with both ACIS and HRC
  - Effective area tests using continuum sources

XRCF: Ground Cal

- Mirror assembly (HRMA) with flight gratings and detector prototypes
- Telescope with flight detectors and gratings
- Flight detectors alone (uniformity tests)

HRMA Effective Area

- Adjustments needed based on XRCF data



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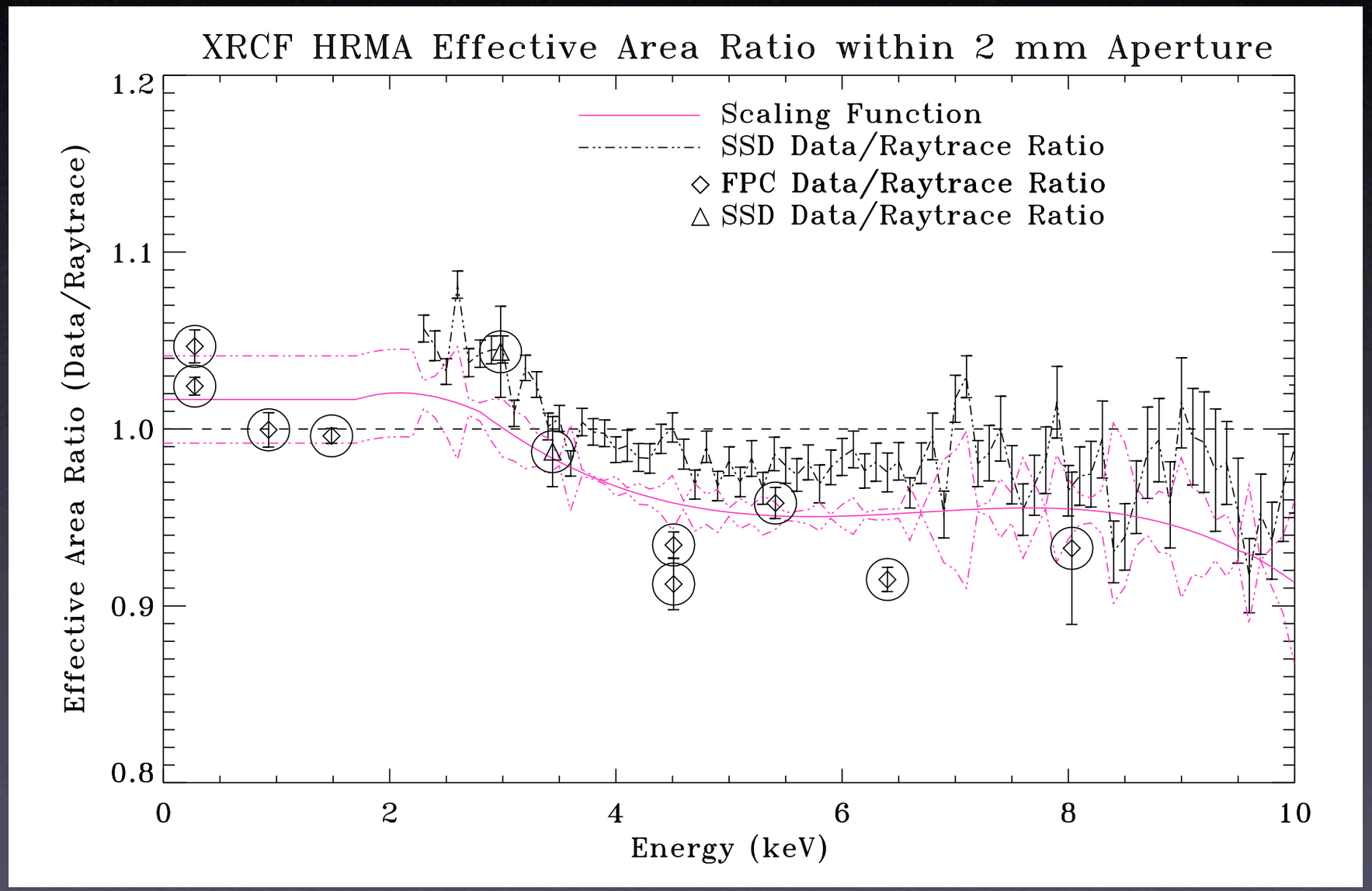
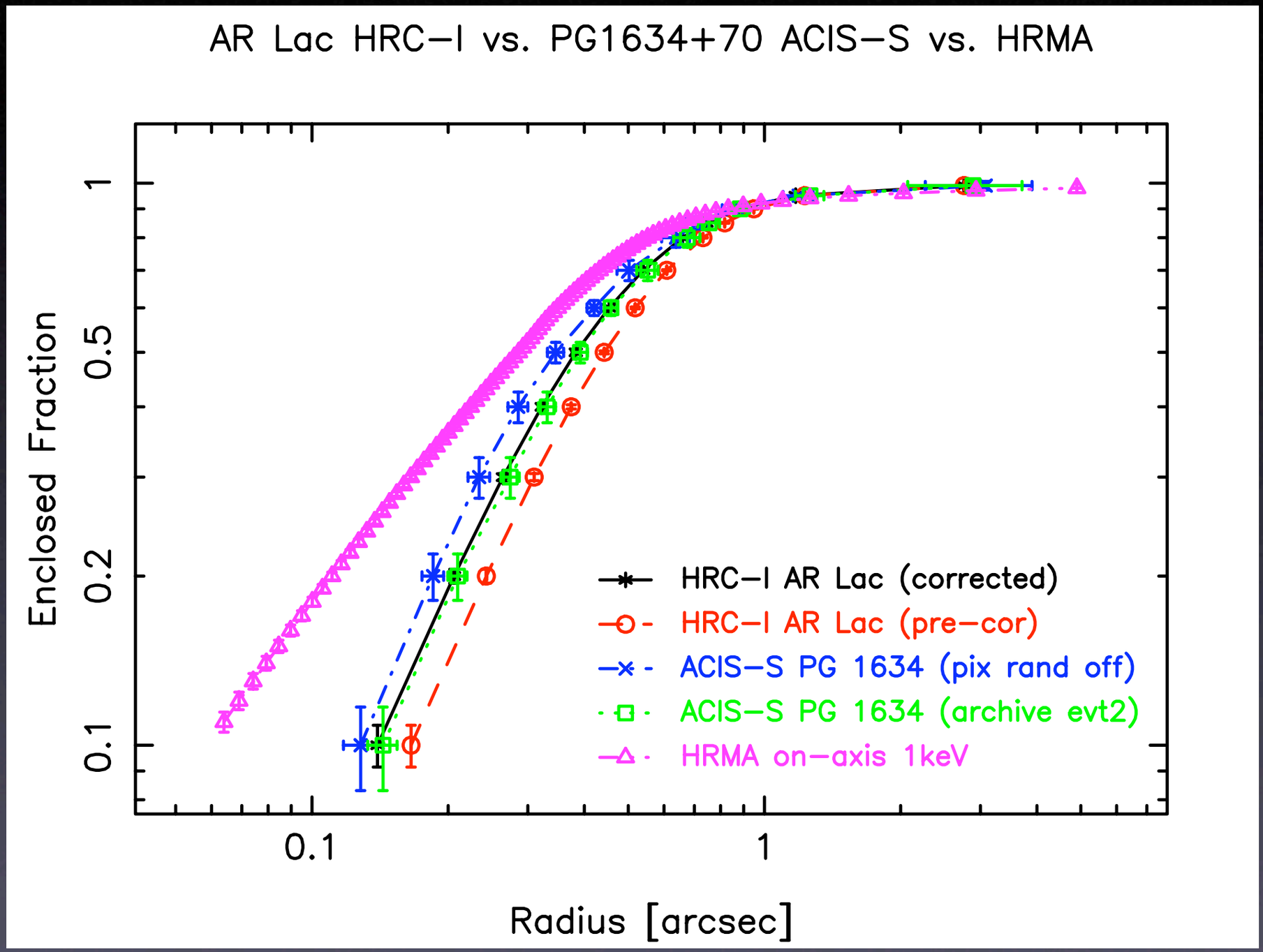


In-Flight HRMA PSF



Pease, Jerius, et al. (2005 CXC Cal Workshop)

HRMA CaI Summary

- Status
  - PSF FWHM
    - 10% uncertainty at 0.277 keV
    - 15% uncertainty at 6.4 keV
    - In-flight PSF: modeled to 10% in 1D
  - Effective area
    - <10% uncertainties across Chandra band
    - Ir-M edge corrected using in-flight data
    - More EA verification in progress, including cross-cal
- Challenges
  - ACIS QE degradation, HRC QE uncertainties
  - Ground-based beam uniformity uncertainties
  - Slight, unmeasured mirror misalignments

HETG Cal: Subassembly

- For each of 144 HEG + 192 MEG facets
  - X-ray diffraction efficiencies at 6 energies
  - grating periods over surfaces (rel. to NIST sample)
  - aligned using polarization
- Synchrotron spectra of two facets
  - component-based: Au, Cr, polyimide
  - facet-dependent bar shape
- Facet periods, alignments used in `marx`
  - simulate line response functions (LRFs)
  - simulate cross-dispersion enclosed power

Grating Cal: XRCF

- System characteristics measured:
  - Efficiencies (grating in vs. HRMA only)
  - Dispersion relation
  - Spectral resolution
- Discovered: scatter, misalignments
- Limitations:
  - Finite source distance, size
    - not flight Rowland distance
    - not flight LRFs or dispersion relation
  - Efficiency measurements
    - modeling L line complexes (E < 1 keV)
    - monochromator beam uniformity

Grating Cal: In-Flight

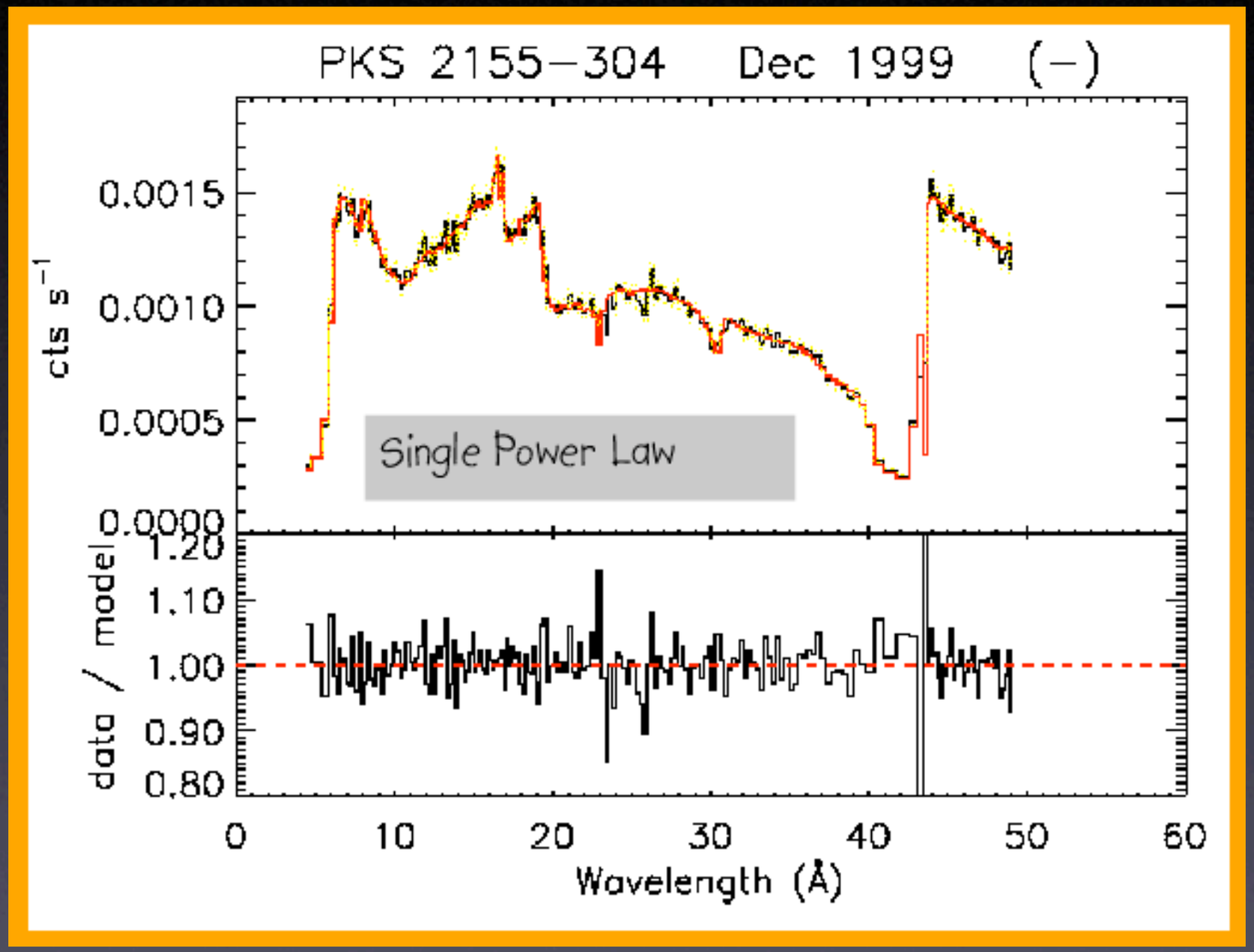
- Line sources (Capella, HR 1099, Procyon)
  - verify dispersion relation
  - verify LRFs
- Continuum sources (PKS 2155-304, Mk 421, 3C 273)
  - verify effective area
  - verify high order efficiencies

System Calibration Status

Characteristic	Det/Grat	Requirement (1 sigma)	Present Uncertainties (CIAO 3.3.0 with CALDB 3.2.1)	Goal
Absolute Positions	HRC/ACIS	1.0"	0.6" (90%)	0.6" (90%)
	ACIS-I		0.1"	0.1"
Relative Spatial Positions	ACIS-S3	0.1"	0.1"	0.1"
	HRC-I		0.3"	0.1"
Absolute Energy Scale	ACIS	1 eV	0.3%	0.3%
	LETG/HRC-S	0.02A	0.010A	0.010A
	MEG/ACIS-S	0.03A (MEG)	$\delta\lambda/\lambda = 1.0 \times 10^{-4}$	$\delta\lambda/\lambda = 1.0 \times 10^{-4}$
	HEG/ACIS-S	0.03A (MEG)	$\delta\lambda/\lambda = 1.0 \times 10^{-4}$	$\delta\lambda/\lambda = 1.0 \times 10^{-4}$
Absolute Effective Area	ACIS	2%	5%	5%
	HRC	7%	7%	7%
Absolute Effective Area (1st order)	LETG/HRC-S	10%	15%	10%
	HETG/ACIS-S	10%	8%	10%
Absolute Effective Area (2nd - 7th Orders)	LETG/HRC-S		20%	15%
	HETG/ACIS-S		20%	15%
Energy Resolution (FWHM)	ACIS	3%	20 eV	20 eV
	LETG/HRC-S	3%	20%	10%
	MEG/ACIS-S	3%	3%	3%
	HEG/ACIS-S	3%	3%	3%
Relative Efficiency (Effective Area)	ACIS	1% on scales of 1'	1.0%	1.0%
	ACIS		5%	3% on scales of 200 eV
	HRC	1% on scales of 1'	0.7%	0.7%
	LETG/HRC-S	3% on scales of 0.05A	6%	3%
	HETG/ACIS-S	3% on scales of 0.05A	5%	3%
Point Spread Function	HRC/ACIS	0.1% of peak within 1" annuli out to 16"	0.004%	0.004%
		0.001% of peak between 16" and 20"	0.00008%	0.00008%
Relative Time Precision	HRC	16 mu s	4-18 mu s	16 mu s
Absolute Time Accuracy	HRC	100 mu s	42 mu s	42 mu s
	ACIS-CC		1.5 m sec	1.5 m s

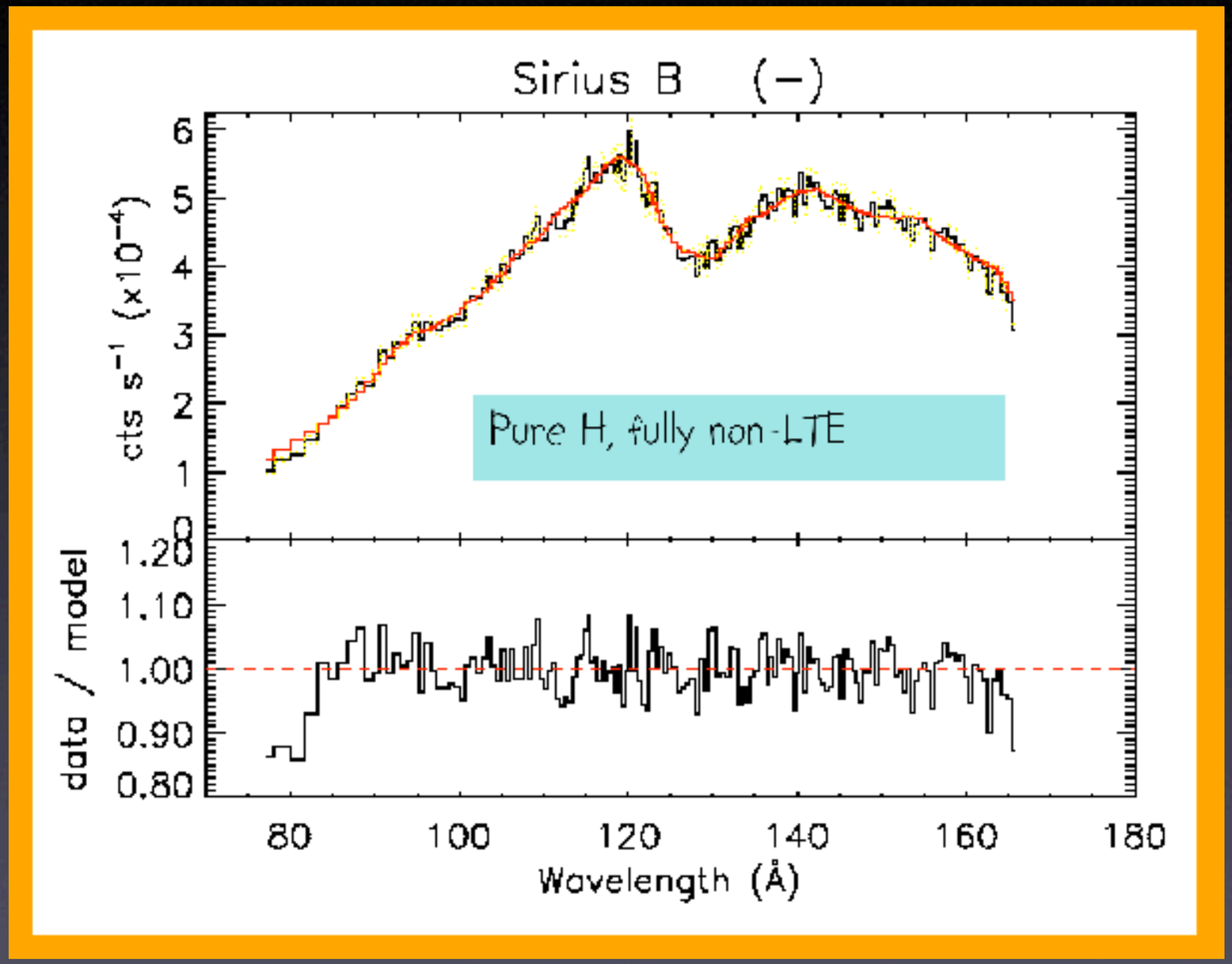
http://asc.harvard.edu/cal/

LETGS Effective Area



Drake, et al. (2005 CXC Cal Workshop)

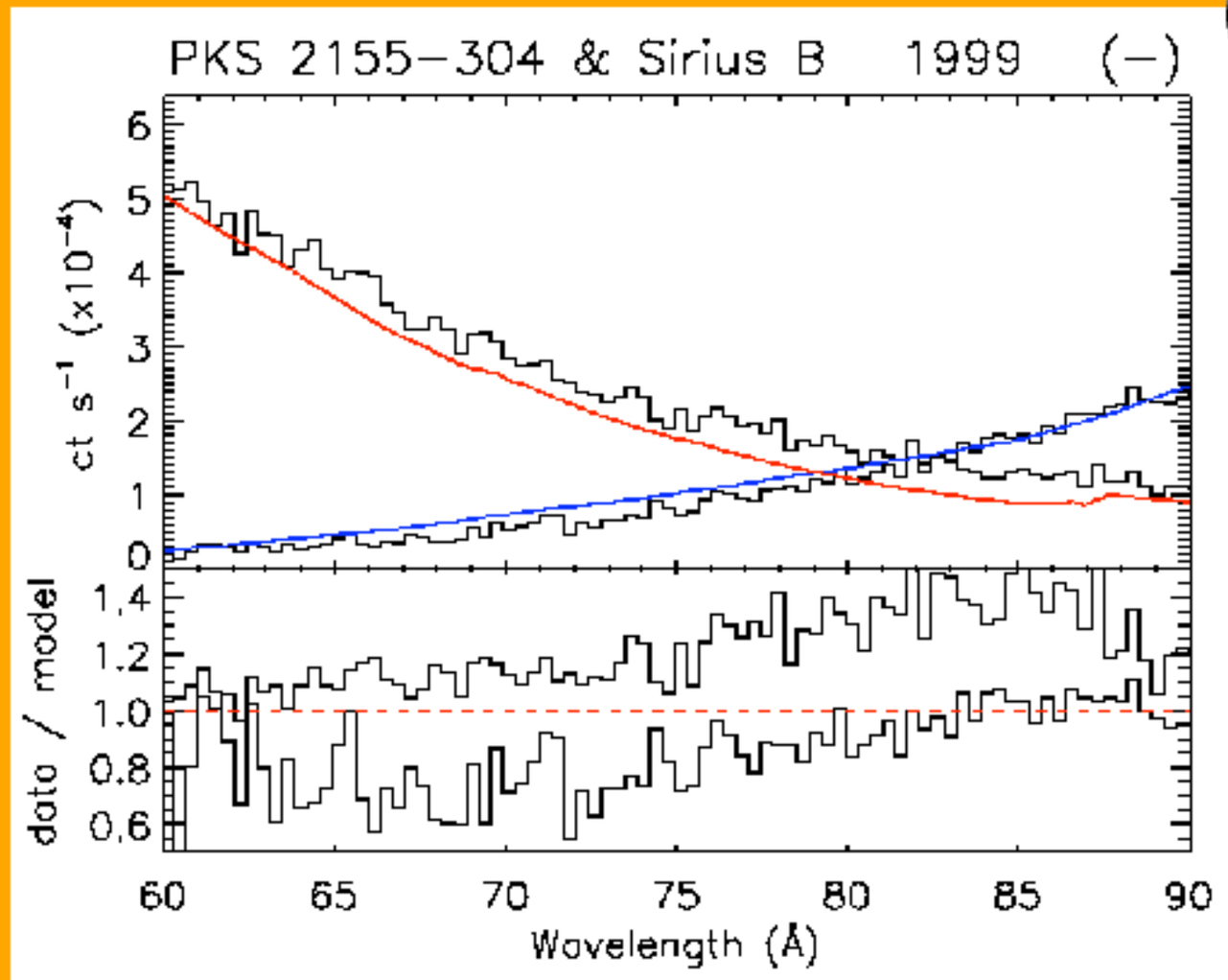
LETGS Effective Area



Drake, et al. (2005 CXC Cal Workshop)

LETGS Effective Area

Problem area: 60-80AA



Drake, et al. (2005 CXC Cal Workshop)

LETG-HRC Summary

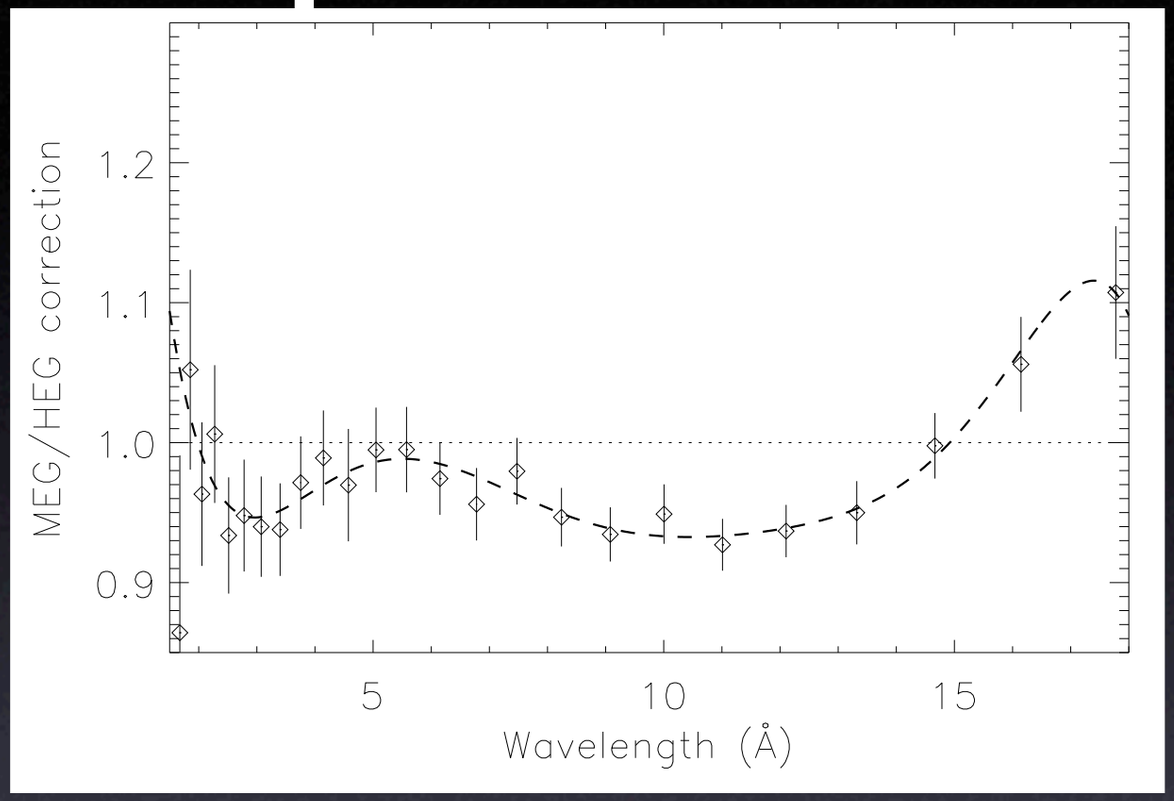
- On-going work
  - Effective Area
    - Cross-cal needed to verify system EA
    - Work needed in 60-80 Å range
  - Dispersion relation: HRC distortions
    - Gain sag, PHA-based background rejection
- Limits to Calibration
  - HRC QE is not physically modeled
    - XRCF HIREFS high orders limited absolute QE cal
    - Electronics changed after ground cal → limited data
  - LETG efficiencies based on model from IR data
    - High order efficiencies from LETG/ACIS data

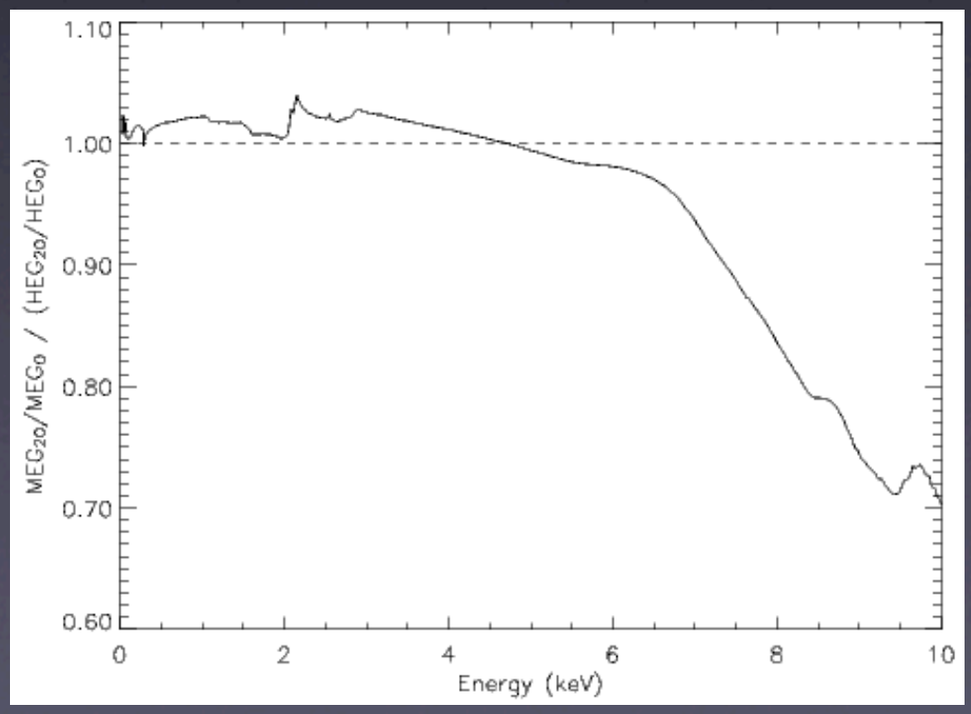
HETGS Flight Cal

- Dispersion relation
  - Corrected detector offsets and rotations
  - Wavelengths:
- Effective Area
  - Compare +1 to -1: ⟶ fix BI/FI QE
  - Compare MEG to HEG: ⟶ HEG/MEG fix
  - Combine many data sets: ⟶ fix Ir-M edge
  - LETG/ACIS:
    - Also used for BI/FI
    - Used to discover and diagnose ACIS contamination

HEG/MEG Comparison

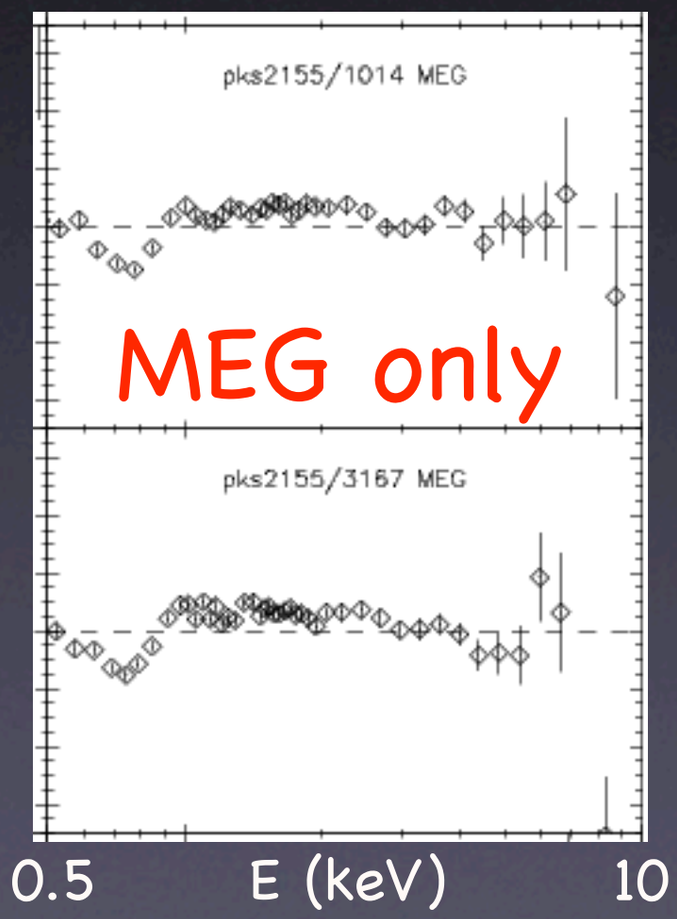
- Mildly dependent on HRMA and ACIS cal
- No absolute correction
  - External info needed to correct HEG or MEG
  - Used consistency of blazar spectra

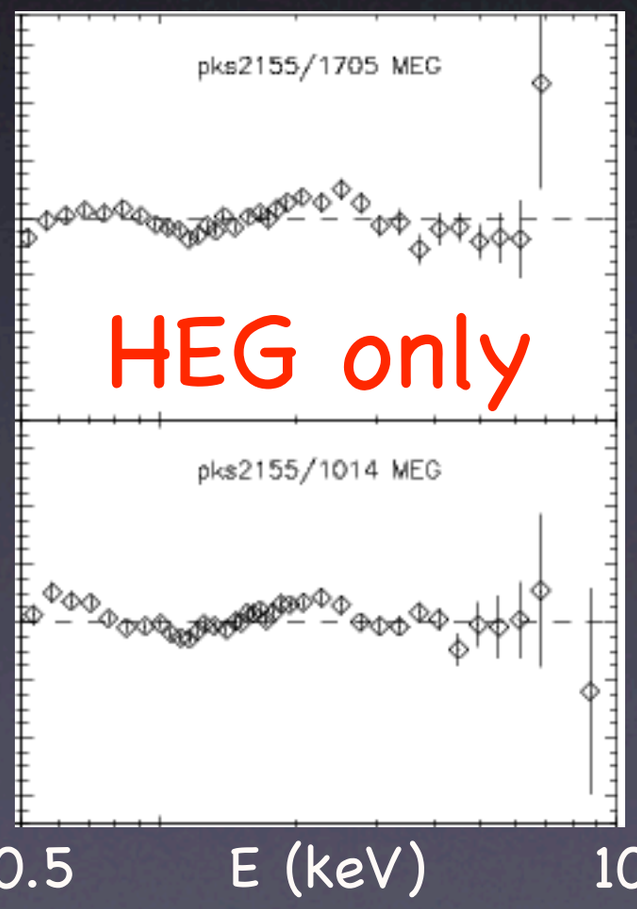


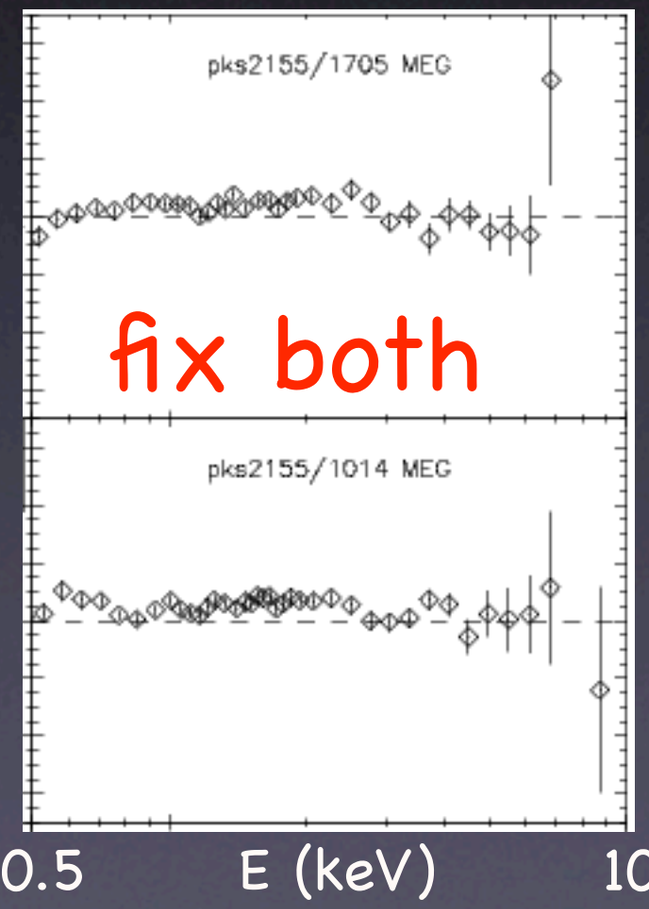


MEG/HEG Fix Allocation

- MEG or HEG fix only gives poor residuals
- Allocate ratio fix crossover at about 1 keV







HETG-ACIS Summary

- Status
  - Relative effective area better than 5%
  - Dispersion relation: good to < .002 Å (dv ~ 50 km/s)
  - Absolute EA testing
    - Cross-calibration underway with XMM and Suzaku
    - Uniformity of blazar fits
- Limitations
  - Pileup
    - dispersed spectra
    - zeroth order
  - Physical model from facets measurements while in-flight observations sample the ensemble