Multi-Mission Study

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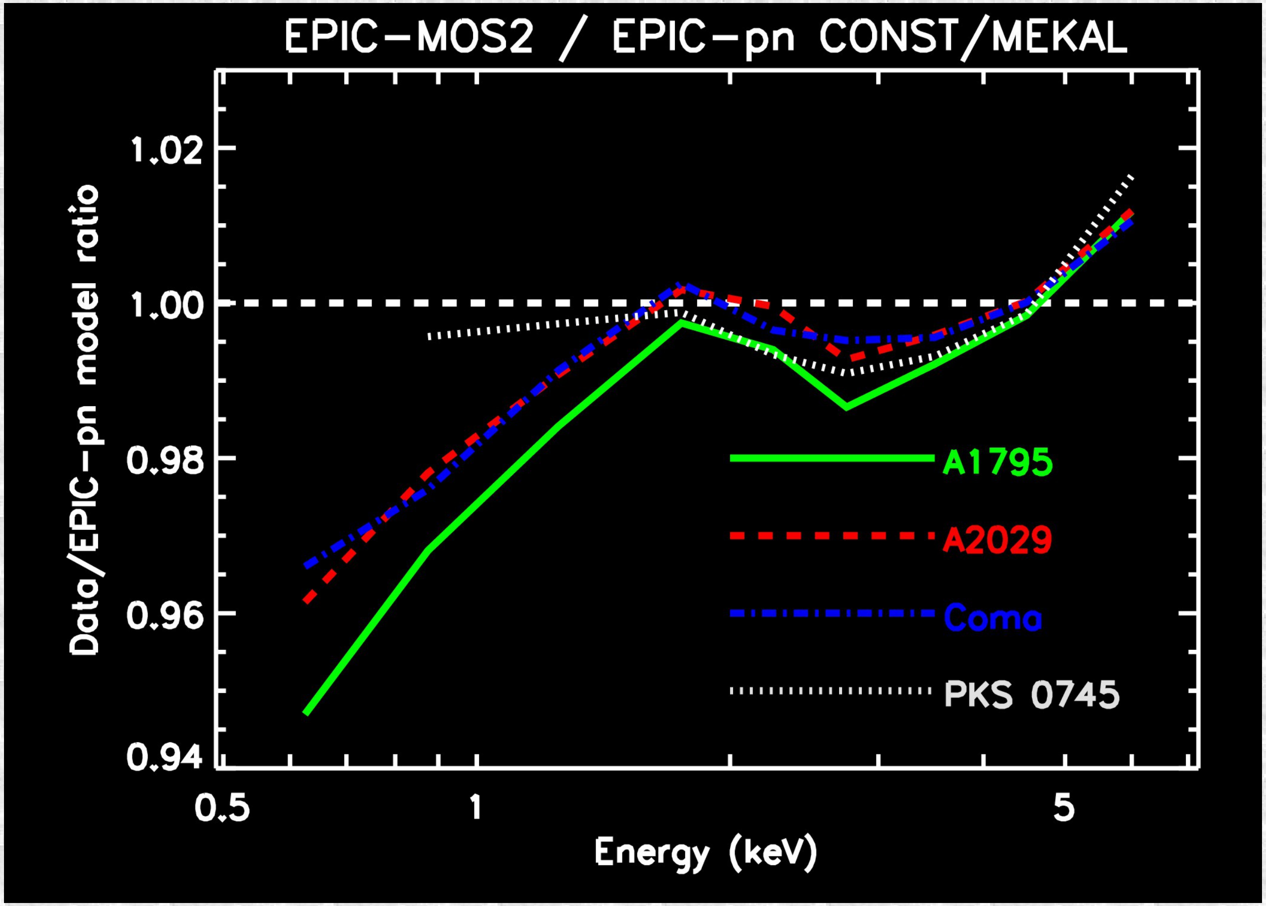
- Comparison of cluster measurements with XMM-Newton/EPIC, Chandra/ACIS, Swift/XRT, Suzaku/XIS, ROSAT/PSPC and NuSTAR: 6 missions, 10 instruments
- Residual ratios to evaluate the effective area cross-calibration:
  - We use EPIC-pn as a reference. (Try also ACIS, **TBD**)
  - For instrument **i** we calculate the median and the mean absolute deviation of the ratio

$$R_{i\,\mathrm{over}\,pn} = \frac{data_i}{model_{pn} \otimes resp_i} \times \frac{model_{pn} \otimes resp_{pn}}{data_{pn}}$$

- The latter term corrects for deviations btw. pn model and pn data which cannot be produced by the model (no point in comparing other data with a model which does not fit pn data)

Model accuracy does not matter much

- For the relative effective area comparison the accuracy of the reference model does not matter much
- Proof: MOS2/pn residuals ratios for the sample using phabs x mekal or a constant model for fitting pn spectra: above 1 keV differeces at the level of statistical error of 2%. A bit bigger at lower energies, why?



Regions

- To study 10% cross-cal effect, we need statistical uncertainties of 1% with a sufficiently small energy bins.
- We use a circular r = 6 arcmin central region for the extraction of the spectra. For the nearby clusters this corresponds to 0.5 Mpc (**better use a fixed X Mpc radius**). This choice enables us to
  - maximise the photon statistics without introducing significant background systematics (**TBD**)
  - minimise the PSF scatter since the region is much larger than any PSF and covers most of the emission of a cluster. Test Suzaku with simulations (**TBD)**
- Due to the relatively large PSF of Suzaku, the exclusion of (possibly) variable point sources would waste a lot of data. Thus, we do not exclude any point sources. The relative effective area comparison with stack residuals ratio still works (**TBD**)

Flux scaling due to obscured detector regions

Instrument	Active area / full r=6 arcmin circle
pn	0.88 – 0.90
MOS1	0.90 – 0.97
MOS2	0.96 – 0.97
PSPC	1.0
NuSTAR	0.98
Swift	0.95

- To cover the exactly same regions with all 10 instruments is nearly impossible. A combined mask using the info of the bad pixels and CCD gaps of all instruments would be very complicated. At the moment we use independent masks for each instrument.

Flux scaling due to obscured detector regions

- For comparison with pn, we account for the different sizes of the extraction regions by scaling the flux linearly to pn area given by the BACKSCAL value (except for ACIS and Suzaku whose software scales the flux to full r=6 arcmin region considering CCD gaps and flux decrease with radius):

$$R_{I\,\mathrm{over}\,pn} = \frac{data_I}{model_{pn} \otimes resp_I} \times \frac{model_{pn} \otimes resp_{pn}}{data_{pn}} =$$

$$\frac{BACKSCAL_{pn}}{BACKSCAL_I} \times \frac{data_I}{model_{pn} \otimes resp_I} \times \frac{model_{pn} \otimes resp_{pn}}{data_{pn}}$$

- Linear scaling not exact, because brightness drops with radius. Possible problem. Needs to be studied in detail. **TBD**

Flux scaling due to obscured detector regions

- We proposed to XMM Users Group a tool like the one available for ACIS, to incorporate the cluster image to do the scaling right
- Saxton put this task higher on the todo list. No action yet.
- I can do this myself, **TBD.** Should first estimate, how big is the effect.

Cluster selection criteria

- The selection criteria for the sample
  - Bright enough, i.e. kT > 6 keV
  - Hot enough so that we 1) have enough counts at the highest energies and 2) minimise the 1 keV line emission (we are studying the effective area, not PSF or energy scale calibr.) i.e. kT > 6 keV
  - Not too nearby so that the ghost rays from the bright out-of-fov regions do not contaminate NuSTAR (r=6 arcmin FOV) signal too much (**Coma not good**) , i.e. > 0.05 so that 6 arcmin = 0.5 Mpc
  - Not too distant so that the cluster is not too faint i.e. z < X

Observation criteria

- For selecting the observations with the above 6 missions, we used these criteria:
  - The total exposure time must be at least 10 ks to obtain good enough statistics. **Rather minimum number of counts.**
  - The center of the cluster must not be too much offset (< 3 arcmin) from the center of FOV so that we don't fold in instrument effects which are different between the central and outer regions of the FOV (e.g. vignetting).

- Should cross-correlate the data bases if there are more possible clusters
- A cluster can be useful even if not covered by all instrument. This will increase the sample size

Sample info (should update)

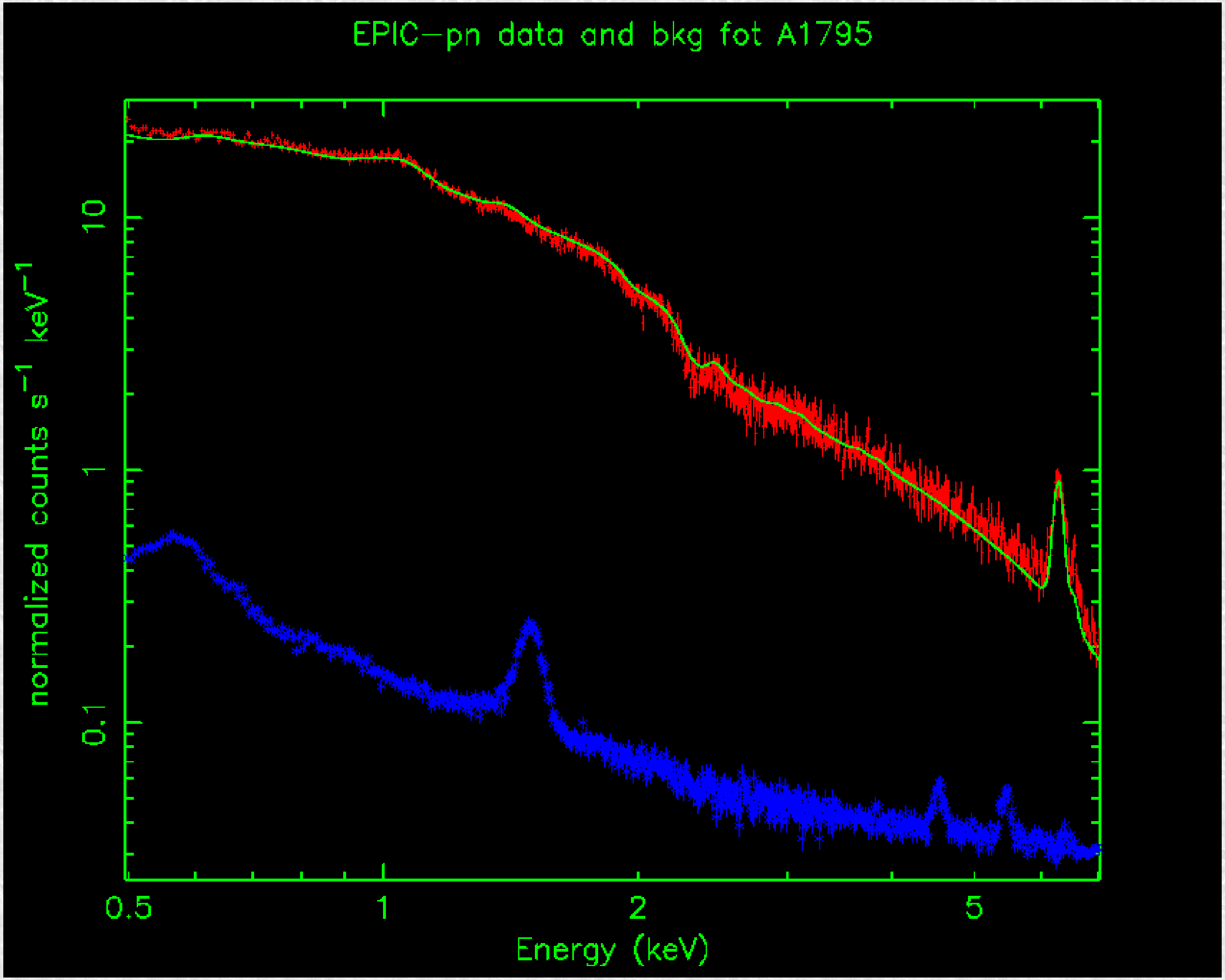
	A1795			A2029			Coma		
Center	207.22083, 26.5902			227.7342, 5.7446			194.9447, 27.9326		
	obsid	off-axis (arcmin)	exp (ks)	obsid	off-axis (arcmin)	exp (ks)	obsid	off-axis (arcmin)	exp (ks)
XIS	800012010	0.7	13	804024010	0.5	8	801097010	1.9	179
XRT	00035184002	3.0	13	00035187004	2.0	26	00035172001	1.9	10
ACIS	5289	0.1	15	6101	0.0	10	13996	1.1	125
EPIC	0097820101	0.2	34	0551780401	1.0	47	0300530301	0.5	31
PSPC	RP800105N00	0.5	36	RP800249N00	0.4	13	RP800005N00	2.3	21
	RP800055n00	1.8	26						

- PKS0745-19

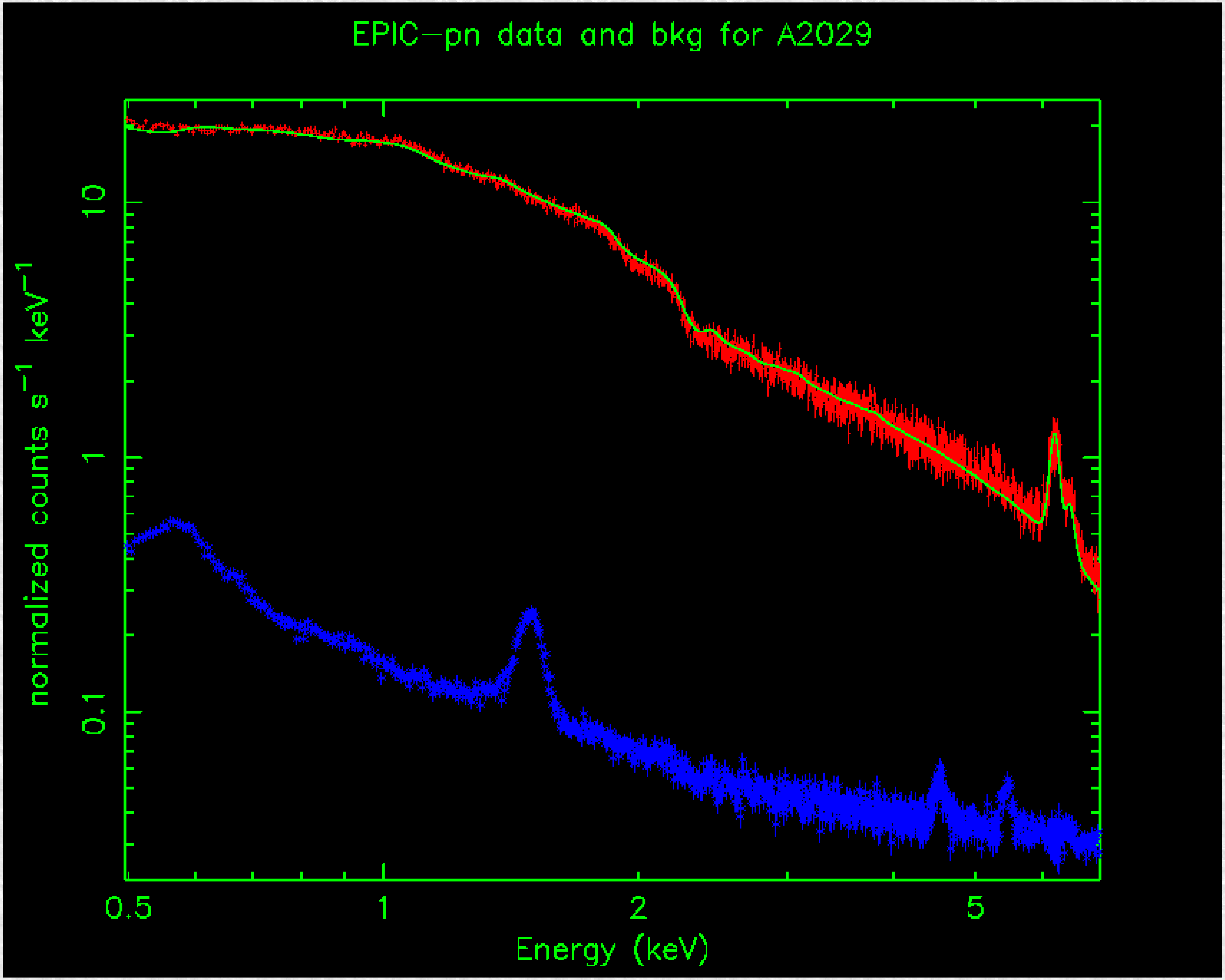
Background systematics

Background systematics

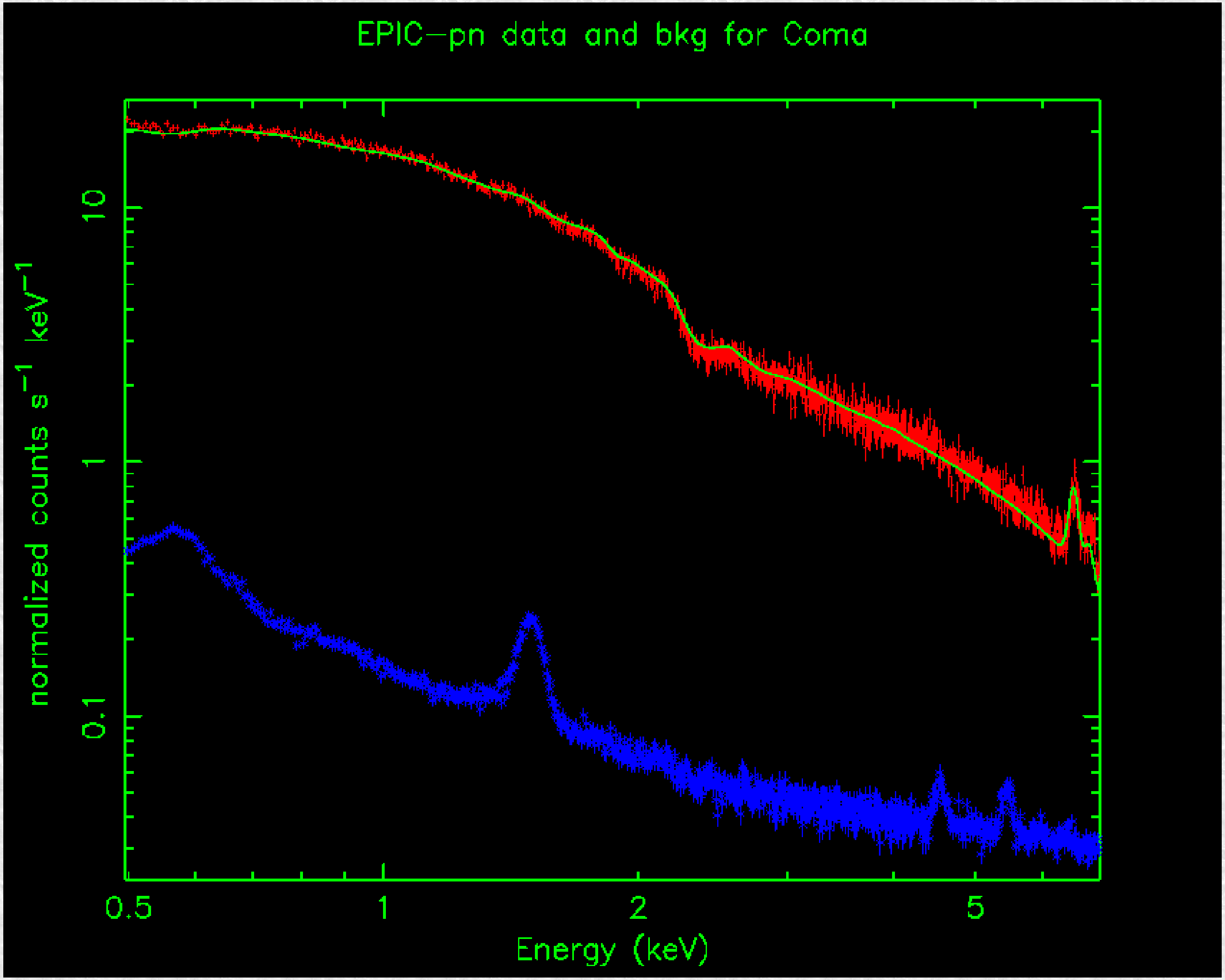
- Increase bkg and calculate stack residuals to find a bkg/source limit which starts to affect the results. Use MOS2/pn for the optimal source as an example. **TBD**



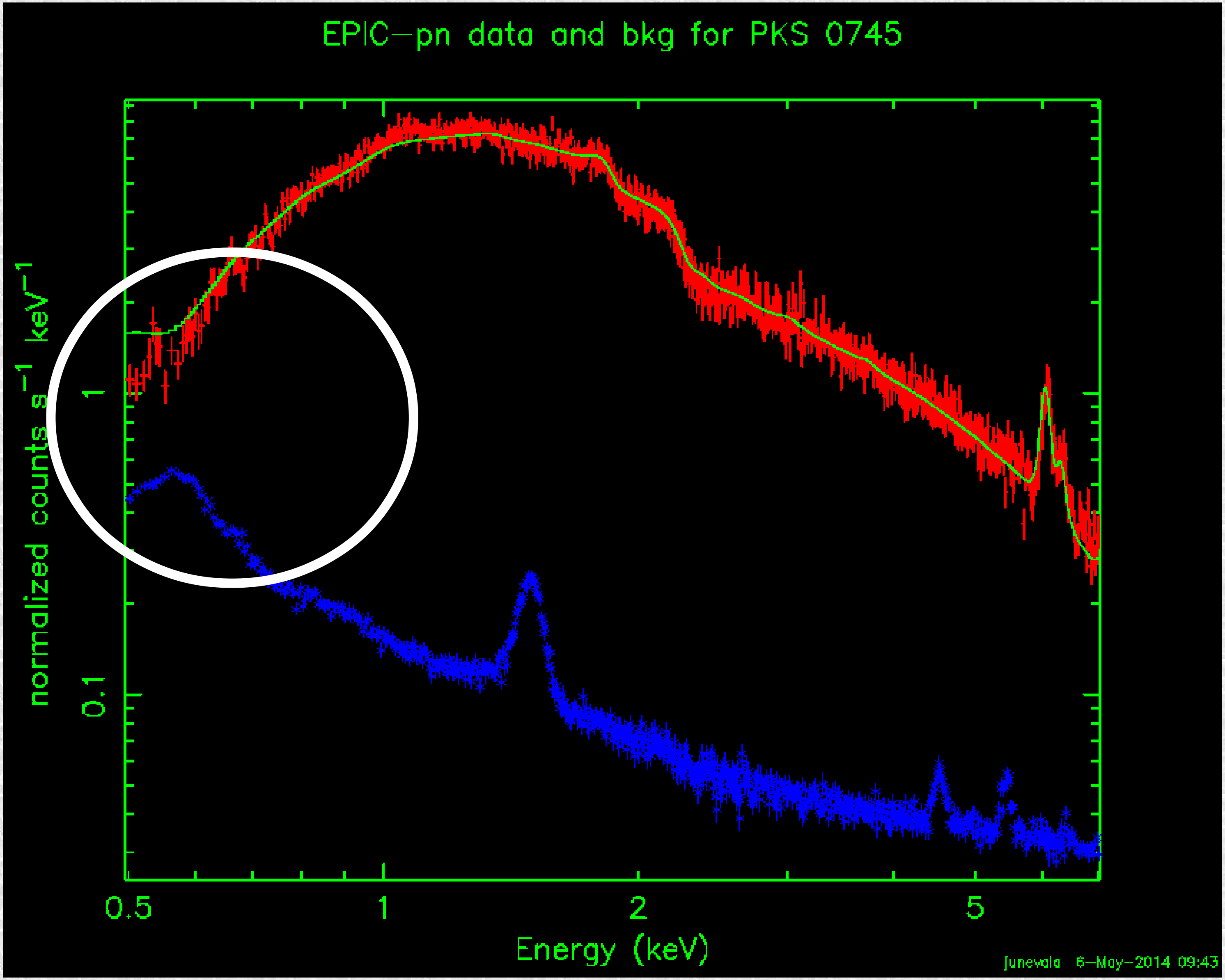
EPIC-pn data and bkg fot A1795
normalized counts s^{-1} keV^{-1}
10
1
0.1
0.5
1
2
5
Energy (keV)



EPIC−pn data and bkg for A2029
normalized counts s^{-1} keV^{-1}
10
1
0.1
0.5
1
2
5
Energy (keV)


EPIC−pn data and bkg for Coma
normalized counts s^{-1} keV^{-1}
10
1
0.1
0.5
1
2
5
Energy (keV)

High NH of PKS reduces a lot the flux at 0.5 keV. Blank sky bkg should be adjusted. At this point PKS spectra cut at 0.7 keV

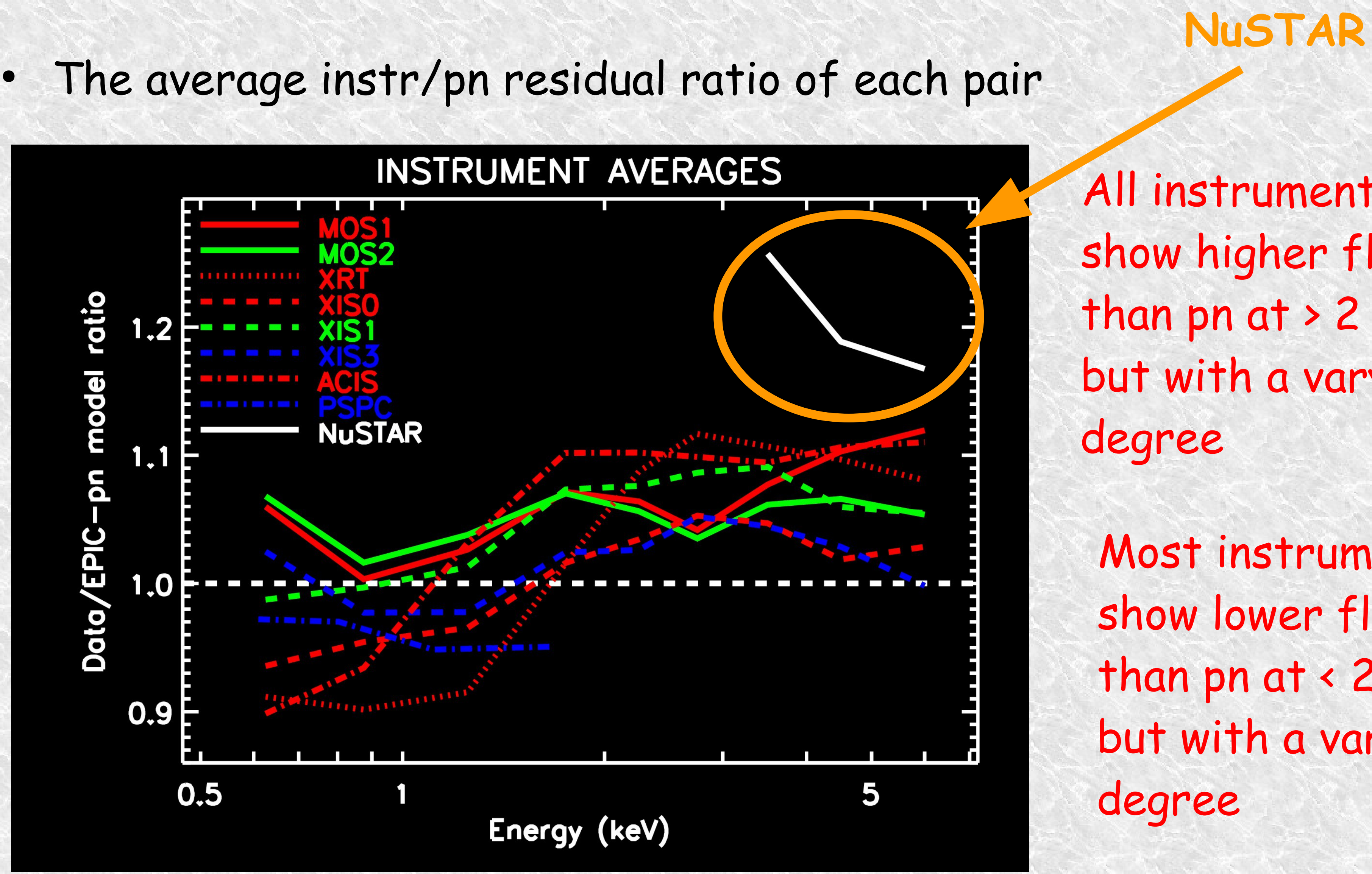


Preliminary results

(ACIS COMA TBD)

Summary of residuals ratios

- The average instr/pn residual ratio of each pair

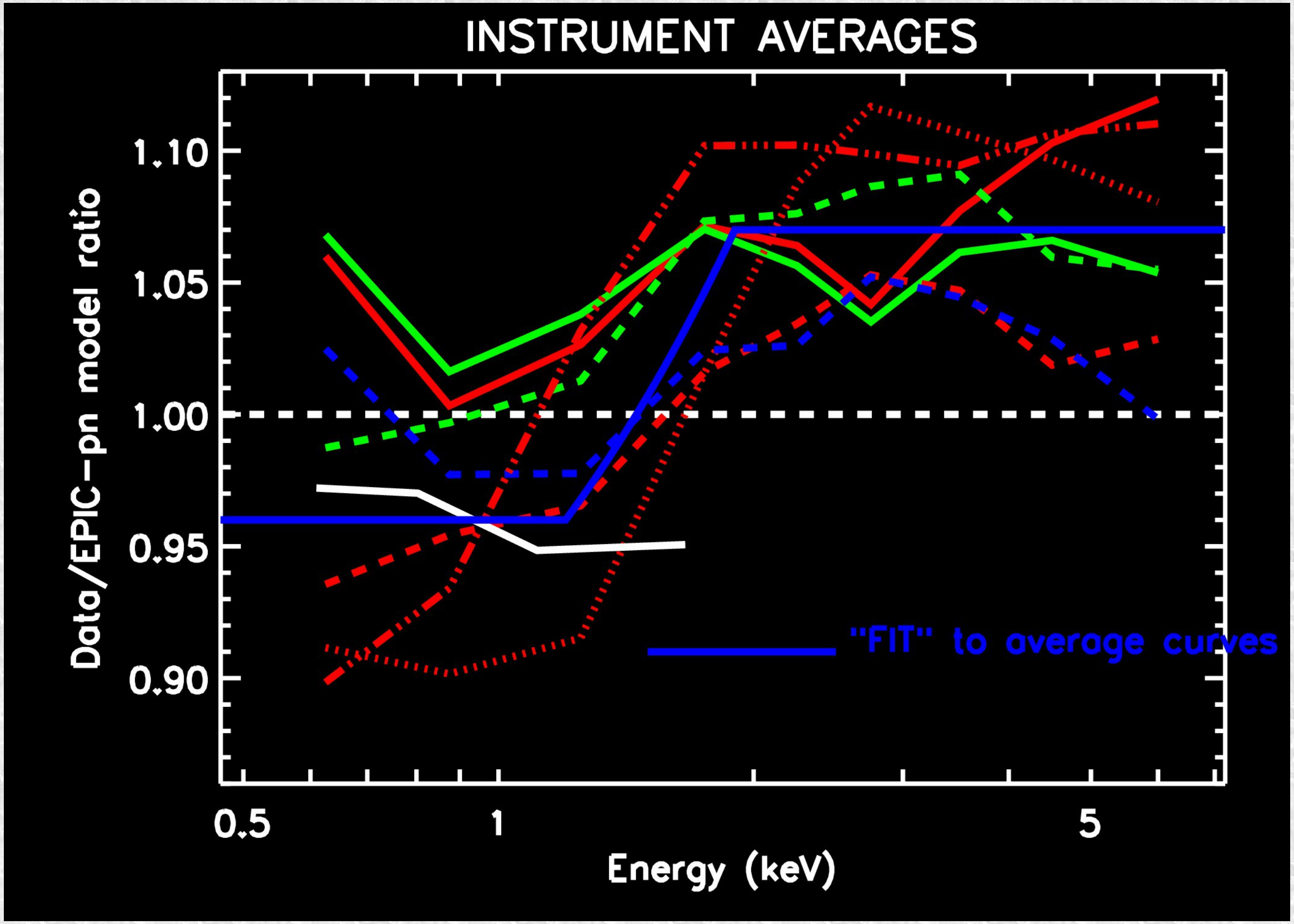


All instruments show higher flux than pn at > 2 keV, but with a varying degree

Most instruments show lower flux than pn at < 2 keV, but with a varying degree

Summary of residuals ratios

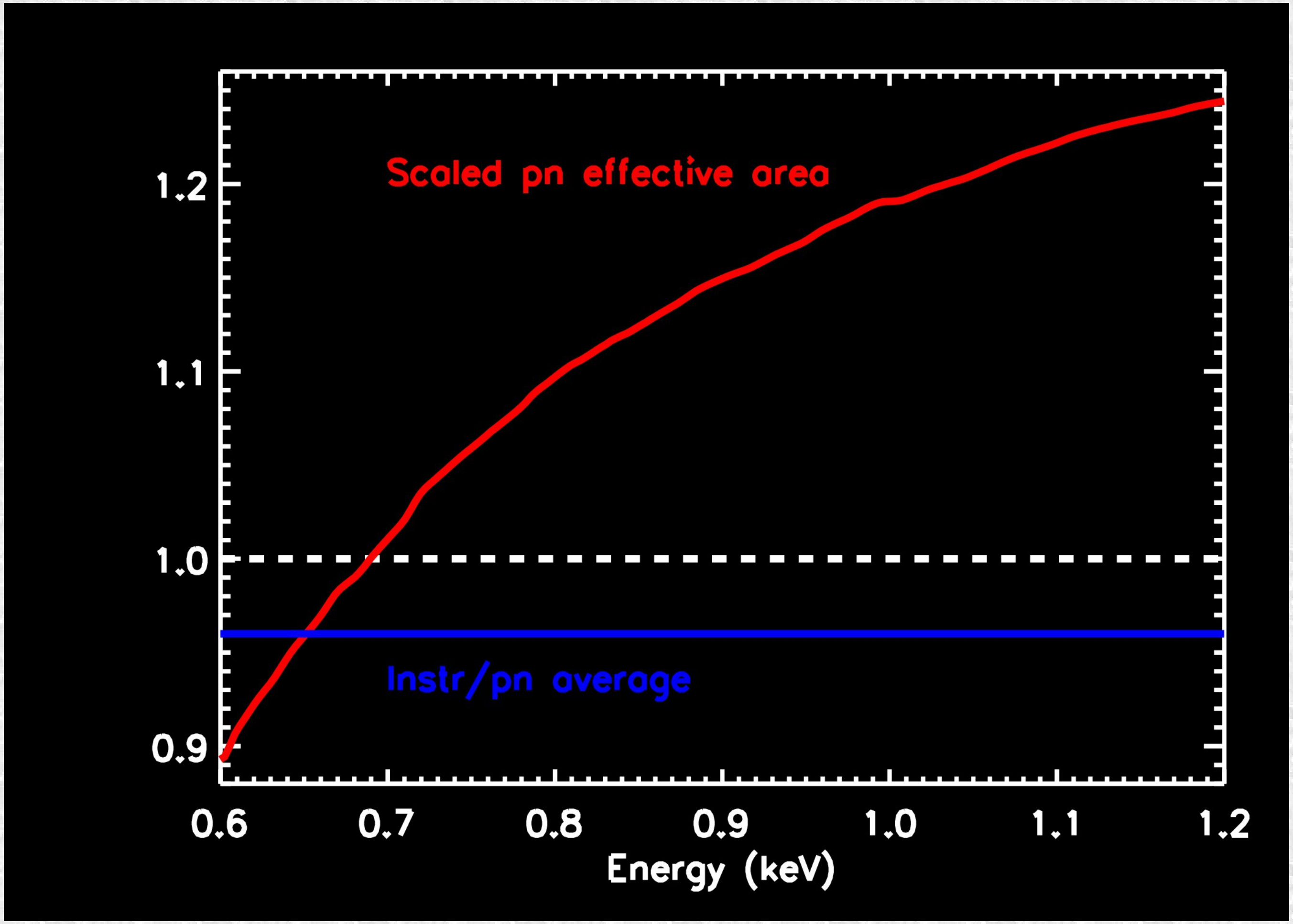
- The average instr/pn residual ratio of each pair



Residuals ratios too high at > 2 keV ➔ pn prediction too low ➔ pn eff area too high ➔ need to be divided by the blue curve

Is this what D. Lumb's new stuff is doing?

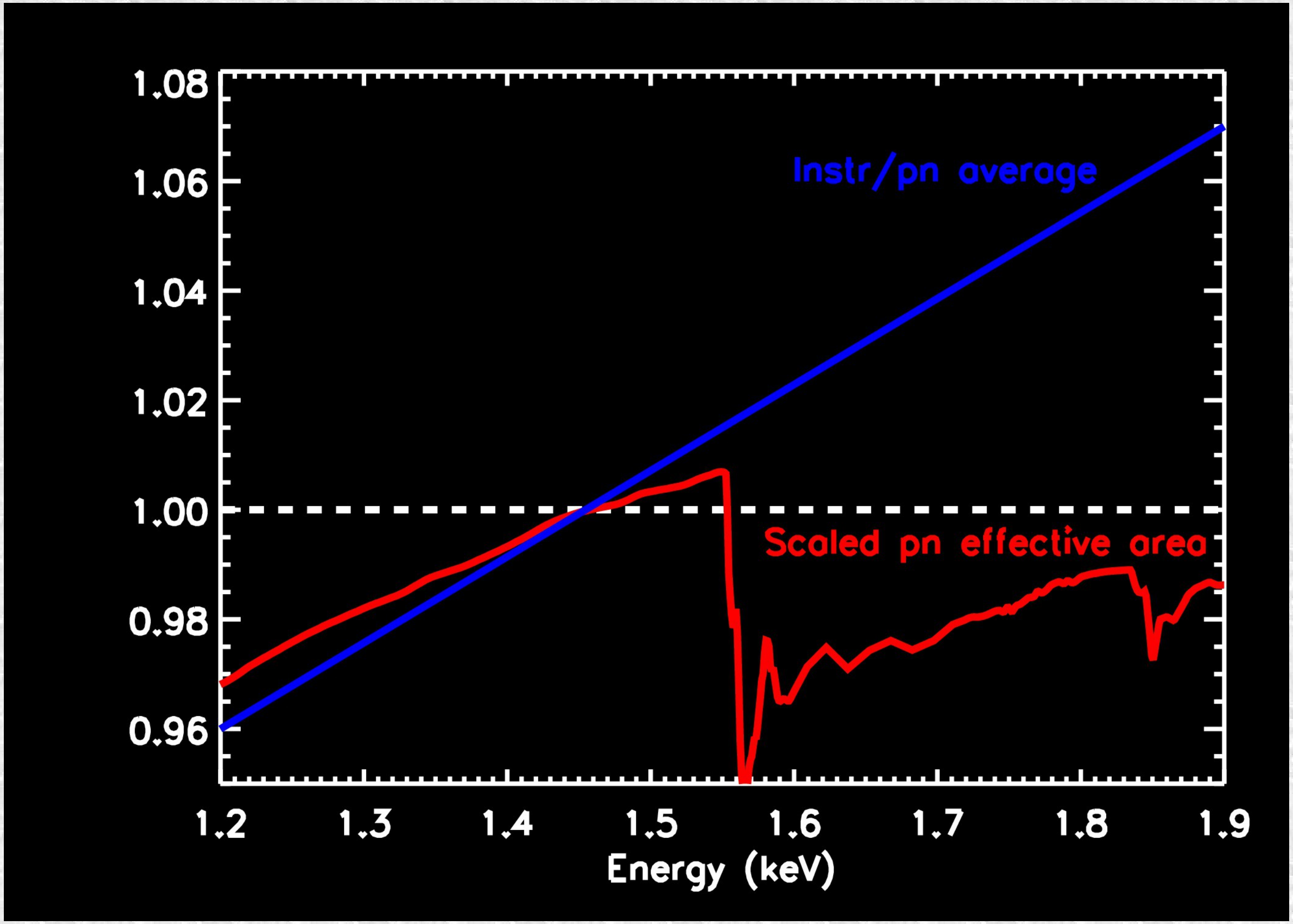
Pn eff area modification?



0.5-1.2 keV band:

Constant 4% increase

Pn eff area modification?

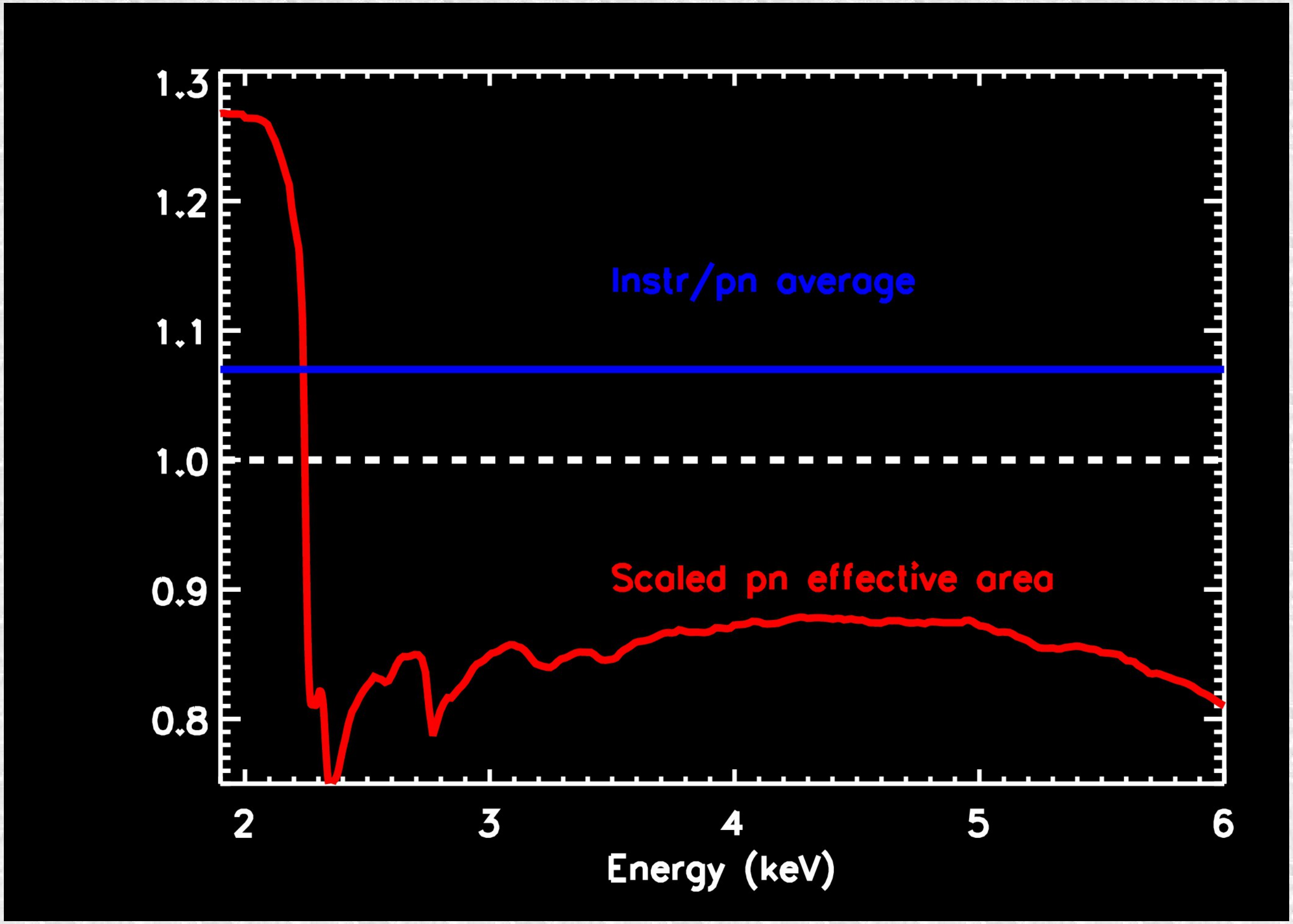


1.2-1.9 keV band:

Energy-dependent increase up to 1.45 keV

Energy-dependent decrease at 1.45-1.9 keV

Pn eff area modification?

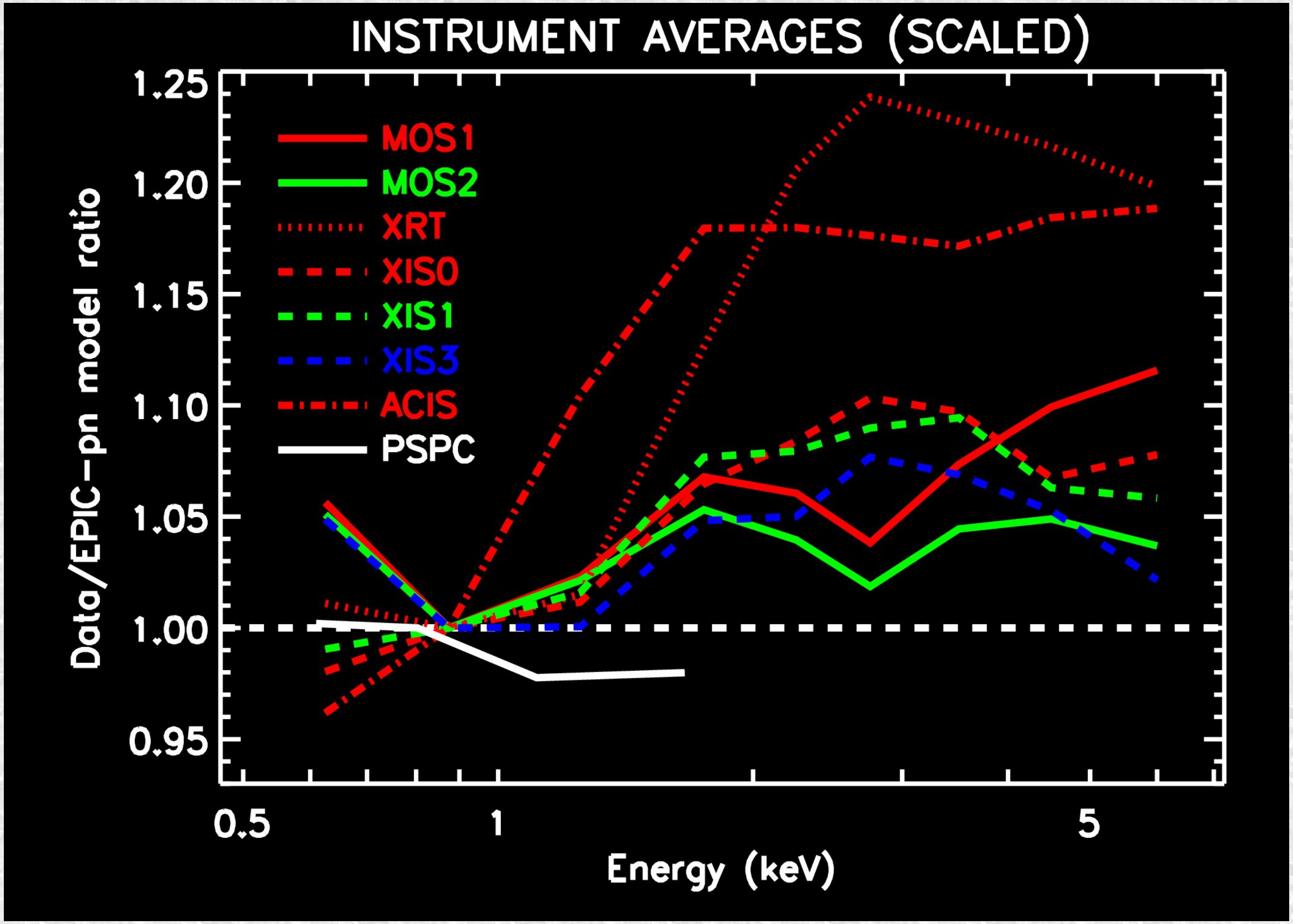


1.9-7 keV band:

Constant decrease by 7%

Summary of scaled residuals ratios

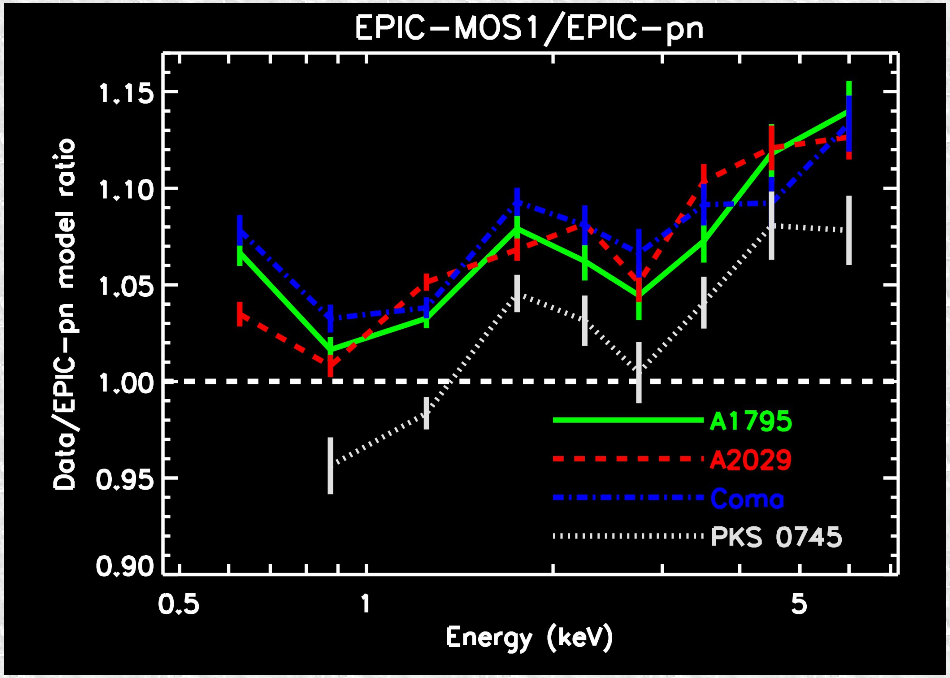
- The average instr/pn residual ratio of each pair, scaled to unity at 0.75-1.0 keV

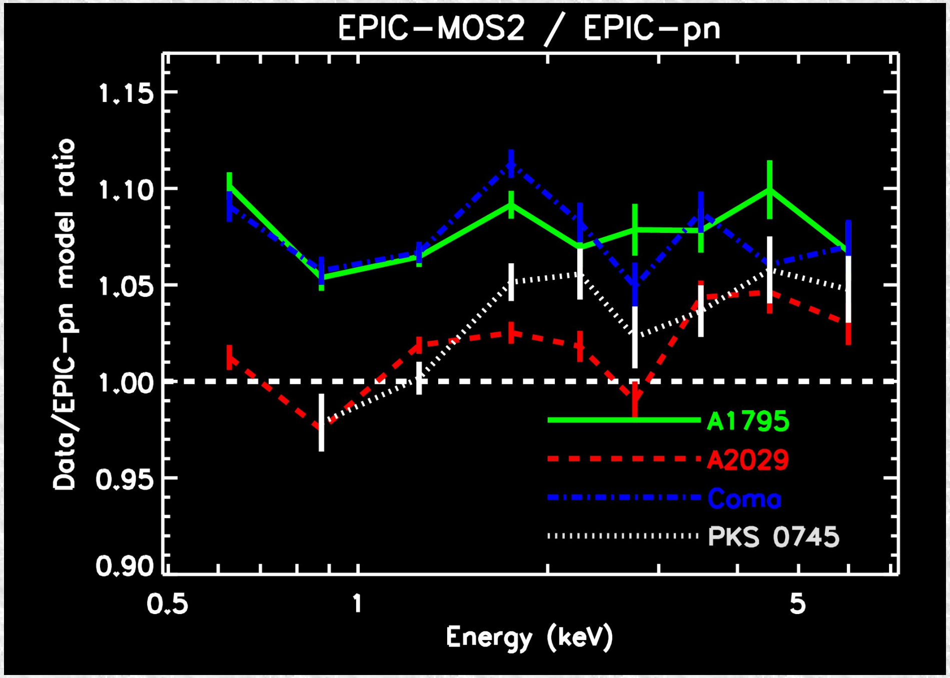


Not only pn is quilty?
Swift/XRT and Chandra/ACIS show a larger magnitude for the 1-2 keV gradient

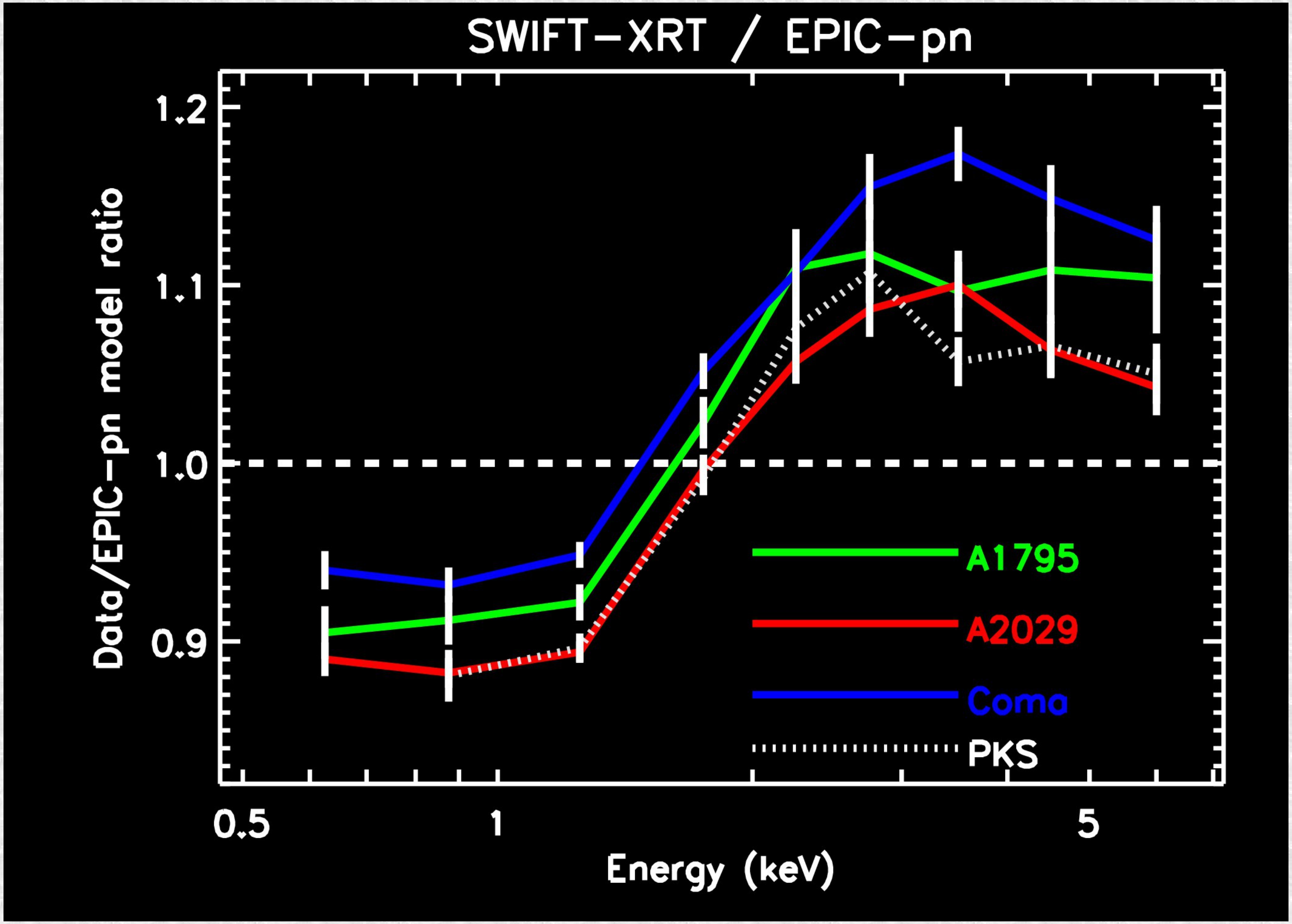
Individual clusters for each instrument pair

MOS/pn

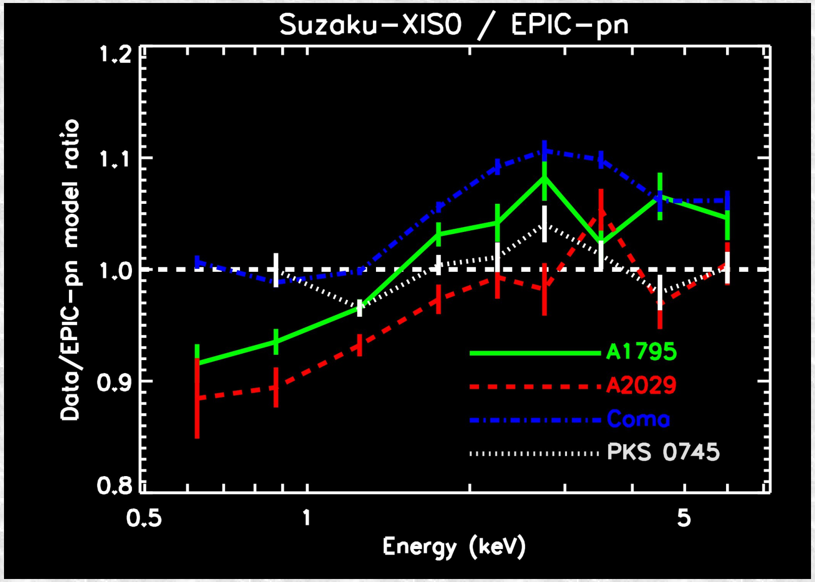

EPIC−MOS1/EPIC−pn
Data/EPIC−pn model ratio
1.15
1.10
1.05
1.00
0.95
0.90
0.5
1
5
Energy (keV)
A1795
A2029
Coma
PKS 0745

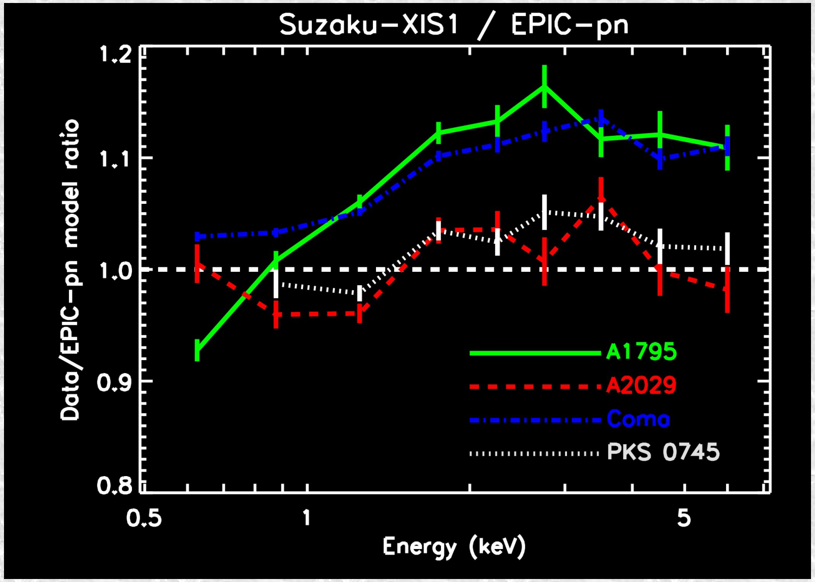

EPIC−MOS2 / EPIC−pn
Data/EPIC−pn model ratio
1.15
1.10
1.05
1.00
0.95
0.90
0.5
1
5
Energy (keV)
A1795
A2029
Coma
PKS 0745

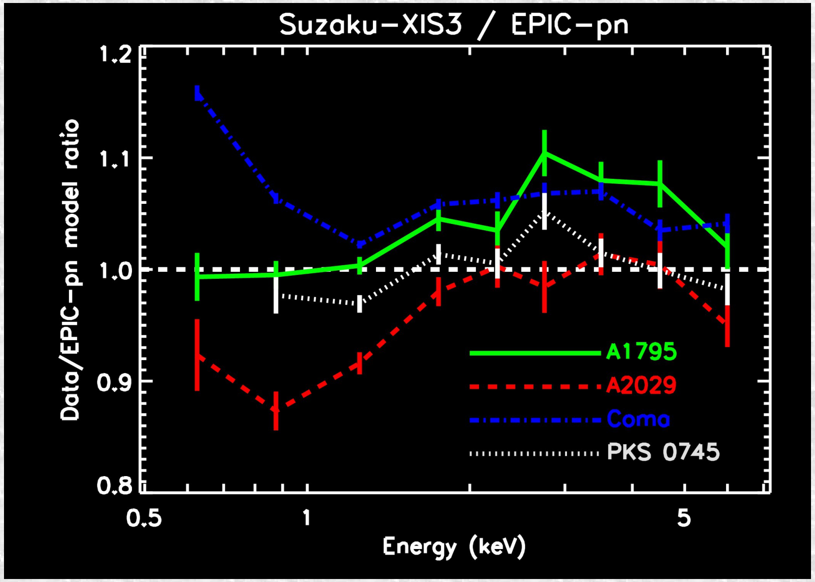
SWIFT/pn


SWIFT-XRT / EPIC-pn
Data/EPIC-pn model ratio
1.2
1.1
1.0
0.9
0.5
1
5
Energy (keV)
A1795
A2029
Coma
PKS

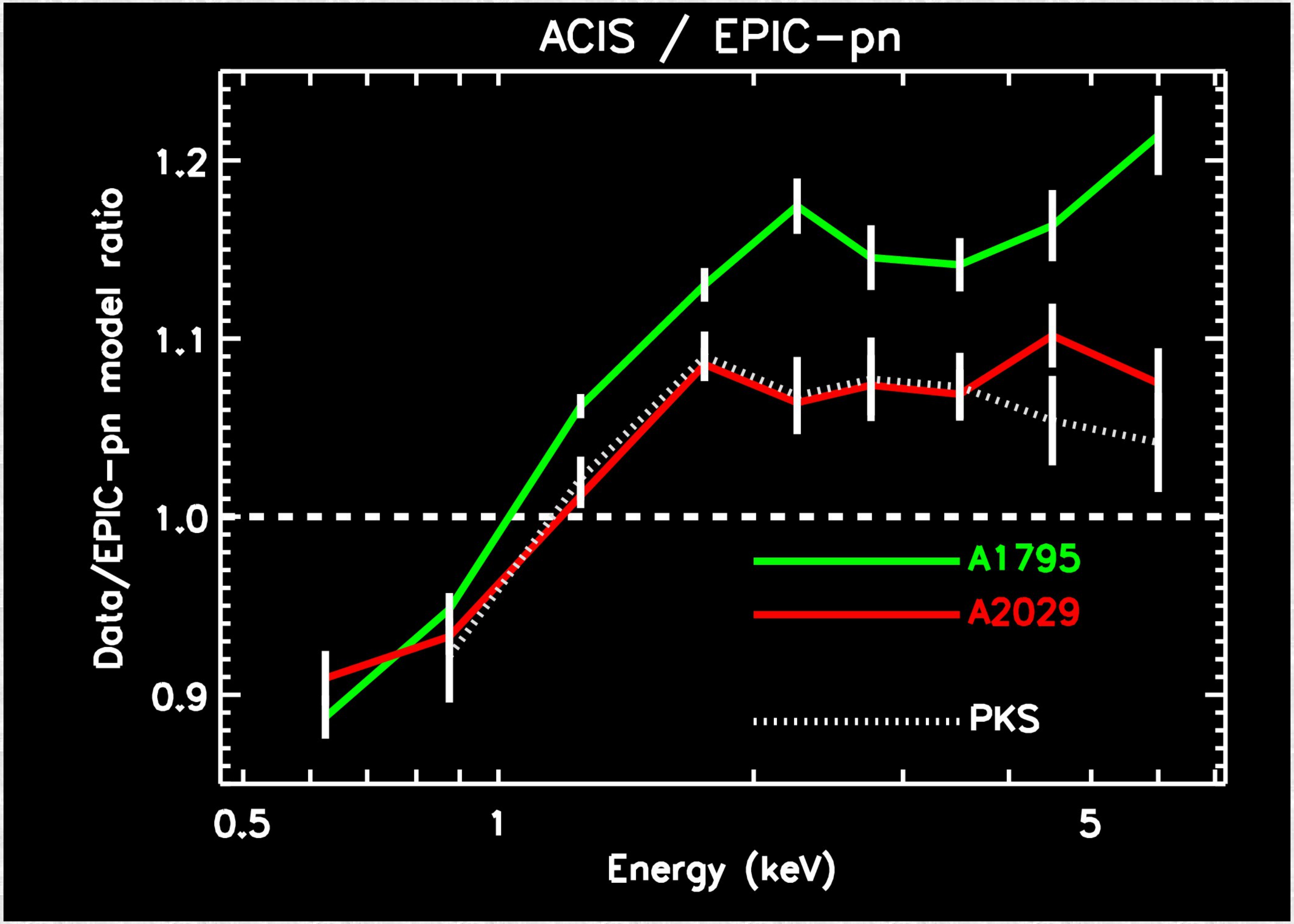
Suzaku/pn


Suzaku−XIS0 / EPIC−pn
Data/EPIC−pn model ratio
1.2
1.1
1.0
0.9
0.8
0.5
1
5
Energy (keV)
A1795
A2029
Coma
PKS 0745


Suzaku−XIS1 / EPIC−pn
Data/EPIC−pn model ratio
1.2
1.1
1.0
0.9
0.8
0.5
1
5
Energy (keV)
A1795
A2029
Coma
PKS 0745


Suzaku−XIS3 / EPIC−pn
Data/EPIC−pn model ratio
1.2
1.1
1.0
0.9
0.8
0.5
1
5
Energy (keV)
A1795
A2029
Coma
PKS 0745

ACIS/pn

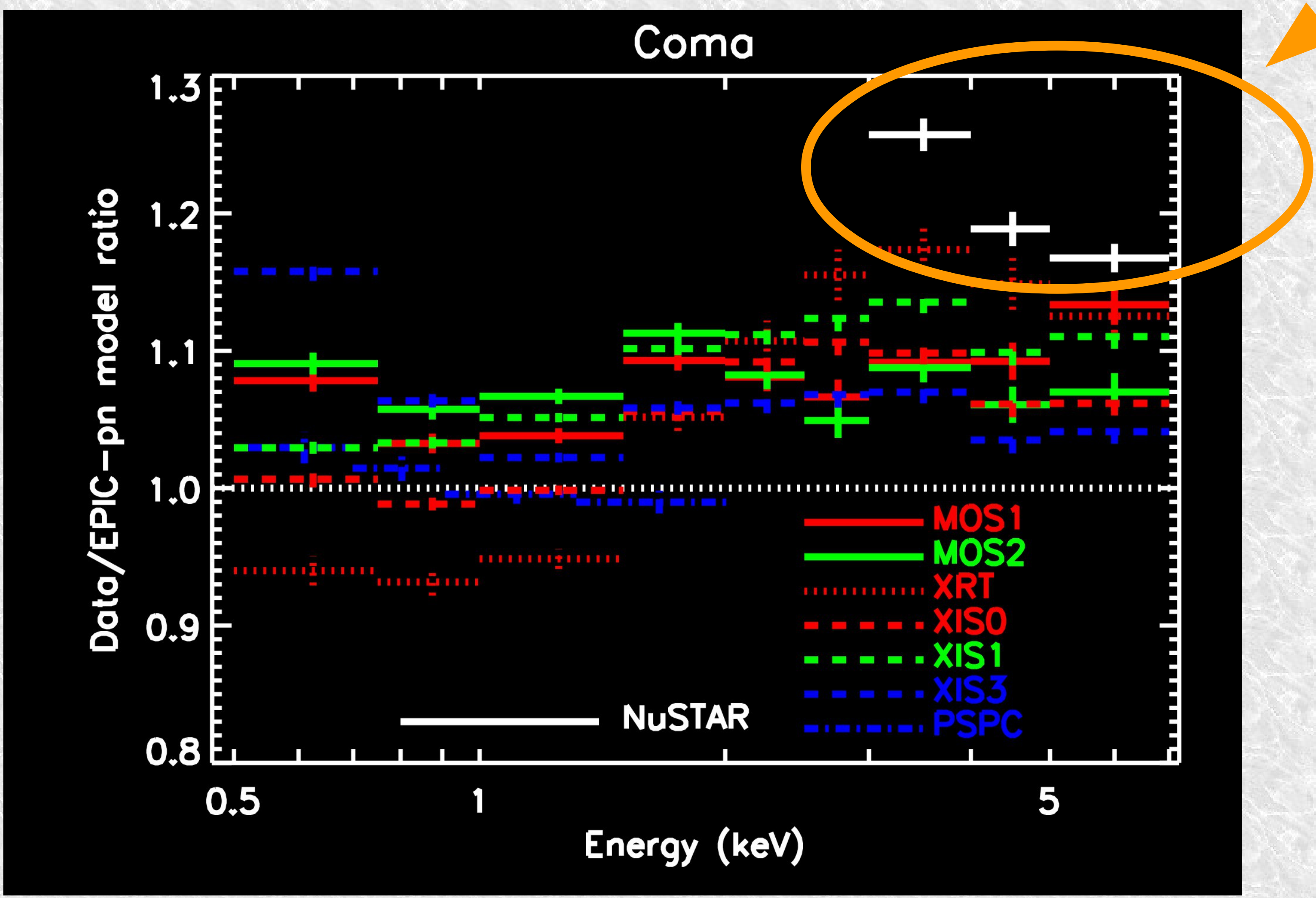


ACIS / EPIC-pn
Data/EPIC-pn model ratio
1.2
1.1
1.0
0.9
0.5
1
5
Energy (keV)
A1795
A2029
PKS

Coma as seen with different instruments

Coma

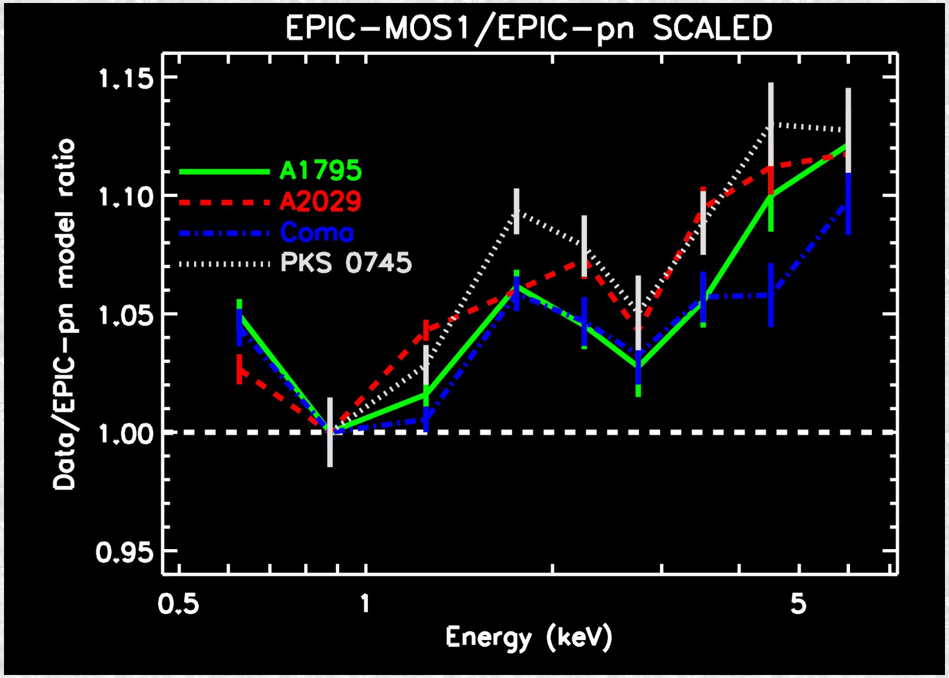
NuSTAR

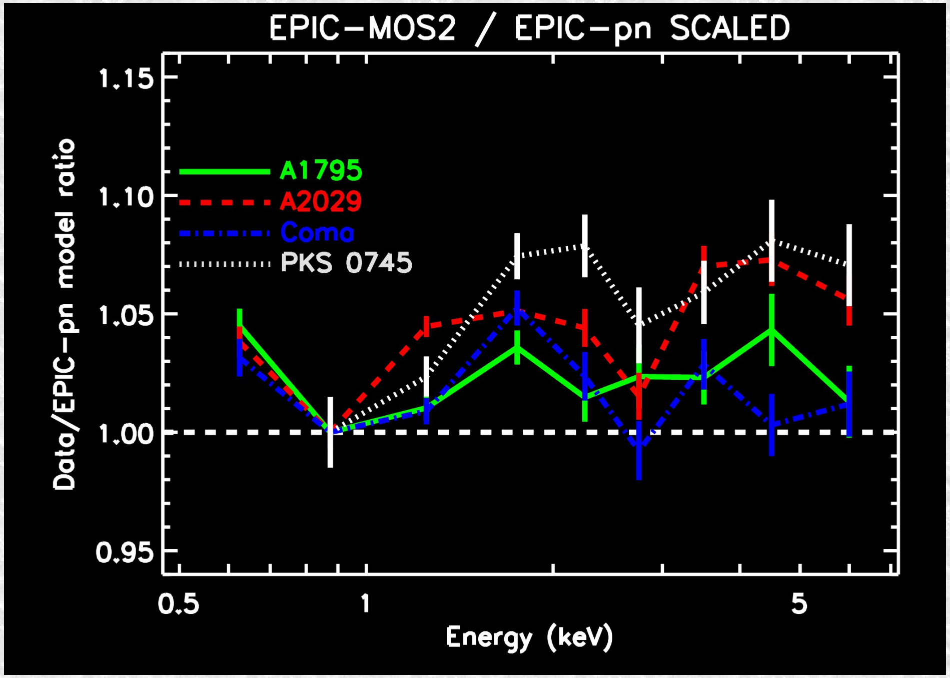


Coma
1.3
1.2
1.1
1.0
0.9
0.8
Data/EPIC–pn model ratio
0.5
1
5
Energy (keV)
NuSTAR
MOS1
MOS2
XRT
XIS0
XIS1
XIS3
PSPC

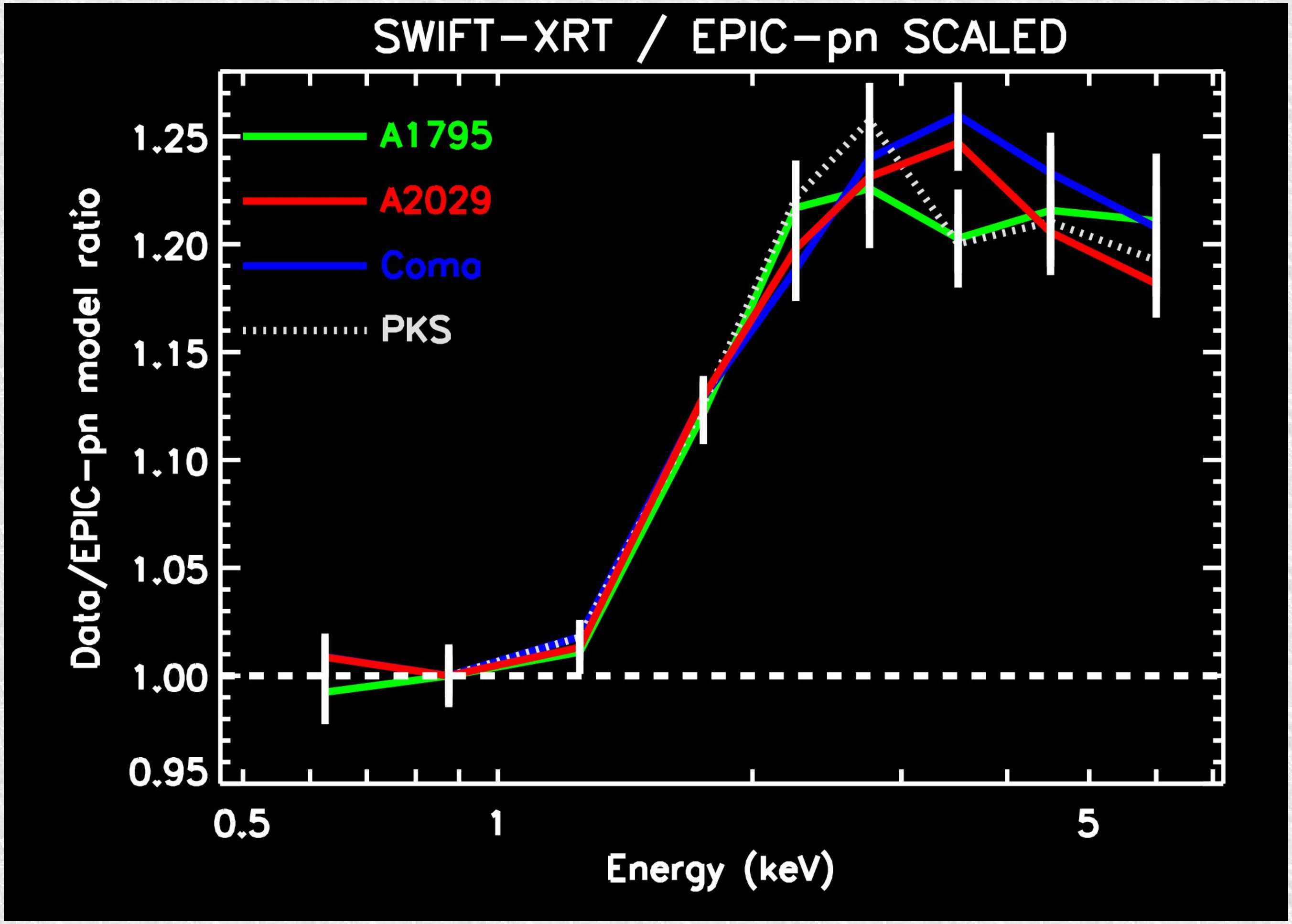
Individual clusters for each instrument pair, scaled to unity at 0.75-1.0 keV

MOS/pn scaled

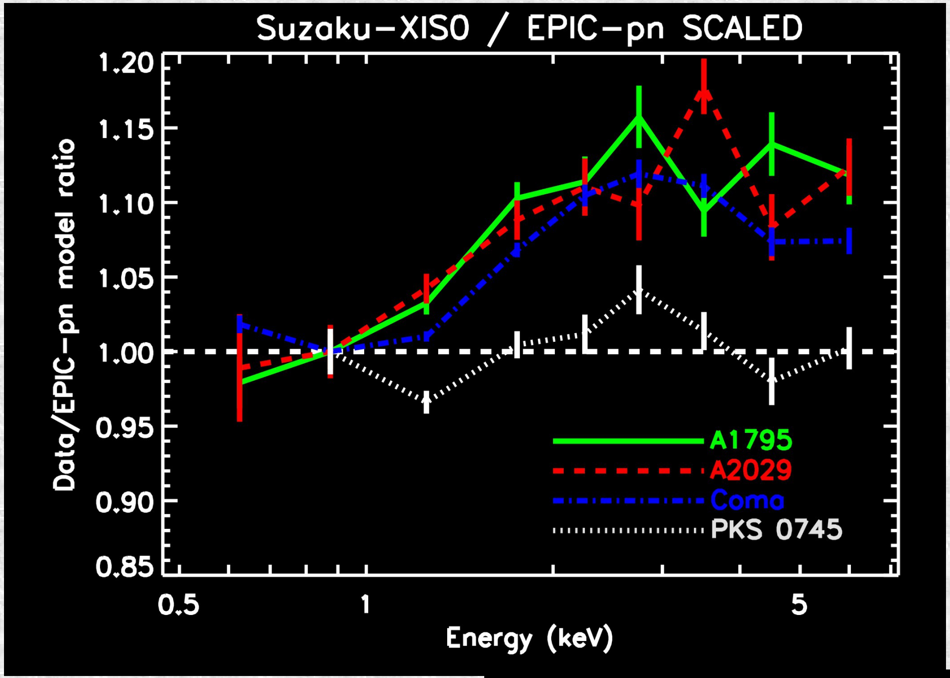


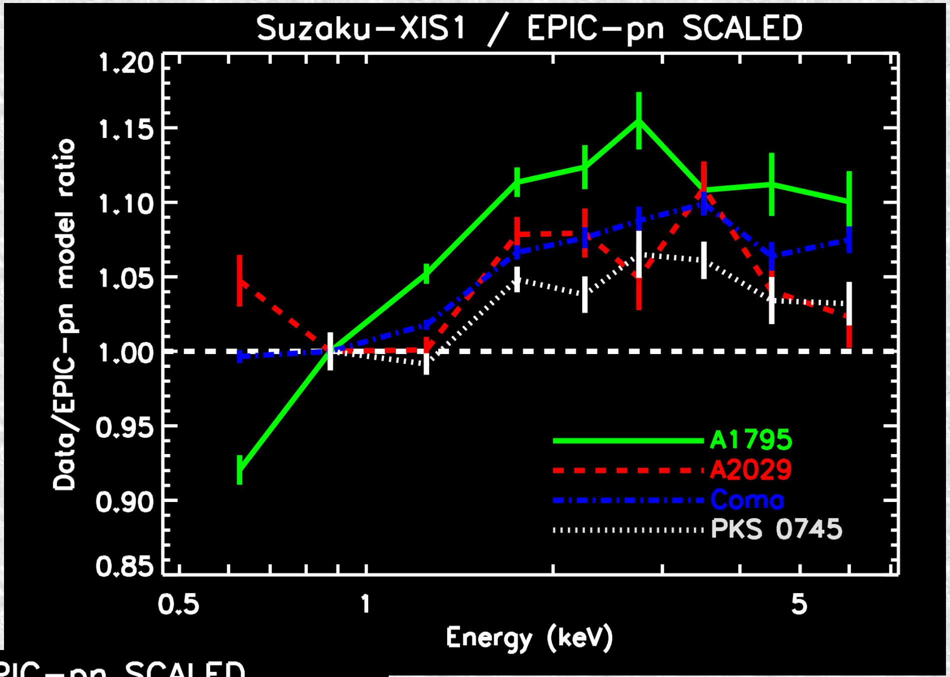


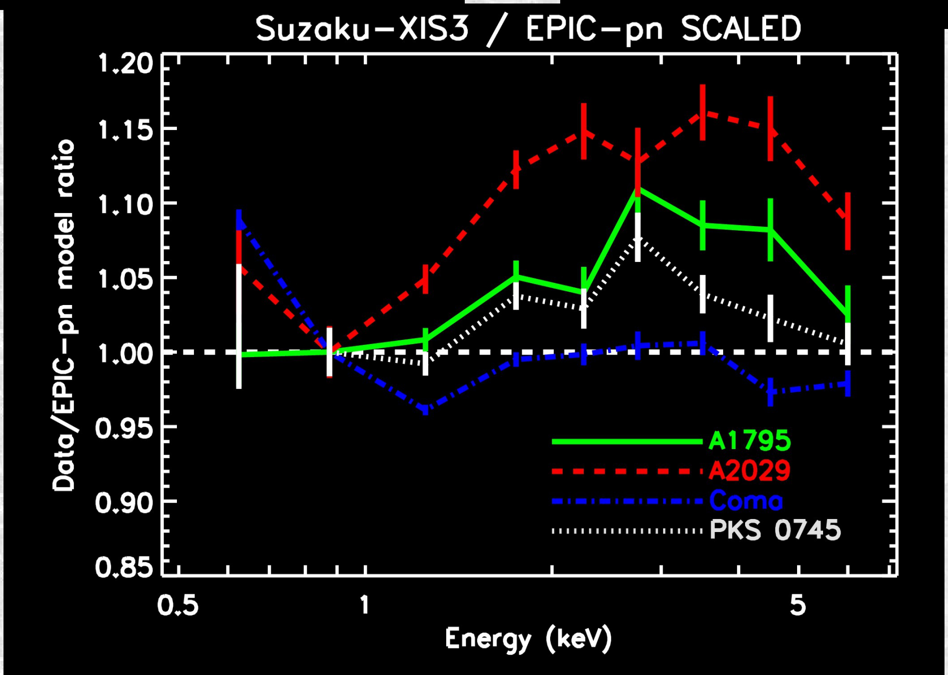
Swift/pn scaled



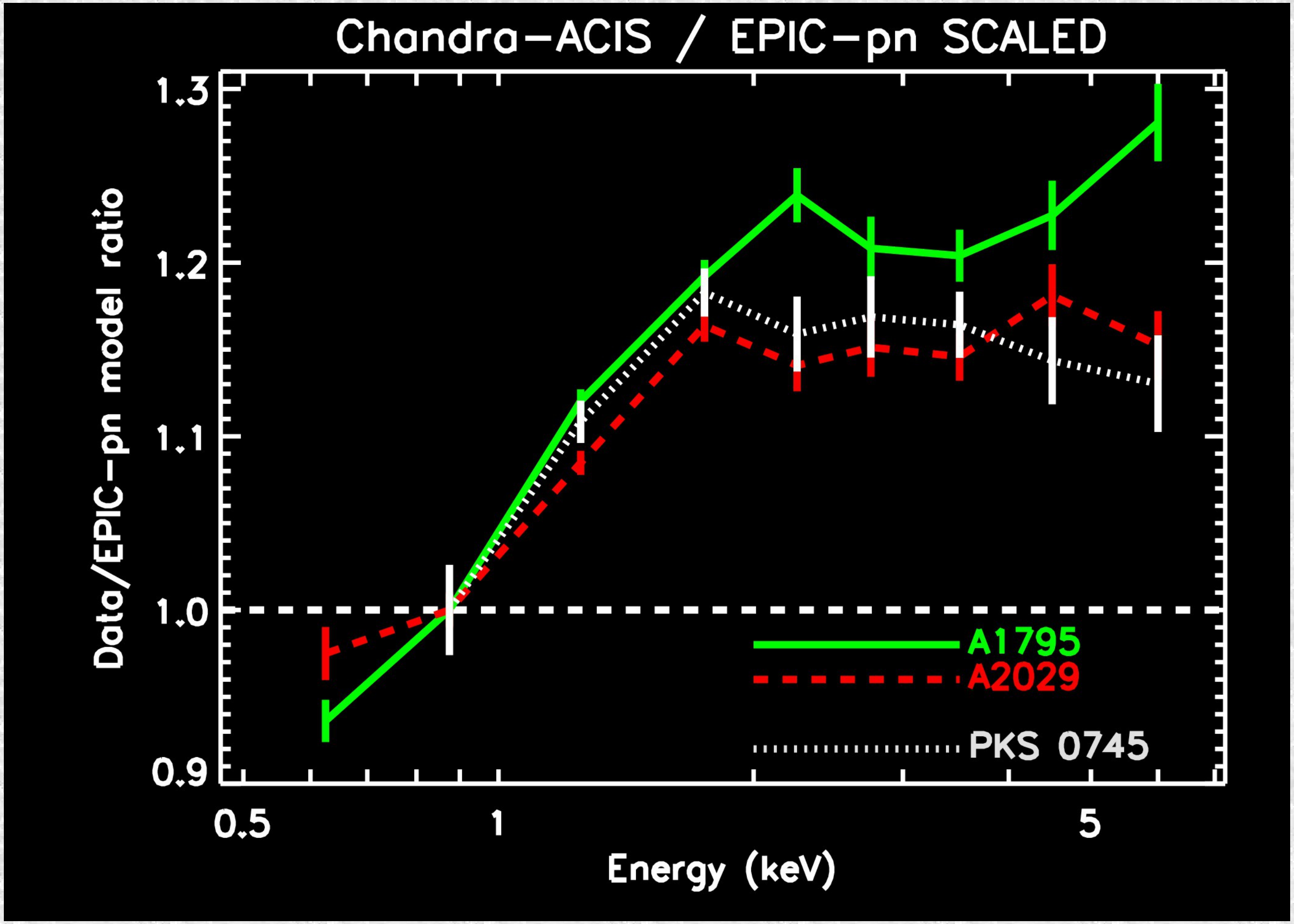
Suzaku/pn scaled







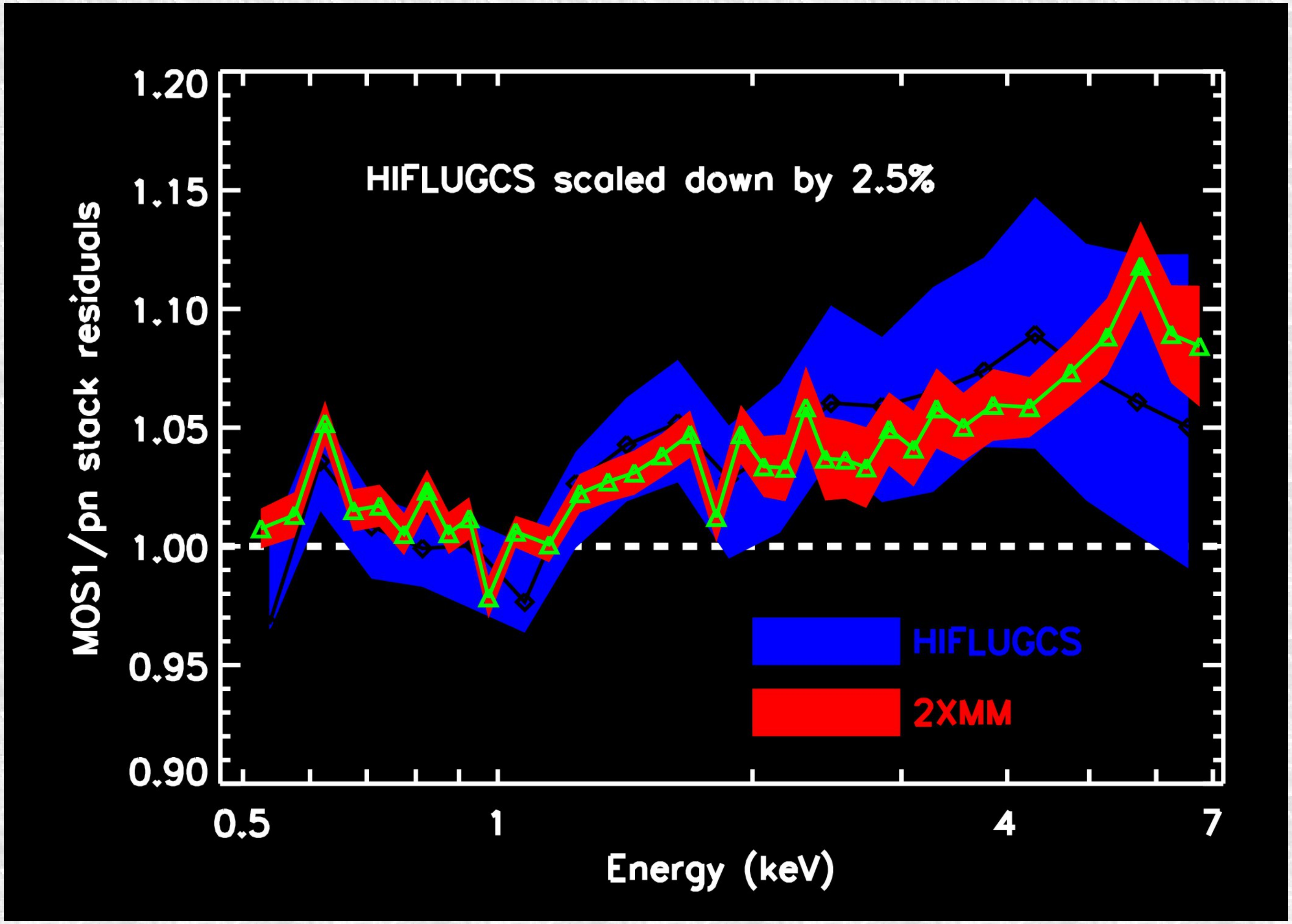
ACIS/pn scaled



Comparison with 2XMM and HIFLUGCS

MOS1/pn

2XMM (Read et al., 2014) and HIFLUGCS (Shellenberger et al., 2014)

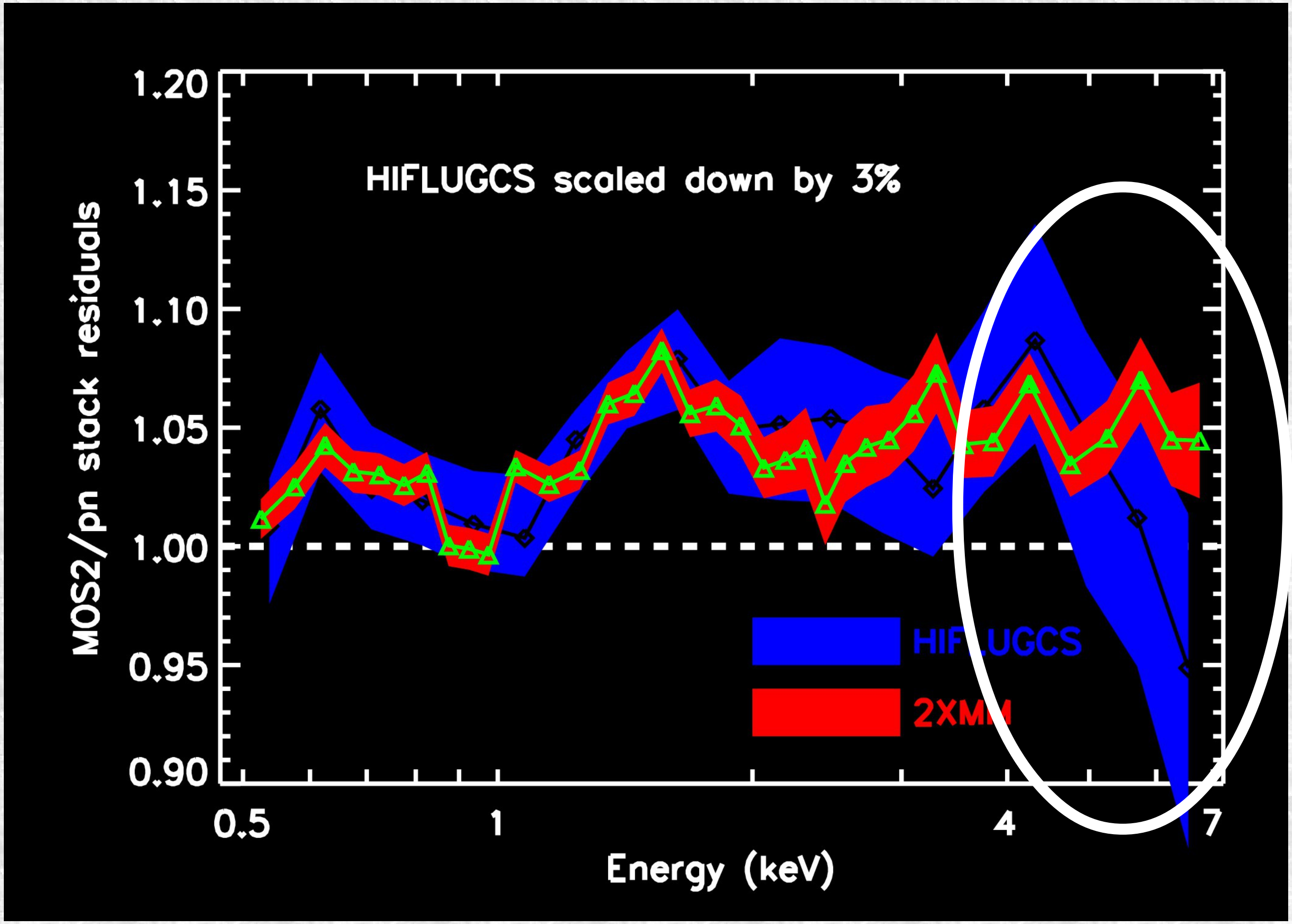


Agreement within the uncertainties

HIFLUGCS errors larger due to inclusion of the scatter between different objects. 2MMS only uses statistical uncertainties of the summed spectrum

MOS2/pn

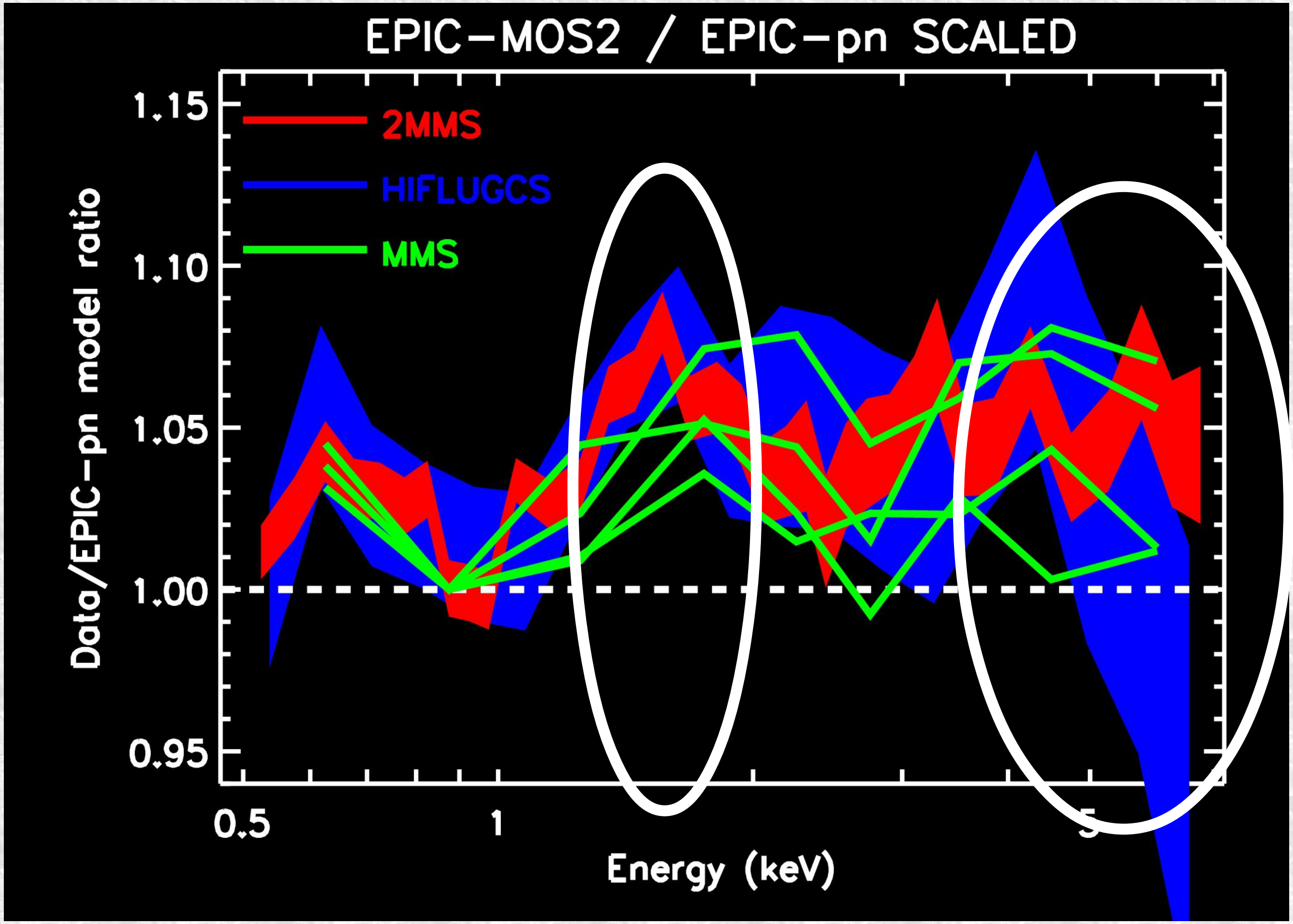
2XMM (Read et al., 2014) and HIFLUGCS (Shellenberger et al., 2014)



Agreement within the uncertainties at 0.5-6 keV

HIFLUGCS indicates a 4-7 keV drop

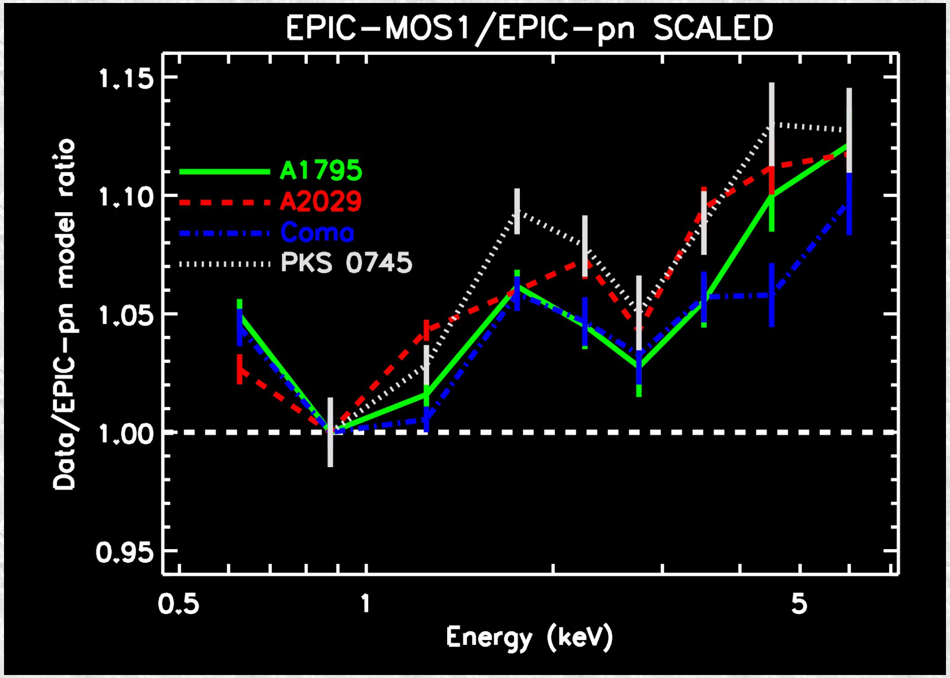
MOS2/pn



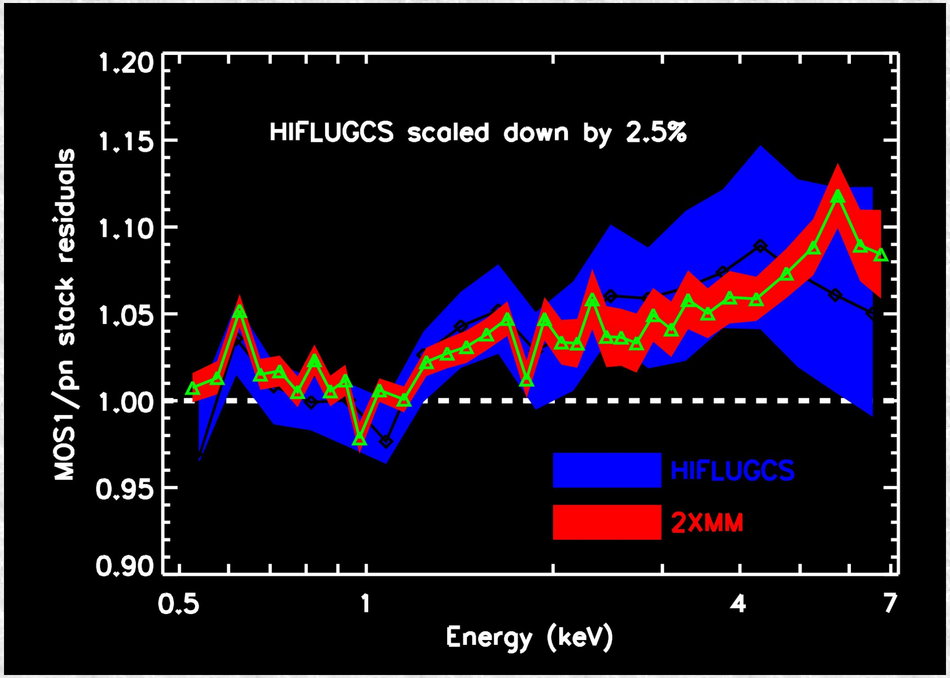
Large scatter in MMS clusters at highest energies

MMS clusters give smaller ratio at 1-2 keV?

MOS1/pn

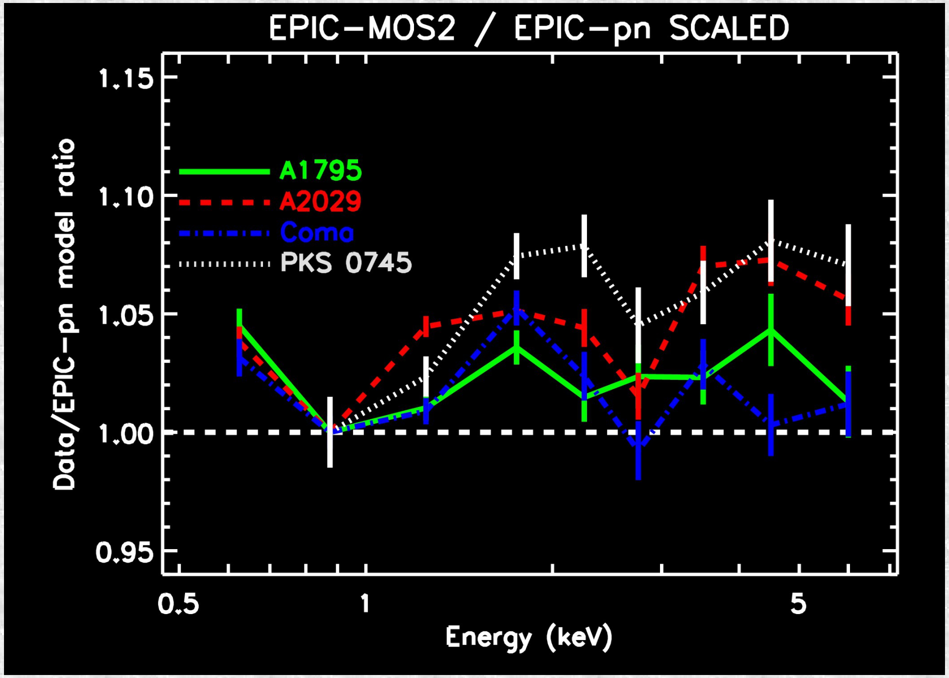


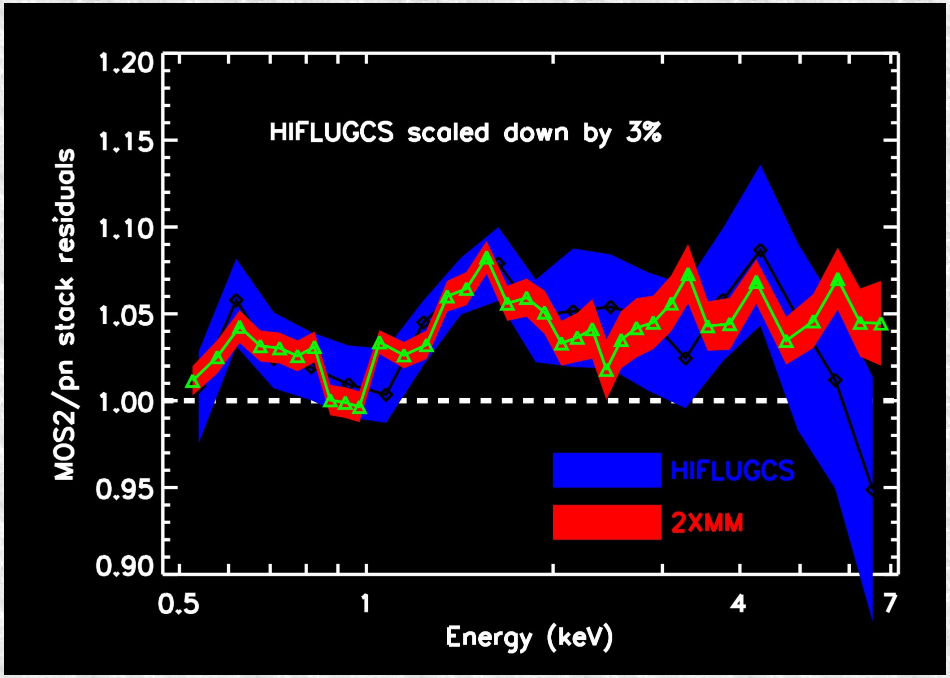
EPIC−MOS1/EPIC−pn SCALED
Data/EPIC−pn model ratio
Energy (keV)
A1795
A2029
Coma
PKS 0745
1.15
1.10
1.05
1.00
0.95
0.5
1
5



HIFLUGCS scaled down by 2.5%
MOS1/pn stack residuals
Energy (keV)
HIFLUGCS
2XMM
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0.5
1
4
7

MOS2/pn


EPIC-MOS2 / EPIC-pn SCALED
Data/EPIC-pn model ratio
1.15
1.10
1.05
1.00
0.95
A1795
A2029
Coma
PKS 0745
0.5
1
5
Energy (keV)


1.20
1.15
1.10
1.05
1.00
0.95
0.90
HIFLUGCS scaled down by 3%
MOS2/pn stack residuals
HIFLUGCS
2XMM
0.5
1
4
7
Energy (keV)