

# IACHEC Concordance & XMM Calibration Implications: In-Flight Calibration of X-ray Telescopes **without** Absolute References

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(Marshall+, 2021, AJ, 162, 254; see also IACHEC talk in Nov. 2021)

# The Goal

- The problems
  - Discrepant results from X-ray observatories in orbit
    - Cluster temperatures and fluxes
    - Blazar fluxes from simultaneous observations
    - SNR line fluxes
  - Imperfect ground cal, performance changes in flight
    - Instrument area priors  $a_i$  differ from “true values”  $A_i$
    - No absolute calibrators across all bands in flight: no “true”  $F_j$
  - Specific task: derive  $\hat{A}_i$  for optimal agreement

→ Let flux  $f_{ij} = c_{ij}/T_{ij}/a_i$   
where  $a_i$  = prior on  $A_i$   
 $c_{ij}$  = observed counts  
 $T_{ij}$  = known exposure time

# Complications III: Assessing Priors

- Collecting **prior** (fractional) uncertainties on effective areas
- Cal scientists assessed their instruments

**Table 1.** Effective Area Uncertainty Priors ( $\tau_i$ )<sup>a</sup>

Instrument	Energy Bands (keV)								
	0.15-0.33	0.33-0.54	0.54-0.8	0.8-1.2	1.2-1.8	1.8-2.2	2.2-3.5	3.5-5.5	5.5-10
Astrosat SXT	...	15	15	10	10	10	10	10	10
Chandra ACIS	3	3	3	3	2.6	3.3	3.3	4.9	5
Chandra HETGS	...	...	10	5	4	4	4	5	7
Chandra LETGS	5	7	7	7	7	7	10	10	
ROSAT PSPC	10	10	10	10	10	...	...	...	
Suzaku XIS1	...	20	15	10	10	15	5	5	5
Suzaku XIS0,2,3	...	...	15	10	10	15	5	5	5
Swift PC/WT	...	15	10	7.5	7.5	10	5	5	5
XMM MOS1,2	20	10	6	6	6	6	6	10	
XMM pn	2	2	2	2	2	2	2	3	
XMM RGS	...	8	5	5	...	...	...	...	

<sup>a</sup>The  $\tau_i$  values are given as percentages. The ellipses indicate bandpasses where the instrument has an insignificant effective area.

**Table 2.** Effective Area Uncertainty Priors ( $\tau_i$ )<sup>a</sup>

Instrument	Energy Bands (keV)					
	2.2-3.5	3.5-5.5	5.5-10	15-25	25-50	50-100
Astrosat CZTI	...	...	...	...	20	20
Astrosat LAXPC	...	15	15	15	15	20
INTEGRAL IBIS	...	...	...	...	8	15
INTEGRAL SPI	...	...	...	...	5	5
NuSTAR	...	4	3	3	15	20
RXTE PCA	5	10	3	3	10	50
RXTE HEXTE	...	...	...	5	5	5
Suzaku HXD	...	...	...	20	20	20
Swift BAT	...	...	...	15	4	12

<sup>a</sup>The  $\tau_i$  values are given as percentages.

# Input Data

- Paper I
  - IE0102 with 13 instruments ( $N=13$ ), O & Ne ( $M=2$ )
  - 2XMM catalog targets,  $N=3$ ,  $M=41$ ; soft, medium, hard
  - XCAL bright targets,  $N=3$ ,  $M=94-108$ ; soft, medium, hard
- New paper (Marshall+, 2021, AJ, 162, 254)
  - Same 3 sets as in Paper I
  - Also Capella with Chandra gratings,  $N=8$ ,  $M=15$
  - Added correlations of XMM hard, medium, soft
  - Added correlations of O, Ne fluxes of IE0102
  - Used heterogeneous tau values

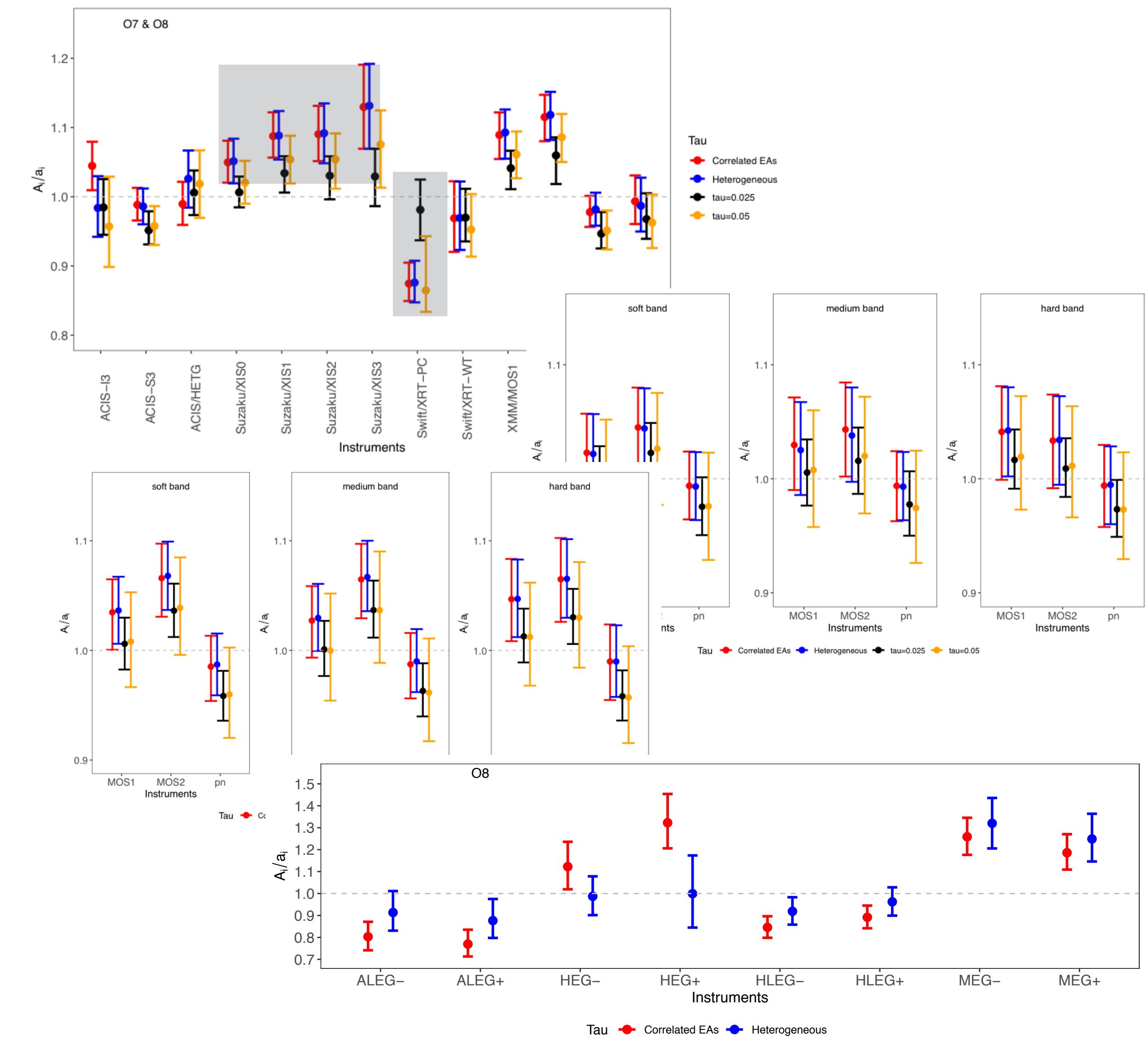
**Table 5.** 2XMM Concordance Fluxes – Medium Band<sup>a</sup>

Target	pn		MOS1		MOS2	
	$f_{ij}$	$\sigma_{ij}$	$f_{ij}$	$\sigma_{ij}$	$f_{ij}$	$\sigma_{ij}$
1127-145	0.481	0.049	0.496	0.053	0.490	0.052
1E0919+515	0.053	0.053	0.069	0.066	0.068	0.065
4C06.41	0.131	0.015	0.142	0.017	0.143	0.018
APM08279+5255	0.085	0.041	0.088	0.042	0.082	0.040
CenX-4	0.088	0.035	0.089	0.022	0.091	0.023
CoD-33 7795	0.275	0.136	0.287	0.143	0.276	0.136
ESO323-G077	0.425	0.184	0.438	0.202	0.439	0.203
GRB080411	0.348	0.006	0.415	0.008	0.419	0.009
Holmberg IX	0.514	0.083	0.517	0.084	0.556	0.090
IRAS13197-1627	0.938	0.818	0.914	0.793	1.000	0.873
LBQS1228+1116	0.154	0.009	0.156	0.010	0.162	0.010
M31 NN1	0.173	0.005	0.196	0.007	0.195	0.007
MS0205.7+3509	0.283	0.087	0.304	0.095	0.293	0.092
MS1229.2+6430	0.326	0.086	0.356	0.092	0.355	0.101
NGC 1313	0.200	0.021	0.212	0.023	0.215	0.023
NGC 4278	0.281	0.032	0.291	0.035	0.307	0.037
NGC 5204 X-1	0.140	0.032	0.140	0.033	0.148	0.036
NGC 5204 X-1	0.192	0.034	0.195	0.035	0.196	0.036
NGC 5252	0.326	0.092	0.327	0.095	0.328	0.091

Sample Data (Marshall+ sub'd.)

# Concordance Results

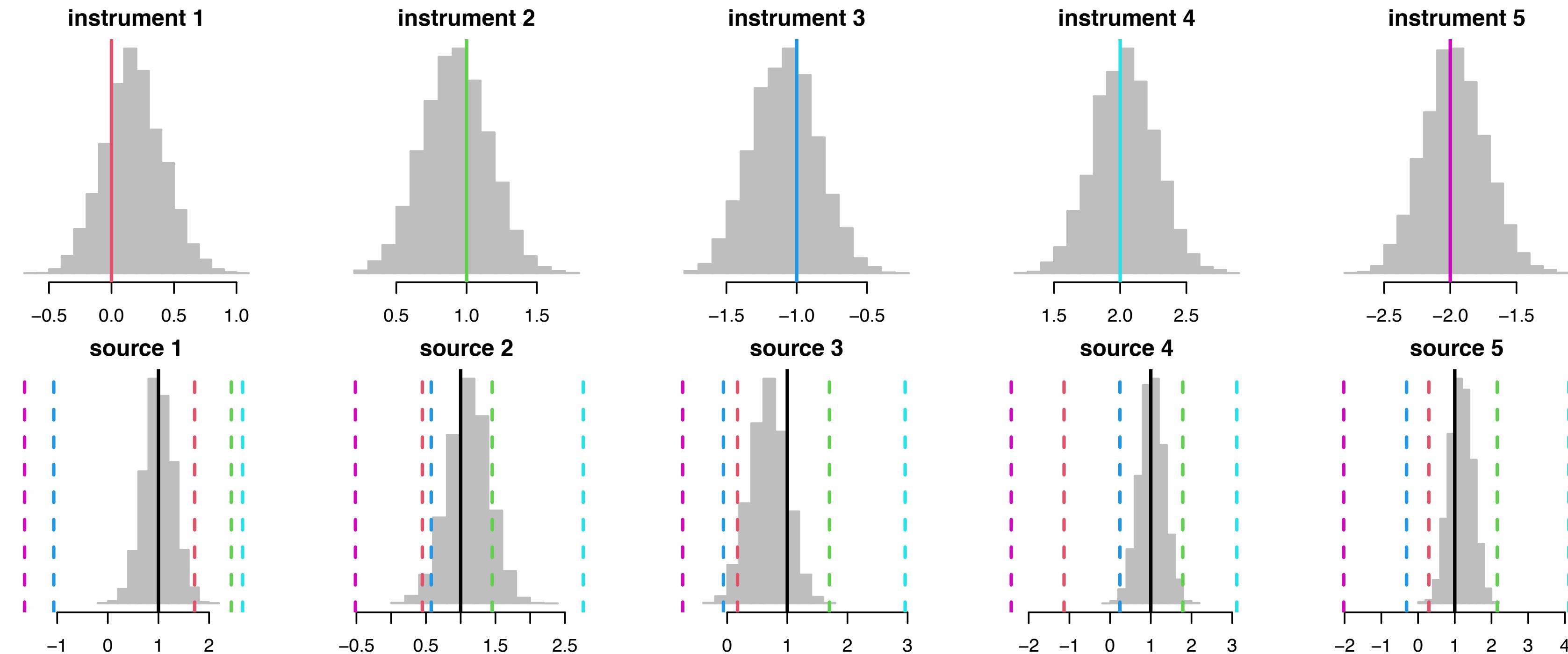
- SNR IE0102: Correlations change results, tau values matter
- 2XMM sample: slight changes when taus are assigned
- XCAL: same as 2XMM
- Capella, Chandra TGs:  $\pm 1$  orders agree, LETG is low of HETG



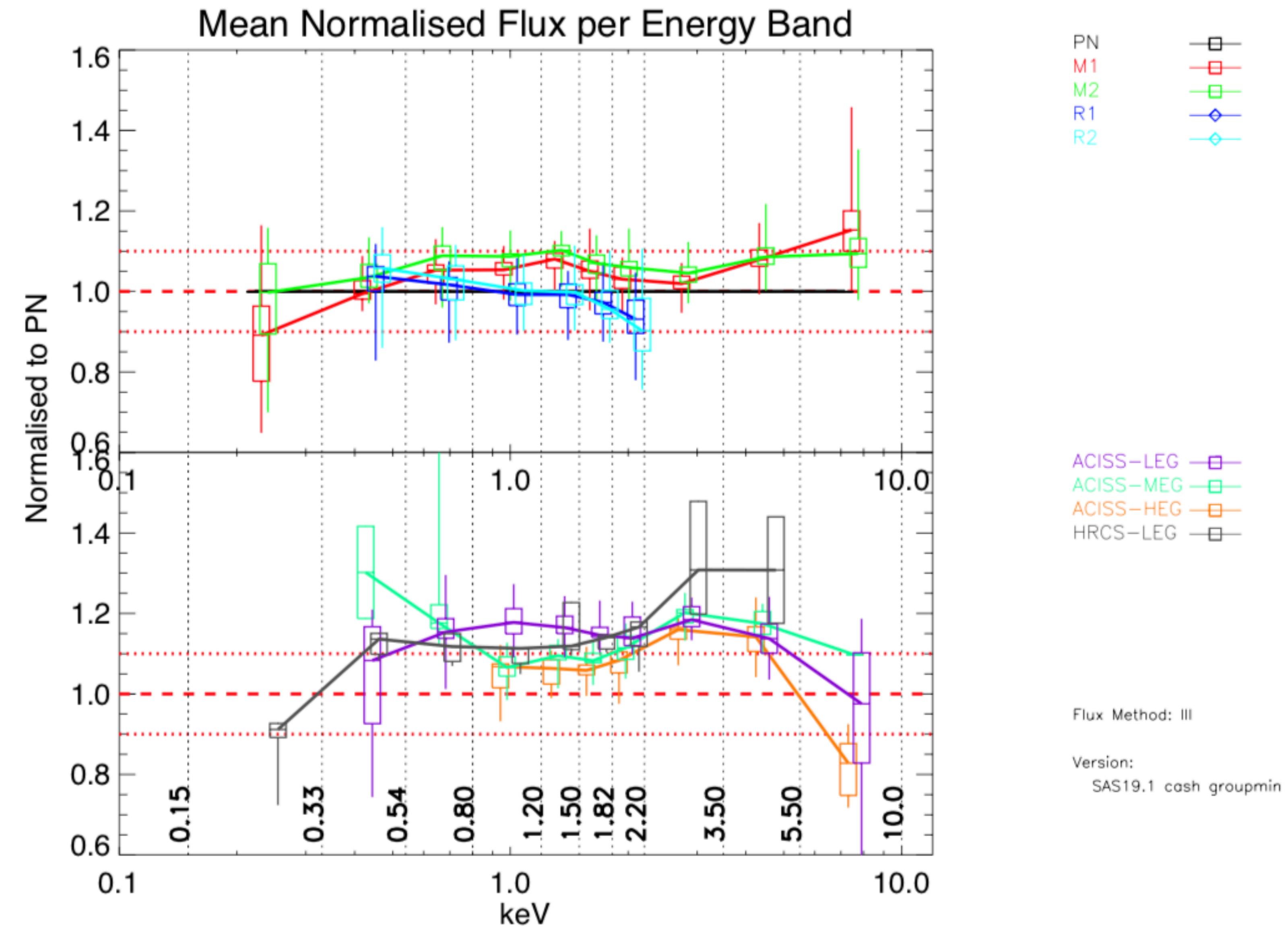
# Validation Simulation I

- 5 Instruments,  $\log A_i/a_i = [0, 1, -1, 2, -2]$ ,  $\tau=1$
- 40 sources,  $\sigma_i = [0.5, 0.5, 0.5, 0.5, 0.1]$  (on  $\log f_{ij}$ )

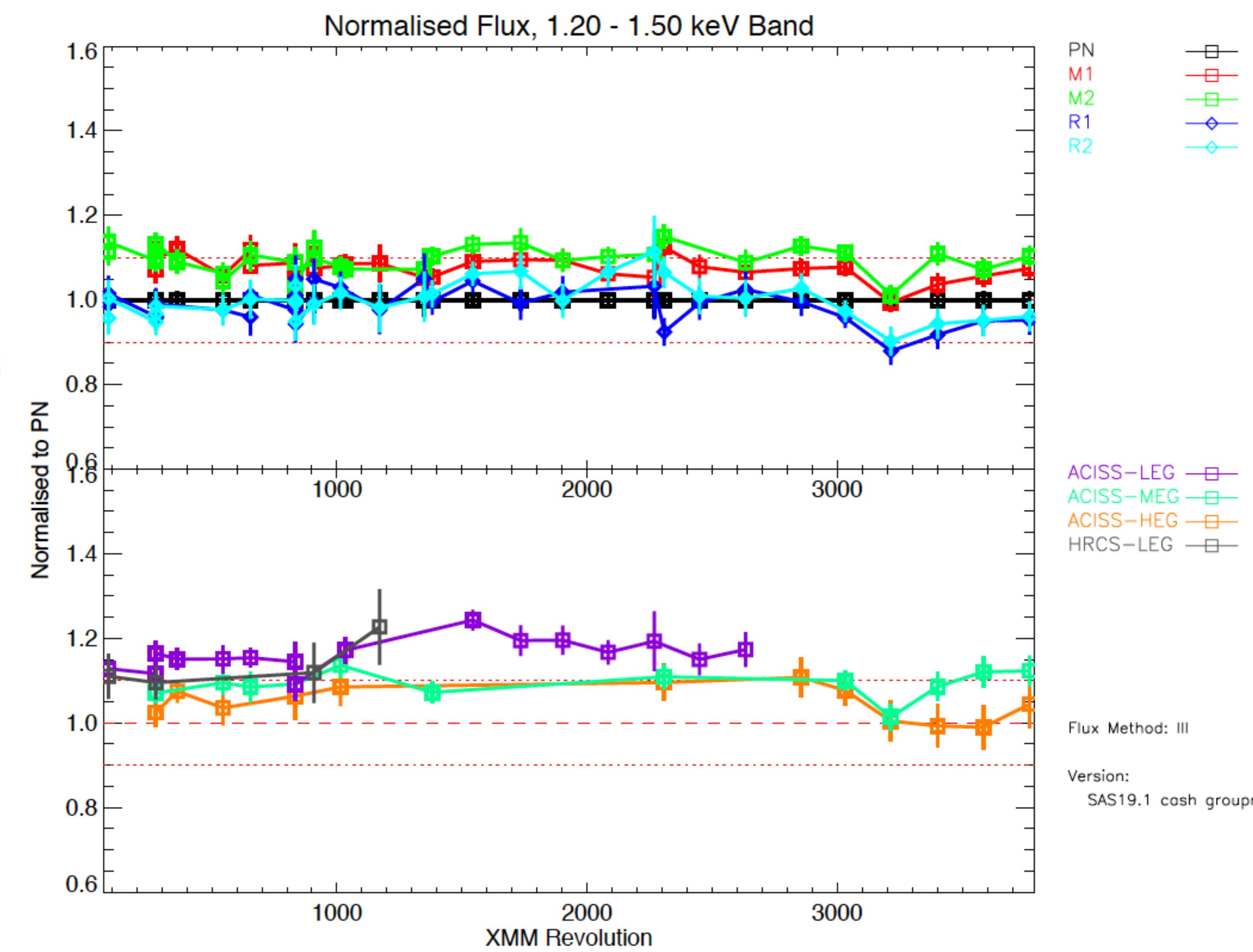
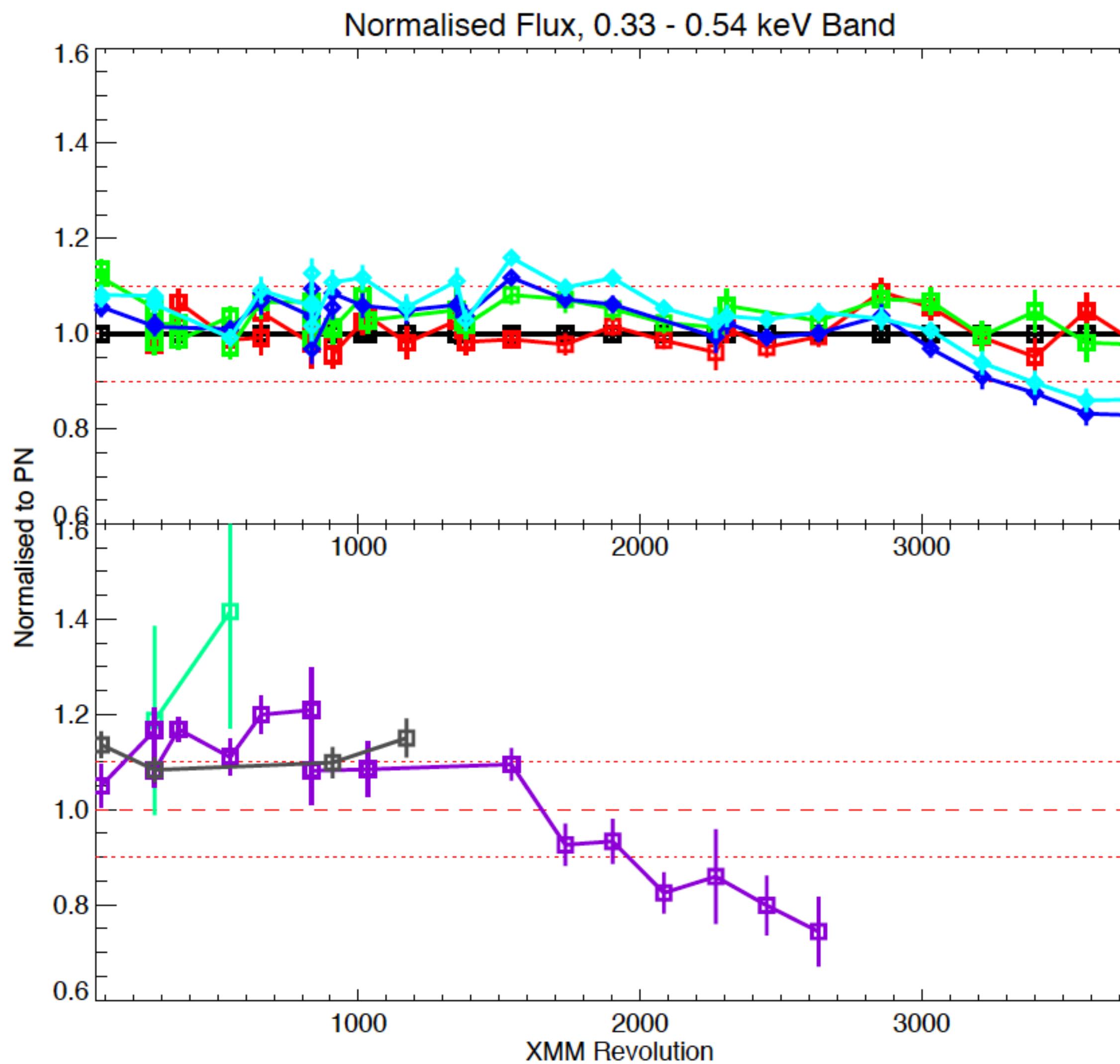
- Concordance:  
unbiased  $A$   
posteriors, good  $F$   
posteriors
- Ratio estimates:  
wide flux ranges



# Next: XMM/Chandra XCAL



# XCAL Time-Dependence



# Conclusions

- Concordance is “operational”
- Simple situations an simulations give reasonable answers
- Possible improvements
  - Outliers handled with t distribution
  - Fluxes in bands are related globally, not independent
  - Instrument areas are time-dependent
- Upcoming: XMM/Chandra cross-cal

