IACHEC Thermal SNRs Working Group Report

Thermal SNRs WG Current Membership

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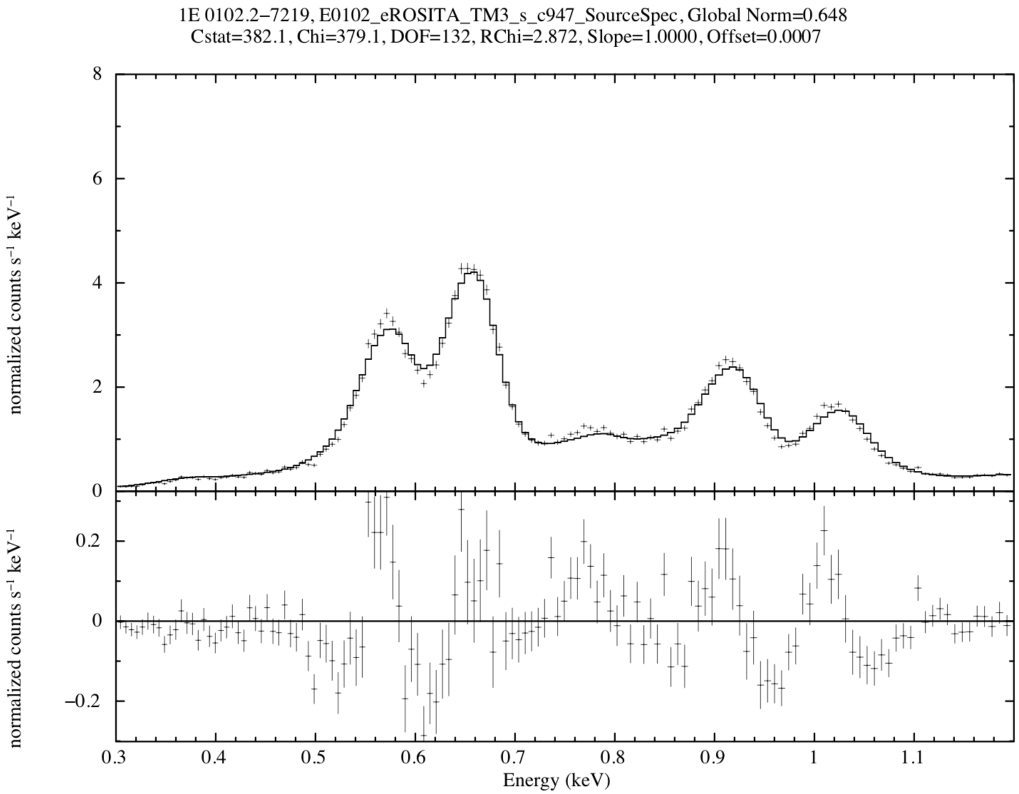
We met 6 times in 2021 by Zoom

E0102: Recent Use of the IACHEC Model

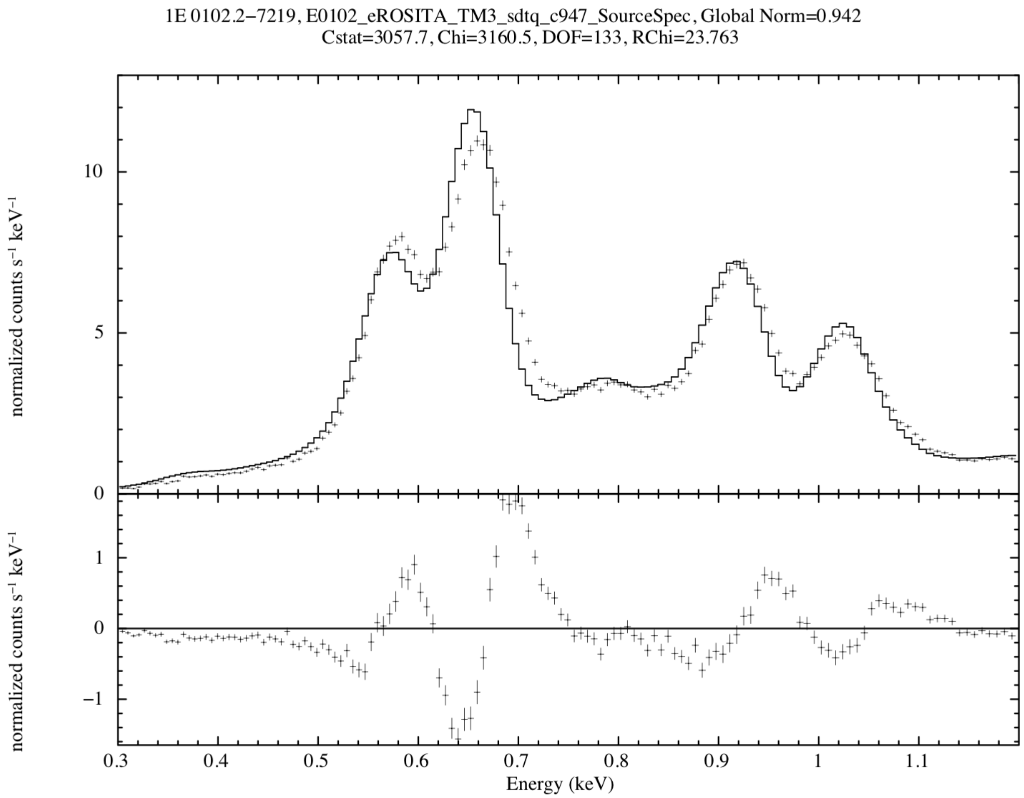
- IACHEC standard, empirical model published in Plucinsky et al. 2017, A&A, 597, A35
- model available at “https://wikis.mit.edu/confluence/display/iachec/Thermal+SNR"
- used to test the temperature-dependent gain correction on eROSITA by Dennerl and Plucinsky
- small offsets for the single “s” spectra for all cameras, but large offset for the TM3 single+double+triple+quad (sdtq) spectrum (remember eROSITA has 7 cameras)
- Dennerl identified a processing issue and this will be fixed

Dennerl (MPE), Plucinsky(SAO)

eROSITA TM3 “s"



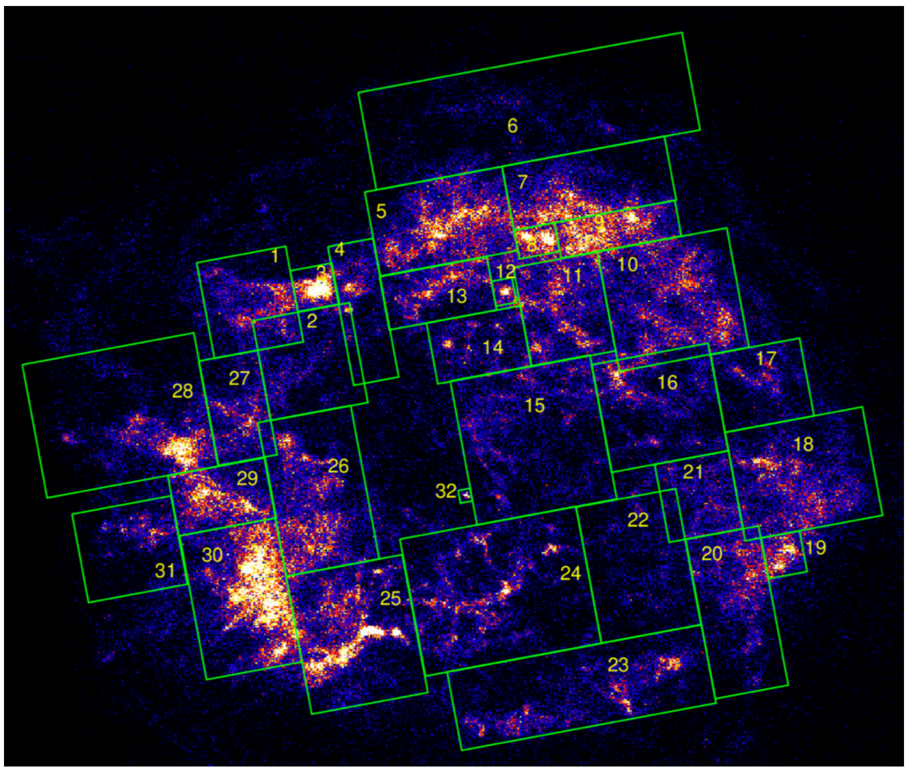
eROSITA TM3 “sdtq”



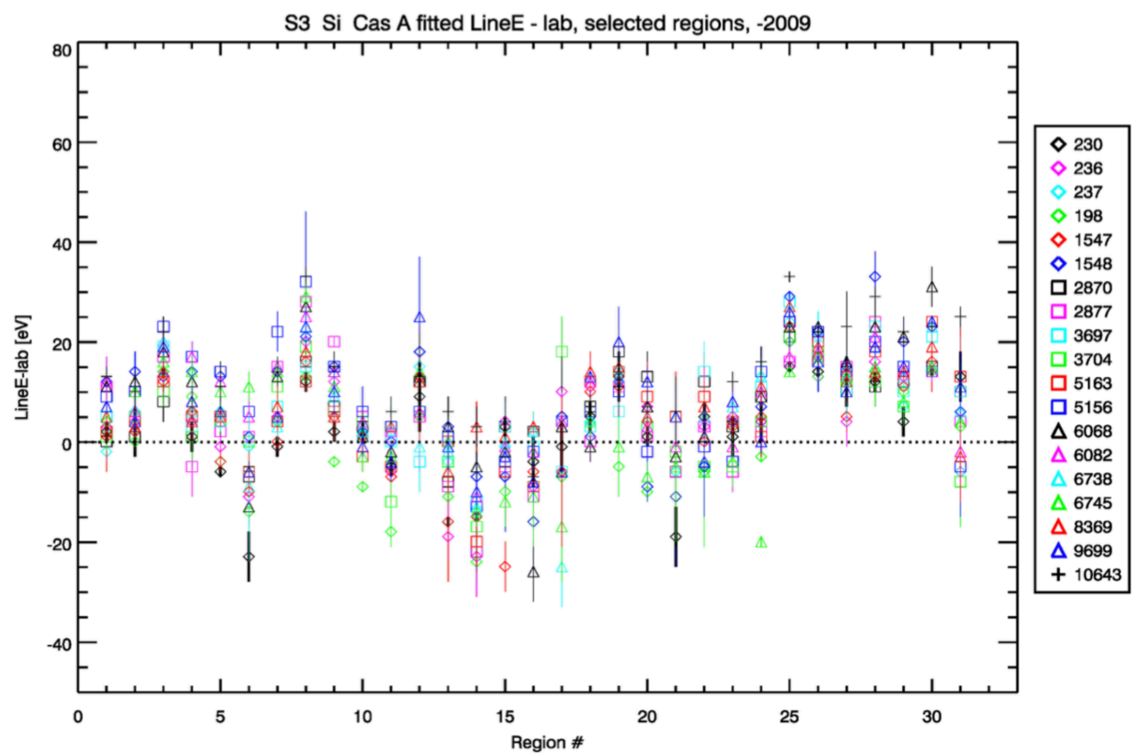
Cas A: Will be used for ACIS gain calibration

- Beardmore (Leicester) developed an IACHEC standard, empirical model, available at "https://wikis.mit.edu/confluence/display/iachec/Cas+A"
- significant spectral variations with position due to different plasma conditions and bulk velocities
- Durham (SAO) developed empirical model to fit ACIS data in different regions and detects energy shifts of the Si XIII complex as described in Willingale at al. (2002), Lazendic et al (2006), Delaney et al. (2010), Rutherford et al. (2014) and Picquenot et al. (2020)

Chandra ACIS S3



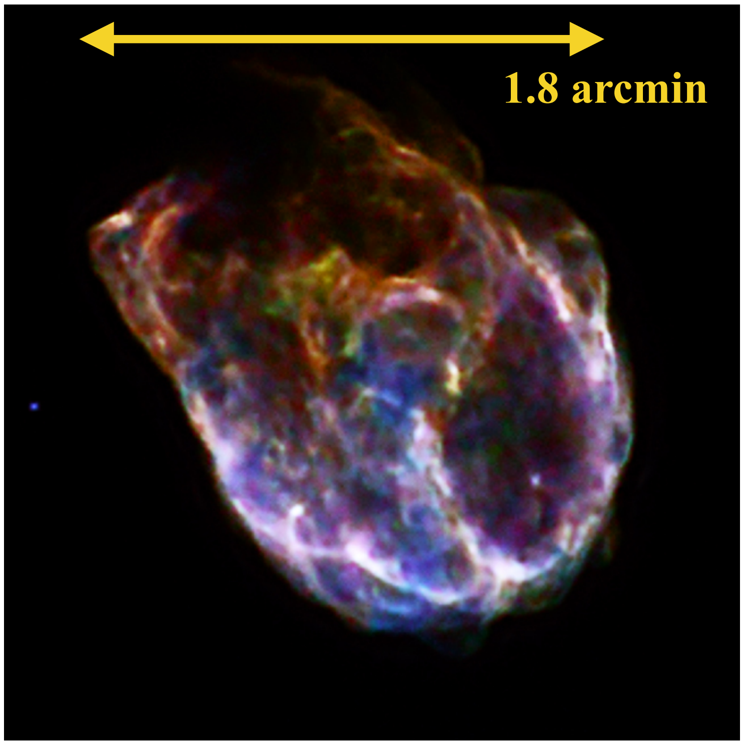
Durham (SAO)



N132D

- Most X-ray luminous SNR in the Local Group
- Spectrum is more complicated than E0102, significant Fe-L and Fe-K emission and multiple (identified) temperature components (Behar et al. 2000, Suzuki et al. 2020)
- More spectral variation with position & slightly larger than E0102
- Routine calibration target for XMM and Chandra LP in 2019/2020

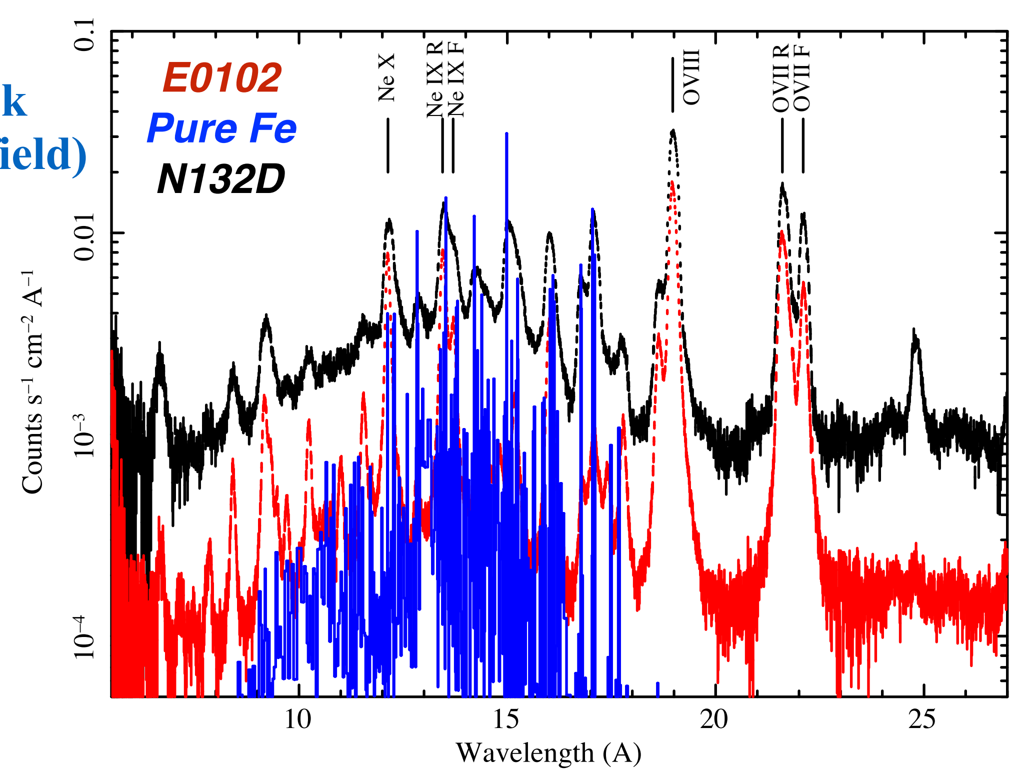
Chandra ACIS



Red (0.3-0.75 keV), Green (0.8-1.1 keV), Blue (1.1 – 2.0 keV)

XMM RGS Spectra of N132D and E0102

Pollock (Sheffield)

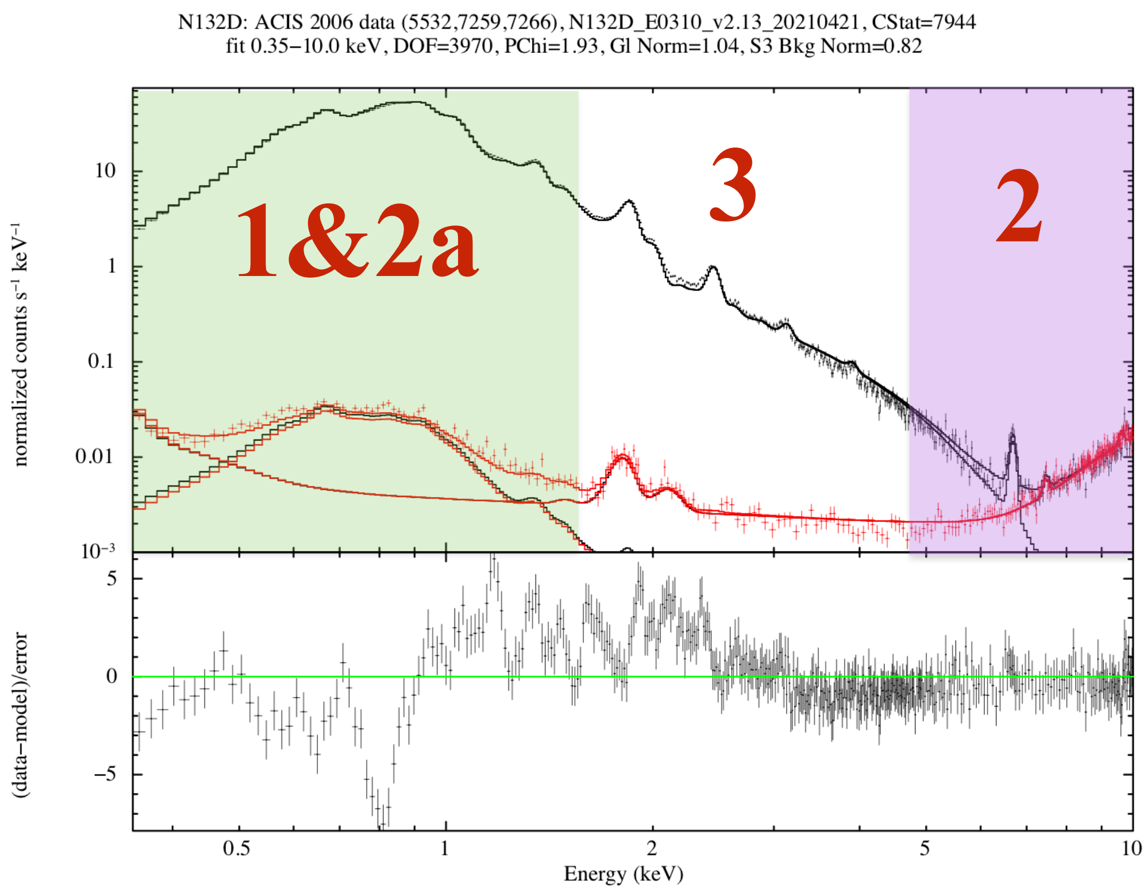


N132D: Update on Model Development

- Current version of the model is available at: "https://wikis.mit.edu/confluence/display/iachec/Current+N132D+model"
- RGS data has driven the empirical model in the 0.3-1.5 keV range. Stuhlinger, Pollock & Guainazzi developed first version in 2012.
- We must develop the model in different stages (energy ranges), given the sensitivities of the various instruments

0.3-1.5 keV: RGS
1.5-4.5 keV: pn, MOS, ACIS, XRT, XIS
4.5-8.0 keV: NuSTAR, pn, MOS, ACIS, XIS

- Thermal SNRs WG has focussed recently on the high energy part of the spectrum taking advantage of the new information from NuSTAR (Grefenstette) and Suzaku (Miller), also Bamba et al. 2018
- Results presented at this meeting will focus on the 4.5-8.0 keV range



N132D Empirical Model

- Empirical model currently consists of:
  - two components for absorption (Galactic and LMC)
  - 132 Gaussians for the lines
  - three nlapec components for the continuum with: $kT_1 = 0.18$ keV, $kT_2 = 1.14$ keV, $kT_3 = 5.48$ keV

Current Objective

- agree on the normalization and temperature of the $kT_2 = 1.14$ keV, $kT_3 = 5.48$ keV nlapec components

Process

- fit in the 3.2-8.0 keV range with norms free but temperatures frozen for the $kT_2 = 1.14$ keV, $kT_3 = 5.48$ keV nlapec components and the norm of the Fe XXV Heα triplet free
- average the normalizations for each instrument/telescope to get consensus values
- evaluate fits with the consensus values, are the fits acceptable ?
- IF the fits are acceptable, fit in the 5.5.-8.0 keV range and allow the Fe XXV Heα triplet normalization to vary
- Compare normalizations of the instruments at 6.7 keV

Order of Presentations

1. ACIS, XISs, pn, MOS	Paul for Adam and Eric
2. NuSTAR	Brian
3. eROSITA	Konrad

The Spectral Fitters

Those who did the work:

NuSTAR	Brian Grefenstette (Caltech)
Suzaku XIS	Eric Miller (MIT)
XMM pn & MOS	Adam Foster (SAO)
Models	Adam Foster (SAO)
XMM-RGS	Martin Stuhlinger (ESAC)
Chandra ACIS	Paul Plucinsky (SAO)

Empirical Model Fit Results

- **incorporate revised Suzaku results from Eric**

Instrument	1.14 keV nlapec norm	5.47 keV nlapec norm	Fe XXV Norm
ACIS	4.27+/-0.10 e-2	7.90+/-1.16 e-4	3.56+/-0.30 e-6
pn	3.34+/-0.03 e-2	9.86+/-0.26 e-4	2.65+/-0.06 e-6
MOS1	3.47+/-0.04 e-2	9.49+/-0.41 e-4	2.97+/-0.10 e-6
MOS2	3.33+/-0.04 e-2	8.21+/-0.38 e-4	2.76+/-0.10 e-6
pn corrected	4.41+/-0.03 e-2	1.14+/-0.03 e-3	3.26+/-0.07 e-6
XIS0	3.71+/-0.07 e-2	1.01+/-0.07 e-3	3.20+/-0.14 e-6
XIS3	3.83+/-0.06 e-2	1.03+/-0.07 e-3	3.23+/-0.14 e-6
XIS1	3.80+/-0.07 e-2	1.06+/-0.07 e-3	3.00+/-0.16 e-6

Suggestion for New Default Values

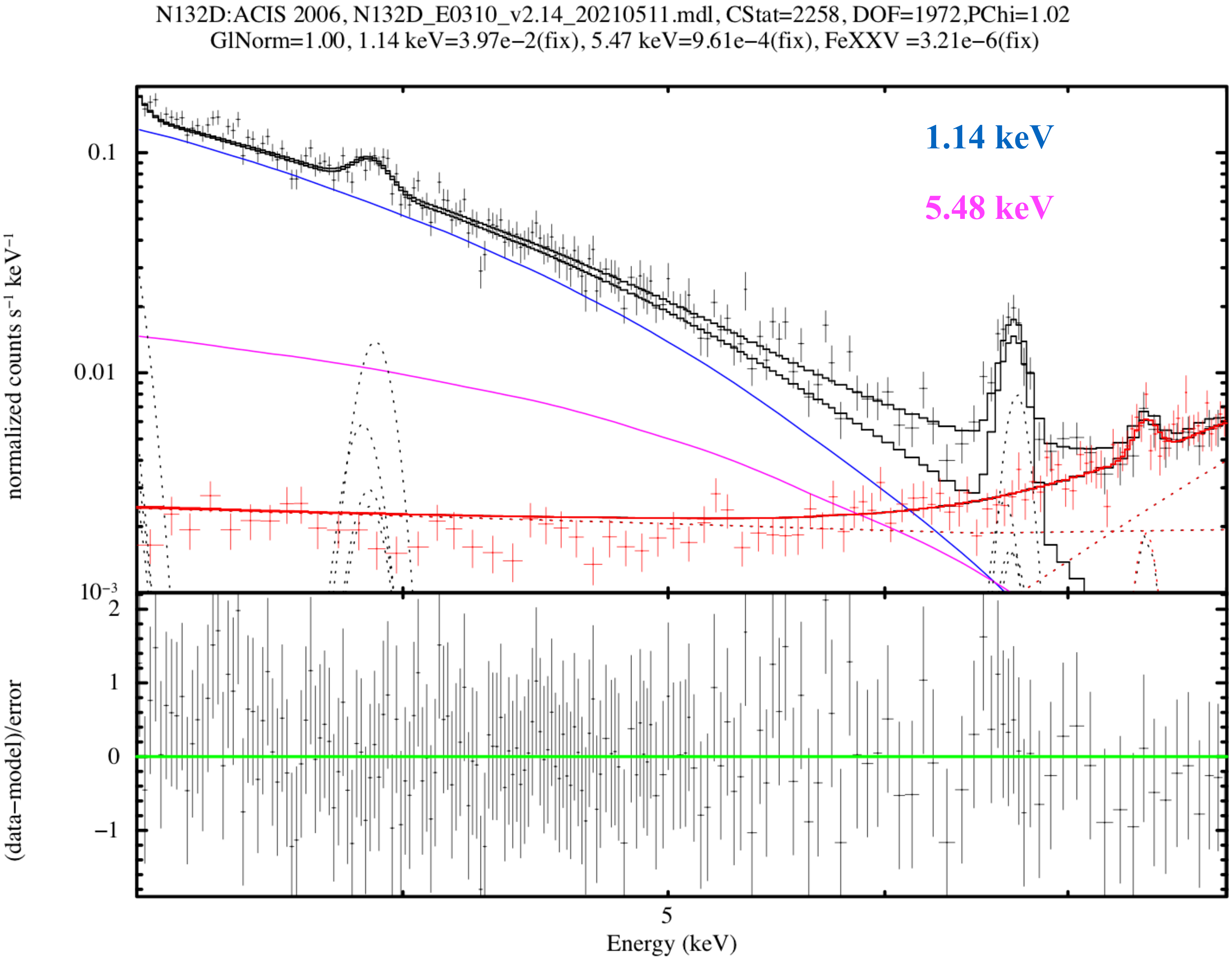
- adopt one value per mission+instrument: one average value of XISs, one average of MOS1 & MOS2, and pn corrected
- adopt the "pn corrected" values, we believe the XMM effective area will be changed to this value. Keeping the MOS uncorrected values is a hedge against this bet
- average the ACIS, MOS, pn, & XIS values to get the suggested values

Instrument	1.14 keV nlapec norm	5.47 keV nlapec norm	Fe XXV Norm
ACIS	4.27E-02	7.90E-04	3.56E-06
MOS1/MOS2	3.40E-02	8.85E-04	2.87E-06
pn corrected	4.41E-02	1.14E-03	3.26E-06
XIS0/3/1	3.78E-02	1.03E-03	3.14E-06
suggested values	3.97E-02	9.61E-04	3.21E-06

ACIS:
2006 data

3.2-8.0 keV with the average norms for the nlapecs. No free parameters

CStat=2258
DOF=1972
PChi=1.02



Suzaku XISs: 3.2-8.0 keV with the average norms for the nlapecs. No free parameters.

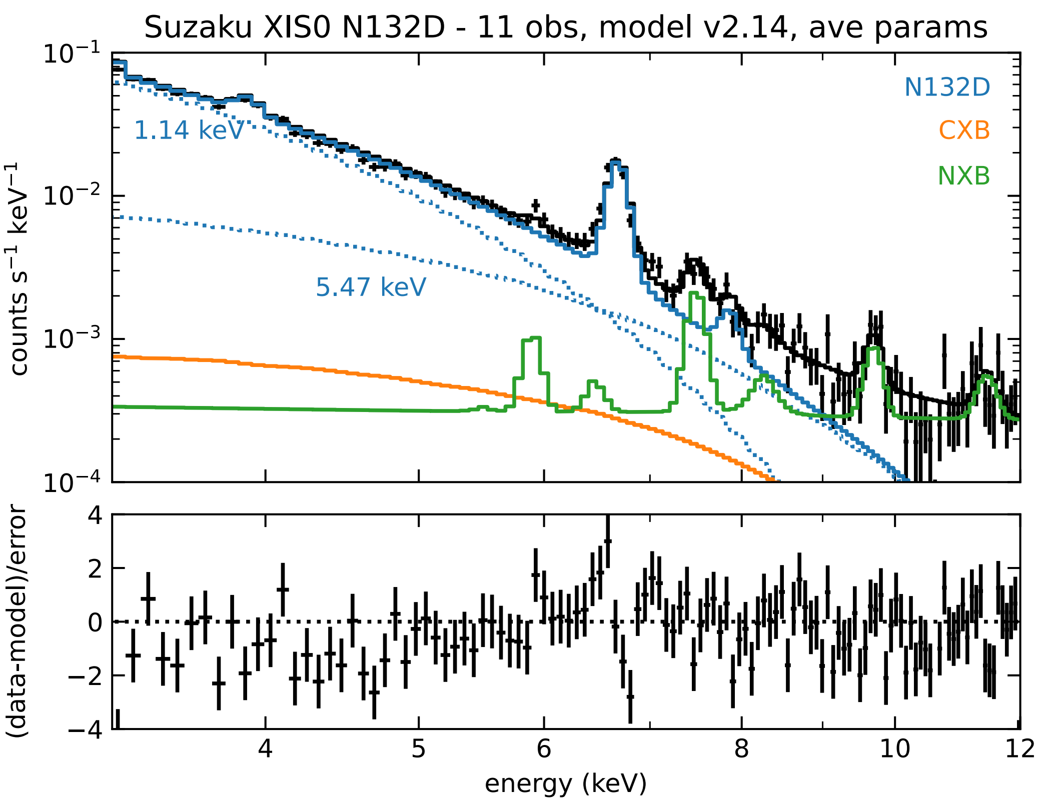
- 11 spectra for each XIS
- optimally binned
- fit statistic calculated in the 3.2-8.0 keV range but spectra plotted up to 12 keV
- lower background of Suzaku in general and FI CCDs in particular is helpful in constraining the 5.47 keV component

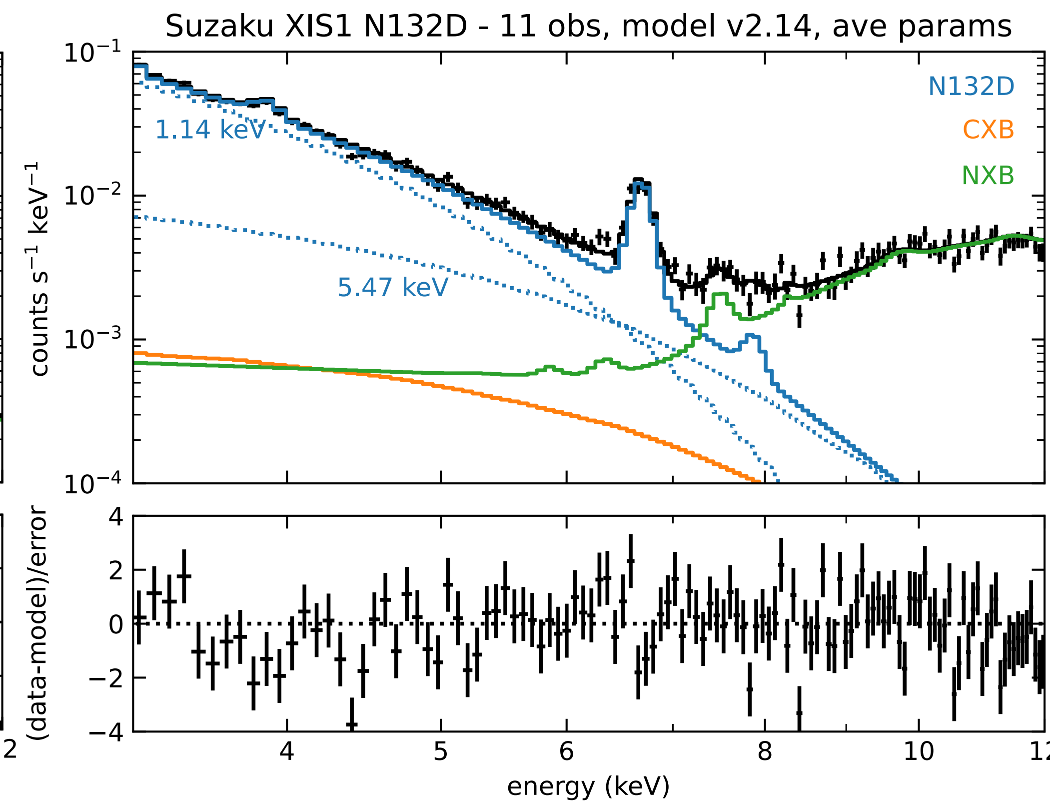
XIS	cstat	dof
XIS0	473.7	405
XIS3	471.0	395
XIS1	510.3	379

FI CCD

BI CCD

Miller (MIT)



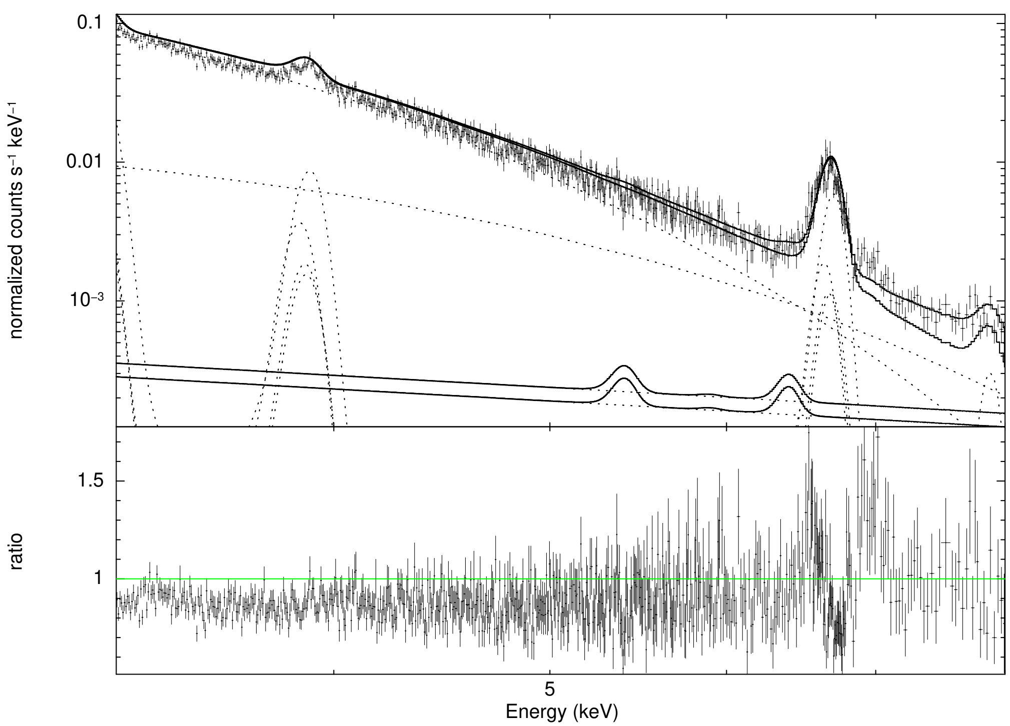


XMM MOS and pn: 3.2-8.0 keV with the average norms for the nlapecs. No free parameters.

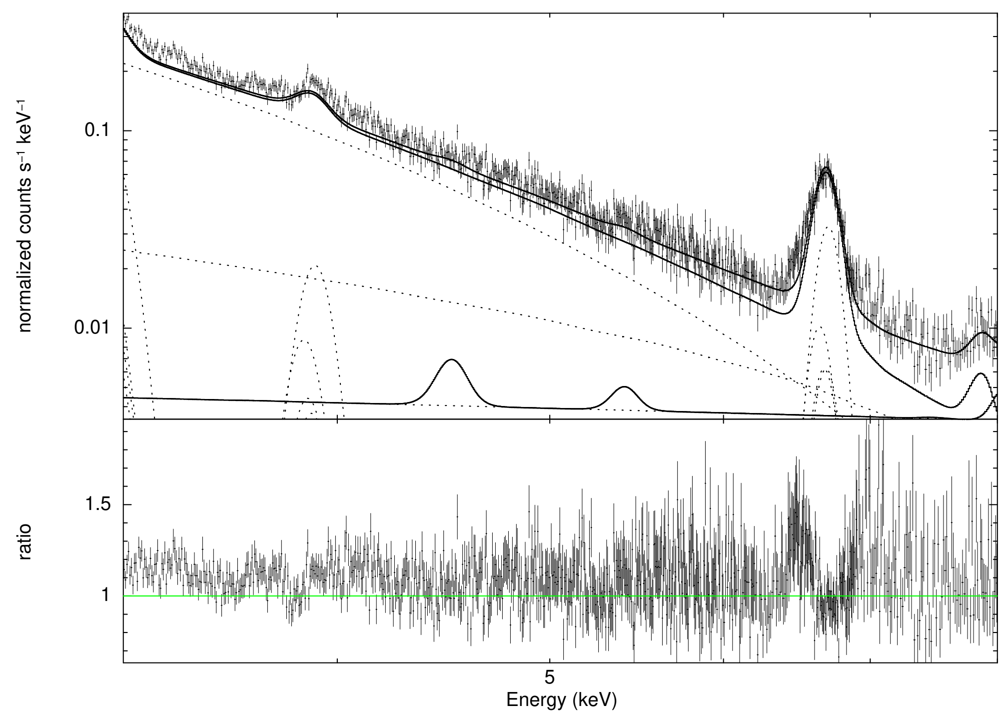
- MOS1&MOS2: CStat=61891, PChi=64964, DOF=67270
- pn: CStat=16585, PChi=16887, DOF=14415
- continuum model ***overpredicts*** for the MOS1 & MOS2 in the 3.2-6.0 keV band, we used the released effective area curve for MOS
- continuum model ***underpredicts*** for the MOS1 & MOS2 in the 3.2-6.0 keV band, we used the candidate effective area curve for pn

Foster (SAO)

MOS1 & MOS2



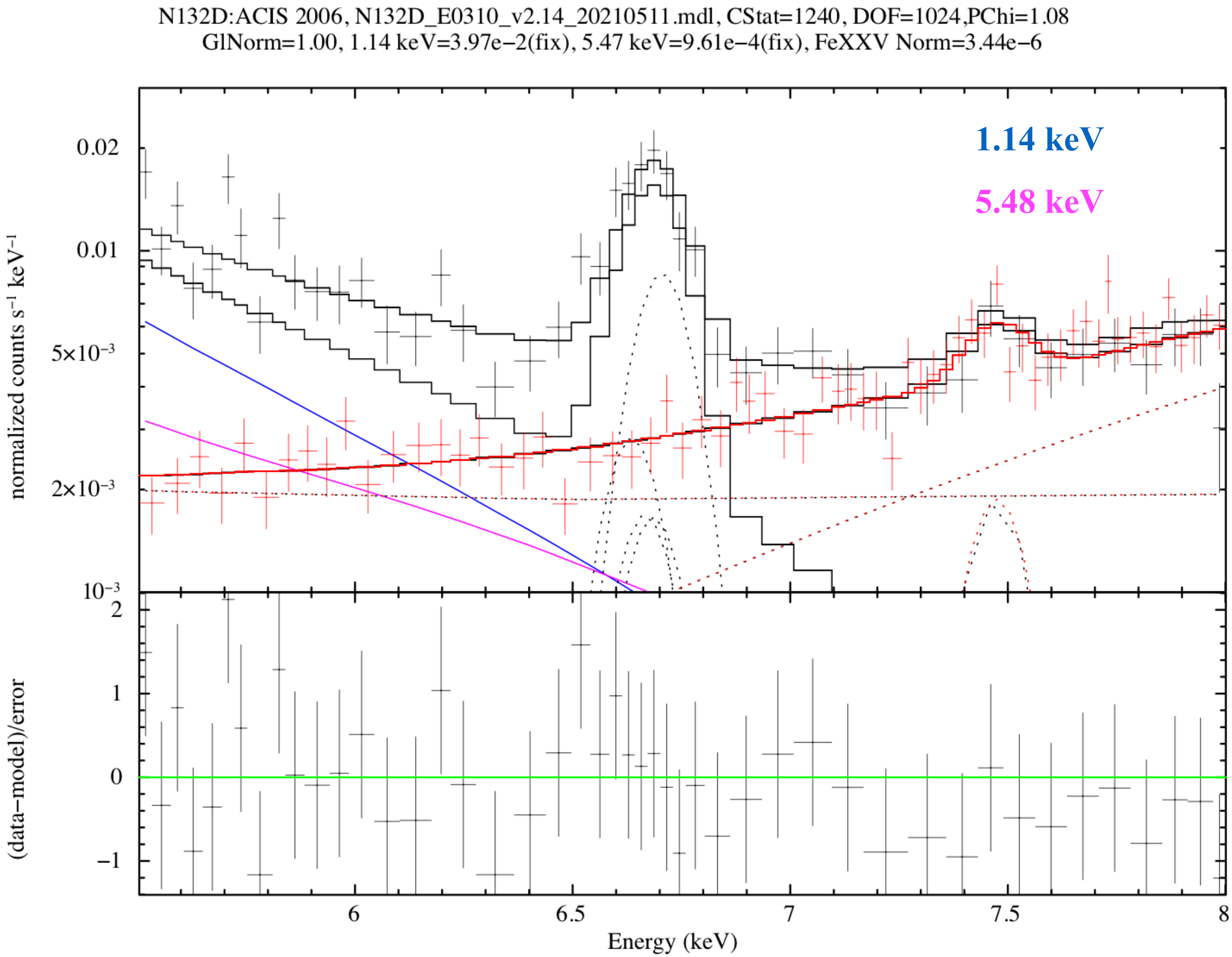
pn



ACIS:
2006 data

5.5-8.0 keV with the average norms for the nlapecs. No free parameters
Fit the Fe XXV Heα norm = 3.44+/-0.30x10^{-6}

CStat=1240
DOF=1024
PChi=1.08



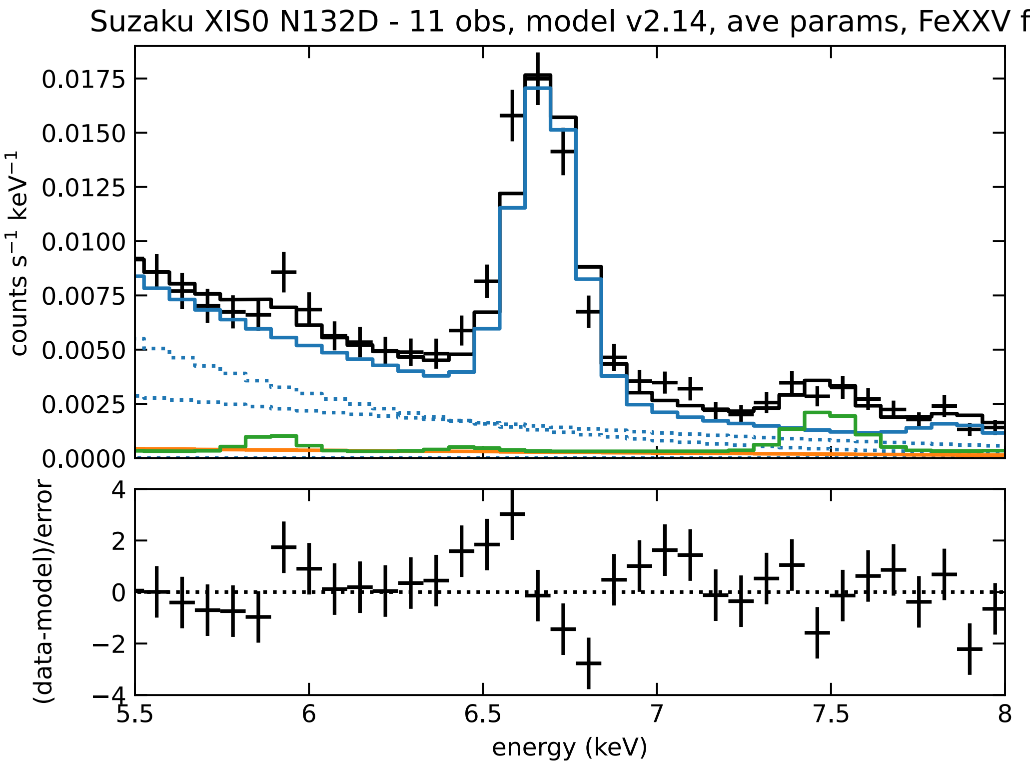
Suzaku XISs: 5.5-8.0 keV with the average norms for the nlapecs. Fit Fe XXV Heα norm

- energies and relative normalizations for the Fe XXV Heα triplet are fixed in the model, overall normalization can vary through the Fe XXV Heα r line normalization as the f & i line normalizations are linked to the r line normalization

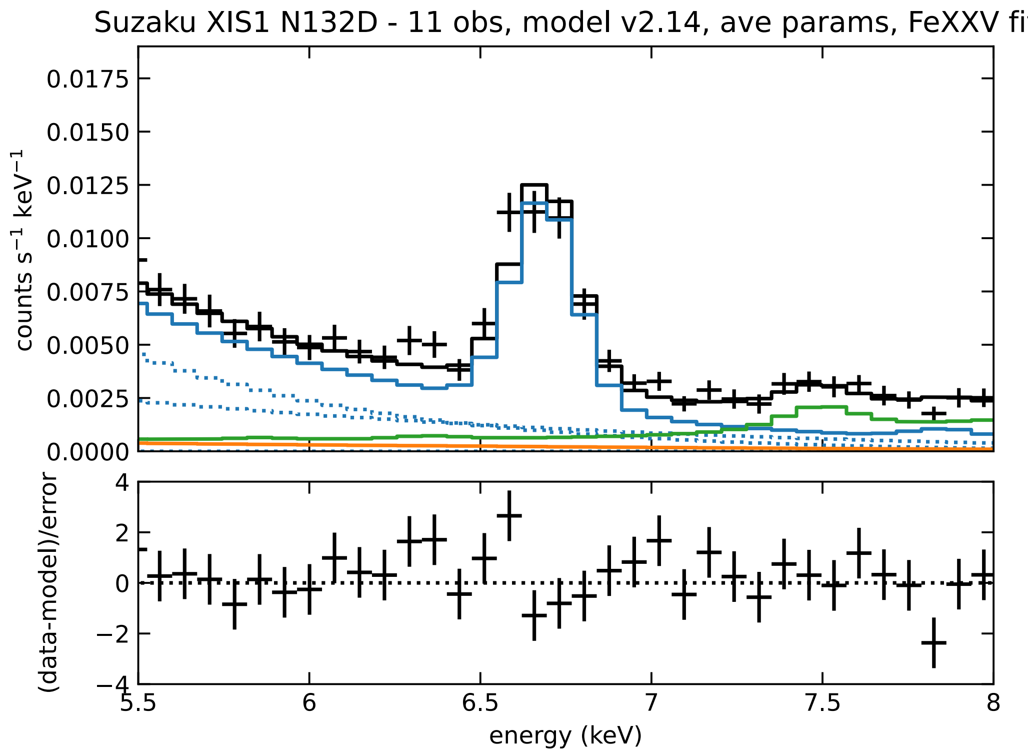
XIS	FeXXV_norm	cstat	dof
XIS0	3.20±0.14e-6	208.4	184
XIS3	3.27±0.13e-6	235.8	176
XIS1	3.05±0.16e-6	230.1	176

Miller (MIT)

FI CCD



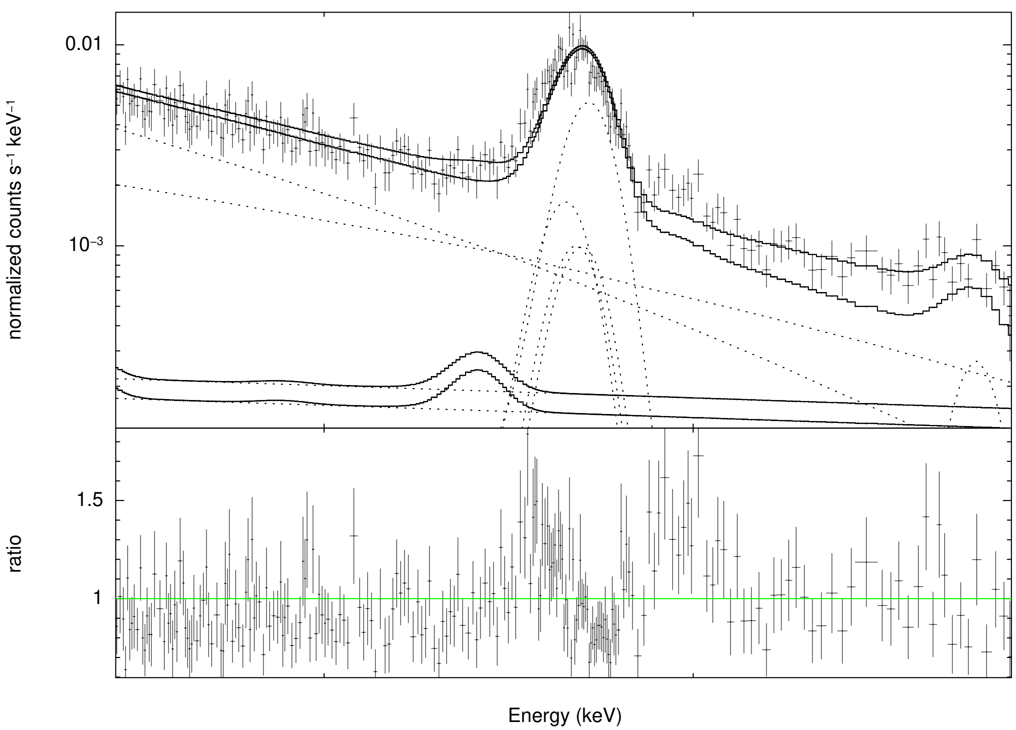
BI CCD



XMM MOS and pn: 5.5-8.0 keV, average norms for the nlapecs. Fit Fe XXV Heα norm

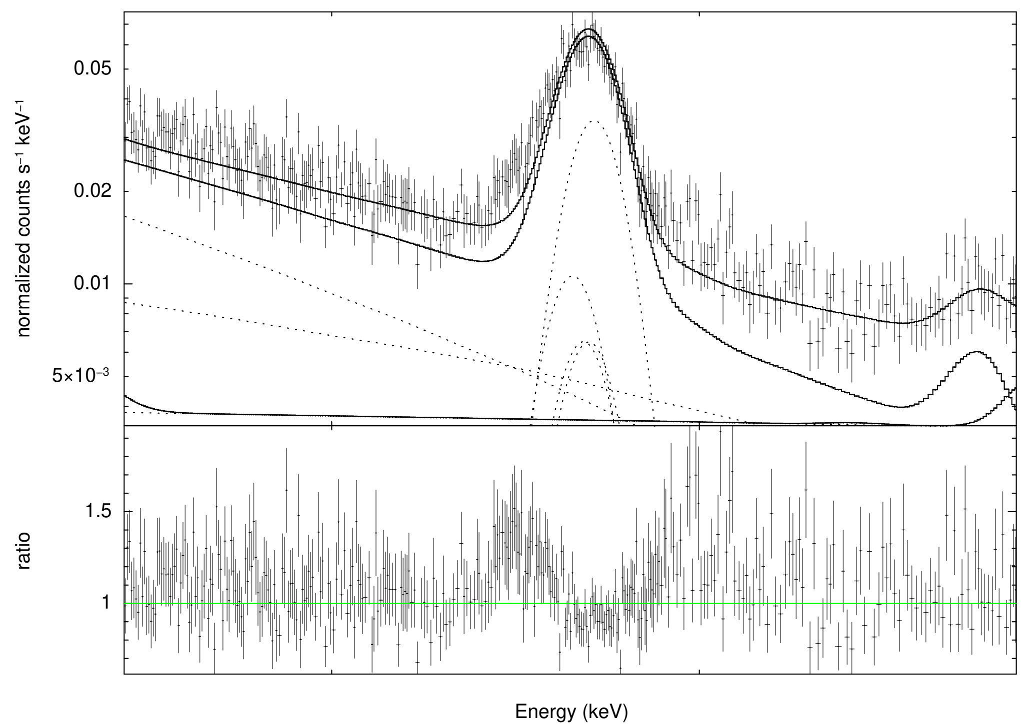
- MOS1&MOS2: CStat=25079, PChi=34994, DOF=34929, Fe XXV norm= 2.82+/-0.07 $\times 10^{-6}$
- pn: CStat=8561, PChi=8430, DOF=7484, Fe XXV norm= 3.34+/-0.07 $\times 10^{-6}$
- norm is lower for MOS, higher for pn, consistent with effective area difference
- evidence for an energy shift, this will need to be investigated as data from many observations are combined to produce these spectra

MOS1 & MOS2

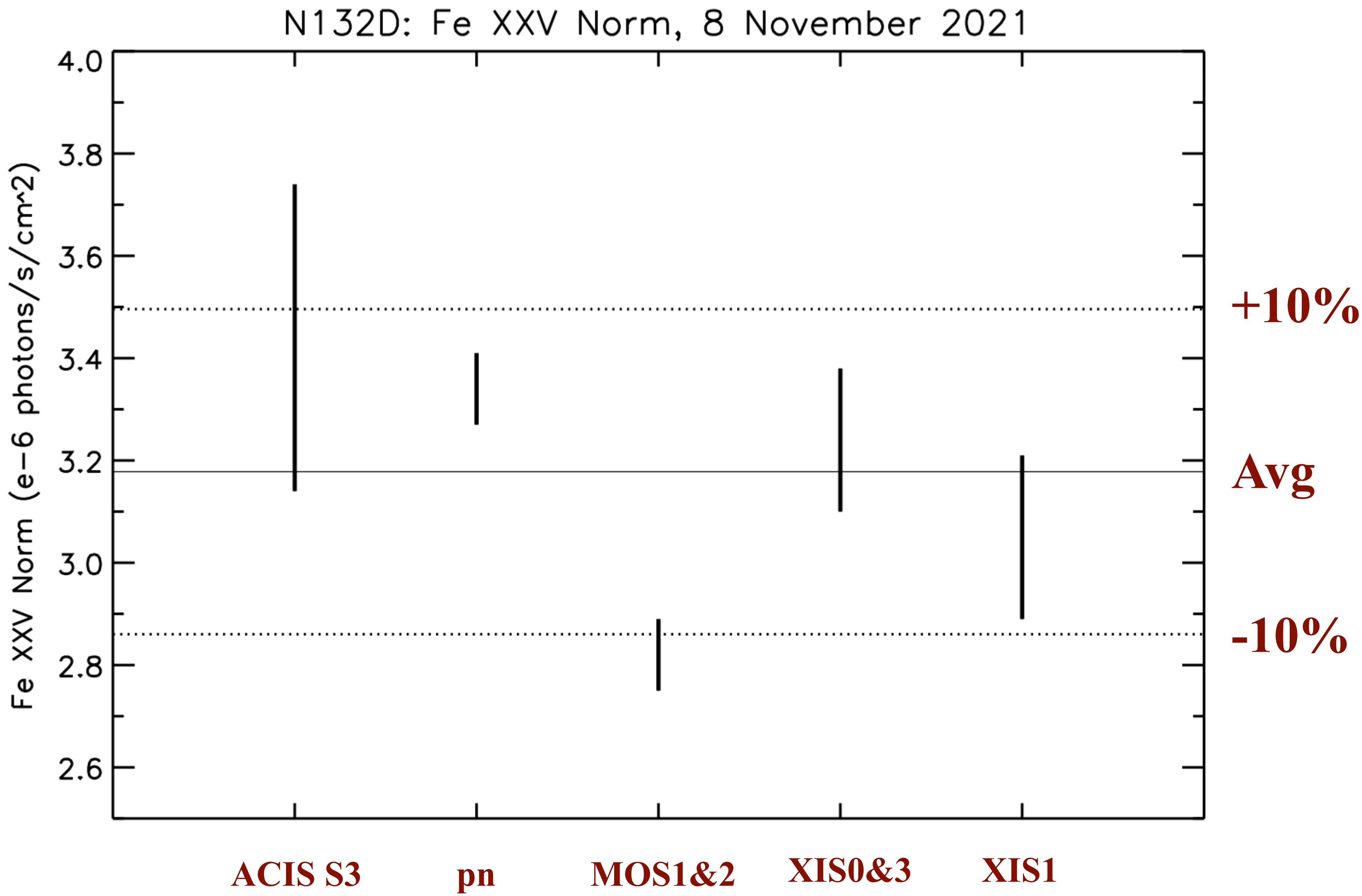


pn

Foster (SAO)



Fe XXV Hea Norm Results



NuSTAR & eROSITA

Brian presents NuSTAR results
Konrad presents eROSITA results

Future Work

- decide on compromise normalizations for the 1.14 keV and 5.48 keV nlapec components
- allow the centroid energy of the Fe XXV Heα complex to vary and explore different ratios for the f,i,r lines in the Fe XXV Heα complex
- finalize the high energy part of the model, release new version for Martin
- Martin refits the lines in the RGS data in the 0.3-1.5 keV range with the new normalization for the 1.14 keV component
- finalize the model in the 0.3-1.5 keV range
- focus on the 1.5-4.5 keV range, this promises to be difficult in that the instruments clearly do not agree with each other