Working group status report

# Non-thermal SNRs : G21.5-0.9

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## Contents

# 1. Background & Goal

- Background
  - Crab has been used as a celestial calibration source since the beginning of the X-ray astronomy.
  - Crab is often too bright for current and future instruments of improved sensitivity.
- Goal
  - Propose G21.5-0.9 as a faint substitute to Crab for current and future missions.
  - Make a comparison among current instruments using this source for cross-calibration.

# 6. Summary

- Analysis done, comparison made, paper drafted.

**Cross-calibration of the X-ray Instruments onboard the Chandra, INTEGRAL, Suzaku, Swift, and XMM-Newton Observatories using G21.5–0.9**

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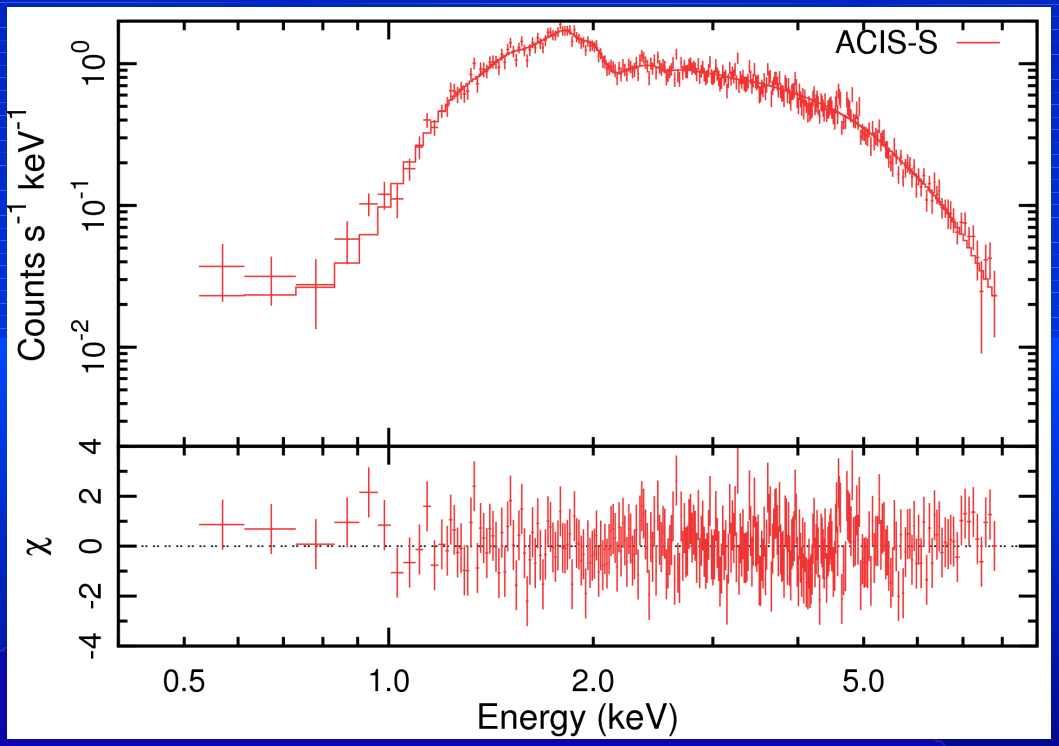
- Some inconsistencies among instruments remain. We do not need to resolve these inconsistencies, but show that these inconsistencies are consistent with previously known results.
- I ask
  - (1) co-authors to read the draft, list possible causes for the inconsistencies, and reexamine the numbers.
  - (2) IACHEC colleagues if the inconsistencies found in G21.5-0.9 are in line with their understanding with their instruments and other IACHEC targets.

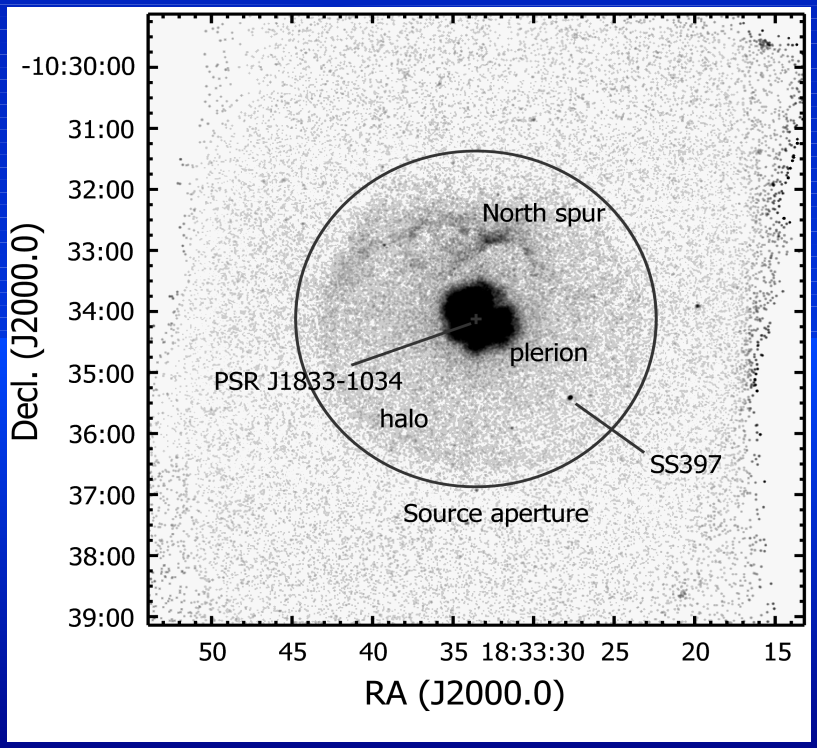
# 2. Target -- G21.5-0.9 --

- Nature : PWN (Age~870 yr, D~4.8kpc)
- Advantages
  - Constant. Simple spectrum (power-law).
  - Faint (~2mCrab). Matches with dynamic range of current and future missions < 10 keV.
  - Compact in size (young, distant). Mitigates the spatial differences of responses.
  - Simple morphology. Makes src/bkg extraction easy.
  - Flat (Gamma~1.8). spectral shape. Extends to >10keV.
  - Soft-band (<1 keV) cut-off. Decouples the uncertainty of contamination on CCDs.
  - Calibration source for Chandra, Swift. Software validation source for XMM.

# 2. Target -- G21.5-0.9 --

- Limitations
  - Extended (~3'). Cannot be used for gratings.
  - Spatial spectral variation (softening of power-law index).
  - Some irrelevant emission.
  - Soft-band cut-off. Carnot be used for soft-band calibration.



# 3. Data (1/2) Instruments

- Tsujimoto (ISAS) ... Suzaku/XIS,HXD(PIN)
- Guainazzi (ESAC) ... XMM/EPIC(MOS)
- Read (Leister) ... XMM/EPIC(pn)
- Plucinsky, Posson-Brown (SAO) ... Chandra/ACIS-S
- Beardmore (Leister) ... Swift/XRT
- Nataluci (INAF) ... INTEGRAL/IBIS

* Dropped instruments : Chandra/HRC, RXTE/PCA. They can rejoin any time.

Instruments

- Soft-band (<10 keV) instruments ... ACIS, EPIC, XIS, XRT (all X-ray CCDs with X-ray telescopes).
- Hard-band (>10 keV) instruments ... HXD, IBIS

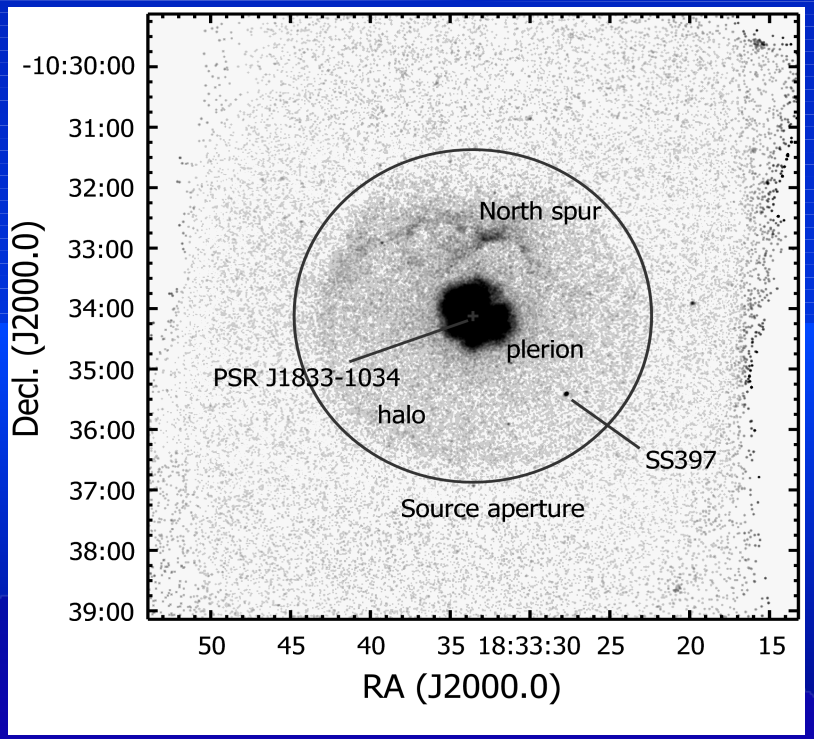
# 3. Data (2/2) Observations

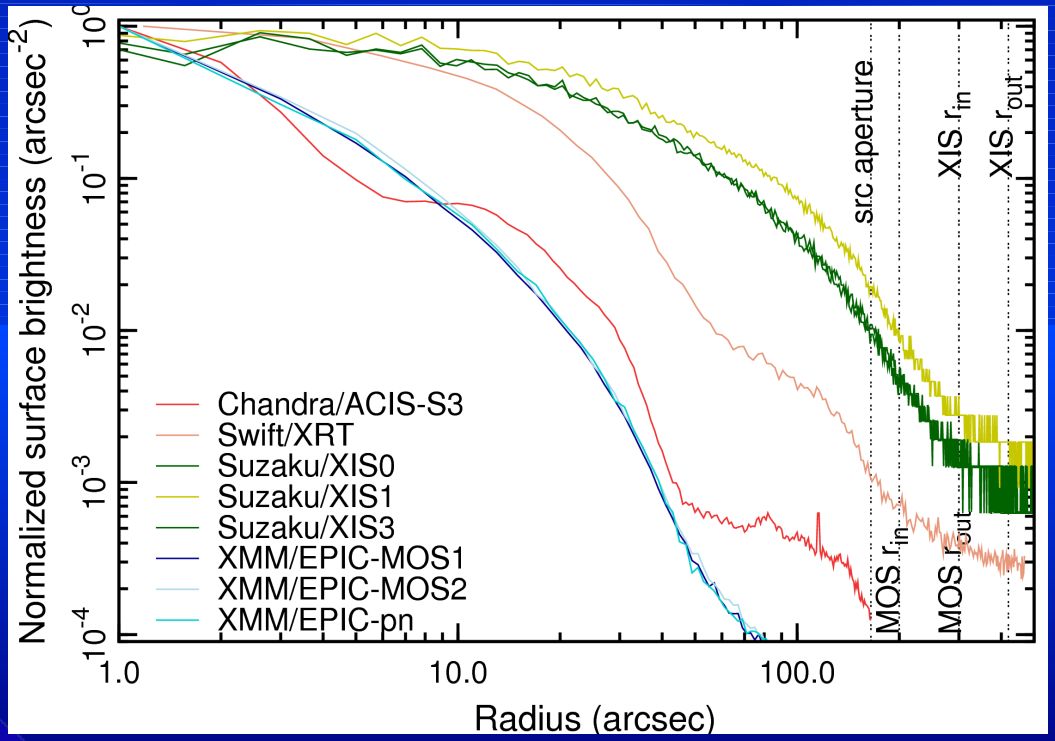
| Label | Observatory | Instrument | ObsID | Date | $t_{exp}$* (ks) | Band† (keV) | $C_{src}$‡ | $C_{bkg}$§ | Cnt‖ $bin^{-1}$ | $r_{in}$# (′) | $r_{out}$# (′) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CS0 | Chandra | ACIS-S3 | 1717 | 2000-05-23 | 7.5 | 2.0–8.0 | 28714 | 1516.1 | 50 | ... | ... |
| CS1 | | | 2873 | 2002-09-14 | 9.8 | 2.0–8.0 | 36794 | 2120.7 | 50 | ... | ... |
| CS2 | | | 3700 | 2003-11-09 | 9.5 | 2.0–8.0 | 35124 | 1887.1 | 50 | ... | ... |
| CS3 | | | 5166 | 2004-03-14 | 10 | 2.0–8.0 | 37157 | 2187.1 | 50 | ... | ... |
| CS4 | | | 5159 | 2004-10-27 | 9.8 | 2.0–8.0 | 36191 | 2459.6 | 50 | ... | ... |
| CS5 | | | 6071 | 2005-02-26 | 9.8 | 2.0–8.0 | 35369 | 1992.4 | 50 | ... | ... |
| CS6 | | | 6741 | 2006-02-22 | 9.8 | 2.0–8.0 | 36362 | 2480.2 | 50 | ... | ... |
| IS0 | INTEGRAL | ISGRI | ... | 2003–2008 | 3130 | 15–70 | $3.39\times10^{6}$ | ... | | ... | ... |
| SI0 | Suzaku | XIS0 | 104023010 | 2009-10-10 | 40 | 2.0–8.0 | 72853 | 1645.5 | 100 | 5.0 | 7.0 |
| SI1 | | XIS1 | | 2009-10-10 | 40 | 2.0–8.0 | 78974 | 2075.6 | 100 | 5.0 | 7.0 |
| SI3 | | XIS3 | | 2009-10-10 | 40 | 2.0–8.0 | 74727 | 1730.6 | 100 | 5.0 | 7.0 |
| SP0 | | PIN | | 2009-10-10 | 30 | 15–70 | 17648 | ... | 800 | ... | ... |
| SX0 | Swift | XRT | 00053600001 | 2006-08-13 | 17 | 2.0–8.0 | 13428 | 395.9 | 20 | | |
| | | | 00053600002 | 2006-08-15 | | | | | | | |
| | | | 00053601001 | 2006-08-23 | | | | | | | |
| | | | 00053601002 | 2006-08-24 | | | | | | | |
| SX1 | | | 00053600004 | 2007-05-09 | 26 | 2.0–8.0 | 18430 | 682.4 | 20 | | |
| | | | 00053600006 | 2007-05-11 | | | | | | | |
| | | | 00053600007 | 2007-05-16 | | | | | | | |
| | | | 00053600008 | 2007-05-17 | | | | | | | |
| | | | 00053600009 | 2007-05-29 | | | | | | | |
| | | | 00053600010 | 2007-05-31 | | | | | | | |
| | | | 00053600011 | 2007-07-04 | | | | | | | |
| | | | 00053600012 | 2007-06-28 | | | | | | | |
| SX2 | | | 00053600021 | 2007-10-06 | 28 | 2.0–8.0 | 20408 | 623.8 | 20 | | |
| | | | 00053600025 | 2007-10-12 | | | | | | | |
| | | | 00053600031 | 2007-10-24 | | | | | | | |
| | | | 00053600032 | 2007-10-25 | | | | | | | |
| SX3 | | | 00053600033 | 2009-10-16 | 27 | 2.0–8.0 | 18849 | 608.7 | 20 | | |
| | | | 00053600034 | 2009-10-18 | | | | | | | |
| XM1 | XMM | MOS1 | 0122700101 | 2000-04-07 | 29 | 2.0–8.0 | 86213 | 4371 | 200 | 3.3 | 5.0 |
| XM2 | | MOS2 | | 2000-04-07 | 29 | 2.0–8.0 | 83345 | 4380 | 200 | 3.3 | 5.0 |
| XP0 | | pn | | 2000-04-07 | 24 | 2.0–8.0 | 186175 | 12587 | 200 | | |

* Net exposure time after cleaning the events

# 4. Analysis (1/2) Extraction

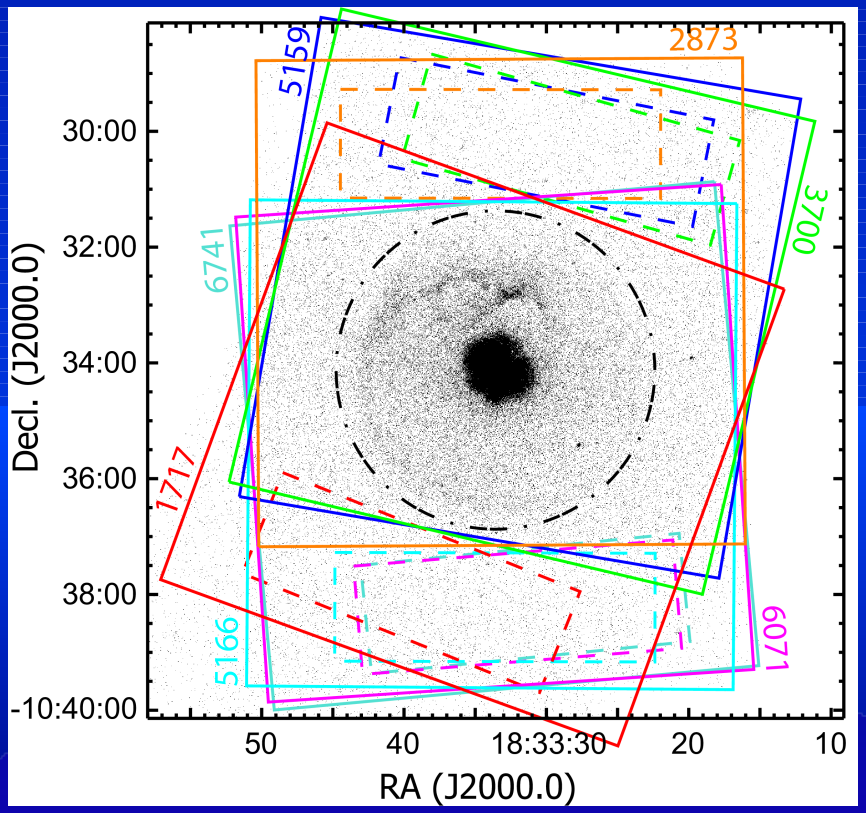
- Source extraction from a 165” circle (soft-band instr.)
  - To encompass all the spatial structure of G21.5-0.9.
  - To fit in one CCD.
  - To leave a room for background.

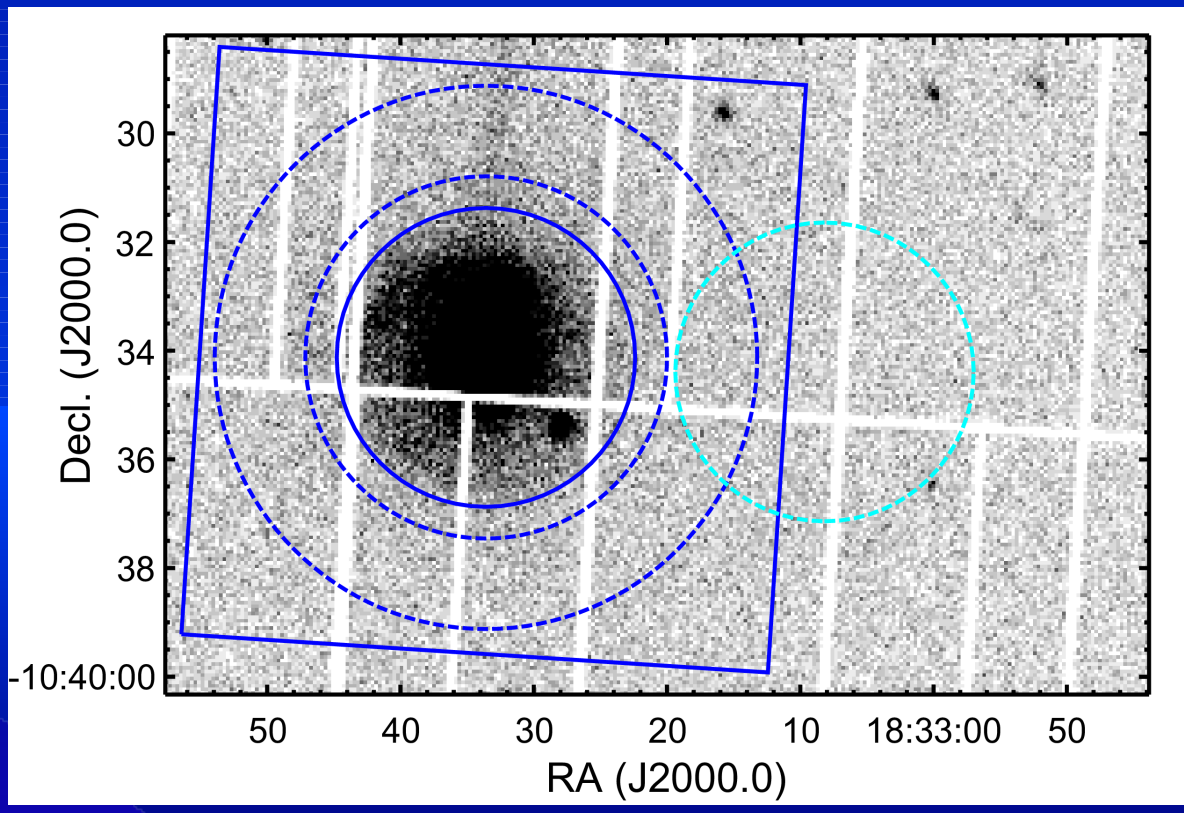


# 4. Analysis (1/2) Extraction

- Background extraction (soft-band instr.).
  - Annulus ... XIS (5'-7'), XRT (?-?), MOS (200”-300”)
  - Others ... ACIS-S3, EPIC (pn)



# 4. Analysis (2/2) Fitting

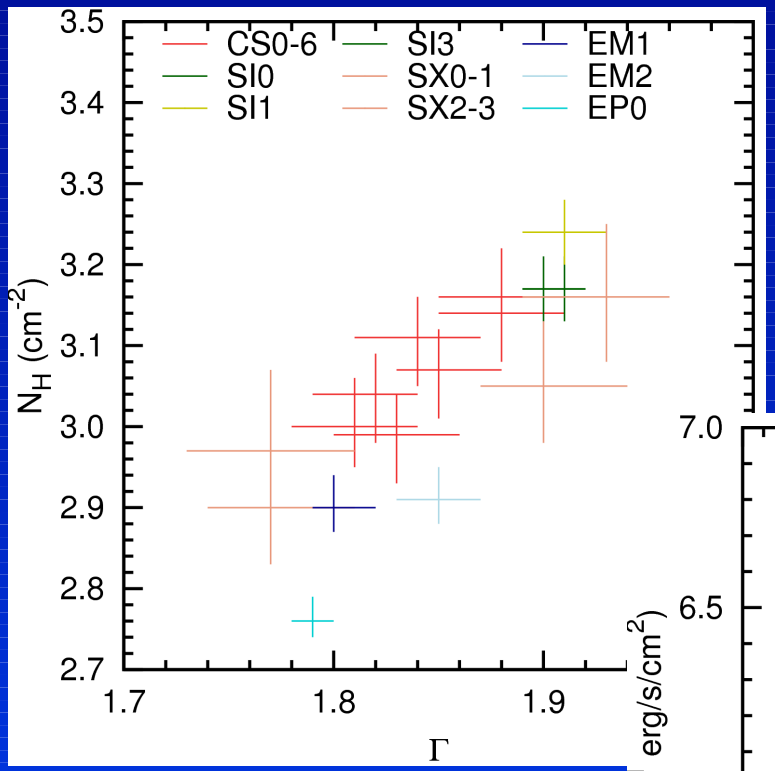
- Model : tbabs*pegpwrlw.
- Photoelectric absorption cross section : Verner et al. 1996.
- Abundance : Wilms et al. 2000.
- Energy band : 2-8 keV.
- Parameters
  - Soft-band instr.: NH, G, Fx (2-8 keV).
  - Hard-band instr.: G, Fx (15-70 keV). NH=$3.2 \times 10^{22}/cm^2$
- No known correction factor for normalization applied.

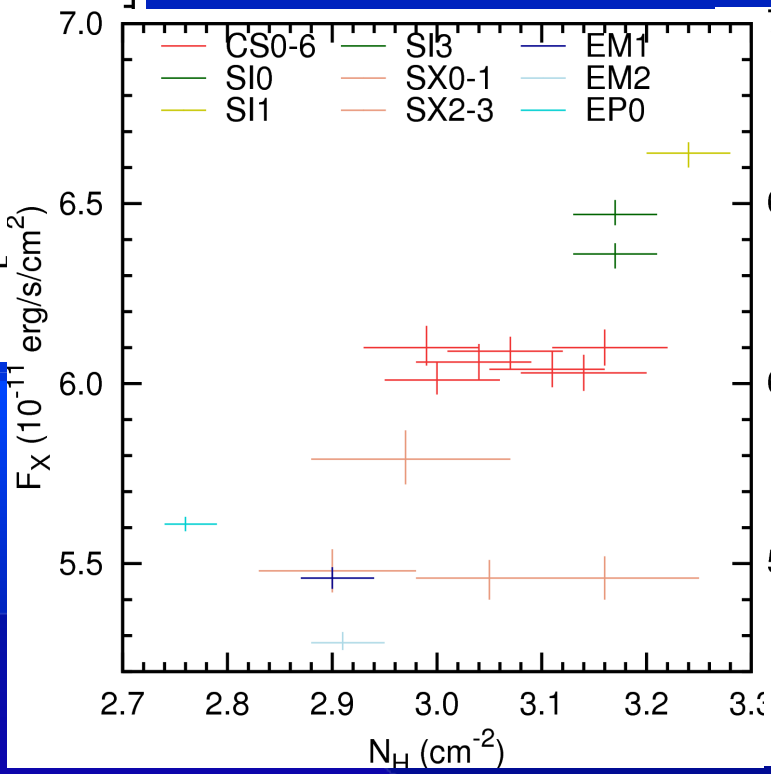
- Xspec used. The traditional chi-square minimization approach adopted.

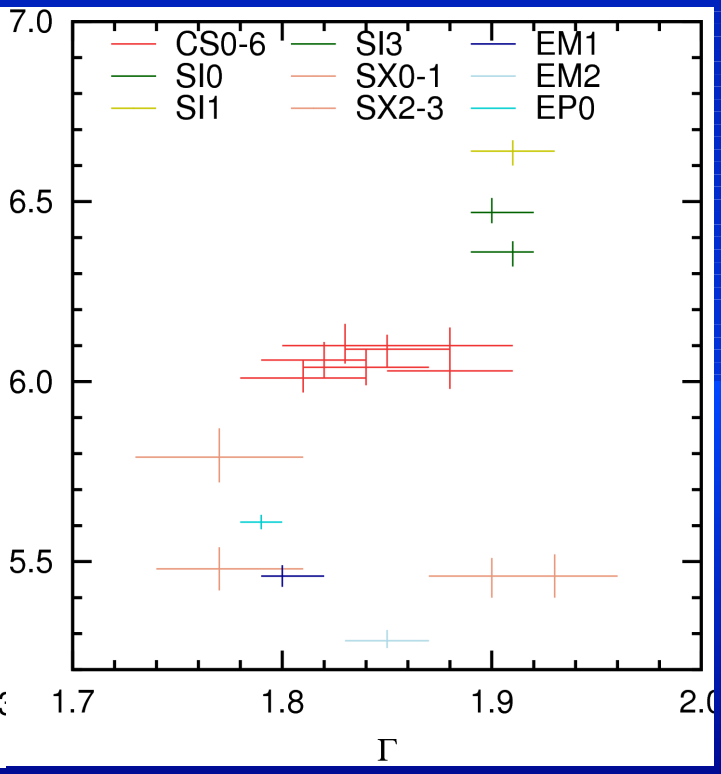
# 5. Results (1/7) Comparison I

| Label | $N_{\rm H}$[2]* ($10^{22}$ cm$^{-2}$) | $\Gamma$[3]† | $F_{\rm X,soft}$[4]‡ ($10^{-11}$ ergs s$^{-1}$ cm$^{-2}$) | $F_{\rm X,hard}$[5]§ | Red-$\chi^2$ /d.o.f. |
|---|---|---|---|---|---|
| Chandra/ACIS-S3 | | | | | |
| CS0 | 2.99 (2.93–3.04) | 1.83 (1.80–1.86) | 6.10 (6.05–6.16) | ... | 0.93/ 302 |
| CS1 | 3.07 (3.01–3.12) | 1.85 (1.83–1.88) | 6.09 (6.04–6.13) | ... | 0.90/ 326 |
| CS2 | 3.04 (2.98–3.09) | 1.82 (1.79–1.84) | 6.06 (6.01–6.11) | ... | 1.04/ 325 |
| CS3 | 3.11 (3.05–3.16) | 1.84 (1.81–1.87) | 6.04 (5.99–6.09) | ... | 0.89/ 327 |
| CS4 | 3.16 (3.11–3.22) | 1.88 (1.85–1.91) | 6.10 (6.05–6.15) | ... | 1.03/ 330 |
| CS5 | 3.00 (2.95–3.06) | 1.81 (1.78–1.84) | 6.01 (5.97–6.06) | ... | 1.06/ 327 |
| CS6 | 3.14 (3.08–3.20) | 1.88 (1.85–1.91) | 6.03 (5.98–6.08) | ... | 1.07/ 326 |
| CS0–6 | 3.07 (3.05–3.09) | 1.84 (1.83–1.85) | 6.06 (6.04–6.08) | ... | 0.99/2281 |
| INTEGRAL/IBIS-ISGRI | | | | | |
| IS0 | 3.20 | 2.18 (2.09–2.26) | ... | 4.25 (4.12–4.38) | 1.72/ 7 |
| Suzaku/XIS and HXD-PIN | | | | | |
| SI0 | 3.17 (3.13–3.21) | 1.91 (1.89–1.92) | 6.36 (6.32–6.39) | ... | 1.10/ 565 |
| SI1 | 3.24 (3.20–3.28) | 1.91 (1.89–1.93) | 6.64 (6.60–6.67) | ... | 1.04/ 569 |
| SI3 | 3.17 (3.13–3.21) | 1.90 (1.89–1.92) | 6.47 (6.44–6.51) | ... | 0.94/ 582 |
| SI0–3 | 3.20 (3.18–3.22) | 1.91 (1.90–1.92) | 6.38 (6.35–6.41) | ... | 1.03/1720 |
| SP0 | 3.20 | 2.28 (2.14–2.42) | ... | 6.10 (5.79–6.42) | 1.40/ 12 |
| SI0–3+SP0 | 3.20 (3.18–3.22) | 1.91 (1.90–1.92) | 6.38 (6.36–6.41) | | 1.03/1733 |
| Swift/XRT | | | | | |
| SX0 | 2.97 (2.88–3.07) | 1.77 (1.73–1.81) | 5.79 (5.72–5.87) | ... | 0.99/ 421 |
| SX1 | 2.90 (2.83–2.98) | 1.77 (1.74–1.81) | 5.48 (5.42–5.54) | ... | 1.03/ 479 |
| SX2 | 3.05 (2.98–3.13) | 1.90 (1.87–1.94) | 5.46 (5.40–5.51) | ... | 1.07/ 488 |
| SX3 | 3.16 (3.08–3.25) | 1.93 (1.89–1.96) | 5.46 (5.40–5.52) | ... | 1.14/ 478 |
| SX0+1 | 2.93 (2.87–2.99) | 1.77 (1.75–1.80) | 5.61 (5.56–5.65) | ... | 1.02/ 903 |
| SX2+3 | 3.10 (3.05–3.16) | 1.91 (1.89–1.94) | 5.46 (5.41–5.50) | ... | 1.11/ 969 |
| XMM-Newton/EPIC | | | | | |
| EM1 | 2.90 (2.87–2.94) | 1.80 (1.79–1.82) | 5.46 (5.43–5.49) | ... | 1.11/ 276 |
| EM2 | 2.91 (2.88–2.95) | 1.85 (1.83–1.87) | 5.28 (5.26–5.31) | ... | 1.07/ 274 |
| EP0 | 2.76 (2.74–2.79) | 1.79 (1.78–1.80) | 5.61 (5.59–5.63) | ... | 1.10/ 655 |
| All | 2.84 (2.82–2.86) | 1.81 (1.80–1.81) | 5.38 (5.36–5.40) | ... | 1.13/1209 |

# 5. Results (2/7) Comparison II

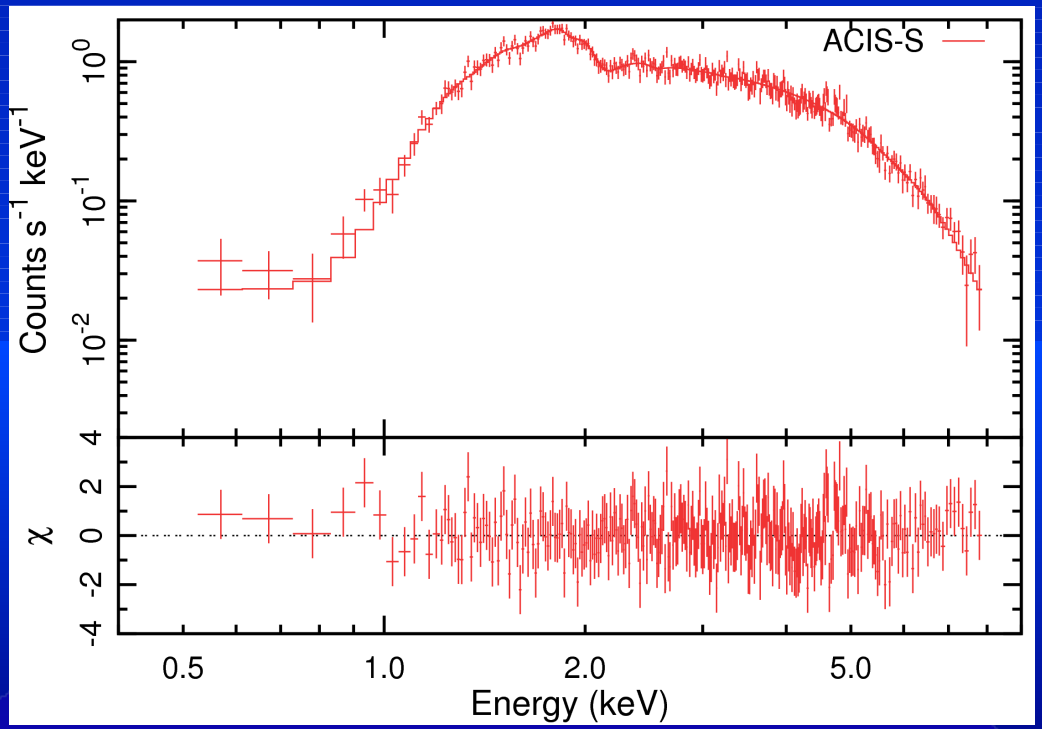


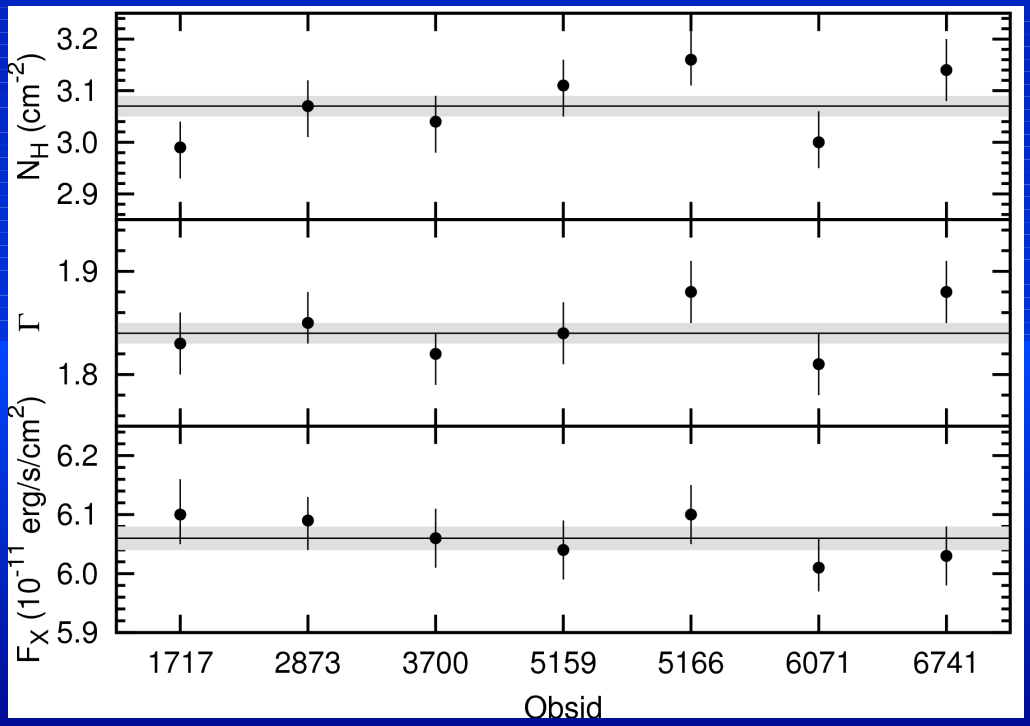



# 5. Results (3/7) Chandra/ACIS

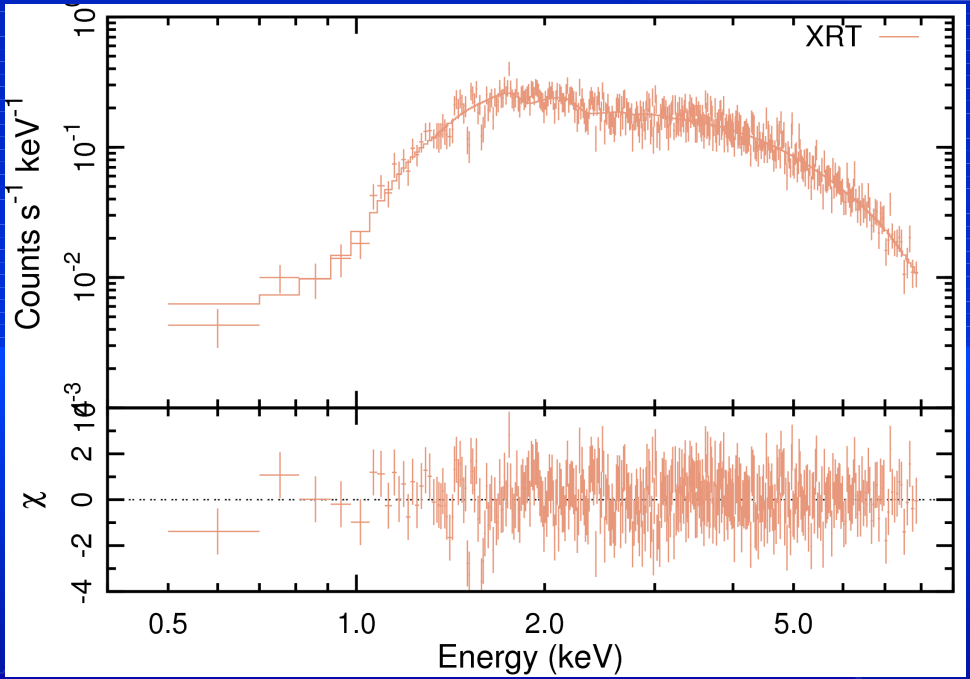
- Inhomogeneity of data set (different epochs, different off-axis positions).

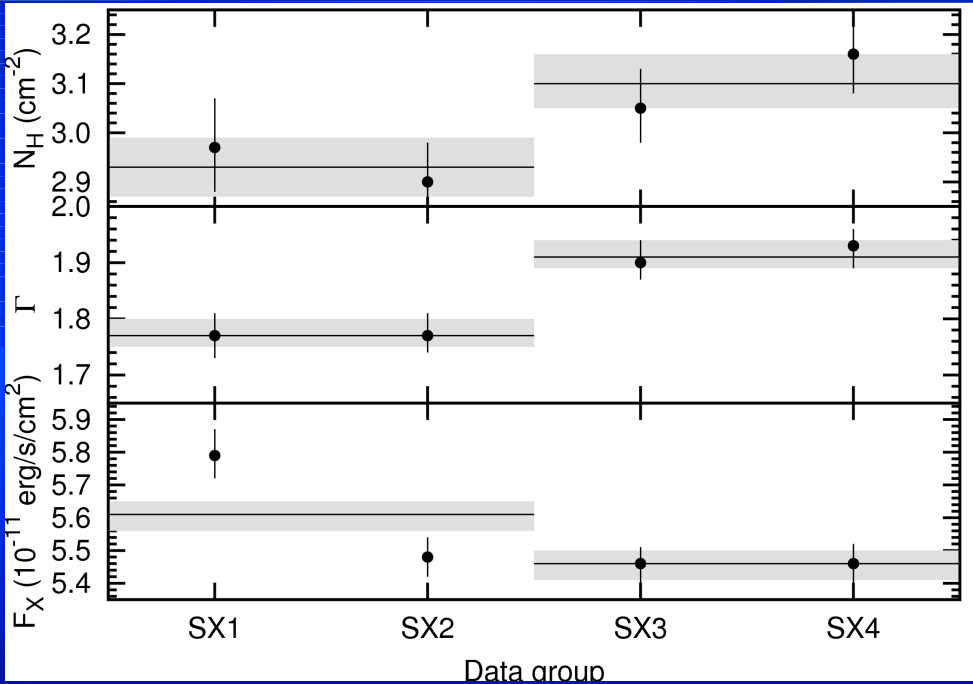


# 5. Results (4/7) Swift/XRT

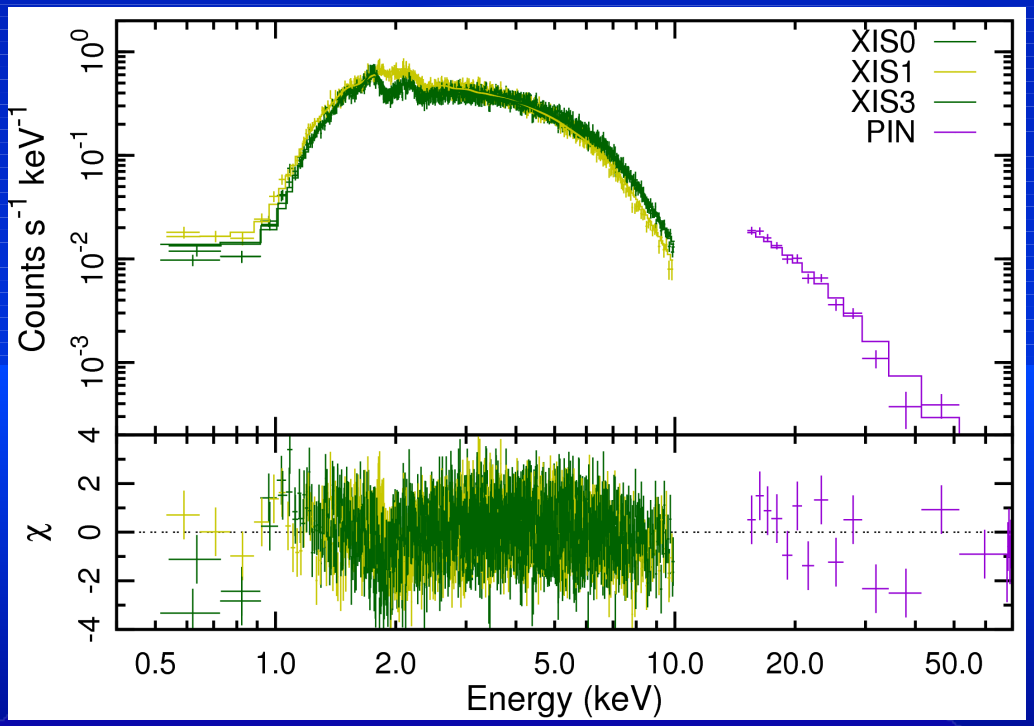
- Inhomogeneity of data set (different epochs).
- RMF change with substrate voltage change.

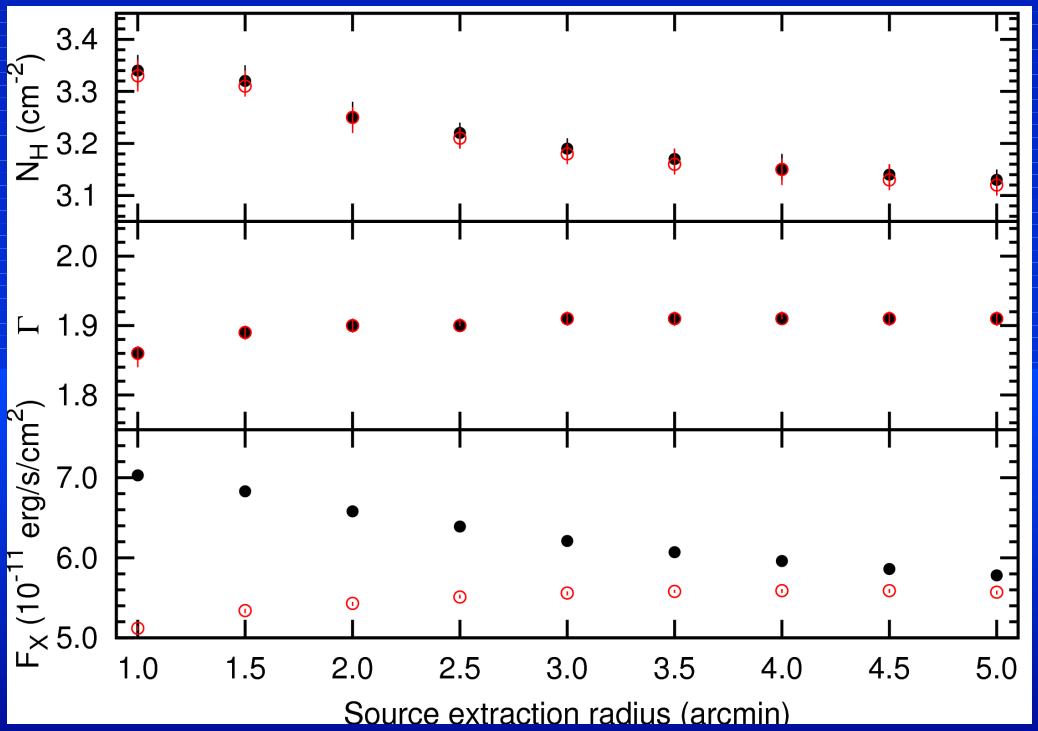


# 5. Results (5/7) Suzaku/XIS

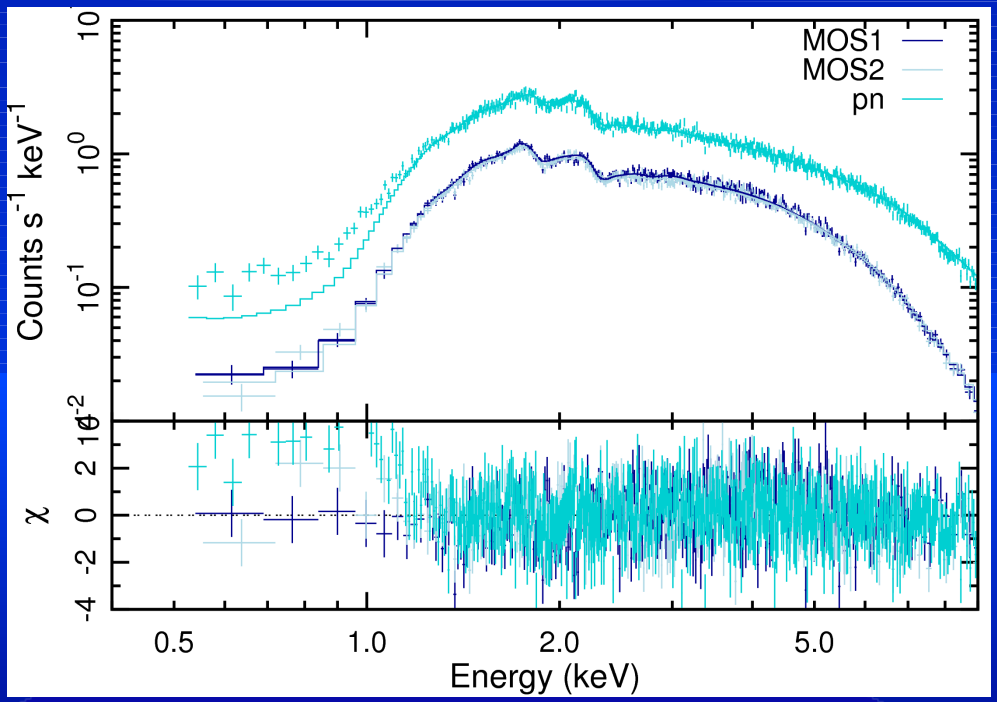
- Flux recovery from outside of the source extraction region by software simulation.

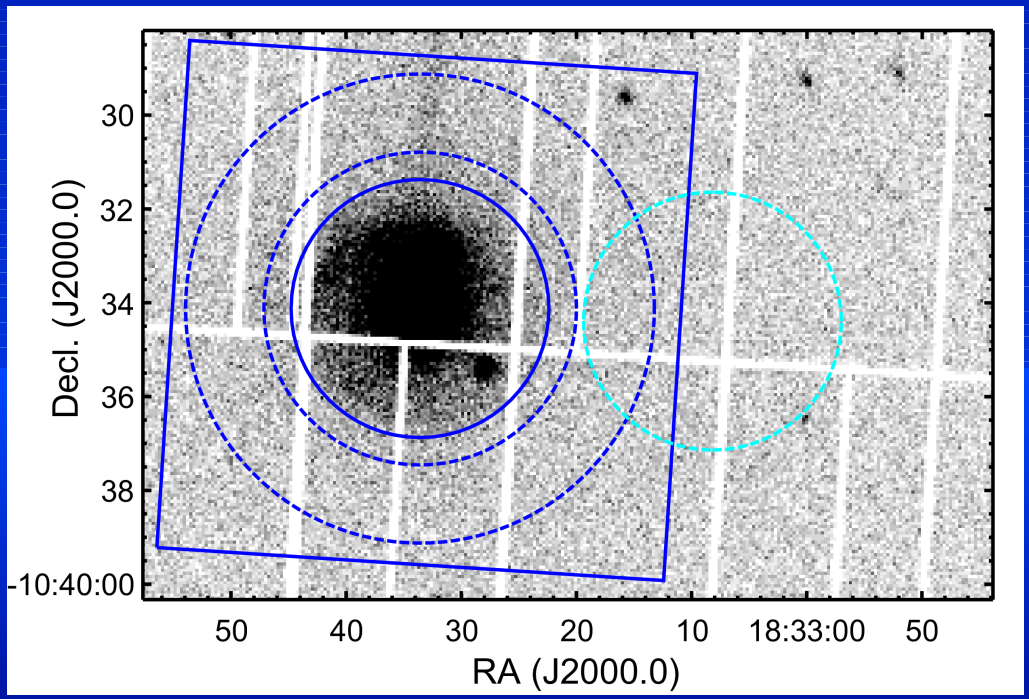


# 5. Results (6/7) XMM/EPIC

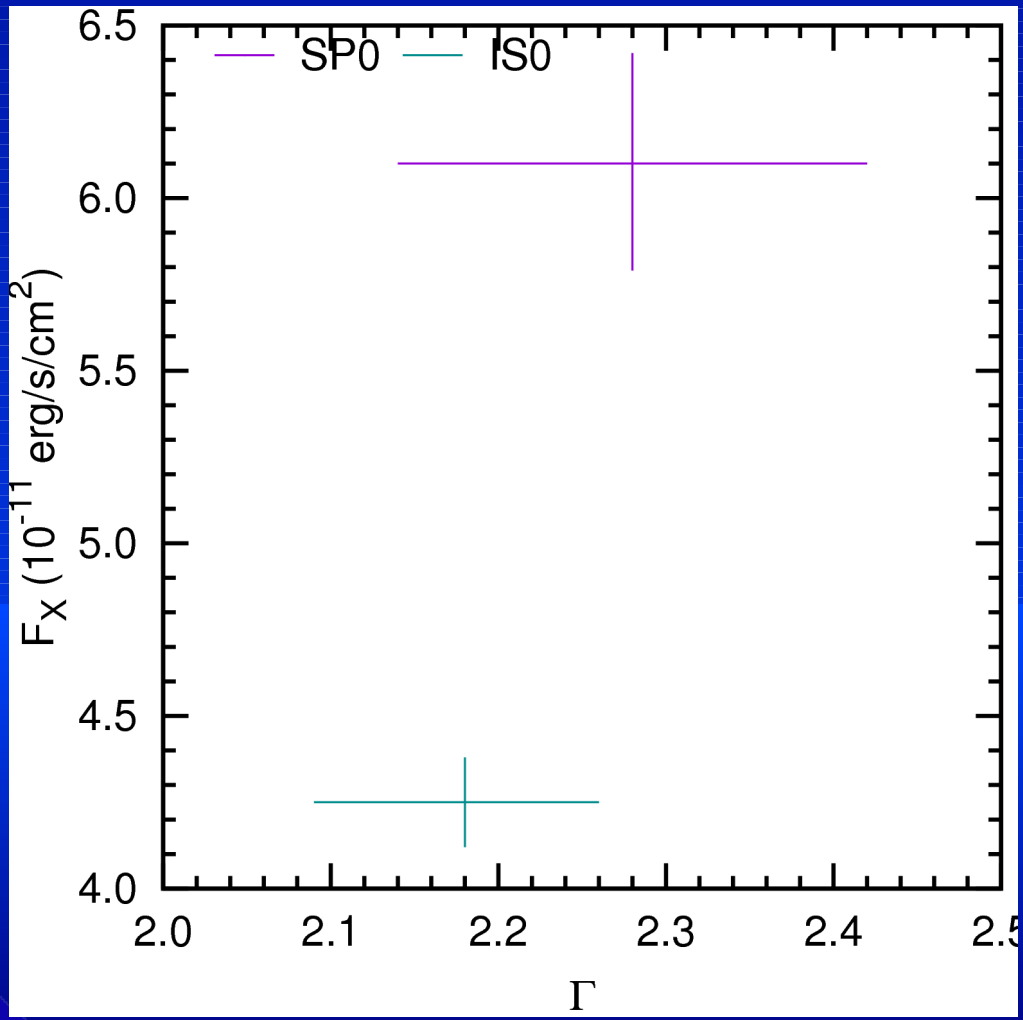
- Background subtraction (pn).
- Low-energy tail of LSF.



# 5. Results (7/7) PIN vs IBIS

- Inconsistency of Fx.



# 6. Summary

- Analysis done, comparison made, paper drafted.
- Some inconsistencies remain.

**Cross-calibration of the X-ray Instruments onboard the Chandra, INTEGRAL, Suzaku, Swift, and XMM-Newton Observatories using G21.5–0.9**

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- I ask:
  - Co-authors to read the draft, list possible causes for the inconsistencies, and reexamine the numbers.
  - IACHEC colleagues if the inconsistencies found in Gw21.5-0.9 are in line with their understanding with their instruments and IACHEC targets.