IACHEC

International Astrophysical Consortium for High Energy Calibration

X-calibration of NuSTAR and Swift

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Cross-calibration: Normal operations

- Require as stable target or strict simultaneity
  - Stable source are extended and faint
- The goldilocks source: 3C 273
  - Hard spectrum:
    - Not too bright for soft instruments
    - Bright enough for hard instruments
  - Fairly stable
    - Low Earth Orbit observatories can't always be simultaneous
  - Fairly featureless
    - Between 1 – 20 keV a power-law
    - Below soft excess
    - Above curvature

Cross normalization

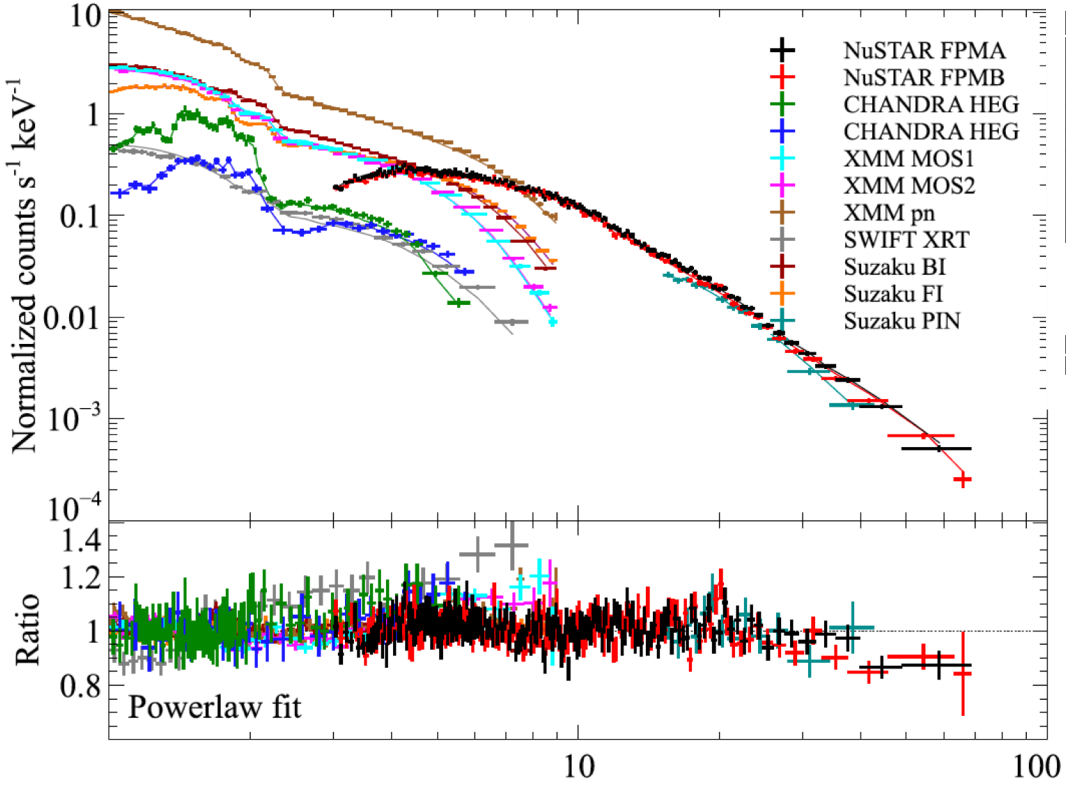


TABLE 5
CROSS NORMALIZATION CONSTANTS (1-5 KEV)

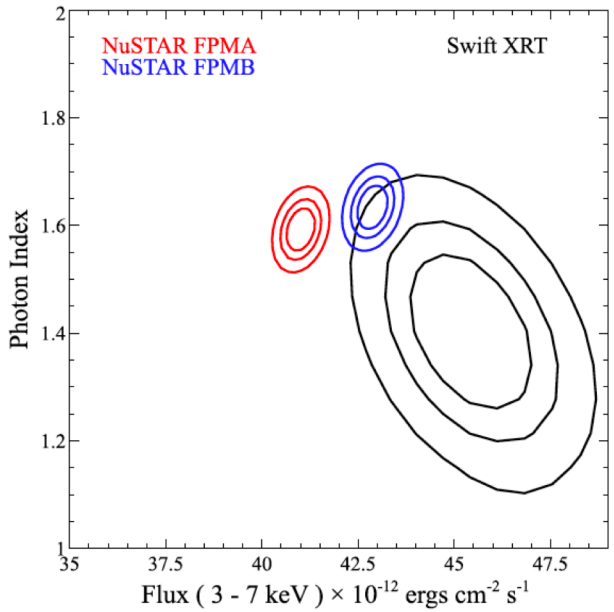
Top/Bottom	LETGS	HETGS	XIS0	XIS1	XIS3	XRT	MOS1	MOS2	pn
LETGS	1	-	0.87(2)	0.90(1)	0.91(2)	0.89(2)	0.89(1)	0.89(1)	0.85(1)
HETGS	-	1	0.93(1)	0.90(1)	0.91(1)	0.93(3)	0.93(1)	0.94(1)	0.85(0)
XIS0	1.15(2)	1.08(1)	1	0.96(3) – 0.97(1)	0.99(1) – 1.04(3)	1.02(2) – 1.03(2)	1.01(1) – 1.01(1)	1.01(1) – 1.02(1)	0.93(1) – 0.97(1)
XIS1	1.11(2)	1.08(1)	1.03(1) – 1.04(3)	1	1.03(1) – 1.08(3)	0.99(1) – 1.05(2)	0.99(0) – 1.03(1)	0.99(1) – 1.04(1)	0.95(1) – 0.95(0)
XIS3	1.10(2)	1.08(1)	0.96(3) – 1.01(1)	0.92(3) – 0.98(1)	1	0.99(1) – 1.04(2)	0.99(0) – 1.02(1)	0.99(1) – 1.03(1)	0.94(1) – 0.95(0)
XRT	1.12(3)	1.08(4)	0.97(2) – 0.98(1)	0.95(2) – 1.01(1)	0.96(2) – 1.01(1)	1	1.00(3) – 1.03(1)	1.01(3) – 1.03(1)	0.92(3) – 0.98(1)
MOS1	1.12(1)	1.08(1)	0.99(1) – 0.99(0)	0.97(1) – 1.01(0)	0.98(1) – 1.01(0)	0.97(1) – 1.00(3)	1	0.96(2) – 1.00(2)	0.86(1) – 0.89(2)
MOS2	1.12(1)	1.07(1)	0.98(1) – 0.99(1)	0.96(1) – 1.01(1)	0.97(1) – 1.01(1)	0.97(1) – 0.99(3)	1.00(2) – 1.05(3)	1	0.86(1) – 0.93(2)
pn	1.18(1)	1.17(1)	1.03(1) – 1.07(1)	1.05(1) – 1.06(1)	1.06(1) – 1.07(1)	1.02(1) – 1.09(4)	1.12(3) – 1.17(2)	1.07(2) – 1.17(2)	1

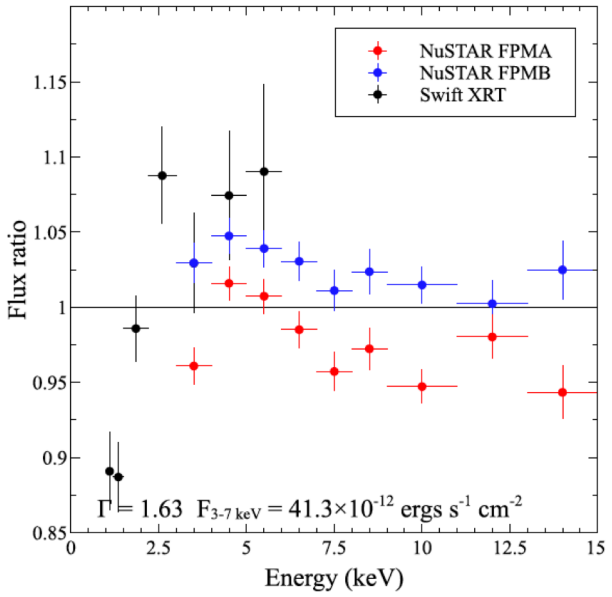
Note - cross-normalization constants from Table 3 and 4. Where a range is given the instrument observed both sources, and the range are directly the lower and higher ratio.

TABLE 6
CROSS NORMALIZATION CONSTANTS (3-7 KEV & 20-40 KEV)

Top/Bottom	LETGS	HETGS	FPMA&FPMB	XIS0	XIS1	XIS3	HXD[a]	XRT	MOS1	MOS2	pn
FPMA & FPMB	1.09(3)	1.10(7)	1	0.91(4) – 0.97(1)	0.87(4) – 0.94(1)	0.95(4) – 0.97(1)	1.12(6)	1.01(7) – 1.08(4)	1.01(5) – 1.03(2)	0.97(4) – 1.03(2)	0.88(2) – 0.90(4)

Note - cross-normalization constants from Table 3 and 4. Where a range is given the instrument observed both sources, and the range are directly the lower and higher ratio.
[a]Energy range: 20-40 keV





WT "Good fit" v. Not a "good fit"

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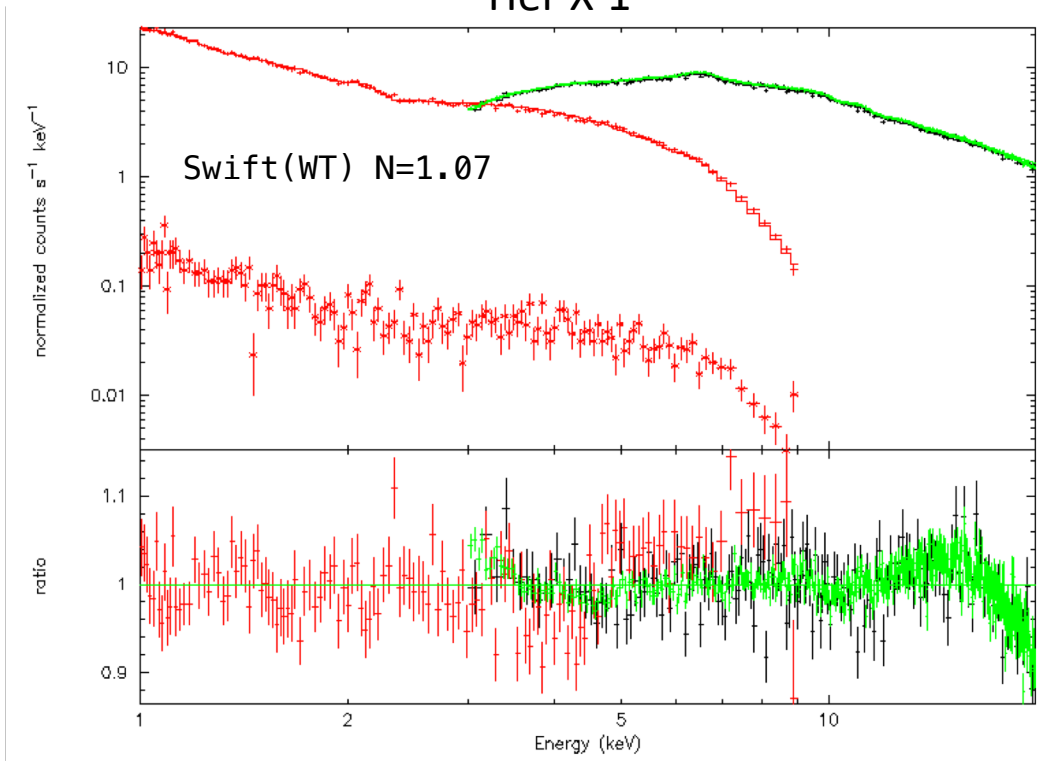
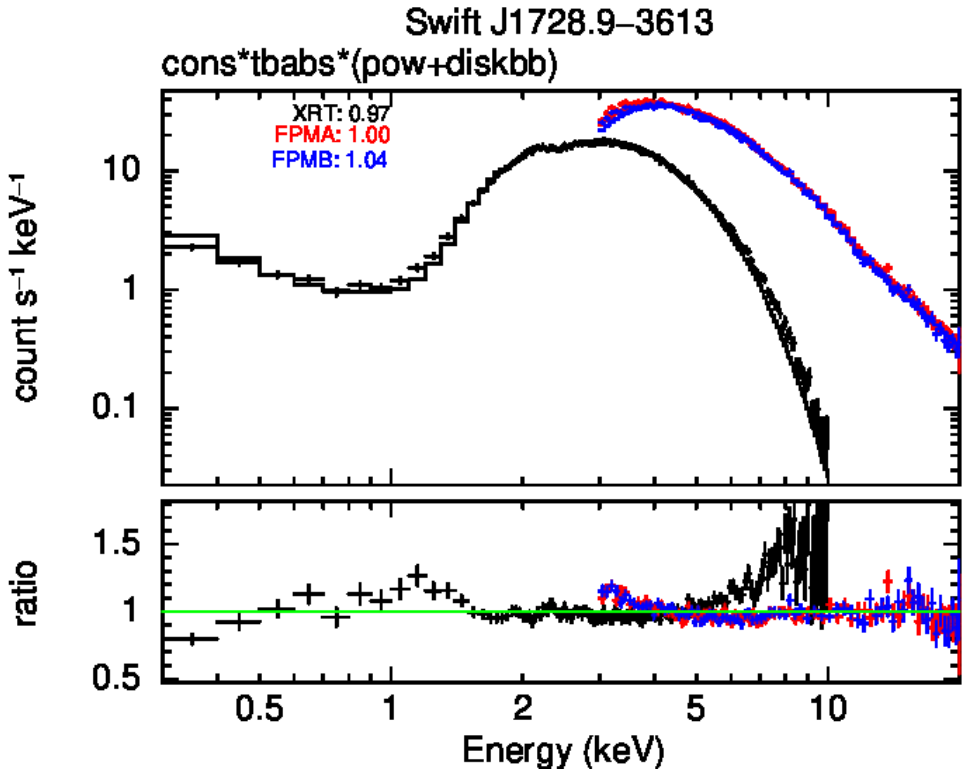
FPMA & FPMB	1.09(3)	1.10(7)	1	0.91(4) – 0.97(1)	0.87(4) – 0.94(1)	0.95(4) – 0.97(1)	1.12(6)	1.01(7) – 1.08(4)	1.01(5) – 1.03(2)	0.97(4) – 1.03(2)	0.88(2) – 0.90(4)

Note - cross-normalization constants from Table 3 and 4. Where a range is given the instrument observed both sources, and the range are directly the lower and higher ratio.
[a]Energy range: 20-40 keV

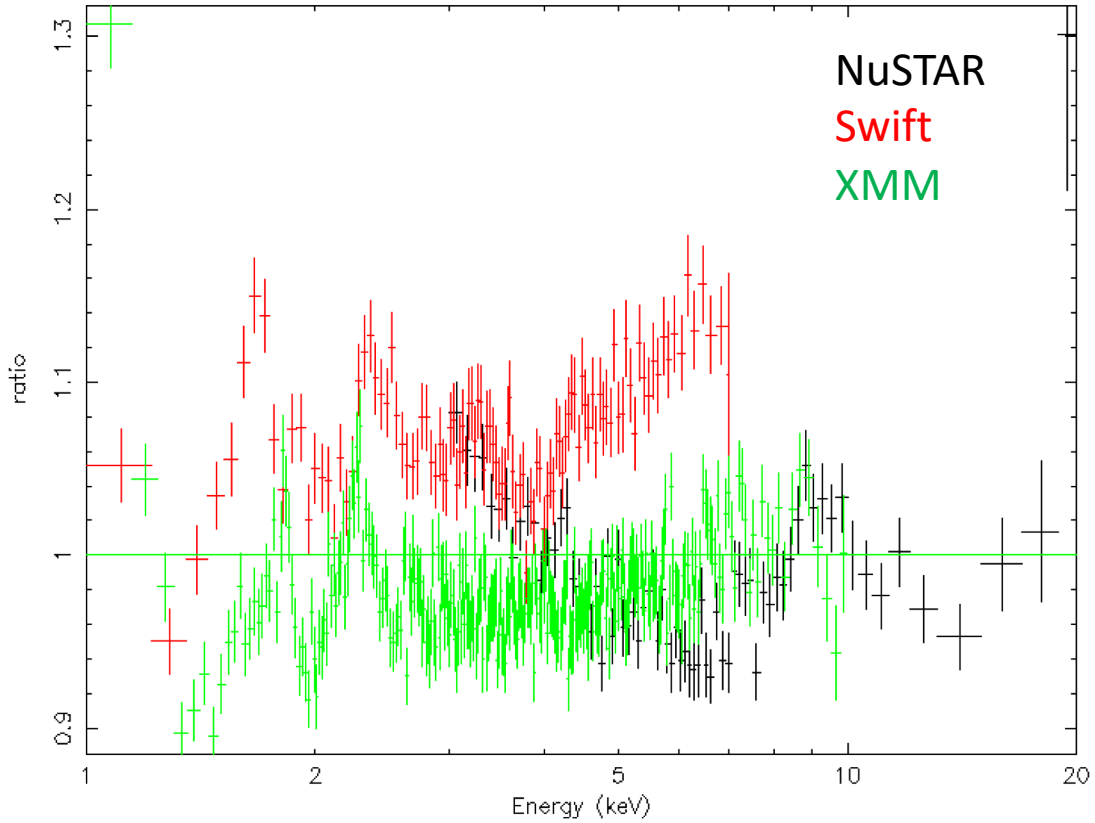
Her X-1





Cross calibration: The issue

- Relevant for galactic high NH sources taken with
  - NuSTAR
  - Swift WT mode
  - Nicer
  - XMM
    - piled up sources
    - timing mode
    - Pn burst mode



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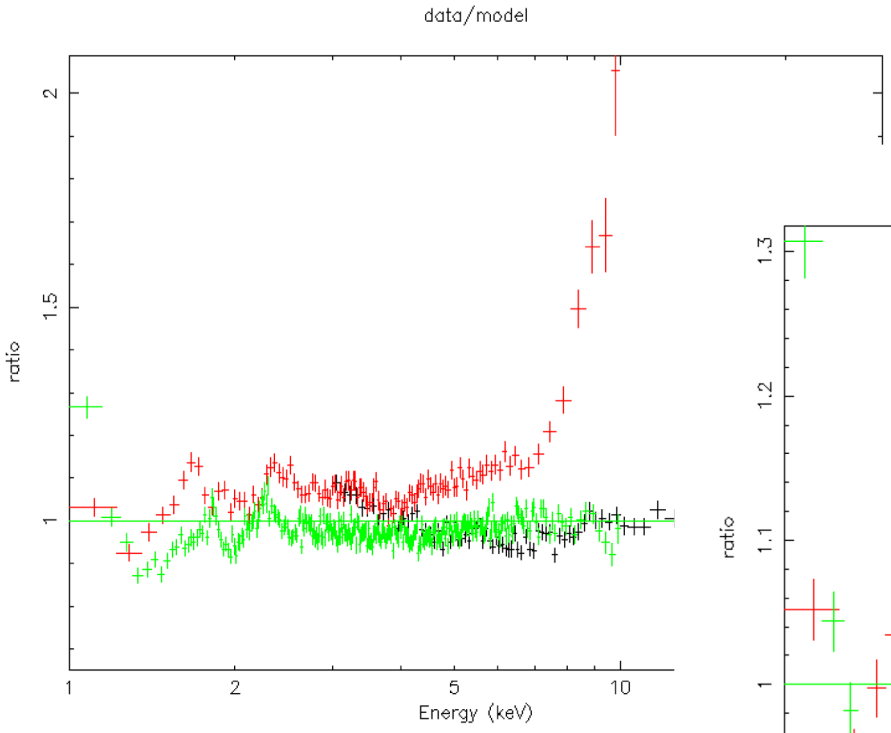
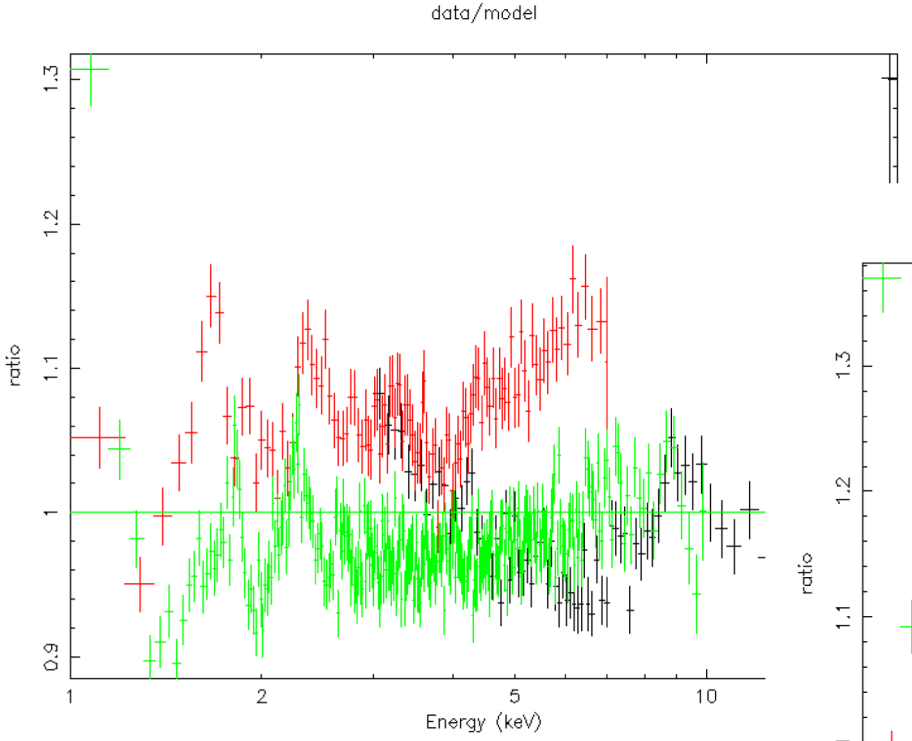
Typical Analysis Cycle

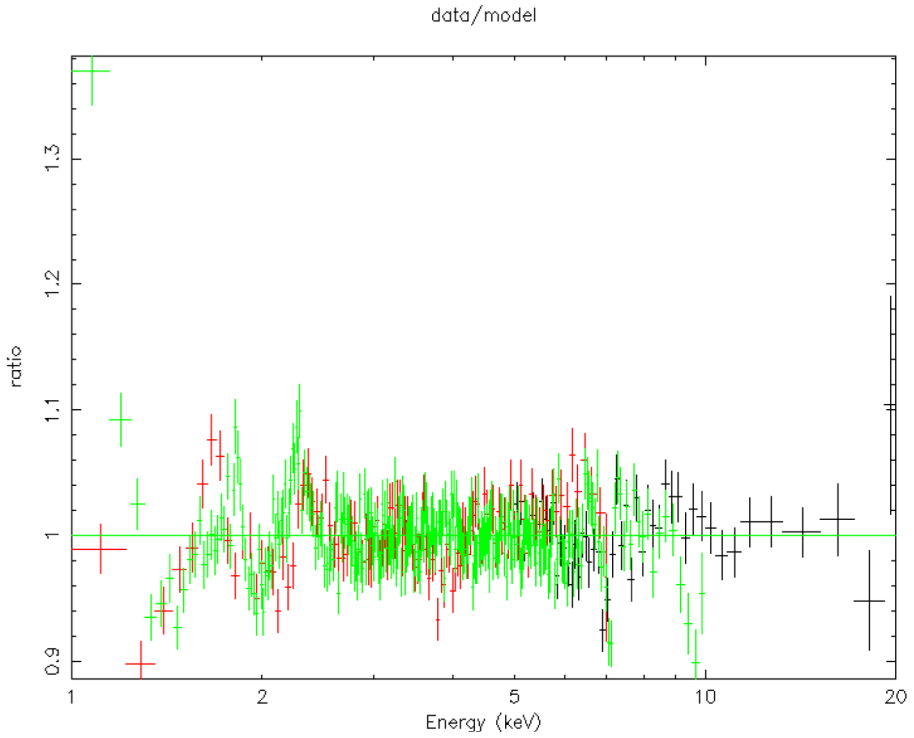


Ignore NuSTAR above 20 keV
Ignore Swift above 7 keV



Ignore NuSTAR between 3 - 5 keV

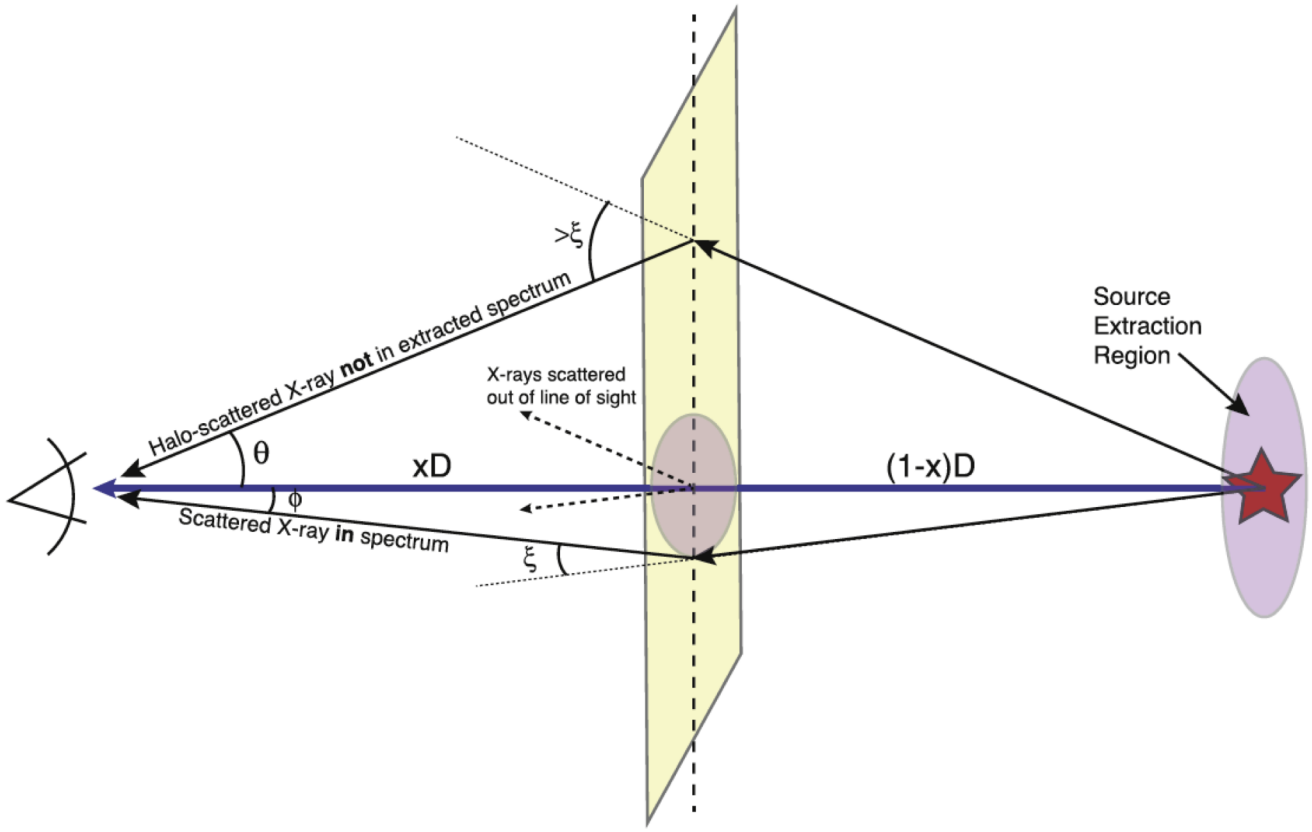
Nustar = 0.95
Swift = 1.09
Xmm= 0.99

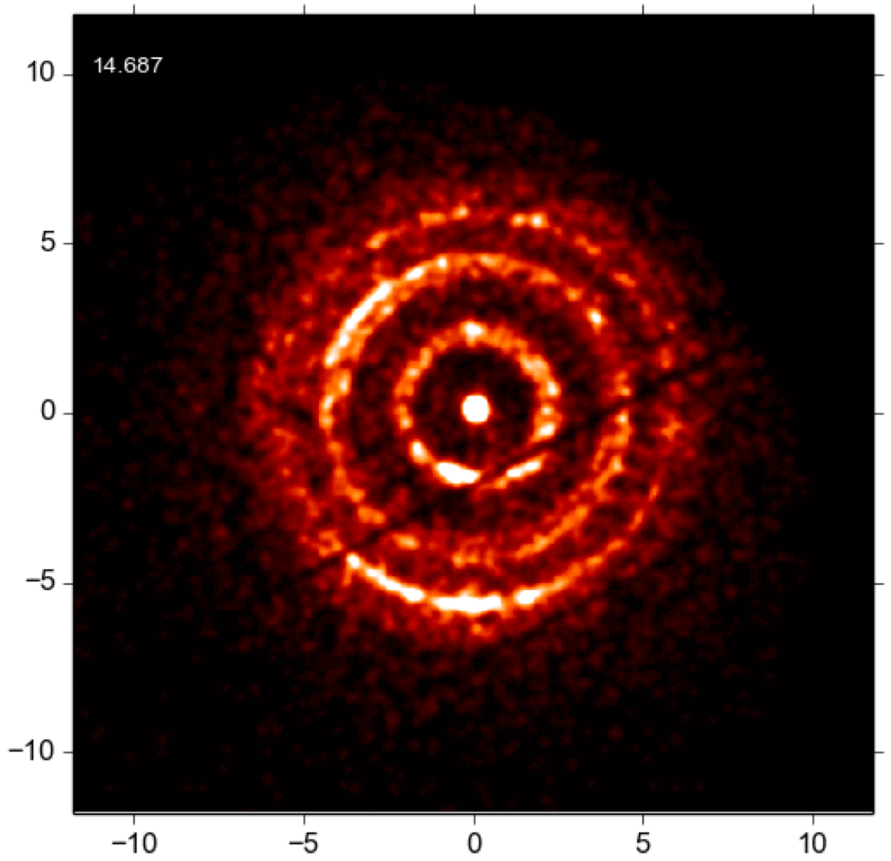


Is it the right thing to do?

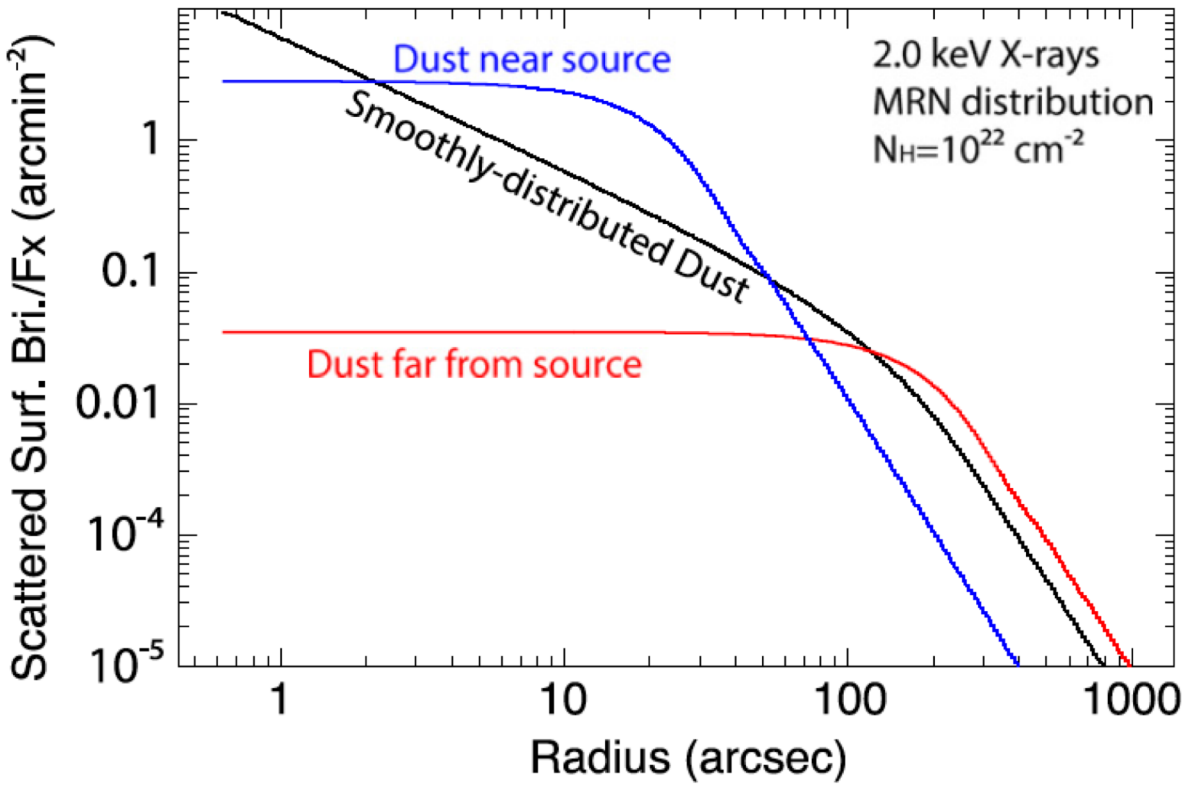
- We all do it (me too… sometimes)
- We prune until the fit statistic is good because reviewers will otherwise question the result
- But
  - We do not know WHICH instrument is right
  - Pruning and chopping off parts of the spectrum will give you a “result”, but not necessarily the right one
  - We attempt to compare apples to apples, but we are really dealing with apples and oranges…

Dust scattering

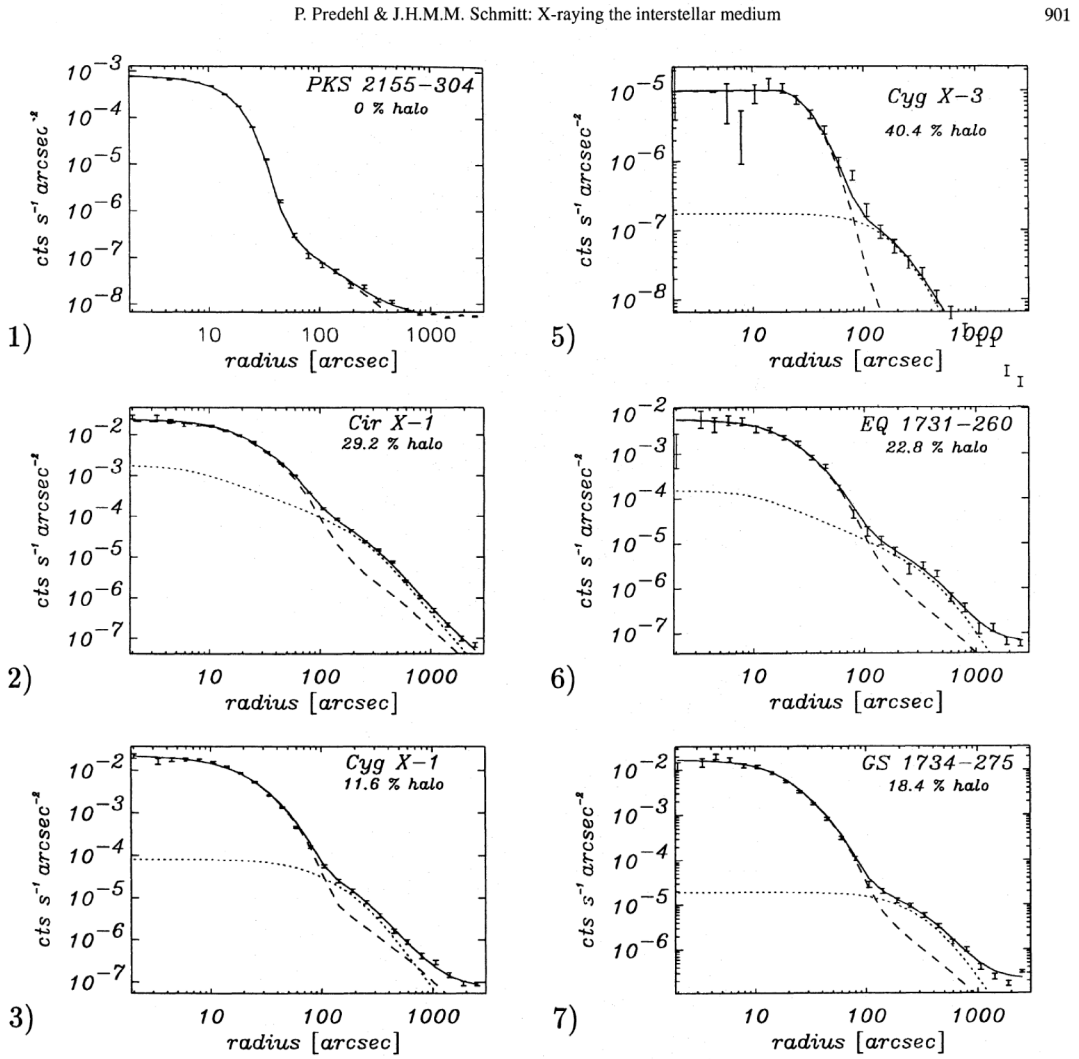




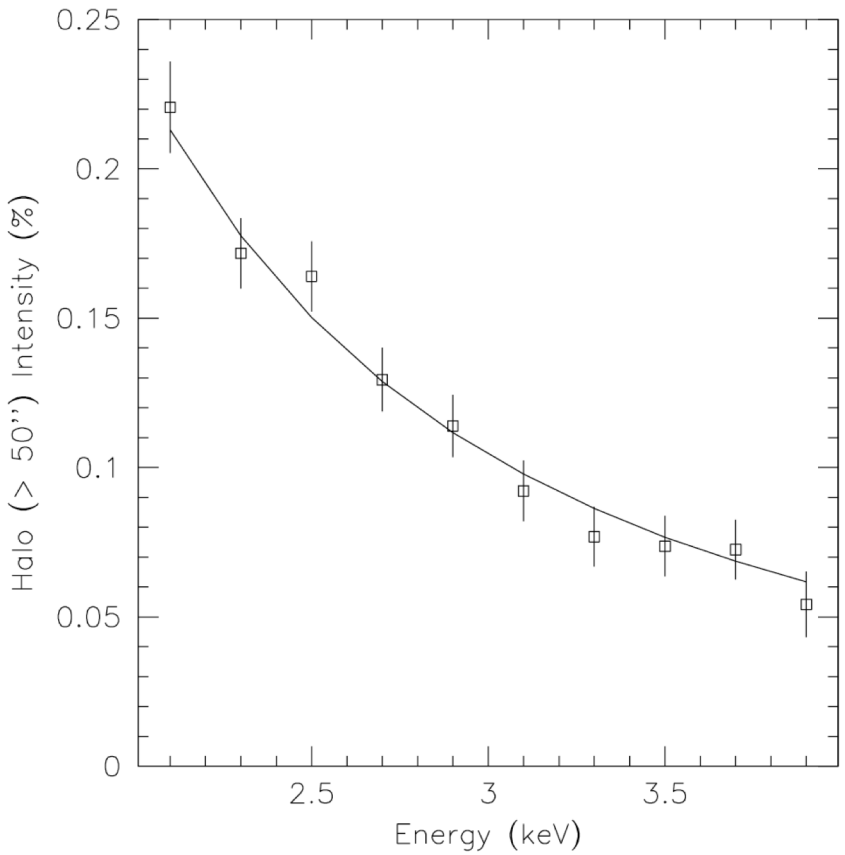
Radial profiles



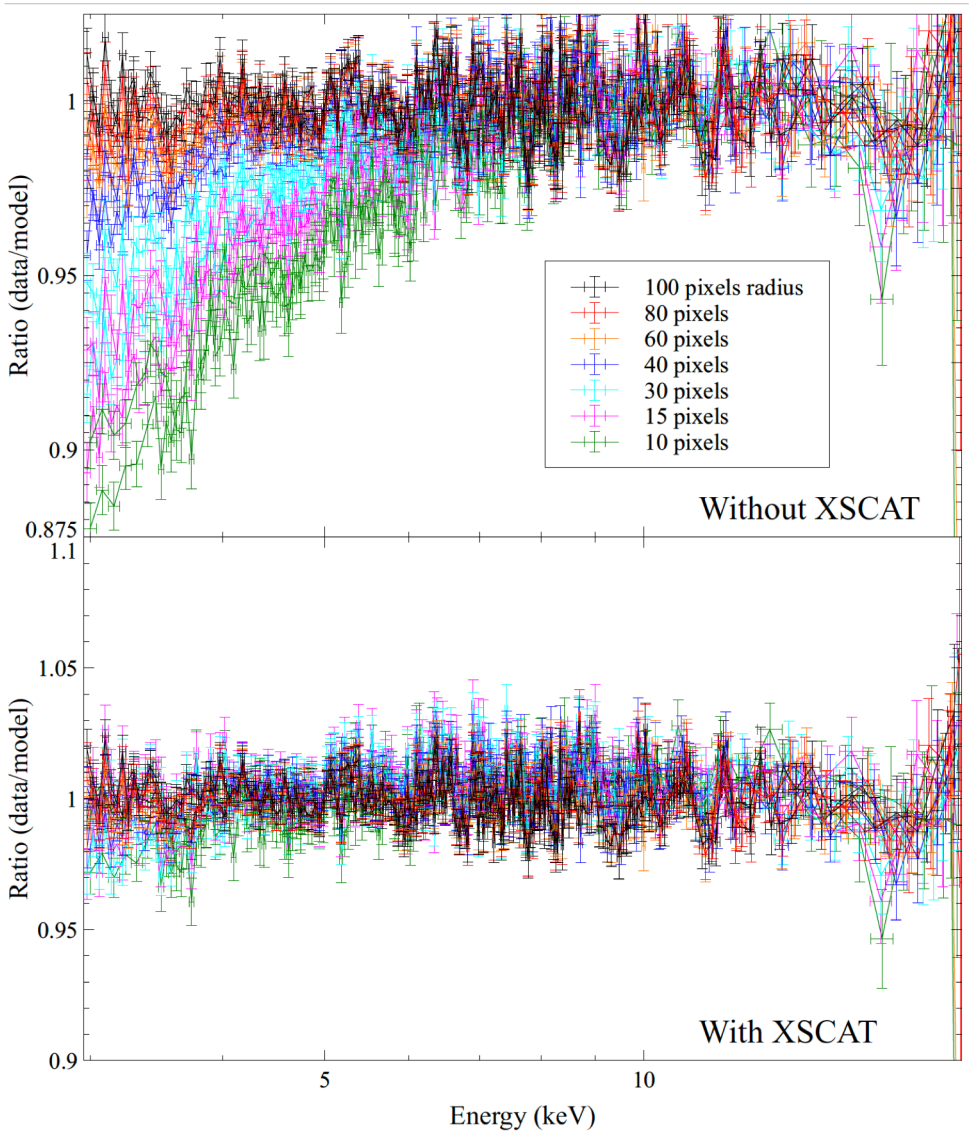
Valencic and Smith, 2015, ApJ, 809



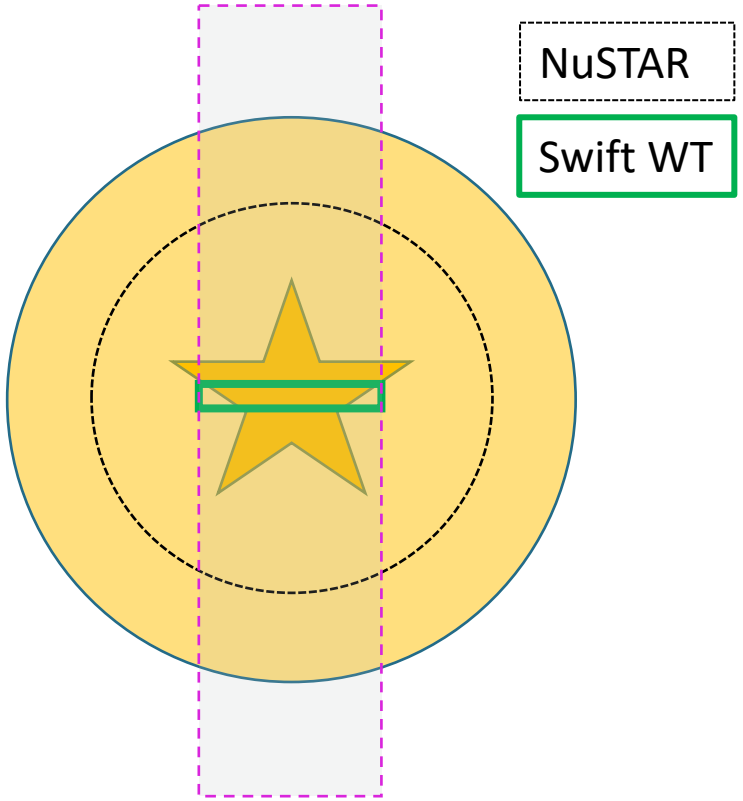
Energy dependency



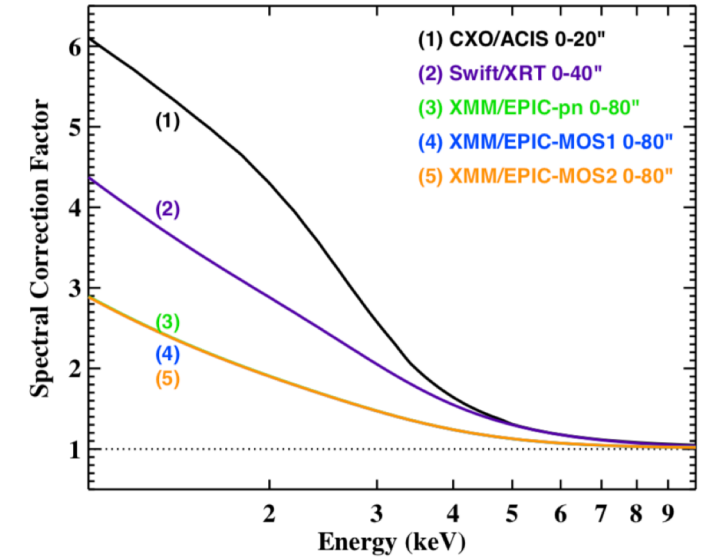
Smith et al, 2002, ApJ, 581

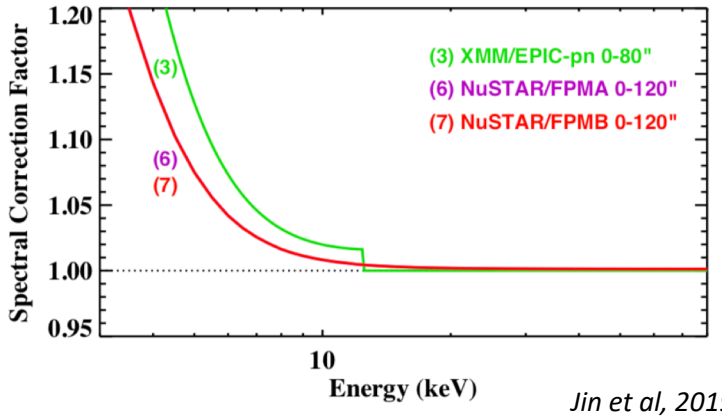


The problem



SWIFT J1658.2-4242

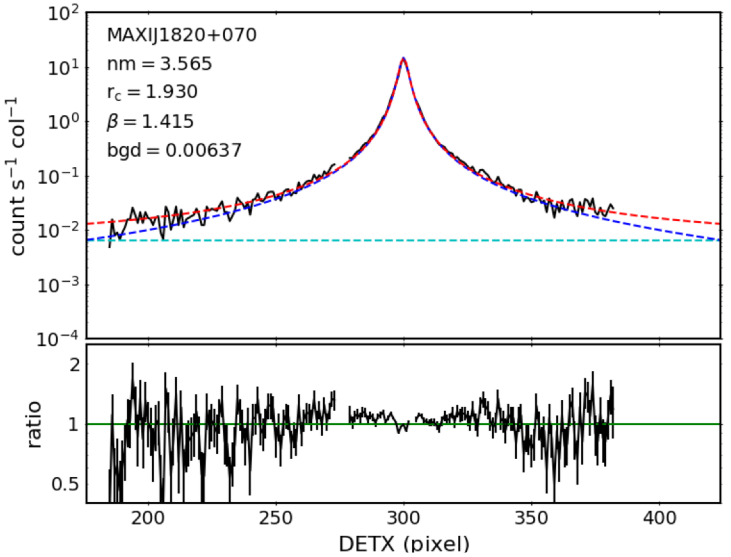


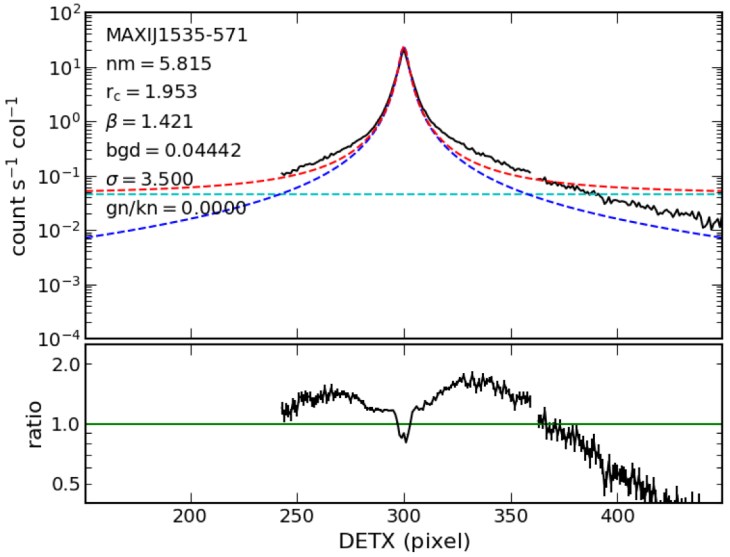


Jin et al, 2019, ApJ

XRT WT Profiles

- Example XRT WT mode 1D profiles from low NH source (MAXIJ1820+70, top) and high NH source (MAXIJ1535-571, bottom)
- latter has extended profile (black) compared with expected profile (red dashed), indicative of halo
- *xrtmkarf* applies EEF correction to ARF for a nominal point source PSF
  - Underestimates corrections for an extended source
  - Gives const factor > 1 when fitting



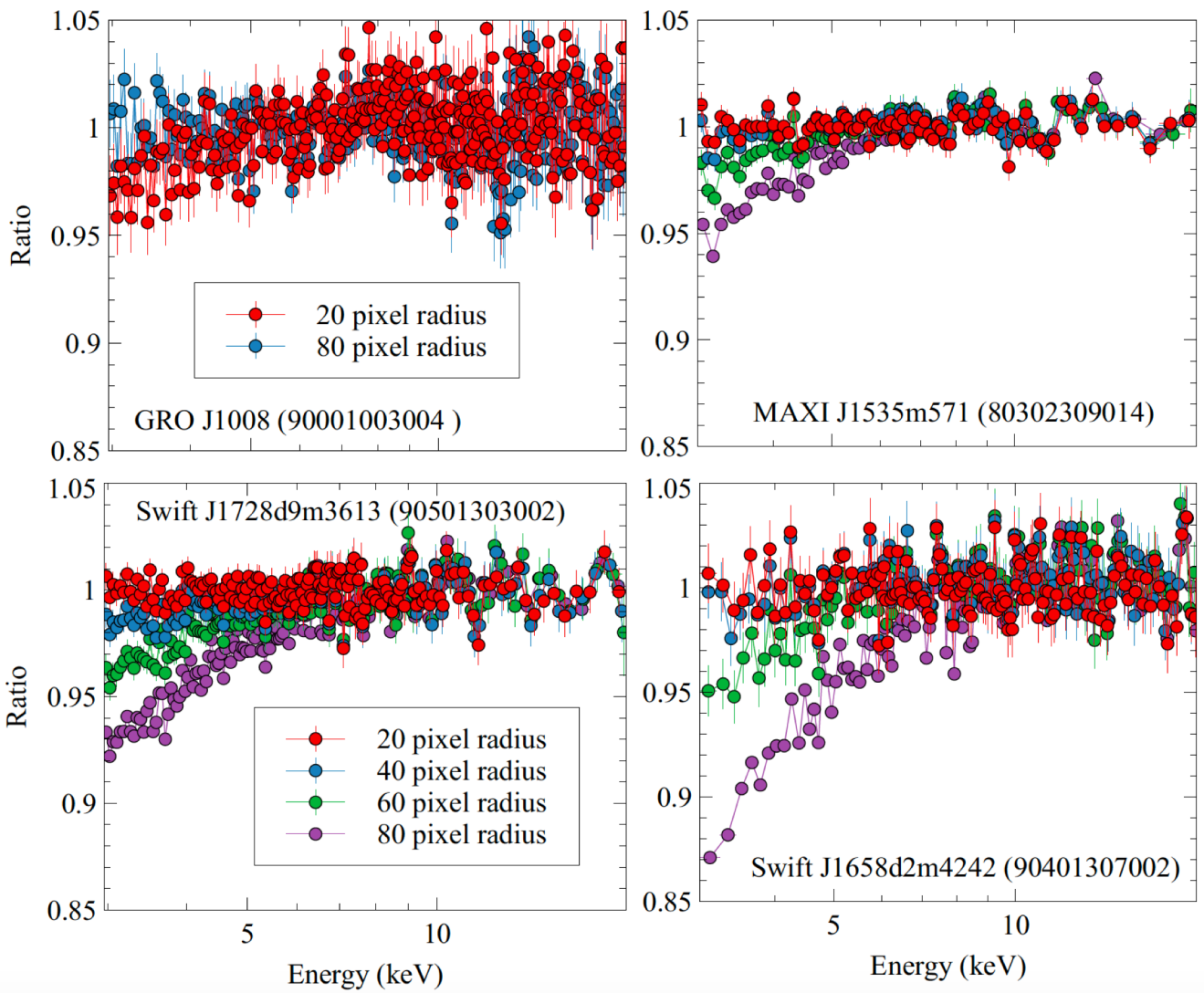


Pilot project

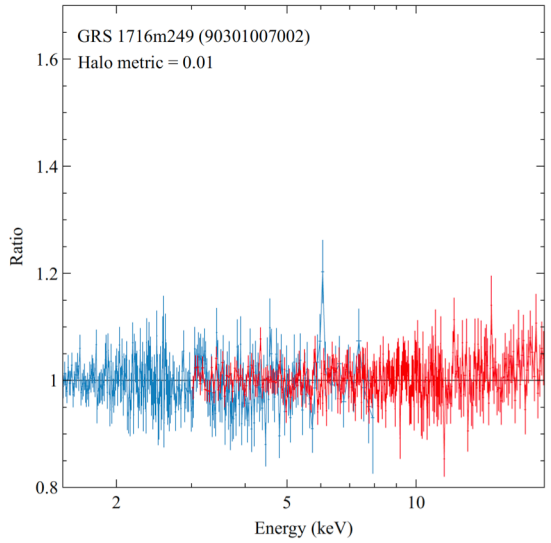
Source Name	NuSTAR OBSID	Swift OBSID	NH (litt.)	Halo Metric	Swift Count Rate (cts/s)	NuSTAR Count Rate
GRS_1716m249	90301007002	00034924051		0.01	85.67	47.3
4U_1957p11	30402011004	00088692001		0.015	30.67	19.5
V0332p53	80102002008	00081588005		0.03	2.624	41.7
GRO_J1008m57	90001003004	00081425002		0.035	48.15	175.7
GRO_J1008m57	80001001002	00031030018		0.04	63.37	231.3
4U_1901p03	90502307002	00088849001		0.05	43.83	148.3
MAXI_J1535m571	90301013002	00010264003		0.05	215.7	666.2
MAXI_J1535m571	80302309014	00088245004		0.06	484.8	738.7
Swift_J1728d9m3613	90501303002	00887541000		0.08	125.8	236.1
GX_340p0	30302030002	00088018001		0.12	85.75	102.4
Swift_J1658d2m4242	90401307002	00810300002		0.14	5.744	31.4

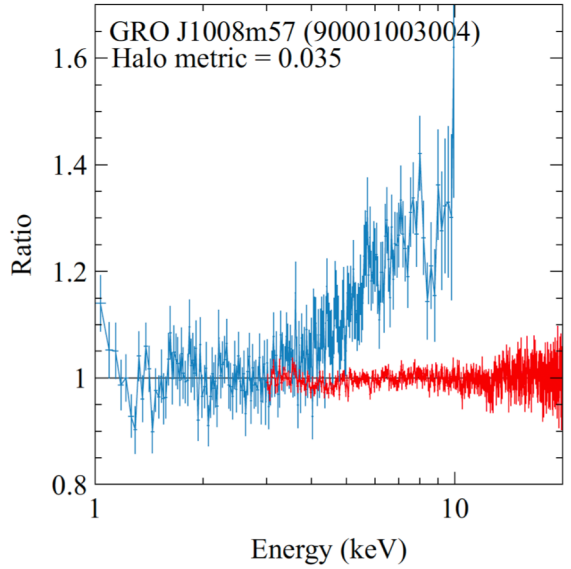
Summer student project started by Isaiah Curtis, Caltech

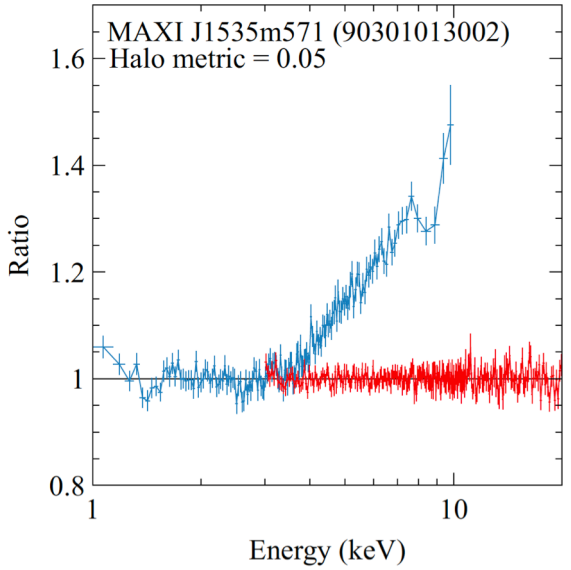
Halo metric: NuSTAR

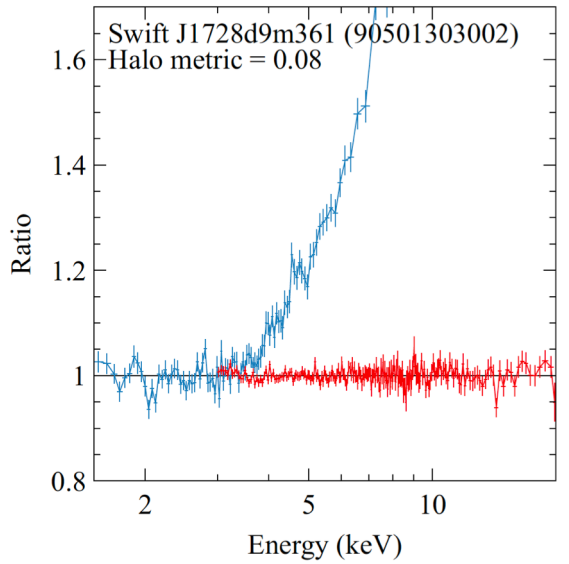


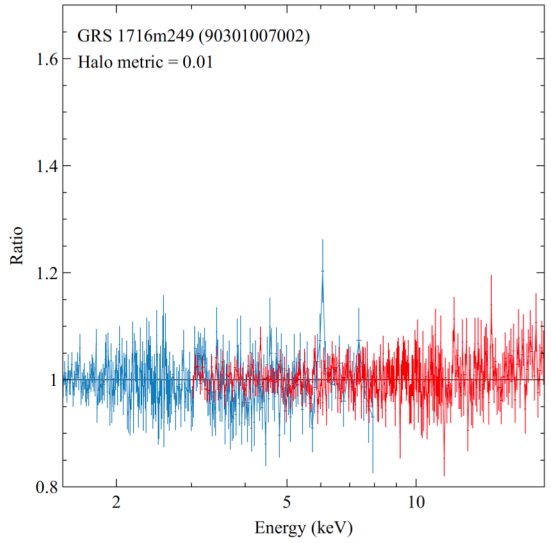
NuSTAR and Swift

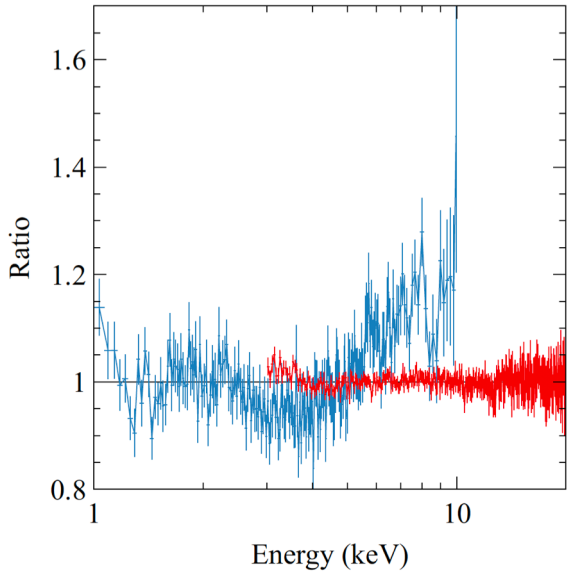


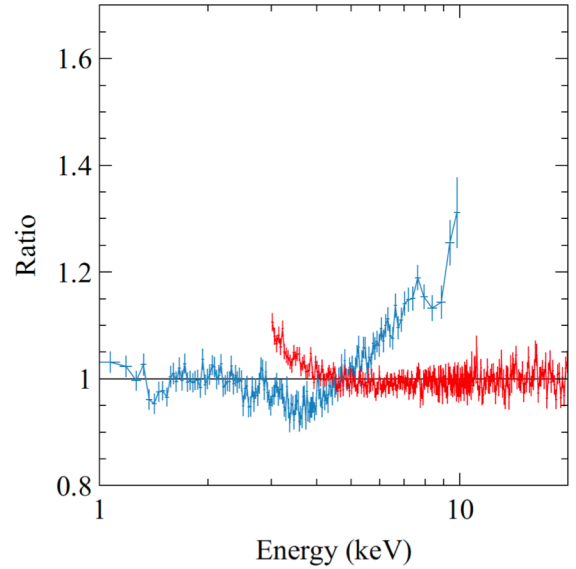


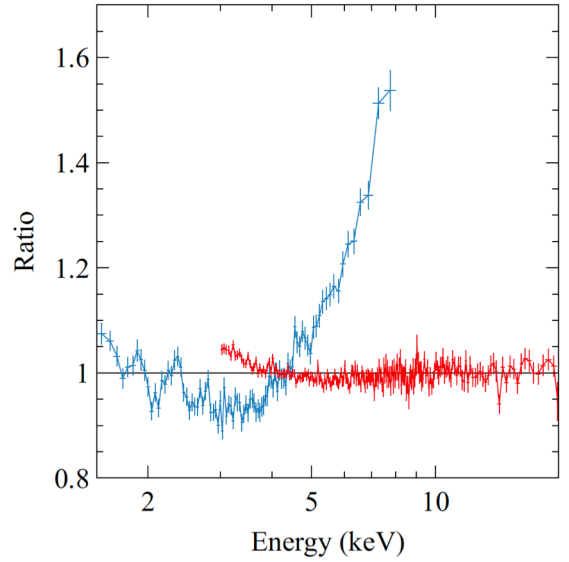




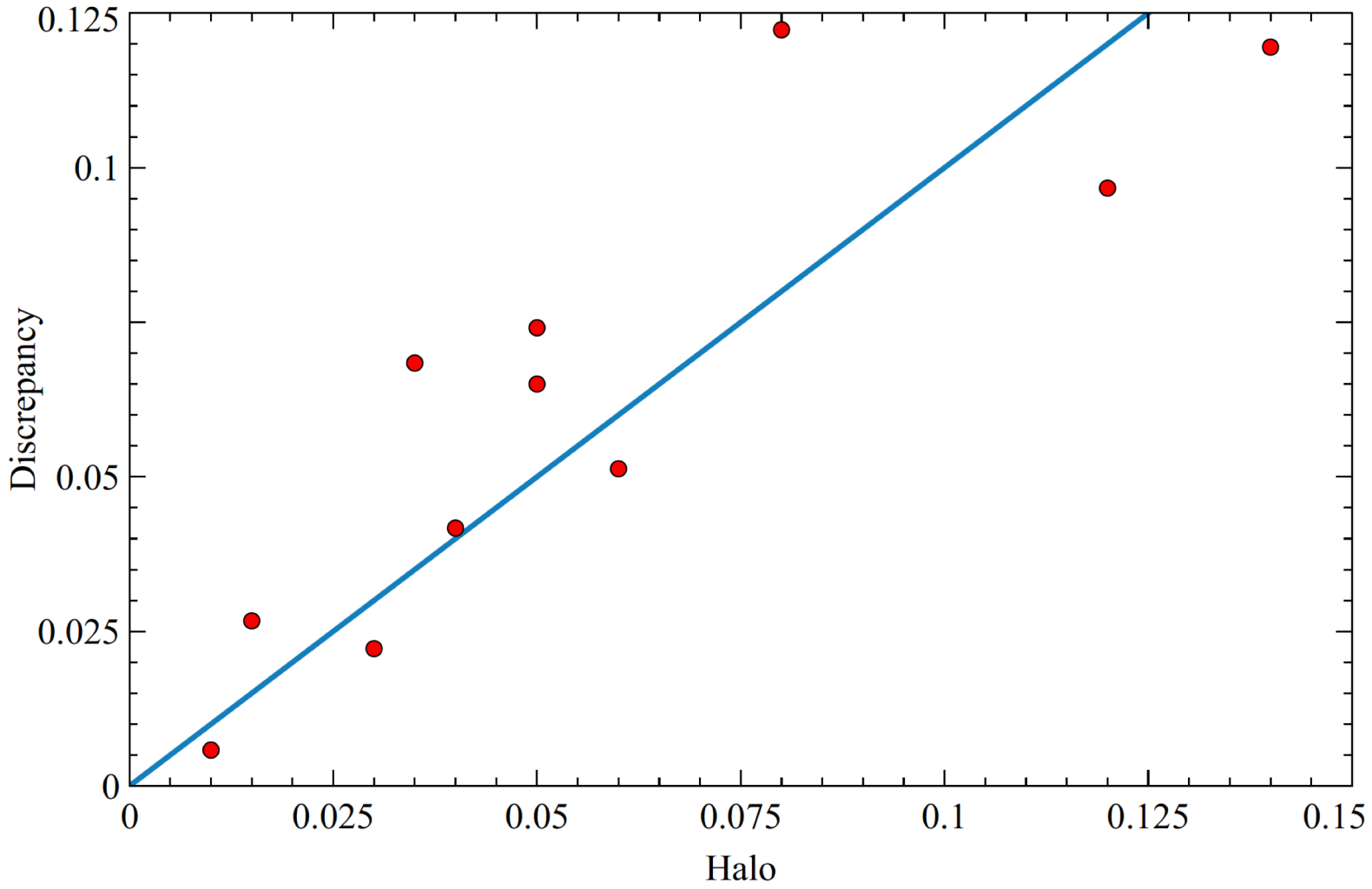








Halo and ‘discrepancy’ correlation



Conclusion and Recommendation

- Conclusion
  - Cross-normalization offsets are expected since the source is ‘extended’ in WT and the PSF correction assumes a point source
  - Clear correlation of ‘discrepancy’ with increasing halo size
  - Shape of ‘discrepancy’ is overall the same and gets worse with larger halos
  - Do we understand it? No…
- Recommendation
  - Allow for large cross-normalization constants between NuSTAR and Swift – that is alright
  - The fit won’t be good in the overlapping region, but DON’T attempt to fix it by adding unphysical components
  - Pruning and chopping can make the fit look pretty, but it won’t be more correct