XMM-Newton EPIC-pn vs. *NuSTAR*

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Amy Joyce, Norbert Schartel for the EPIC-pn IDT and SOC USG
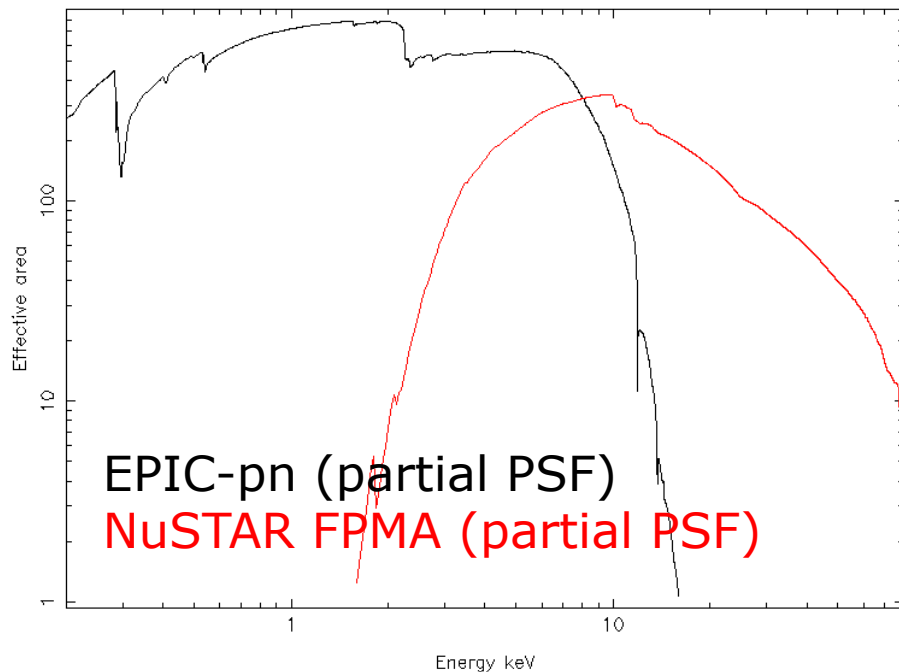
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XMM-Newton and *NuSTAR* should be a great team

Effective areas and energy resolutions (150eV for pn, ~400eV for *NuSTAR*) are well matched.

Simultaneous observations are encouraged (shared time in each others TACs).

Over 150 coordinated observations per year!

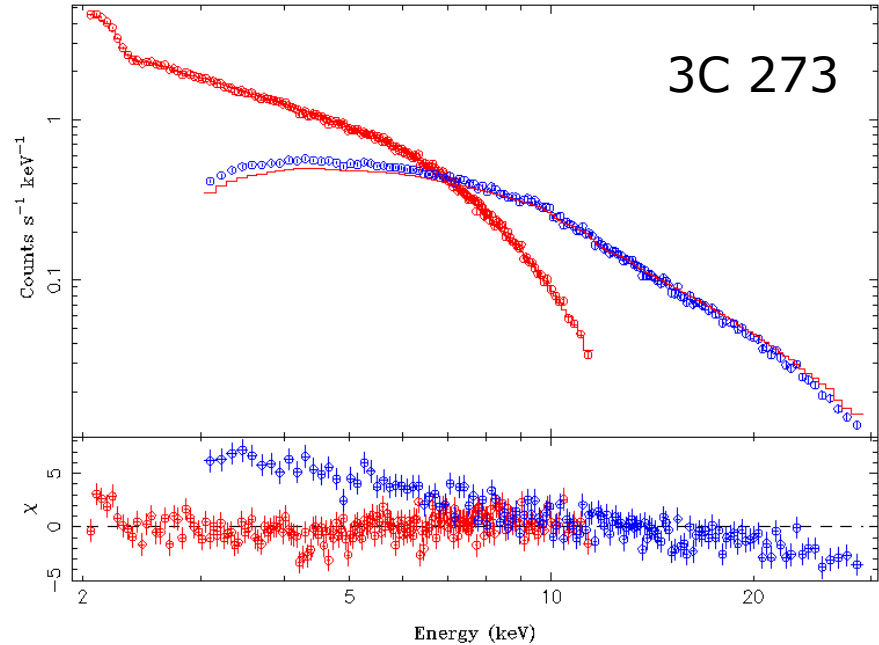EPIC-pn (partial PSF)
NuSTAR FPMA (partial PSF)

Current cross-calibration status

My current understanding of the cross-calibration status is (wrt to EPIC-pn):

- *NuSTAR* flux typically higher by 15-20%
- *NuSTAR* spectrum somewhat softer ($\Delta\Gamma \sim 0.1$)

But some caveats to this general statements exist!

Quantify differences: systematic approach

Ansatz 1: all 3C 273 observations (~ yearly as a dedicated cross-calibration target)

Ansatz 2: simultaneous scientific observations of AGN (*cf.* Master thesis of Andrea Gokus, 2017)

Ansatz 3: explore other source populations (science data), e.g., X-ray binaries for higher S/N

Current caveats
- small (large) window mode of EPIC-pn only; no other *XMM-Newton* instruments.

- Spectral model fits to "real" scientific sources may be complicate and/or biased

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3C 273 observations

XMM-Newton	StartDate	EndDate	NuSTAR	StartDate	EndDate
0414191401	**2018**-07-04 17:54:16	2018-07-05 15:34:16	10402020006	2018-07-04 17:21:09	2018-07-05 15:46:09
0414191301	**2017**-06-26 19:15:23	2017-06-27 13:52:03	10302020002	2017-06-26 17:41:09	2017-06-27 14:21:09
0414191201	**2016**-06-26 20:22:08	2016-06-27 15:02:08	10202020002	2016-06-26 19:11:08	2016-06-27 16:26:08
0414191101	**2015**-07-13 21:03:55	2015-07-14 17:10:35	10002020003	2015-07-13 14:01:08	2015-07-14 17:11:08
0414191001	**2012**-07-16 11:59:23	2012-07-16 22:48:01	10002020001	2012-07-14 00:06:07	2012-07-19 23:36:07

Reduction and analysis approach

XMM-Newton

EPIC-pn only
Small Window mode
36" extraction radius
Using 2-12 keV

- Filter for Background flares
  -> max 20% data loss
- Check for pile-up with annulus
  -> typically excised 6.75"
- Check for X-ray loading
  -> removed with annulus
- Check for gainshift
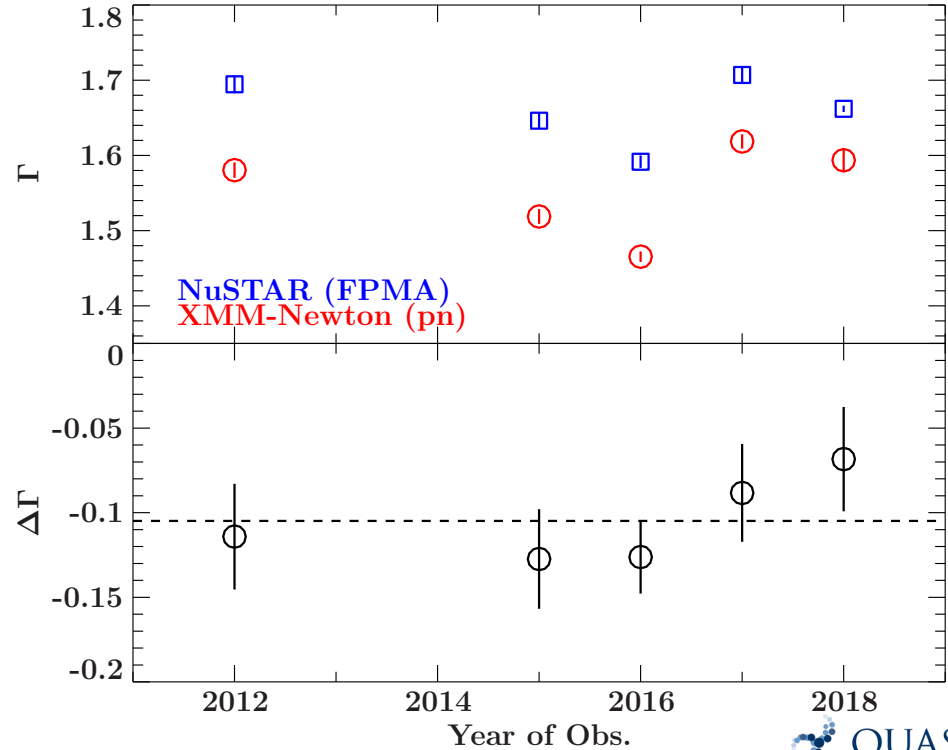 -> mostly minimal

NuSTAR

Fitting only FPMA
90" extraction radius
Using 3-30keV

No special data treatment
(e.g. standard SAA
filtering, mode 1 only)

Results

Photon Index of *NuSTAR* about 0.1 higher than *XMM-Newton* EPIC-pn.

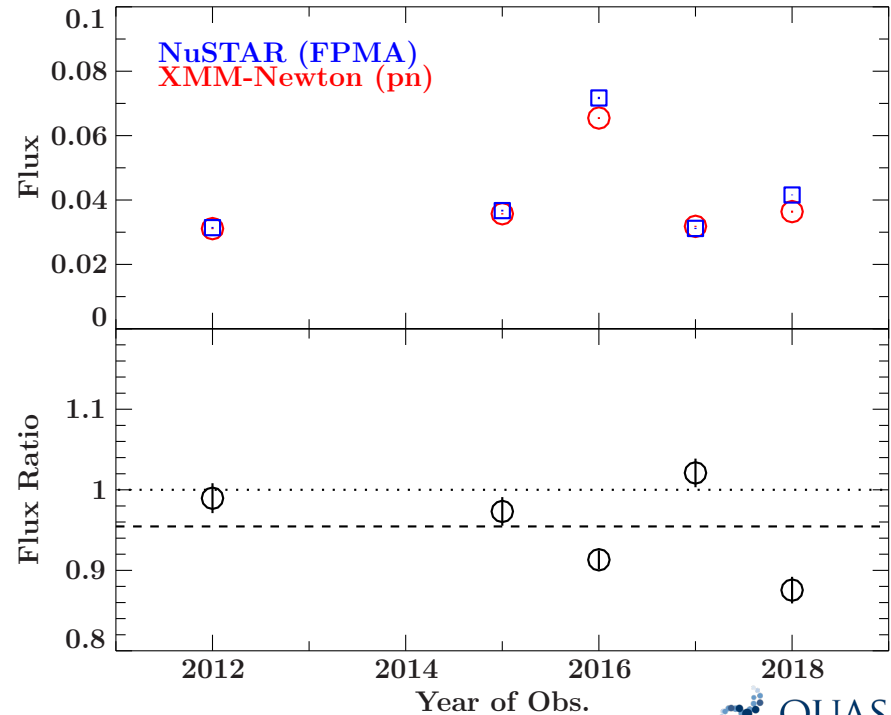Difference is relatively constant with time. But is it getting larger lately?

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Results

Measured fluxes are more similar.

Flux in 3-10keV in keV/s/cm^2

Latest observations shows 15% difference.

Summary

Known Issues
Results need to be rigorously checked on influence of selected energy bands for fitting, absorption column, event patterns, and common GTIs.

Comparison to Madsen et al. (2017) TBD.

Goals
Use *NuSTAR* stray-light Crab observations results for absolute flux and correct pn response accordingly.

Compare results and correction with larger source sample.

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AGN sample

Work done by Irish National Trainee at ESAC, Amy Joyce.

Based on previous work by Andrea Gokus.

Idea: large sample of "well-behaved" AGN in a semi-automated pipeline for *XMM-Newton* and *NuSTAR* to allow rapid checking of new calibration.

Gokus 2017

Source	Instrument	ObsID	Start Time	End Time	Method
3C 120	EPIC-pn	0693781601	2013-02-06 12:39	2013-02-08 00:51	1, 2
	FPM	60001042002	2013-02-06 12:46	2013-02-06 23:51	1, 2
3C 273	EPIC-pn	0414191001	2012-07-16 11:59	2012-07-16 22:48	1, 2
	FPM	10002020001	2012-07-14 00:06	2012-07-19 23:36	1, 2
Ark 120	EPIC-pn	0693781501	2013-02-18 11:40	2013-02-19 23:54	1, 2
	FPM	60001044002	2013-02-18 10:46	2013-02-20 09:36	1, 2
Centaurus A	EPIC-pn	0724060601	2013-08-07 12:27	2013-08-07 15:47	2
	FPM	60001081002	2013-08-06 13:01	2013-08-07 16:06	2
Fairall 9	EPIC-pn	0741330101	2014-05-09 02:20	2014-05-10 17:37	1, 2
	FPM	60001130002	2014-05-09 02:16	2014-05-09 23:01	1, 2
		60001130003	2014-05-09 23:01	2014-05-11 15:26	1
HE 1136-2304	EPIC-pn	0741260101	2014-07-02 07:44	2014-07-03 14:24	1, 2
	FPM	80002031002	2014-07-02 08:16	2014-07-02 22:31	1, 2
		80002031003	2014-07-02 22:31	2014-07-04 10:01	1, 2
MCG-6-30-15	EPIC-pn	0693781201	2013-01-29 12:08	2013-01-31 01:25	1, 2
	FPM	60001047002	2013-01-29 11:16	2013-01-30 00:11	1, 2
	EPIC-pn	0693781301	2013-01-31 12:01	2013-02-02 01:18	1, 2
	FPM	60001047003	2013-01-30 00:11	2013-02-02 00:41	1, 2
	EPIC-pn	0693781401	2013-02-02 12:02	2013-02-03 01:37	1, 2
	FPM	60001047005	2013-02-02 10:51	2013-02-03 02:41	1, 2
Mrk 915	EPIC-pn	0744490401	2014-12-02 13:08	2014-12-04 02:38	1, 2
	FPM	60002060002	2014-12-02 13:56	2014-12-03 18:46	1, 2
	EPIC-pn	0744490501	2014-12-07 07:46	2014-12-08 03:01	1
	FPM	60002060004	2014-12-07 06:51	2014-12-08 12:46	1
NGC 4593	EPIC-pn	0740920401	2015-01-02 04:46	2015-01-02 11:59	1
	FPM	60001149006	2015-01-02 03:21	2015-01-02 16:36	1
	EPIC-pn	0740920601	2015-01-06 15:01	2015-01-06 23:52	1, 2
	FPM	60001149010	2015-01-06 15:26	2015-01-07 02:31	1, 2
Swift J2127.4+5654	EPIC-pn	0693781701	2012-11-04 17:34	2012-11-06 07:12	1, 2
	FPM	60001110002	2012-11-04 17:21	2012-11-05 18:06	1, 2
		60001110003	2012-11-05 18:06	2012-11-06 08:01	1, 2
	EPIC-pn	0693781801	2012-11-06 17:26	2012-11-08 07:04	1, 2
	FPM	60001110005	2012-11-06 17:56	2012-11-08 07:06	1, 2
	EPIC-pn	0693781901	2012-11-08 17:18	2012-11-09 13:17	1, 2
	FPM	60001110007	2012-11-08 16:51	2012-11-09 13:41	1, 2

Table 4.1: All observations included in the data sample. The spectra were studied using two different methods; the column Method shows whether a source was included in both analysation methods or just one.
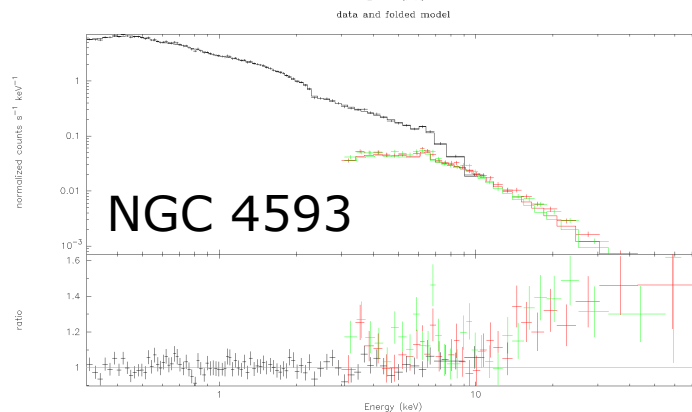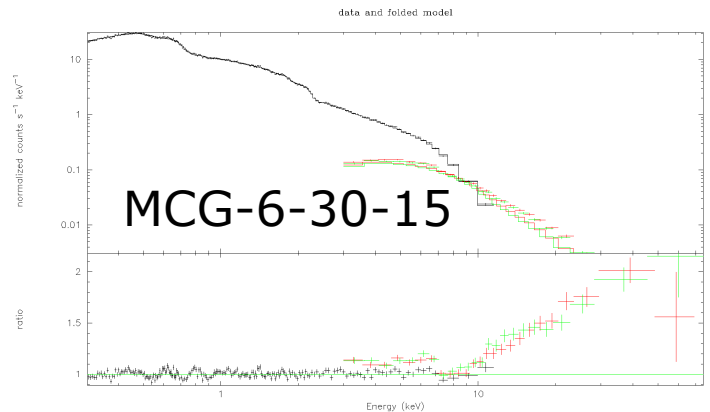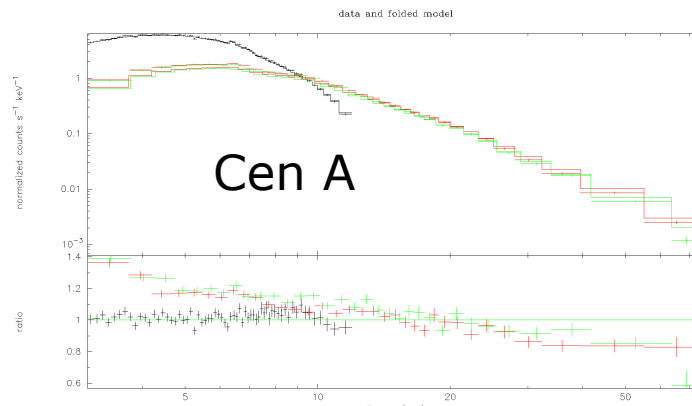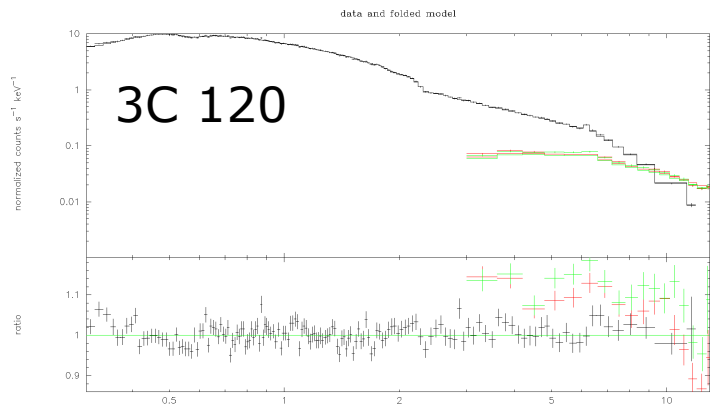
data and folded model
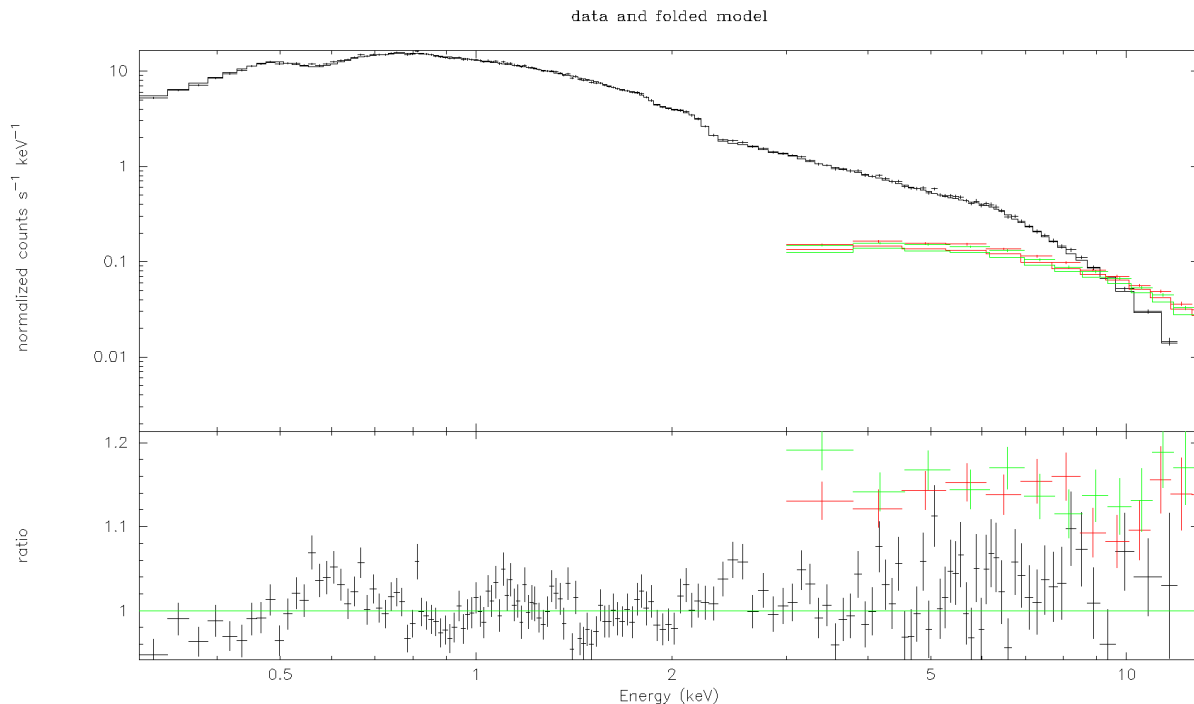
Find best-fit model to
EPIC-pn data only
(in this case
tbnew*tbnew(relxill+bbody
+2x zgauss))

Evaluated for *NuSTAR*
(not fitted to *NuSTAR*!)

More examples: gallery

Current status and outlook

Flux difference of ~15% obvious in all sources.

Slope difference not always clear. It is model dependent and might be lost in lower S/N sources.

Results above 10keV unreliable, as fit only done to *XMM-Newton* data.

Outliers like Cen A make life even more complicated (see Fürst et al., 2016 for detailed analysis of Cen A's issues).

Work is ongoing to create automated pipeline, add more sources. Any change to calibration can be immediately checked.
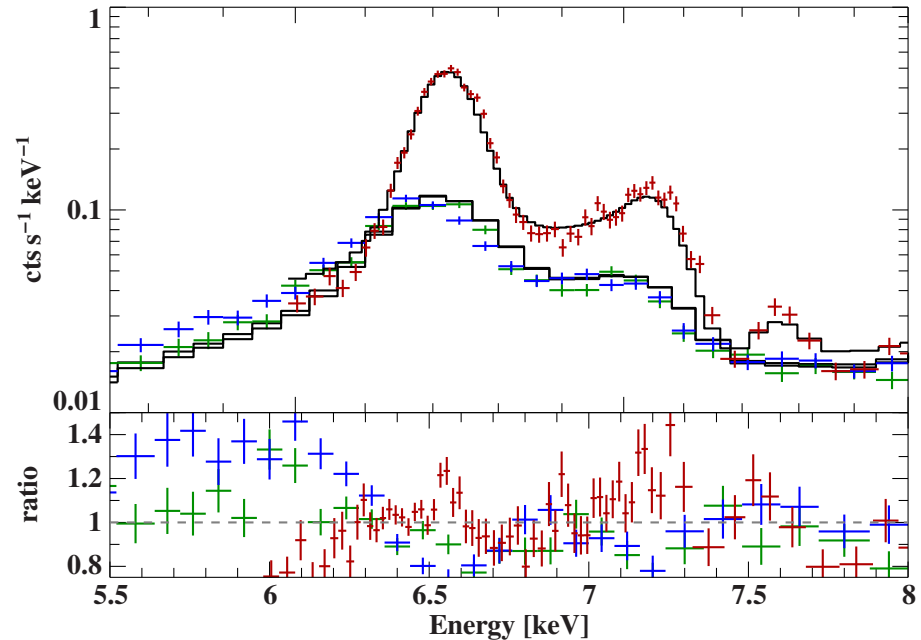
X-ray binaries (bright sources)

One example, courtesy of Ralf Ballhausen (Remeis observatory).

IGR J16318-4848; very strongly absorbed accreting X-ray binary with strong iron Kα line.

Responds to strong line is difficult to model; line energies show mismatch between EPIC-pn and *NuSTAR.*
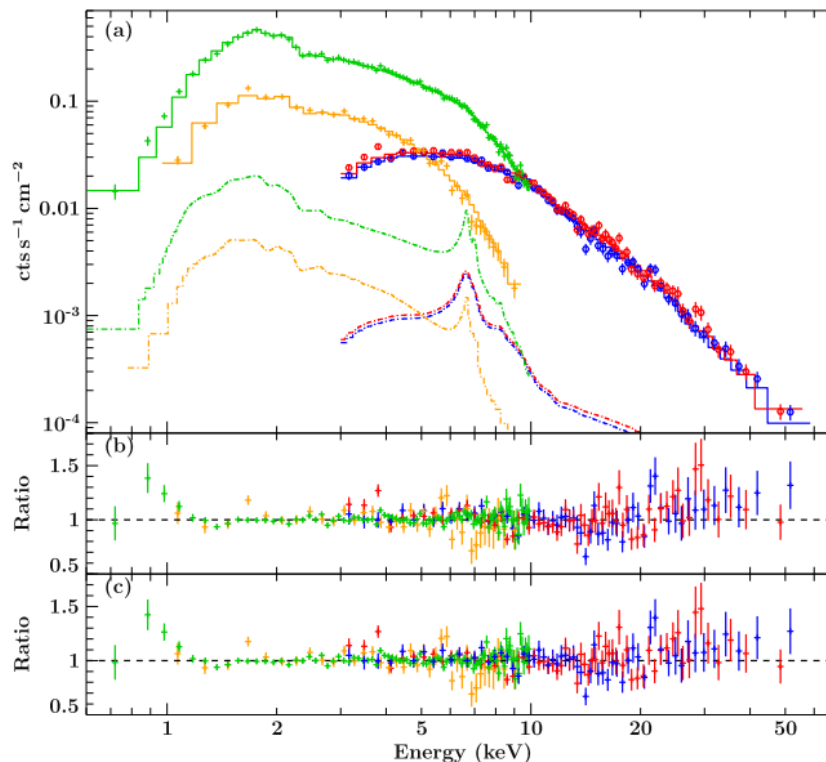-> work in progress.

X-ray binaries

New simultaneous science
observations upcoming:
Vela X-1 (PI Grinberg),
1E1147.1 (PI Fürst).

Work in progress!

EPIC-pn and *NuSTAR*
differences not always that
large, see GRS 1739-278
(Fürst et al. 2016).

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Conclusion

IACHEC cross-calibration observations and AGN provide a good set to measure and test the cross-calibration between EPIC-pn and *NuSTAR.*

Project only recently started (but based on lots of previous work).

Current cross-calibration is far from perfect, but hopefully stable and can be characterized well in the short-term.

Long-term goal: change EPIC-pn response to match "true" spectrum better.