XMM-Newton EPIC-pn vs. *NuSTAR*

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Coordinated XMM-NuSTAR & NuSTAR sample

GOAL1 (✅): Reduce and analyze a large sample of "coordinated XMM-Newton & NuSTAR" targets (**mostly XRBs**) in a semi-automated pipeline for *XMM-Newton* (EPIC-pn in **timing mode**) and *NuSTAR*

GOAL 2 (working): Quantify the discrepancy found between XMM pn-timing and NuSTAR FPM spectra

GOAL 3: Solve the problem (eventually!)

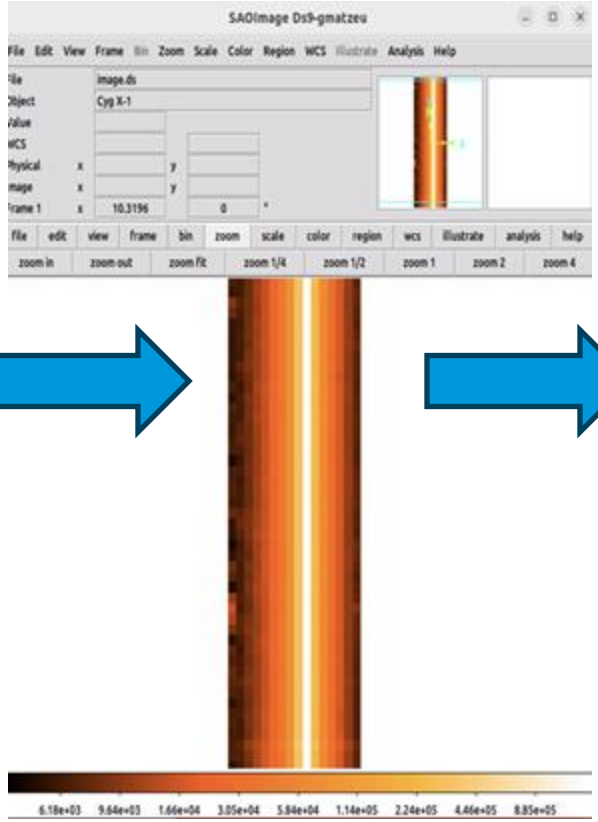
26 obs – THICK FILTER
11 obs – MEDIUM
29 obs – THIN

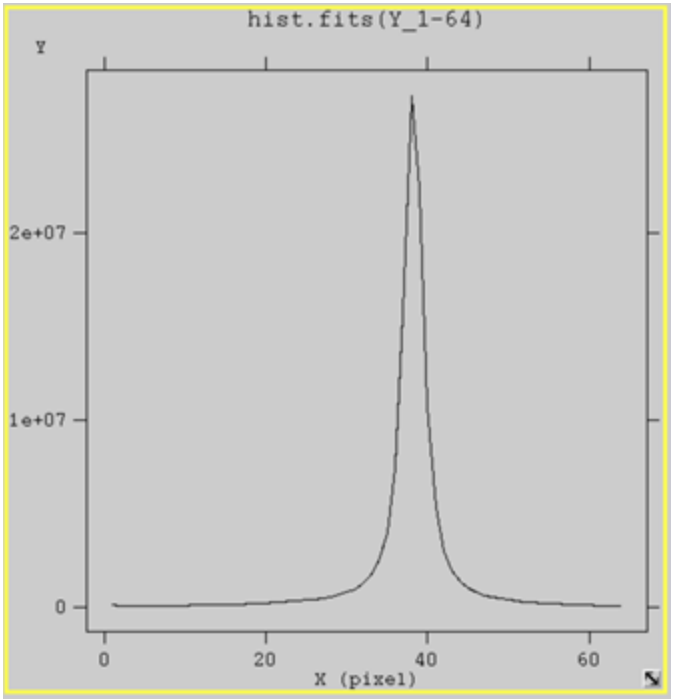
Some obs. had to be discarded

Reduction and analysis approach

XMM-Newton
EPIC-pn
Timing mode
RAWX =1-64
Using 3-10 keV

In the Timing mode, spatial information is maintained only in one dimension, along the column (RAWX) axis.

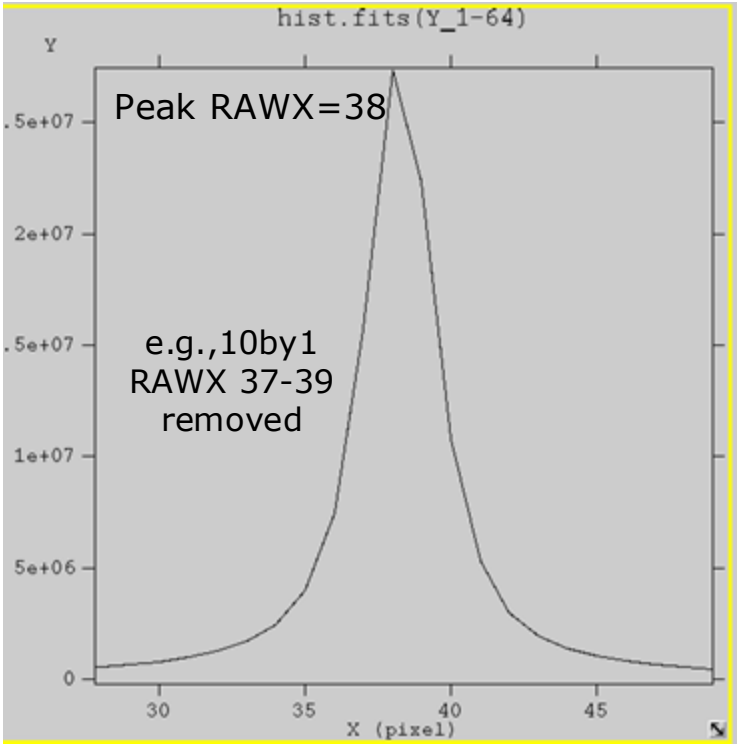




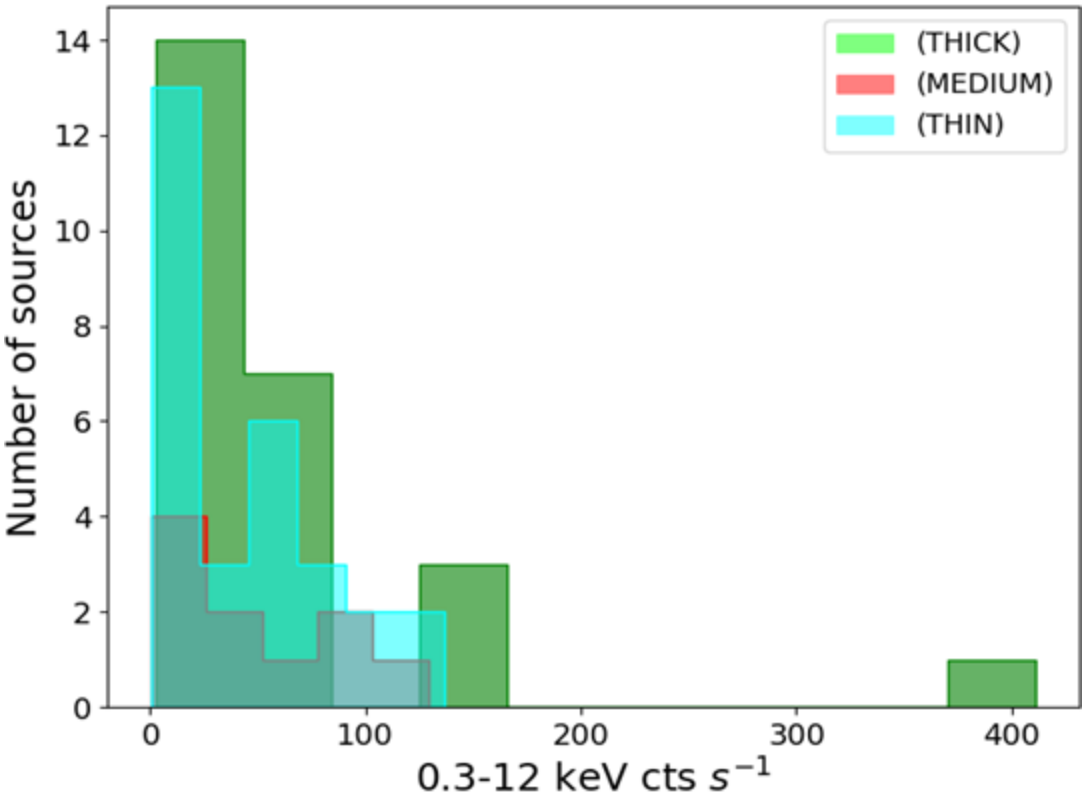
Reduction and analysis approach

XMM-Newton EPIC-pn SASv21
Timing mode
RAWX by (central RAWX excl)
10by0 … 10by4 depending on pileup
Using 3-10 keV for analysis
Mincount=25 and oversample=3
arfgen
applyabsfluxcorr=yes

NuSTAR
Fitting FPMA and FPMB
90” extraction radius both src and bkg
Using 3-20keV
Mincount=50



Histogram of 0.3-12 cts/s for all 10by0 observations

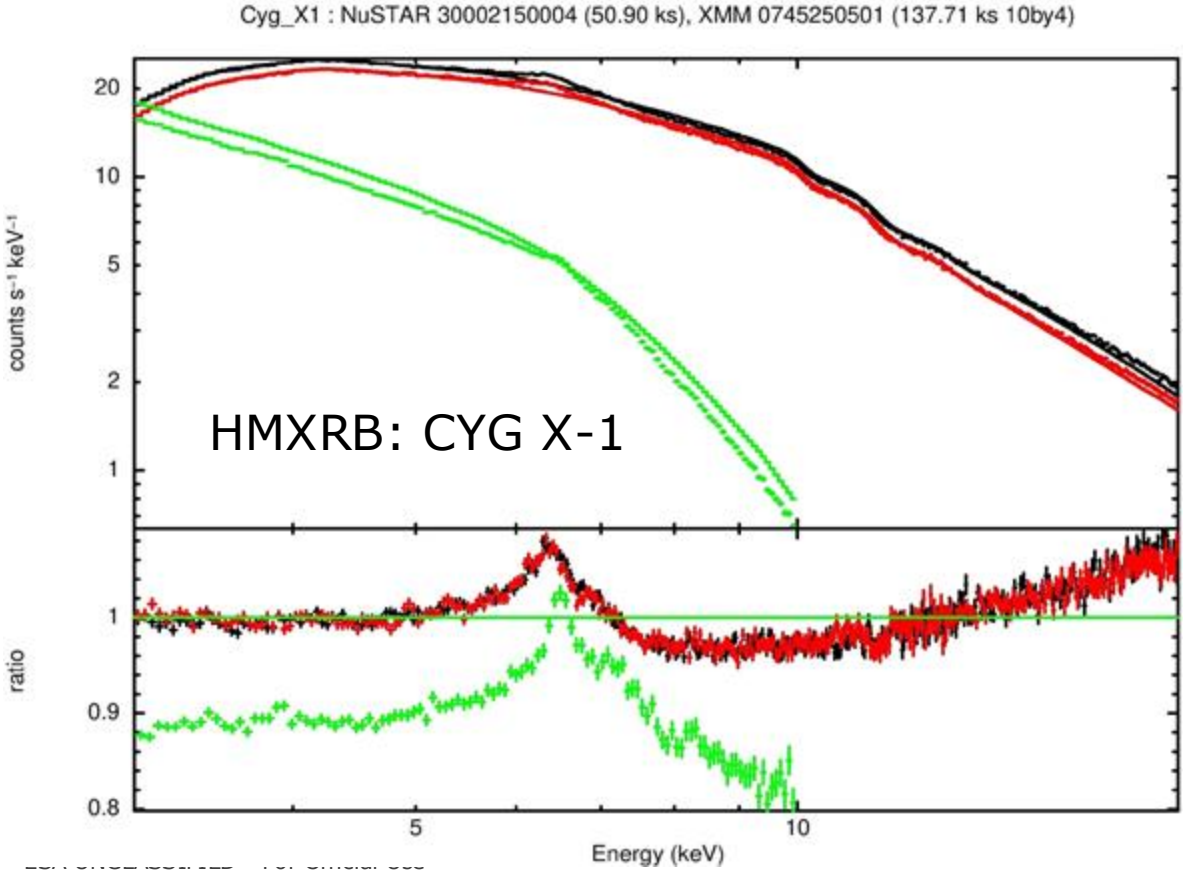


The cts/s are measured from all 10by0 EPIC-pn spectra in timing mode between 0.3-12 keV

<450 cts/s threshold for pileup for timing mode

Although some of them seem piled-up from the SAS epatplot which can be subjective

Example 1 from 2024:



Find best-fit continuum model to *NuSTAR* data only
(in this case: constant*pow)

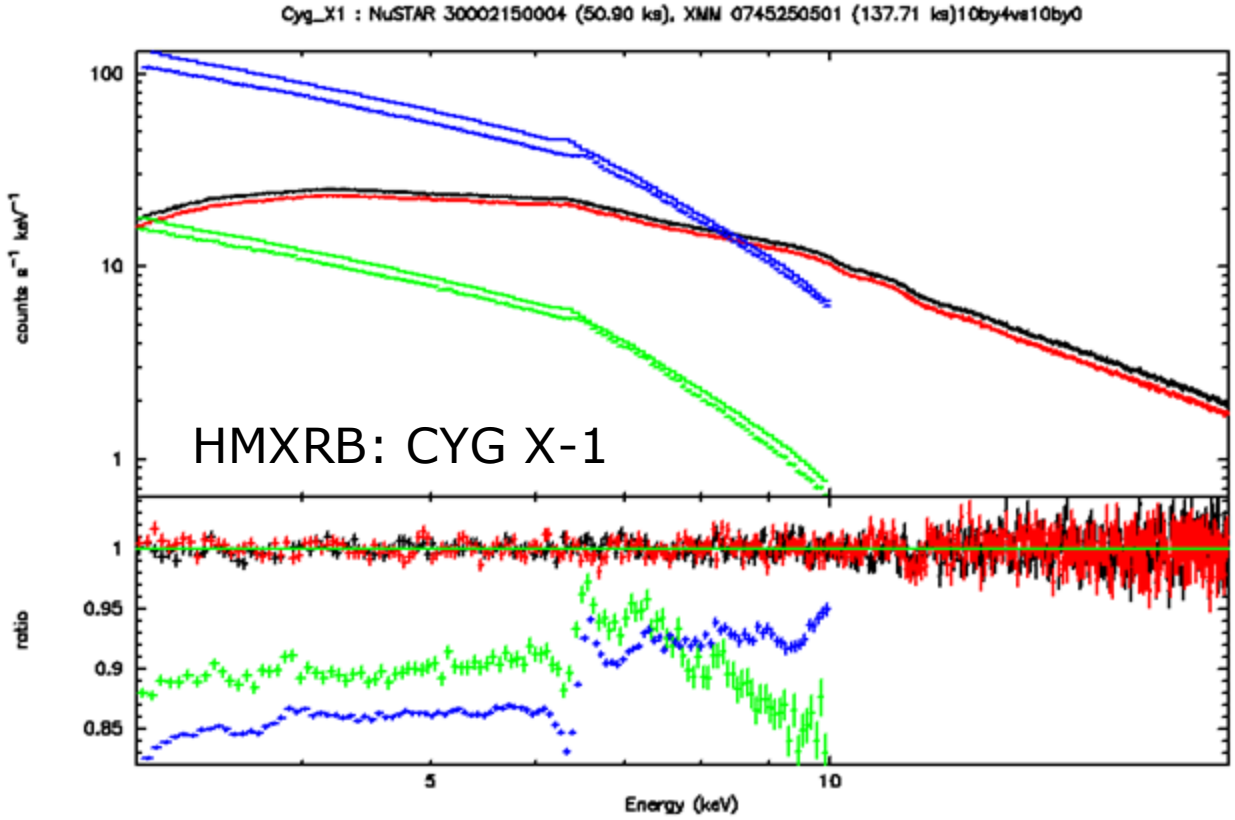
(*XMM* EPIC-pn not fitted)

EPIC-pn photo-index wrt *NuSTAR*: harder

(*XMM* EPIC-pn not fitted)

arfgen
applyabsfluxcorr=yes

Example 1:



Find best-fit continuum model to *NuSTAR* data (spline*constant*pow)

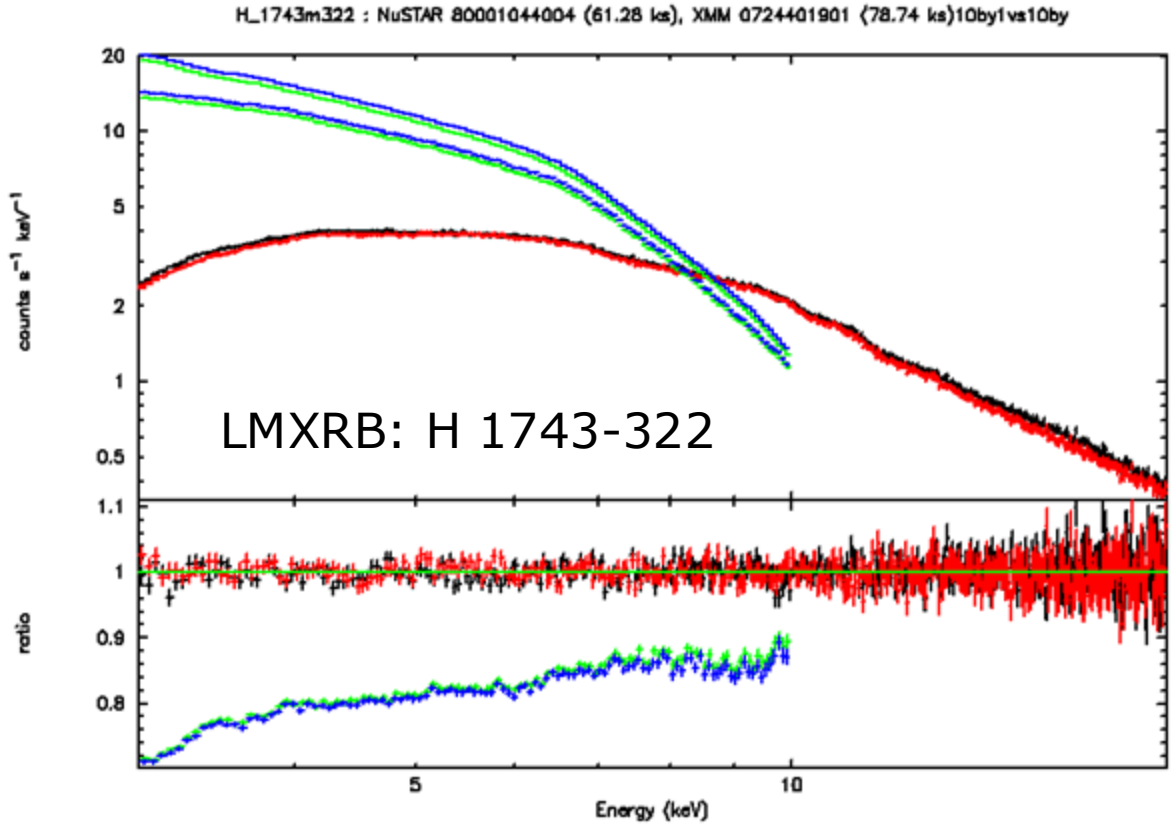
(*XMM* EPIC-pn not fitted)

EPIC-pn photo-index wrt *NuSTAR*: harder

(*XMM* EPIC-pn NOT fitted)

arfgen applyabsfluxcorr=yes

Example 2:



Find best-fit continuum model to *NuSTAR* data only (model:spline*constant*pow)

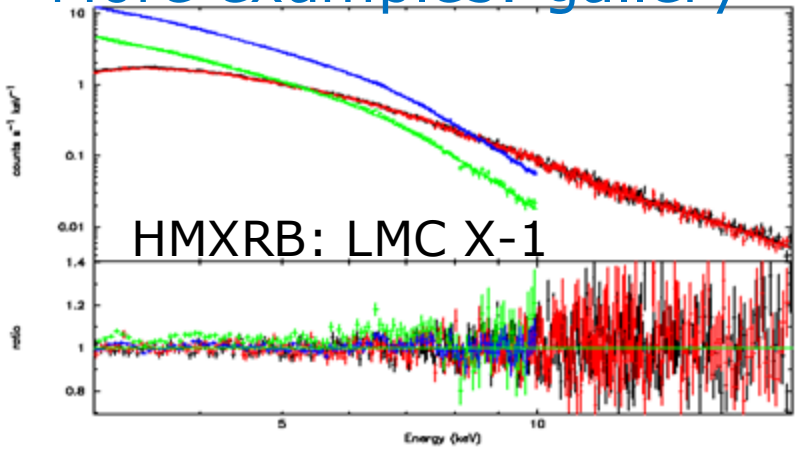
(*XMM* EPIC-pn not fitted)

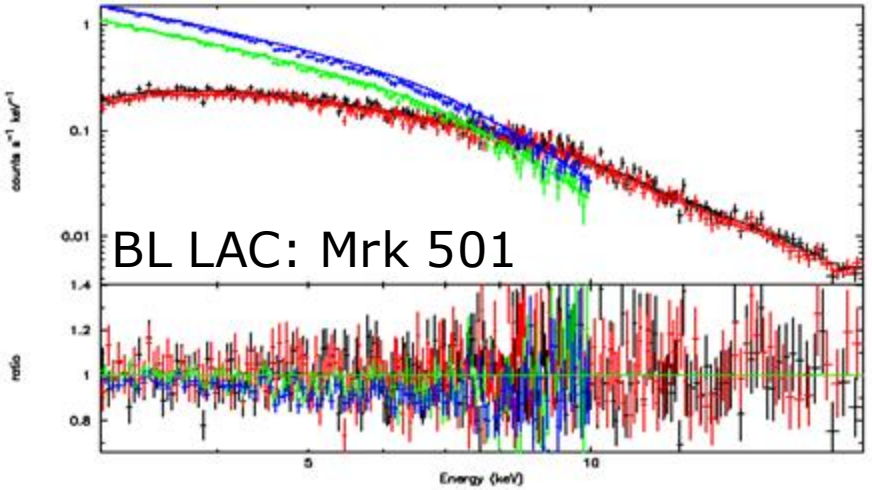
EPIC-pn photo-index wrt *NuSTAR*: harder

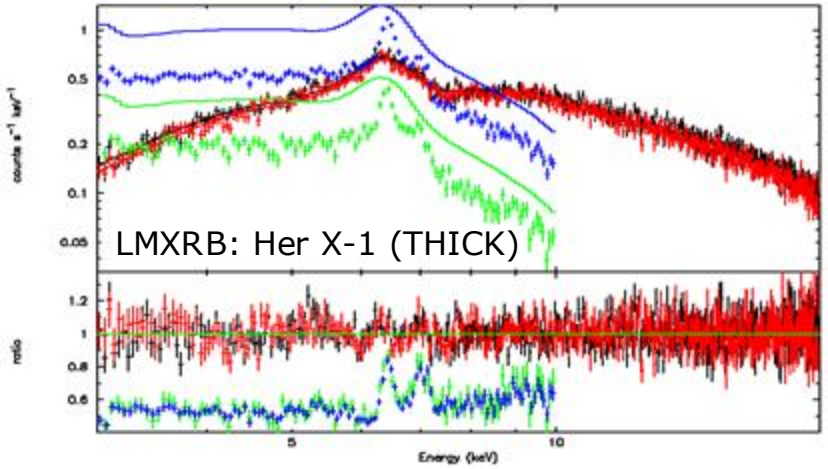
(*XMM* EPIC-pn not fitted)

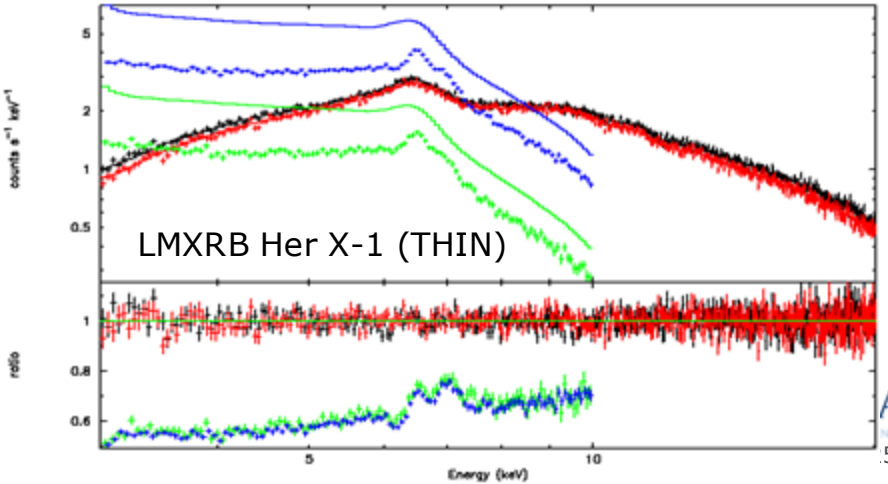
arfgen applyabsfluxcorr=yes

More examples: gallery









TEST 1 example – EPIC-pn VARIABLE CONSTANT

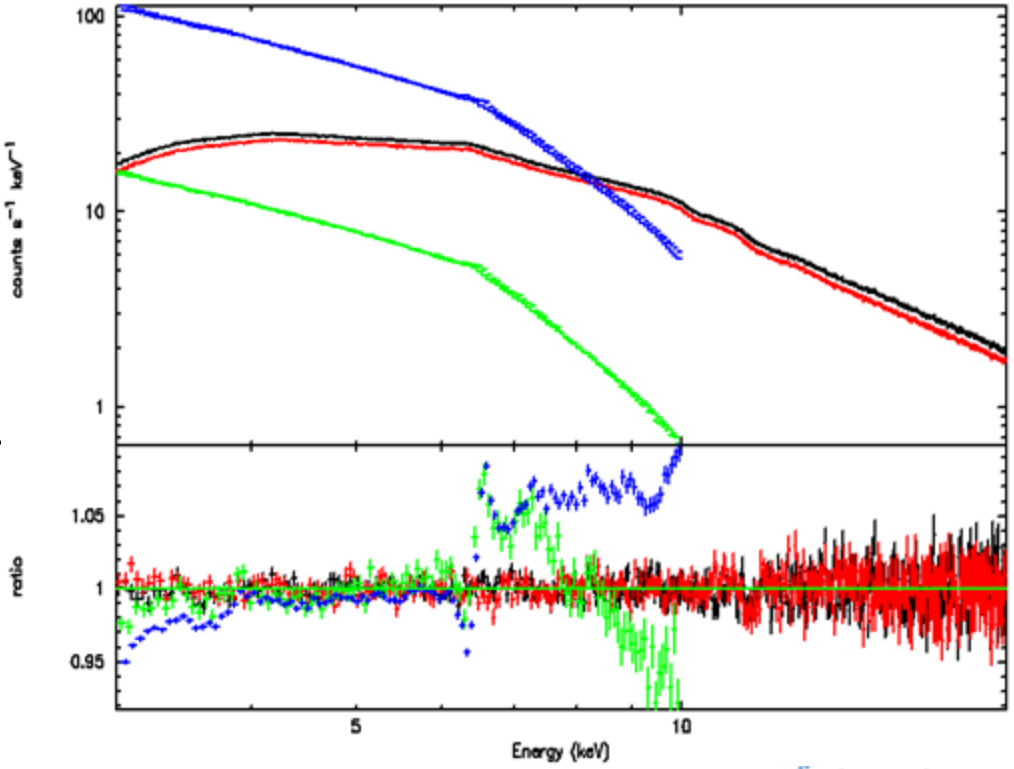
CYG X-1; An accreting high mass X-ray binary with strong iron Kα line.

Fe Ka centroid energy lines is shifted by ~10 eV

Δconst = 1 – constant (EPIC-pn) = 0.10 - 10by4

Δconst = 1 – constant (EPIC-pn) = 0.15 – 10by0

-> work in progress.



TEST 1b example – EPIC-pn VARIABLE CONSTANT

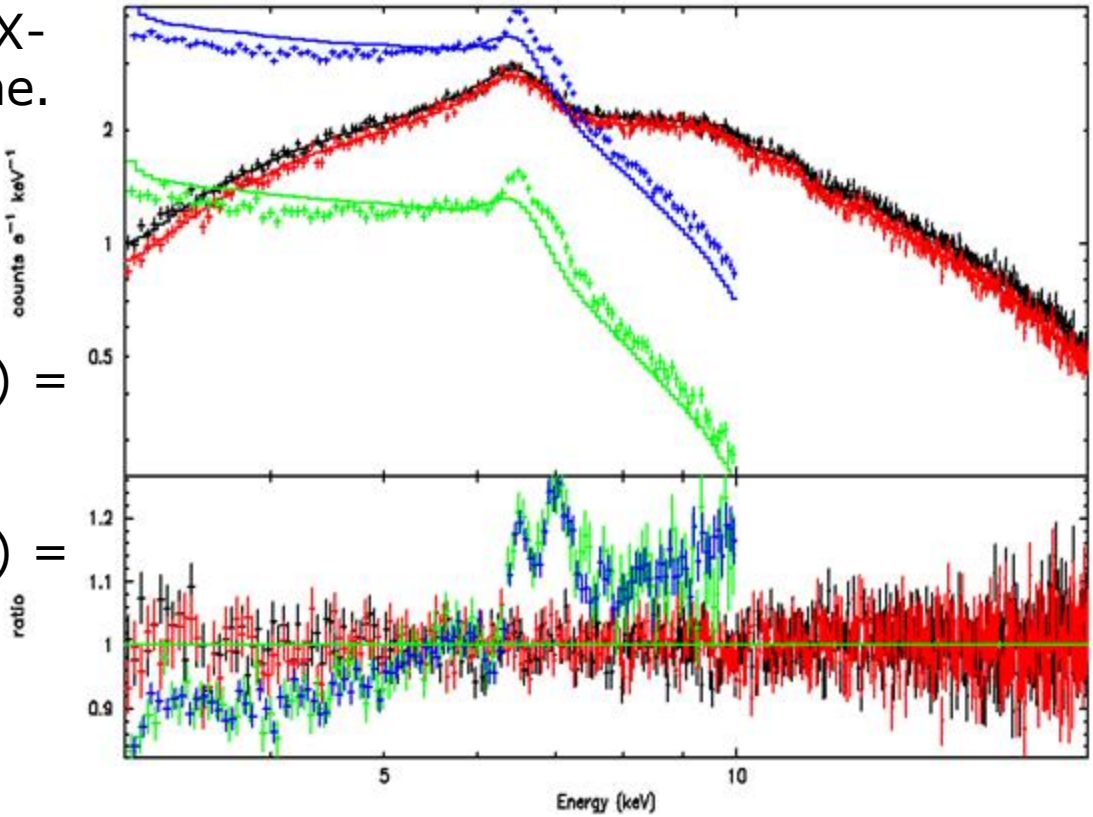
Her X-1; An accreting low mass X-ray binary with strong iron Kα line.

Fe Ka centroid energy lines is shifted by ~10 eV

Δconst = 1 – constant (EPIC-pn) = 0.38 - 10by4

Δconst = 1 – constant (EPIC-pn) = 0.40 – 10by0

-> work in progress.



TEST 2 example – EPIC-pn VARIABLE Γ

CYG X-1; An accreting high mass X-ray binary with strong iron Kα line.

Fe Ka centroid energy lines is shifted by ~10 eV

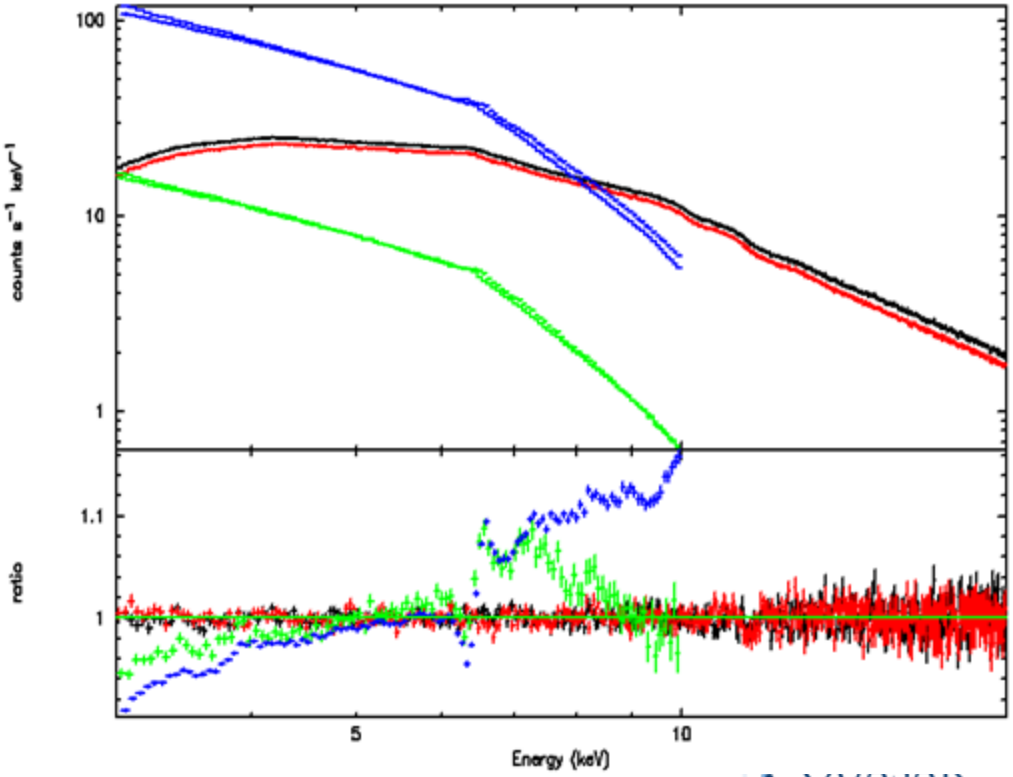
$\Delta\Gamma = \Gamma(\text{FPMA}) - \Gamma(\text{pn}) = 0.06$

10by2

$\Delta\Gamma = \Gamma(\text{FPMA}) - \Gamma(\text{pn}) = 0.09$

10by0

The majority of EPIC-pn slopes are softer w.r.t. *NuSTAR FPMA/B*



TEST 2b example – EPIC-pn VARIABLE Γ

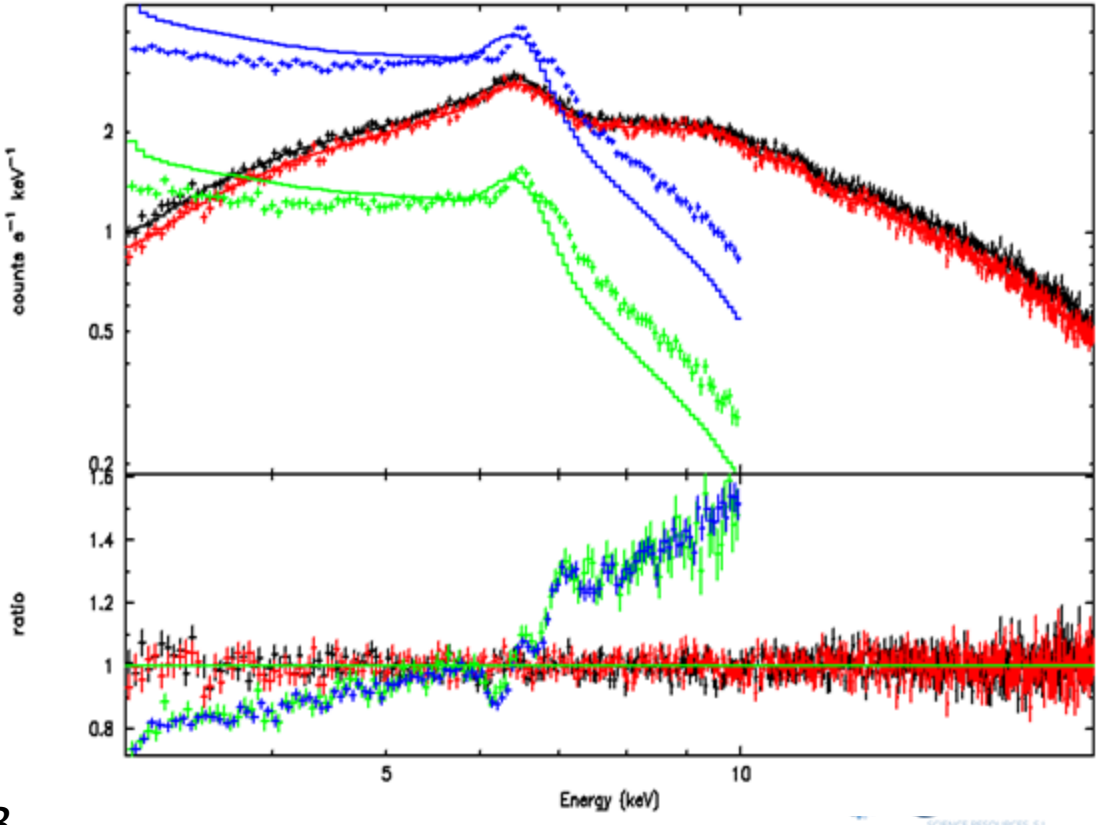
Her X-1; An accreting low mass X-ray binary with strong iron Kα line.

Fe Ka centroid energy lines is shifted by ~10 eV

$\Delta\Gamma$ = Γ (FPMA) - Γ (pn) = -0.32
10by2

$\Delta\Gamma$ = Γ (FPMA) - Γ (pn) = -0.33
10by0

The majority of EPIC-pn slopes are softer w.r.t. *NuSTAR FPMA/B*



Results

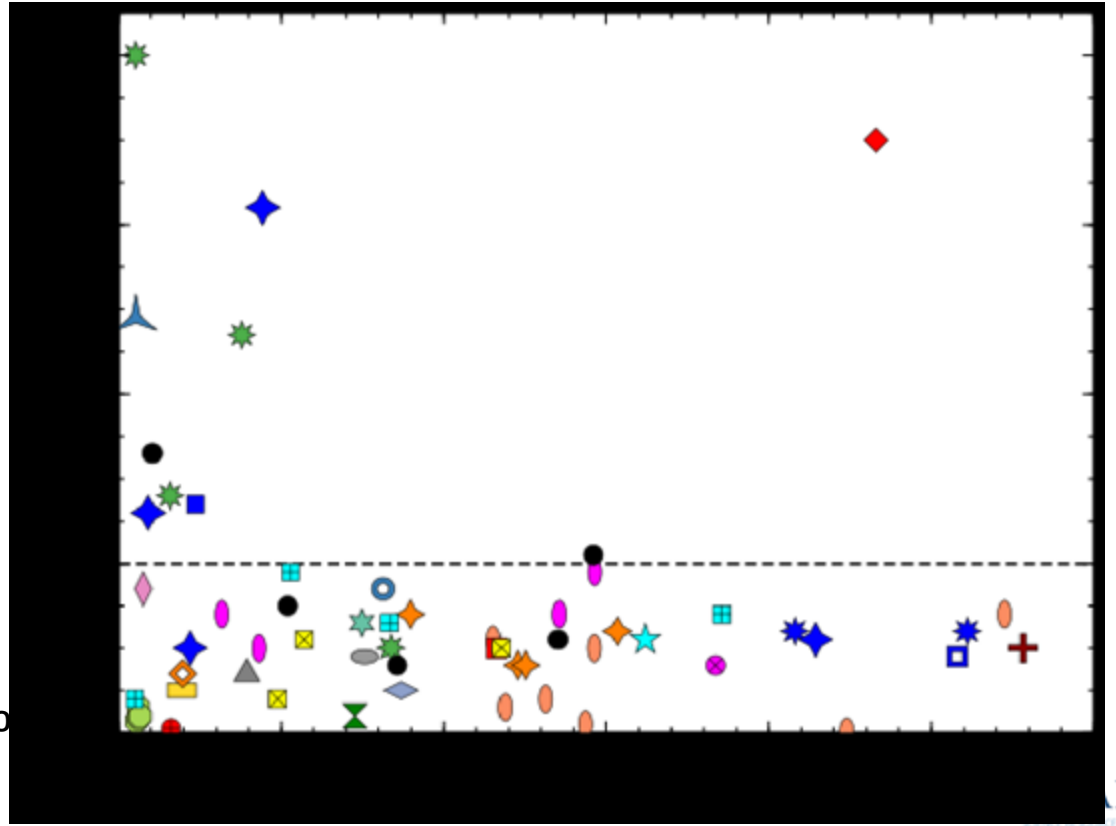
EPIC-pn 0.3-12 keV Counts/s vs Δconstant

High S/N so 1-3% error

There is a considerable scatter without any recognizable correlation

Larger discrepancies when cts/s are lowest

EPIC-pn and *NuSTAR* differences not always that large but mostly within 20%



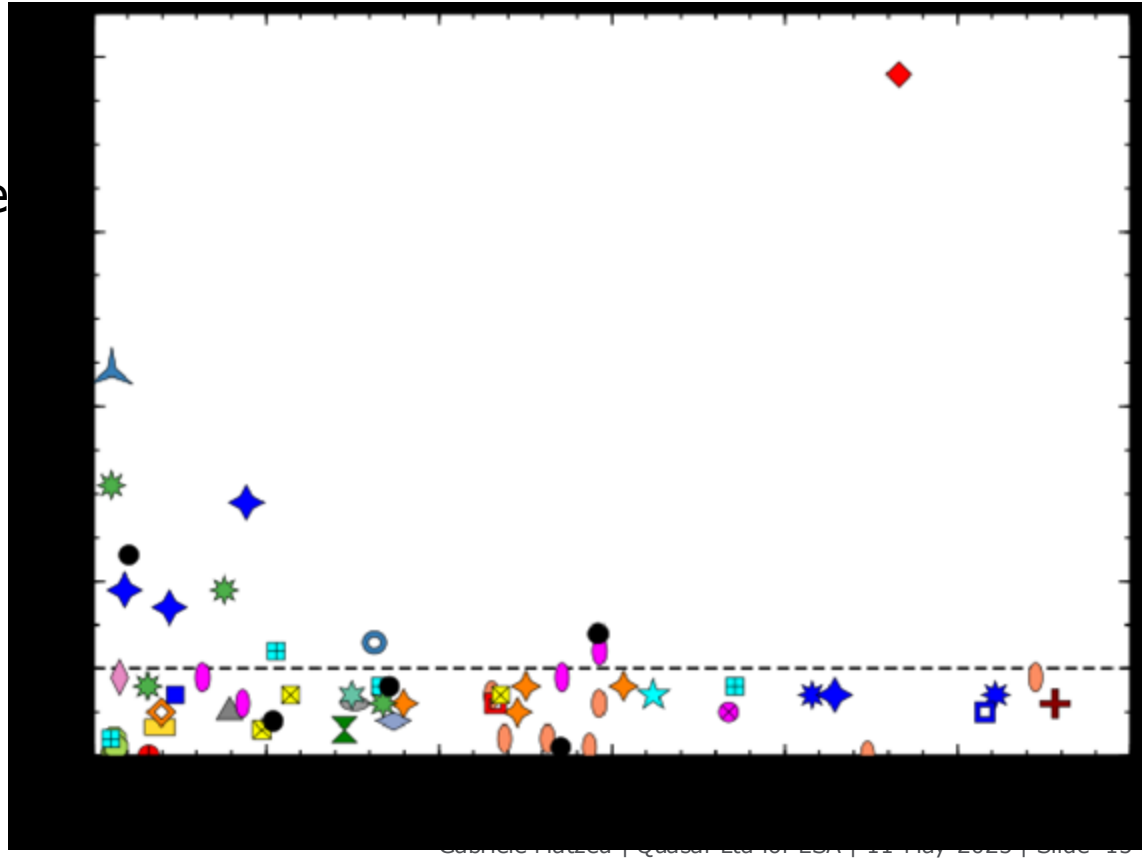
Results

0.3-12 keV Counts/s vs |ΔΓ|

High S/N so 1-3% error

There is also a considerable scatter

Larger discrepancies when cts/s are lowest



Results

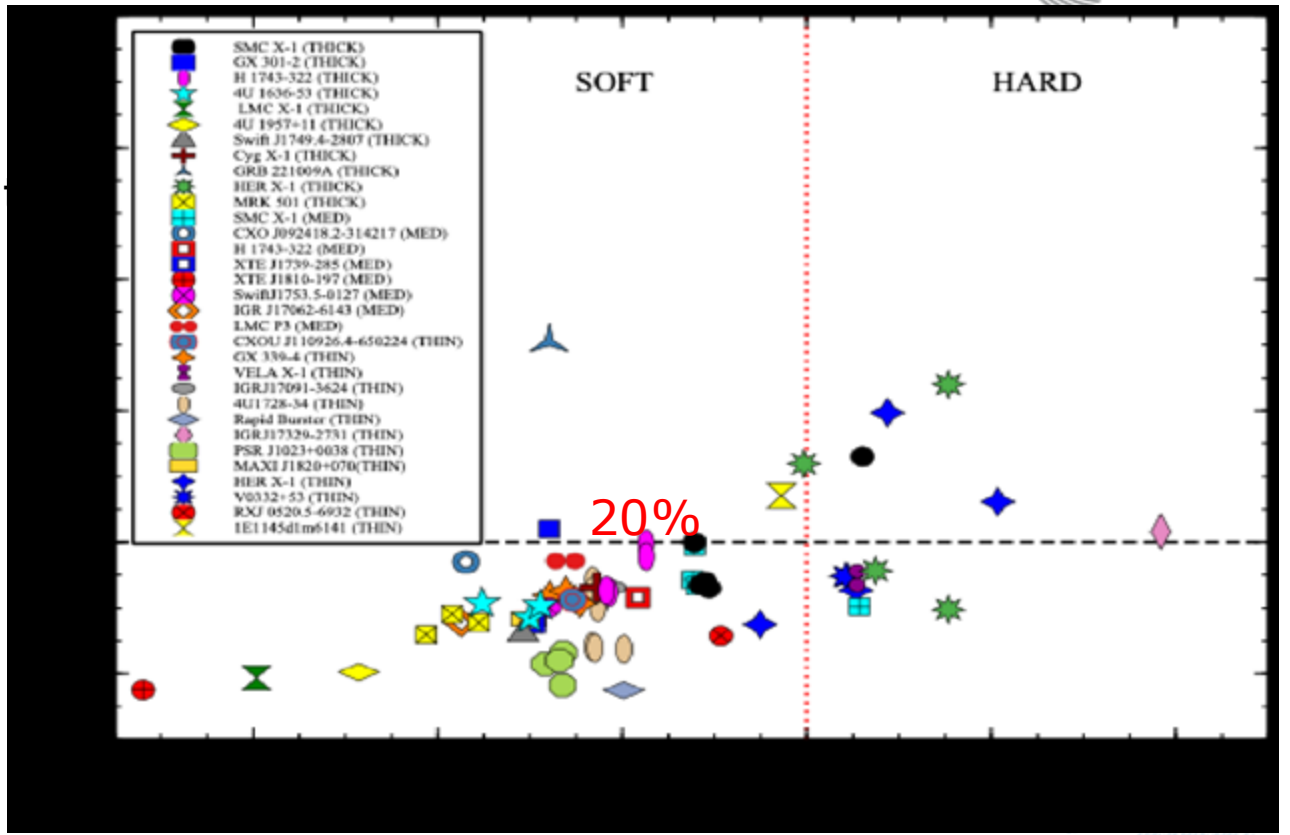
(H–S)/(H+S) HR cts/s vs (1 – constant$_{pn}$)

High S/N so 1-3% error

There is an improvement in HER X1 by using HR

There is some scatter above (1-const.) = 0.2

Work in still in progress!



Results

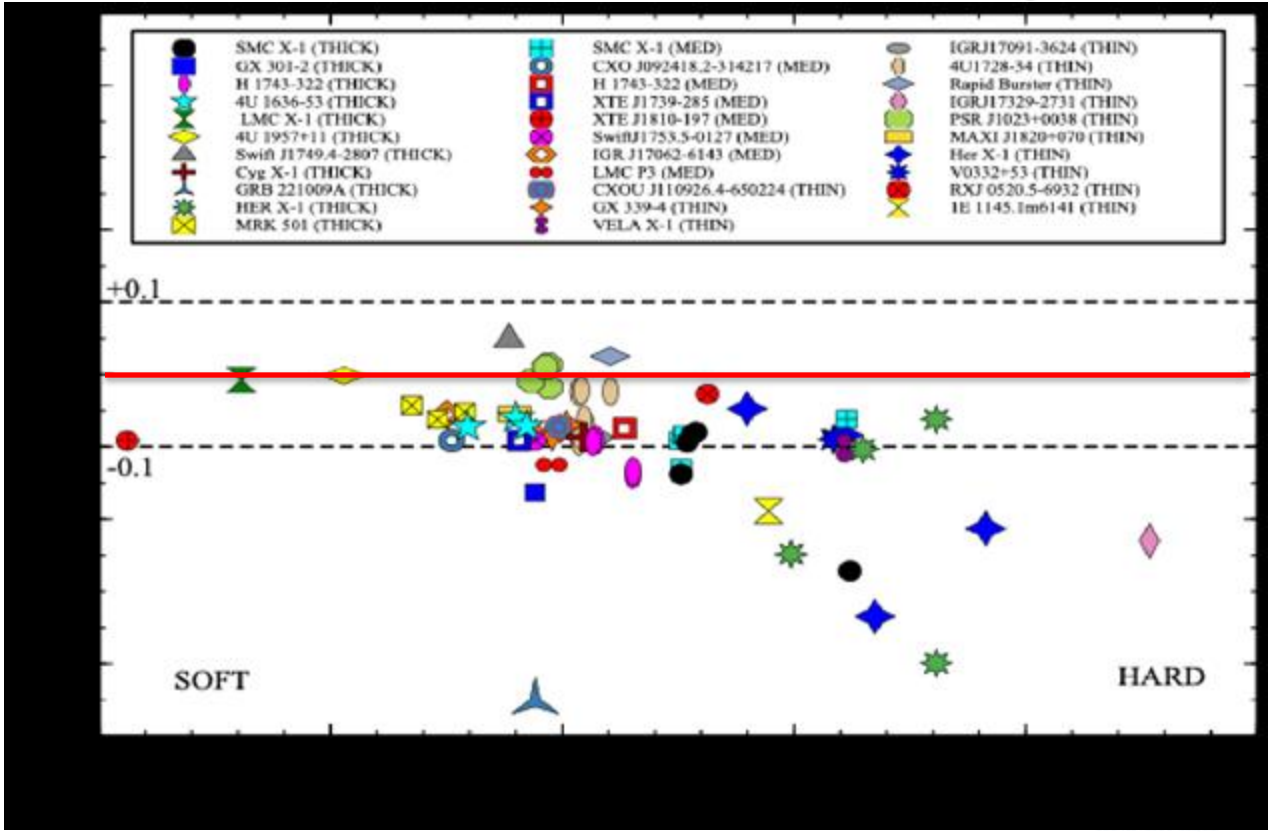
(H–S)/(H+S) HR cts/s vs ΔΓ

High S/N so 1-3% error

There is some scatter above ΔΓ = ±0.1

Hard pn spectra tend do disagree most with FPMA

Work in progress!



Current status and outlook

Flux difference of ~20% obvious in most of the sources with some outliers

Slope difference of ±0.1 for most of the all targets with some pronounced outliers

As this is all in working progress we still searching some more forms of correlations (if any!).

Outliers like MAXI J1348-630, HER X-1, 4U1636-53 will make my life even more complicated

w.r.t. *NuSTAR*
XMM flux typically lower by ~ 20%
XMM spectrum softer ($\Delta\Gamma \sim 0.1$)

Work is ongoing to create automated pipeline, add more sources. Any change to calibration can be immediately checked.

Conclusion

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

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

Short-term goal: Investigate the Δconst, ΔΓ by using HR cts/s (✅).

Short-term goal: Optimize the analysis by considering **COMMON GTIs** (when possible as not many coordinated observations have necessarily a common GTI).

So case by case study might be required

Mid-term goal: Investigate the Δconst, ΔΓ behavior w.t.r. to the **number of columns removed** for pileup sources.

Long-term goal: Also investigate the change in centroid energy of Feκα emission line seen between EPIC-pn timing mode and NuSTAR.