ENERGY SCALE IN EPIC-PN TIMING MODE

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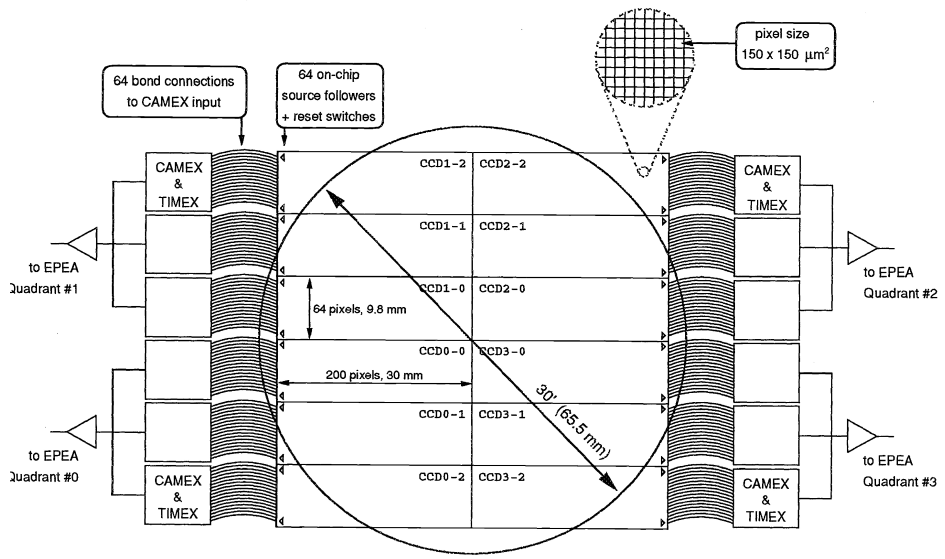
Outline

- What is the “Timing Mode” in EPIC-pn?
- Count rate dependence of the energy scale
  - Initial solution: Rate-Dependent CTI (RDCTI)
  - Underlying cause: X-Ray Loading (XRL)
- A new scheme to calculate the EPIC-pn Timing Mode energy scale in SASv13
- Accuracy of the energy reconstruction
- Future work

Refresher on Timing Mode

(Kendziorra et al., 1997, SPIE, 3114, 155; 1999, SPIE, 3765, 204)



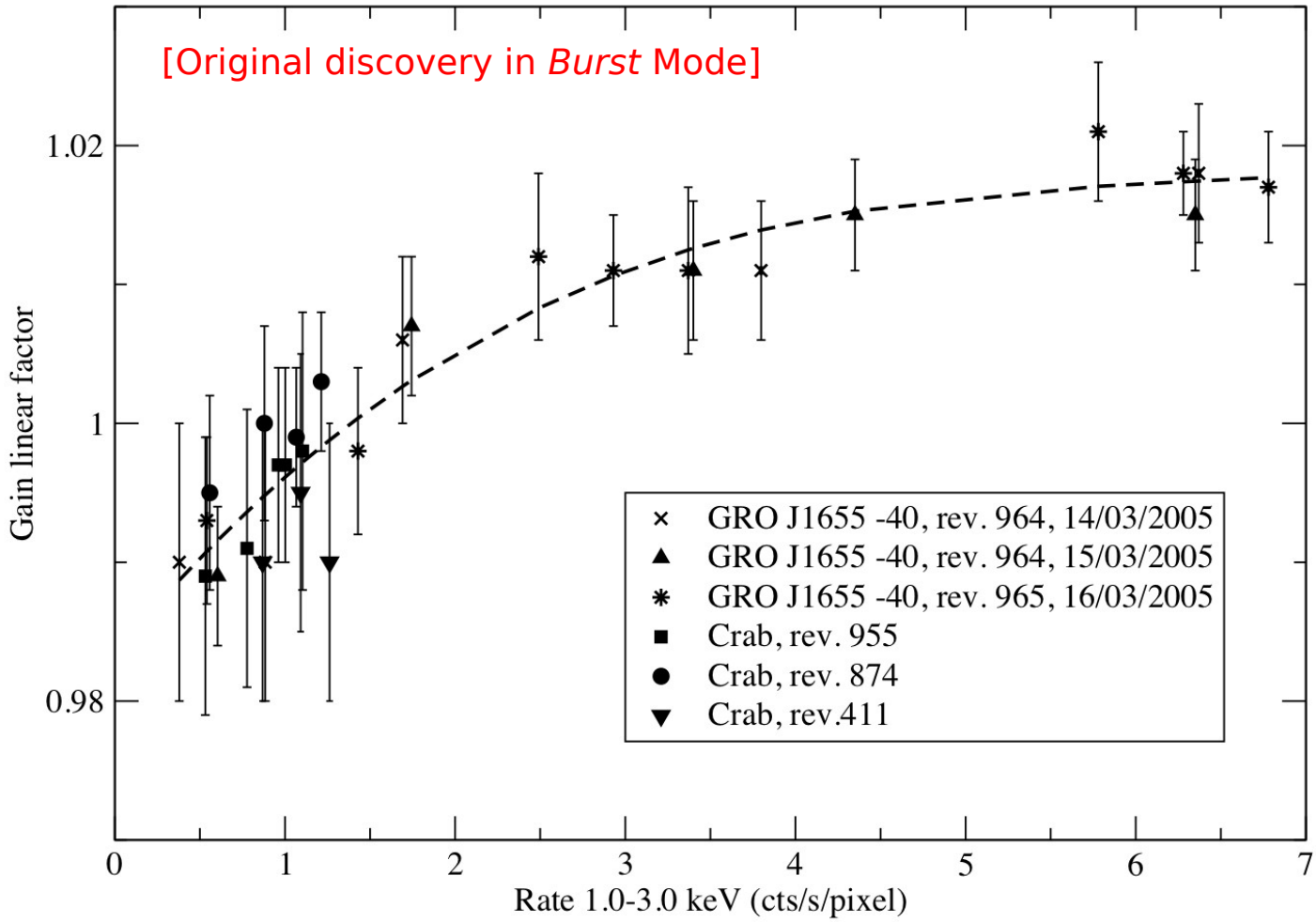
Mode	Integration Time[1] *in msec*	Transfer Time [2] *in ms*	Readout Time/CCD *in ms*	Max. Surface Brightness *in Ph./cm² sec*	Brightest Point Source for XMM[3] *in mCrab*
Full Frame 400 x 384 pixel	65.6	N.A.	4.654	$2.0\ 10^3$	0.67
Large Window 200 x 256 pixel	27.1	0.072	2.494	$6.8\ 10^3$	1.62
Timing (eff.pixel 150 x 1500 μm²)	0.03	N.A.	N.A.	$3.7\ 10^5$	146
Burst (180 lines read)	0.007	N.A.	4.195	$1.6\ 10^7$	$6.31\ 10^3$

- Only CCD#4 is operated
- The CCD is read-out continuously
- Information of 10 lines (“macro-pixels”) is shifted to the anodes; the integrated charge of 64x10 pixels are converted by the CAMEX and further processed
- All events are “out-of-time” ⇒ the positional information along the shifting direction is lost
- 0.03 ms time resolution with a 99.5% live time
- Pile-up threshold ~800 counts/seconds
- Preferred mode to observe bright X-ray Binaries (XRBs; ~300 observations in the science archive)

Rate-dependent energy scale

(Sala et al., 2006, ESASP, 604, 291)

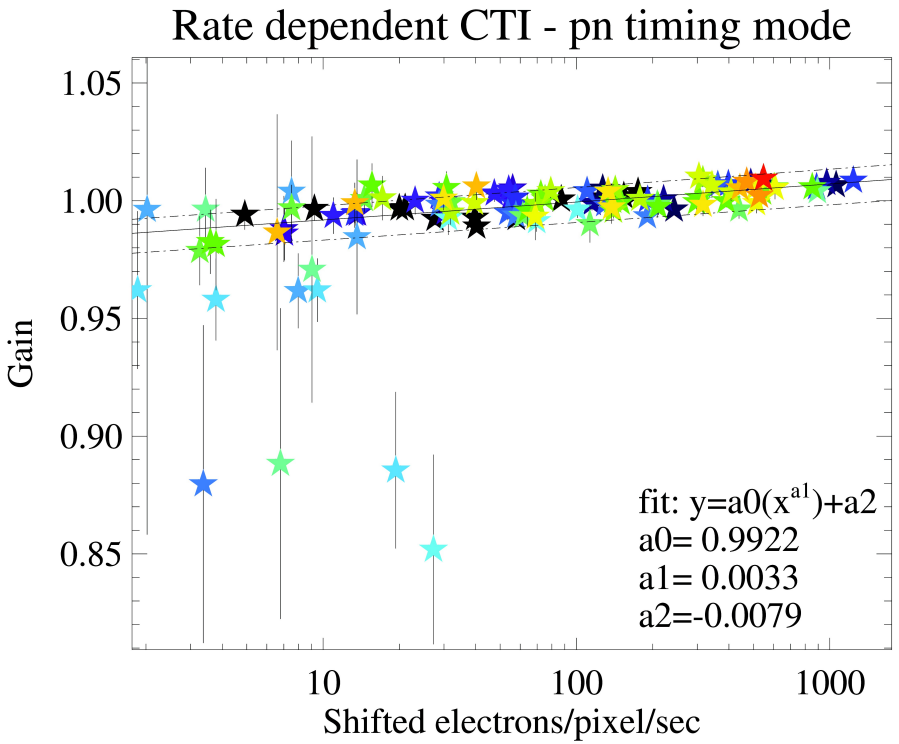
2005: the energy scale in EPIC-pn Fast Mode depends on the count rate



First calibration: RDCTI

(Guainazzi et al., 2008, XMM-CCF_REL-0245; Guainazzi, 2009, XMM-CAL-SRN-0256)

- First calibration of this effect: **Rate Dependent CTI** (**M.Kirsch**)
- Applied as a gain factor: $G=E_{orig}/E_{corr}$
- Calculated as the `gain fit` factor minimizing the χ^2 statistics in the 1.5-3 keV energy band on a sample of non-variable XRB spectra
- Calibrated against the number of shifted electron *in a given column*
- Applied by the SAS task `epfast`
- Issues:
  - Dependence on the astrophysical model chosen to fit the data
  - Not fully self-consistent: the RMF assumes a pattern fraction distribution on the whole PSF, which may differ from that of a single column
  - Wrong energy dependence if CTI
- However, it works: ±20 eV for E≤4 keV; ±50 eV for E≈6 keV

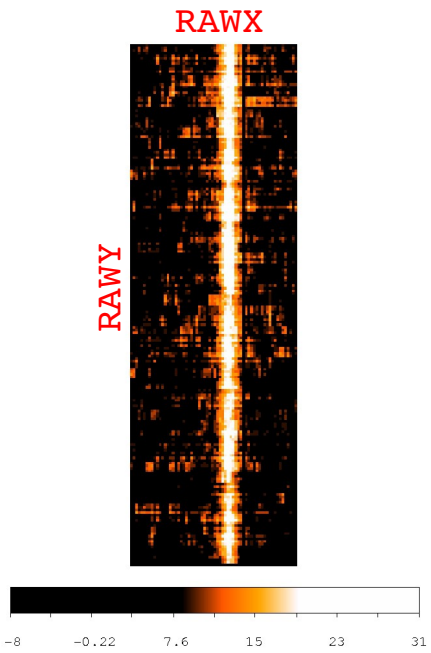


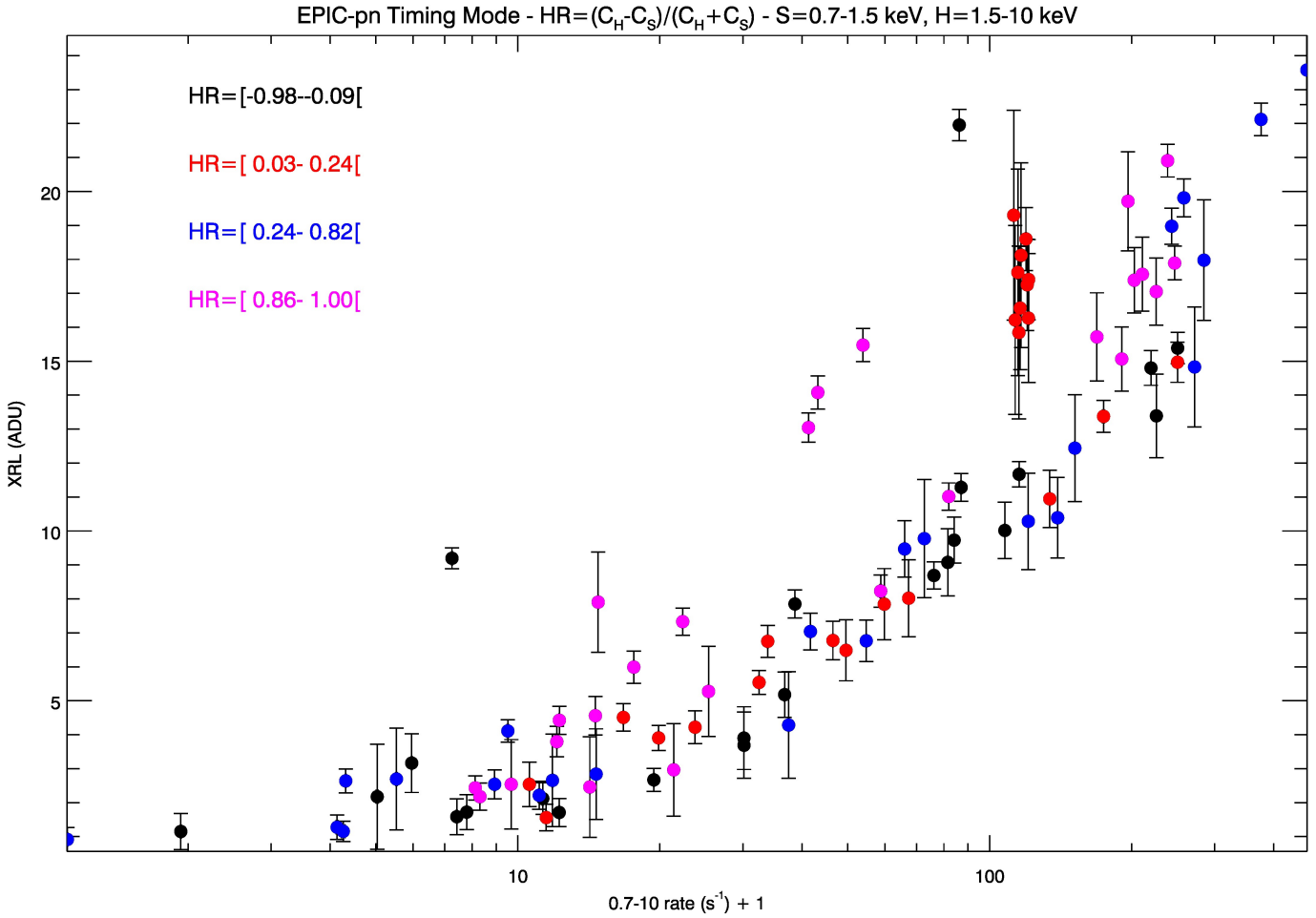
X-Ray Loading (XRL)

(Smith, 2004, XMM-SOC-CAL-TN-0050; Guainazzi et al., 2012, XMM-SOC-CAL-TN-0083)

2009: serendipitous “re-discovery”[1] (**M.Smith**) of ubiquitous X-Ray loading (XRL)

Offset map with XRL
(= source contamination)





[1]original discovery by **K.Dennerl** and **M.Freyberg**

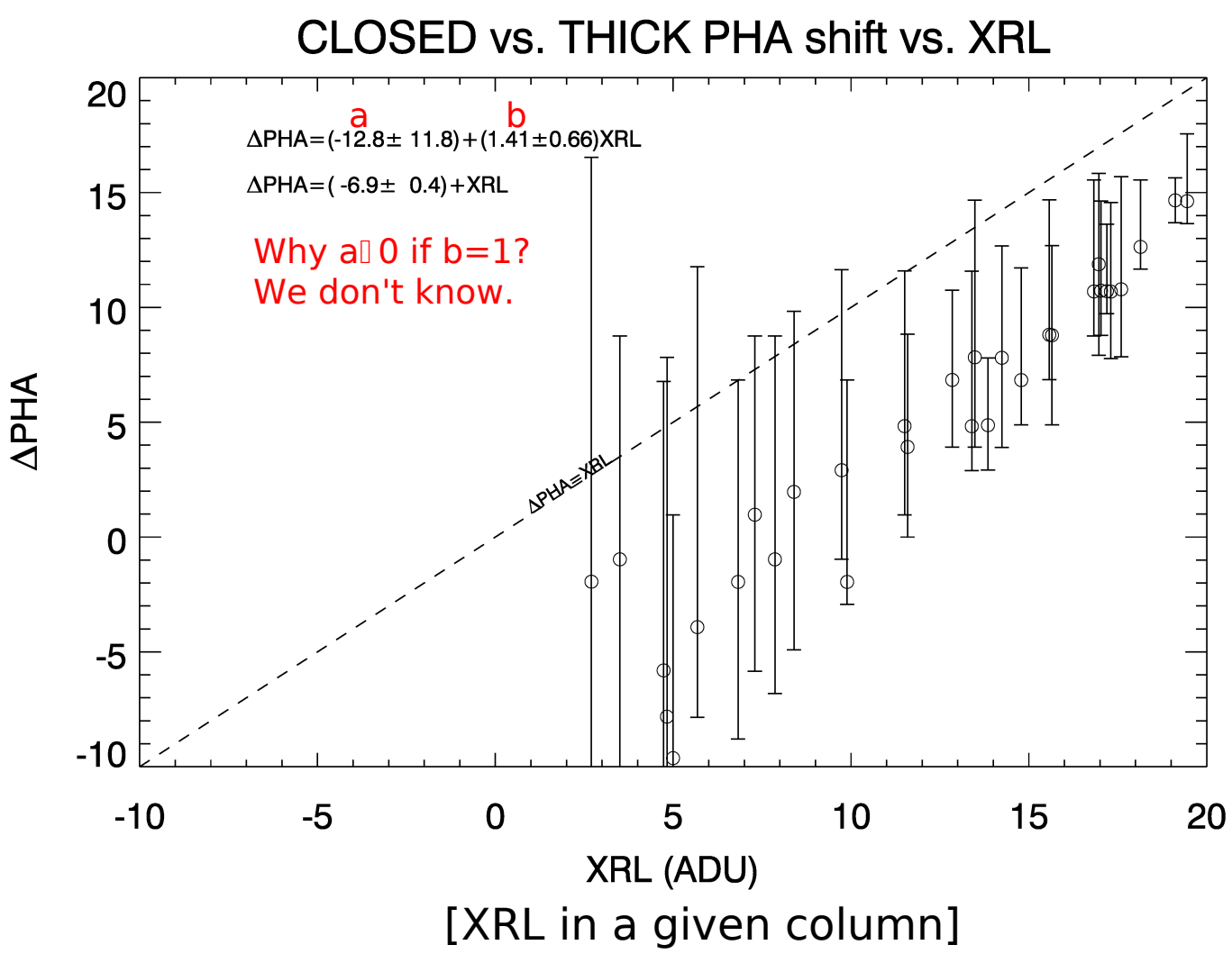
EPIC-pn Timing Mode energy scale re-calibration

- As of May 2012 offset maps prior to EPIC-pn exposures in Timing Mode are taken in CLOSED filter, to avoid contamination by celestial sources
- However, we have 12 years of data in the archive affected by XRL re-calibration required!
- Strategy:
  - Evaluate the spectral impact of XRL by comparing the PHA spectrum taken with an offset map in science filter against a spectrum taken with an offset map in CLOSED filter experiment performed on the Crab Nebula in September 2012
  - Re-calibrate any residual rate-dependent effect of the energy scale through a) an algorithm independent of any astrophysical assumption and, b) without passing through XSPEC spectral fitting
  - *[XRL has an effect on the energy scale as a function of count rate which is the opposite to what observed by Sala et al. In 2006. Some sort of RDsomething is still required after XRL is corrected]*
- Status: calibration completed. New software installed in SASv13, undergoing science validation
- Results on the energy scale accuracy are therefore still **preliminary**

XRL spectral impact

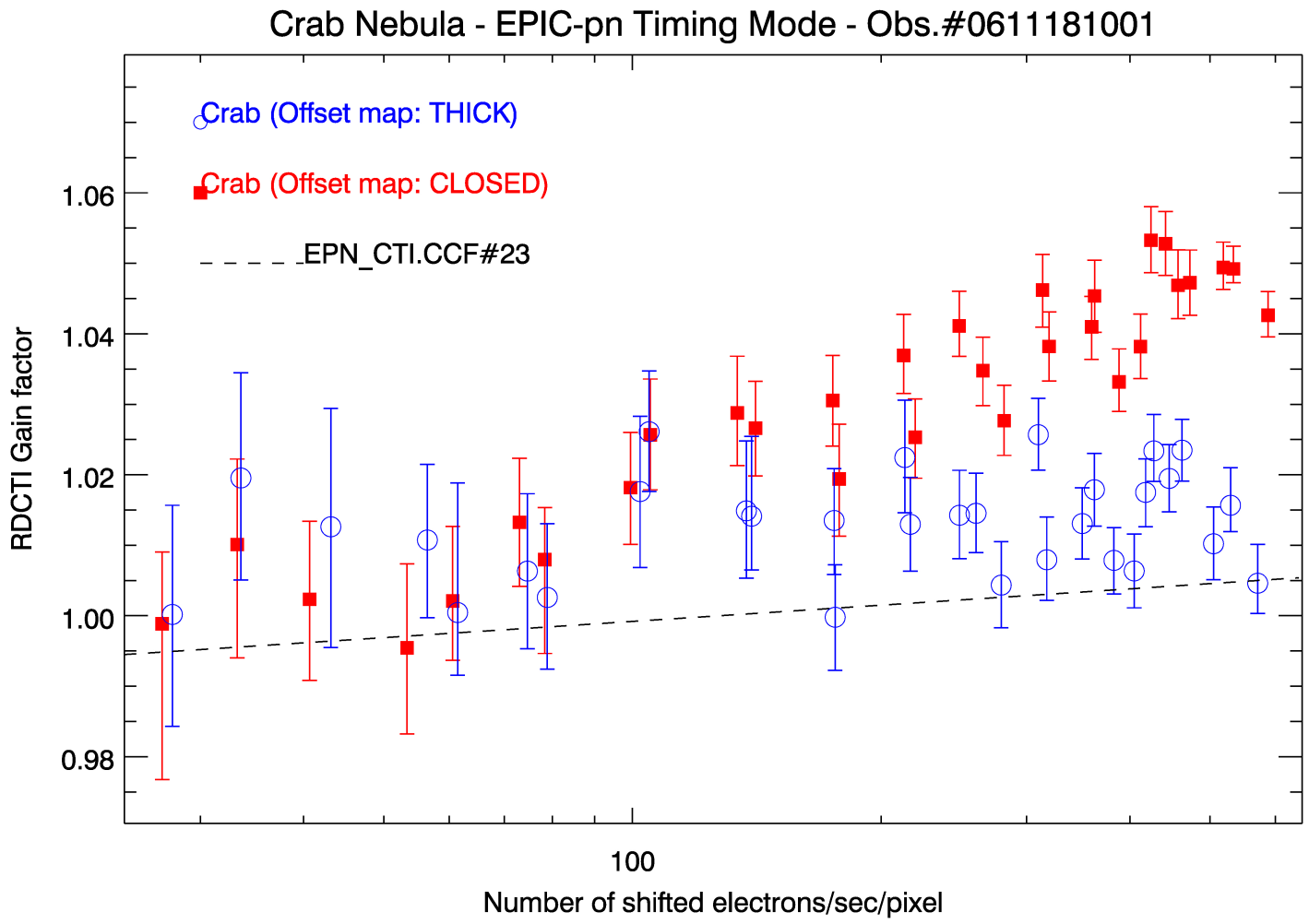
(Guainazzi & Smith, 2013, XMM-CCF-REL-0296)

Shift in PHA scale required to optimally re-align the spectrum taken with an offset map in CLOSED to the spectrum taken in THICK filter



Post-XRL correction RD*something*

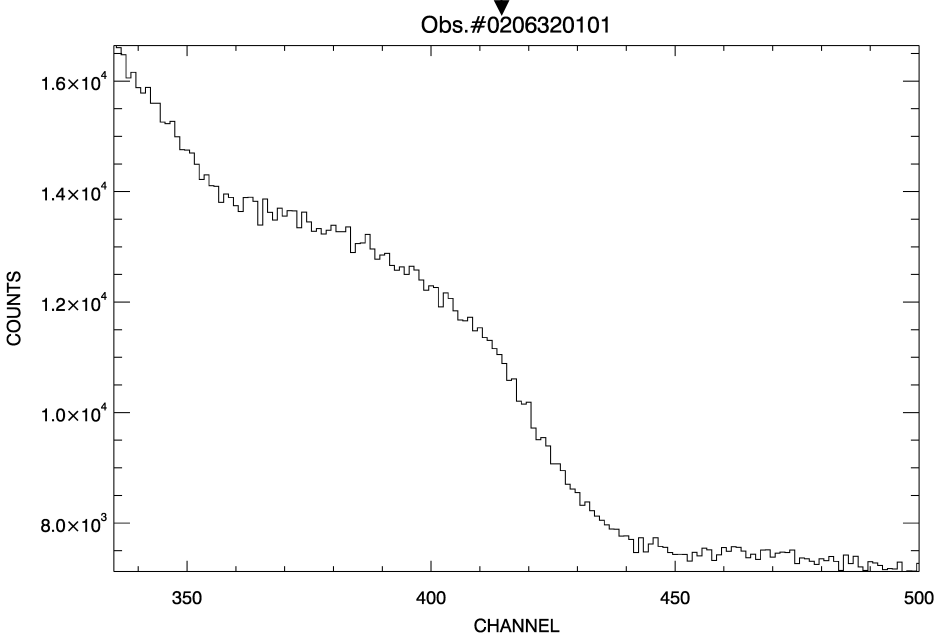
(Guainazzi, 2013, XMM-CCF-REL-0295)

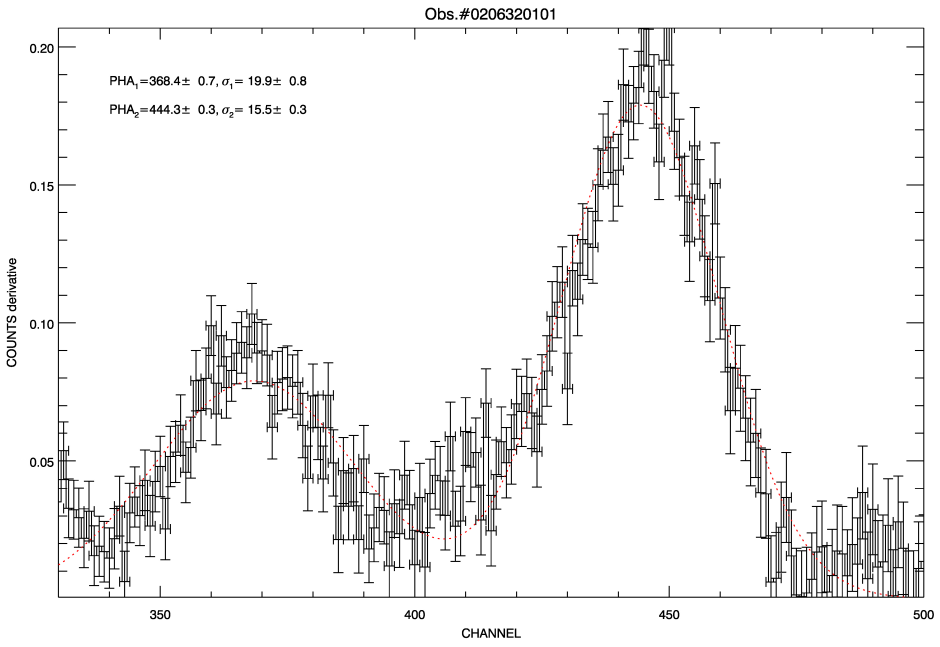


A novel approach: the RDPHA correction

(Guainazzi, 2013, XMM-CCF-REL-0295)

Original spectrum in PHA space $\Rightarrow$ $dC/d(\mathrm{PHA})$ $\Rightarrow$ "derivative" PHA spectrum

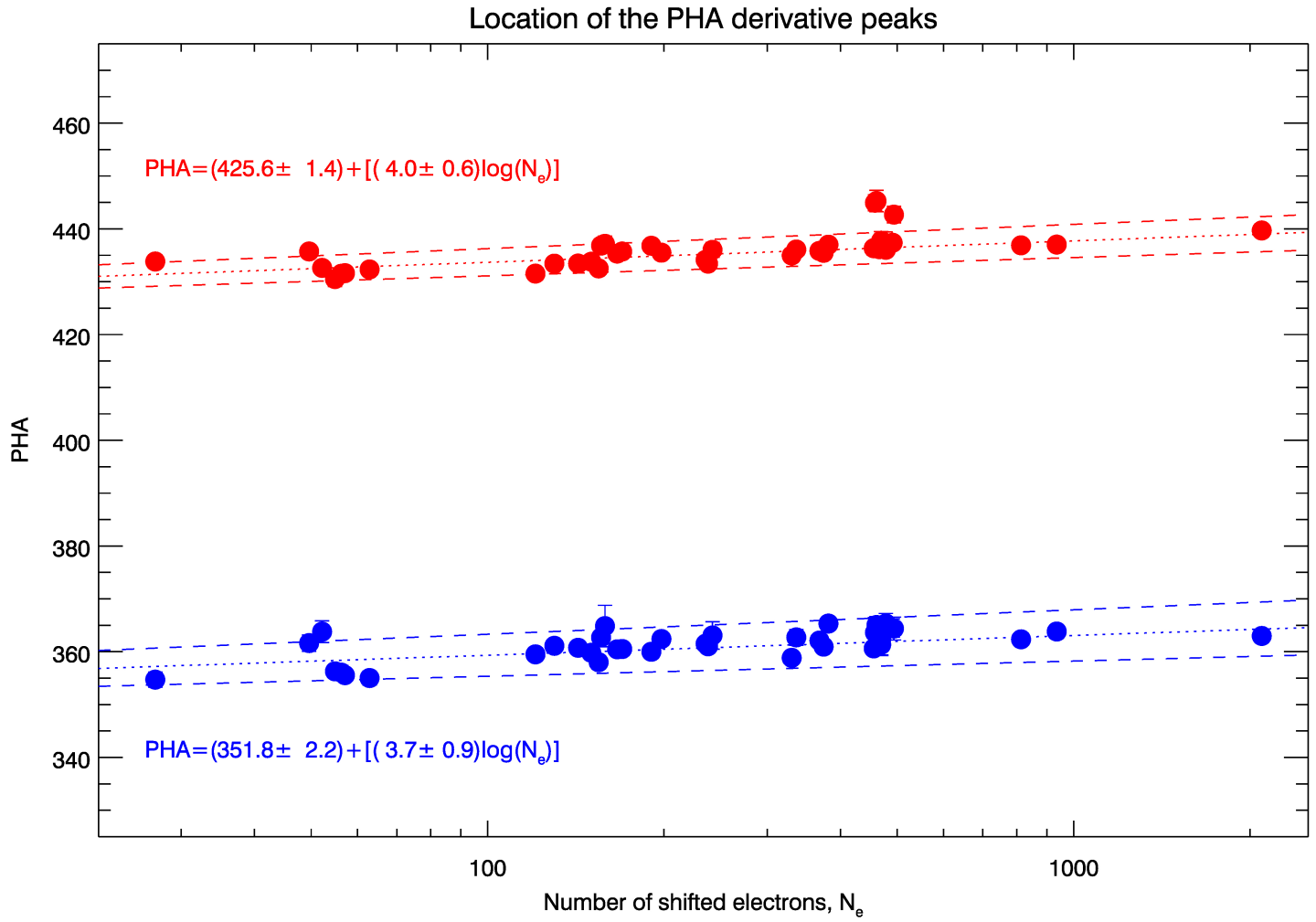




In the derivative spectrum, the location of the effective area large gradients can be used as a sensitive probe of the energy scale

RDPHA calibration

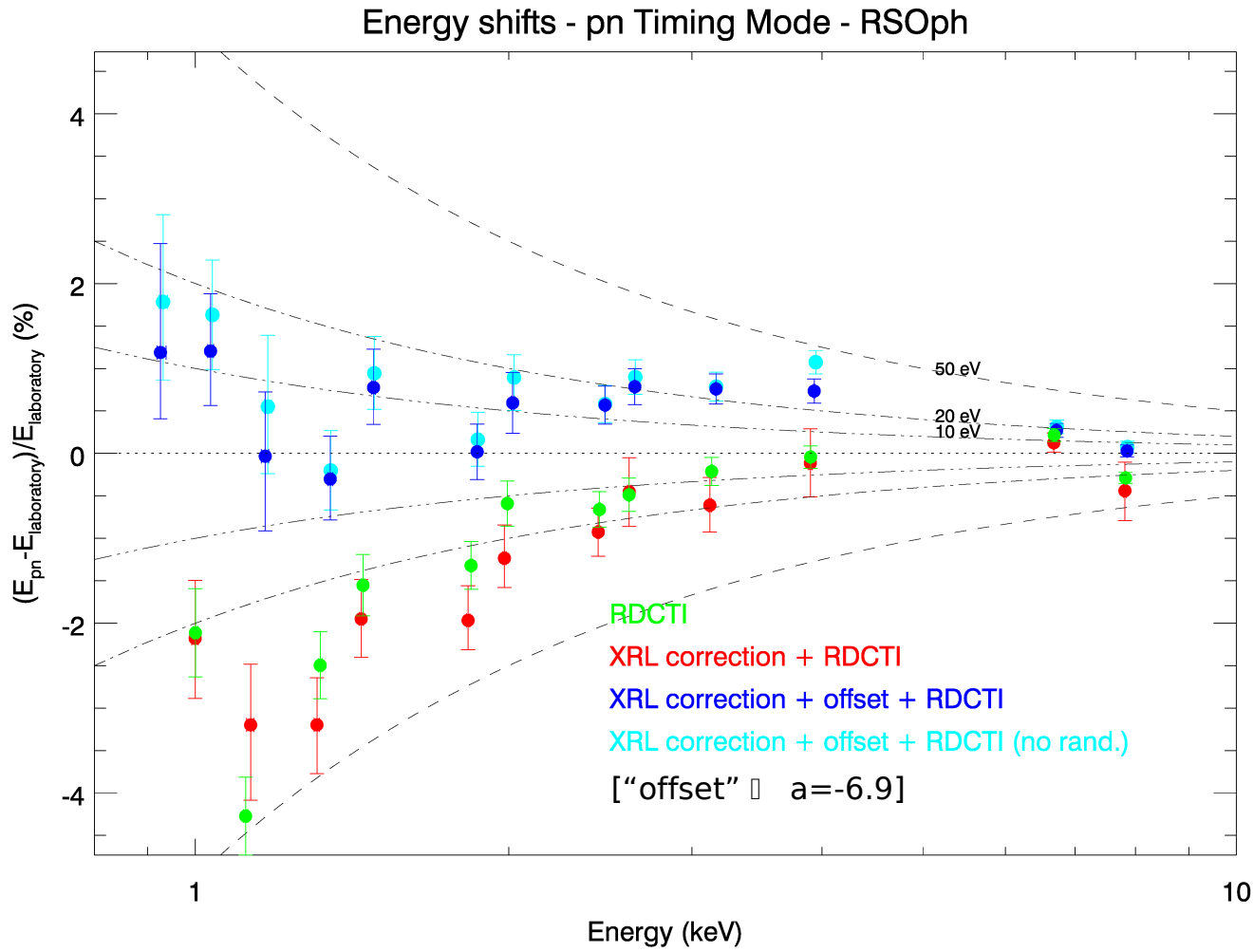
(Guainazzi & Freyberg, in preparation)



Implemented in `epevents` (SASv13)

Performances: energy scale on RSOph

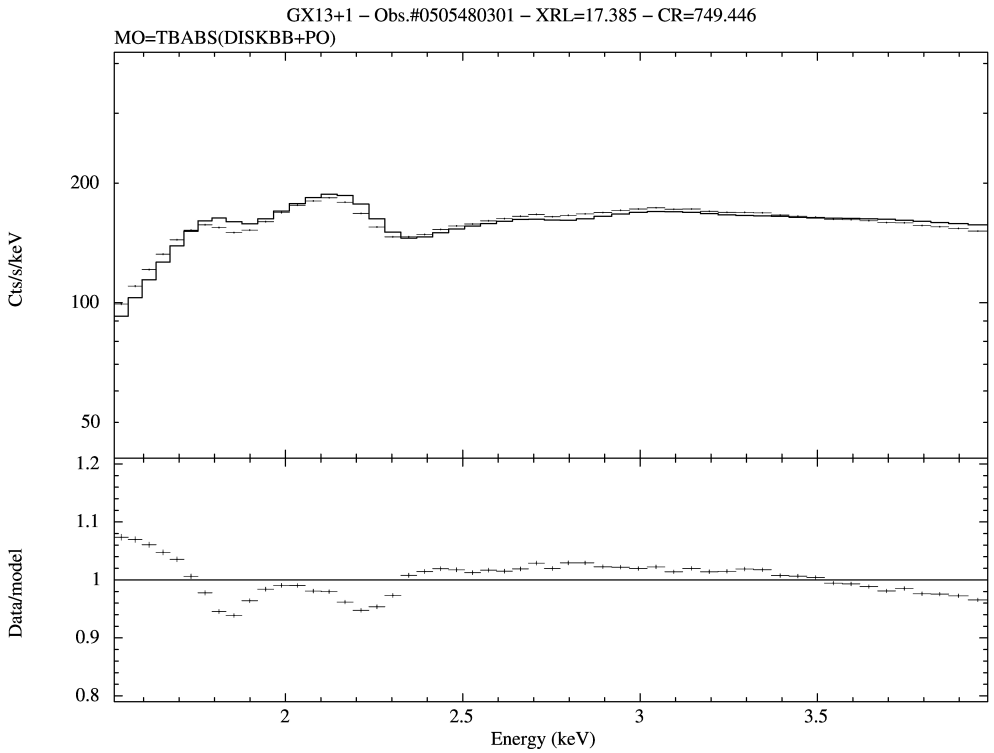
(Guainazzi & Freyberg, in preparation)



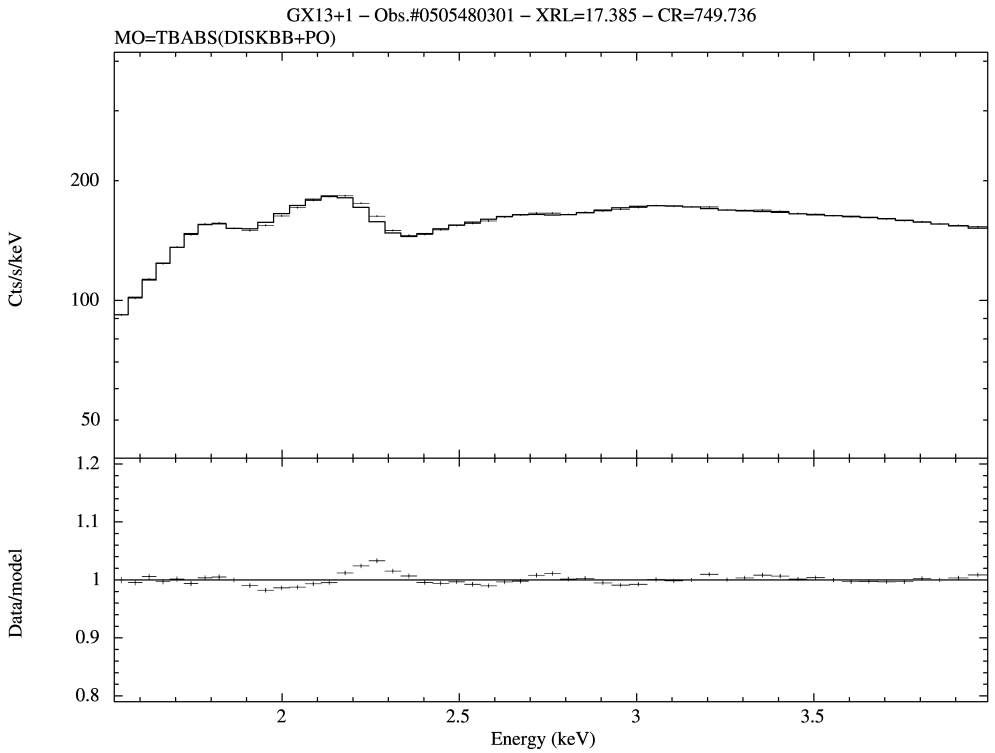
Performances: Si+Au instrumental edges

(Guainazzi & Freyberg, in preparation)

Without RDPHA



With RDPHA

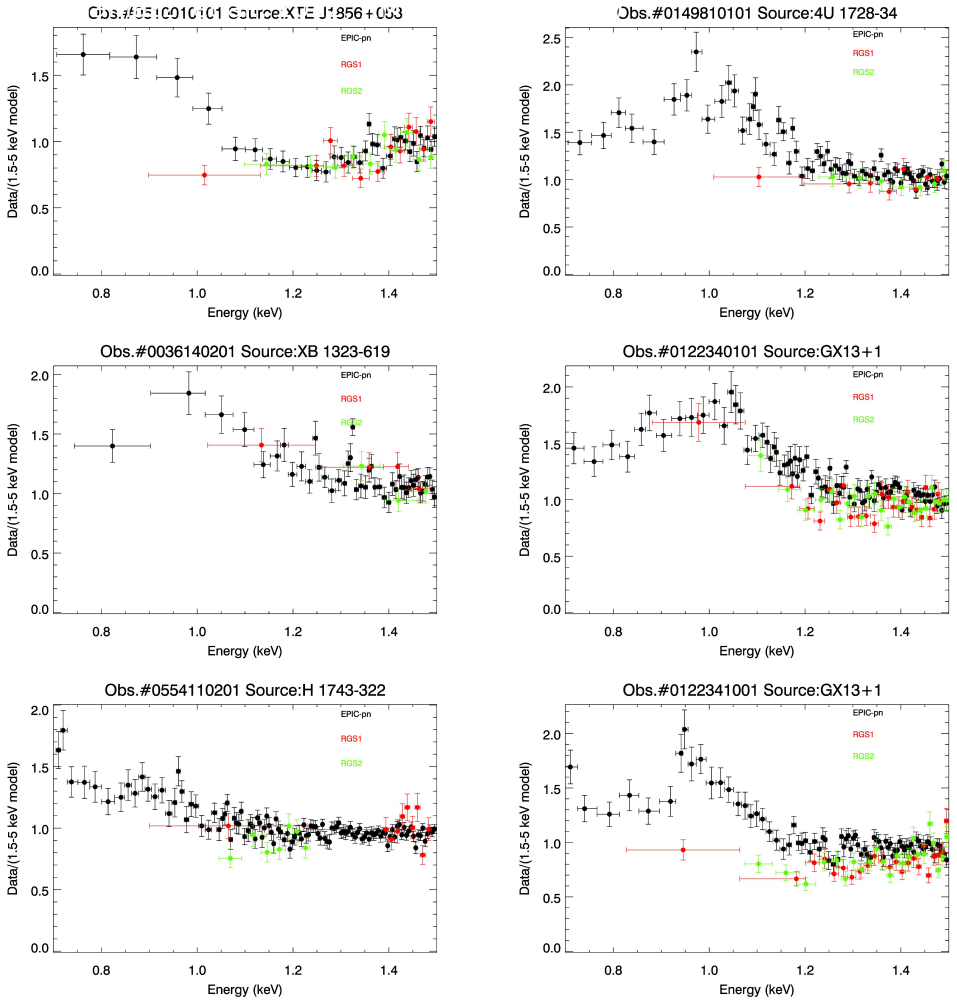


[This observations is a quite extreme case, count rate close to pile-up]

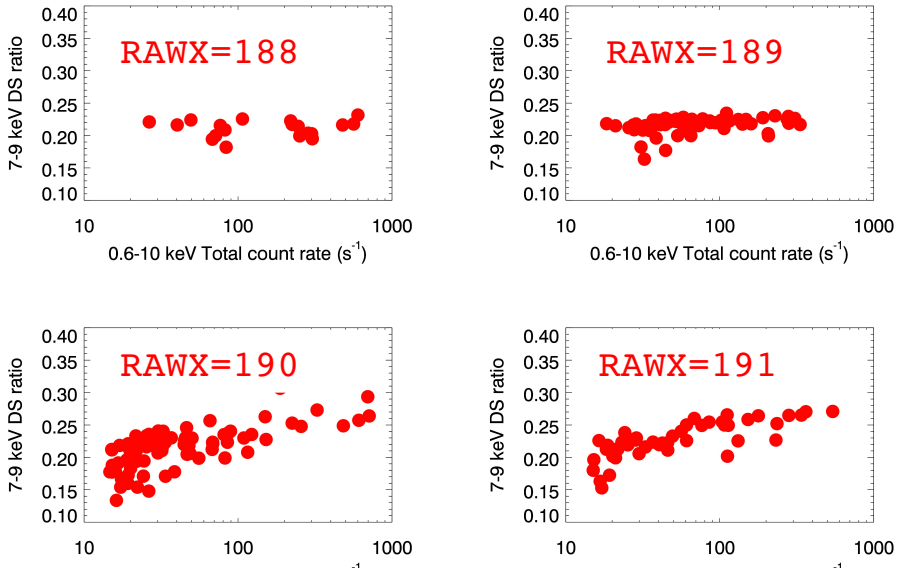
Soft X-ray redistribution

(Guainazzi et al., 2012, XMM-SOC-TN-0083)

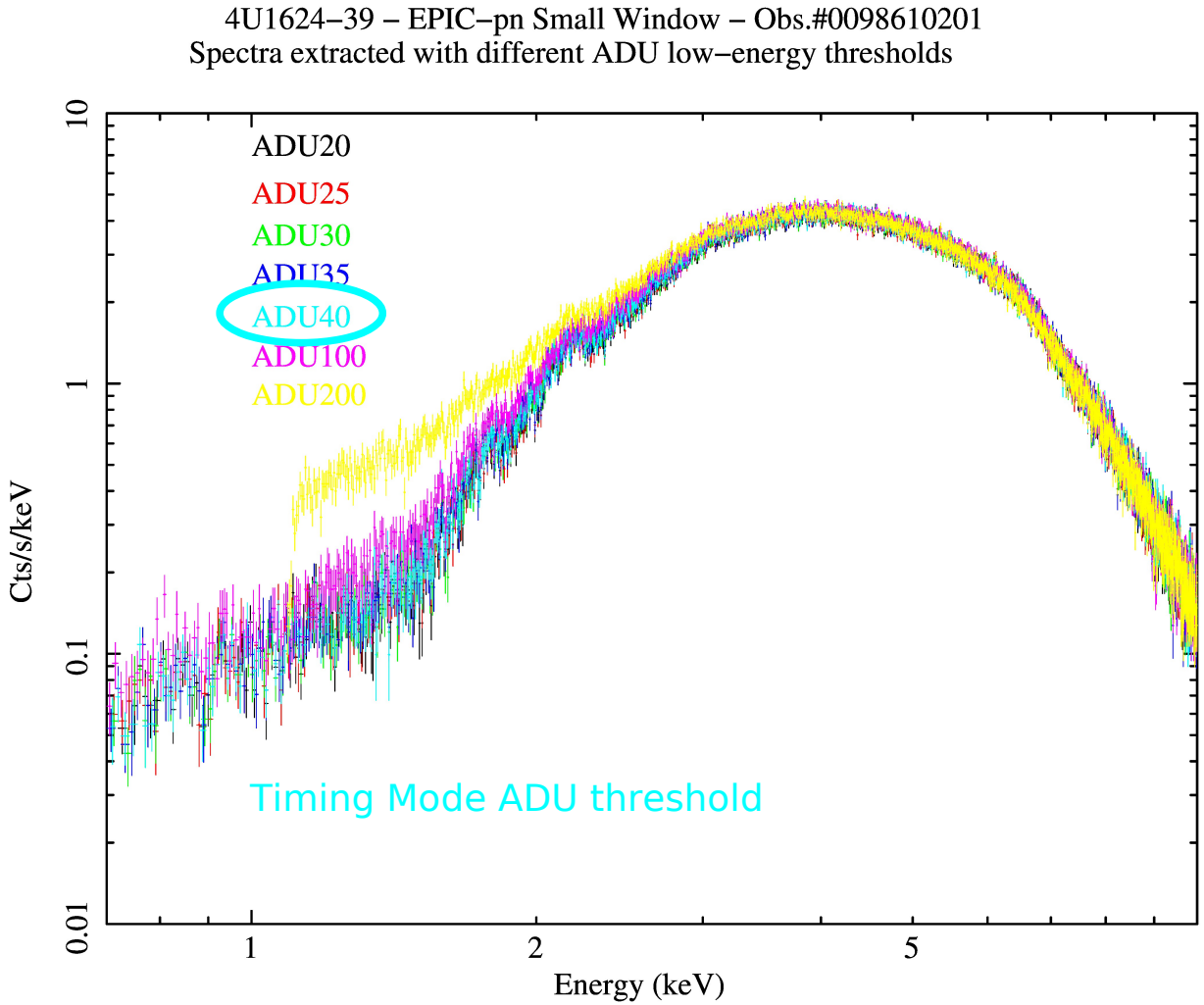
(Guainazzi et al., 2009, XMM-CCF-REL-265)



Double-to-single ratio in the 7-9 keV energy band for different source boresight positions



Threshold effect?



Conclusions

- Stay tuned to the SASv13 Science Validation Report (to be published in the second half of April)!
- On a longer time-scale, we aim at applying the same scheme to EPIC-pn *Burst* Mode
- Redistribution: should we coordinate an observation of an obscured binary between PN/TM, XRT/WT and ACIS/CC?
  - For PN it would be interesting to observe it in two different position with respect to the first micro-pixel border