

Updating the EPIC-pn effective area with the help of *NuSTAR*

Felix Fürst • 06.04.2021

A dark blue diagonal gradient bar that starts from the bottom left corner and extends towards the top right corner, covering the lower half of the slide.

Overview

Basic Problem

Simultaneous observations between *XMM-Newton* and *NuSTAR* always often cross-calibration residuals (slope, off-set and other small features).

Expected outcome

Correction to EPIC-pn ARF to remove/reduce those features, or, as a first step a table model to improve the issue.

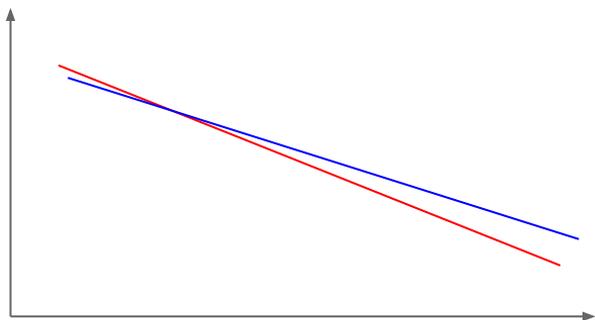
Approach

Use simultaneous observations of Crab and 3C 273 and test with sample of AGN.

Split problem in half

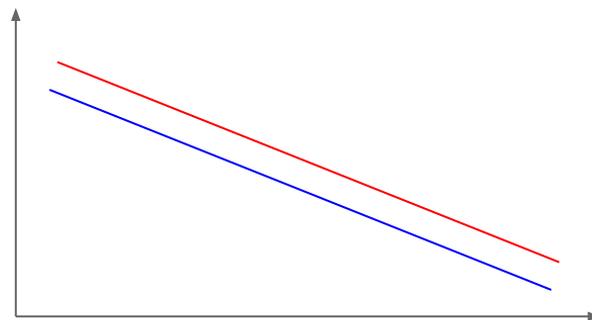
Step 1:

Correction of slope and other spectral features



Step 2:

Correction of off-set aka absolute flux calibration.

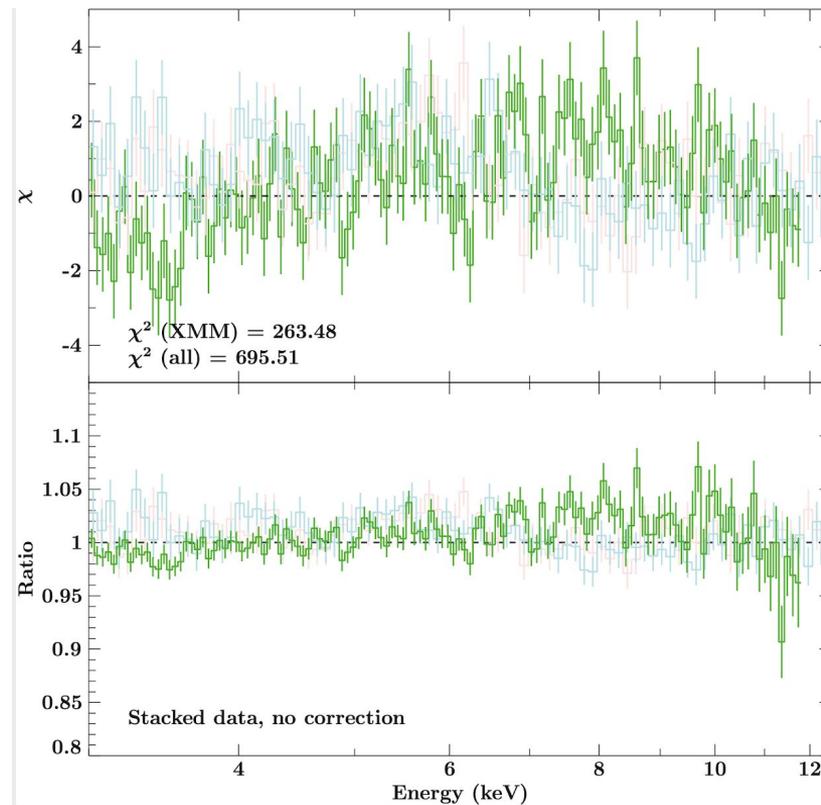


Same issues for sample of AGN

33 AGN observations, with EPIC-pn in small window mode, simultaneously observed with *NuSTAR*.

Fitted with phenomenological models simultaneously, residuals stacked.

Based on work by Amy Joyce.



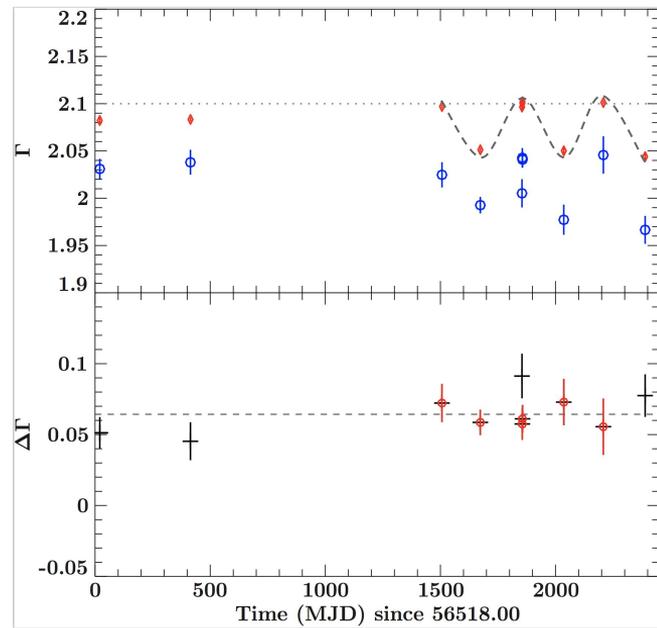
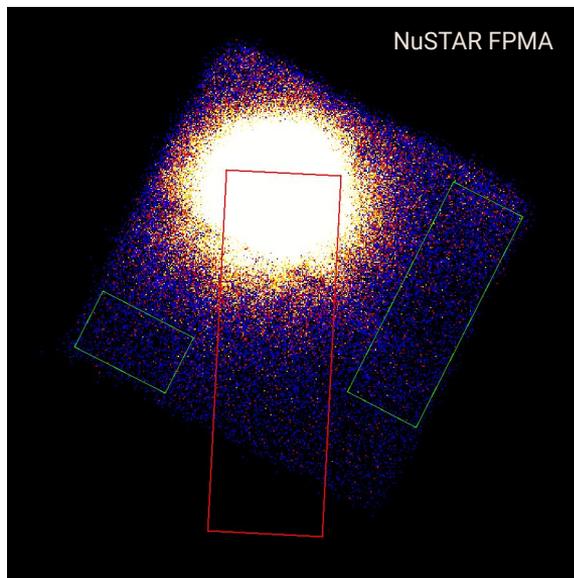
Calibration source: Crab

Crab is extended

EPIC-pn is operated in timing mode.

We need to make sure that *NuSTAR* data is extracted from same source region as CCD4 pn footprint on the sky.

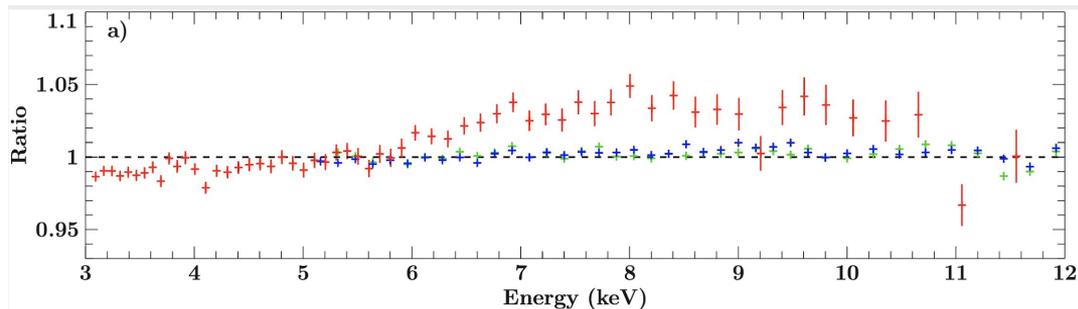
Seasonal change between Northern and Southern are of the remnant.



Crab also shows the “bump”

Stacked residuals of 10 Crab observations between 2013-2020.

Fitted with same photon index for pn and *NuSTAR*.

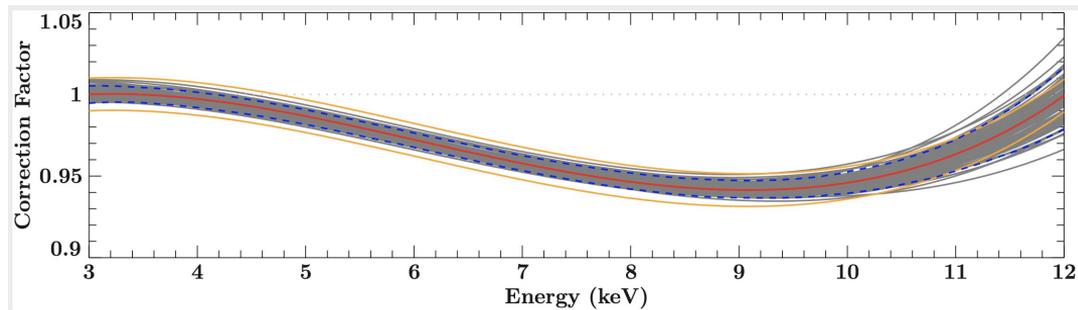
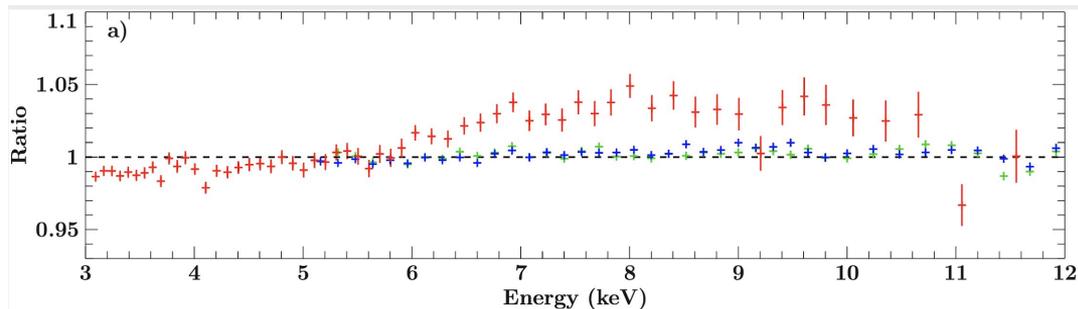


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Correct these residuals with a simple spline, anchored at 3 and 12keV.

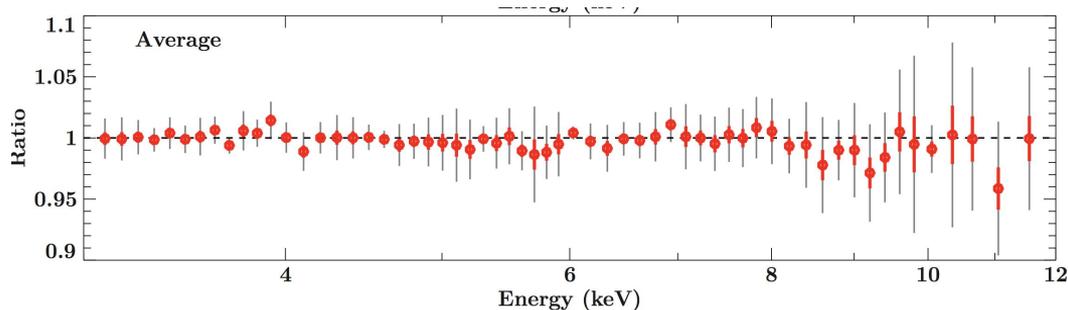


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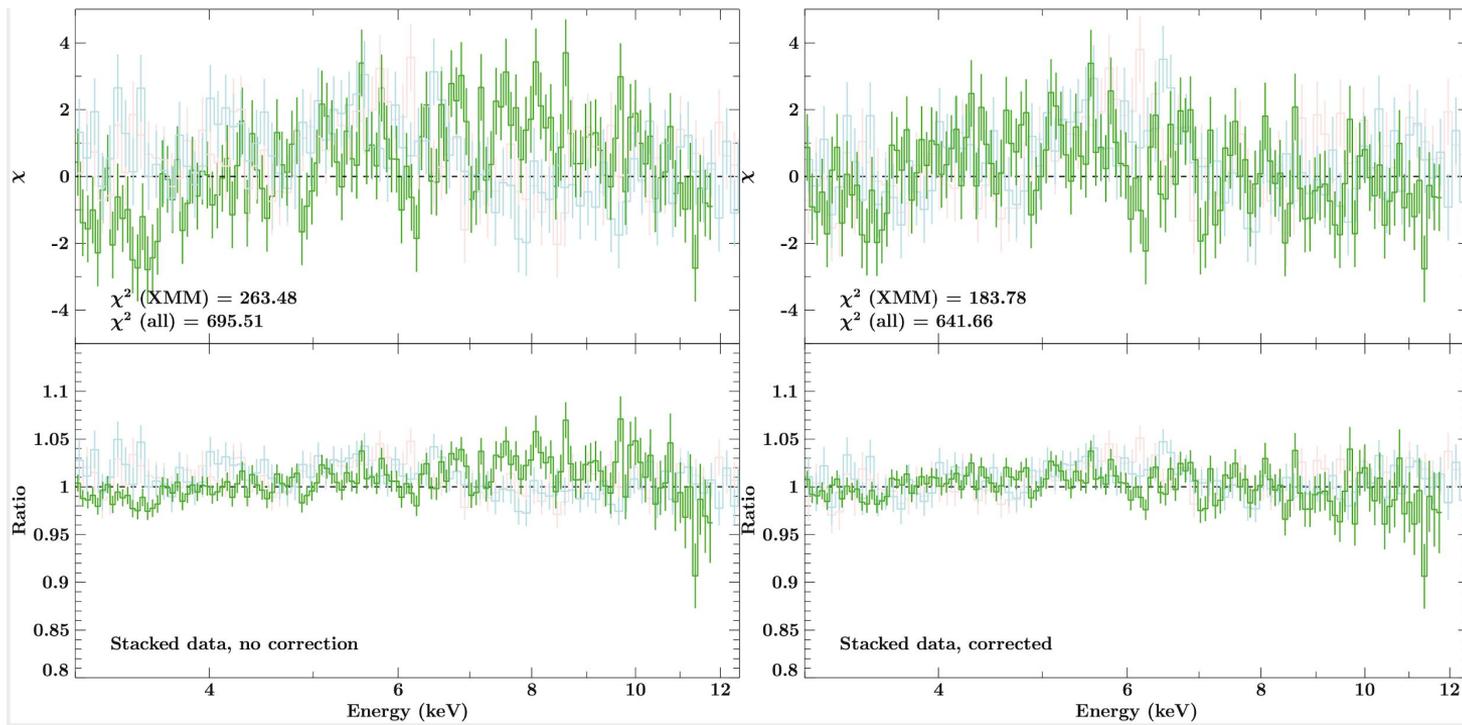
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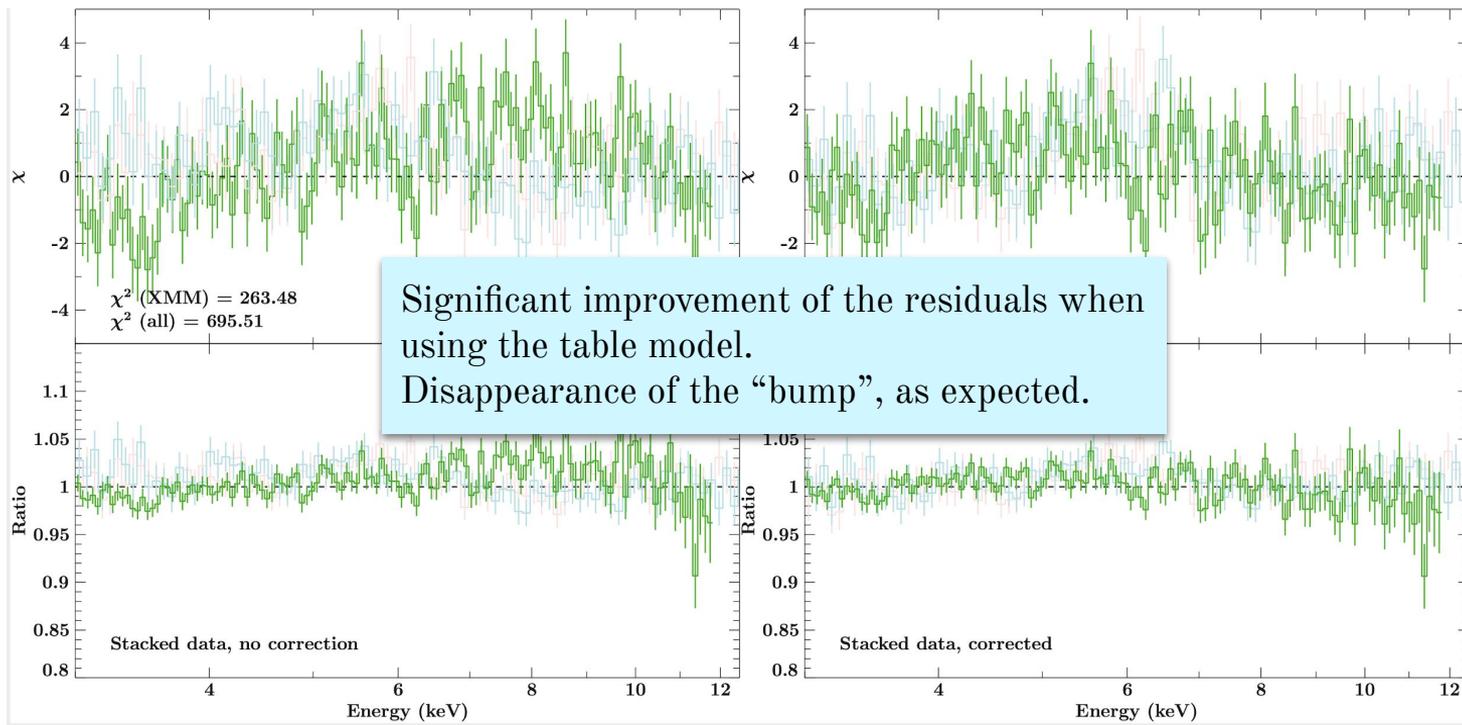
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AGN sample also shows improves



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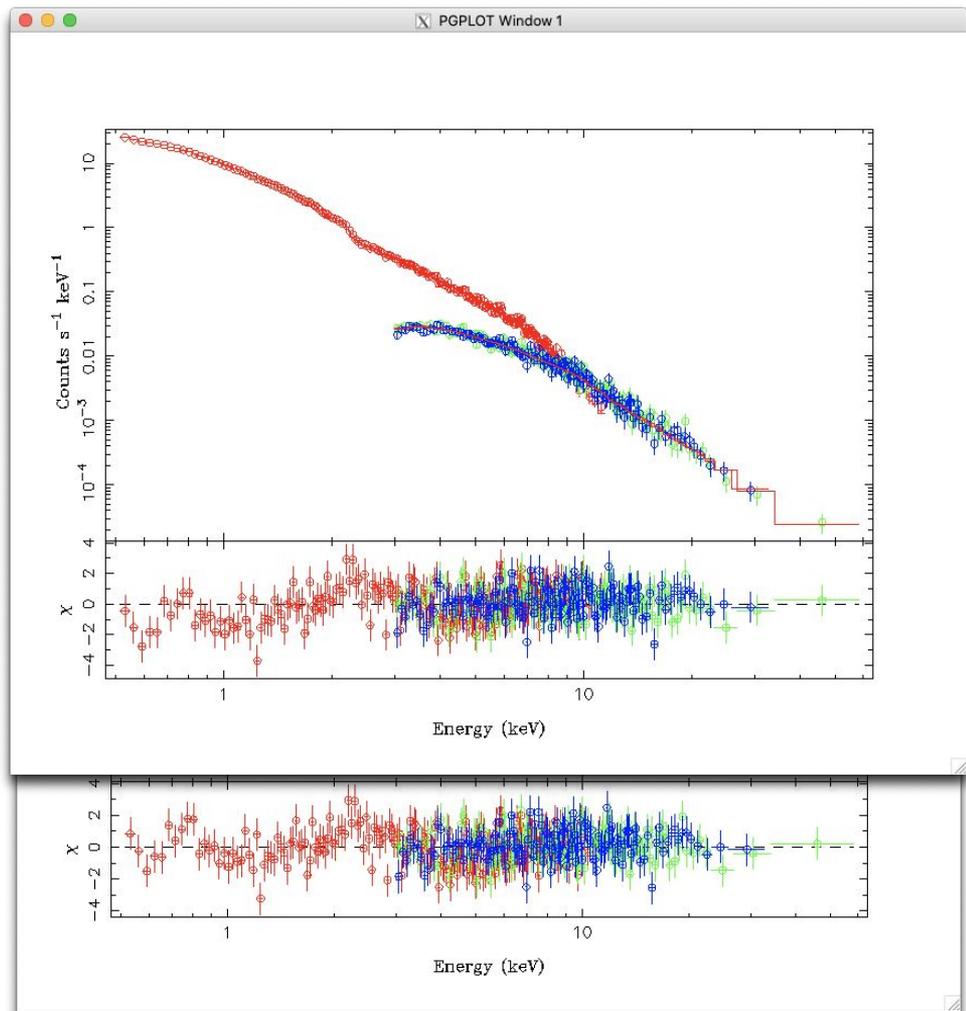


Further tests -- soft band

Correction currently only applied to
>3keV (where we have *NuSTAR* data).

Check that things don't go wonky at
lower energies.

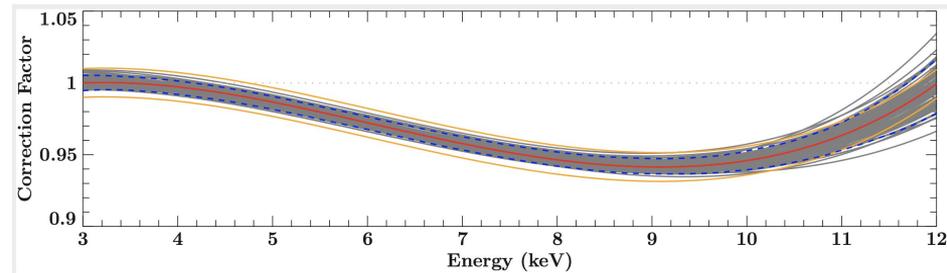
Test for example with PKS 2155-304
(ongoing), but looking good.



Step 1 done

Simple spline smoothes out the “bump” and difference in photon index between EPIC-pn and *NuSTAR*.

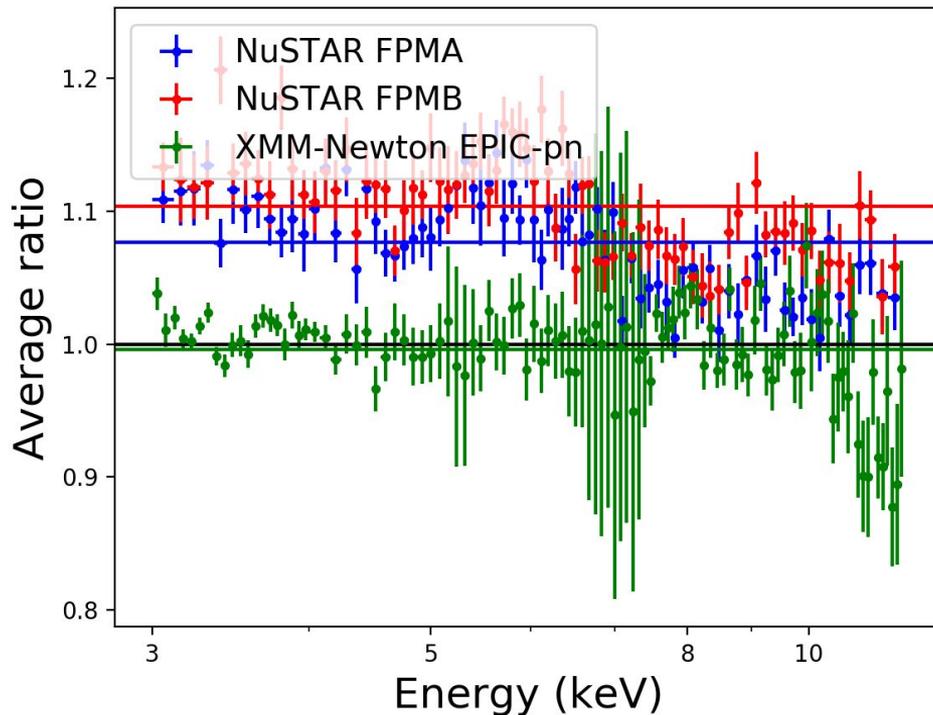
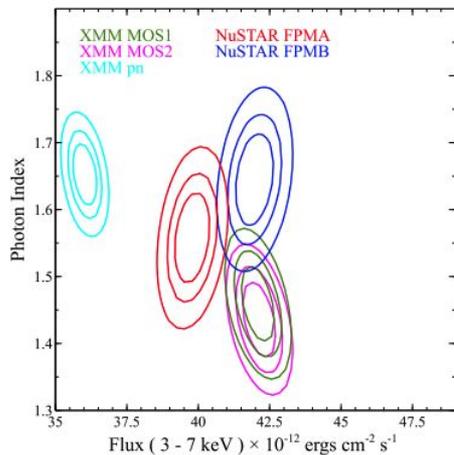
Correction is ~5% at 9keV.



Step 2: flux calibration

EPIC-pn fluxes are typically 10%-15% **lower** than *NuSTAR* fluxes.

See also IACHEC paper (Madsen et al., 2017a)



Absolute Flux correction

NuSTAR observed the Crab as “stray light”, i.e., without the optics.

Avoids largest calibration uncertainty.

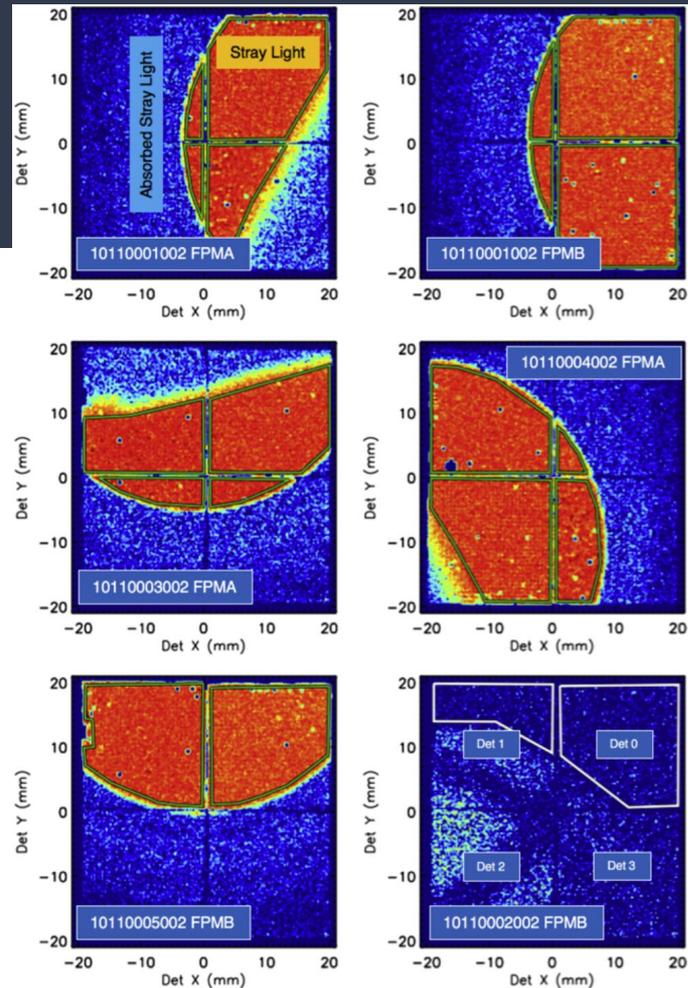
Gives a “true” answer to the Crab flux and spectrum:

$$\Gamma = 2.106$$

$$\text{Flux} = 3.368e-8 \text{ erg/cm}^2/\text{s} \text{ (3-50keV)}$$

i.e., ~12% higher than implied from pointed / calibrated observations

(Madsen et al., 2017b)



NuSTAR correction

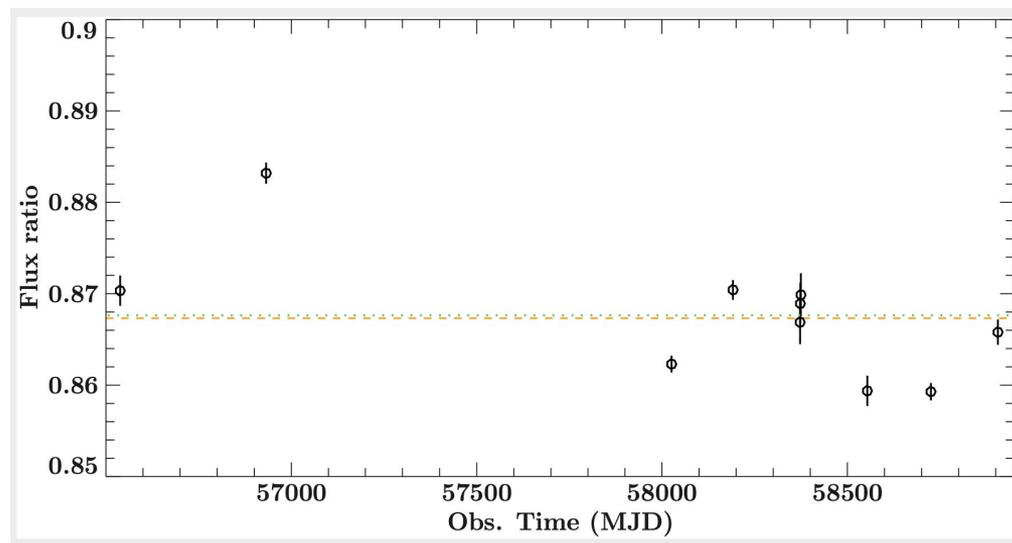
In *NuSTAR* we can extract a very large region (200"), covering all of the Crab, just like the stray light.

NuSTAR is already calibrated assuming the Crab has $\Gamma = 2.1$, which is very close to the truth.

Main difference: flux!

Correction factor: focused/stray = 0.866

See also Madsen et al. 2017b

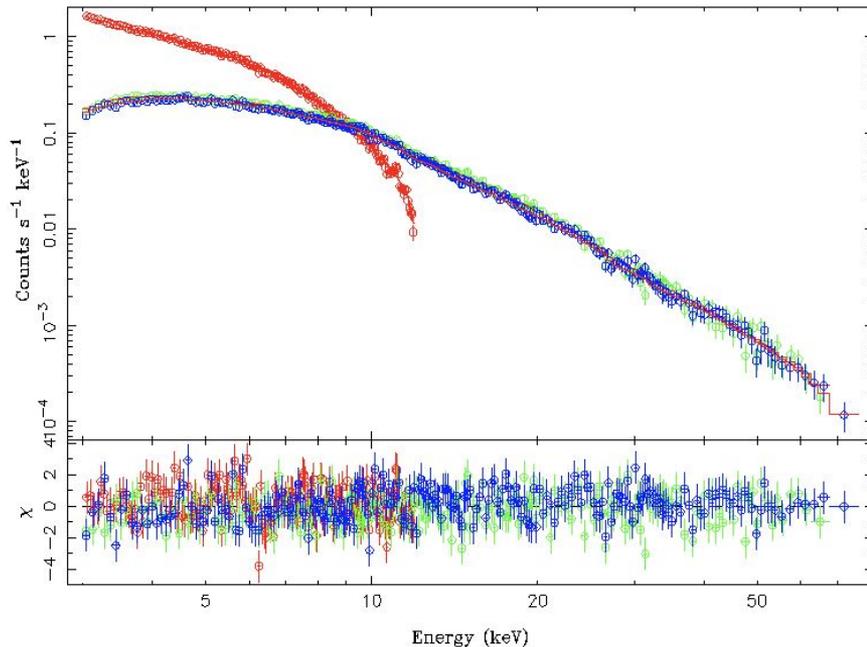


Apply Correction to 3C 273

7 epochs of 3C 273 data between 2012-2020.

Fitted with `cutoffpl + xillver` (`xillver` normalization fixed in all epochs, distant reflection, see Madsen et al. 2015).

Apply correction shape from Crab fitting; fix FPMA constant to 0.866



Apply Correction to 3C 273

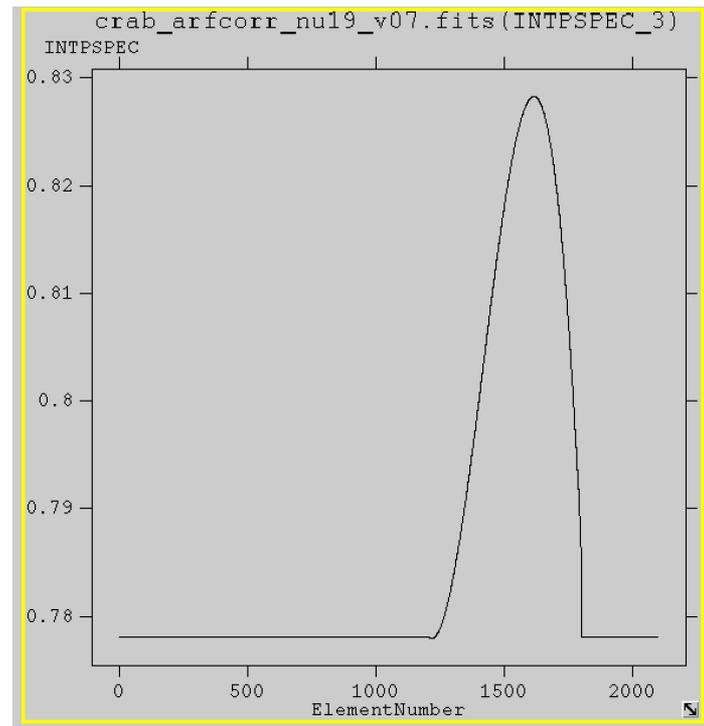
Model provides a very good fit ($\chi^2_{\text{red}} \sim 1.0$).

Correction factor is

0.7824 +/- 0.0023

EPIC-pn effective area / flux reduced by >20%!!

(errors are only statistical, we have much larger systematic uncertainties)



Current status

Absolute flux calibration still under investigation.
Implied change is **huge** for EPIC-pn.

Slope and “bump” corrections on the other seem robust.

We have a multiplicative XSPEC table model available to use those corrections in spectral fitting:

`Crab_arfcorr_nu19_v07c.fits`

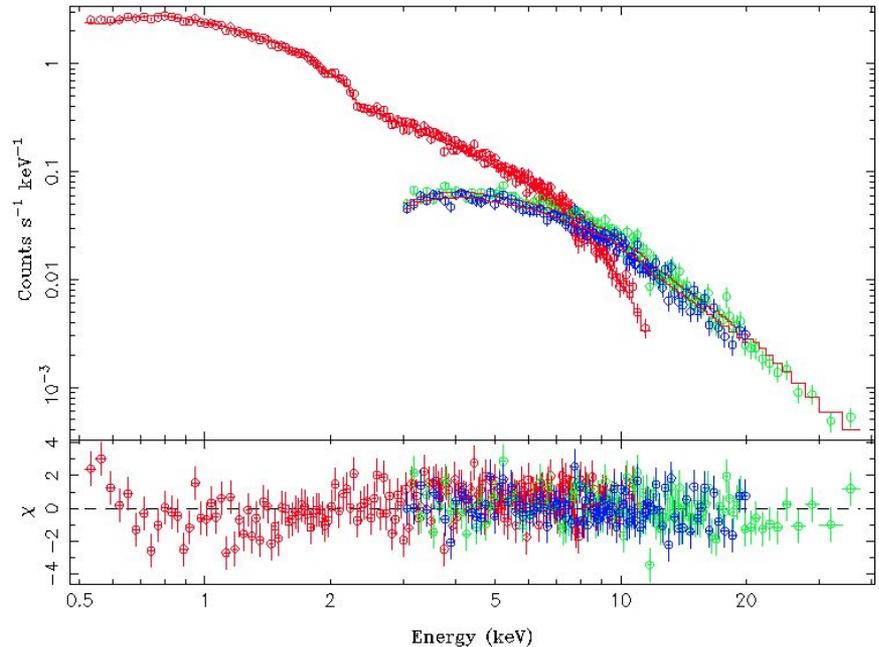
Let me know if you're interested in testing it!

Next source: 1ES 0229+200

As a possible new good calibration source this BL Lac might be perfect:

- Not too bright / not too faint
- Rather hard power law ($\Gamma \sim 1.8$)
- Simple spectrum (power-law or log-parabola)
- Can even be extended down to UV wavelengths!

Existing data not simultaneously (2009 and 2013)



Appendix



Testing corrections with Amy's database

Amy's pipeline part 1

- Extraction of pn and NuSTAR data
- Filtering for common GTIs
- Check of pile-up in pn
- Find best good model by hand, ~~fit only to XMM-Newton data~~
- Fit NuSTAR and XMM-Newton simultaneously, update models to include more complex shapes (reflection)

Felix pipeline in ISIS

- ~~Evaluate model to NuSTAR~~
- ~~Combine the residuals of all spectra~~
- Stack all data and models, then calculate residuals
- Allows us to calculate improvement in terms of χ^2 directly.

Advantage of ISIS: rebinning of spectra within ISIS, no need for "master observation" and 'grppha' -> more freedom.

Current sample is 33 AGN on Small Window mode