Revealing the coronal properties of Seyfert galaxies with NuSTAR

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on behalf of the
NuSTAR AGN Physics WG

Florence
High Energy processes around compact objects
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Overview

- Brief introduction on high-energy cutoff measurements
- Nearby AGN seen by NuSTAR
- Results
- Conclusions and future perspectives

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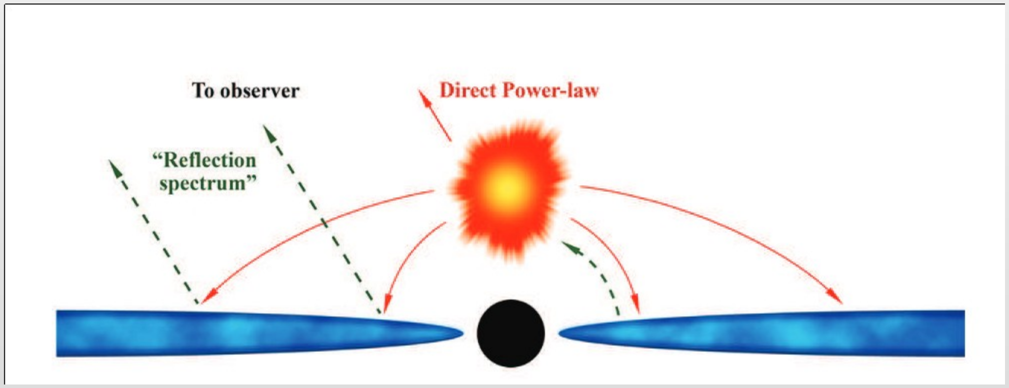
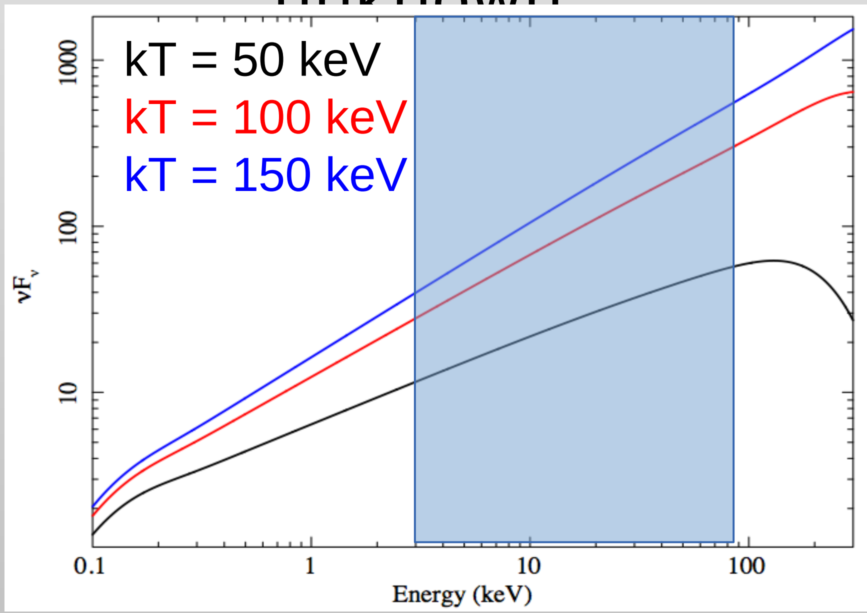
Introduction

One of the main open problem for AGN is the nature of the primary X-ray emission.

It is due to Comptonization of soft photons, but the geometry, optical depth and temperature of the emitting corona are largely unknown

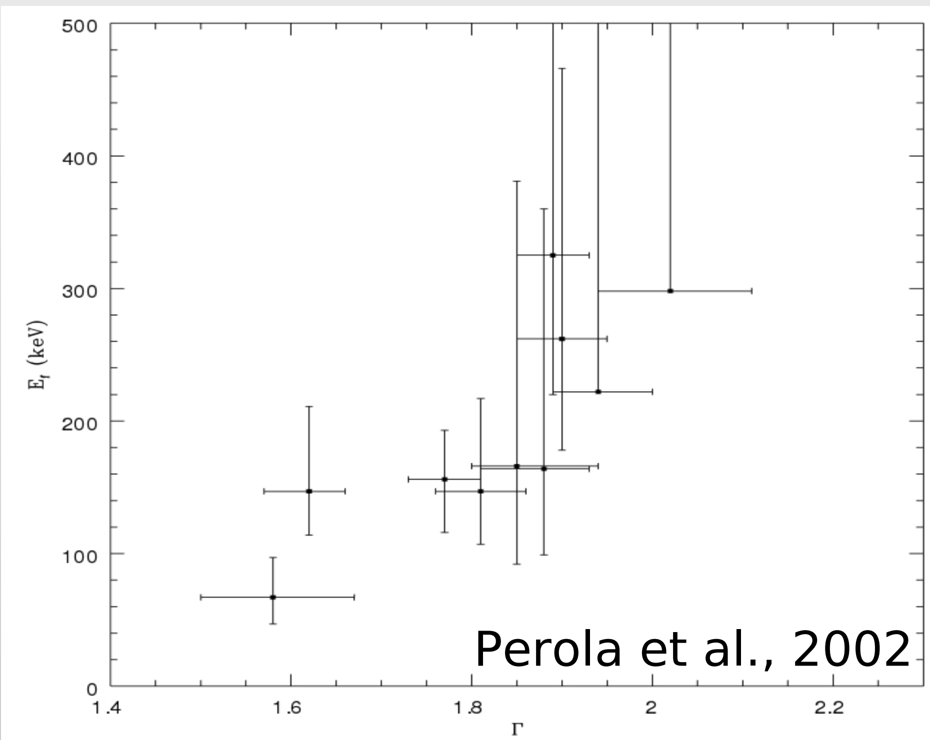


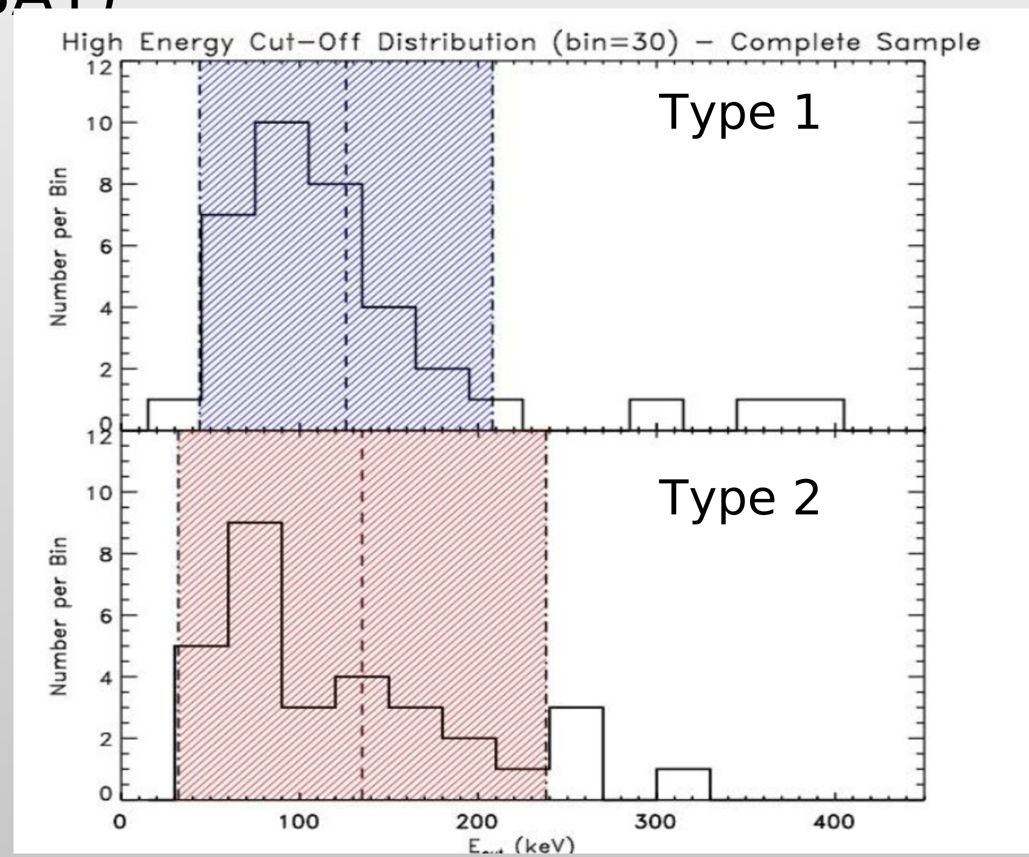


Most popular models imply E_{cut}=2-3 kT, so measuring E_{cut} helps constraining Comptonization models.

Introduction

So far, we have only a handful of results based on non focusing, and therefore strongly background-dominated, satellites (BeppoSAX-PDS, Suzaku HXD-PIN, INTEGRAL, Swift-BAT)





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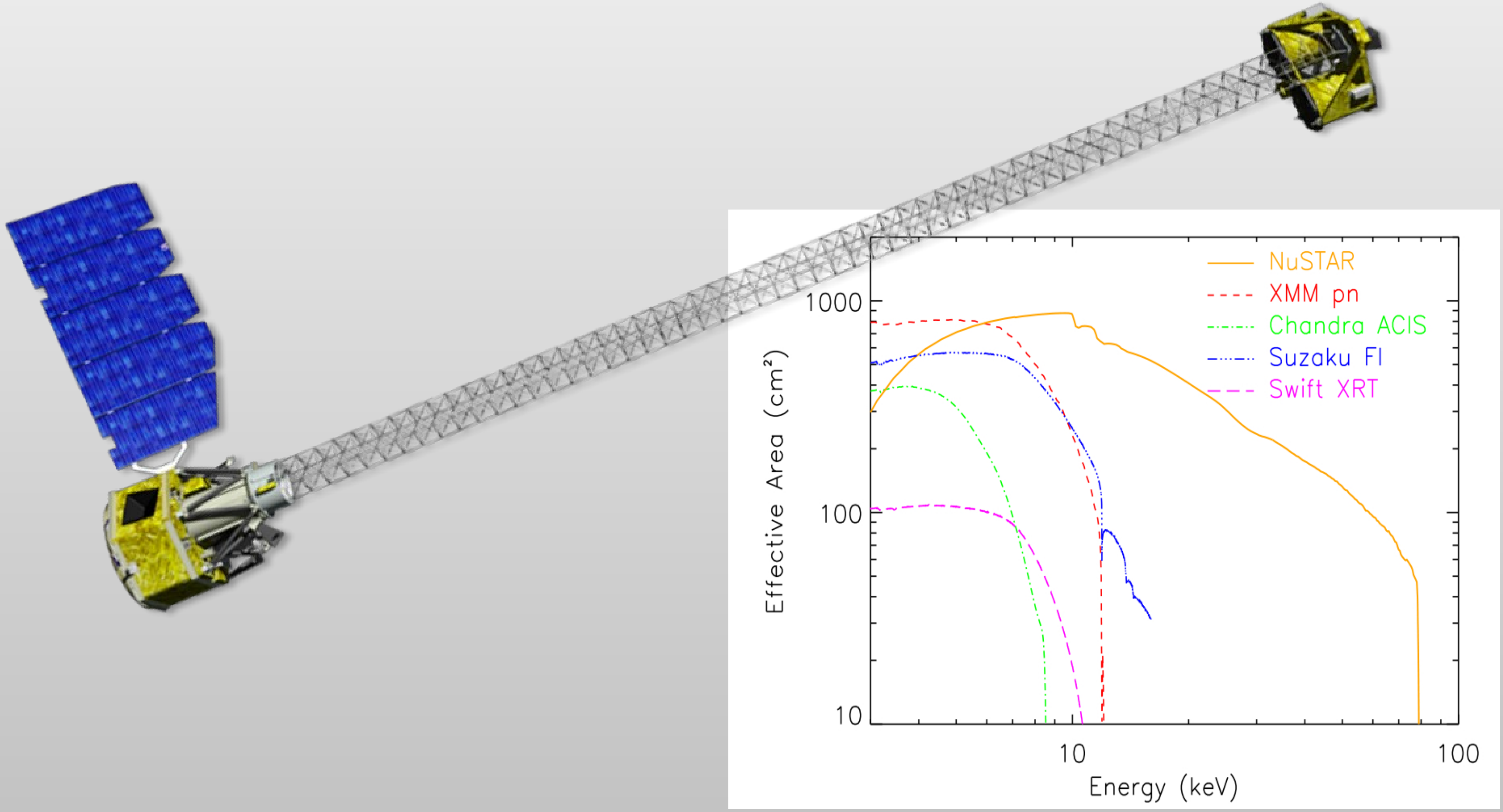
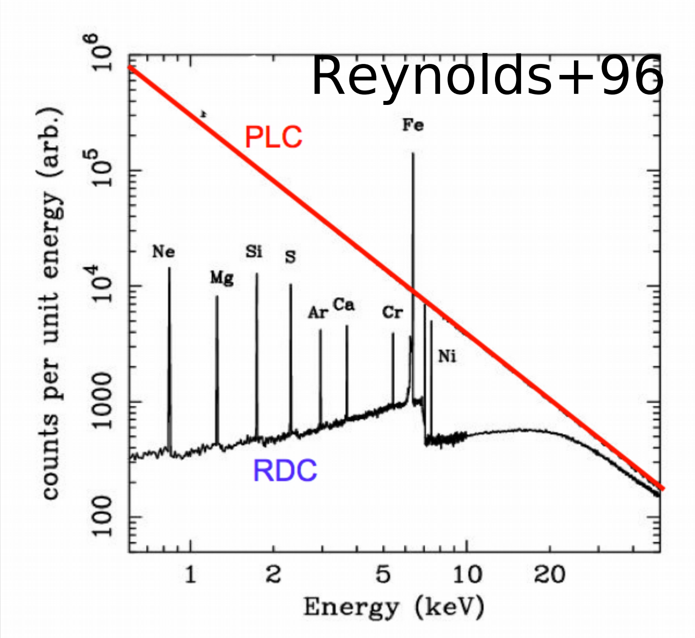
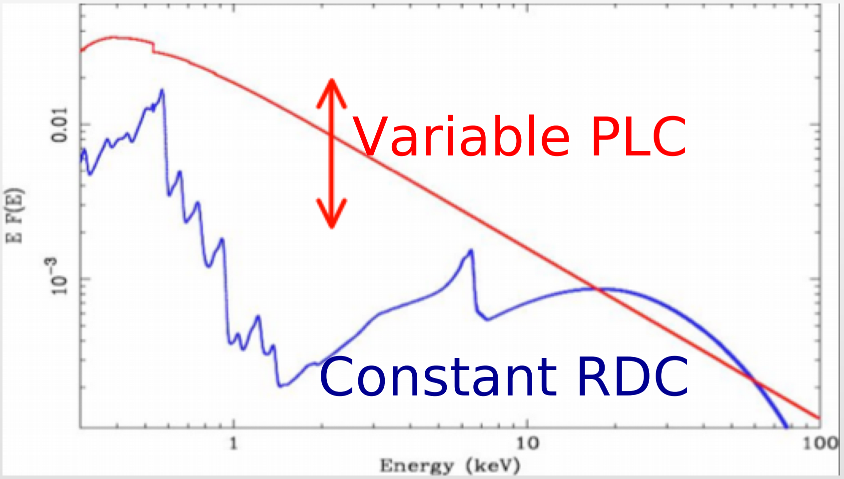
The NuSTAR satellite

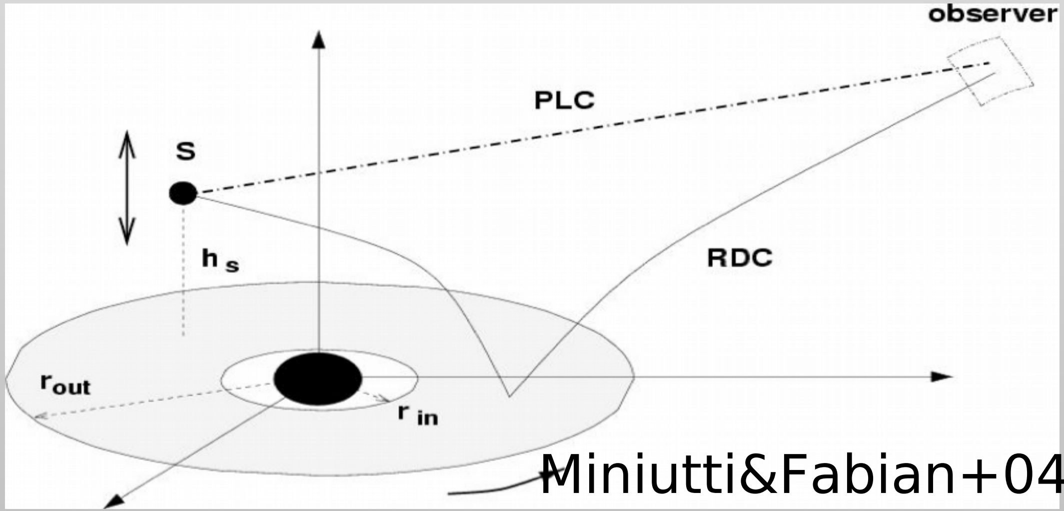


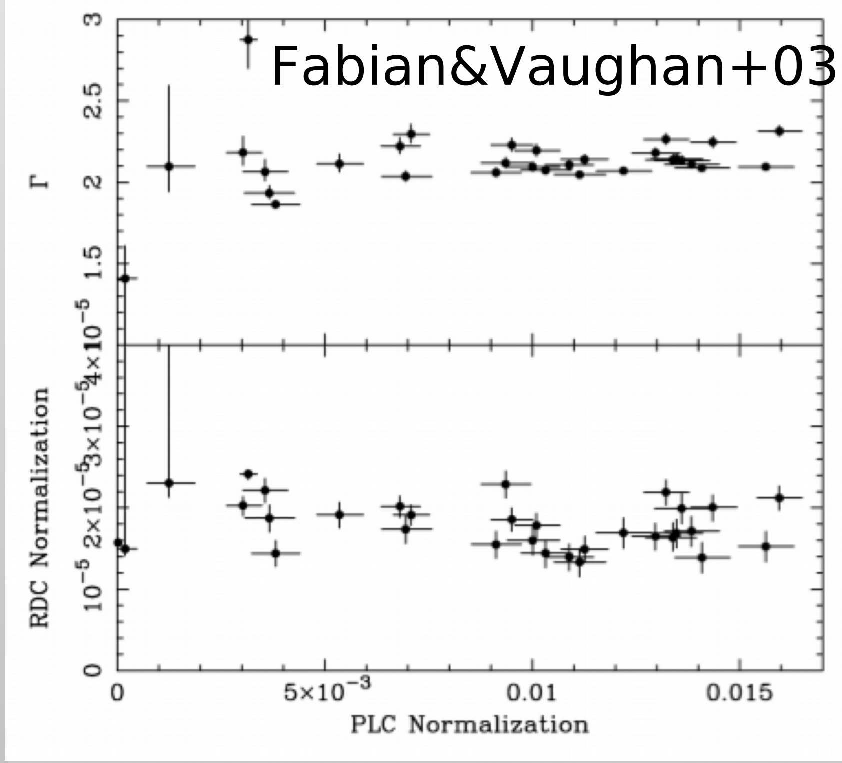
Reflection scenario





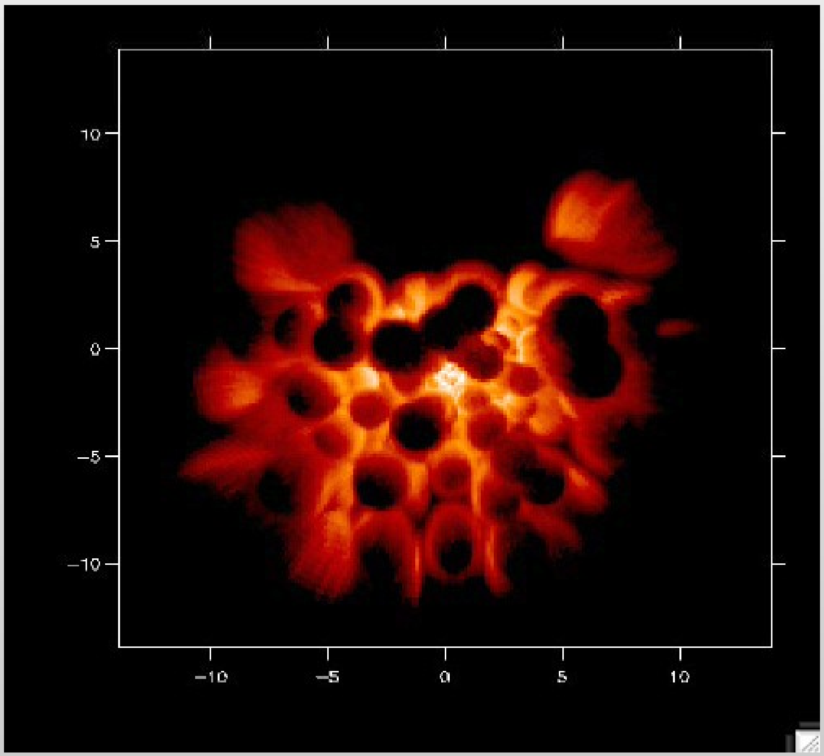
Light bending model: much of the flux is bent onto the disk giving a constant, strong RDC





Absorption scenario

An alternative interpretation explains the spectral variability in terms of absorption changes



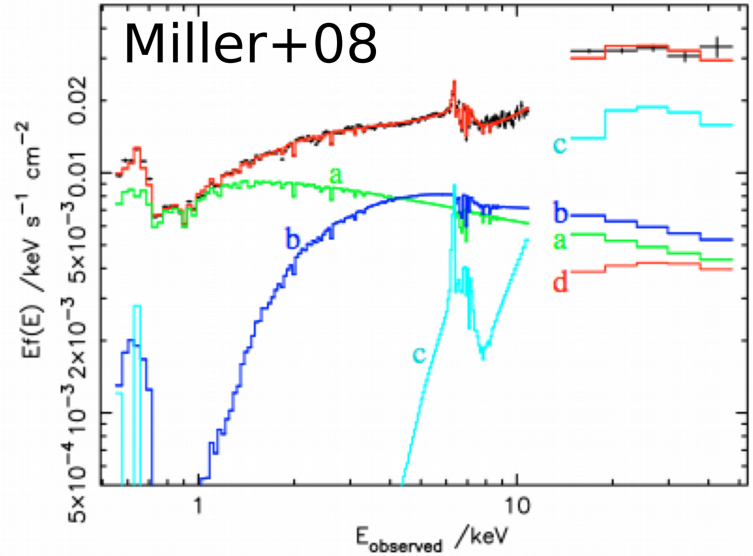


Fig. 4. Illustration of the spectral model. The upper curve shows the model fitted to the mean *Suzaku* spectrum, with XIS data below 11 keV and PIN data above 15 keV. Points with error bars show the unfolded data (see Sect. 5.6 for details). The three emission components are shown as (a) primary directly-viewed power-law, absorbed by zones 1 and 2; (b) partially covered power-law, absorbed by zones 1, 2, 3 and 5; (c) reflection, absorbed by zones 1, 2, 3 and 4. In the fit to the PCA components, zone 3 is excluded from eigenvector one; in the fit to the actual data, zone 3 is allowed to absorb all components. Also shown is the expected contribution of the cosmic X-ray background to the *Suzaku* PIN band (d) included in the model.

"3+2" MODEL

3 fully covering warm absorbers

1 ionized absorber fully covering the distant reflection component ($N_H \sim 5 \times 10^{23}$ cm^{-2}, log$\xi \sim 2.0$)

1 ionized absorber partial covering the X-ray source ($N_H \sim 4 \times 10^{22}$ cm^{-2}, log$\xi \sim 1.5$)

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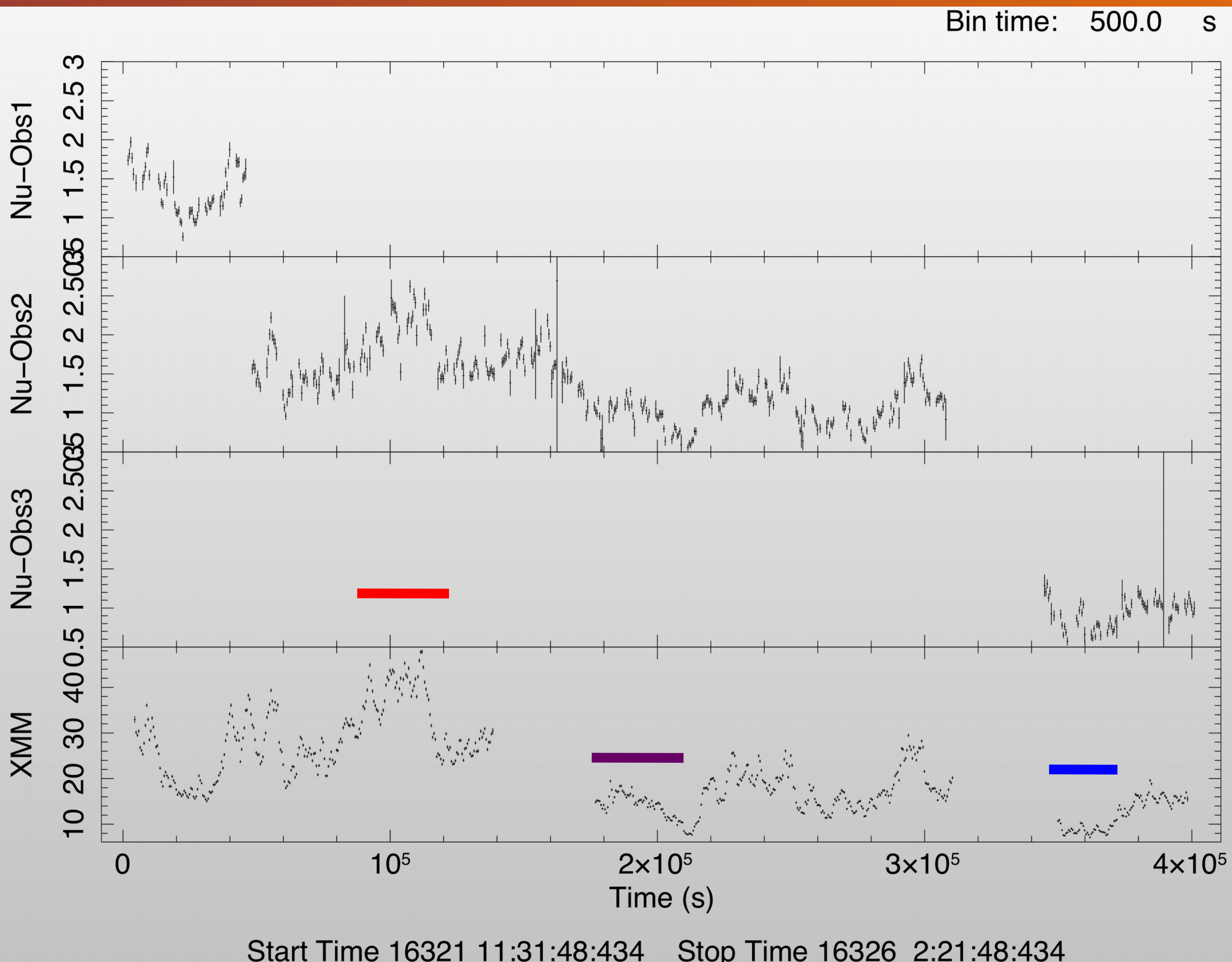
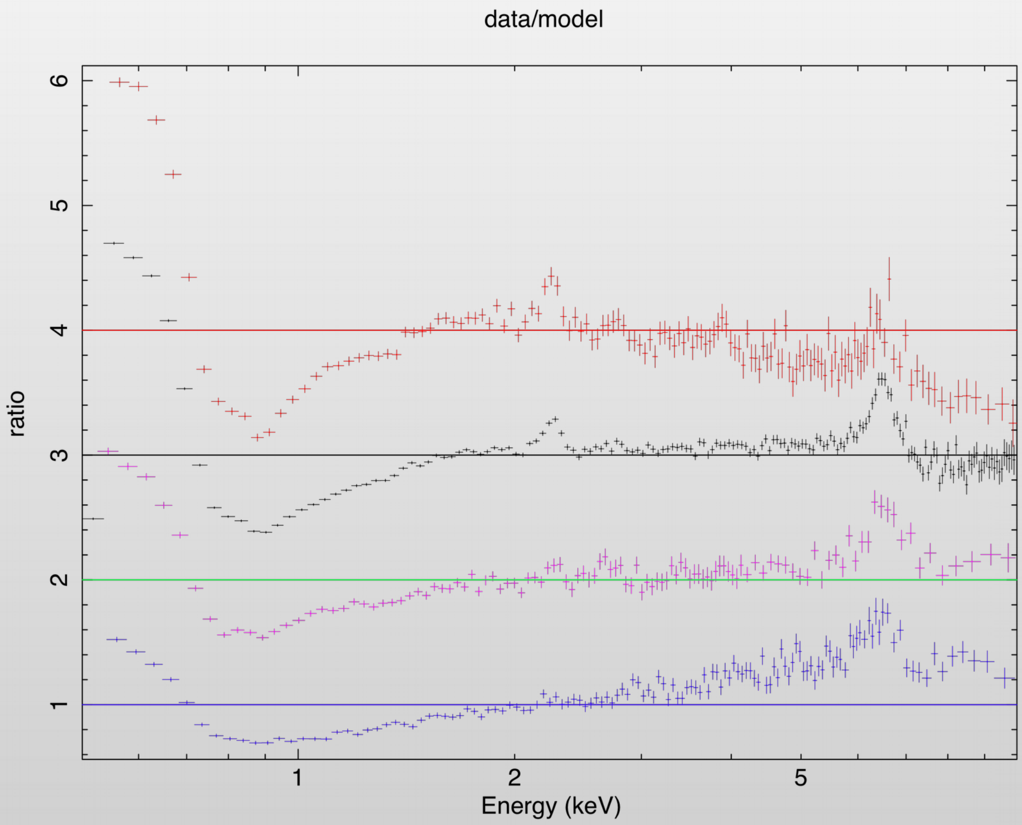
NuSTAR-XMM light curves

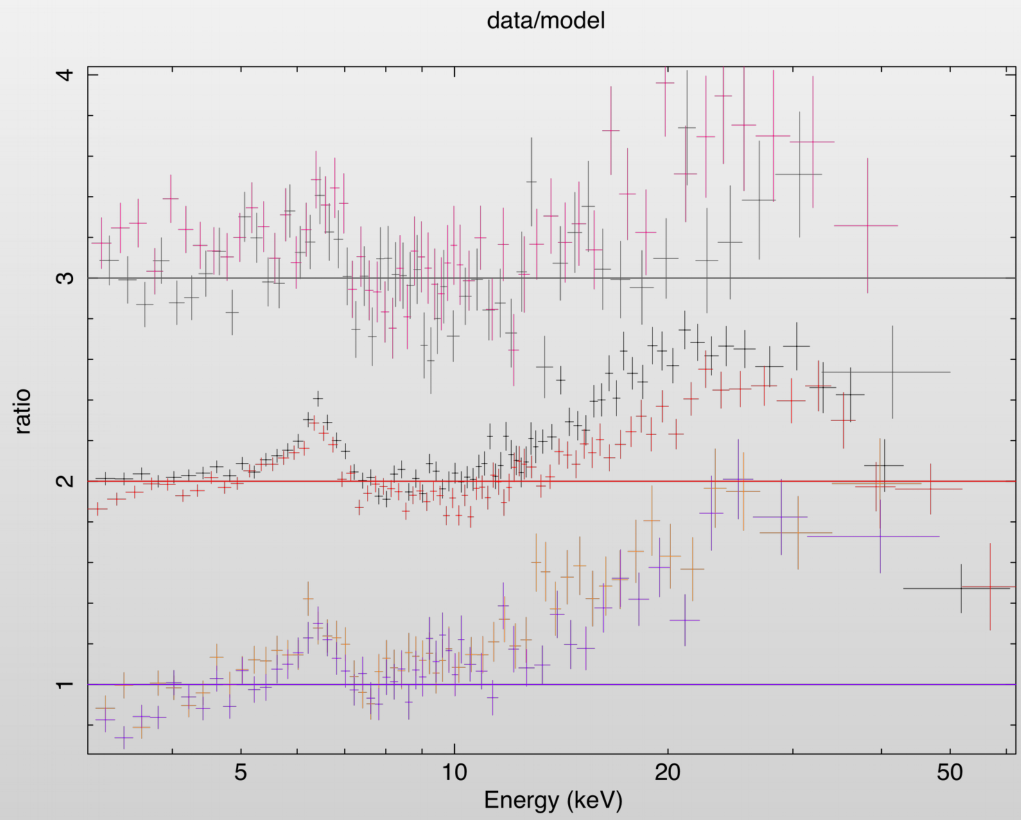


Spectral features

XMM-Newton EPIC-Pn



NuSTAR FpmA-FpmB



A broad Iron line, an intense soft excess and a strong Compton hump are present in the low flux spectrum (fit to a Γ=2 power law).

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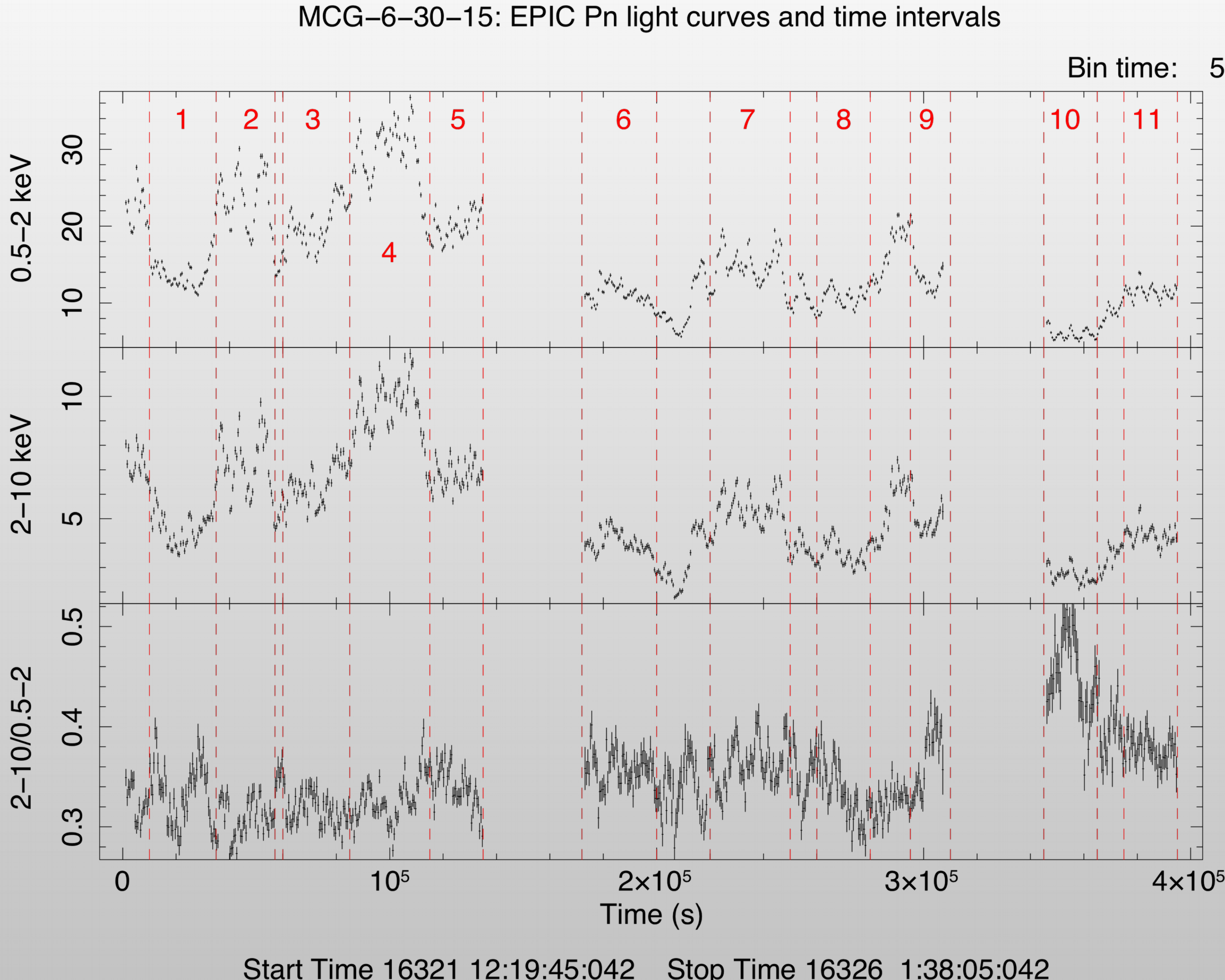
Fitting strategy



Fitting strategy

Warm Absorbers	→	Underlying Continuum
	←	
Combined RGS spectra	→	EPIC-Pn + NuSTAR FpmA,B

REFLECTION	ABSORPTION
2*XSTAR*DUST x (Xillver + Relconv*Xillver + zpow)	2*XSTAR*DUST x (XSTAR*Xillver + XSTAR*zpo + zpo)

XSTAR tables

XILLVER instead of REFLIONX:

http://hea-www.cfa.harvard.edu/~javier/xillver/

Iron UTA tables for dust

RELCONV for relativistic blurring:

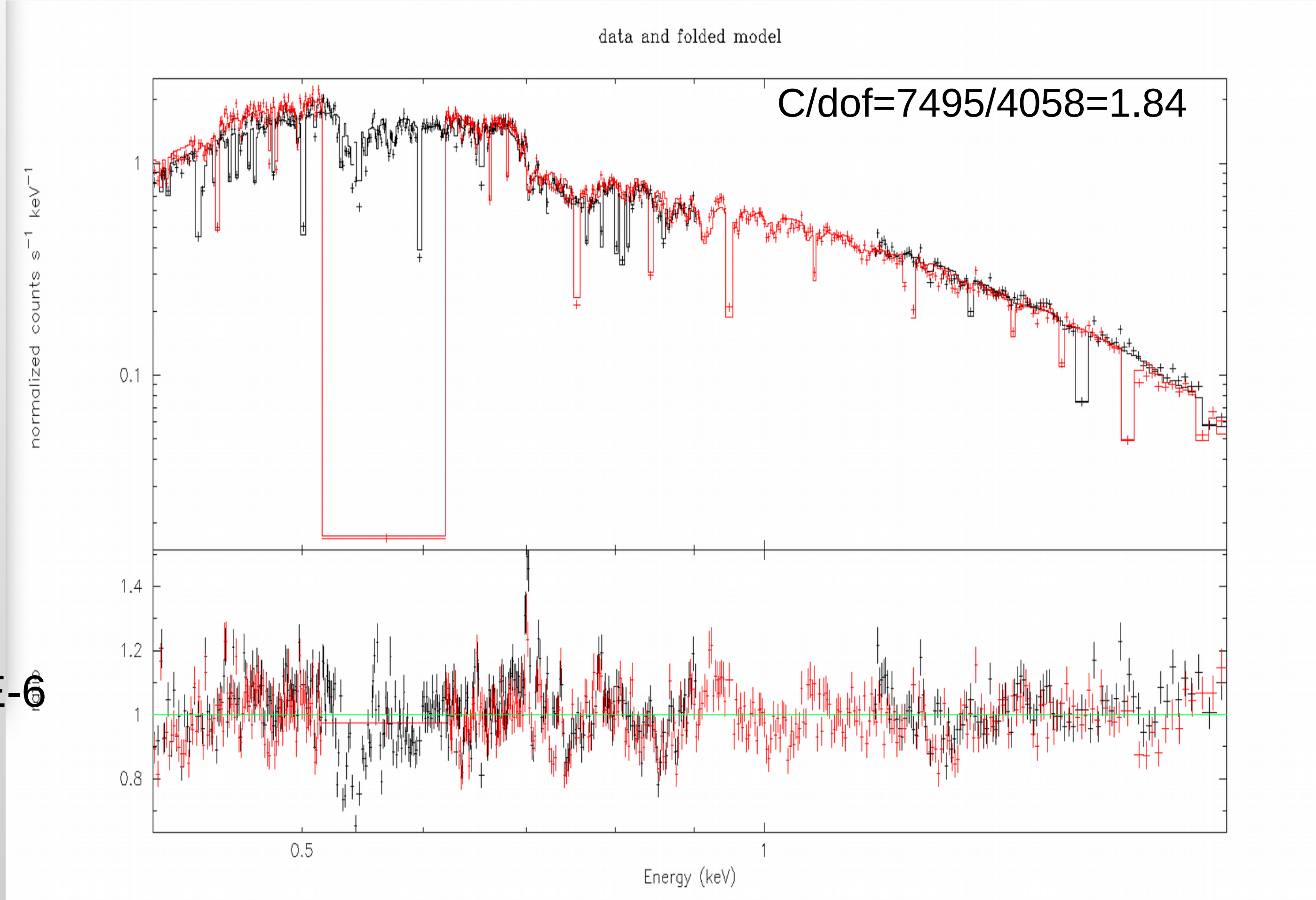
http://www.sternwarte.uni-erlangen.de/~dauser/research/relline/

Combined RGS1+2 analysis

N_{H1} =(4.6 +/- 0.8) x10^{20} cm^{-2}
logξ_1=1.47+/- 0.2
v~2000 km s^{-1}
N_{H2}=(1.3 +/- 0.2) x10^{20} cm^{-2}
logξ_2=0.08+ 0.10
N_{H3}=(1.00+/- 0.04) x10^{22} cm^{-2}
logξ_3=2.03+ 0.01
logN_{Fe}=17.32+/-0.02

xillver Norm = 9.3E-06 +/- 0.8E-6

Γ=2.03 +/- 0.02
norm 1.58E-02 +/- 0.02E-2



We then applied the combined best fit to the three separate RGS1+2 data sets

Separate RGS1+2 analysis

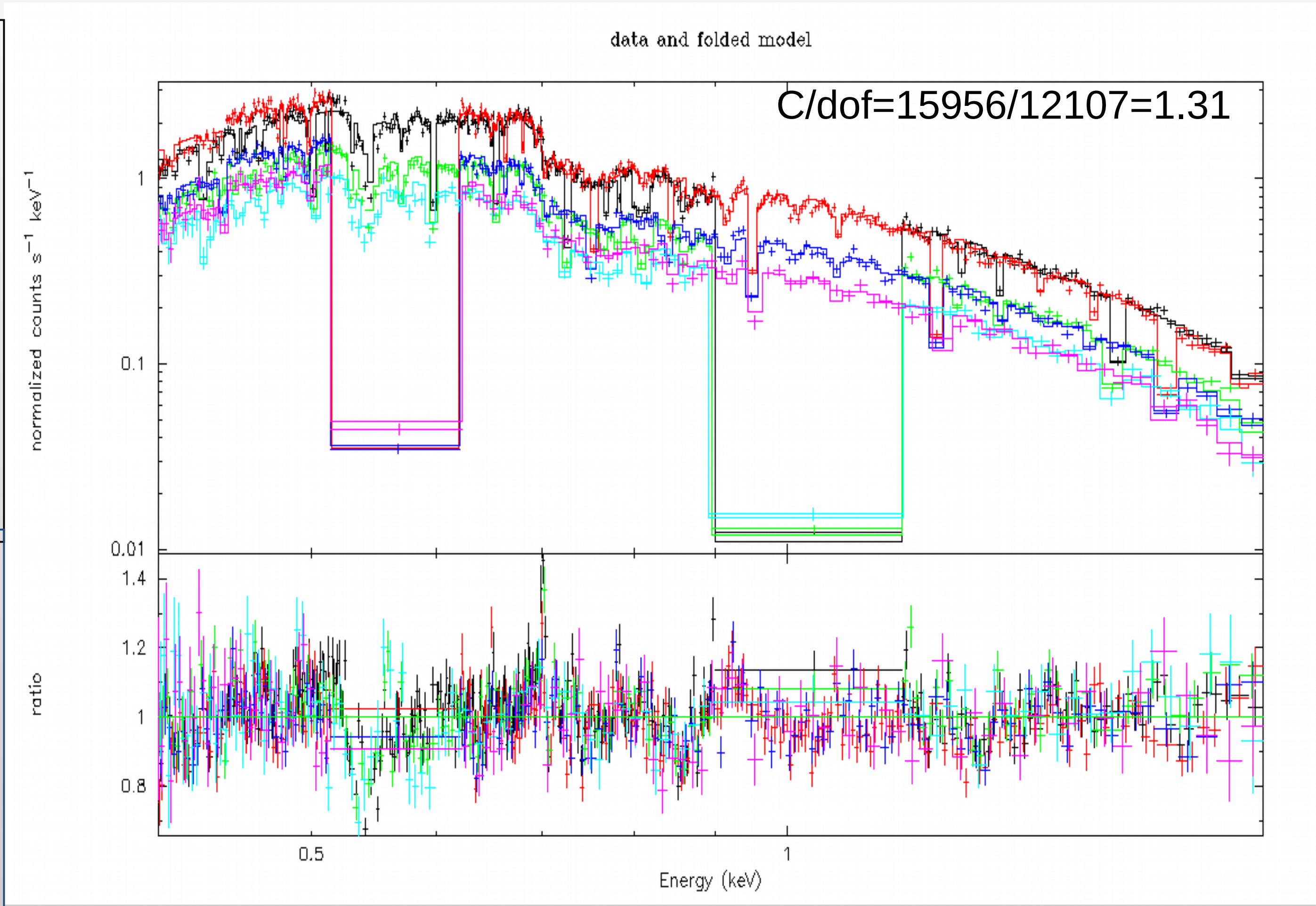
Orbit 1

N_{H1} (5.6 +/- 1.7) x10^{20} cm^{-2}
$\log\xi_1$ 1.82+/- 0.05
v~2000 km s^{-1}
N_{H2} (8.6 +/- 1.8) x10^{20} cm^{-2}
$\log\xi_2$ 1.47+ 0.05
N_{H3} (1.00+/- 0.04) x10^{22} cm^{-2}
$\log\xi_3$ 2.04+ 0.01
$\log N_{Fe}$ 17.33 +/- 0.02

xillver norm 9.3E-06 +/- 0.8E-06
$\Gamma=2.03*$
norm 1.58E-02 +/- 0.02E-2

Orbit 2

N_{H1} (4.0 +/- 1.8) x10^{20} cm^{-2}
$\log\xi_1$ 1.85+/- 0.1
v~2000 km s^{-1}
N_{H2} (2.9 +/- 0.5) x10^{20} cm^{-2}
$\log\xi_2$ 1.34+ 0.13
N_{H3} (1.00+/- 0.09) x10^{22} cm^{-2}
$\log\xi_3$ 2.02+ 0.02
$\log N_{Fe}$ 17.27 +/- 0.04
$\Gamma=2.03$
norm 1.22E-02 +/- 0.02E-02

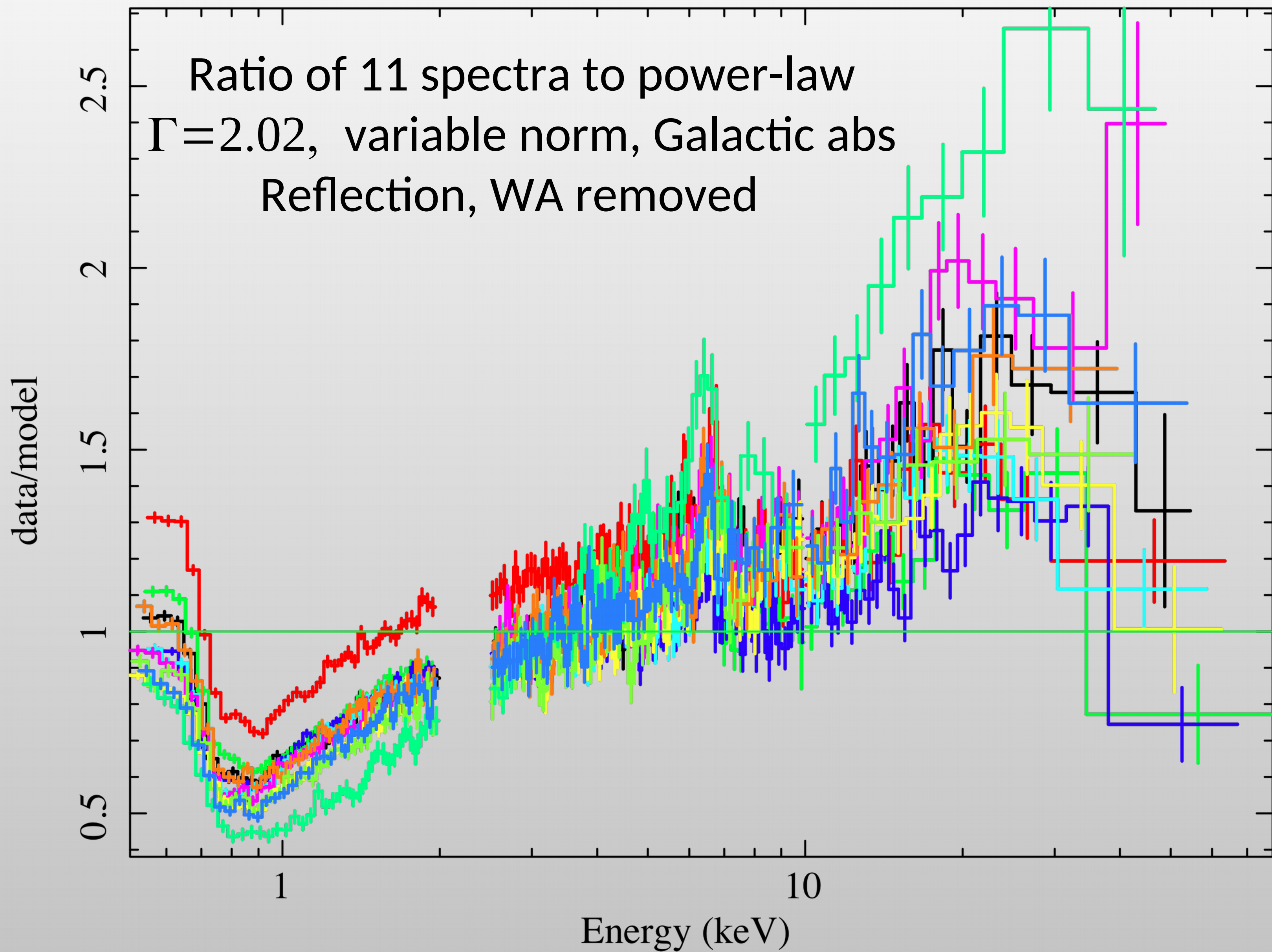


No significant variation has been found in the warm absorbing structure

Orbit 3

N_{H1} (5.1 +/- 2.5) x10^{20} cm^{-2}
$\log\xi_1$ 1.75+/- 0.23
v~2000 km s^{-1}
N_{H2} (5.0 +/- 1.0) x10^{20} cm^{-2}
$\log\xi_2$ 1.3+/- 0.3
N_{H3} (0.88+/- 0.02) x10^{22} cm^{-2}
$\log\xi_3$ 2.00+ 0.03
$\log N_{Fe}$ 17.08 +/- 0.12
$\Gamma=2.03$
norm 0.8E-02 +/- 0.4E-03

Time resolved simultaneous analysis



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Results: reflection

Warm absorbers

$N_{H1}=(0.6\text{-}\underline{2.5})\ \times 10^{22}\ cm^{-2}$

$\log\xi_1=1.98 \pm 0.01$

$N_{H2}=(\underline{0.5}\text{-}3.0)\ \times 10^{21}\ cm^{-2}$

$\log\xi_2=1.27\pm0.02$

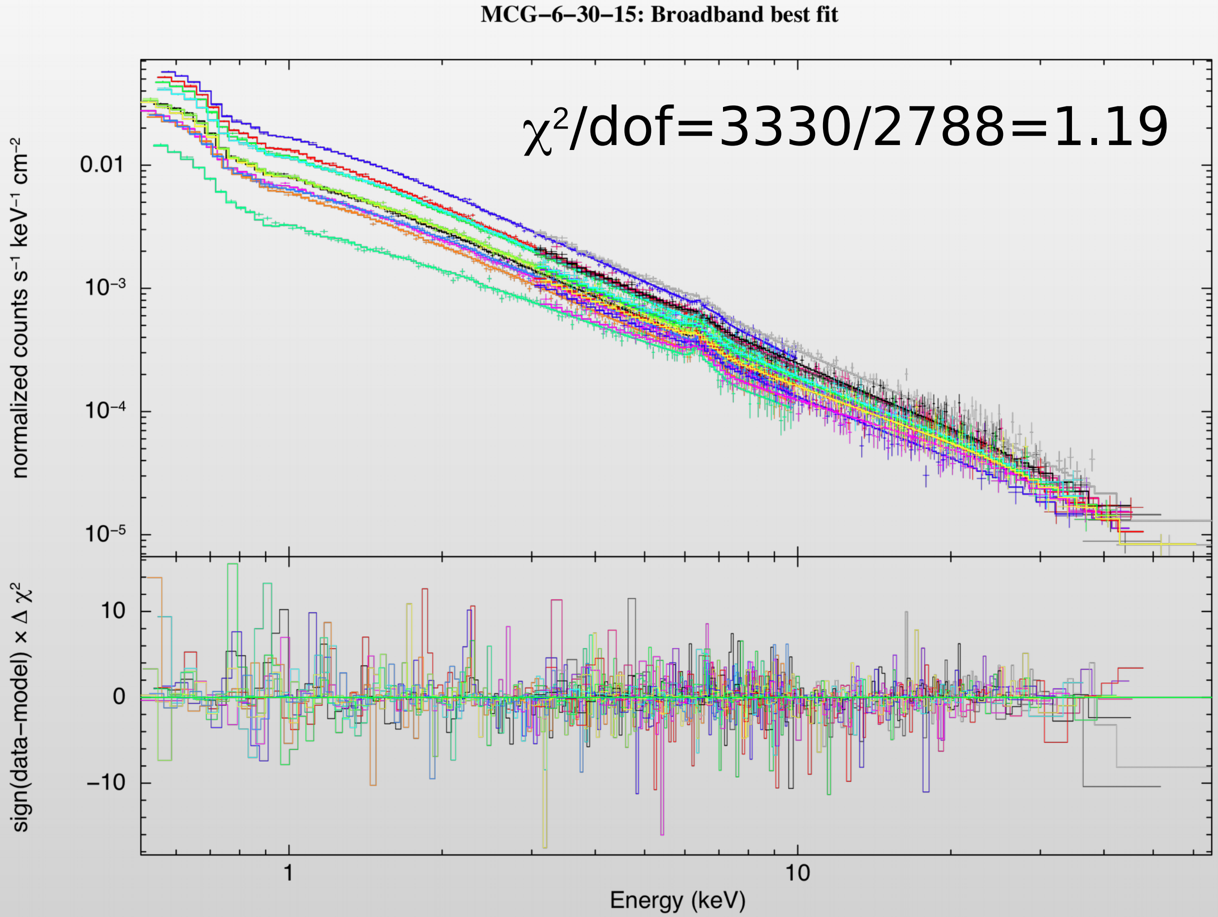
$\log N_{Fe}=16.6 \pm 0.2$

Reflection parameters

(q=3.0 a=0.998 incl=37°)

$\log\xi=0.2\text{-}3.0$

$A_{Fe}=1.56\pm0.32$

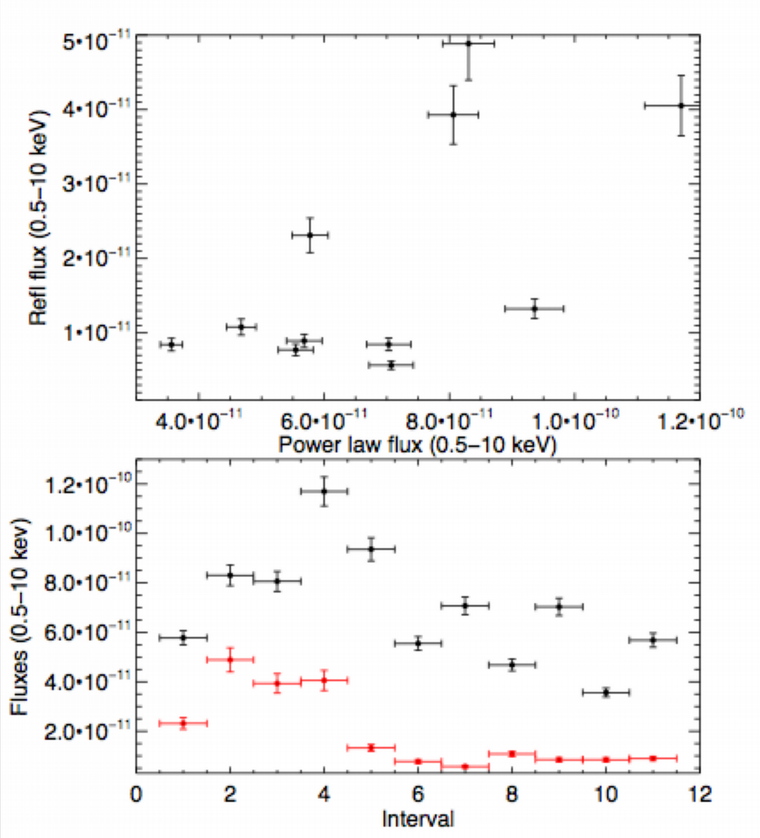


Primary emission parameters

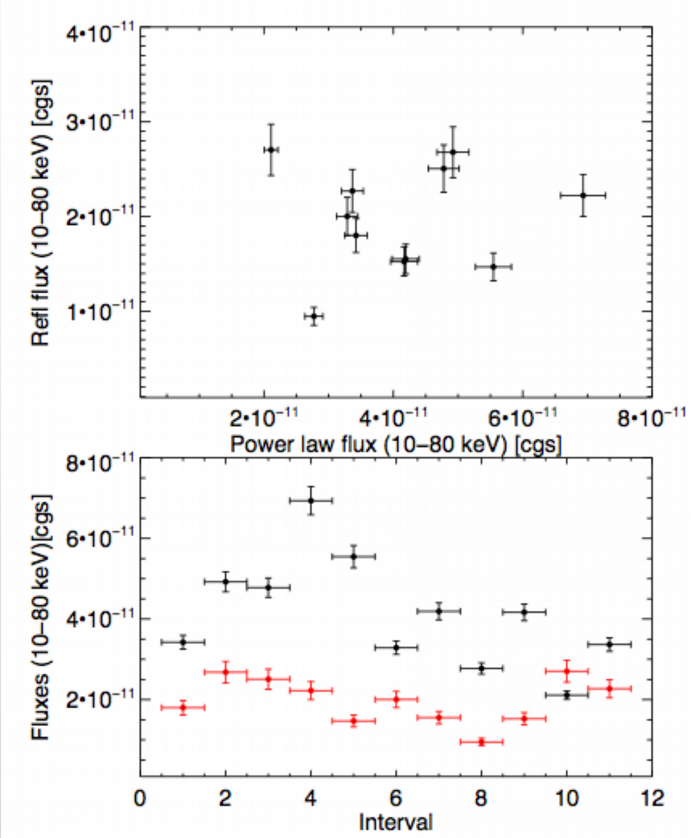
$\Gamma=2.050\pm0.005$

$E_c>100$ keV

RDC vs PLC fluxes



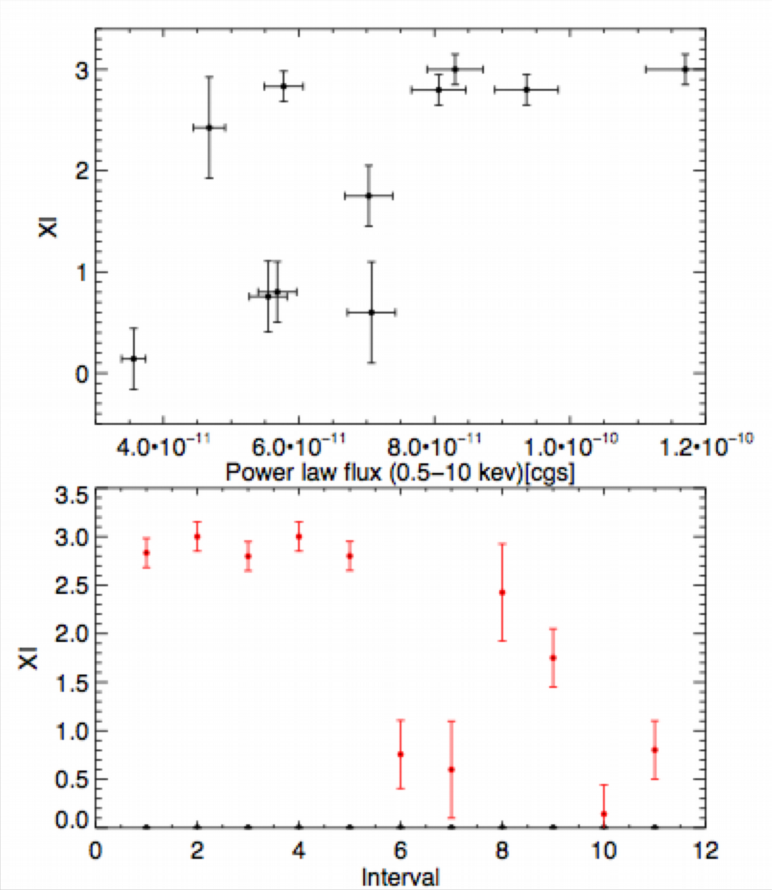
Variation of a factor ~2 observed in the RDC between 0.5-10 keV, in agreement with the PCA (Parker et al., submitted)

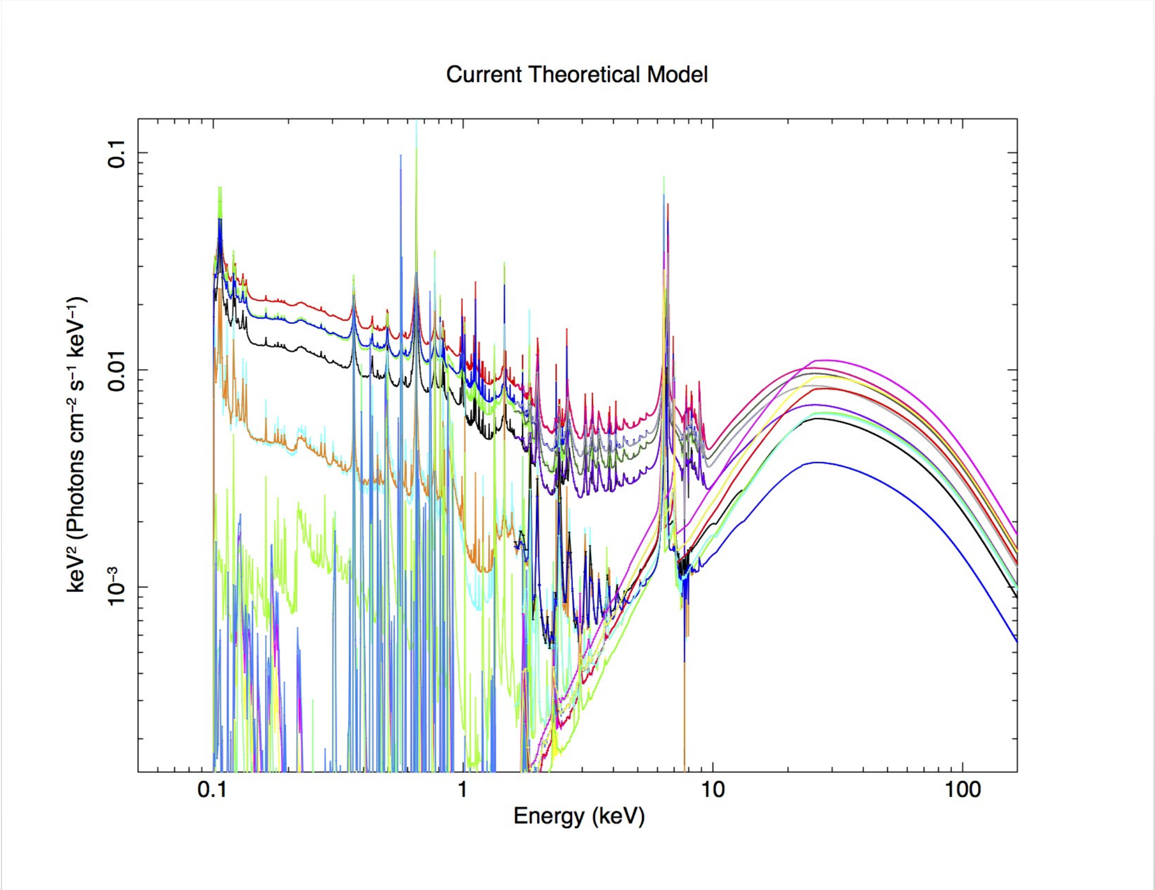


Constancy of the RDC between 10-80 keV (thanks to NuSTAR)

Marginal response from the accretion disk to the nuclear emission?

Accretion disk response





There is a response of the ionization state of the accretion disk to the variation of the PLC

Results: absorption

2 warm absorbers

N_{H1}=(1.3±0.2) x10^{22} cm^{-2}
$\log\xi_1$=1.95 ± 0.02

N_{H2}=(4.2±1.5) x10^{21} cm^{-2}
$\log\xi_2$=2.82±0.05

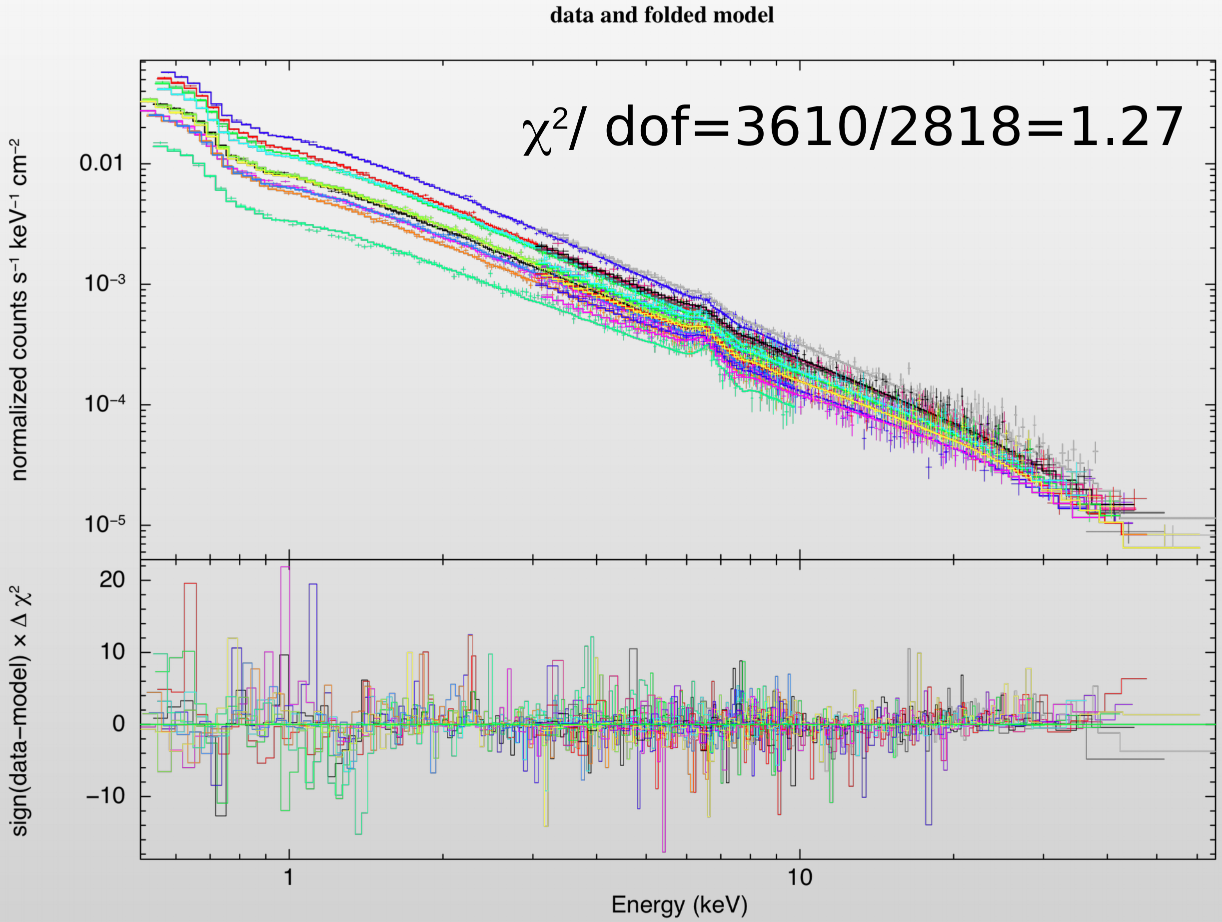
$\log N_{Fe}$=16.9 ± 0.1

Further absorbers

(Xillver: $\log\xi$=2.4±0.05;
A_{fe}=0.5±0.1_p) ✓

N_{H3}=(3.0±0.4) x10^{23} cm^{-2}
$\log\xi_3$=2.11 ± 0.01 ✓

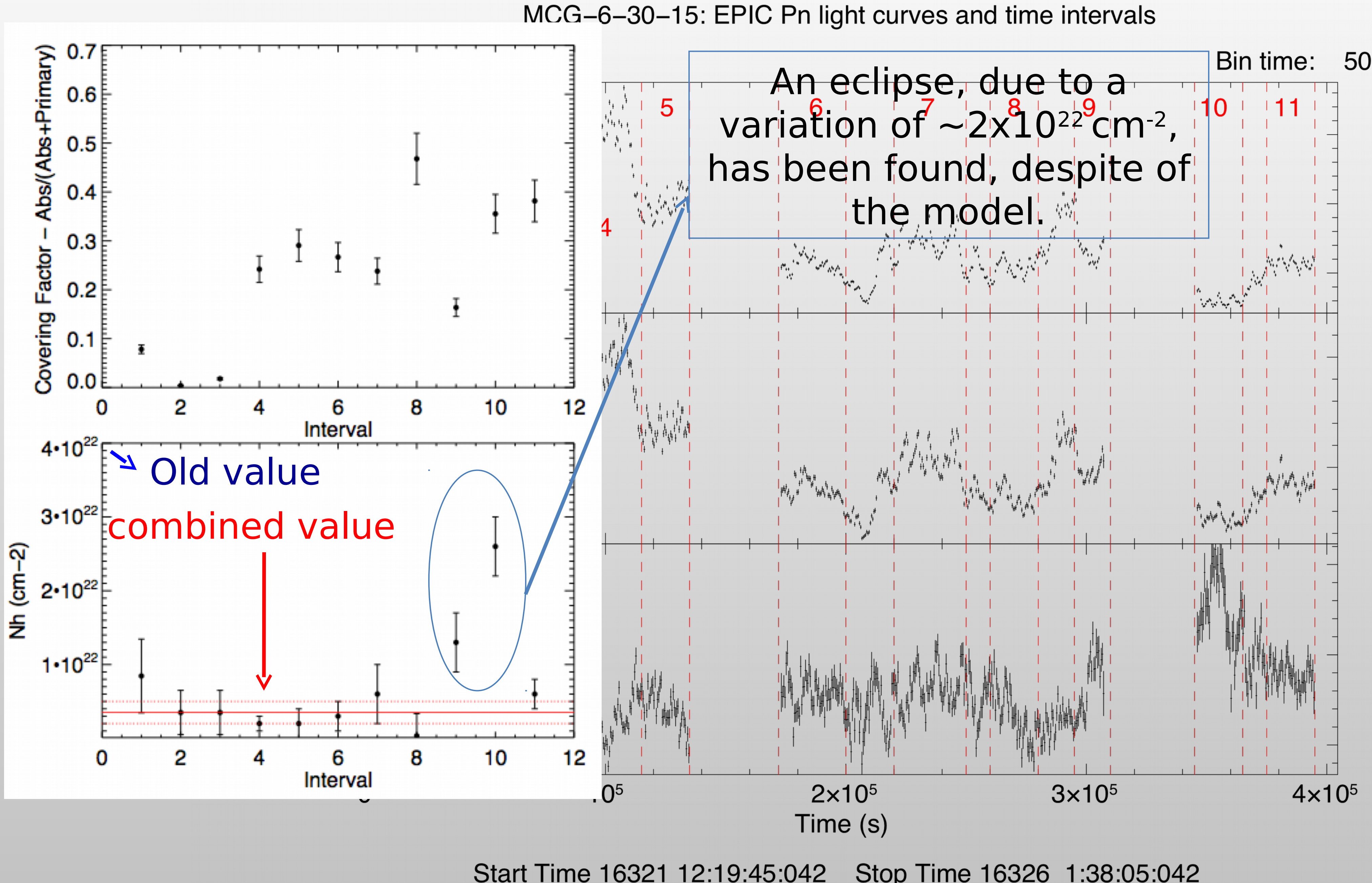
N_{H4}=(0.3-27) x10^{21} cm^{-2}
$\log\xi_4$=(0.0015±0.0005) ✗
[almost neutral]



Primary emission parameters

Γ=2.16±0.01
E_c>100 keV

Covering factor time evolution



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Conclusions

- The warm absorbing structure is consistent with literature, except for the lack of highly ionized absorption lines;

- The reflection scenario well explains the behavior of the source, from 0.4 keV up to 80 keV and it is statistically preferred

- Spectral variability can be explained in terms of strong variations of the PLC and to marginal variations in the RDC

- An alternative is that the spectral variability can be attributed to a change in covering fraction of the X-ray source AND to a change of N_{H}.

Future perspectives

- Explore the parameter space with greater detail (leaving other parameters free to vary);

- Increase the S/N: spectra with longer exposure times should, in principle, allow us to discriminate between a model with Γ=2.05 and Γ=2.15;

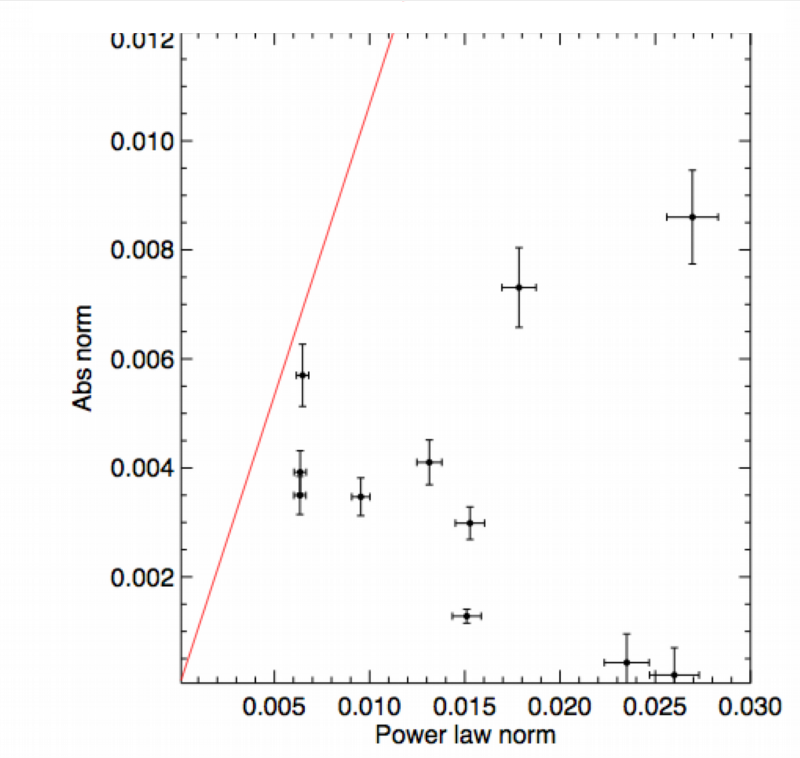
- Time intervals with constant HR AND comparable flux (in a fixed energy band) could be co-added.

- Measure cut-off energy (so far only a lower limit of 100 keV has been inferred)

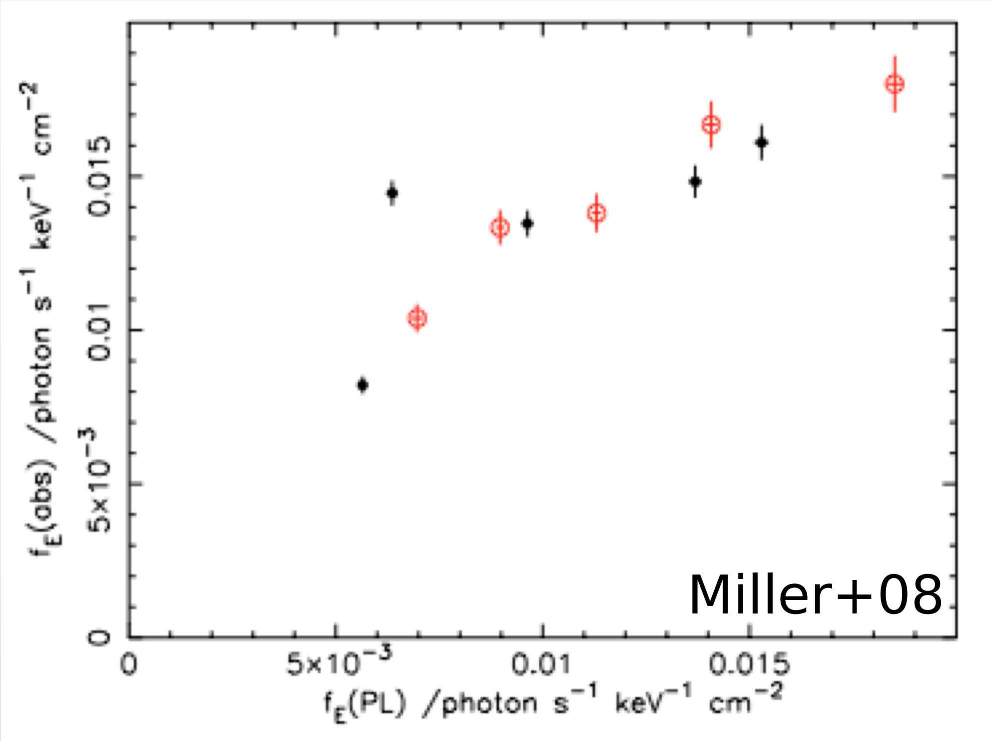
- Measure Black Hole spin throughout the 300 ks observation


Thanks!

Backup

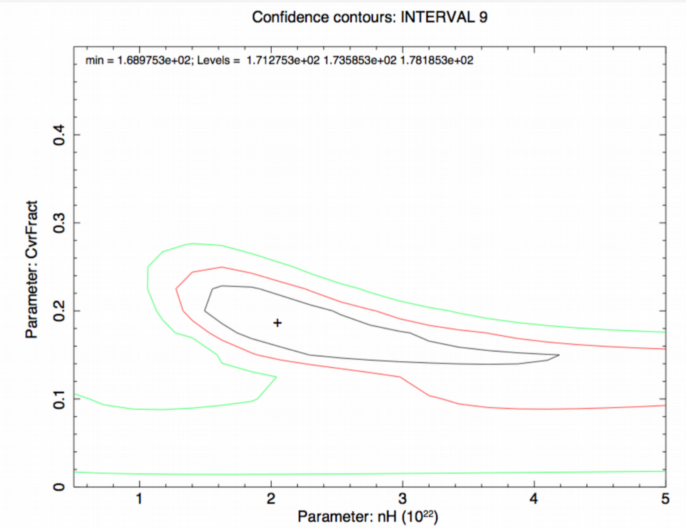


Abs norm
Power law norm
0.002
0.004
0.006
0.008
0.010
0.012
0.005
0.010
0.015
0.020
0.025
0.030

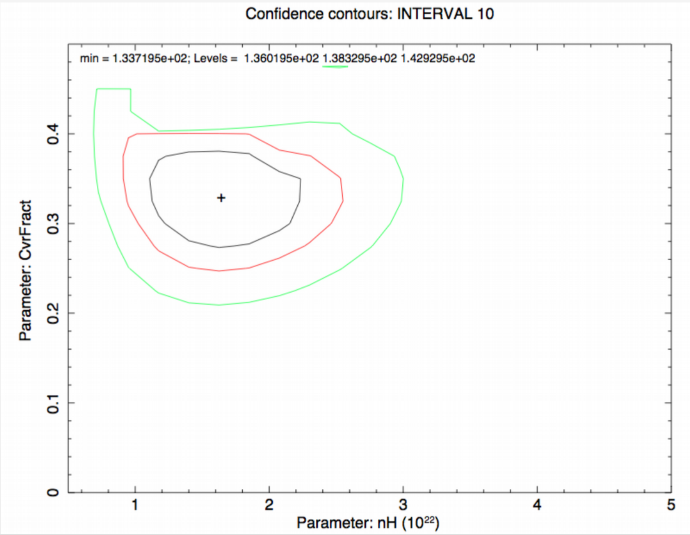


f_E(abs) /photon s^{-1} keV^{-1} cm^{-2}
f_E(PL) /photon s^{-1} keV^{-1} cm^{-2}
0
5×10^{-3}
0.01
0.015
Miller+08

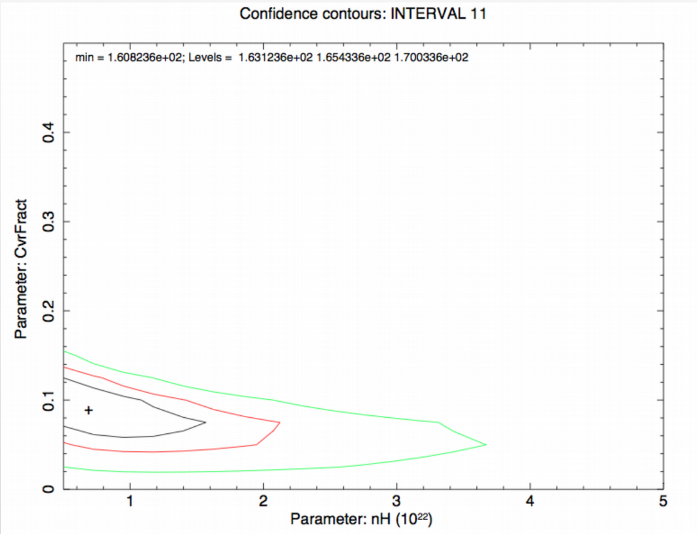
Backup



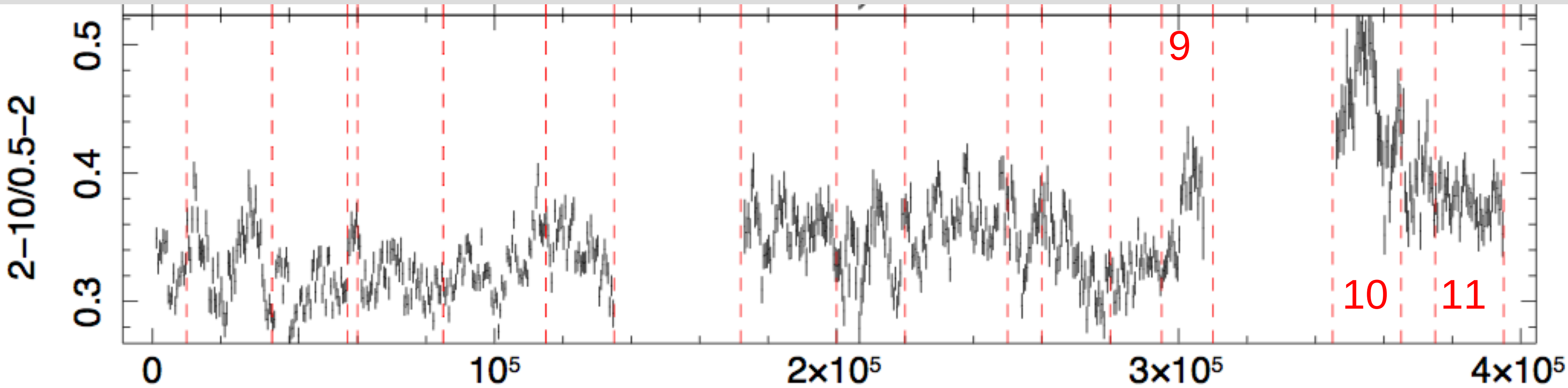
Confidence contours: INTERVAL 9
min = 1.689753e+02; Levels = 1.712753e+02 1.735853e+02 1.781853e+02
Parameter: CvrFract
Parameter: nH (10^{22})



Confidence contours: INTERVAL 10
min = 1.337195e+02; Levels = 1.360195e+02 1.383295e+02 1.429295e+02
Parameter: CvrFract
Parameter: nH (10^{22})

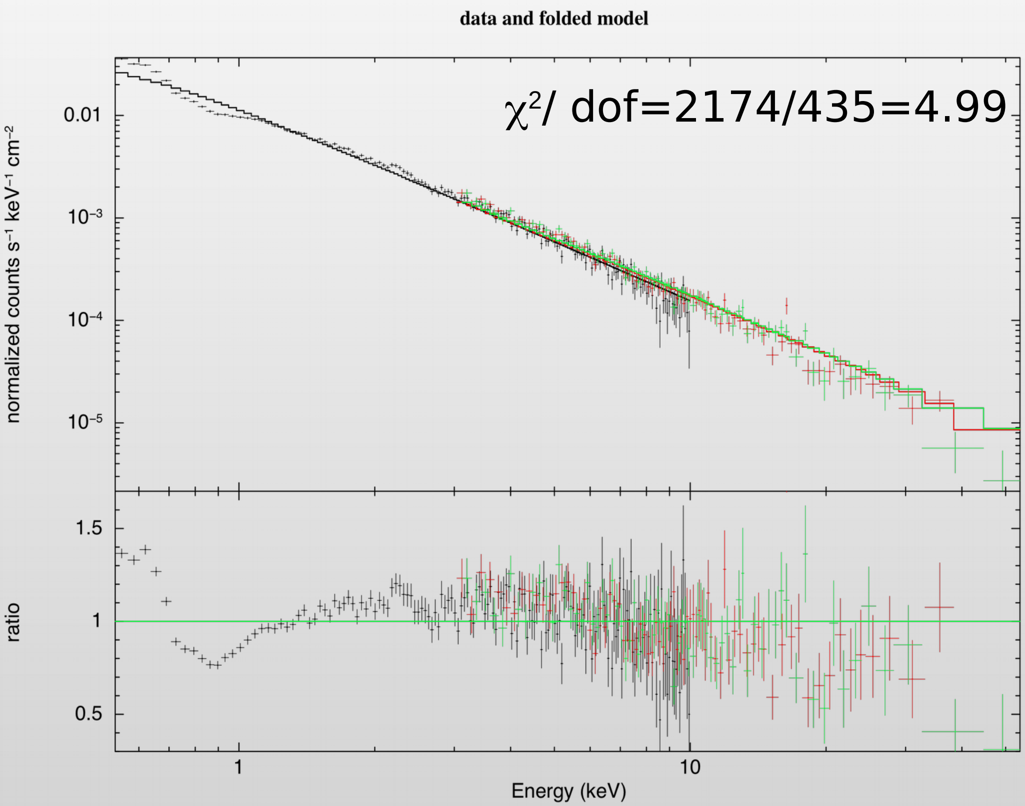


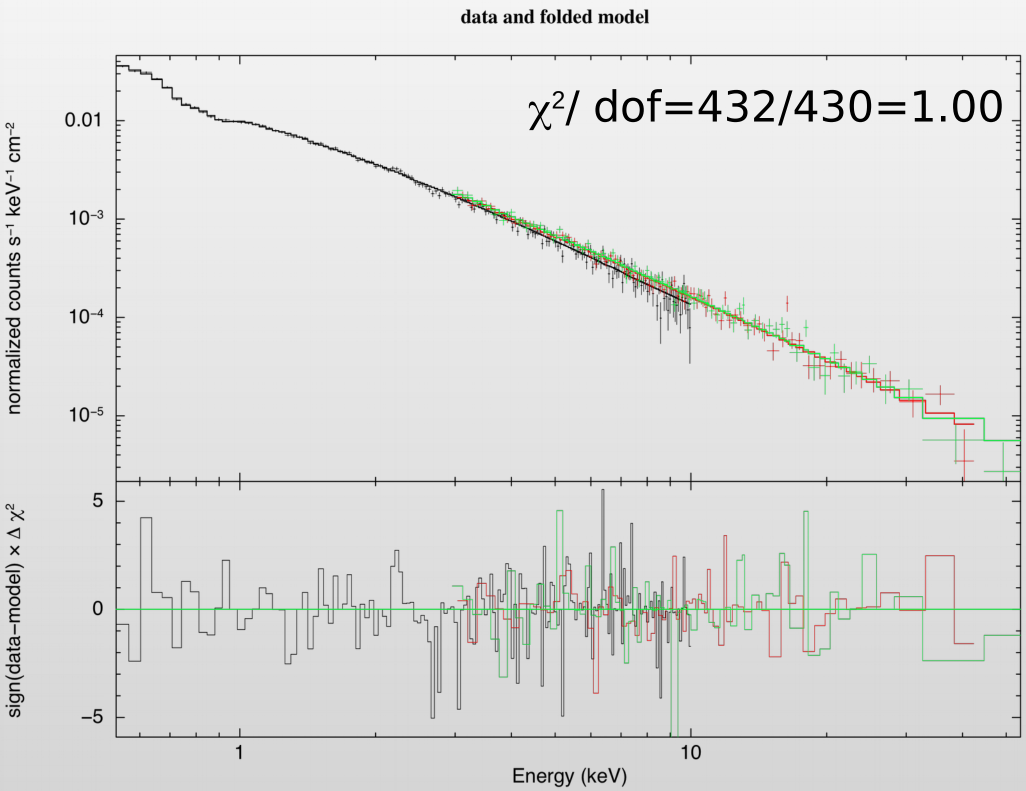
Confidence contours: INTERVAL 11
min = 1.608236e+02; Levels = 1.631236e+02 1.654336e+02 1.700336e+02
Parameter: CvrFract
Parameter: nH (10^{22})



2–10/0.5–2
9
10
11

Backup





Difference between the highest flux spectrum (42.19±0.07 cts/s) and a low flux one with constant HR (17.79±0.04 cts/s)

A first fit with an absorbed power law leads to strong residuals, mainly due to the warm absorbing structure

$N_{H1}=(9.8\pm2.5)\times10^{21}$ cm^{-2}

$\log\xi_1=2.0 \pm 0.1$

$\Gamma=2.16\pm0.03$

$N_{H2}=(2.1 \pm1.9)\times10^{21}$ cm^{-2}

$\log\xi_2=1.4\pm0.2$

$\log N_{Fe}=17.2 \pm 0.3$