# A long simultaneous XMM-NuSTAR look of MCG-6-30-15

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and the NuSTAR AGN Physics WG

Sexten - From the Dolomites to the Event Horizon
July 18, 2013

# Overview

- Brief introduction on MCG-6-30-15
- The XMM-NuSTAR 2013 observational campaign
- Testing the two different scenarios
- Results
- Conclusions and future perspectives

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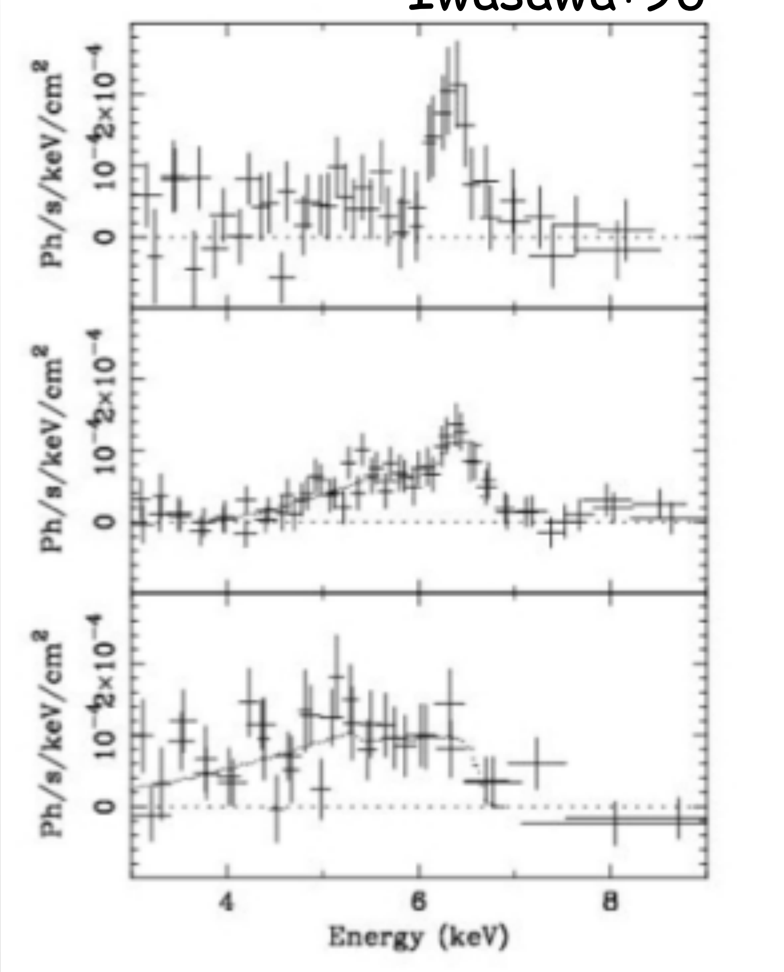
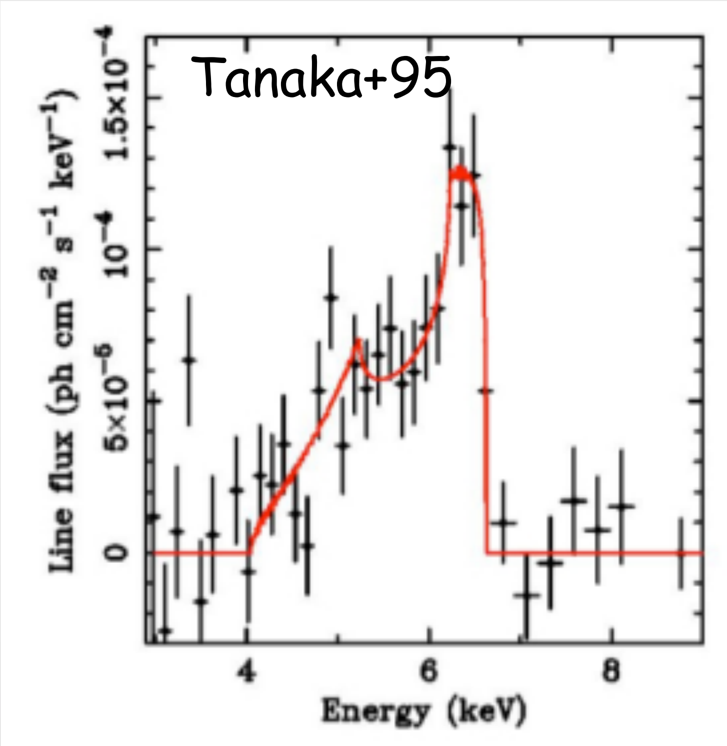
# Introduction

First broad Fe Kα line observed (Tanaka+95) and interpreted as originating from a rapidly spinning BH (Iwasawa+96)

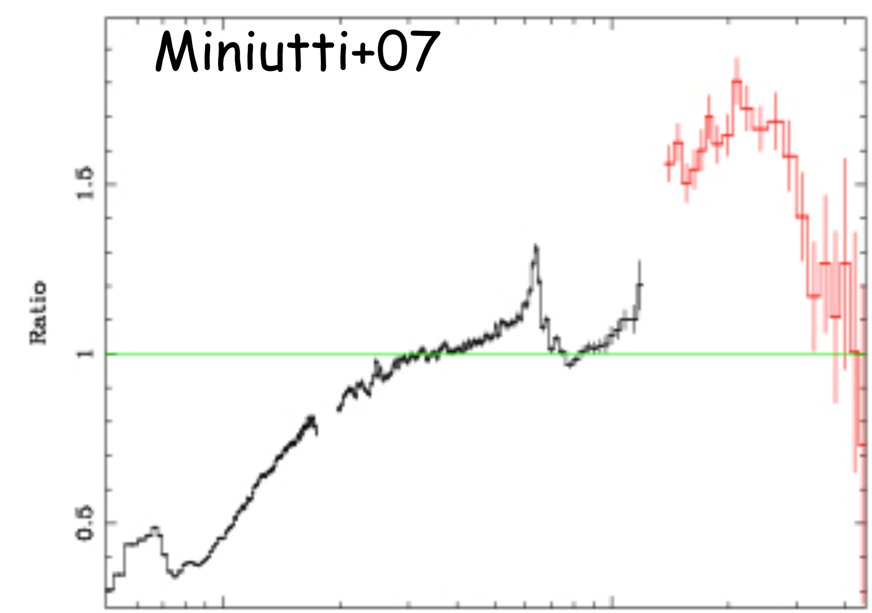
Iwasawa+96



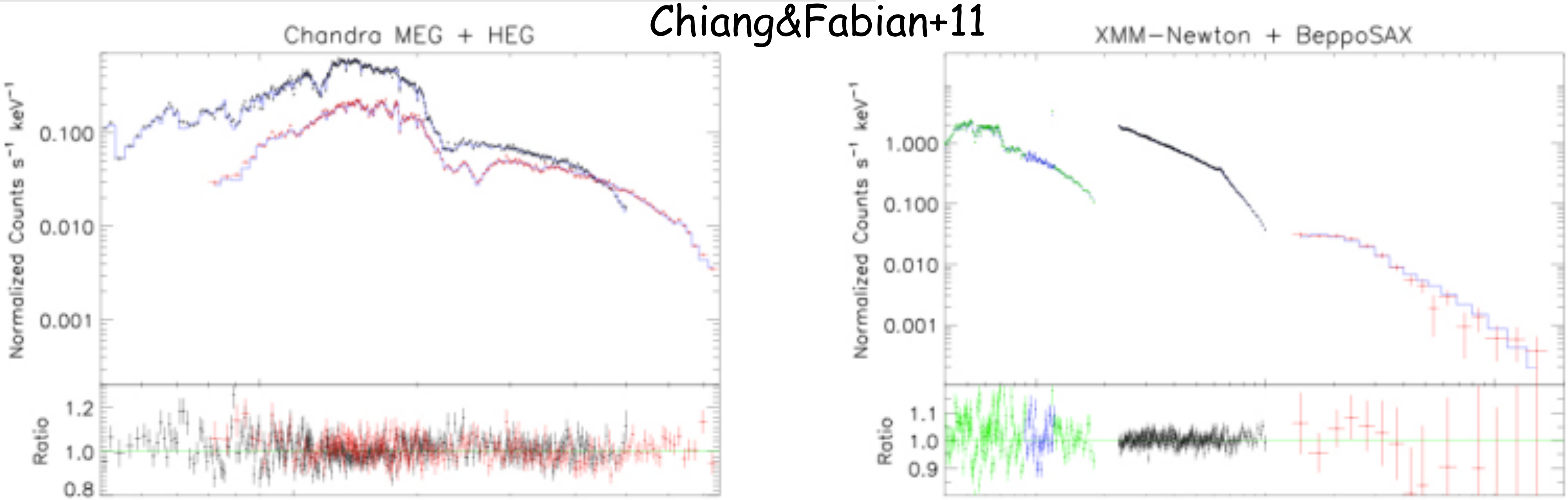



# X-ray observations

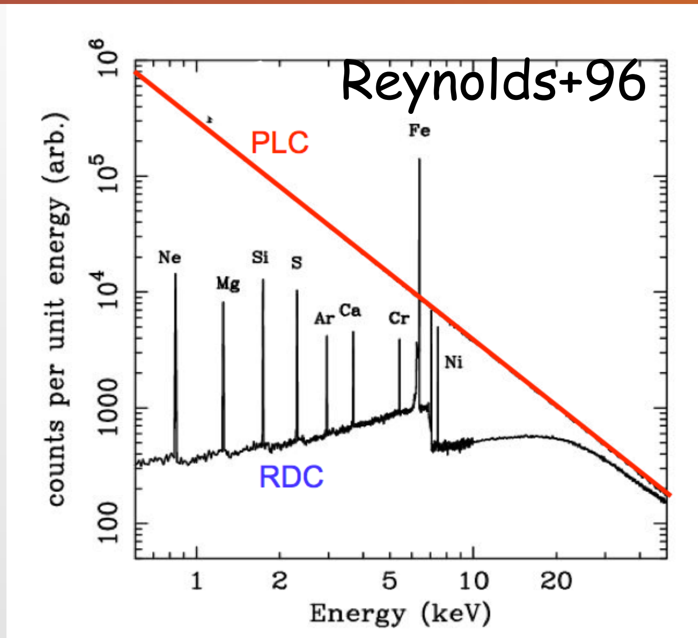
Extensively observed in the X-rays:
- complex absorption (Lee+01, Chiang&Fabian+11)
- strong refletion hump (Miniutti+07)
- very broad Fe Ka line (Brenneman&Reynolds+06)

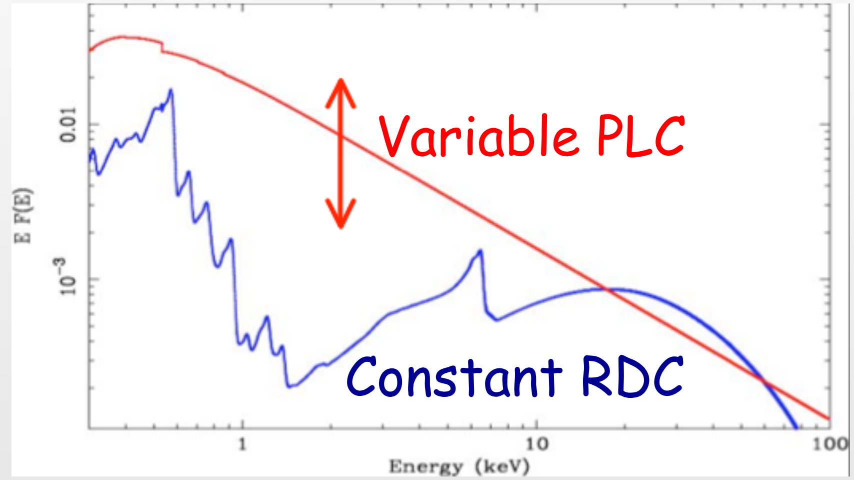



Chiang&Fabian+11

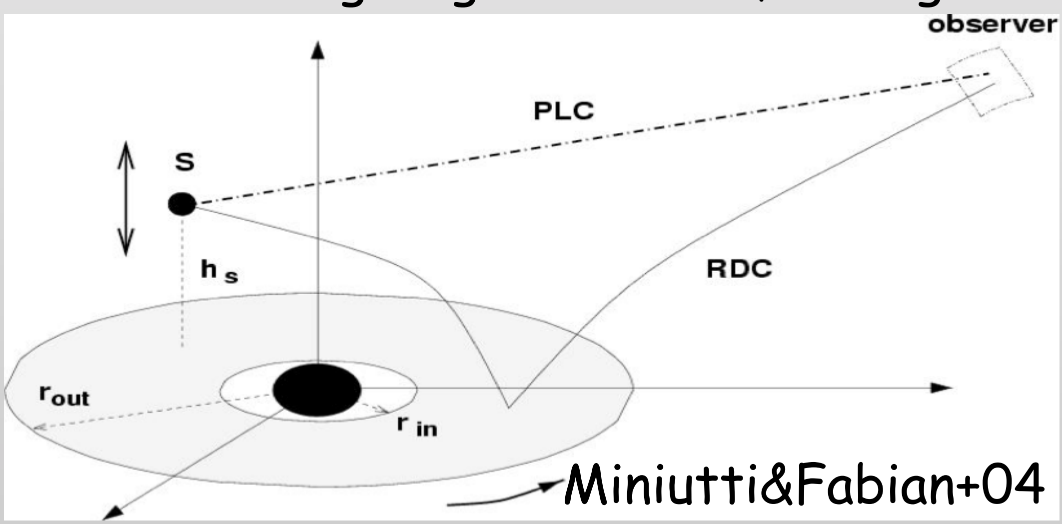


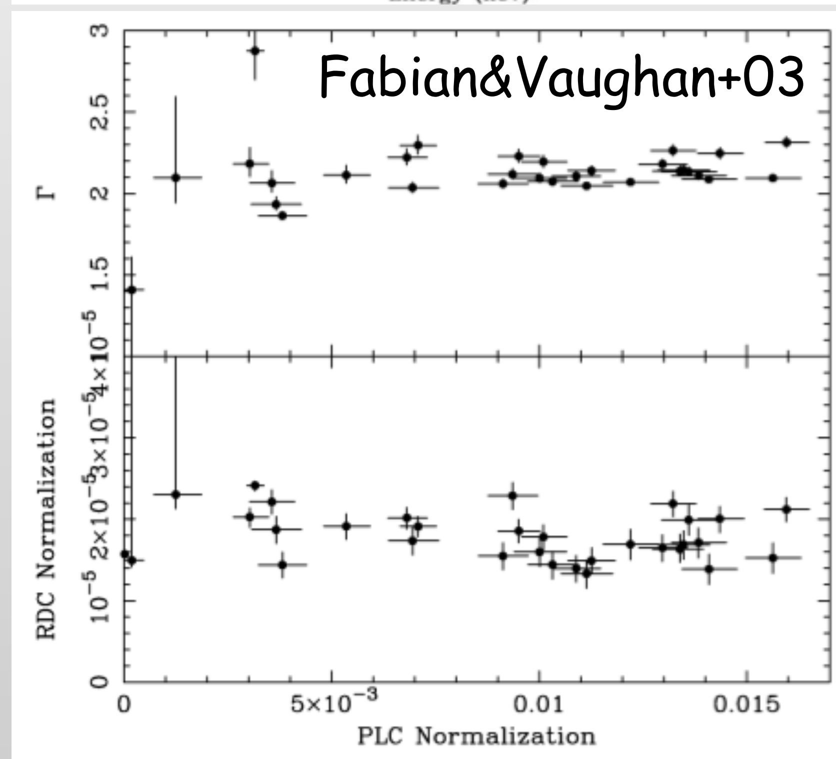
# Reflection scenario



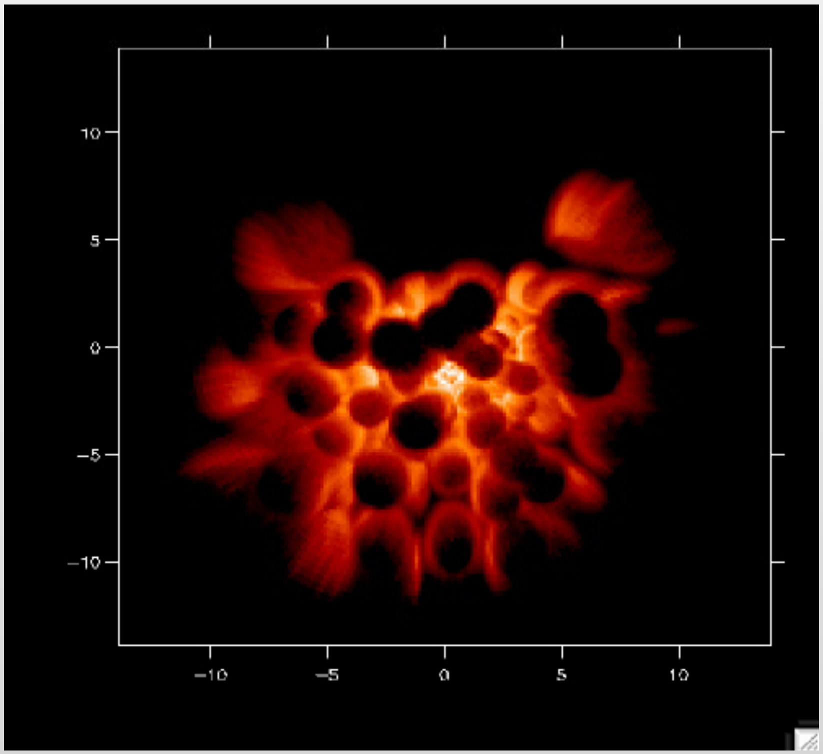

Light bending model: much of the flux is bent onto the disk giving a constant, strong RDC

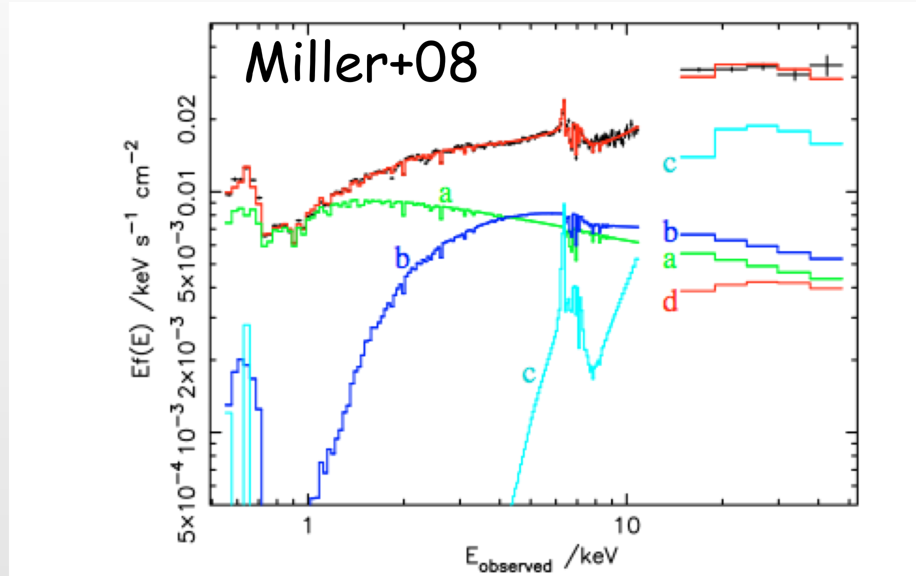


# Absorption scenario

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




"3+2" MODEL

3 fully covering warm absorbers

1 ionized absorber fully covering the distant reflection component ($\sim 5\times10^{23}$ cm$^{-2}$, log$\xi\sim2.0$)

1 ionized absorber partial covering the X-ray source ($\sim 4\times10^{22}$ cm$^{-2}$, log$\xi\sim1.5$)

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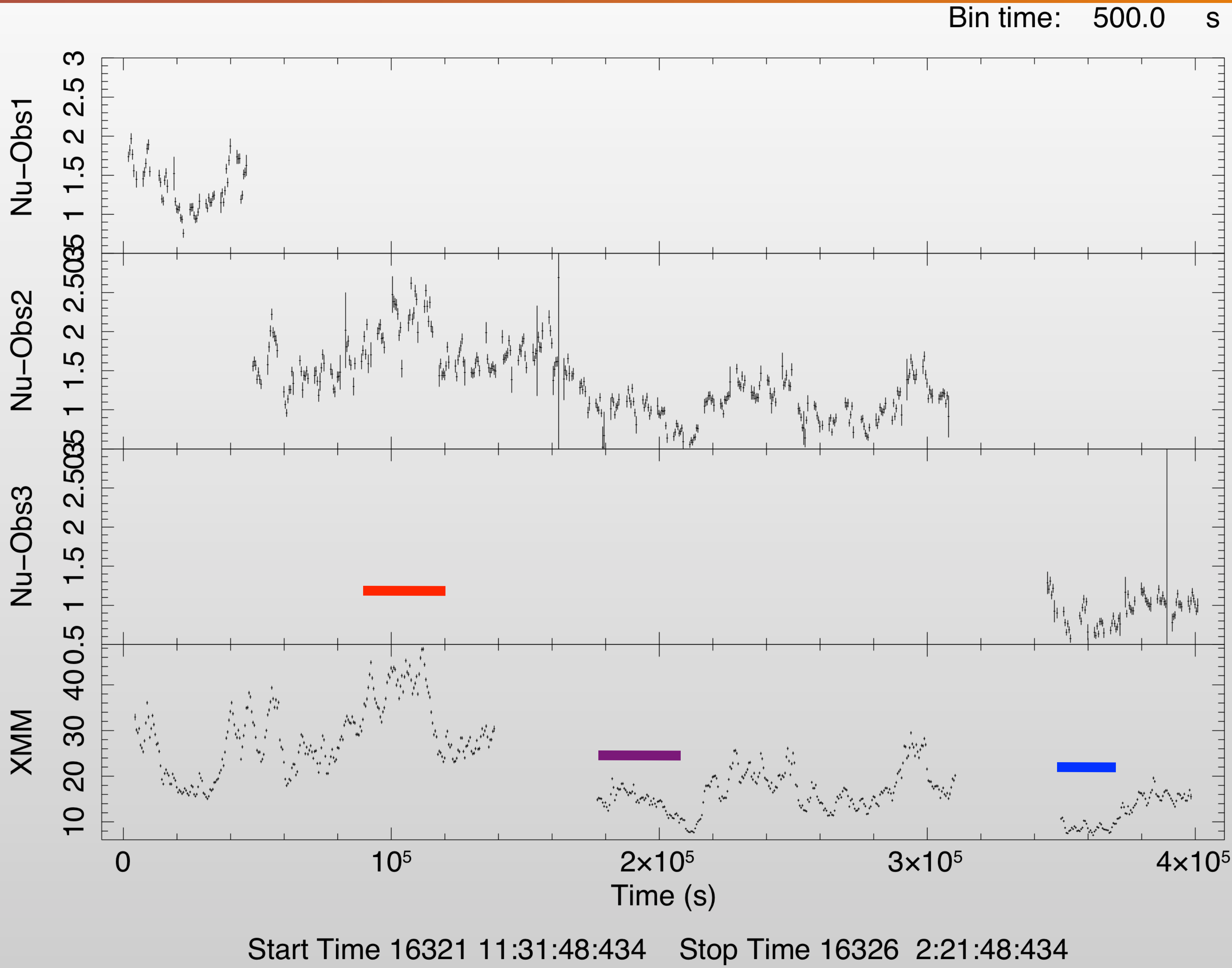
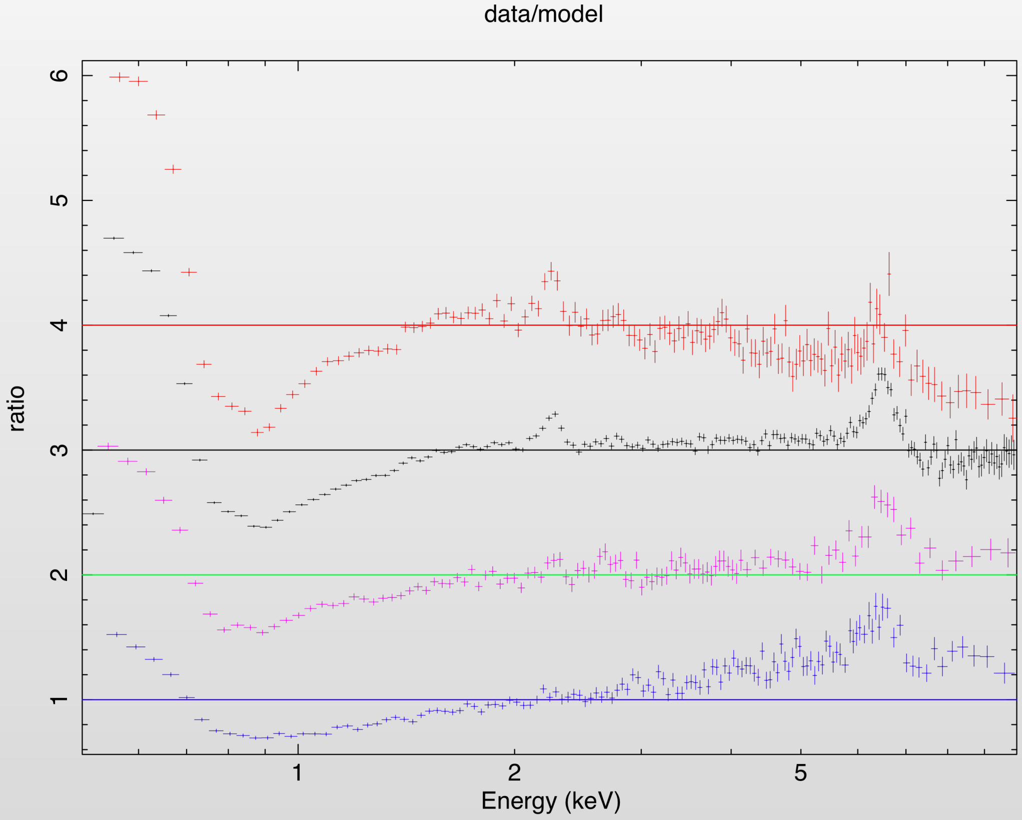
# NuSTAR-XMM light curves

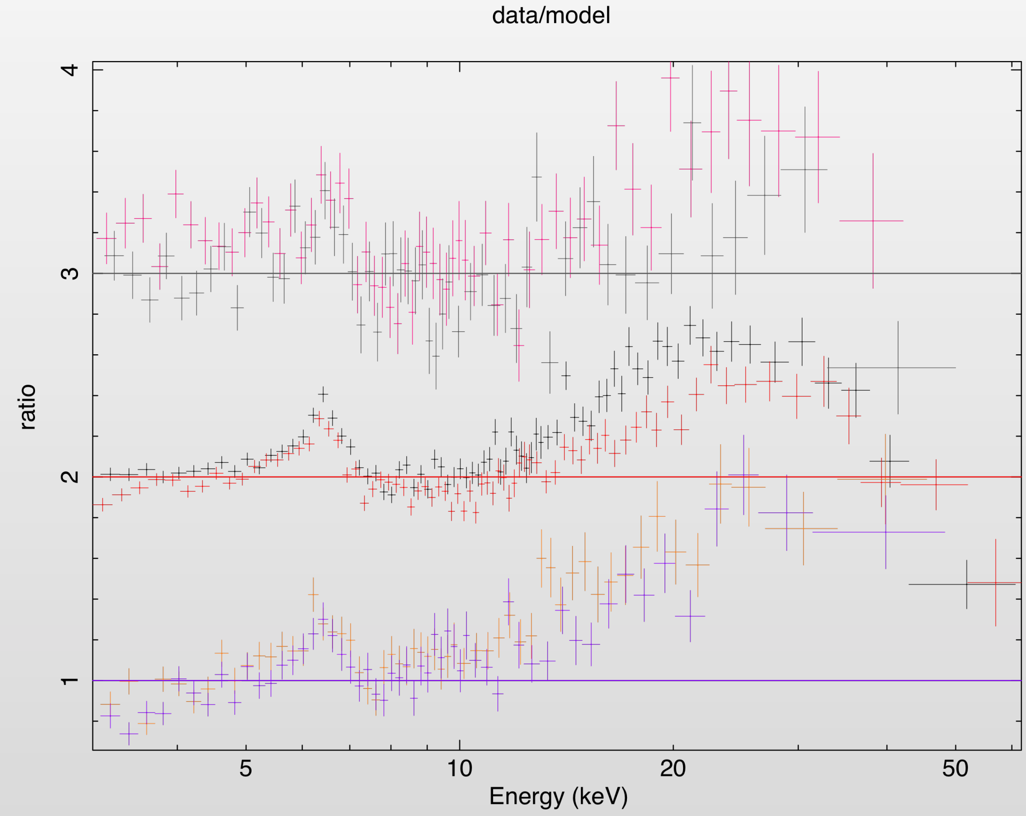


# Spectral features

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 $\Gamma$=2 power law).

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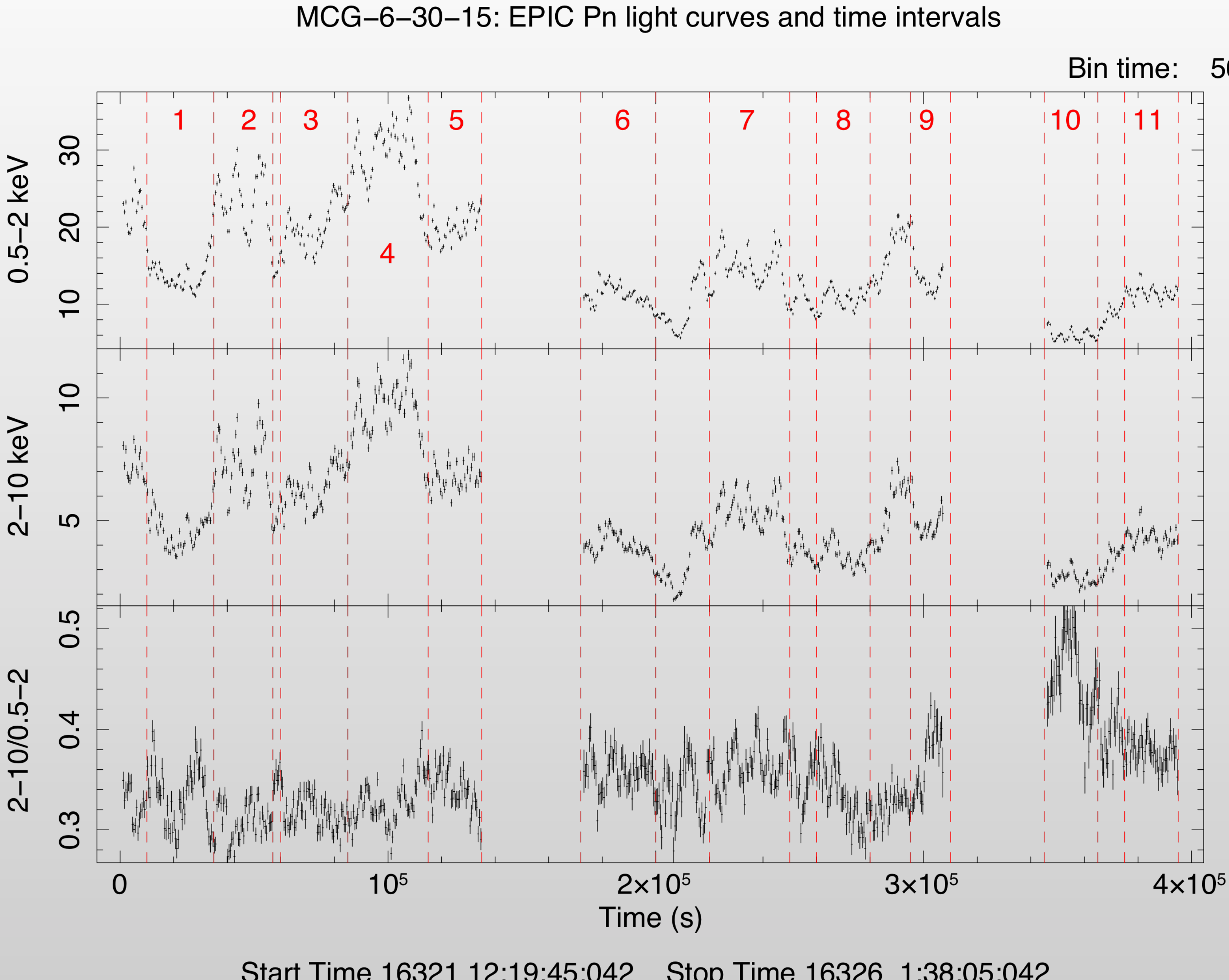
# Fitting strategy



# Fitting strategy

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

| REFLECTION | ABSORPTION |
| --- | --- |
| 2*XSTAR*DUST<br>x<br>(Xillver + Relconv*Xillver + zpow) | 2*XSTAR*DUST<br>x<br>(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:

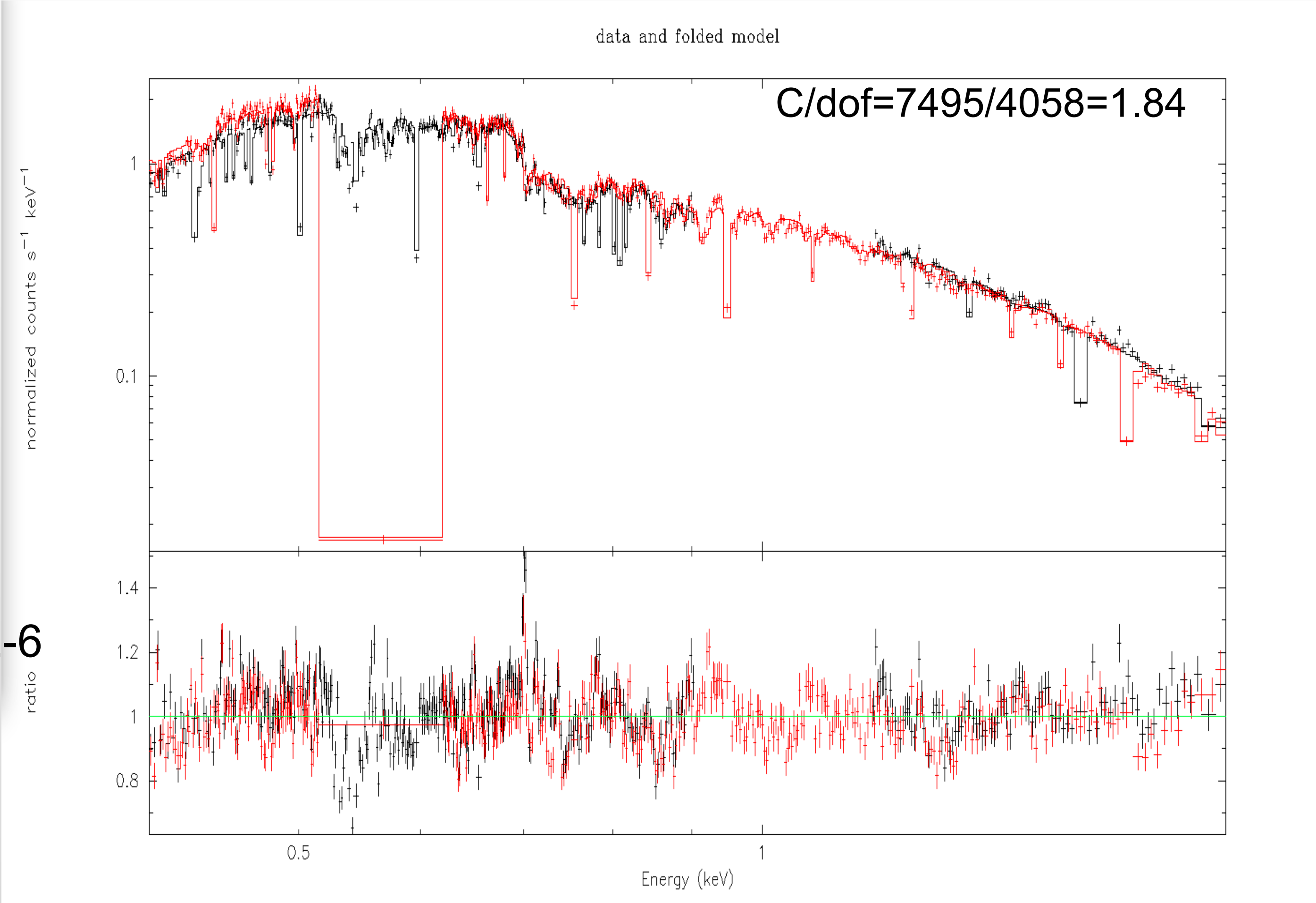
http://www.sternwarte.uni-erlangen.de/~dauser/research/relline/

# Combined RGS1+2 analysis

$N_{H1}$ =(4.6 +/- 0.8) x$10^{20}$ $cm^{-2}$
$\log\xi_1$=1.47+/- 0.2
v~2000 km $s^{-1}$
$N_{H2}$=(1.3 +/- 0.2) x$10^{20}$ $cm^{-2}$
$\log\xi_2$=0.08+ 0.10
$N_{H3}$=(1.00+/- 0.04) x$10^{22}$ $cm^{-2}$
$\log\xi_3$=2.03+ 0.01
$\log N_{Fe}$=17.32+/-0.02

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

$\Gamma$=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

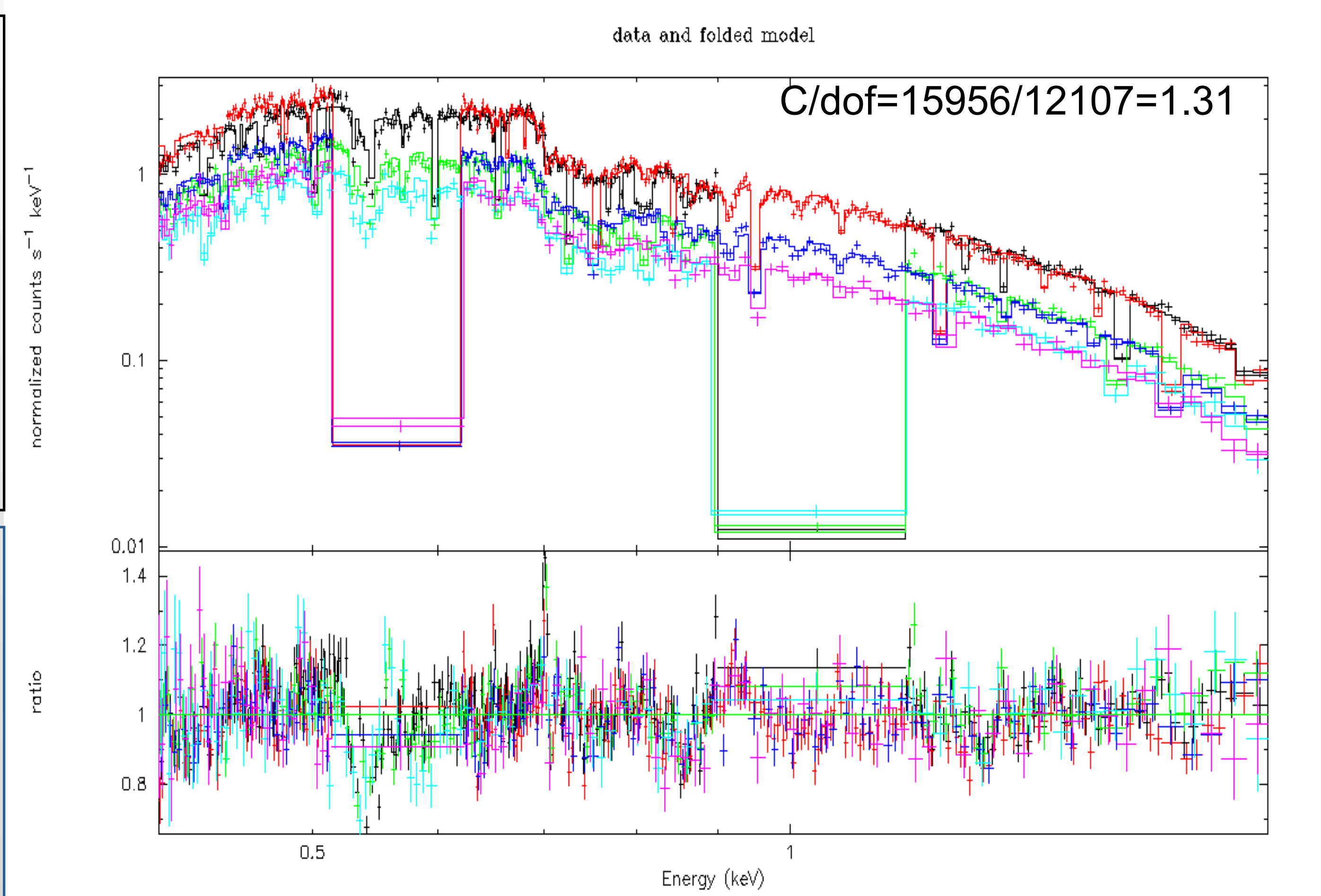
**Orbit 1**

$N_{H1}$ (5.6 +/- 1.7) x$10^{20}$ $cm^{-2}$
$\log\xi_1$ 1.82+/- 0.05
v~2000 km $s^{-1}$
$N_{H2}$ (8.6 +/- 1.8) x$10^{20}$ $cm^{-2}$
$\log\xi_2$ 1.47+ 0.05
$N_{H3}$ (1.00+/- 0.04) x$10^{22}$ $cm^{-2}$
$\log\xi_3$ 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) x$10^{20}$ $cm^{-2}$
$\log\xi_1$ 1.85+/- 0.1
v~2000 km $s^{-1}$
$N_{H2}$ (2.9 +/- 0.5) x$10^{20}$ $cm^{-2}$
$\log\xi_2$ 1.34+ 0.13
$N_{H3}$ (1.00+/- 0.09) x$10^{22}$ $cm^{-2}$
$\log\xi_3$ 2.02+ 0.02
$\log N_{Fe}$ 17.27 +/- 0.04
$\Gamma$=2.03
norm 1.22E-02 +/- 0.02E-02

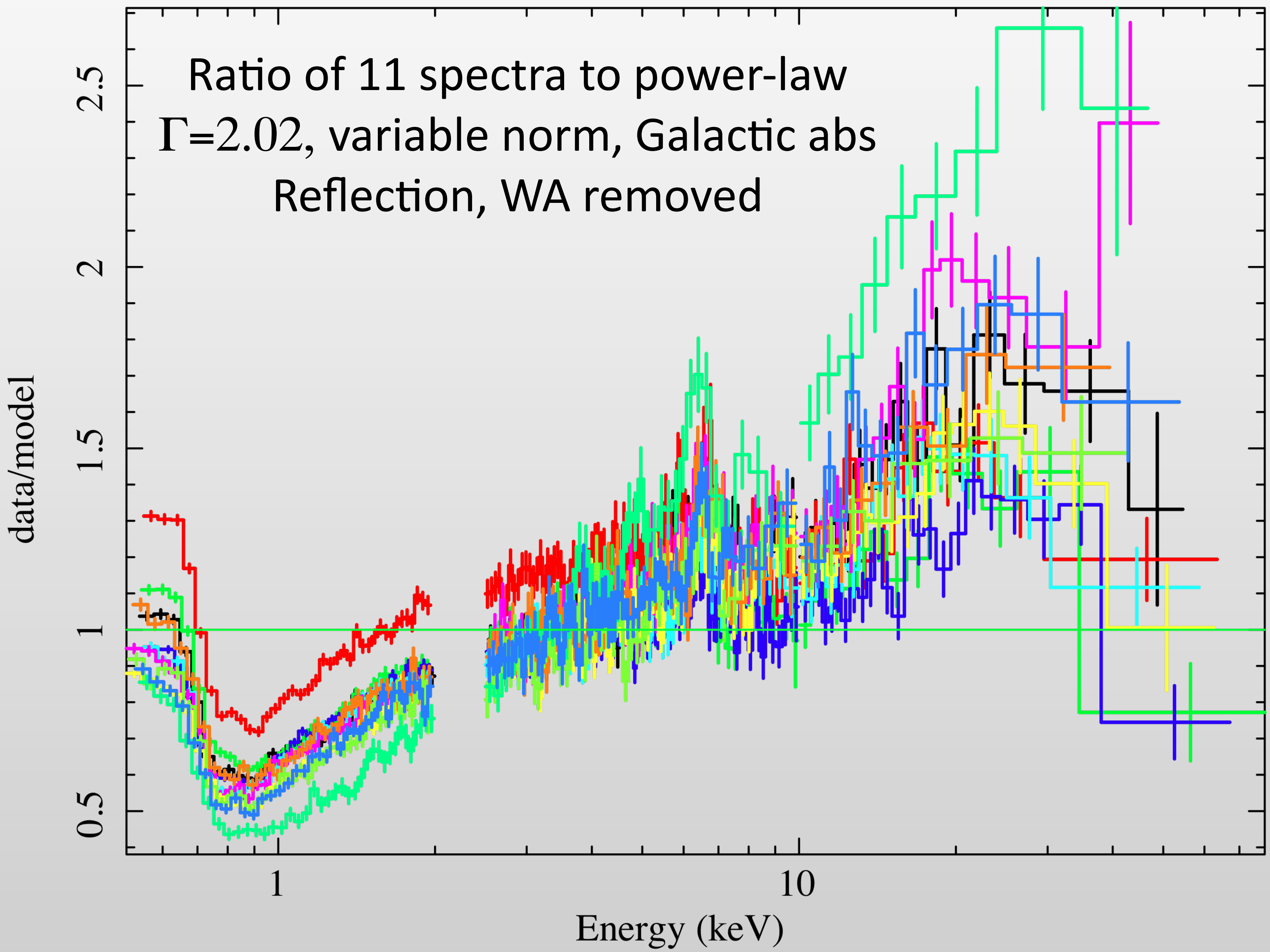



**Orbit 3**

$N_{H1}$ (5.1 +/- 2.5) x$10^{20}$ $cm^{-2}$
$\log\xi_1$ 1.75+/- 0.23
v~2000 km $s^{-1}$
$N_{H2}$ (5.0 +/- 1.0) x$10^{20}$ $cm^{-2}$
$\log\xi_2$ 1.3+/- 0.3
$N_{H3}$ (0.88+/- 0.02) x$10^{22}$ $cm^{-2}$
$\log\xi_3$ 2.00+ 0.03
$\log N_{Fe}$ 17.08 +/- 0.12
$\Gamma$=2.03
norm 0.8E-02 +/- 0.4E-03

No significant variation has been found in the warm absorbing structure

# Time resolved simultaneous analysis



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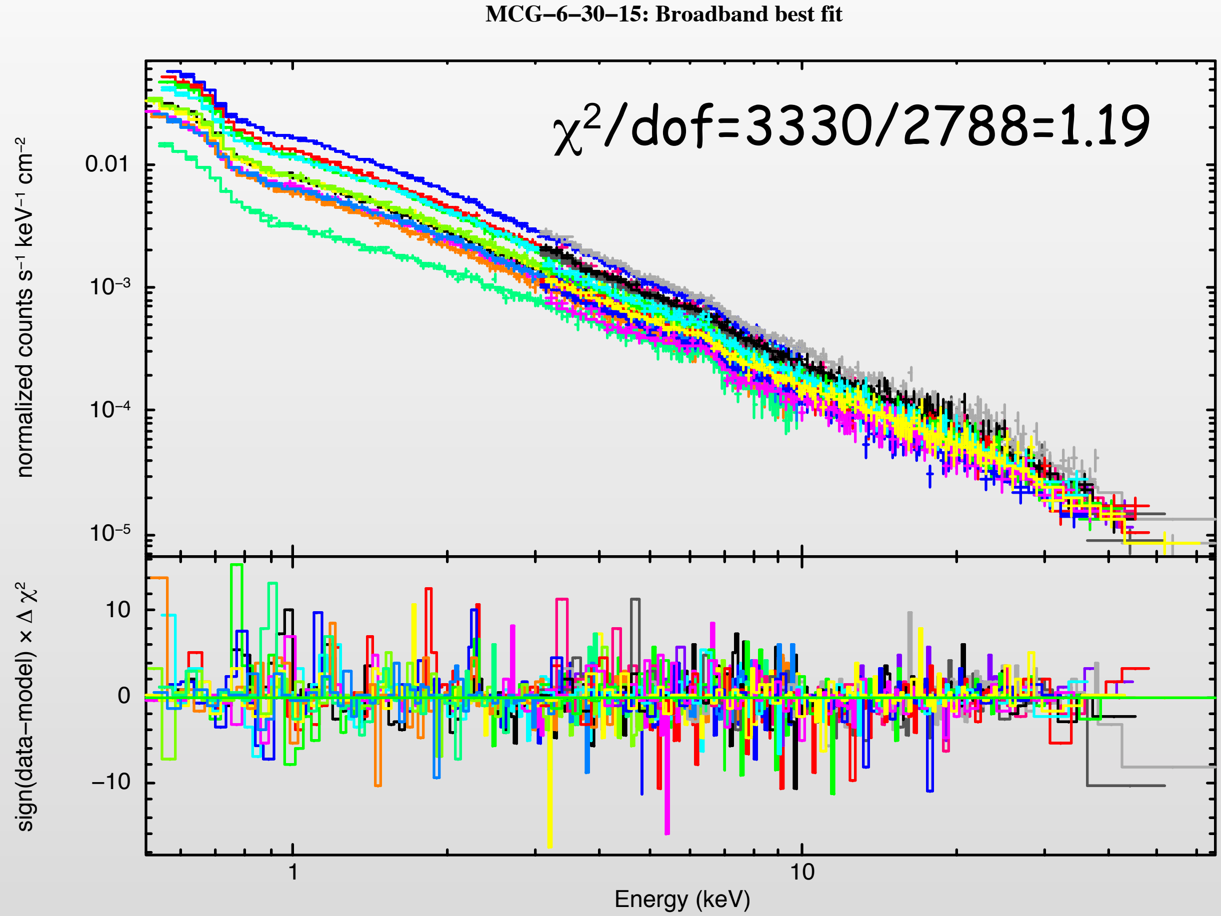
# Results: reflection




## Warm absorbers

$N_{H1}$=(0.6-<u>2.5</u>) x$10^{22}$ $cm^{-2}$
log$\xi_1$=1.98 ± 0.01

$N_{H2}$=(<u>0.5</u>-3.0) x$10^{21}$ $cm^{-2}$
log$\xi_2$=1.27±0.02

log$N_{Fe}$=16.6 ± 0.2

## Reflection parameters

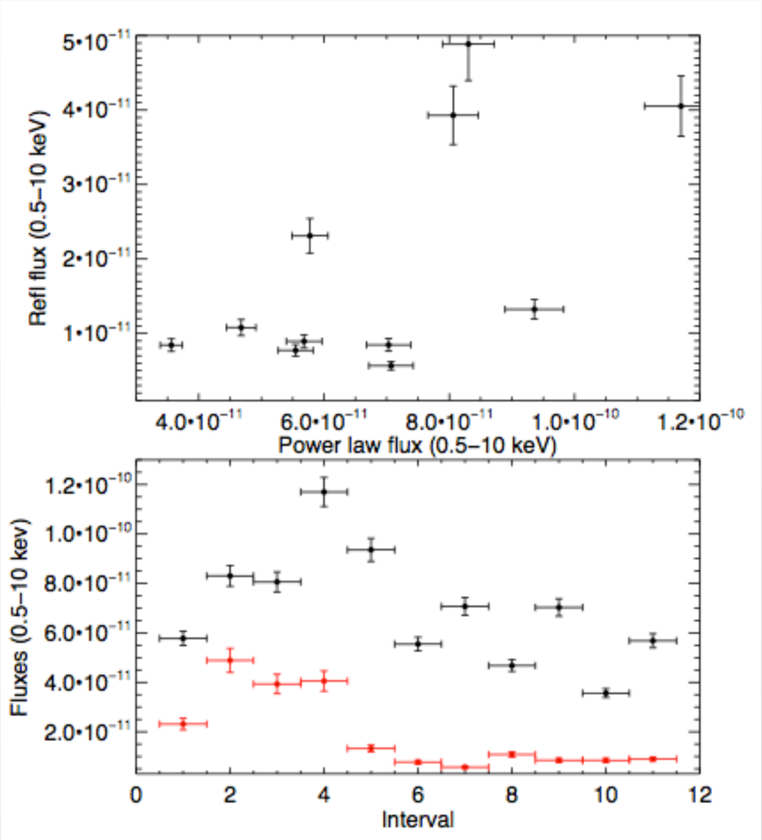
(q=3.0 a=0998 incl=37°)

log$\xi$=0.2-3.0
$A_{Fe}$=1.56±0.32

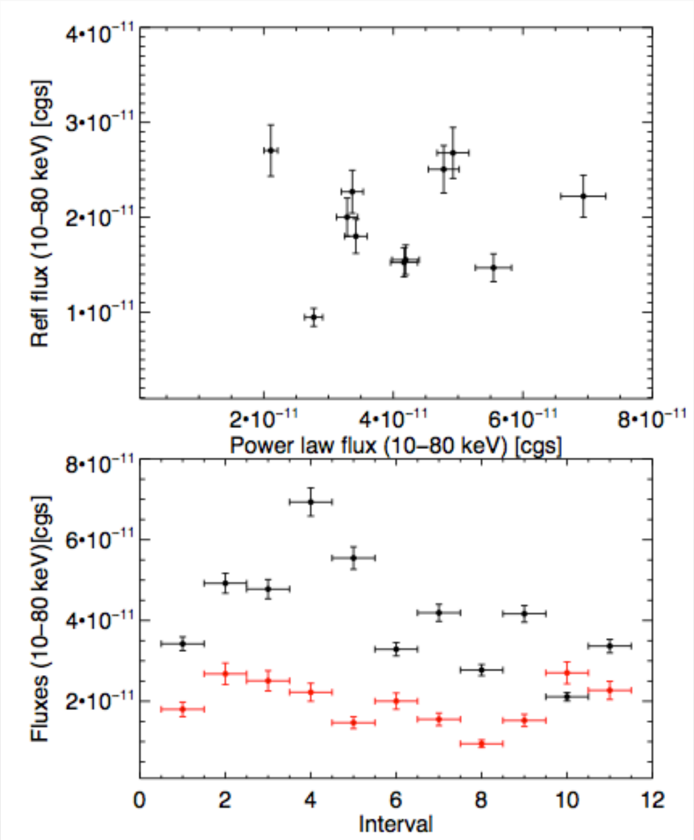
## Primary emission parameters

$\Gamma$=2.050±0.005
$E_c$>100 keV

# RDC vs PLC fluxes



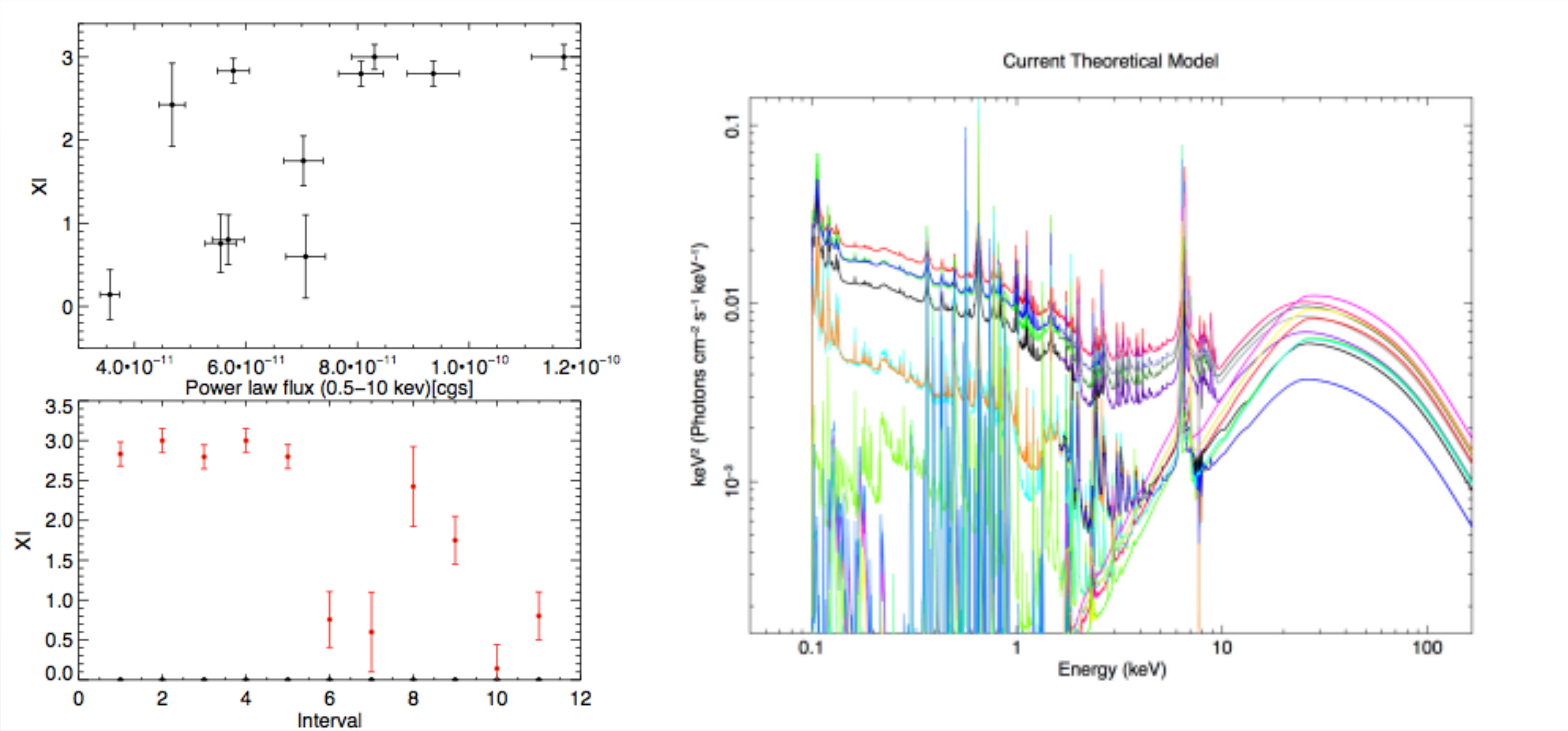

Variation of a factor ~2 observed in the RDC between 0.5-10 keV (in agreement with the PCA presented by Michael P.)




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) x$10^{22}$ $cm^{-2}$
$\log\xi_1$=1.95 ± 0.02

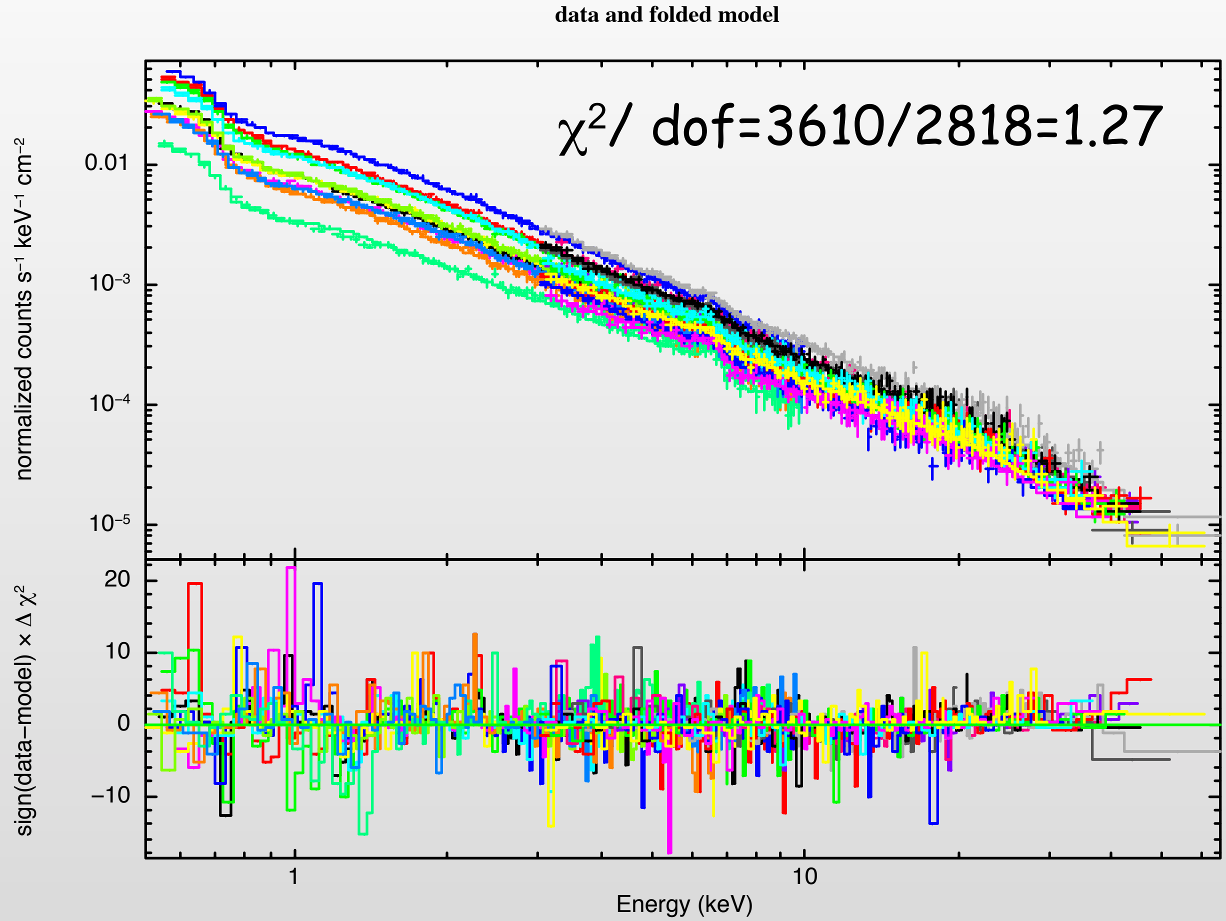
$N_{H2}$=(4.2±1.5) x$10^{21}$ $cm^{-2}$
$\log\xi_2$=2.82±0.05

$\log N_{Fe}$=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) x$10^{23}$ $cm^{-2}$
$\log\xi_3$=2.11 ± 0.01

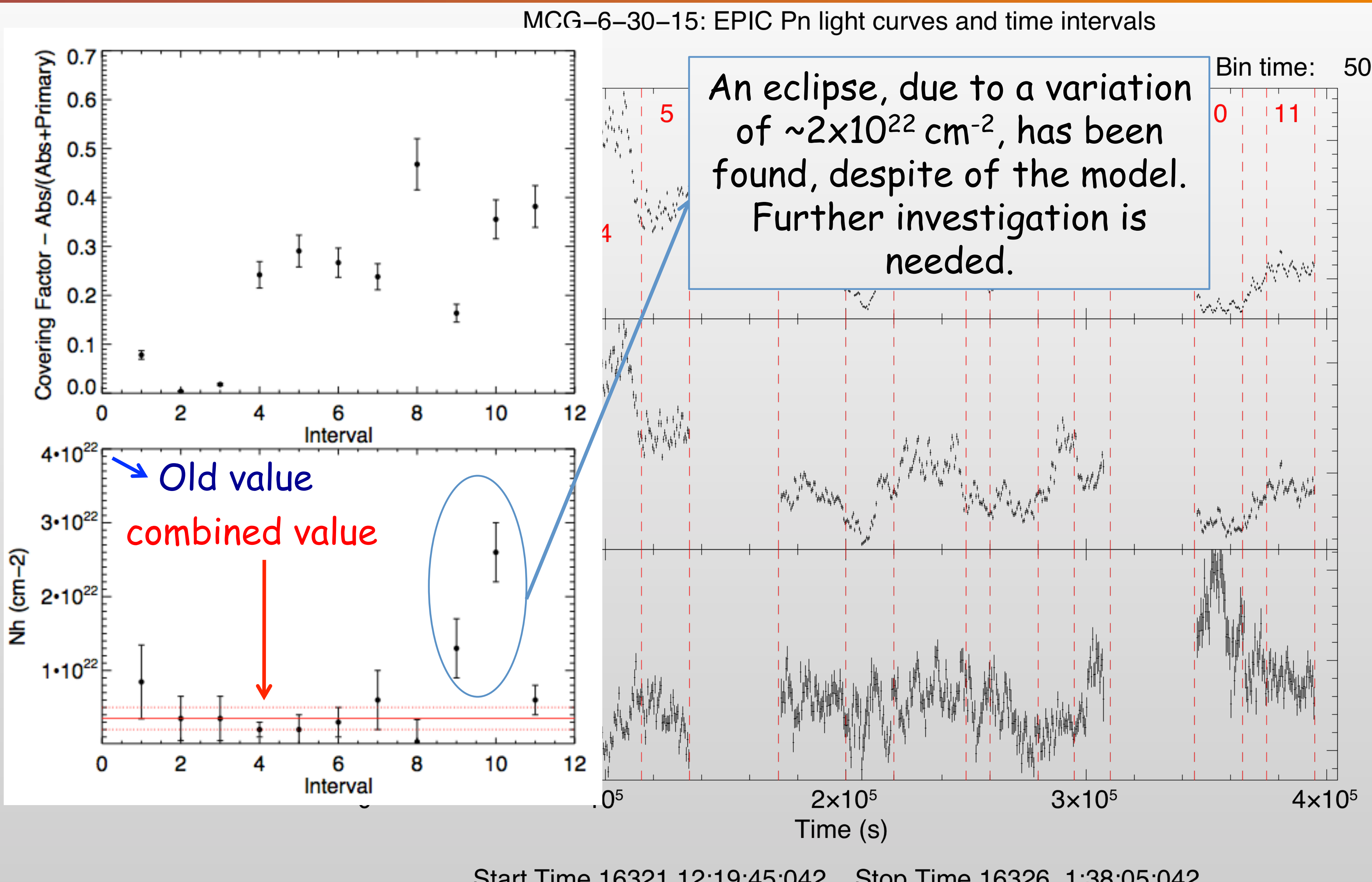
$N_{H4}$=(0.3-27) x$10^{21}$ $cm^{-2}$
$\log\xi_4$=(0.0015±0.0005)
[almost neutral]




Primary emission parameters

$\Gamma$=2.16±0.01
$E_c$>100 keV

# Covering factor time evolution




An eclipse, due to a variation of ~$2\times10^{22}$ $cm^{-2}$, has been found, despite of the model. Further investigation is needed.

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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 attributed to 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 $\Gamma$=2.05 and $\Gamma$=2.15;

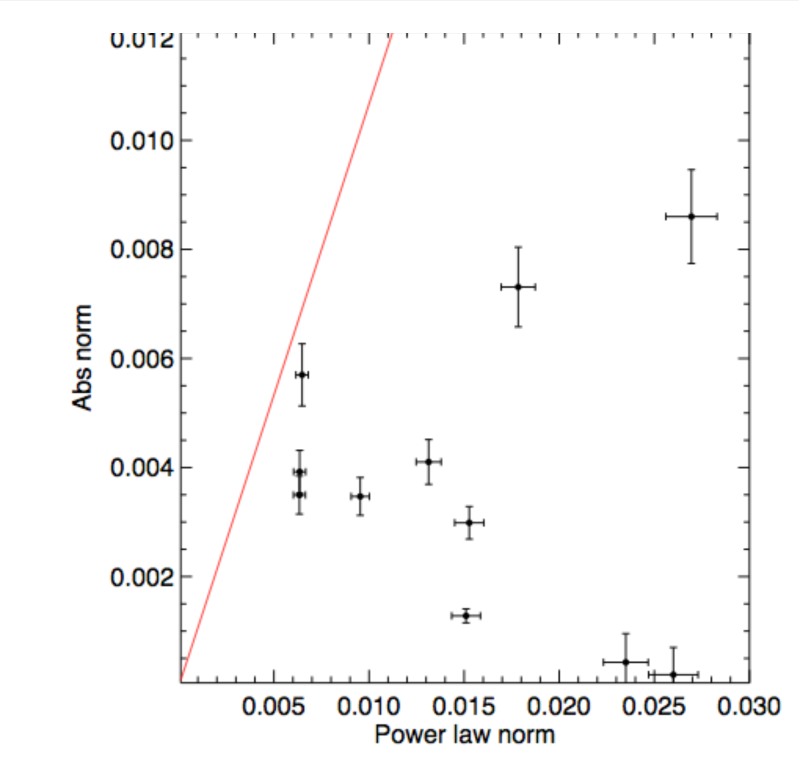
- Time intervals with constant HR AND comparable flux (in a fixed energy band) could be co-added.

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

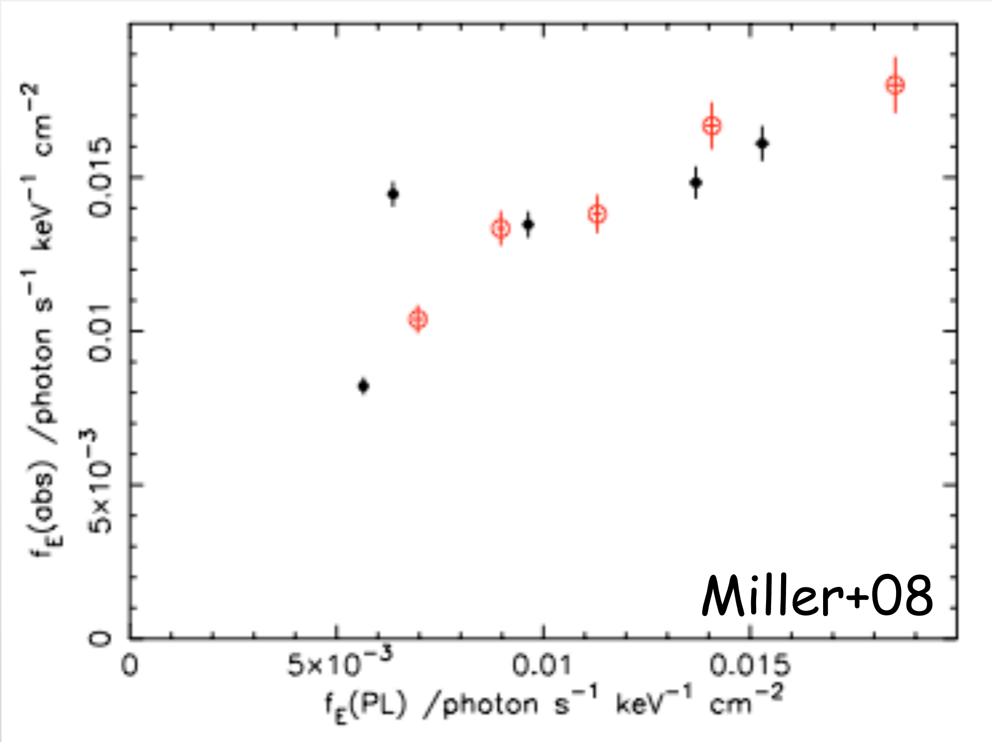
- Measure Black Hole spin throughout the 300 ks observation


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
$5\times10^{-3}$
0.01
0.015
Miller+08