The broad iron Kα line feature in Cygnus X-1

with

XMM-Newton, RXTE and INTEGRAL

Refiz Duro

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ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

Black Hole Universe

Friedrich-Alexander-Universität Erlangen-Nürnberg

The result

Our data show:

Cygnus X-1 is a highly rotating black hole!

$$a \sim 0.9$$
$$-0.998 \leq a \leq +0.998$$

Reflection fitting method:

(Duro+ 2011,2012)

(Fabian+ 2012)

Continuum fitting method:

(Gou+ 2011)

Inclination: $i = 27^{\circ}$

Distance: $\mathrm{d} = 1.86$ kpc

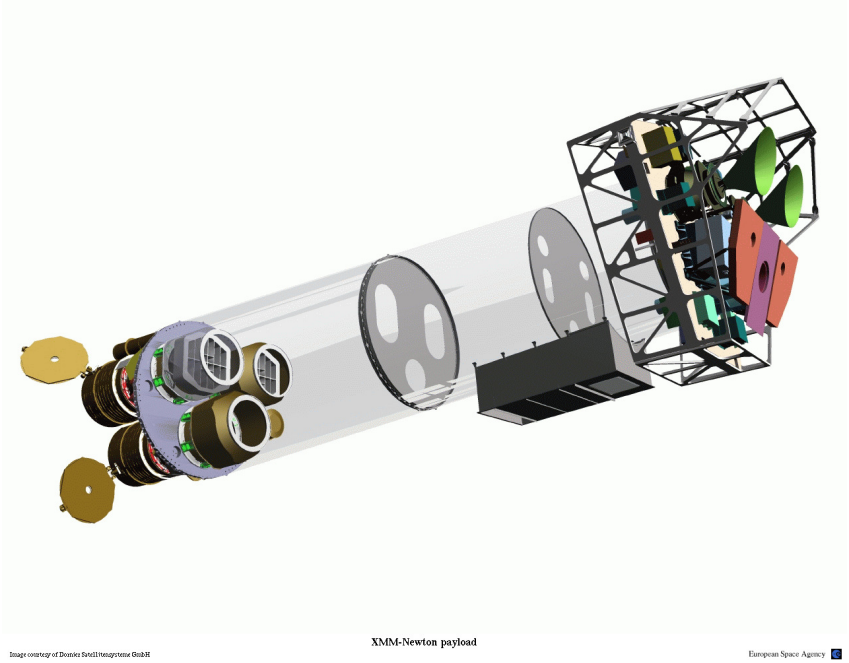
Mass BH: $M_{\mathrm{BH}} = 14.8\ \mathrm{M}_{\odot}$

(Reid+ 2011) (Orosz+ 2011)

Bright sources with *XMM-Newton's* EPIC-pn

Fast modes and obstacles:

- Burst & Timing mode
- low S/N & telemetry limit
  $\sim$ 450 c/s



Photo, ESA/XMM-Newton

Solution:

- Modified Timing mode:
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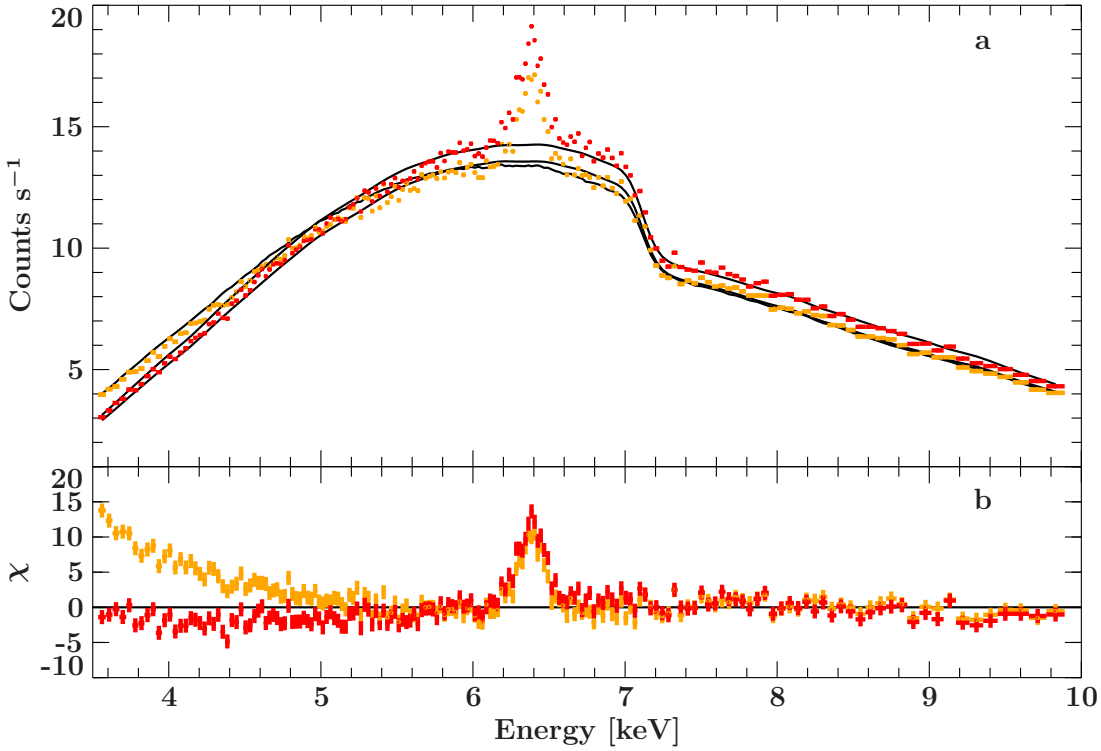
Vela X-1 (**thick filter**)



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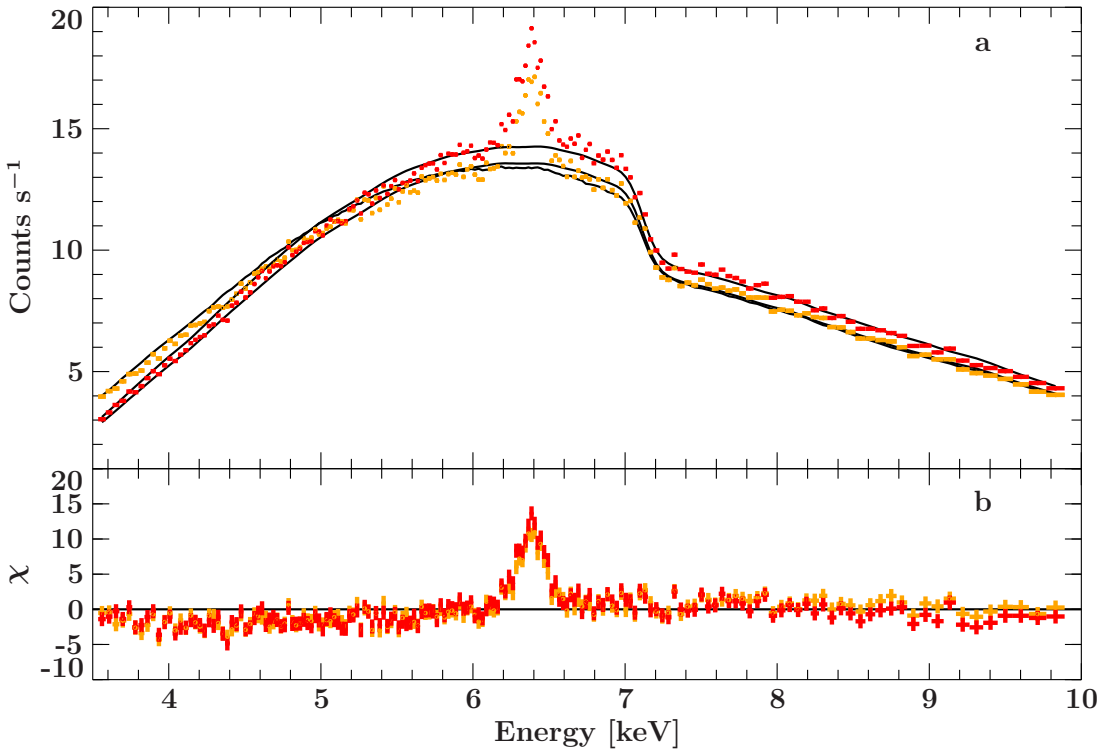

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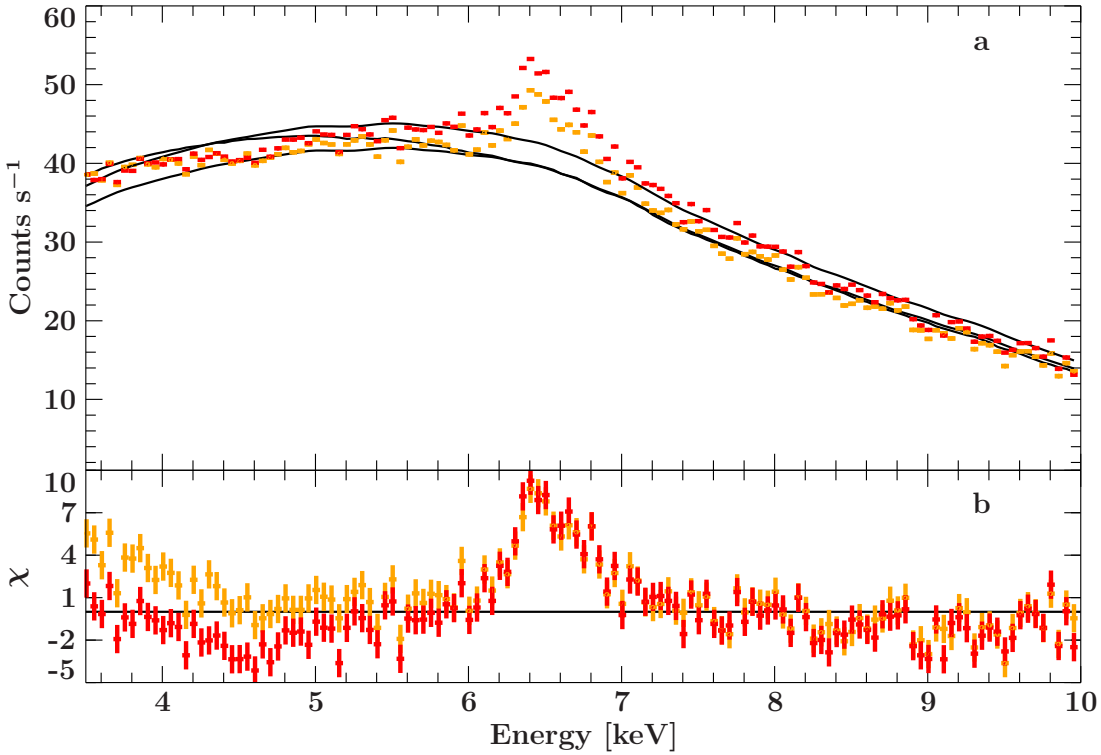
Her X-1 (**medium filter**)



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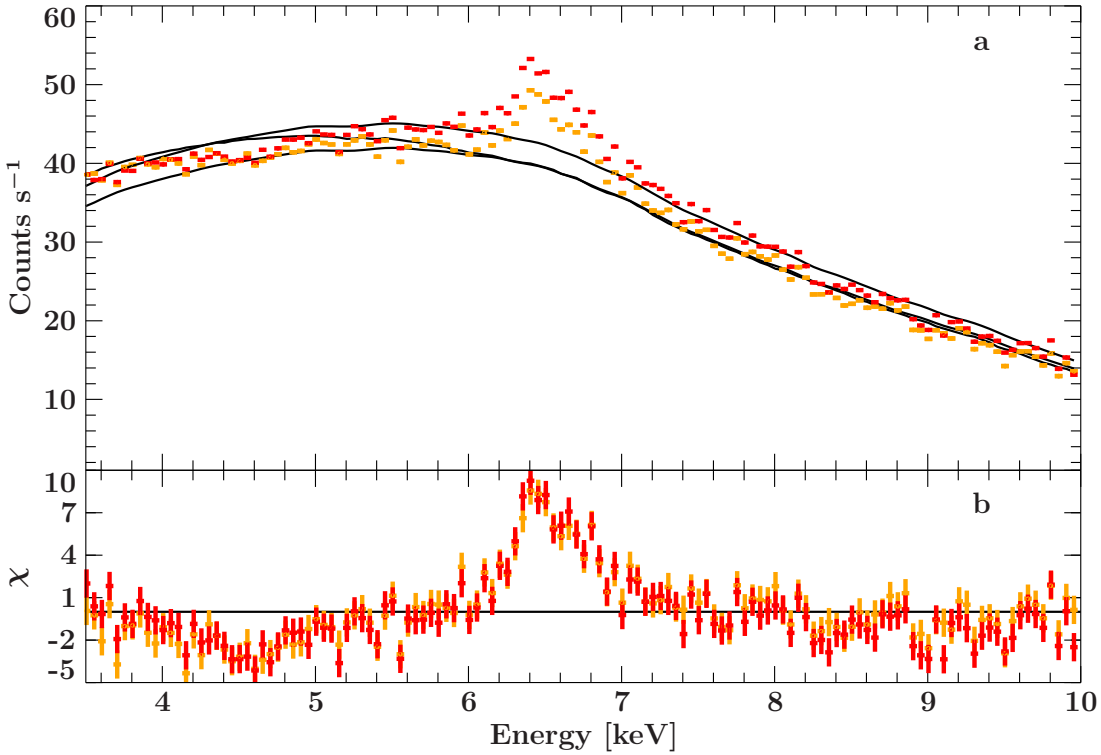

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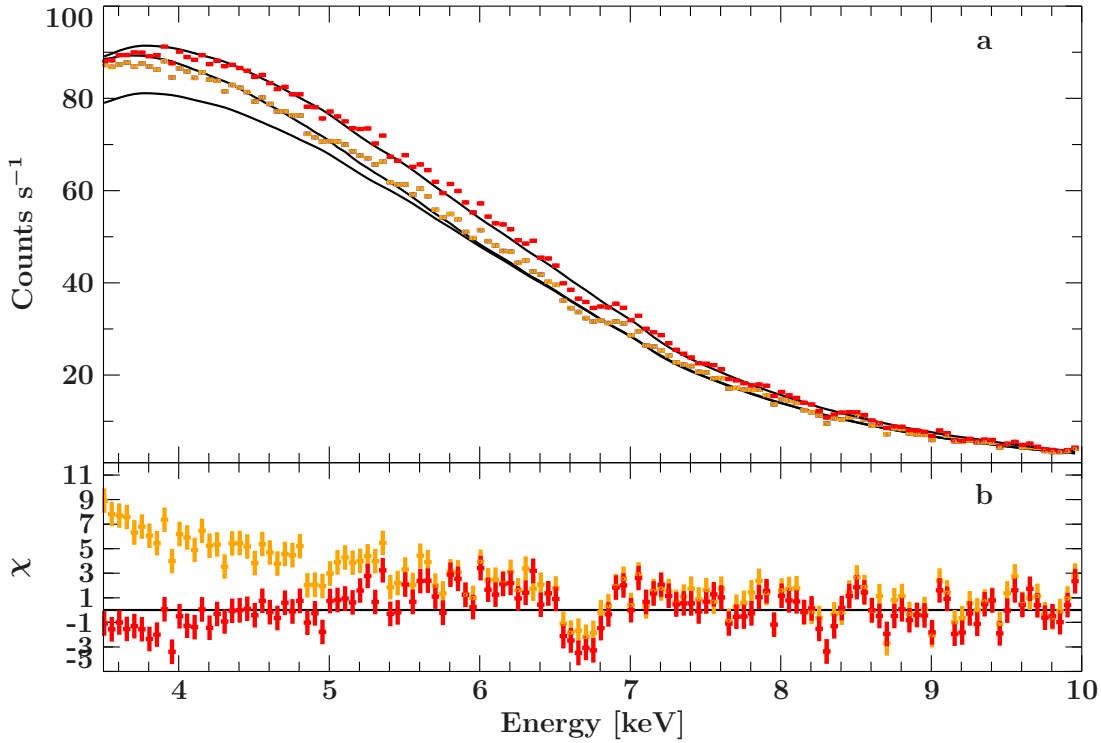
Circinus X-1 (**thin filter**)



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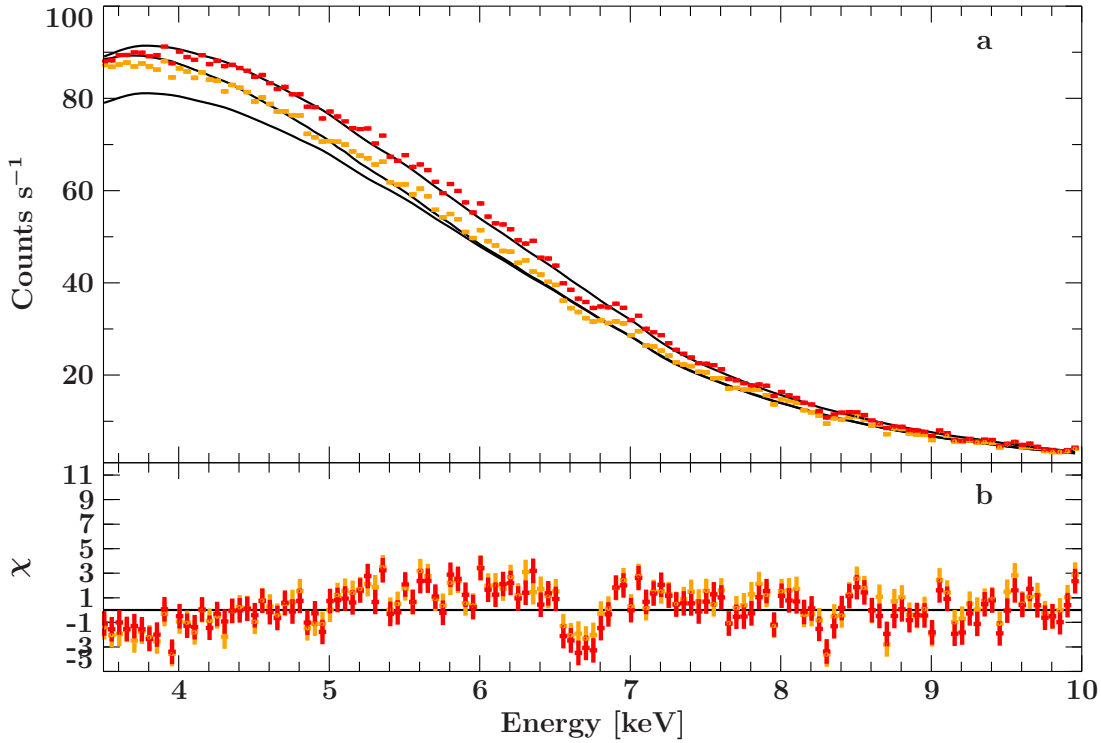

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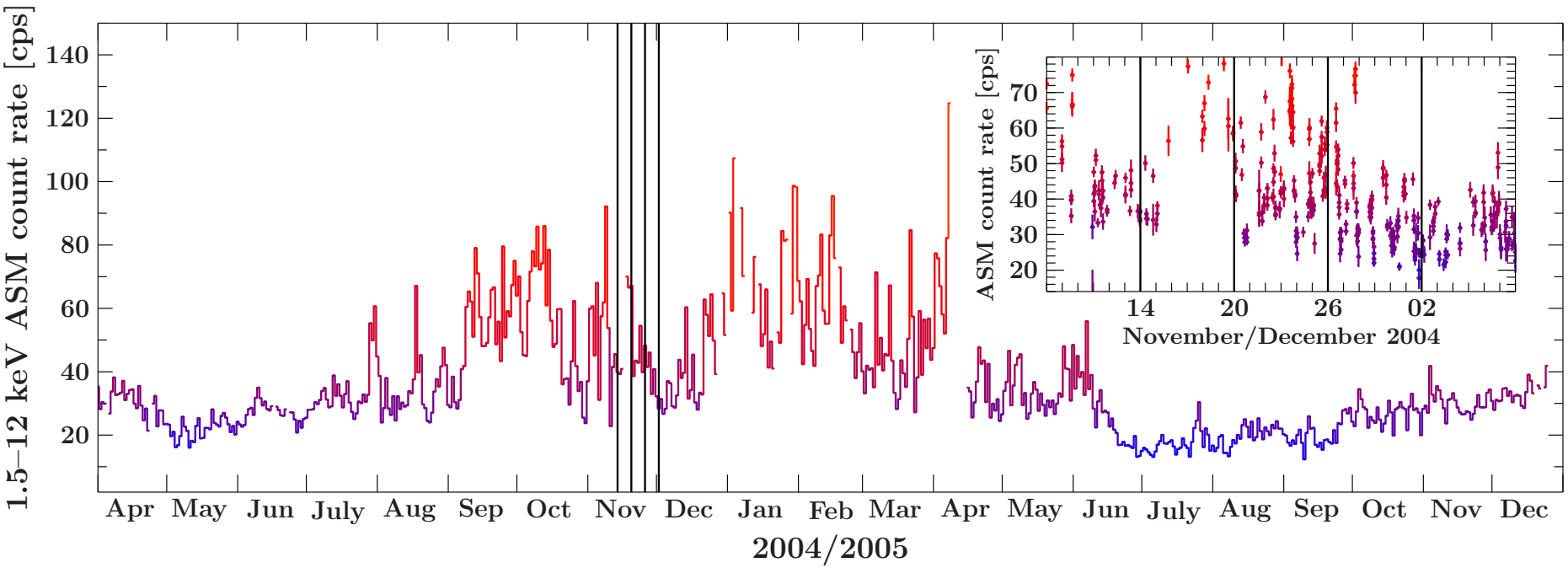
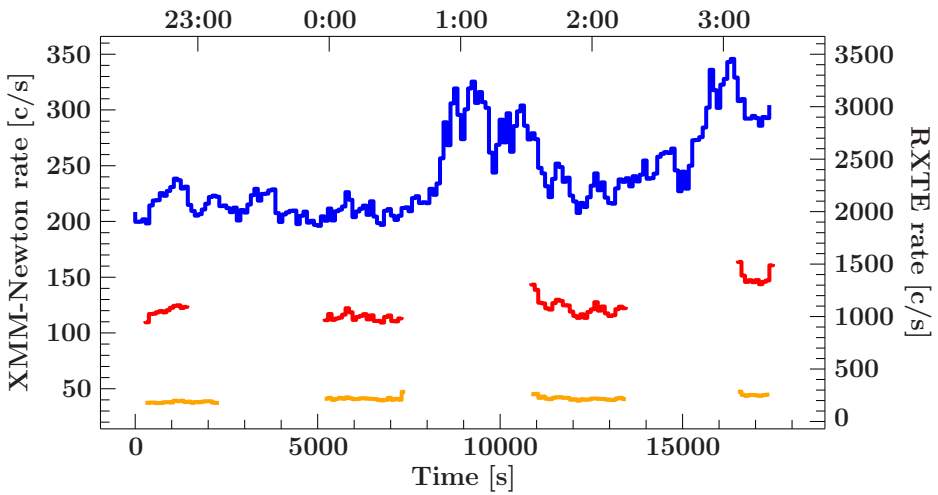
Cygnus X-1 with *RXTE* All Sky Monitor in 2004

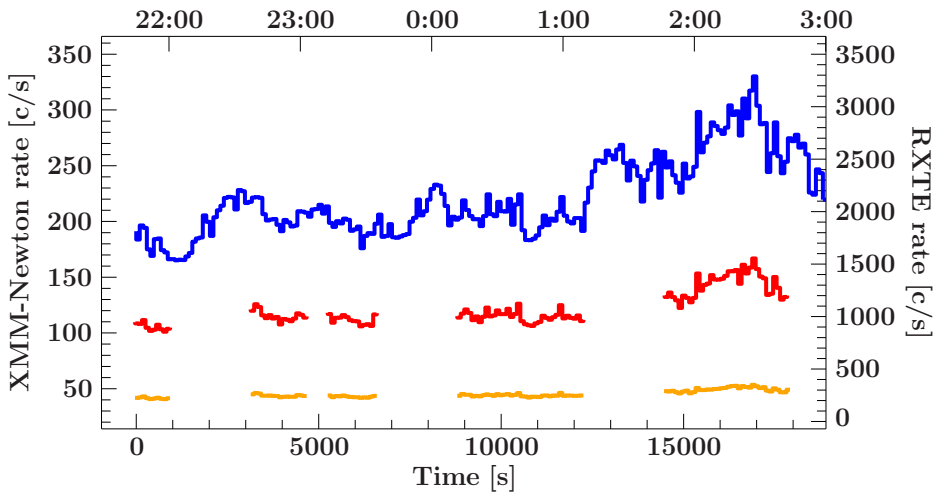


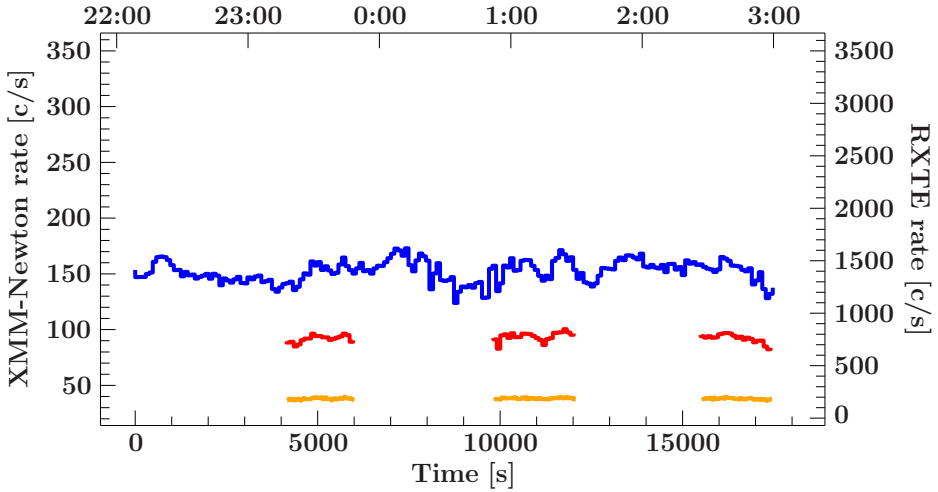
Cygnus X-1 is in a hard intermediate state.

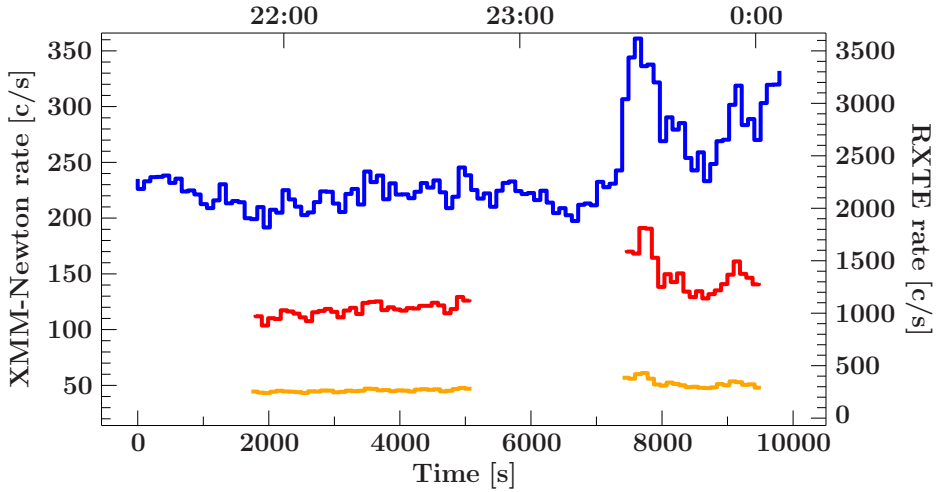
- $\Gamma \sim 1.6$
- ASM mapping (hardness-counts) (Grinberg+ 2012)
- radio emission during the observation

Lightcurves: EPIC-pn, PCA, HEXTE









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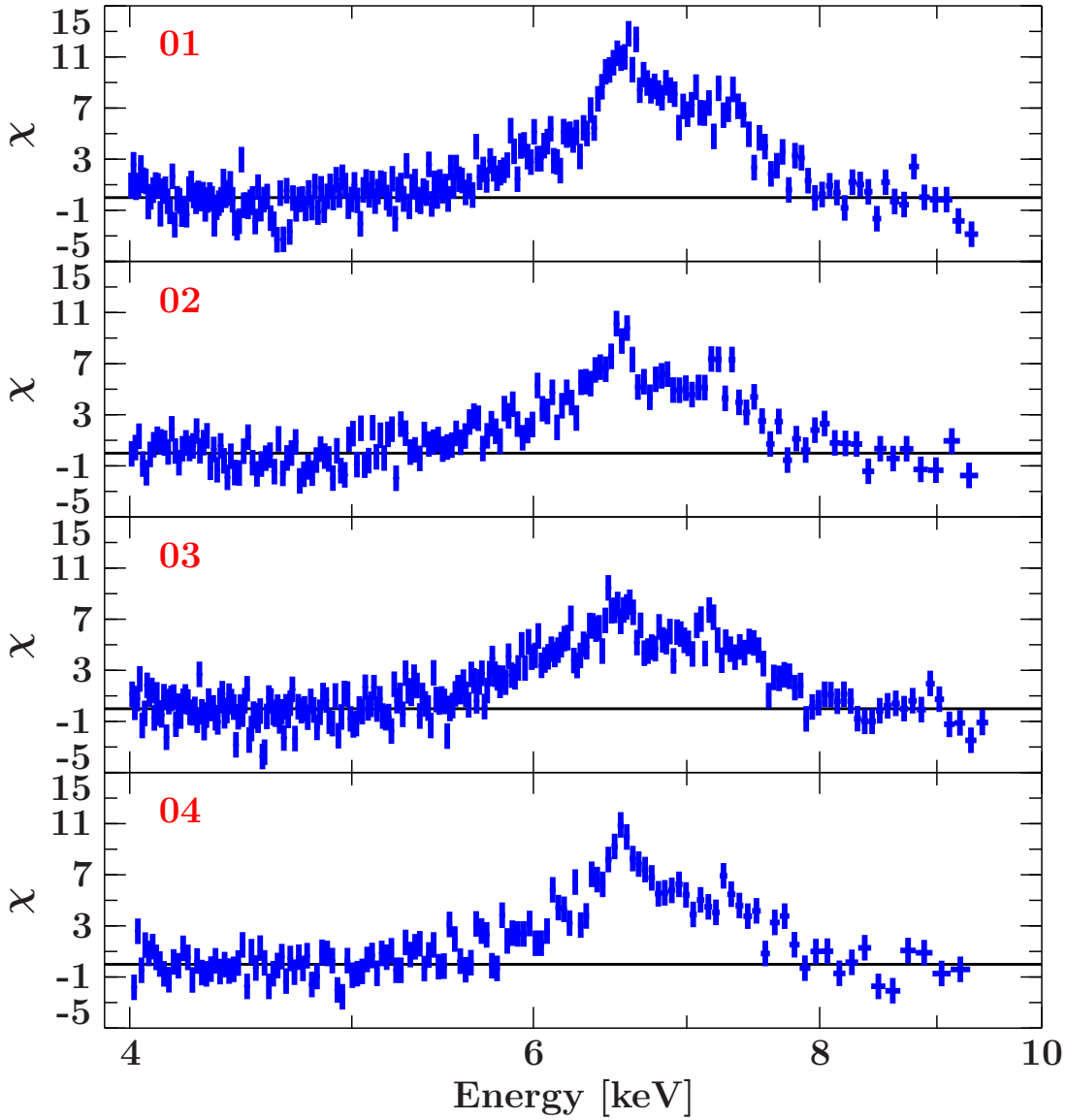


Models

Const $\star$ gabs $\star$ (cutoffpl + diskbb + gauss + (GEOMETRY))

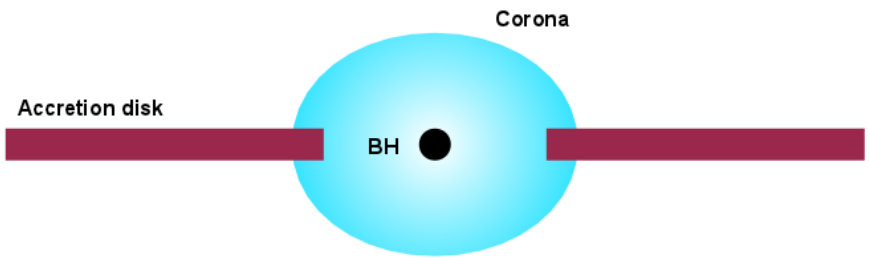
Dauser+ 2010, 2012, Ross+ 2005, Fabian+ 2010

Coronal geometry:

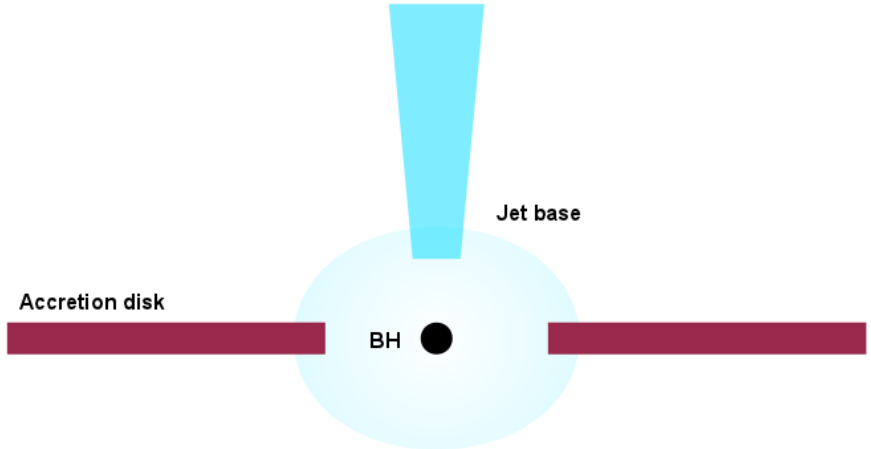
relconv $\otimes$ reflionx

Lamp-post geometry:

relconv_lp $\otimes$ reflionx



Corona



Jet base

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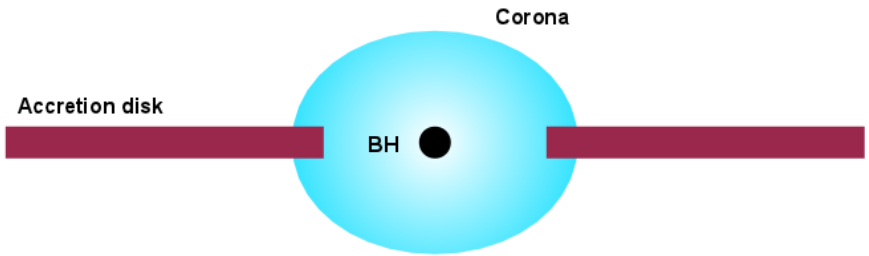
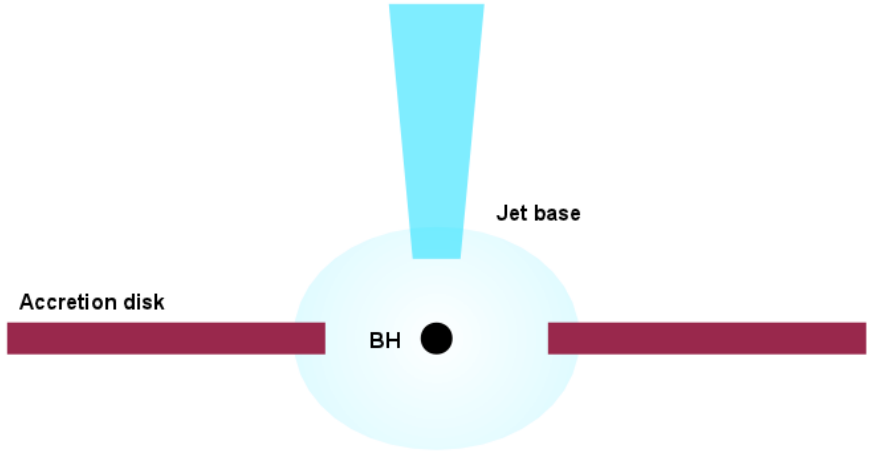


Corona



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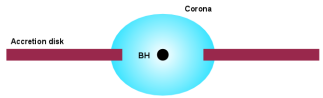
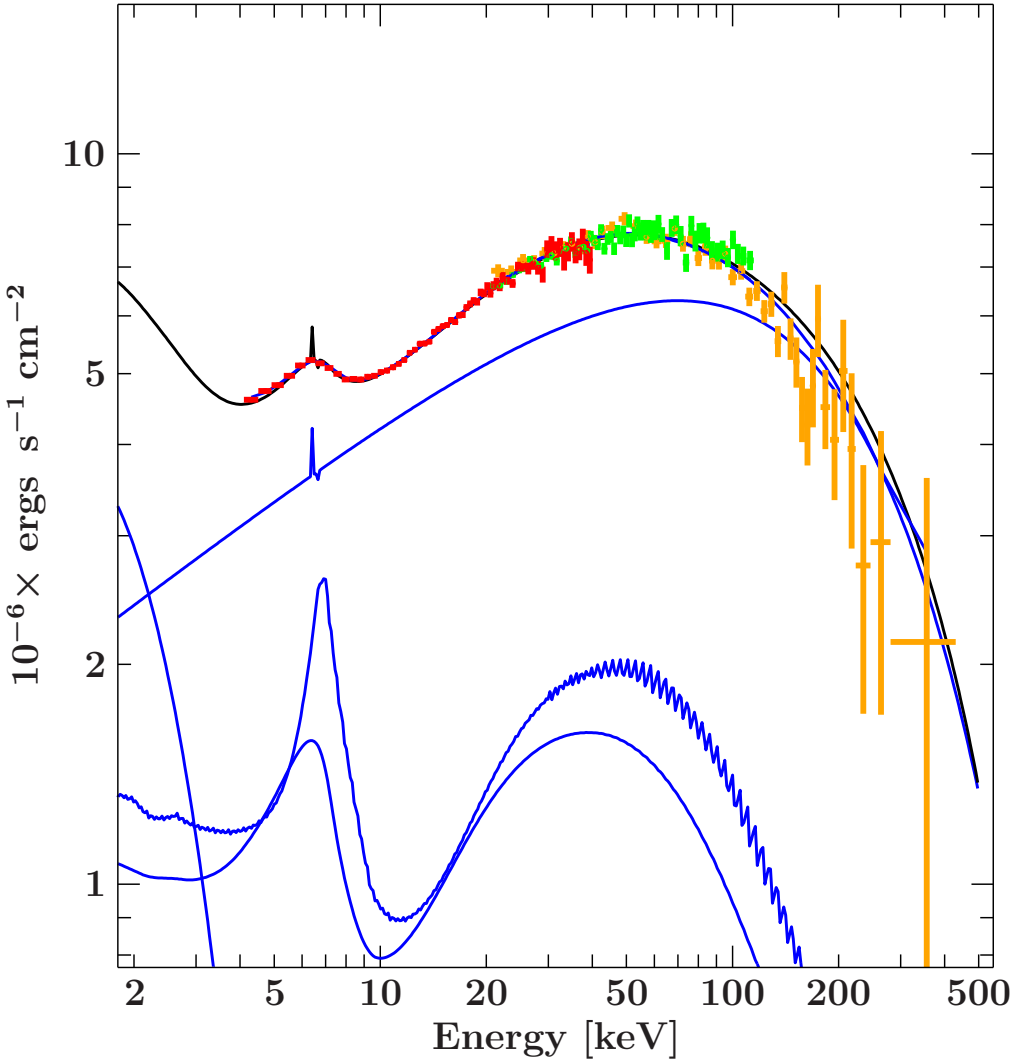
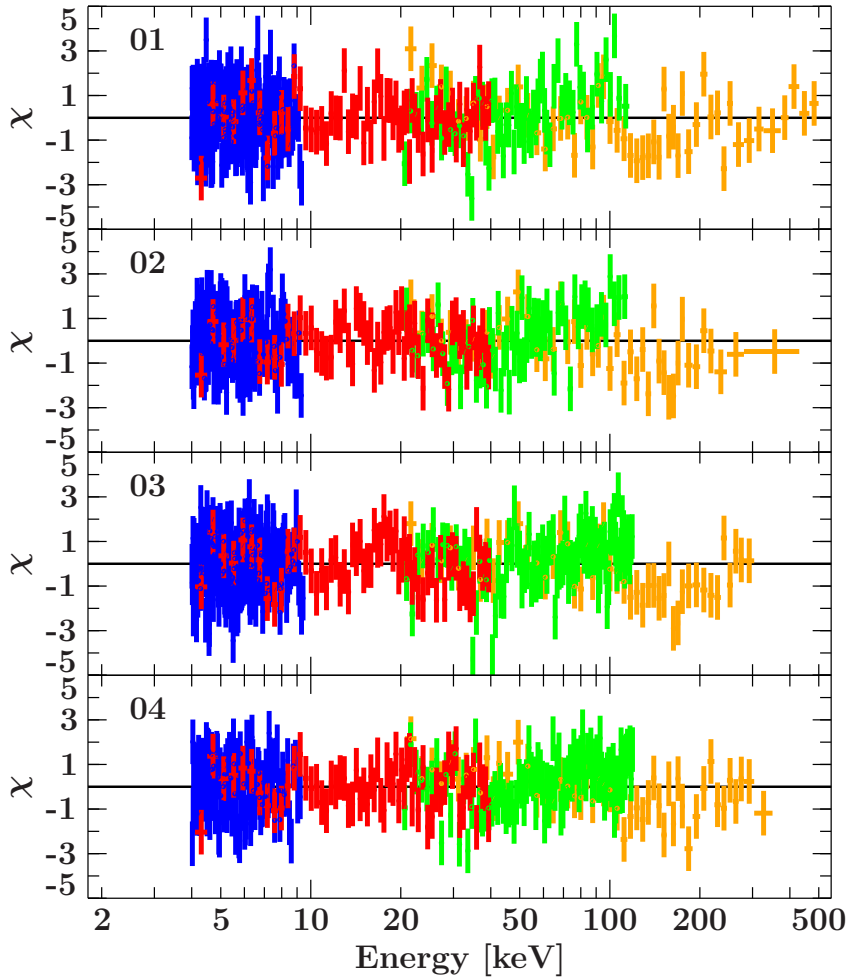
Results for **Coronal geometry:**

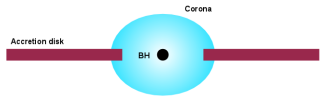






Results for **Coronal geometry:**

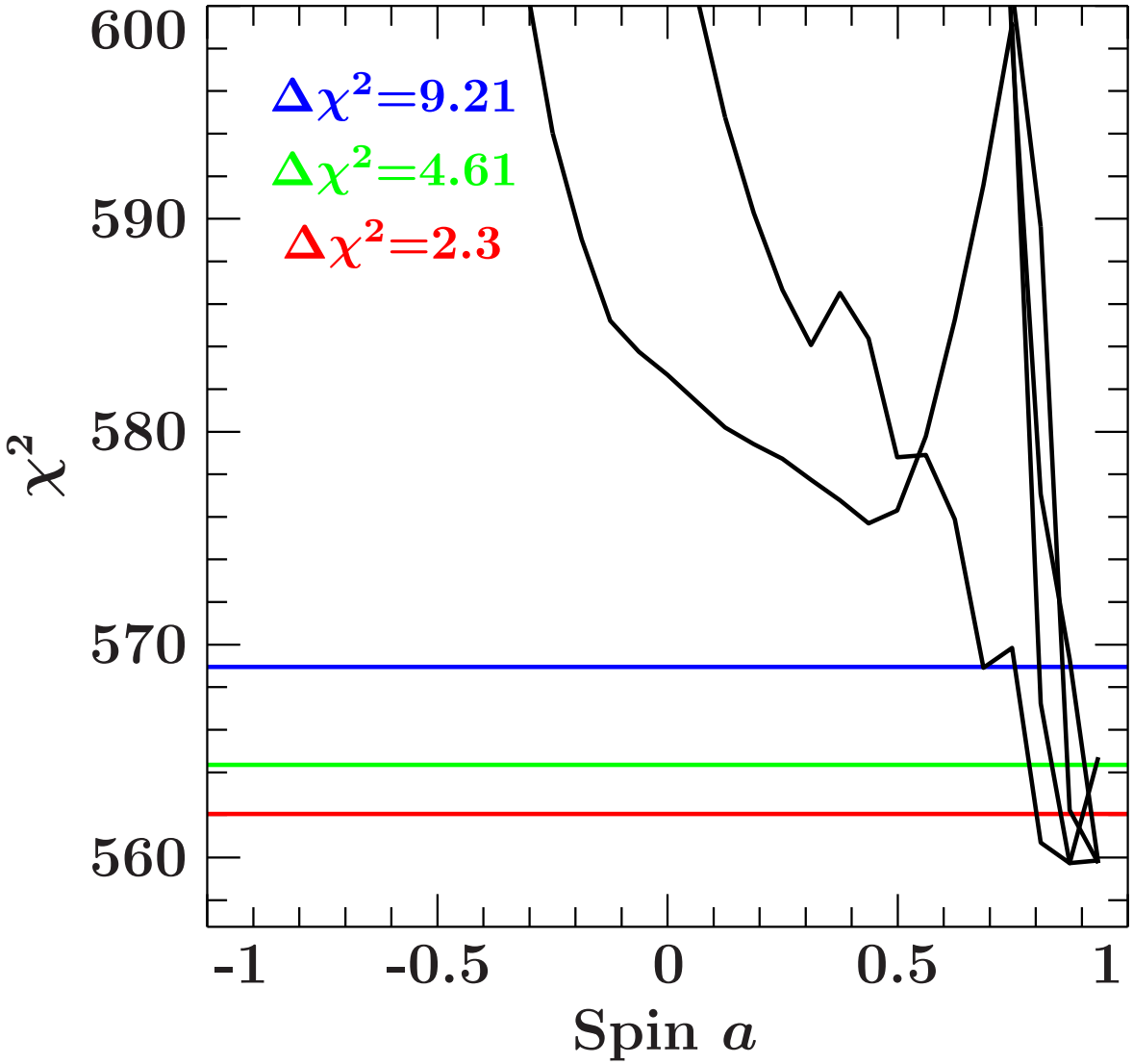
Line emissivity with $r^{-\epsilon}$ profile:

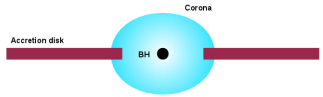


- broken power law $\epsilon_{\rm out} = 3$ and $\epsilon_{\rm in} = \text{free}$
- single power law with $\epsilon = 3$

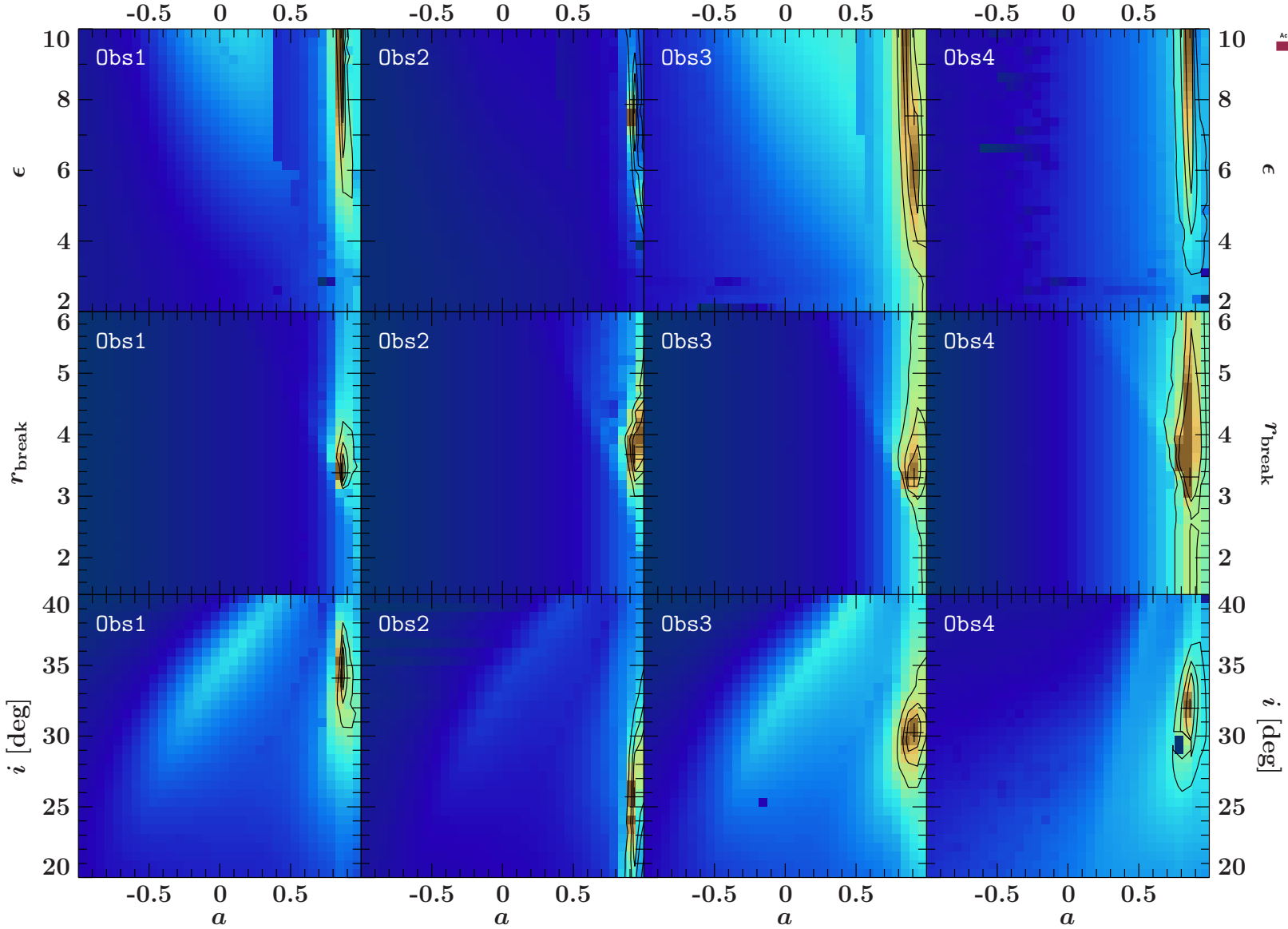
Parameter	Obs1	Obs2	Obs3	Obs4
$\Gamma_{\rm pl}$	1.748 ± 0.014	$1.600^{+0.022}_{-0.019}$	$1.614^{+0.009}_{-0.013}$	$1.587^{+0.016}_{-0.015}$
$E_{\rm fold}$ [keV]	177^{+14}_{-13}	170 ± 9	180^{+10}_{-9}	164^{+12}_{-10}
$\rm Fe/Fe_{\odot}$	$3.6^{+0.7}_{-0.4}$	$6.0^{+0.0}_{-1.7}$	$4.4^{+1.6}_{-1.0}$	$4.3^{+1.3}_{-0.8}$
$\epsilon_{\rm in}$	$10.0^{+0.0}_{-3.0}$	$5.4^{+4.6}_{-0.7}$	$7.5^{+2.5}_{-3.1}$	10^{+0}_{-6}
$r_{\rm br}$ [$\rm GM\,c^{-2}$]	$3.38^{+0.27}_{-0.15}$	$4.0^{+0.7}_{-0.6}$	$3.3^{+0.7}_{-0.4}$	$3.31^{+0.78}_{-0.24}$
a	$\mathbf{0.856^{+0.026}_{-0.020}}$	$\mathbf{0.989^{+0.009}_{-0.088}}$	$\mathbf{0.91^{+0.05}_{-0.07}}$	$\mathbf{0.86 \pm 0.05}$
i [deg]	$34.1^{+2.4}_{-1.8}$	28 ± 4	$30.2^{+1.6}_{-2.5}$	$32.0^{+2.8}_{-2.9}$
$\chi^2_{\rm red}$	1.41	1.24	1.30	1.21

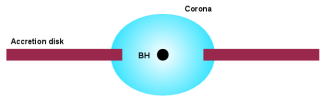
χ^2 behaviour when changing spin a



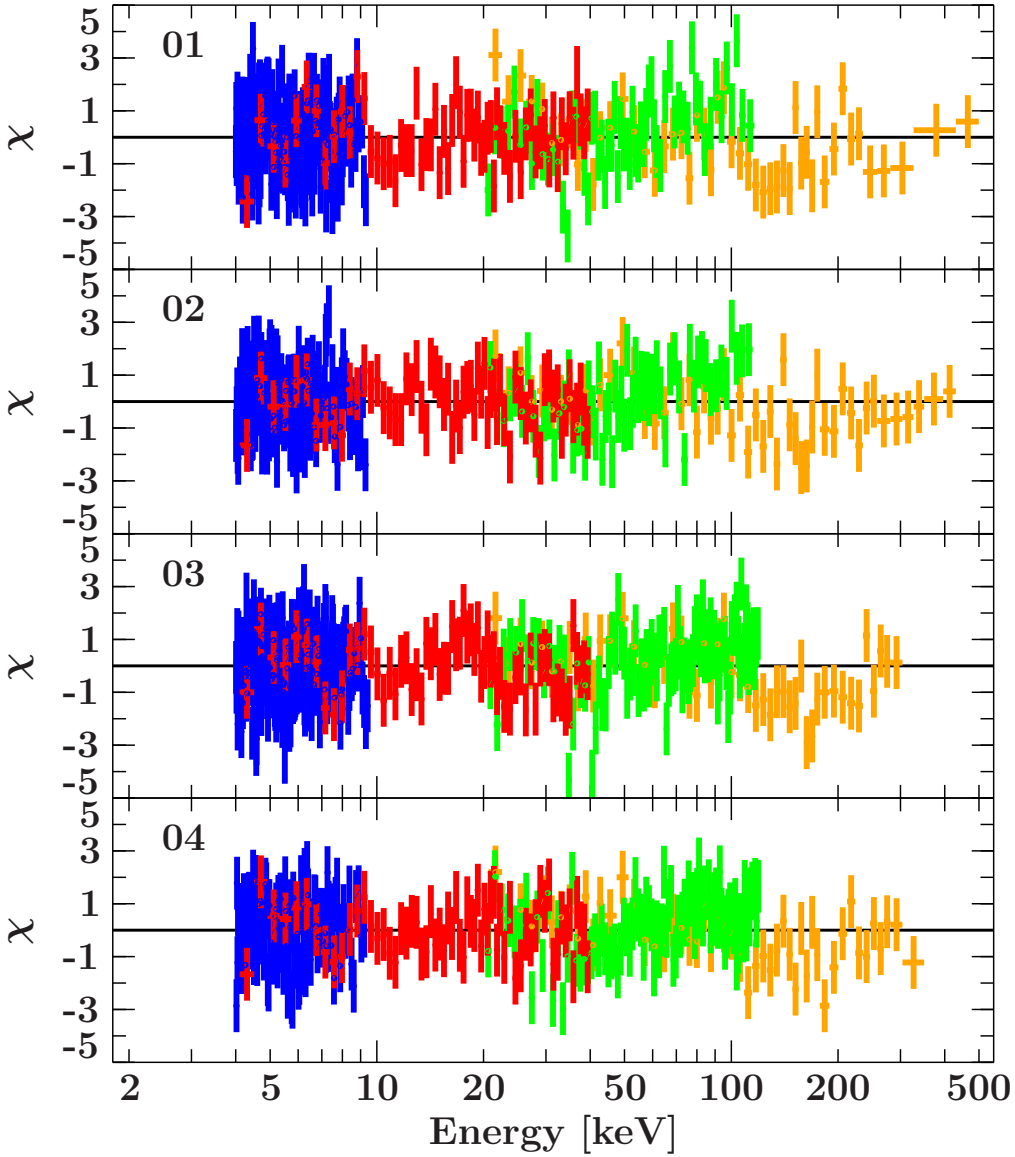


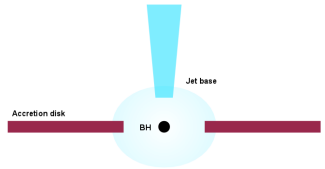
χ^2 significance contours





Results for **Lamp post geometry:**





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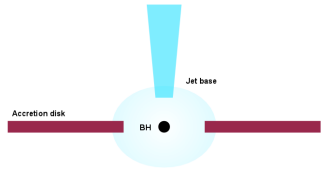

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$E_{\rm fold}$ [keV]	180^{+15}_{-16}	176^{+16}_{-15}	180^{+12}_{-10}	166^{+10}_{-12}
$\rm Fe/Fe_{\odot}$	3.8 ± 0.6	$3.5^{+0.9}_{-0.7}$	$4.0^{+0.8}_{-0.7}$	$3.9^{+0.9}_{-0.8}$
h [$\rm GM/c^2$]	$3.00^{+0.23}_{-0.00}$	$3.00^{+0.22}_{-0.00}$	$3.20^{+0.62}_{-0.21}$	$3.0^{+0.9}_{-0.0}$
a	$\mathbf{0.99^{+0.00}_{-0.11}}$	$\mathbf{0.99^{+0.00}_{-0.04}}$	$\mathbf{0.995^{+0.004}_{-0.074}}$	$\mathbf{0.90^{+0.07}_{-0.06}}$
i [deg]	$36.4^{+1.4}_{-1.2}$	$33.1^{+2.4}_{-2.2}$	$33.6^{+1.9}_{-2.9}$	$35.0^{+1.6}_{-5.1}$
$\chi^2_{\rm red}$	1.46	1.29	1.32	1.22

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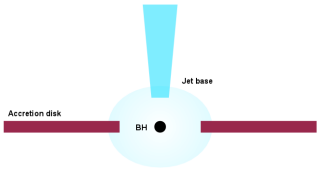

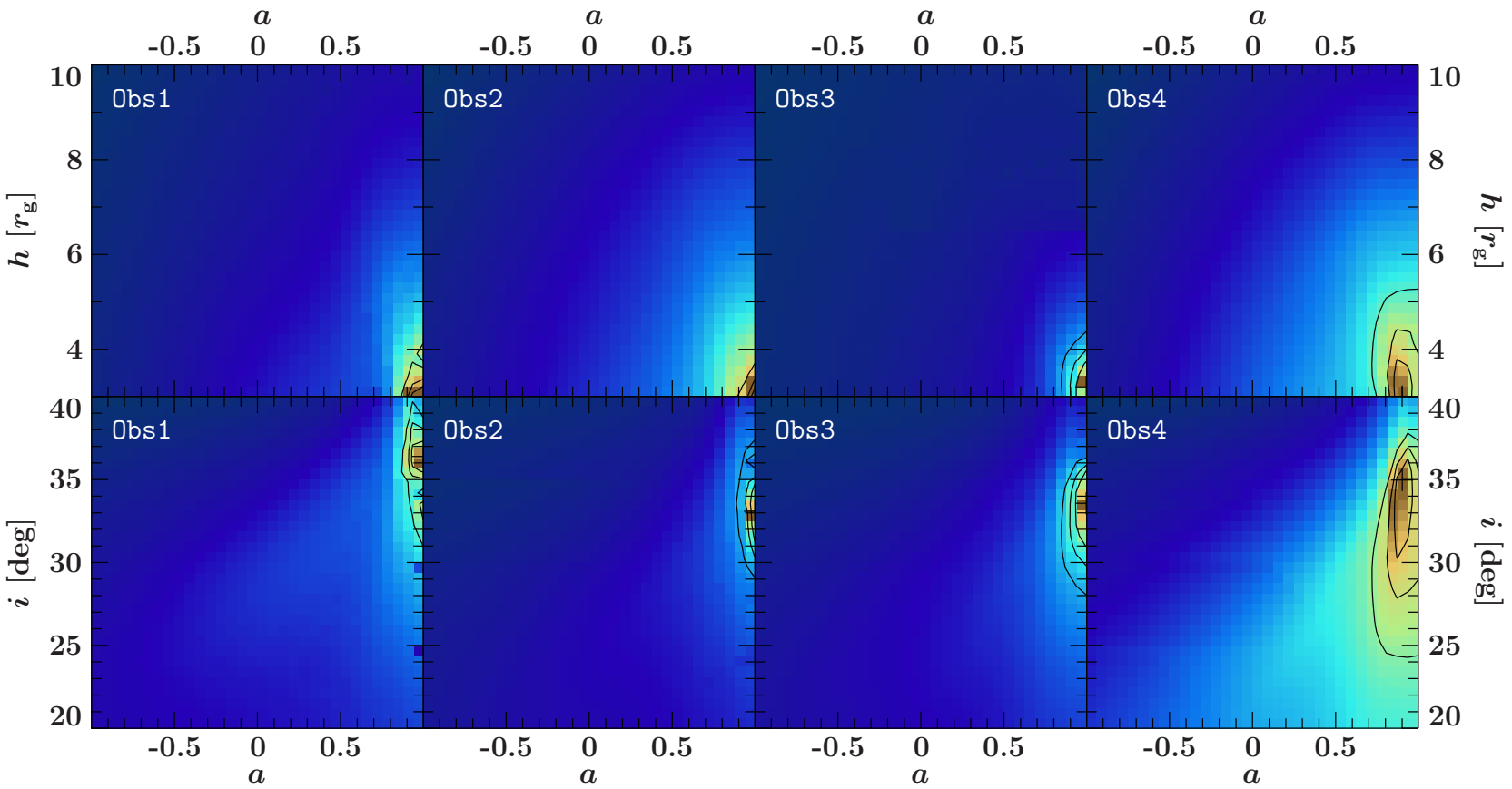

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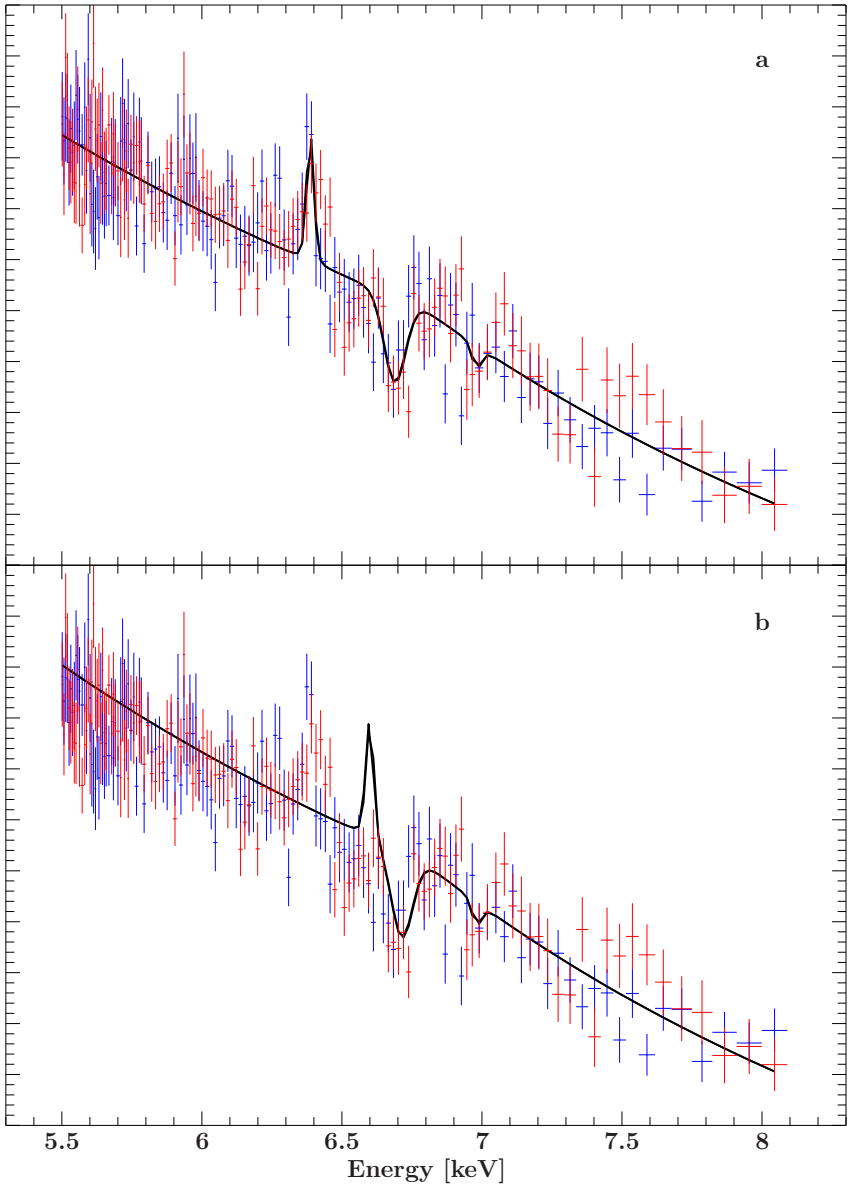
Agreement with Continuum-fitting method result by Gou+ 2011
& Reflection fitting method result by Fabian+ 2012

The gainshift in EPIC-pn from Chandra data



The gainshift in EPIC-pn fitted with PCA