Broad iron Kα feature in Cygnus X-1 spectra

with XMM-Newton

Refiz Duro

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ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

Black Hole Universe

Friedrich-Alexander-Universität Erlangen-Nürnberg

The result

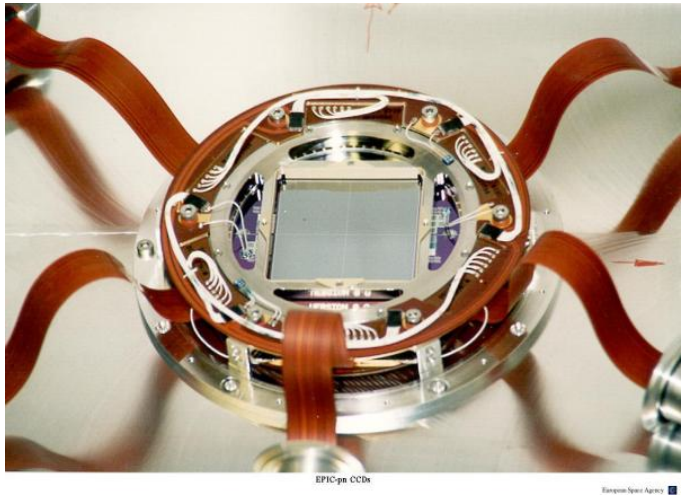
Our data show:

Cygnus X-1 is a highly rotating black hole!

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

Observing modes:

- Burst mode
- Timing mode



Photo, ESA/XMM-Newton

Main obstacles:

- Burst mode - low S/N
- Telemetry limit of $\sim$100 mCrab

Solution: Modified Timing Mode

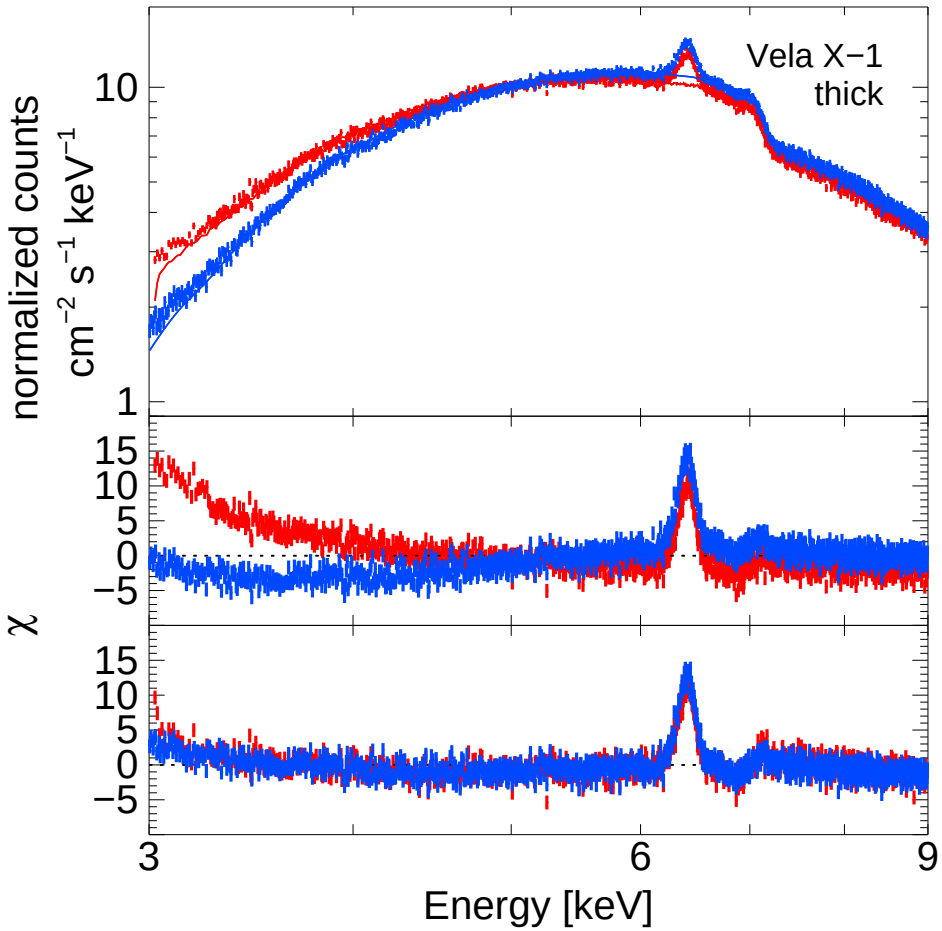
Modification:

- increase telemetry to EPIC-pn
- increase lower energy threshold limit (introduces soft excess)

Wilms+ 2005

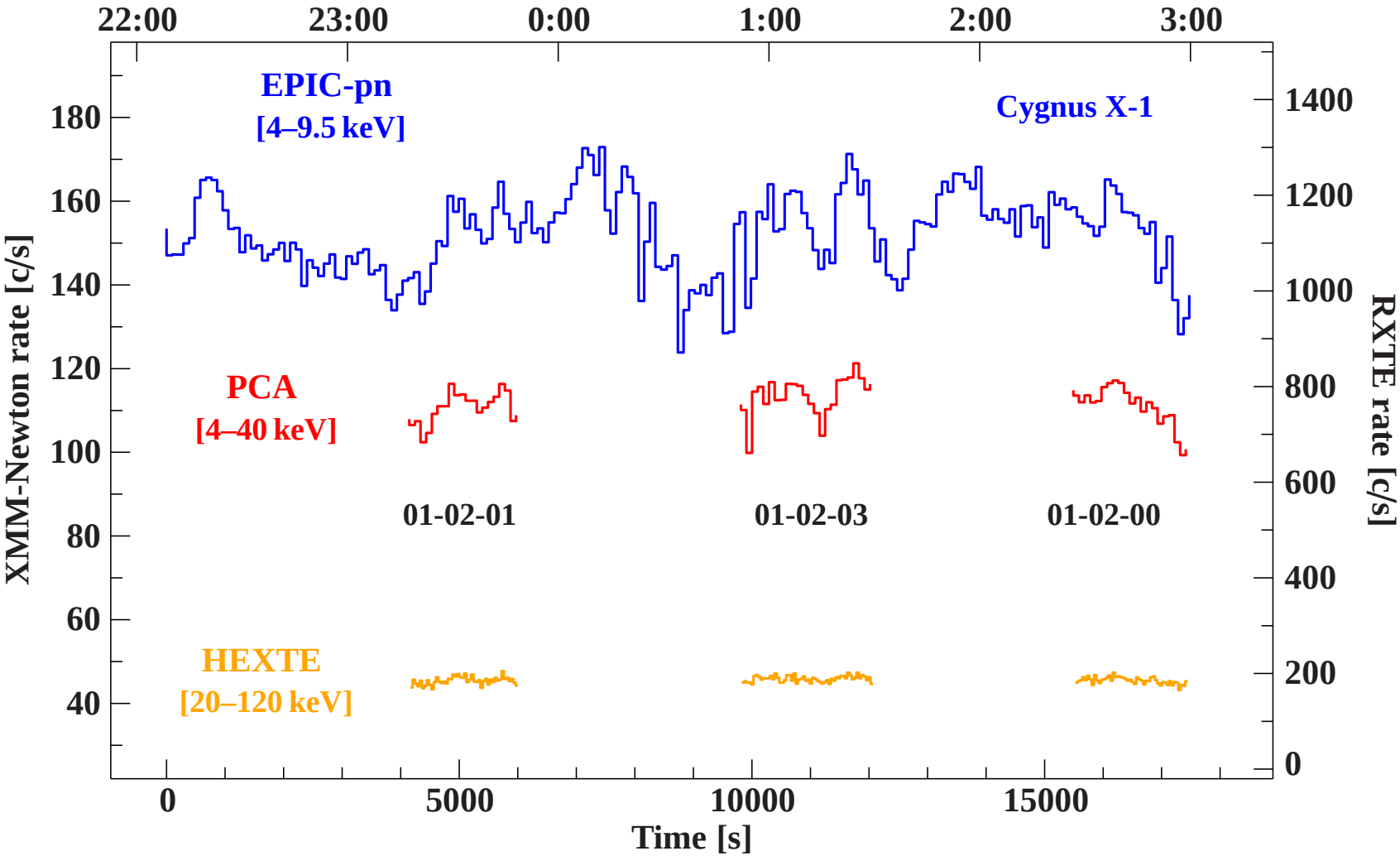
Improvement:

- Timing Mode spectrum
- Modified Timing Mode spectrum

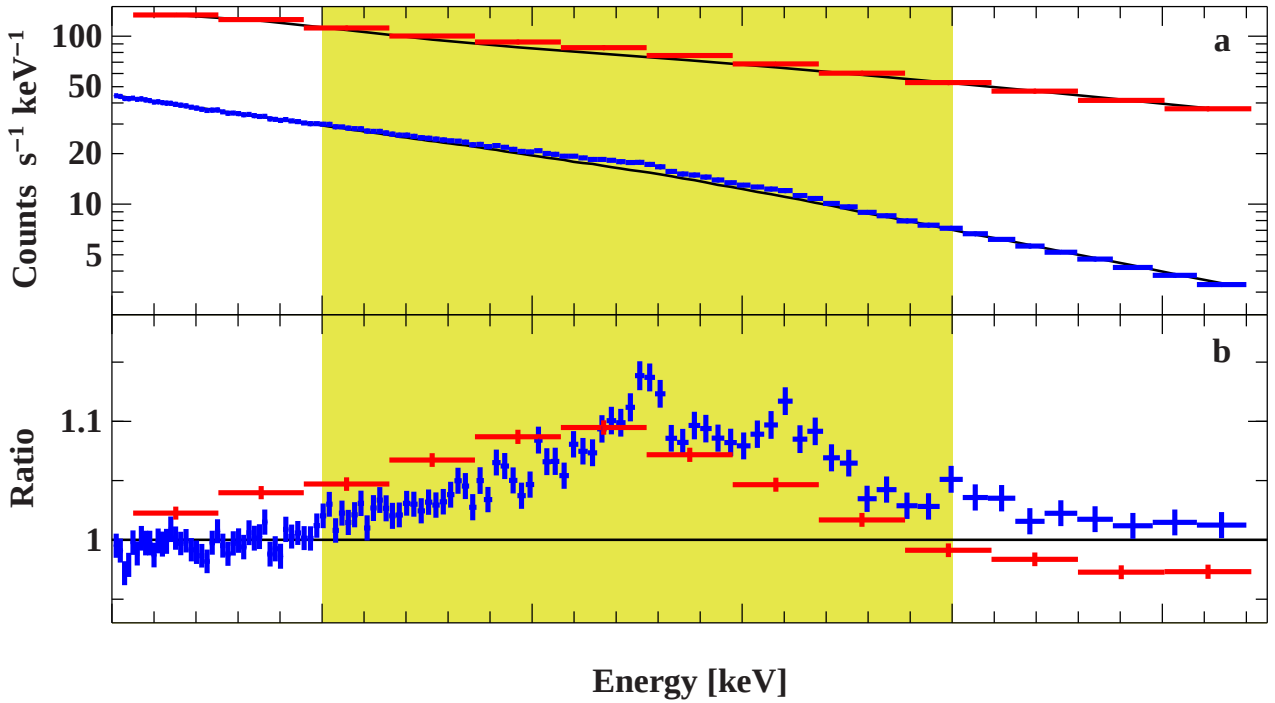


Absorbed power law (Fritz 2009)

Lightcurves - simultaneous data for Cygnus X-1



Iron line feature



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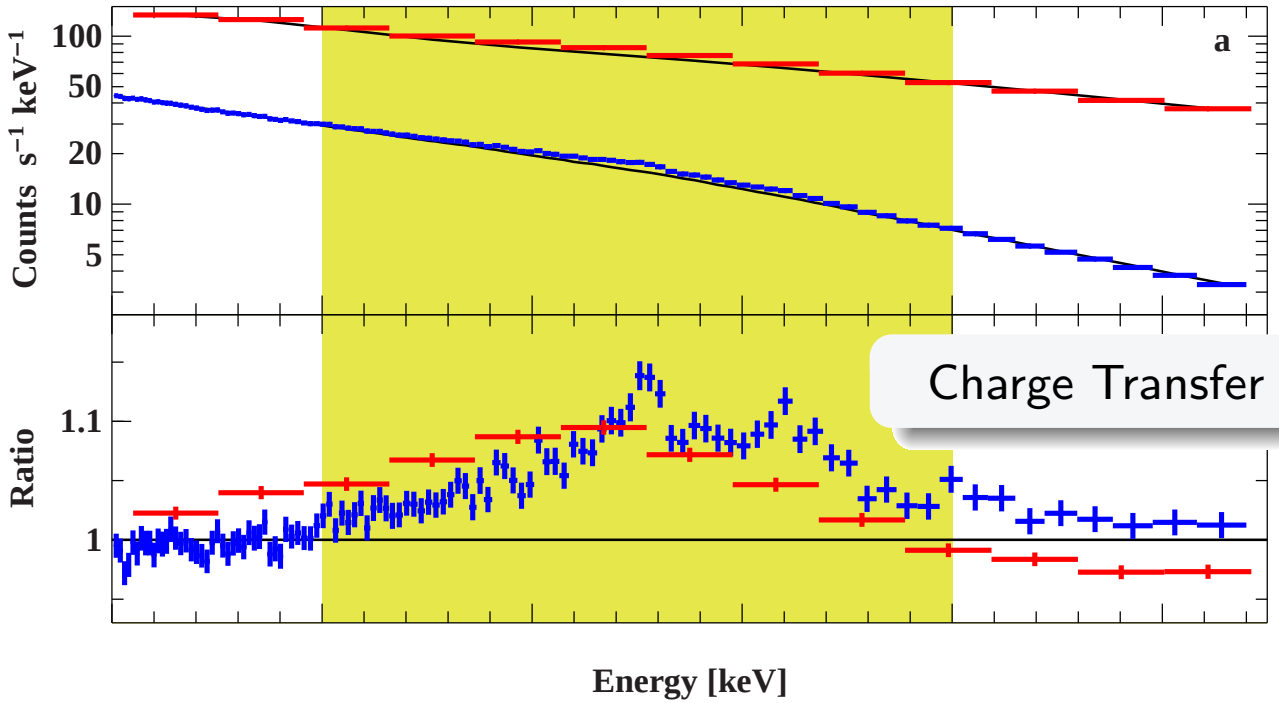
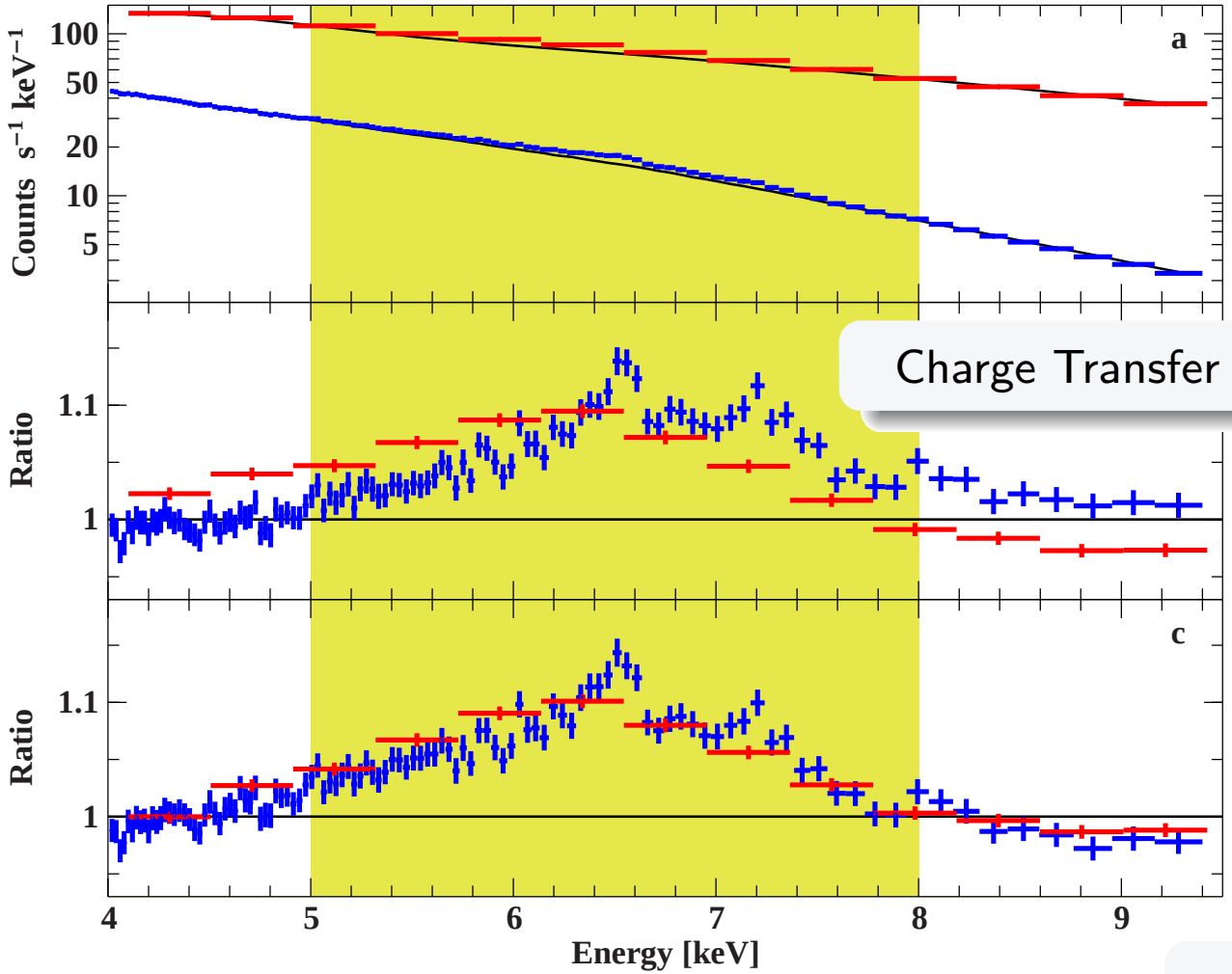


Charge Transfer Inefficiency!

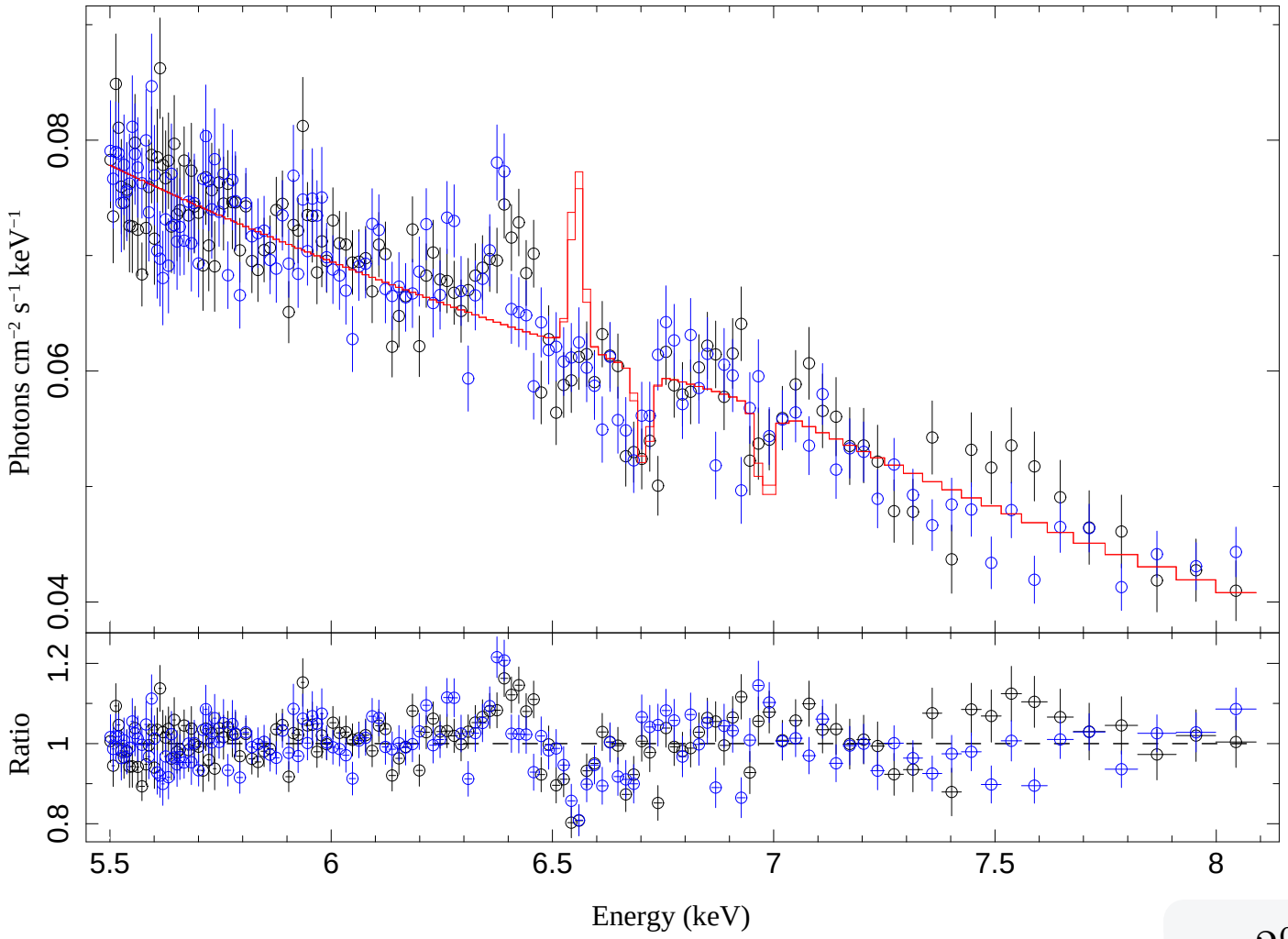
Iron line feature - gainshift



Charge Transfer Inefficiency!

$\sim 2\%$

Iron line feature - gainshift

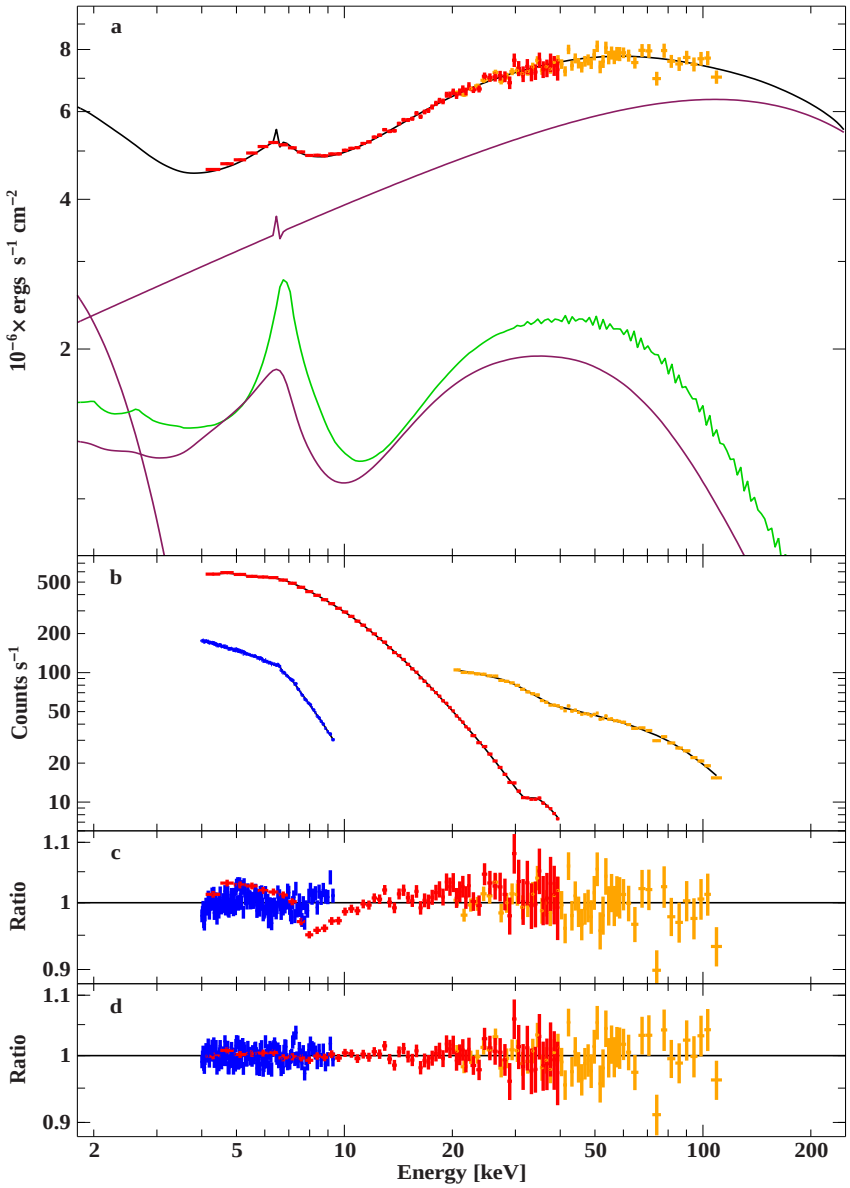


$\sim 2\%$

Model

Const $\star$ gabs $\star$ (cutoffpl + diskbb + gauss + (relconv $\otimes$ reflionx))

Parameter	ϵ frozen	ϵ free
$\Gamma_{\rm pl}$	1.670 ± 0.018	$1.663^{+0.019}_{-0.017}$
$E_{\rm fold}$ [keV]	290^{+70}_{-50}	290^{+80}_{-50}
$E_{\rm Fexxv\ K\alpha}$ [keV]	6.646	6.646
$E_{\rm Fexxvi\ K\alpha}$ [keV]	6.955	6.955
ξ [erg cm s^{-1}]	1400^{+300}_{-200}	1700^{+300}_{-400}
Fe/Fe$_\odot$	$1.7^{+0.5}_{-0.4}$	$1.6^{+0.5}_{-0.4}$
a	$0.88^{+0.07}_{-0.11}$	-0.1 ± 0.4
i[deg]	32 ± 2	36^{+2}_{-4}
ϵ	3	10^{+0}_{-6}
$s_{\rm gainshift}$	$1.0240^{+0.0019}_{-0.0018}$	$1.0230^{+0.0019}_{-0.0017}$
χ^2/dof	261/238	254/237
$\chi^2_{\rm red}$	1.10	1.08



Dauser+ 2010
Hanke+ 2010

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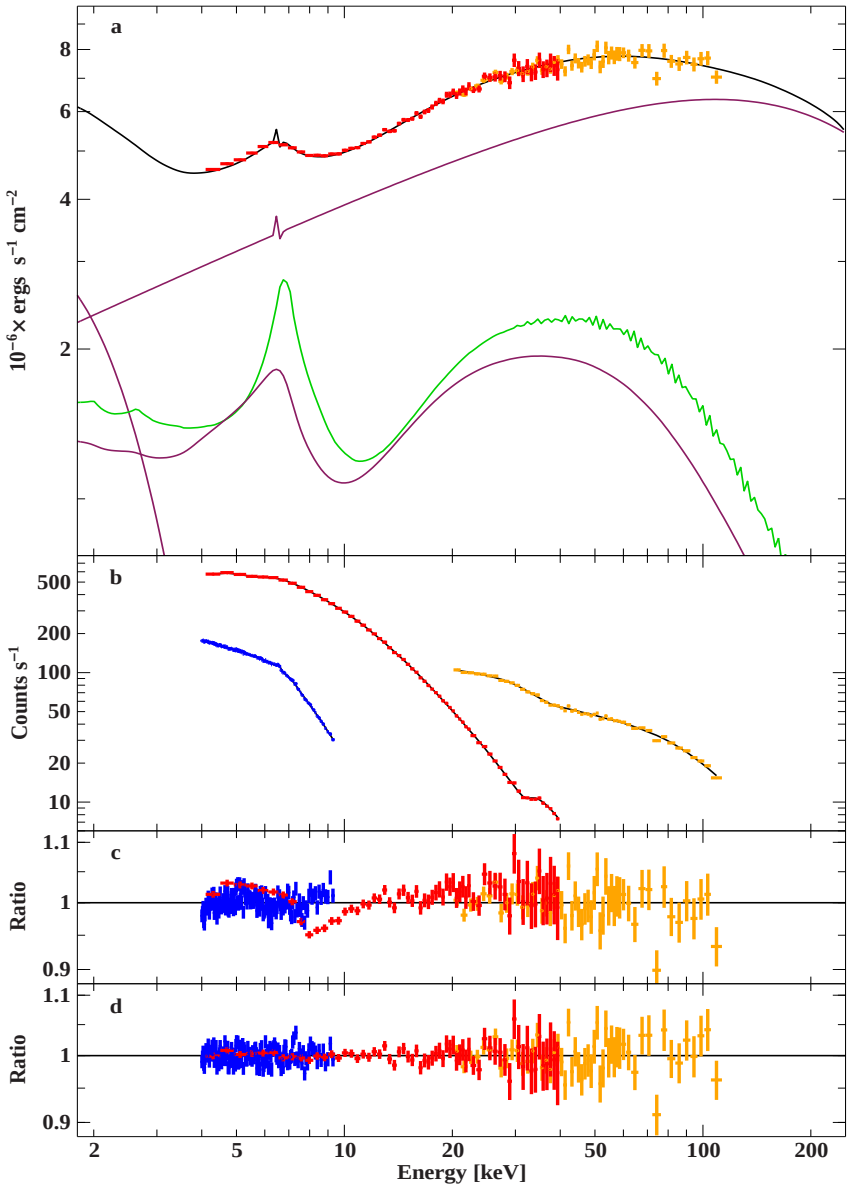

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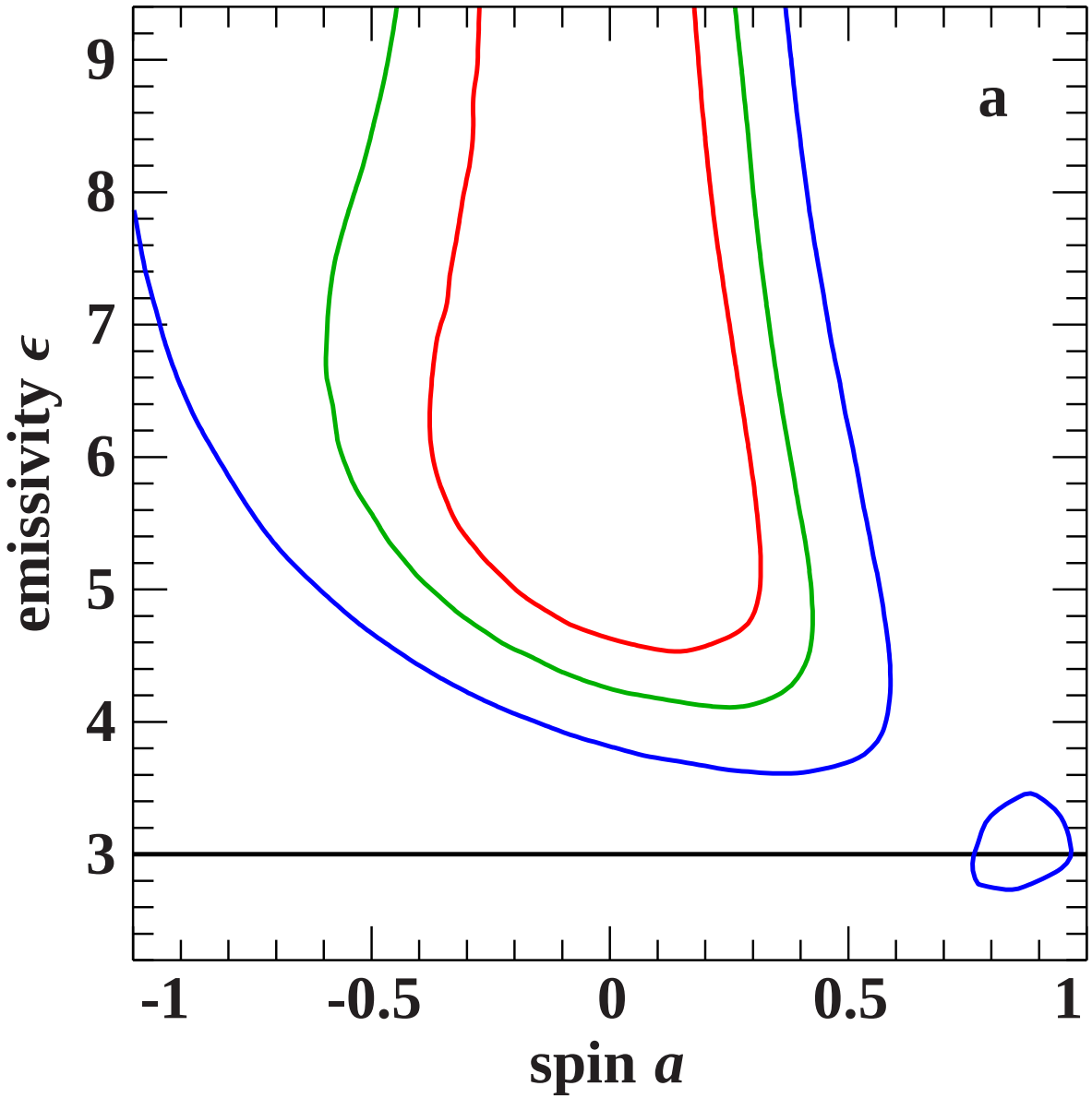
Hanke+ 2010

Low ϵ high spin



Summary

- Modified Timing Mode provides possibility to observe bright sources with high S/N
- Simultaneous observations with XMM-Newton & RXTE
- Broad iron 6.4 keV $K\alpha$ line feature
- Gainshift of $\sim 2\%$ to EPIC-pn data
- Rel. convolved reflection describes the data best

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Cygnus X-1 has high spin ~ 0.9

Duro+ 2011

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Duro+ 2011

Gou+ 2011

See poster by Thomas Dauser on: **Modeling Relativistic Reflection: Lamp Post vs. Coronal Geometry**

There is no more

(Modified) Timing Mode of *XMM-Newton's* EPIC-pn

Obstacles:

- Low S/N if observed in Burst Mode
- Telemetry limit of $\sim$100 mCrab in Timing Mode

Solution:

- 2 EPIC-MOS instruments switched off
- Increased lower energy threshold limit to 2.8 keV

Kendziorra+ 2004

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New rmf:

- split events soften the spectra
- simulate MTM by using Timing Mode observations

Observing bright objects with *XMM-Newton*

Obstacles:

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- Telemetry limit of $\sim$100 mCrab in Timing Mode

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Kendziorra+ 2004

New rmf:

- split events soften the spectra
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Iron line

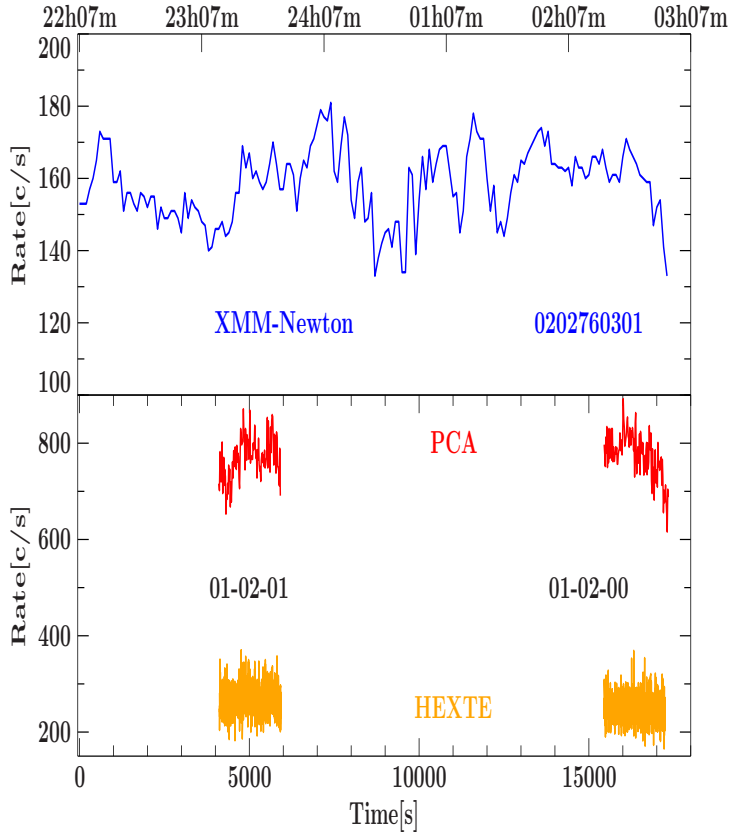
Object	a	**Method/Model**	**Reference**
Cygnus X-1	0.05	Reflection & Continuum	Miller et al., 2009
4U 1543-475	0.3	Reflection & Continuum	Miller et al., 2009
GRO J1655-40	0.87	Reflection & Continuum	Miller et al., 2009
XTE J1652-453	0.5	Iron line	Hiemstra et al.,2010
GX 339-4	0.1-0.5	Continuum	Kolehmainen et al., 2011
GX 339-4	$\leq$0.9	Iron line	Kolehmainen et al., 2011
GX 339-4	0.935	Iron line	Miller et al., 2004

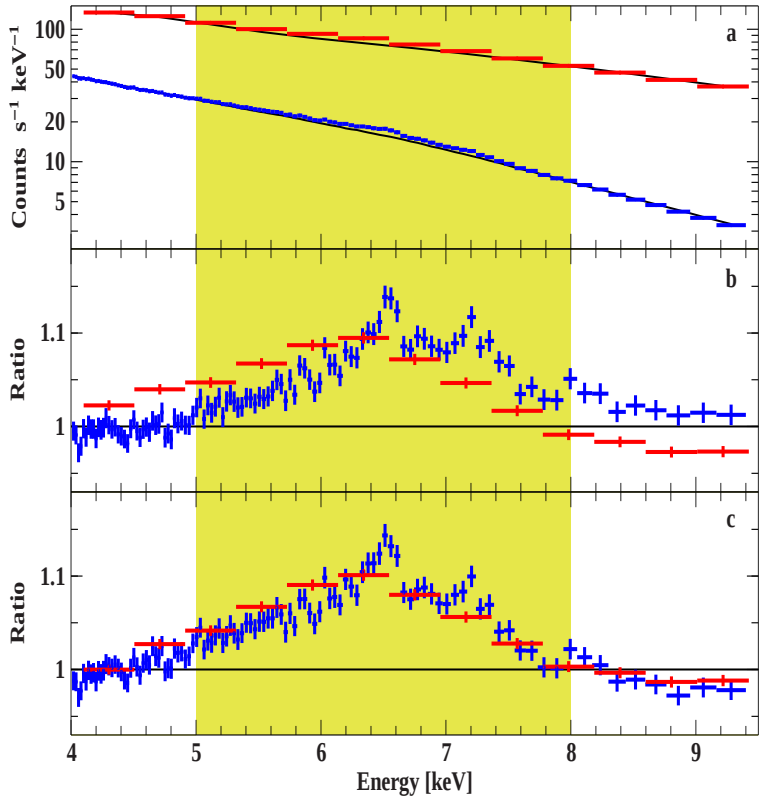
Observations

XMM-Newton & RXTE

Simultaneous data show relatively stable flux.

Broadened iron line: Doppler & relativistic effects.



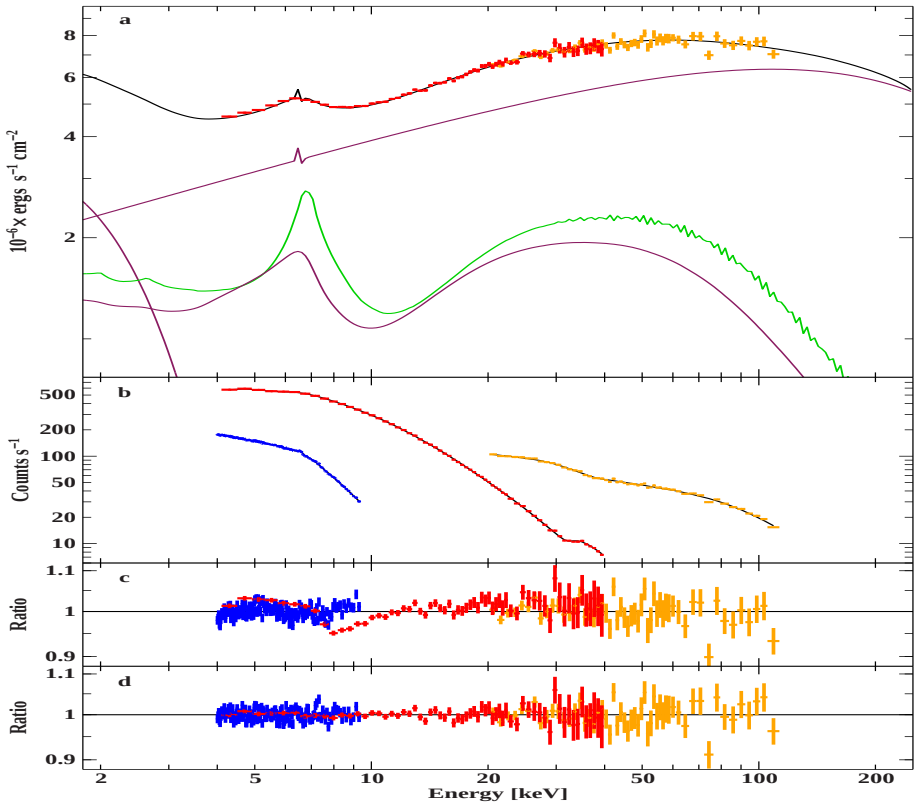


Method

Model:

$$Const \star gabs \star (cutoffpl + diskbb + gauss + (relconv \otimes reflionx))$$

Parameter	Value
$\Gamma_{\rm pl}$	1.67 ± 0.02
$\mathrm{norm}_{\rm pl}$	$1.22^{+0.09}_{-0.07}$
$E_{\rm fold}$ [keV]	$\left(3.1^{+1.4}_{-0.6}\right) \times 10^2$
$E_{\rm abs1}$ [keV]	$6.65^{+0.10}_{-0.00}$
τ_1	$\left(0.3^{+0.3}_{-0.2}\right) \times 10^{-2}$
ξ [erg cm s^{-1}]	$(1.4 \pm 0.2) \times 10^3$
$\mathrm{Fe}_{\rm solar}$	1.6 ± 0.5
a	$0.89^{+0.08}_{-0.11}$
θ [deg]	33 ± 2
$\mathrm{slope}_{\rm gainshift}$	$1.0234^{+0.0020}_{-0.0019}$
stat/dof	272/243
$\chi^2_{\rm red}$	1.12



What we have

Cygnus X-1:

- rotating with high spin $a \approx 0.9$
- relativistically broadened iron line
- convolved reflection model

- inclination angle θ - Ninkov et al., 1987
- folding energy - Wilms et al., 2006
- parameters indicative of intermediate state