A Multi-Instrument Study of Cygnus X-1

Sonja Fritz[1]

Jörn Wilms[2], Eckhard Kendziorra[1], Ingo Kreykenbohm[1,3], Katja Pottschmidt[4], Mike A. Nowak[5], Marcus G. F. Kirsch[6], Andrea Santangelo[1]

[1]Institut für Astronomie und Astrophysik, Universität Tübingen, Germany
[2]Dr. Remeis-Sternwarte, Bamberg, Germany
[3]*INTEGRAL* Science Data Centre, Versoix, Switzerland
[4]UMBC/GSFC, USA
[5]MIT, Center for Space Research, Cambridge MA, USA
[6]European Space Astronomy Centre (ESA), Madrid, Spain

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Cygnus X-1

Why Cygnus X-1?

- Very bright → measurements with high signal to noise
- Broad Fe Kα line
- Strong, energy dependent variability

2 main parts of analysis:

Broadband Continuum

- constrain models for Comptonizing plasma (non-thermal Comptonization?)
- constrain amount of Compton reflection

Iron Line

- search for structure of the Fe Kα line (relativistic broadening)
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INTEGRAL, *RXTE*

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XMM-Newton

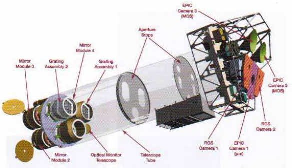
THE OBSERVATIONS

Cyg X-1 was observed simultaneously by

- *XMM-Newton* (total observation time: ~40 ksec)
- *RXTE* (total observation time: ~152 ksec)
- *INTEGRAL* (total observation time: ~320 ksec)

for 4 times in November / December 2004

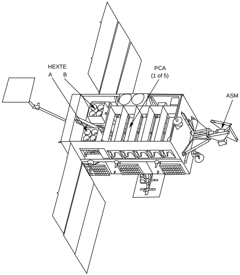
2.8 – 10 keV



ESA

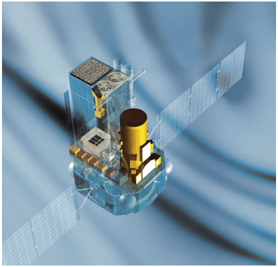
SPECIAL MODE NEEDED

3 – 120 keV



Wilms (1998)

4 keV – 1 MeV



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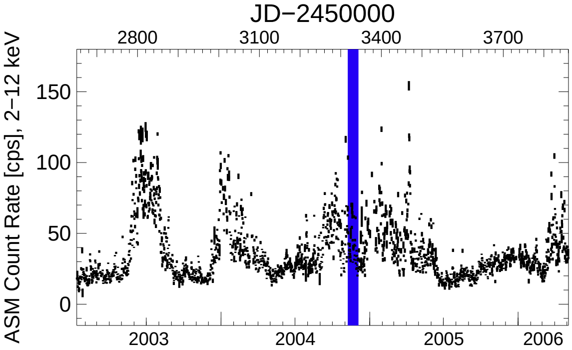
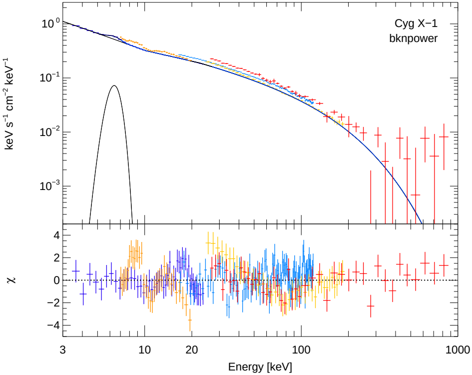


Broken Powerlaw Fits

Typical values

$\Gamma_1 \sim 2.0$
$E_{\mathrm{break}} \sim 10.0\,\mathrm{keV}$
$\Gamma_2 \sim 1.6$
$E_{\mathrm{cut}} \sim 24.6\,\mathrm{keV}$
$E_{\mathrm{fold}} \sim 137\,\mathrm{keV}$
$E_{\mathrm{K}\alpha} \sim 6.29\,\mathrm{keV}$
$\sigma_{\mathrm{K}\alpha} \sim 0.53\,\mathrm{keV}$

χ^2_{red} between 1.77 and 1.35



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Comparison with previous results

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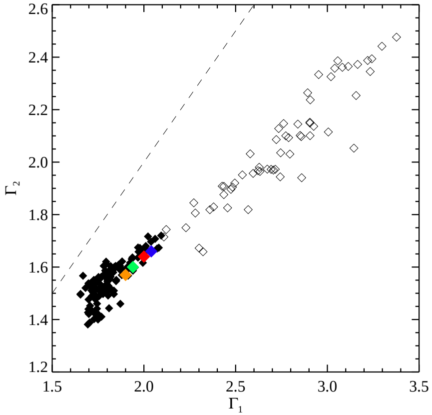


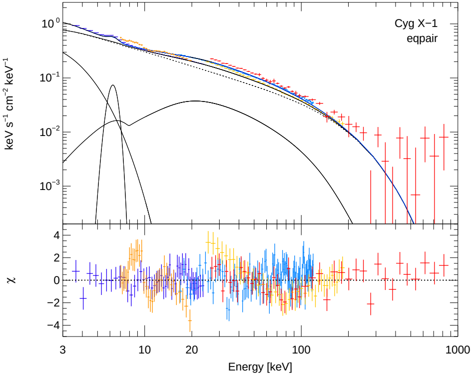
$\Longrightarrow$ good agreement with previous results

EQPAIR FITS - THERMAL MODEL

TYPICAL VALUES

$kT_{\mathrm{in}} \sim 0.90\,\mathrm{keV}$
$\ell_{\mathrm{h}}/\ell_{\mathrm{s}} \sim 3.56$
$\tau_{\mathrm{p}} \sim 1.24$
$\Omega/2\pi \sim 0.30$
$\xi \sim 1$
$E_{\mathrm{K}\alpha} \sim 6.22\,\mathrm{keV}$
$\sigma_{\mathrm{K}\alpha} \sim 0.82\,\mathrm{keV}$

χ^2_{red} between 2.19 and 1.37



Fritz et al. (2007)

EQPAIR Fits - Thermal Model

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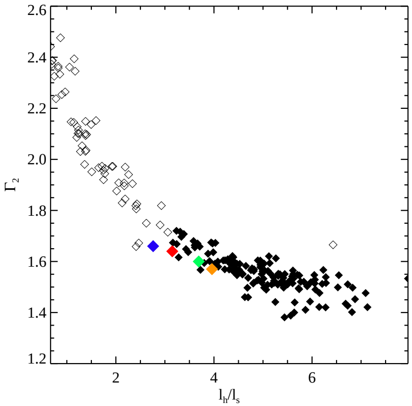


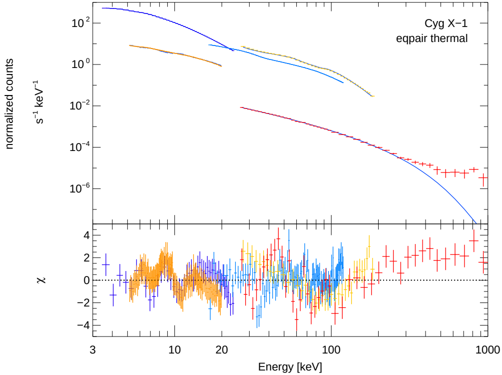
Fritz et al. (2007)

EQPAIR Fits - Thermal Model

Thermal Model:

above 300 keV strong residuals present in the averaged spectrum

χ^2_{red} = 1.65 (324 dof)



Fritz et al. (2007)

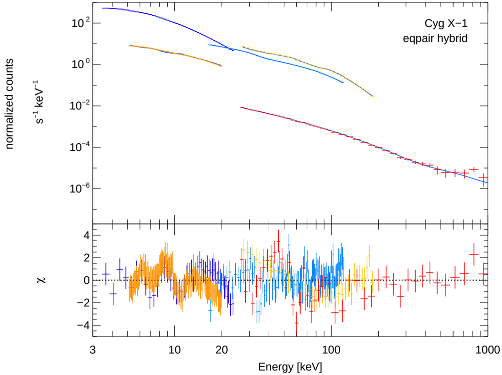
EQPAIR FITS - HYBRID MODEL

Hybrid Thermal / Non-thermal Model:

Best fit:
$\ell_{\rm nth}/\ell_{\rm h} \sim 0.67$

$\Longrightarrow$ 67% of the power supplied to electrons in corona is in the non-thermal component

$\chi^2_{\rm red}$ = 1.40 (323 dof)



Fritz et al. (2007)

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XMM-Newton

Problem:
Cyg X-1 Too Bright For XMM!!!

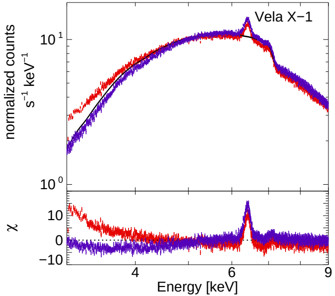
THE *XMM-Newton* MODIFIED TIMING MODE

IMPORTANT TO NOTE

cps limit of EPIC-pn timing mode due to *telemetry*, NOT due to camera capabilities!

Therefore:

- switch off EPIC-MOS
- disregard soft photons



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increase lower energy threshold in EPIC-pn from 200 eV to 2.8 keV

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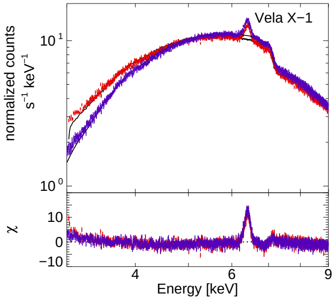

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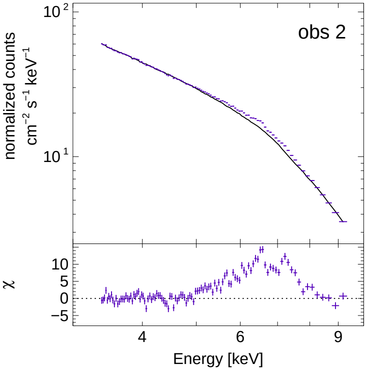
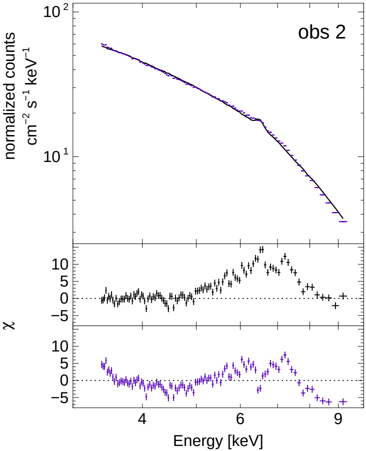
XMM-Newton SPECTRUM



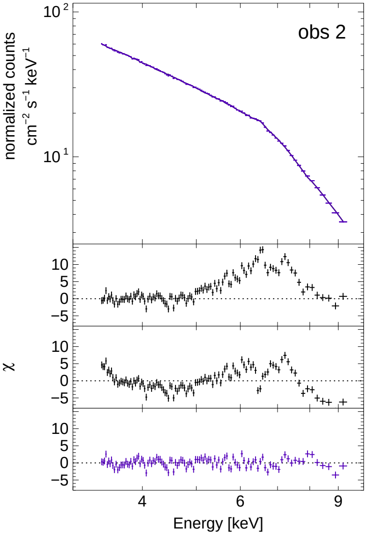
- Power-law fit ($\Gamma = 1.89$): strong residuals in Fe Kα region

XMM-Newton Spectrum



- Power-law fit ($\Gamma = 1.89$): strong residuals in Fe Kα region
- adding narrow line ($E = 6.52\,\mathrm{keV}$, $\sigma = 50\,\mathrm{eV}$): still strong residuals in Fe Kα region

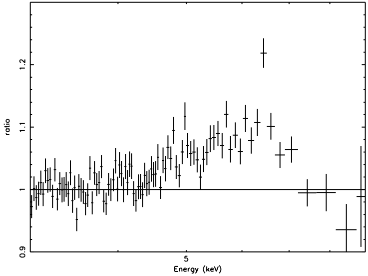
XMM-Newton Spectrum



- Power-law fit ($\Gamma = 1.89$): strong residuals in Fe Kα region
- adding narrow line ($E = 6.52$ keV, $\sigma = 50$ eV): still strong residuals in Fe Kα region
- adding relativistic line ($E = 5.88$ keV, emissivity $\propto r^{-2.8}$): fit improves significantly ($\chi^2_{\text{red}} = 1.8$)

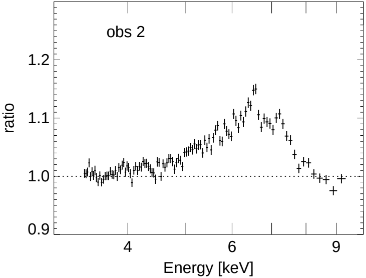
Chandra - XMM comparison

Chandra (Miller et al., 2002)



$E_{K\alpha,narrow}$ = 6.42 keV
$E_{K\alpha,broad} = 5.85^{+0.01}_{-0.01}$ keV
$EW_{K\alpha,broad}$ = 60 eV
$R_{in} = 7^{+6}_{-1} R_g$
$i = 40^{+10}_{-10}$ deg

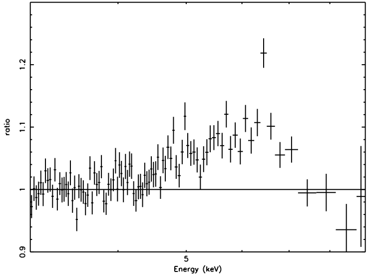
XMM



$E_{K\alpha,narrow} = 6.52^{+0.03}_{-0.02}$ keV
$E_{K\alpha,broad} = 5.88^{+0.08}_{-0.12}$ keV
$EW_{K\alpha,broad}$ = 226 eV
$R_{in} = 8^{+1}_{-2} R_g$
$i = 90^{+0}_{-19}$ deg

CHANDRA - XMM COMPARISON

Chandra (Miller et al., 2002)



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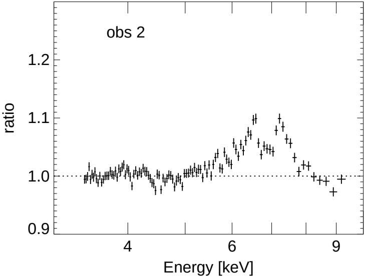
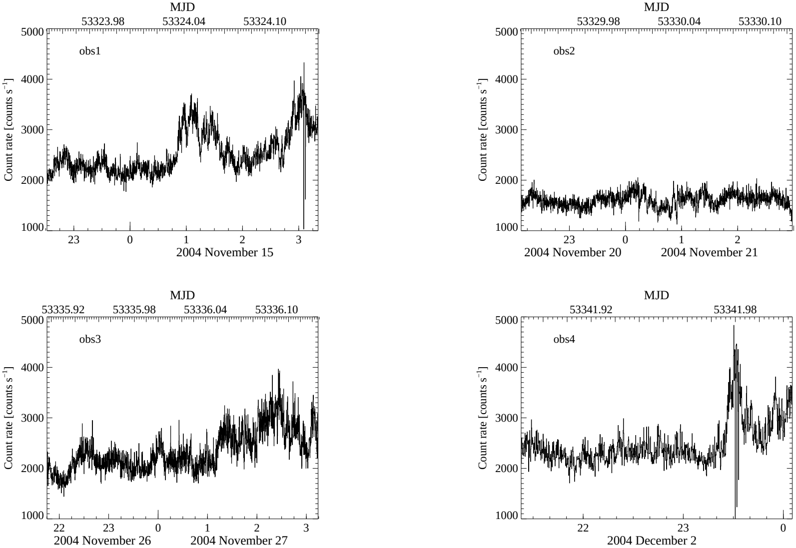
XMM - fixed inclination



$$E_{\mathrm{K}\alpha,narrow} = 6.51^{+0.03}_{-0.02}\,\mathrm{keV}$$
$$E_{\mathrm{K}\alpha,broad} = 6.81^{+0.06}_{-0.04}\,\mathrm{keV}$$
$$\mathrm{EW}_{\mathrm{K}\alpha,broad} = 123\,\mathrm{eV}$$
$$\mathrm{R}_{\mathrm{in}} = 16^{+6}_{-3}\,R_g$$
$$i = 45\,\mathrm{deg}\ \mathrm{(fixed)}$$

XMM Lightcurves



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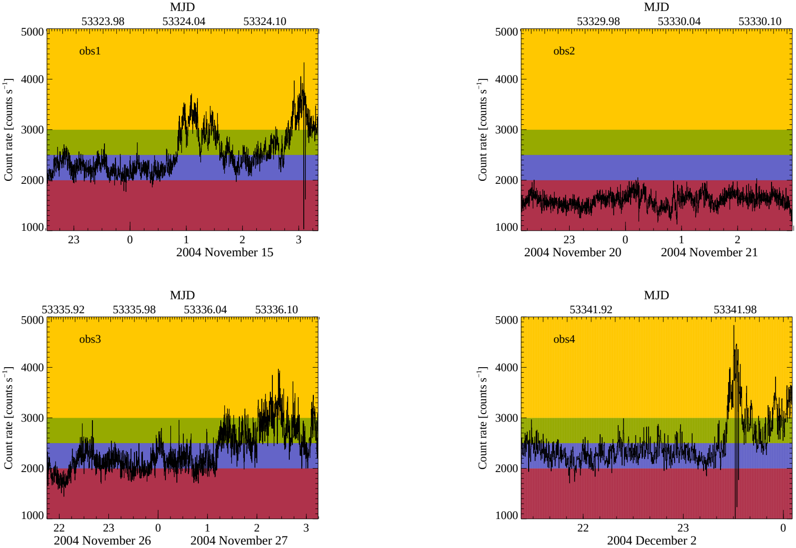
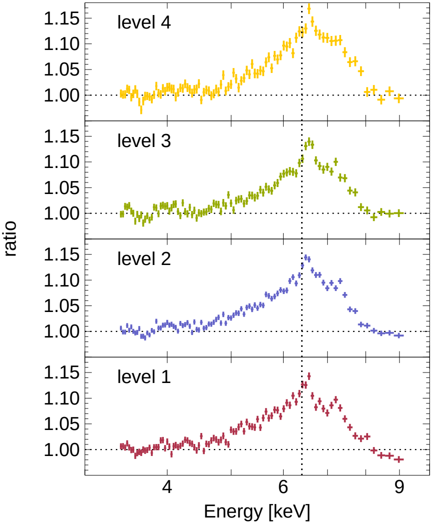


Flux Variability of the Iron Line



$E = 6.22^{+0.08}_{-0.08}$ keV EW=246 eV

$E = 6.24^{+0.07}_{-0.05}$ keV EW=191 eV

$E = 6.04^{+0.04}_{-0.04}$ keV EW=218 eV

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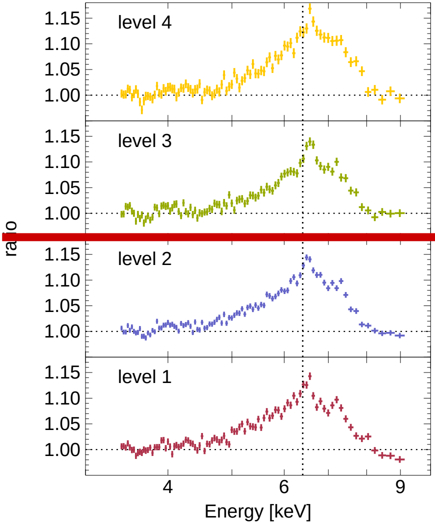

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Summary

Broadband Continuum

- Cyg X-1 was in the Intermediate State
- good agreement with previous results
- 67% of power supplied to electrons in corona in non-thermal component

Iron Line

- confirmation of relativistically broadened Iron Line
- broad line most likely from ionized Fe
- Fe Kα line shows strong variability during the observations