The broadband spectrum of Cygnus X-1

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[3]Center for Astrophysics and Space Sciences, University of California at San Diego, USA
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Astroteilchenschule, 7th Oct. 2006

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Outline

The Cygnus X-1 System

General

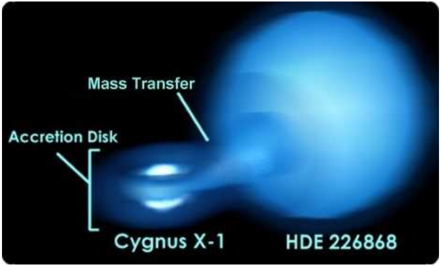
- discovered 1964 during a rocket flight
- distance 2.5 kpc
- orbital period 5.6 days
- accretion through focused wind

Optical Companion HDE 226868

- O9.7Iab
- $M \approx 18\,M_\odot$
- $R \approx 17\,R_\odot$

Compact Object

- $M \approx 10\,M_\odot$
- $R_S \approx 30\,\mathrm{km}$



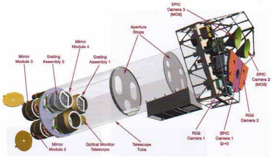
The Observations

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

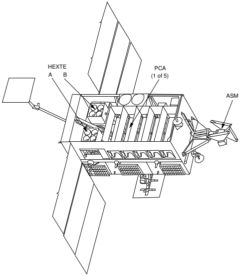
2.8 – 10 keV



ESA

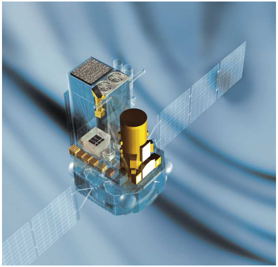
SPECIAL MODE NEEDED

3 – 120 keV



Wilms (1998)

4 keV – 1 MeV



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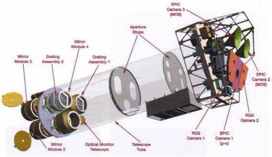

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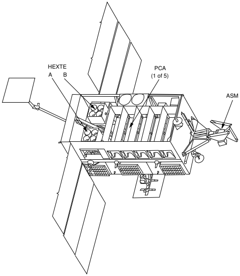

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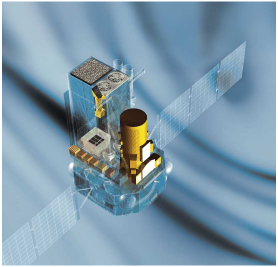

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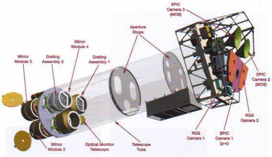

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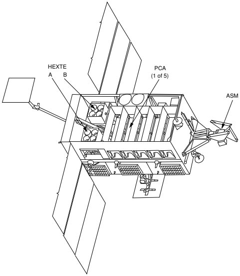

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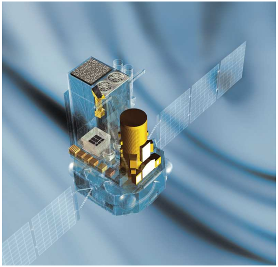

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2.8–10 keV	3 – 120 keV	4 keV – 1 MeV
XMM-Newton	*RXTE*	*INTEGRAL*

⟹ one of the best resolved broadband spectra ever obtained

What do we want to get out of the data?

2 main parts of analysis:

Broadband Continuum

- constrain models for Comptonizing plasma $\Longrightarrow$ search for / study effects of non-thermal Comptonization
- constrain amount of Compton reflection

$\Longrightarrow$ *INTEGRAL*, *RXTE*

Iron Line

- search for structure of the Fe Kα line (relativistic broadening)
- determine shape and strength of the Fe K edge

$\Longrightarrow$ *XMM-Newton*

How to model the broadband continuum

Phenomenological Approach

Modeling the spectrum by a broken powerlaw with exponential cutoff

Main fit parameters of the model: Γ_1, E_{break}, Γ_2, E_{cut}, E_{fold}

Additional to all models

Interstellar absorption

Fe Kα line (modeled as Gaussian)

How to model the broadband continuum

Phenomenological Approach

Modeling the spectrum by a broken powerlaw with exponential cutoff

Main fit parameters of the model:

Γ_1, E_{break}, Γ_2, E_{cut}, E_{fold}

"Physical" Approach

Modeling the spectrum by `eqpair` (with seed photons from `diskpn`, reflection included)

Main fit parameters of the model:

kT_{in}, $\ell_{\mathrm{h}}/\ell_{\mathrm{s}}$, $(\ell_{\mathrm{nth}}/\ell_{\mathrm{h}})$, τ_{p}, $\Omega/2\pi$, ξ

Additional to all models

Interstellar absorption

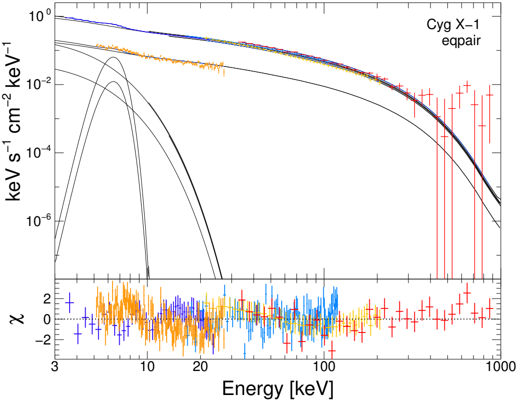
Fe Kα line (modeled as Gaussian)

EQPAIR Fits

Typical values

$kT_{in} \sim 1.1$ keV
$\ell_h/\ell_s \sim 3.1$
$\tau_p \sim 0.7$
$\Omega/2\pi \sim 0.28$
$\xi \sim 0$
$E_{K\alpha} \sim 6.3$ keV
$\sigma_{K\alpha} \sim 0.7$ keV

χ^2_{red} between 1.73 and 1.19



Fritz et al. (in prep.)

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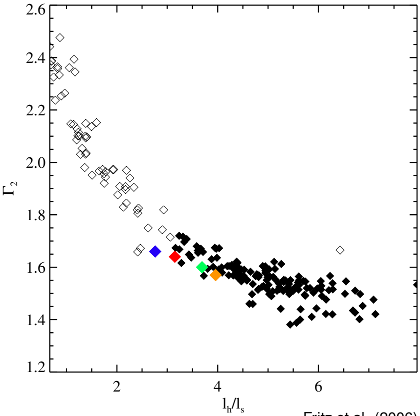
Comparison with previous results

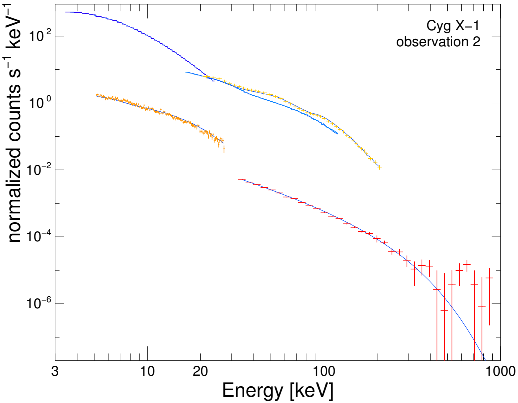


Fritz et al. (2006)

$\Longrightarrow$ good agreement with previous results

Is there a hard tail?

`eqpair` model:
indications for a hard tail above $\sim 300\,\text{keV}$
but: rather poor statistics with *SPI* in individual observations



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Is there a hard tail?

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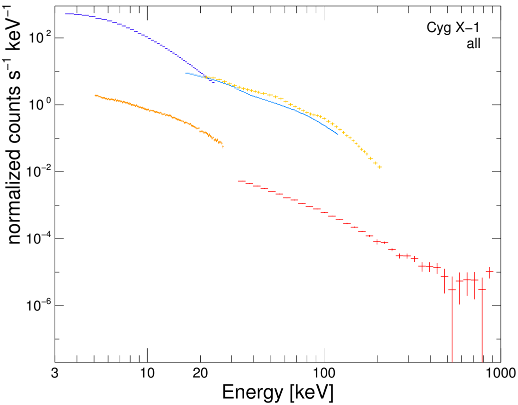
$\Longrightarrow$ combine all 4 observations (although Cyg X-1 was highly variable during the observation time)



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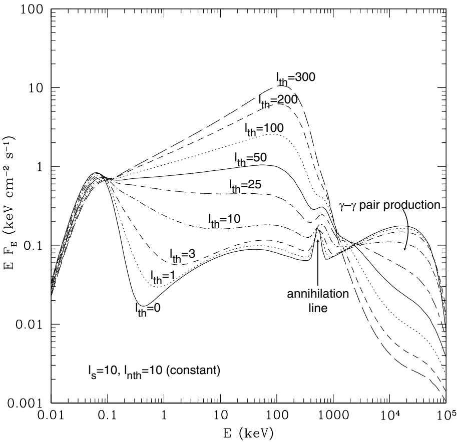
How to model a hard tail?



Coppi (1999)

Shape of the Comptonization spectrum changes according to energy distribution of the electrons

$\Longrightarrow$ Hard tail could be modeled as non-thermal electron distribution in the hot plasma

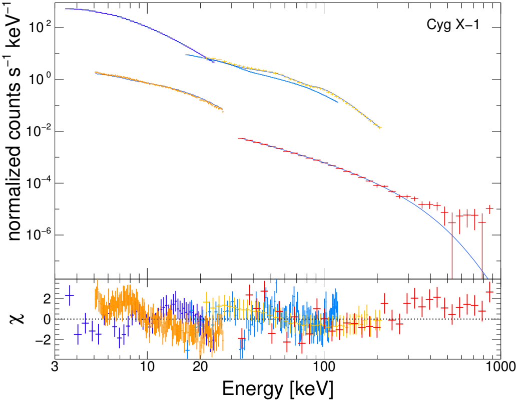
$$\ell_{\mathrm{h}} = \ell_{\mathrm{th}} + \ell_{\mathrm{nth}}$$

Time averaged Spectra - Thermal Model

Thermal Model:

Residuals above 300 keV still present in the averaged spectrum

χ^2_{red} = 1.52 (341 dof)



Fritz et al. (in prep.)

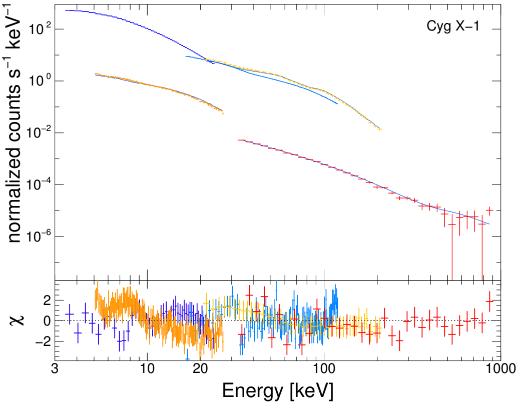
TIME AVERAGED SPECTRA - HYBRID MODEL

Hybrid Thermal / Non-thermal Model:

Best fit: $\ell_{nth}/\ell_h \sim 0.78$

$\Longrightarrow$ 78% of the power supplied to electrons in corona is in the non-thermal component

$\chi^2_{red} = 1.44$ (340 dof)



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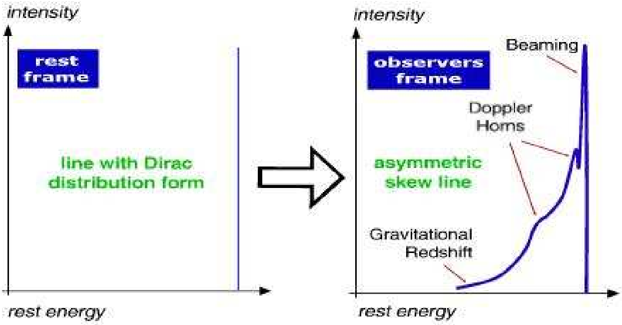
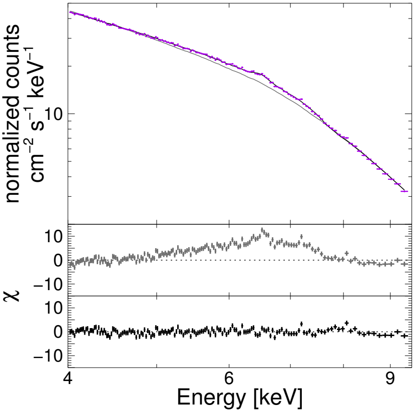
Relativistically broadened Iron Lines



Fe Kα line originates from material just a few gravitational radii from the black hole
$\Longrightarrow$ profile is shaped by (relativistic) Doppler shifts and gravitational redshift effects

XMM-Newton Spectrum



Fritz et al. (2006)

best fit with a narrow and a relativistic line:

- Power law
  $\Gamma = 1.90 \pm 0.01$
- narrow line
  $E = 6.52 \pm 0.02\,\mathrm{keV}$
  $\sigma = 80 \pm 35\,\mathrm{eV}$
  equivalent width=14 eV
- relativistic line (Kerr)
  $E = 6.76 \pm 0.1\,\mathrm{keV}$
  emissivity $\propto r^{-4.3\pm0.1}$
  equivalent width=400 eV

χ^2_{red} = 1.3 (149 dof)

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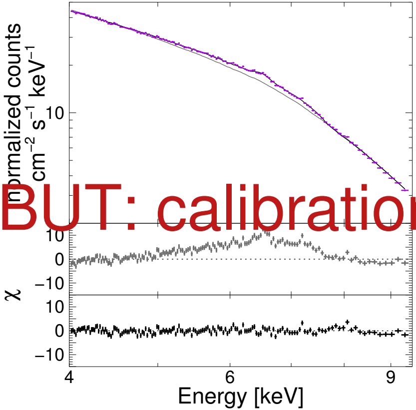

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BUT: calibration not yet finalized

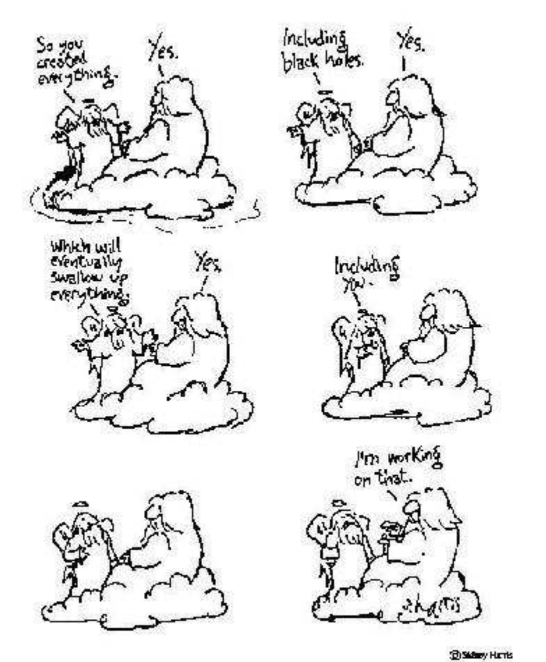
Summary and Outlook

- we got one of the best resolved broadband spectra
- comparison with previous results $\Longrightarrow$ good agreement
- Comptonizing plasma is most likely a hybrid thermal / non-thermal plasma
- confirmation of relativistically broadened Iron Line

Next steps:

$\Longrightarrow$ Final calibration of *XMM-Newton* Modified Timing Mode
$\Longrightarrow$ Combination of all 3 instruments to model the whole broadband spectrum

Outlook


So you created everything.
Yes.
Including black holes.
Yes.
Which will eventually swallow up everything.
Yes.
Including you.
I'm working on that.
© Sidney Harris