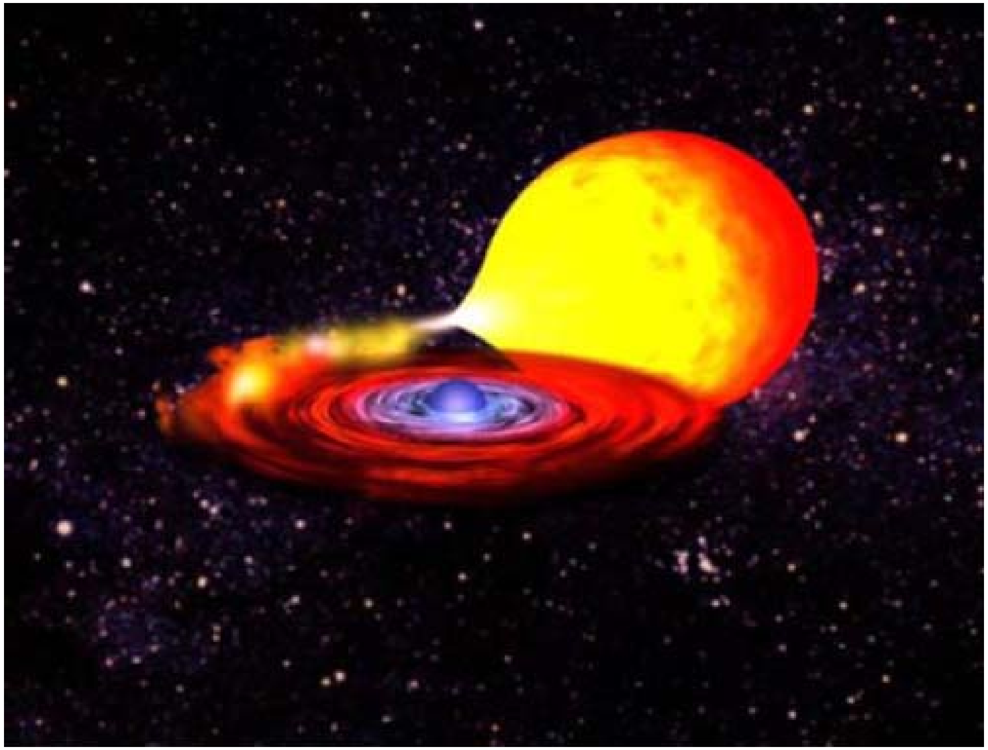
Why is the Low-Mass X-ray Binary EXO 0748-676 dipping?



Master Candidate:

Guillermo JENARO

Under the supervision of:

María DÍAZ TRIGO

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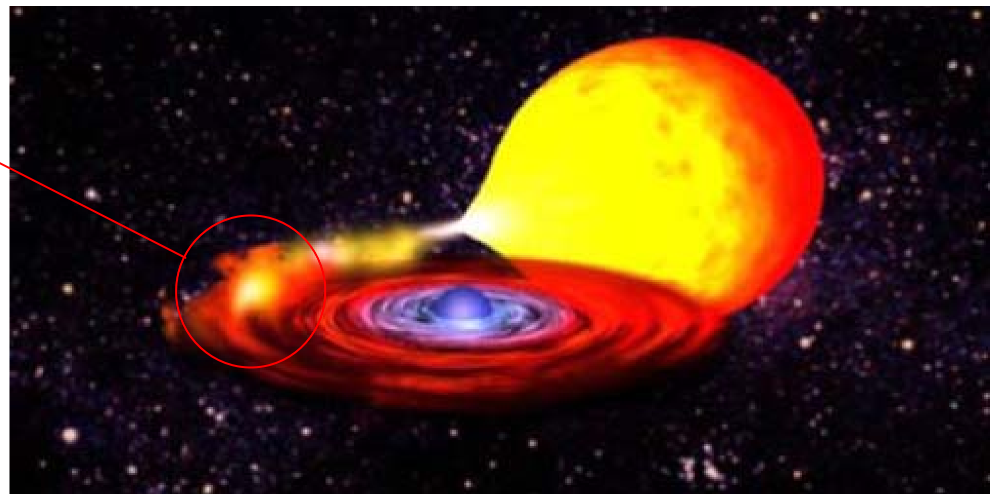
Contents

Introduction (cont'd)

- A Low-Mass X-ray Binary (LMXB) system is either a Neutron Star (NS) or a Black Hole (BH) accreting from a low-mass companion, generally through and Accretion Disc (AC)

Bulge:
Neutral
+
photo-ionized absorber



Black body:

NS

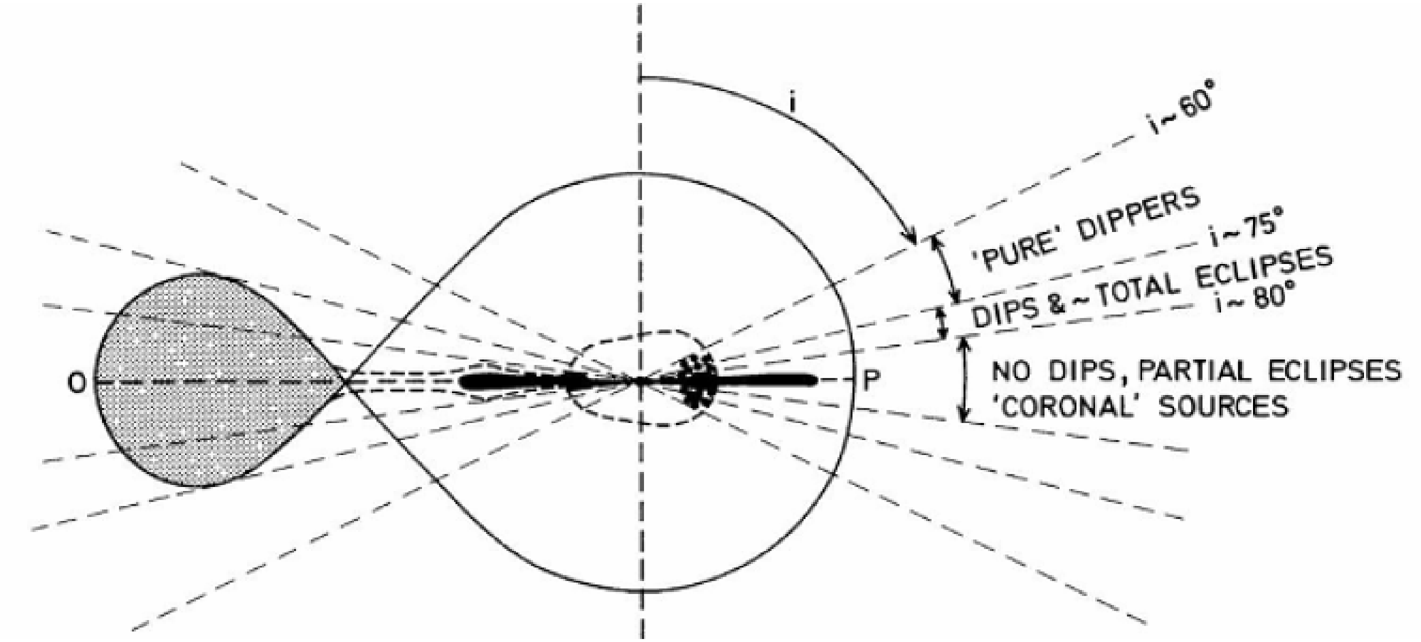
Inner AD

Power-law:

AD Corona

Introduction

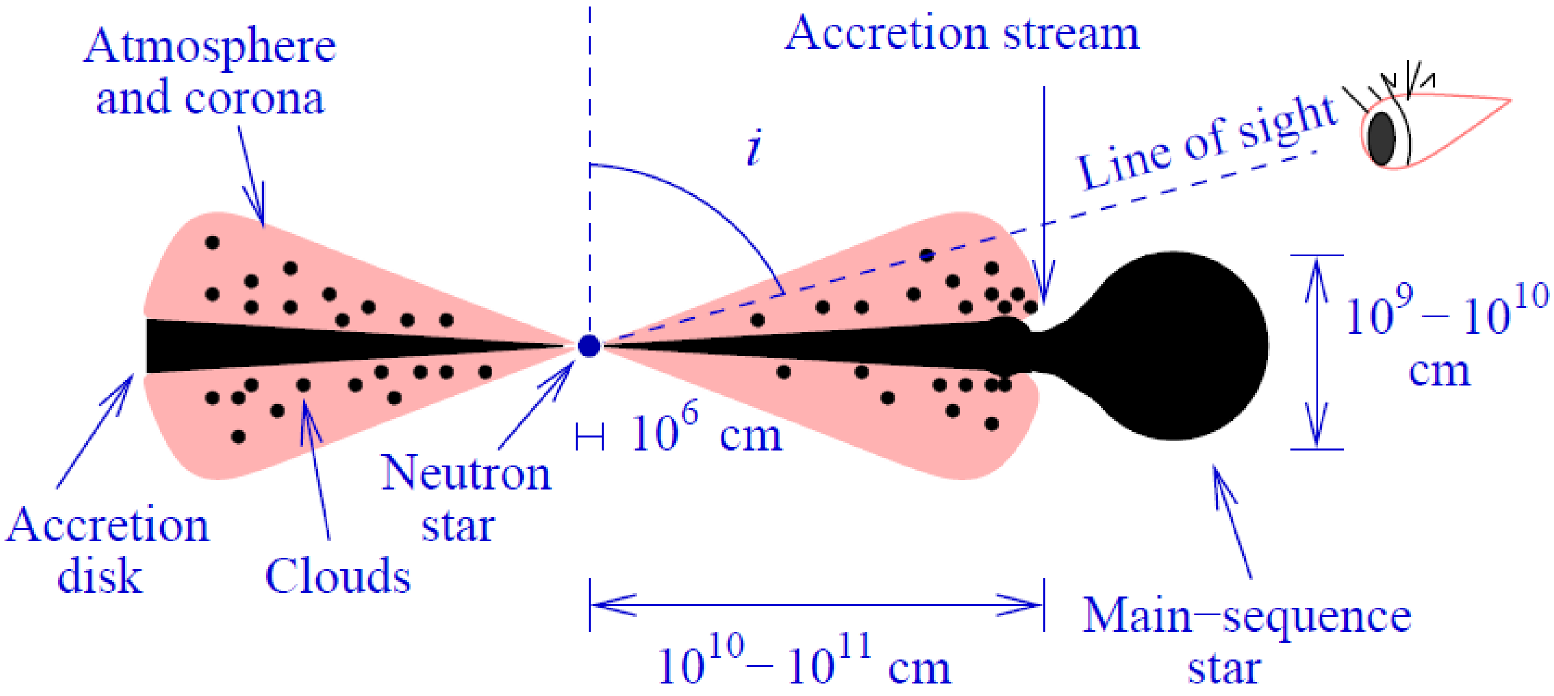
- ~10 LMXBs exhibit dips in their X-ray intensity
- Dips are thought to be caused by obscuration by material located in a thickened outer region of the AD due to its interaction with the inflowing gas stream from the companion (White et al. 1982)
- Dipping LMXBs: line of sight close to AD plane



Frank et al. 1987

Introduction (cont'd)

Modelling of spectral changes during dips provides a powerful means of studying the structure and location of the emitting and absorbing regions in LMXBs



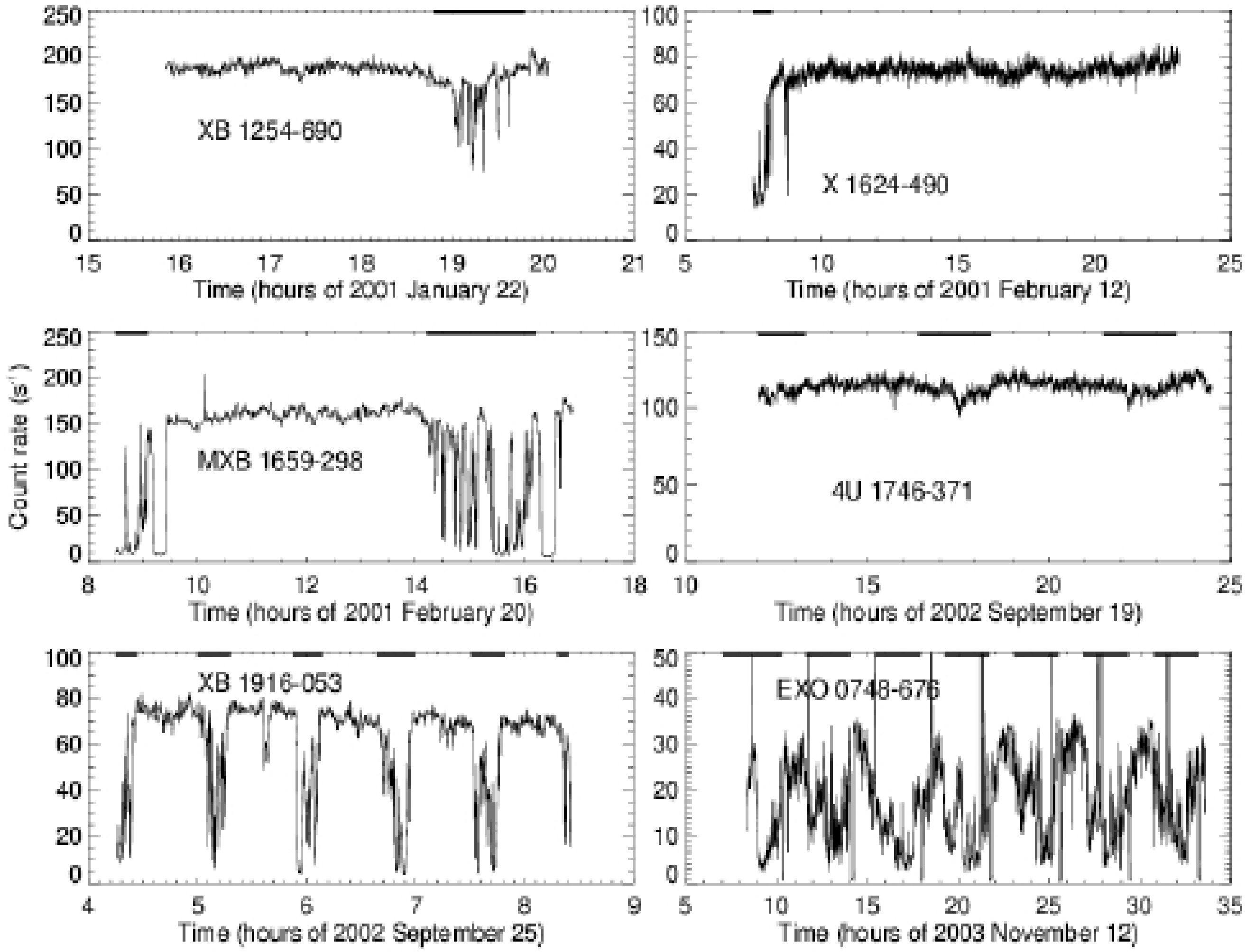
Jiménez-Garate et al. 2002

Introduction (cont'd)

- Three approaches used to explaining dipping spectra:
  - "absorbed + unabsorbed approach" (Parmar et al. 1989)
  - Complex continuum (Church et al. 1995)
  - Highly-ionized absorber: the major breakthrough is to include a photo-ionized absorber during dips (Boirin et al., 2005)

    Díaz Trigo et al. (2006) applied the model successfully to all dippers LMXBs observed by XMM-Newton.

Introduction (cont'd)



Díaz Trigo et al. (2006)

Introduction (cont'd)

But …

- The photo – (and highly) – ionized absorber approach has only been tested at 0.5 – 10 keV energy band (XMM-Newton EPIC detector) so far.

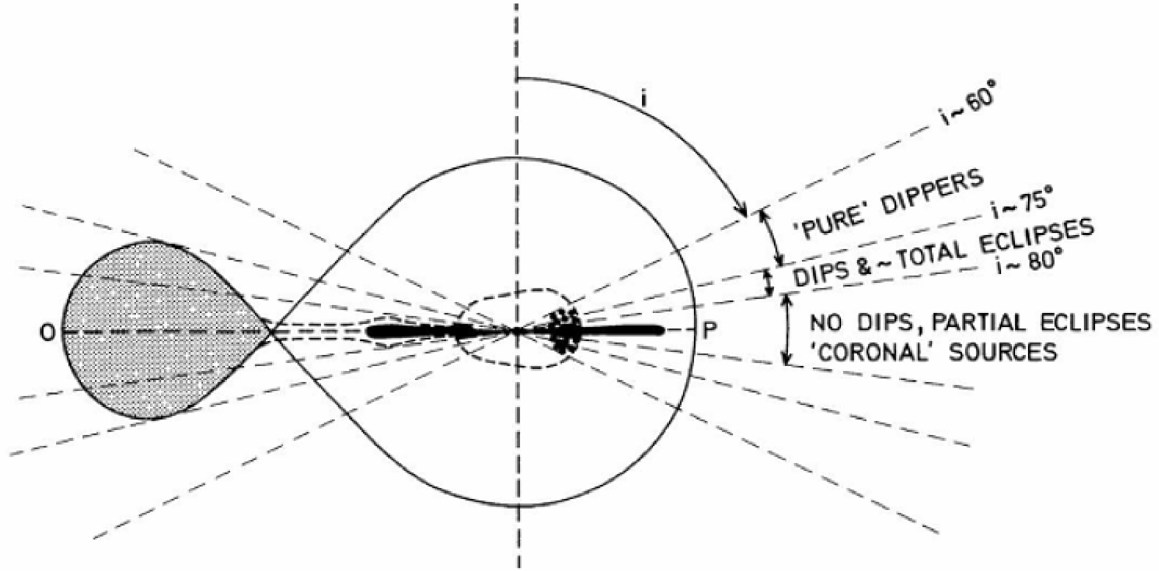
- Church et al. 2005 have criticised this model: "increase electron column density (N_e) … would cause a decrease in X-ray continuum at every energy due to Thomson scattering by a factor exp(- $N_e\sigma_T$)" (σ_T: Thomson cross-section)
  - too large decrease in the band 20-50 keV flux compared to BeppoSAX observations

- Boirin et al. (2005) argue that the electron optical depth is energy dependent and Thomson approx. does not hold at high energy

- In this Thesis, I tested for the first time the highly-ionized absorber model for the 0.5-40 keV broad energy band with Suzaku observations.

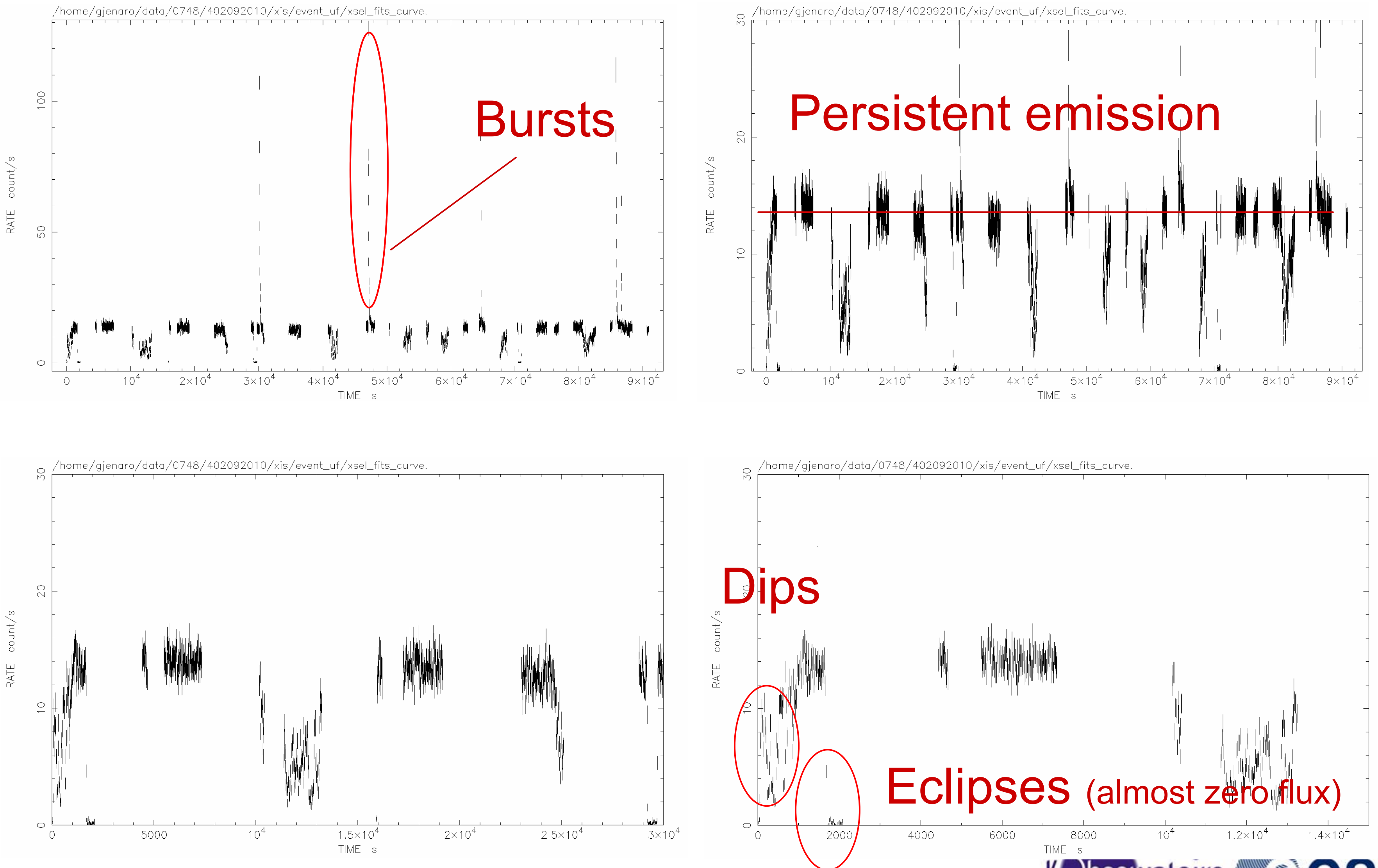
Why EXO 0748-676?

- EXO 0748-676 is a dipping LMXB with a NS
  - High inclination 75°<i<82° (Parmar et al., 1986, based on light curves)
  - Neutron Star with low-mass companion (< 0.5 M⊙) filling the Roche lobe ⇒ stable mass rate transfer through L1
  - X-ray light curves: eclipses, dips, bursts, persistent emission
  - Distance to Sun ~5-10 kpc (Wolff et al. 2005)



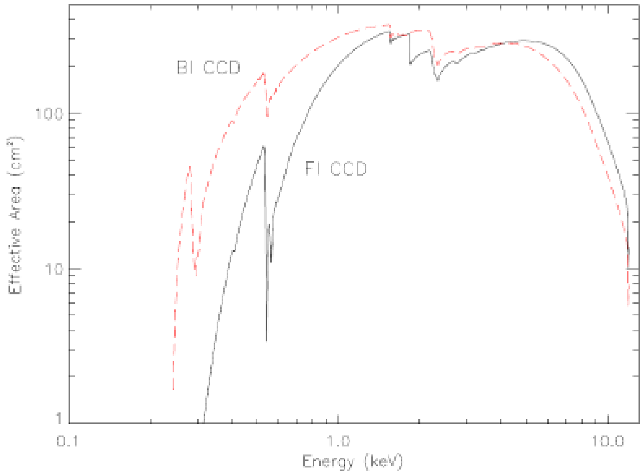
Frank et al. 1987

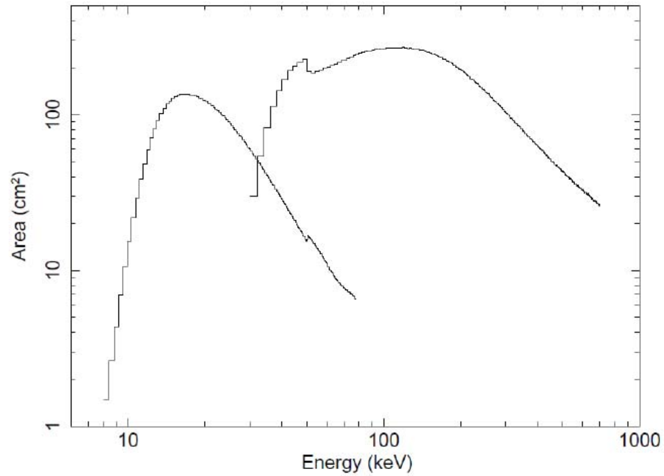
Why EXO 0748-676?



Suzaku Mission

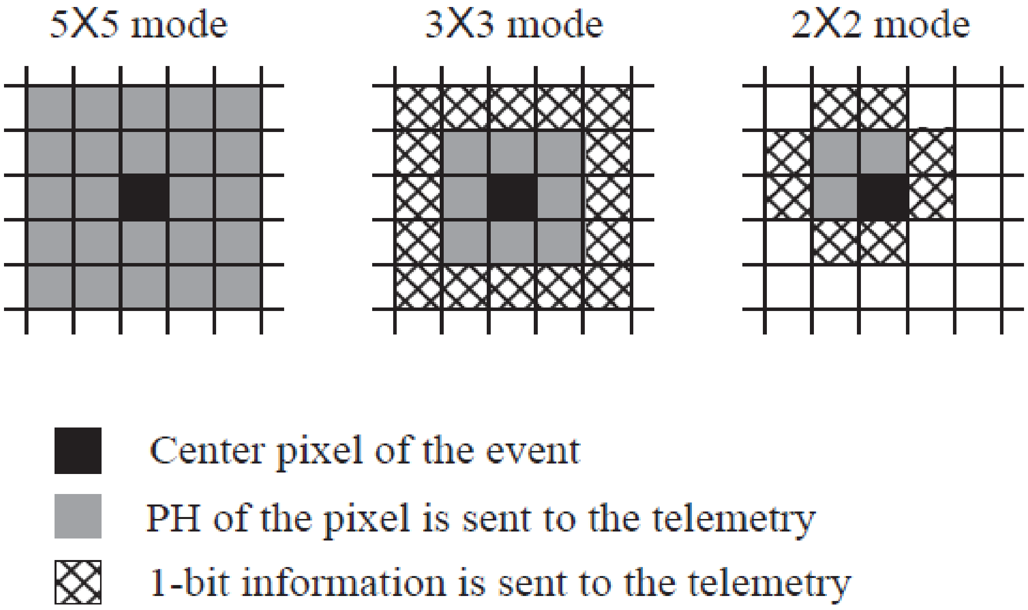
- X-ray binaries: X-ray band emission ~1000x brighter than optical band
- X-ray: Space telescopes (due to atmospheric absorption)
- Currently 5 operational missions: Rossi-XTE ('95), Chandra ('99), XMM-Newton('99), Swift ('04) and Suzaku ('05)
- Suzaku
  - Broad-band 0.5 keV – 600 keV (RXTE 15-250 keV, ΔE~9keV @ 60 keV)
  - Equipped with the highest resolution spectrometer in flight (failed after 1 month of operation)
  - 4 X-ray Image Spectrometers (1 inoperative since Nov 06)
  - 1 Hard X-ray Detector





Data Reduction

- Observation:
  - From 25/12/2007 05:41:13 to 26/12/2007 07:00:24 UTC (91 ks)
  - Normal mode: read out interval 8 s (integration time)
  - Editing mode 3x3, 5x5 (satellite operations team decision)

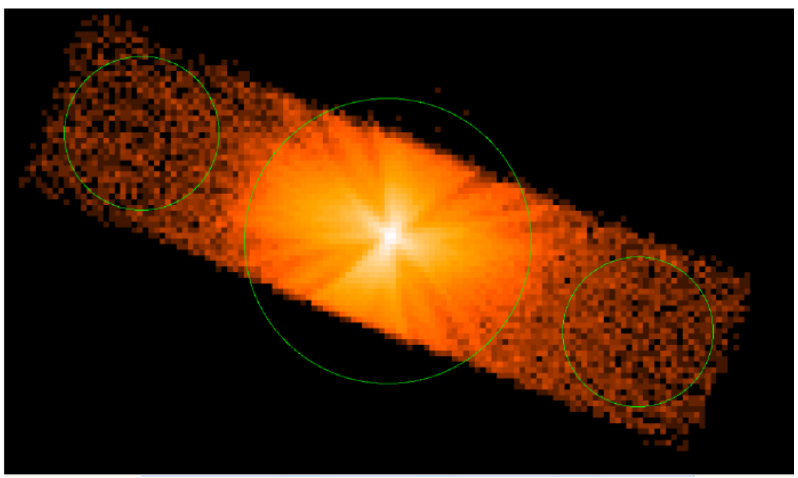


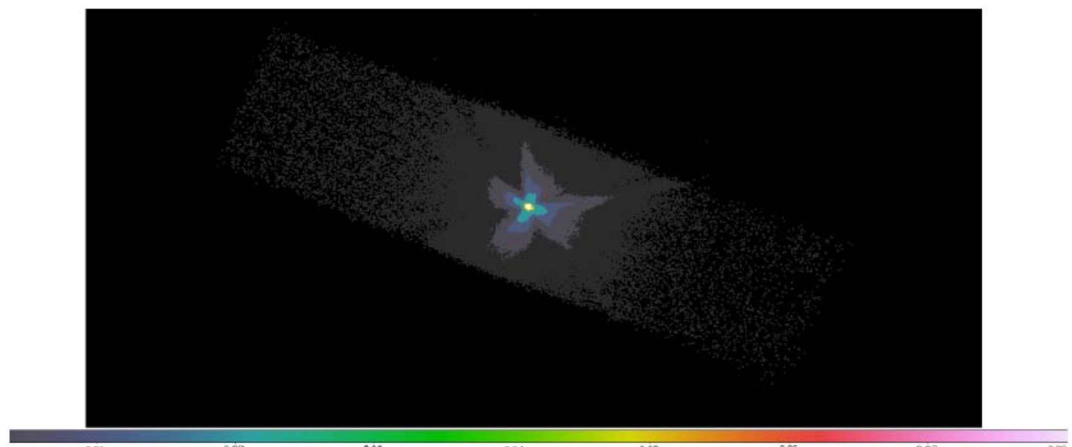
Data Reduction (cont'd)

XIS reduction

- Clean-up:
  - Coordinates correction
  - Bad pixels/flickering pixel
  - Grade filter
  - Background

- Pile-up: 2 or more photons arrive at the same pixel or at adjacent pixels:
  - Hardening of spectra
  - Rejection of events above threshold





Data Reduction (cont'd)

HXD reduction

The most important task is to generate proper background file.
Two components:

–Cosmic X-ray Background:

Modelled through

$$CXB(E) = 8.810^{-4} \left(\frac{E}{1\,\mathrm{kev}}\right)^{-1.29} \exp\left(\frac{-E}{40\,\mathrm{kev}}\right) \mathrm{photons\,cm^{-2}\,s^{-1}\,FOV^{-1}\,kev^{-1}}$$

–Non-cosmic X-ray Background:
extremely low in HXD

Spectra extraction

- From Flux to detector flux:

$$C(h) = \int_0^\infty \sum_i R_i(h,E)\ A_i(E)\, S_i(E)\, dE dT + b(h)$$

$C(h)$	$R_i(h,E)$	$A_i(E)$	$S_i(E)$	$b(h)$
Detected counts	Response Matrix	Effective Area	Source Spectra	Background counts

E : energy

h: pulse invariant channel (discrete)

dT: integration time

- To obtain spectra

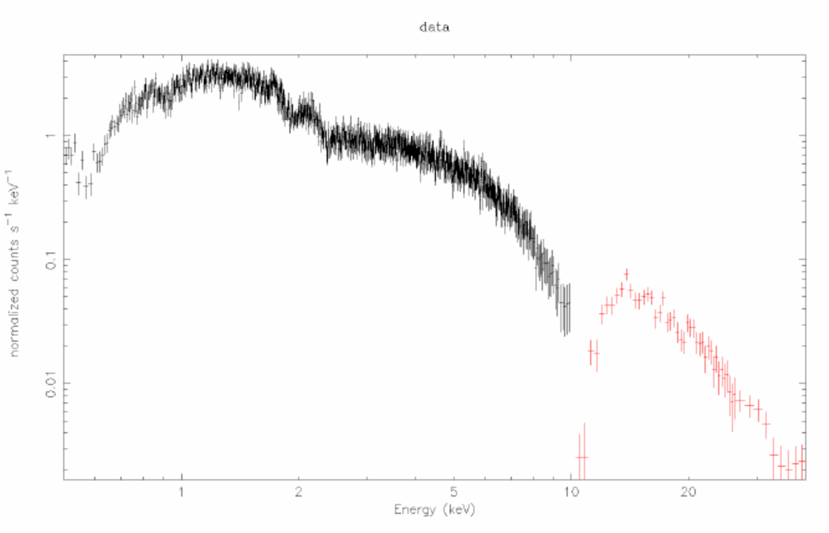
RMF : Response Matrix File

ARF: Ancillary Response File – Monte Carlo Simulation with X-ray tracers.

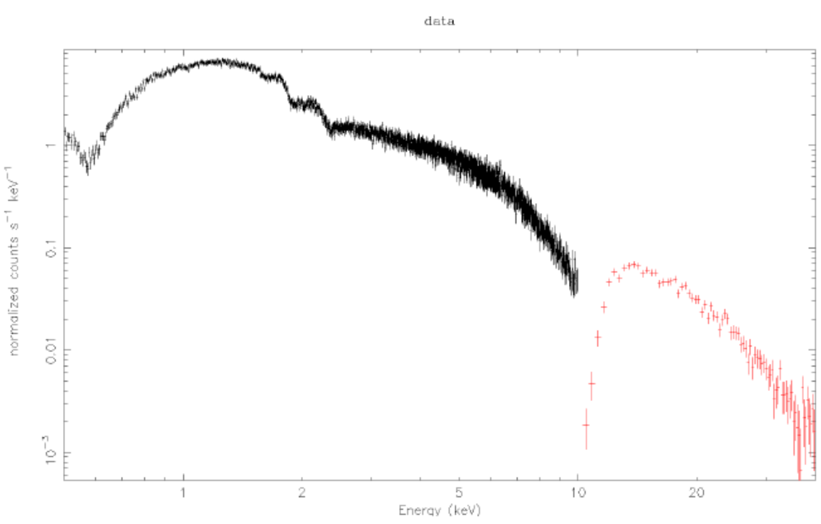
Spectra extraction

- XIS1 and XIS3 are added
- XIS Cameras are rebinned to over-sample the energy resolution of the CCDs by a factor of 2

Dip Intervals spectra



Persistent Intervals spectra



Models to fit

- Power law(`powerlaw`): phenomenological description for the Comptonization of soft photons in a hot plasma

$$A(E) = k\, E^{-a}$$

- Black Body (`bb`):

$$A(E) = \frac{K\, 8.0525\, E^2\, dE}{(kT)^4\, [e^{E/kT} - 1])}$$

- Interstellar Medium (ISM) (`Tbabs`): Neutral absorption from the ISM. Local neutral absorption form the bulge is as well expected.

- Warm absorber (`warmabs`):

$N_h^w abs$	:	column density of the photo-ionized plasma
$\log \xi = \log \frac{L}{n_e r^2}$	:	photo-ionization parameter, where L is the source luminosity, n_e the electron density and r the distance to the source
C_i	:	element abundances
σ_v	:	turbulent velocity broadening of the absorber
z	:	redshift of the absorber

Models to fit and fitting

- Gaussian law (`gaussian`): represents a Gaussian line profile

$$A(E) = K \frac{1}{\mathrm{par2}\,\sqrt{2\pi}} \exp\left(\frac{E - \mathrm{par2}}{2\,\mathrm{par2}}\right)$$

- Fitting is based on the χ^2 fit-goodness statistic, for which reduced χ_{υ}^2 should be close to 1 for a good fitting.

- The fitting is performed sequentially :

```
Constant*Tbabs(powerlaw+highercut*powerlaw)
```

↓

```
Constant*Tbabs(powerlaw+bb+highercut*powerlaw)
```

↓

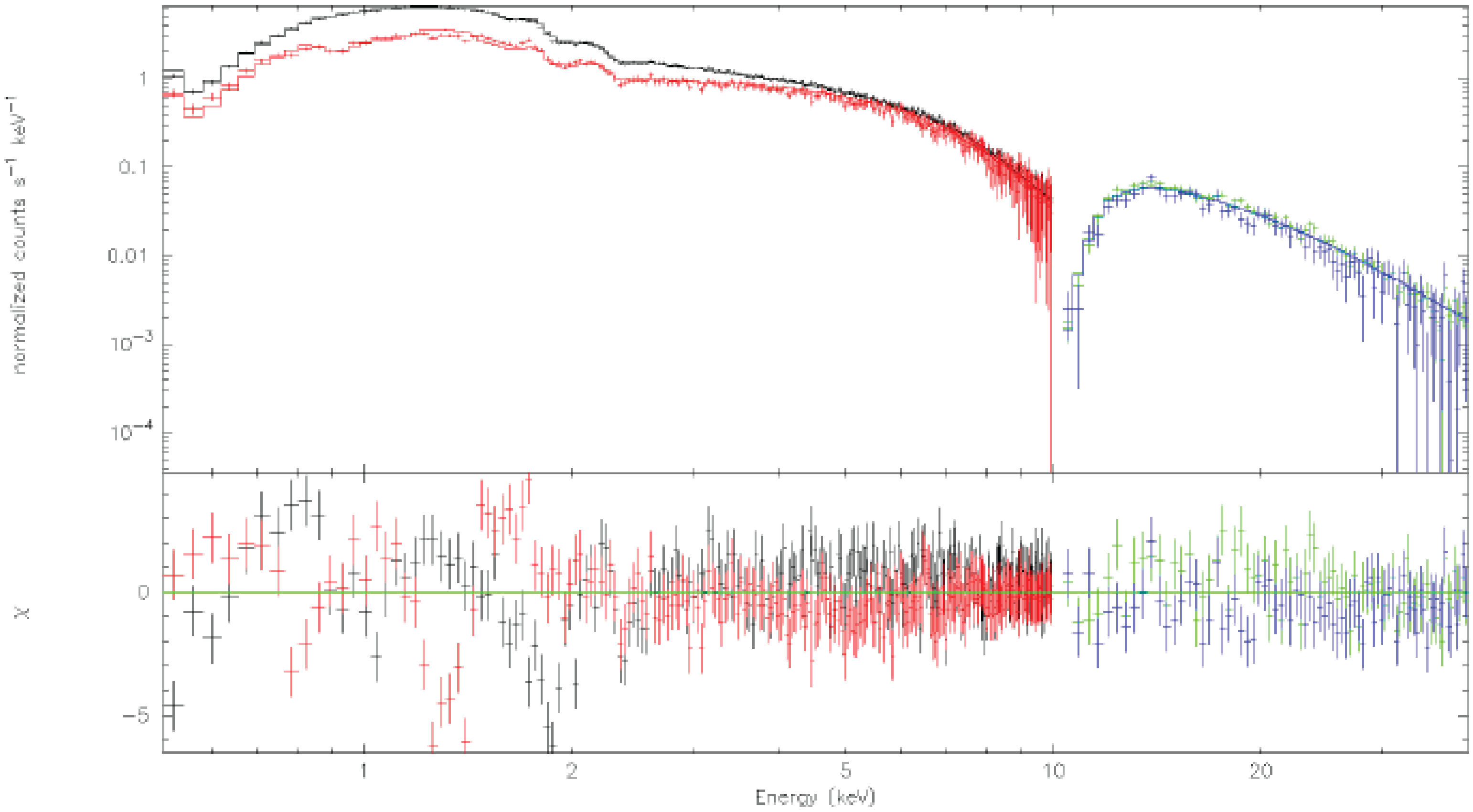
```
Constant*Tbabs*warmsabs(powerlaw+highercut*powerlaw)
```

Best-fit Results

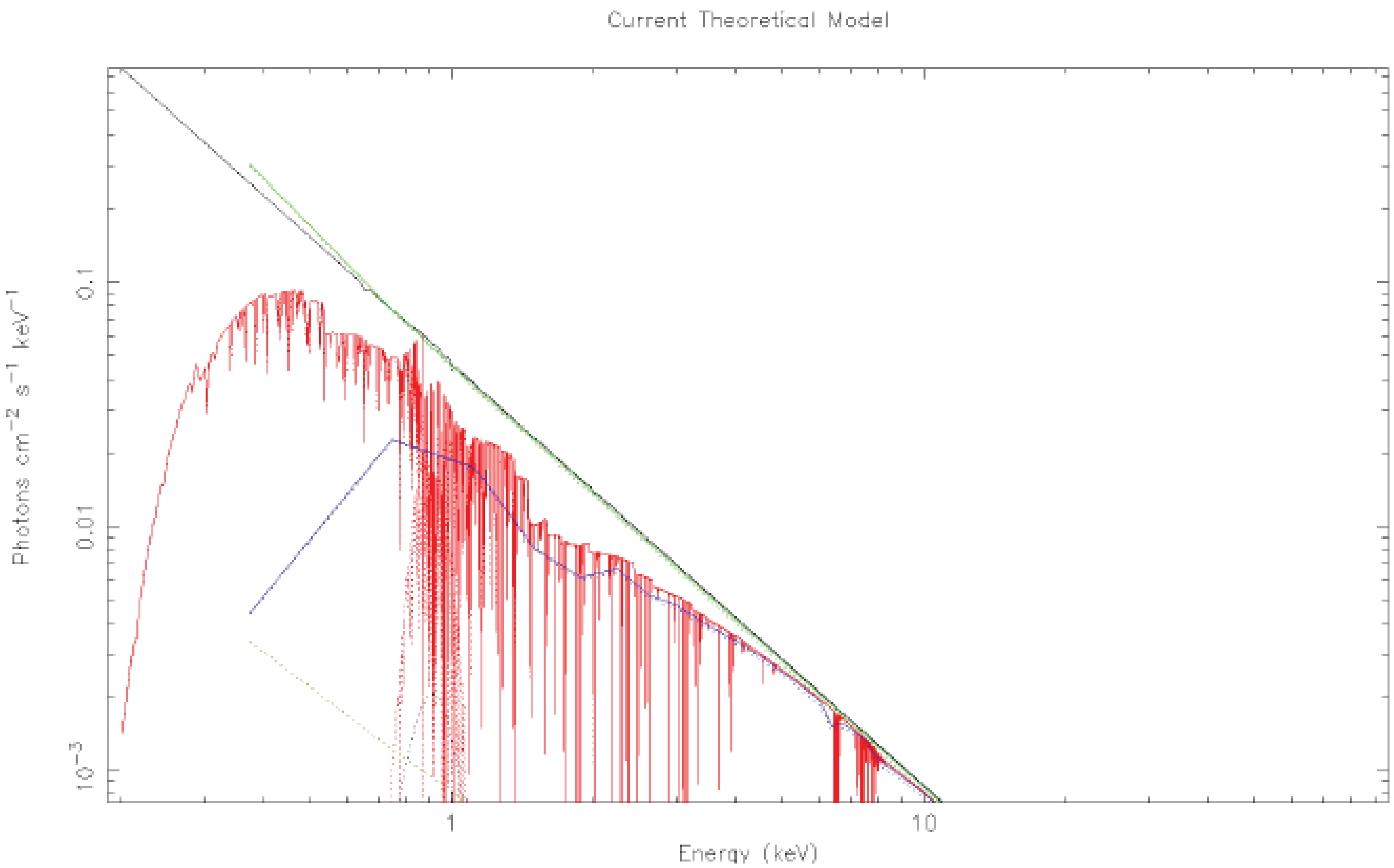
- Best-fit parameters:
  - – The constant is fixed to 0.96 for the HXD to compensate possible flux differences between XIS & HDX.
  - –The continuum is equal for all the cameras and regimes
  - –Redshift parameter is fixed to 0

Parameter	Comp.	Persistent	Dips
	Tbabs		
N_h $(10^{22}\mathrm{cm}^{-2})$		< 0.0005	$0.086^{+0.007}_{-0.022}$
	powerlaw		
a		1.7306 ± 0.004	
k		0.0463 ± 0.0002	
	warmabs		
N_h^{wabs} $(10^{22}\mathrm{cm}^{-2})$		-	$11.5^{0.3}_{-1.0}$
$\log \xi$		-	$2.56^{+0.02}_{-0.05}$
σ_v (km/s)		-	207^{+61}_{-21}
	gaussian		
E (keV)		0.915	
σ (keV)		-	$0.0826^{+0.005}_{-0.007}$
K $(\mathrm{cm}^{-2}\,\mathrm{s}^{-1})$		-	0.0152 ± 0.002
χ^2_ν	1.7046		
$F_x(10^{-10}\mathrm{ergcm}^{-2}\mathrm{s}^{-1})$		2.73	1.96

Best-fit results (cont'd)



Best-fit results (cont'd)



Discussion

- The black body component does not improve significantly the fitting, probably is present but not detected by Suzaku.
- χ_υ^2 is 1.7 for 644 degrees of freedom
- For the soft energy band (<2 keV) structured residuals are still present below 2 keV after fitting of the spectra with the given model
- The best-fit is compared with the presented in Díaz Trigo et al (2006) with XMM-Newton observations as follows:
  - –Power law 1.57 ± 0.05 slightly harder than the one I obtained (1.731 ± 0.004)
  - –An emission line of NeIX is identified at 0.915 keV (also in 2006) but the normalization is higher in the present fitting
  - –Díaz Trigo et al. Identified a black body component at 1.9 keV
  - –The unabsorbed 0.6-10 keV flux during persistent emission was 23% lower in 2003 than in 2007 and supports the conclusion that EXO 048-676 was in a lower state luminosity with respect to other LMBXs analysed.

Thank you for your attention
Questions?

I'd like to thank to ESAC Faculty for this opportunity, my supervisor María Díaz Trigo for her support, explanations, report and presentation review and Deborah Baines for organizing all this.