Studying the stellar wind in the Vela X-1 system
with *XMM-Newton*/RGS

ESAC trainee project

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esa European Space Astronomy Centre
European Space Agency

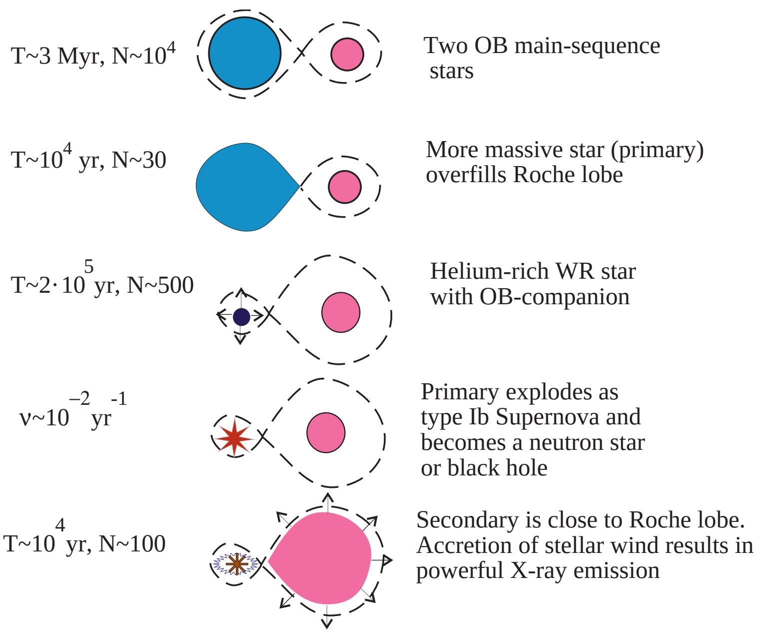
Overview

- **The Vela X-1 system I – known facts**
  general concept of NS HMXB systems
  and evidences in the case of Vela X-1
  [¡ theory → observation !]

- **The Vela X-1 system II – unresolved issues**
  physical effects in an XRB system
  and goals of this project
  (to constrain the physical parameters)
  [¿ observation → theory ?]

- **First results**
  - modelling of two high resolution spectra in eclipse
  - a flare in the latest *XMM*-observation

The high-mass X-ray binary Vela X-1 / HD 77581



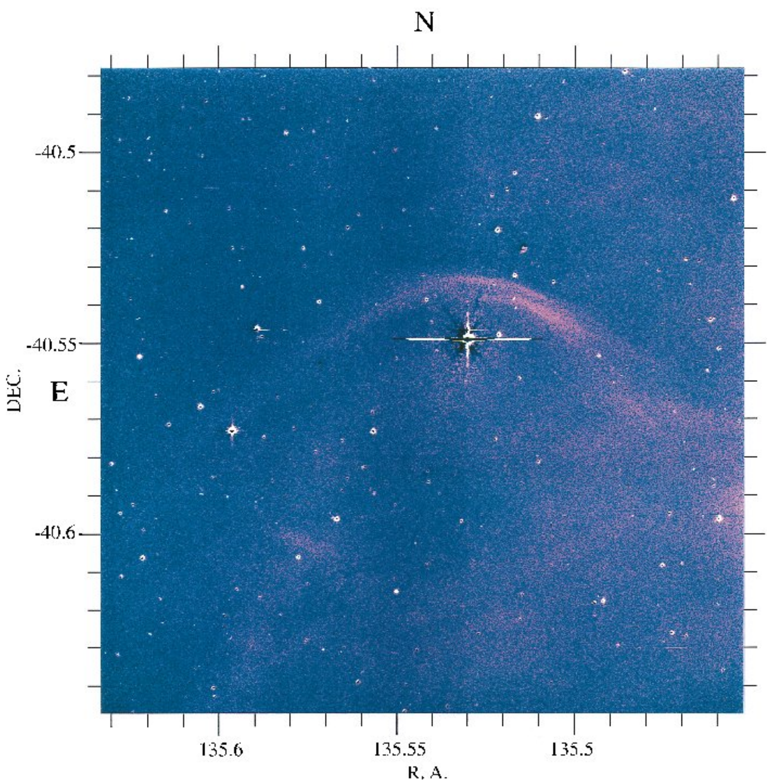
The evolution of a compact binary.

(after Postnov & Yungelson, 2006, Fig. 4)

Under certain conditions (Blaauw, 1961), the supernova explosion does not disrupt the binary system, but gives a kick velocity.

Vela X-1 is an X-ray binary, consisting of a neutron star and the 23.5 $M_\odot$ B0.5 Ib supergiant star HD 77581.

A bow shock around HD 77581



(corrected Hα image; Kaper et al., 1997, Fig. 1)

The star HD 77581 has a large proper motion ($\gtrsim$ 7 mas/yr).

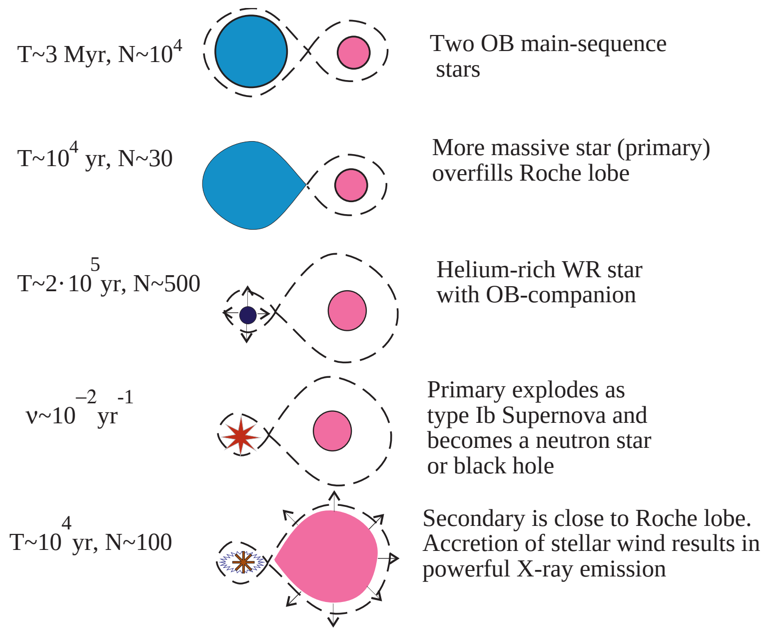
(distance = 1.82 kpc)

$\Rightarrow$ space velocity $\gtrsim$ 90 km/s

$\Rightarrow$ HD 77581 is a runaway star

Due to the supersonic motion through the ISM, the strong stellar wind causes shock fronts.

The high-mass X-ray binary Vela X-1 / HD 77581



The evolution of a compact binary.
(after Postnov & Yungelson, 2006, Fig. 4)

Vela X-1 is an X-ray binary, consisting of a neutron star and the 23.5 $M_\odot$ B0.5 Ib supergiant star HD 77581.

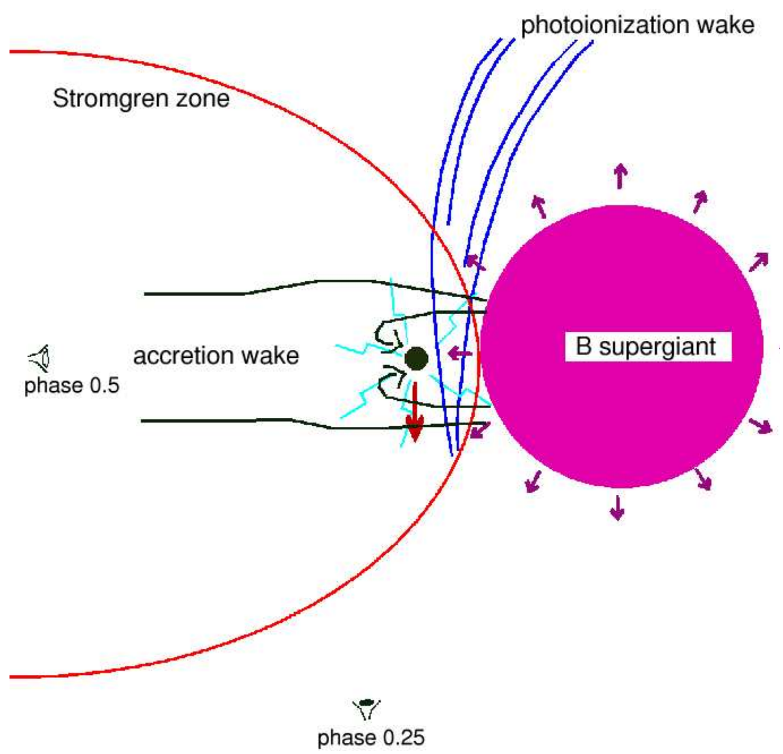
While orbiting the companion (in 8.96 days), only 0.8 stellar radii from its surface, the neutron star sweeps up part of the stellar wind.

This accretion releases gravitational energy in the form of X-rays.

As a young neutron star has still a strong B-field, Vela X-1 is an X-ray pulsar with a period of 282 s.

The neutron star is the most massive known: $M_{ns} = (1.86 \pm 0.32)\, M_\odot$

X-ray photoionization of the stellar wind



(Goldstein et al., 2004, Fig. 4)

The photoionization of the stellar wind by the hard X-rays from the neutron star creates very complex structures in the system.

Fully ionized material becomes transparent to the star's radiation pressure.

Recent simulations (Mauche et al., 2007) have shown that rather chaotic structures may emerge – just from the interaction of the X-rays with the wind (in the rotating system).

X-ray spectrum of Vela X-1 in eclipse

Due to the system's high inclination $> 73°$, the neutron star (X-ray source) is eclipsed from orbital phase $\phi = 0.9$ to $\phi = 0.1$.

⇒ Reprocessed X-rays from the (in parts) highly ionized wind / circumstellar material, which has been excited, becomes visible:

- Emission lines from highly ionized ions
  $n\mathrm{p} \rightarrow 1\mathrm{s}$ [H-like], $1\mathrm{s}\, n\mathrm{p} \rightarrow 1\mathrm{s}^2$ [He-like]
- Radiative recombination continua
  $\mathrm{e}^- + \mathrm{X}^{+(\mathrm{n}+1)} \rightarrow \mathrm{X}^{+\mathrm{n}}$
- Fluorescent Kα emission lines
  $1\mathrm{s}\, 2\mathrm{s}^2 2\mathrm{p}^\mathrm{x} \cdots \rightarrow 1\mathrm{s}^2\, 2\mathrm{s}^2 2\mathrm{p}^{\mathrm{x}-1} \ldots$

Can we perform a time-resolved high-resolution spectroscopy?

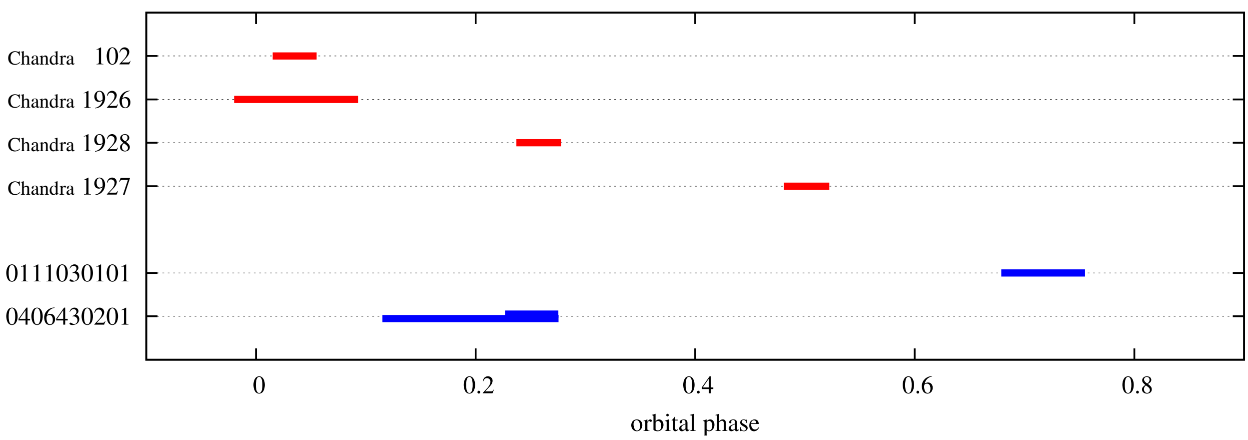
Can we test the predictions of the wind-simulations by observational means?

Can we put any constraints on the accretion flow?

High resolution X-ray observations of Vela X-1

Capable instruments currently in orbit:

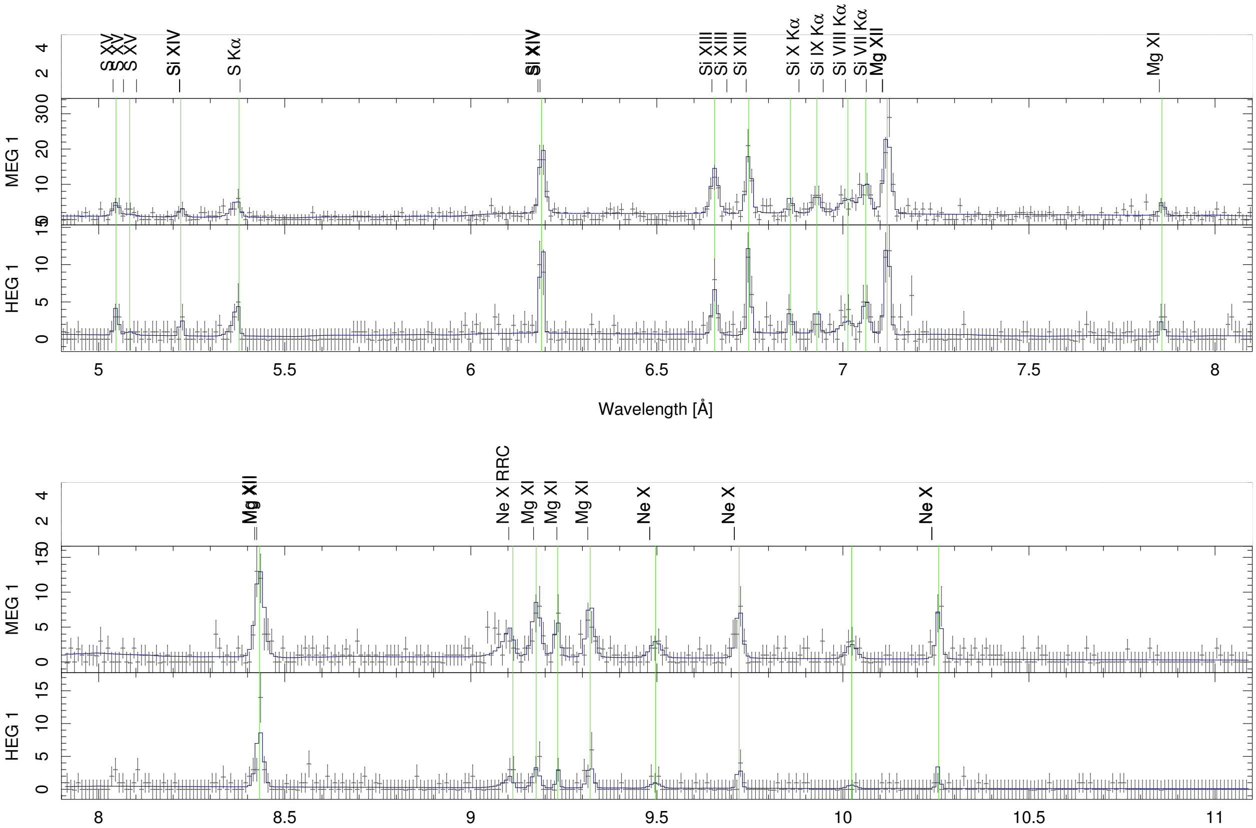
Chandra / High Energy Transmission Grating Spectrometer (HETGS)
XMM-Newton / Reflection Grating Spectrometer (RGS)



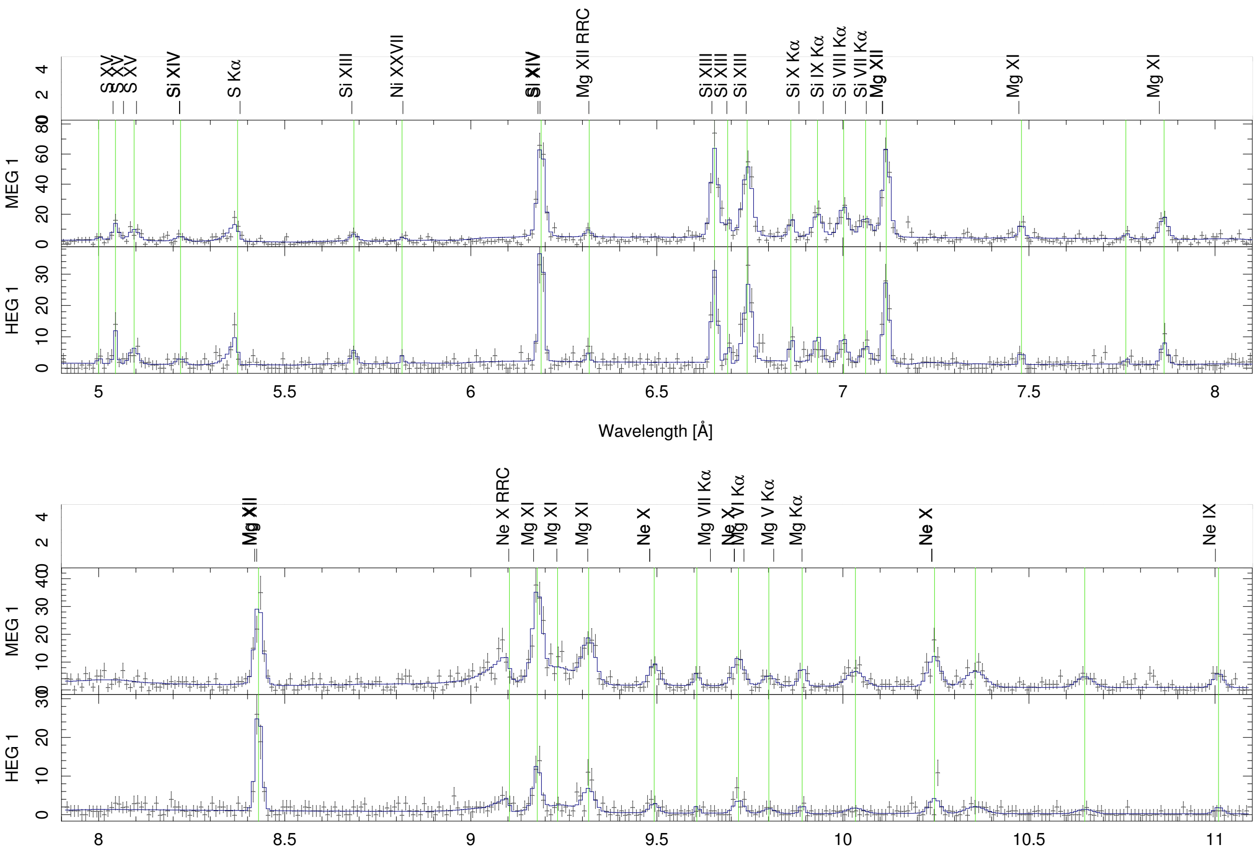
There are $4 + 2$ observations of Vela X-1 from 2000 & 2001 and 2000 & 2006.

The latest *XMM*-observation has an exposure time of almost 125 ks.

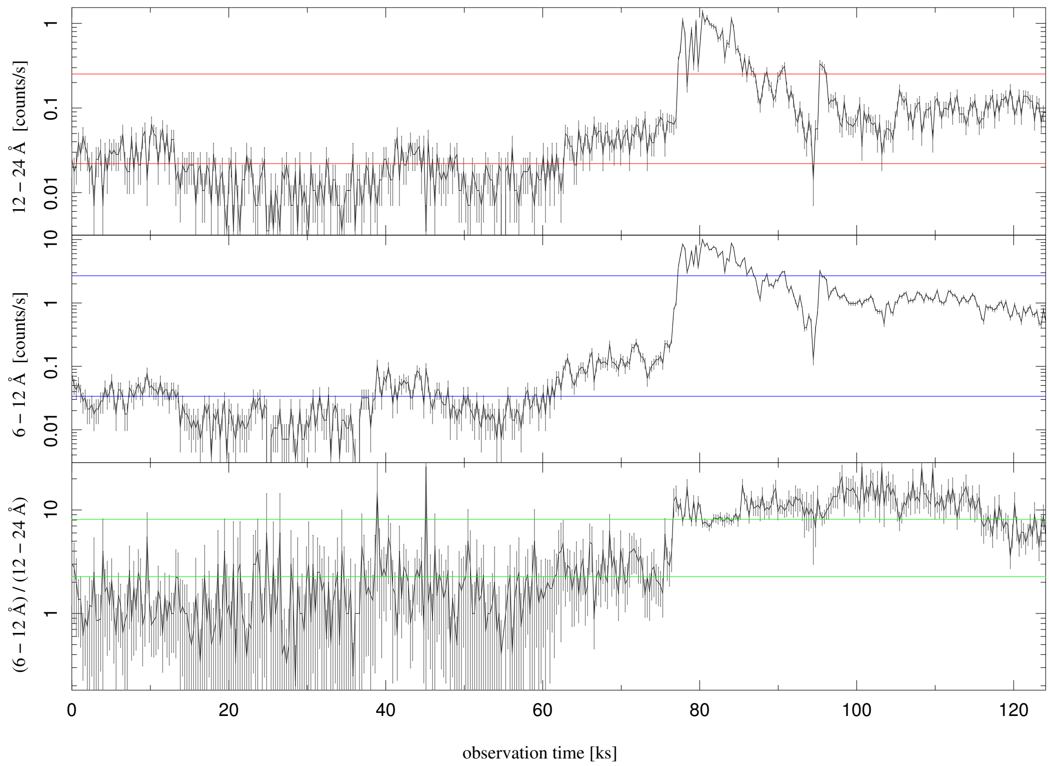
First results: Modelling the spectrum of *Chandra*-obs. # 102



First results: Modelling the spectrum of *Chandra*-obs. # 1926

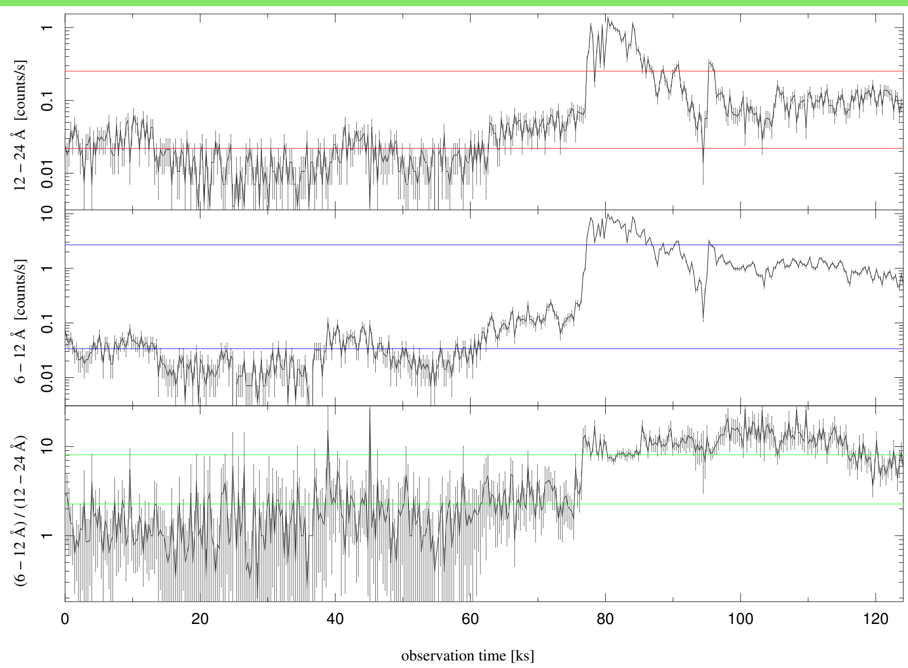


XMM-observation # 0406430201 of Vela X-1



These light curves show the count rate of RGS 2 in different energy bands and the corresponding 'hardness' ratio as a function of time.

XMM-observation # 0406430201 of Vela X-1



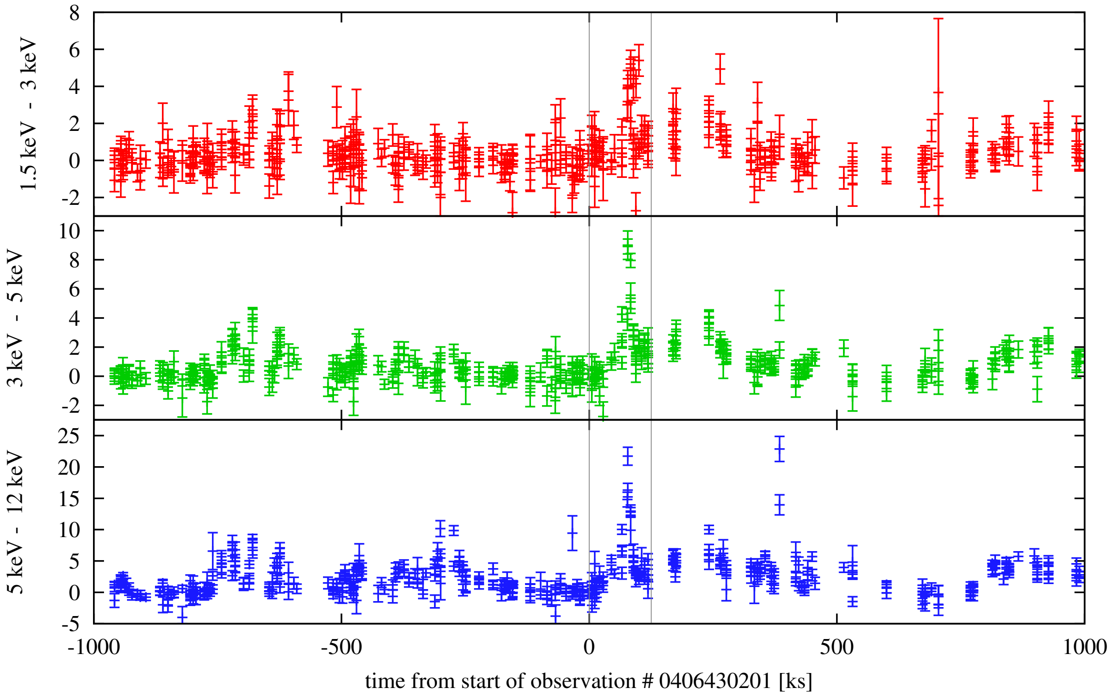
77 ks after the start of this observation, the spectrum changes significantly:

The *low* energy (12–24 Å) count rate increases by $\times 10$,
and the *high* energy (6–12 Å) count rate even by $\times 100$.

What is the nature of this flare-like event?

ASM light curves during the *XMM*-observation # 0406430201

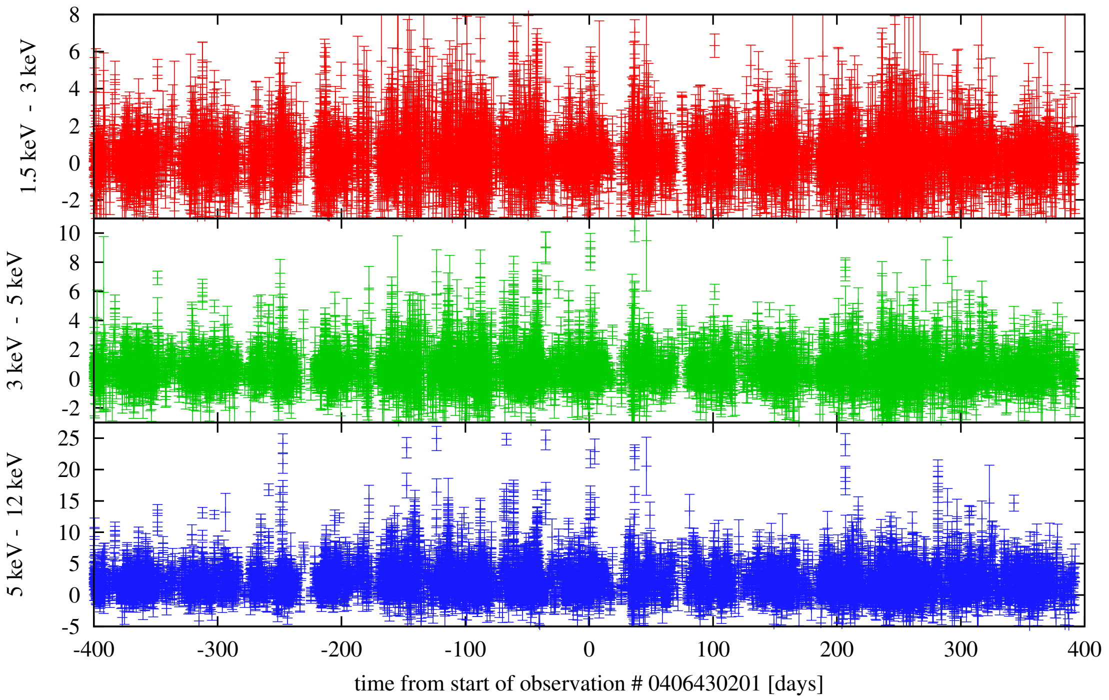
The All Sky Monitor onboard *RXTE* confirms this flaring behaviour:



(The orbital period is 774 ks, i.e., this shows one period before and one period after the observation.)

ASM light curves before and after this *XMM*-observation

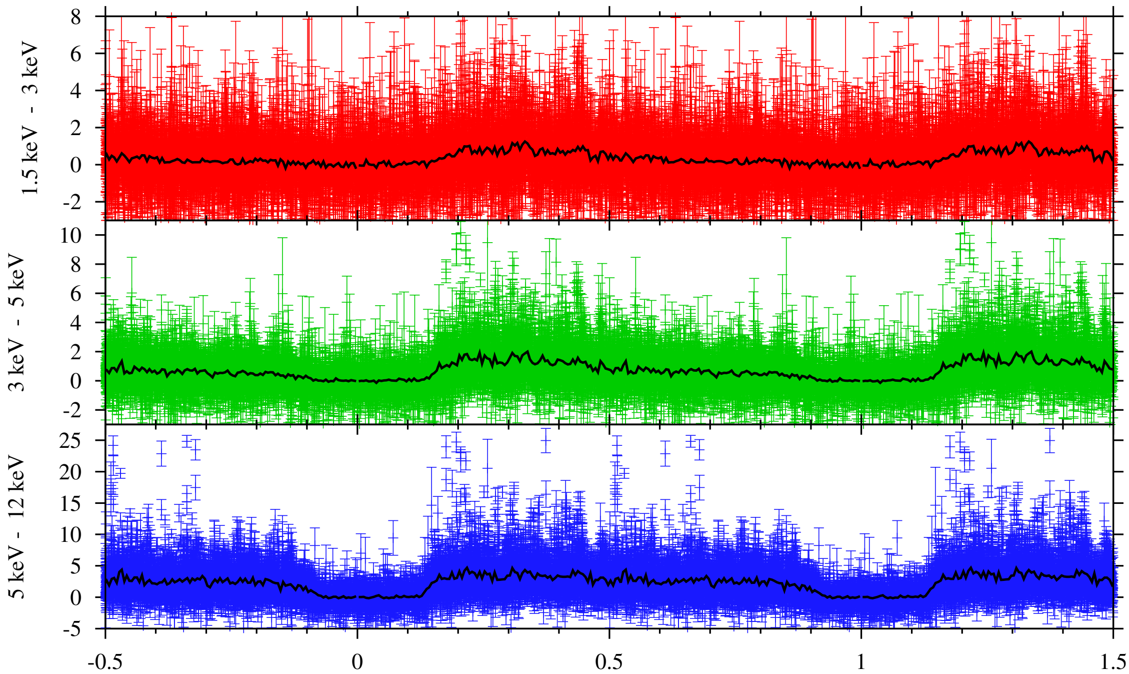
Such flares are, however, not uncommon, as a longer view shows:



(The orbital period is 8.96 days.)

ASM light curves before and after this *XMM*-observation

In the last 2 years, such flares were only seen in orbital phases 0.15…0.70.



(orbital period ≡ 1)

The end

As you may guess:

There is still a lot to find out.

THANK YOU FOR YOUR ATTENTION!

References

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