ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

Friedrich-Alexander-Universität Erlangen-Nürnberg

Highly structured Wind in Vela X-1 : Giant Flares and Offstates

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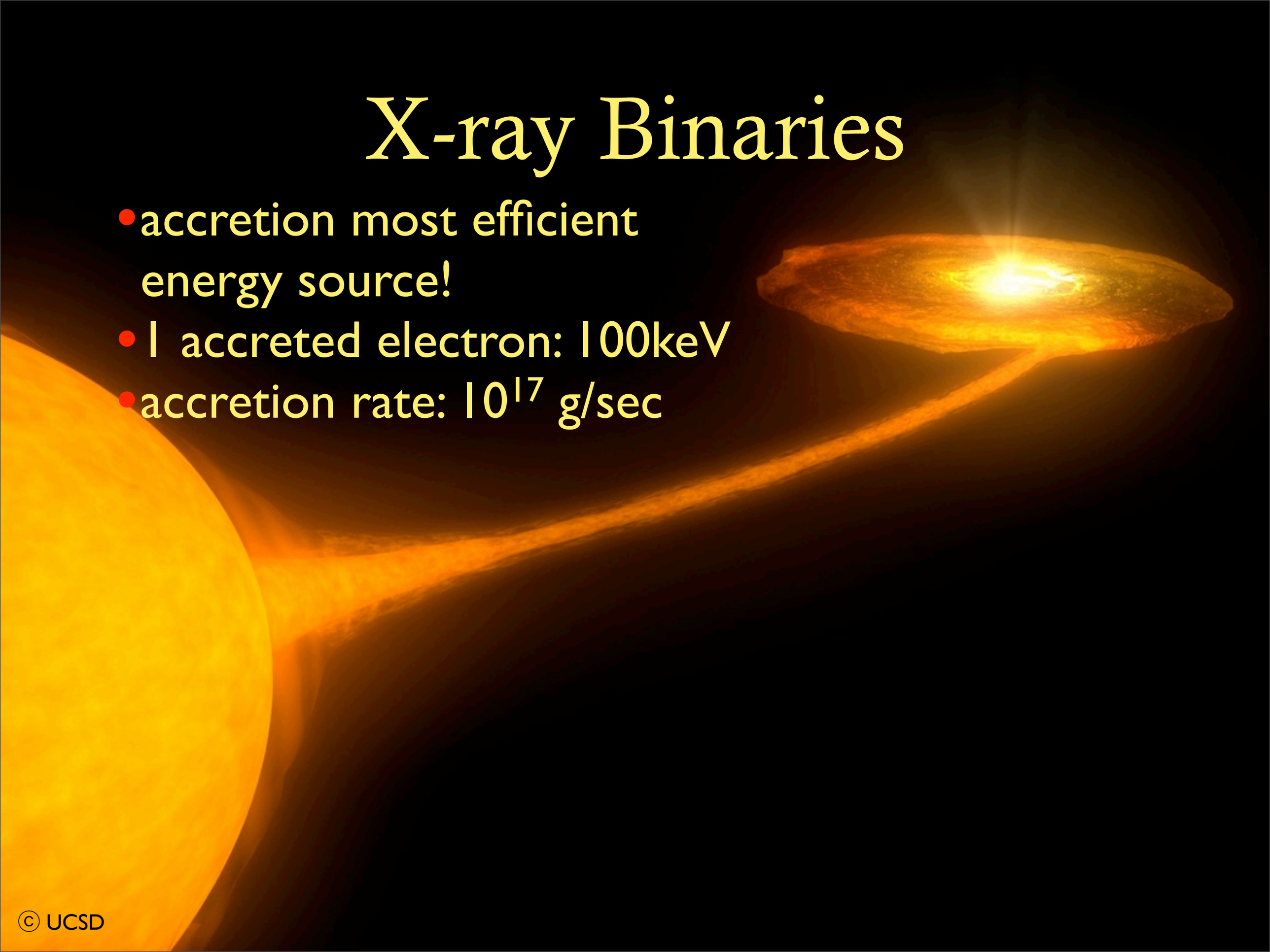
ESAC Science Seminar, November 20, 2008

X-ray Binaries

- accretion most efficient energy source!
- 1 accreted electron: 100keV
- accretion rate: 10^{17} g/sec



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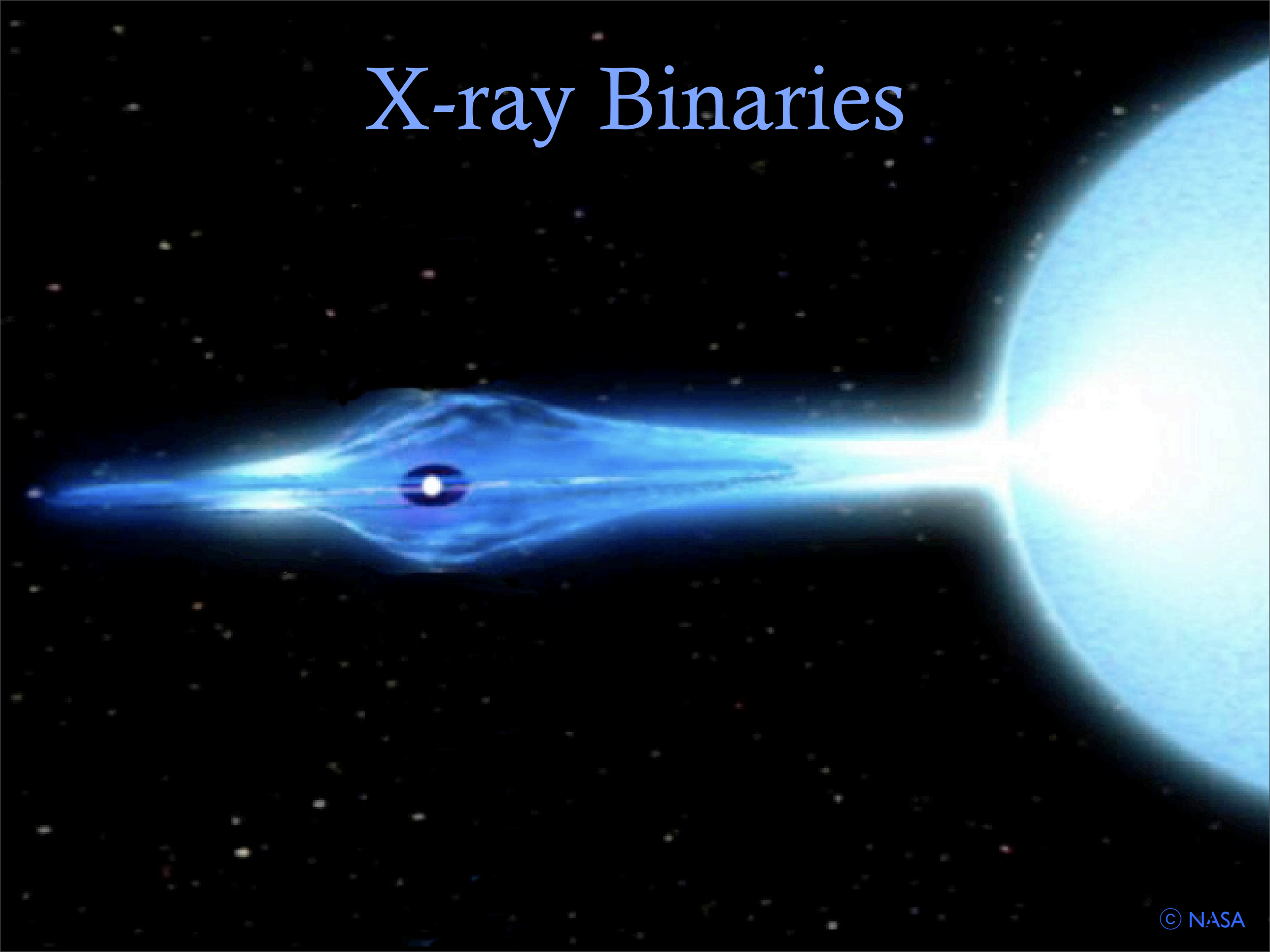
      - ➡ Roche Lobe Overflow
      - accretion disk
      - old system
      - weak magnetic field
      - no pulsations

X-ray Binaries



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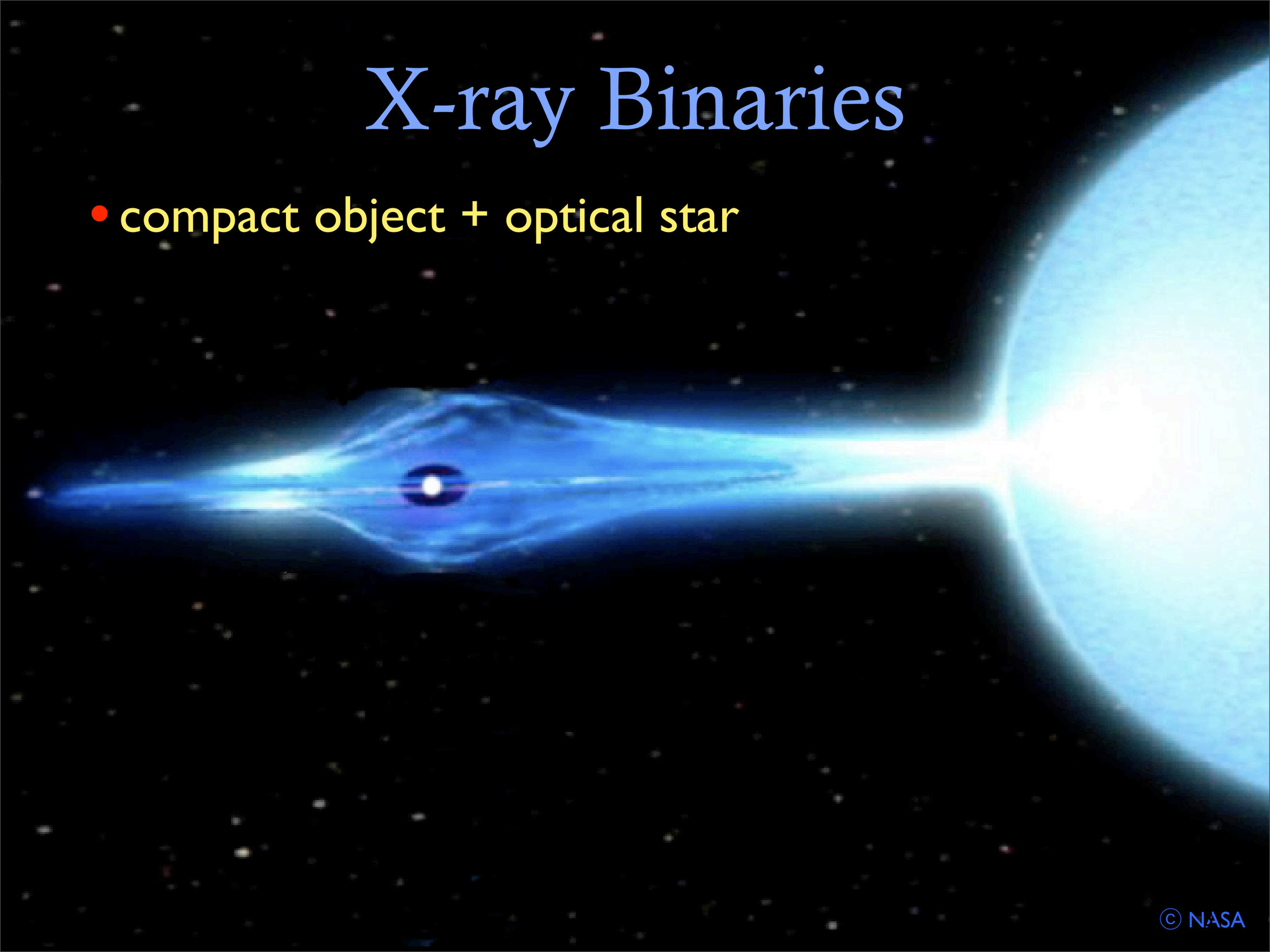

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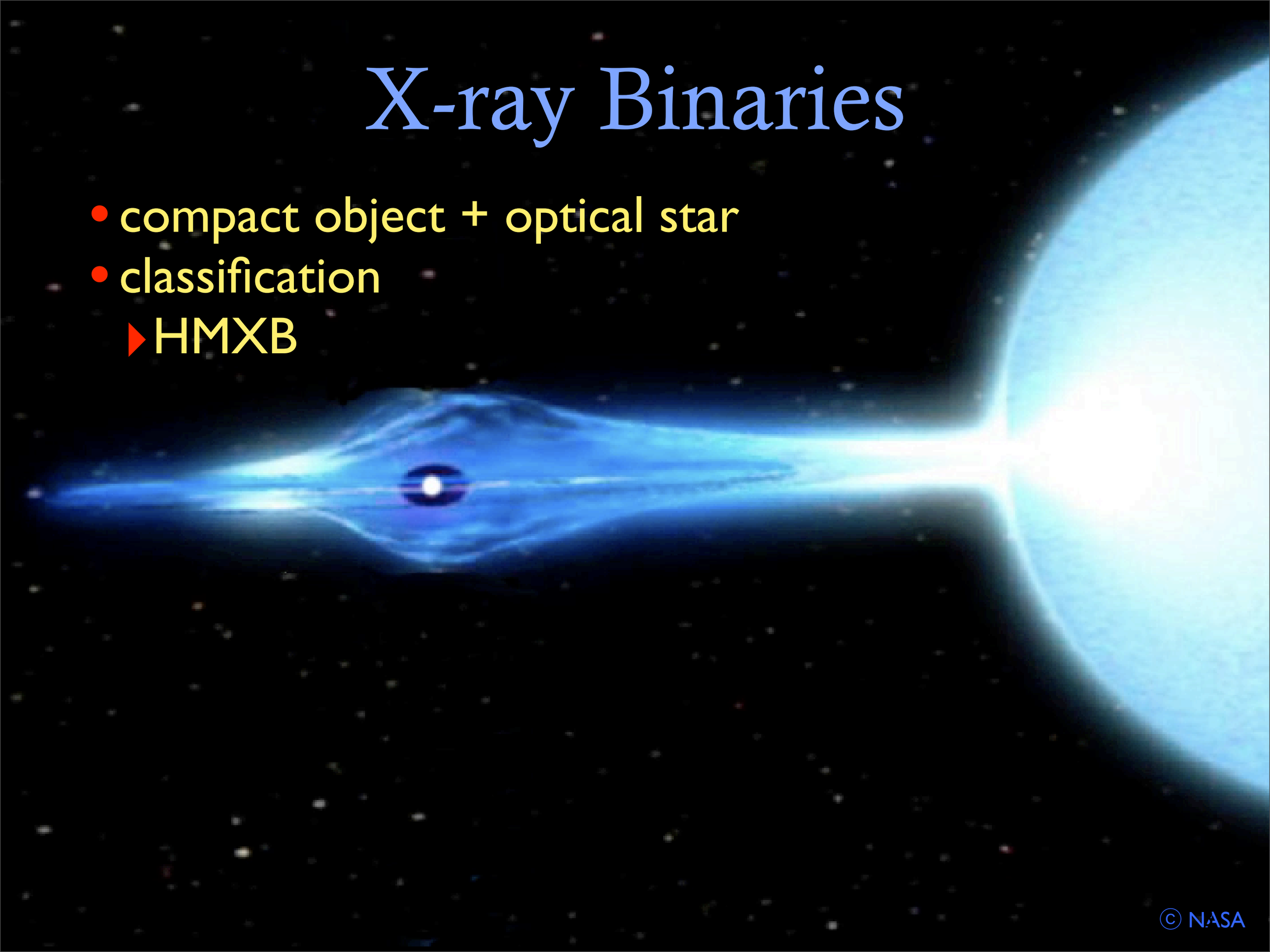

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- compact object + optical star
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➡ Wind accretion
➡ Be mechanism

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- young systems
- strong magnetic field
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X-ray Pulsars

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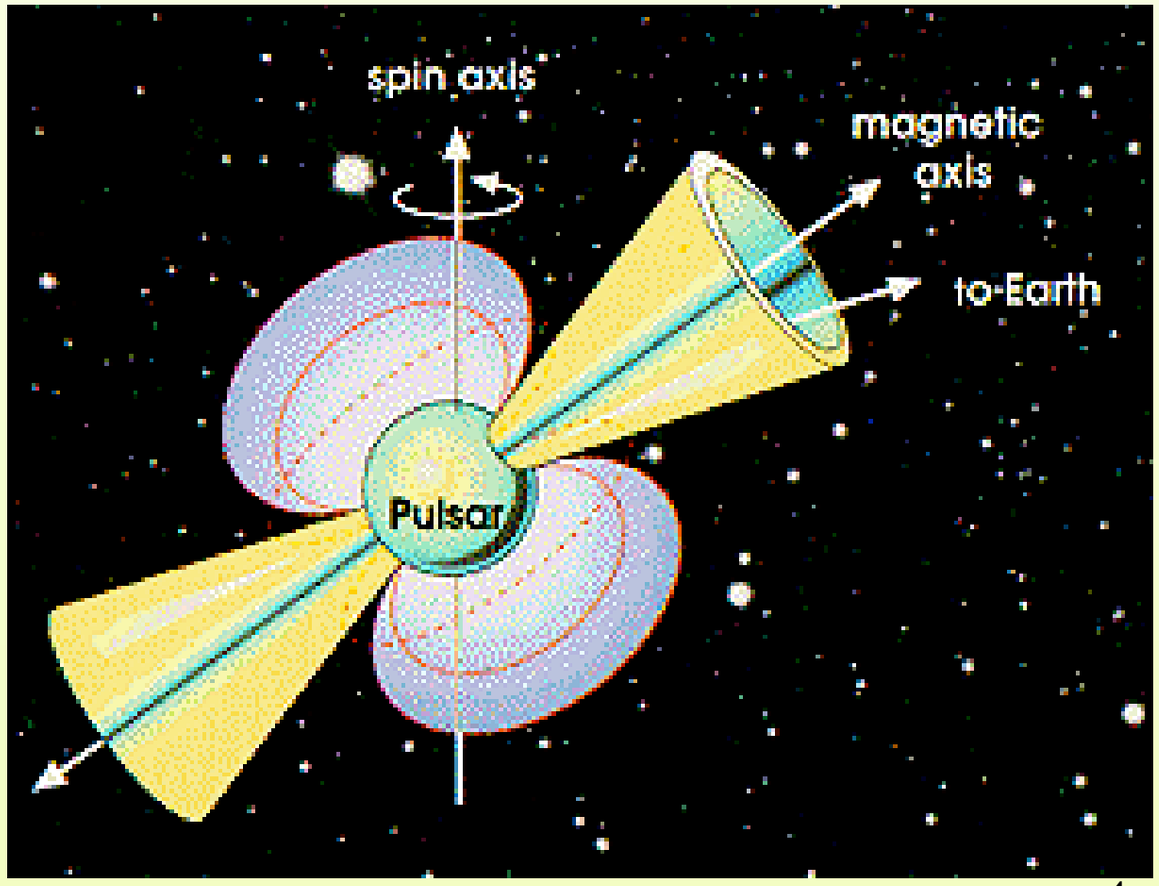
- material couples to magnetic field lines
- material is channeled onto the magnetic poles
  $\Rightarrow$ hotspots emerge

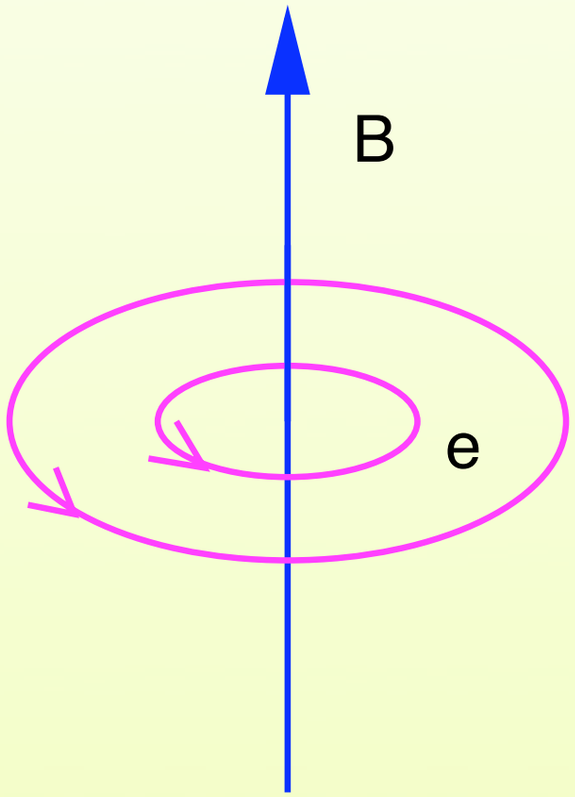
X-ray Pulsars

- Neutron stars have strong magnetic field: $B \sim 10^{12}$ G (flux conservation in SN collaps)
- material couples to magnetic field lines
- material is channeled onto the magnetic poles ⇒ hotspots emerge
- offset of magnetic and rotational axis ⇒ pulsations



Cyclotron Lines

strong magnetic field: electron energies are quantized in Landau levels:



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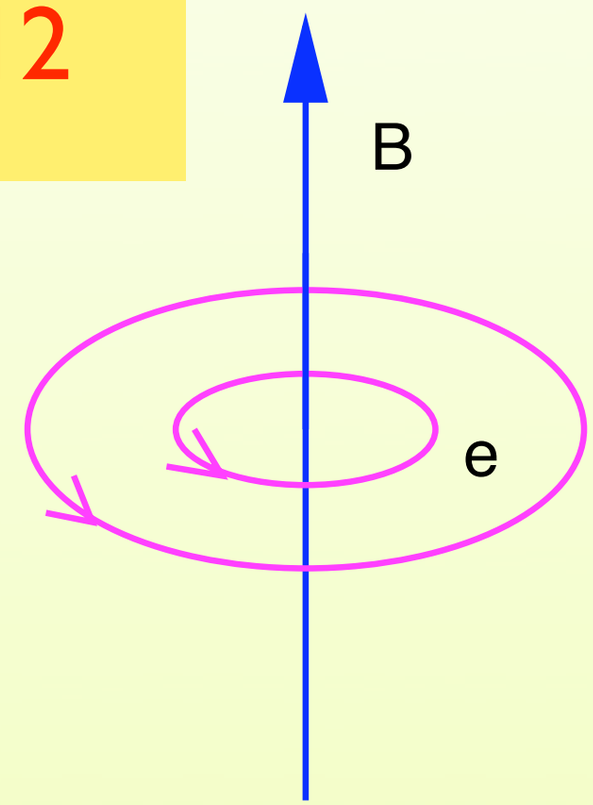
$$E_{\rm cyc} = \frac{\hbar e}{m_e c^2} = 11.6\,{\rm keV}\left(\frac{B}{10^{12}{\rm G}}\right)$$

12-B-12



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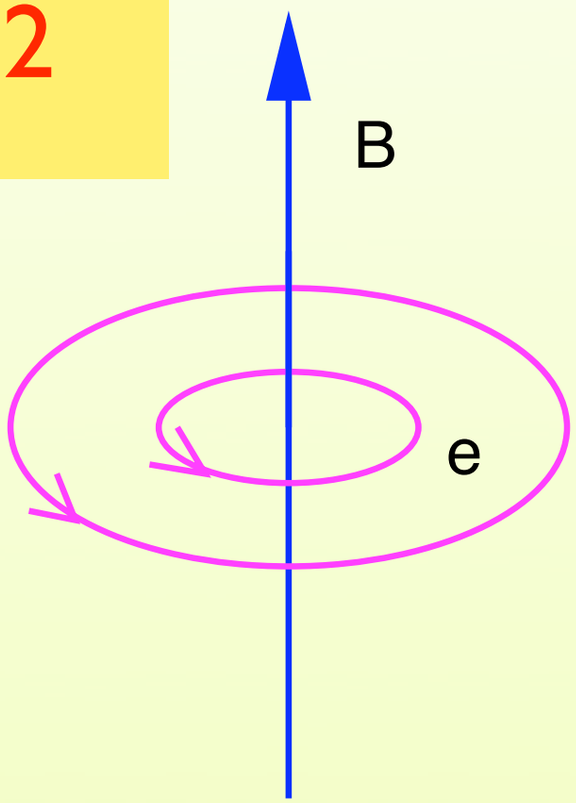

Cyclotron resonance scattering features (CRSFs)

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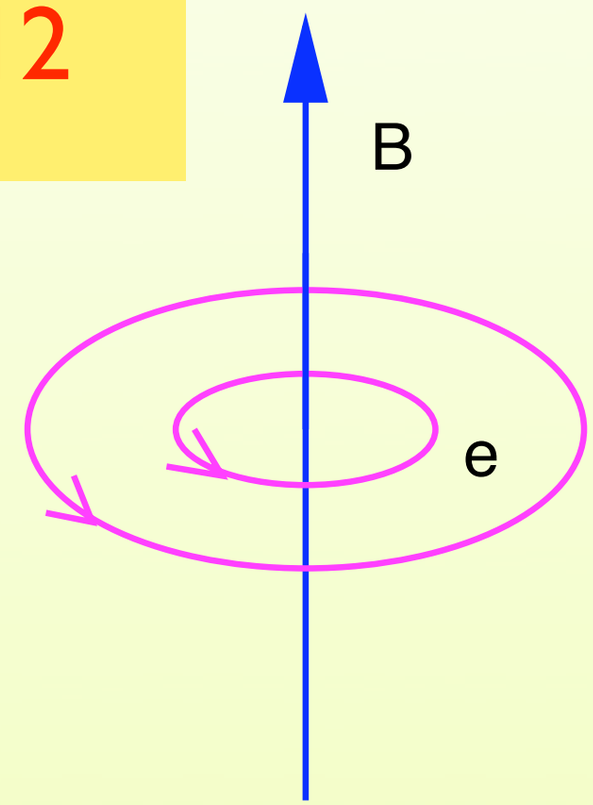

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$$E_n = nE_{\rm cyc} = (1+z)E_{\rm n,obs}$$

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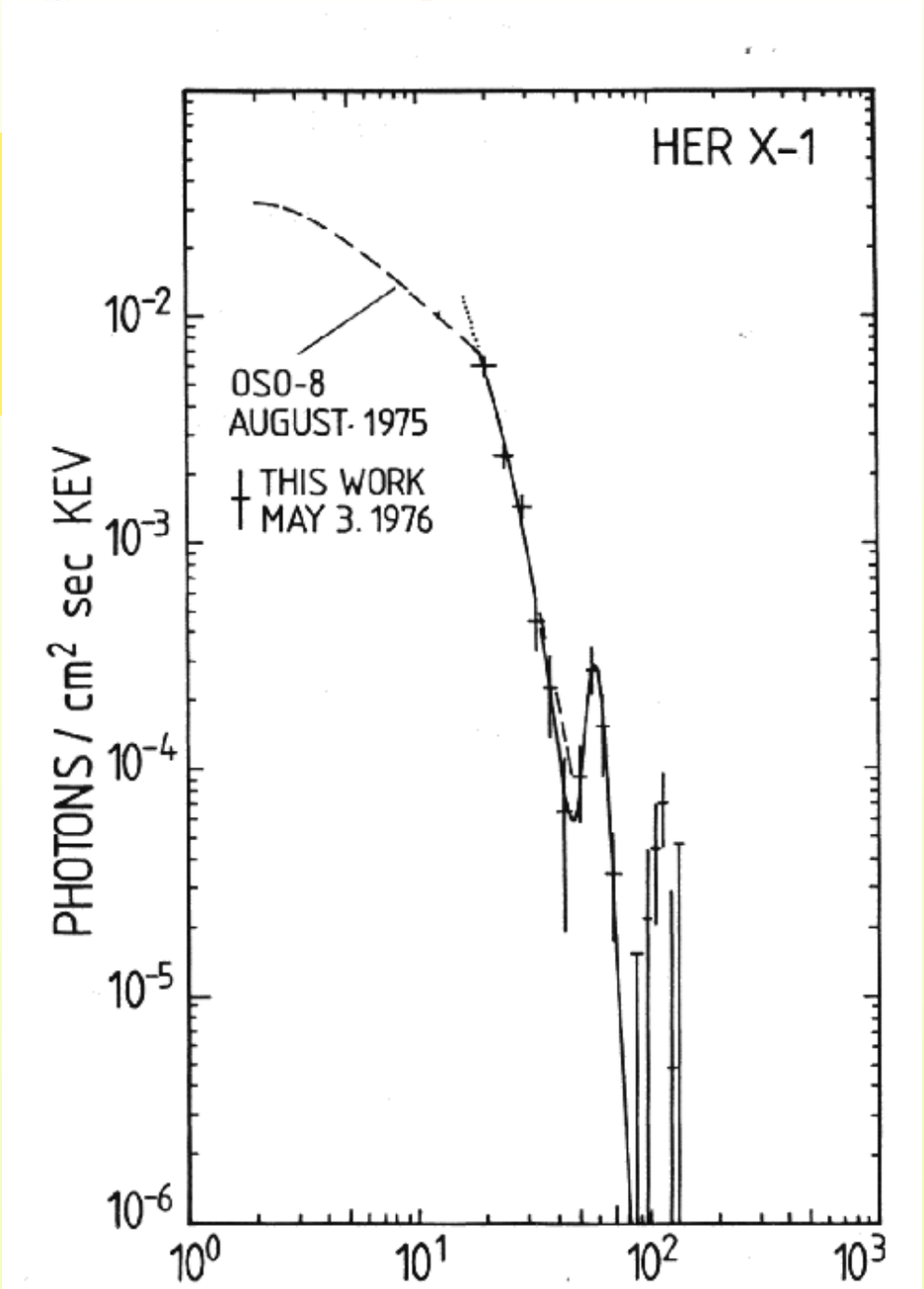

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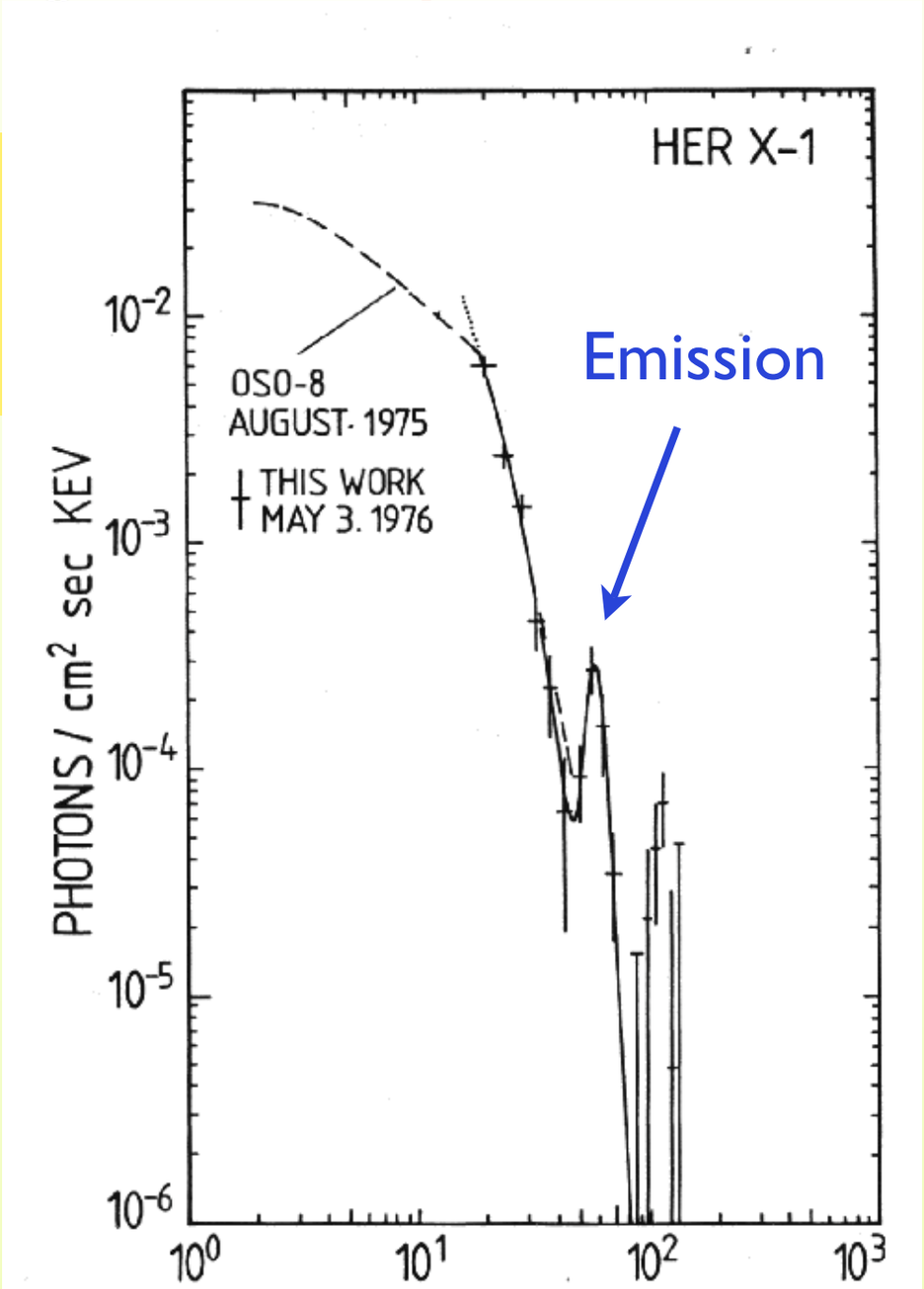

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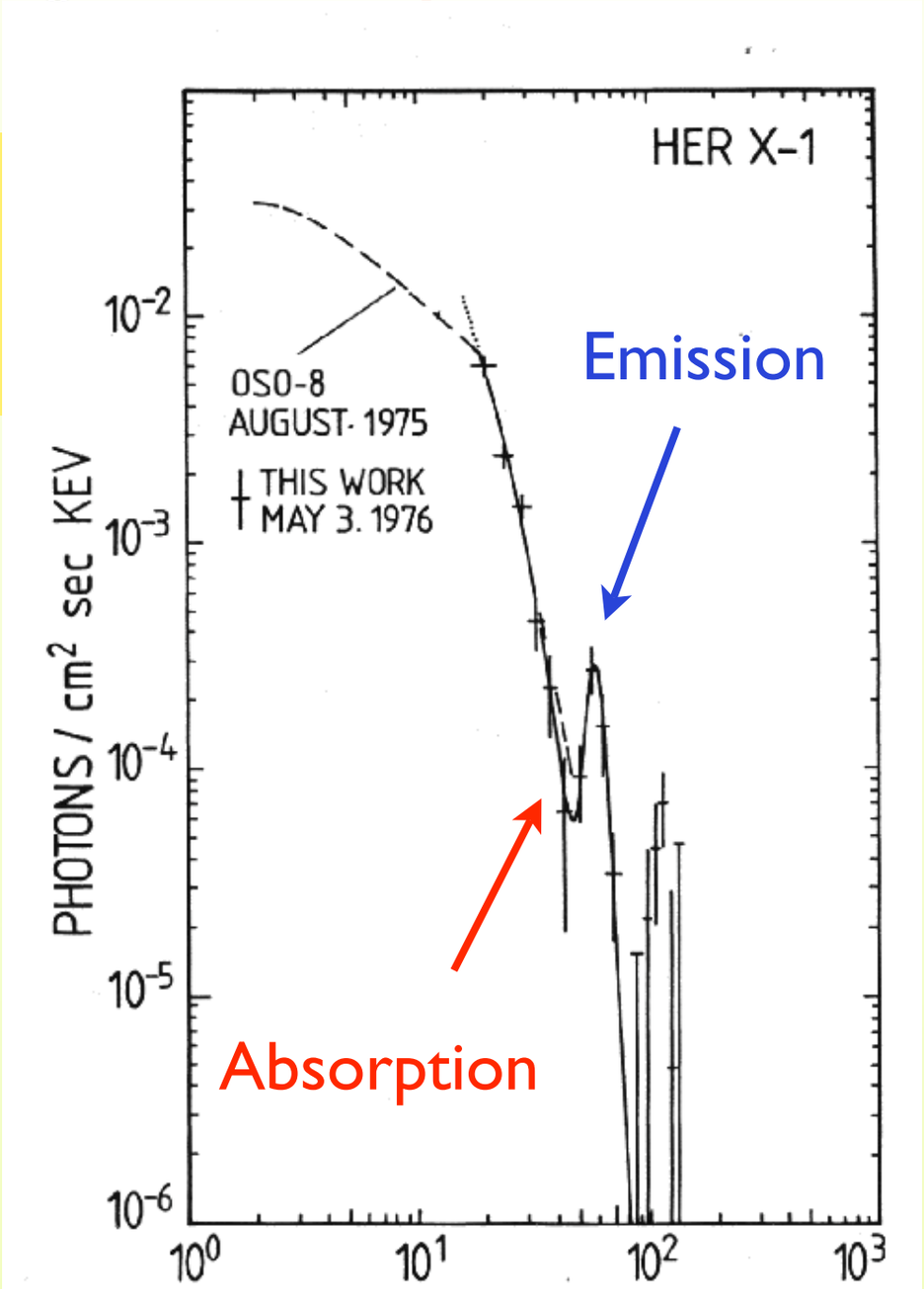
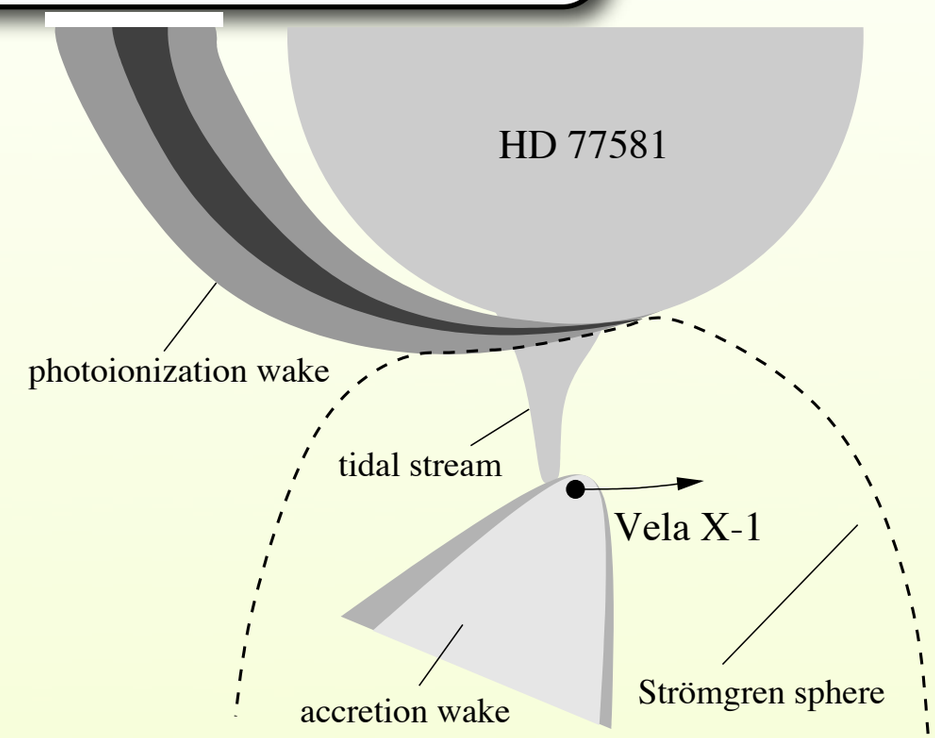
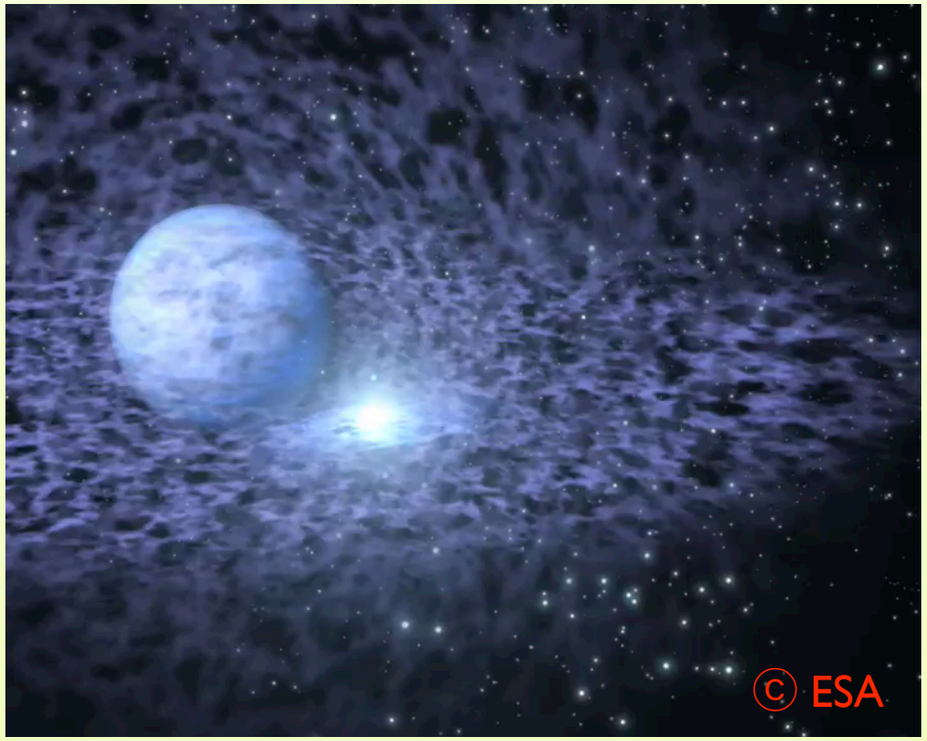
E_{cyc} = 40 keV



Vela X-1

- NS + B0.5Ib GP Vel super giant companion
- dense Wind: $\dot{M} = 4 \times 10^{-6}\, M_\odot$
- orbital Period 8.96 d
- heaviest known neutron star: 1.8 $M_\odot$





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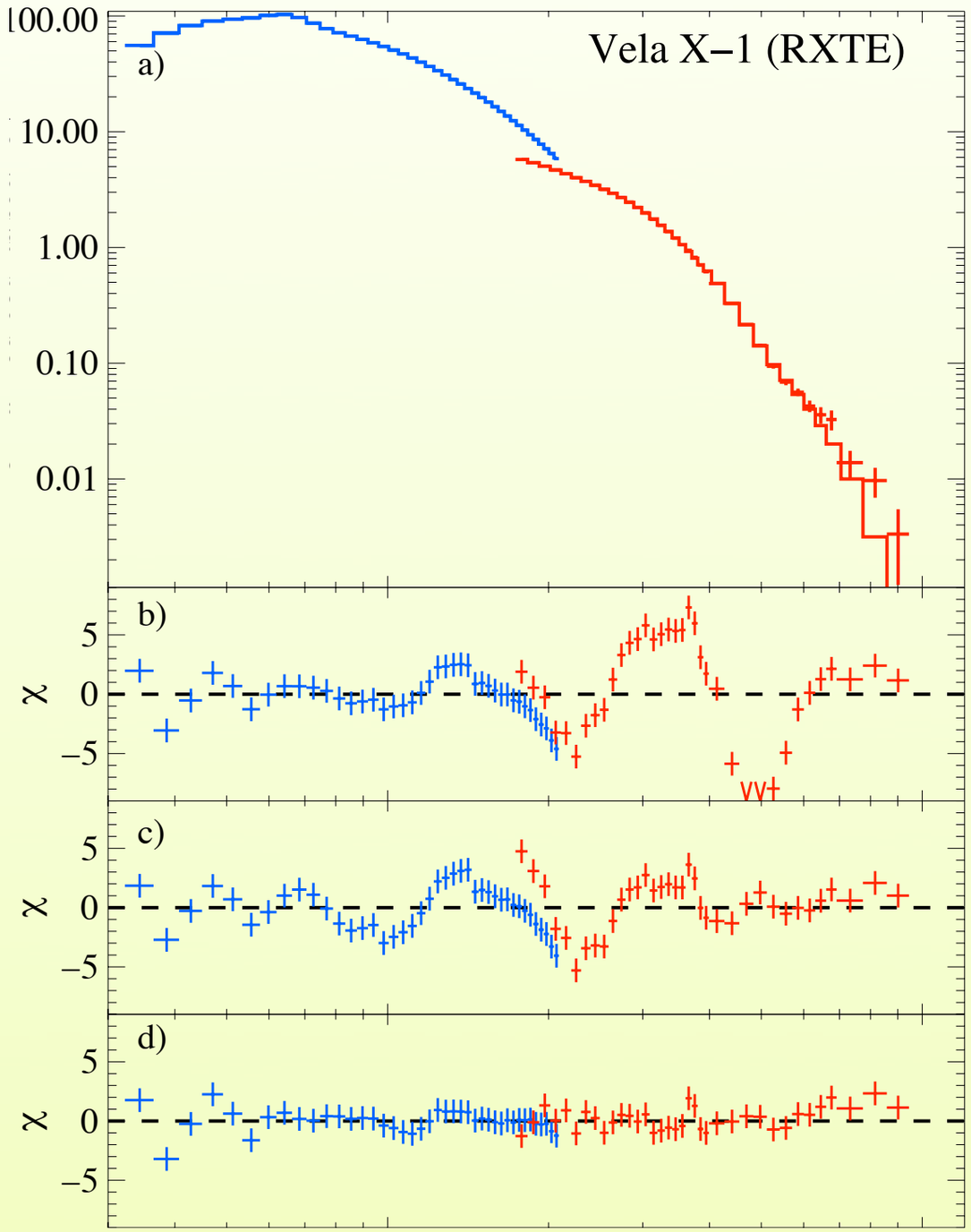
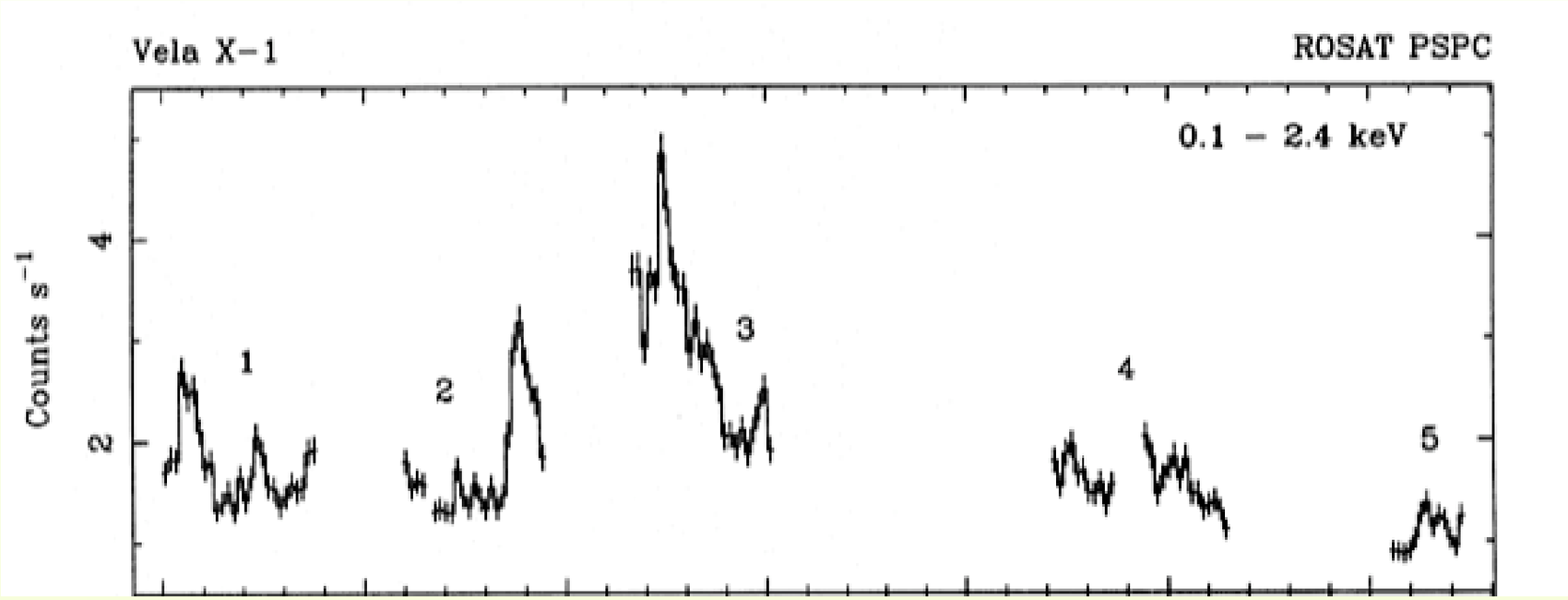
- dense Wind: $\dot{M} = 4 \times 10^{-6}\, M_\odot$
- orbital Period 8.96 d
- heaviest known neutron star: 1.8 $M_\odot$
- typical XRB spectrum CRSFs at 25 and 50keV



History



Haberl (1994)

- Vela X-1 known to be variable:
  - Flares: ROSAT, Granat, EXOSAT, RXTE

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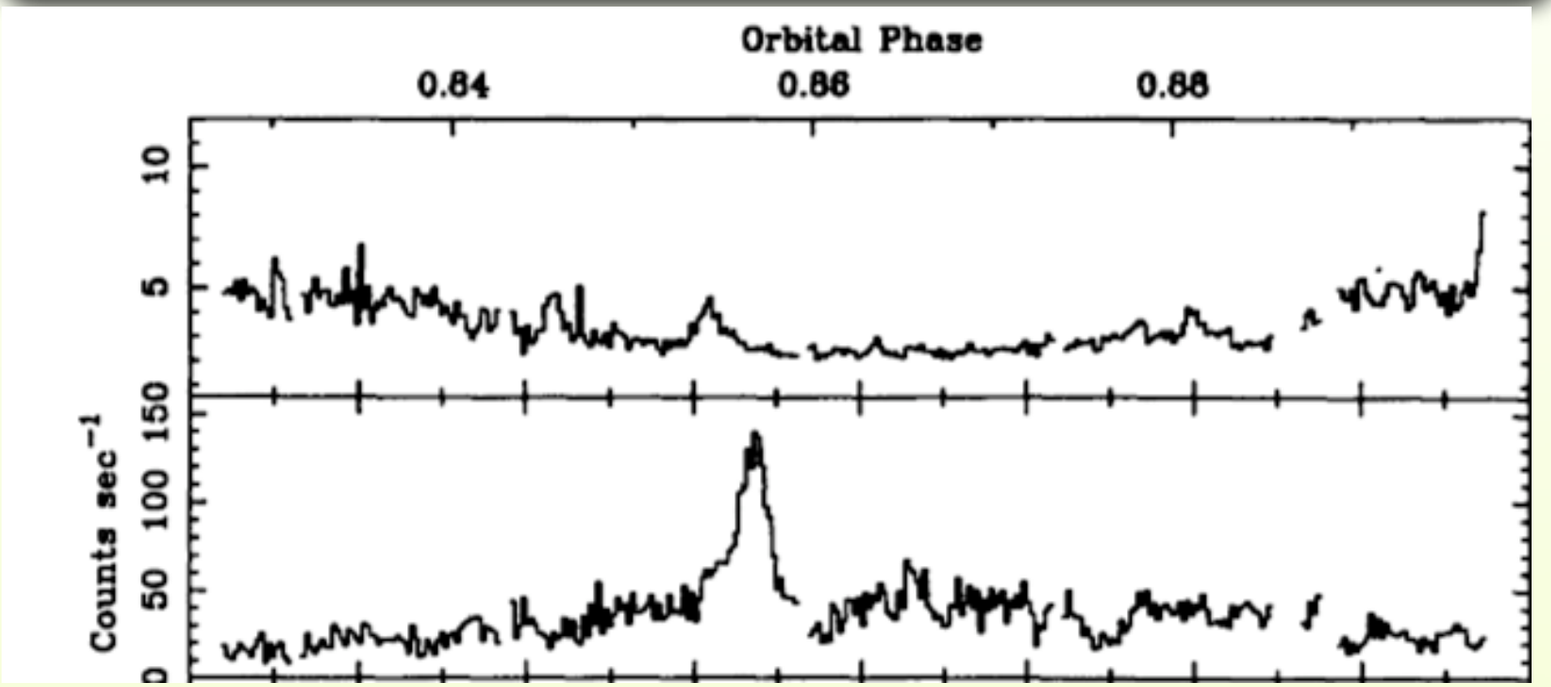

Haberl & White (1990)

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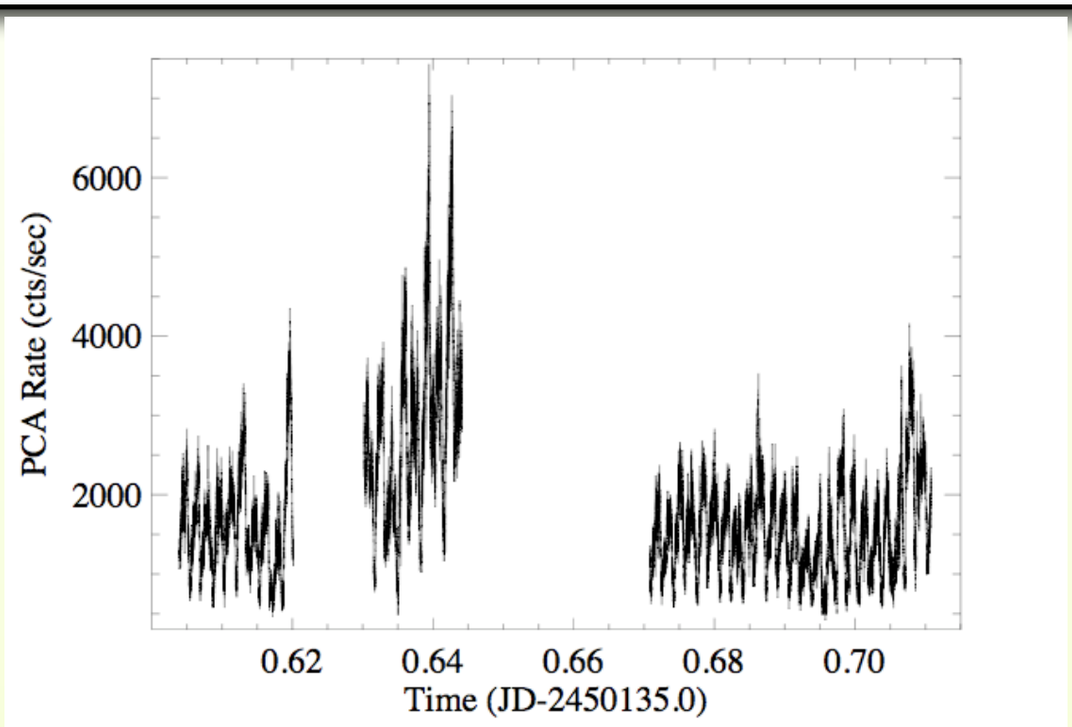

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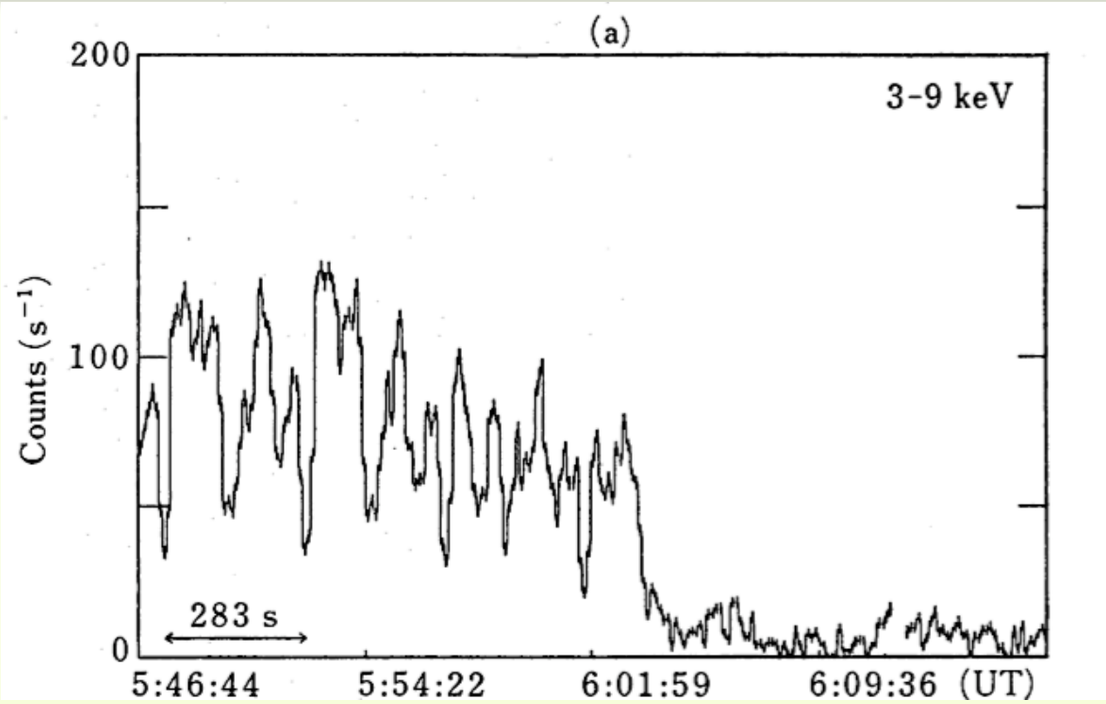
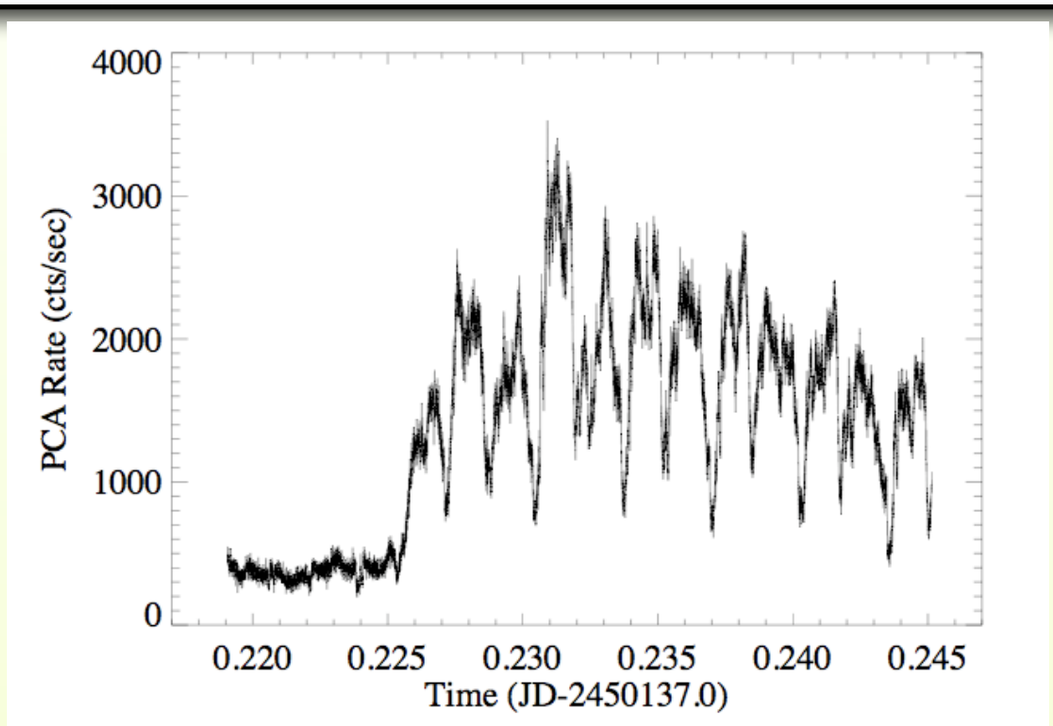


Inoue (1984)

- Vela X-1 known to be variable:
  - Flares: ROSAT, Granat, EXOSAT, RXTE
  - “Dips”: Tenma, Granat, RXTE
- various ideas, cause unkown

History



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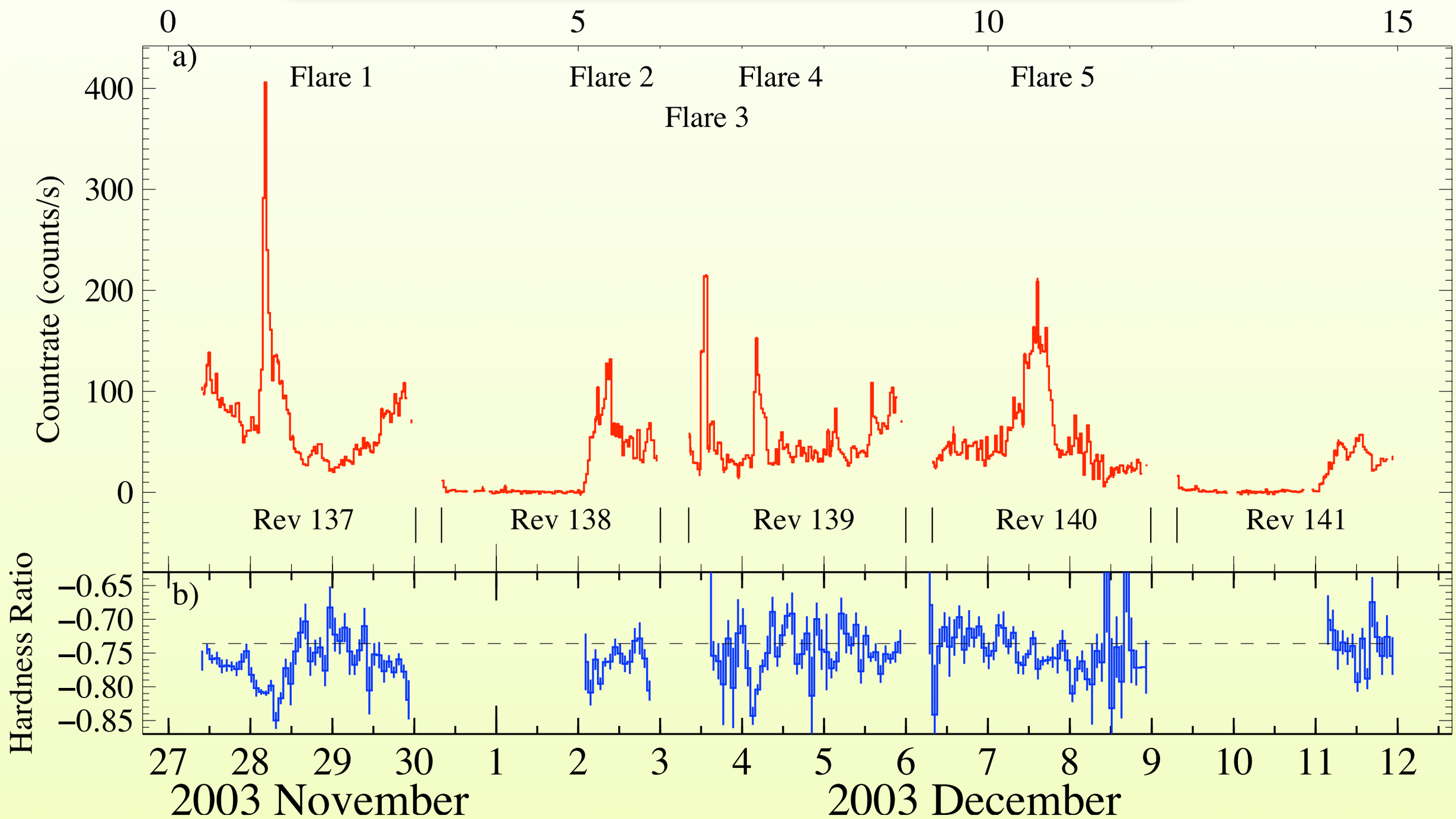
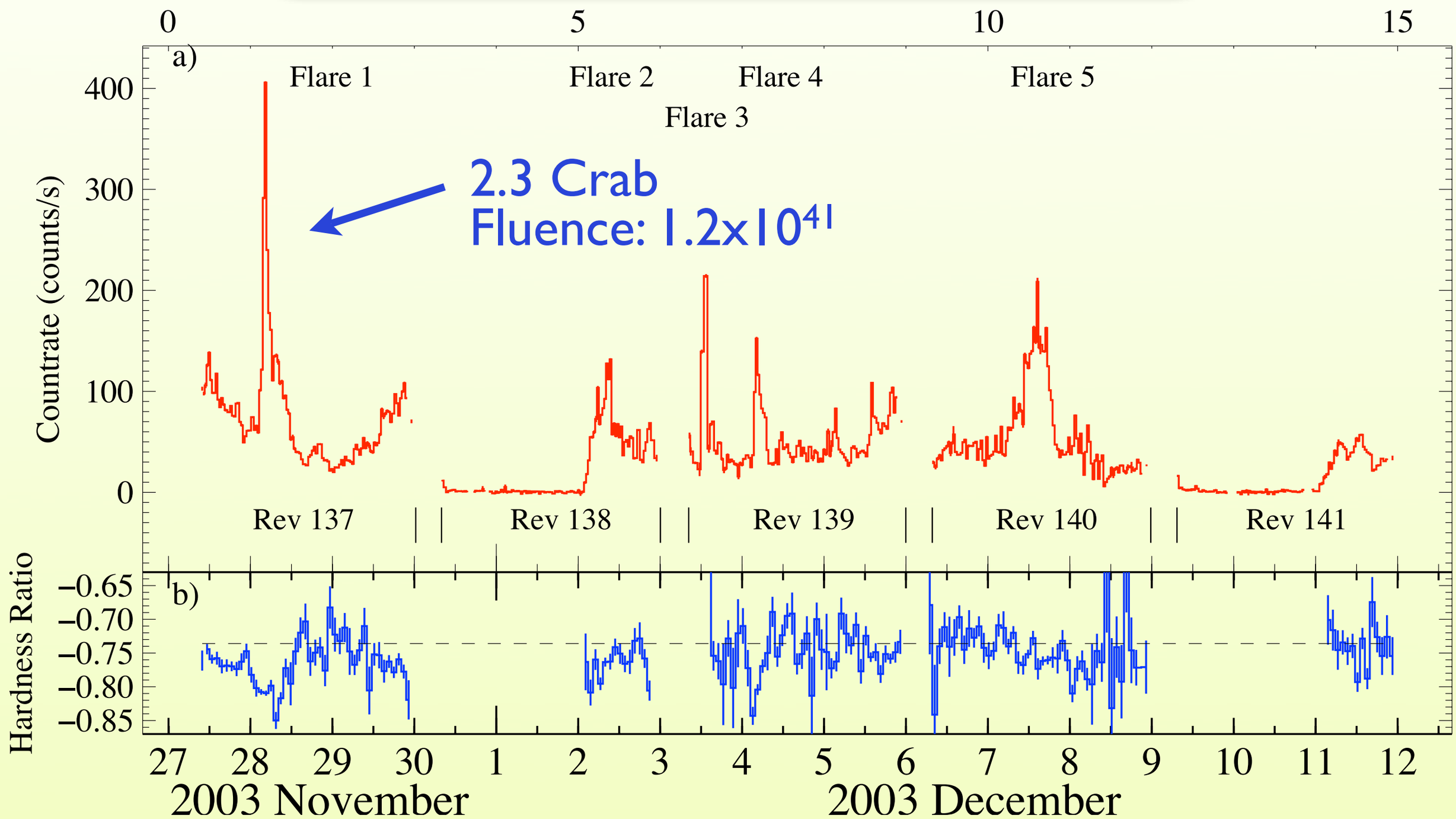
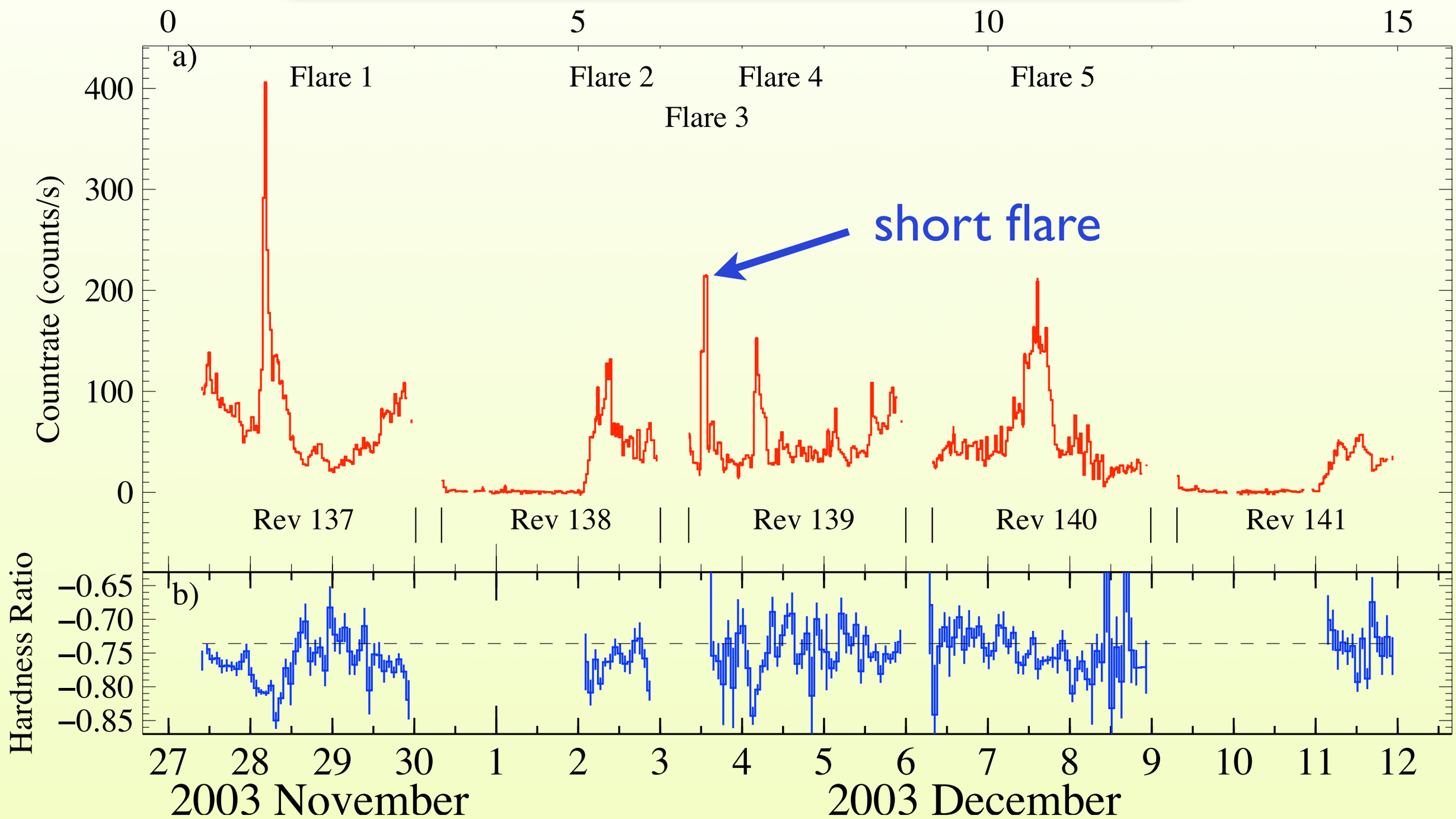
INTEGRAL


a)
Flare 1
Flare 2
Flare 3
Flare 4
Flare 5
Countrate (counts/s)
Rev 137
Rev 138
Rev 139
Rev 140
Rev 141
b)
Hardness Ratio
2003 November
2003 December

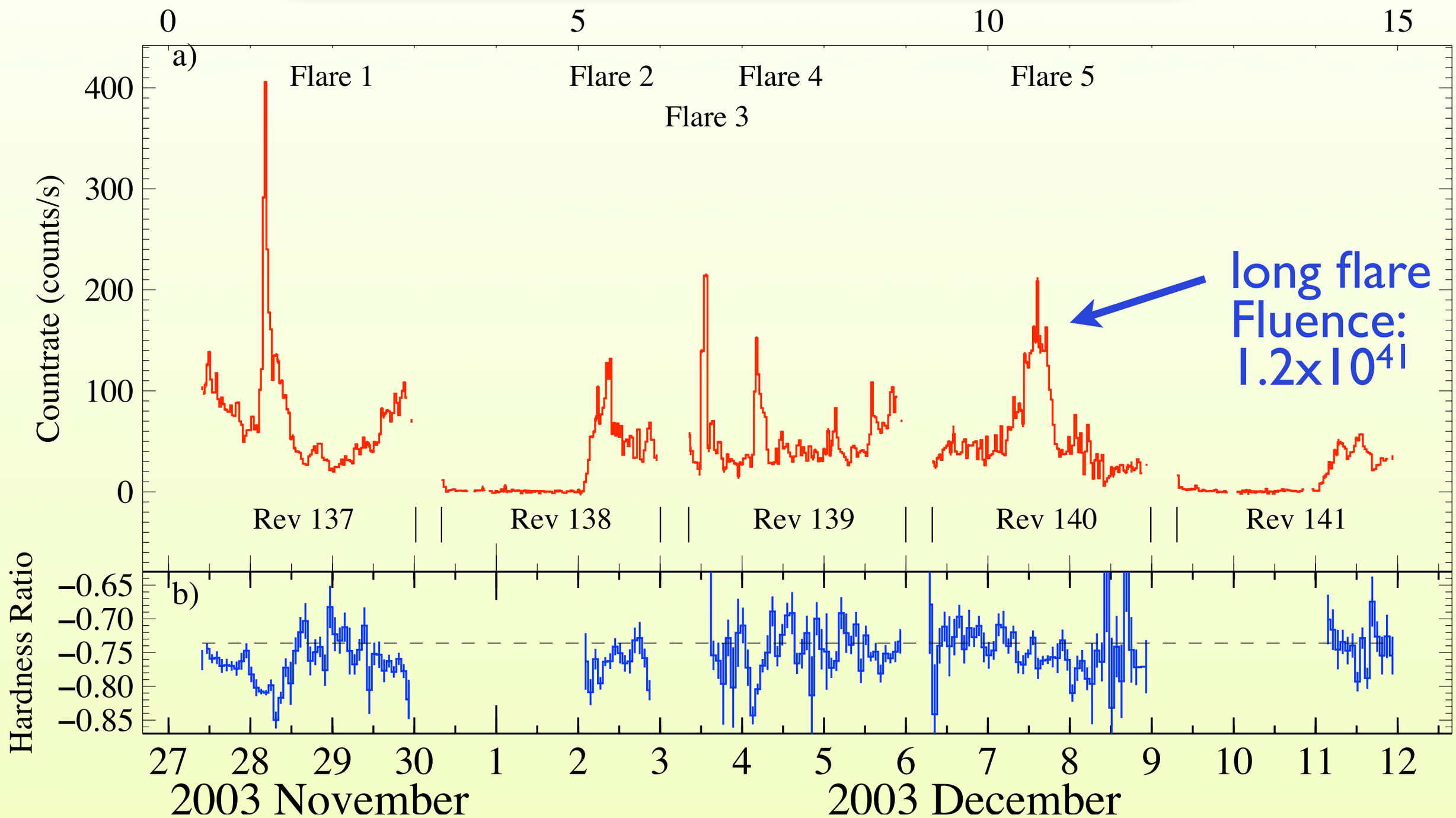
INTEGRAL


a)
Flare 1
Flare 2
Flare 3
Flare 4
Flare 5
2.3 Crab
Fluence: 1.2x10^41
Countrate (counts/s)
Rev 137
Rev 138
Rev 139
Rev 140
Rev 141
b)
Hardness Ratio
2003 November
2003 December

INTEGRAL


a)
Flare 1
Flare 2
Flare 3
Flare 4
Flare 5
short flare
Countrate (counts/s)
Rev 137
Rev 138
Rev 139
Rev 140
Rev 141
b)
Hardness Ratio
2003 November
2003 December

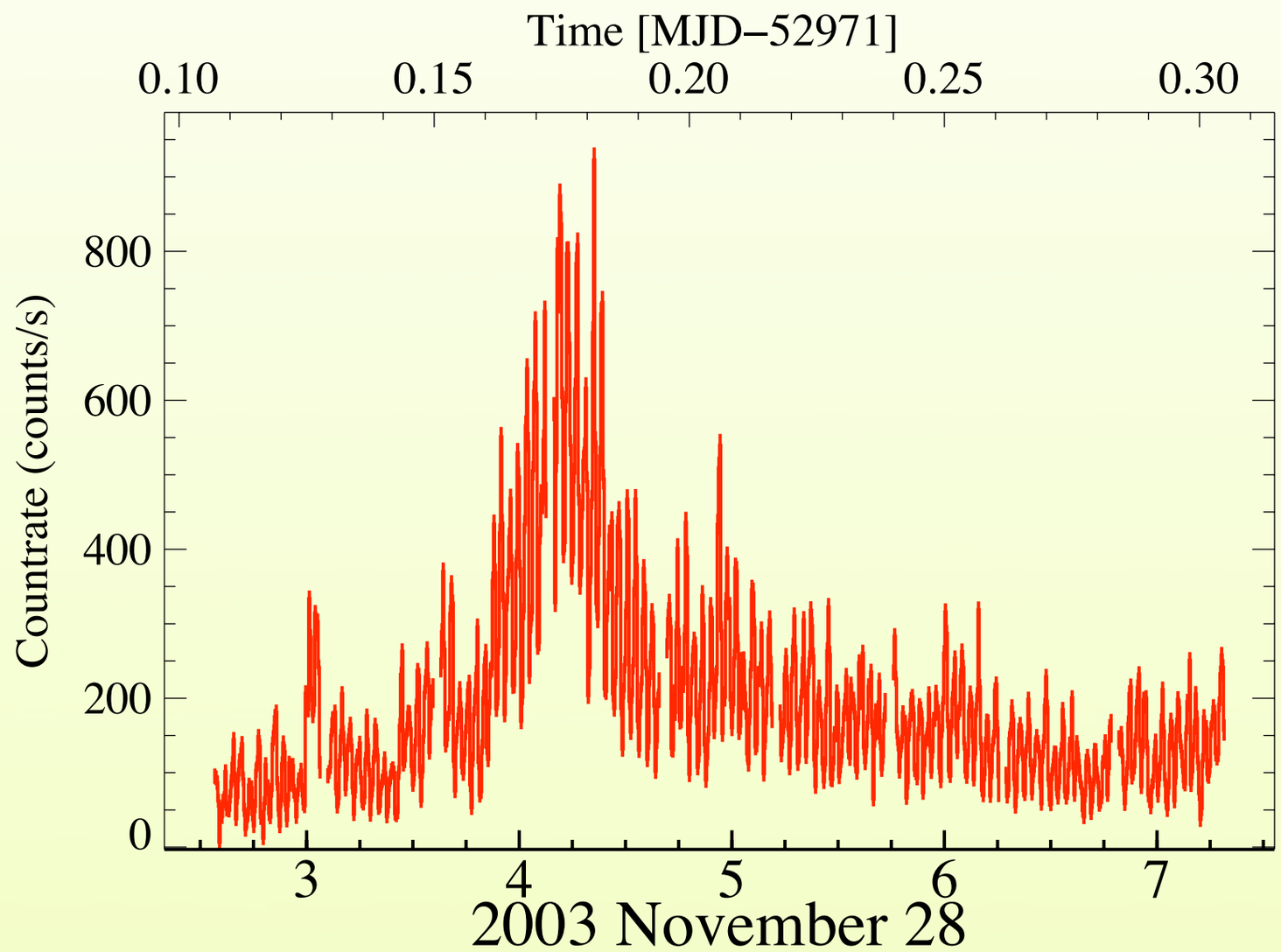
INTEGRAL


a)
Flare 1
Flare 2
Flare 3
Flare 4
Flare 5
Countrate (counts/s)
Rev 137
Rev 138
Rev 139
Rev 140
Rev 141
long flare
Fluence:
1.2x10^41
b)
Hardness Ratio
2003 November
2003 December

Flares

Flare 1:

- Peak: 5.2 Crab
- Duration: 11200 sec
- spectrum "softer"
- fast rise: $\tau = 0.15$



$$\tau = T_{rise} / T_{total}$$

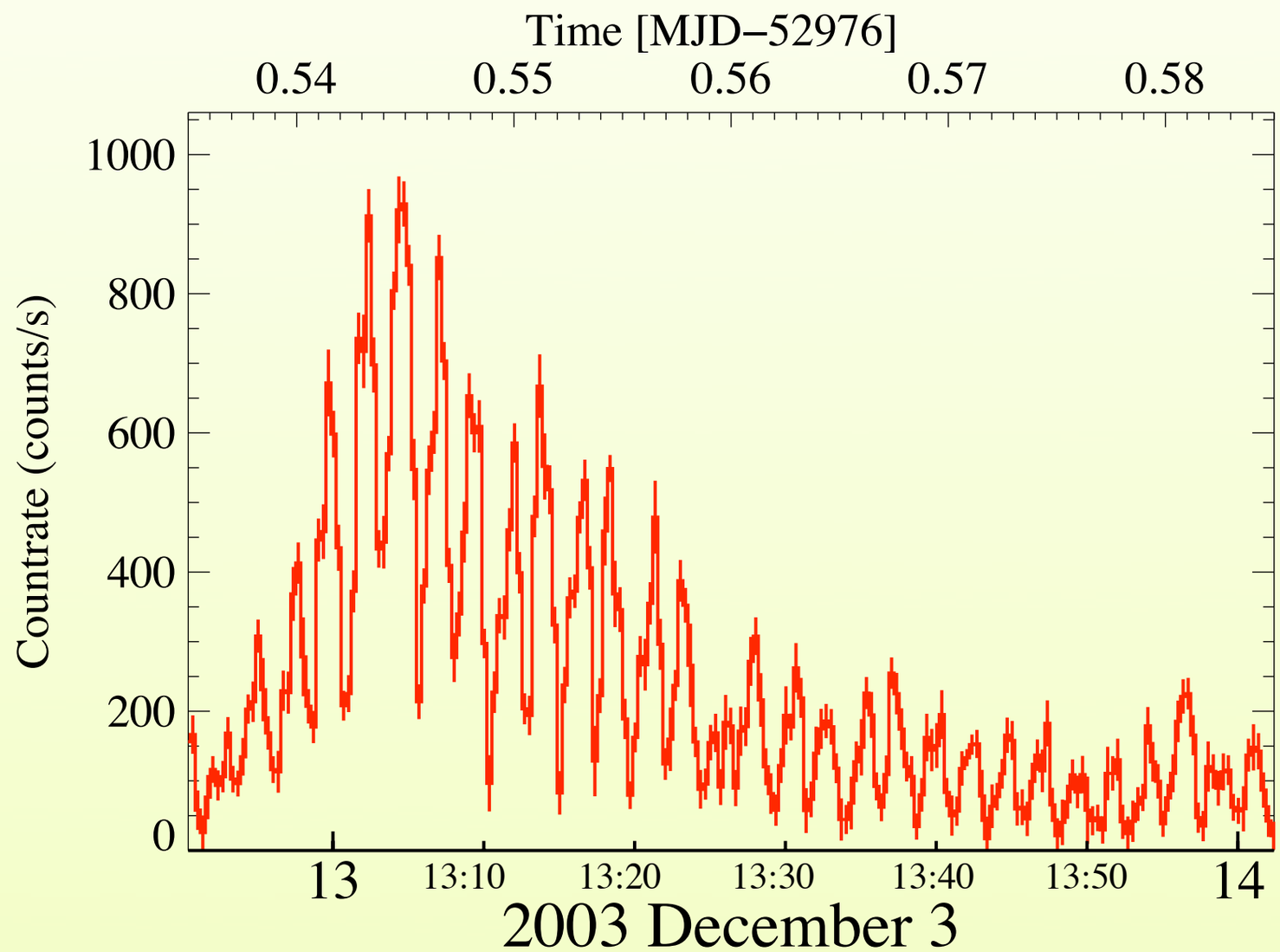
Flares

Flare 1:

- Peak: 5.2 Crab
- Duration: 11200 sec
- spectrum "softer"
- fast rise: $\tau = 0.15$

Flare 3:

- Peak 5.3 Crab
- Duration 1800 sec
- fast rise: $\tau = 0.28$



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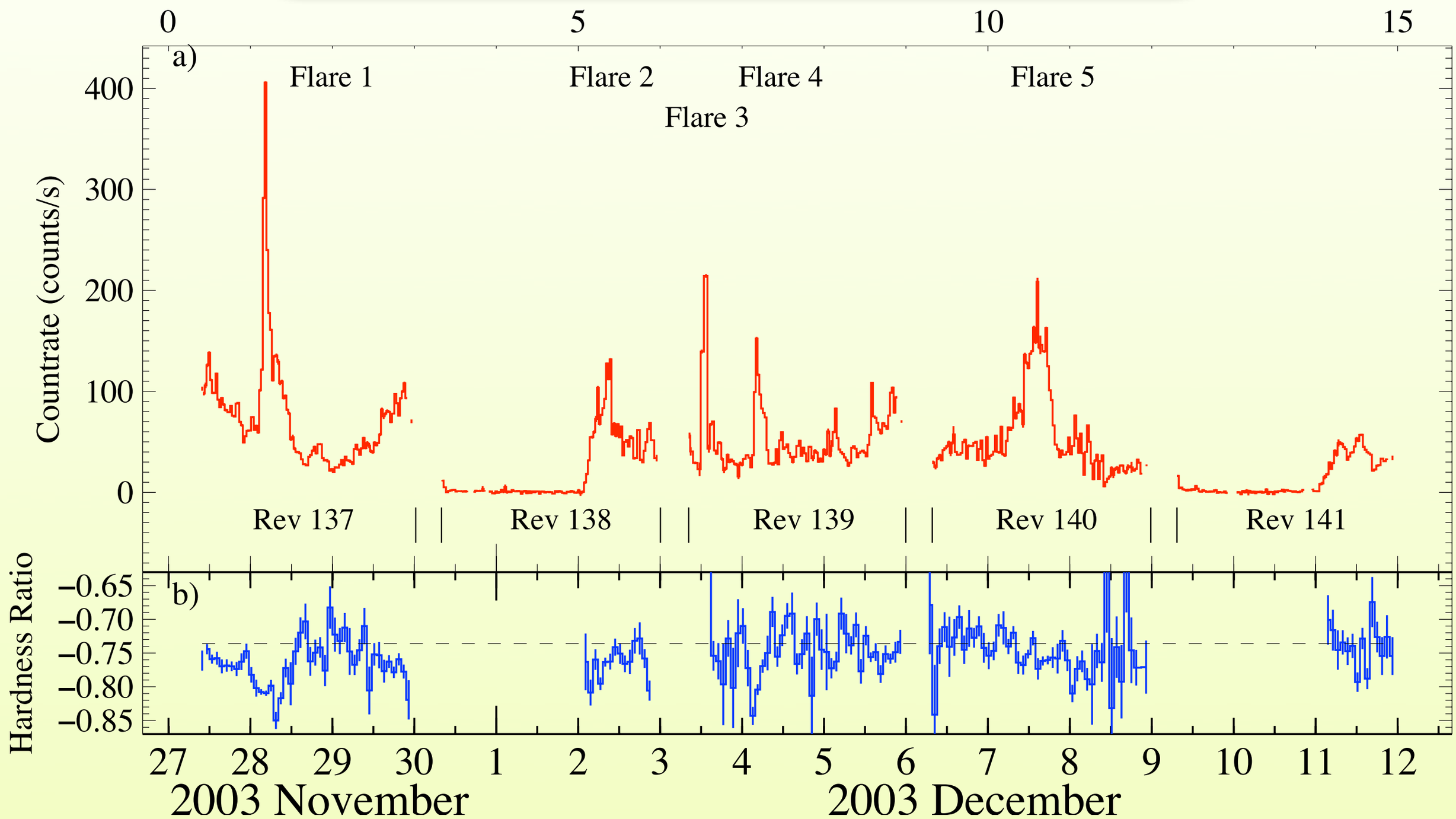
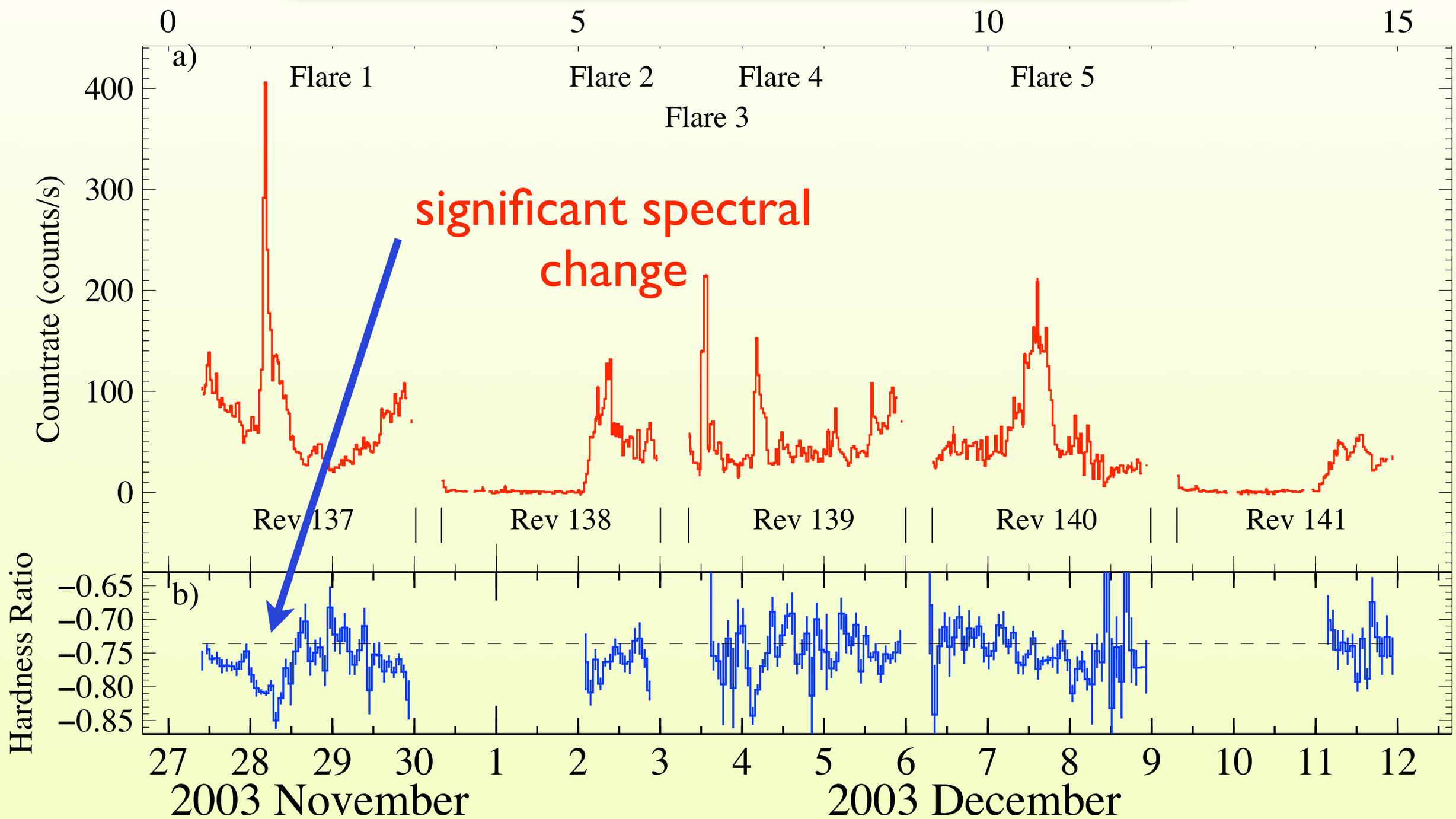
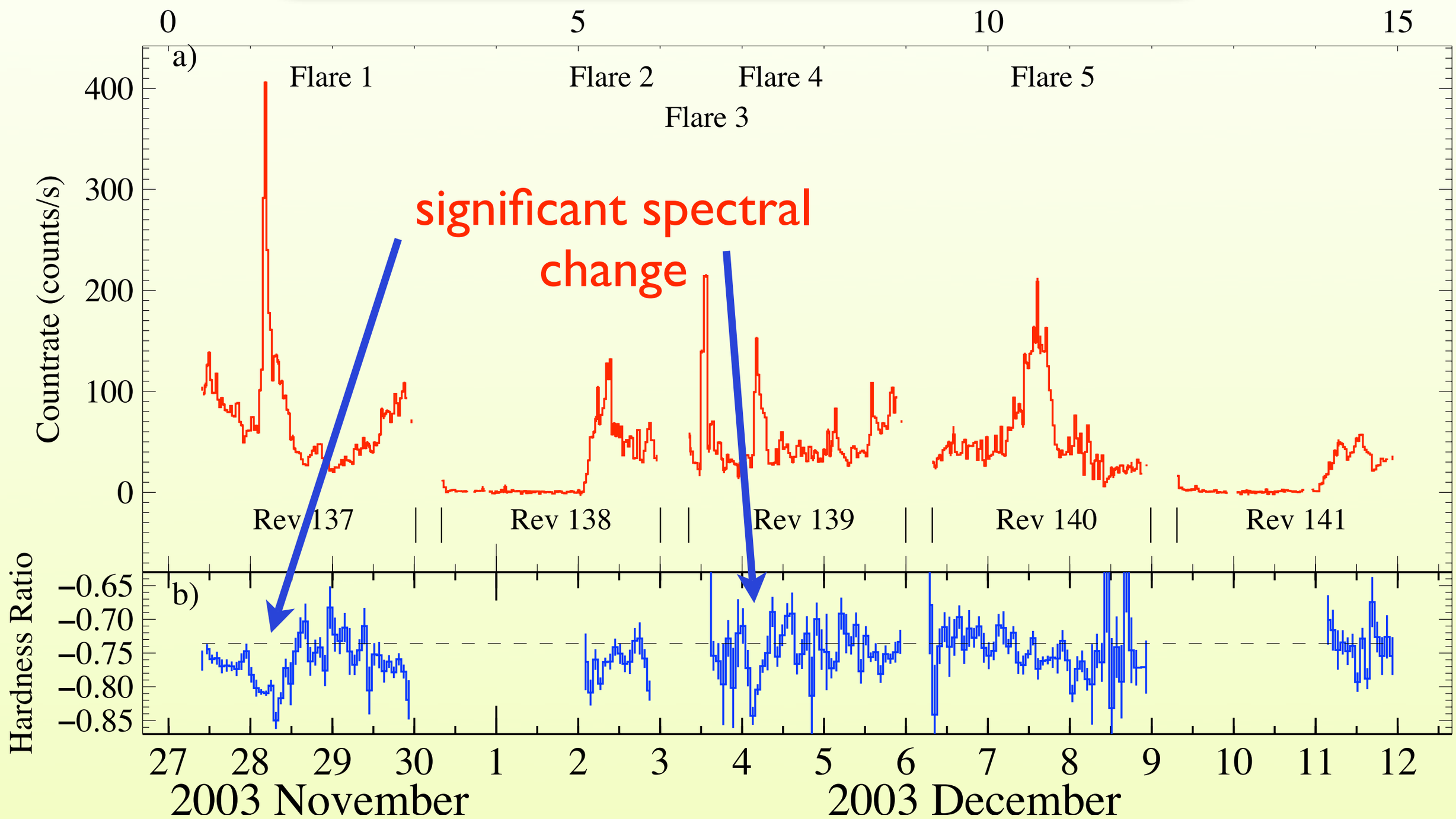
Hardness


a)
Flare 1
Flare 2
Flare 3
Flare 4
Flare 5
Countrate (counts/s)
400
300
200
100
0
Rev 137
Rev 138
Rev 139
Rev 140
Rev 141
b)
Hardness Ratio
−0.65
−0.70
−0.75
−0.80
−0.85
0
5
10
15
27
28
29
30
1
2
3
4
5
6
7
8
9
10
11
12
2003 November
2003 December

Hardness


a)
Flare 1
Flare 2
Flare 3
Flare 4
Flare 5
Countrate (counts/s)
400
300
200
100
0
0
5
10
15
Rev 137
Rev 138
Rev 139
Rev 140
Rev 141
significant spectral change
b)
Hardness Ratio
−0.65
−0.70
−0.75
−0.80
−0.85
27
28
29
30
1
2
3
4
5
6
7
8
9
10
11
12
2003 November
2003 December

Hardness


a)
Flare 1
Flare 2
Flare 3
Flare 4
Flare 5
Countrate (counts/s)
400
300
200
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0
0
5
10
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Rev 137
Rev 138
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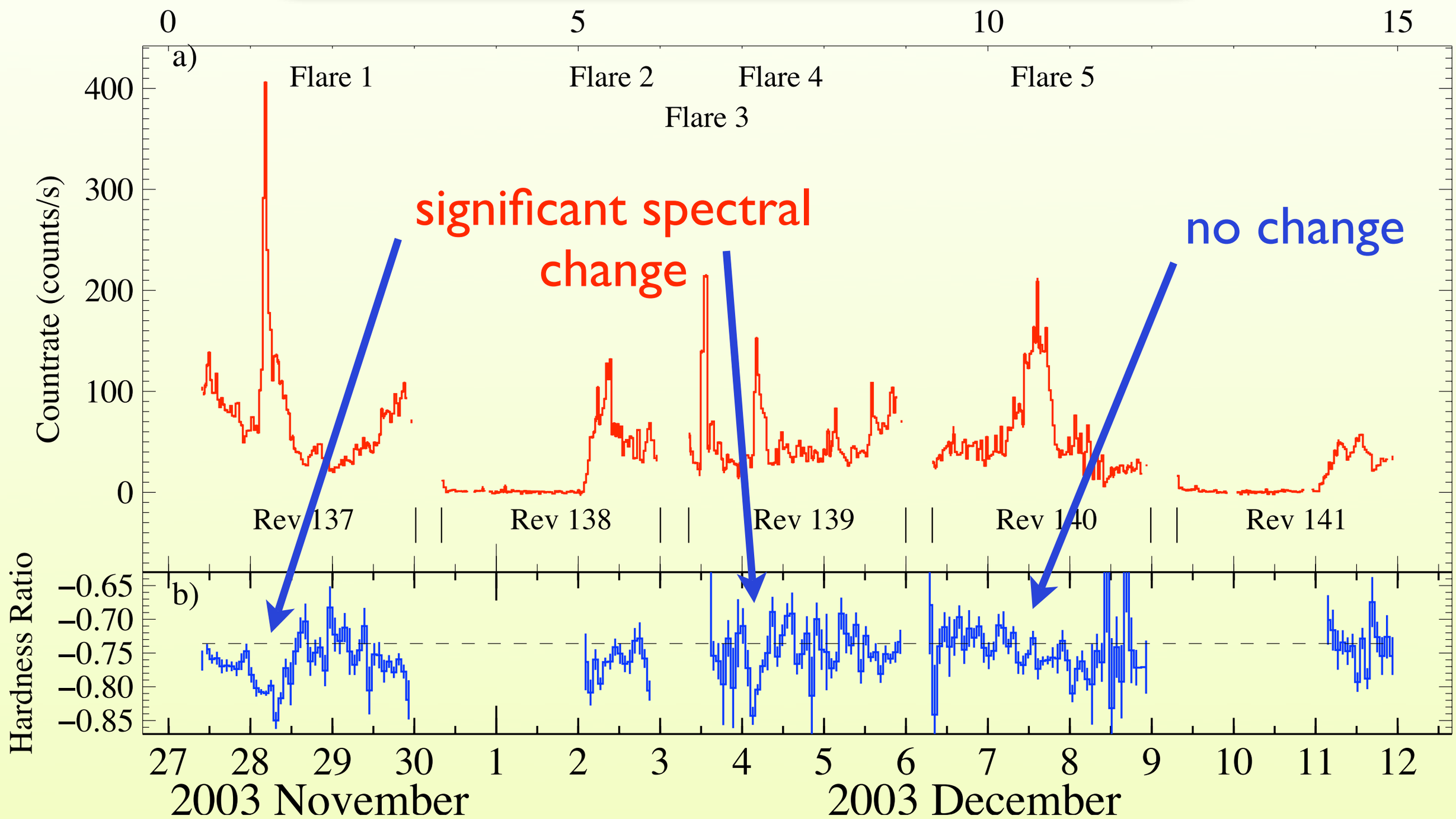
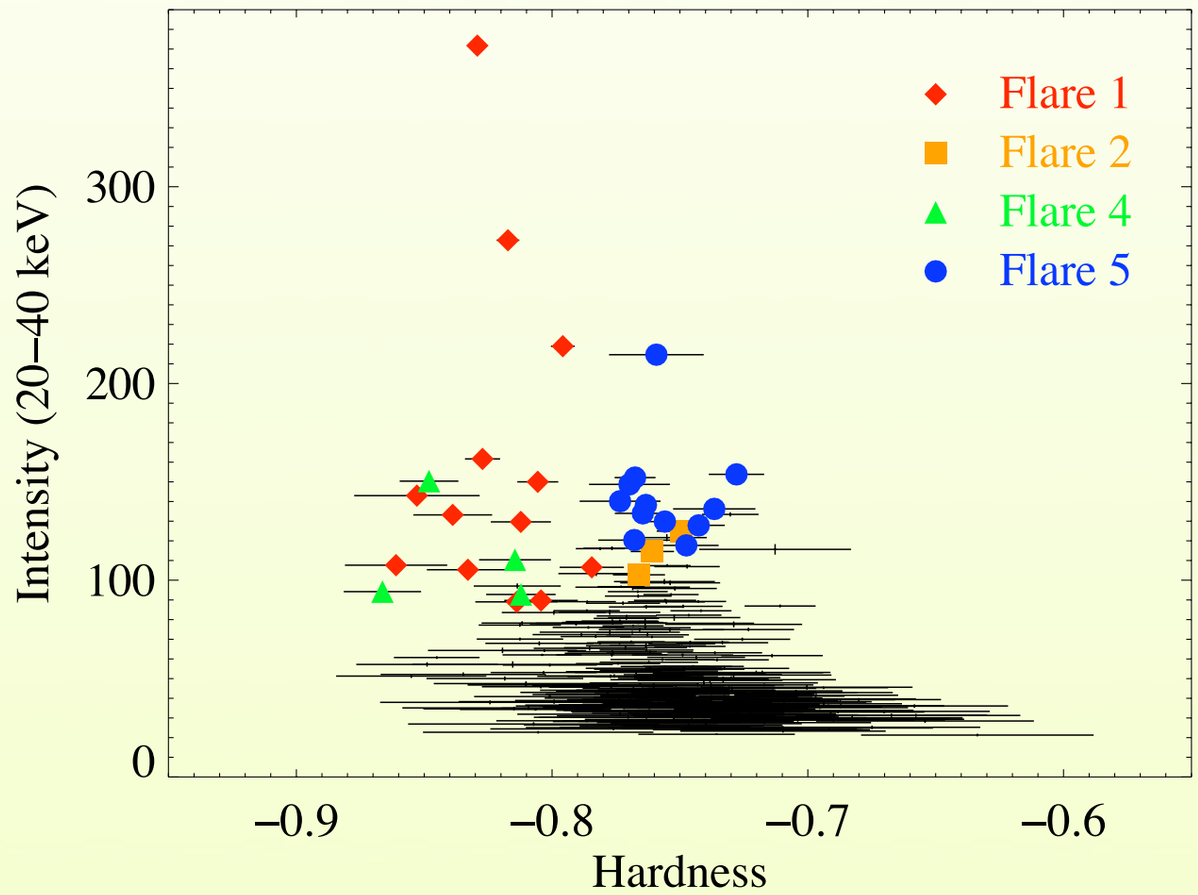
2003 November
2003 December

Hardness


a)
Flare 1
Flare 2
Flare 3
Flare 4
Flare 5
Countrate (counts/s)
400
300
200
100
0
Rev 137
Rev 138
Rev 139
Rev 140
Rev 141
significant spectral change
no change
b)
Hardness Ratio
−0.65
−0.70
−0.75
−0.80
−0.85
0
5
10
15
27
28
29
30
1
2
3
4
5
6
7
8
9
10
11
12
2003 November
2003 December

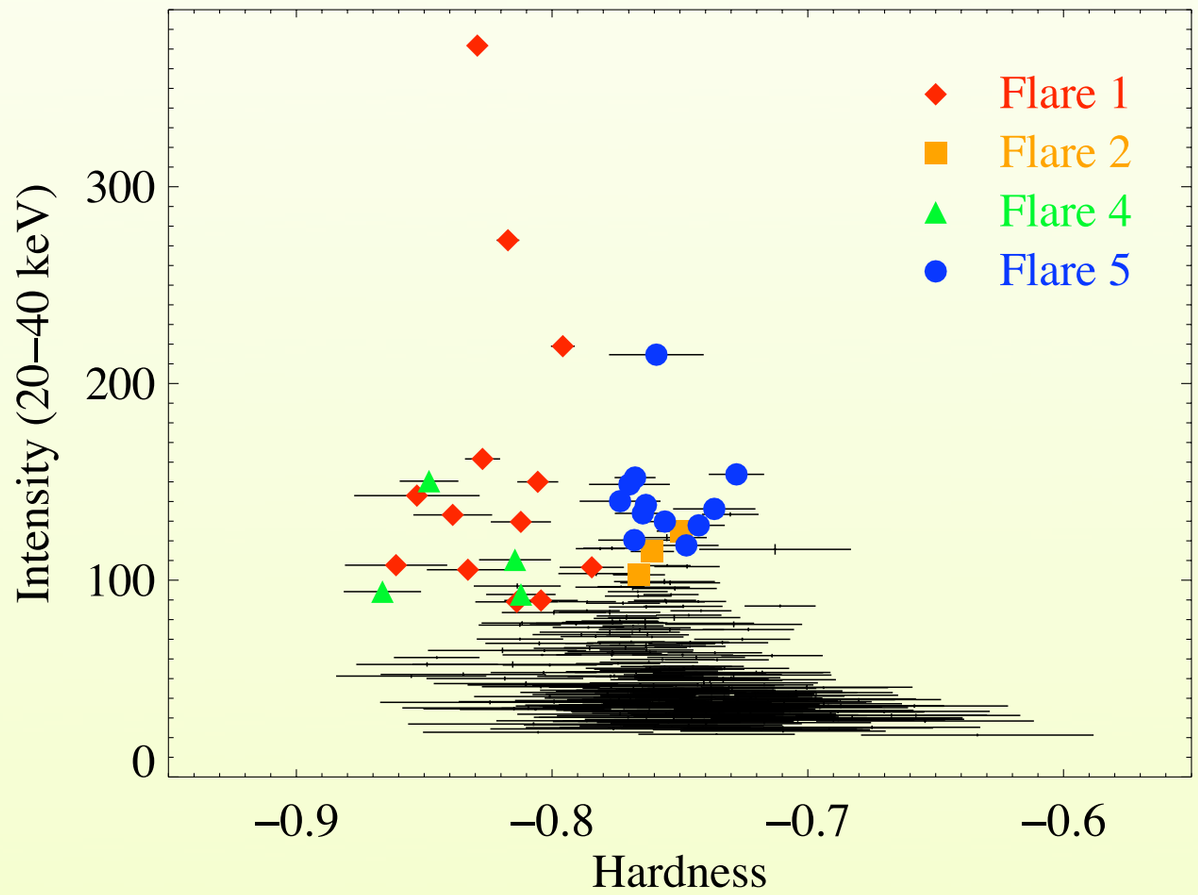
HID



Flare 1	Flare 2	Flare 3	Flare 4	Flare 5
τ=0.15	τ=0.83	τ=0.28	τ=0.13	τ=0.63

HID

- hardness mostly constant (no evolution w/ phase)



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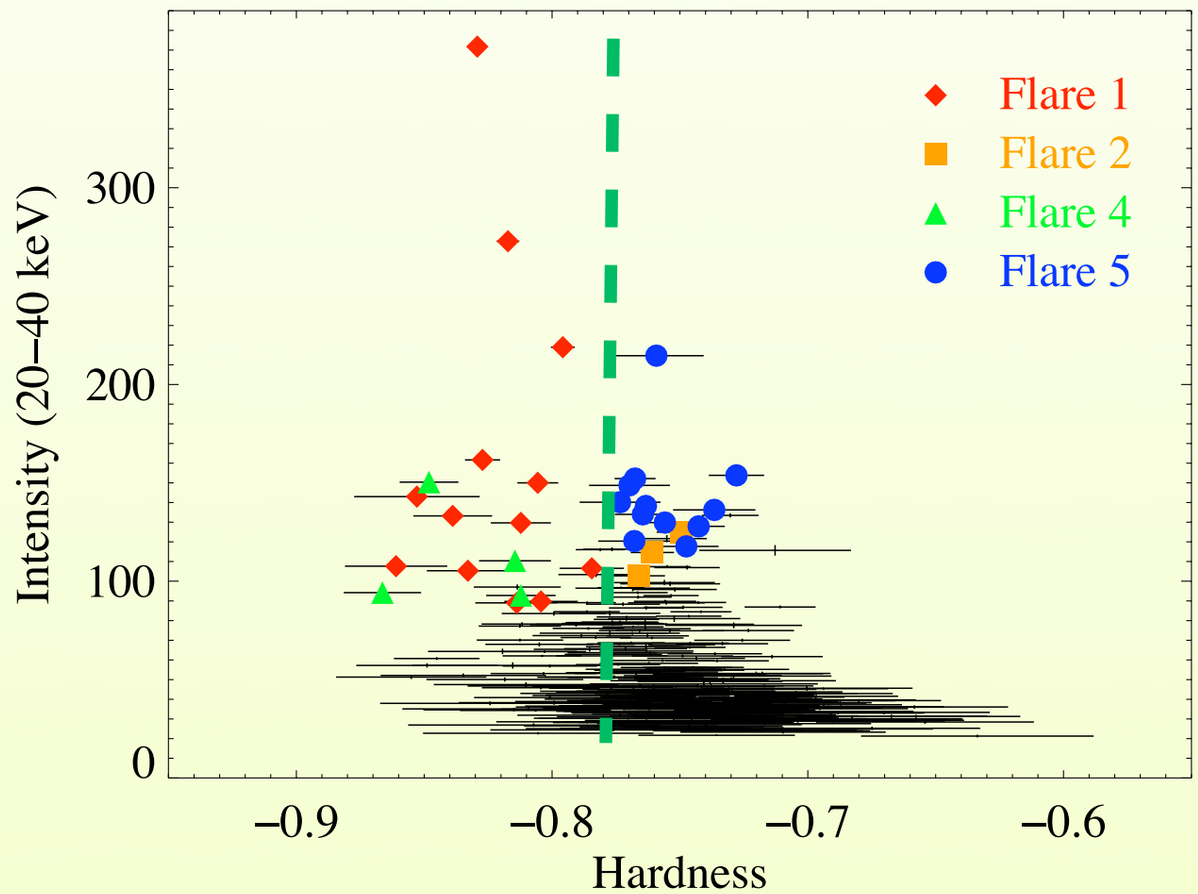
HID

- hardness mostly constant (no evolution w/ phase)
- significant change during Flares 1 and 4
- NO change during Flares 2 and 5



Flare 1	Flare 2	Flare 3	Flare 4	Flare 5
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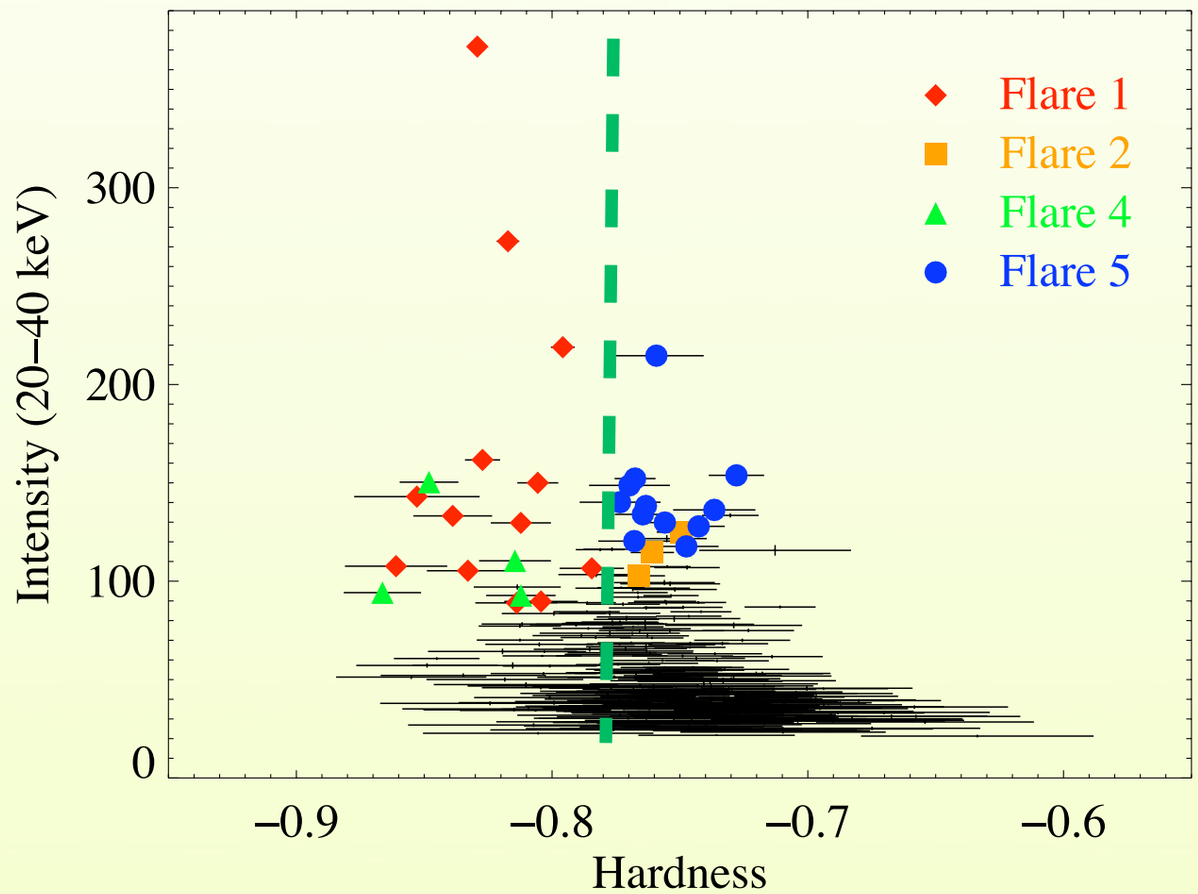
HID

- hardness mostly constant (no evolution w/ phase)
- significant change during Flares 1 and 4
- NO change during Flares 2 and 5

➡ two types of flares:

- fast rise, spectral change
- slow rise, no spectral change



Flare 1	Flare 2	Flare 3	Flare 4	Flare 5
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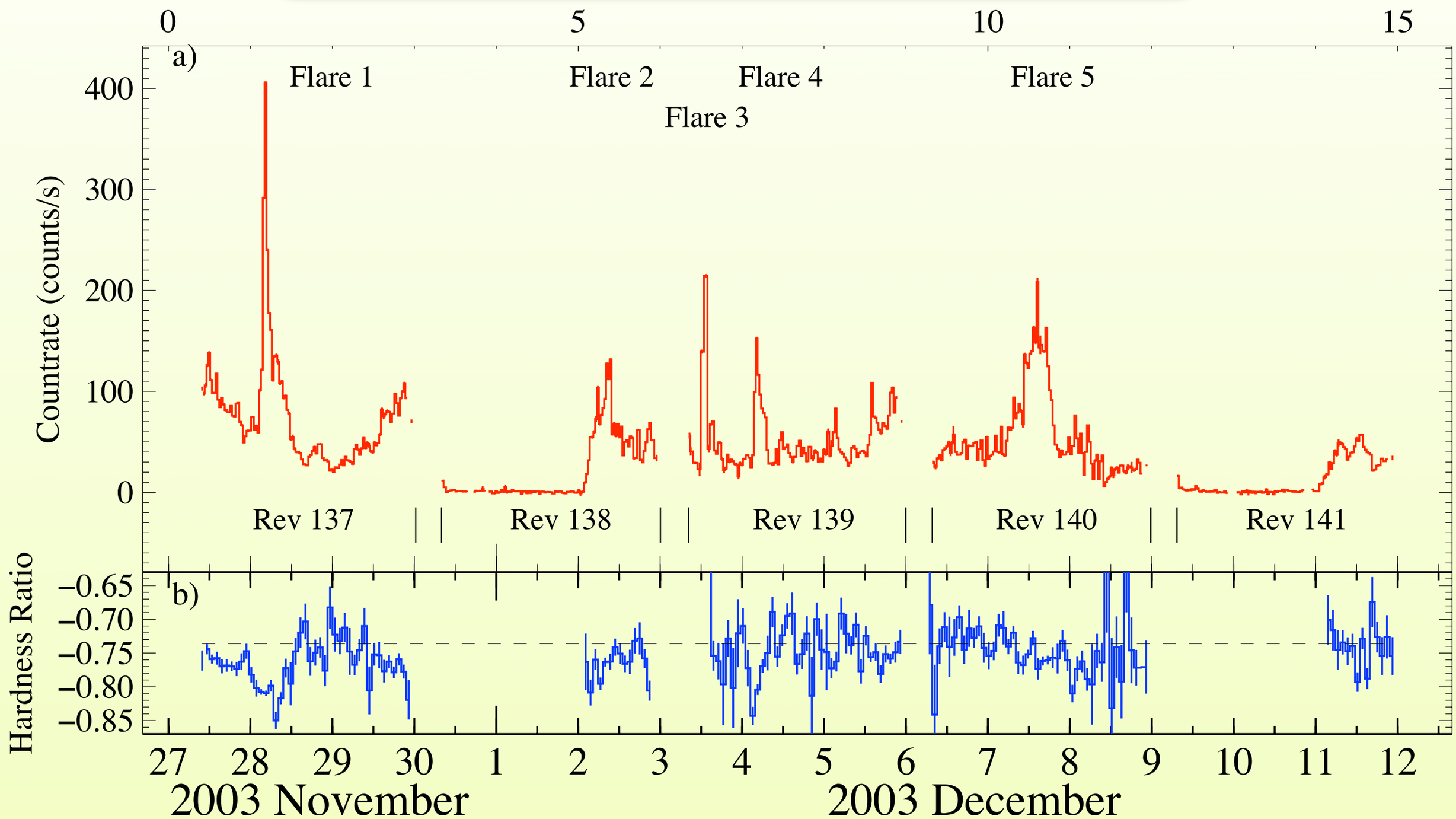
Offstates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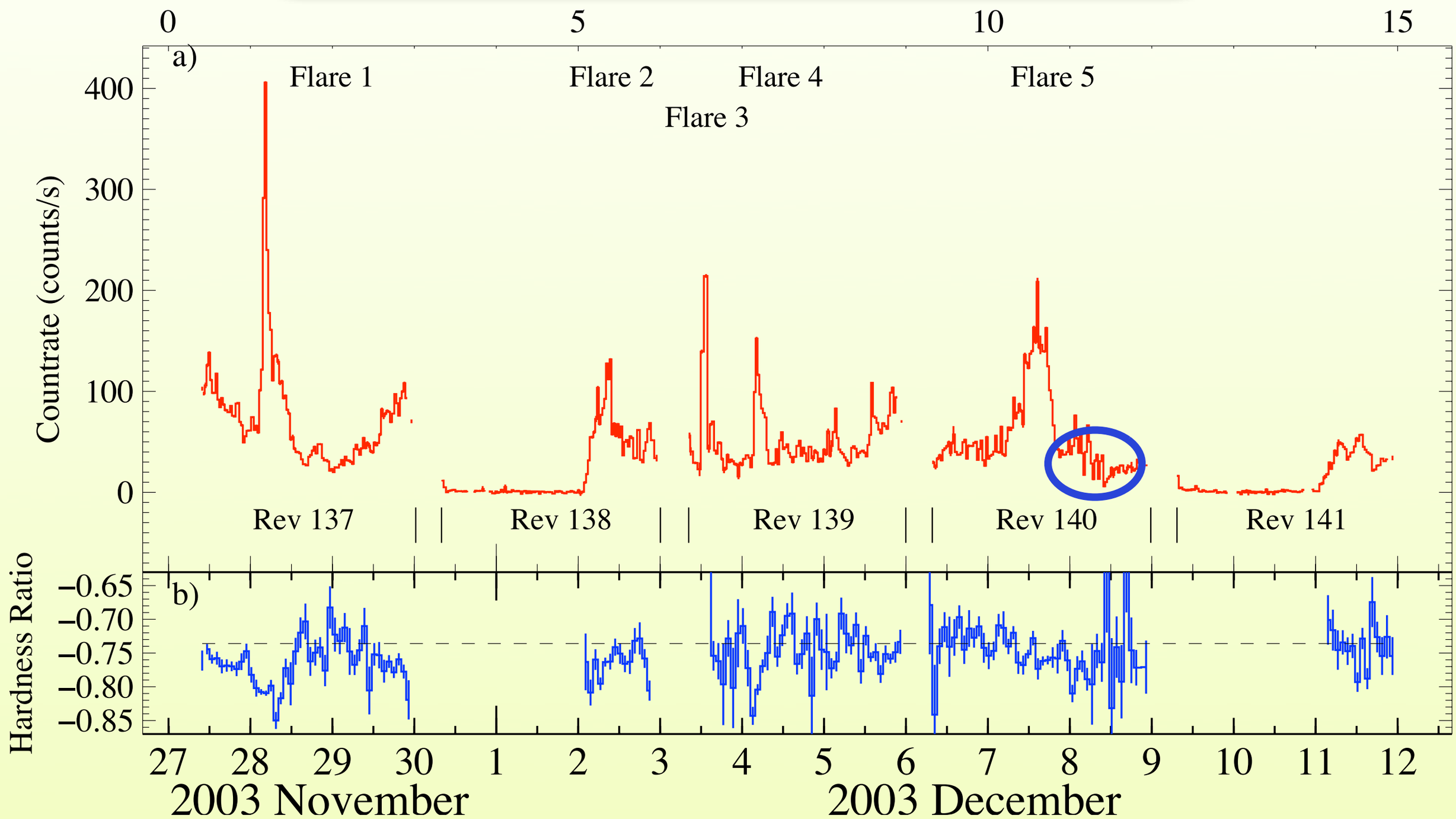
Offstates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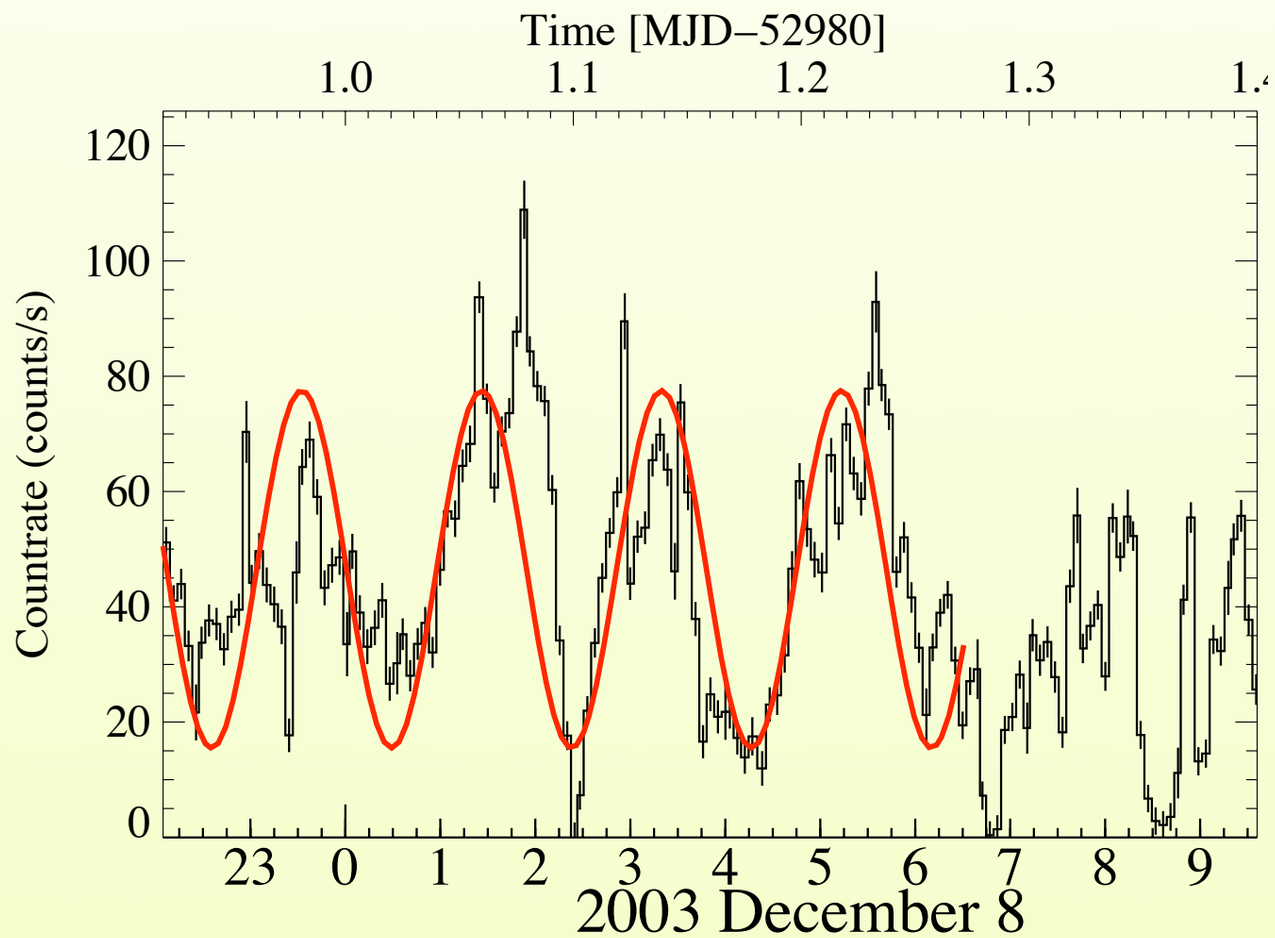
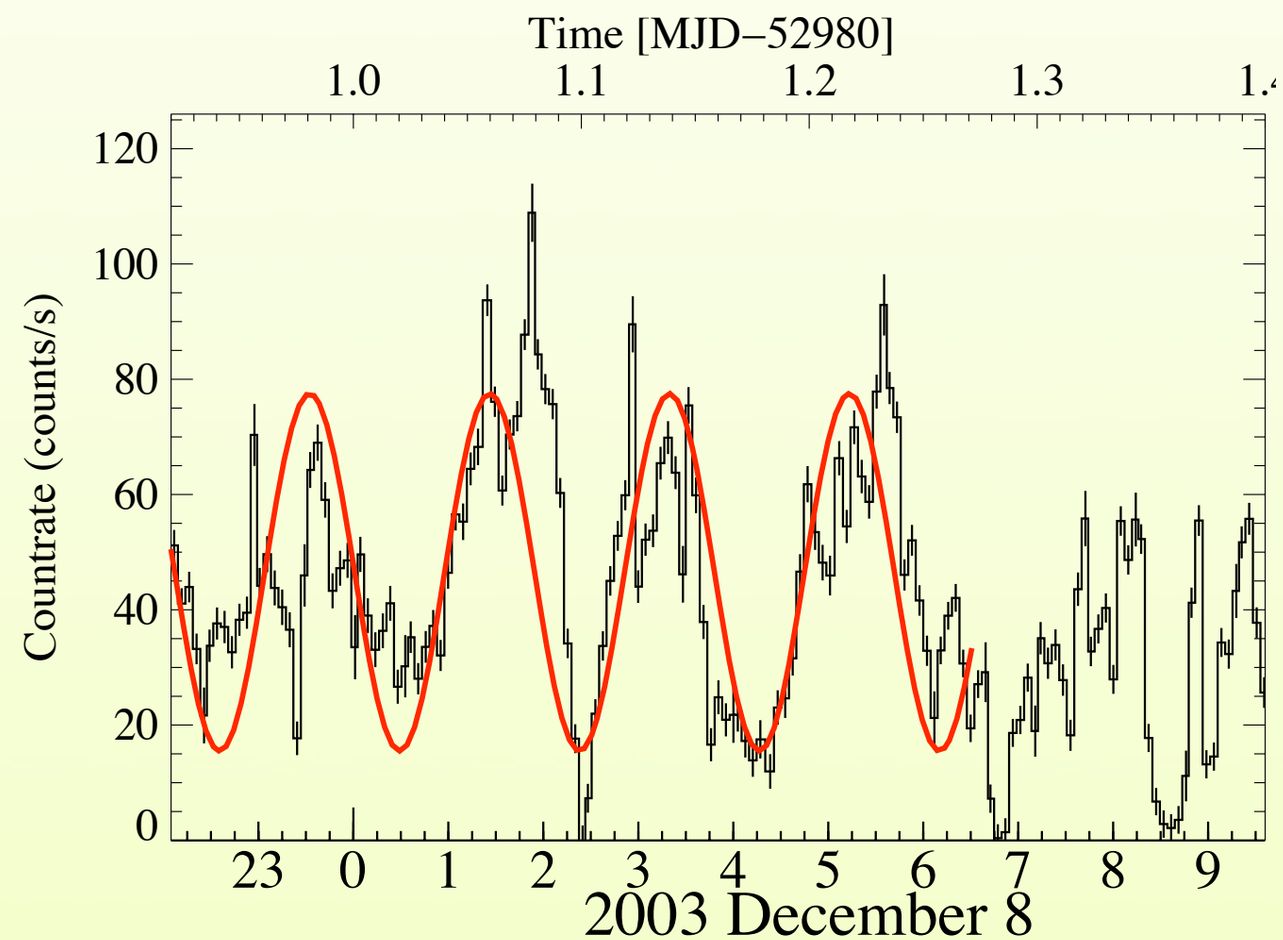
Hardness Ratio
2003 November
2003 December

Offstates


Time [MJD−52980]
1.0
1.1
1.2
1.3
Countrate (counts/s)
120
100
80
60
40
20
0
23
0
1
2
3
4
5
6
7
8
9
2003 December 8

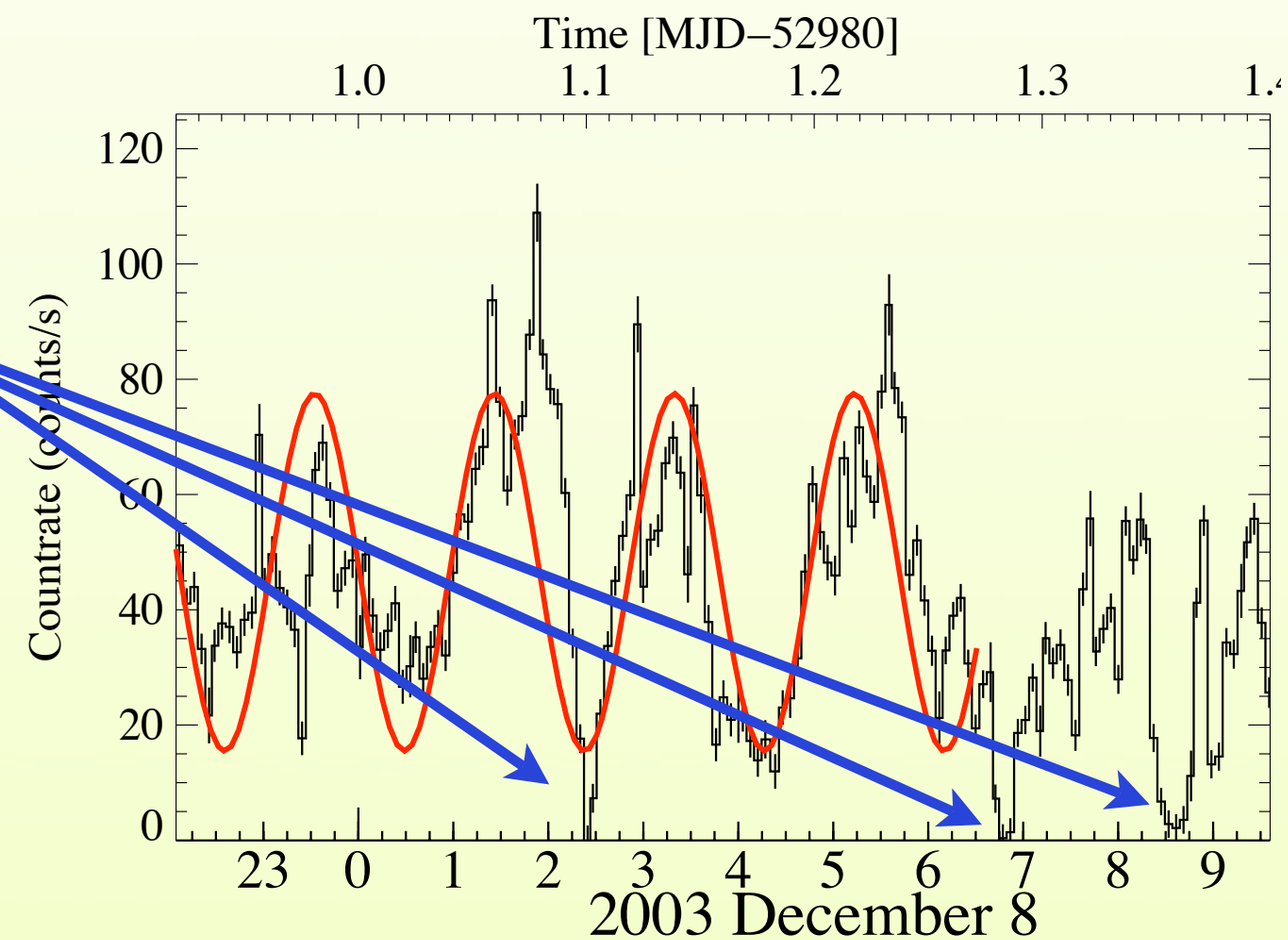
Offstates

- quasi periodic behavior
- Period: 6820 sec



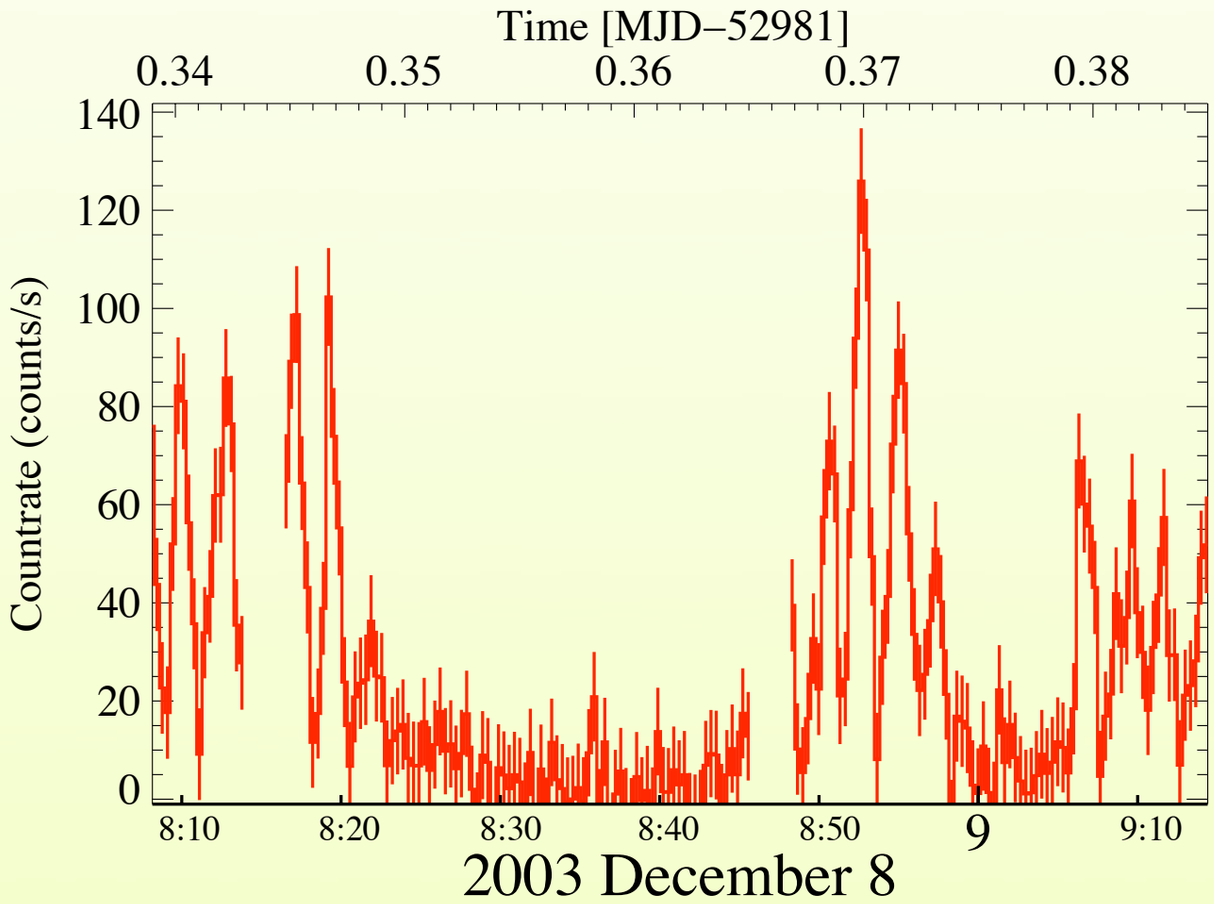
Offstates

- quasi periodic behavior
- Period: 6820 sec
- flux decreases to zero



Offstates

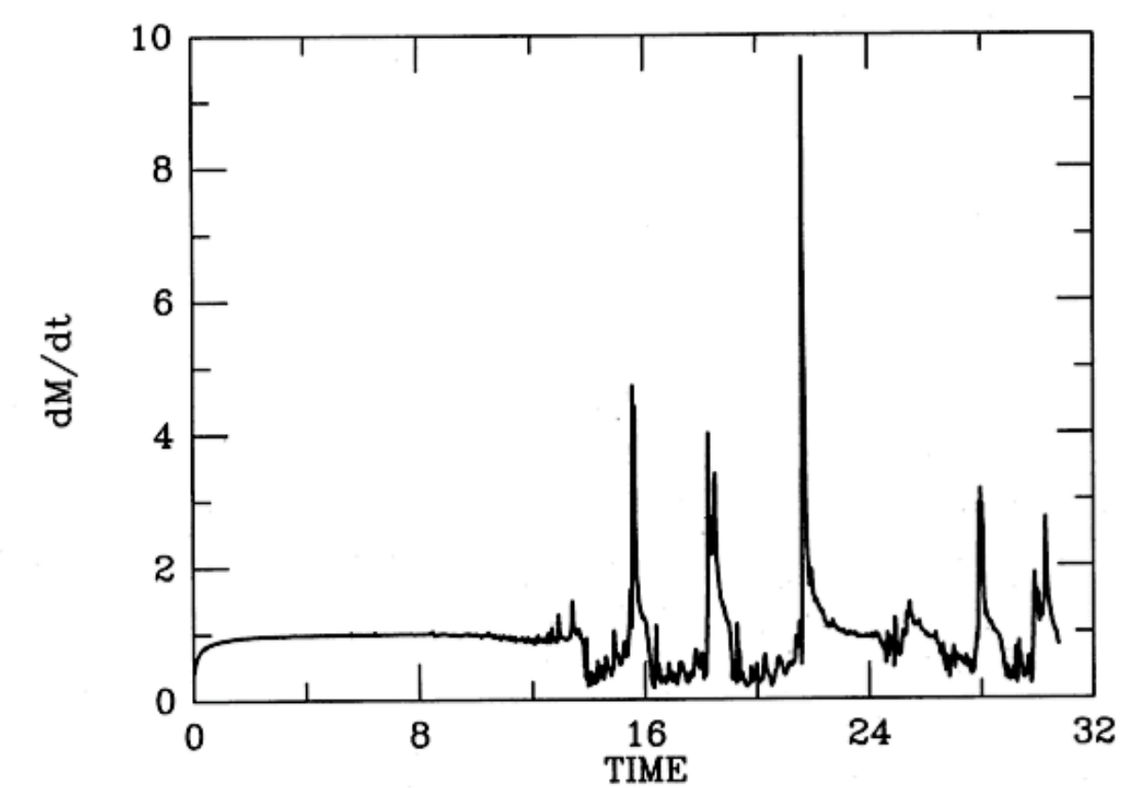
- 5 offstates detected
- no residual flux detectable
- countrate drops / increases extremely rapidly
- increase within 20 sec from 0 to ~100 cts/sec
- duration 500 - 2000 sec
- similar to previous offstates, but observed in detail



Discussion

- wind in a HMXB system very complex (X-ray photoionization...)
- time dependence (CAK wind model not sufficient)

➡ need 2D/3D simulations



Taam & Fryxell (1989)

⊙ short flares: highly variable density/velocity structure

- shock fronts, dense filaments, accretion stream oscillates: flip-flop instability
- predicted time scales: flares ~45min (flares 2,3,4)!

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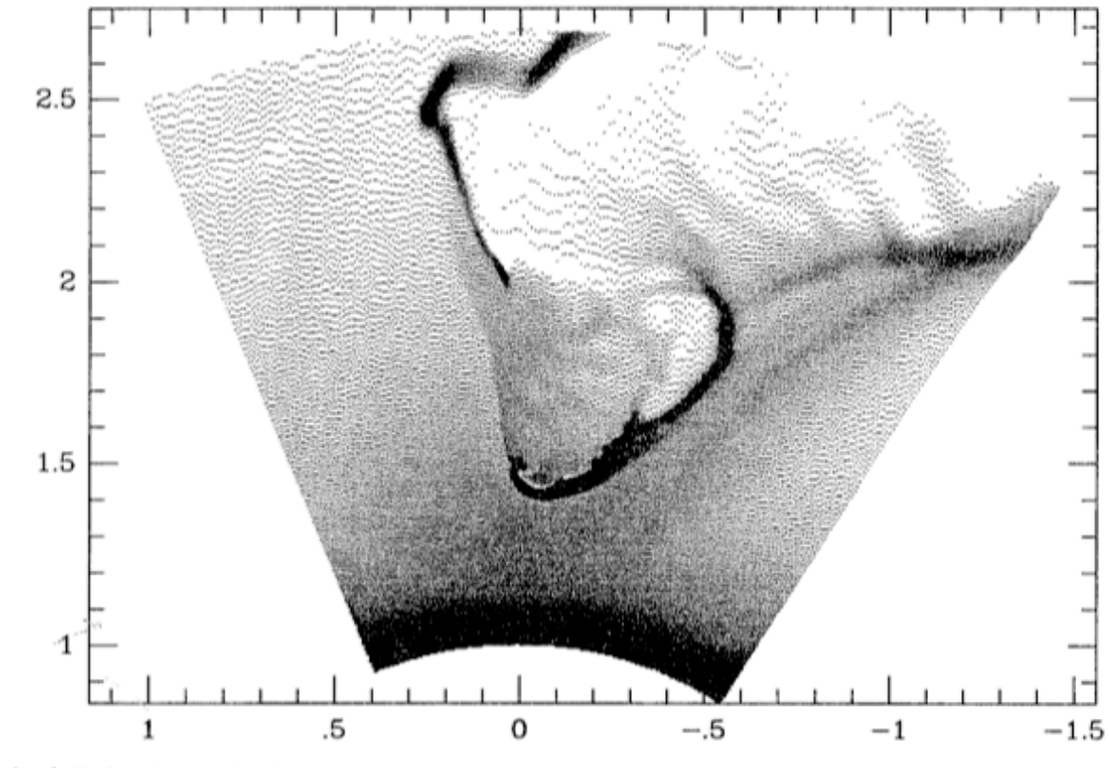

Blondin et al. (1990)

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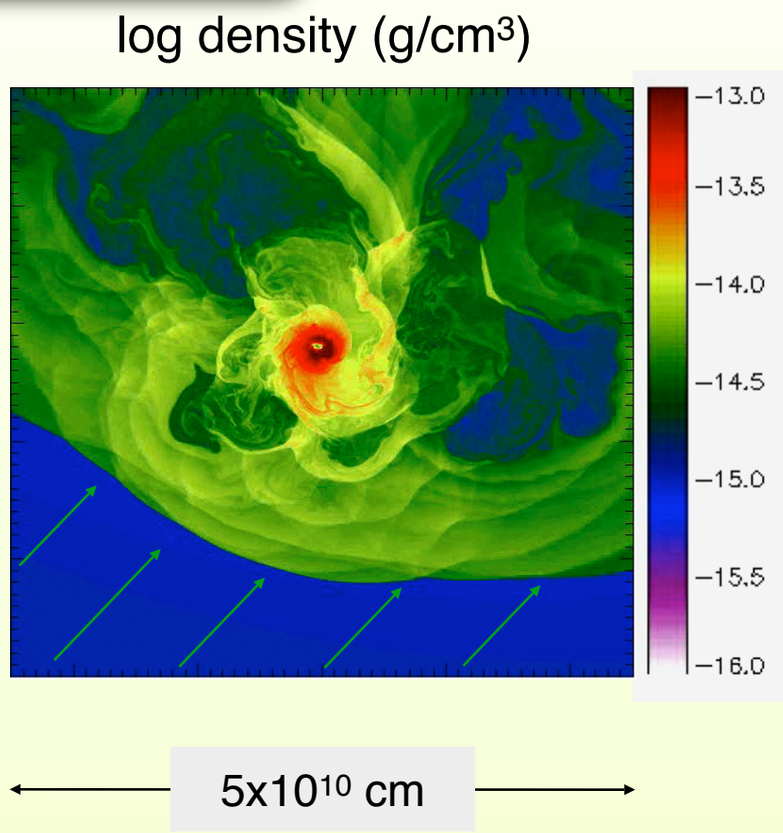

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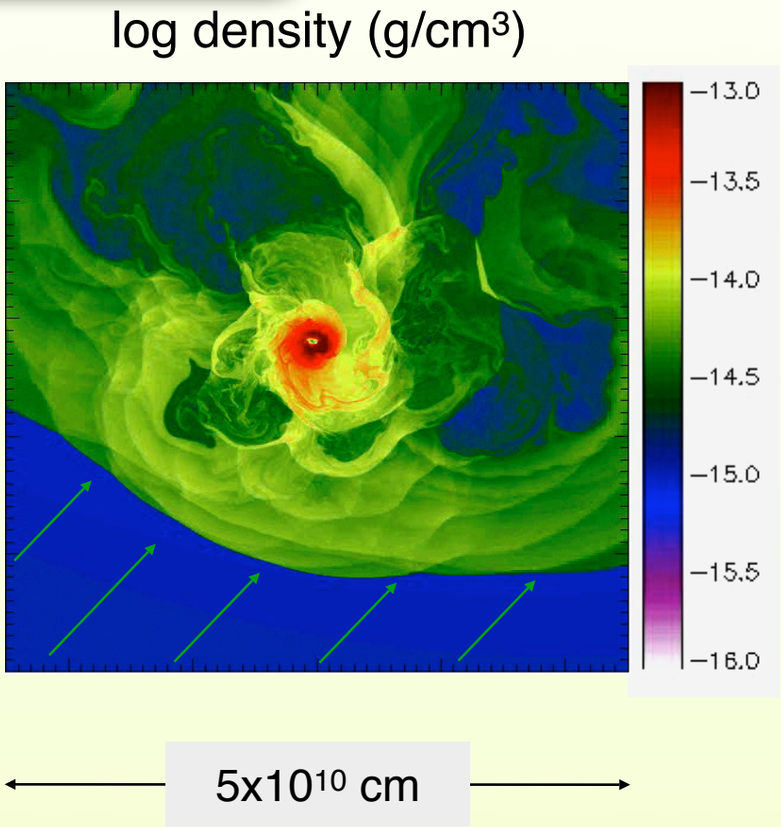
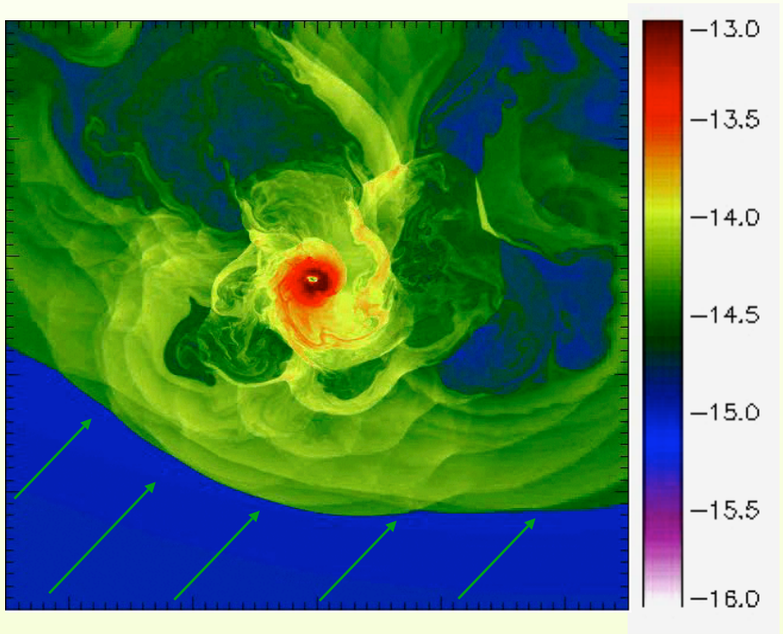


➡ blobs (or clumps) in the stellar wind
But: flares quite long and Blobs very fast!
significant fraction of binary orbit

- blob is viscously smeared out in accretion disk

Discussion

log density (g/cm³)



5x10¹⁰ cm

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➡ can feed NS for several hours (flares 1 & 5)

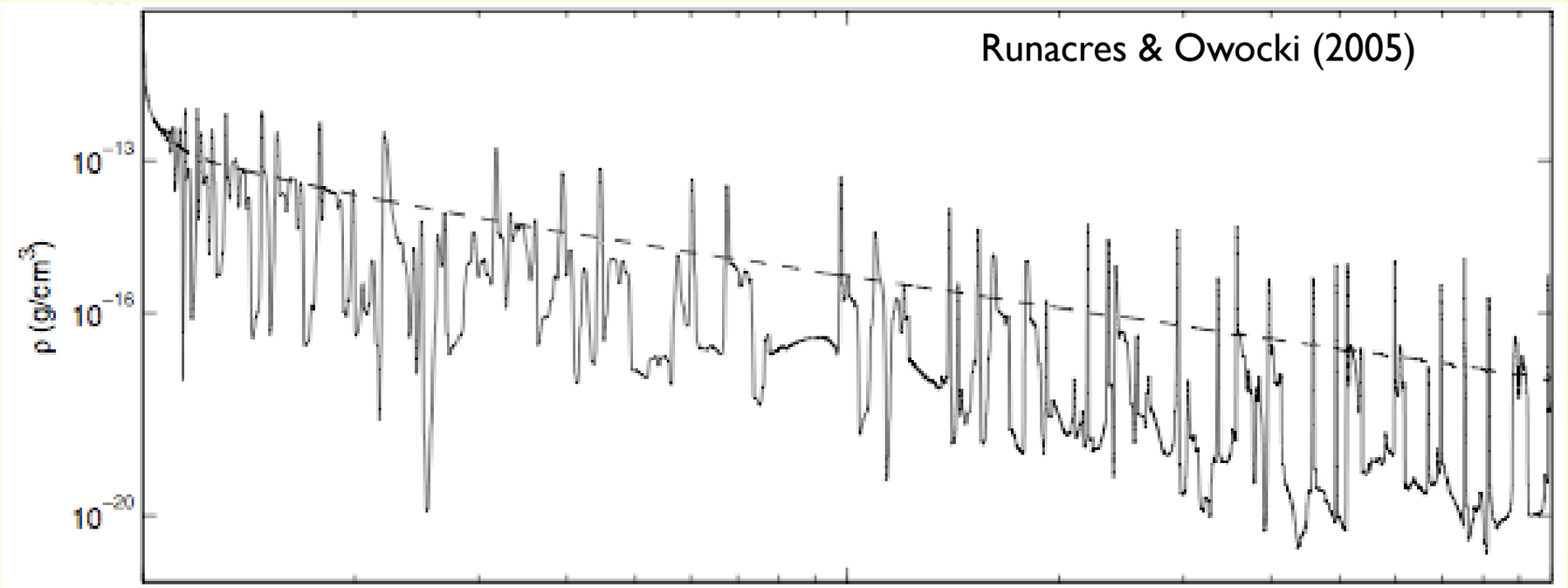
Discussion

Offstates:

➡ absorption impossible

➡ not only blobs but also holes in stellar wind!

➡ density drops by factor 10^5



SFXTs

- drop in acc. rate
- why no pulsations? why so sudden?

➡ onset of propeller effect?

- calculate flux for onset of propeller:

$$F_X = 4.3 \times 10^{-7} \times \left(\frac{B}{10^{12}}\right)^2 \times P^{-7/3} \times \left(\frac{d}{1kpc}\right)^{-2} \times \left(\frac{M}{1.4M_\odot}\right)^{-2/3}$$

➡ $F_X = 1.1 \times 10^{-12}$ erg cm^{-2}s^{-1} ➡ 10^{33} erg s^{-1}

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Vela X-1 enters region of low density ➡ propeller

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➡ Vela X-1 just opposite: rarely in propeller regime

Conclusions

- stellar wind in Vela X-1 is structured (clumps, holes)
- short and long flares up to 5.3 Crab
- Hardness ratio changes during rapidly rising flares
  ➞ also (sometimes) seen in SFXTs
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Thank you for your attention!