Cyclotron lines in High Mass X-ray Binaries

Ingo Kreykenbohm
Dr. Karl Remeis Observatory

Vulcano, May 31, 2012

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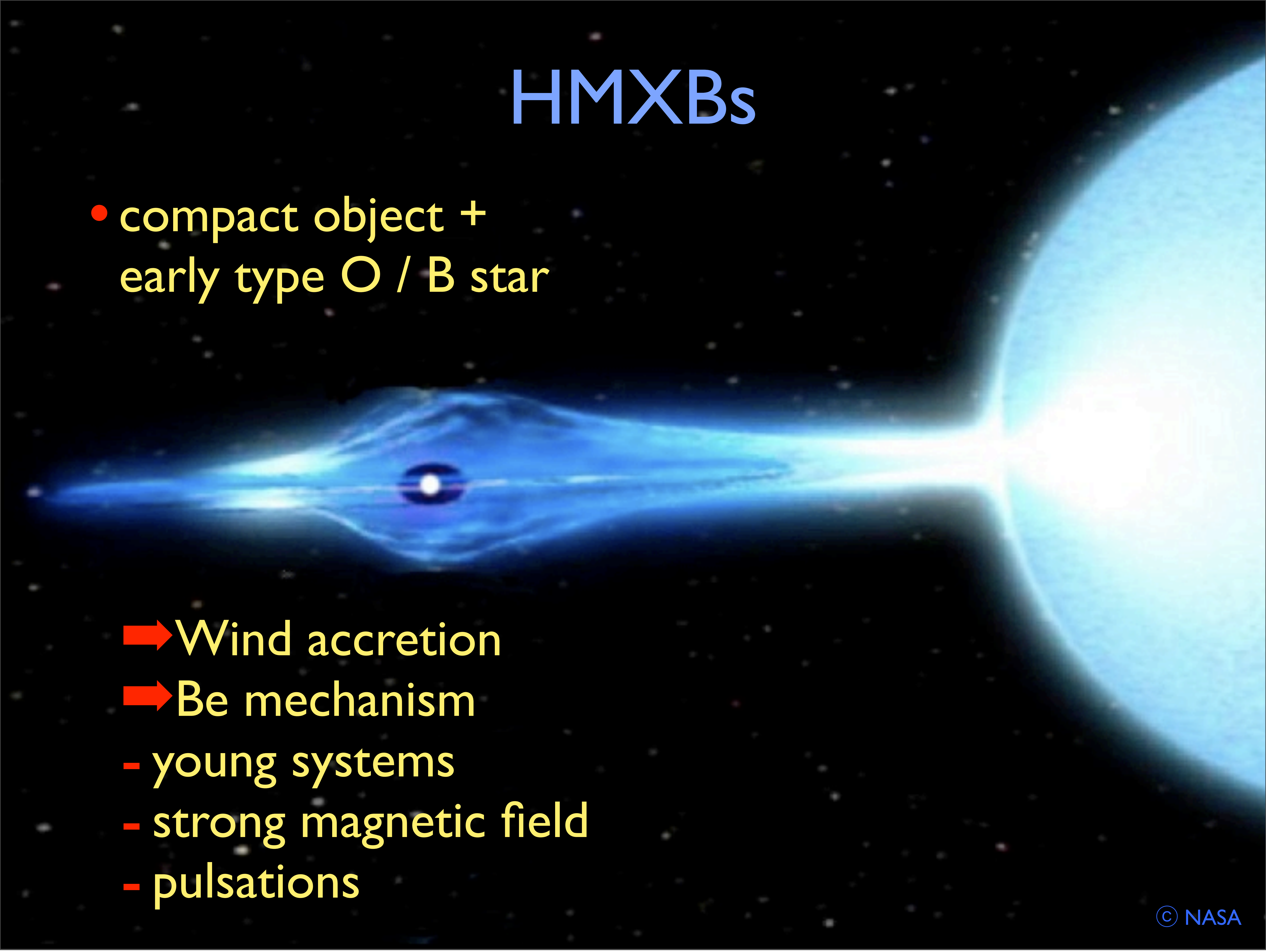
HMXBs

- compact object + early type O / B star



➡ Wind accretion

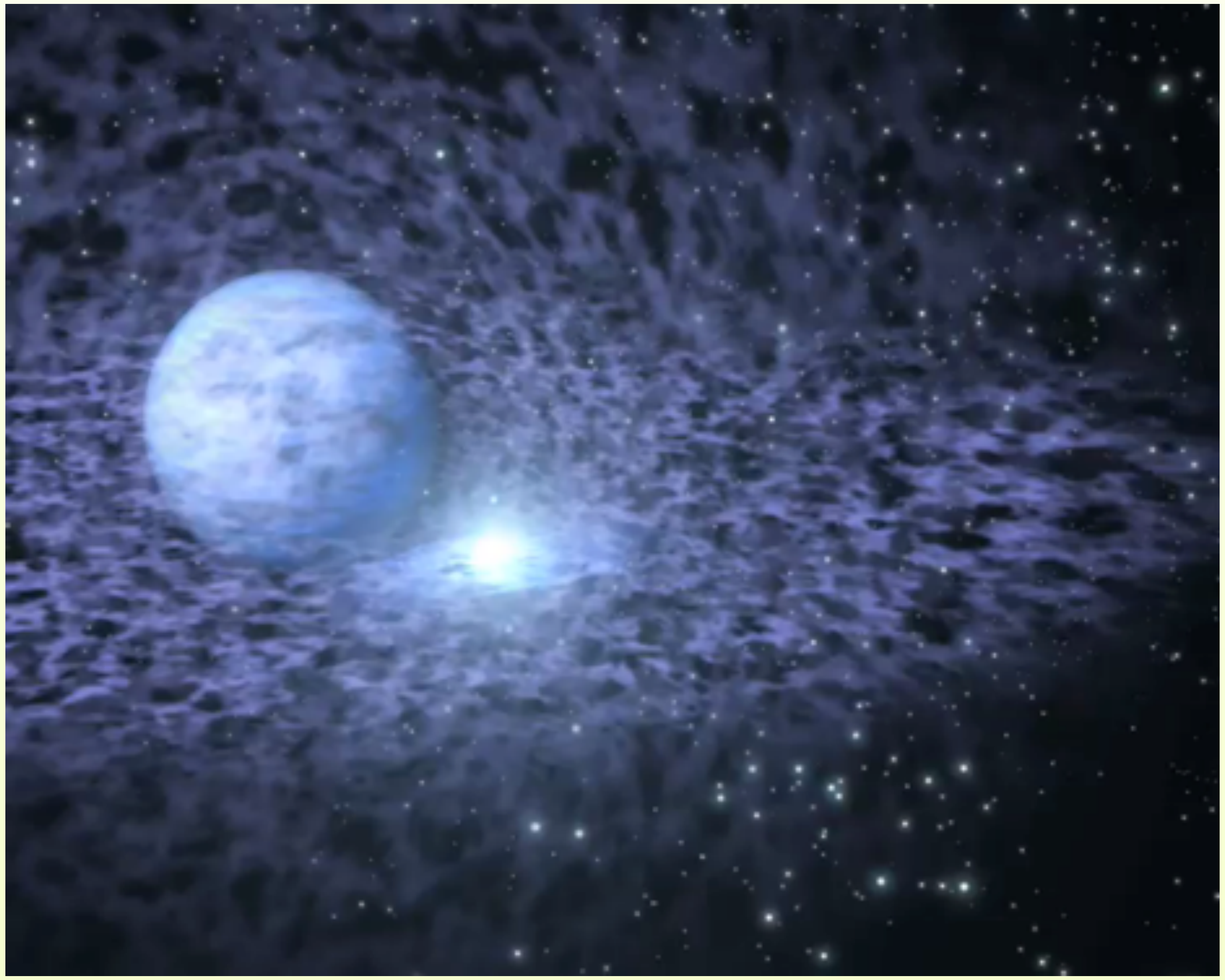
➡ Be mechanism

- young systems
- strong magnetic field
- pulsations

© NASA

Be/HMXBs

- intense stellar wind
- medium is structured
- strongly variable absorption!
- strong gravitation:
  - influence on medium!
- strong magnetic field
- strong gravitation + strong magnetic field: extreme physics!

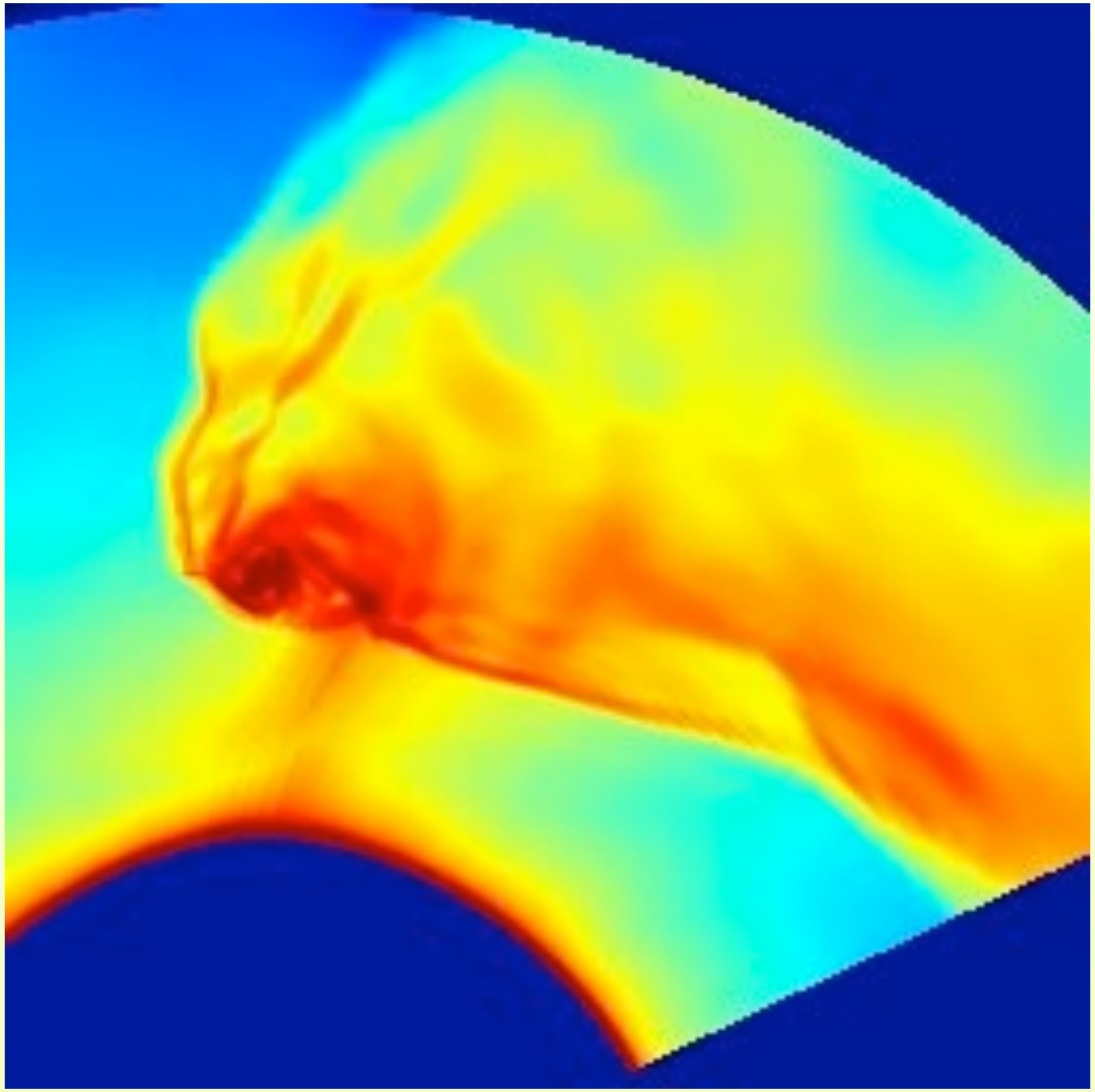


Be/HMXBs

- intense stellar wind
- medium is structured
- strongly variable absorption!
- strong gravitation:
  - influence on medium!
- strong magnetic field
- strong gravitation + strong magnetic field: extreme physics!

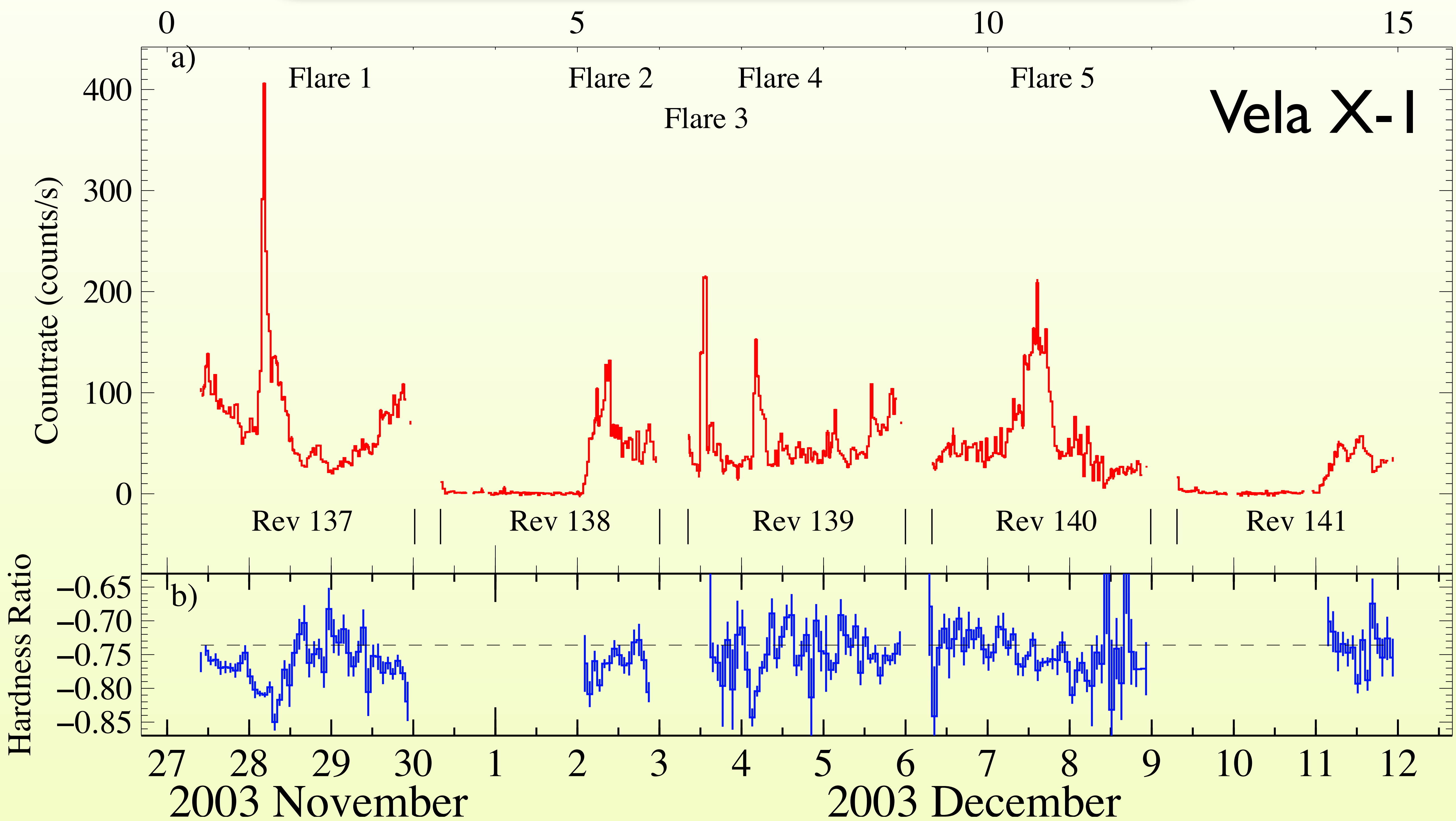
wind accretion

- compact object disturbs medium
- focused wind
- shock fronts emerge
- instabilities
- velocity and density varies
- wind is clumpy

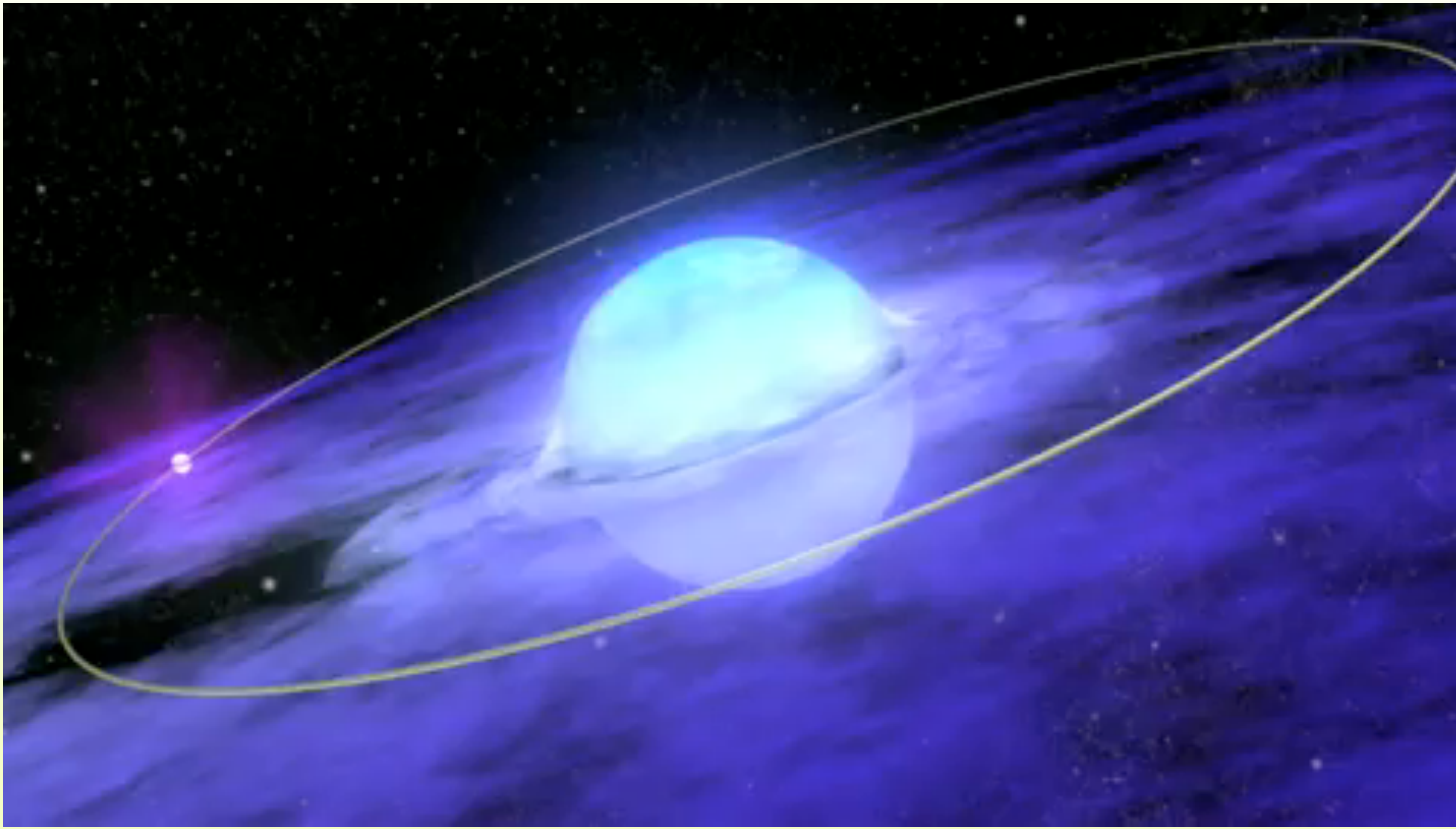


(Blondin 1991)

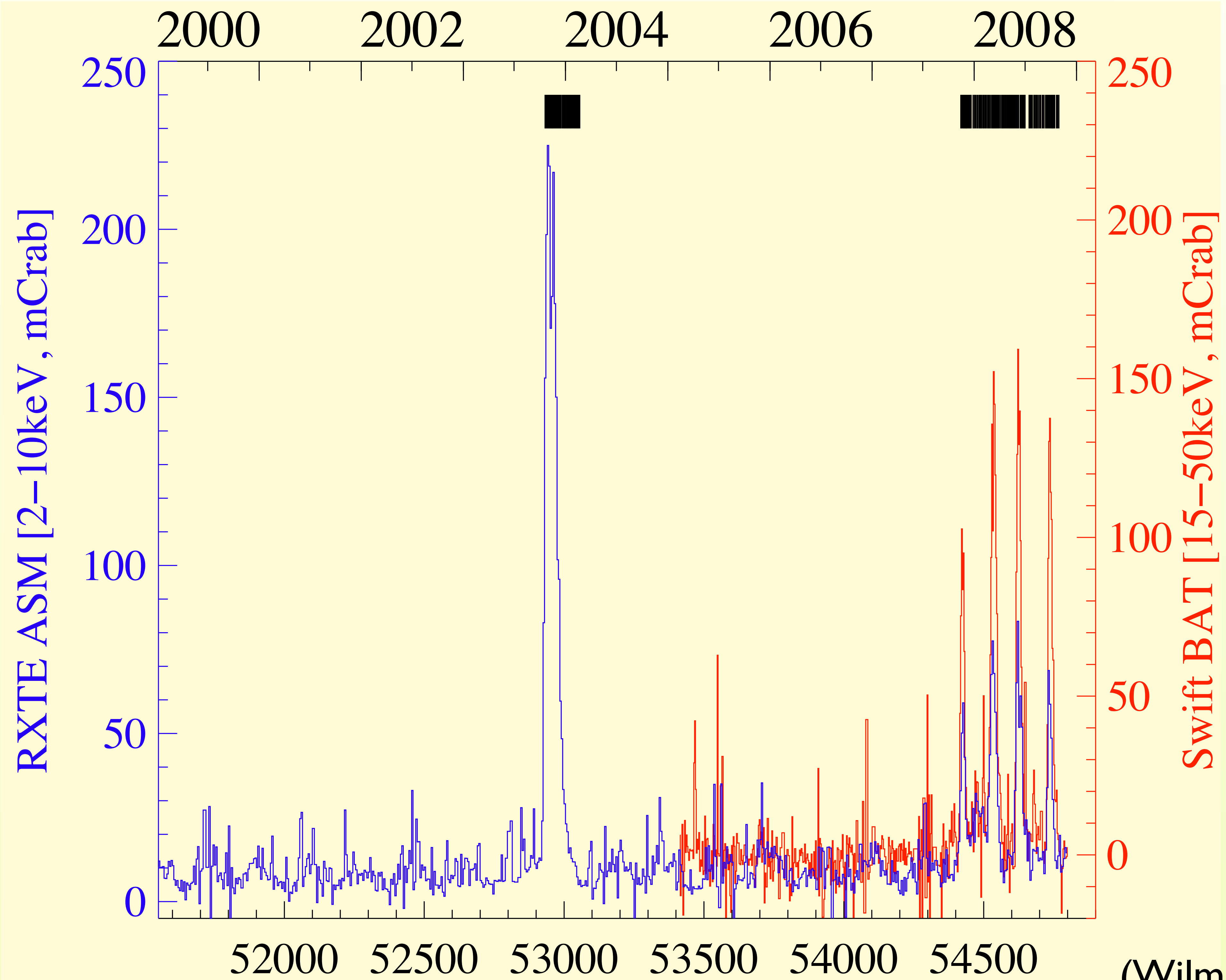
Variability



Be/HMXBs



Outbursts



(Wilms 2010)

Accreting 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

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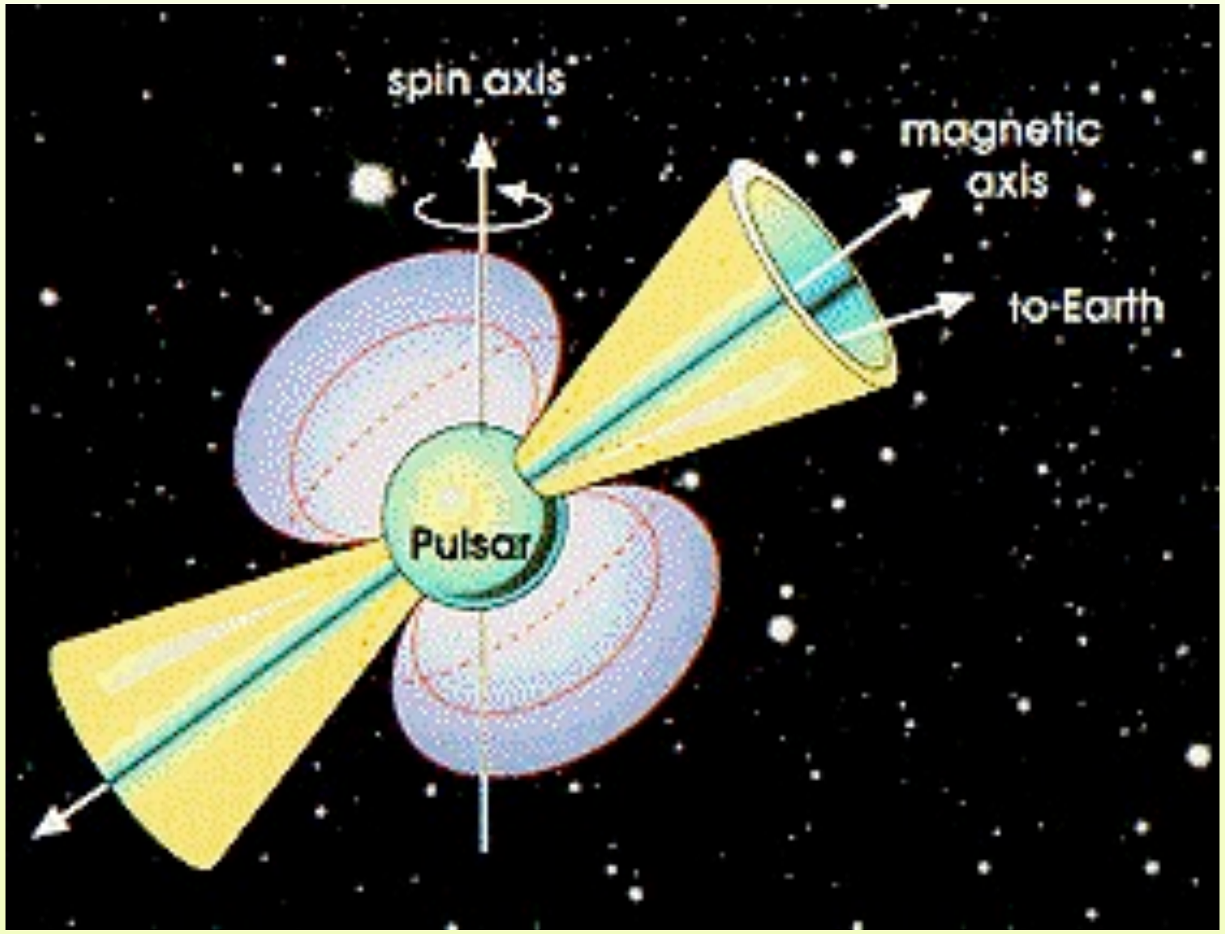


accretion column

high L_X sources:
radiative shock
dominates formation of observed spectrum

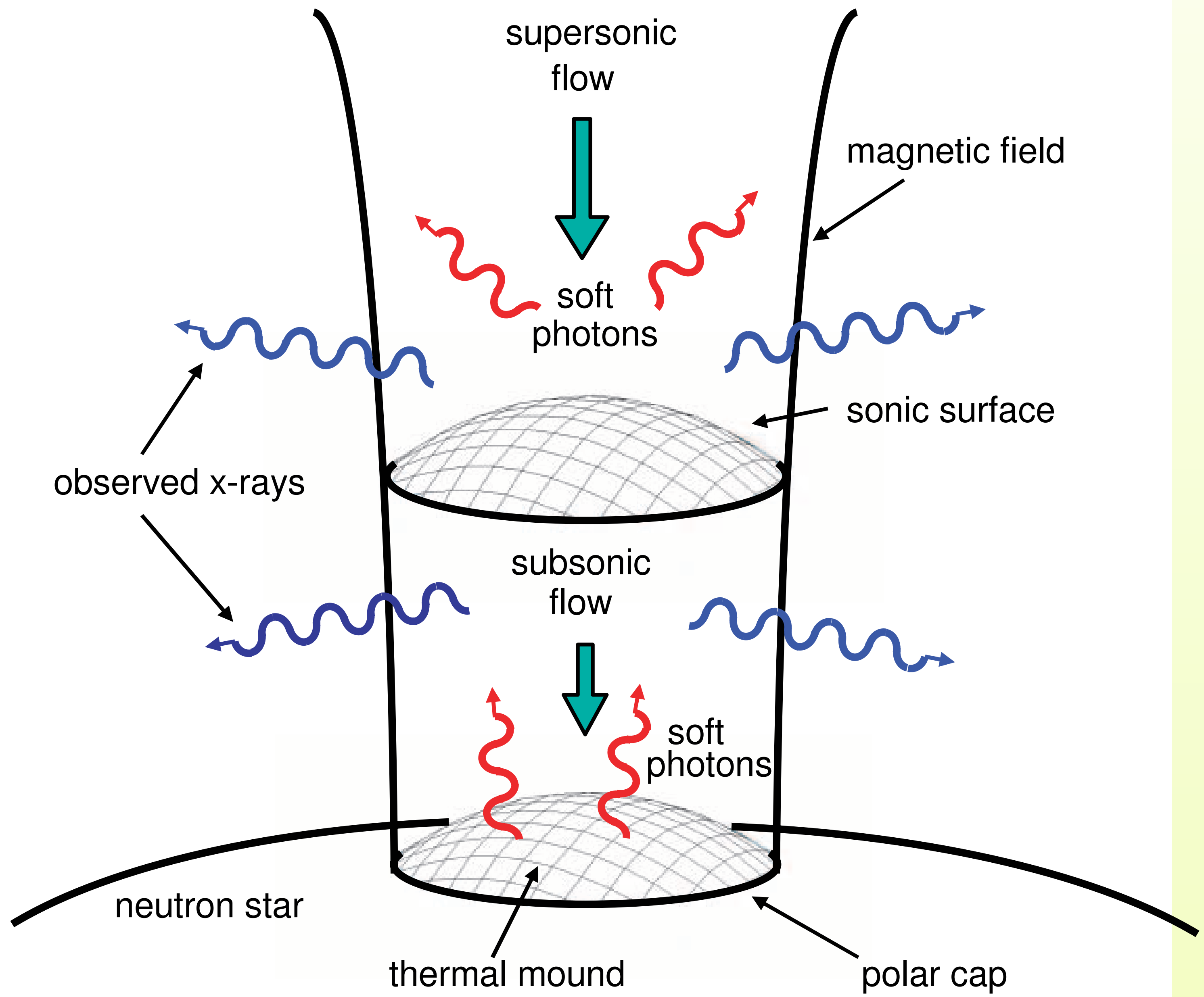
thermal mound:

soft X-rays

bulk motion comptonization in accretion shock

hard X-rays through the walls ➔ fan beam

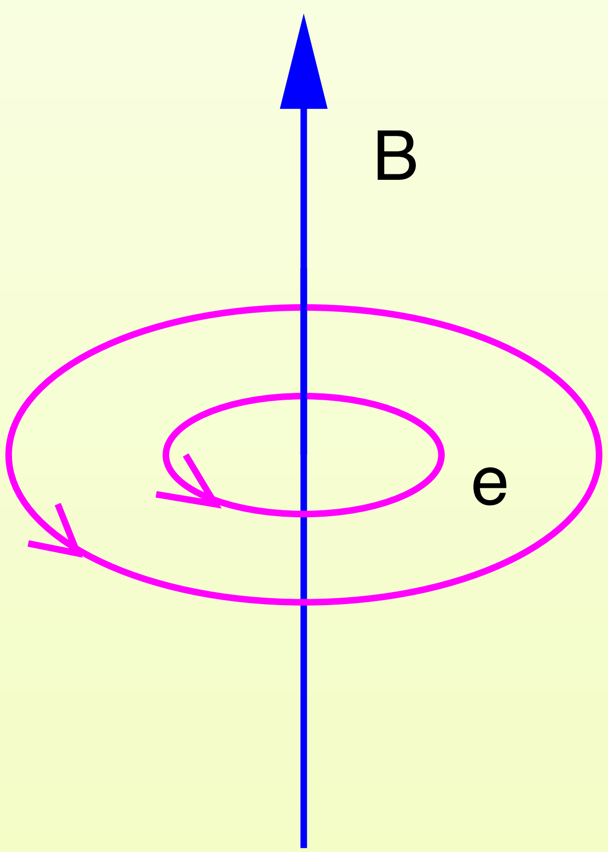
Becker & Wolff (2005,2007)



Cyclotron Lines

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

$$E_n = m_e c^2 \times \sqrt{1 + \left(\frac{p_{||}}{m_e c^2}\right)^2 + 2n\frac{B}{B_{\mathrm{crit}}}}$$



$P_{||}$ momentum of electron || B-field

at critical magnetic field: $E_{\mathrm{cyc}} = m_e c^2$

$$B_{\mathrm{crit}} = \frac{m_e^2 c^3}{e\hbar} \approx 4.4 \times 10^{13}\,\mathrm{G}$$

Cyclotron Lines

$B \ll B_{crit}$ distance between Landau levels:

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

12-B-12 rule

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⇒ Cyclotron resonance scattering features (CRSFs)

Cyclotron Lines

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⇒ Cyclotron resonance scattering features (CRSFs)

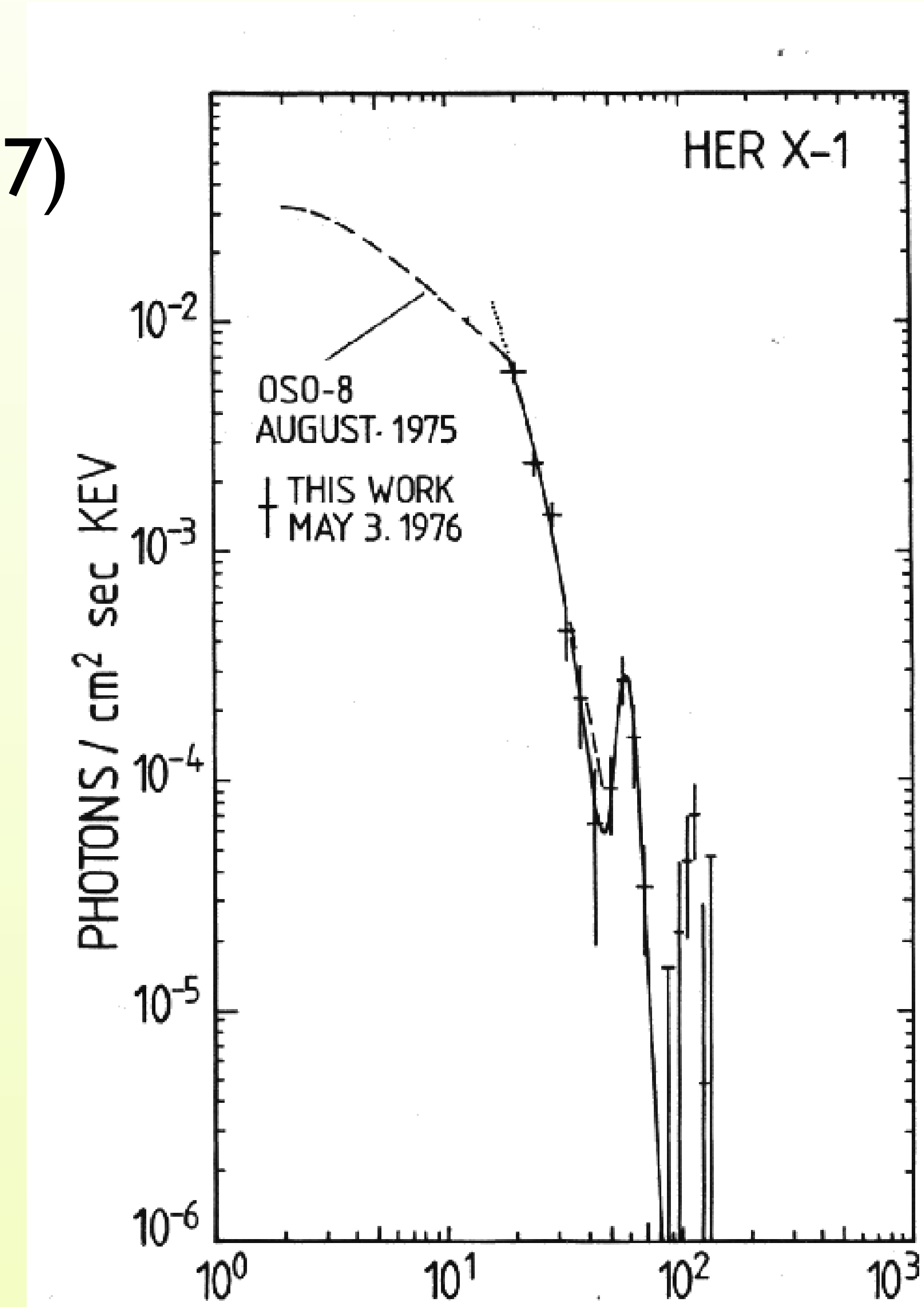
$$E_n = nE_{cyc} = (1+z)E_{\mathrm{n,obs}}$$

gravitational redshift: z ~ 0.25

relativistic corrections: $$E_n = \left[\sqrt{1+2n\sin^2\theta\frac{B}{B_{\mathrm{crit}}}}-1\right]\times\frac{1}{\sin^2\theta}$$

Cyclotron Lines

First obsrvation by Trümper et al. (1977) in Hercules X-1:



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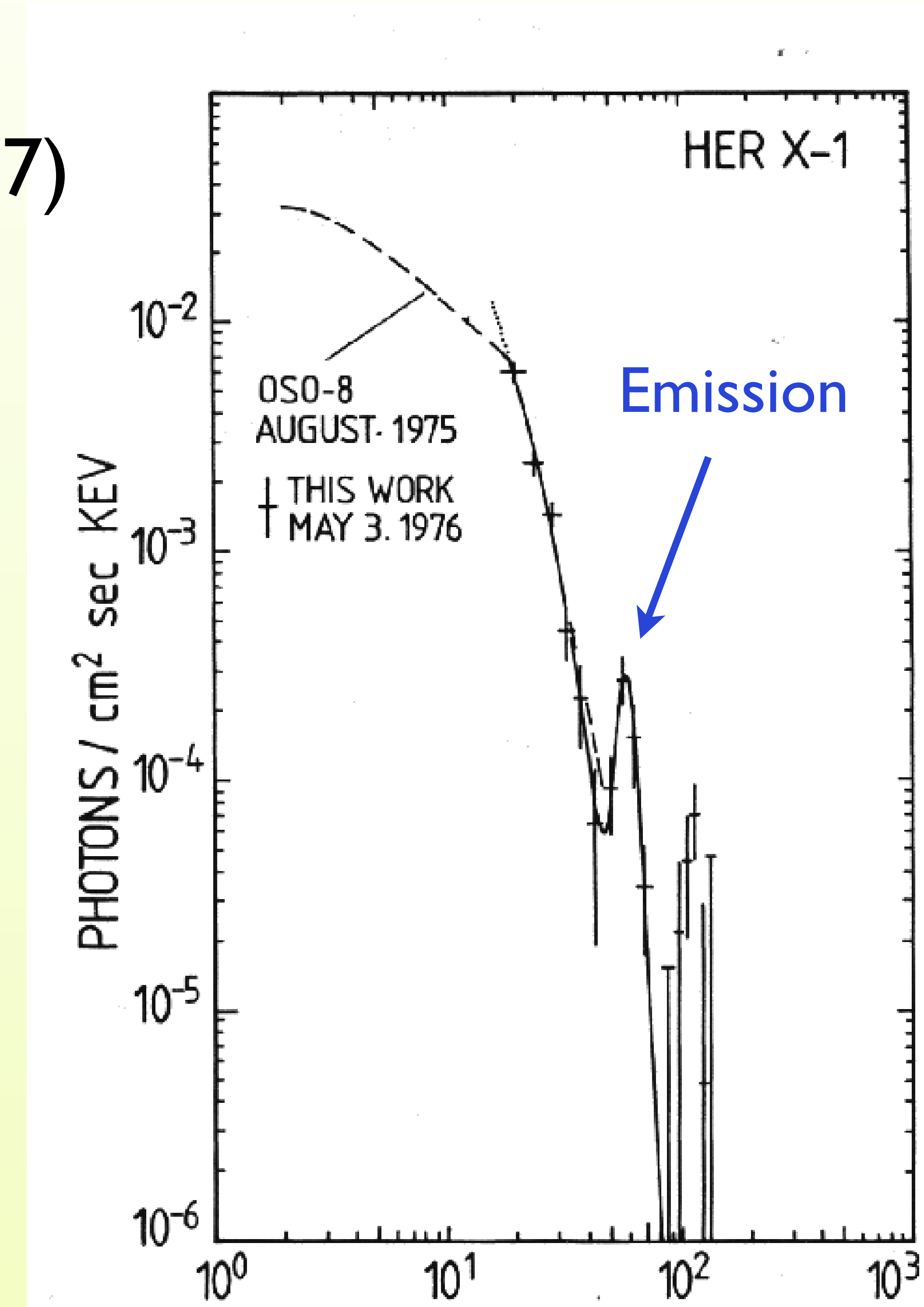
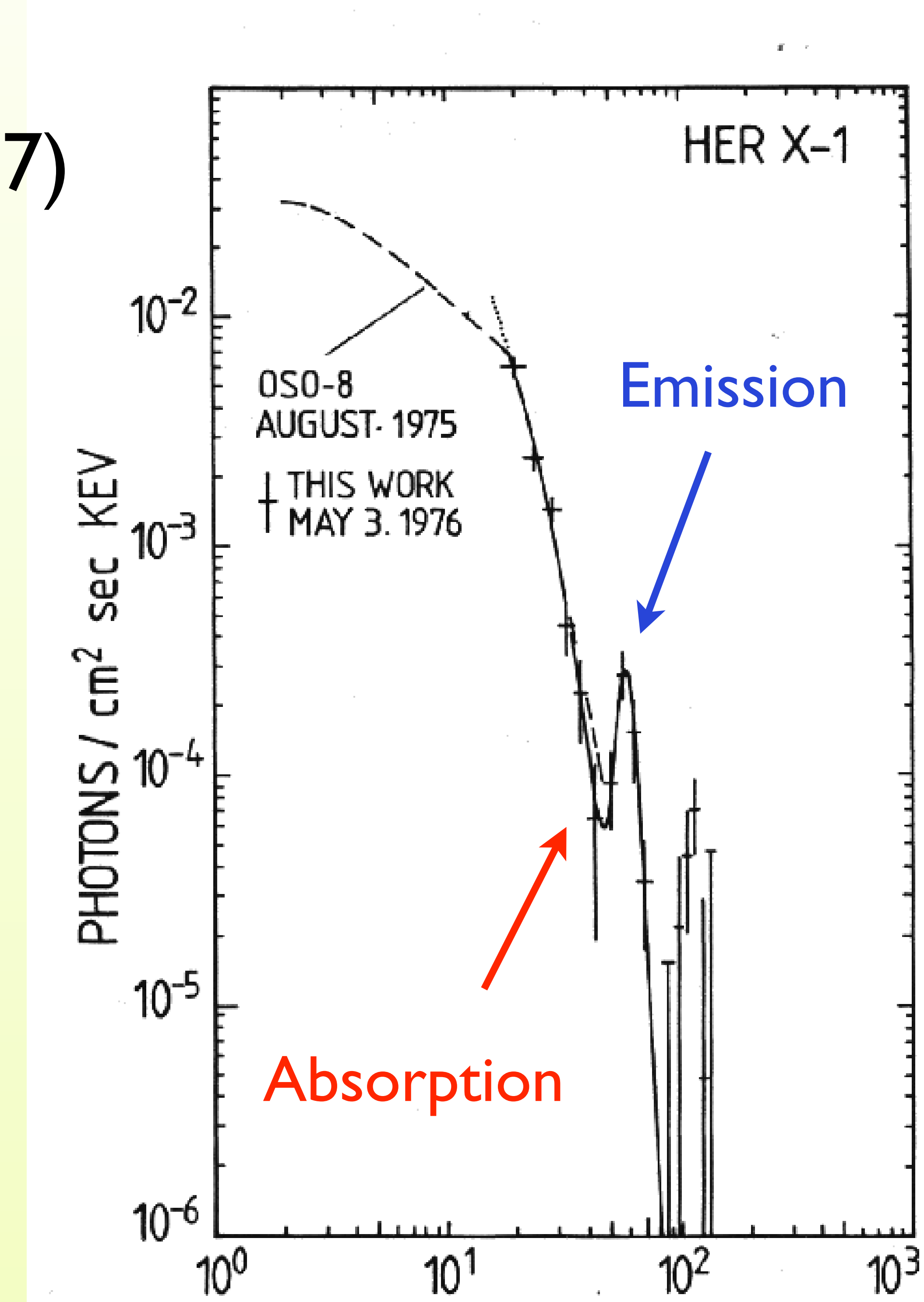


Cyclotron Lines

First obsrvation by Trümper et al. (1977) in Hercules X-1:

$E_{cyc} = 40$ keV



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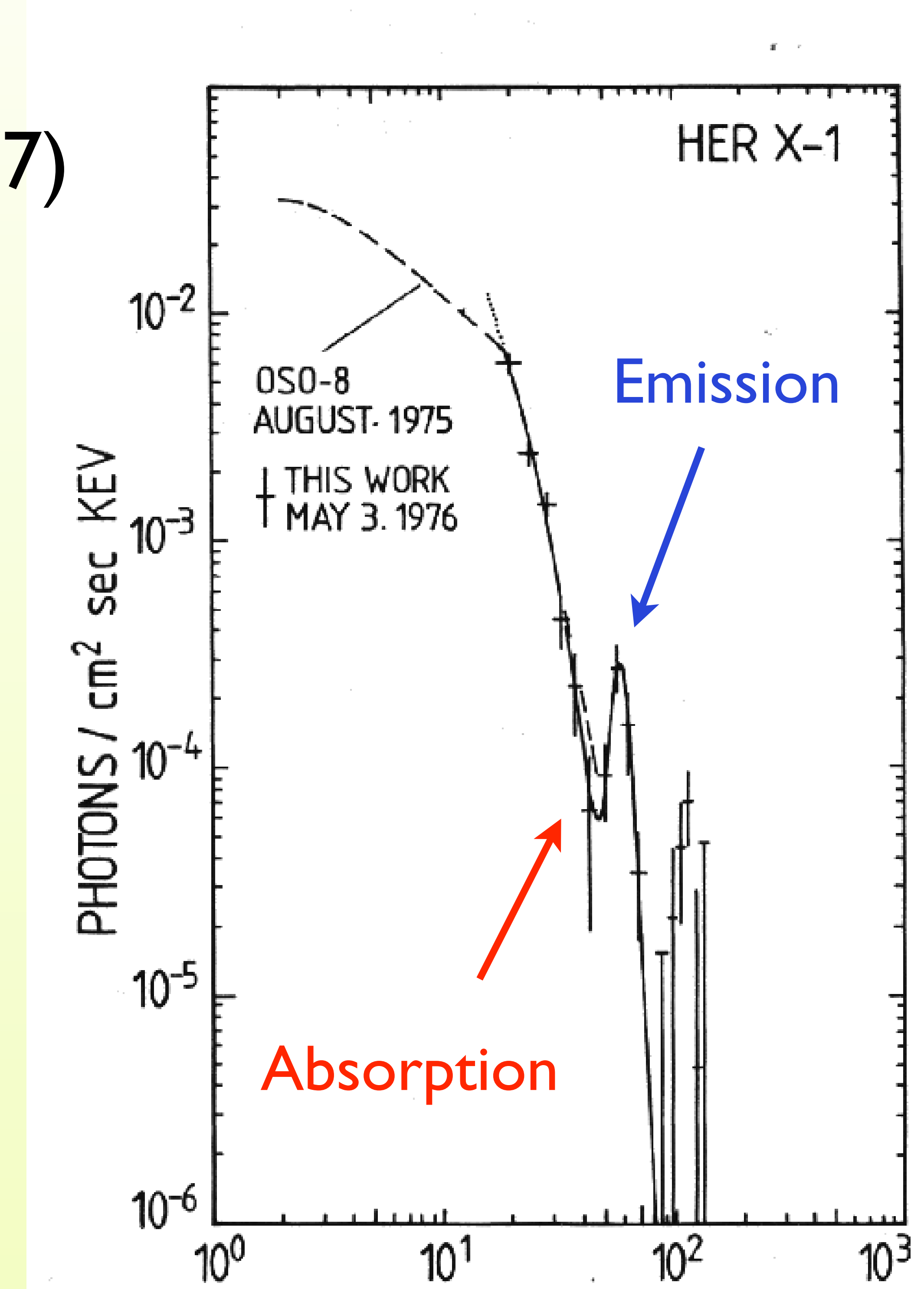
Apply relativistic corrections:

$$E_{\rm cyc}^{\rm obs} = \frac{E_{\rm cyc}}{1+z} = E_{\rm cyc} \times \sqrt{1 - \frac{2GM_{\rm X}}{Rc^2}}$$



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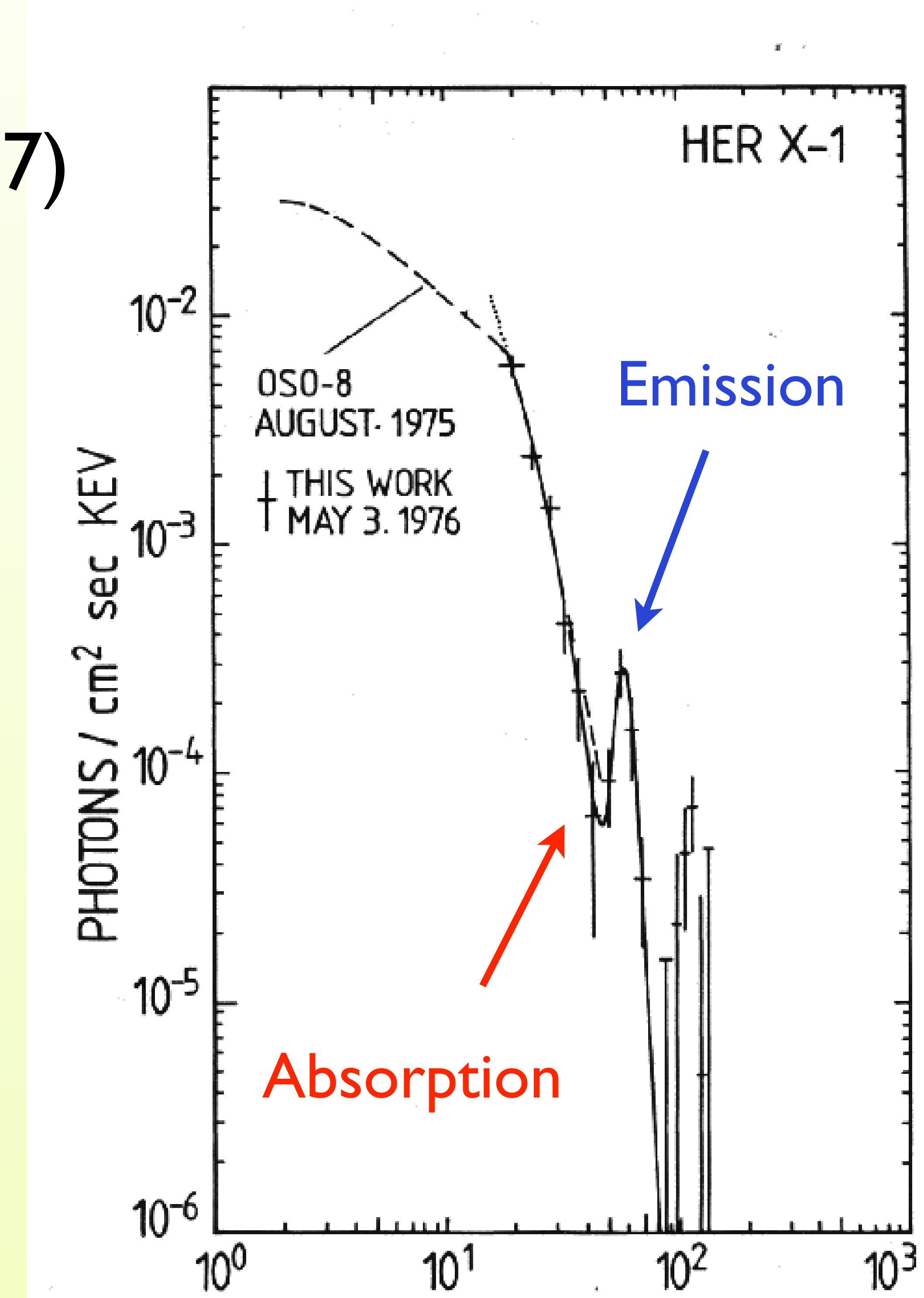
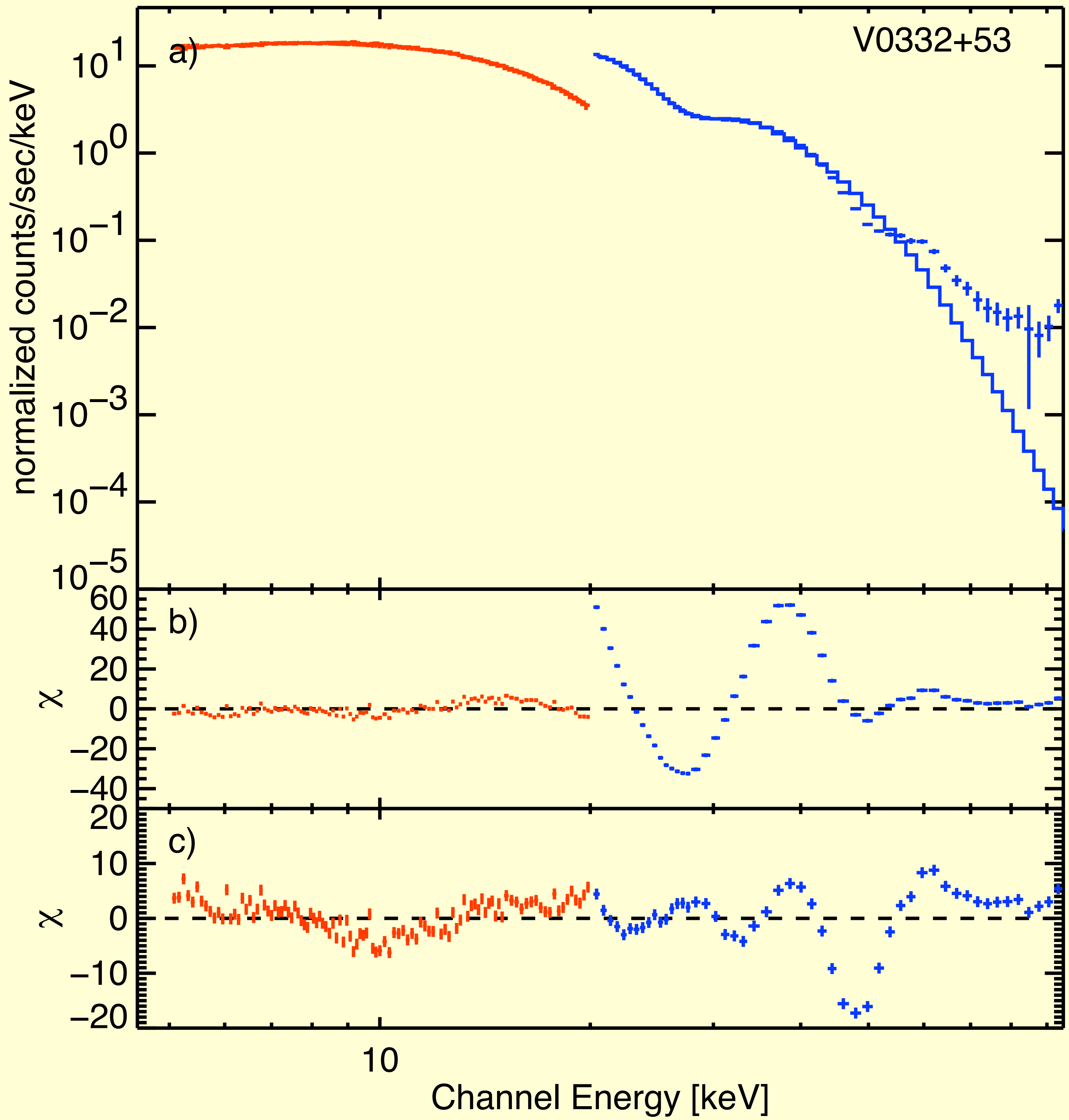
Transitions from higher levels!

$$E_{\rm cyc,n} \approx n \times E_{\rm cyc}$$



V0332+53

CRSFs @
26.5 keV
50.5 keV
71.7 keV



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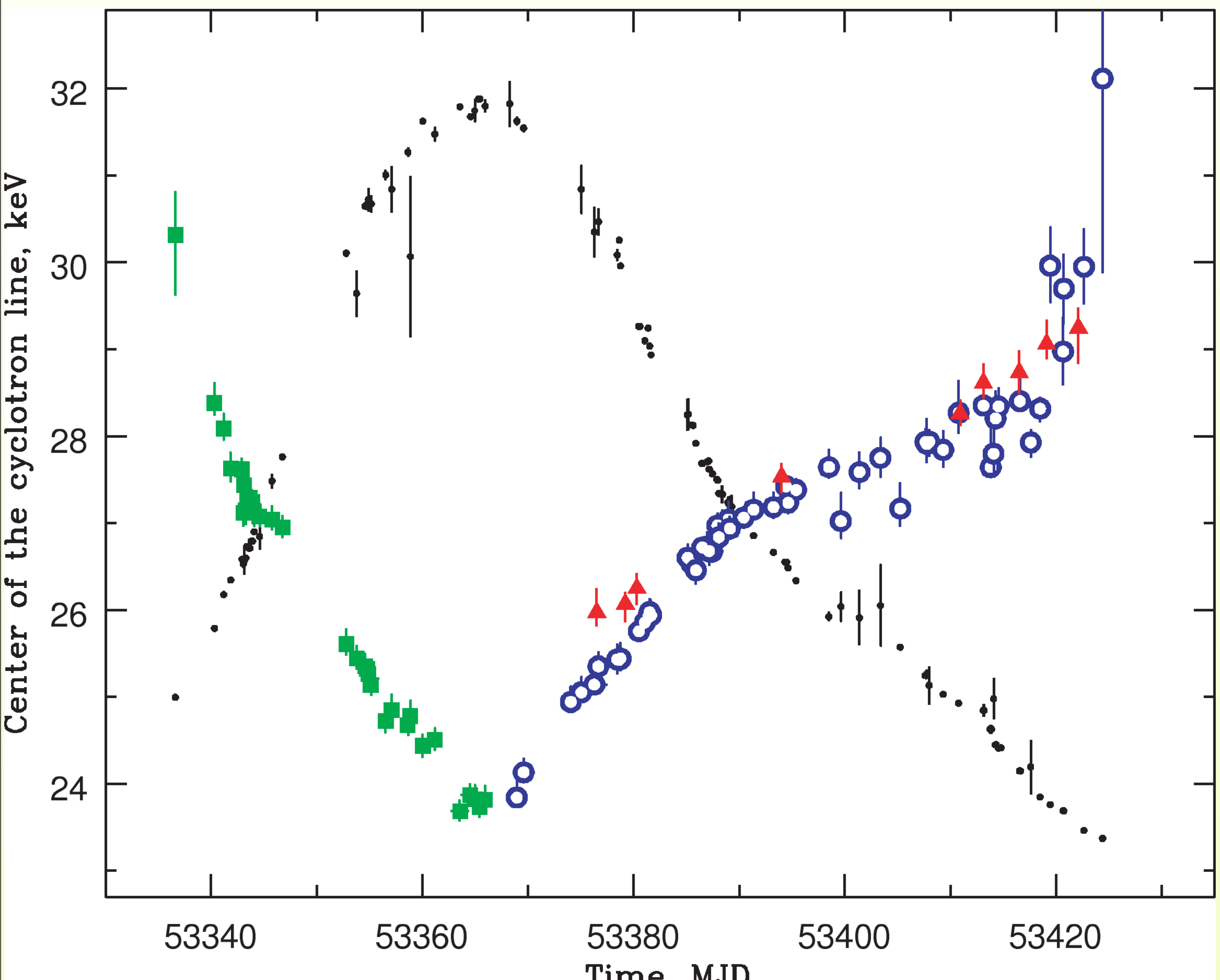
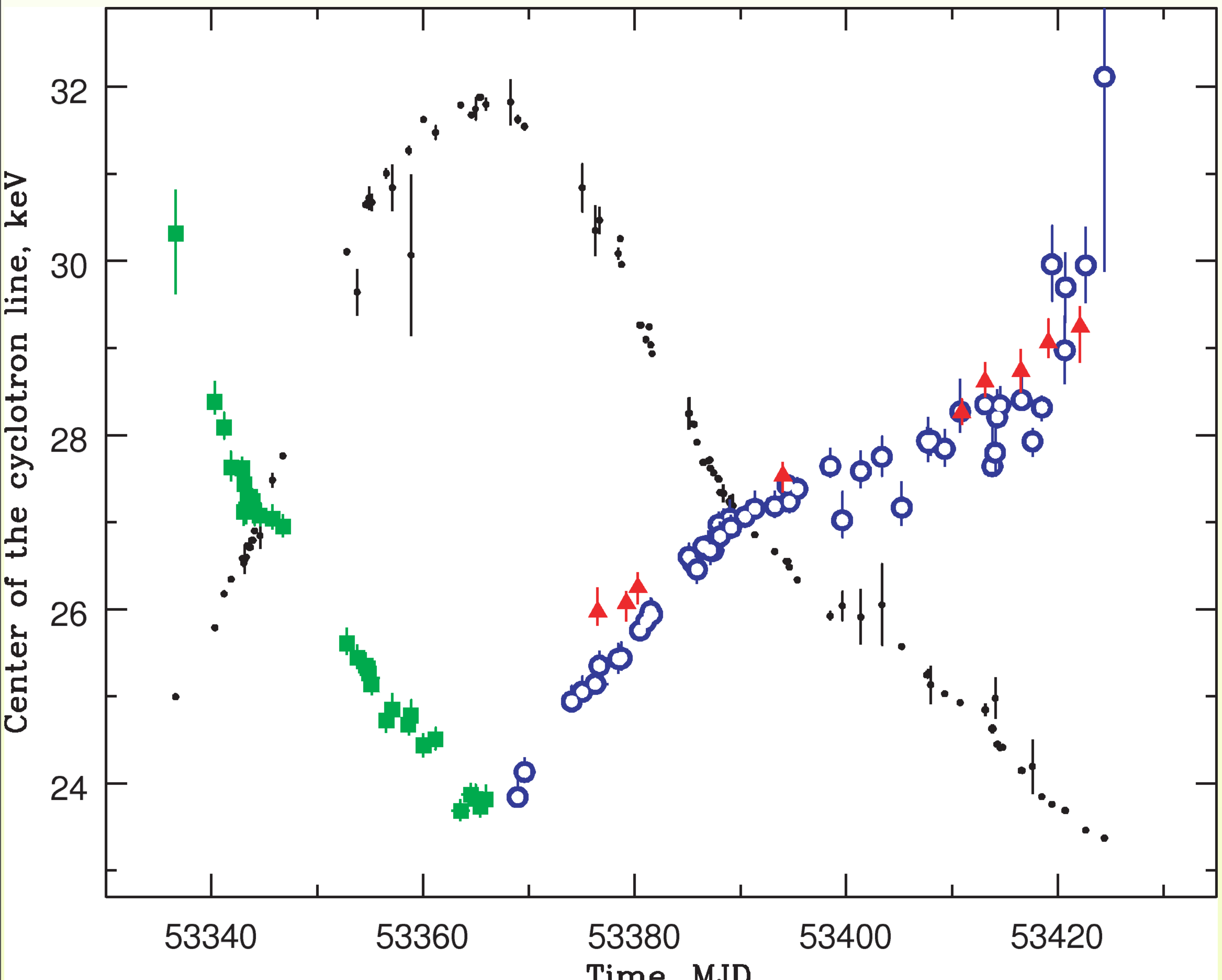


Evolution of the CRSF energy over the outburst

(Tsygankov et a. 2010)

V0332+53

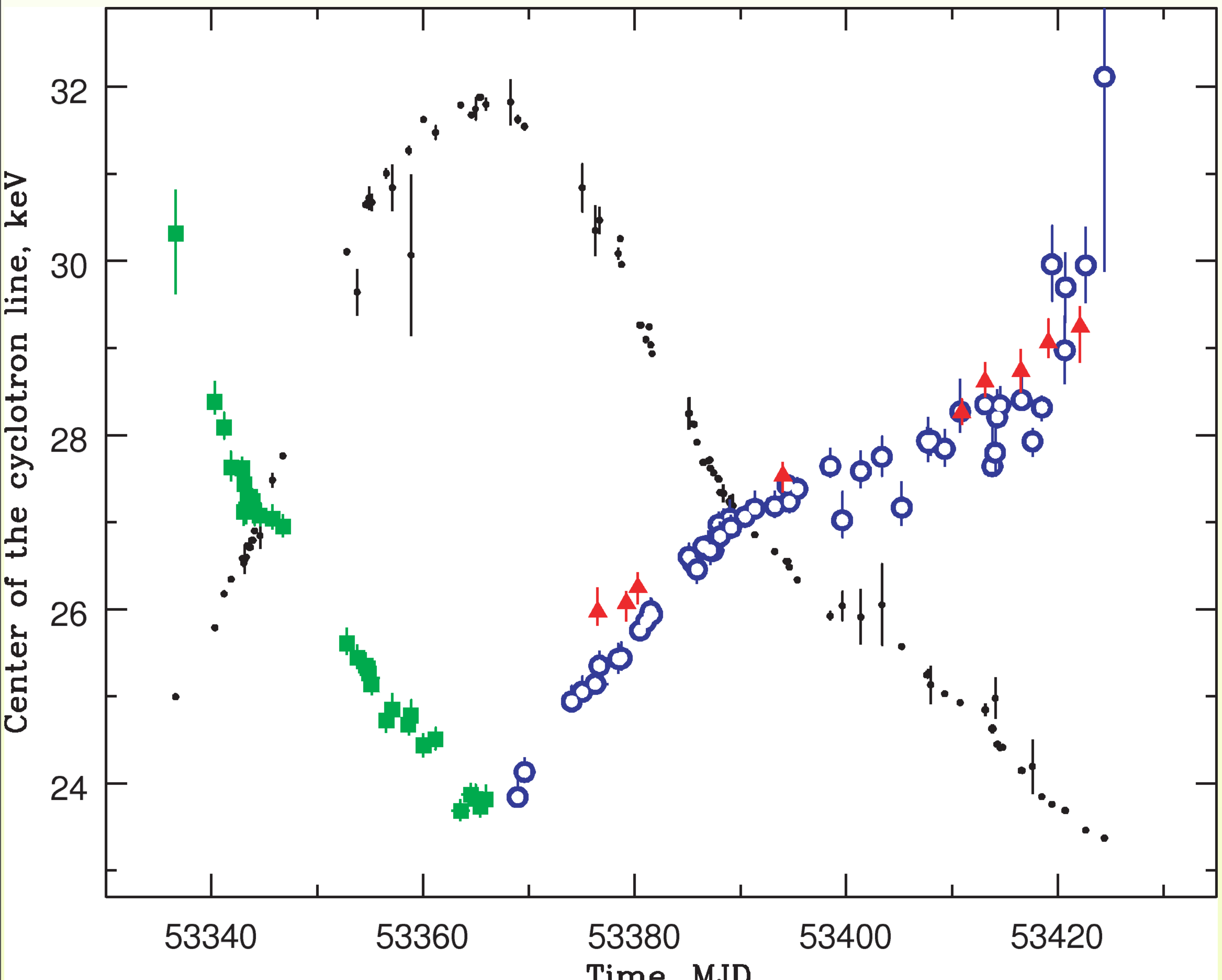


Evolution of the CRSF energy over the outburst

negative correlation

(Tsygankov et a. 2010)

V0332+53



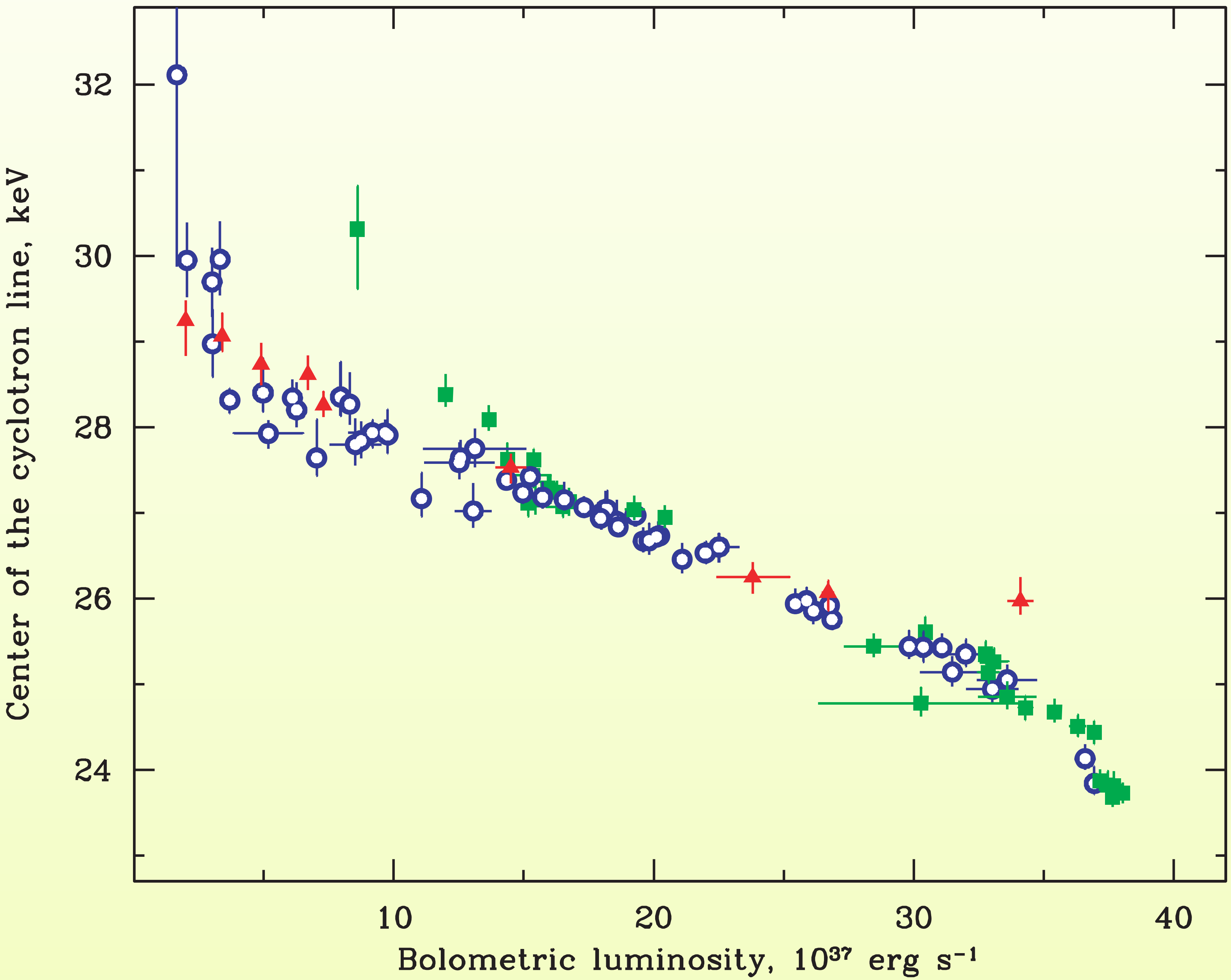
Evolution of the CRSF energy over the outburst

negative correlation

$L_X > L_{crit}$

(Tsygankov et a. 2010)

V0332+53

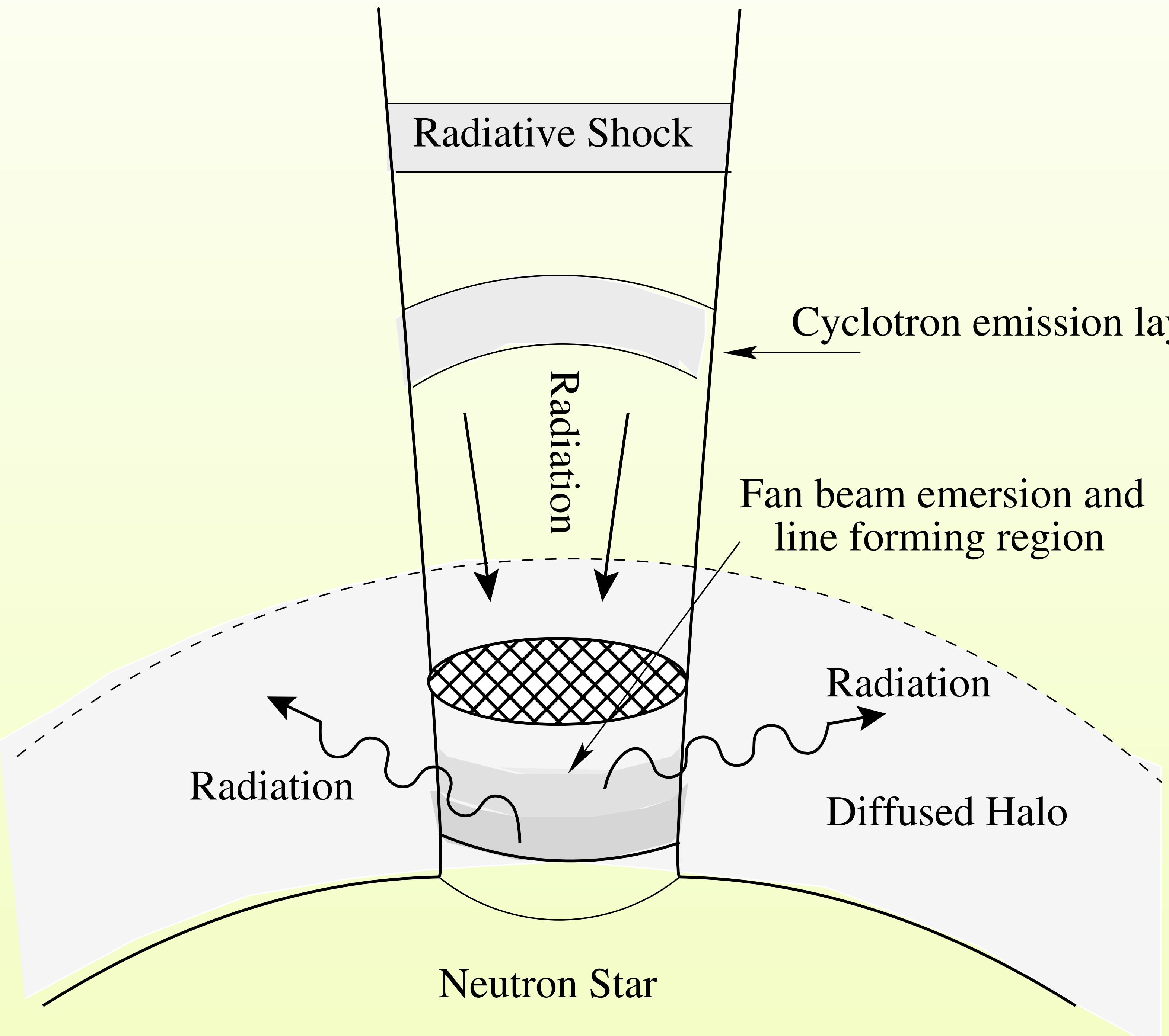


Evolution of the CRSF energy with luminosity

negative correlation

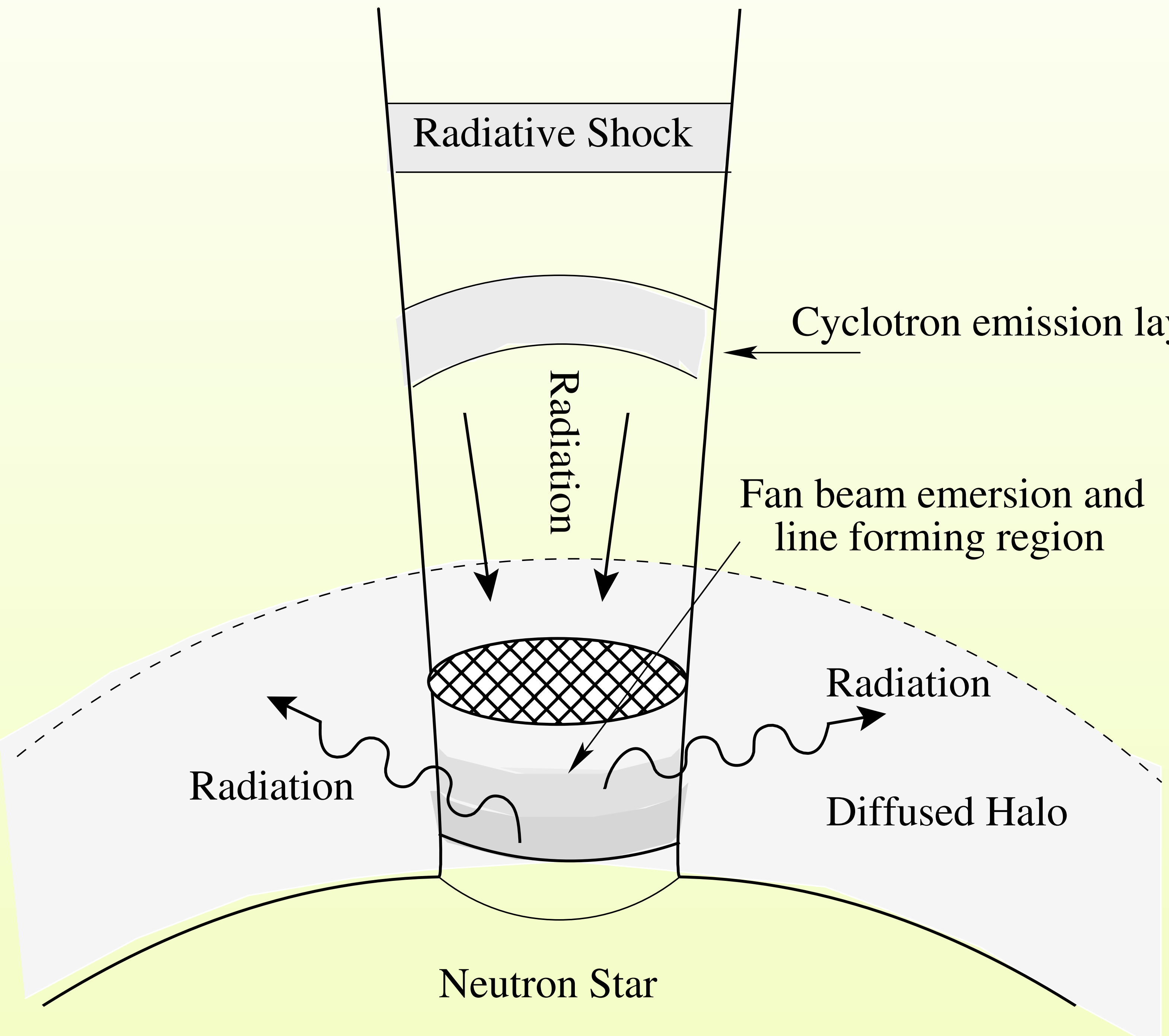
(Tsygankov et a. 2010)

Interpretation



(Ferrigno et al. 2010)

Interpretation



(Ferrigno et al. 2010)

line forming region moves in height

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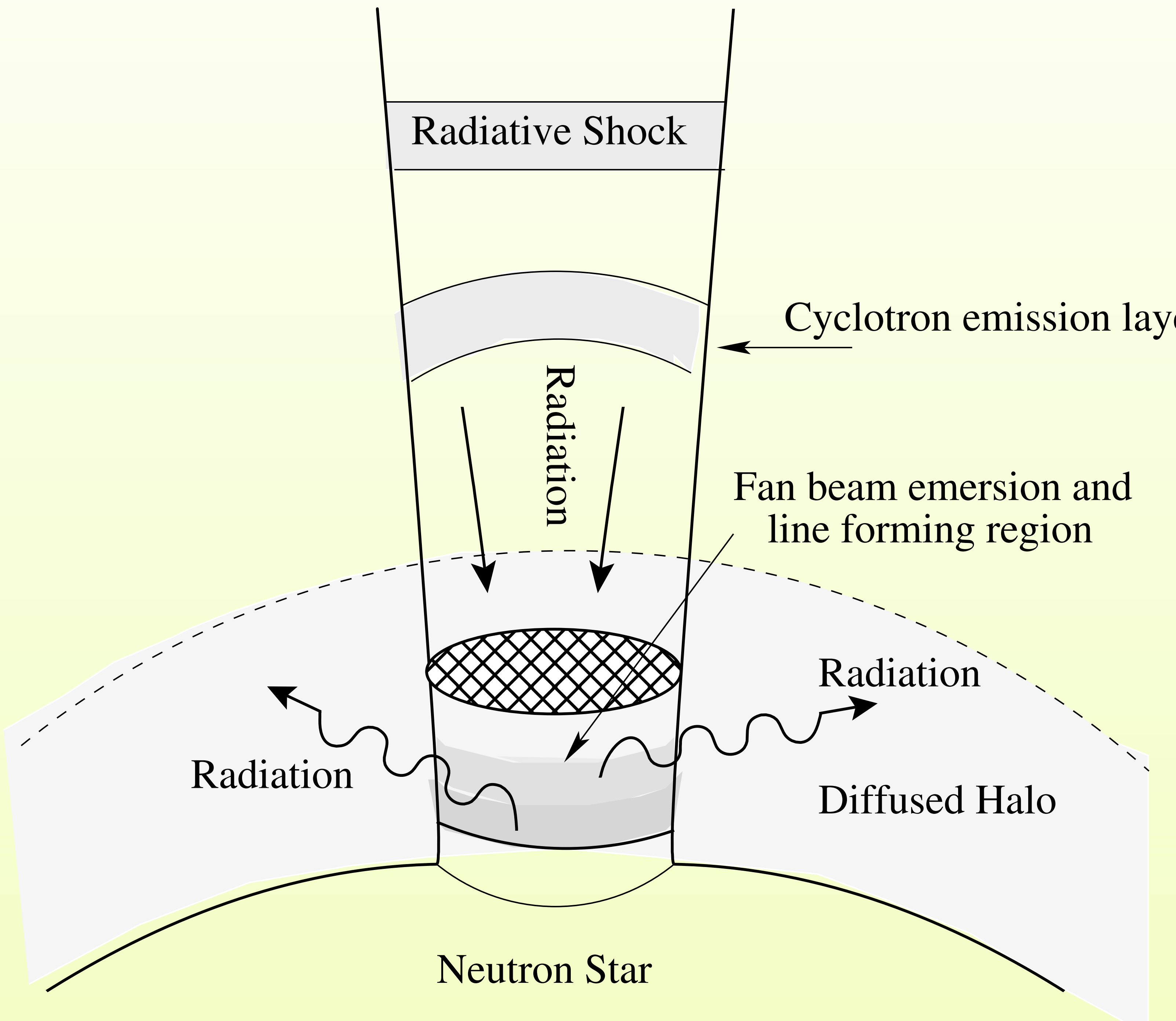


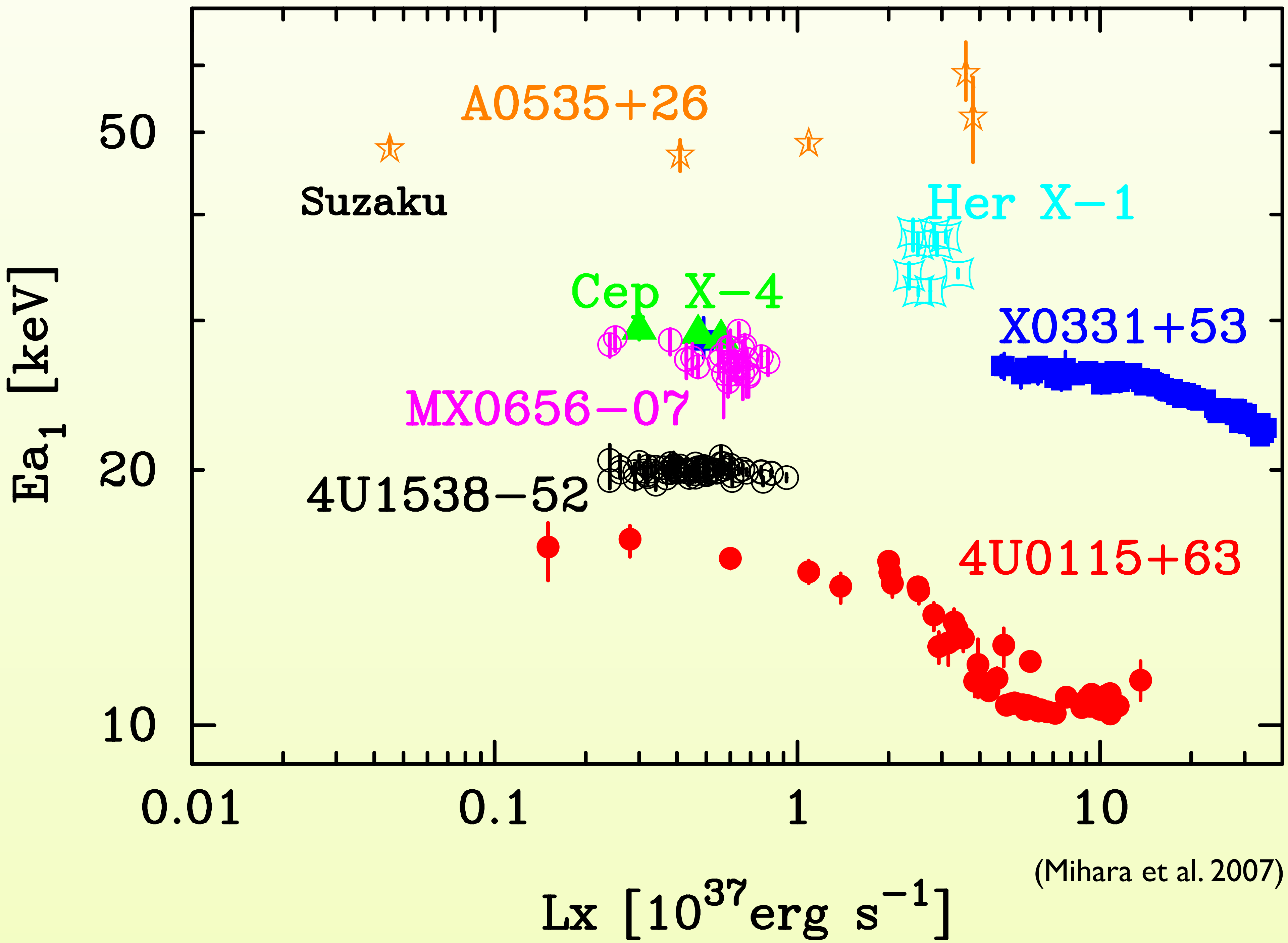
(Ferrigno et al. 2010)

line forming region moves in height

V0332+53: 330m

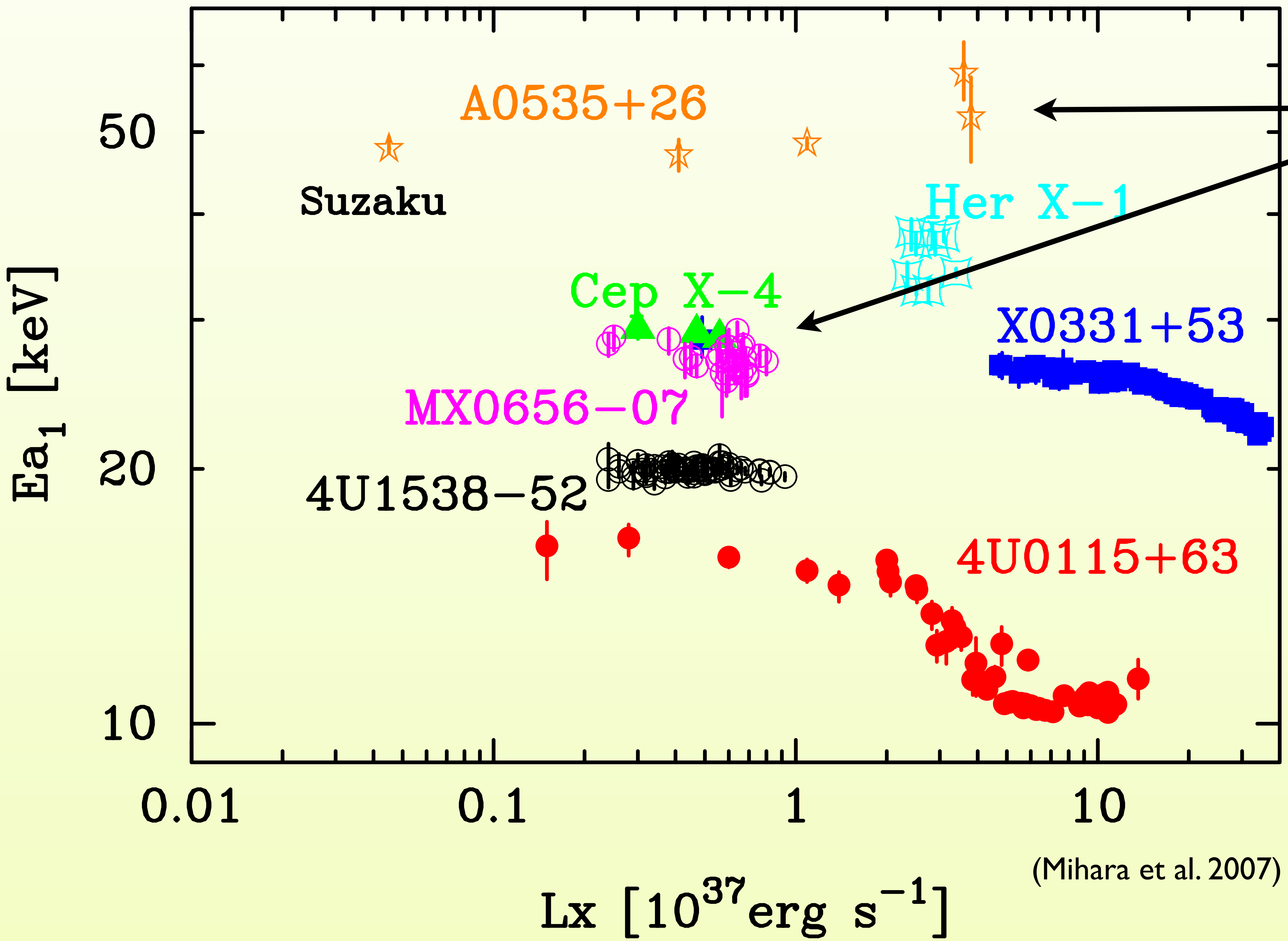
4U0115+63: 1100m

E_{cyc} vs. L_X



(Mihara et al. 2007)

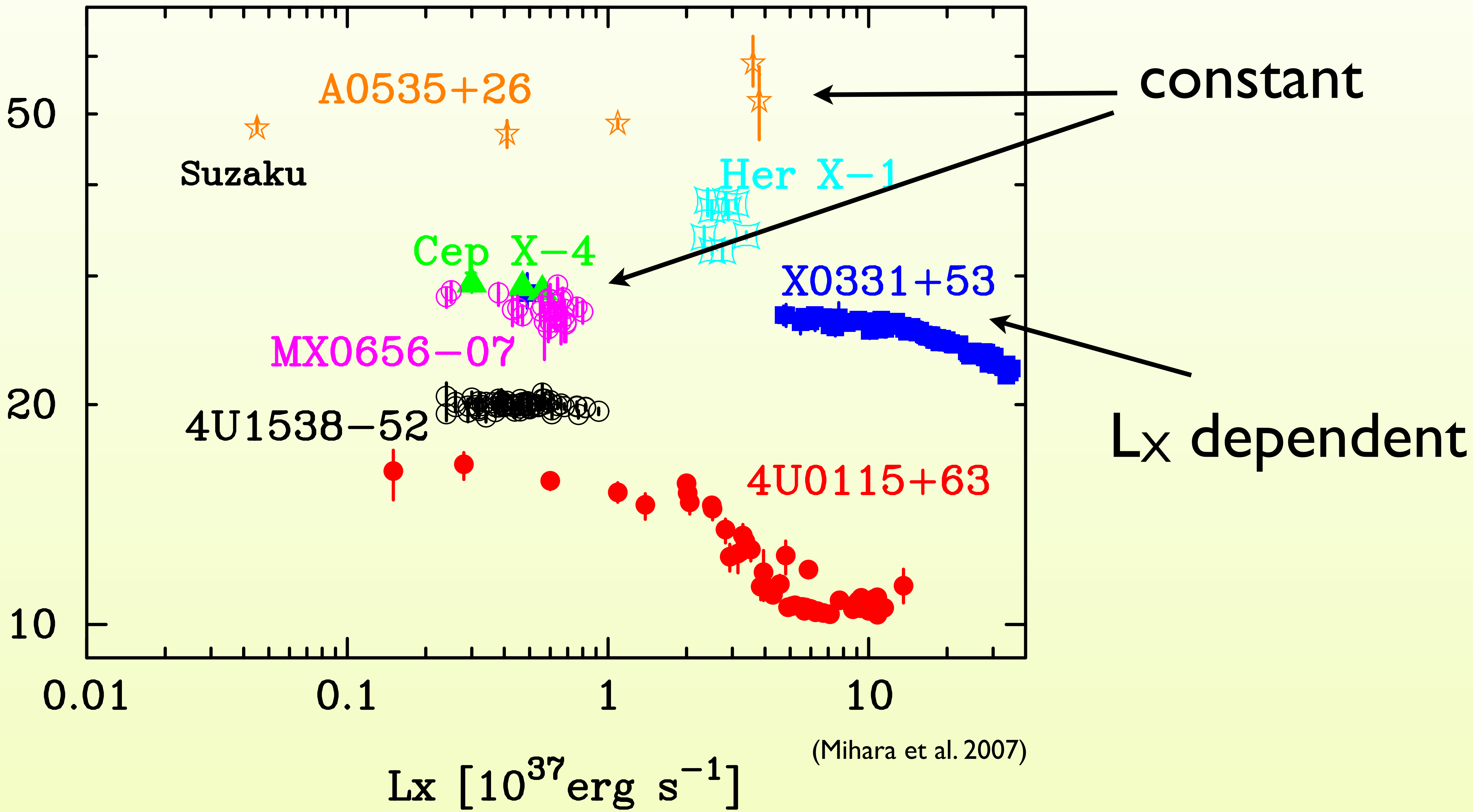
E_{cyc} vs. L_X



constant

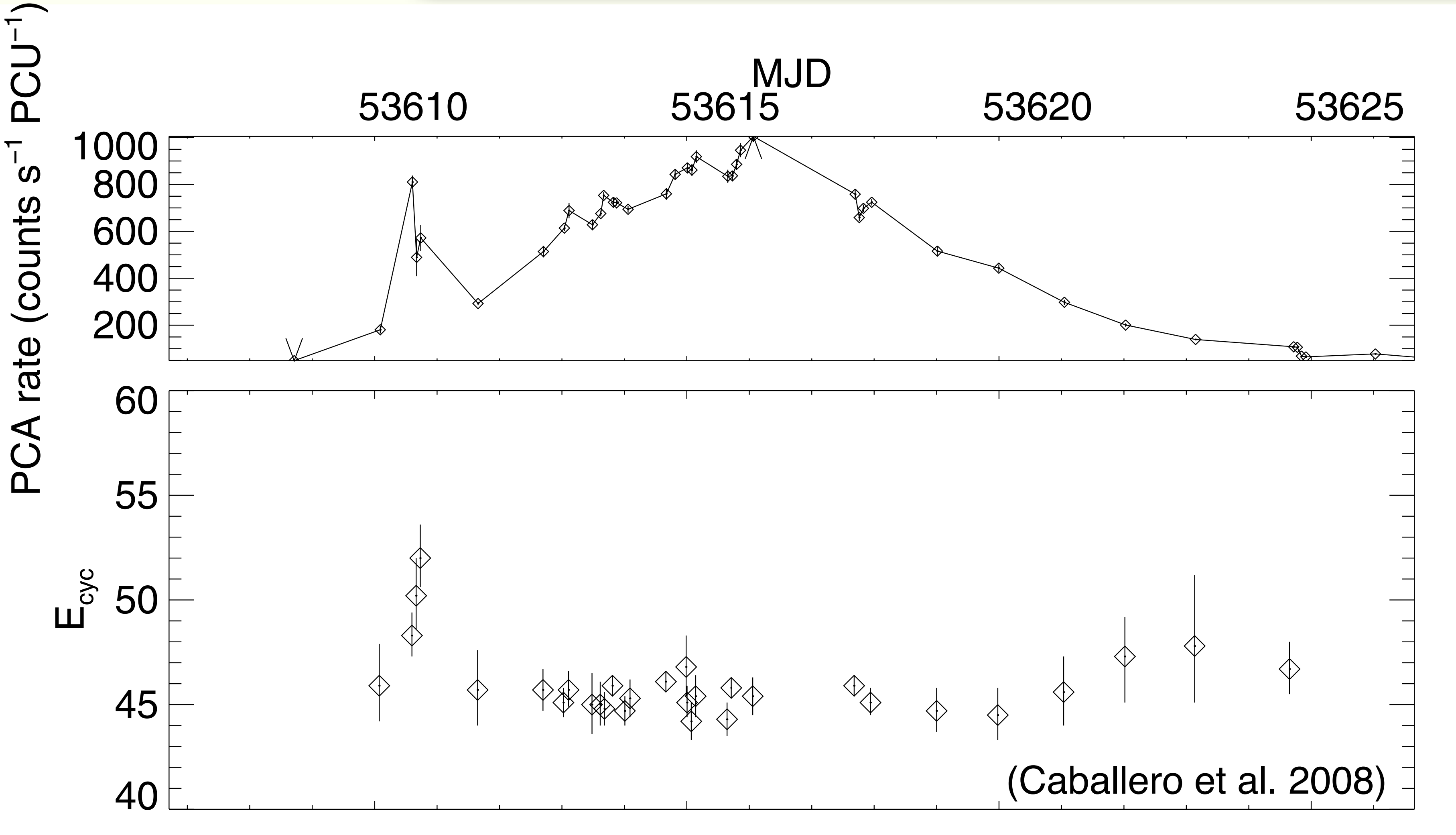
(Mihara et al. 2007)

E_{cyc} vs. L_X



(Mihara et al. 2007)

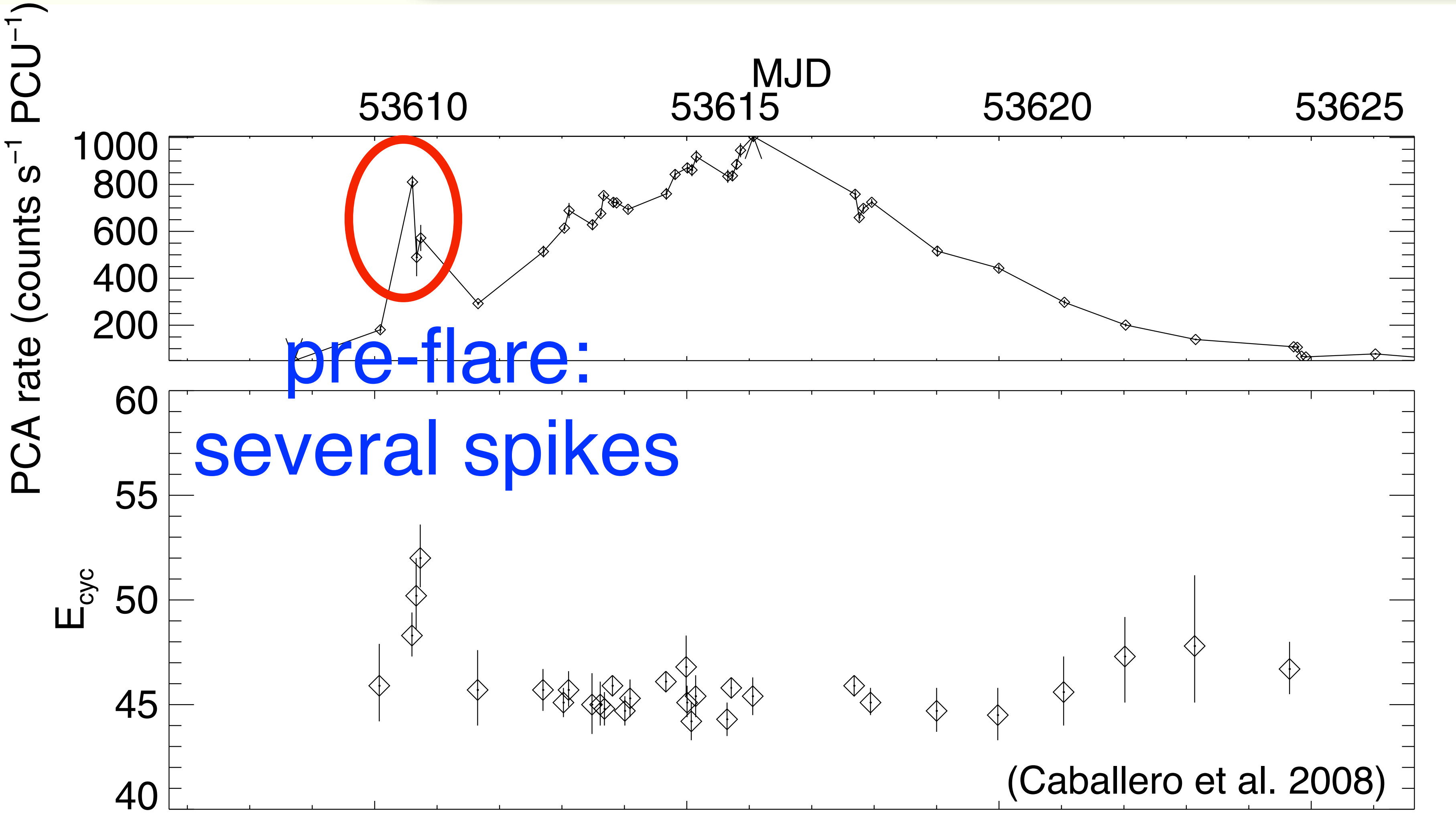
mag. Instabilities



2005 outburst of A0535+26

E_{cyc} constant over whole outburst...

mag. Instabilities



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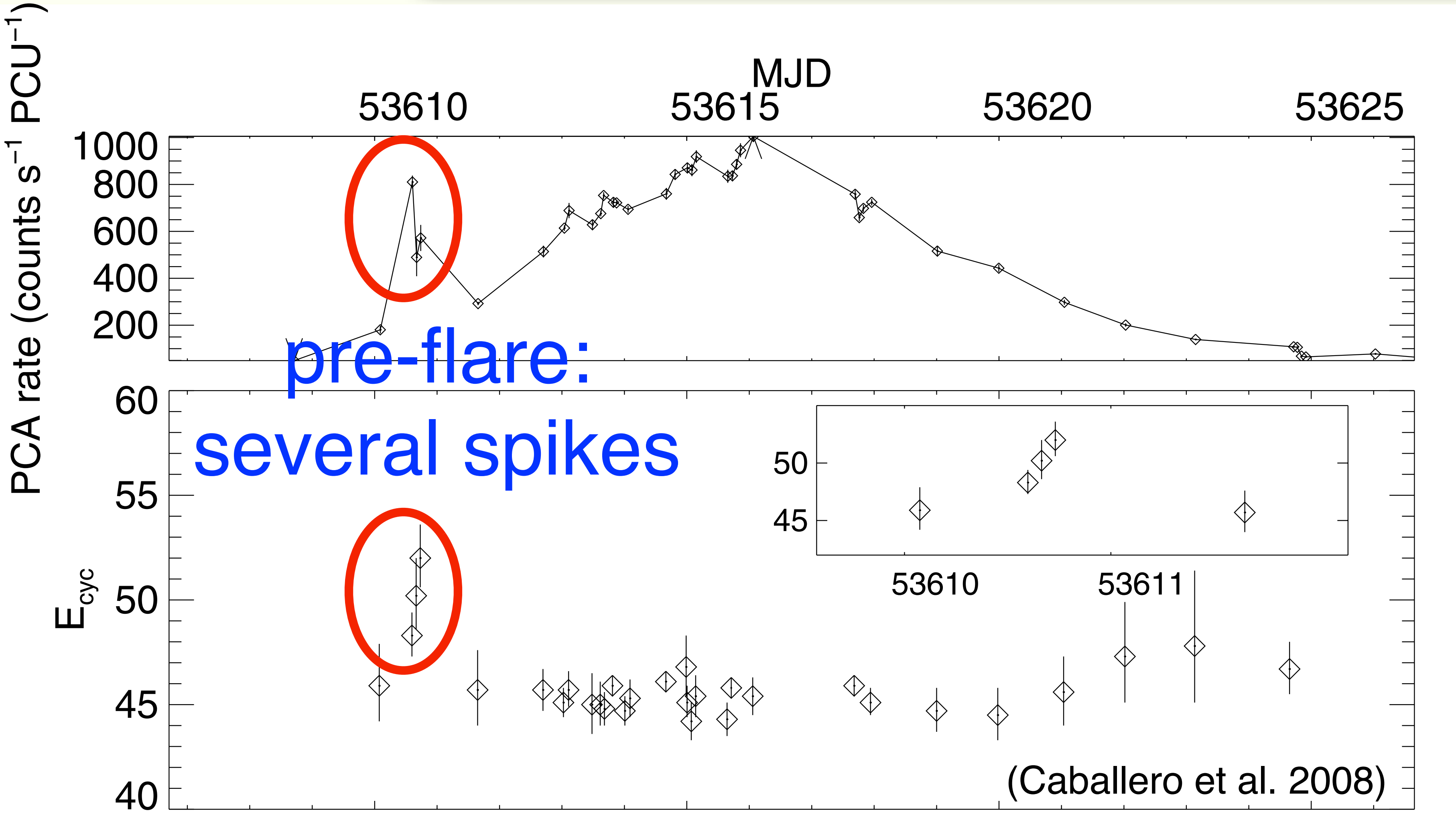

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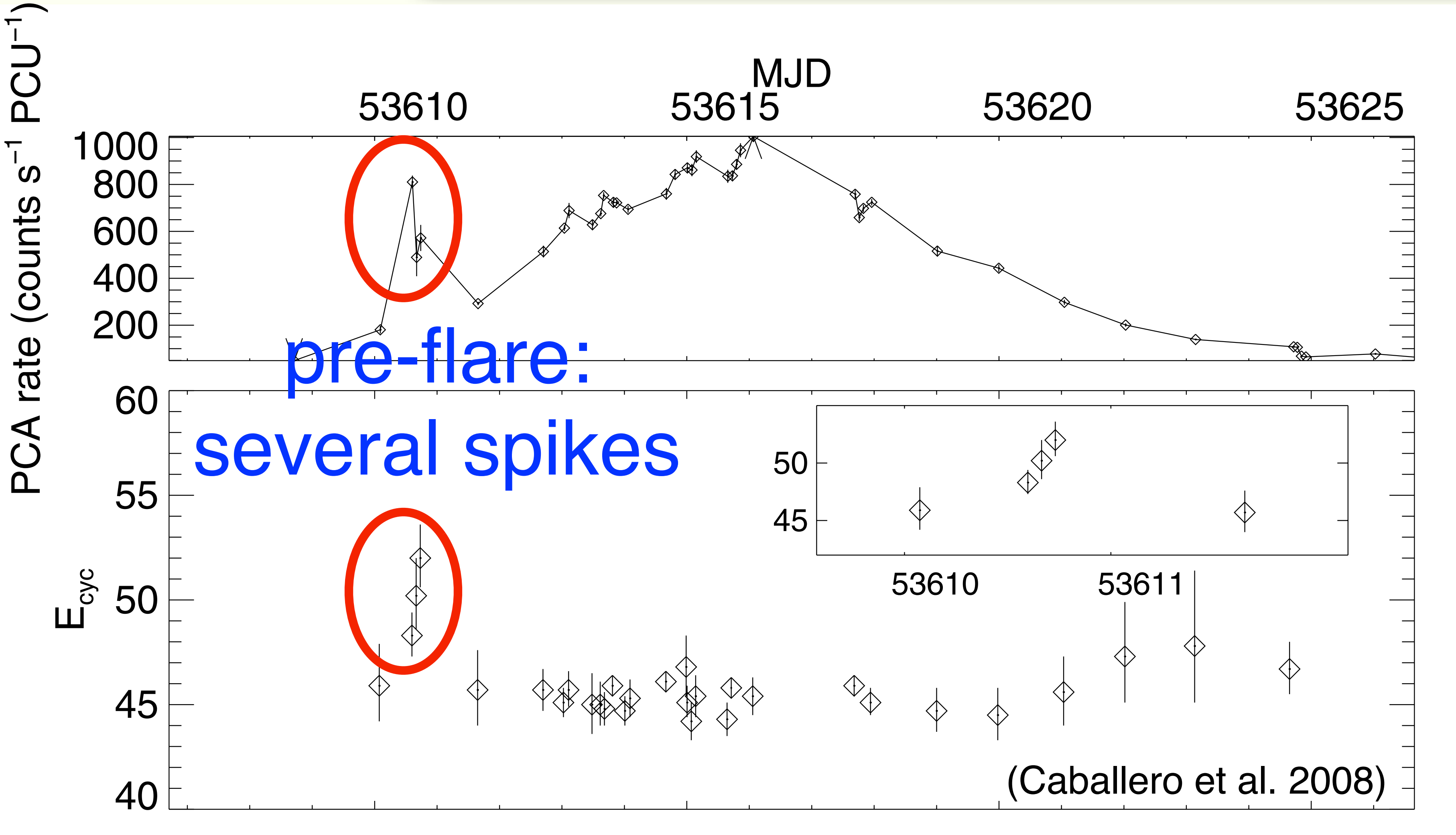


pre-flare:
several spikes

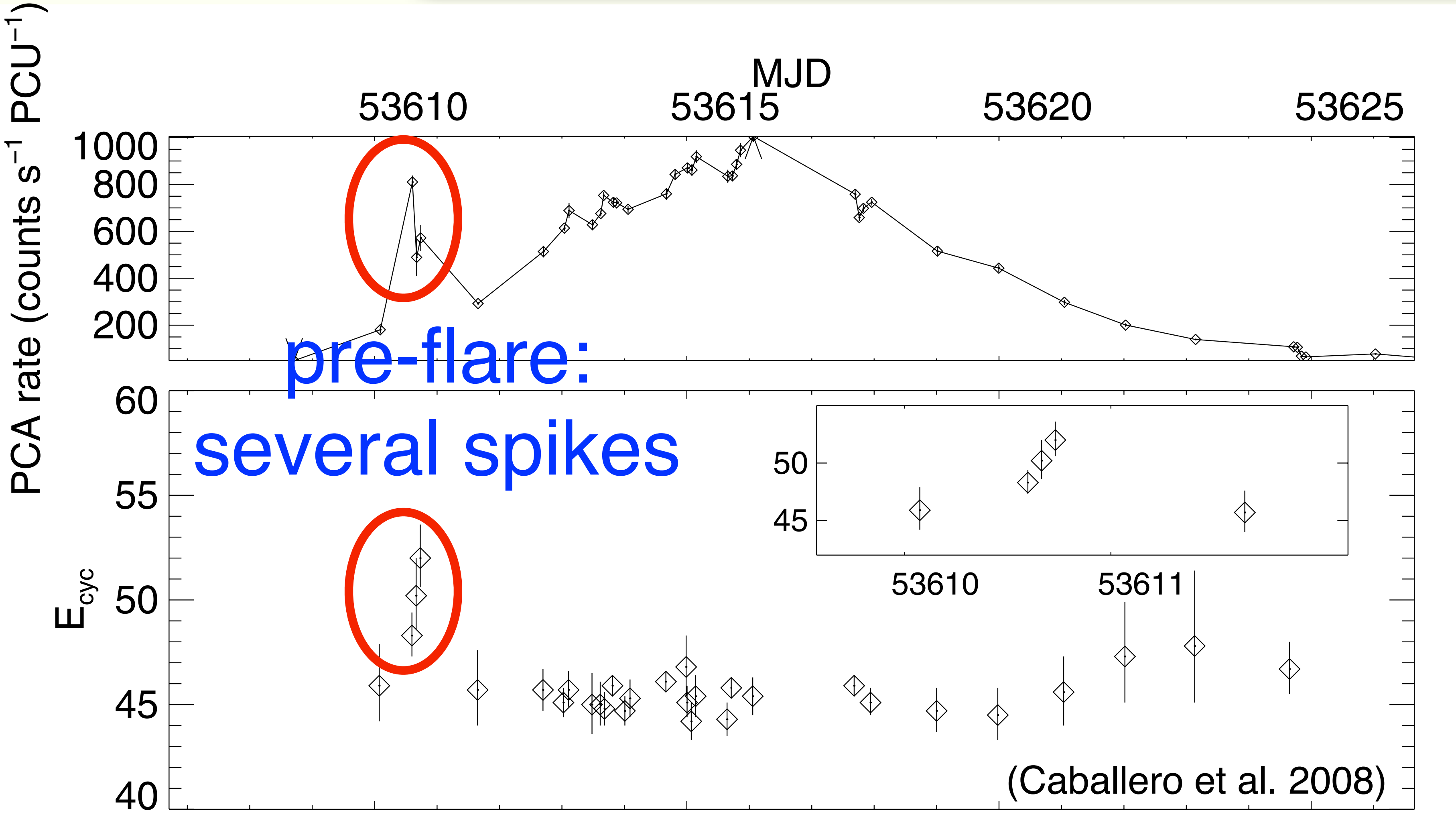
2005 outburst of A0535+26

E_{cyc} constant over whole outburst...

almost

significant jump of E_{cyc} from 46 to 52 keV

mag. Instabilities



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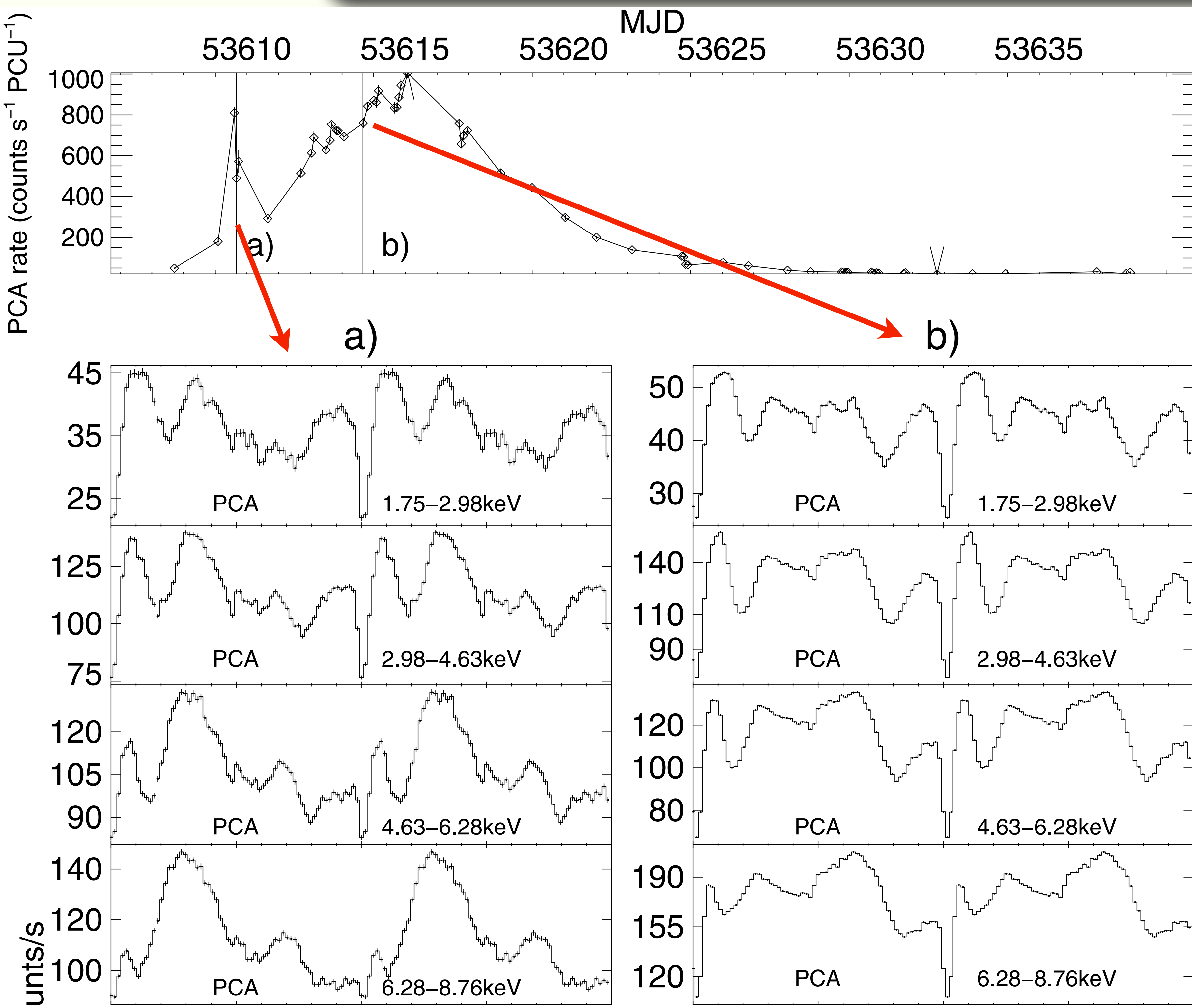
Interpretation: magnetospheric instabilities?

(Postnov et al. 2008)

mag. Instabilities



(Caballero et al. 2008)

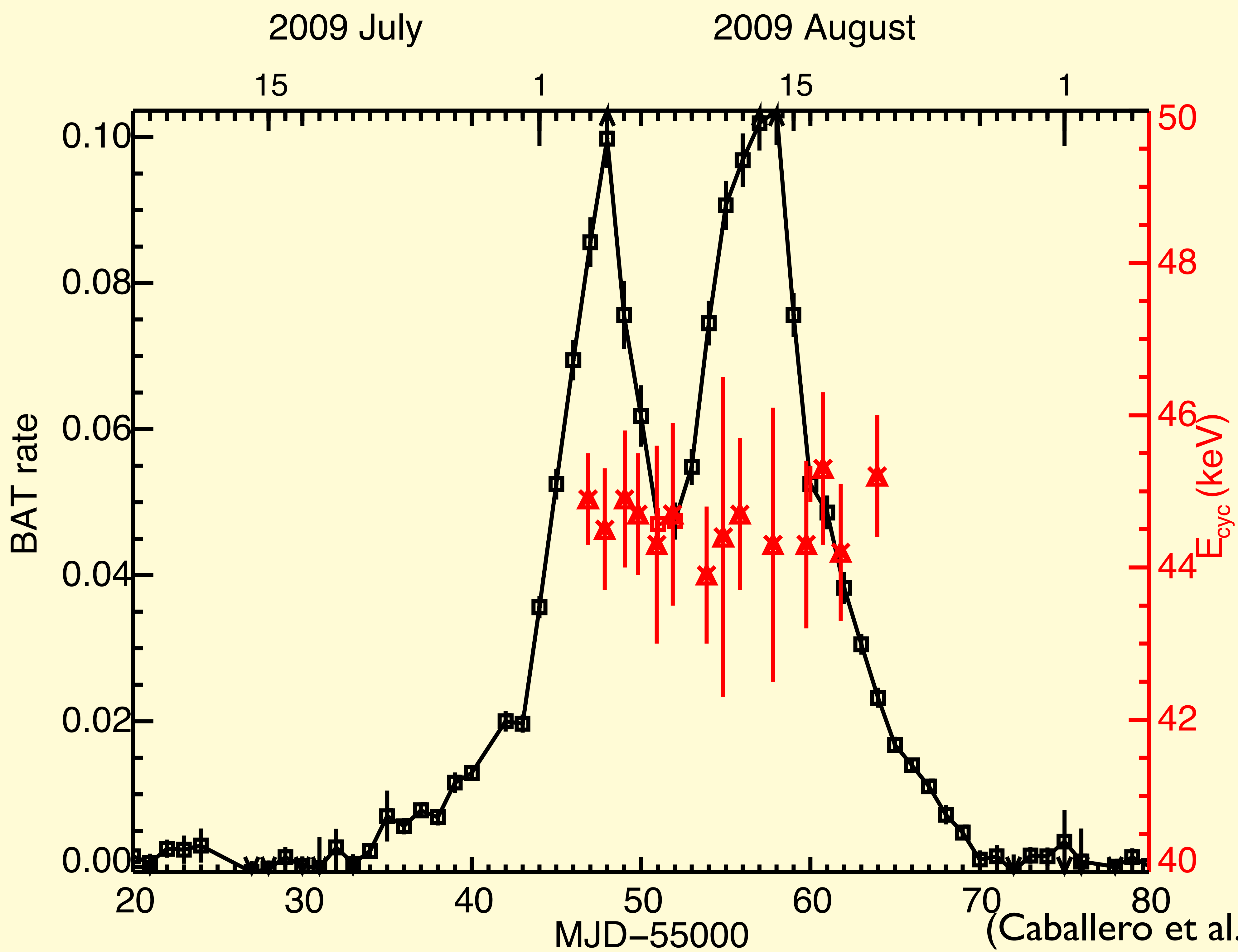
2005 outburst of A0535+26

dramatic change of pulse profiles

also explained by mag. instabilities

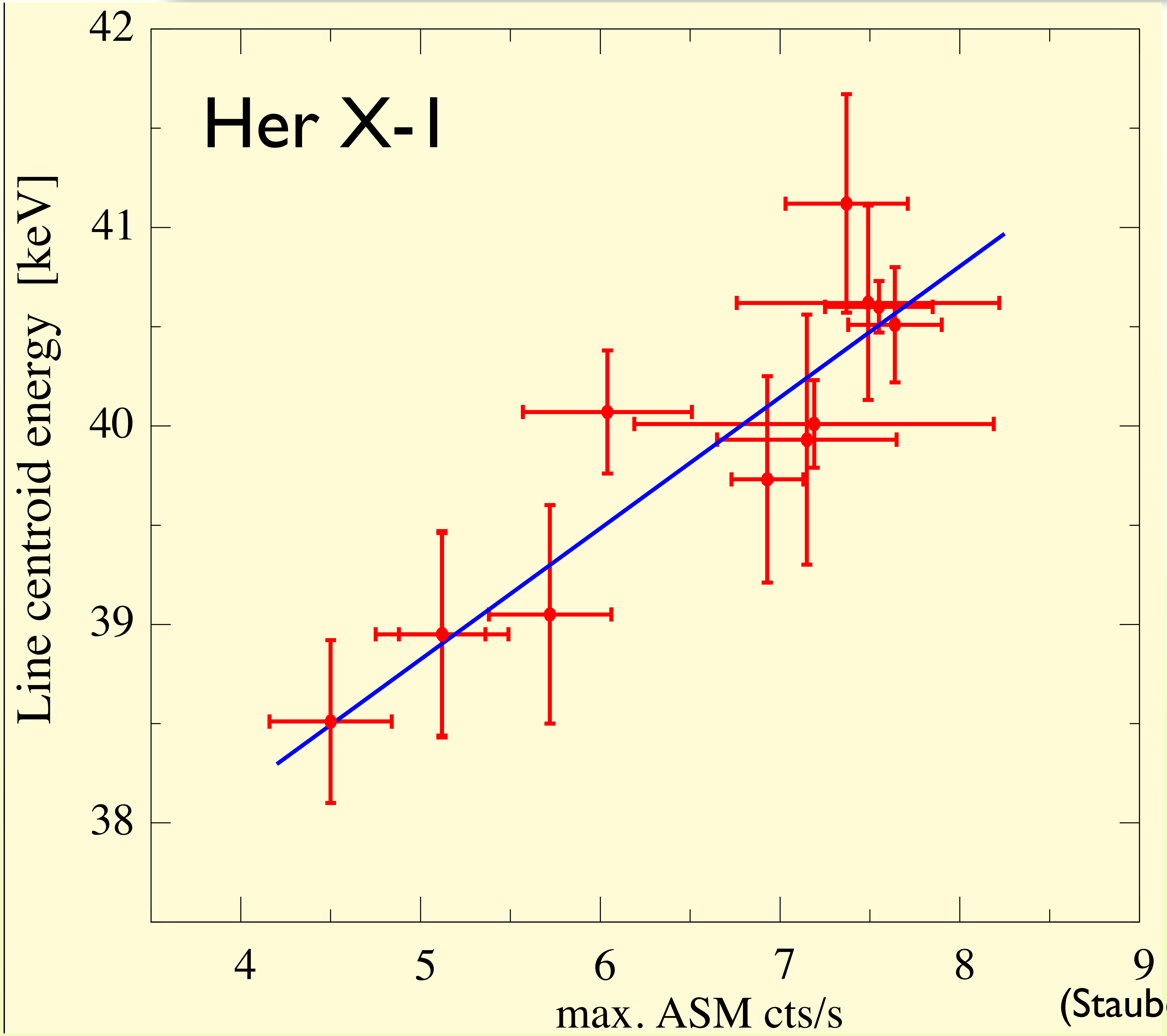
(Postnov et al. 2008)

A0535+26



(Caballero et al. 2009)

positive Correlation

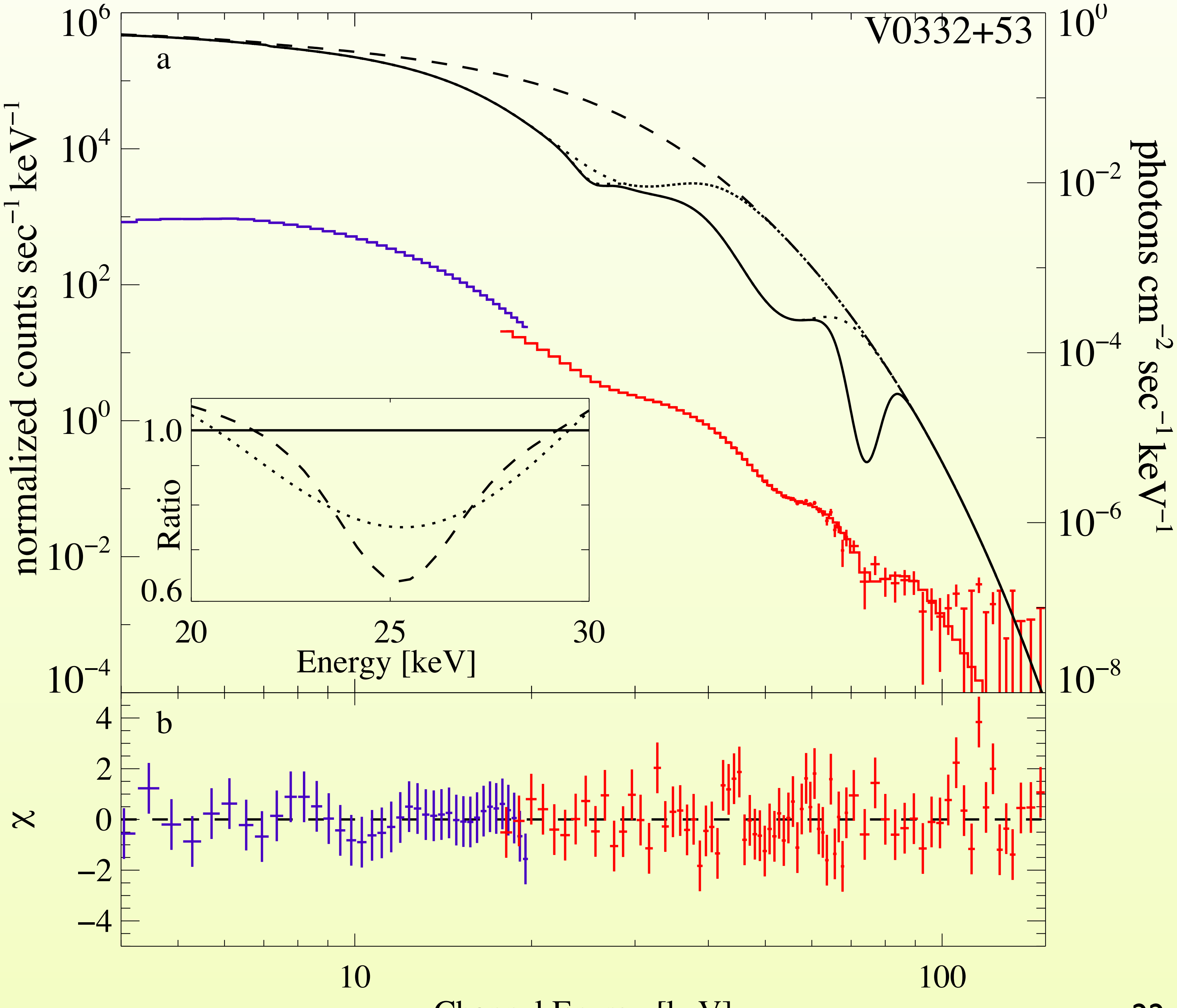


$L_X < L_{crit}$

(Staubert et al. 2007)

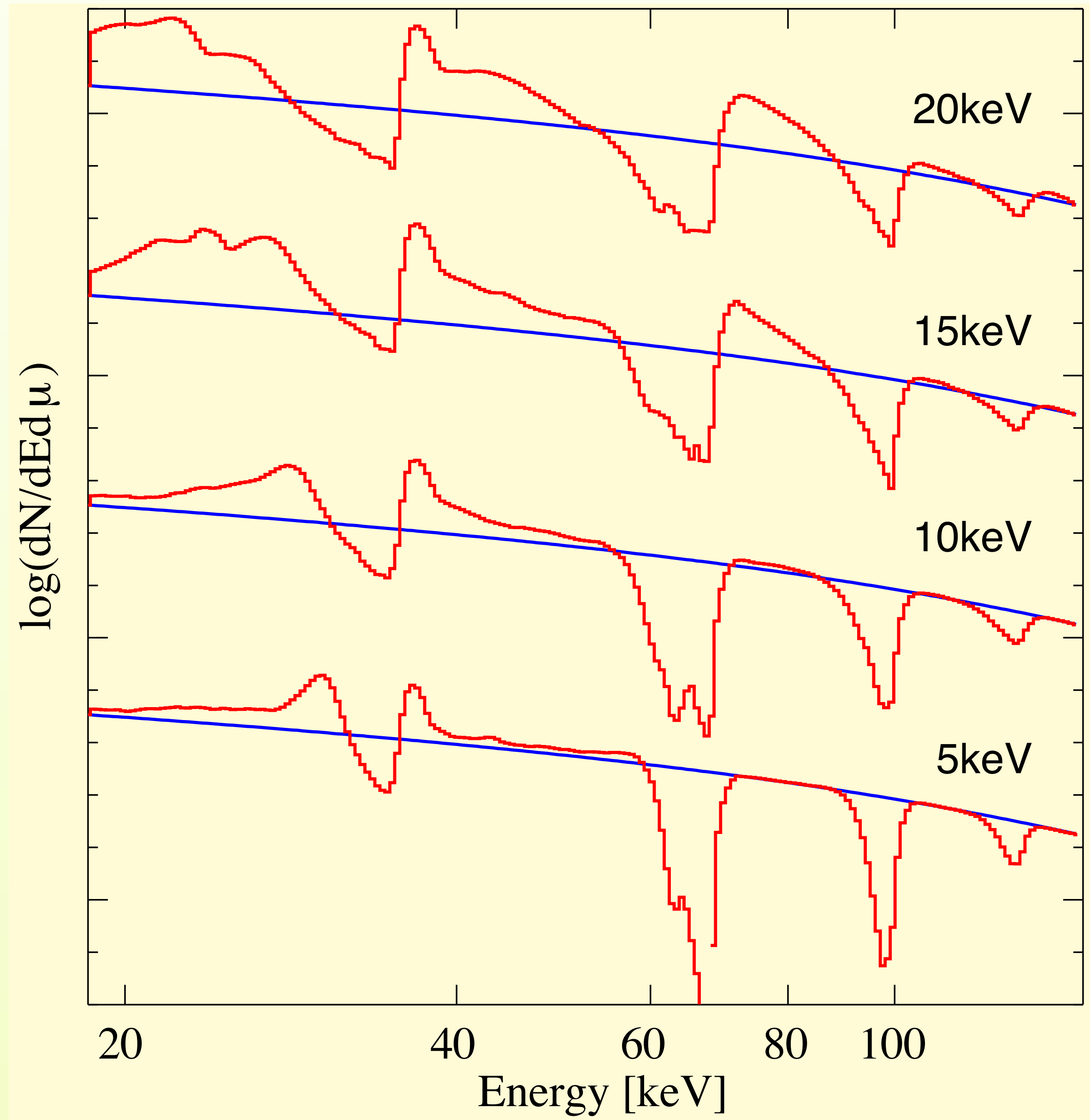
V0332+53

- fundamental has structure!
- Gaussians @ 24.9, 29.0, 50.5, 71.7 keV
- Monte Carlo simulations to model CRSFs



CRSFs

- use Monte-Carlo simulation of lines
- dependence on electron temperature
- dependence on angle
- dependence on optical depth
- B-field



(Schönherr et al. 2007)

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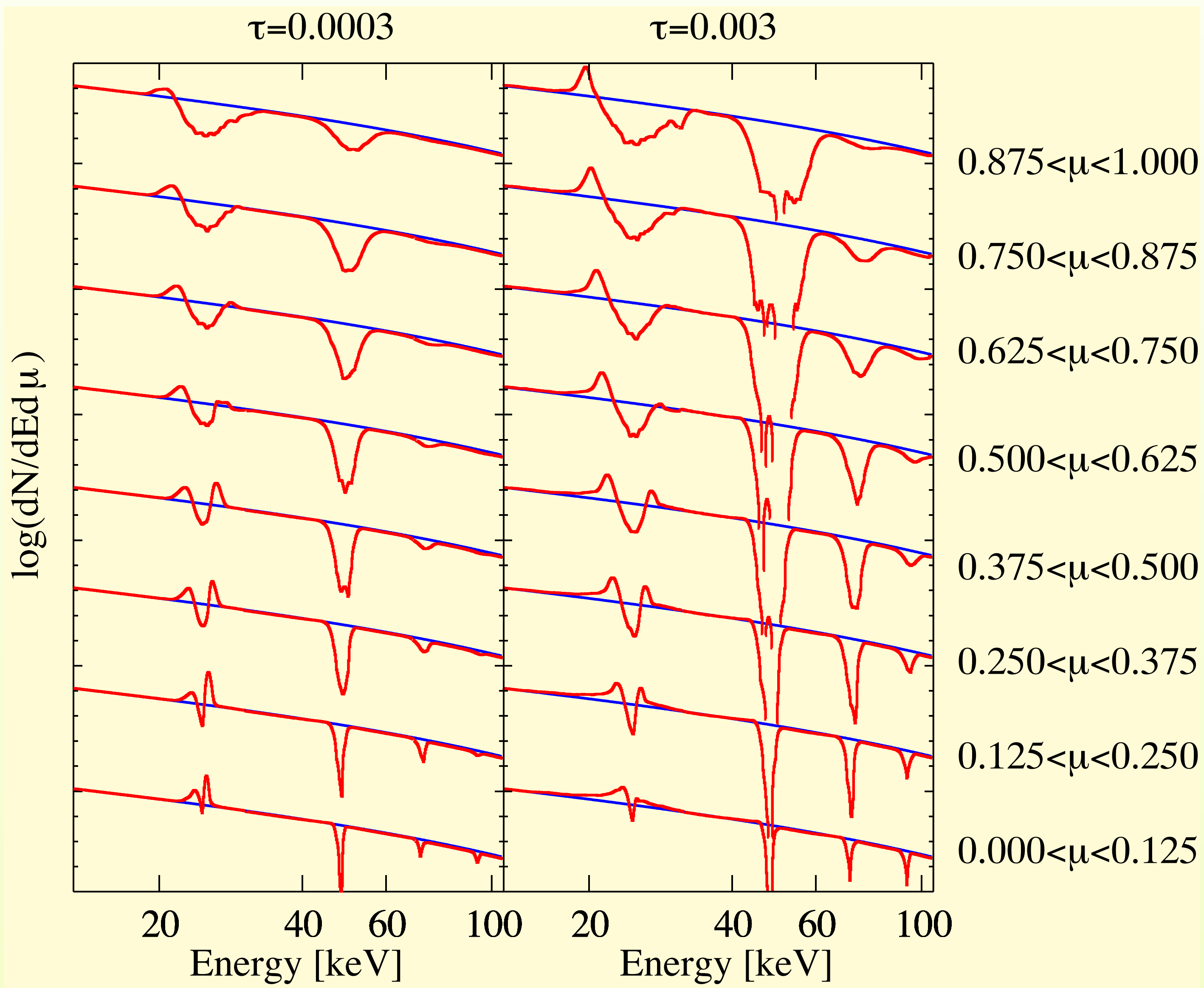

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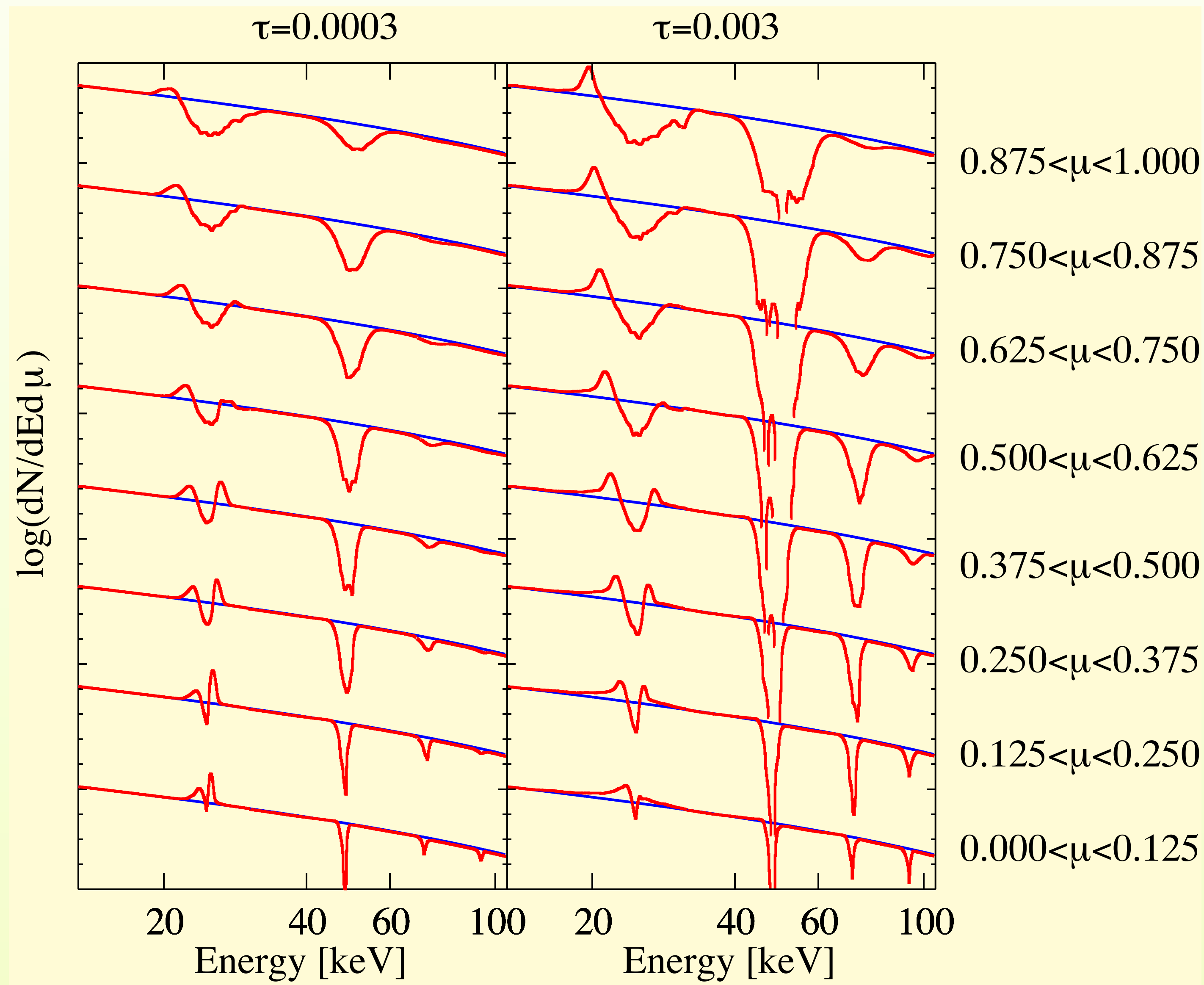

get physical parameters for line formation region

(Schönherr et al. 2007)

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Source List

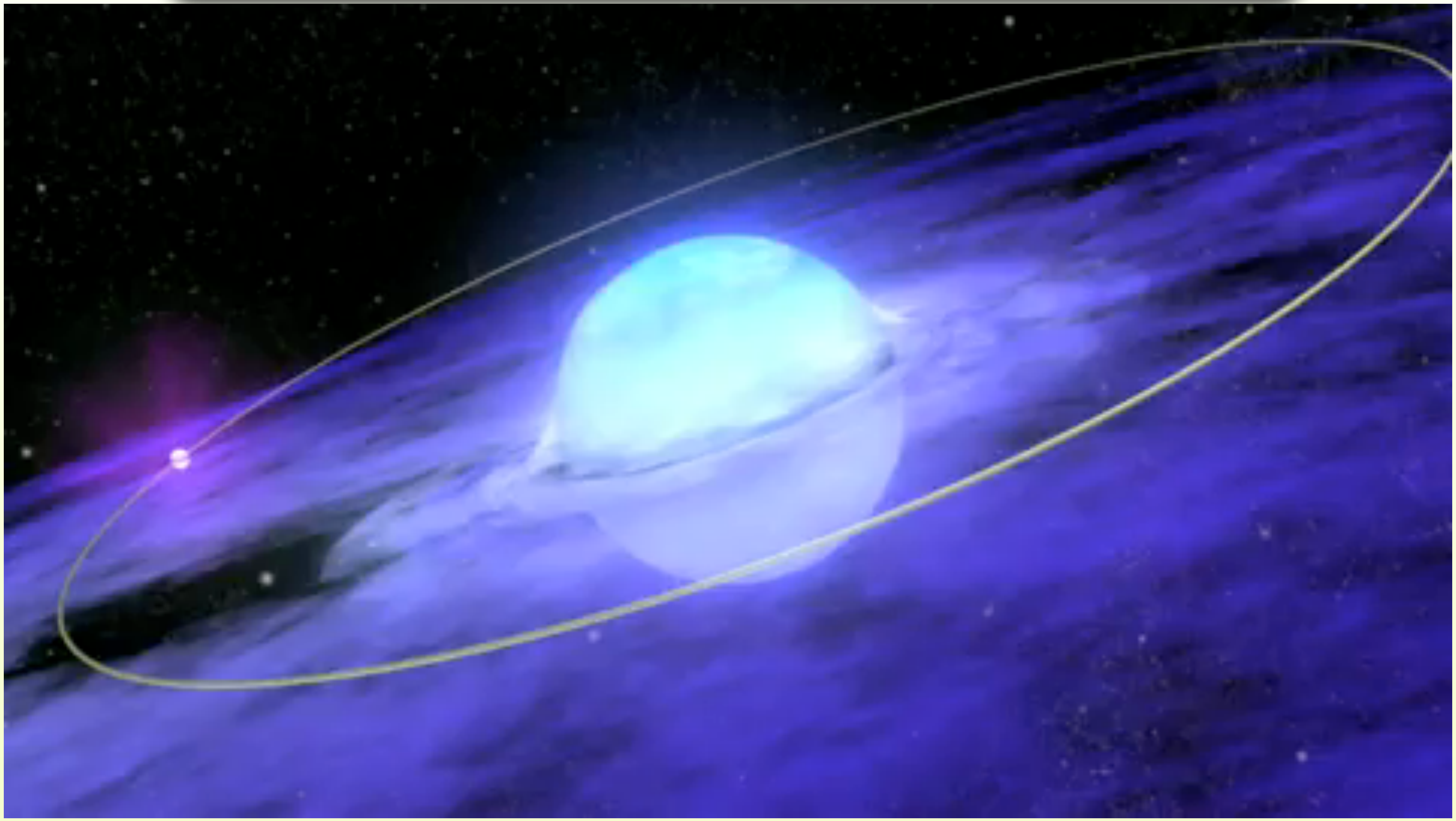
Source	E_{cyc} (keV)	P_{puls} (s)	P_{orb} (d)	companion	discovery
Swift J1626.6−5156	10	15	132.9	Be	RXTE (deCesar, '09)
4U 0115+63	14, 24, 36, 48, 62	3.6	24.31	Be	HEAO-1 (Wheaton, '79) RXTE, SAX (Heindl '99, Sant.,'99)
4U 1907+09	18, 38	438	8.38	B2 III–IV	SAX (Cusumano, '98)
4U 1538−52	22, 47	530	3.73	B0I	Ginga (Clark,'90), RXTE (Rodes-Roca, '09)
Vela X-1	24, 52	283	8.96	B0.5Ib	Mir-HEXE (Kendziorra, '92), RXTE (Kreykenbohm, '02)
V0332+53	27, 51, 74	4.37	34.25	Be	Ginga (Makishima, '90)
Cep X-4	28	66.25	>23	B1	Ginga (Mihara, '91)
Cen X-3	29	4.8	2.09	O6.5II	SAX (Santangelo, '98) RXTE (Heindl, '98)
X Per	29	837	250.3	B0 III–Ve	RXTE (Coburn, '01)
MXB 0656−072	33	160	100?	O9.7Ve	RXTE (Heindl, '03)
XTE J1946+274	36	15.8	169.2	B0-1V-IVe	RXTE (Heindl, '01)
4U 1626−67	37	7.66	0.028	0.04 $M_\odot$	SAX (Orlandini, '98) RXTE (Heindl, '98)
GX 301−2	37	690	41.5	B1.2Ia	Ginga (Mihara, '95)
Her X-1	41	1.24	1.7	A9-B	Ballon-HEXE (Trümper, '78)
A0535+26	50, 110	105	110.58	Be	HEXE (Kendziorra, '92, '94), CGRO (Maisack, '97)
1A1118−61	55	408	400-800 d?	O9.5IV-Ve	RXTE (Doroshenko, '10)
GRO J1008−57	88?	93.5	247.8	B1–B2	CGRO (Shrader, '99)

Summary

- CRSFs are detected in ~18 sources
  study CRSF sources as a class
- CRSFs (sometimes) move with L_X
  positive and negative correlation!
  calculate height change in column
- Monte Carlo simulations of CRSFs:
  obtain parameters of CRSF formation region, but models still need to be improved
- rise and decay of outburst different
  magnetic instabilities?

Summary

Summary



Thank you for your Attention!