The mystery of the γ Cas type X-ray sources

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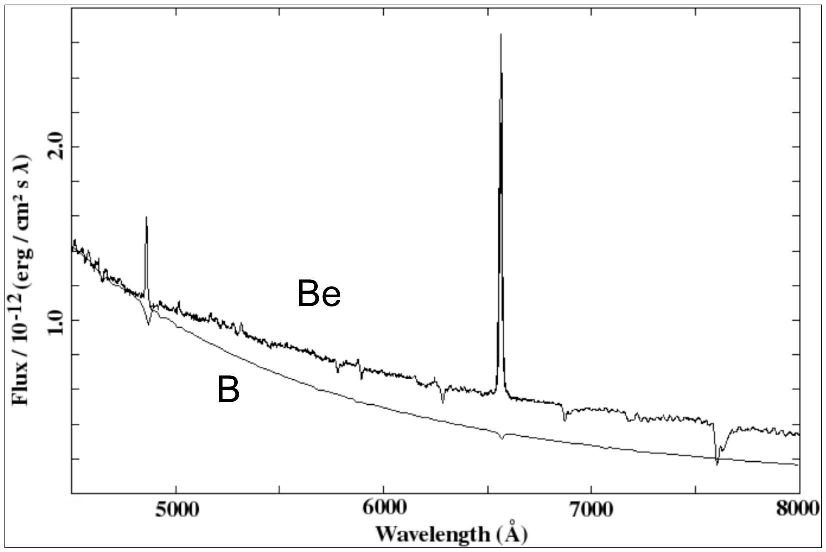
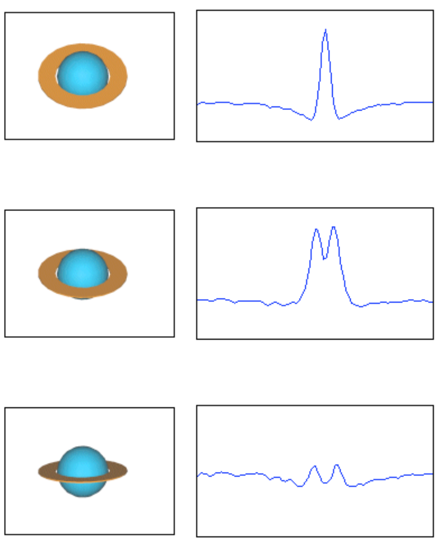
Be stars: (arguably) the oldest unsolved mystery of Astrophysics



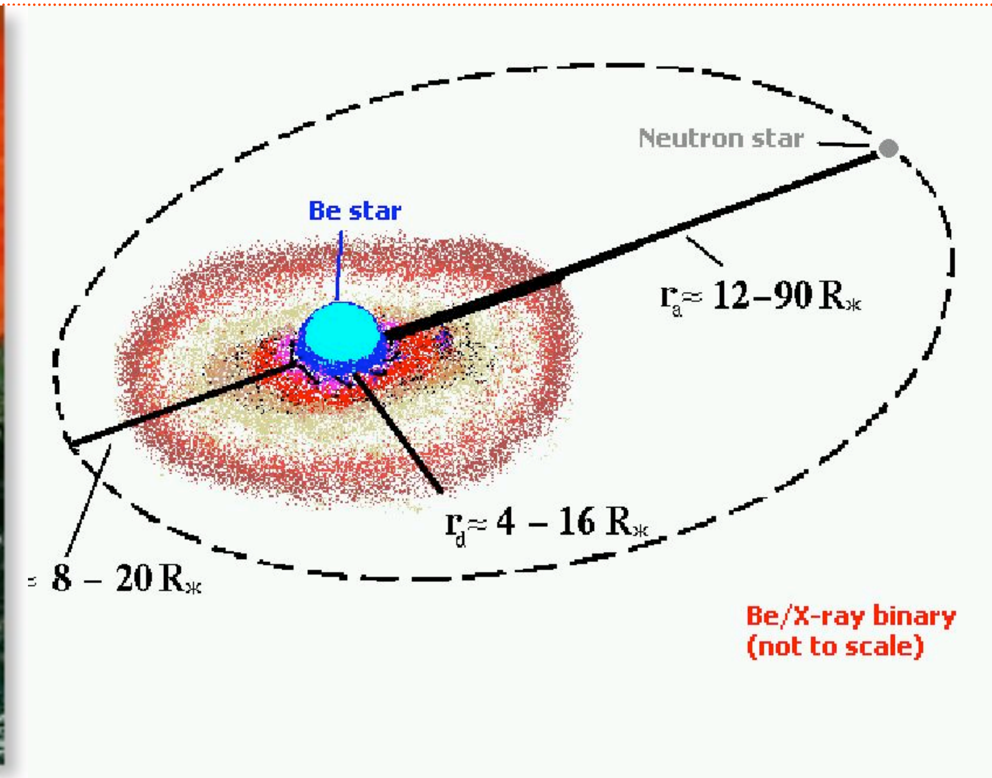


- γ Cas is a Be star.
- Be stars harbour a circumstellar envelope.
- Bound-bound transitions: emission lines
- Free-Free transitions (thermal Bremsstrahlung): IR excess

Discovered in 1866 (Secchi, A. 1867, *Astron. Nachr.* 68, 63)

Non exotic objects! (20% of all B stars are Be)

Be/X-ray binaries



Transients: outbursts Type I (periastron), Type II (giant; stochastic)

Spectrum: non thermal components (bb+pl)

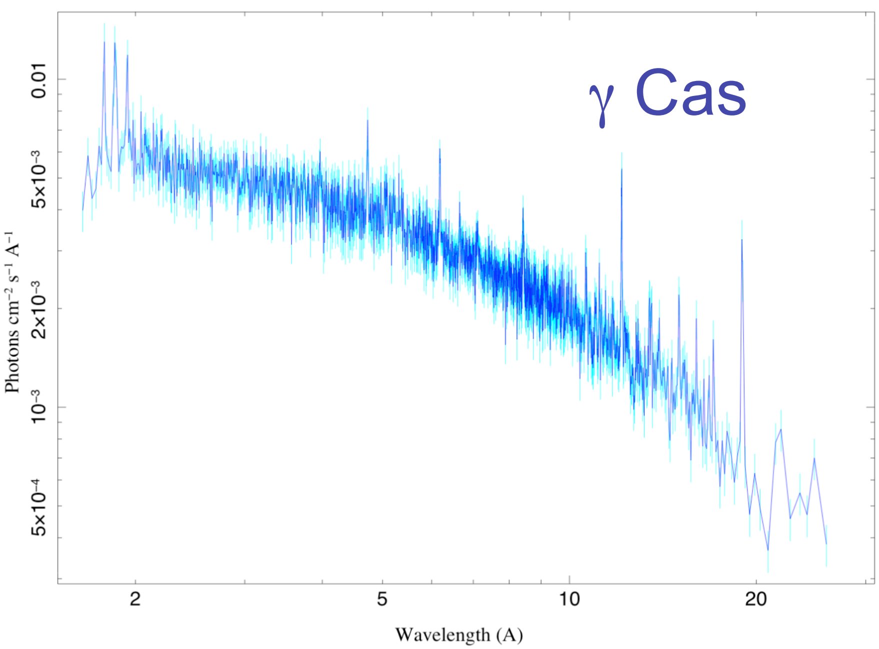
$L_x \sim 10^{36\text{-}37}$ erg/s

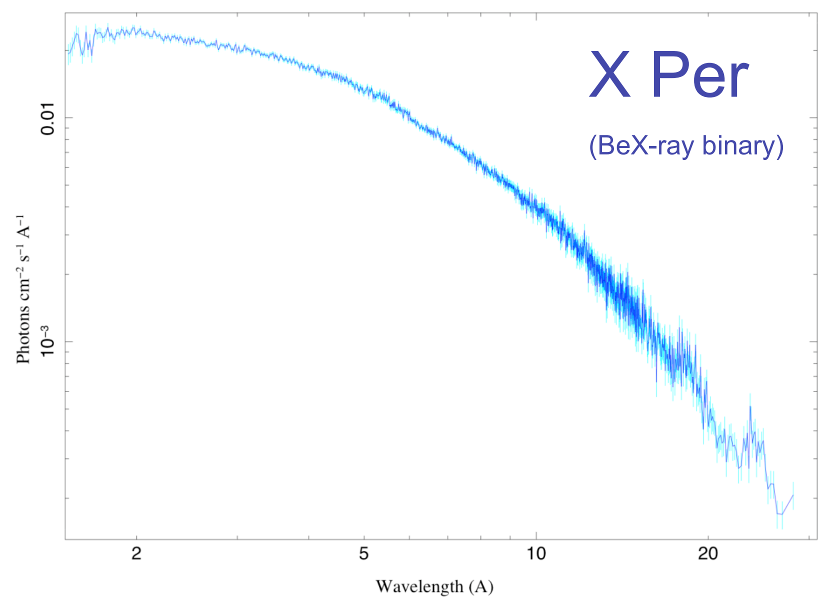
Non exotic either!: 70 % of X-ray pulsars are BeX

γ Cas X-ray emission: an enigma inside the mystery

- Persistent
- No pulsations
- Spectrum thermal: optically thin plasma @ ~ 10 keV
- $L_x \sim 10^{32}$ erg/s
- Irony: γ Cas first Be star discovered and prototype of classical Be stars!

Chandra HETG data





γ Cas X-ray emission: an enigma inside the mystery

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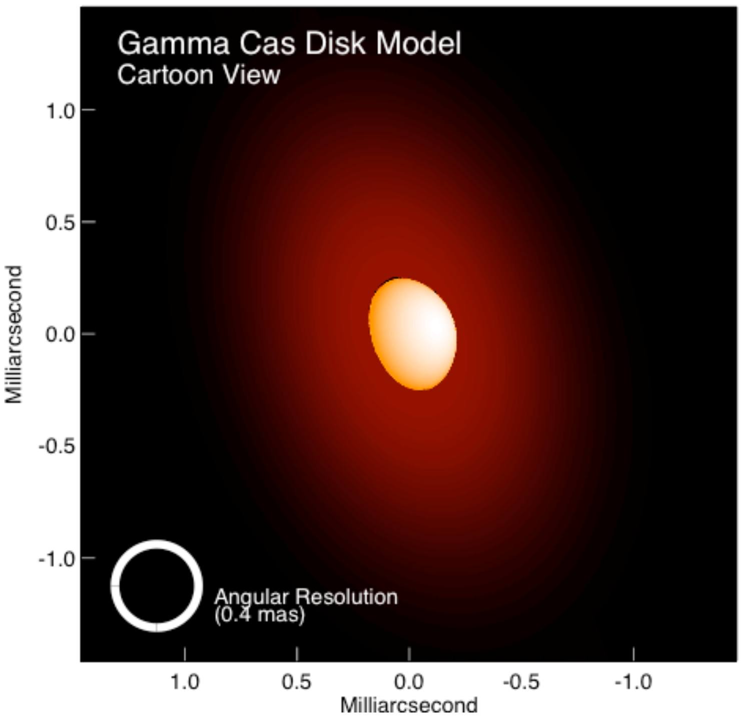
- Explanations:
  - Be + WD binary
  - Magnetic Star - Disk interaction (Balbus-Hawley mechanism).
  - Both are challenging.

γ Cas: the prototype and the brightest



(Smith et al. 2012)

d = 168 pc

i = 43º

Binary with a ~ 1M_{sun} companion

P_{orb} = 203.6 d

e ~ 0

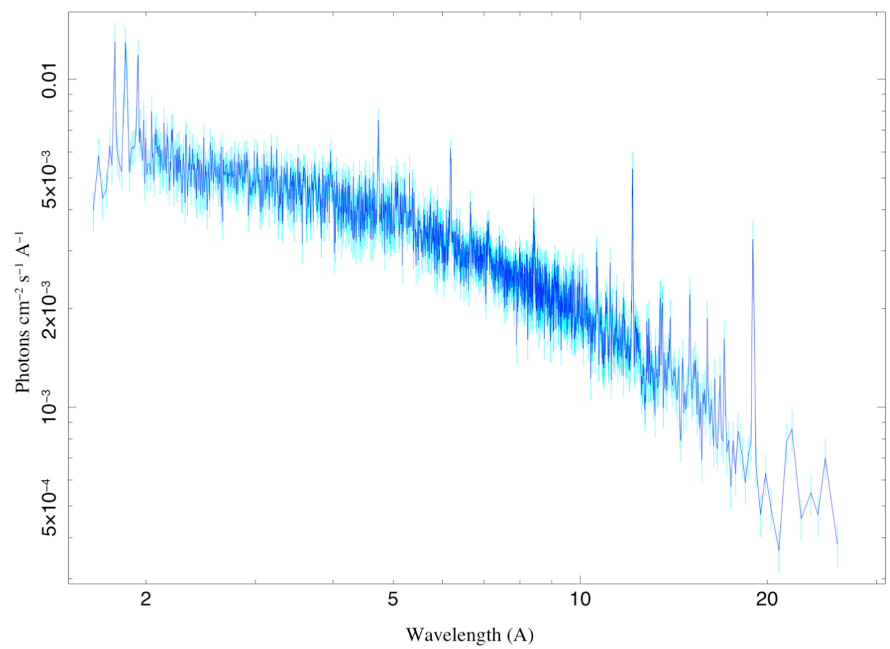
Addition of thermal plasmas (MEKAL) @ 12, 3, 1, 0.1 keV

Z^{hot}_{Fe}= 0.25 Z_O

$Z^{warm\text{-}cool}_{Fe}$ ~ 1 Z_O

Degeneracy: 12 keV component can be replaced by a powerlaw.

(Smith at el. 2004)



γ Cas: X-ray vs *V* correlations

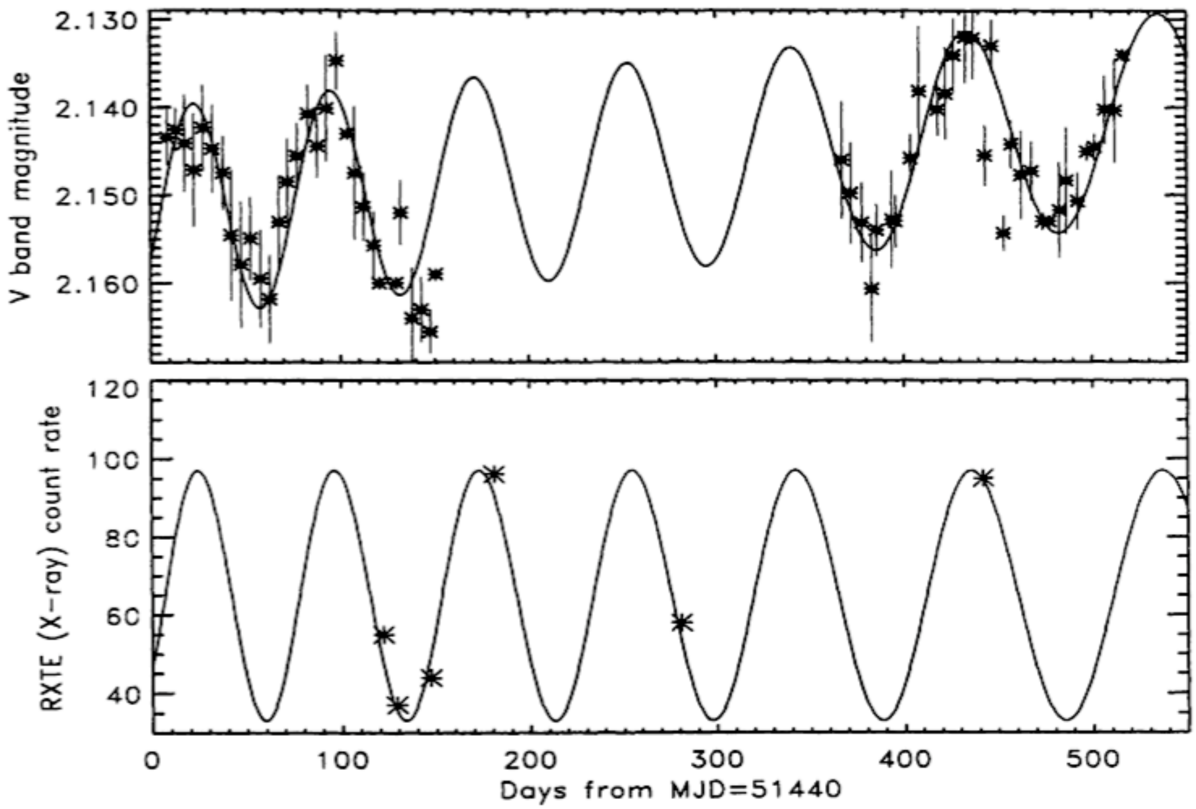


Figure 2. Comparison of optical X-ray mean fluxes: *(top)* Average V-band observations of γ Cas for the 1999 and 2000 observing season. Solid line is an interpolated sinusoid with lengthening period; *(bottom)* star symbols are 27-hour flux averages. Solid line is the top sinusoid scaled to the X-ray extremum fluxes.

(Robinson, Smith & Henry, 2002)

Strong correlation suggest common origin

V variations driven by **density variations in the circumstellar disk** at [2-3]R_*

Density variations produced by ***B* field variations**.

B field variations produced by **disk magnetic dynamo** excited by the Balbus-Hawley mechanism.

γ Cas: disk dynamo amplifies stellar field

Balbus-Hawley mechanism: magneto rotational instabilties (MRI) in the inner part of the circumstellar (decretion) disk (close to the Keplerian co-rotaion radius R_K) enhance a seed B field (from the star) through a disk dynamo mechanism. That is to say, turbulence amplifies the seed ***B*** field.

(Balbus & Hawley 1998, Rev. Mod. Phys. 70, 1)

Material below R_K will rotate faster; beyond R_K will rotate slower.

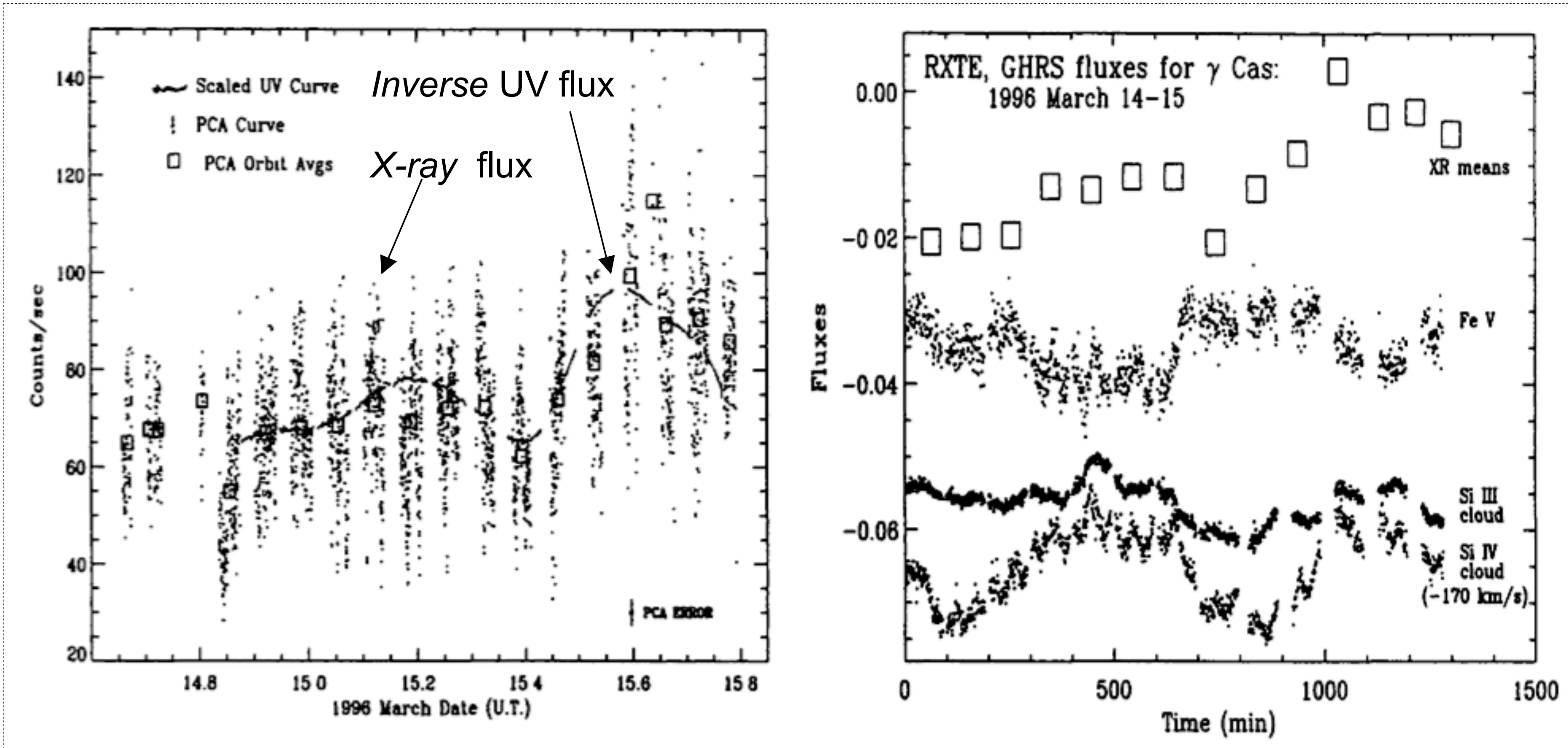
As a consequence:

B field lines stretch and sever accelerating (magnetic sling) particles (e, p) which impact the photosphere heating it locally to MK temperatures

B field lines reconnect: cyclic dynamo with a period ~ 30 times the Keplerian period.

(Brandenburg et al. (1996)

γ Cas: X-ray vs UV correlations

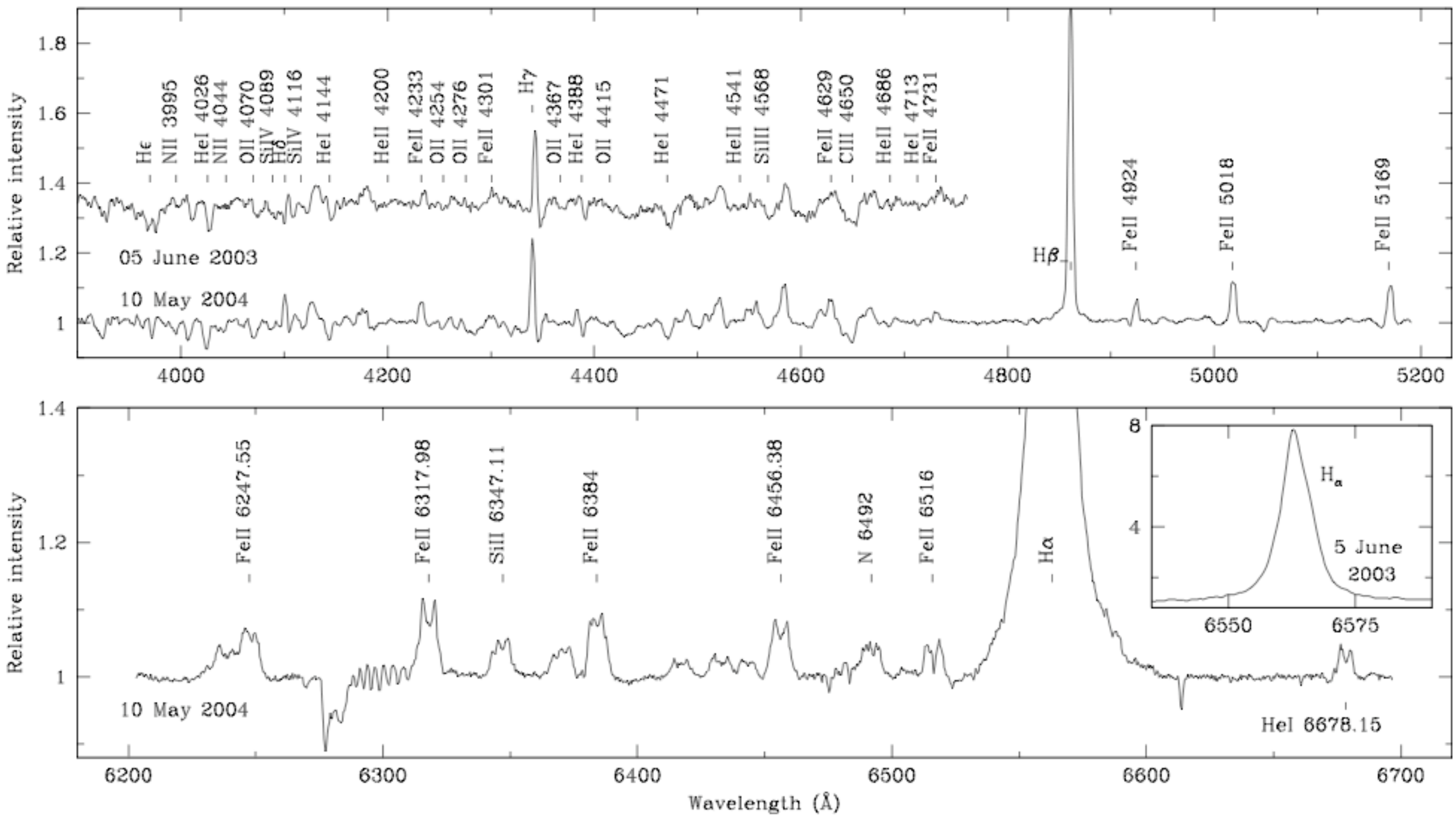


Dips in UV: translucent clouds passing in front of the photosphere.
Coincide with maximum X-ray activity: co-rotating clouds dragged by the ***B*** field.

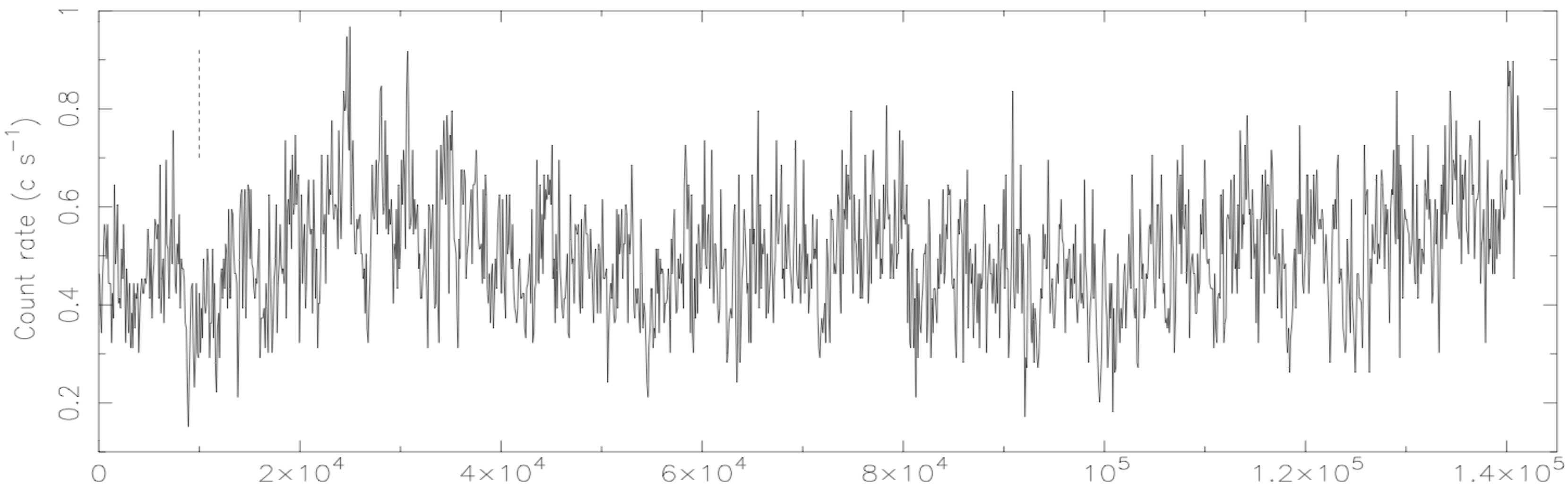
(Smith & Robinson, 2003)

BZ Cru (HD110432): the *edge-on* system

- Discovered by Torrejón & Orr (2001); classified as "γ Cas analog" by Smith & Balona (2006)
- Very large and/or dense circumstellar disk. Seen almost **edge on** (Lopes de Oliveira et al 2007).
- Has the hottest hard component.
- d = 374 pc



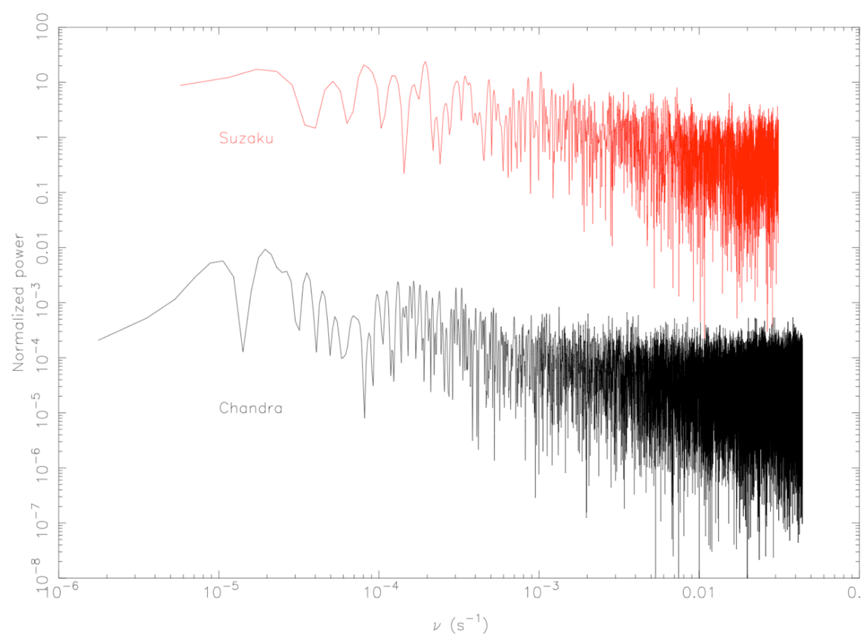
BZ Cru (HD110432): no pulsations



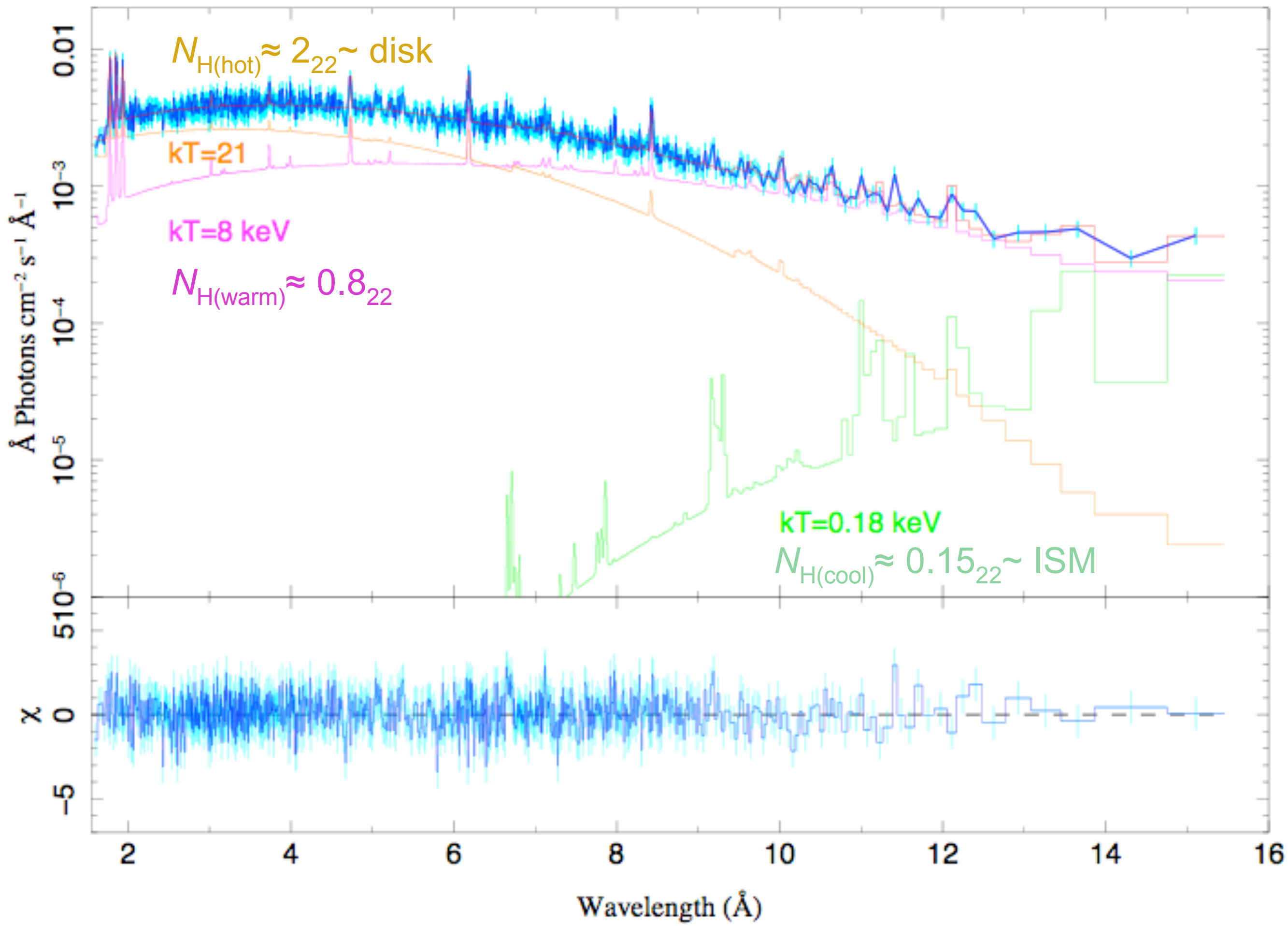
- 150 ks Chandra HETG observation. The longest uninterrupted observation of any gamma Cas analog so far.

- No significant coherent period found

(Torrejón et al. 2012a)



BZ Cru (HD110432)



3 thermal plasmas @ 21, 8 0.15 keV

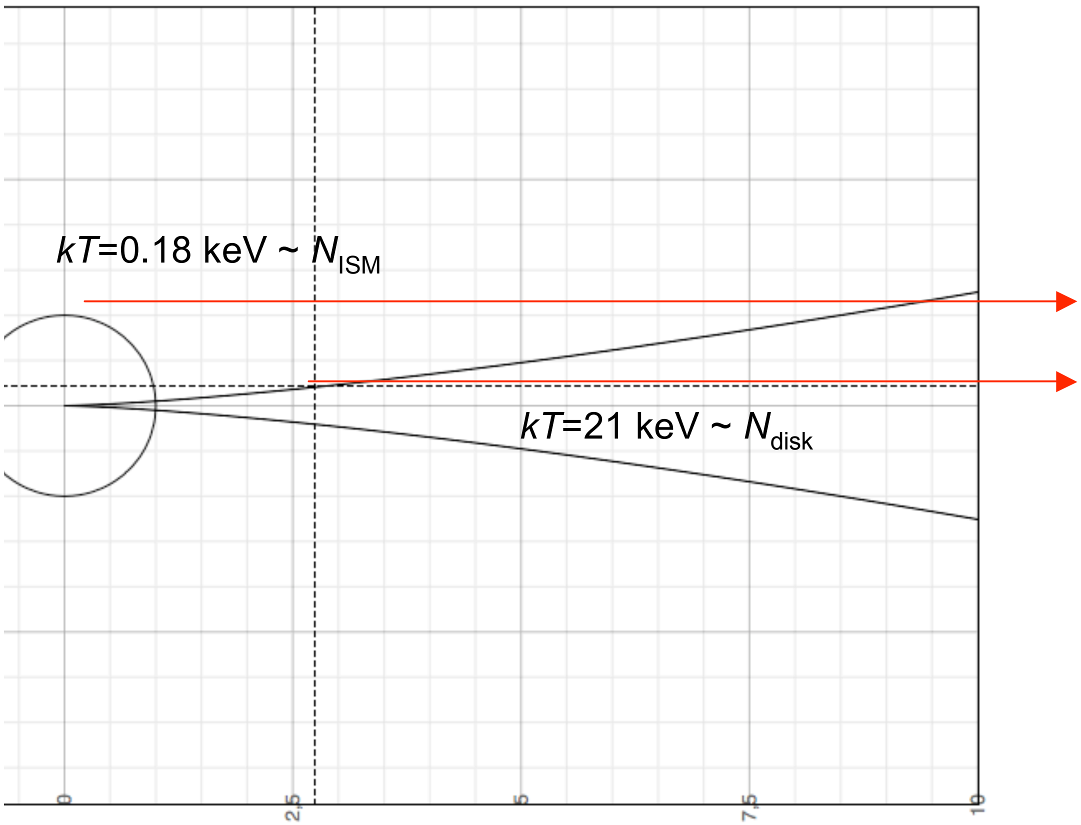
$N_{H(cool)}$ ~ ISM

$N_{H(hot)}$ ~ disk

X-ray production site at

$$r \simeq (2\text{–}3)R_*$$

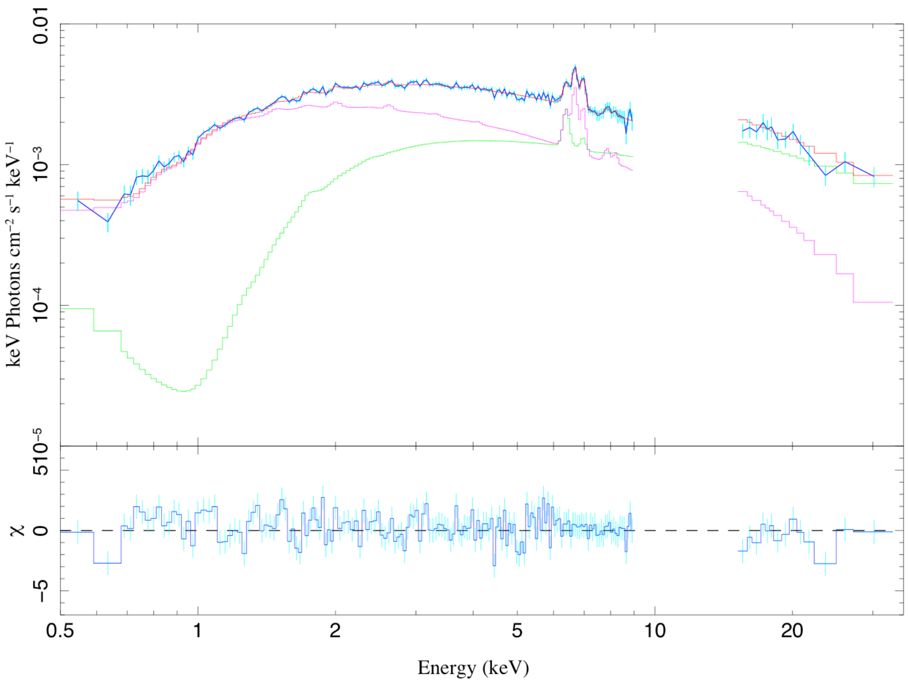
BZ Cru (HD110432): latitudinal variation of plasma temperature?

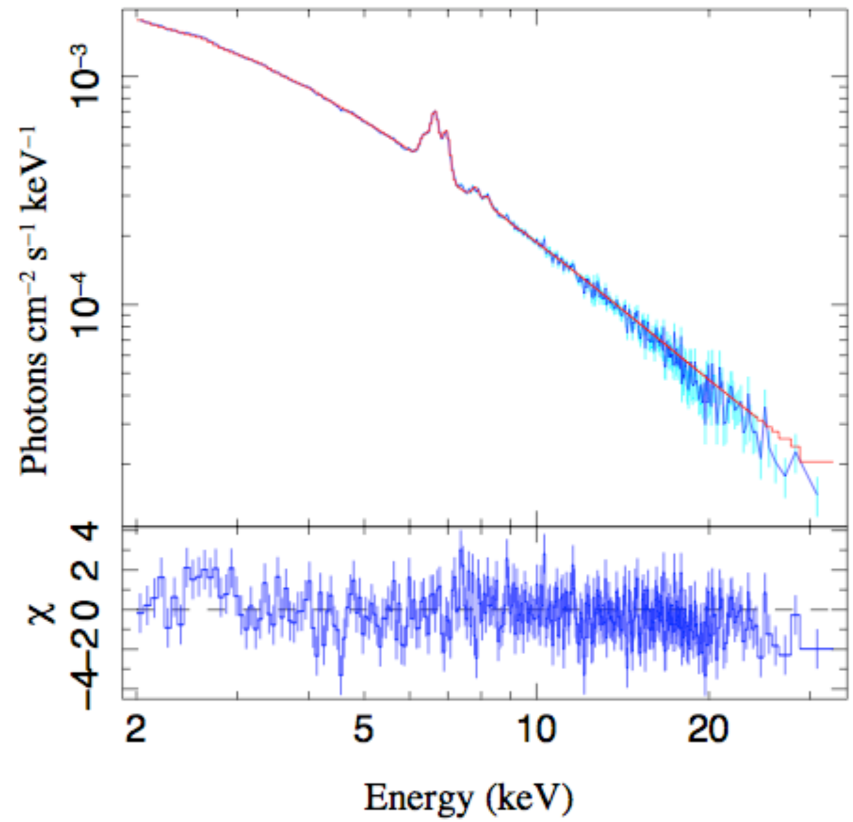


to Earth

- Where is Fe Kα produced?
- hot plasma --> powerlaw

BZ Cru (HD110432)





30 ks *Suzaku* observation

Degeneracy: 21 keV component --> powerlaw

25 ks LOFT observation (requirements)

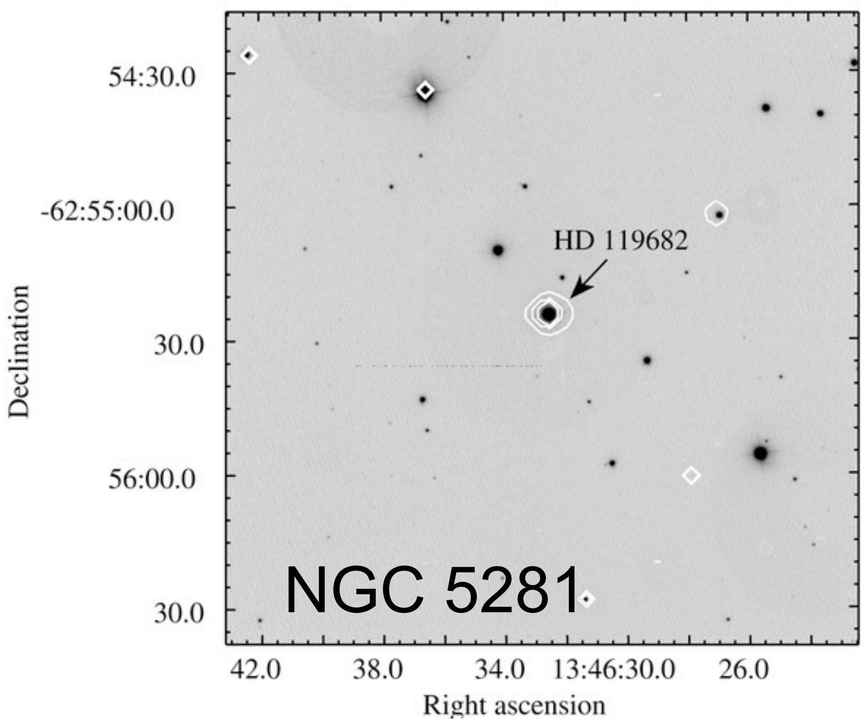
The statistics can discriminate perfectly between both models

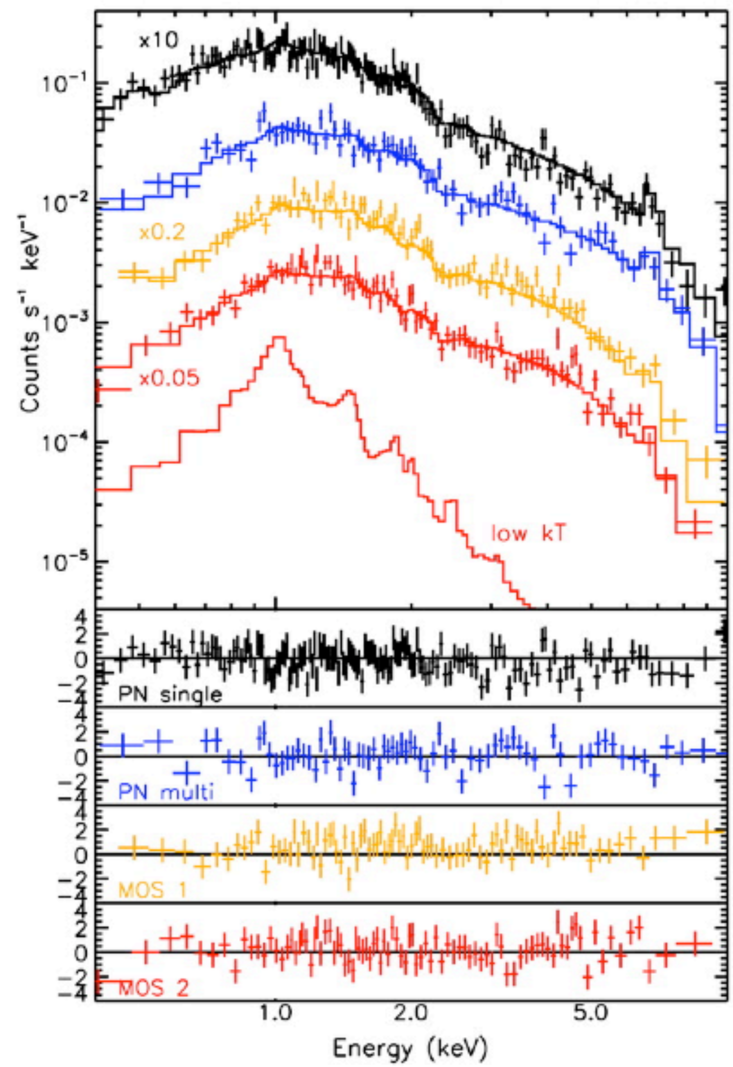
HD119682

Discovered by Rakowsky et al. (2006)
XMM-Newton

Safi-Harb et al (2007):

- B0.5Ve
- *d* = 1300 pc
- possible *P* ~ 1500 s





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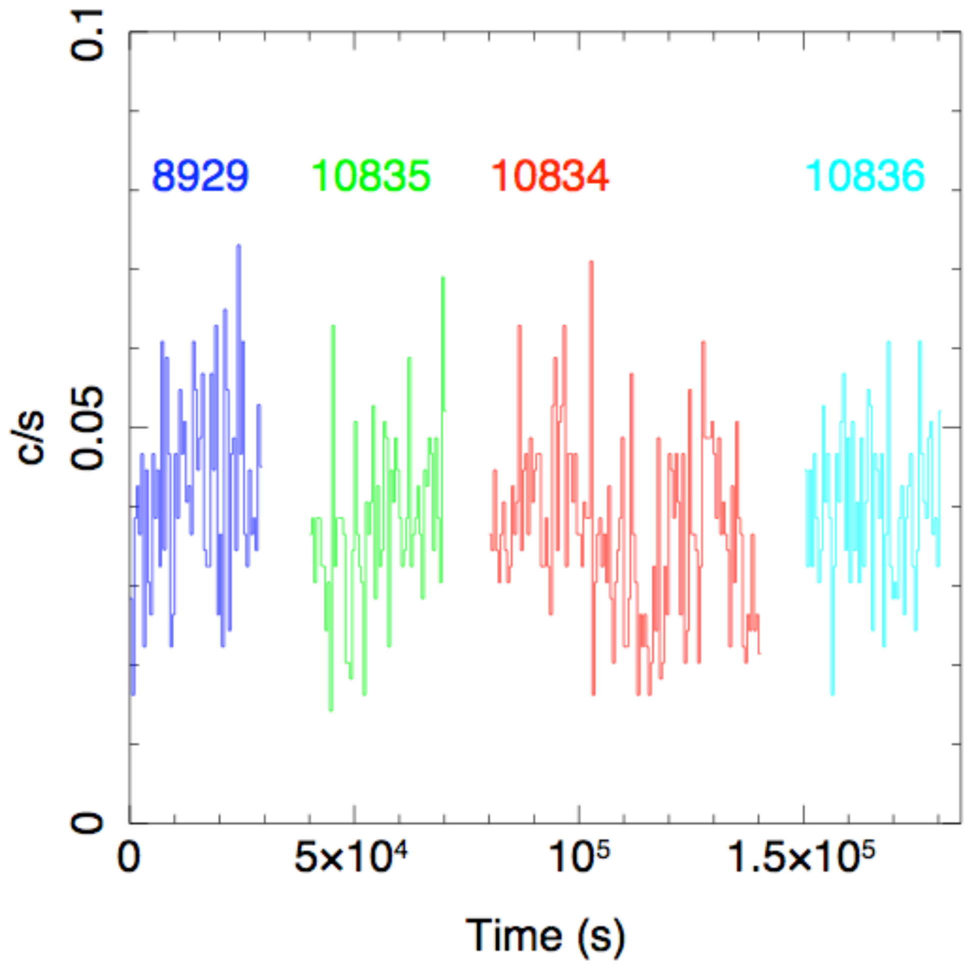

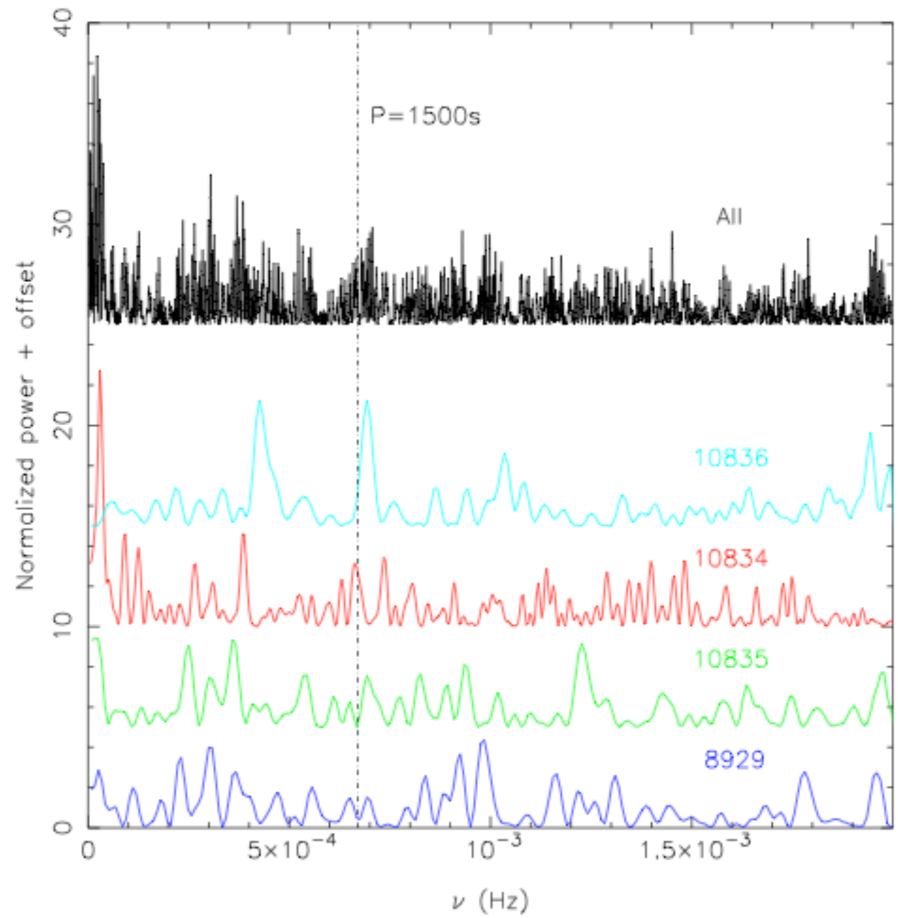

150 ks Chandra *HETG* data (Torrejón et al. 2012b)

HD119682

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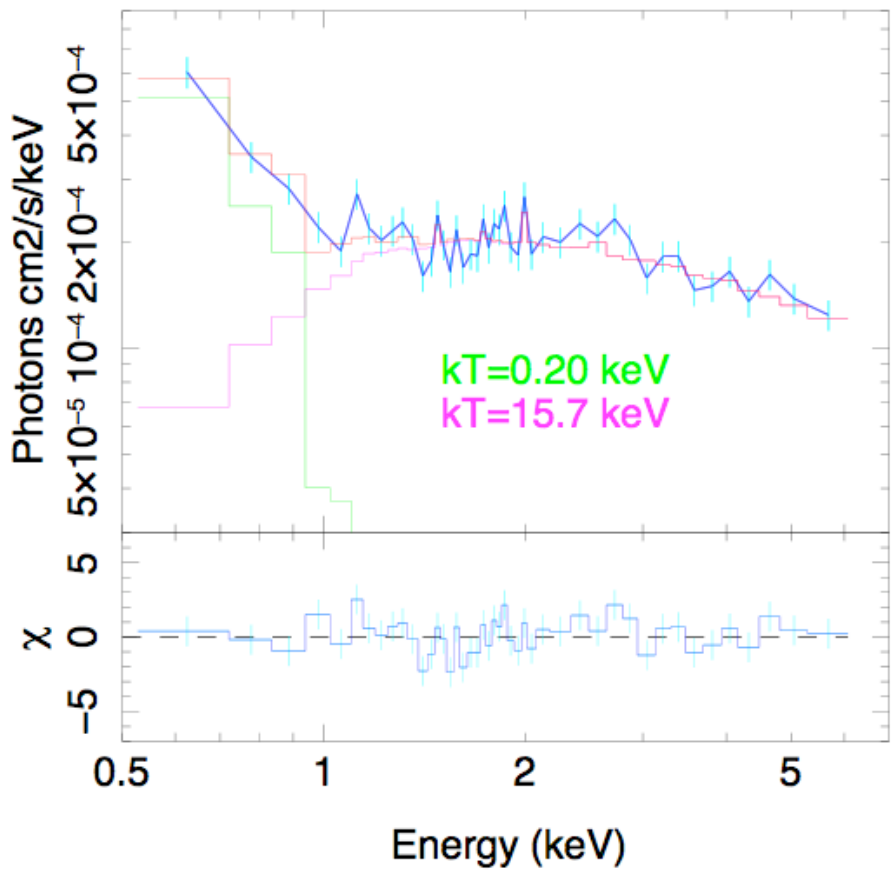


MODEL PARAMETERS FOR *Chandra* HETG DATA.

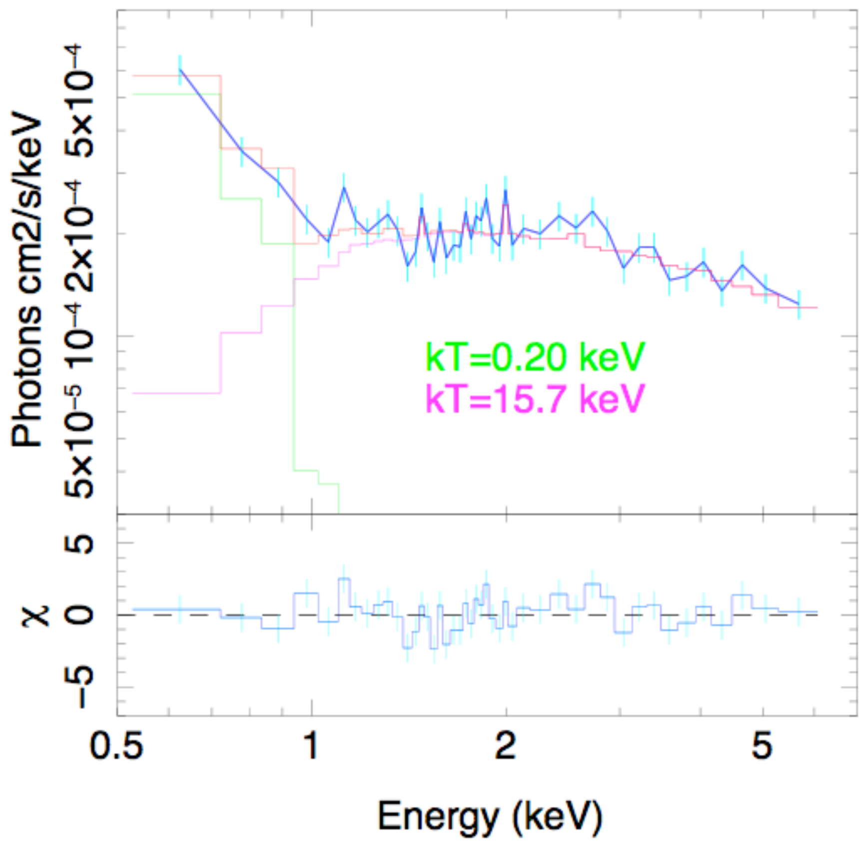
Component	Parameter	Value	
		PO+APEC	2 APEC
	N_H^a	$0.15^{+0.15}_{-0.03}$	$0.20^{+0.15}_{-0.03}$
powerlaw	Norm	$0.00026^{+0.0005}_{-0.0004}$	...
	Γ	$1.36^{+0.15}_{-0.01}$	...
apec 1	Norm	...	$0.0018^{+0.0005}_{-0.0006}$
	kT (keV)	...	$15.7^{+4.7}_{-5.4}$
apec 2	Norm	$0.0003^{+0.0003}_{-0.0001}$	$0.0005^{+0.0001}_{-0.0002}$
	kT (keV)	$0.21^{+0.02}_{-0.03}$	$0.20^{+0.03}_{-0.02}$
	Flux^b	1.78	1.81
	χ_r^2 (dof)	1.48 (86)	1.35 (86)

[a] In units of $\times 10^{22}$ cm^{-2}
[b] Unabsorbed 0.5–10 keV flux in units of $\times 10^{-12}$ erg s^{-1} cm^{-2}

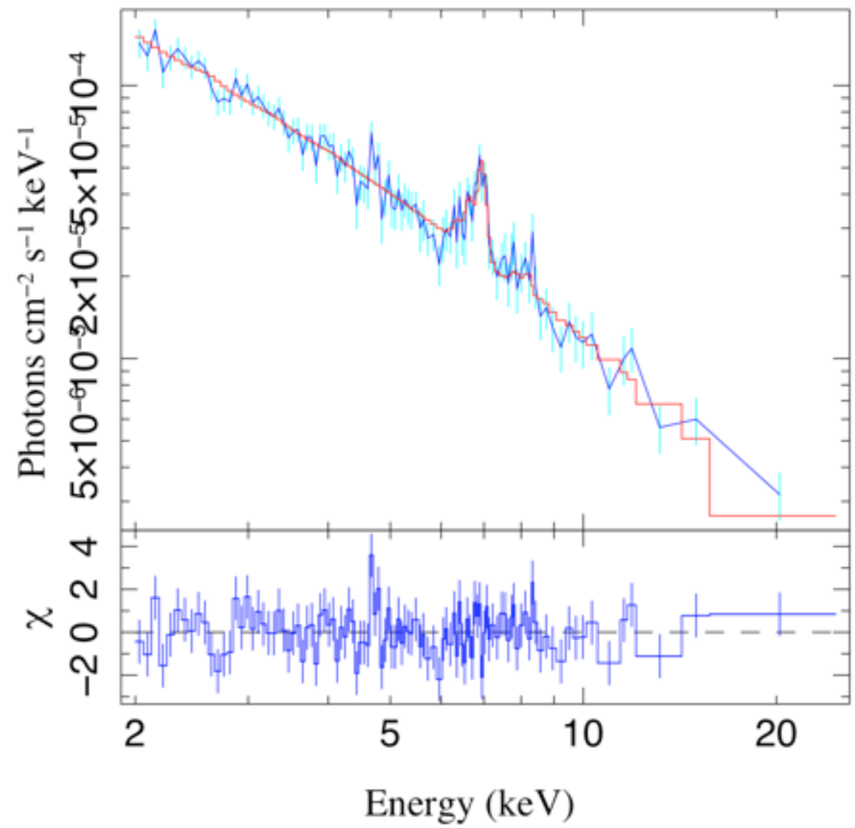
Supports the fully thermal model

But, again, the degeneracy thermal vs pl

Faint members with LOFT



150 ks Chandra



25 ks LOFT LAD (requirements)

We need big area telescopes if we want to ever characterise the class!

Conclusions 1

The available data favor the X-ray emission from standalone active Be stars.

Caveats:

1) Details of X-ray production mechanism still unclear (***B* fields in early type stars?**)

2) Why **other Be stars** with similar optical characteristics **do NOT show X-ray emission**?
For example: π Aqr (B1IIIe, shell), V1294 Aql, HD58978 and HD180968 (B0.5IVe), etc.

3) Presence of possible power law.

Binary scenario still tenable:

At least three members of the class are ***Blue Stragglers***. Blue stragglers form through mass transfer in binary systems (Geller & Mathieu 2011, *Nature* 478, 356) leaving a WD behind.

Even if so: Is the accretion over the WD the origin of X-rays? So far only γ Cas is known to be a binary.

Or is the mass transfer (which rejuvenates the B star) what sparks the X-ray production on the Be star itself?

Currently, we have no answers for these questions.

Conclusions 2

1) The mystery of the gamma Cas X-ray sources challenges our current understanding of the massive stars structure and/or how the massive binaries evolve.

2) We present a nice example of science where LOFT can play a key role, <u>in a field for which LOFT has not been designed for</u>.