Jet formation in black-hole X-ray transients and implications

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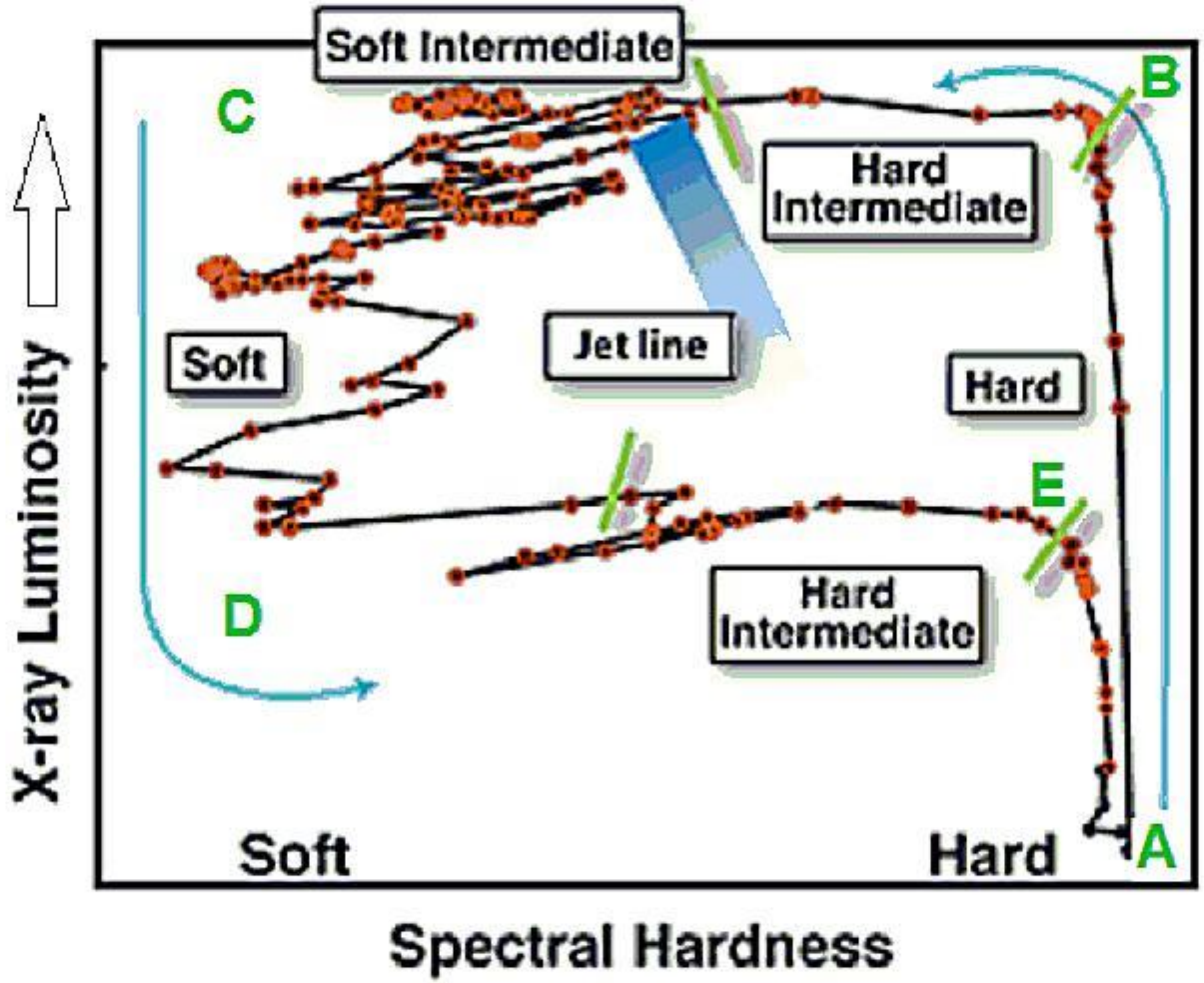
Introduction

- In a **Hardness-Luminosity Diagram**, XRTs exhibit a characteristic "q"-shaped curve, sometimes called **hysteresis curve** (next slide).

- At the beginning and the end of the outburst, the spectrum is hard (**hard state**). At the peak of the outburst, the spectrum is soft (**soft state**).

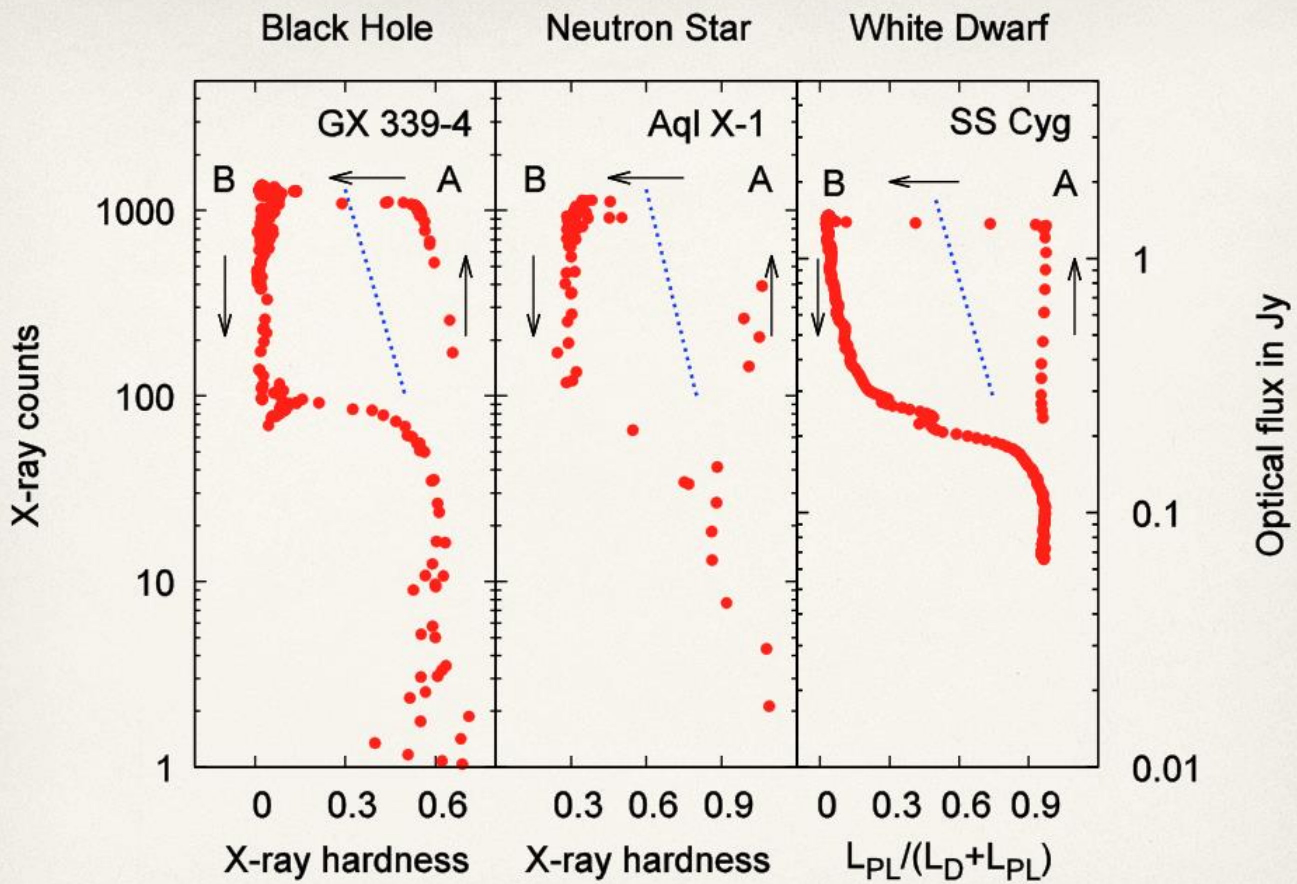
- I will use GX 339-4 as the prototype.

GX 339-4



Soft Intermediate
C
B
Hard Intermediate
Soft
Jet line
Hard
E
D
Hard Intermediate
X-ray Luminosity
Soft
Hard
A
Spectral Hardness

Similar behavior for BH, NS, WD !!!



The jet line in the Hardness-Intensity Diagram (Kording *et al.* 2008)

Knowledge?

- Up to recently, no **physical** interpretation had been proposed for the q-shaped curve.

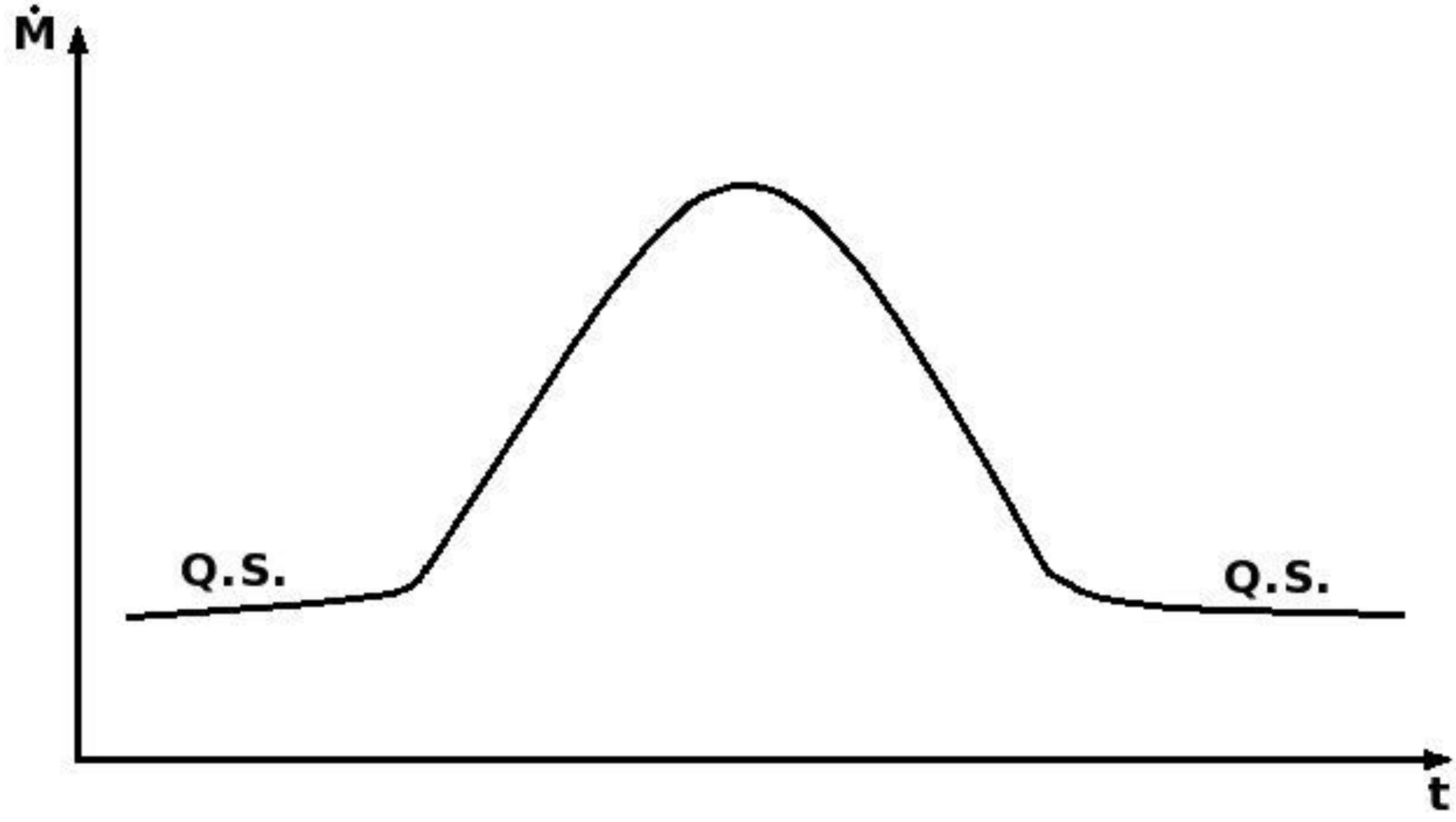
- The question of the **counterclockwise traversal** was not even asked by most people!

- In a recent Paper (Kylafis & Belloni 2015), we offered a **physical interpretation** for the q-shaped curve.

Assumptions in our work

- We have made only two assumptions:
- 1. During an outburst, the accretion rate as a function of time is a generic "bell-shaped curve" (next slide). This assumption is **self-evident**.
- 2. At low accretion rates the accretion flow is ADAF-like (hot, geometrically thick, optically thin). At high accretion rates the accretion disk is Shakura-Sunyaev – type (cold, geometrically thin, optically thick). This has been **confirmed** by MHD simulations (Ohsuga et al. 2009).

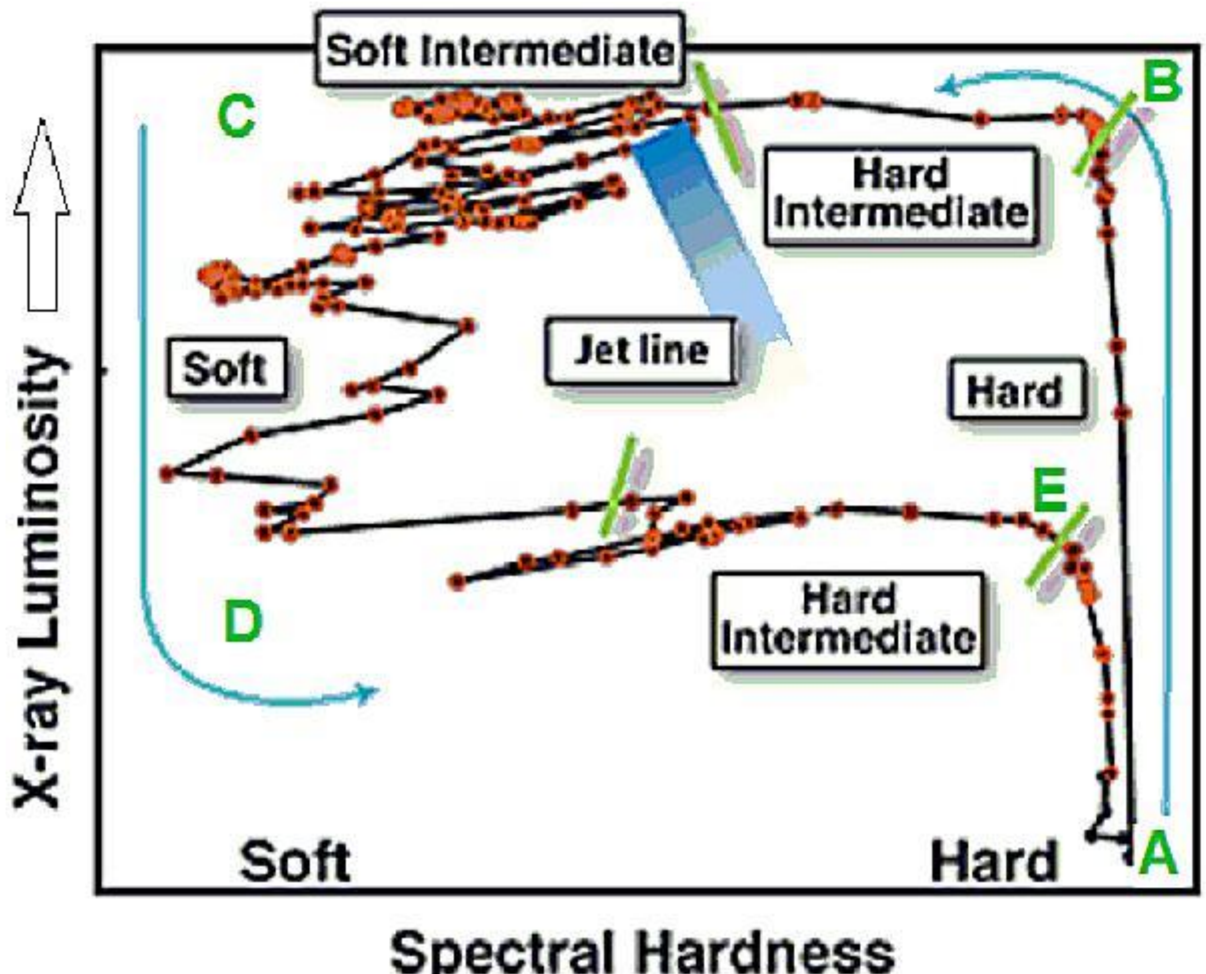
Accretion rate during outburst.
It is the **only parameter** in our picture.

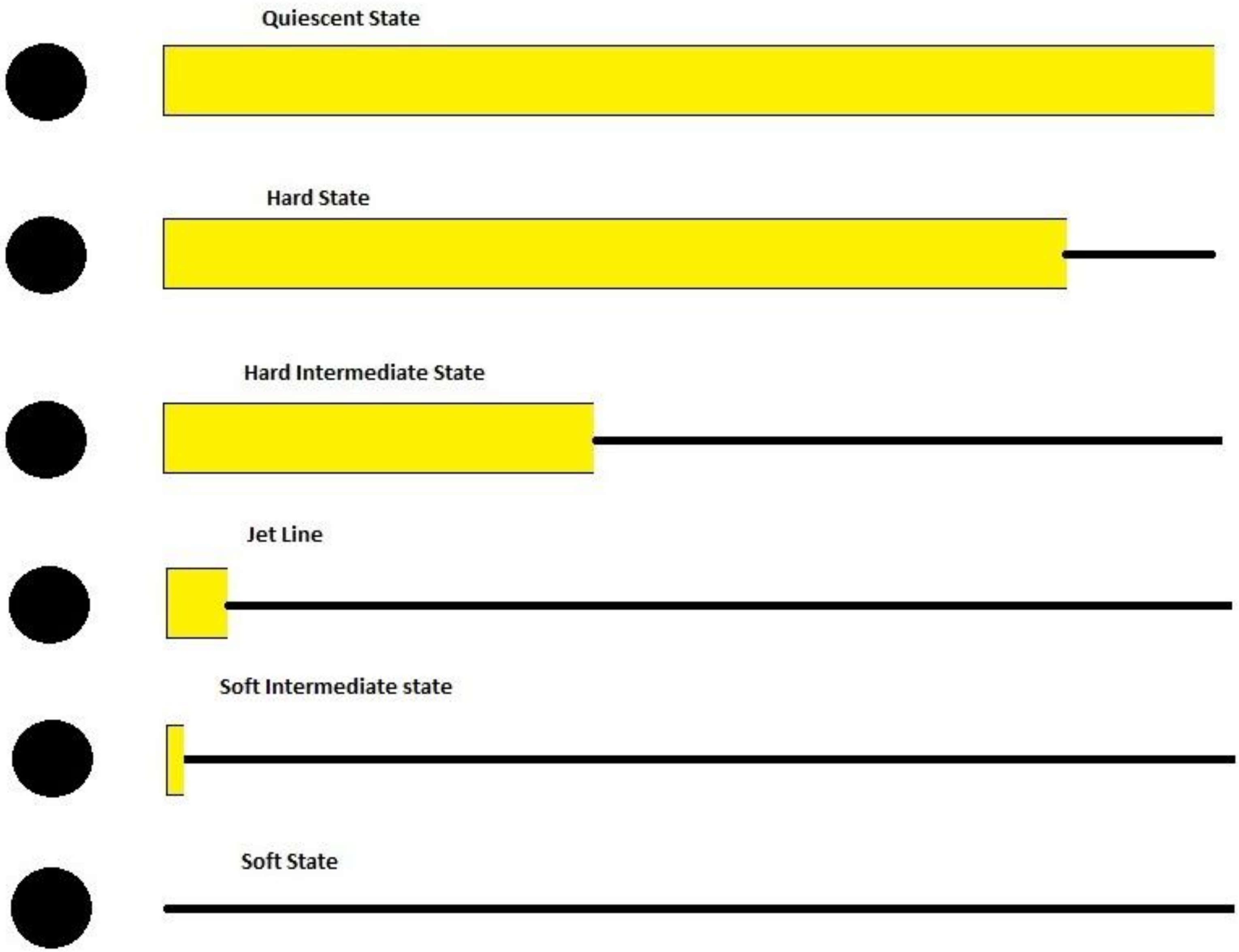


Interpretation

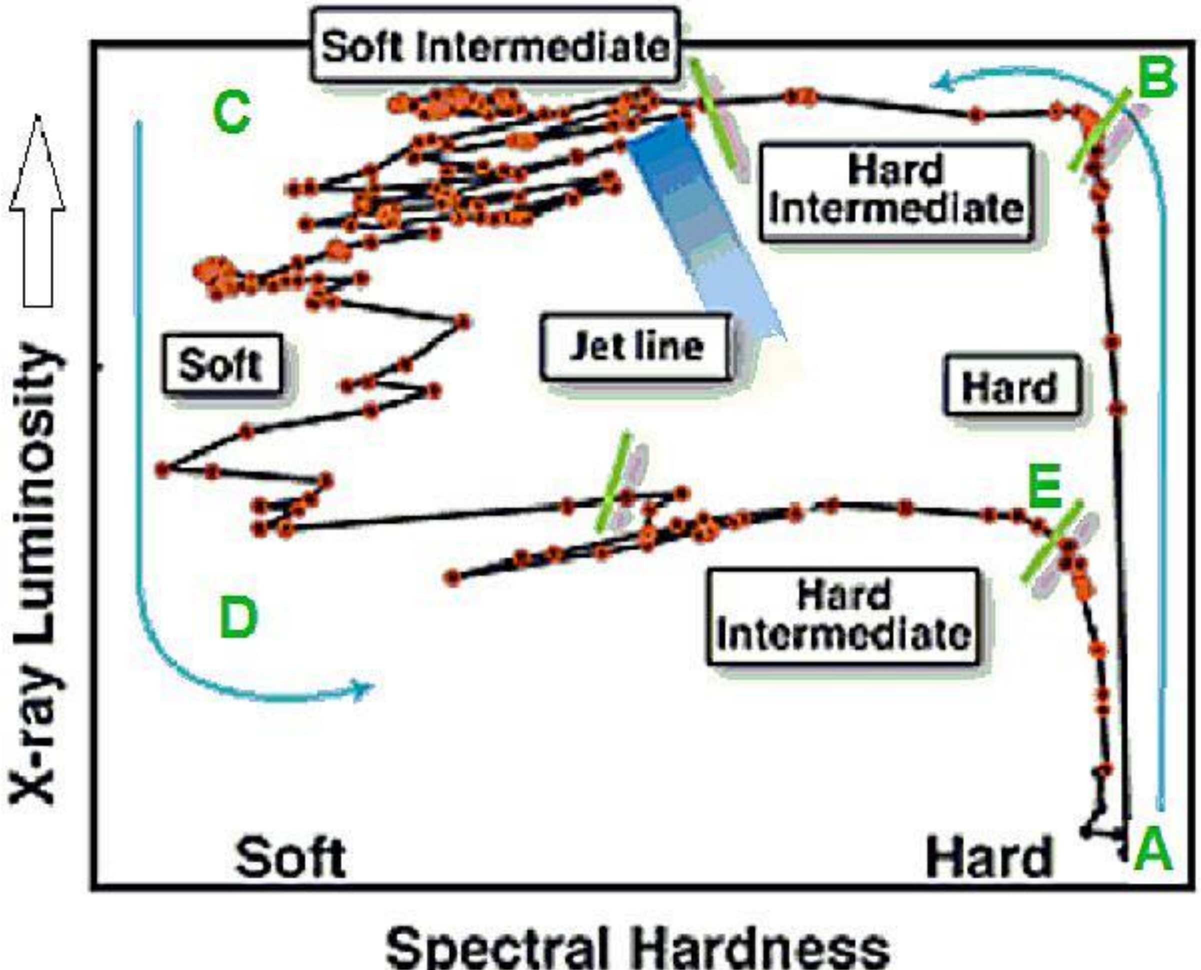
- I will now describe what the accretion flow looks like during the various stages of the outburst.

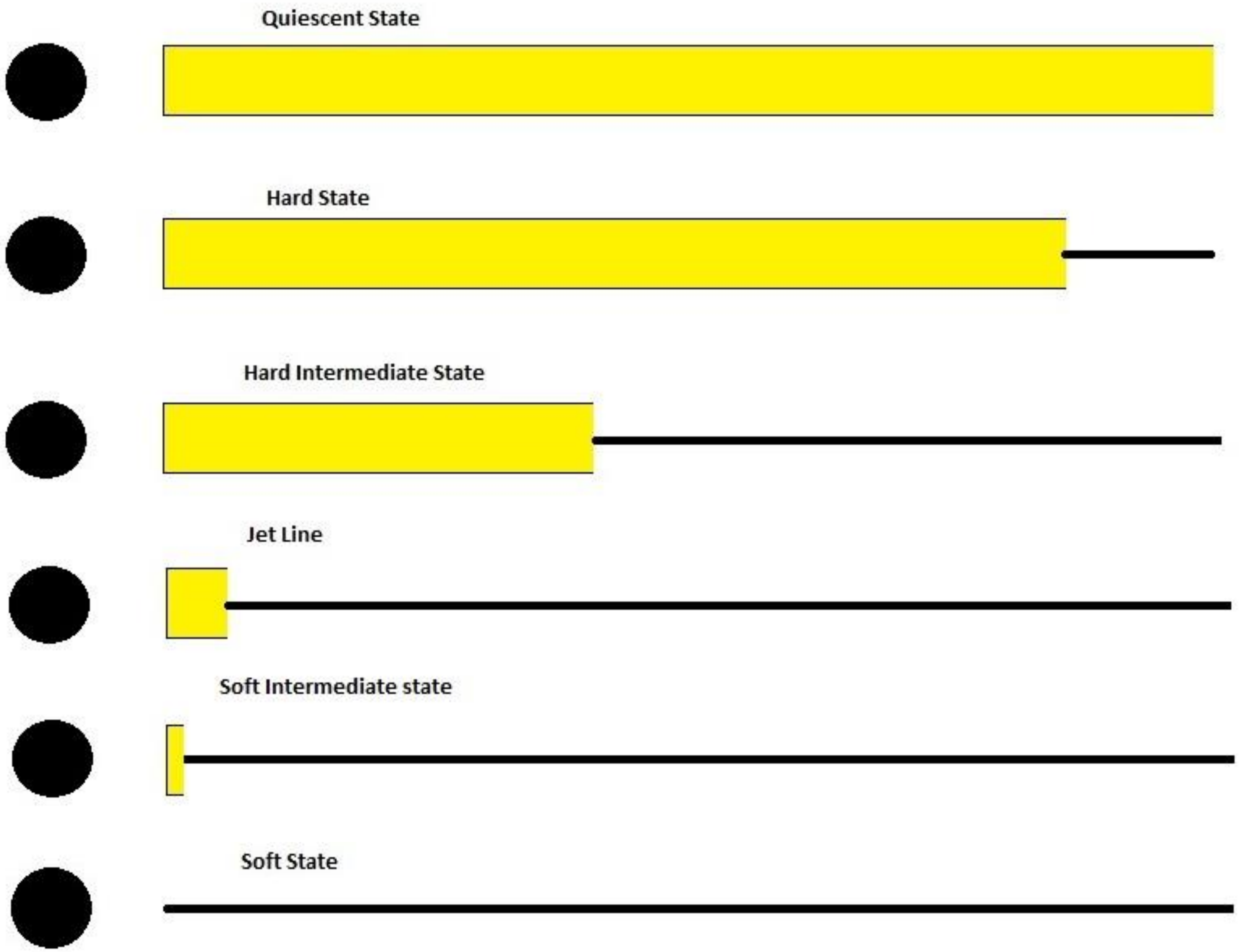
From A to B and then to C




Quiescent State
Hard State
Hard Intermediate State
Jet Line
Soft Intermediate state
Soft State

From C to D, to E, and then to A




Quiescent State
Hard State
Hard Intermediate State
Jet Line
Soft Intermediate state
Soft State

What creates the hard spectrum? The jet or the ADAF?

- Equally good hard X-ray model spectra are produced by jet models and by ADAF models.

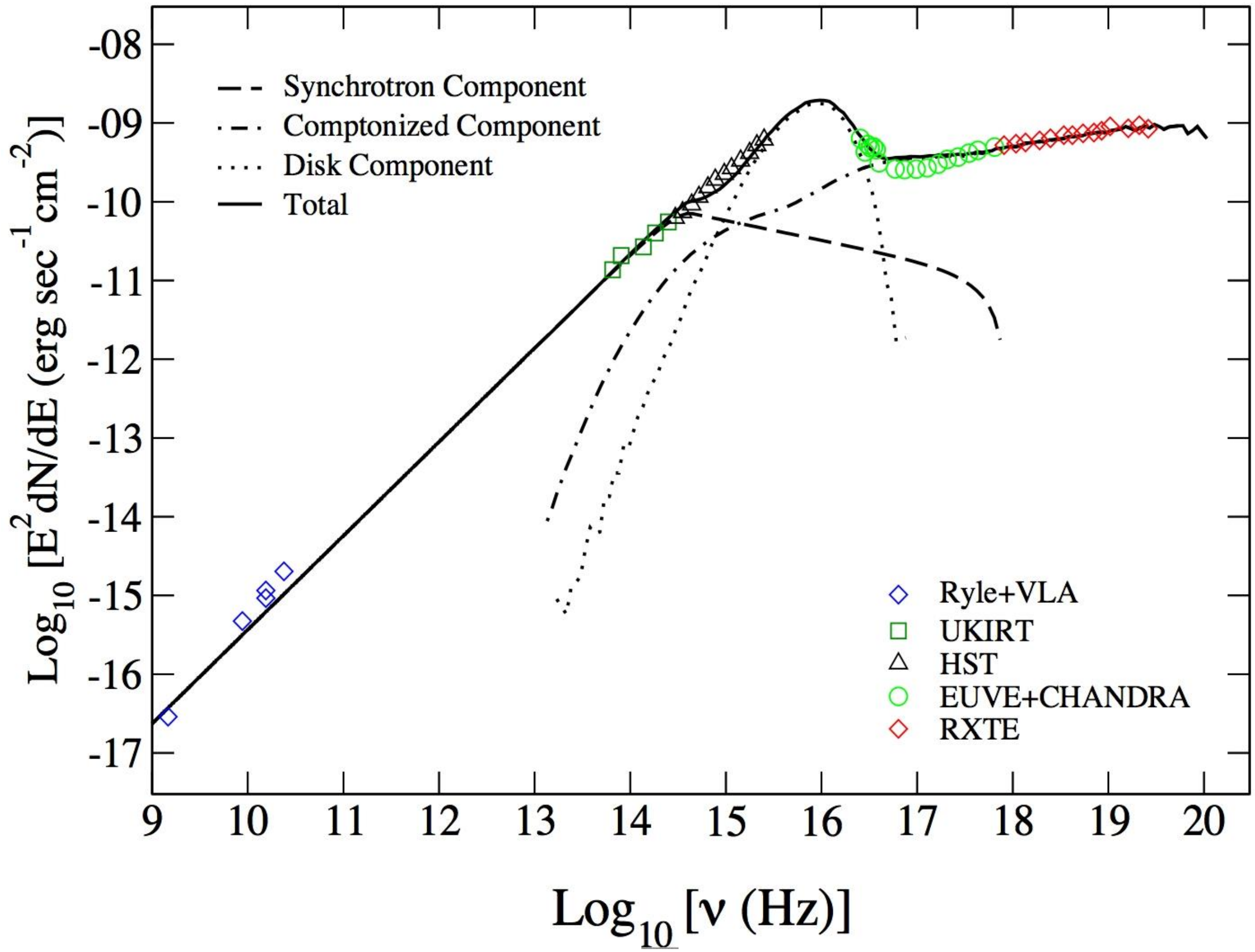
- Thus, we need to test the two models against other observational constraints.

Jet model

- Over the years, our group has developed a simple jet model that explains quantitatively:

- The spectrum (Reig et al. 2003; Giannios 2005).

Giannios (2005)



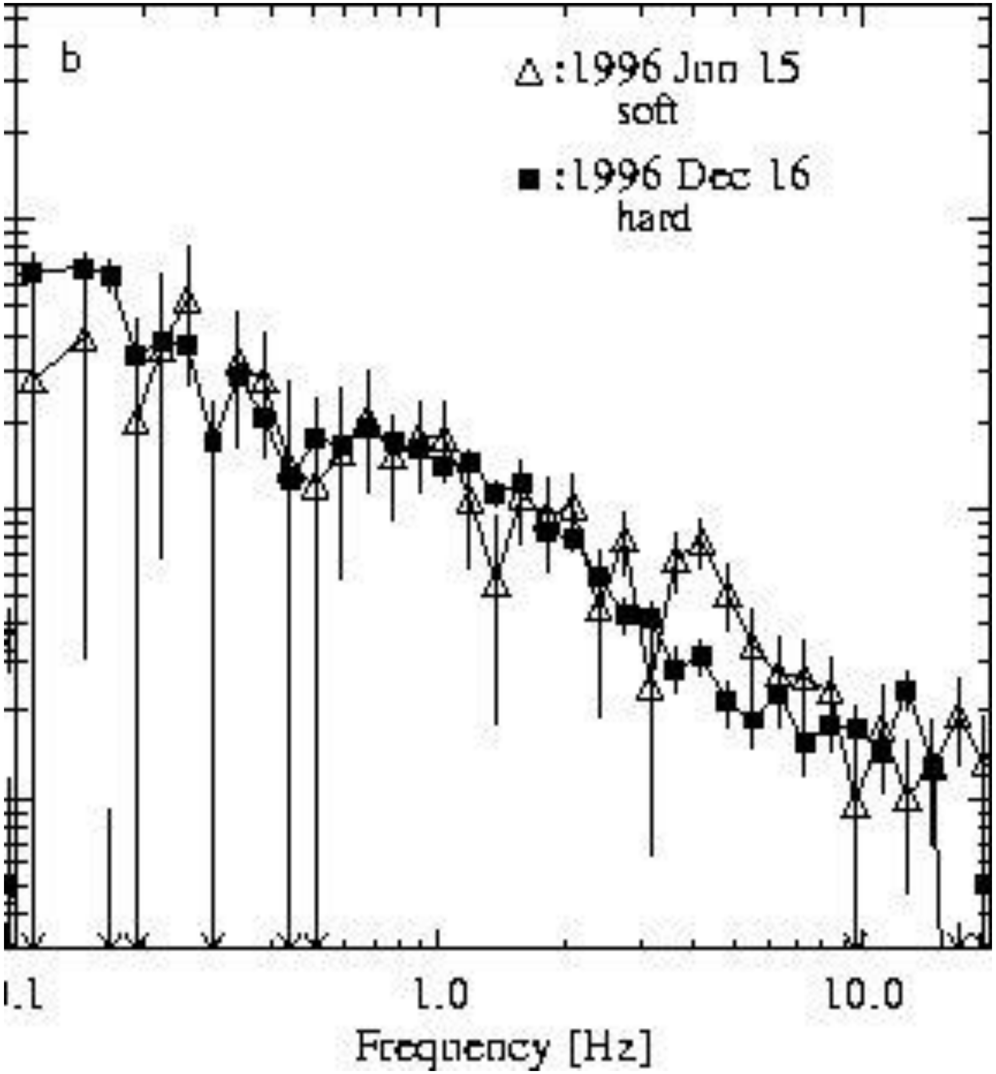
- Observations and model for XTE J 1118+480

Jet model

- The time-lags as a function of Fourier frequency (Reig et al. 2003).

Time lag vs Fourier frequency

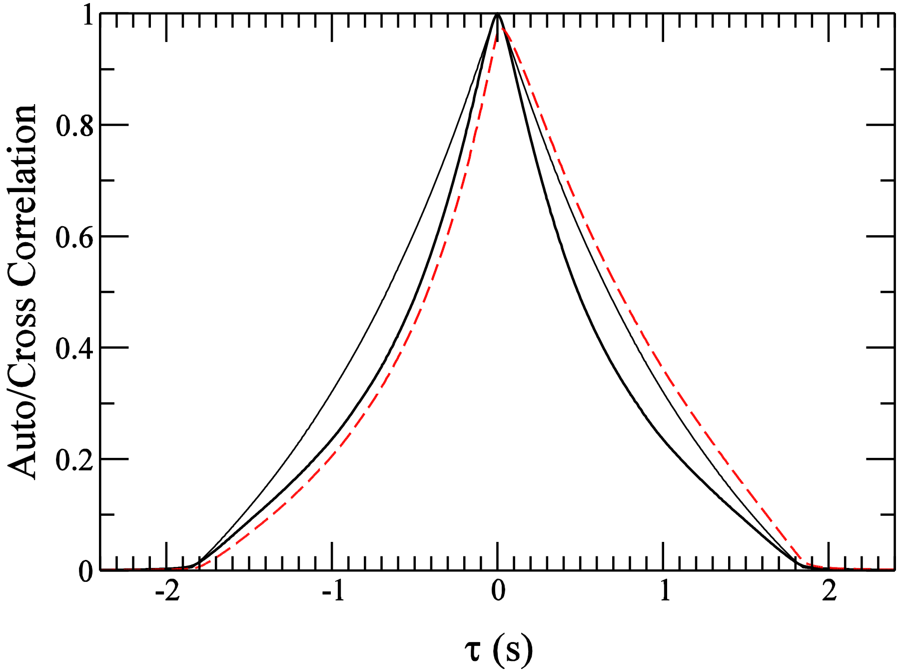
- (Pottschmidt et al. 2000, A&A).

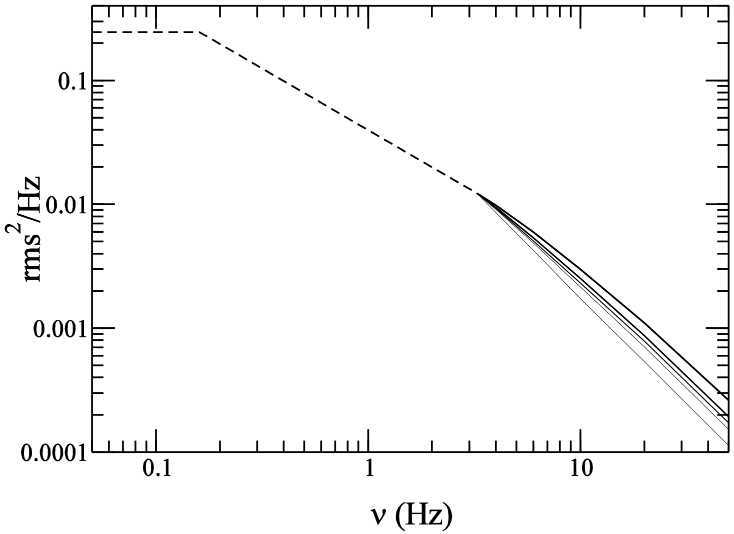


Jet model

- The shape of the autocorrelation function (Giannios et al. 2004).

Maccarone et al. (2000)
Nowak et al. (1999)

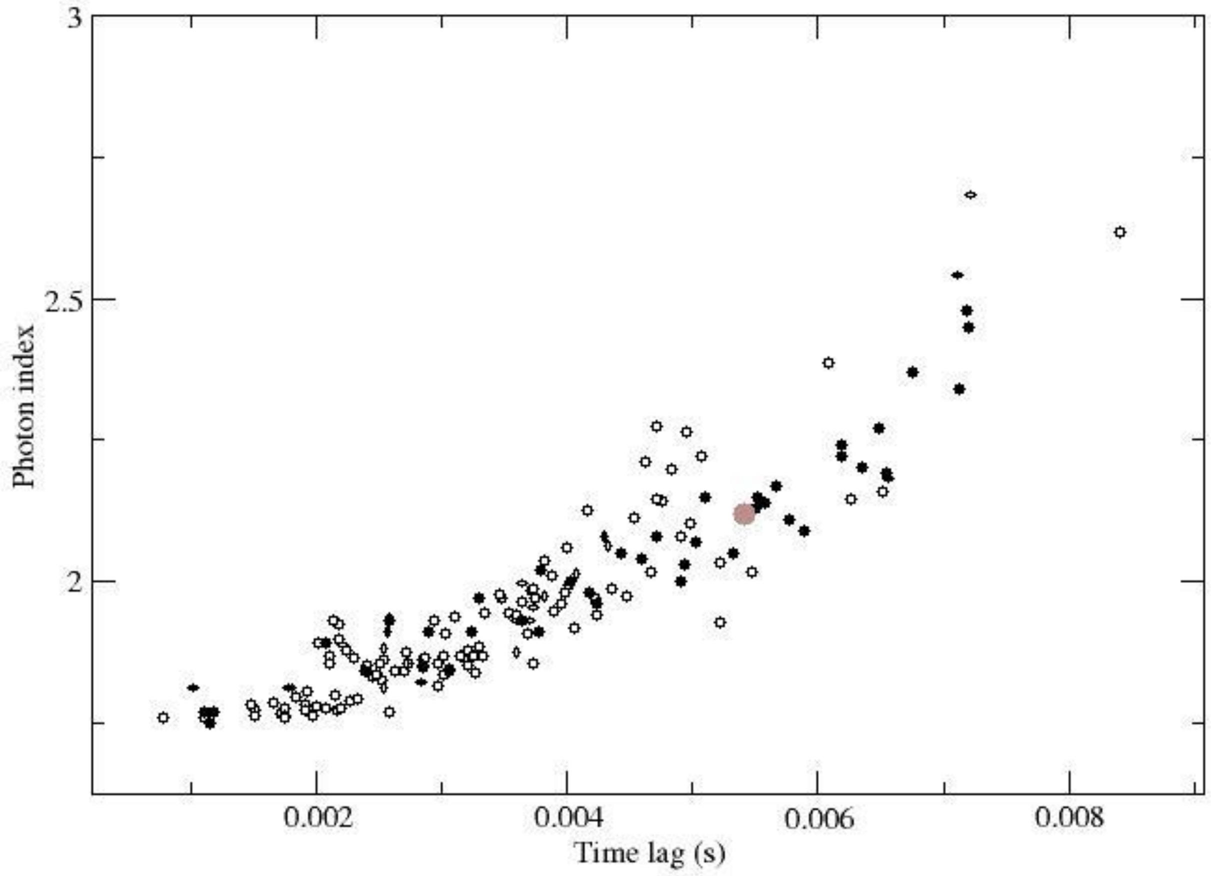




Jet model

- The correlation Γ – <time lag> for Cyg X-1 (Kylafis et al. 2012).

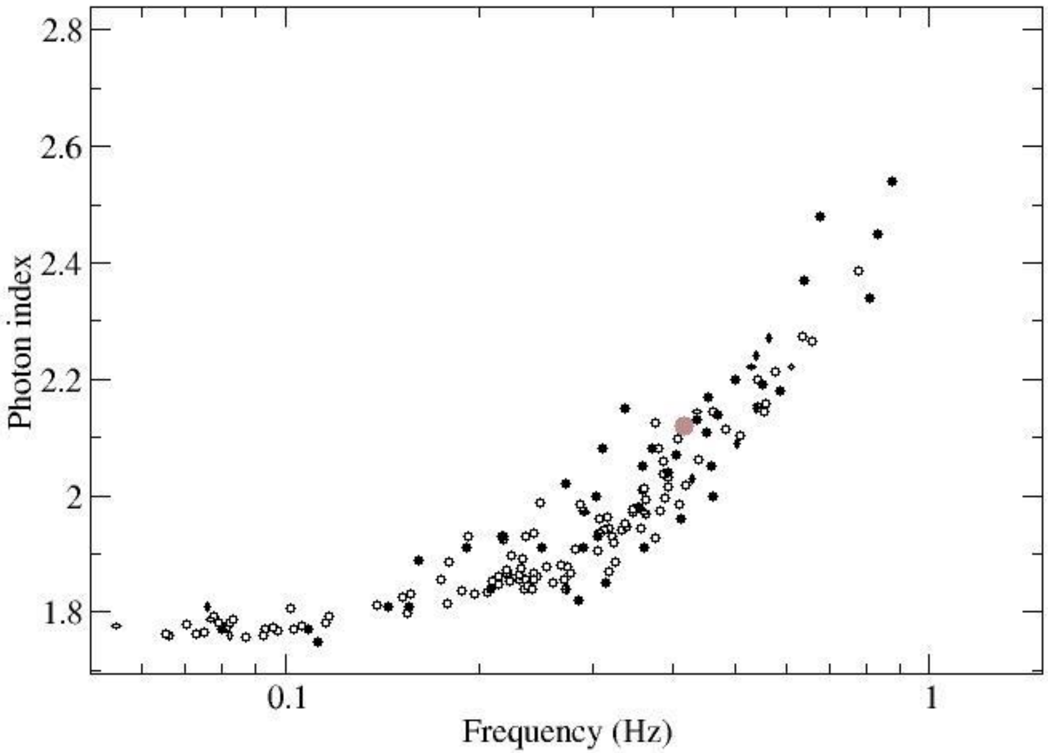
Γ vs. <time lag>



Jet model

- The correlation Γ – Fourier peak frequency for Cyg X-1 (Kylafis et al. 2012).

Γ vs. peak frequency



New constraints

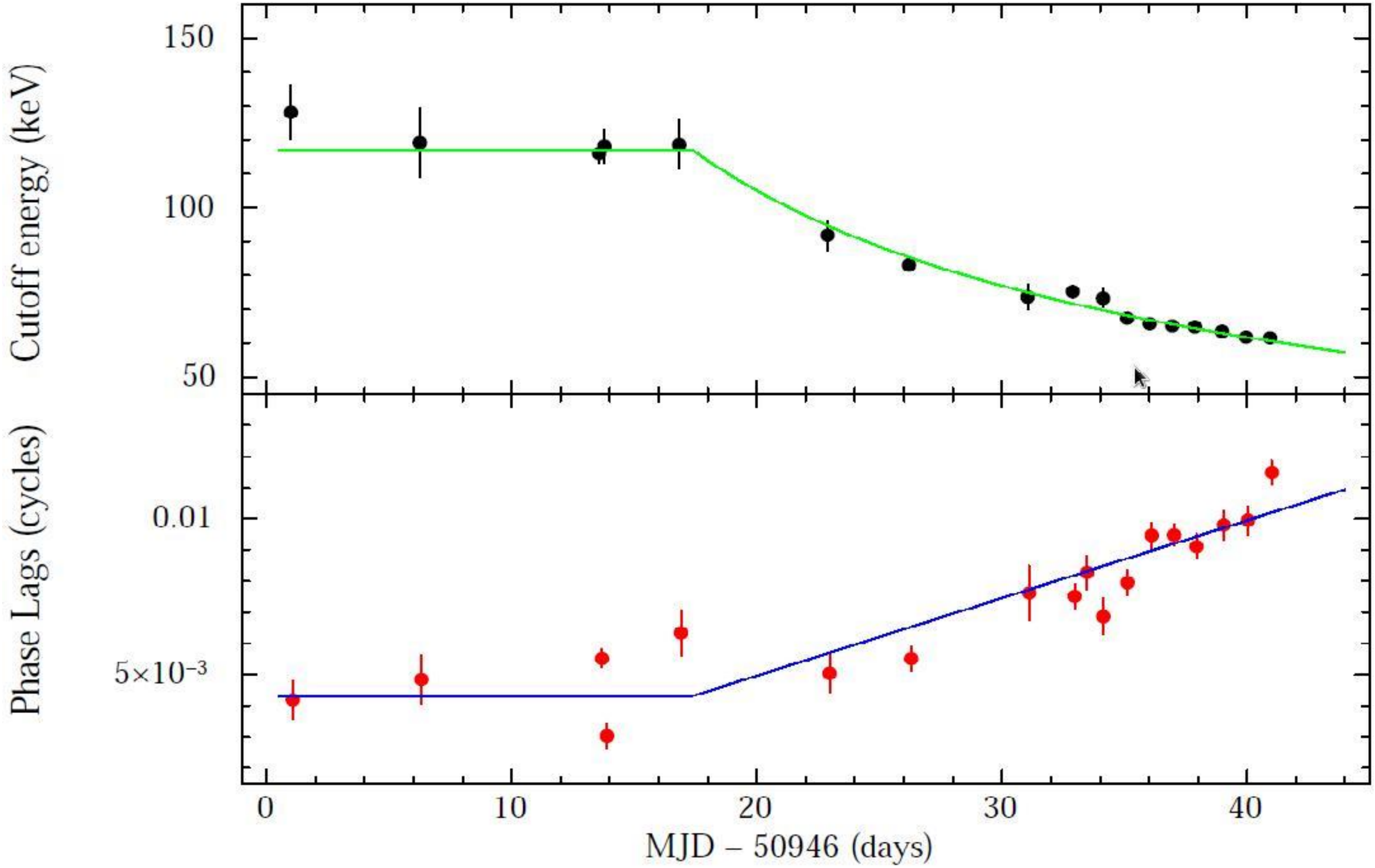
- Very recently, Altamirano & Mendez (2015) reported extremely stringent constraints from the observations of GX 339-4.

- As the source moves from the hard state to the hard-intermediate one,

- The phase lags increase,
- The cutoff energy decreases,
- The photon index Γ increases.

- The models must explain them simultaneously. Our model does.

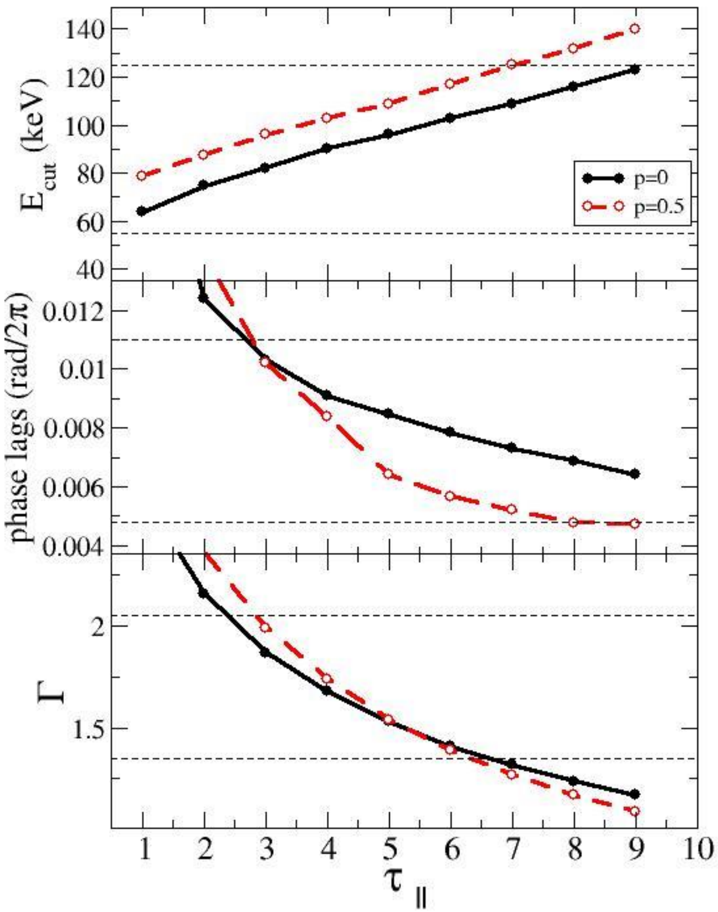
Altamirano & Mendez (2015)



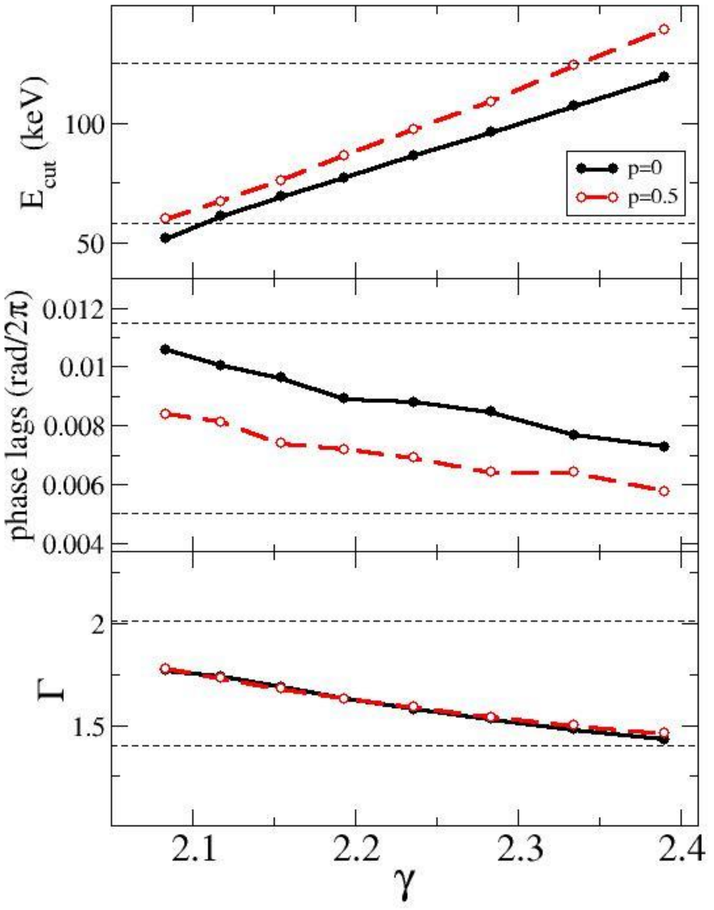
Parameters

- As the source moves from the hard to the hard-intermediate state, the jet weakens and cools.
- Thus, we varied the optical depth of the jet and the Lorentz factor γ of the electrons.
- Both parameters give trends similar to the ones observed.

Variation of τ



Variation of γ



Variation of τ and γ.

- Not surprisingly, we can fit all three observations **quantitatively** very well if we assume a linear variation of τ with γ.

Conclusions

- The jet model seems to have an edge at this point.

- The supporters of the ADAF model are smart people! I am sure that they will come up with an idea, but the quantitative explanation will be difficult.

- The same model must explain ALL the correlations!

- We will see in the future which model prevails.

THANKS

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- And Γ increases.

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