Interpretation of the **Hardness – Luminosity Diagram** of Black-hole X-ray Transients

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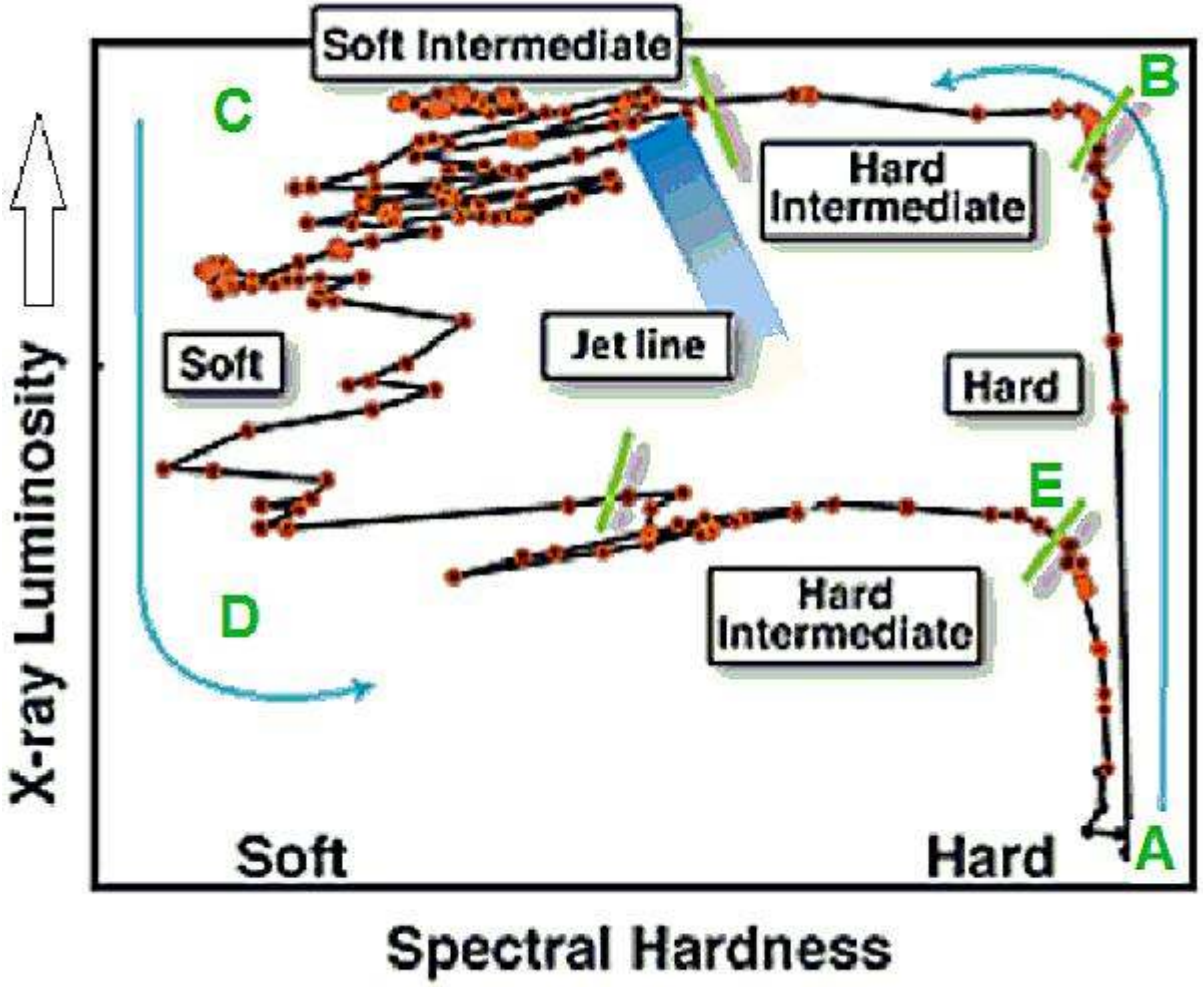
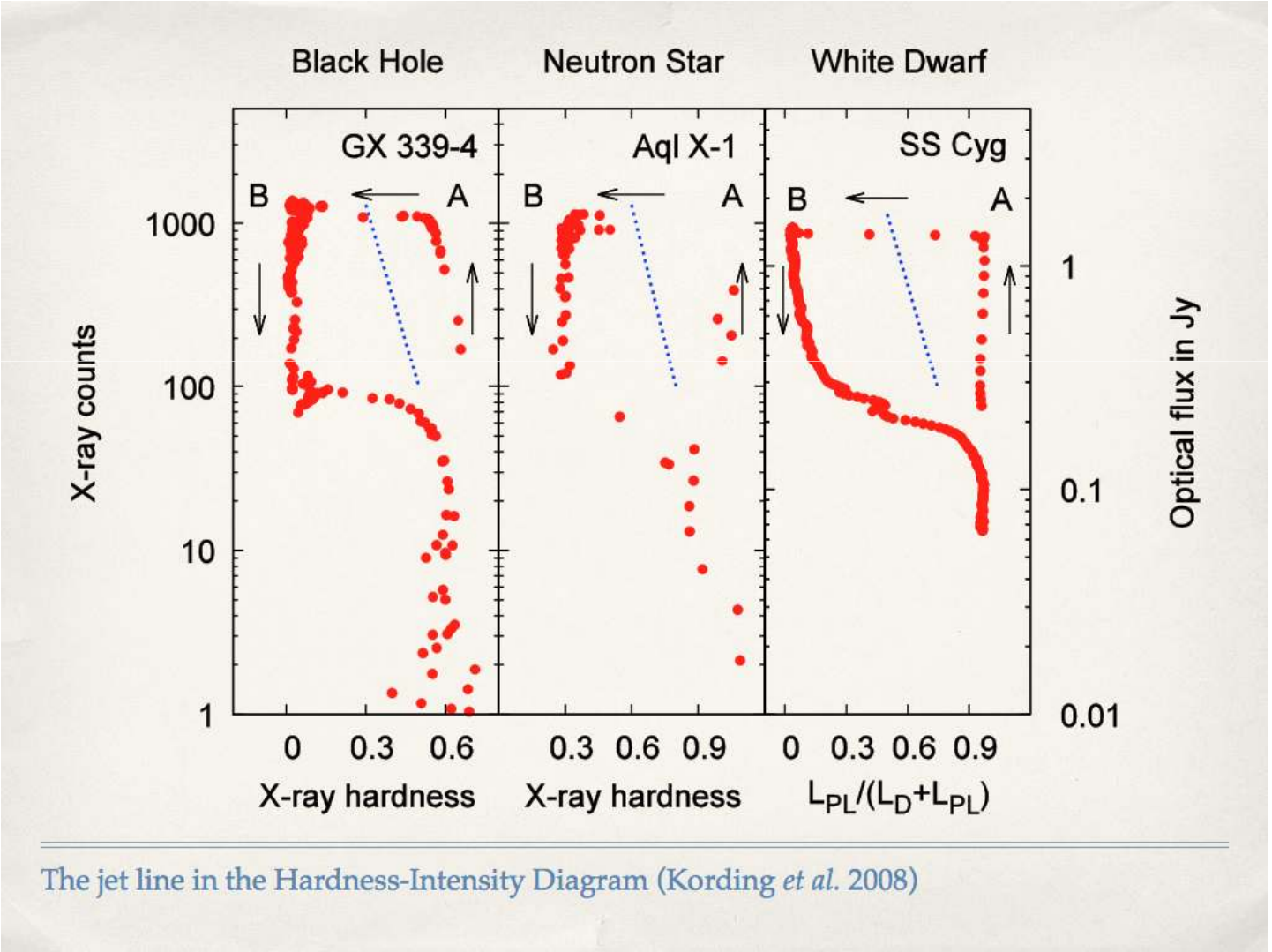
Introduction

- Black-hole X-ray transients (XRTs) exhibit outbursts.
- 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**).

GX 339-4


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

Similar behavior for BH, NS, WD.

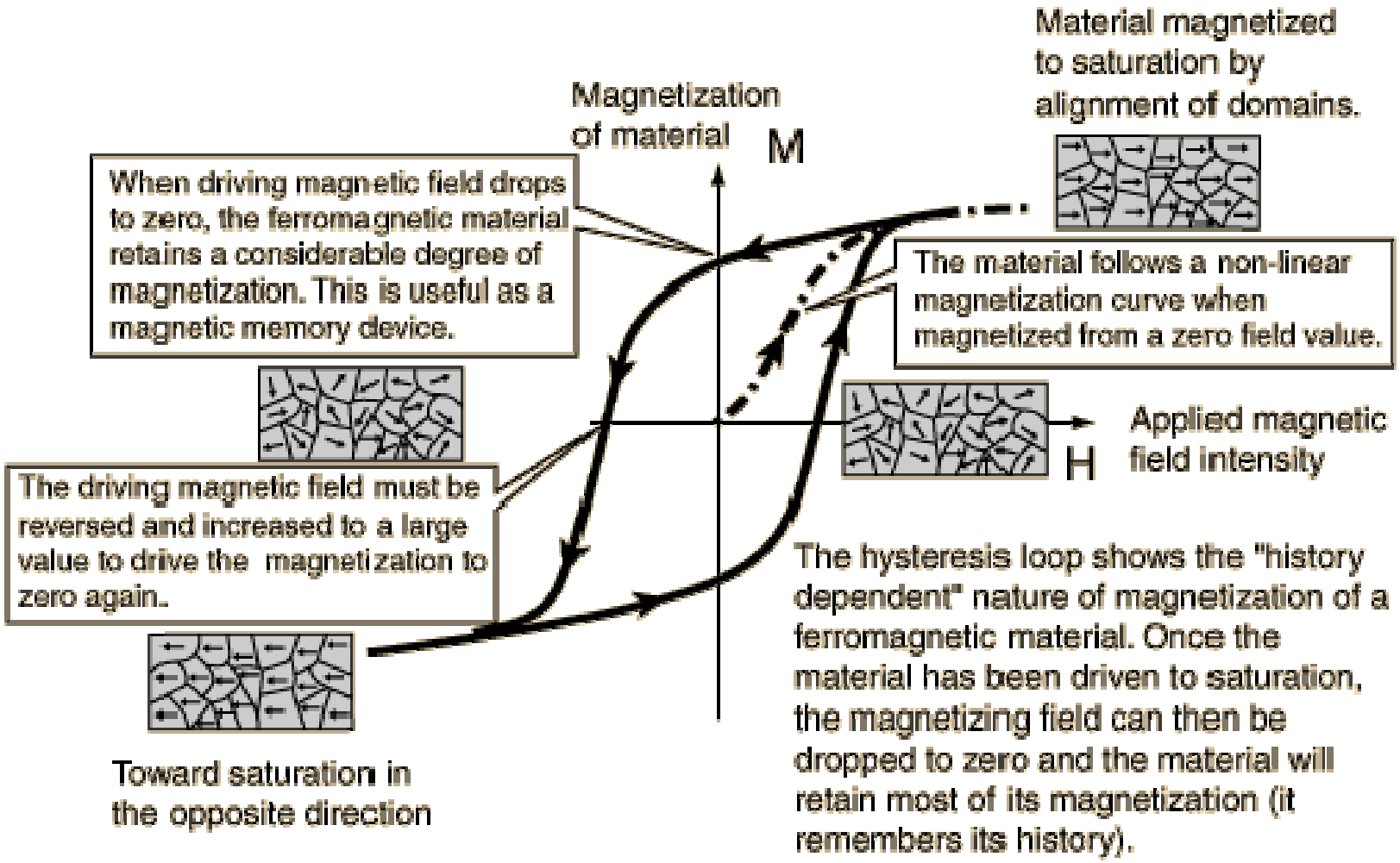


The jet line in the Hardness-Intensity Diagram (Kording *et al.* 2008)

IMPORTANT !

- The q-shaped curve (hysteresis curve) is traversed in the **counterclockwise** direction.
- There must be a reason for this!
- We understand the physics of the hysteresis curve MAGNETIZATION vs. EXTERNAL MAGNETIC FIELD, which is also traversed in the **counterclockwise** direction (see next slide).
- We should similarly understand the physics of the q-curve.

Magnetization vs. External Mag. Field for ferromagnetic materials



Knowledge?

- So far, no **physical** interpretation has been proposed for the q-shaped curve.
- The question of the **counterclockwise traversal** is not even asked!
- There is a **phenomenological** interpretation of the q-diagram , with a central corona and an accretion disk.
- I will convince you that this phenomenological interpretation has a **severe problem**!

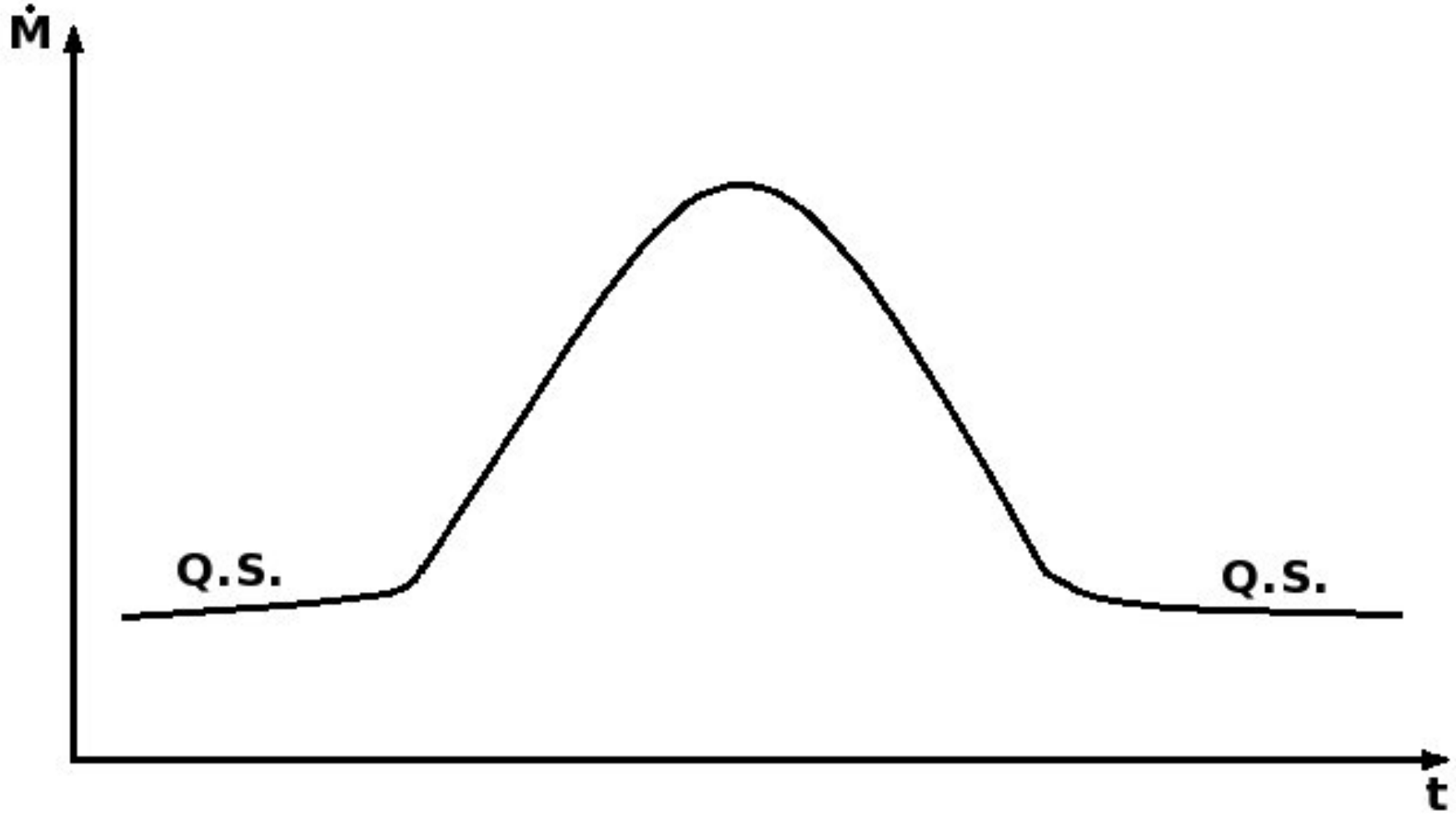
Assumptions in our work

- 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 disk 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).

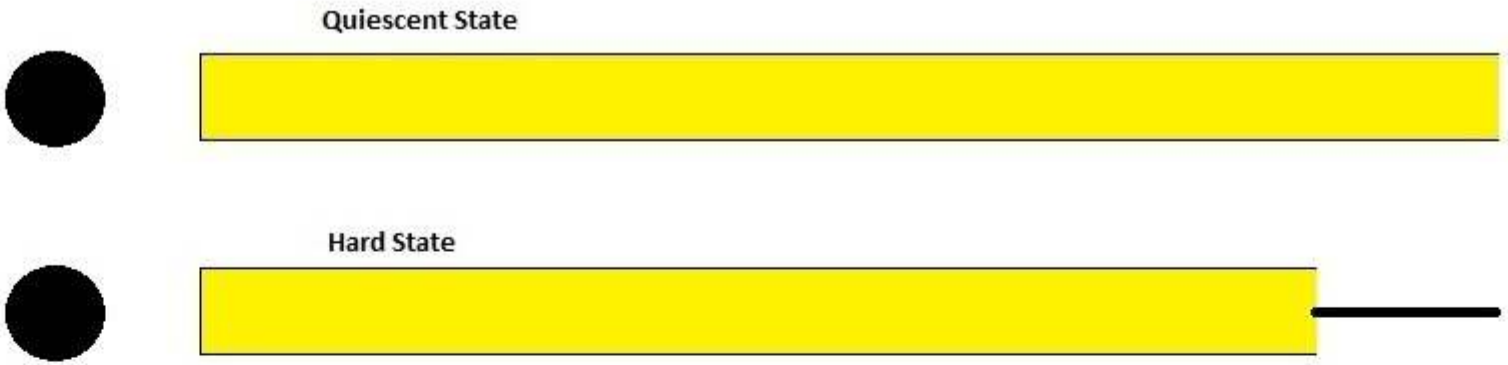
Accretion rate during outburst

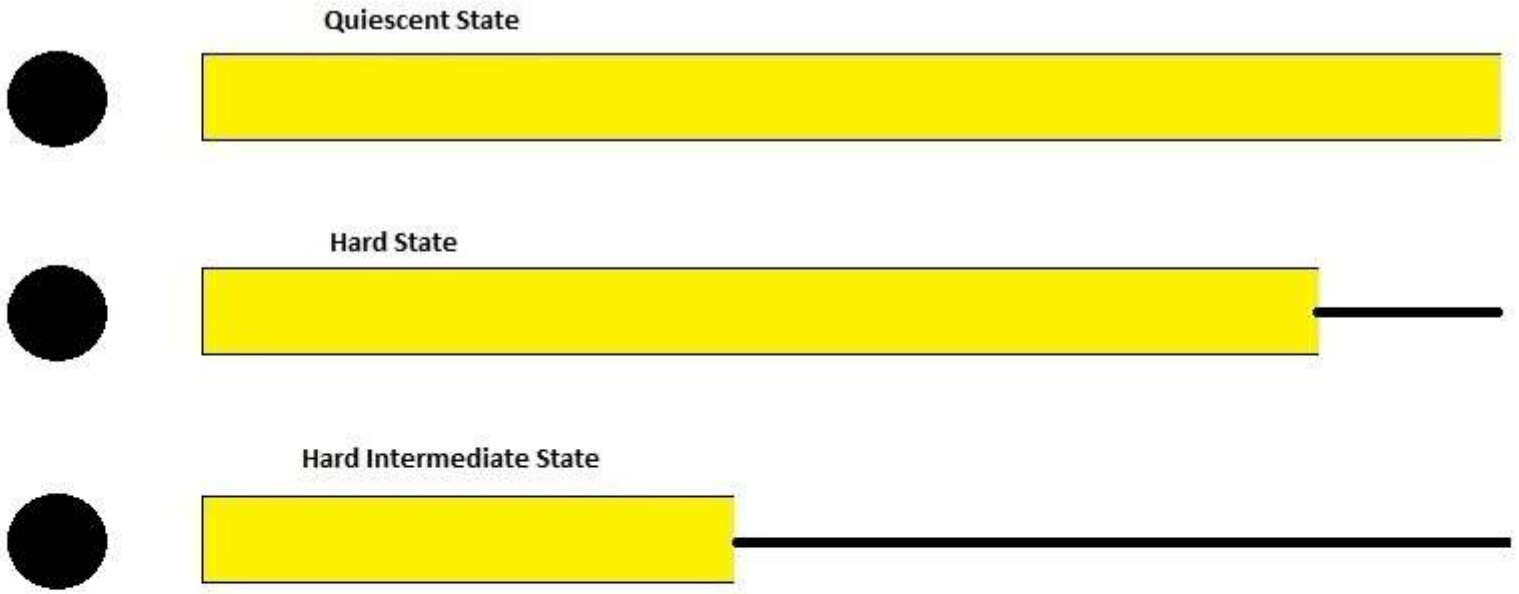


Interpretation

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

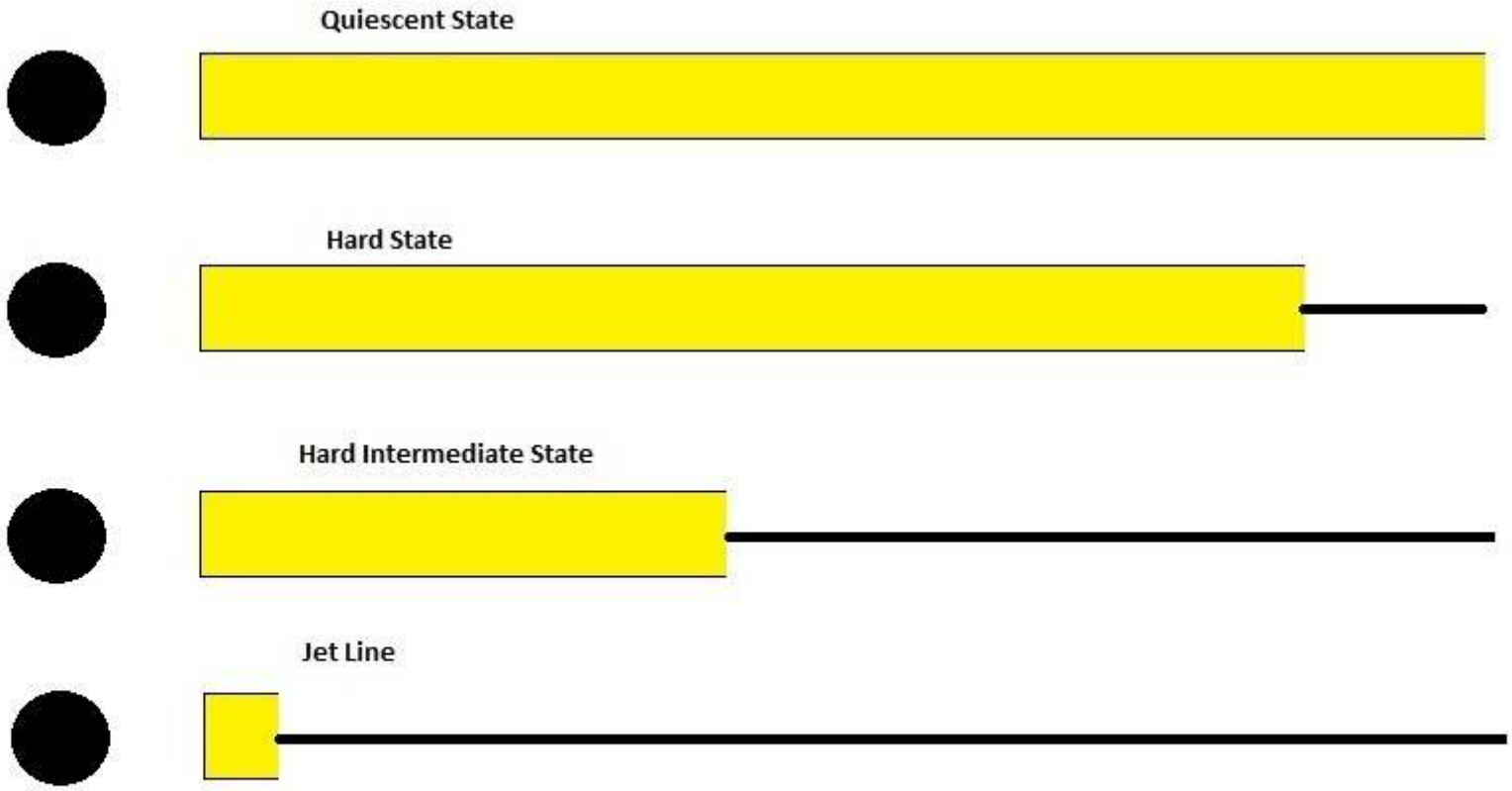

Quiescent State

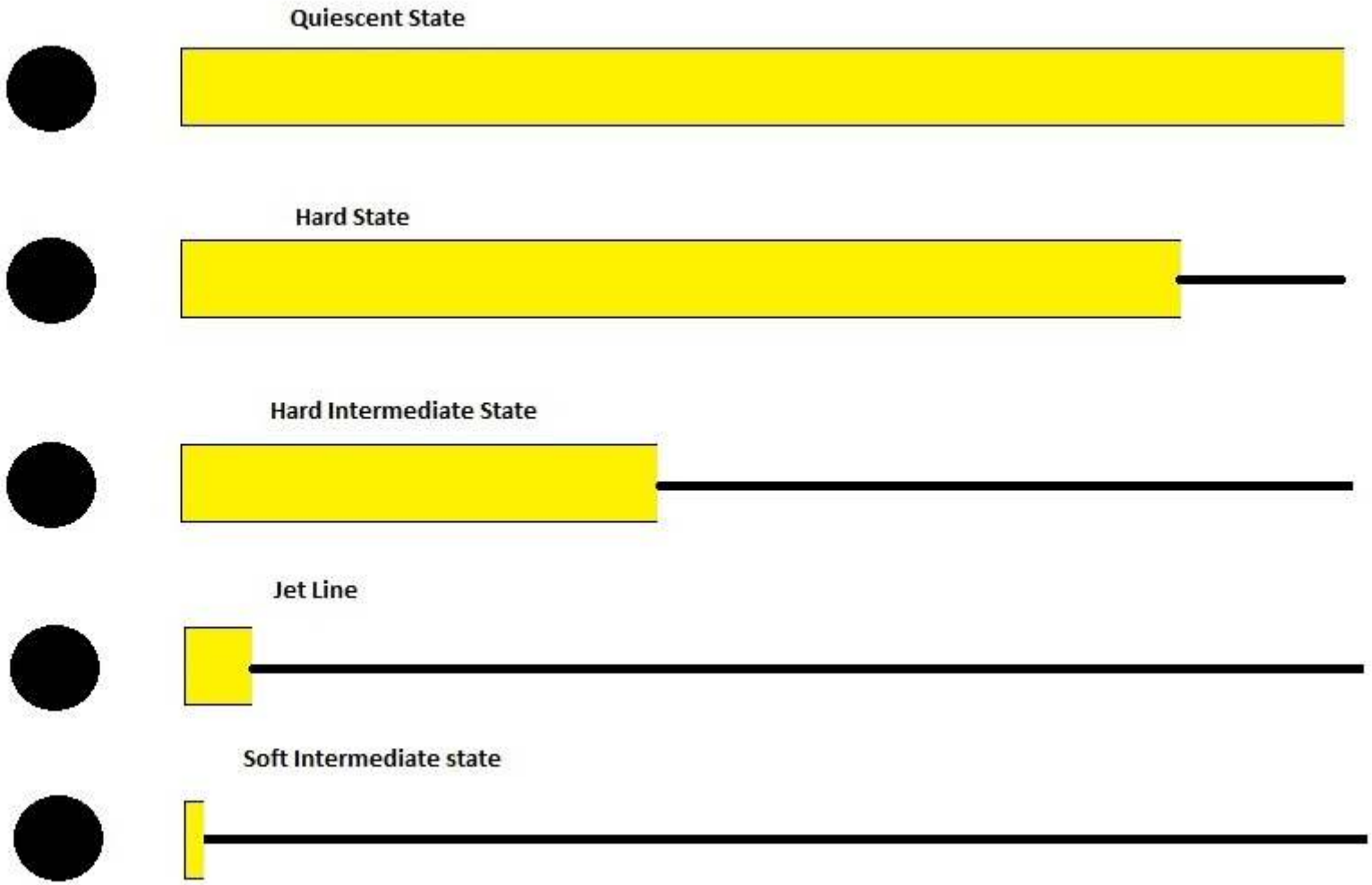

Quiescent State
Hard State

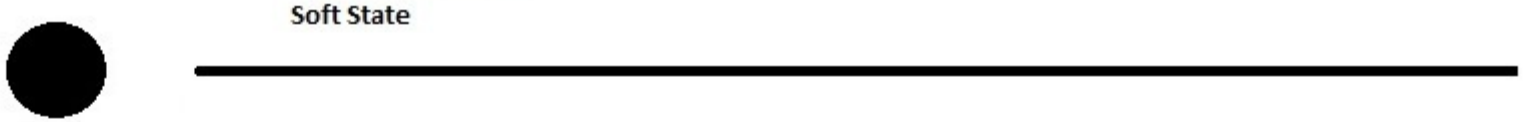

Quiescent State
Hard State
Hard Intermediate State

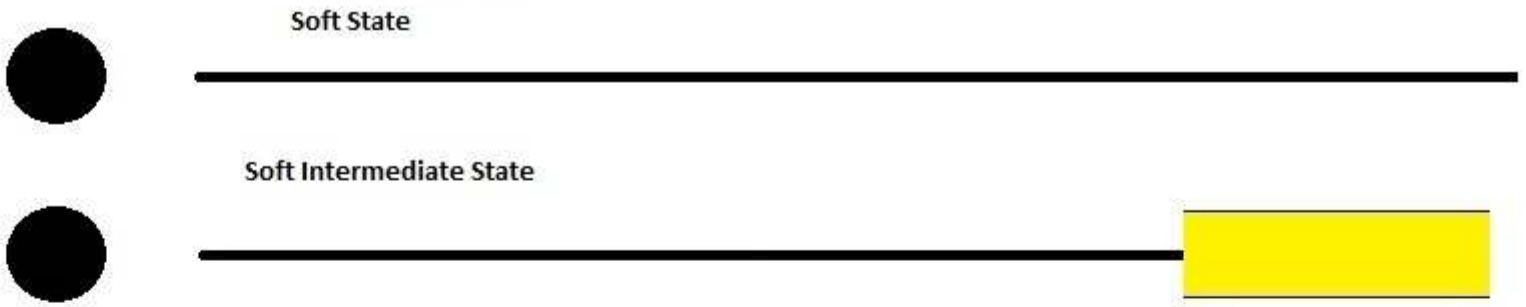
Jet

- In all three of the previous states the inner part of the accretion disk is ADAF-like, the **Cosmic Battery** (Contopoulos & Kazanas 1998) works efficiently, and a compact jet is **always** present (Kylafis et al. 2012).
- Then, the jet line is approached.
- The thin disk cannot sustain the high magnetic field that was created in the thick disk. This is well known analytically and from MHD simulations.
- The magnetic field recombines and produces huge eruptions (**eruptive jet**).


Quiescent State
Hard State
Hard Intermediate State
Jet Line

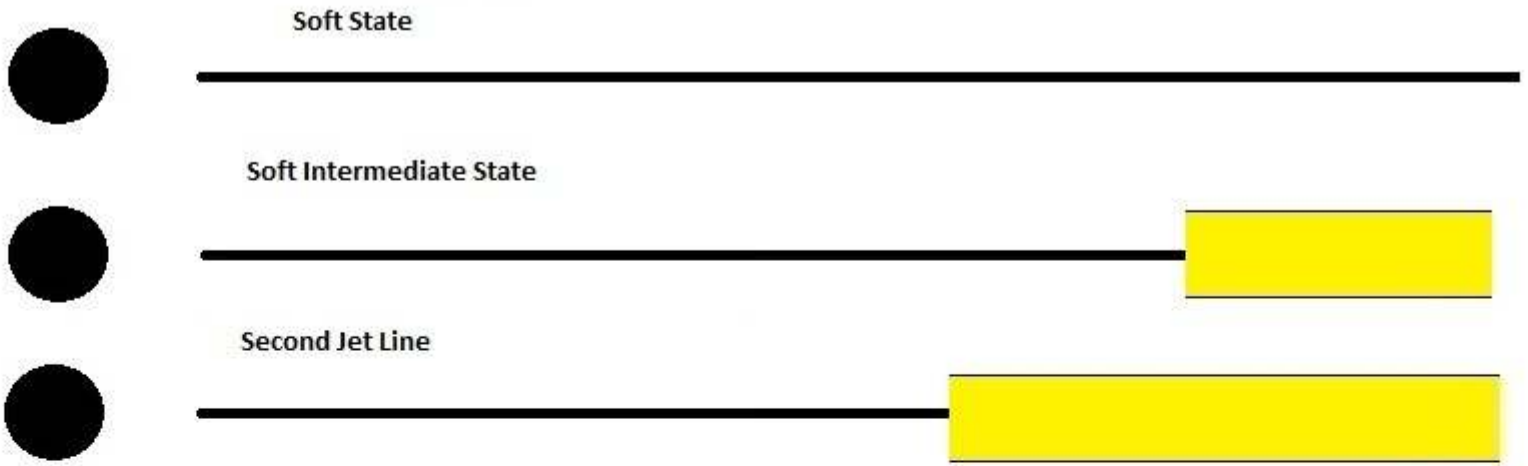

Quiescent State
Hard State
Hard Intermediate State
Jet Line
Soft Intermediate state

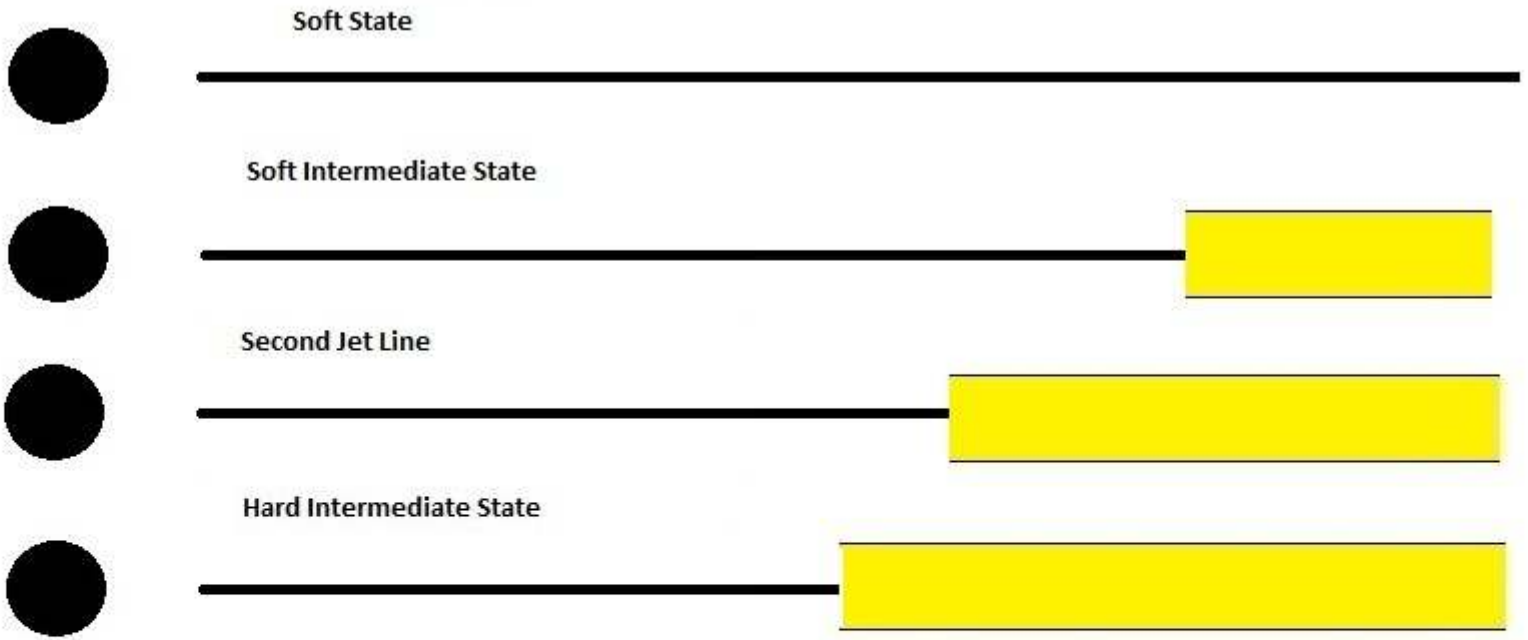

Soft State

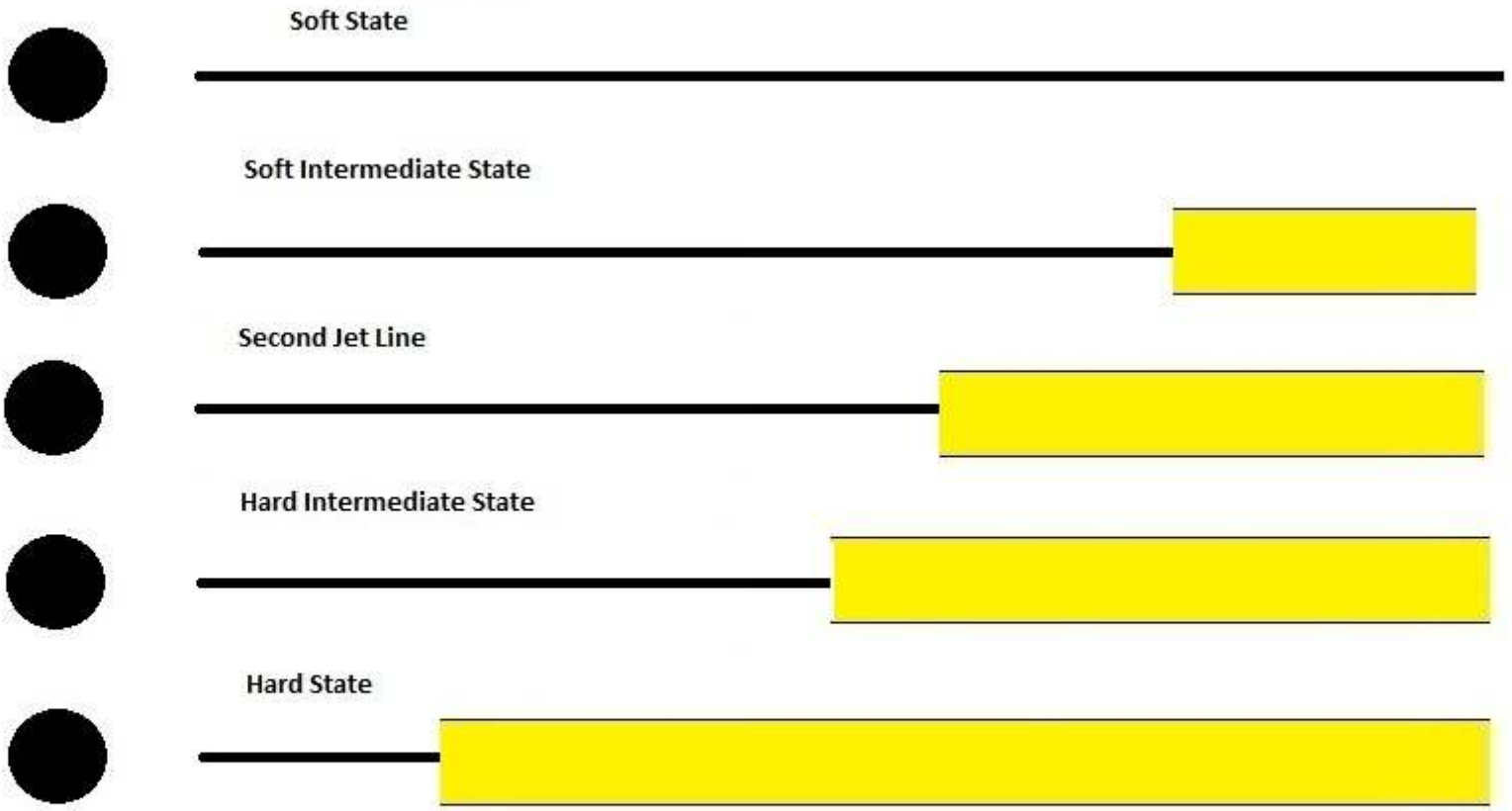

Soft State
Soft Intermediate State

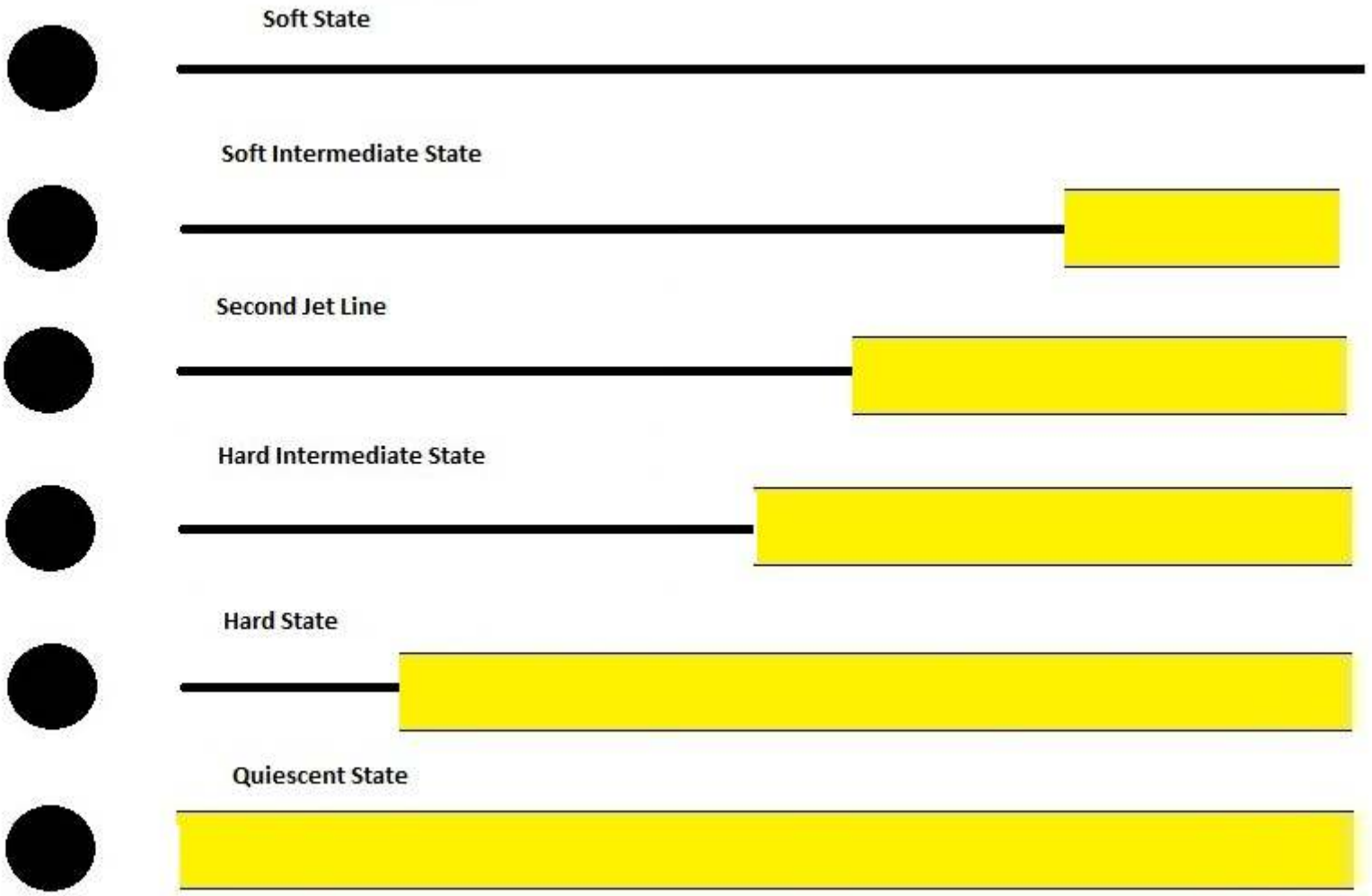
Jet

- Now, that a significant part of the accretion disk has become ADAF-like, the Cosmic Battery works again efficiently, and **a jet begins to form**.
- No eruptive phenomena occur. The jet **builds up steadily** and becomes detectable as a compact jet when the source approaches the hard state.
- This was **confirmed** in great detail by Corbel et al. last month. The jet is first optically thin and later becomes compact.


Soft State
Soft Intermediate State
Second Jet Line

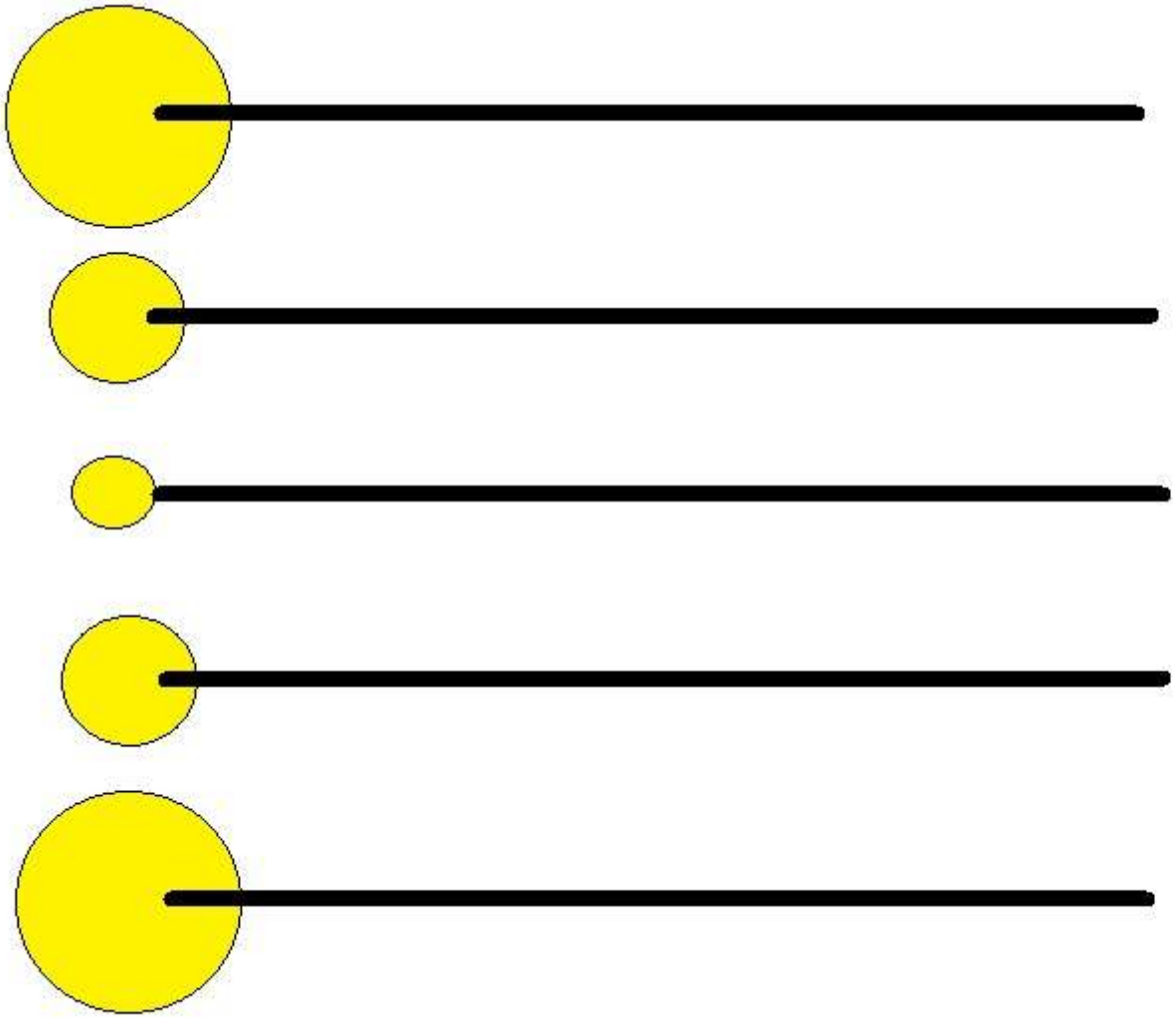

Soft State
Soft Intermediate State
Second Jet Line
Hard Intermediate State


Soft State
Soft Intermediate State
Second Jet Line
Hard Intermediate State
Hard State

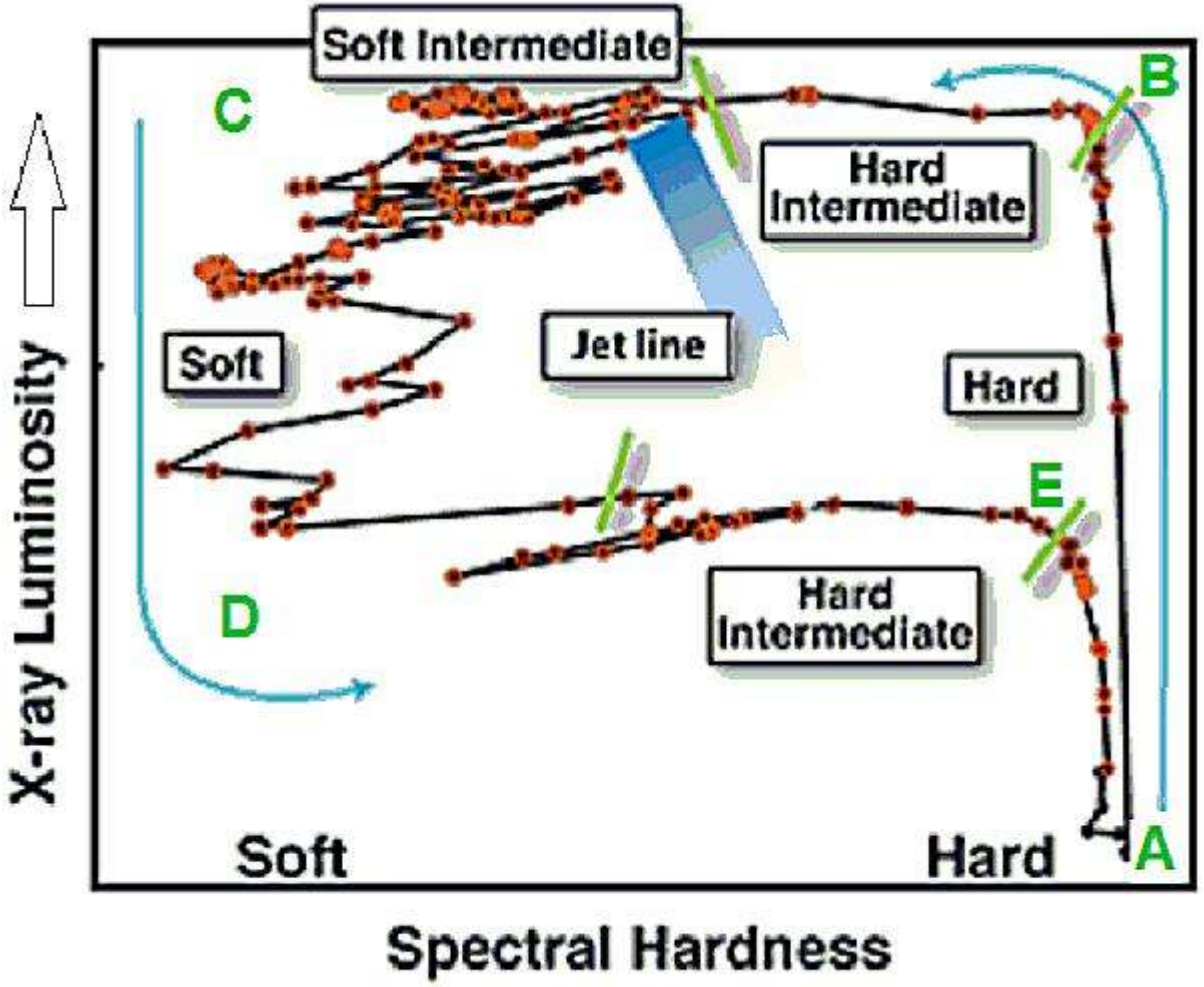

Soft State
Soft Intermediate State
Second Jet Line
Hard Intermediate State
Hard State
Quiescent State

Simple phenomenological picture

- What's wrong with the simple phenomenological picture of a **central corona** and an **accretion disk**?
- Let's examine it.



GX 339-4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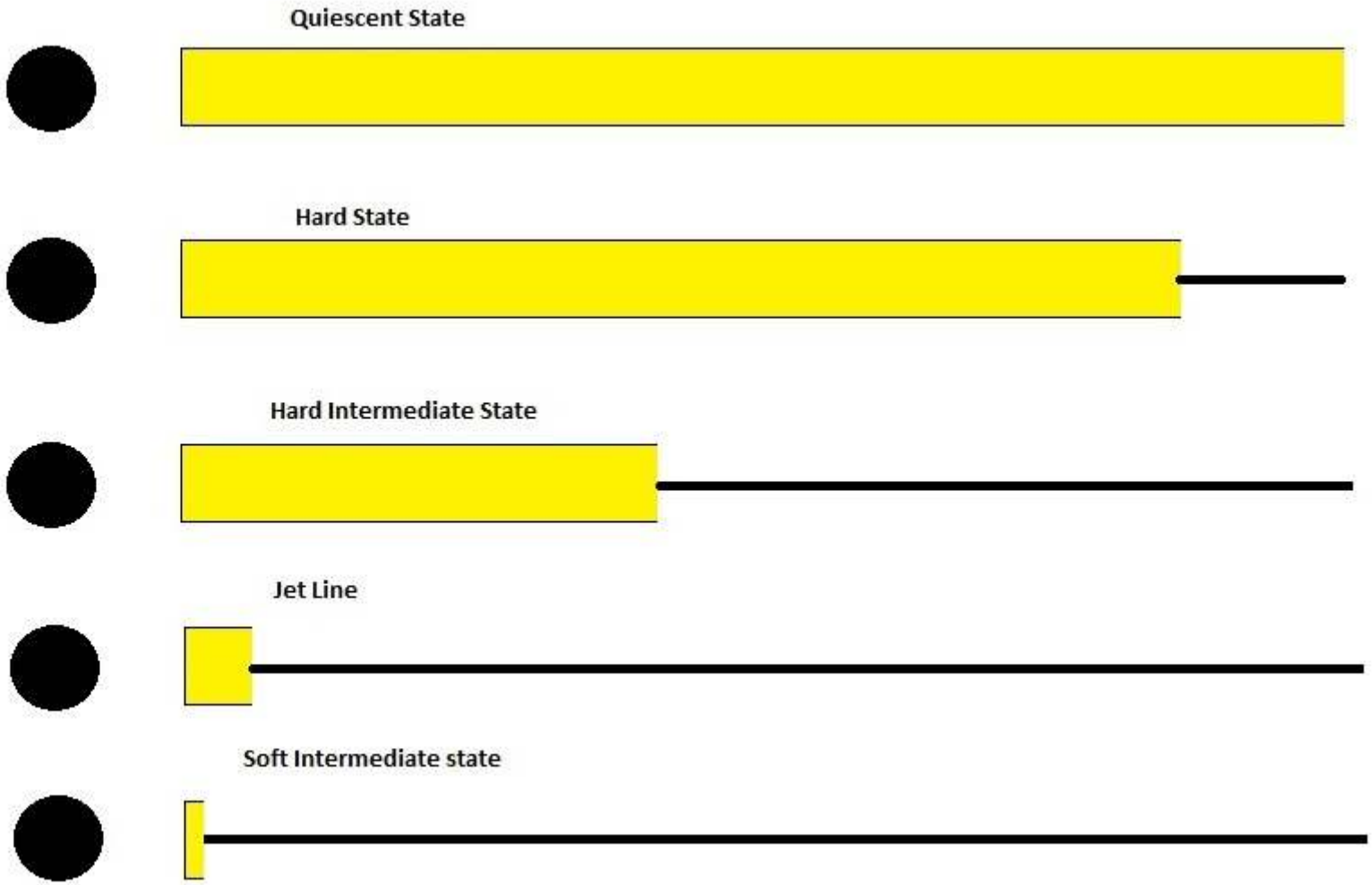
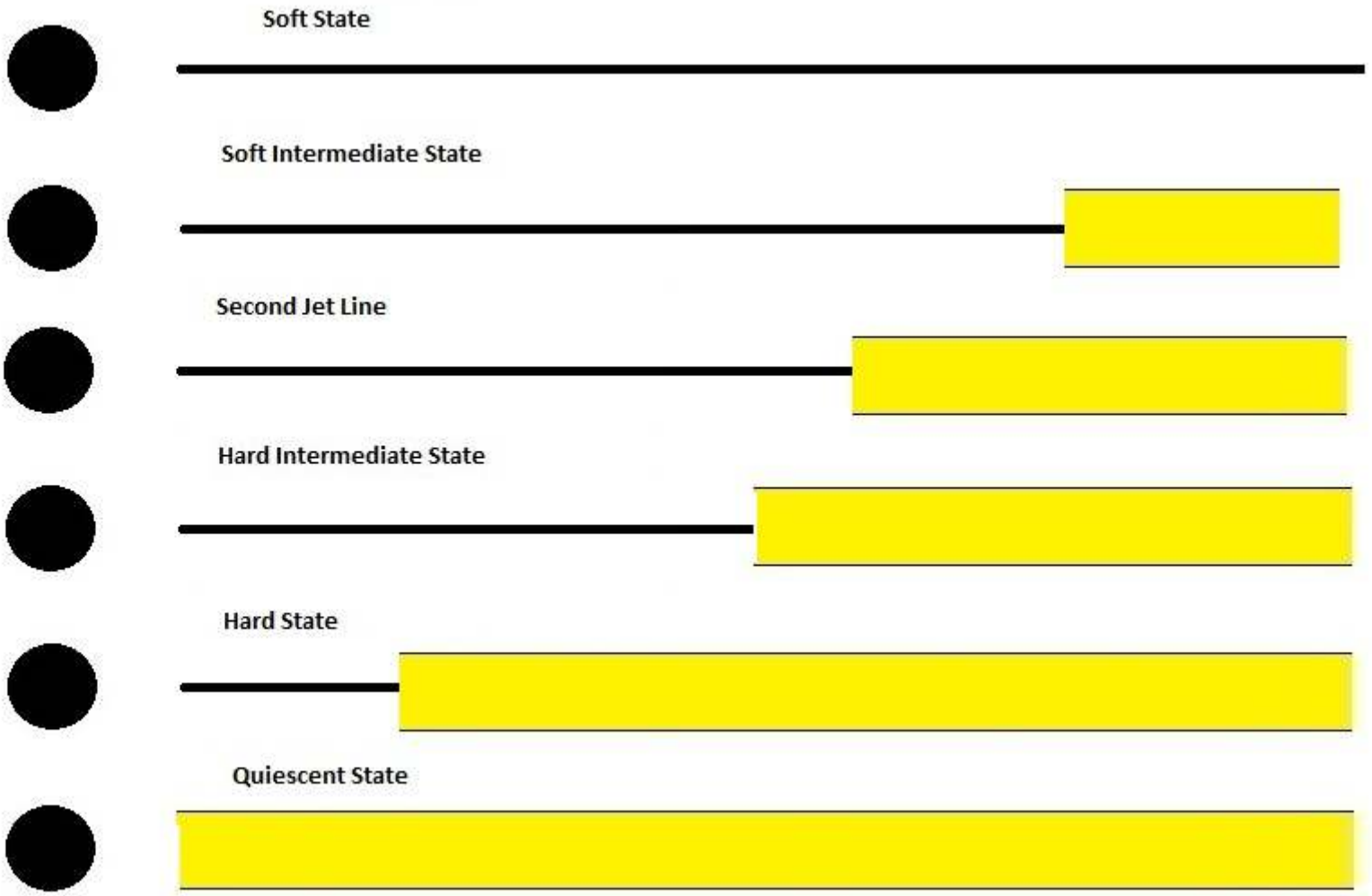
Symmetry breaking

- In the **physical** picture that we propose, the symmetry is broken.
- When the accretion rate **increases** at the beginning of the outburst, **the thin disk is outside** and the thick inside.
- When the accretion rate **decreases**, it is the opposite.


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


Soft State
Soft Intermediate State
Second Jet Line
Hard Intermediate State
Hard State
Quiescent State

Conclusions

- We claim that no X-ray Transient will ever be seen to traverse the “q”-shaped curve in the clockwise direction.
- The disappearance of the jet will **always** be eruptive. The reappearance of the jet will **never** be eruptive.
- Our picture makes the specific prediction that the **average timelag** of the hard X-rays with respect to the soft X-rays will **decrease with time** both in the upper and the lower branches of the q-shaped curve.
- THANKS