Constraints on the physical origin of disk winds in Black Hole X-ray binaries thanks to Athena

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on behalf of the Athena A&A Special Issue proposal team

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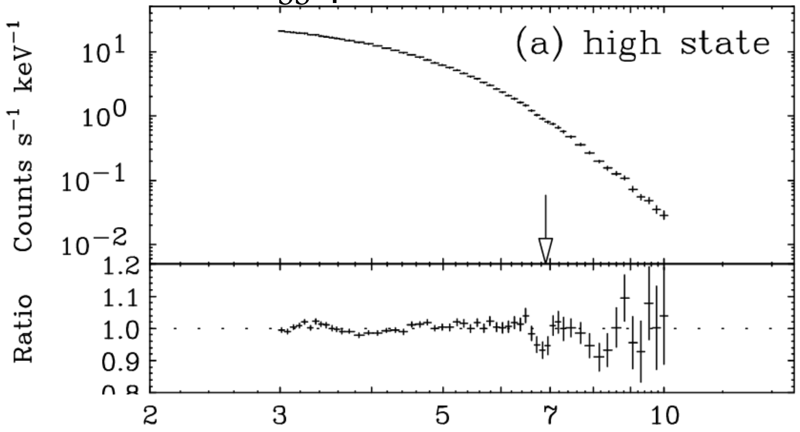
Disk Winds: Observational facts

◉ First **discoveries** of narrow absorption features **(Fe XXV, Fe XXVI)** with ASCA (e.g., GROJ1655–40 Ueda et al. 1998, Yamaoka et al. 2001; GRS 1915+105, Kotani et al. 2000) → **Hot wind**

GRO J1655-40 in soft state



Ueda et al. (1998)

◉ Measured energy shift < a few 1% **(up to a few 1000 km/s)**

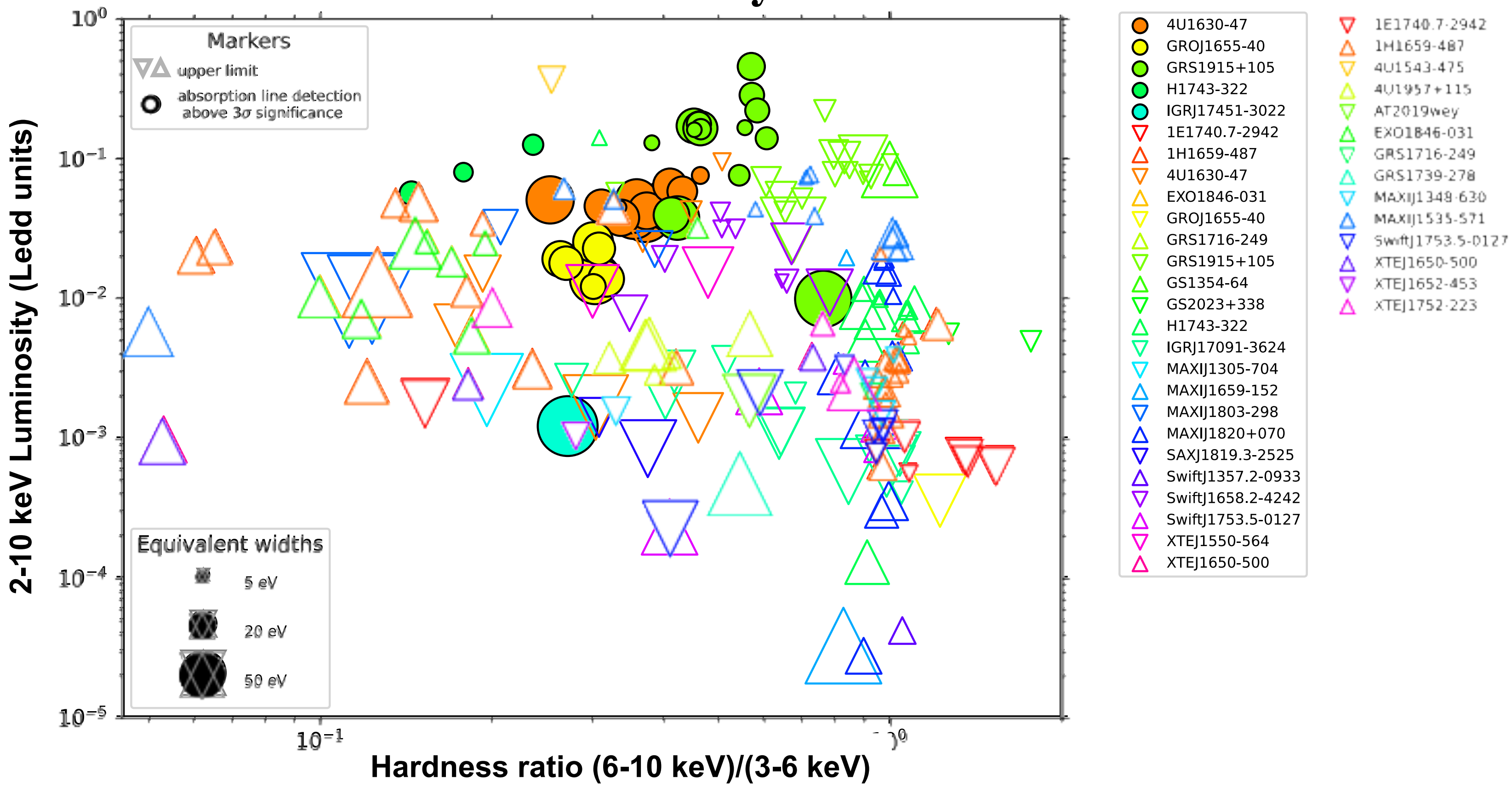
◉ Absence of P Cyg profile: **the absorber does not flow isotropically**

◉ Lack of any orbital phase dependence of the features (e.g., Yamaoka et al. 2001; Boirin & Parmar 2003) except during dips: **the absorber is close to the compact object**

Disk Winds: Observational facts

- Overwhelming presence of **X-ray** absorption features **in high inclined systems in « soft state »** (e.g., Ponti et al. 2012, Diaz Trigo & Boirin 2016, Parra et al. in prep.)

all BH XrB observed by XMM



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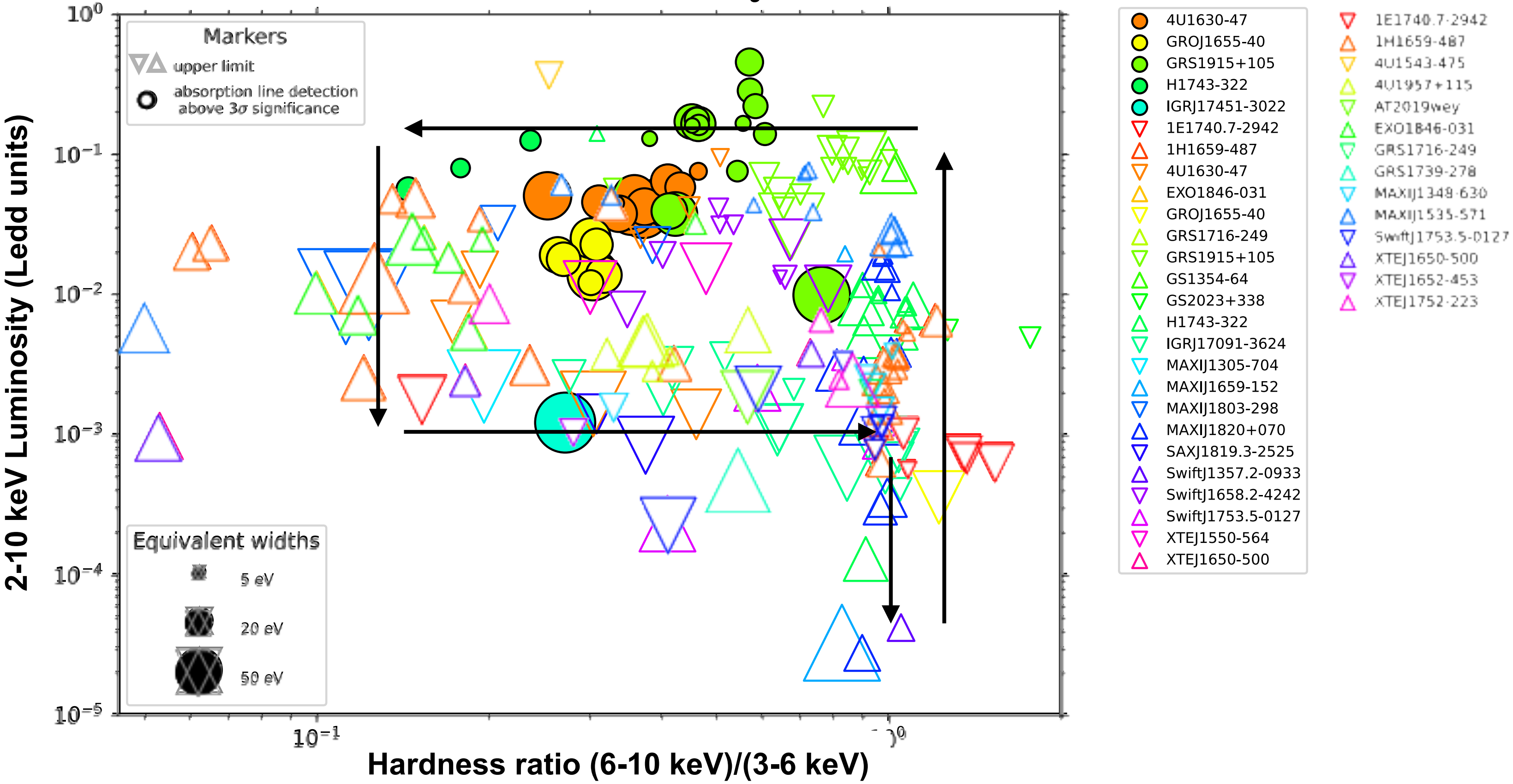

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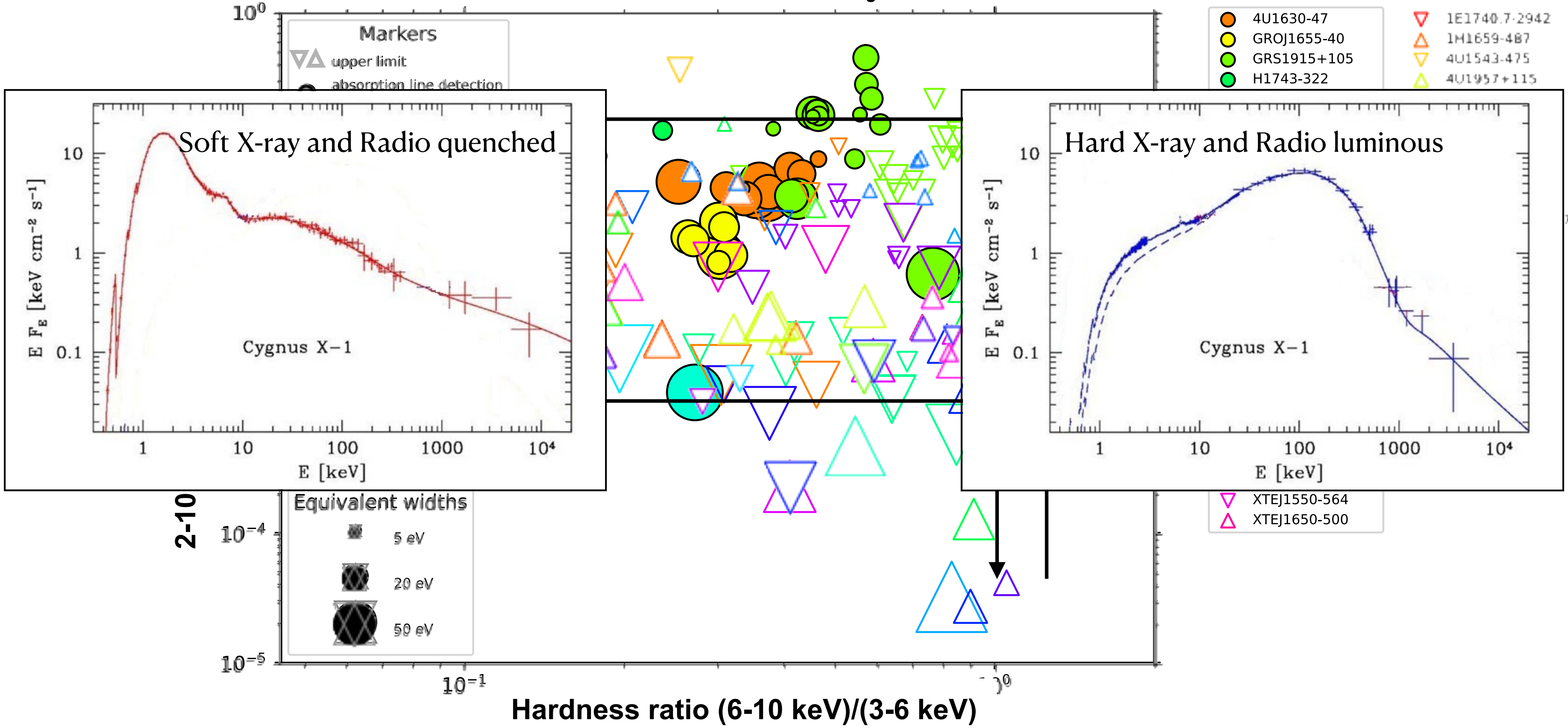

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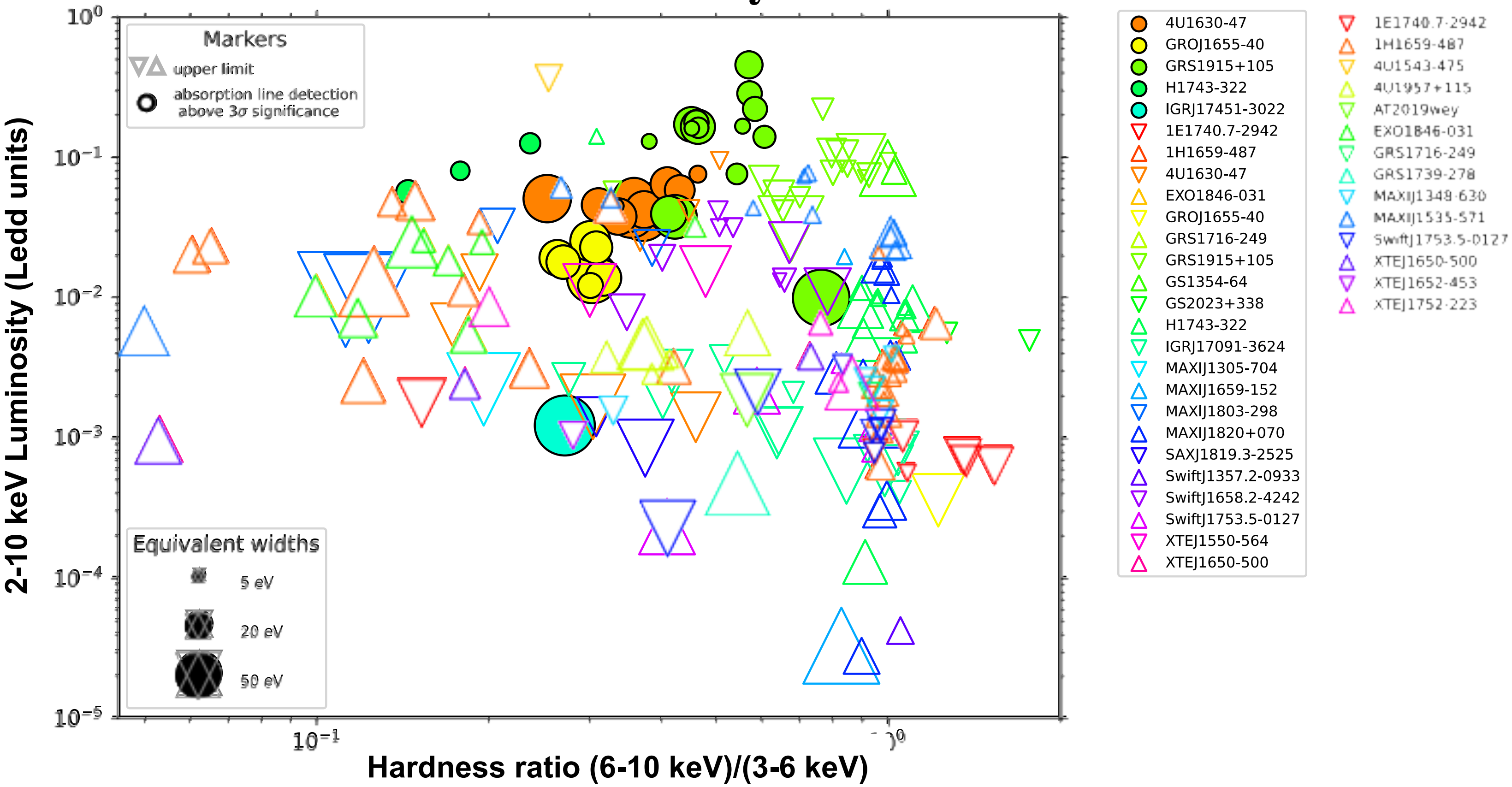
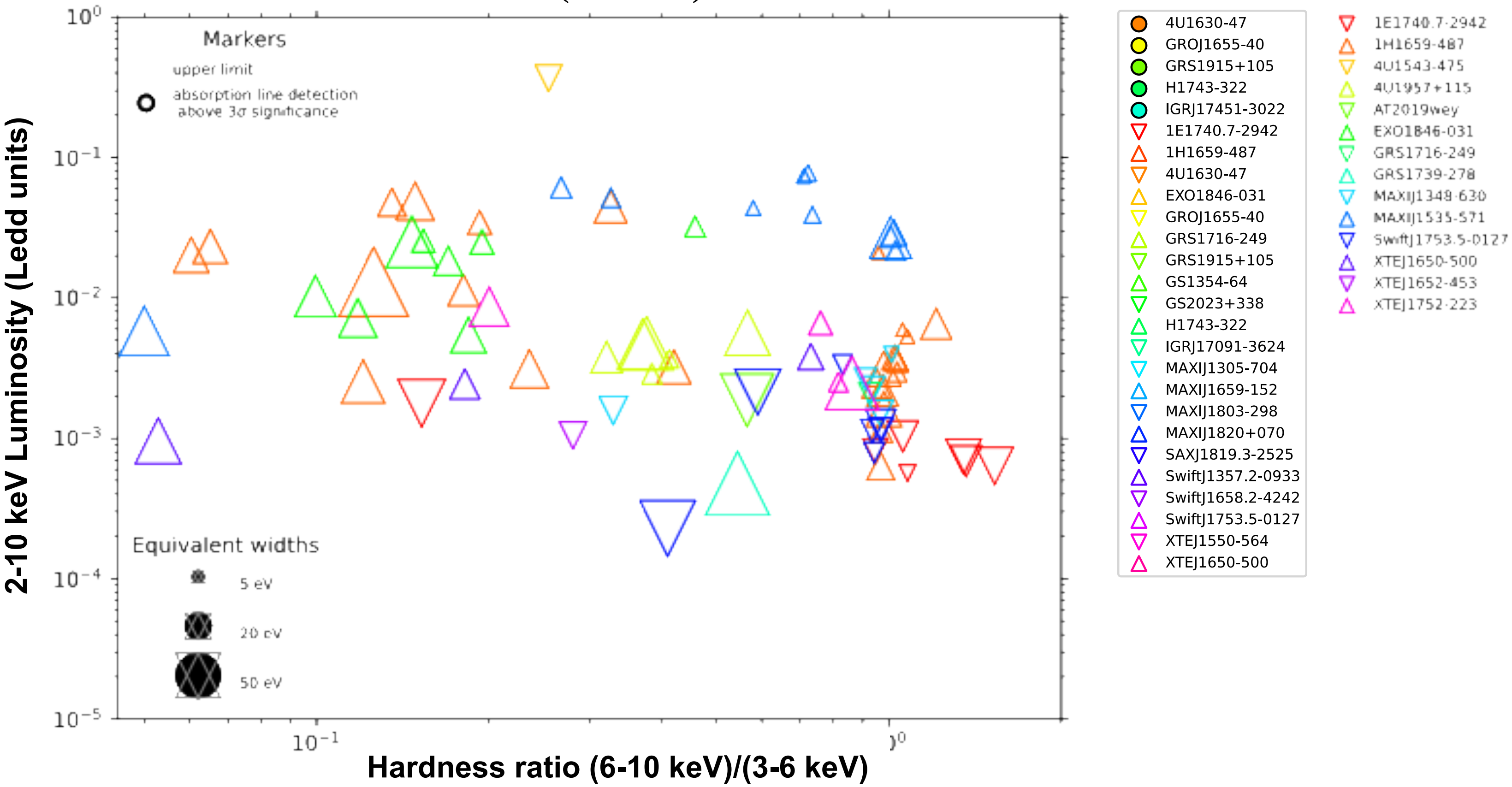


Disk Winds: Observational facts

- Overwhelming presence of **X-ray** absorption features **in high inclined systems in « soft state »** (e.g., Ponti et al. 2012, Diaz Trigo & Boirin 2016, Parra et al. in prep.)

Low inclined (< 55 °) BH XrB



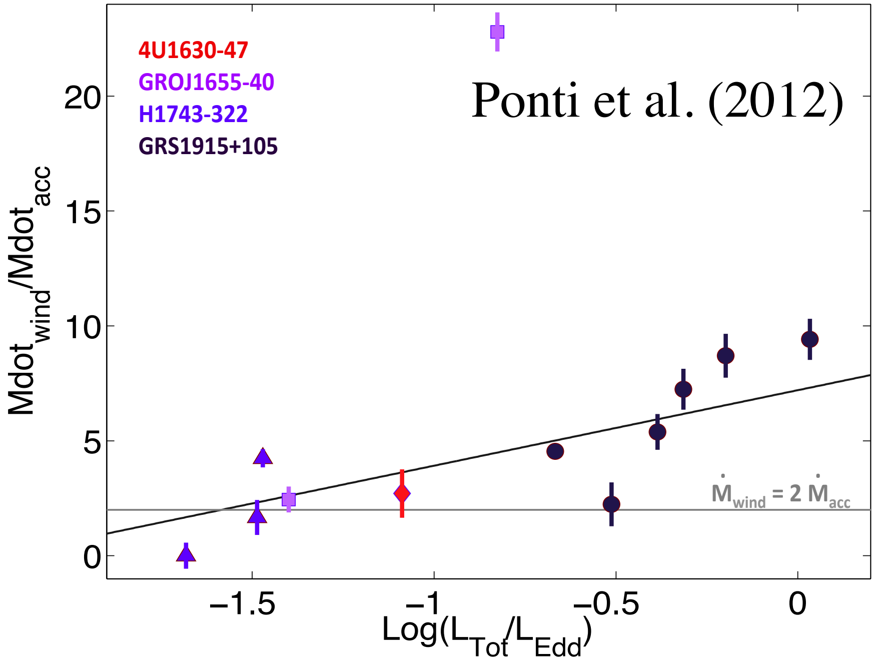
➡ **equatorial geometry** with opening angles of few tens of degrees

Disk Winds: Observational facts

- Wind mass loss rate:

$$\dot{M}_{wind} = 4\pi\rho R^2 v_{out} = 4\pi \frac{L}{\xi} m_p v_{out} \geq \dot{M}_{acc}$$

➡ Crucial component for the **XrB evolution**



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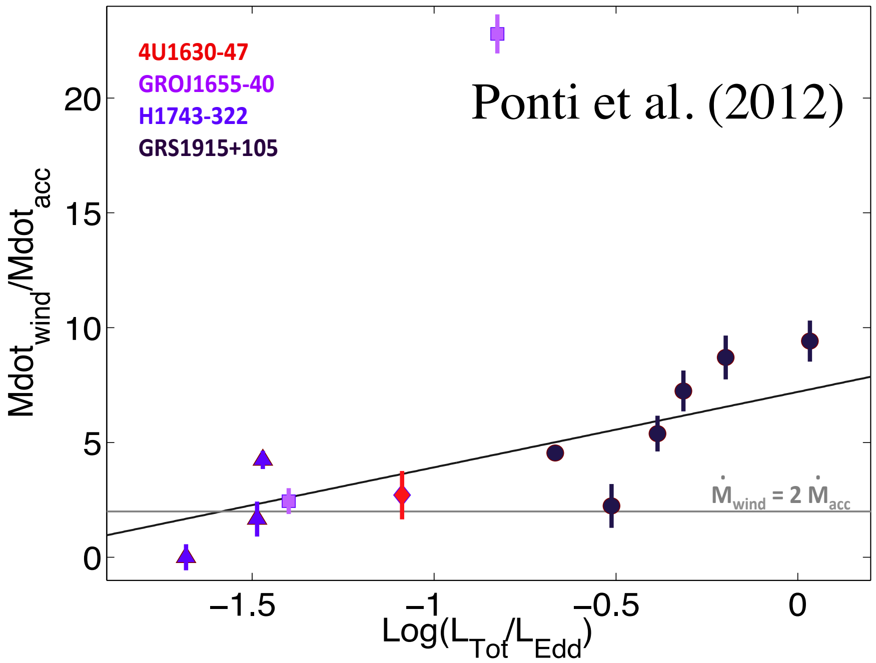
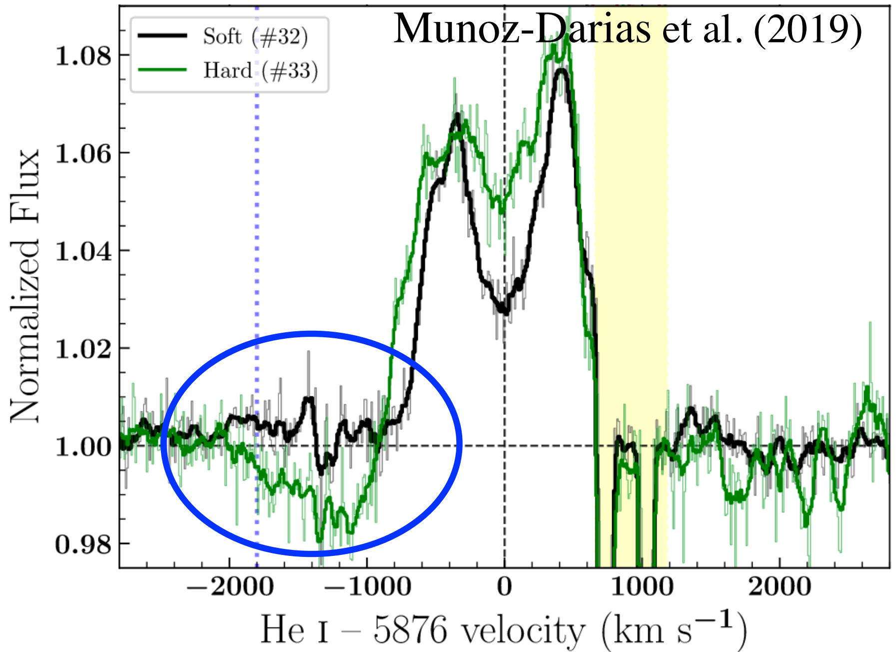


- (Cold) Wind signatures observed in the **IR/Opt/UV** mainly in the **Hard state** (e.g. Munoz-Darias et al. 2019, Mata Sanchez et al. 2022)

➡ **ubiquitous (?)**

➡ Are Hot and Cold winds **the same component?**



Disk Winds: Launching processes

Thermally driven

◉ Compton Heated Wind (Begelman et al. 1983)

$$T_{IC} = \frac{\int EF_E(E)dE}{4k\int F_E(E)dE} \sim 10^{6-8}\ K$$

◉ Disc atmosphere escape when: $V_{th}(T_{IC}) = \left(\frac{2kT_{IC}}{m_p}\right)^{1/2} > V_{esc}(R) = \left(\frac{2GM_{BH}}{R}\right)^{1/2}$

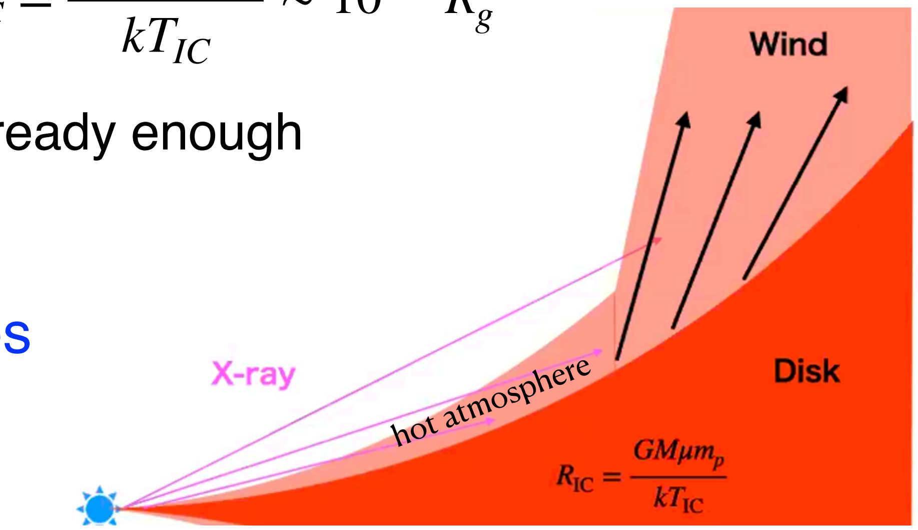
$$\text{i.e. when } R > R_{IC} = \frac{GM_{BH}m_p}{kT_{IC}} \sim 10^{5-6}R_g$$

➡ Simulations show that $R > 0.1R_{IC}$ is already enough

→ requires large disk

→ small range in velocities

(e.g. Woods et al. 1996; Done et al. 2008; Dyda et al. 2017; Tumaru et al. 2019)



(Credits: R. Tomaru)

Disk Winds: Launching processes

MHD driven

- The same mechanisms that produce jets from disk (e.g. Blandfold & Payne 1982) can apply for Winds

- Key parameter: the magnetization $\mu = \dfrac{P_{mag}}{P_{tot}}$

  ➡ JET: high $\mu \rightarrow$ powerful radio emission, high speed, no absorption features

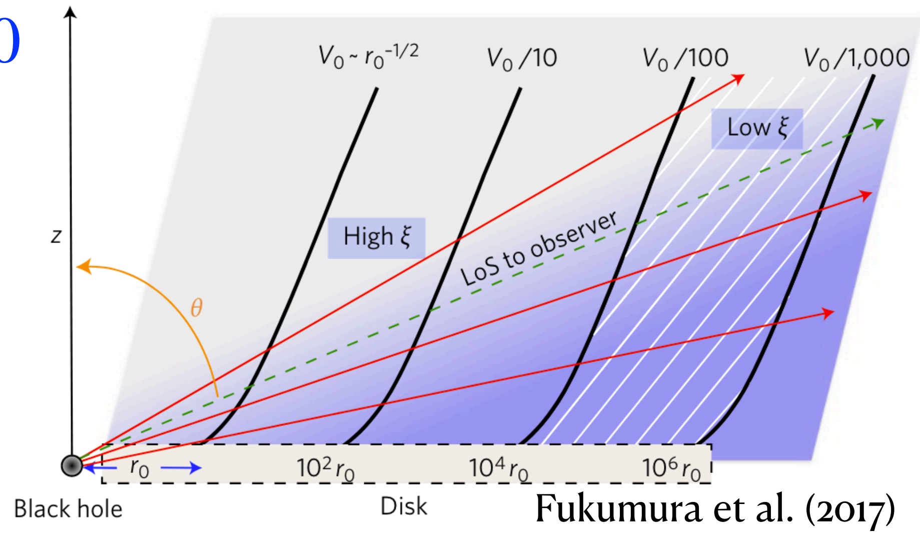
  ➡ WIND: low $\mu \rightarrow$ weak radio emission, low speed, absorption features

$\rightarrow$ MHD wind can be produced wherever $\mu > 0$

$\rightarrow$ Wide range in velocity, depending on the wind radial extension

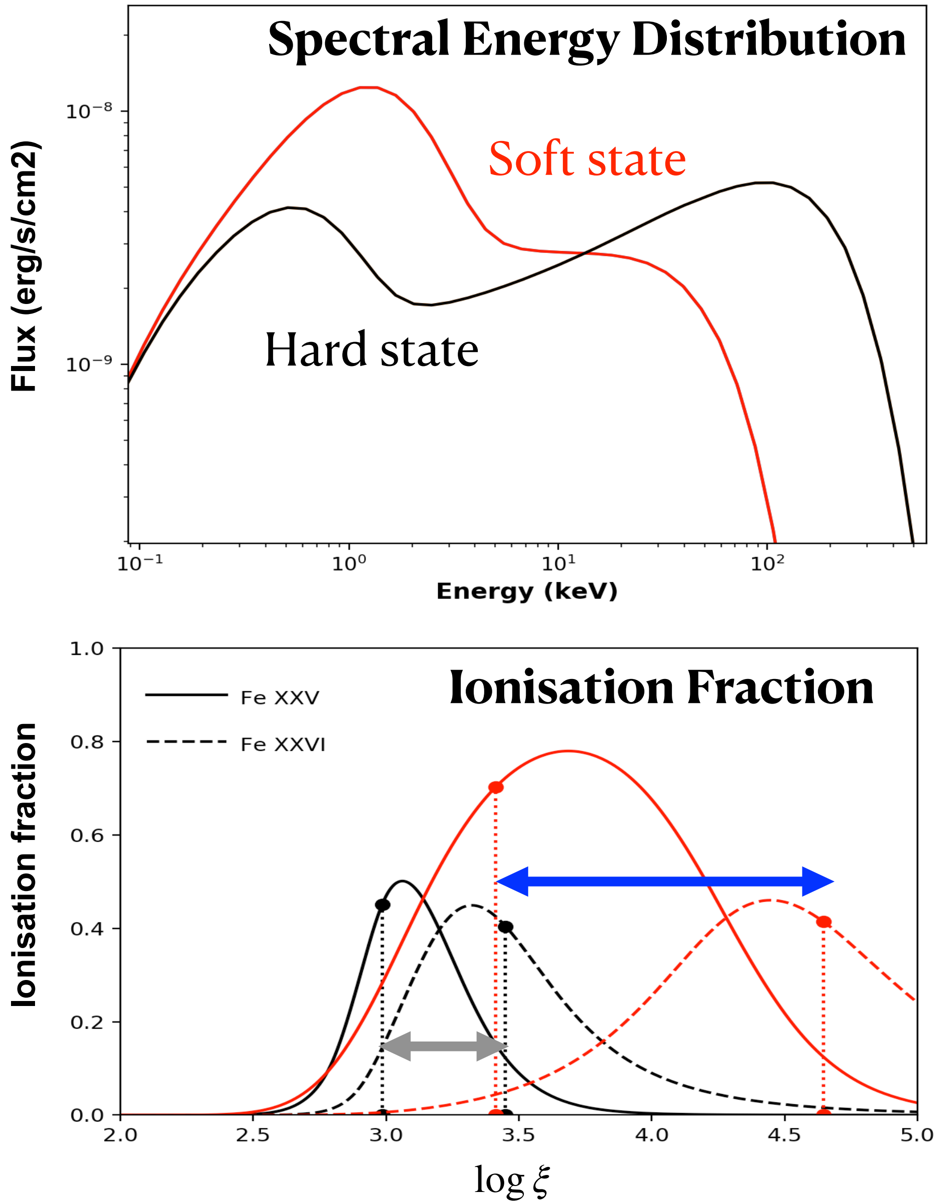
(e.g. Chakravorty et al. 2016, 2022; Fukumura et al. 2017, 2021)

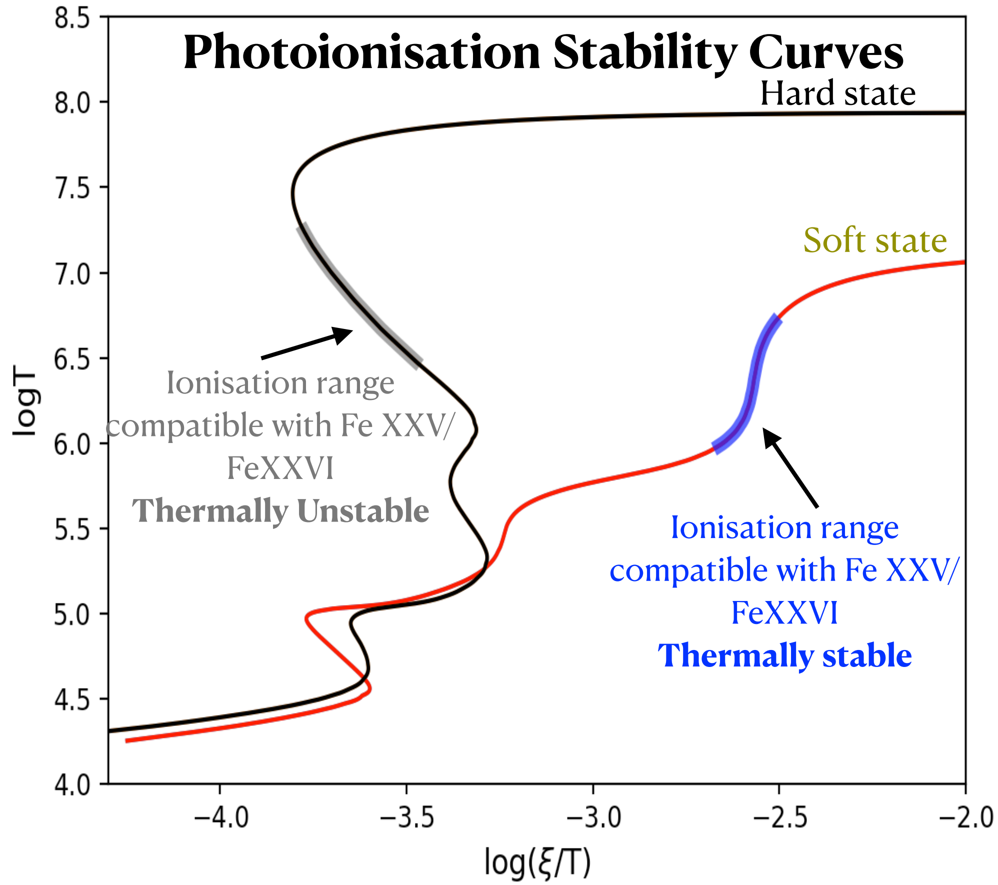
But… both processes could (should?) be present (e.g., Everett 2005; Neilsen & Homan 2012; Waters & Proga 2018)



Fukumura et al. (2017)

Disk Winds: Thermal Stability



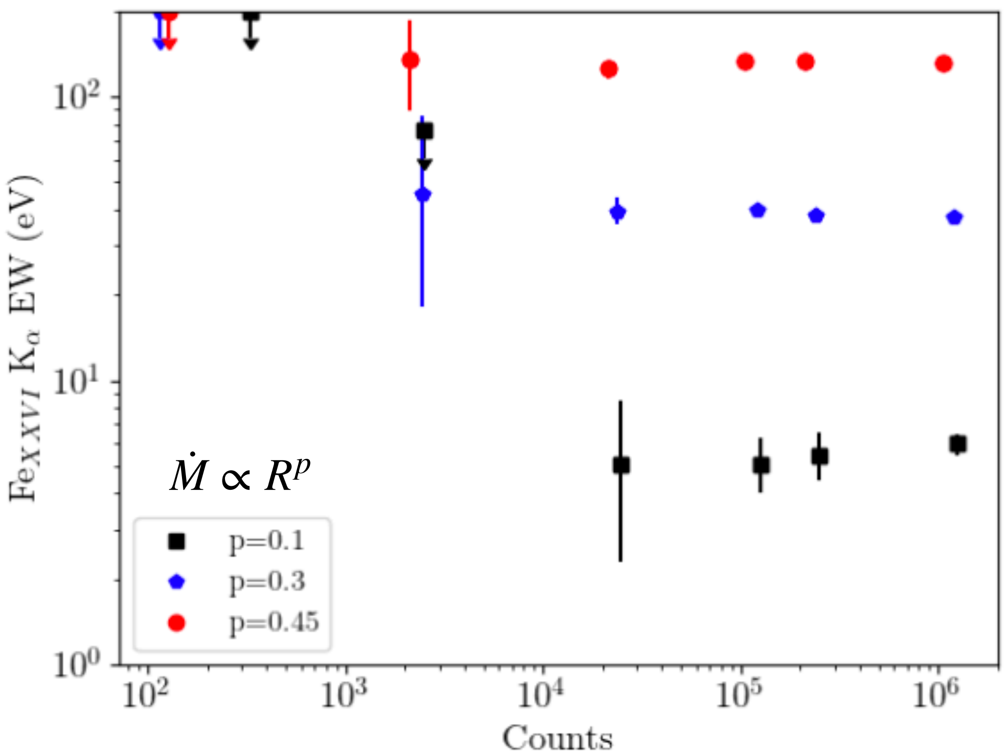


Could explain the absence of (hot) wind detection in Hard State (e.g., Chakravorty et al. 2013, 2016; Bianchi et al. 2017)

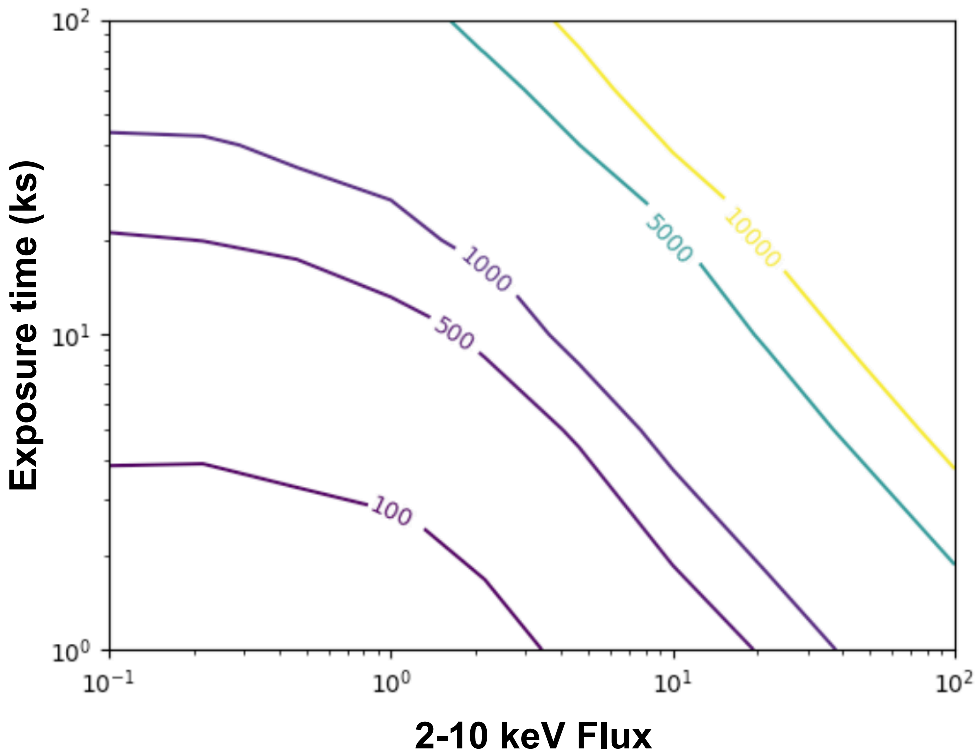
The revolution of X-ray High Spectral Resolution

Large number of counts needed...

Chakravorty et al. (2022)



Athena 6-8 keV counts



➡ Counts > several 10^3 in the 6-8 keV range to constraints lines of < 10 eV

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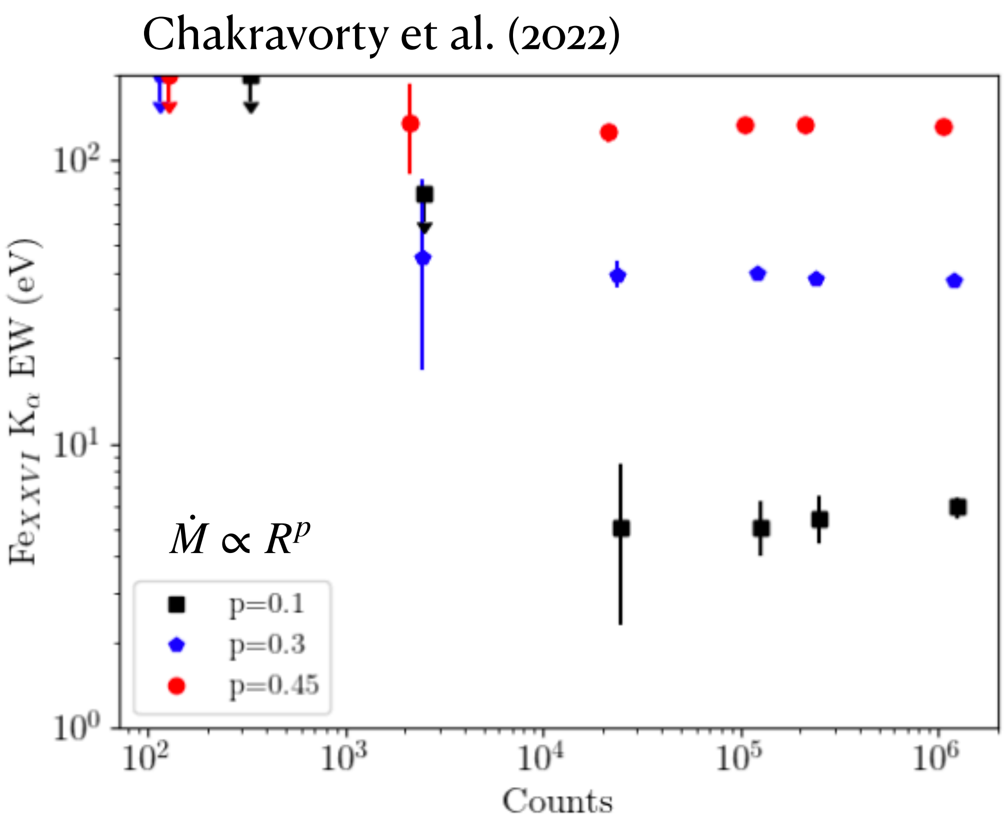

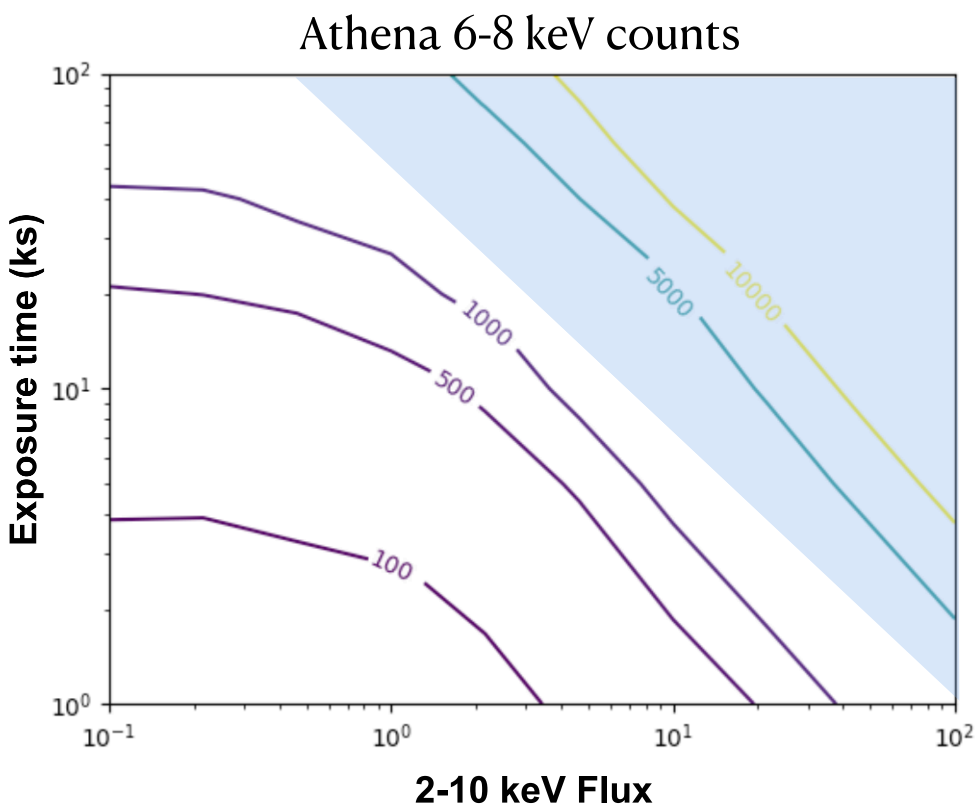

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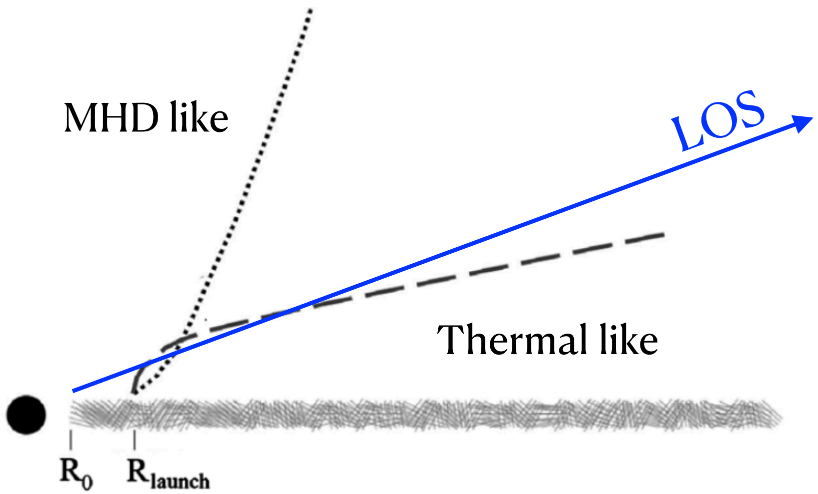
Constraints on Launching Processes

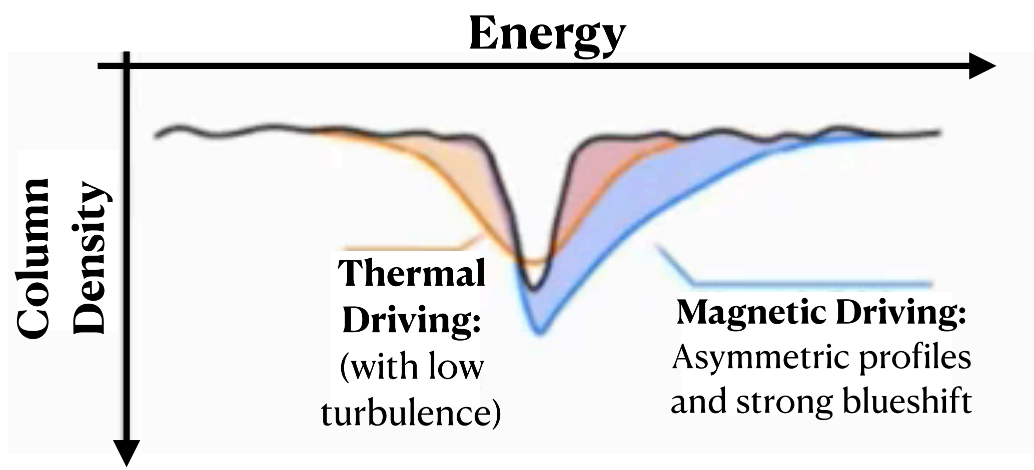
◉ Up to now, **both types of processes manage to reproduce** the main characteristics (density, velocity,…) of the observed absorption features (e.g., Fukumura et al. 2017; Chakravorty et al. 2016, Tomaru et al. 2019)

◉ The **difference in the velocity profiles** is expected to produce different line profiles (Fukumura et al. 2021, Chakravorty et al. 2022, Tomaru et al. 2022)

- MHD wind: $v_{los}(R) \propto R^{-1/2}$
- Thermal wind: $v_{los}(R)$ a few 100 km/s



Giustini & Proga (2012)



Gandhi et al. (2022)

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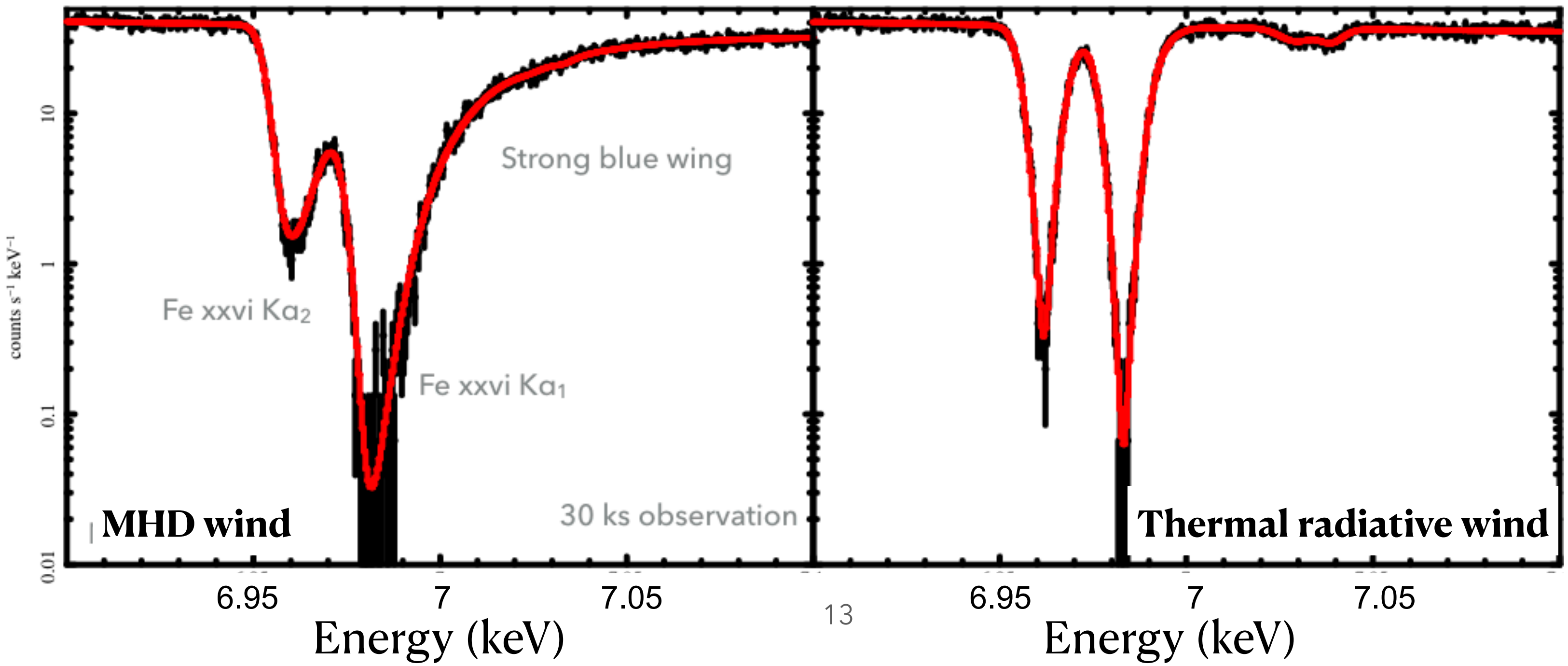

Tomaru et al. (2022)

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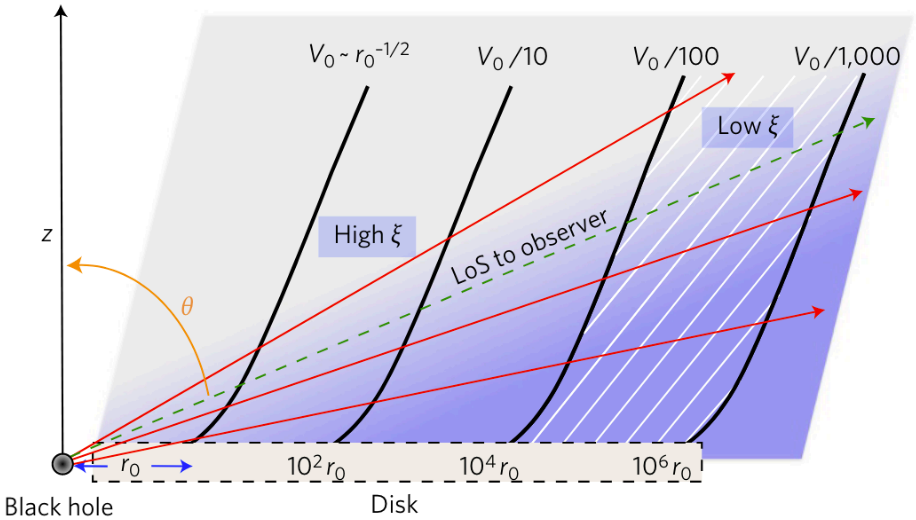

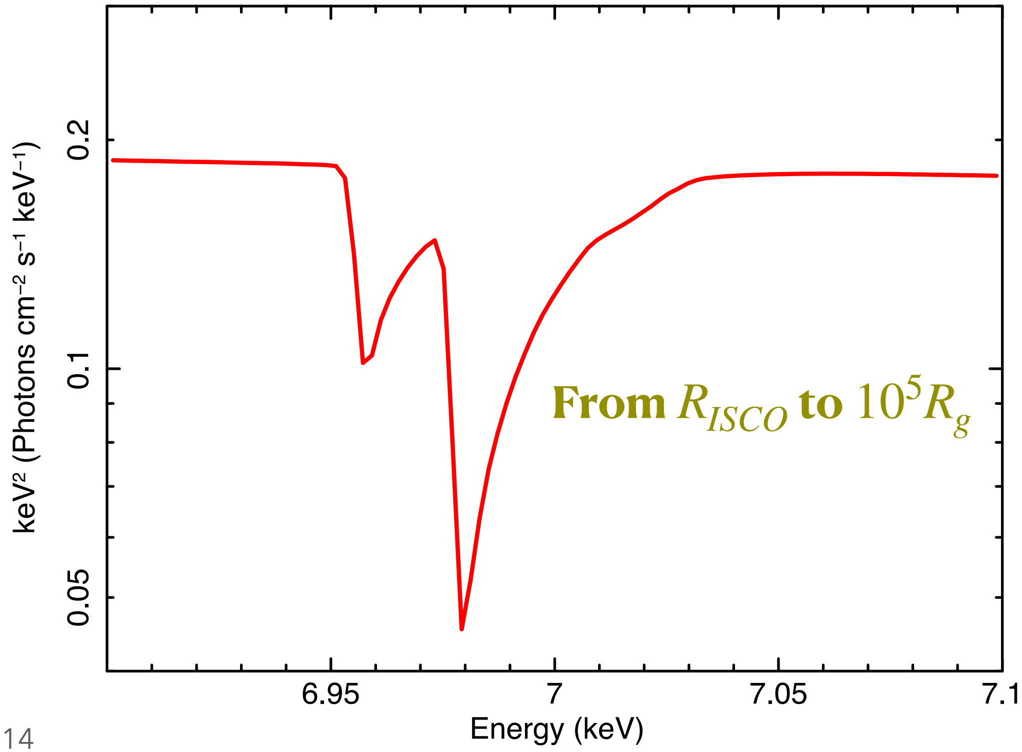

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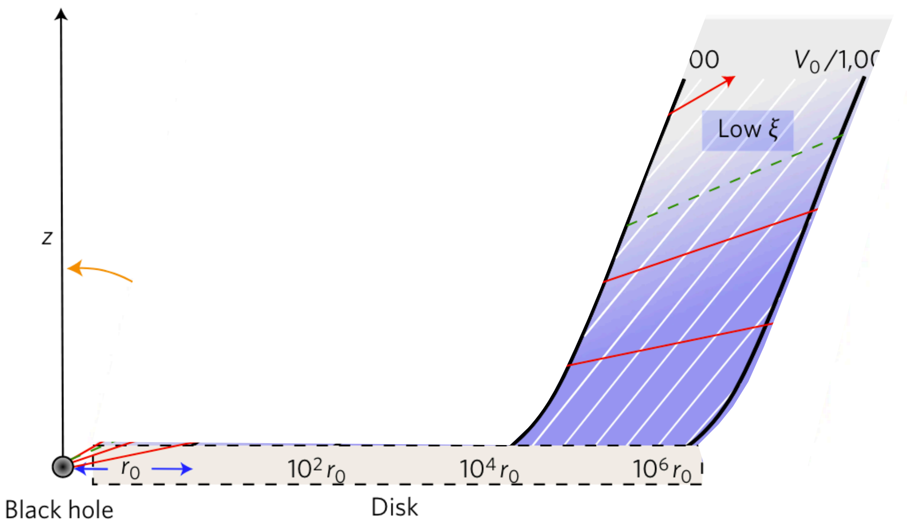

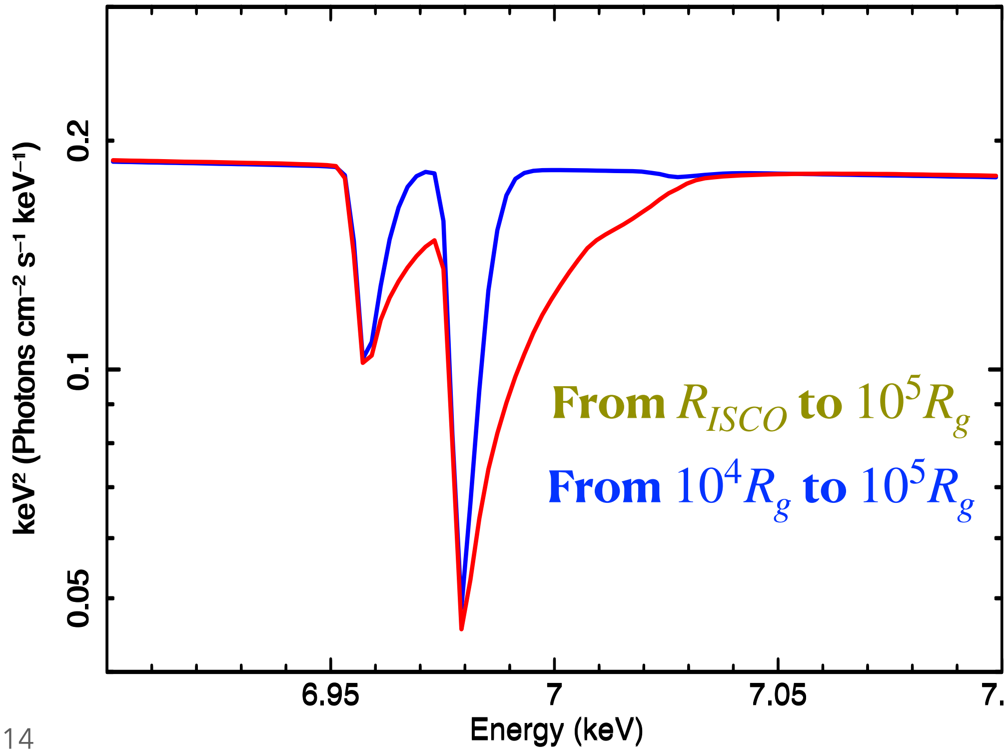

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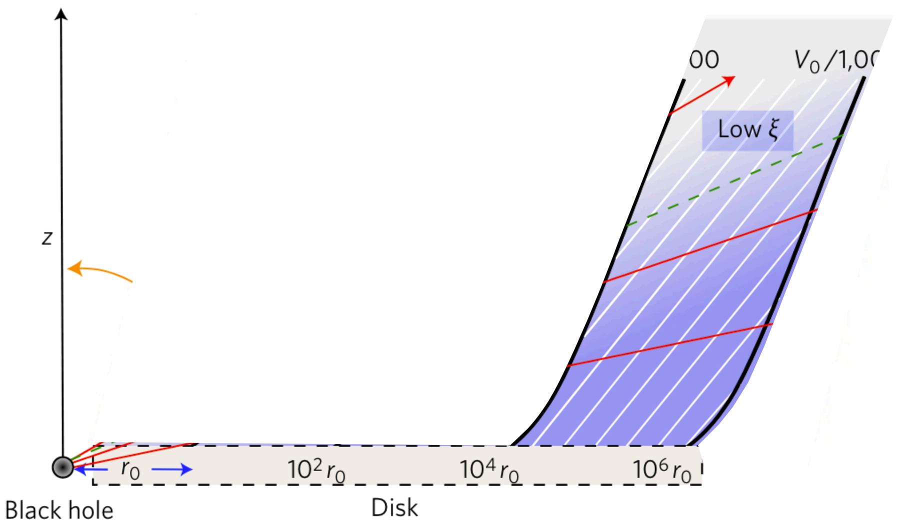
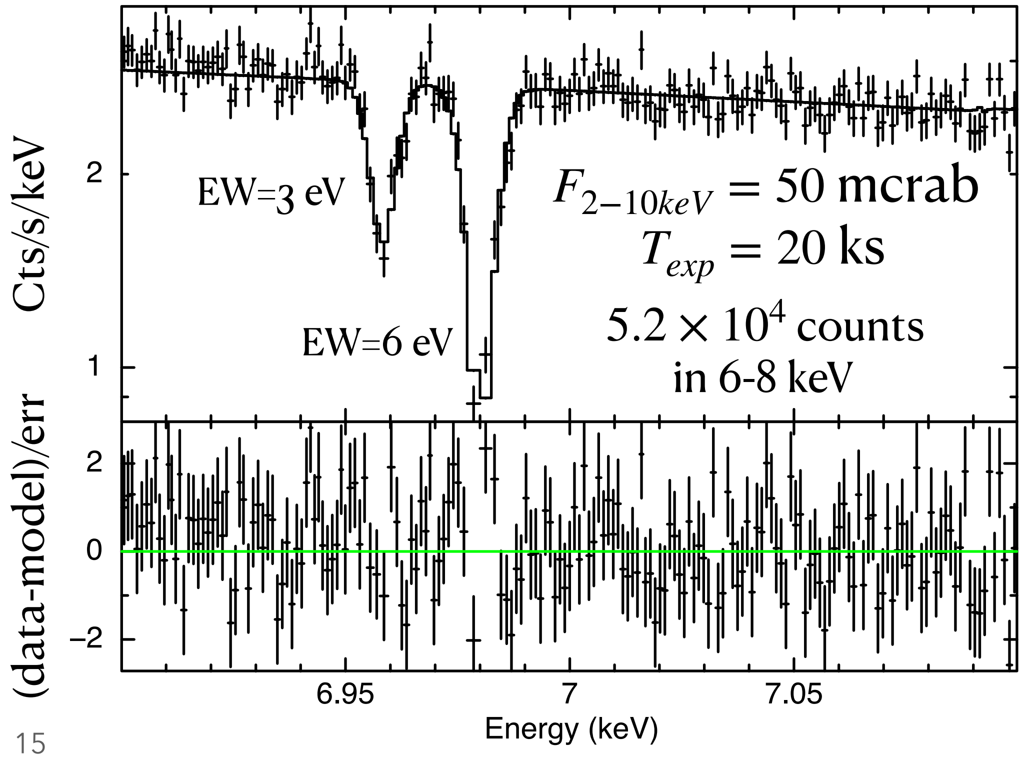
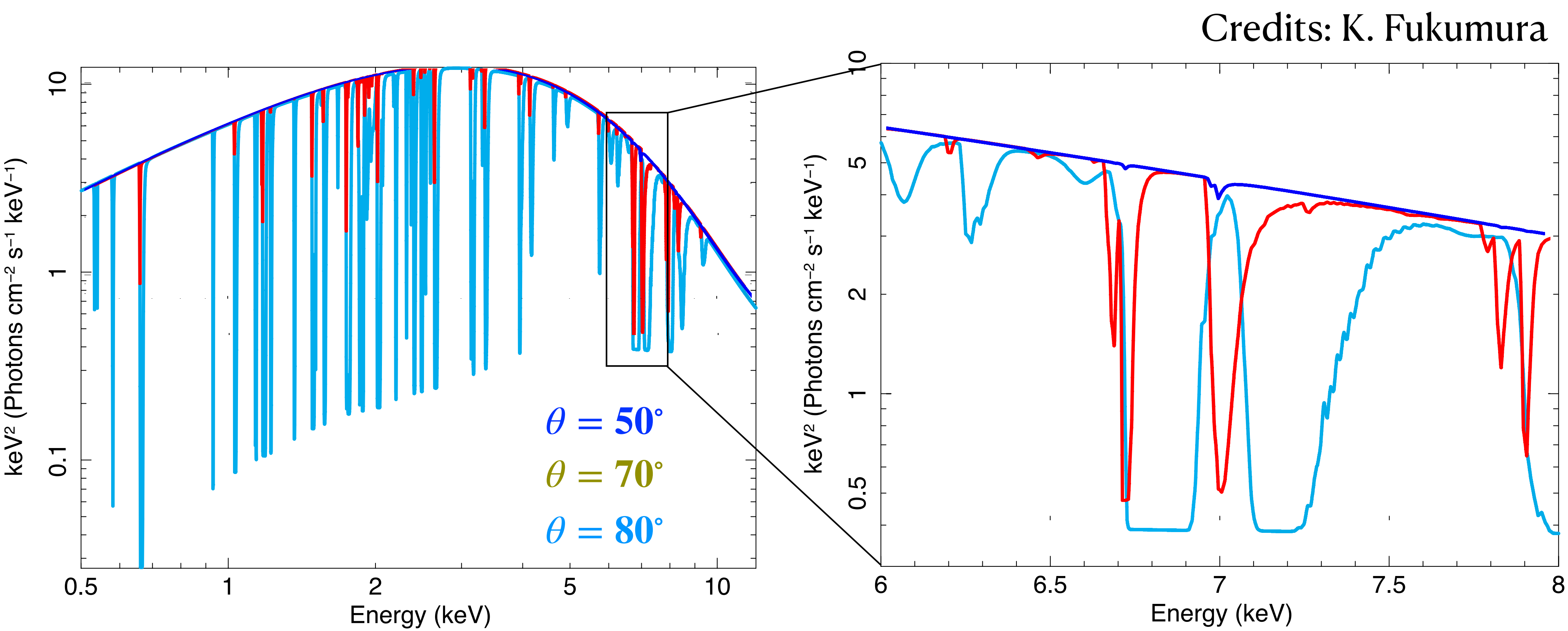




Constraints on the geometrical/ physical properties

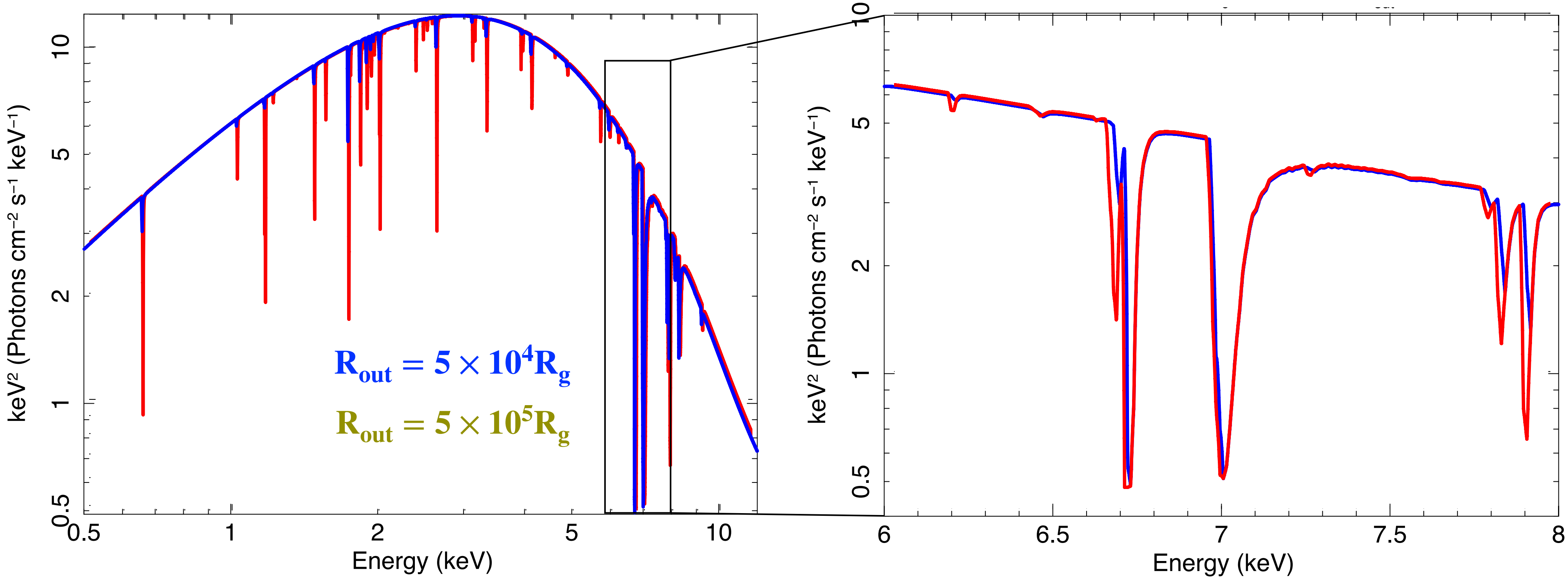
LOS inclination angle



Constraints on the geometrical/ physical properties

Disk Extension

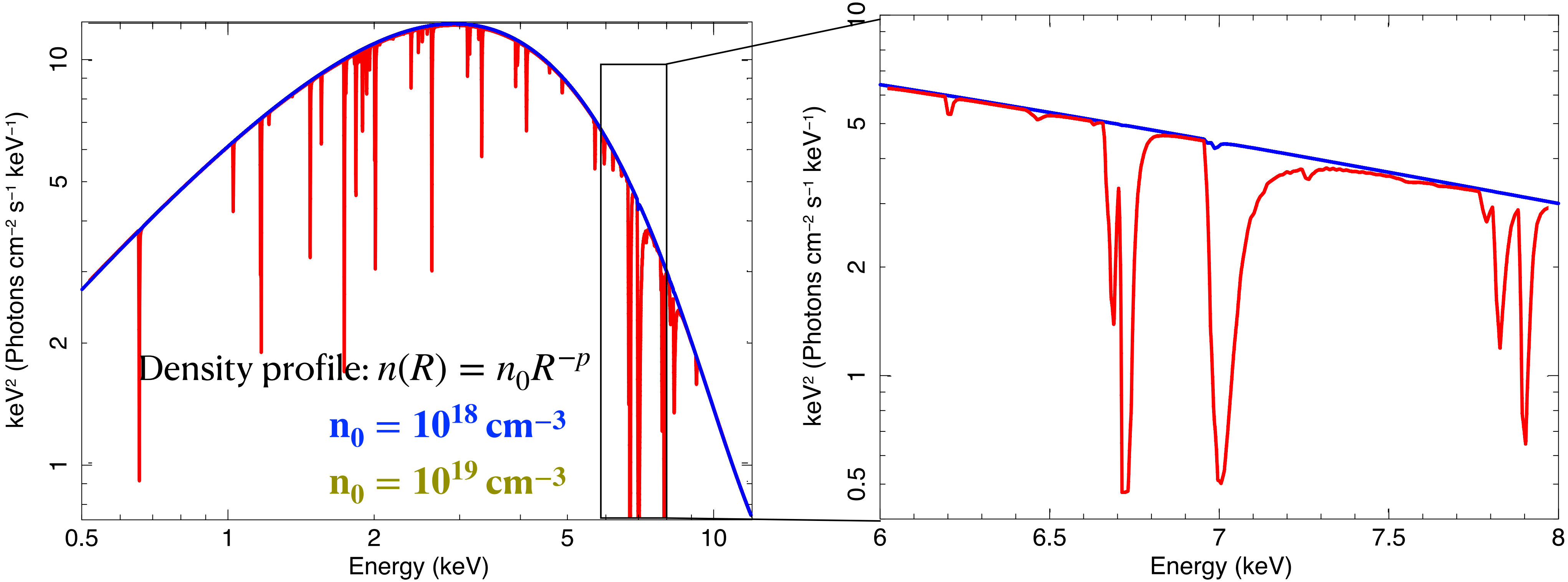
Credits: K. Fukumura



Constraints on the geometrical/physical properties

Wind Density

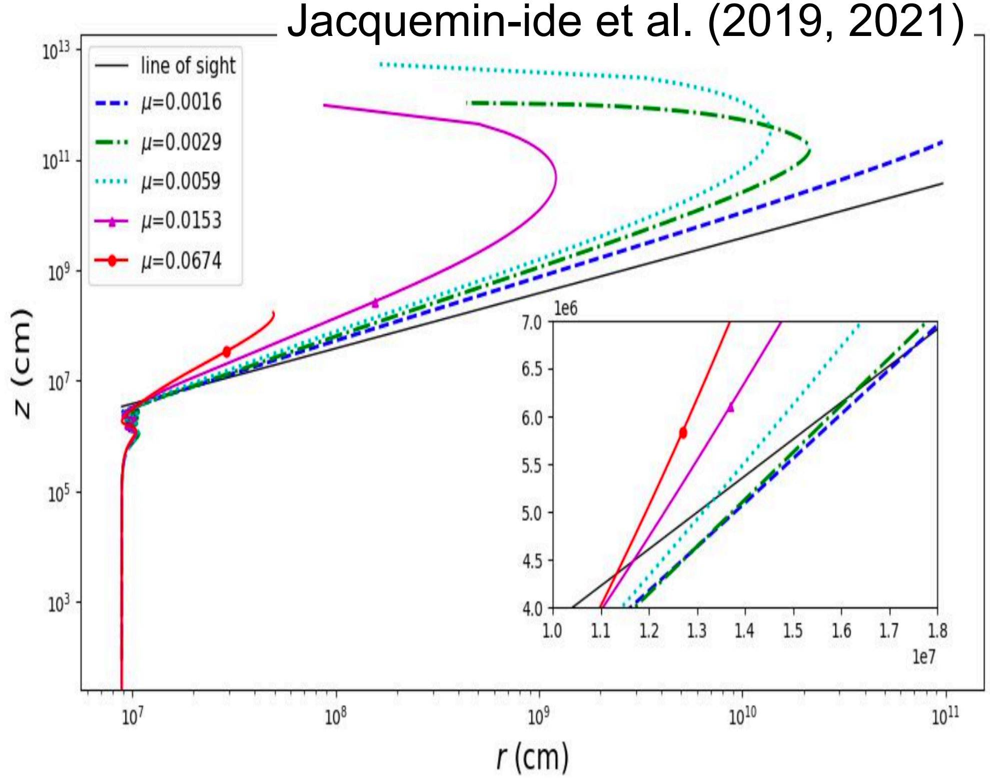
Credits: K. Fukumura

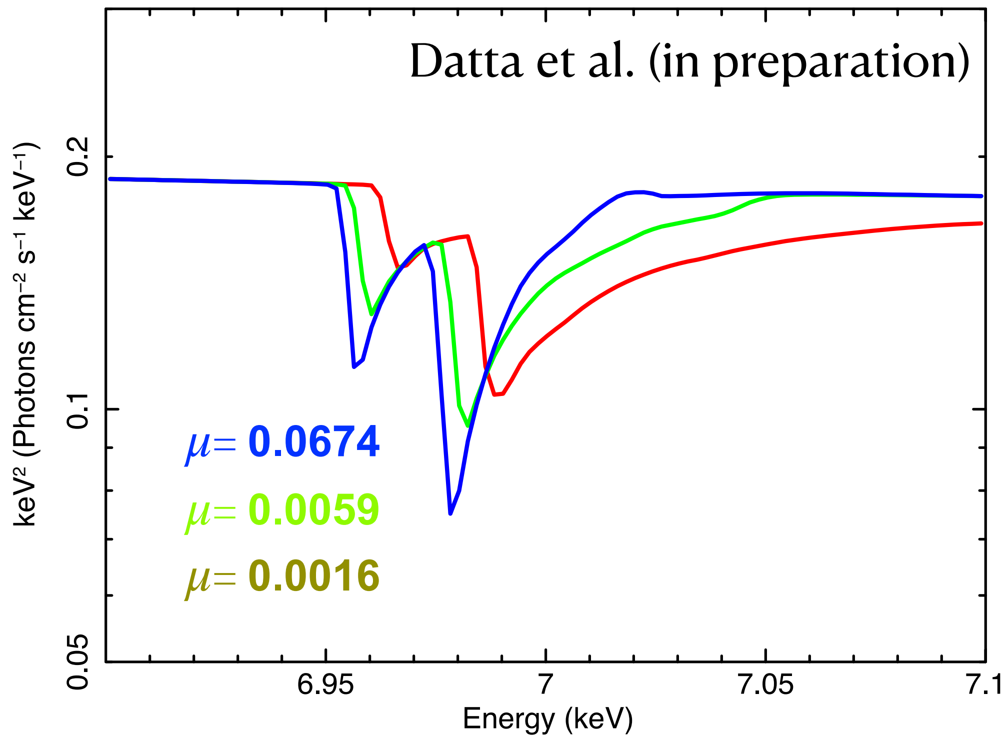


Constraints on the geometrical/ physical properties

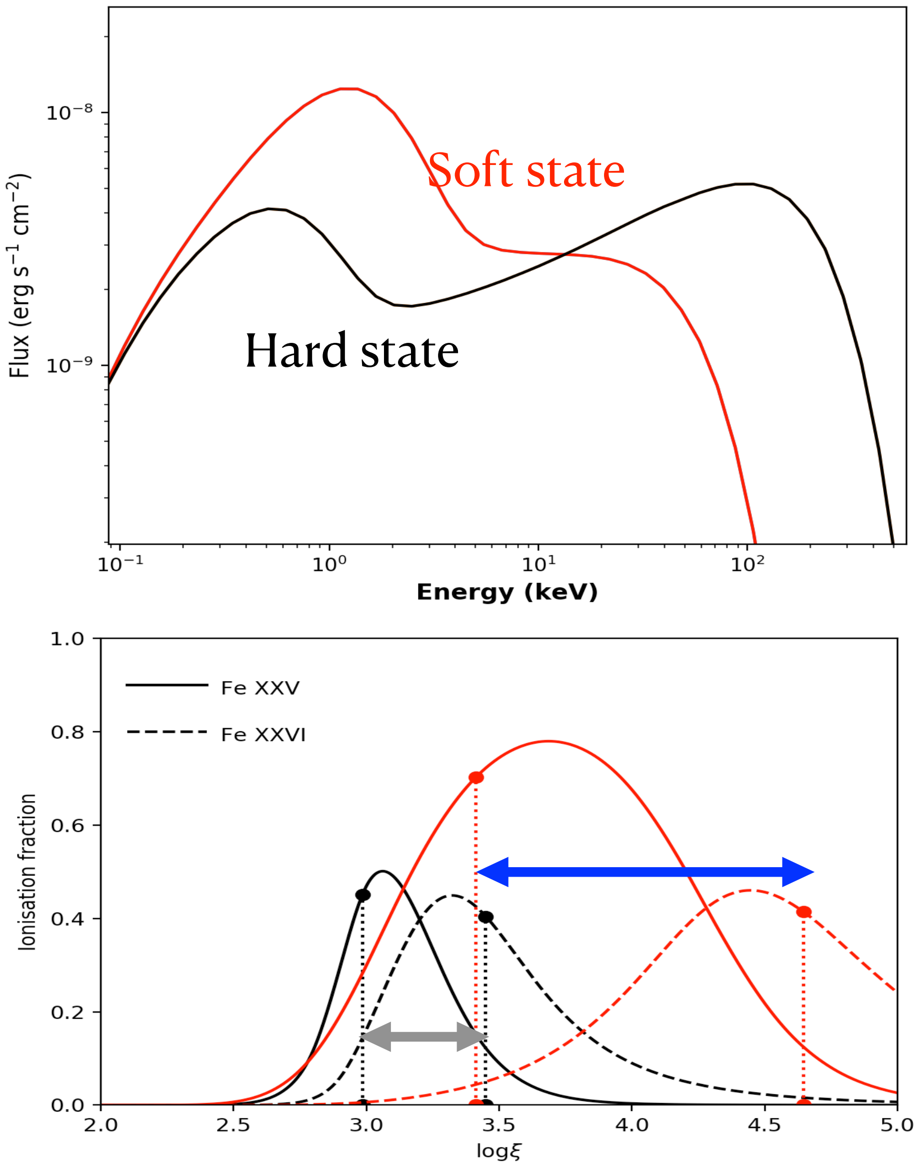
Disk Magnetization

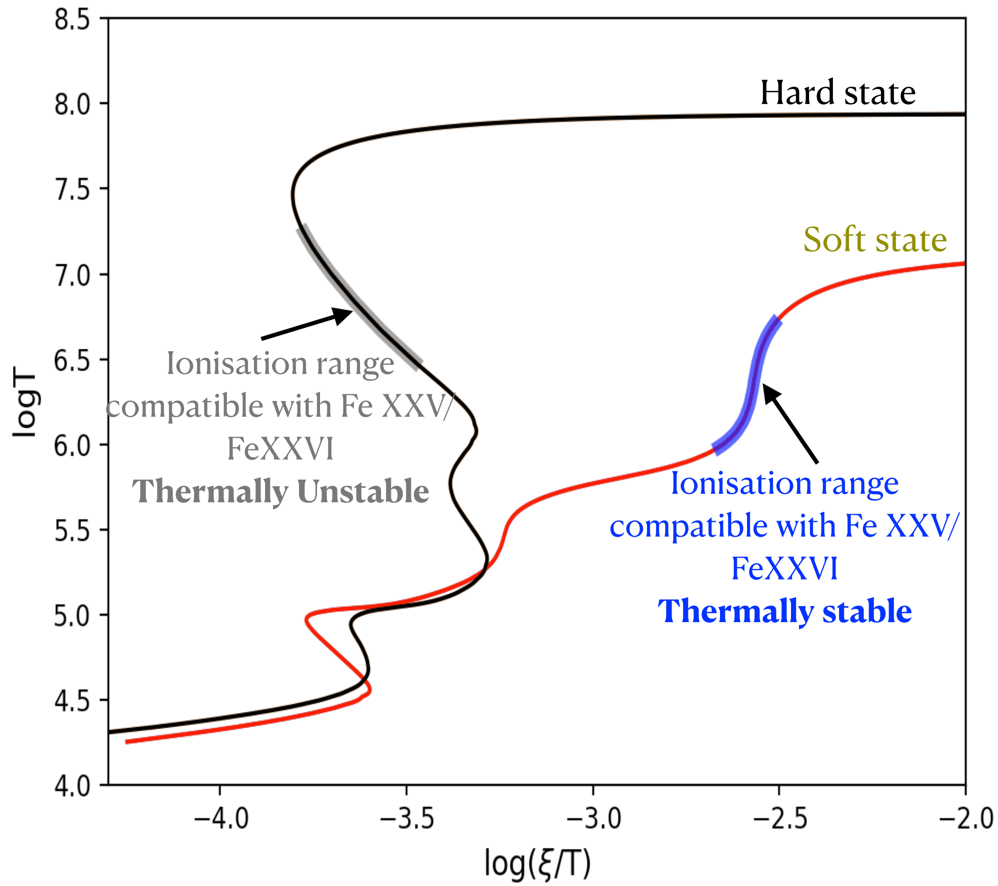
- In case an MHD wind is present, the wind properties (density, velocities,...) along the LOS will depend on the magnetisation





Detection in the Hard State?





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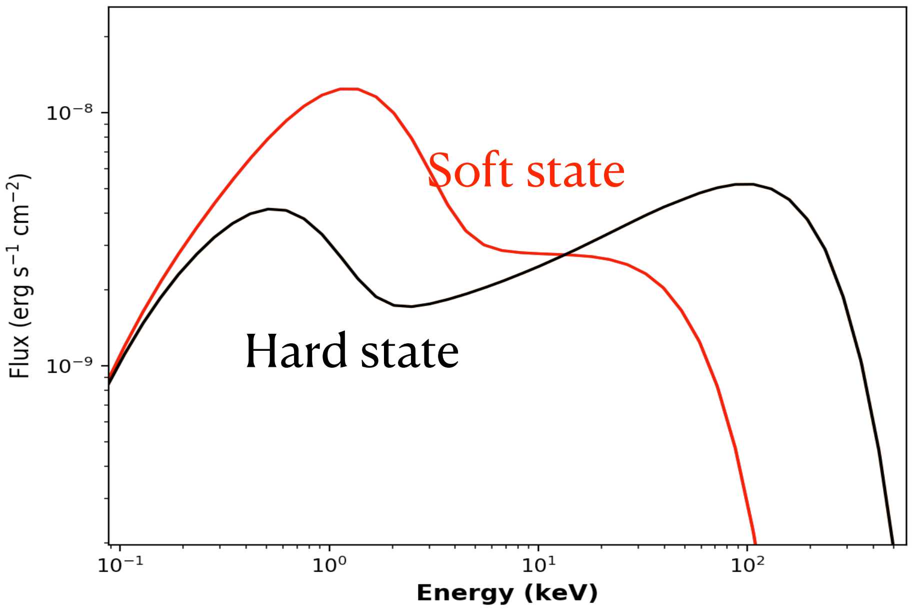
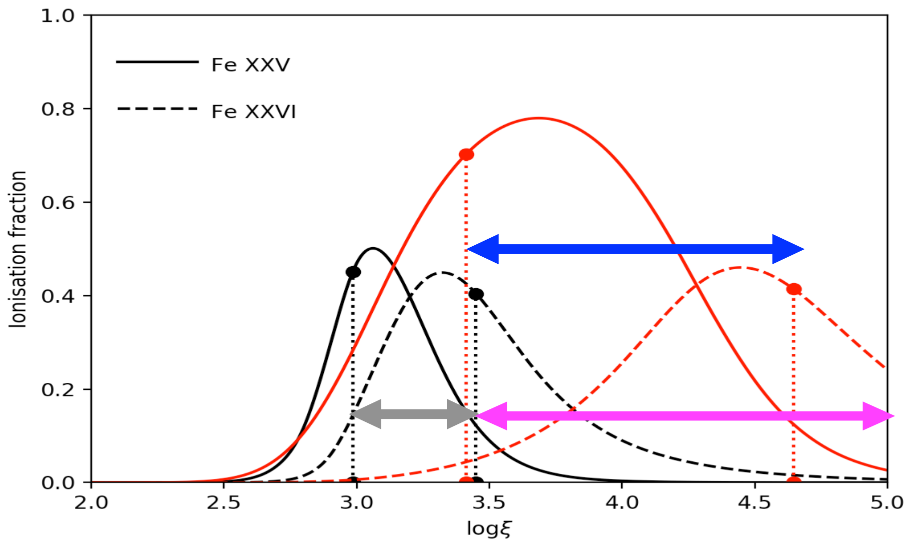
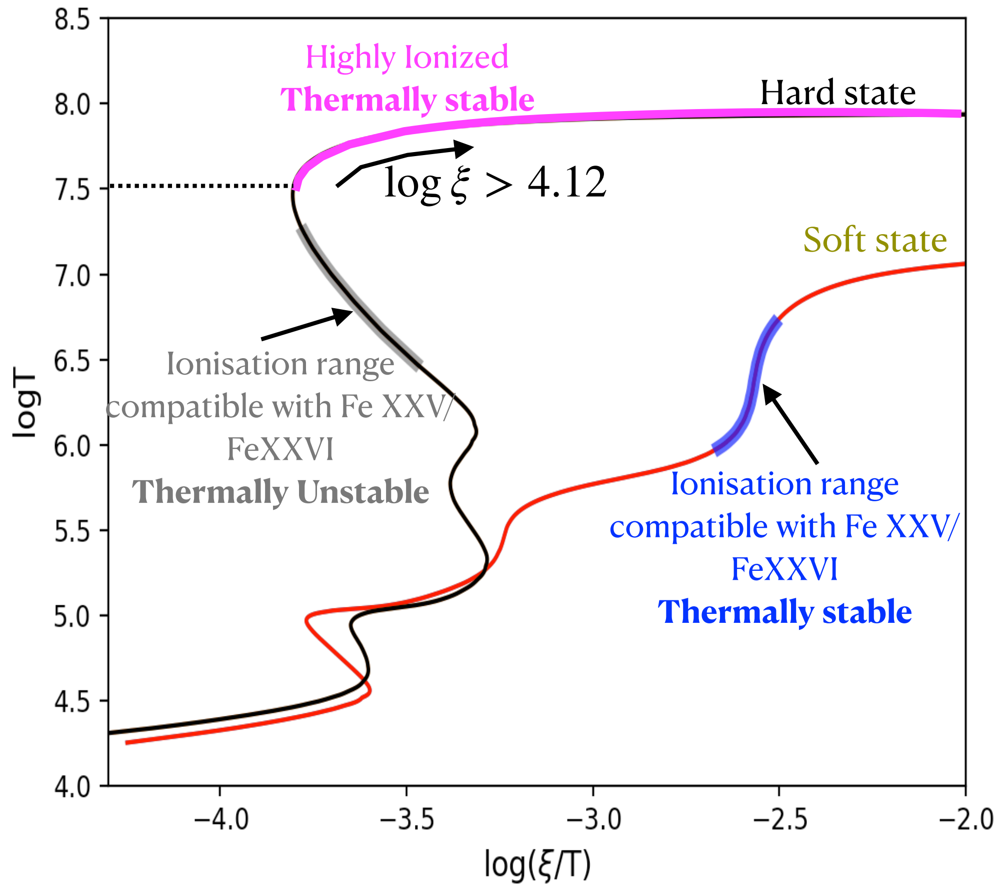
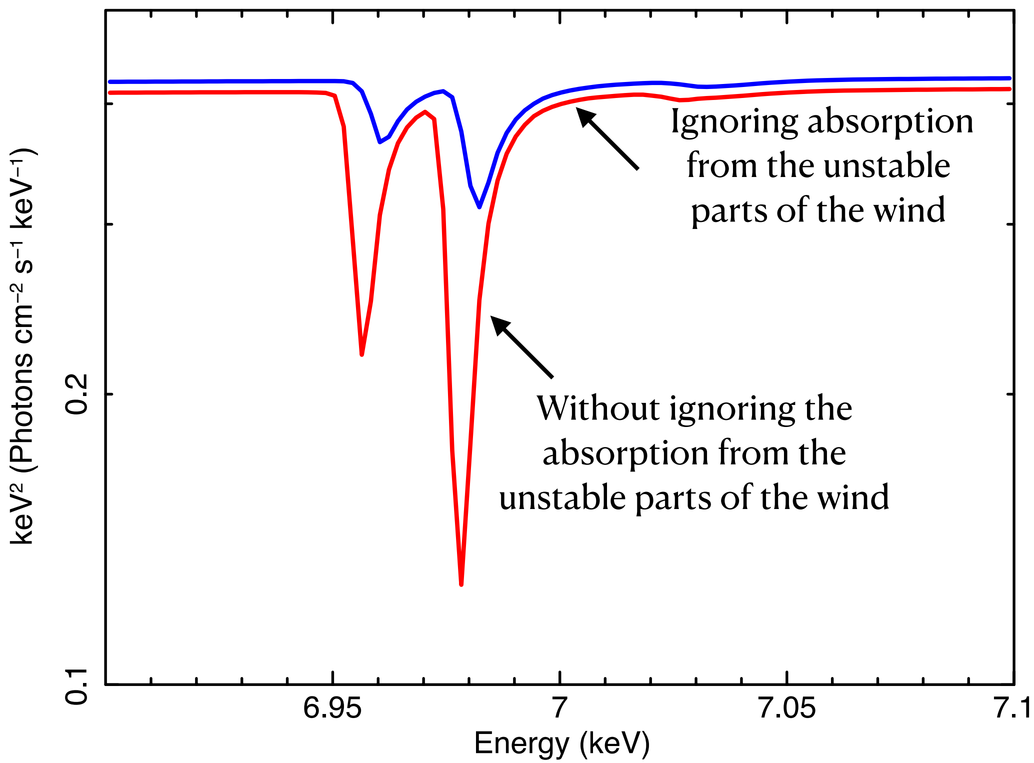


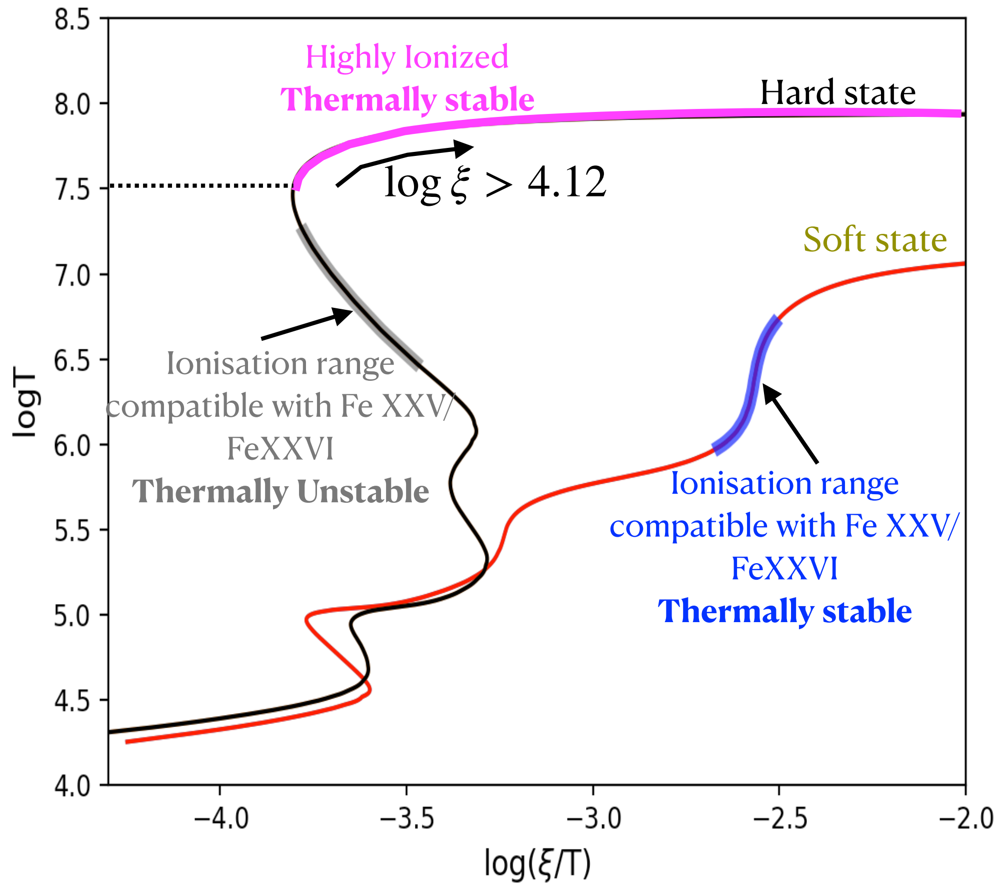




Detection in the Hard State?

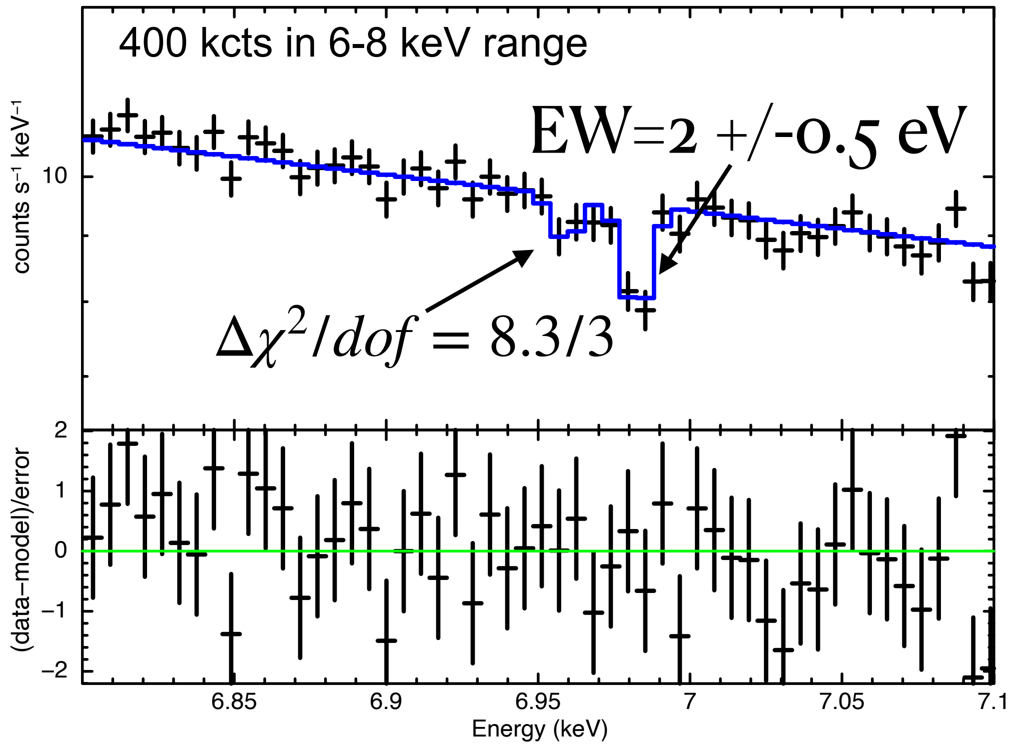
Credits: S. Datta

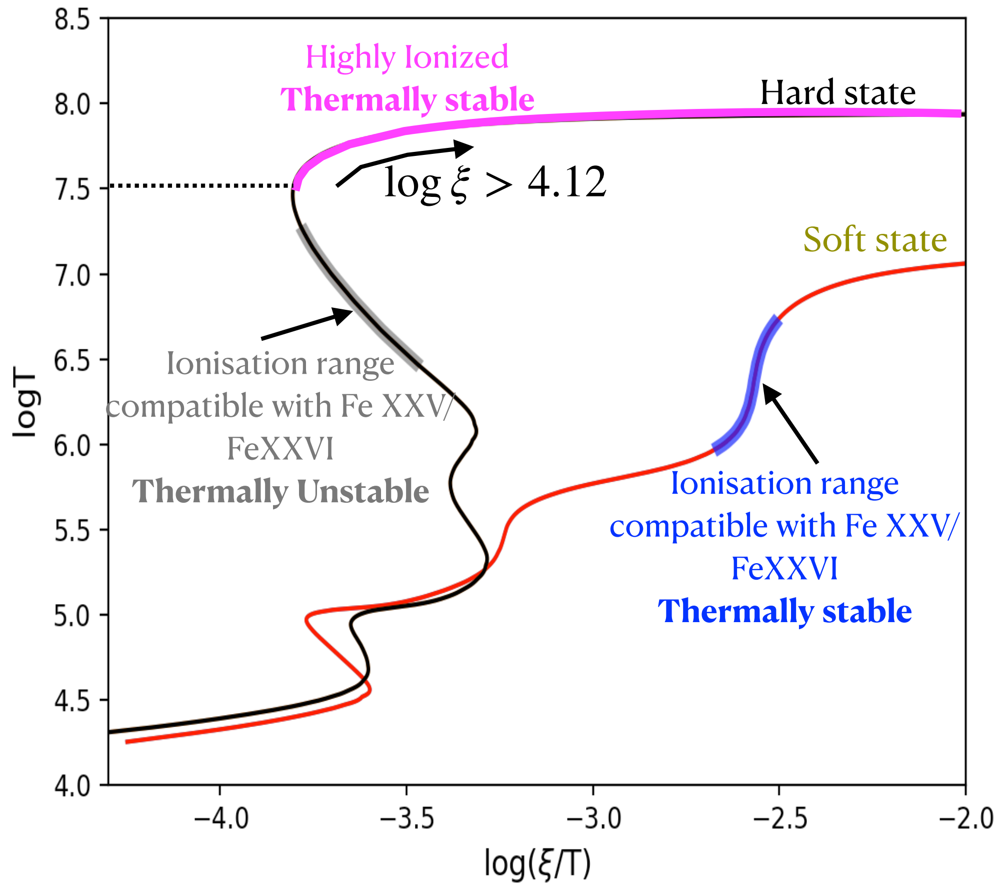




Detection in the Hard State?

Source of $F_{2-10keV} = 10^{-9}$ erg/s /cm2 (50 mcrab) observed during 200 ks with Athena





Conclusions

- Disk winds in XrB certainly play a crucial role in the evolution of these systems.

- High Spectral Resolution Missions (XRISM/Athena) will provide crucial constraints on:

  ✓ Launching process (MHD vs Thermal)
  ✓ Wind properties (inclination, density distribution, ...)
  ✓ Disk magnetisation
  ✓ X-ray wind detection in hard states?
  ✓ ...

Thanks!