State transitions triggered by inversion of magnetic field: application to high-mass X-ray binaries?

Shuangliang Li

Shanghai Astronomical Observatory (SHAO)

Collaborator: Zhen Yan (SHAO)

Outline

- I Introduction of the state transition in BH X-ray binaries
- II Model for the advection and magnification of the large-scale magnetic field
- III Conclusions and Discussion

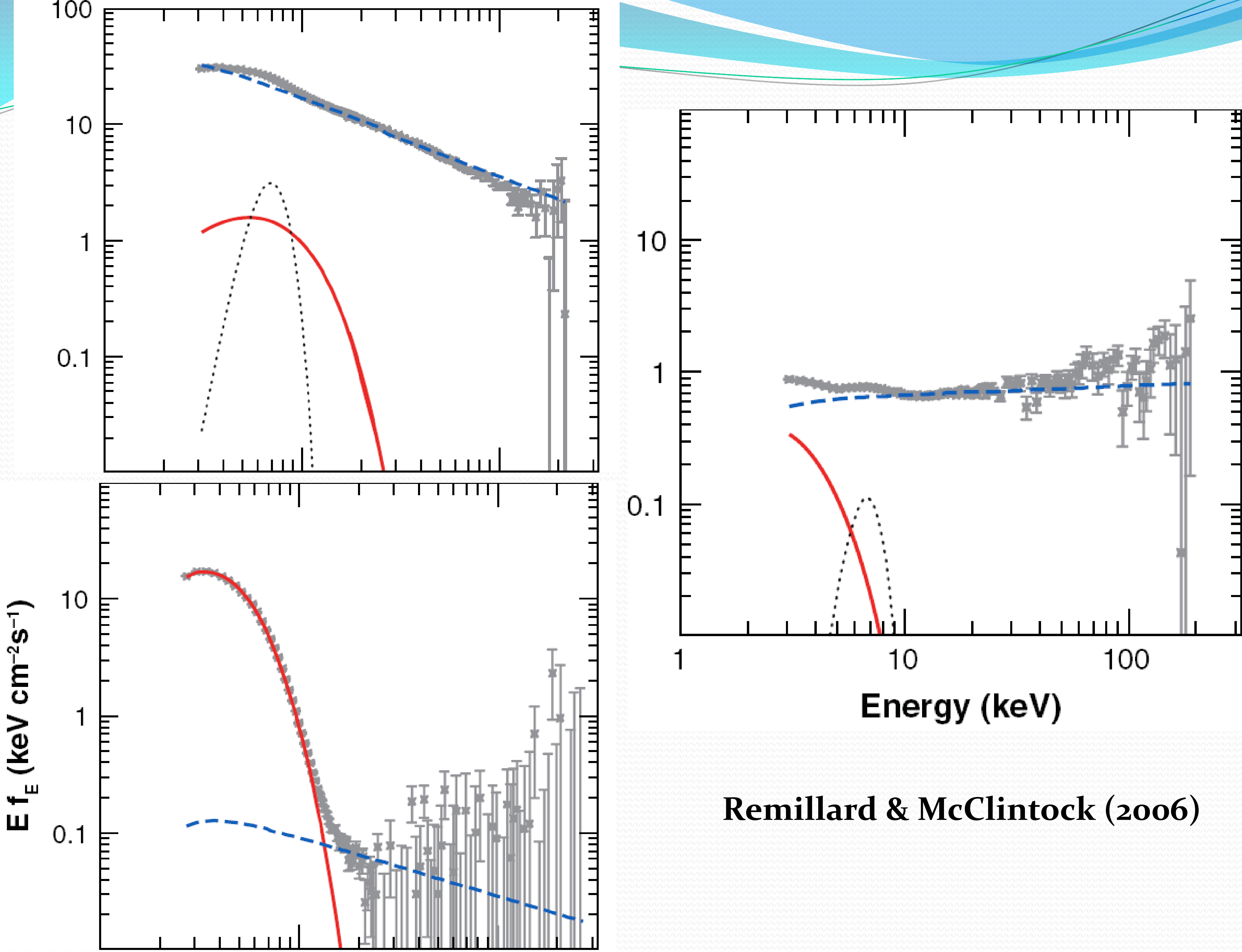
Introduction

- Black hole X-ray binaries are usually highly variable.

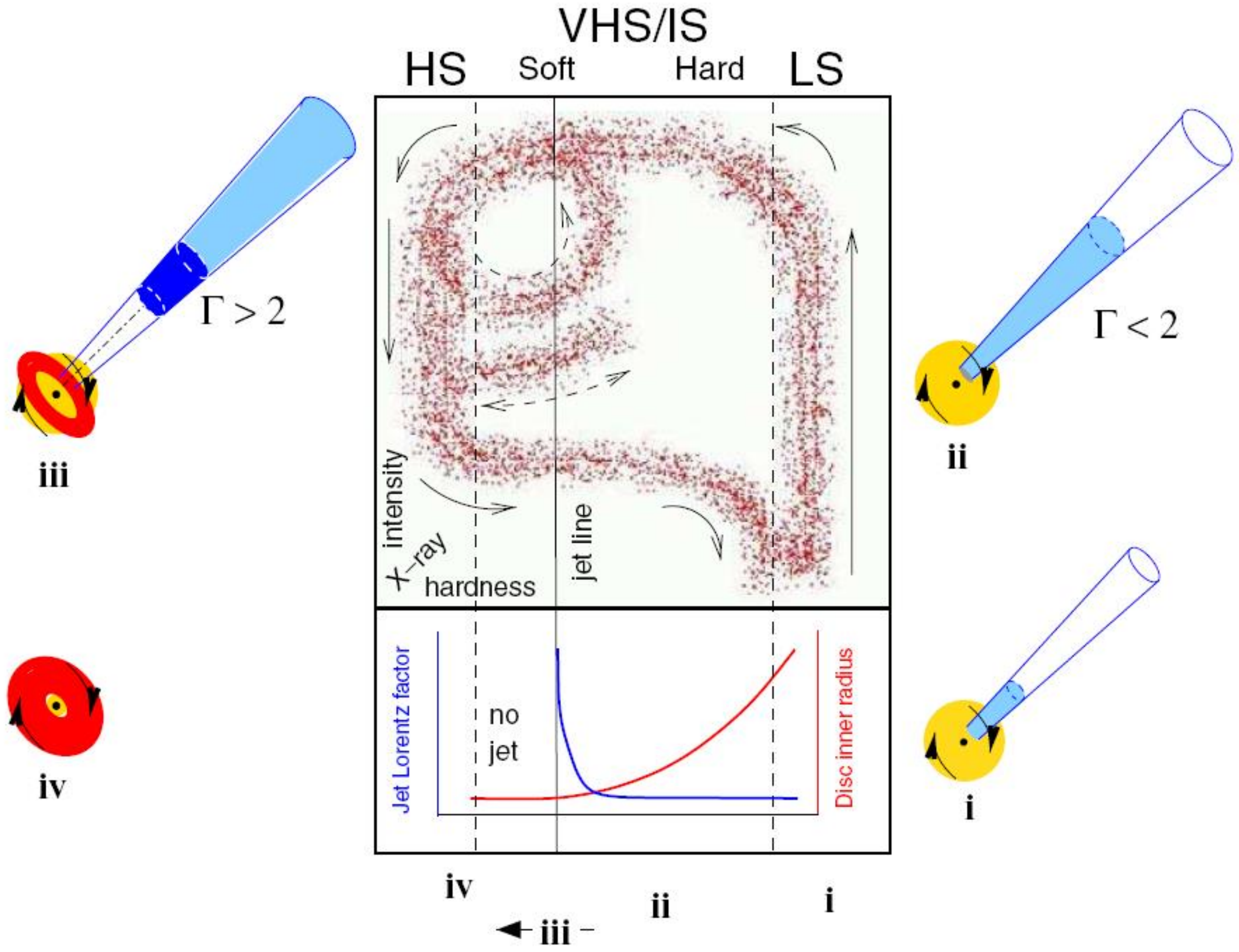
- Three basic states:
- **HS (high/soft) state**, where X-ray is dominated by a thermal component coming from an optically thick and geometrically thin disk

- **LH (low/hard) state**, where X-ray is dominated by a non-thermal component coming from a hot accretion flow

- **SPL (steep power law, or very high or intermediate) state**, where both thermal and non-thermal components are important.

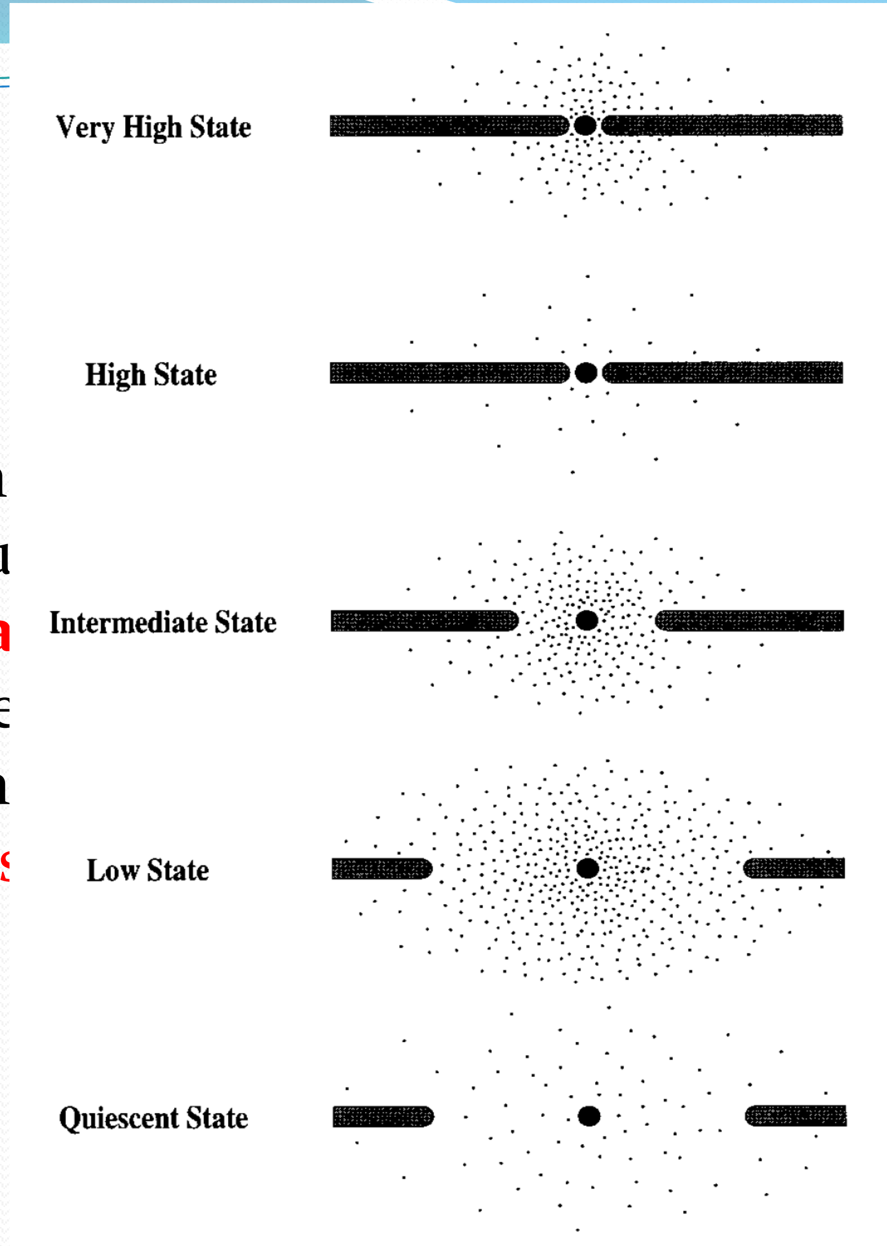


Remillard & McClintock (2006)



Fender et al. (2004)

- Traditional m **sk-corona**
model. In tru vided into
two parts by **a** nner
radiatively ine ter thin disk.
The state tran d by the
change of mas



Esin et al. 1997

- In theory, the state transition occurs at a nearly constant luminosity (several percent of Eddington luminosity). However, in observation, the hard-to-soft transition luminosity can vary up to two orders of magnitude (Homan et al. 2001; Gierli´ nski & Done 2003; Zdziarski et al. 2004; Yu & Yan 2009). Therefore, many other parameters have been proposed.

- The size of Comptonizing region (Homan et al. 2001);
- Recent accretion history (Homan & Belloni 2005);
- Disk mass (Yu & Dolence 2007; Yu & Yan 2009).

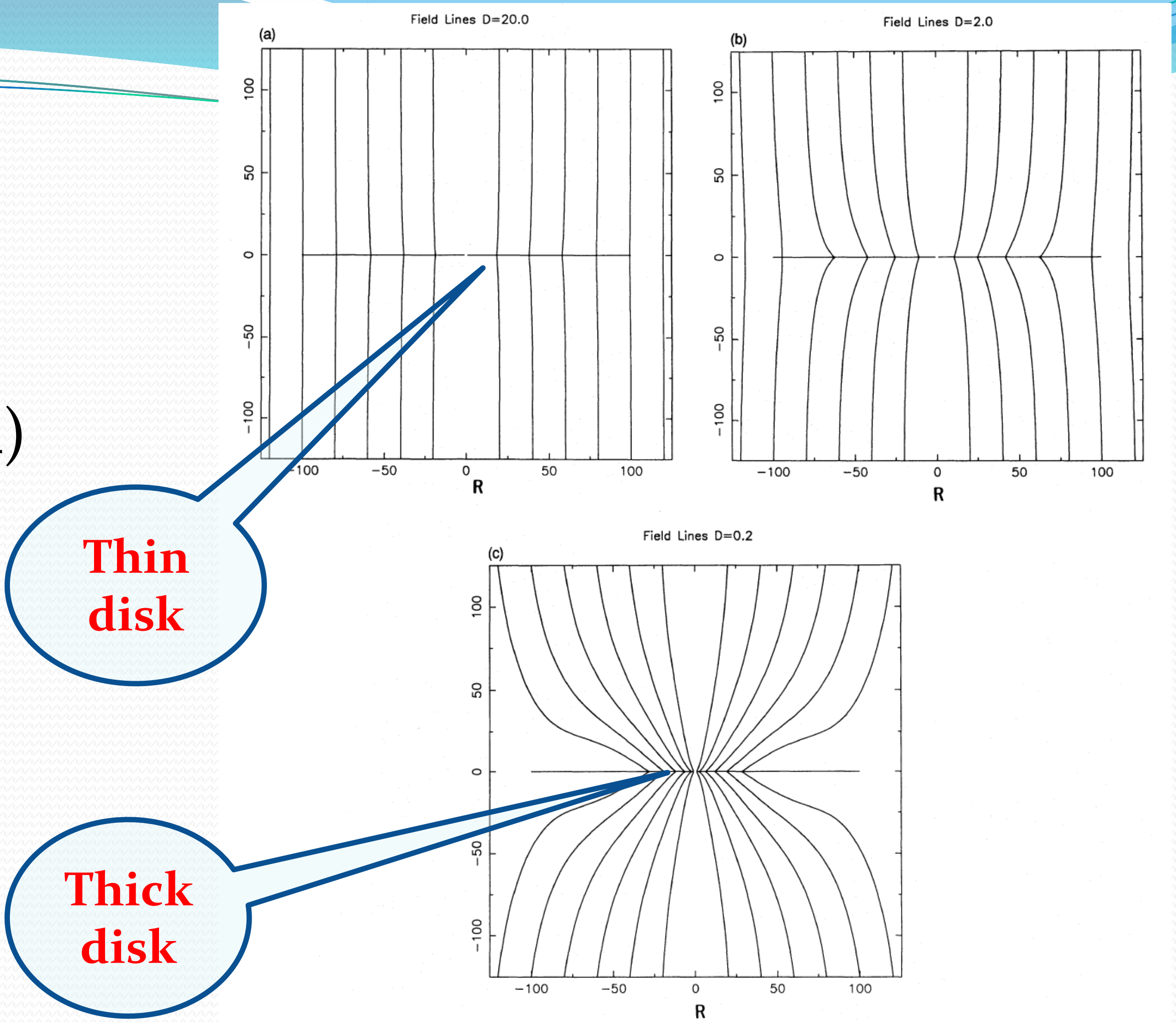
Large-scale Magnetic fields

- Livio et al. (2003) suggested that the LH state could be a result of the large-scale magnetic field forming in inner disk through dynamo processes, which transfer lots of locally dissipated energy to jet and thus cause the disappearance of thermal component.

- Considering both the effects of large-scale field strength on viscosity parameter and the ability to effectively drag large-scale field inward in thick disk, Begelman & Armitage (2014) suggested that a transition from LH to SPL state could be induced when the Shakura-Sunyaev parameter $\alpha \sim 1$ and the luminosity L is $\sim L_{Edd}$.

- Igumenshchev (2009) and Dexter et al. (2014) pointed out that a magnetosphere could form in the inner region of disk by accumulating enough magnetic flux, where the state transition could be triggered by accreting inverted magnetic field.

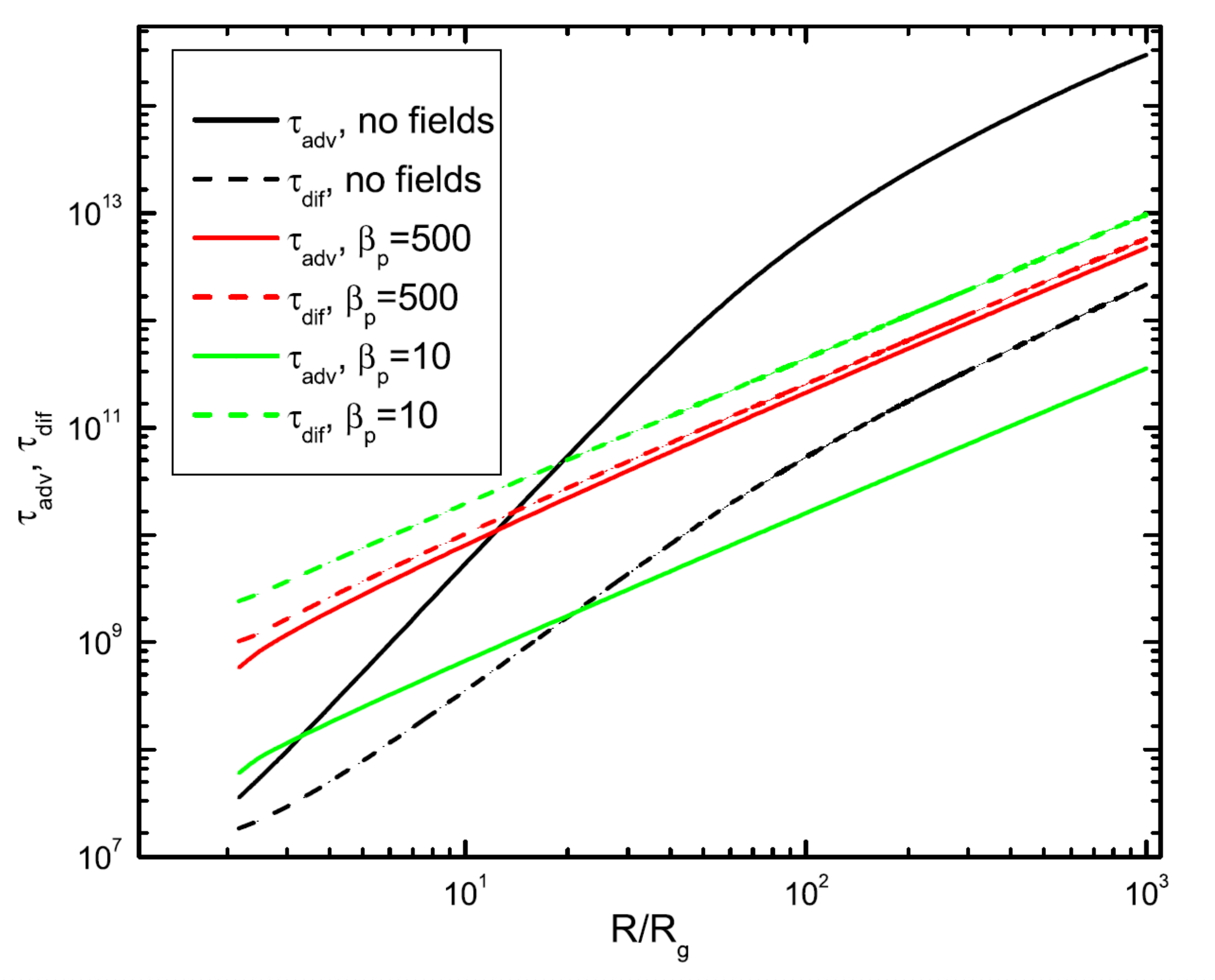
- Lubow et al. (1994)



- Spurit & Uzdensky (2005), field bundles
- Cao & Spruit (2013), Li & Begelman (2014), large scale magnetic fields

Model

- Whether the magnetic field can be effectively dragged inwards depends on the competition between advection timescale τ_{adv} and diffusion timescale τ_{dif} . We consider a realistic thin disk which accretes gas from the companion star in X-ray binaries.



Li & Begelman (2014)

In order to get $\tau_{adv} << \tau_{dif}$, the magnetic torque $T_m >> W_{r\phi}$ (the viscous torque) is required.

α=0.1, $B_{\phi} = 0.1B_p$, R = $10^4 R_g$, and m_dot = 0.1

- The ratio of magnetci torque to the viscous torque is:

$$\frac{T_{\rm m}}{W_{\rm R\phi}} \sim \frac{0.2R}{H\alpha\beta_{\rm p}} \sim \frac{130}{\beta_{\rm p}}$$

- where $T_m = B_p B_{\phi} R/2\pi$ (Livio et al. 1999), $W_{R\phi} = 2HP_{tot}$ and $\beta_p = (P_{gas} + P_{rad})/(B^2_p/8\pi)$

- When $\beta_p < 10$, $T_m >> W_{r\phi}$

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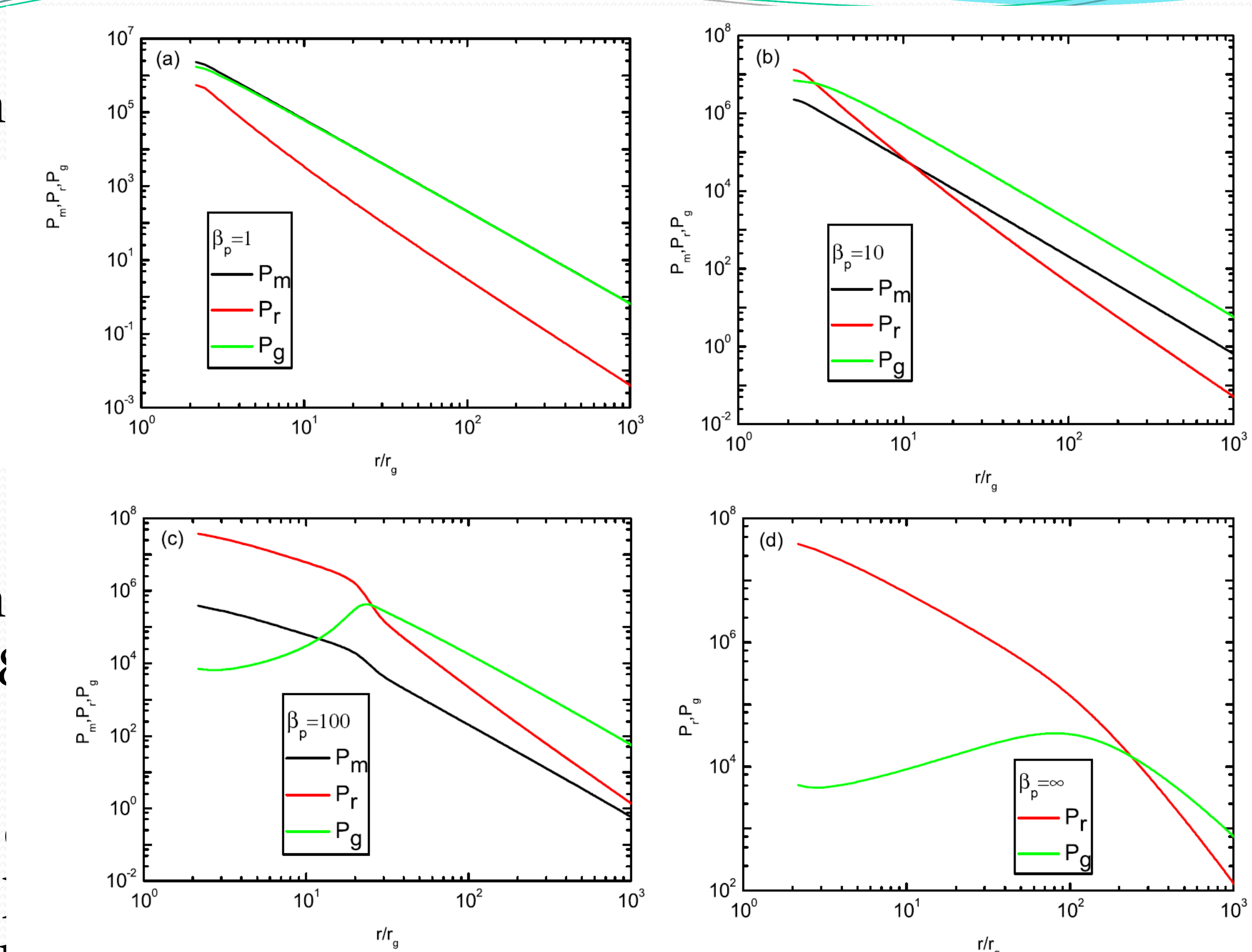
  a thin disk is required.



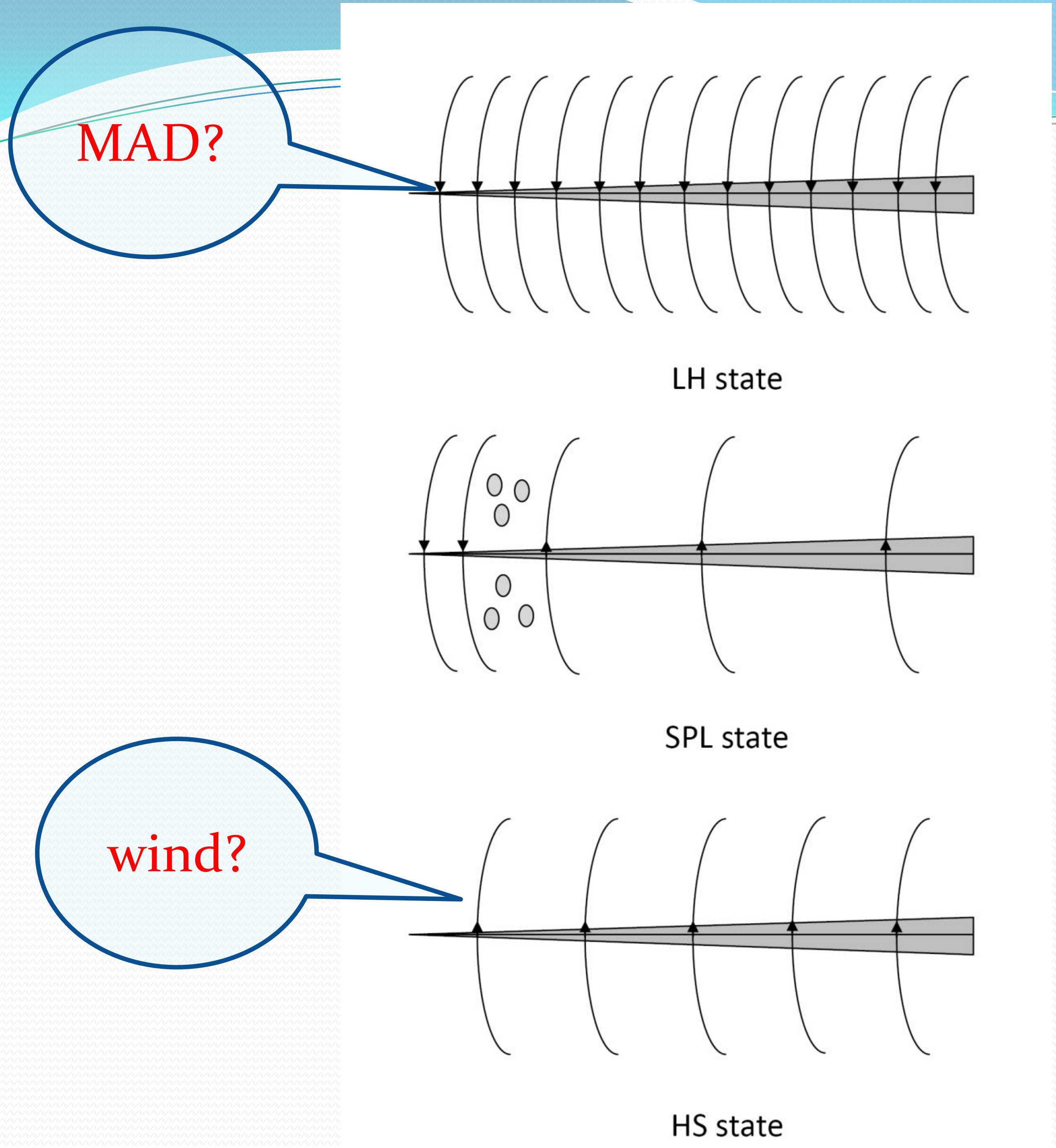
Li (2014)

- As far as we know, most Galactic BH XRB systems harbor a low mass companion star (K-type). The average magnetic field strength of K-type stars is ~ 20 G. The magnetic field strengths of stars in the catalog of Bychkov et al. (2009) roughly follow a positive correlation with the star mass.

- Cygnus X-1 is the only currently known Galactic BH XRB to harbor a high mass companion star, the spectral type of which is O9.7 (Bolton 1972;Orosz et al. 2011). The average magnetic field strength of O-type stars in Bychkovet al. (2009) is ≈ 340 G, resulting on $\beta_p \sim 3$.

Conclusions and Discussion

- In this work, we investigate whether an ordered magnetic field can be magnified from the outer boundary of a thin disk, which is the key point for the mechanism that a state transition can be triggered by accreting an inverse magnetic field from a companion star. According to our calculations, a quite strong initial magnetic field of $B \sim 10^2 - 10^3$ G is required in order to magnify the large-scale magnetic field. Thus, such a picture is probably present in some high-mass X-ray binaries, for example, Cygnus X-1.


MAD?
LH state
SPL state
wind?
HS state

Thanks!