清華大學 Tsinghua University

Accretion onto black holes with saturated magnetic pressure

Jiahui Huang (Tsinghua)

huangjh19@mails.tsinghua.edu.cn

Collaborators: Hua Feng, Yan-Fei Jiang, Shane W. Davis, James M. Stone,

Matthew J. Middleton, Wei-Min Gu, Wen-Biao Wu

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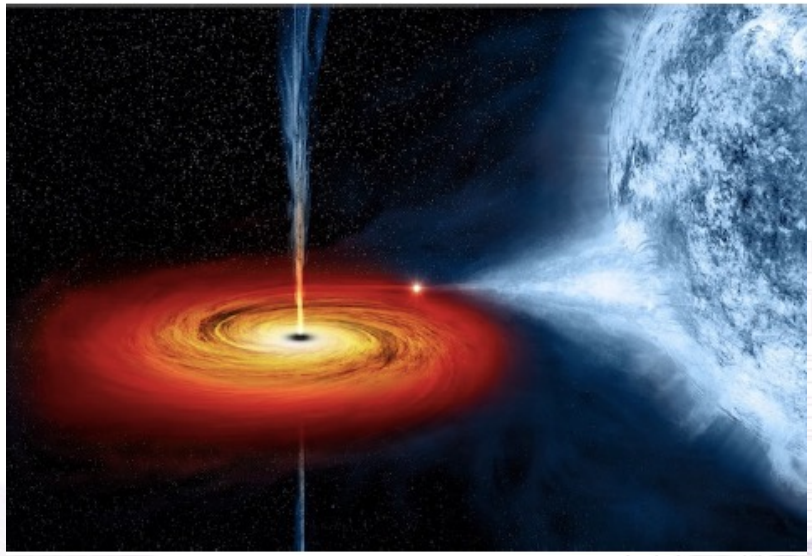
Black Hole X-ray Binaries



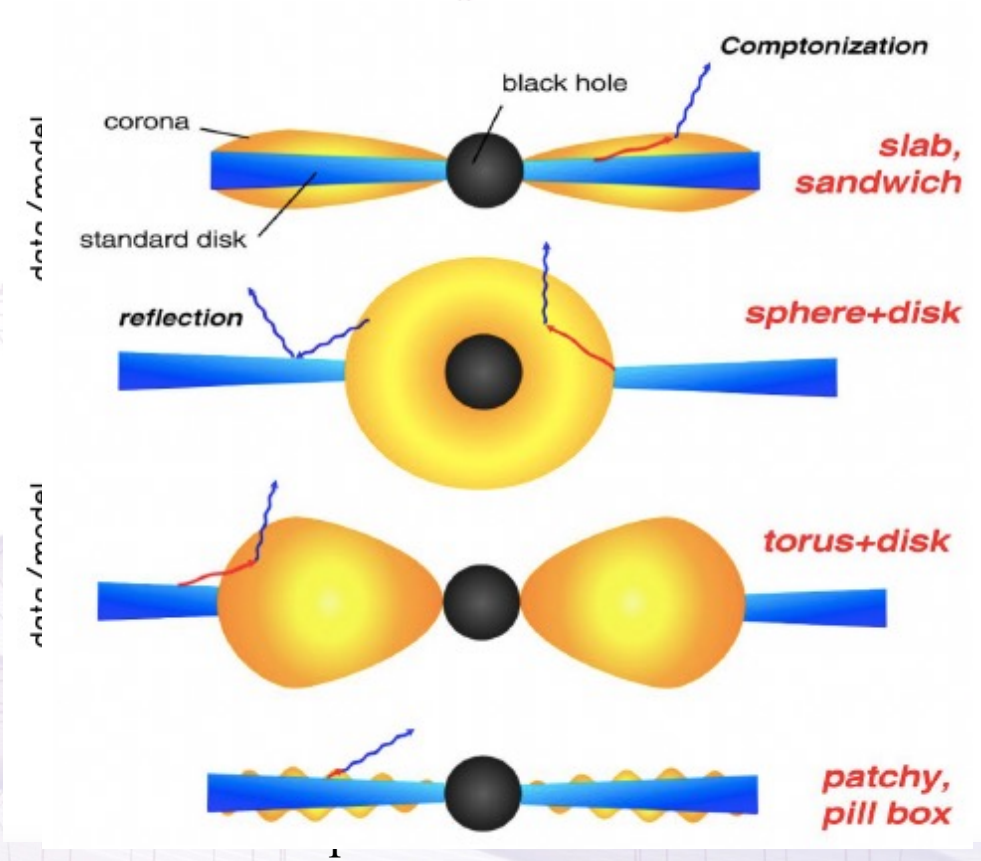
$\sim 0.01\dot{M}_{\rm crit}$ $\geq \dot{M}_{\rm crit}$

ADAF | standard disk | slim disk

- $Q_{\rm vis} = Q_{\rm adv}$
- $Q_{\rm vis} = Q_{\rm rad}$
- $Q_{\rm vis} = Q_{\rm adv}$

Limitations of Classical Models

- Outflows confirmed by absorption lines
- Geometry of coronae
- Magnetic field: MRI & turbulence



Miller et al. 2016

Muller 2004

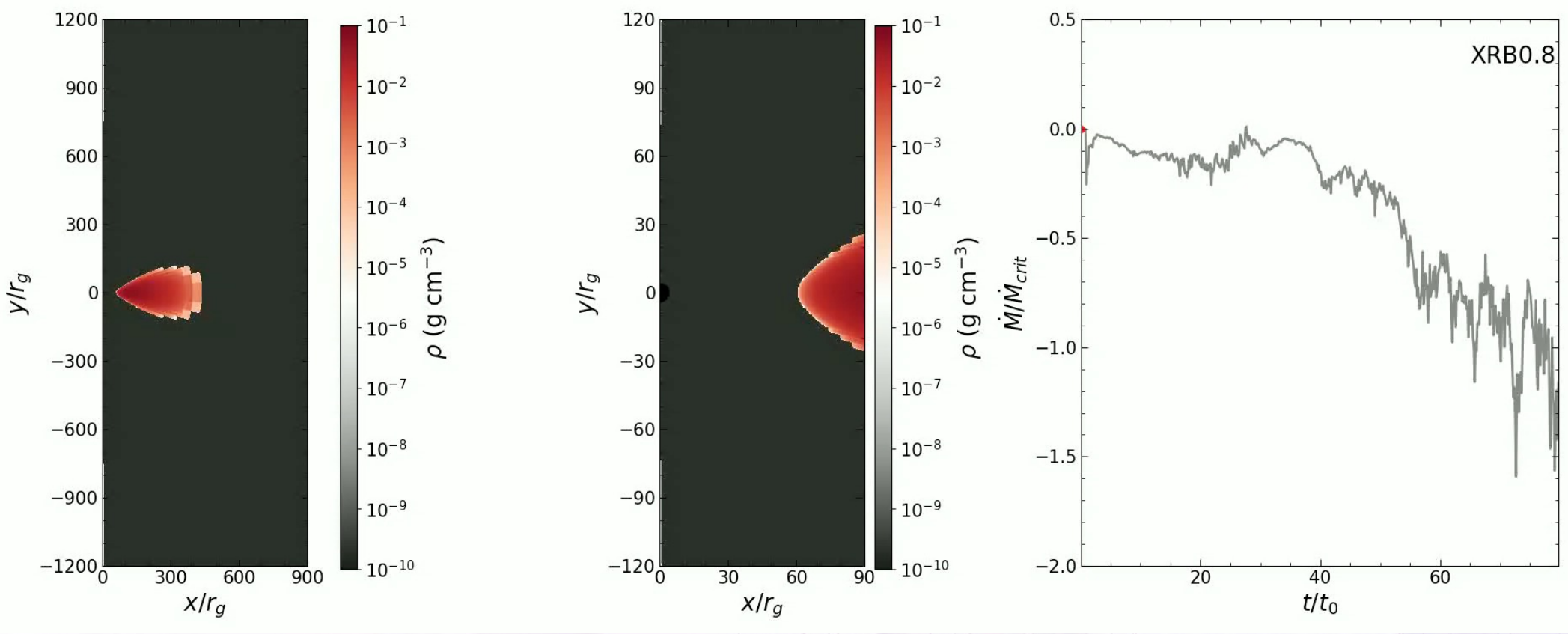
3D RMHD Simulation

Density:

Global

Zoom-in

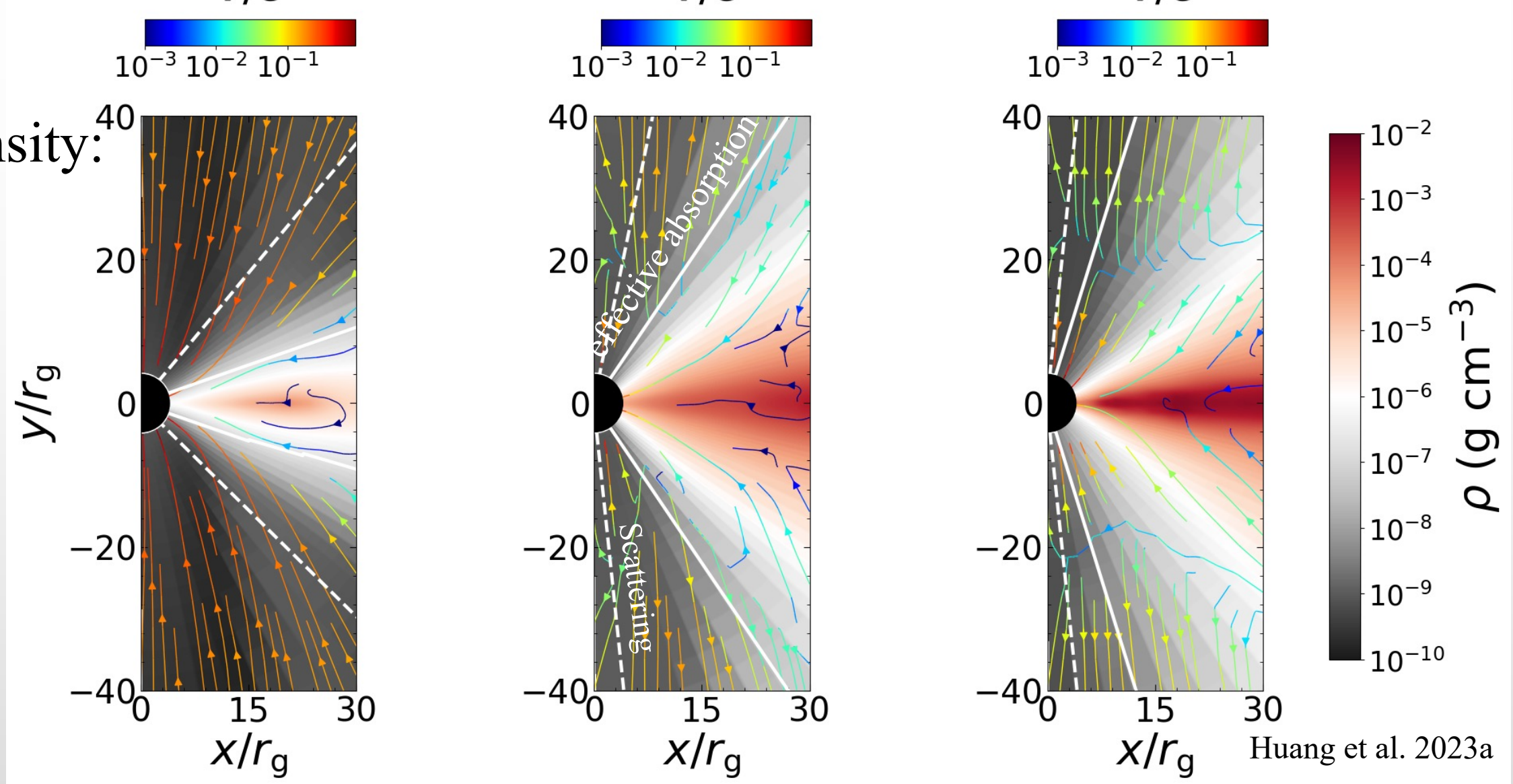
Huang et al. 2023a



➢Different magnetic field configurations and initial densities leads to different $\dot{m}$

$\dot{M}/\dot{M}_{\rm crit}$: XRB0.01 XRB0.8 XRB0.9

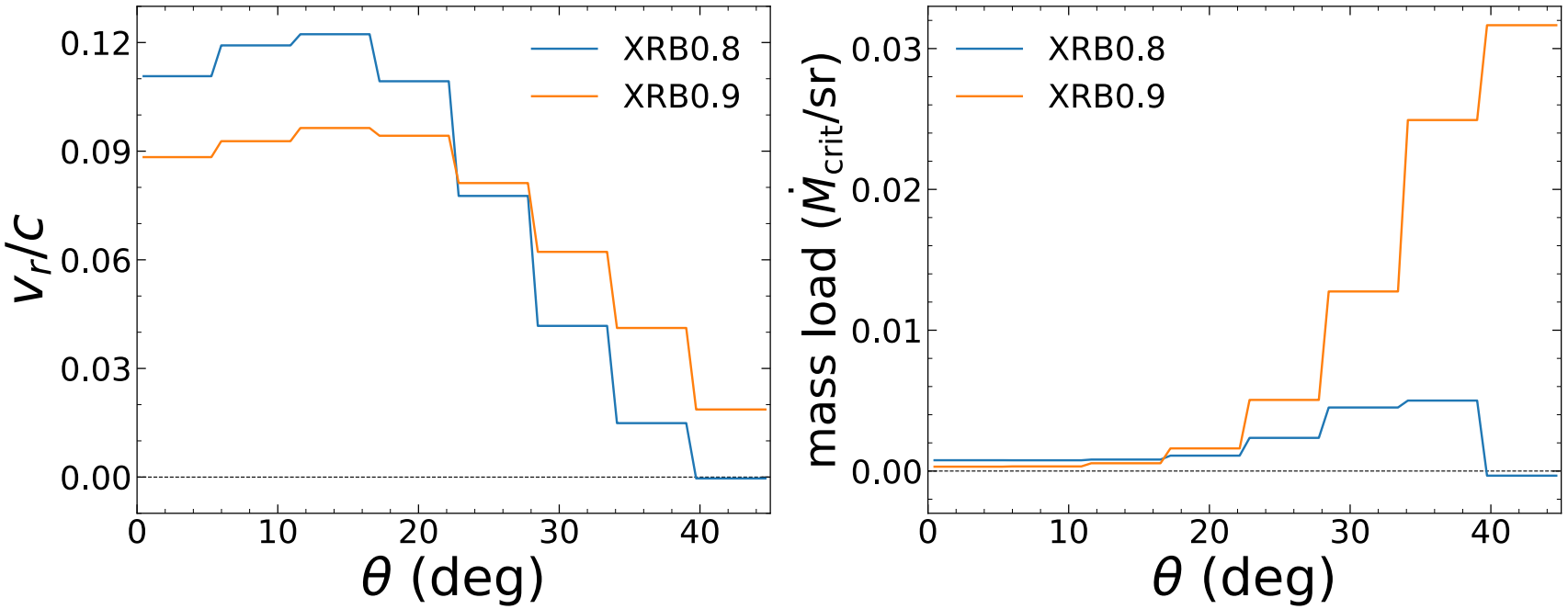
Density:



Huang et al. 2023a

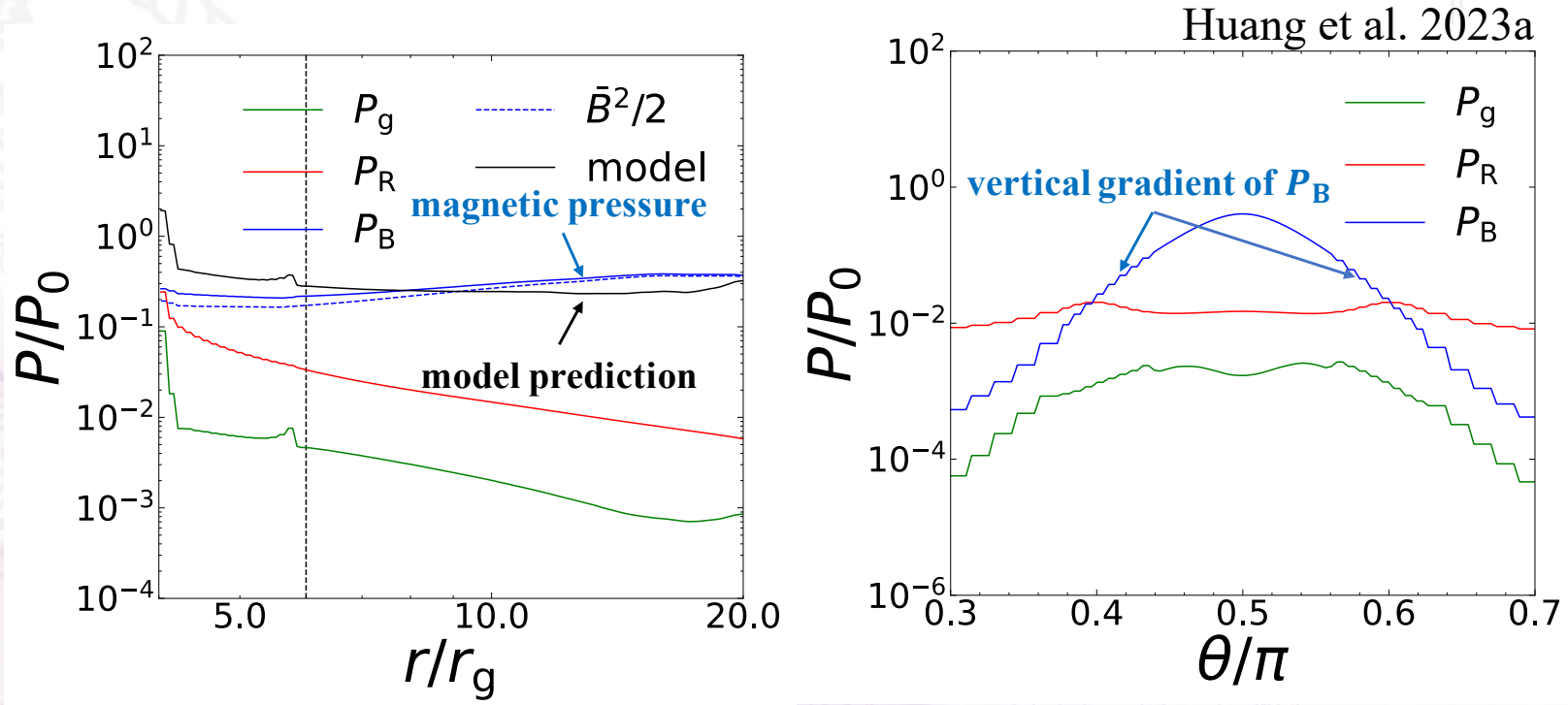
Outflows

Huang et al. 2023a



- Velocity peaks around axis, $v \sim 0.1c$
- Mass load rate peaks at the surface of the disk

Magnetic Pressure



- Comparable magnitude of magnetic / radiation pressure
- Gradient of magnetic pressure supports the disk
- Saturated magnetic pressure: $P_B \sim \rho c_g V_K$ (Begelman & Pringle 2007)

Analytical Model

➢Outflows: $\dot{M} \propto R^p$ (Blandford & Begelman 1999) (mass conservation)

$p = \lambda(H/R)$ (Wu et al. 2022)

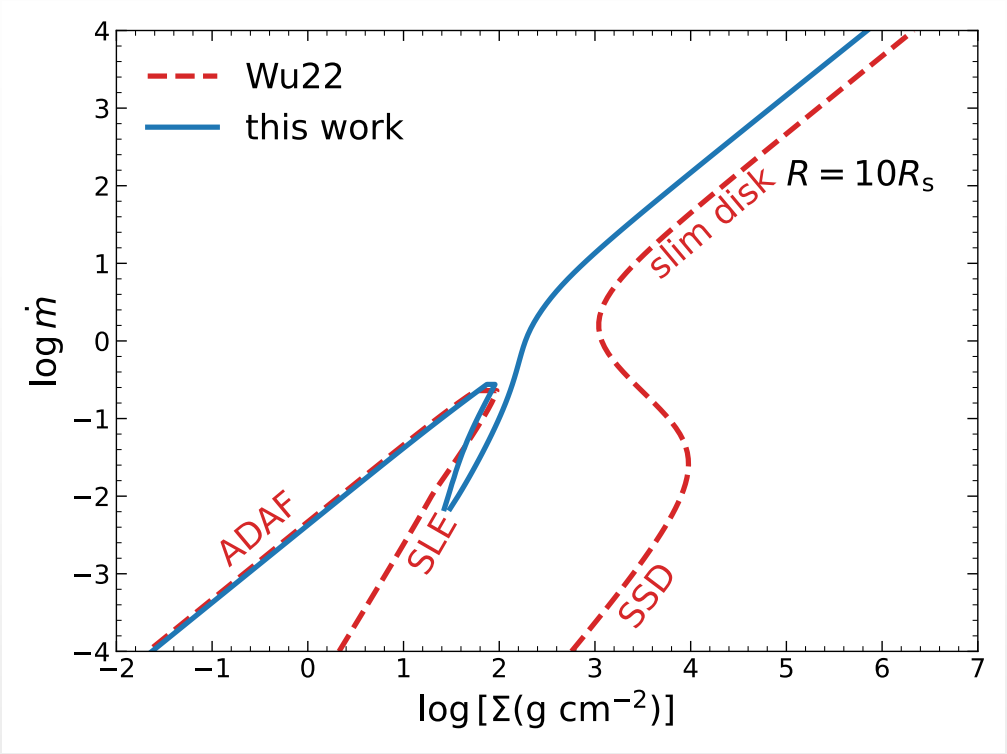
$$-\frac{1}{R}\frac{d}{dR}(R^3 \Sigma V_R \Omega) + \frac{1}{R}\frac{d}{dR}\left(R^3 \nu \Sigma \frac{d\Omega}{dR}\right) - \frac{(lR)^2 \Omega}{2\pi R}\frac{d\dot{M}_{\rm w}}{dR} = 0$$ (momentum conservation)

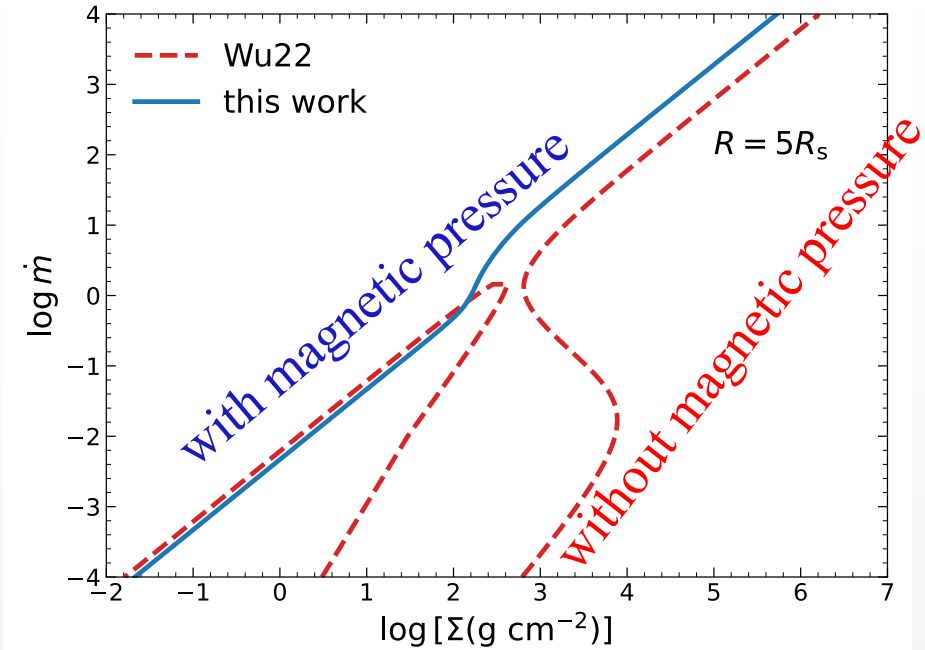
$$Q_{\rm vis} = Q_{\rm rad} + Q_{\rm adv} + Q_{\rm w}$$

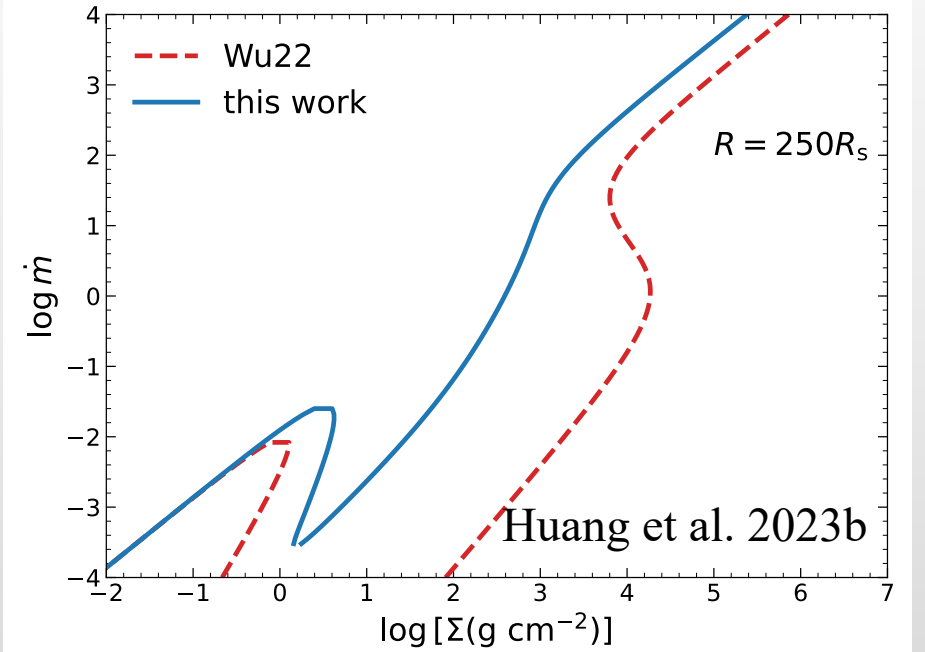
(energy conservation: viscous heating = radiative + advective + wind cooling)

➢Magnetic pressure: $P_B = \rho c_{\rm g} V_{\rm K}$ (Begelman & Pringle 2007) (confirmed by simulation)

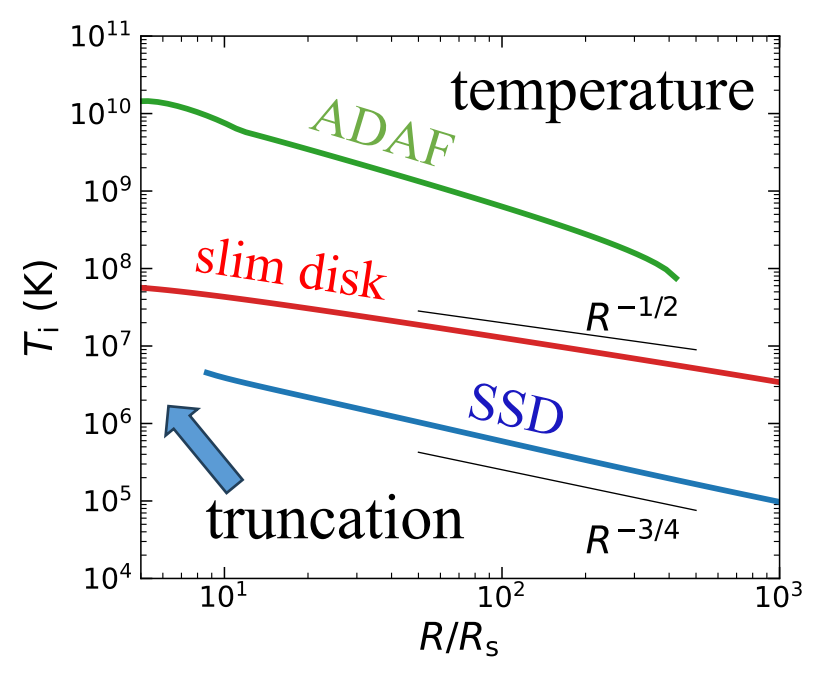
➢Thermal equilibrium solutions



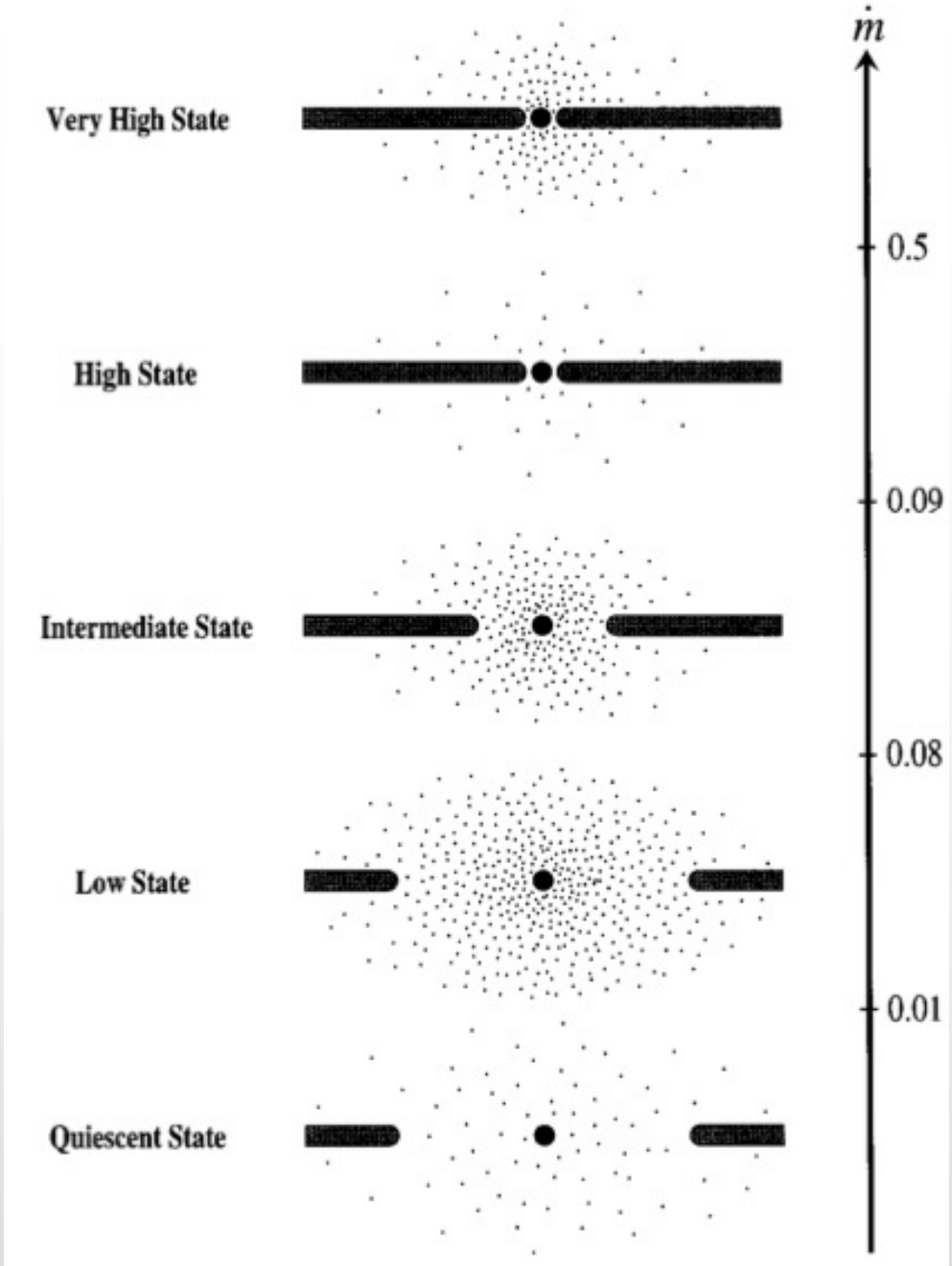




➢Standard disk branch appears only at large R

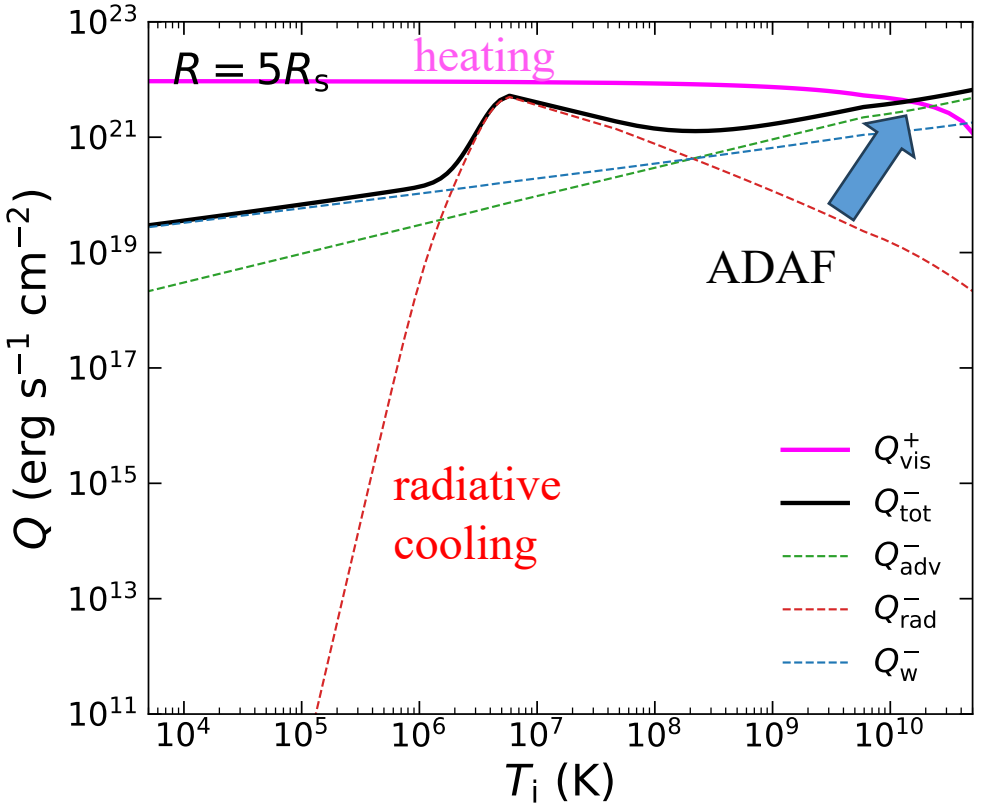


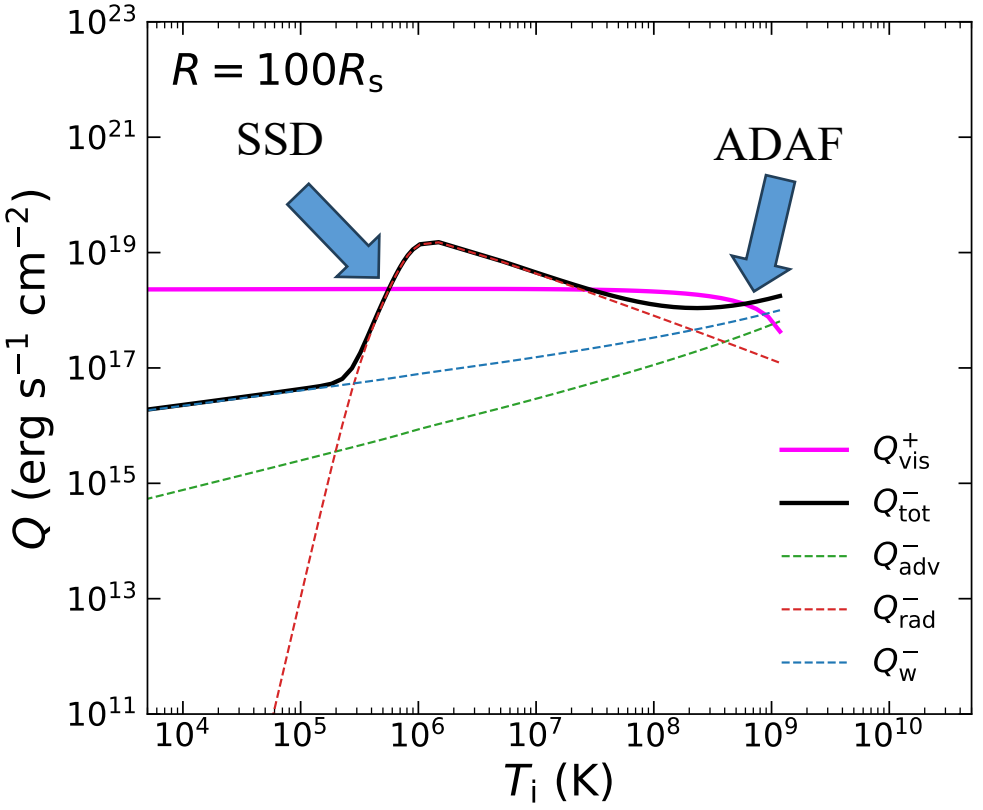
Huang et al. 2023b



Esin et al. 1997

Solution Existence

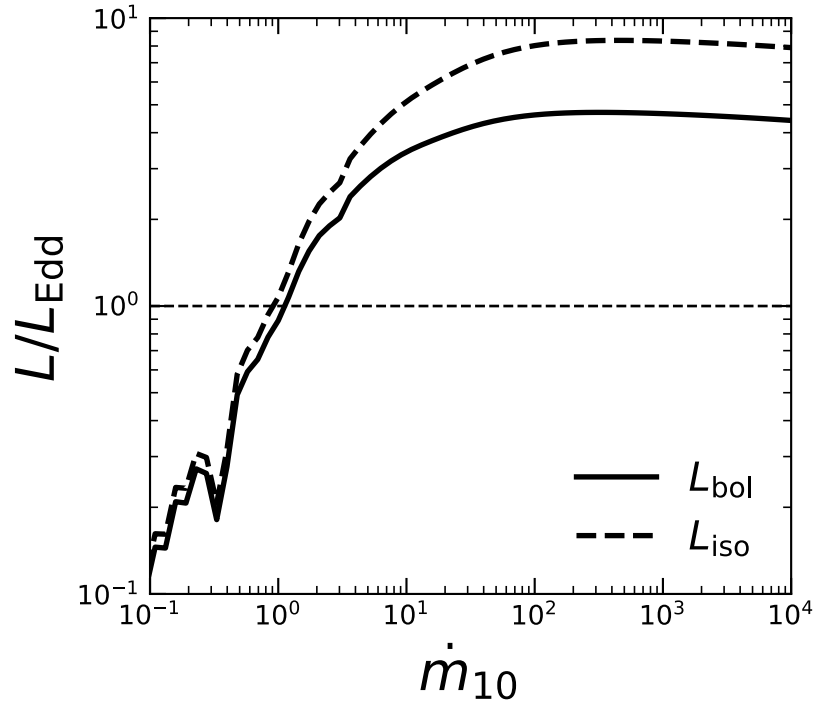




Huang et al. 2023b

- At smaller R, $Q_{vis} \gg Q_{rad}$, no SSD

Luminosity



Huang et al. 2023b

$$L_{\rm bol} = \int_{R_{\rm in}}^{R_{\rm out}} 2\pi R Q_{\rm rad} dR\,,$$

$$L_{\rm iso} = \frac{1}{b} L_{\rm bol} \approx \frac{1}{1-\cos\theta} L_{\rm bol}\,,$$

- Luminosity has a saturated value similar to AGN (Wang et al. 2014)

Summary

- Background: limitation of classical models
- Simulation: outflows in the near critical runs with velocity $\sim 0.1c$
- Simulation: vertical structure supported by magnetic pressure, $P_B \sim \rho c_S v_K$
- Analytical model with outflows and P_B: SSD exists only at larger radius

Thank you!