RADIATIVE GRMHD SIMULATIONS OF SUB-EDDINGTON ACCRETION: THE PUFFY DISC

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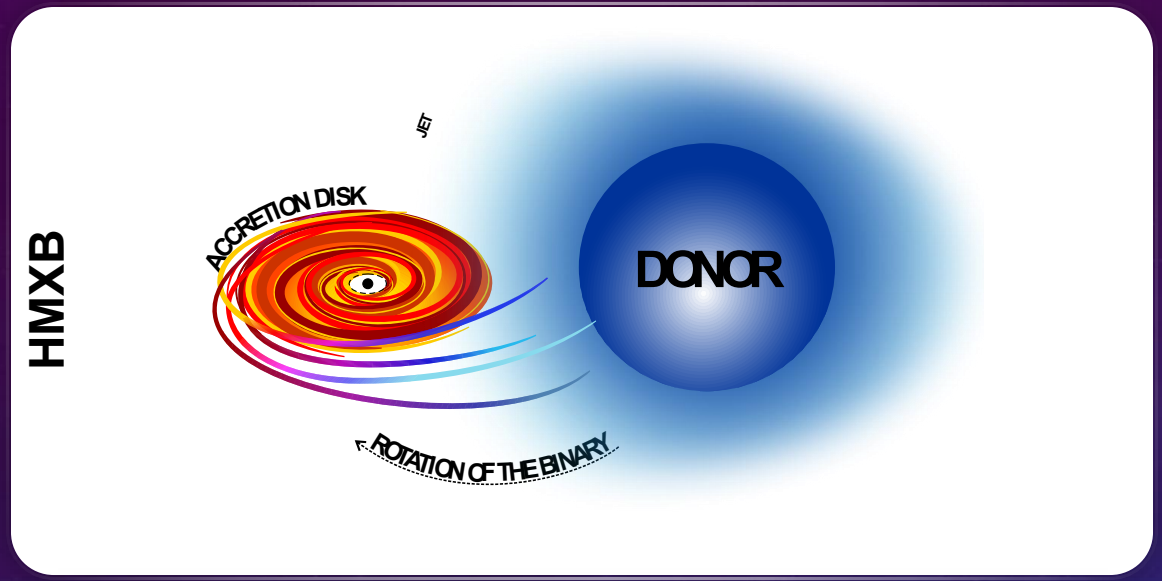
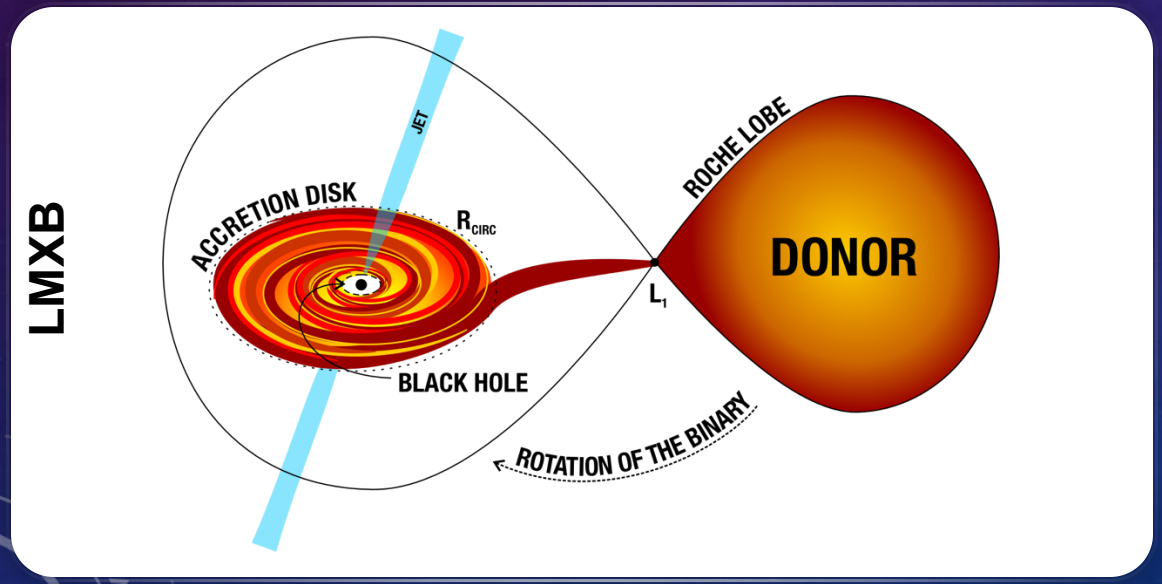
Warsaw

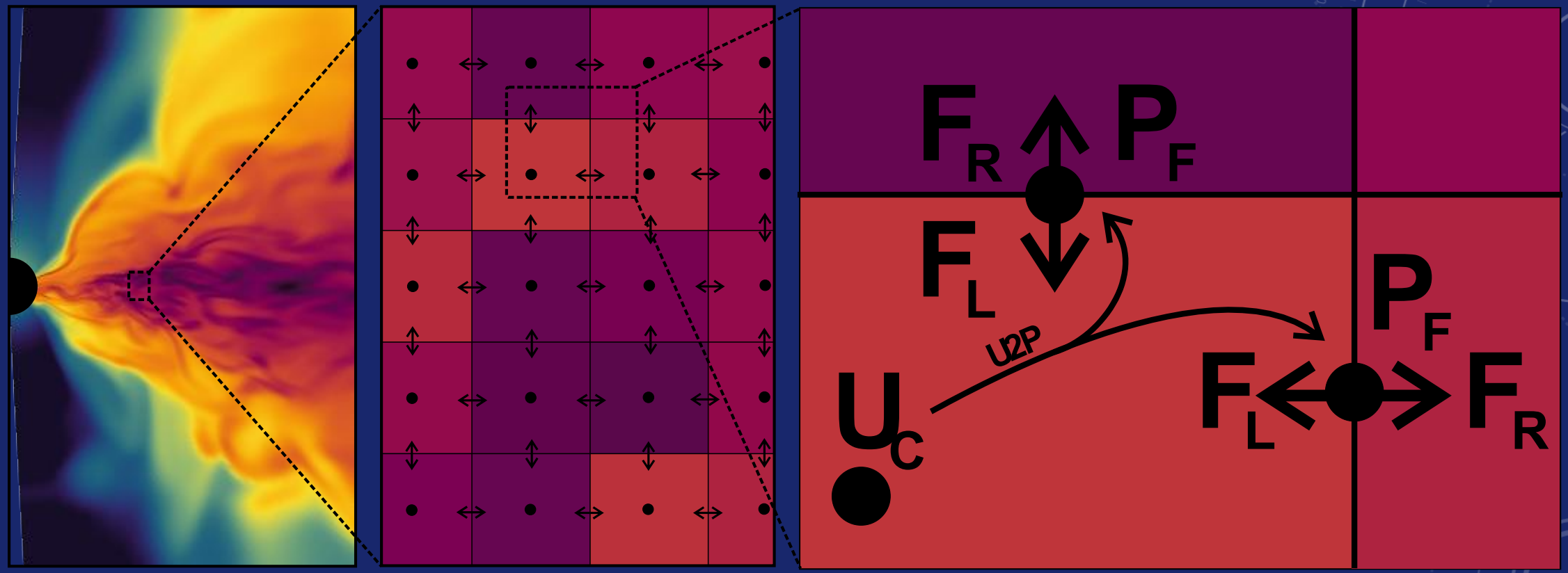
(MILDLY-) SUB-EDDINGTON ACCRETION DISCS





- Thin disc model – Shakura&Sunyaev 1973, Novikov&Thorne 1973
- Observed all around the universe, e.g. XRBs, microquasars, galactic centres, …
- Used to fit X-ray data and get BH parameters
- Inner edge on ISCO
- Unstable when radiation pressure dominates!
- Sądowski 2016; Lančová+ 2019, 2023; Wielgus+ 2022 – Puffy accretion disc

GLOBAL GR RADIATIVE MAGNETOHYDRODYNAMICS - KORAL



$$\nabla_\mu (\rho u^\mu) = 0$$

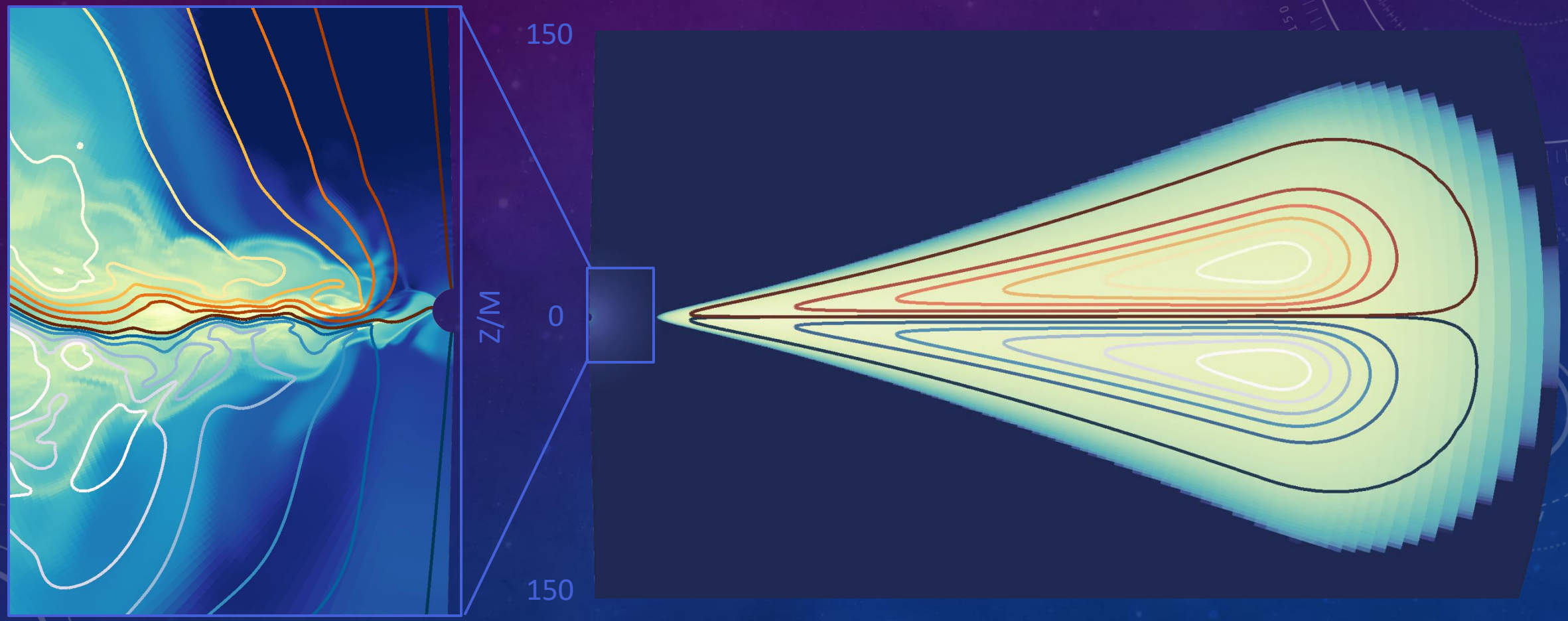
$$\nabla_\mu T^{\mu\nu} = G^\nu$$

$$\nabla_\mu F^{*\mu\nu} = 0$$

$$\nabla_\mu R^{\mu\nu} = -G^\nu$$

M1 closure
MPI paralelised
Sądowski+ 13, 14, 17, …

INITIAL STATE

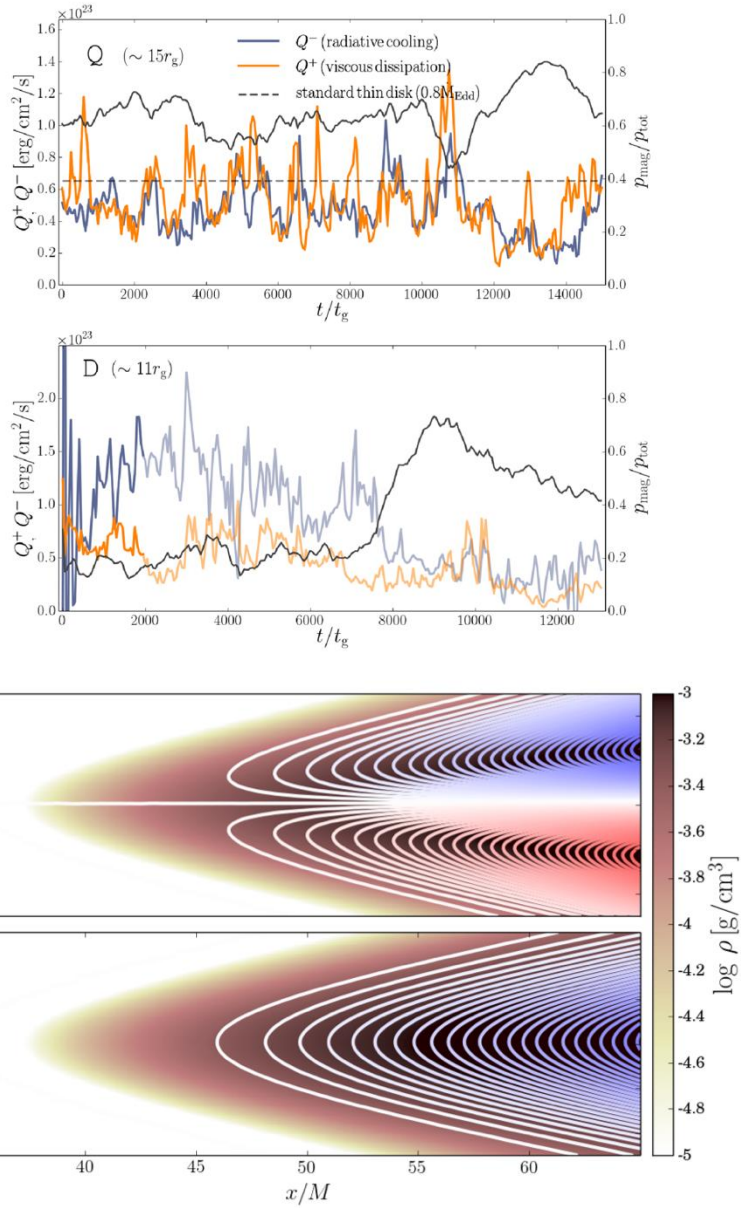


STABILIZATION BY THE MF

- Magnetic pressure ~ radiation pressure in the midplane
- Vertical flux is needed (Mishra 2022, Fragile&Sądowski 17)
- Strongly magnetised, but not MAD (poloidal flux is low)

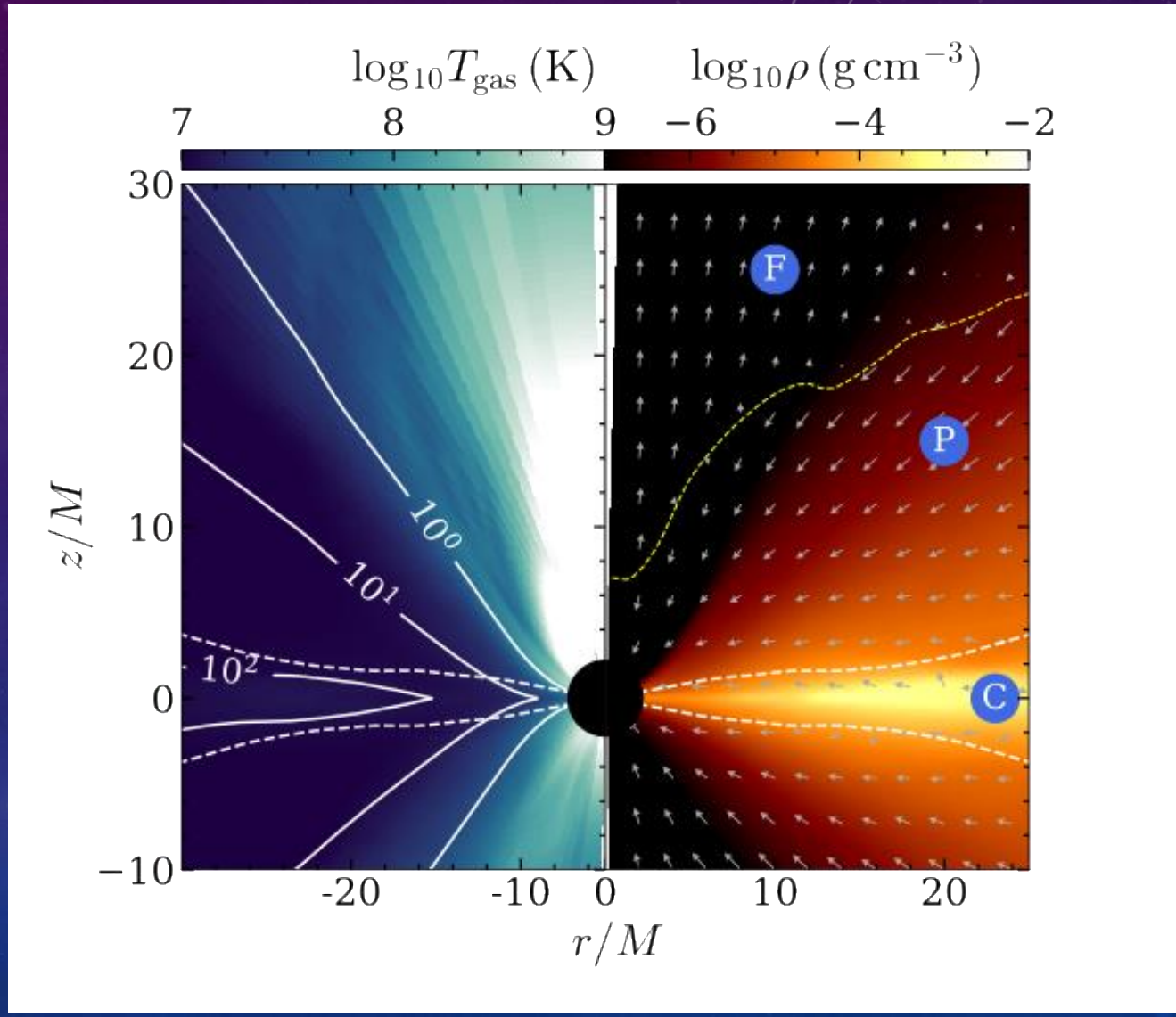
$$\left.\frac{\mathrm{d}\log Q^-}{\mathrm{d}\log p_{\rm rad}}\right|_{\Sigma} = 1. \qquad \left.\frac{\mathrm{d}\log Q^+}{\mathrm{d}\log p_{\rm rad}}\right|_{\Sigma,\, p_{\rm mag}} = 2(1-\beta'),$$

Sądowski 16



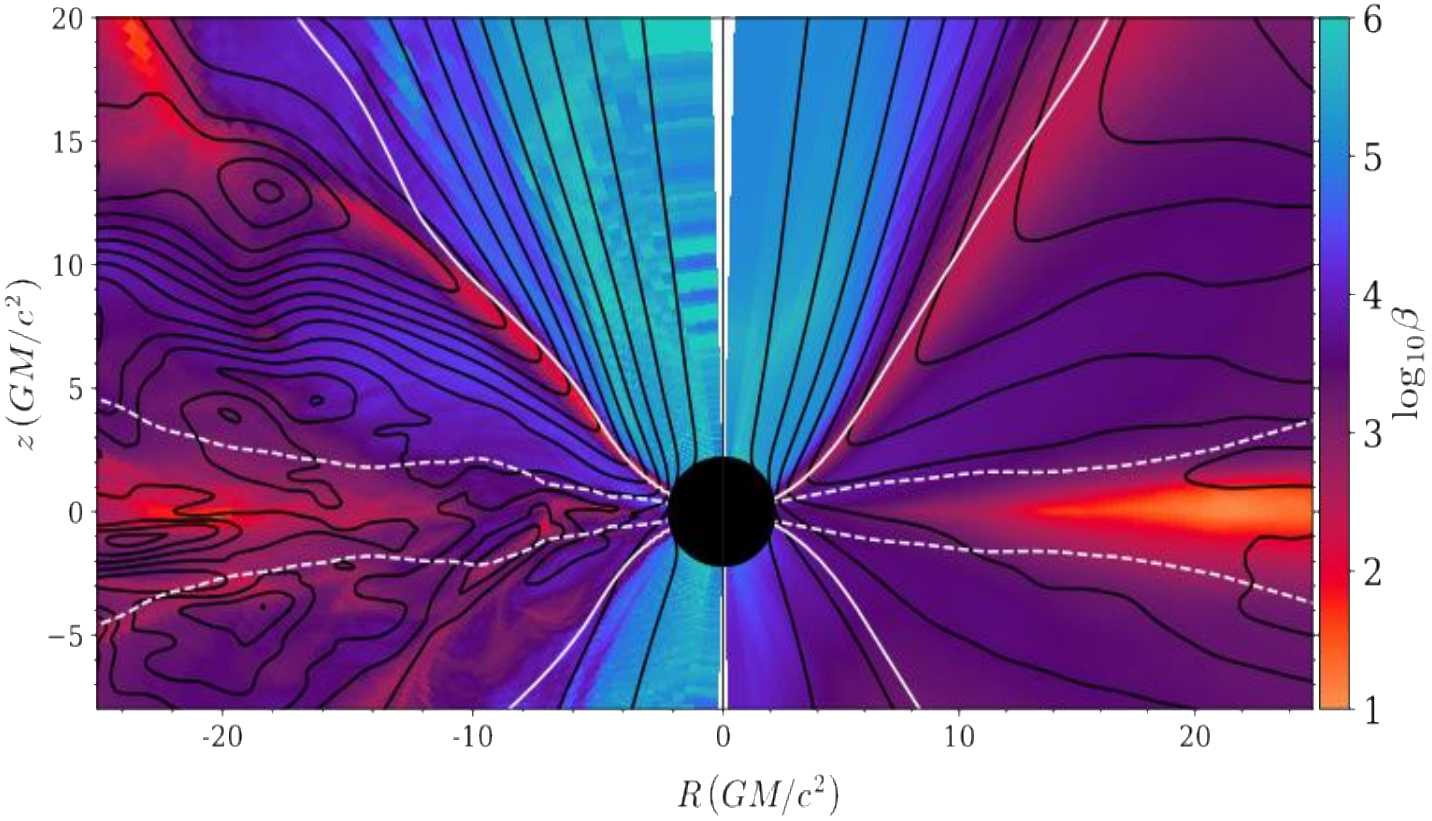
THE PUFFY DISC

- Distinquished vertical structure
- Core – resembling a thin disc
- Puffy region – optically thick, low density, high gas velocity
- Funnel – optically thin, fast outflow, narrow around the axis
- Gas temperature $> 10^7\ K\ (0.9\ keV)$ in the core, $\sim 10^8\ K\ (8.6\ keV)$ at the photosphere



PUFFY DISC

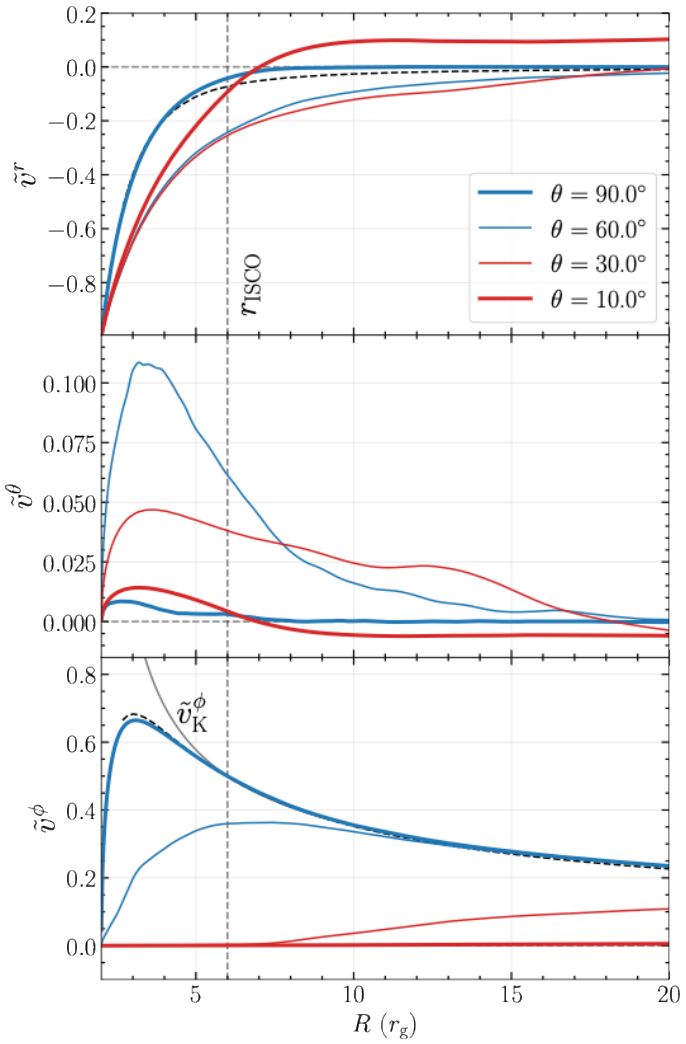
- The magnetic field supports the vertical structure
- Poloidal in the funnel, toroidal (turbulent) in the disc
- Vertical structure does not depend much on the mass accretion rate

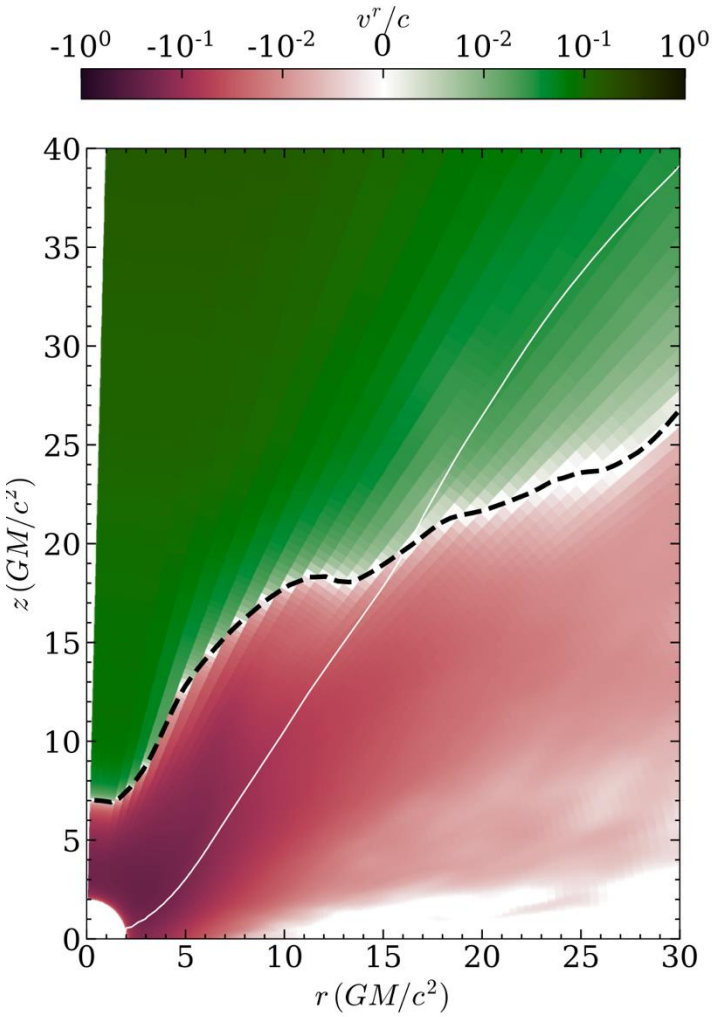


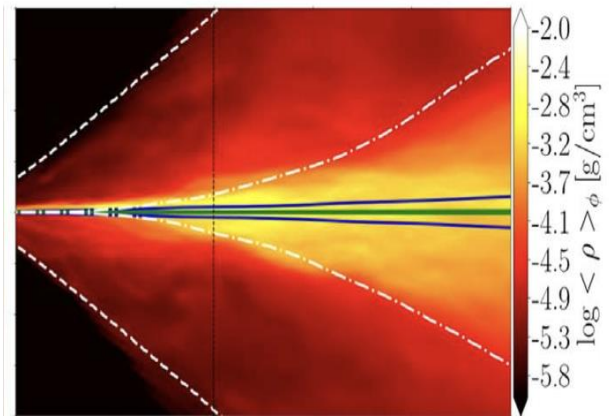
Simulation	$\dot{m}$	h_ρ/r	h_τ/r	$\Delta t\,(t_{\rm g})$	$L/L_{\rm Edd}$	T_c ($\times 10^7$ K)	$r_{sp}\,(r_{\rm g})$
S06	0.58	0.10	1.0	17400	0.36	2.23	4.92
S09	0.89	0.15	1.0	20000	0.31	2.24	4.53
S15	1.51	0.20	1.0	5600	0.59	2.10	3.87

ACCRETION FLOW

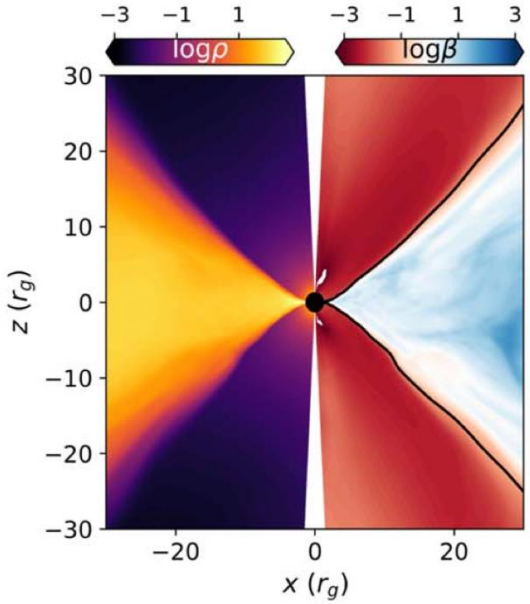
- Fast radial inflow in the innermost part and around the photosphere
- Strongly deviates from any analytical model
- May explain some polarometric observations (Poutanen+ 2023, Ratheesh+ 2024)





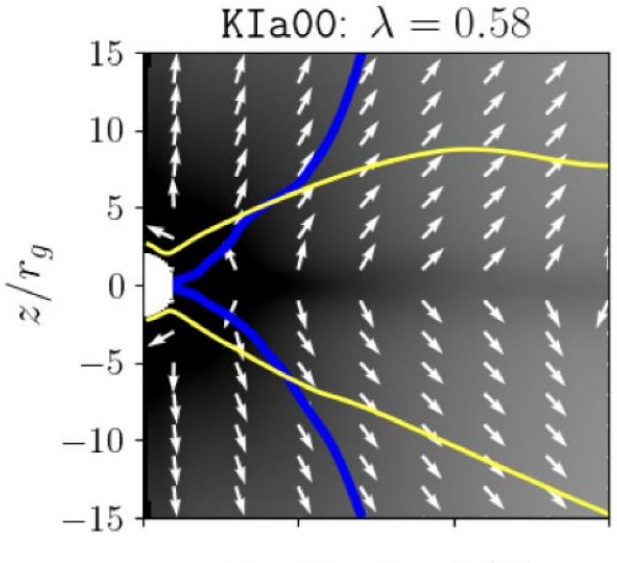


B. Mishra+ 2022

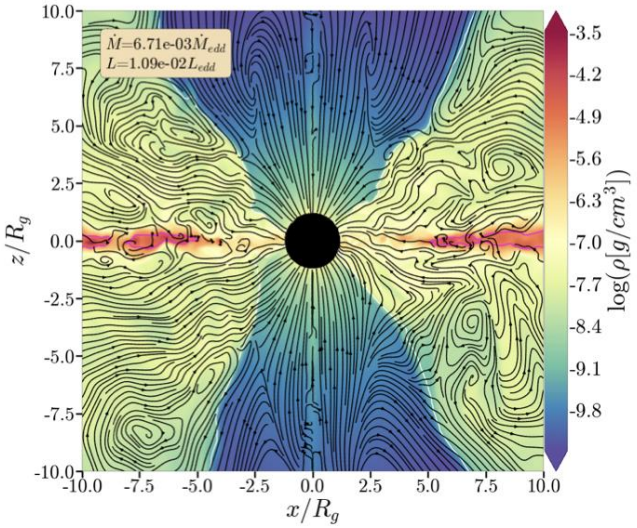


Dexter+ 2021

Koral&MAD

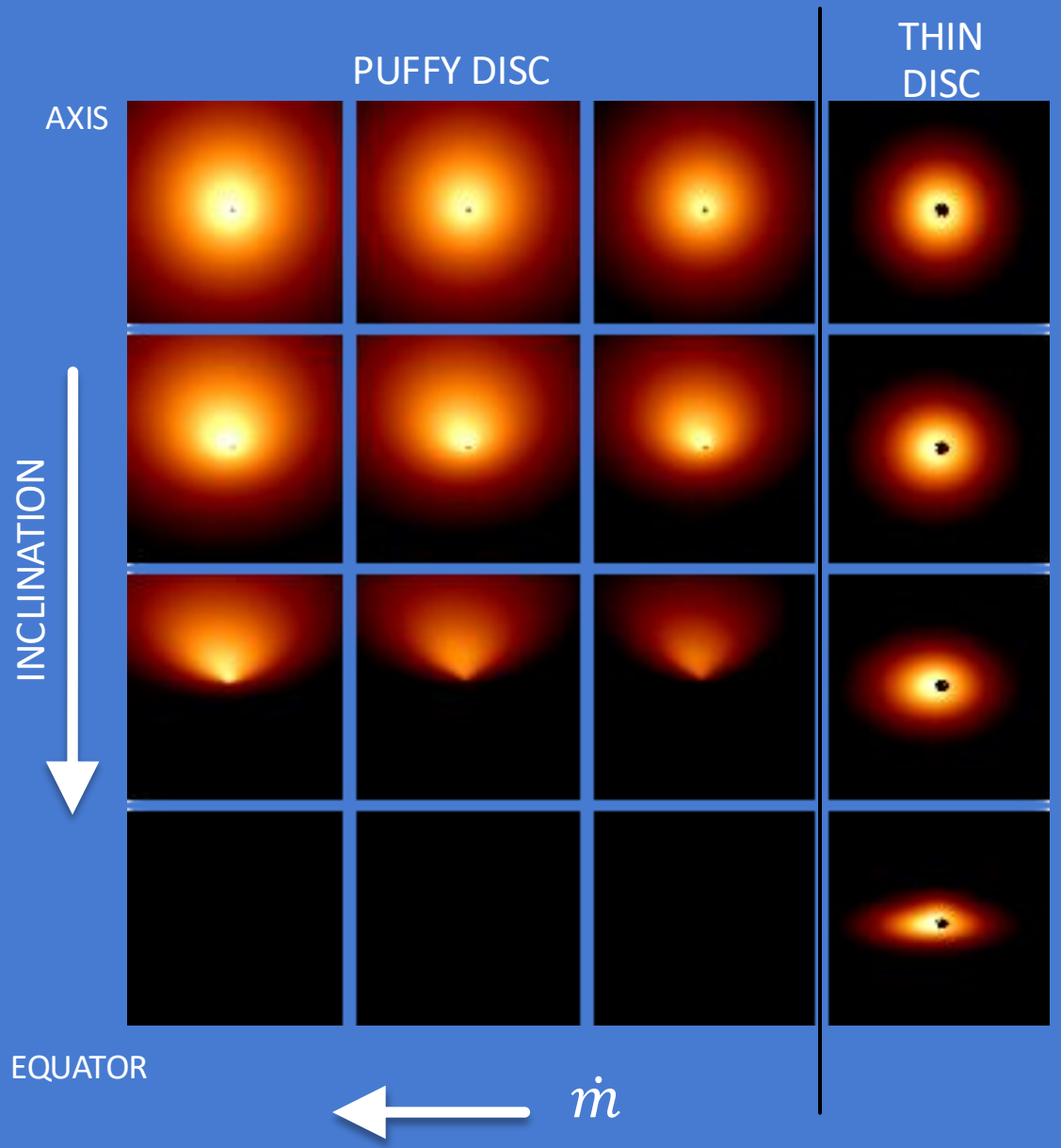


Curd+ 2023

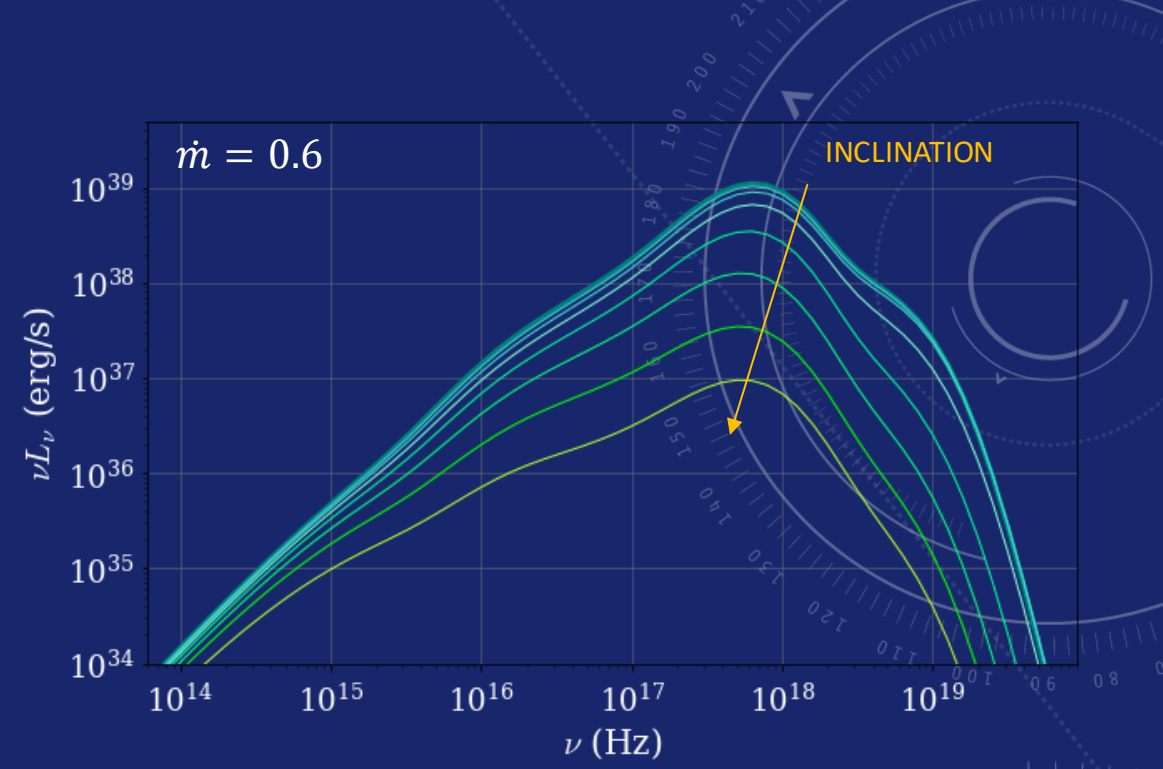


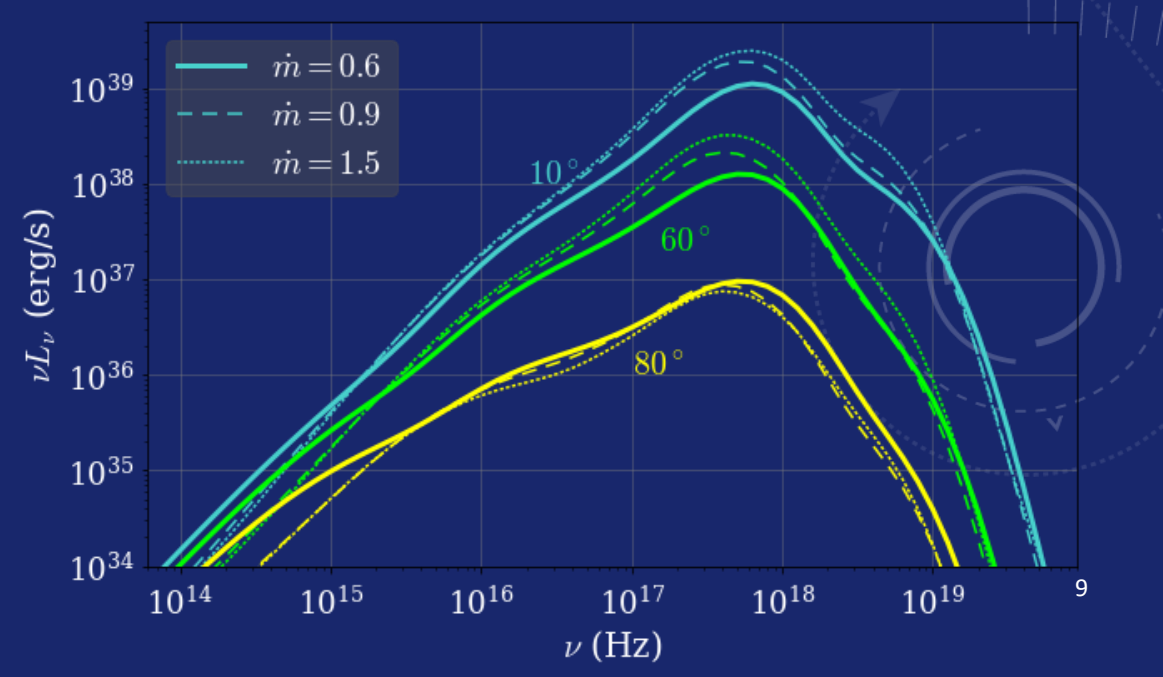
Liska+ 2024

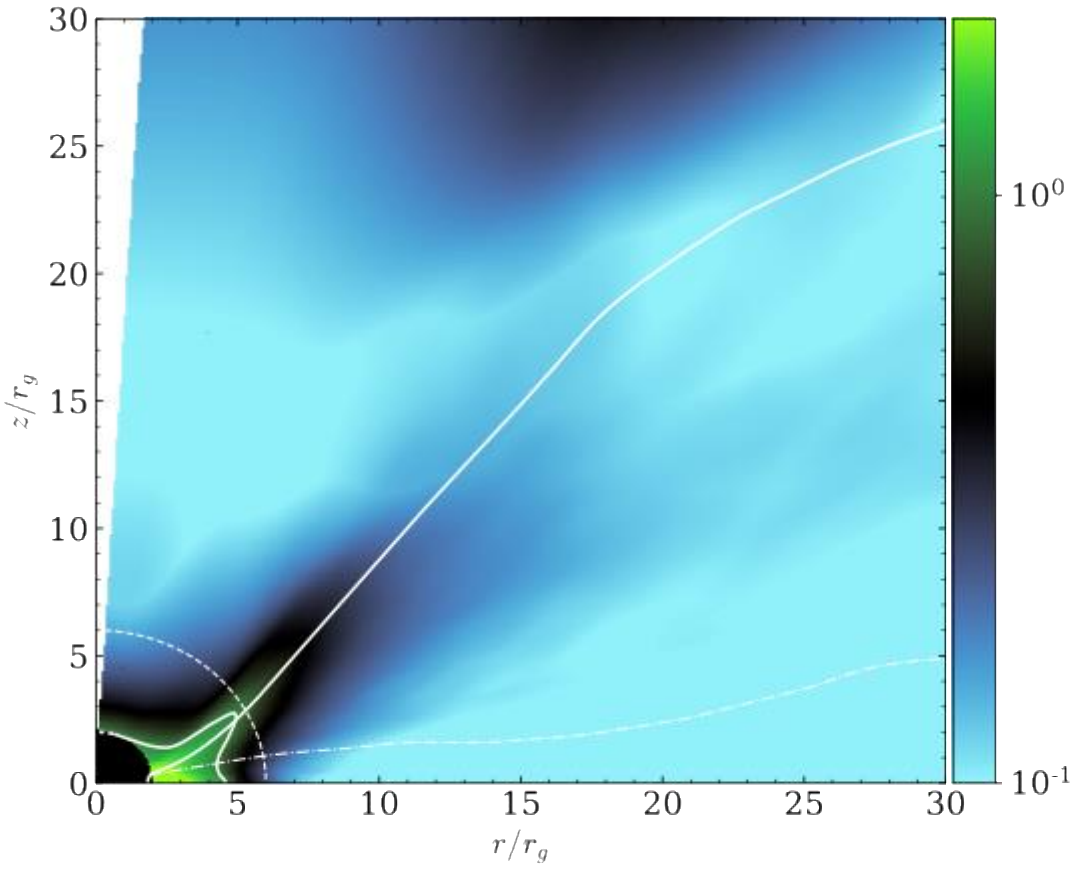
DIFFERENT APPROACHES, SAME RESULT – RADIATION-PRESSURE DOMINATED DISCS ARE NOT THIN

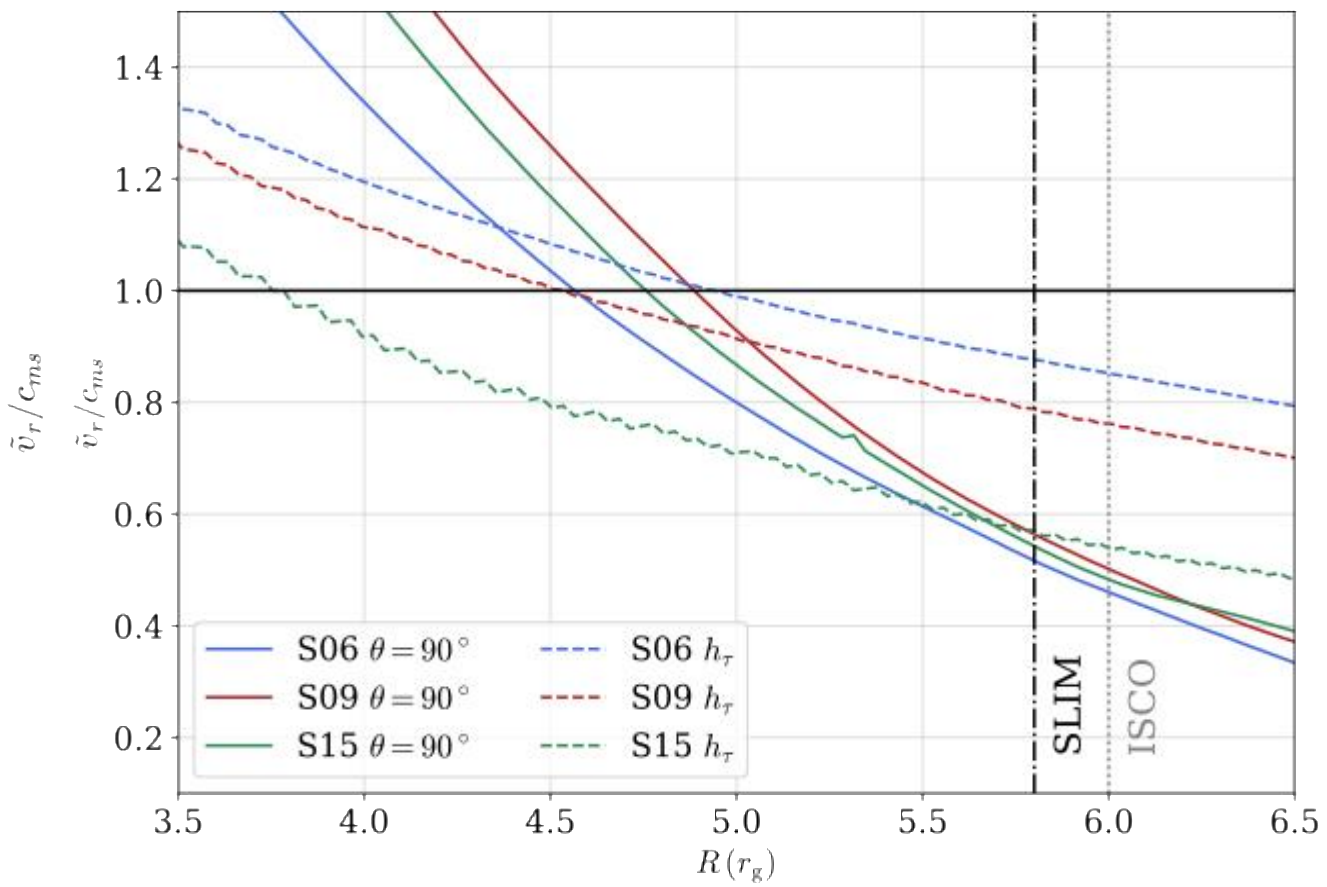


WIELGUS+ 2022

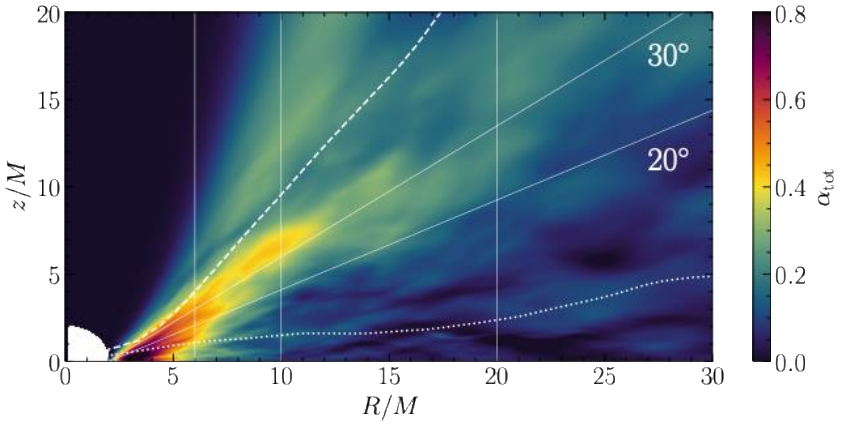


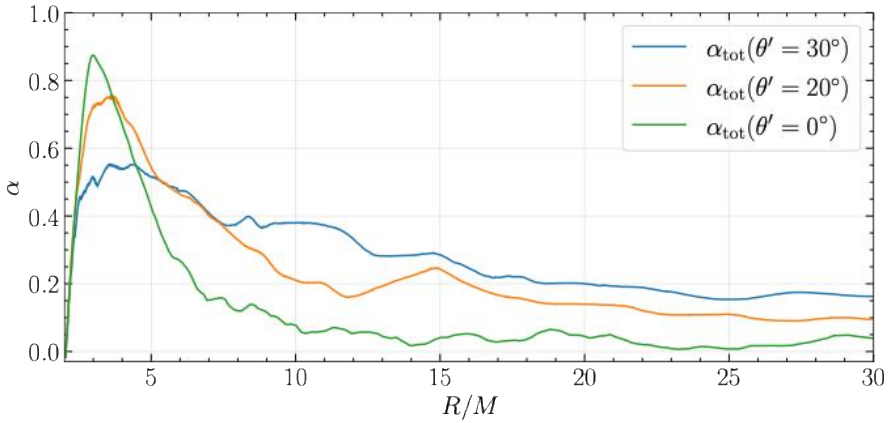


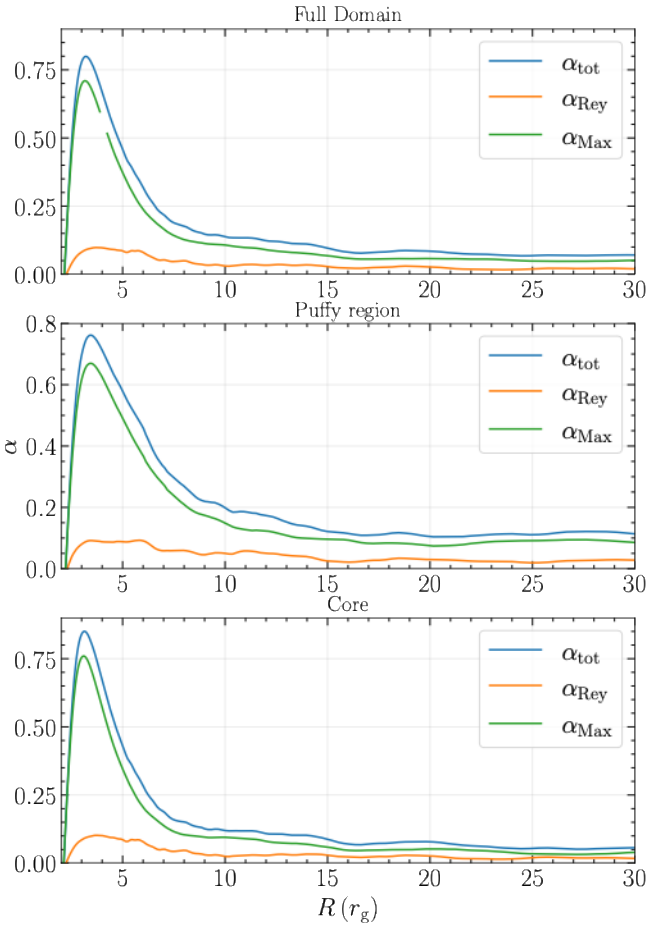




INNER EDGE – SONIC POINT







$$\alpha = \frac{T_{\hat{r}\hat{\phi}}}{p_{\rm tot}} = \frac{T^{\rm Rey}_{\hat{r}\hat{\phi}} + T^{\rm Max}_{\hat{r}\hat{\phi}}}{p_{\rm tot}},$$

- Based on Pena+ 2013
- Strong radial dependence
- Peak inside the ISCO

EFFECTIVE VISCOSITY

SUMMARY

- Radiation pressure-dominated discs are supported by magnetic pressure
- They are not thin and do not end on ISCO
- Observables highly depend on inclination

PLANS FOR PUFFY

- Spinning BH and possible formation of jets – comparison to microquasars
- Also, the inner edge dependence on spin and observational consequences
- Lower mass accretion rate, higher resolution
- Transition from gas-pressure dominated thin disc to radiation (and magnetic-) pressure dominated regime
- Simulation for supermassive BH and the properties of the puffy region compared to a warm corona (Agata Różańska's group)

THANK YOU FOR YOUR ATTENTION

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