Jets and disc-winds from magnetically driven flows around black holes

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Credit: NRAO/AUI

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Motivations:

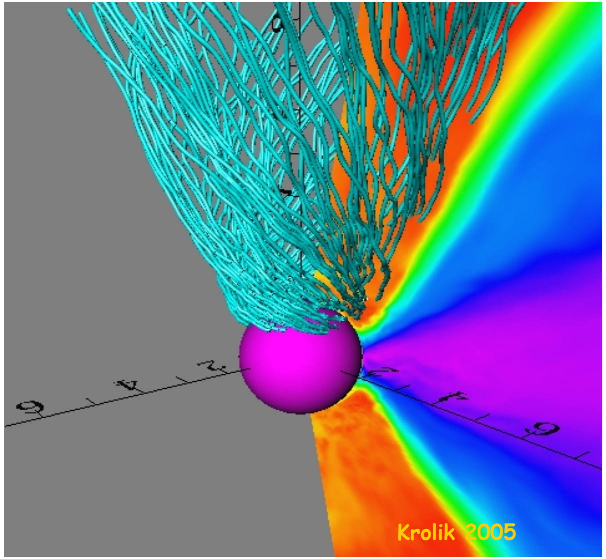
How are jets launched?

– **Disk-launching vs. BH spin?**

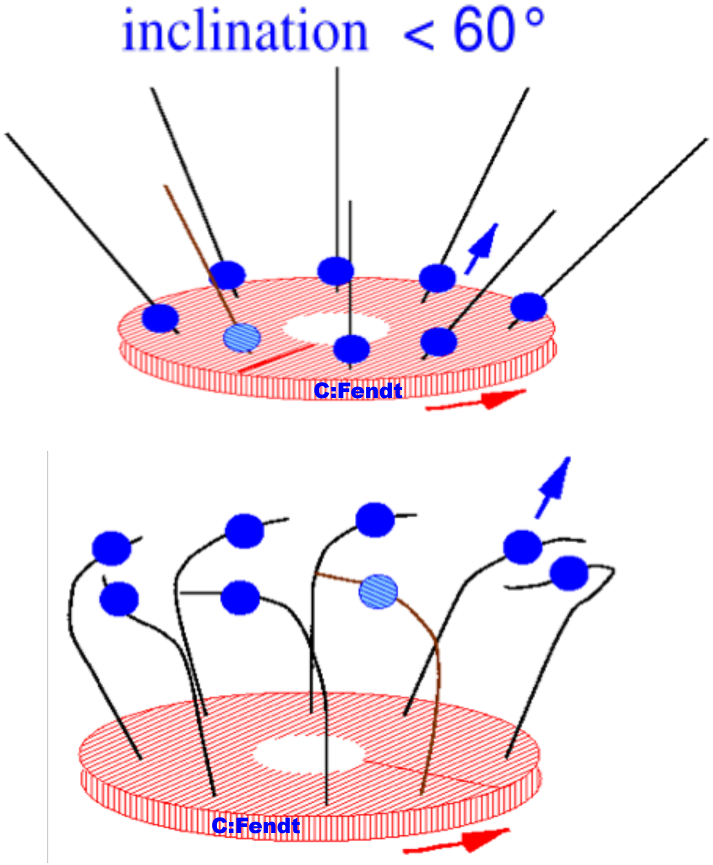
– **How is mass loaded onto jets?**

How are jets collimated?

Why do jets shine? etc.



Blandford & Znajek 1977



Blandford & Payne 1982

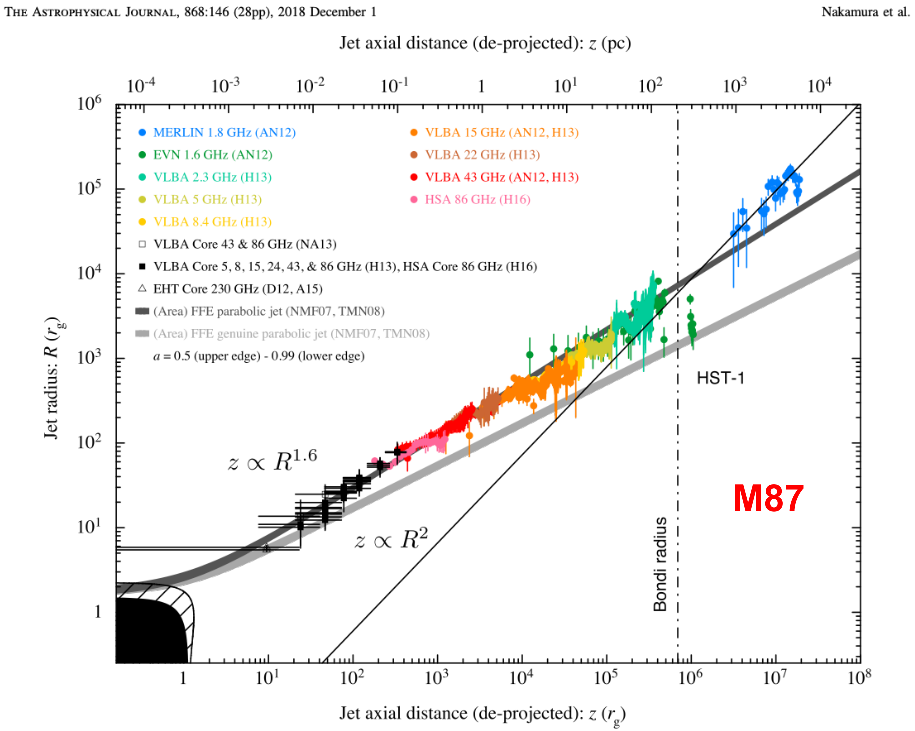
Motivations:

Torus based GRMHD simulations:

DeVilliers+2003, Gammie+2003,Noble+2006, DelZanna+2007, Tchekhovskoy+2010, Liska+2018, Nathanail+2020, and more.

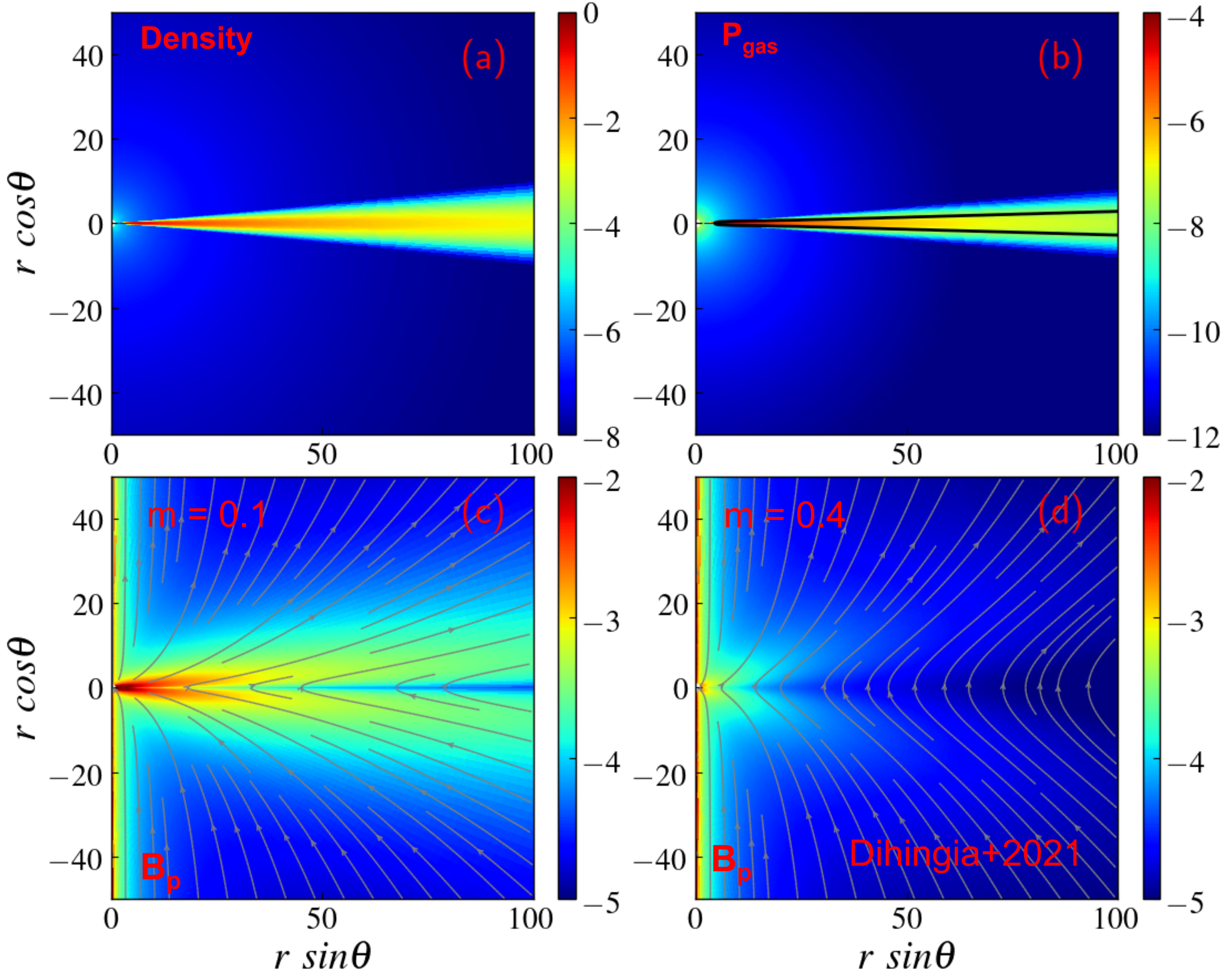
Disc based GRMHD simulations:

Koide+1999, Qian+2018, Vourellis+2019,2021, Dihingia+2021, and very few.



Jet launching radius for M87 is about 5.5 Rg (Nakamura+2018), while for Cyg A it is about 227 Rg (Boccardi+2016)

Initial setup:



Initial setup for thin disc around Kerr BH. Using code BHAC (Porth+2017; Olivares+2019)

Our initial conditions are based on the Novikov & Thorne model (Novikov & Thorne (1973)).

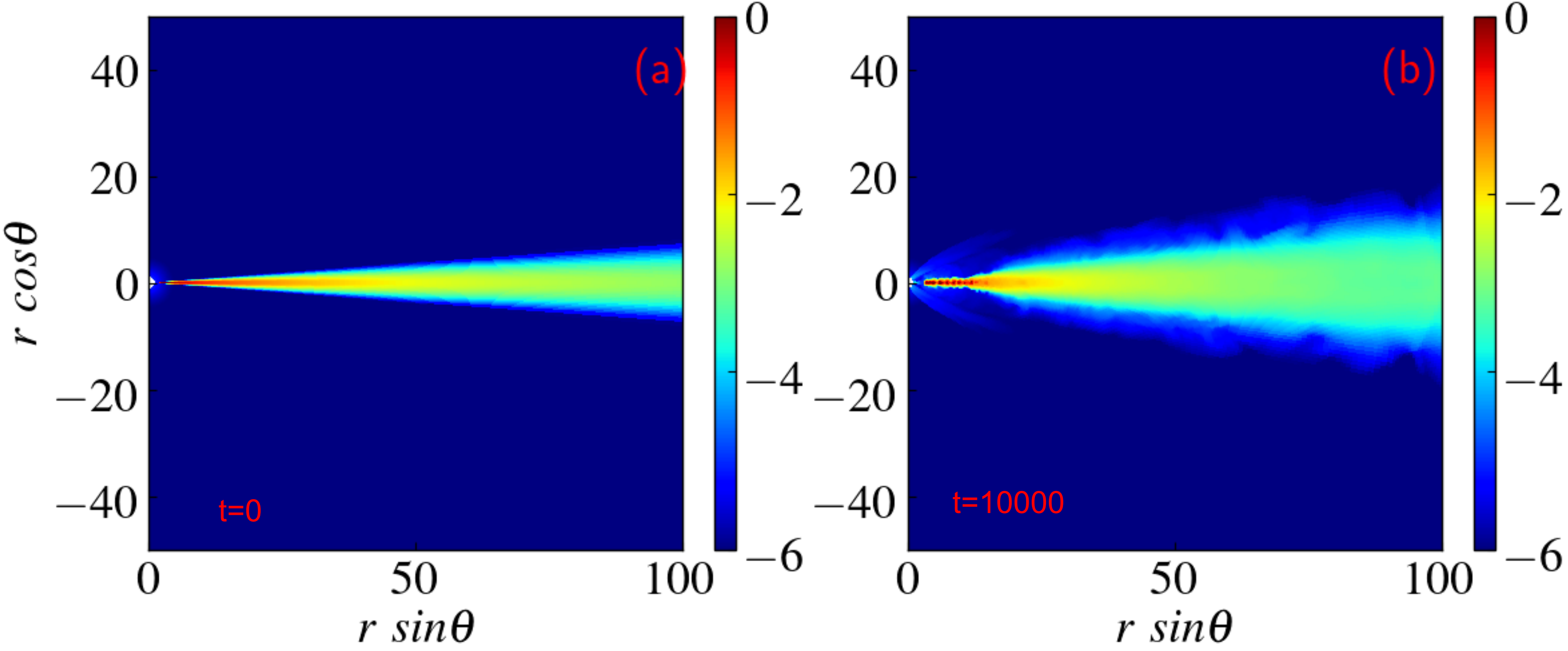
Vector potential:

$$\mathcal{A}_\phi \propto (r\sin\theta)^{3/4}\frac{m^{5/4}}{(m^2+\tan^{-2}(\theta-\pi/2))^{5/8}},$$

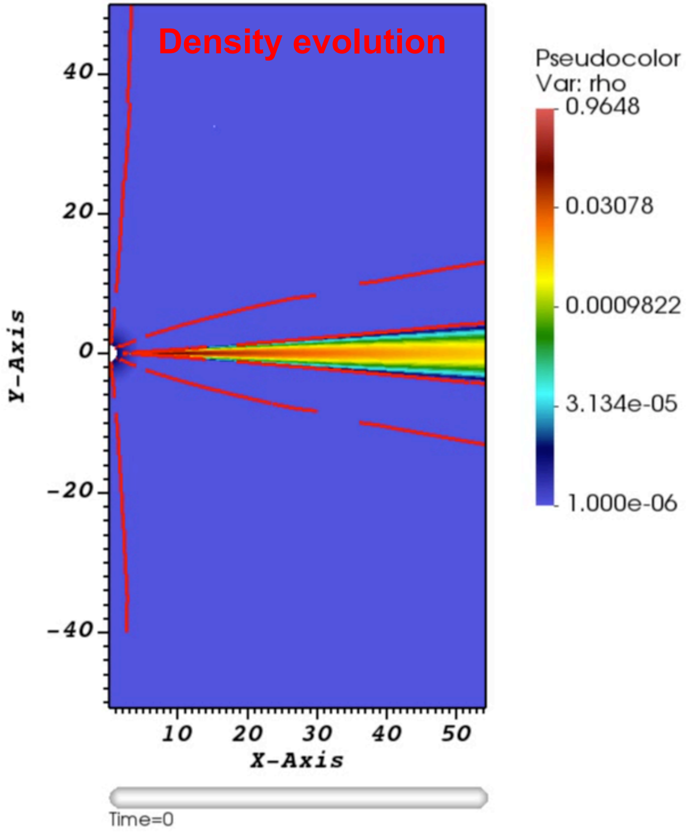
Zanni+2007

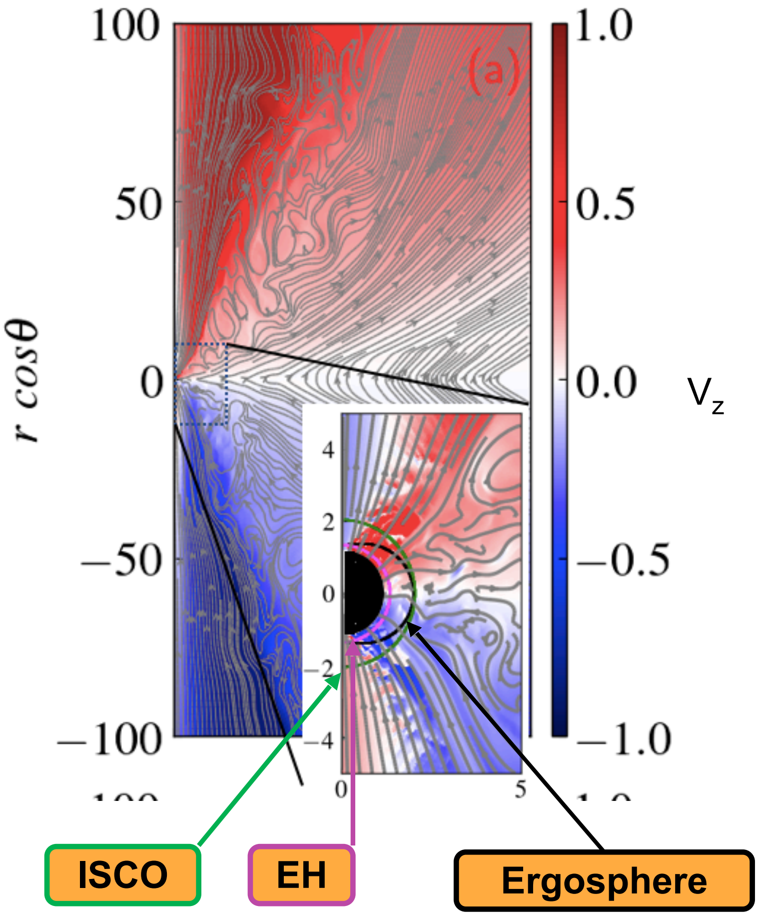
$H/r_{max} \sim 0.07$

Hydrostatic evolution

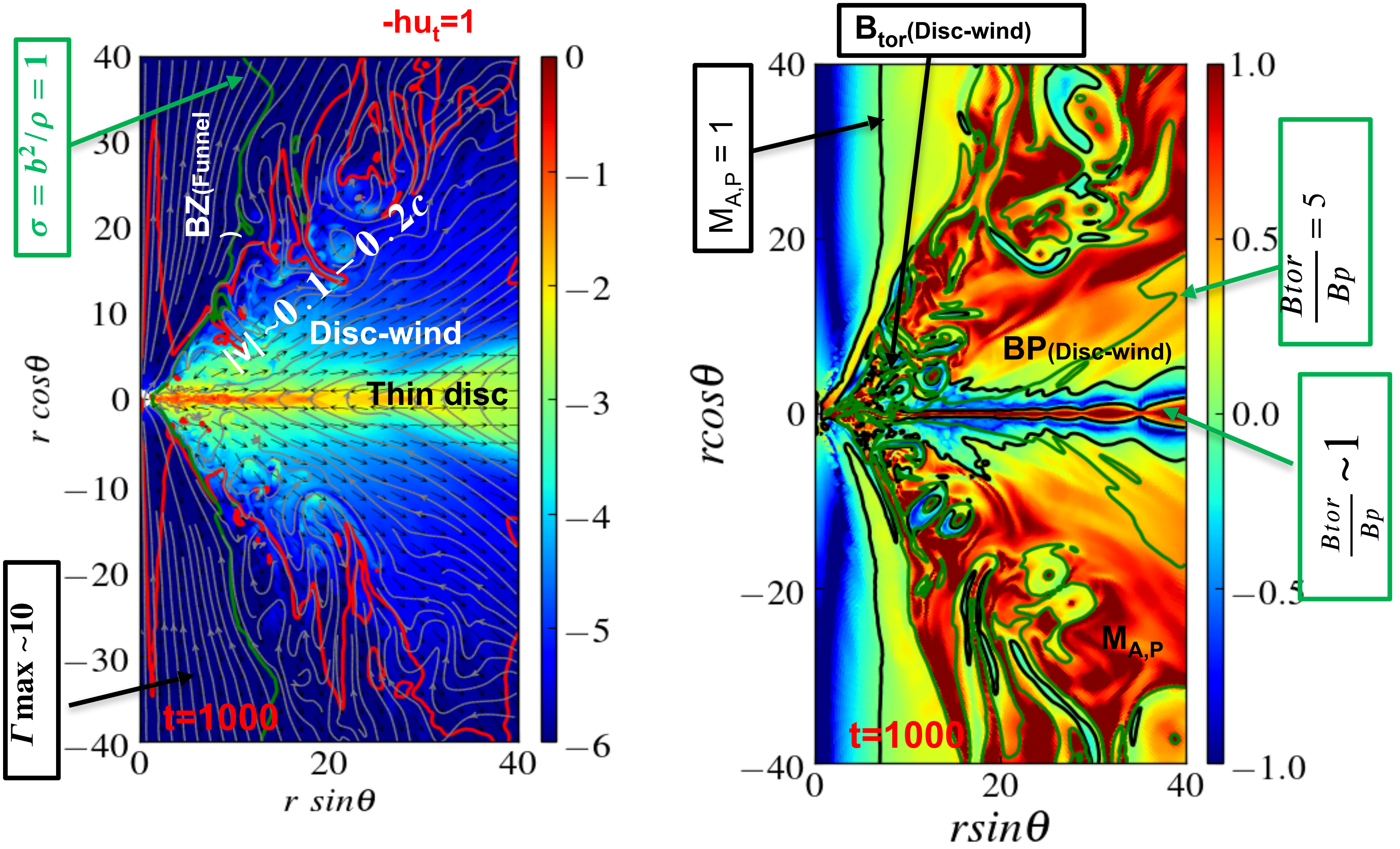


Temporal Evolution



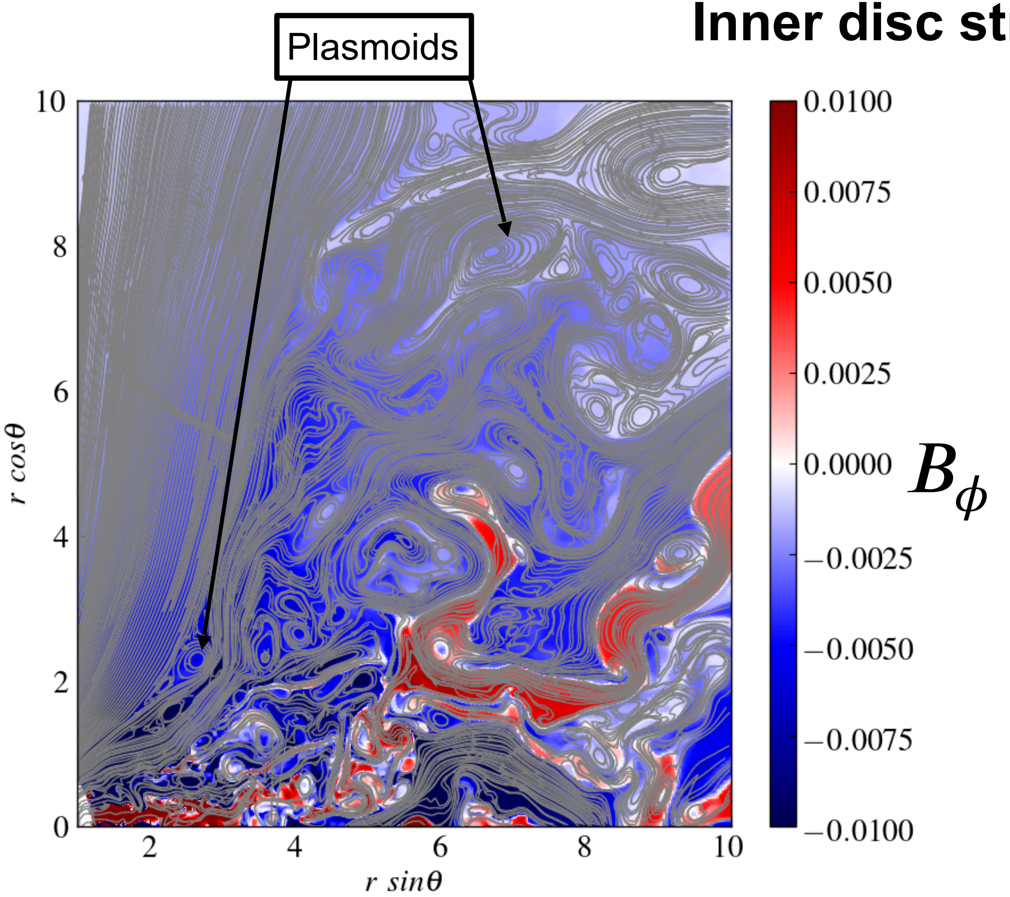


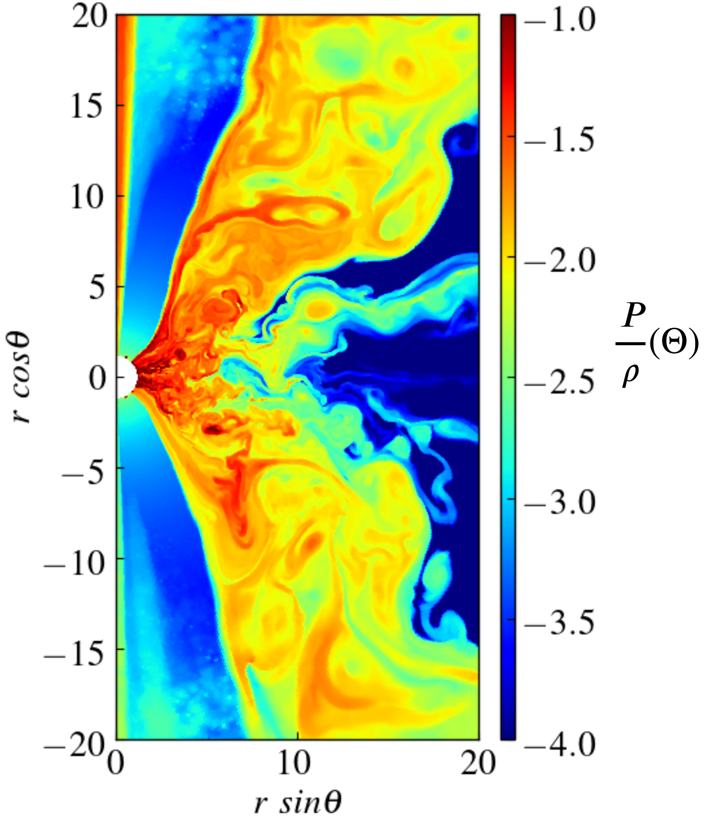
Wind and jet:



-hu_t=1
σ = b²/ρ = 1
BZ(Funnel)
|v| ~0.1−0.2c
Disc-wind
Thin disc
Γmax ~10
t=1000
r cosθ
r sinθ
B_tor(Disc-wind)
M_A,P = 1
BP(Disc-wind)
Btor/Bp = 5
Btor/Bp ~1
M_A,P
t=1000
rcosθ
rsinθ

Inner disc structure:

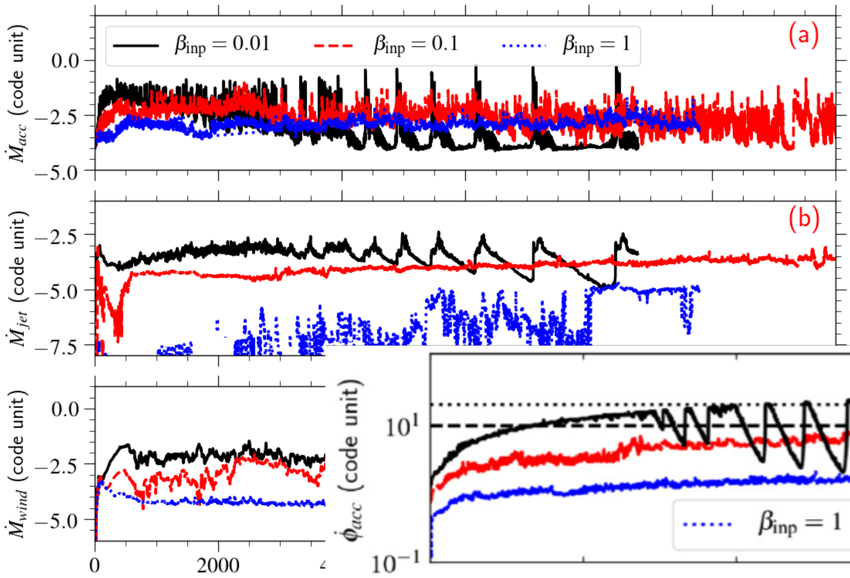


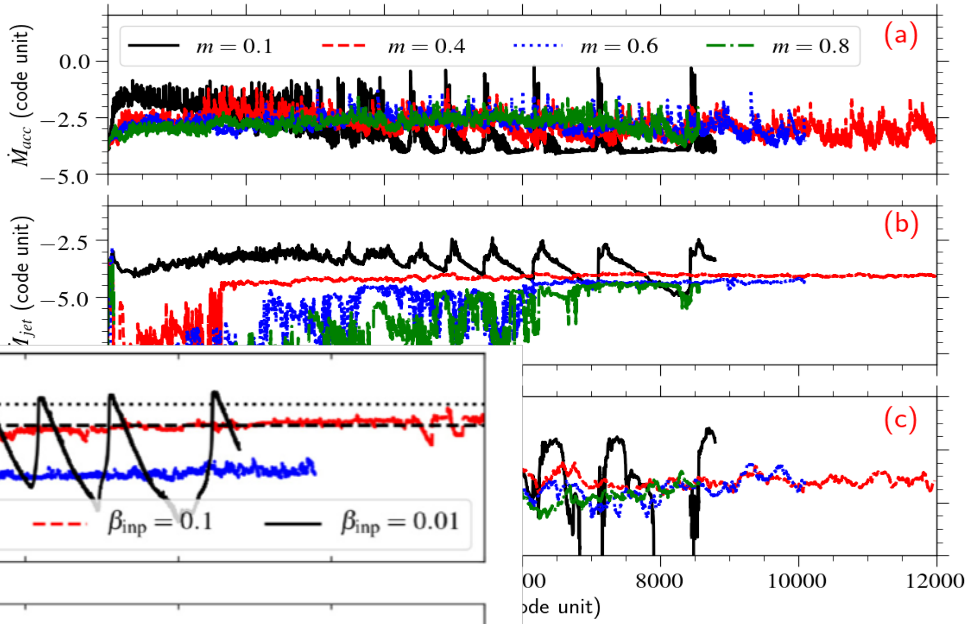


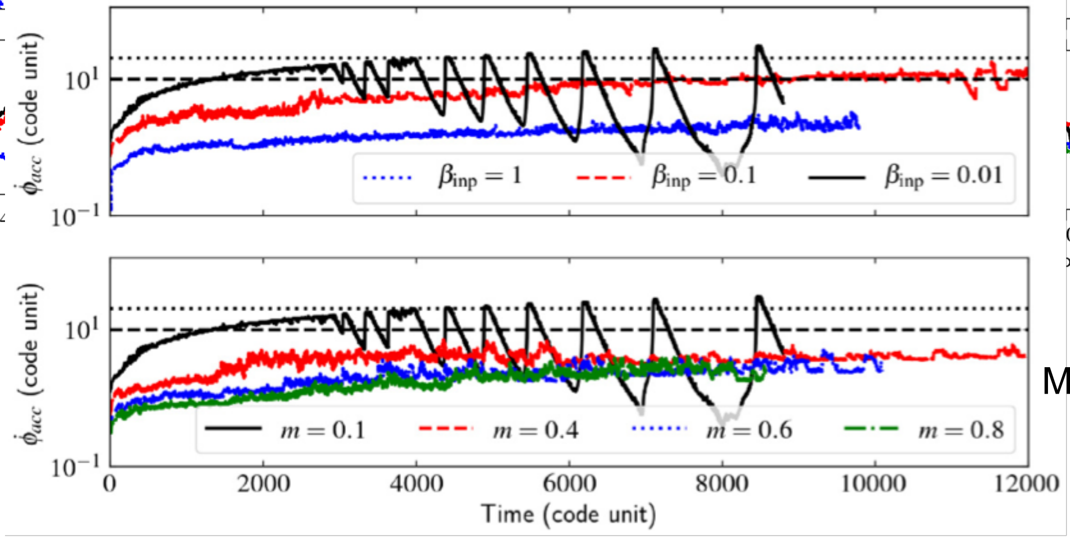
Source of turbulence: **MRI** $(\beta > 1)$ and **MRTI** (may be) $\left(\beta < 1\right)$.

(e.g., Igumenshchev+2008, Avara+2016, Marshall+2018, etc.)

Mass flux rates:





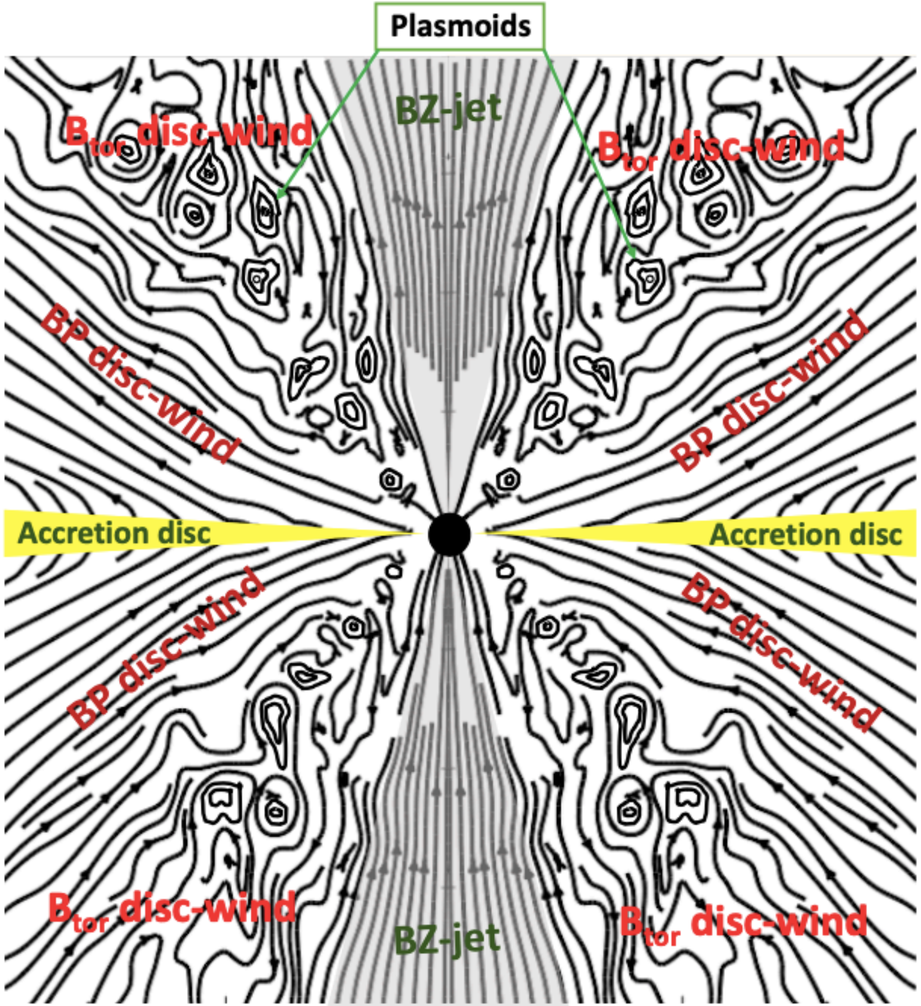


$\dot{\phi}_{acc} \sim 15$

MAD, Tchekhovskoy+2011

Magnetic flux eruption events in MAD triggers such NIR flares (3D GRMHD: Dexter+2020, Porth+2020,Chatterjee+2020).

Toy model:

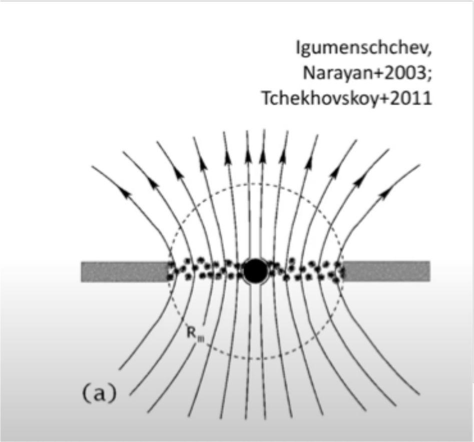


Highlights:

- **BZ jet (polar field lines).**
- **B_{tor} wind (turbulent): helps in collimation of jet, act as disc-wind corona.**
- **BP wind (magneto-centrifugal): prone with strong and inclined magnetic fields.**
- **Plasmoids: ideal sites for particle acceleration.**

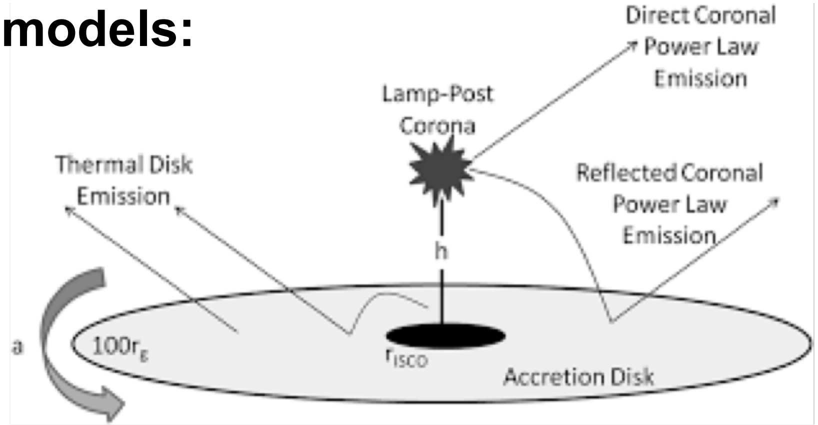
Dihingia+2021

Truncated disc/corona models:

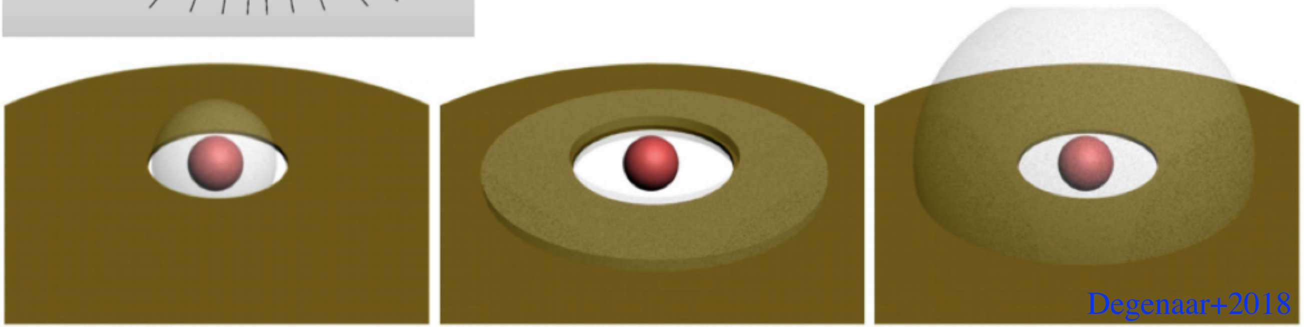


Lamp post model

EHT cartoon diagram



Hoormann+2018



Degenaar+2018

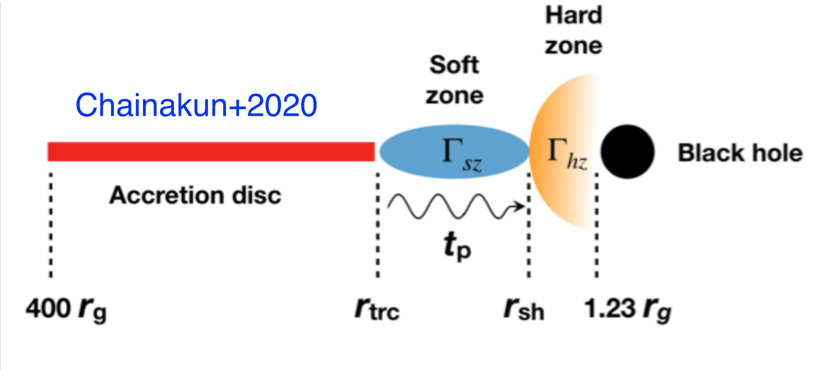
Extended corona model

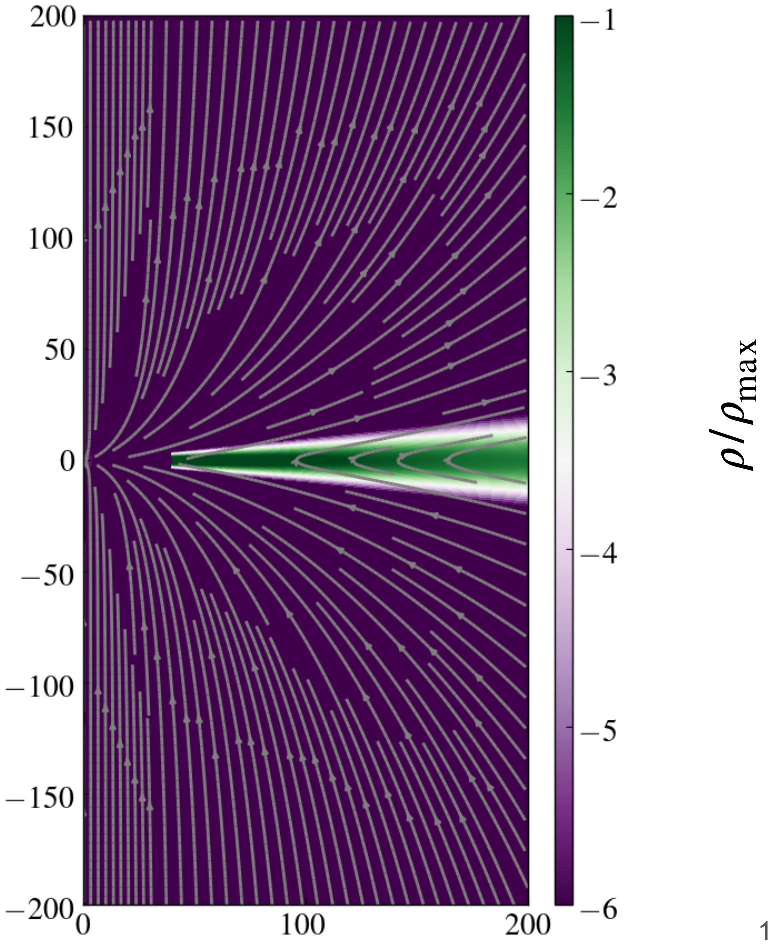
Fig. 2 Cartoon images of the possible location and geometry of the hot electron corona in LMXBs. The NS is presented as the red central sphere and the disk as the surrounding brown area. *Left*: A spherical corona that fills the inner region of the accretion flow. *Middle*: A corona that sandwiches the accretion disk. *Right*: An intermediate geometry in which a spherical hot flow is overlapping with the cold disk

The setup

Model	Effective resolution	r_{tr}	β_{max}
2DTr-40A	2048 × 1024	40	100
2DTr-40B	2048 × 1024	40	500
2DTr-40C	2048 × 1024	40	1000
2DTr-50	2048 × 1024	50	100
2DTr-60	2048 × 1024	60	100

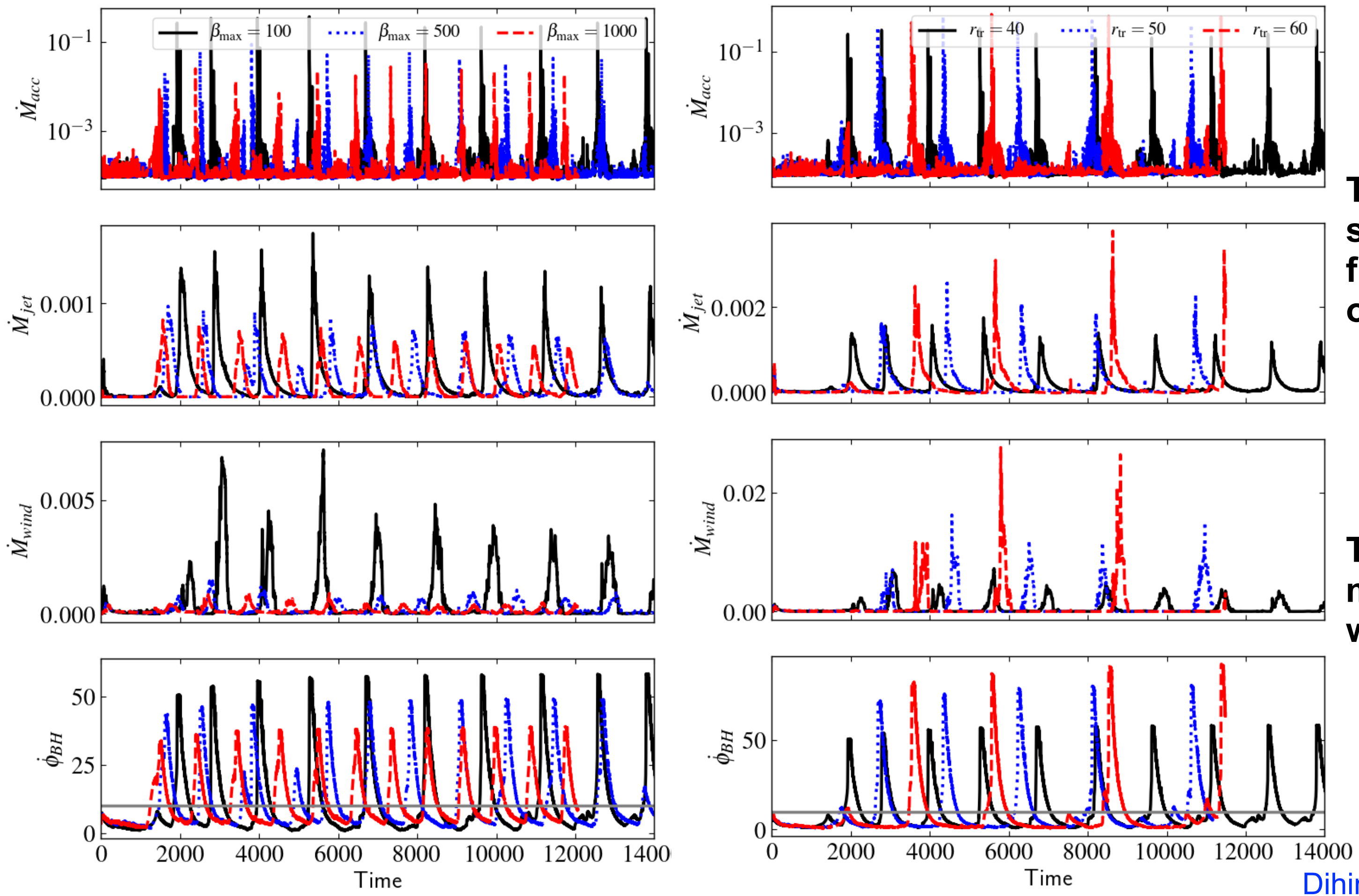
Table 1. The explicit values of effective resolution, and truncation radius r_{tr} for different simulation models.





Dihingia+2021, In prep.

Possible controls



Truncation radius and strength of the magnetic field can control these oscillations.

There may be many more ways to control it, waiting to be explored!

Dihingia+2021, In prep.

Summary:

- We find unified simulation models with BZ jet and BP disc-wind (disc-jet) for the first time.
- $B_{\rm tor}$ disc-wind act as a hot disc-wind corona around black holes. It can have tremendous applications in astrophysics.
- MAD along with plasmoids is viable to explain the observed NIR flares in Sgr A*.
- We setup a truncated accretion disc setup following different corona models.
- The oscillations of the inner part of the MAD can be controlled with magnetic field strength and truncation radius of a truncated accretion disc.
- Rigorous simulations with GRRT are required for applications in AGNs as well as BH-XRBs.

Thanks for your attention