Jet energy dissipation mechanisms

Anna Chashkina
(Tel Aviv University)

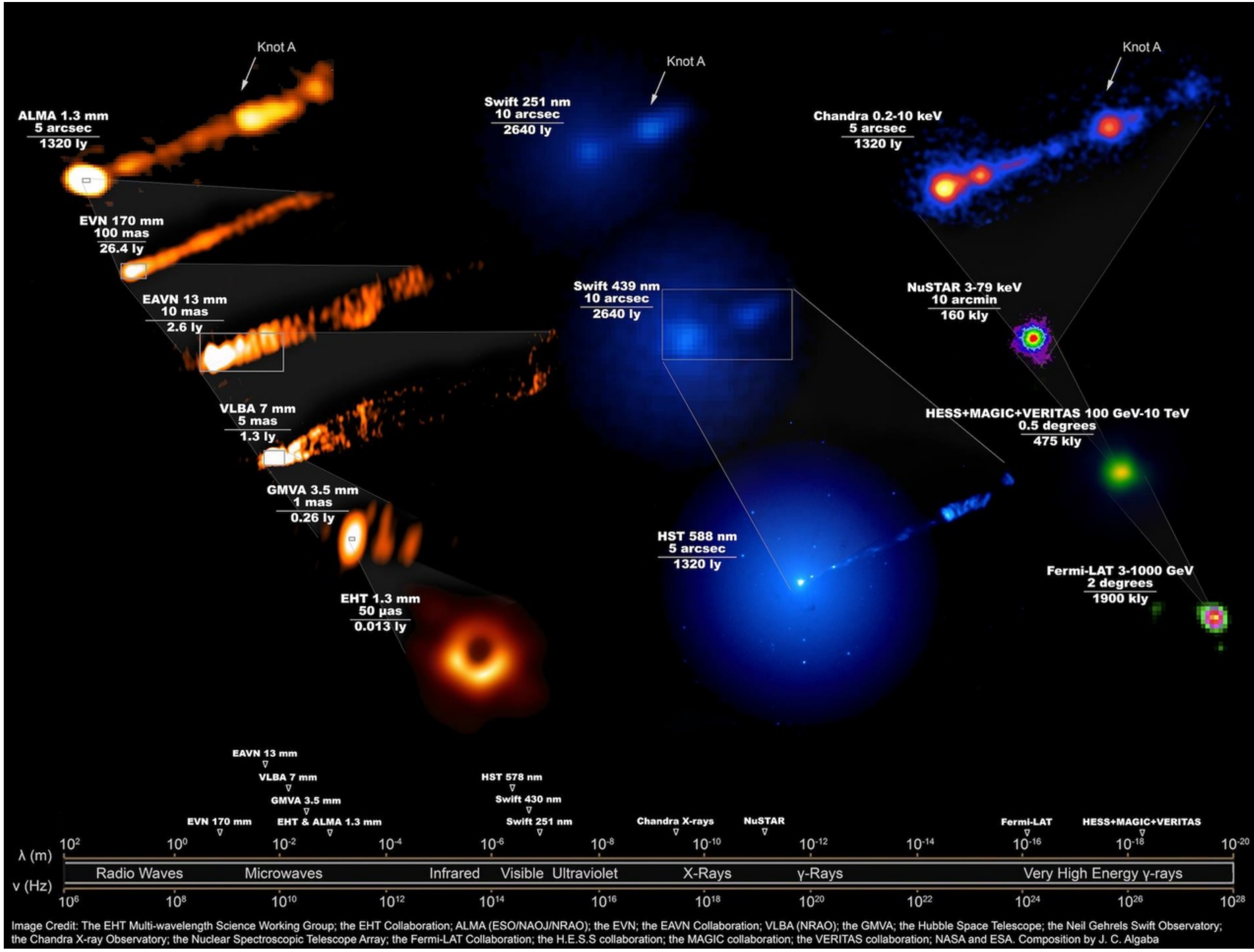


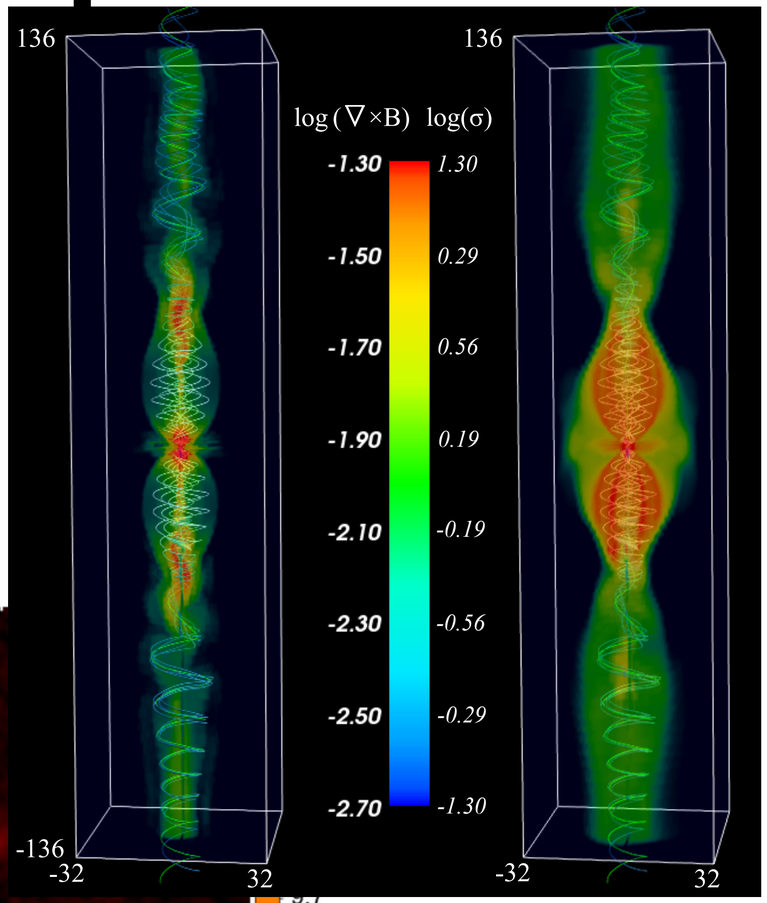
Image Credit: The EHT Multi-wavelength Science Working Group; the EHT Collaboration; ALMA (ESO/NAOJ/NRAO); the EVN; the EAVN Collaboration; VLBA (NRAO); the GMVA; the Hubble Space Telescope; the Neil Gehrels Swift Observatory; the Chandra X-ray Observatory; the Nuclear Spectroscopic Telescope Array; the Fermi-LAT Collaboration; the H.E.S.S collaboration; the MAGIC collaboration; the VERITAS collaboration; NASA and ESA. Composition by J. C. Algaba

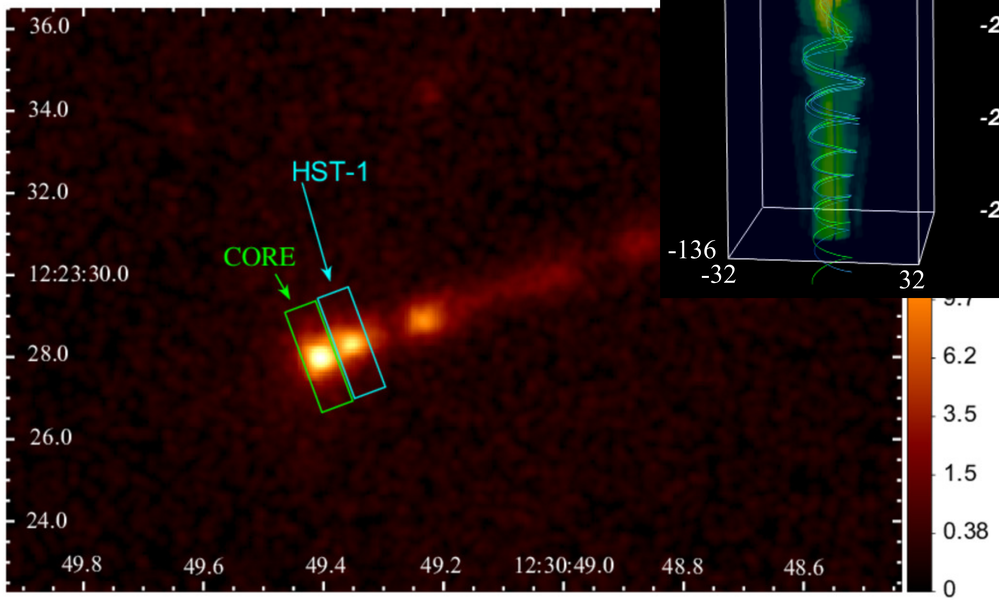
Jet emission and dissipation

- Jet emit from many different regions
- Observed radiation has different spectral and temporal properties
- More than one dissipation mechanism is required

(Bromberg, Tchekhovskoy, 16)

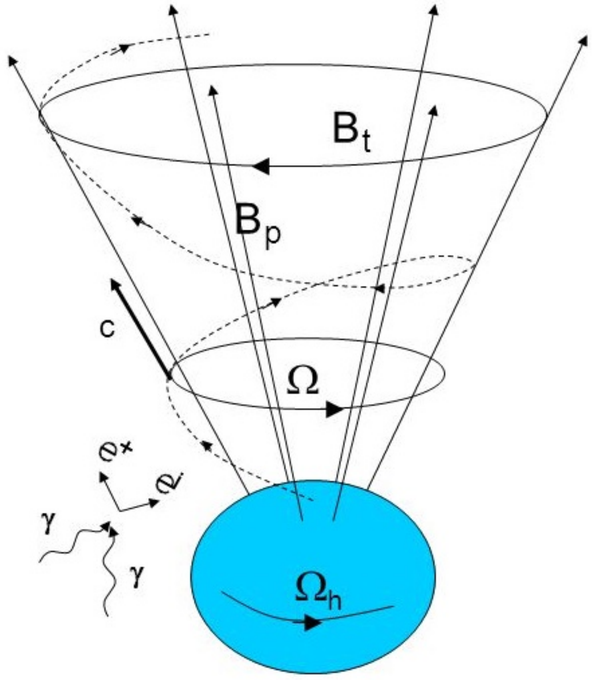
- Kink instability may be responsible for the emission seen as HST-1 knot in M87

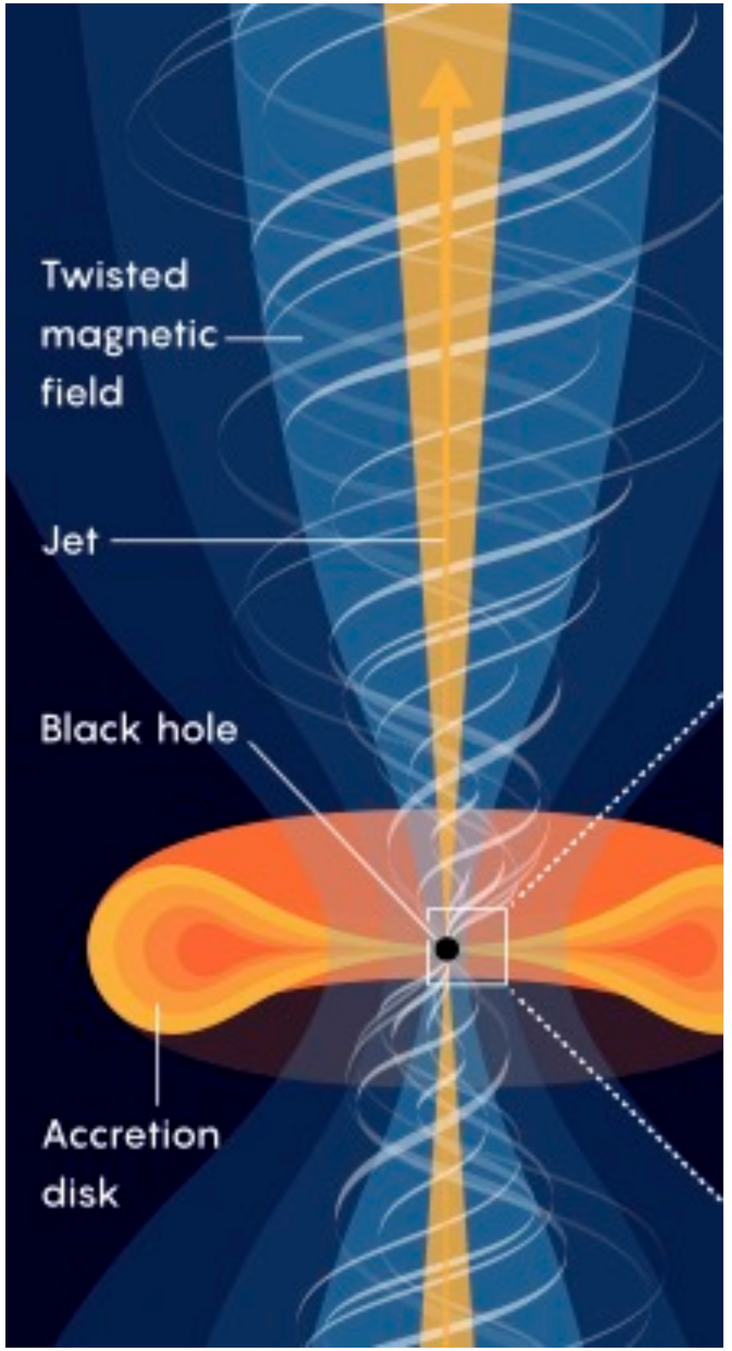




Jet launching

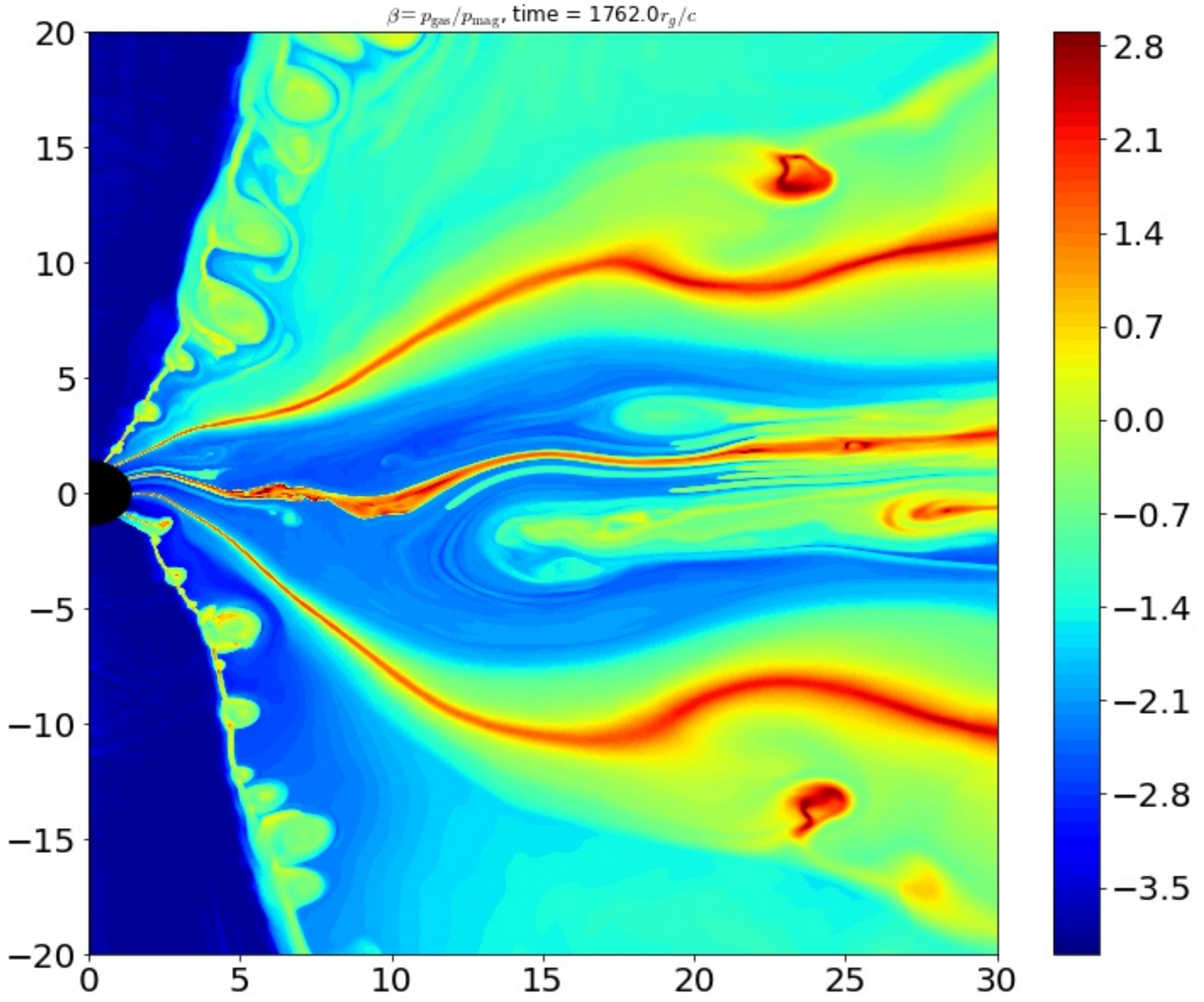
Jets are launched by spinning BHs in the presence of large-scale magnetic field due to frame dragging





GRMHD simulations of BH activation by small magnetic loops: formation of striped jet and active coronae

Anna Chashkina, Omer Bromberg and Amir Levinson
(Tel Aviv University)

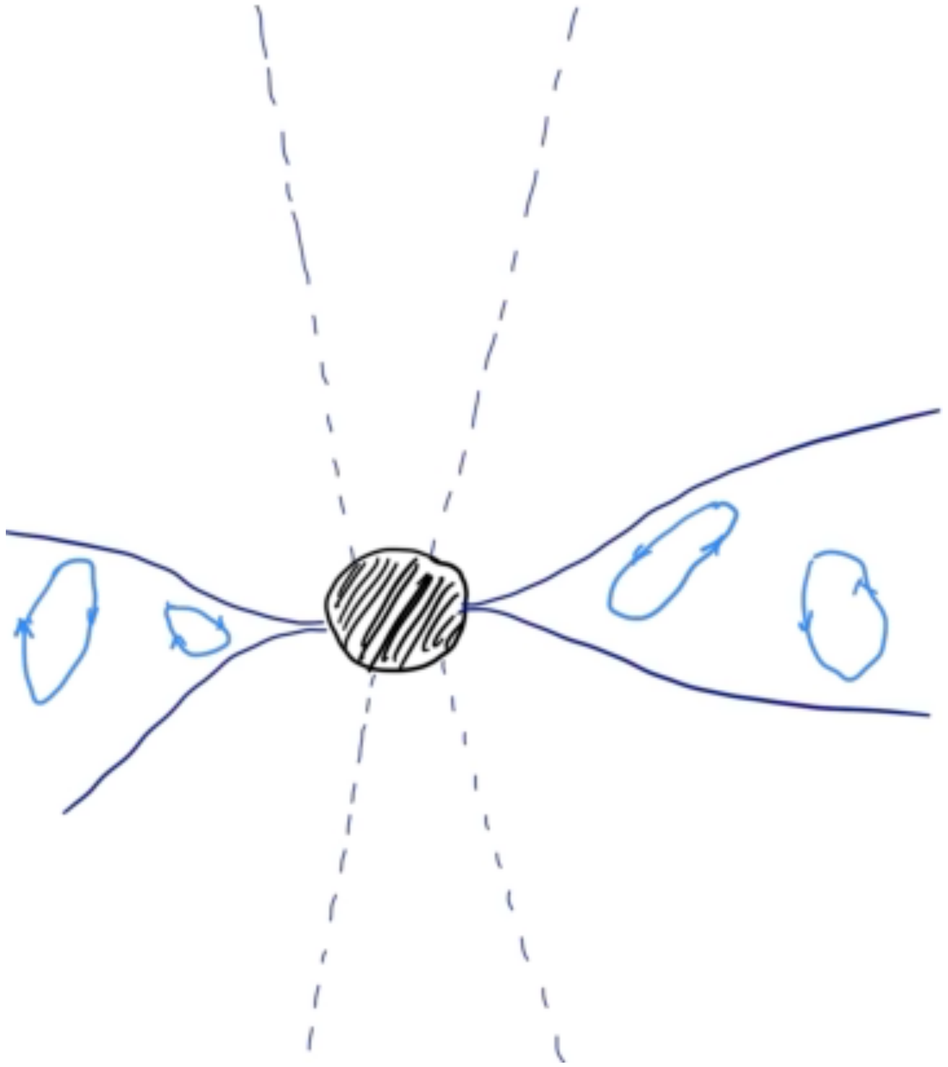


arxiv: 2106.15738

Striped jets

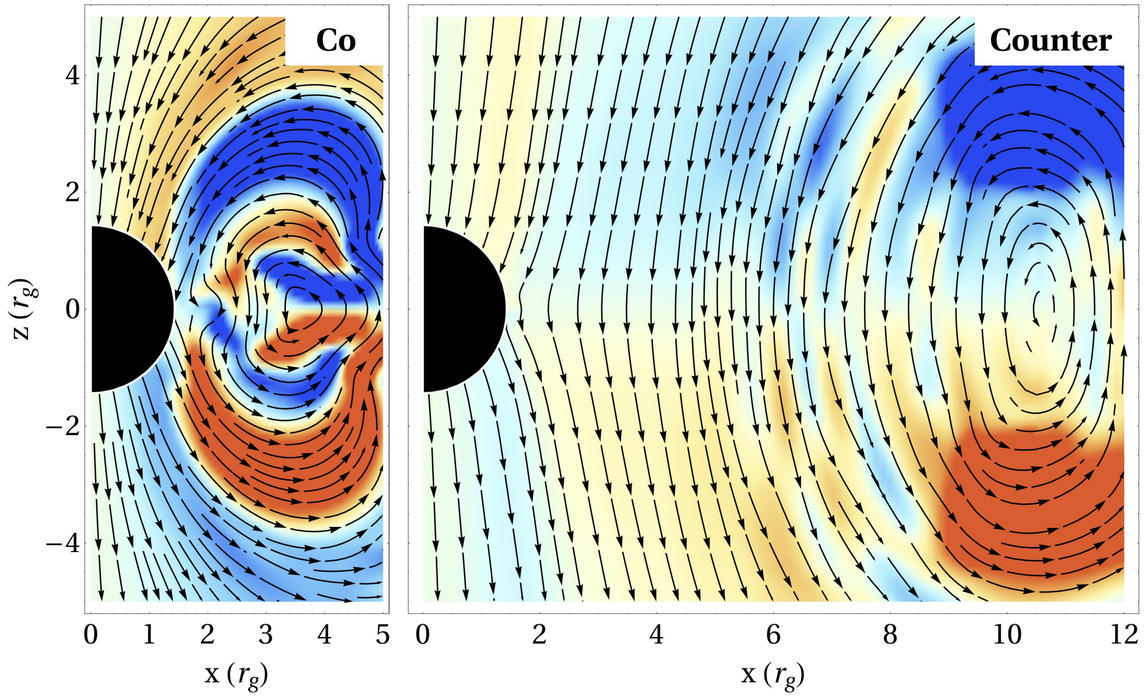
Switching of polarity in the disc leads to switching of polarity in the jet -> Striped jet launches (Parfrey+ 15, Mahlmann+ 20)

Blobs of different polarity reconnect in the jet -> energy dissipation

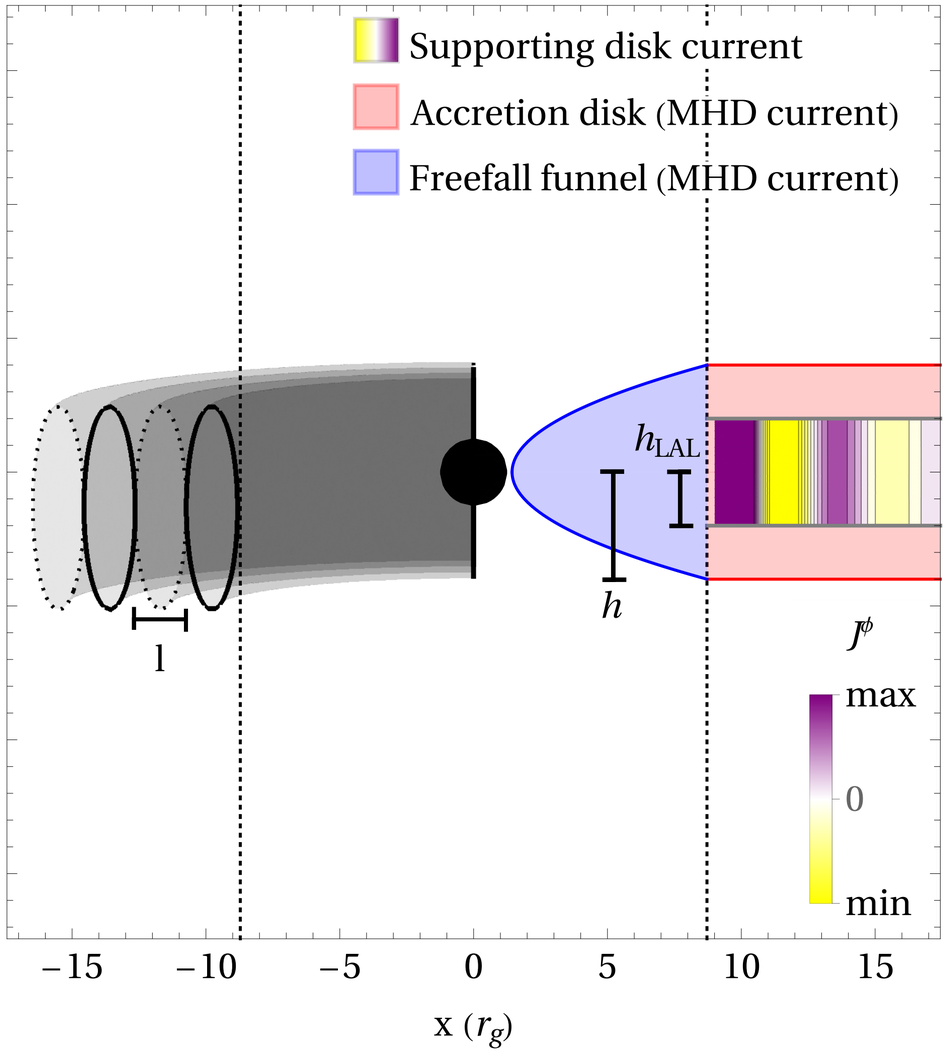


BH activation by small scale field

- GR-FFE simulations (Parfrey+ 15, Mahlmann+ 20)
- Currents set as boundary conditions
- No disc physics. Can the loop survive? What is the efficiency?



Visualization of the plasma regimes



(Mahlmann+ 20)

BH activation by small scale field

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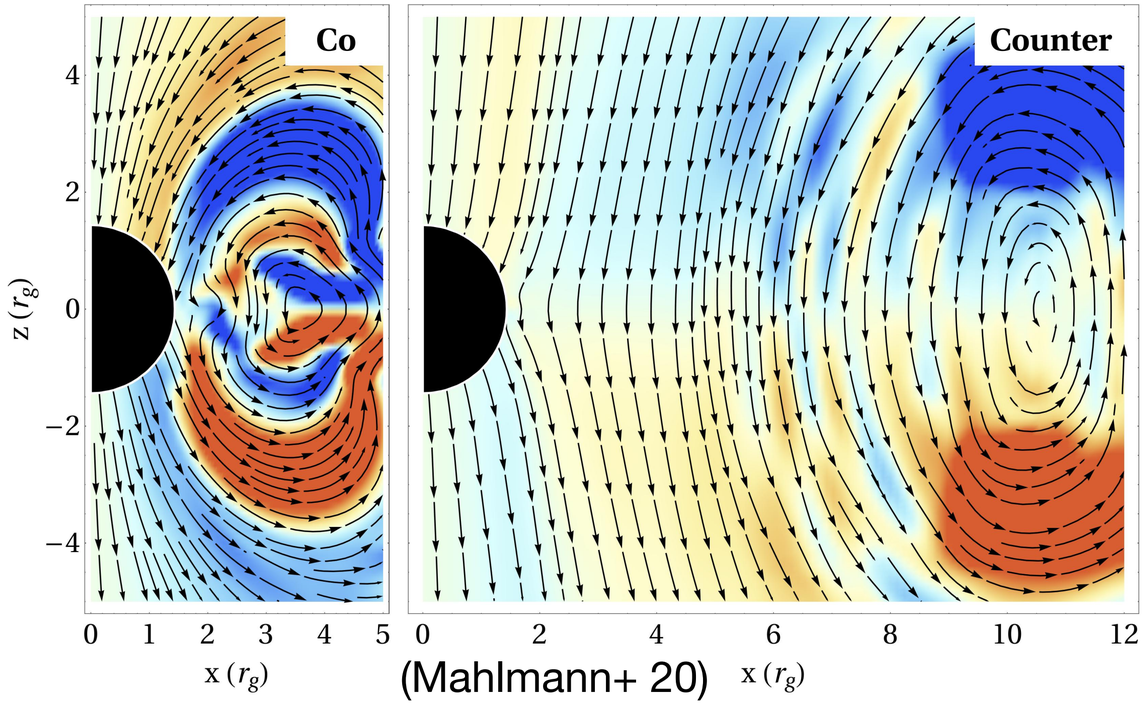
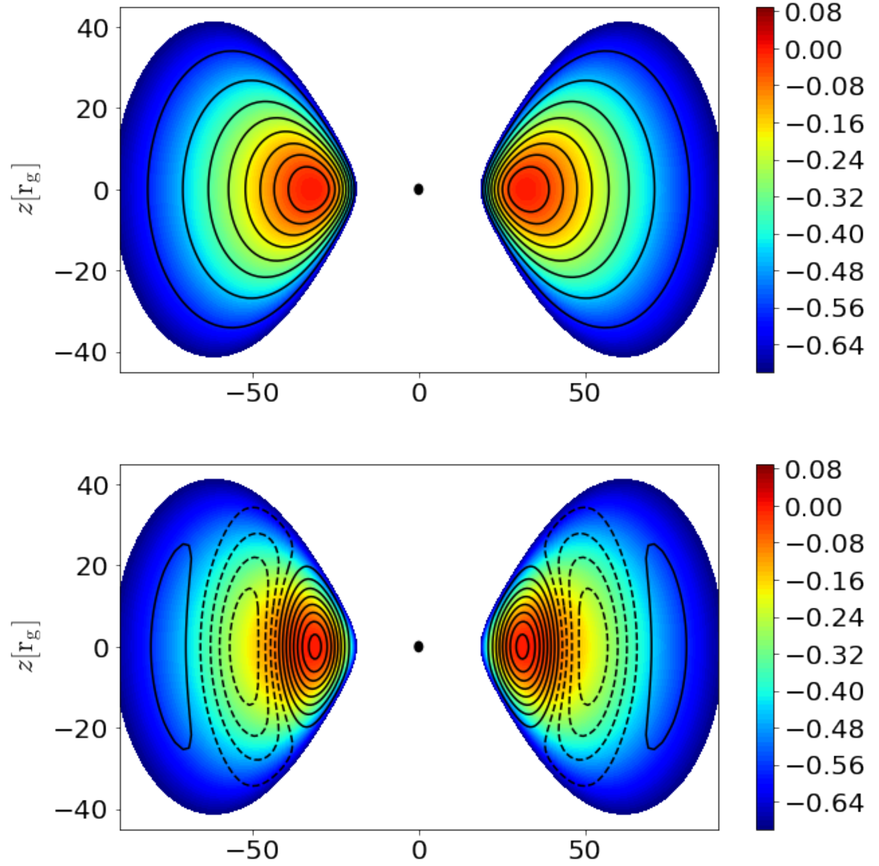


(Mahlmann+ 20)

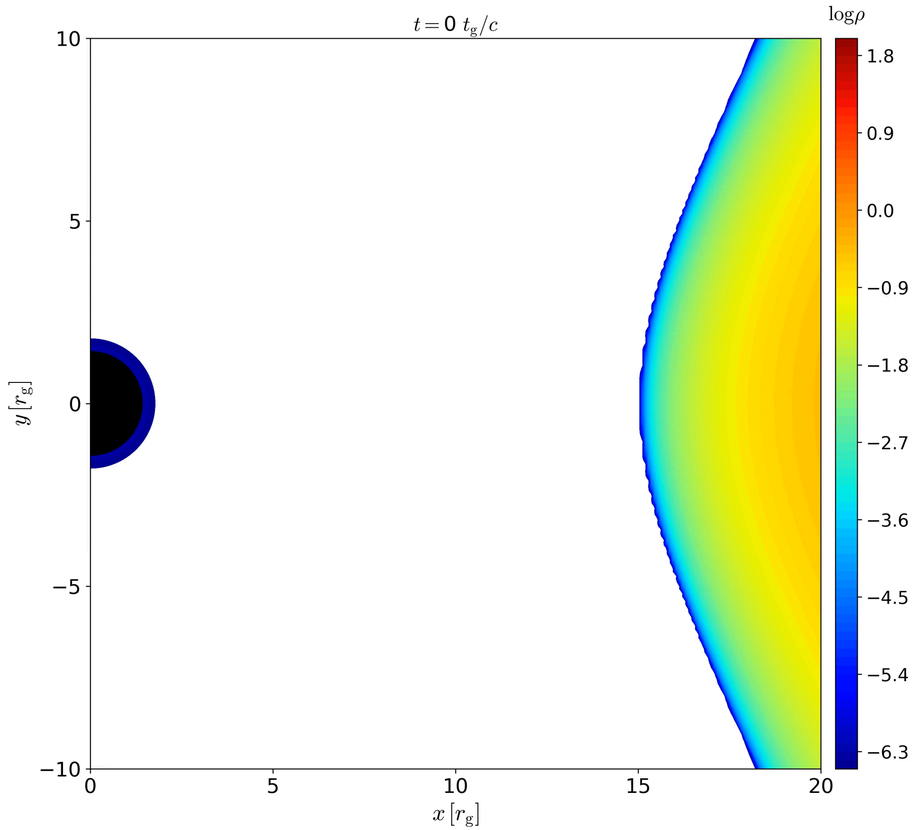
- GR MHD simulations (Chashkina+ 21, Nathanail+ 20, Beckwith+ 08,09)

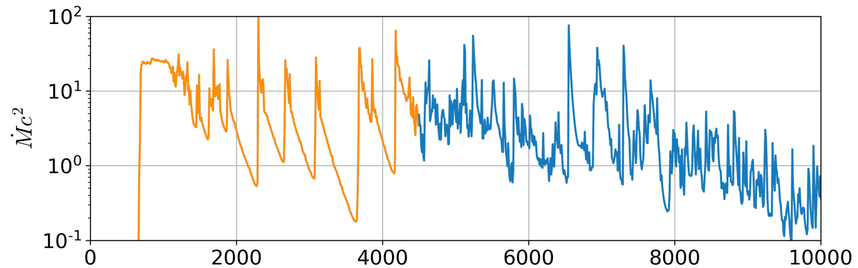


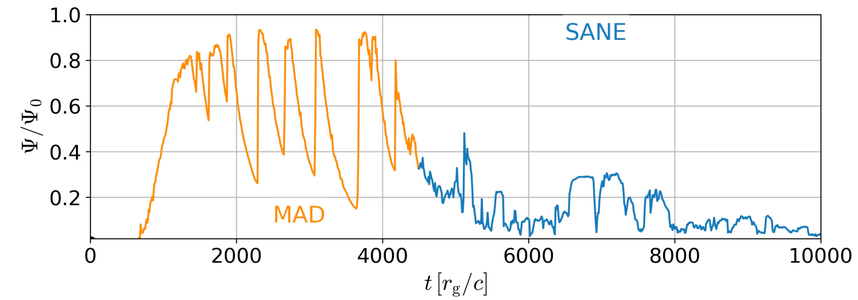
(Chashkina+ 21)

BH Activation modes: 1 loop

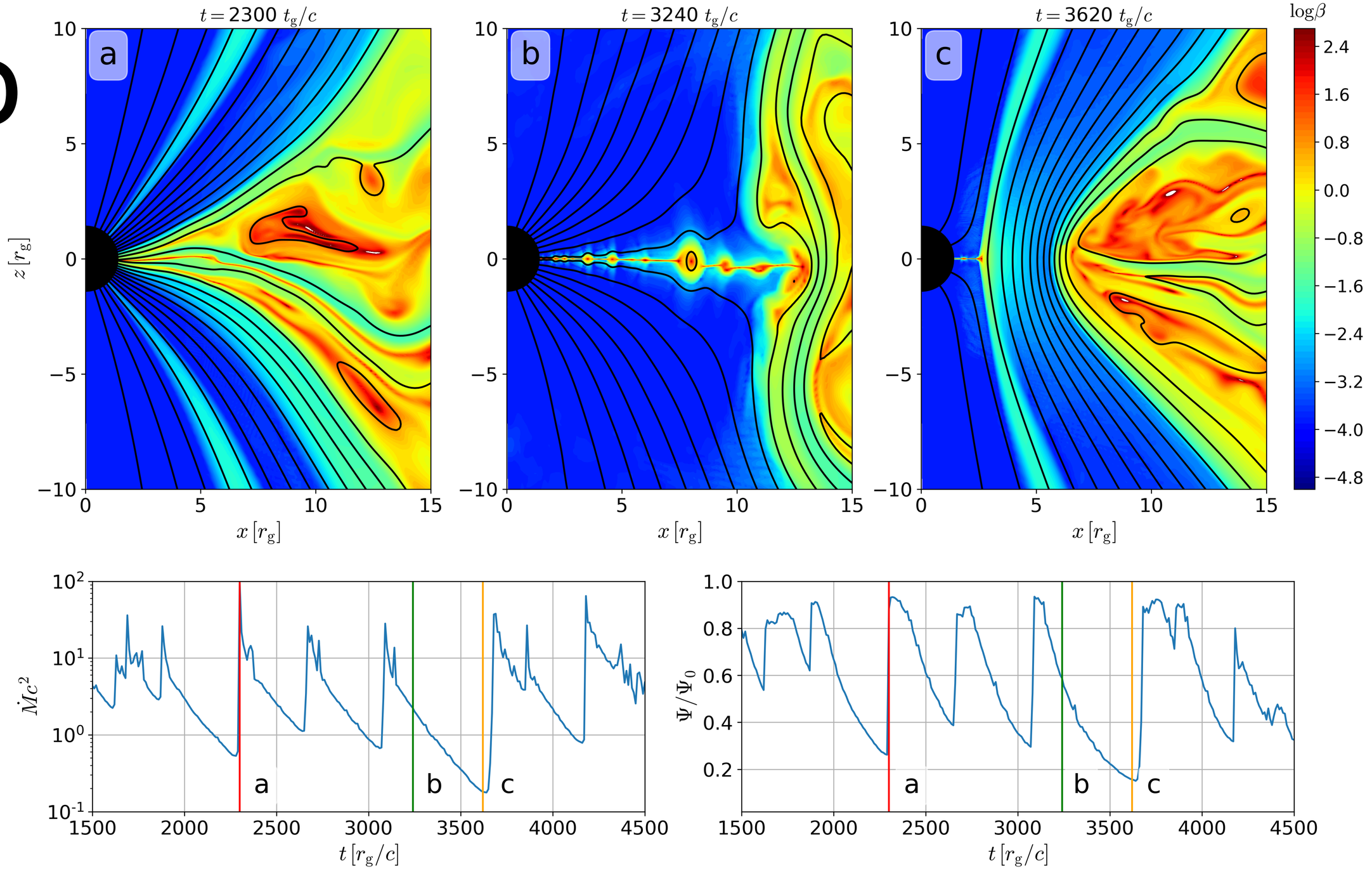
- 2 modes: MAD and SANE.
- MAD (Magnetically Arrested Disc):
  - large scale fields
  - $\dot{M}$ and Ψ are correlated
  - Switch between high and low modes
  - Intermittent jet launching
- SANE (Stable And Normal Evolution):
  - small scale fields
  - $\dot{M}$ and Ψ are uncorrelated, Ψ is low
  - No jet launching



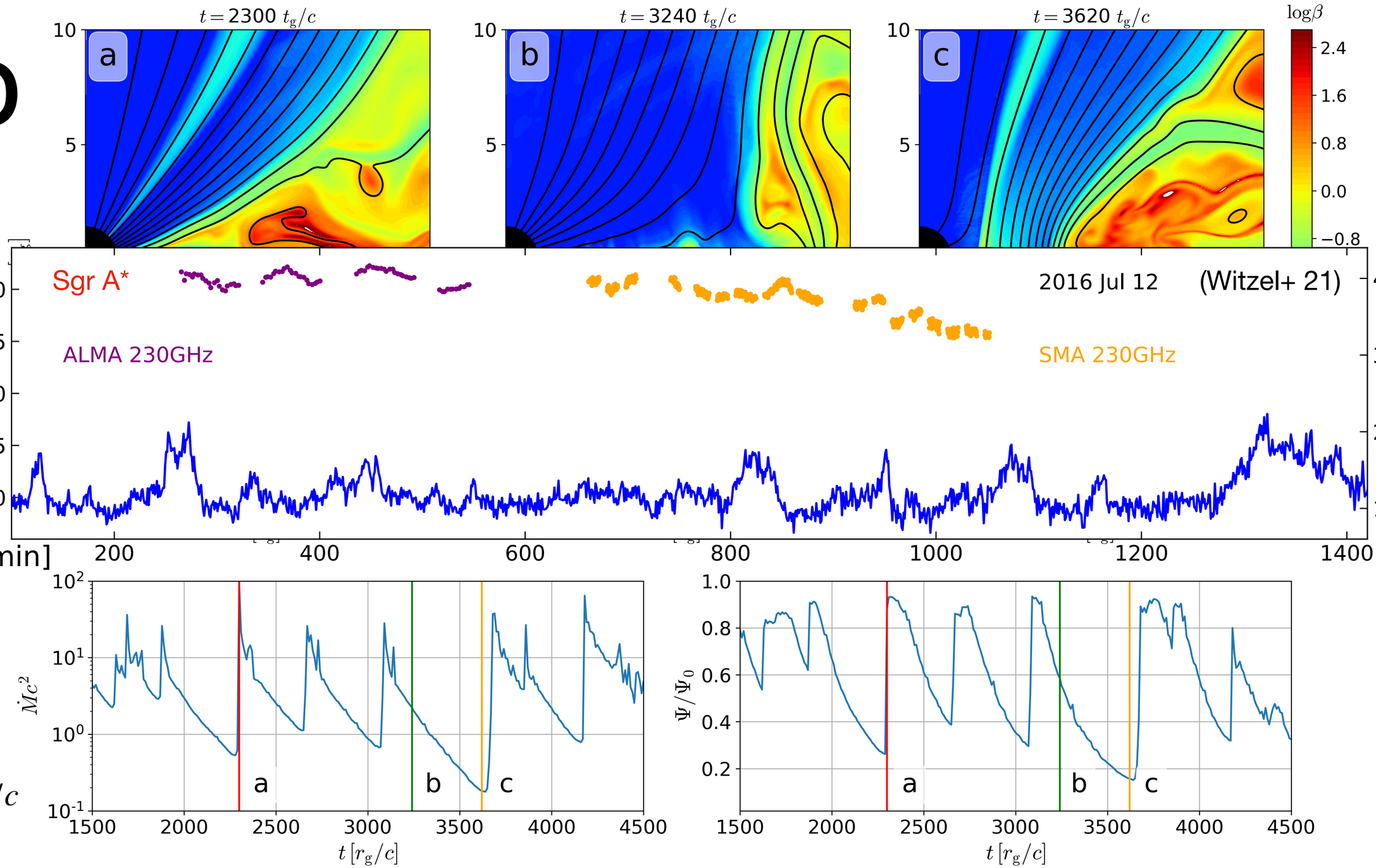




MAD (2D)

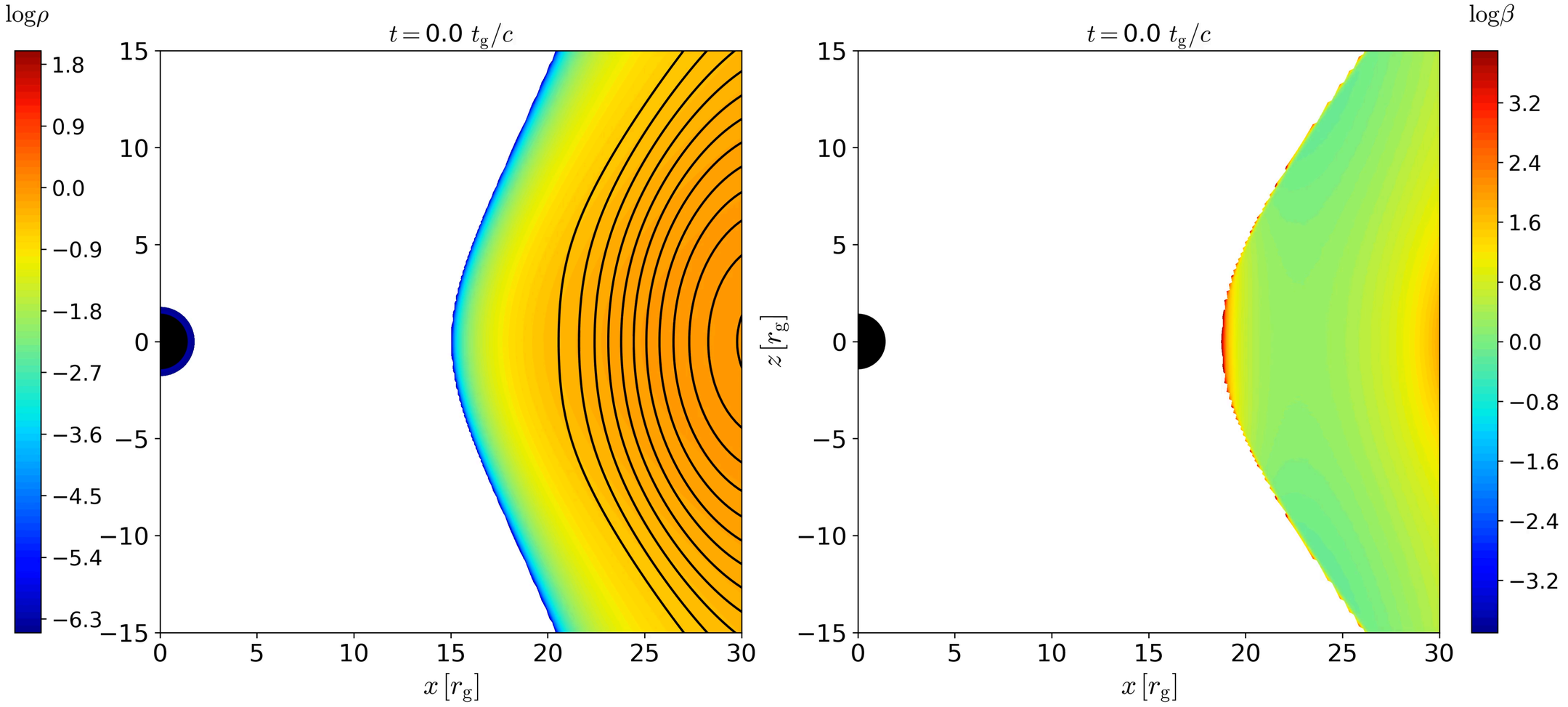

$t = 2300\ t_g/c$
$t = 3240\ t_g/c$
$t = 3620\ t_g/c$
a
b
c
$\log\beta$
2.4
1.6
0.8
0.0
−0.8
−1.6
−2.4
−3.2
−4.0
−4.8
$z\,[r_g]$
$x\,[r_g]$
$\dot{M}c^2$
Ψ/Ψ_0
$t\,[r_g/c]$

MAD (2D)



$t_{\rm decay} \sim 140\, r_g/c$

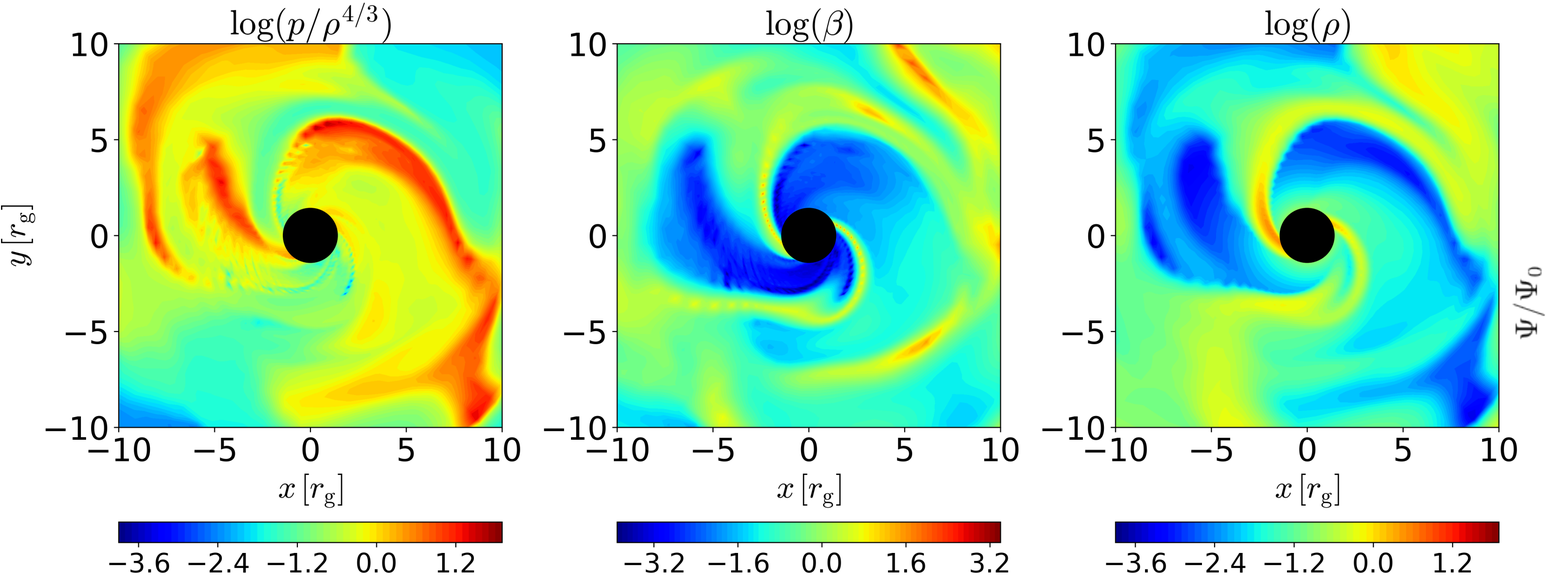
Activation modes:Multiple loops in 2D

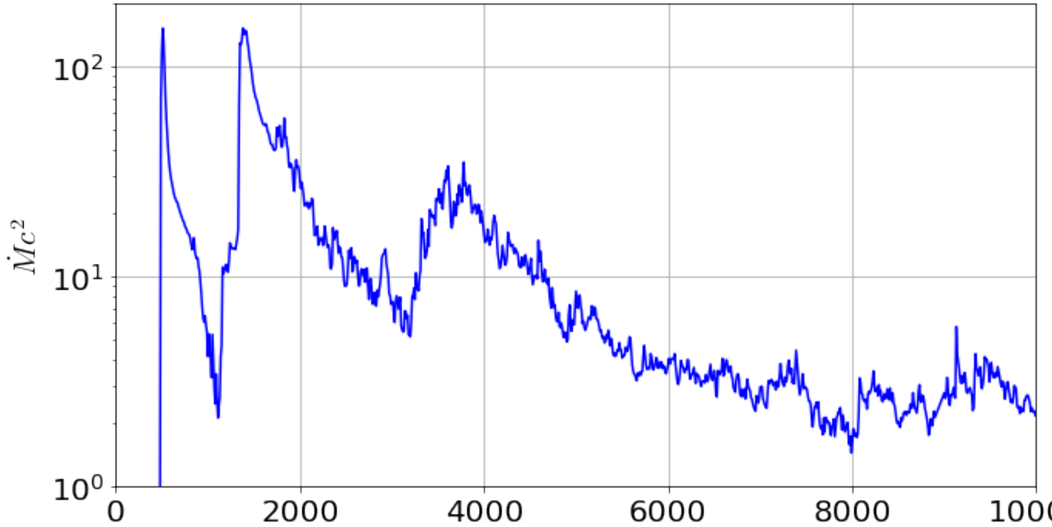


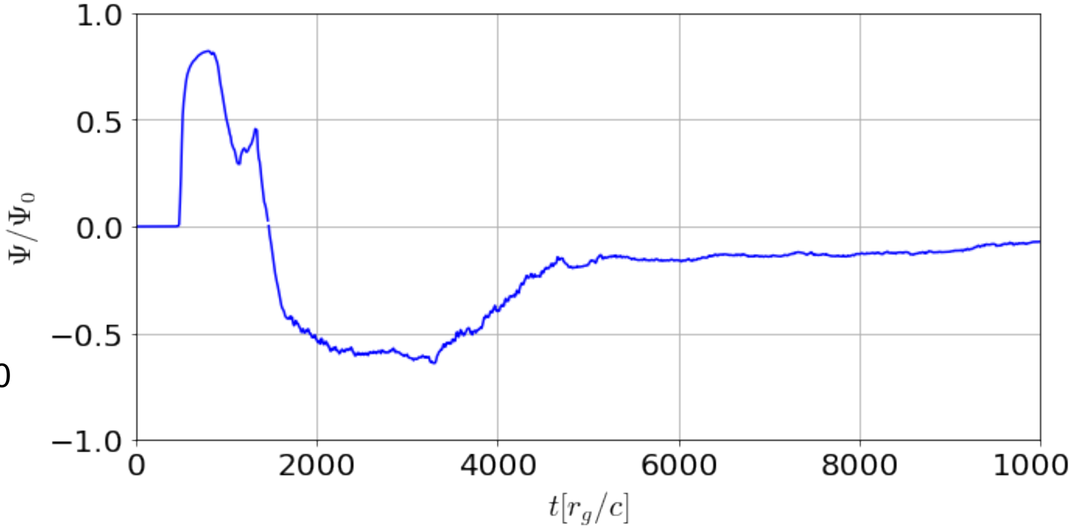
- The second loop compresses the first one -> effective current sheets production
- Striped jet launches

Multiple loops in 3D

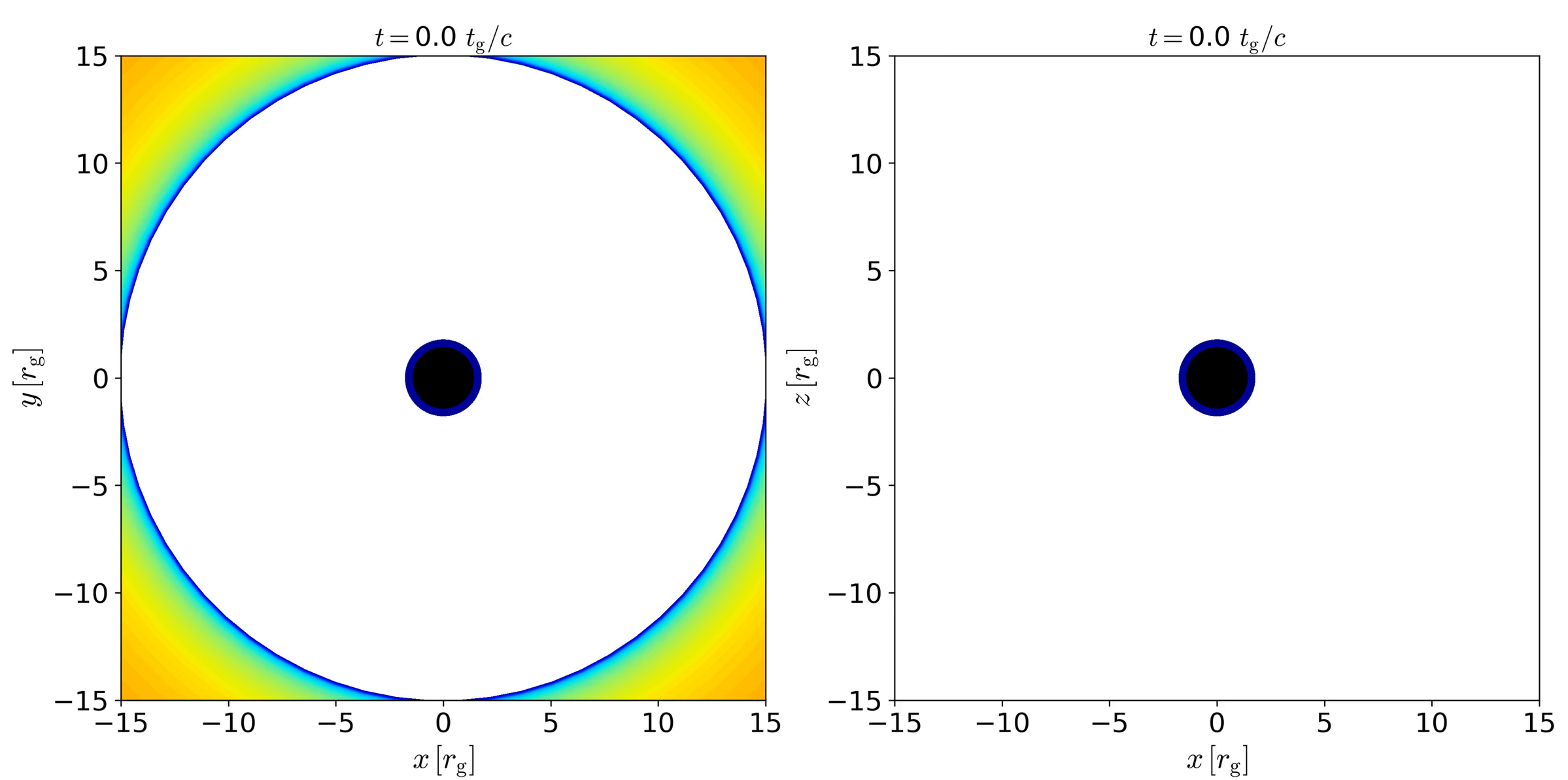
- the variability of $\dot{M}$ and Ψ is much smoother than in 2D
- Magnetic field can not prevent accretion at all azimuths



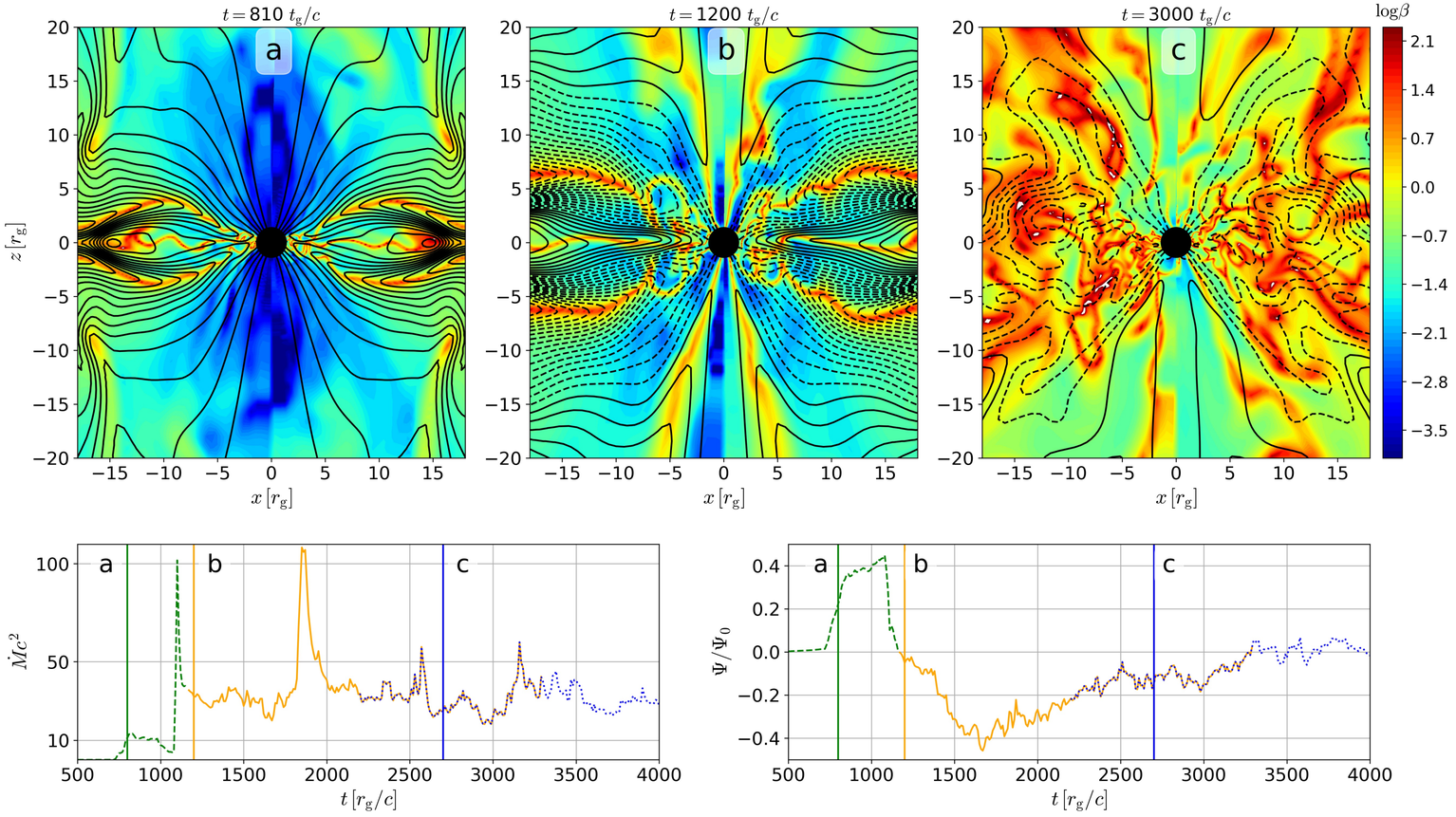


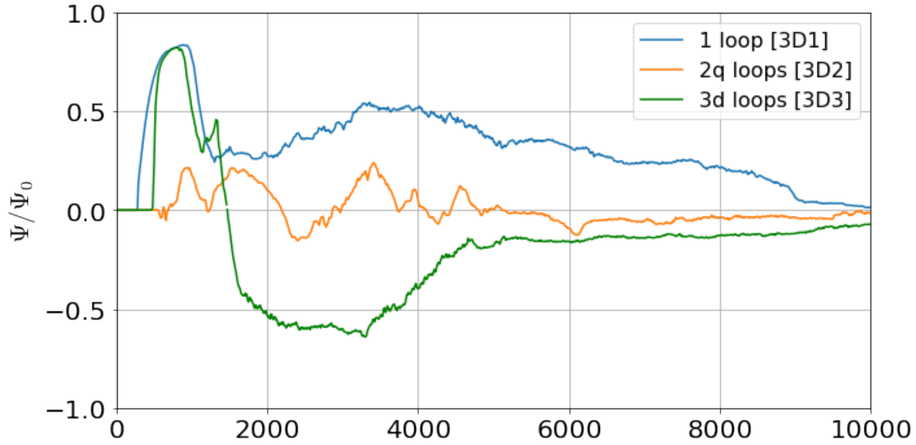


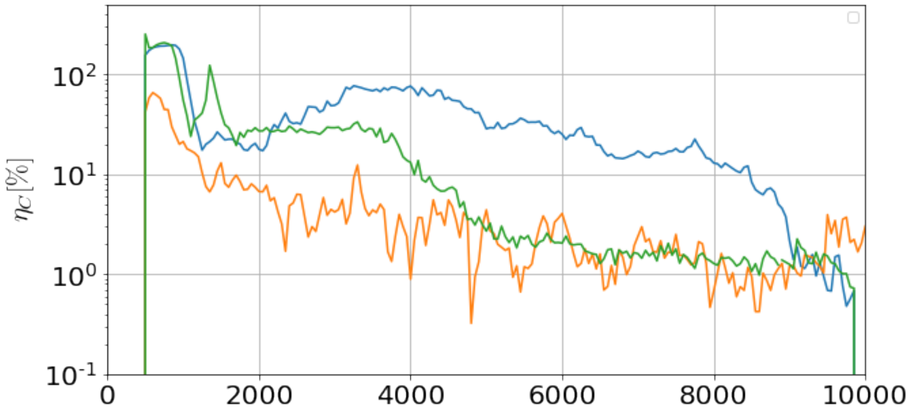
Multiple loops in 3D

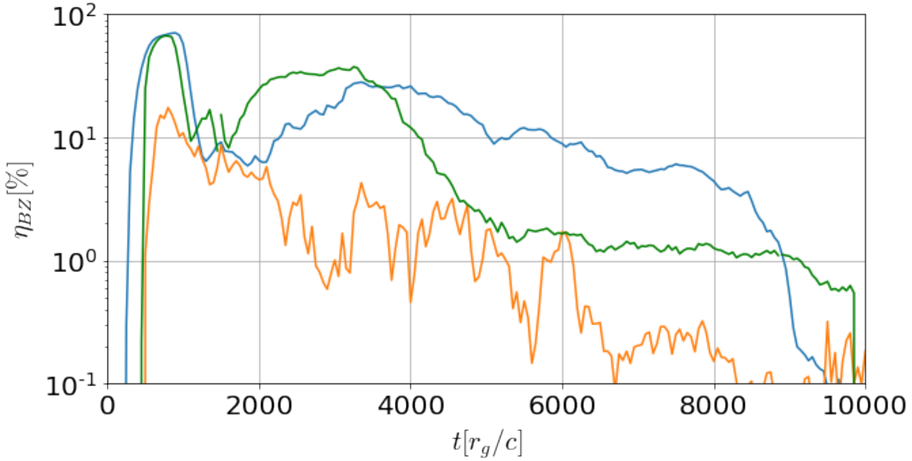


Jet efficiency



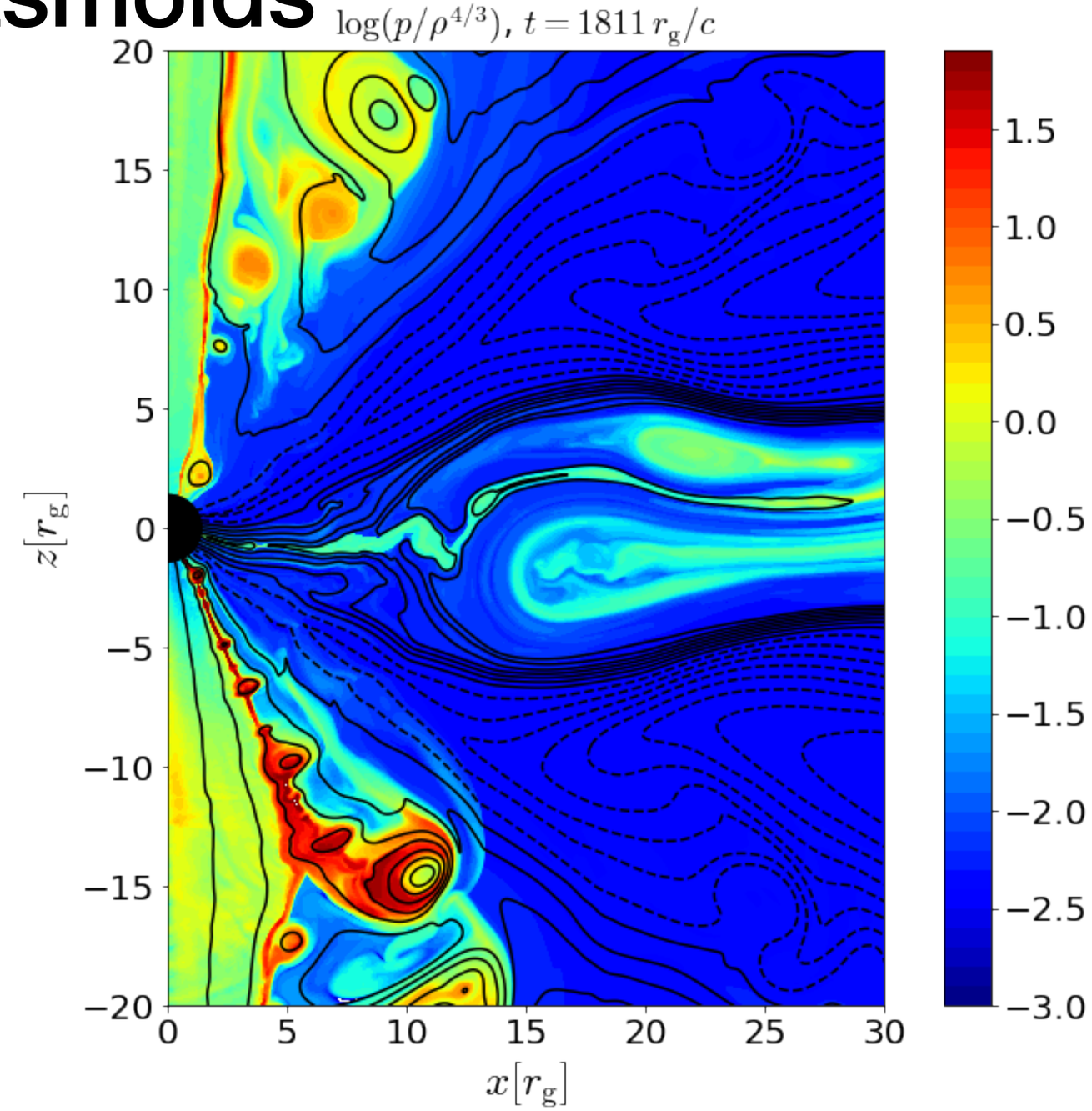




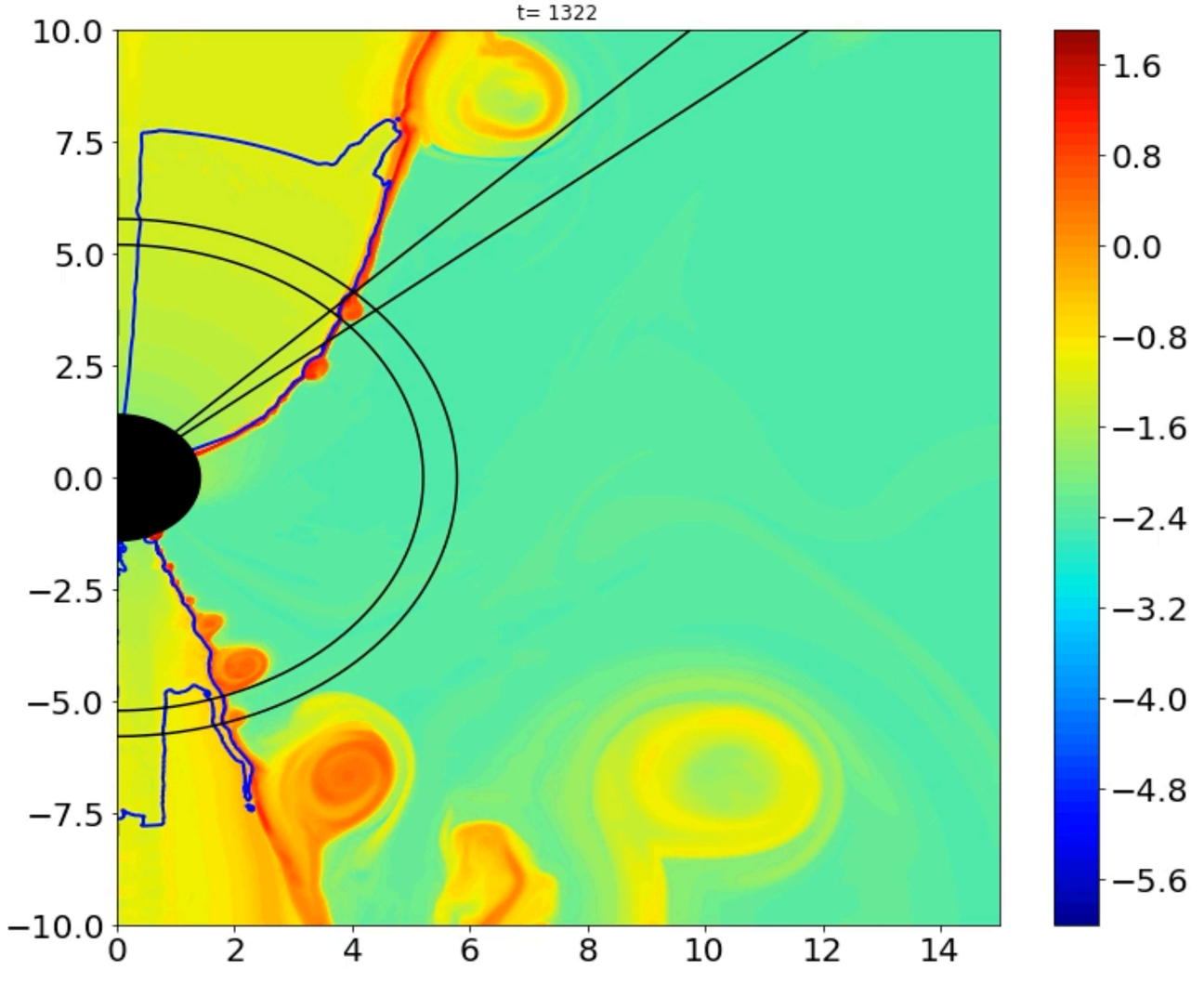


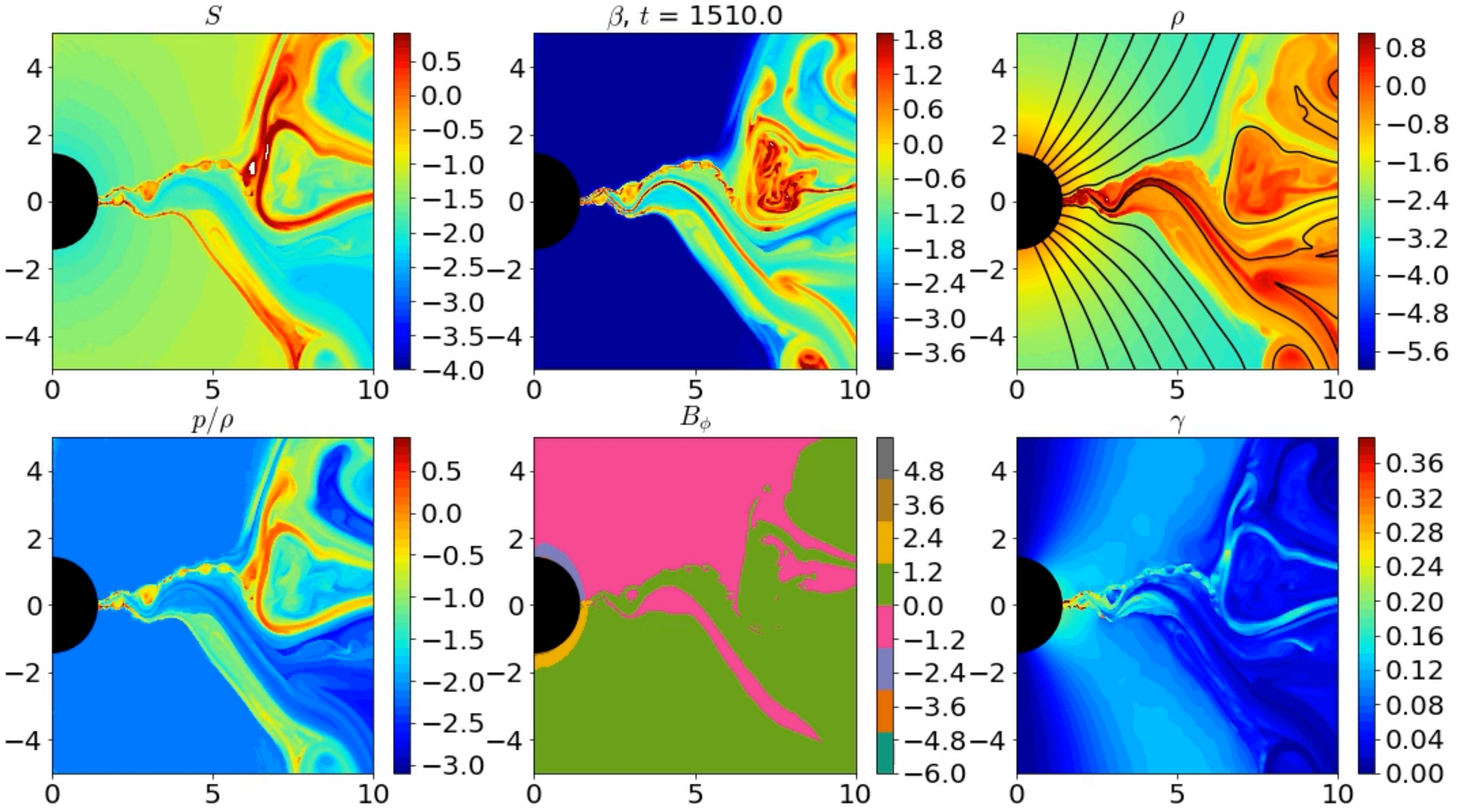
Current sheets and plasmoids

- Current sheets:
  - equatorial plane: MAD + loop switches
  - Jet-disc boundary: loop switch
- Plasmoids merge and grow in size
- Accelerate up to $0.3c$
- Energy in the plasmoids is comparable to the jet energy
- May evolve to radio blobs at larger radii



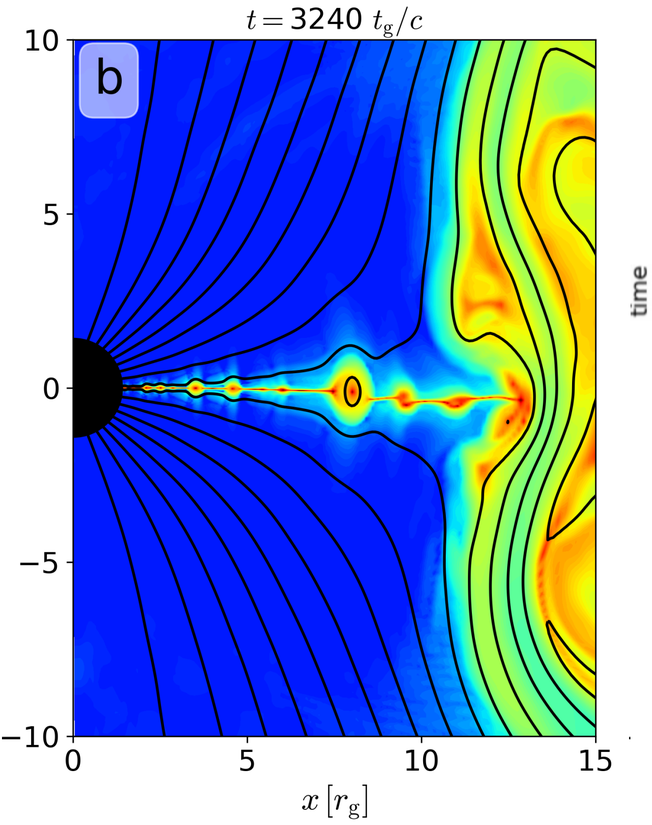
Current sheets and plasmoids

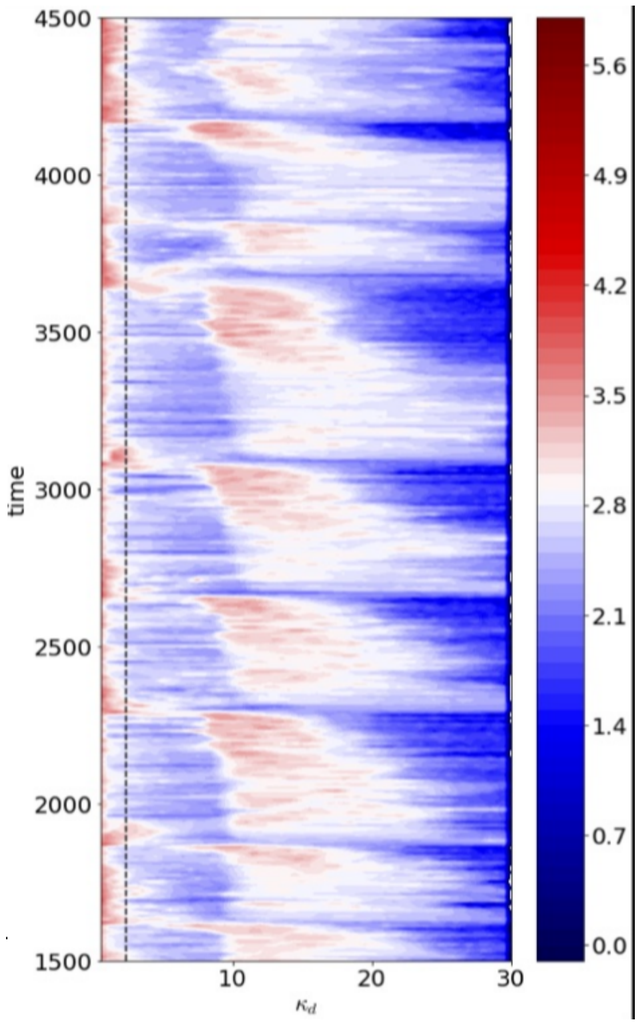



S
β, t = 1510.0
ρ
p/ρ
B_ϕ
γ

How to find plasmoids in 3D?

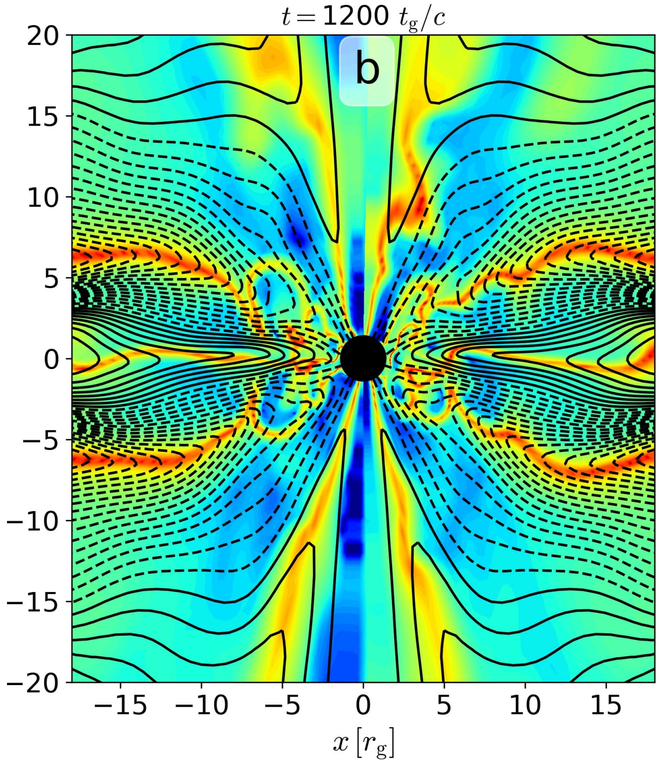
2D

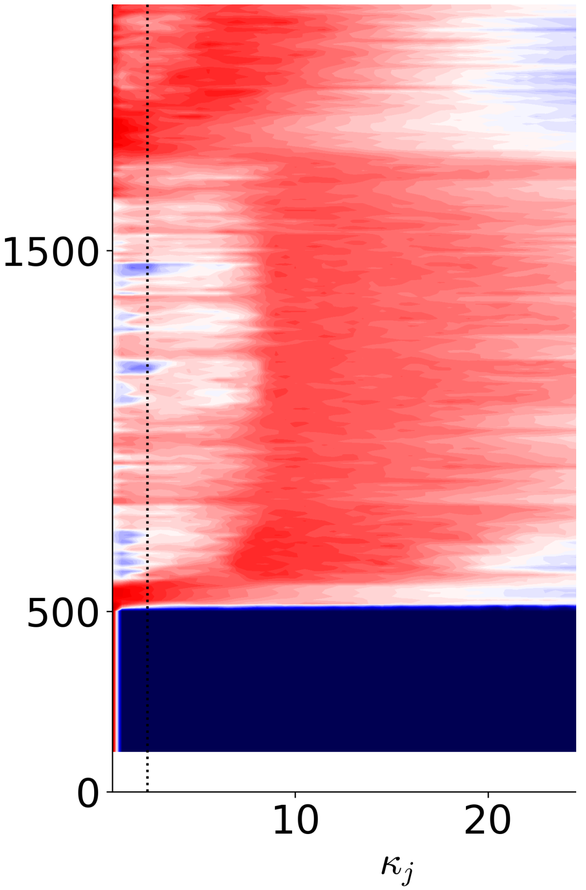




3D

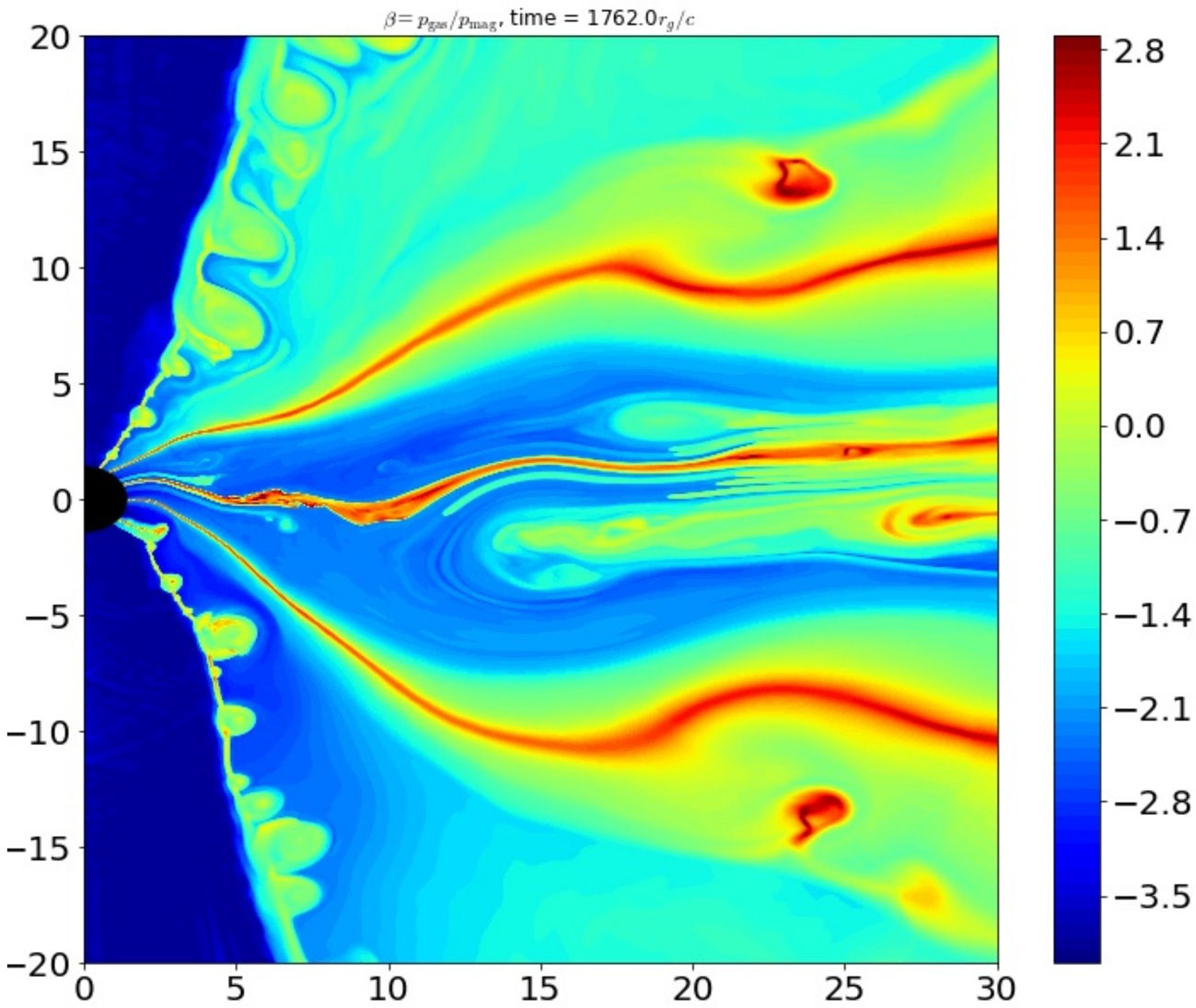
$$\kappa = \frac{|\mathbf{B_p}|}{[\nabla \times \mathbf{B}]_\phi}$$





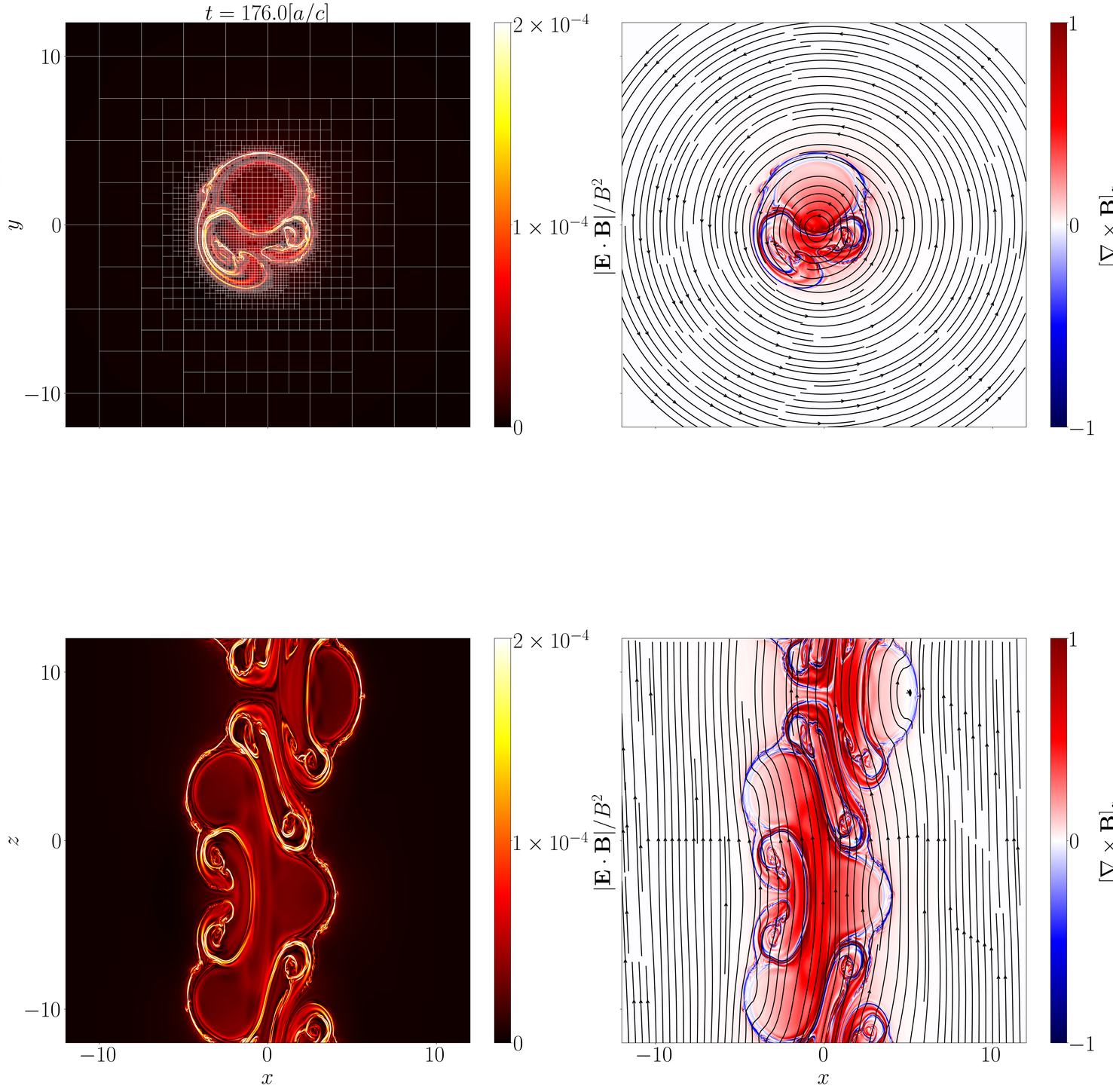
Summary

- In order to have a global reconnection at large distances one possibility is to launch striped jets
- Striped jets can be launched from opposite polarity loops, they can be quite efficient
- Reconnection in the vicinity of a BH during polarity switching produces a chain of very energetic plasmoids at the edge of the jet, that could be the source of X-ray and gamma ray emission in the vicinity of a BH, or may evolve into radio blobs at later time



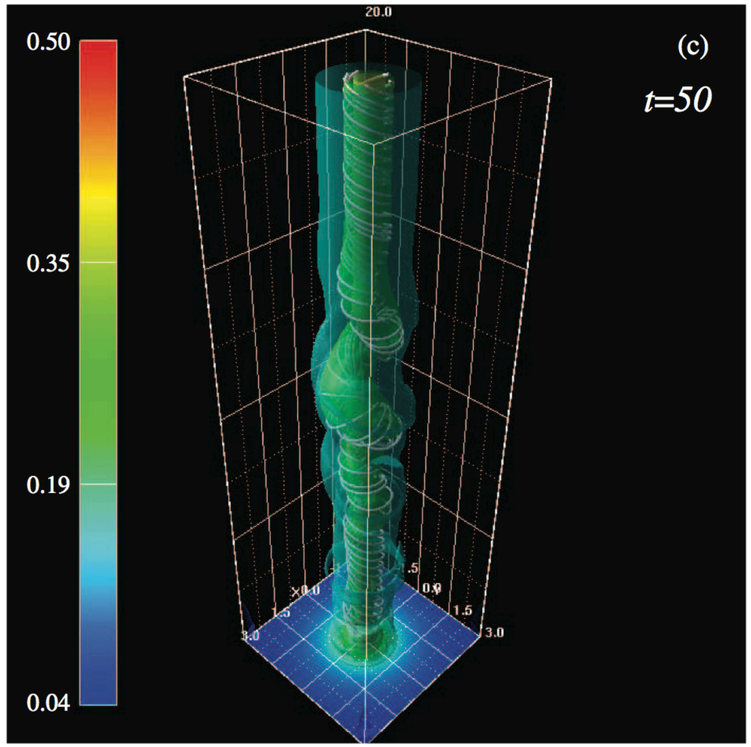
Relativistic magnetic reconnection and turbulence in kink-unstable jets

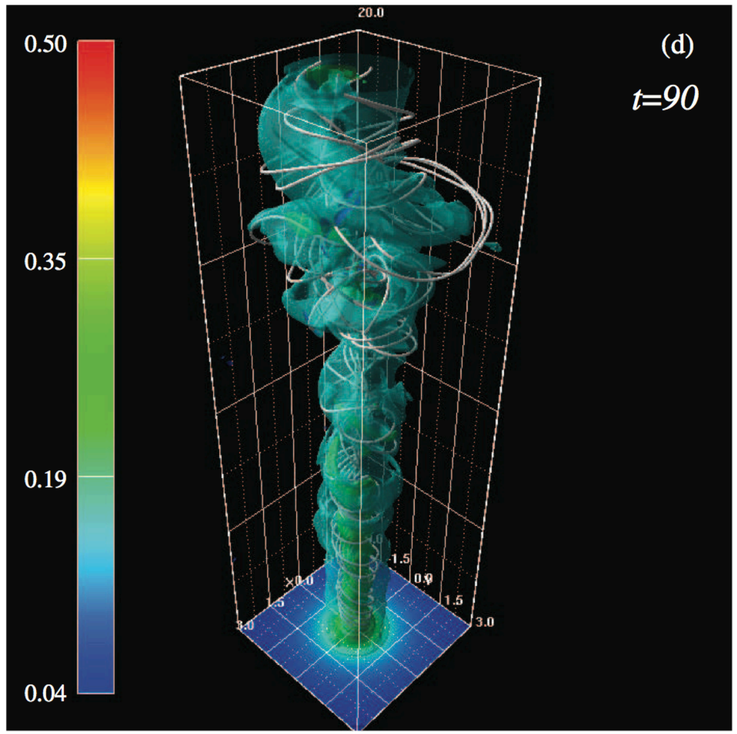
Bart Ripperda, Anna Chashkina, Alexander Chernoglazov, Sasha Philippov, Jordy Davelaar, Omer Bromberg and Lorenzo Sironi



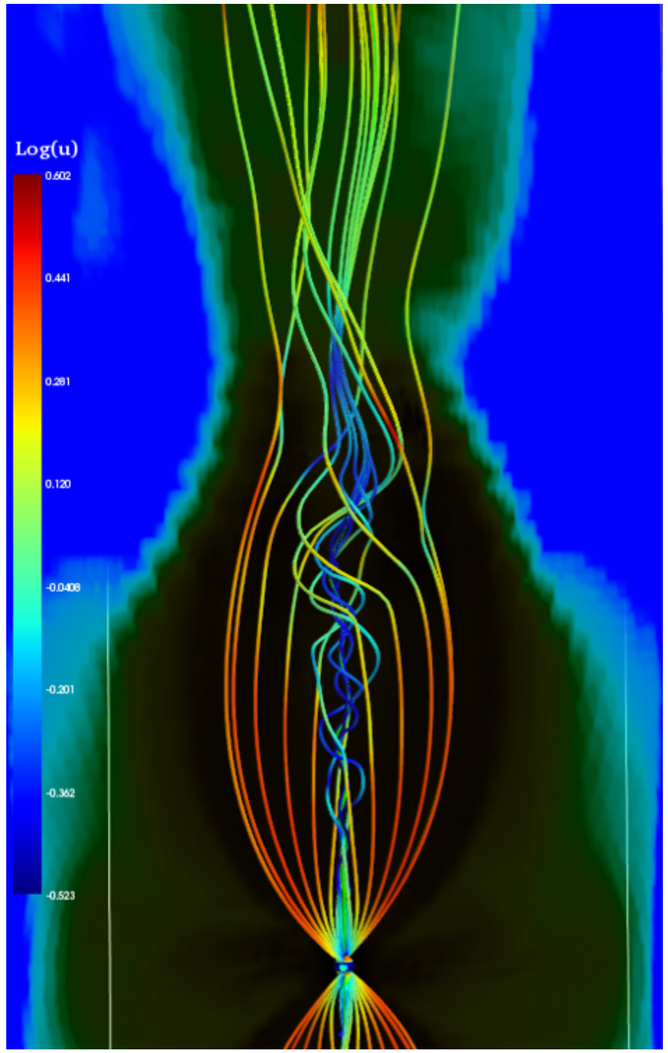
Kink instability

- Toroidal field is unstable to kink mode
- Generates helical twist in the jet, leads to reconnection
- The fastest CD instability





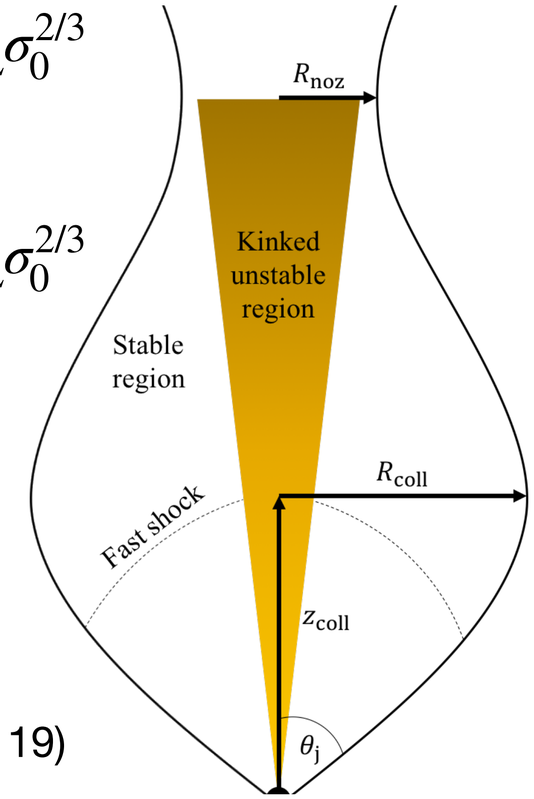
(Mizuno+ 2014)



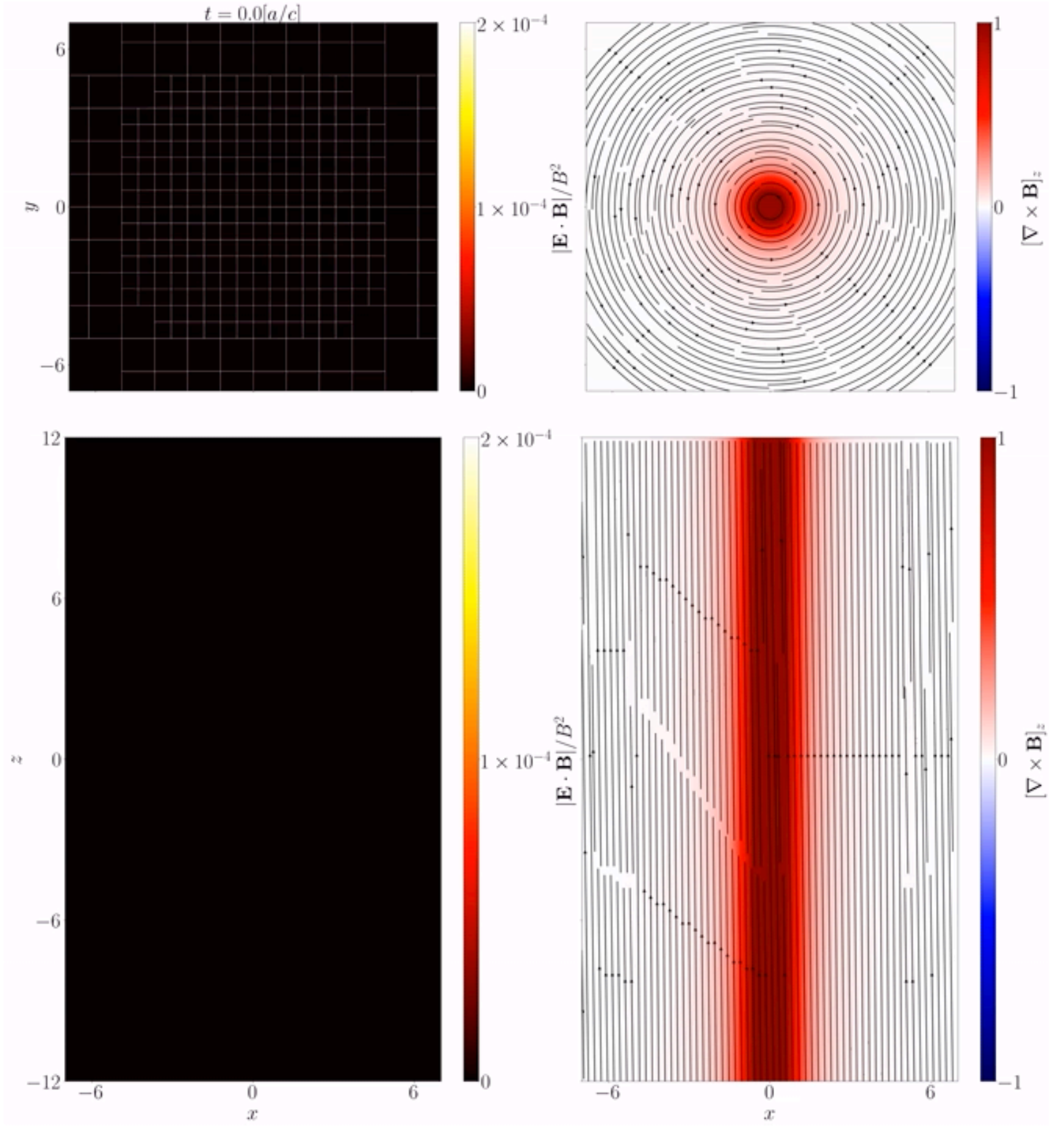
(Bromberg, Tchekhovskoy+ 2016)

Kink instability

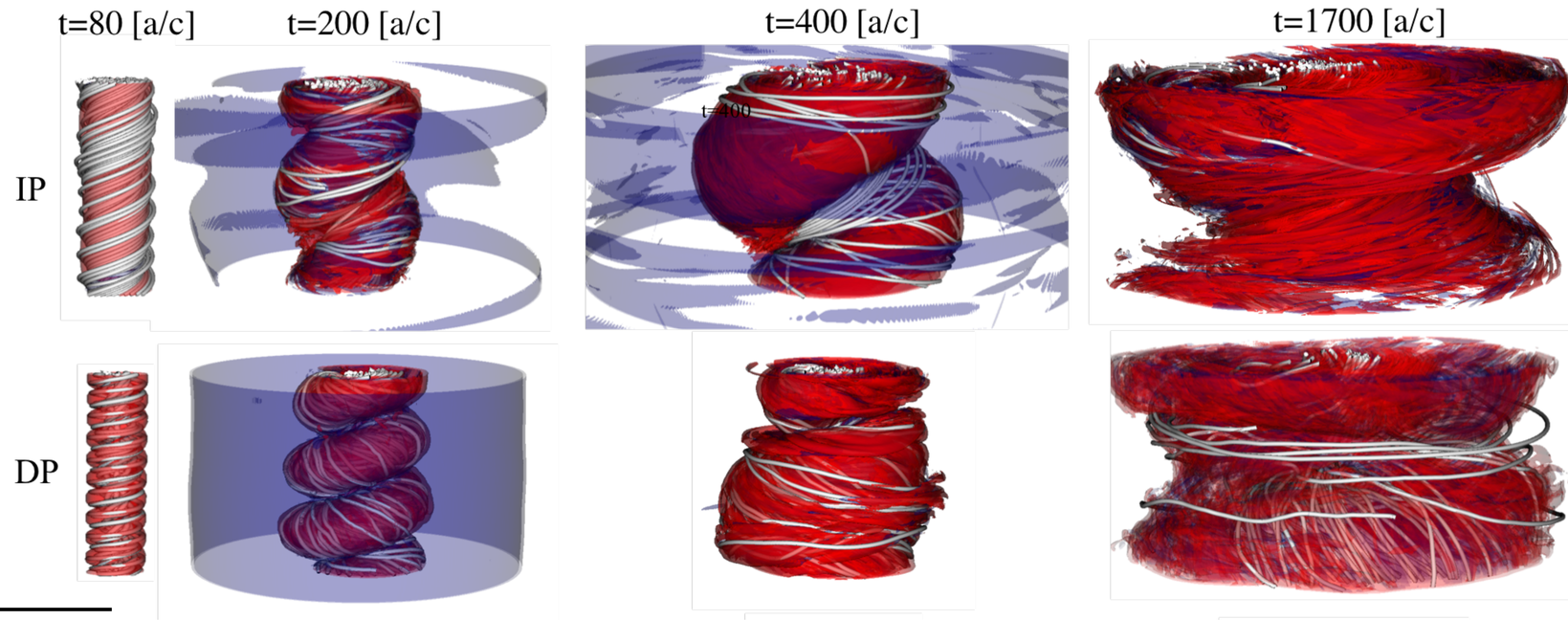
- The fastest growing instability
- Effective close to the jet axis (Bromberg, Tchekhovskoy, 2016):
- $\theta_{\rm diss} = \sqrt{\dfrac{R_L}{z_{\rm coll}}}$ if $z_{\rm coll} < R_L \sigma_0^{2/3}$
- $\theta_{\rm diss} = \dfrac{R_L}{z_{\rm coll}} \sigma_0^{1/3}$ if $z_{\rm coll} > R_L \sigma_0^{2/3}$
-



(Bromberg+ 19)



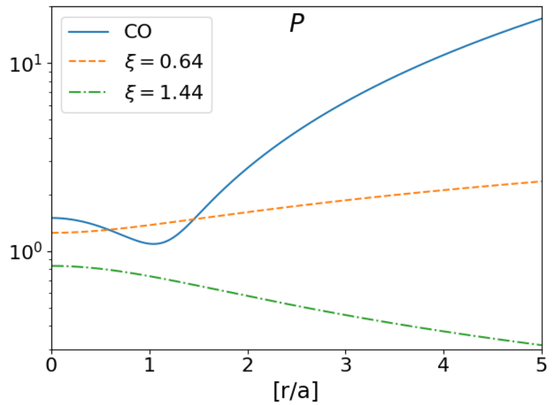
Kink instability

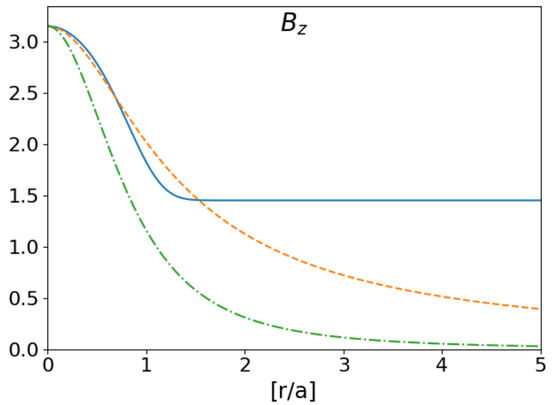


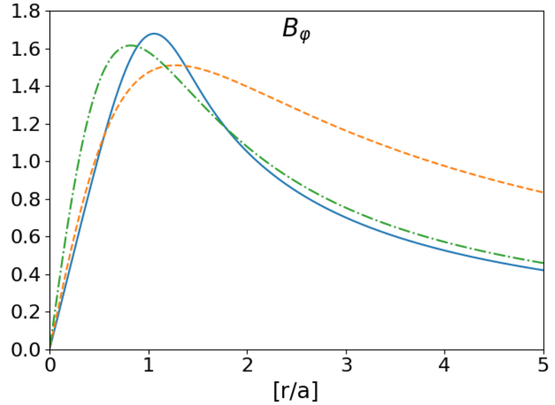
- Magnetic field structure:
- $B_r(r) = 0$
- $B_z(r) = \dfrac{B_0}{[1 + (r/a)]^{\alpha}}$
- $B_\phi(r) = \dfrac{aB_z}{r}\sqrt{\dfrac{[1 + (r/a)^2]^{2\alpha} - 1 - 2\alpha(r/a)^2}{2\alpha - 1}}$

(Bromberg+ 19)

- Pitch: $P = rB_z/B_\phi$
- Increasing pitch (IP): $P > 1, \alpha > 1$
- Decreasing pitch (DP): $P < 1, \alpha < 1$





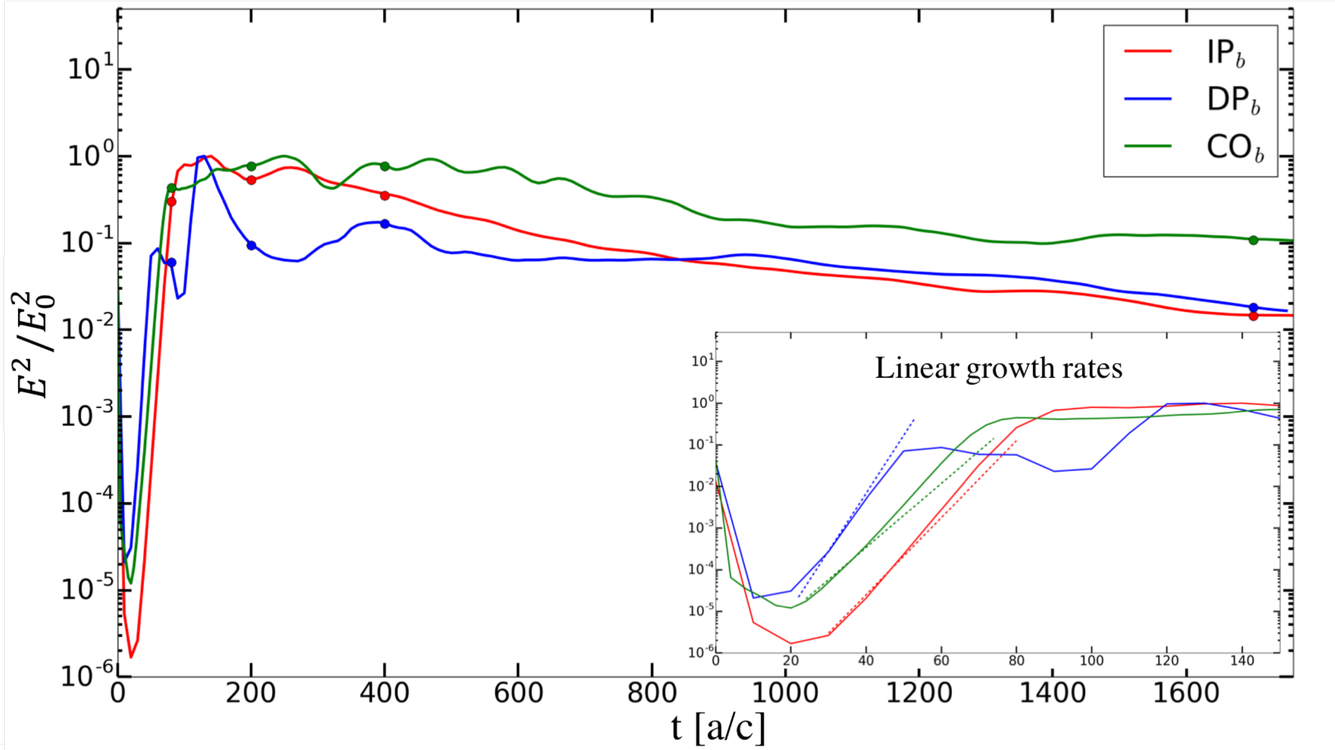


Kink instability

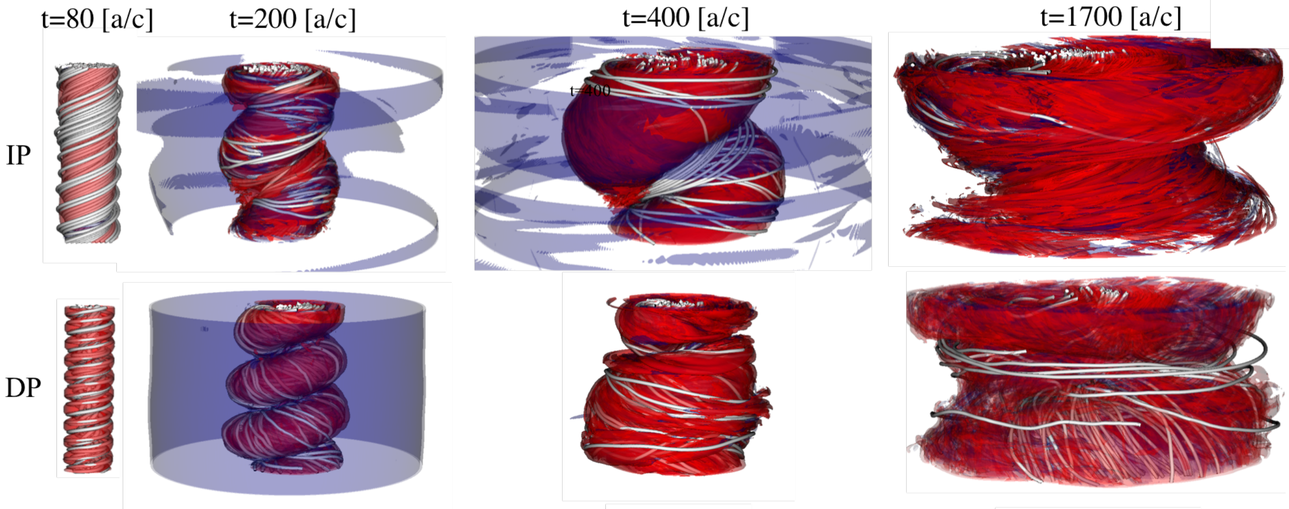
What do we know?

- Growth rate
- Energy dissipation
- Relaxation condition (Taylor state)

For non-rotating jet



(Bromberg+ 19)

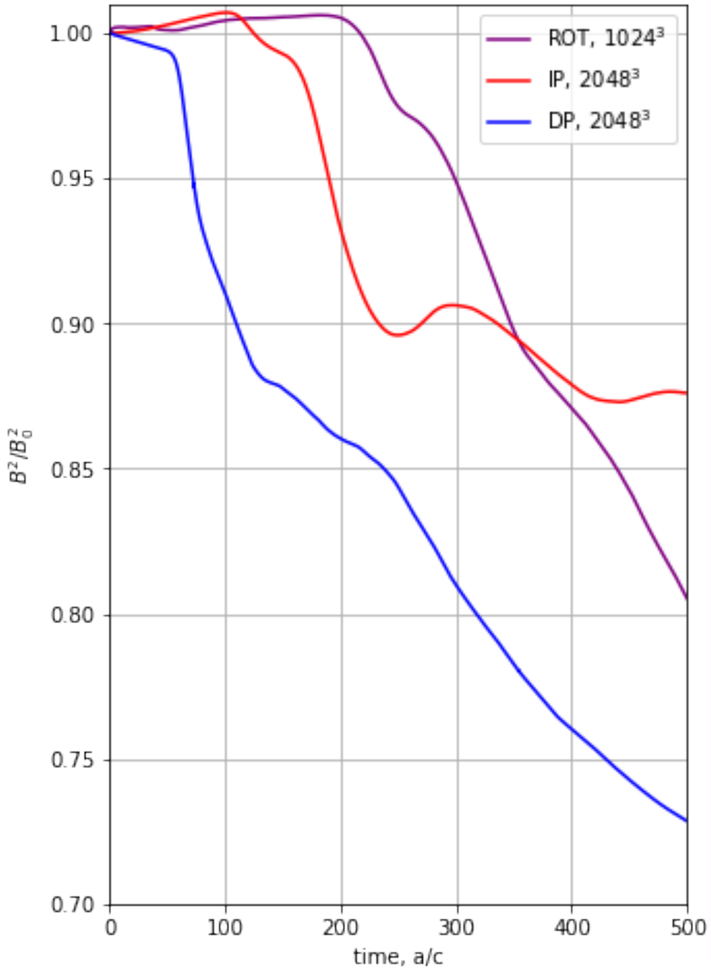


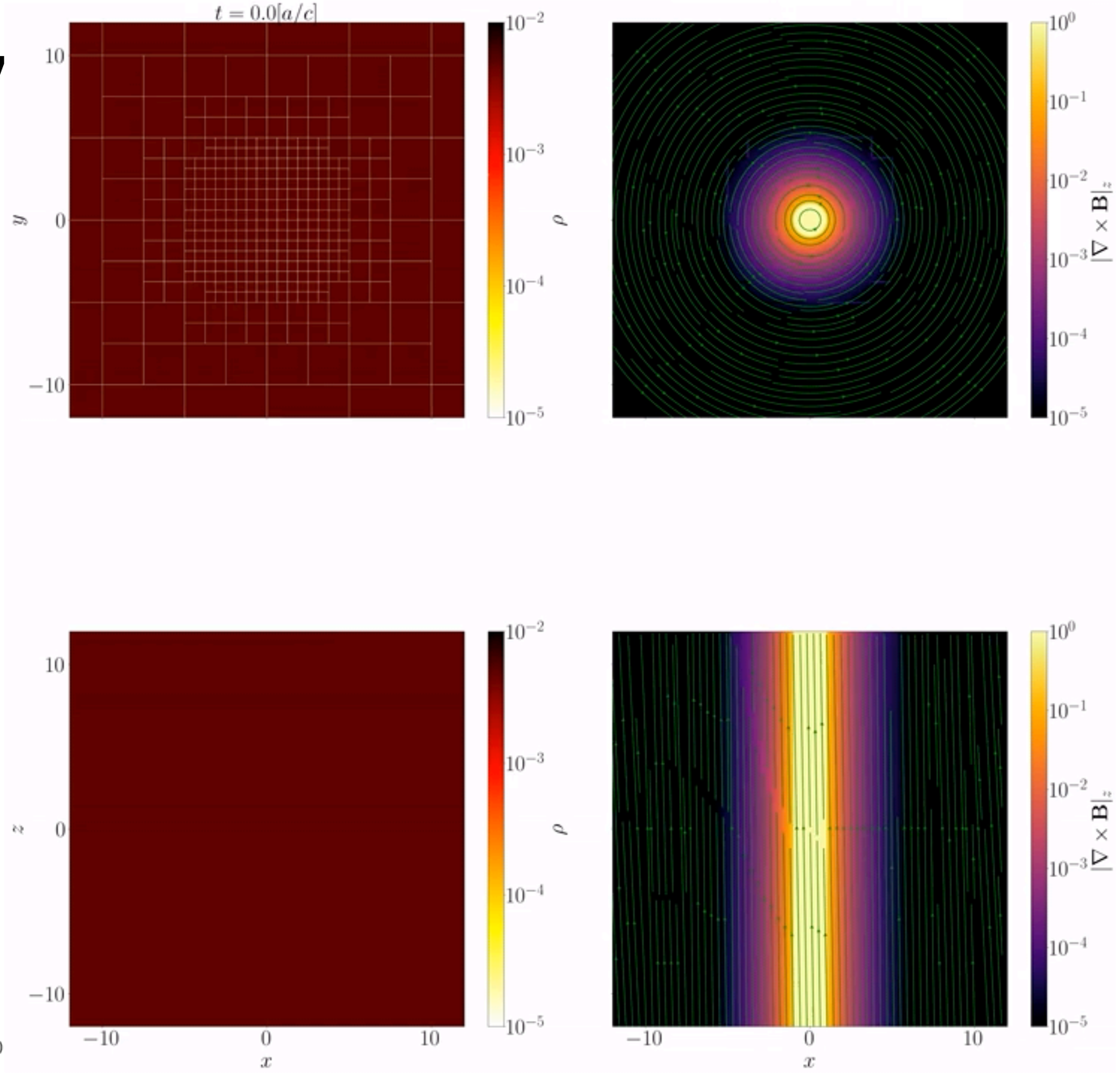
What do we want to know?

- How rotation affects the energy dissipation, relaxation condition

Kink instability

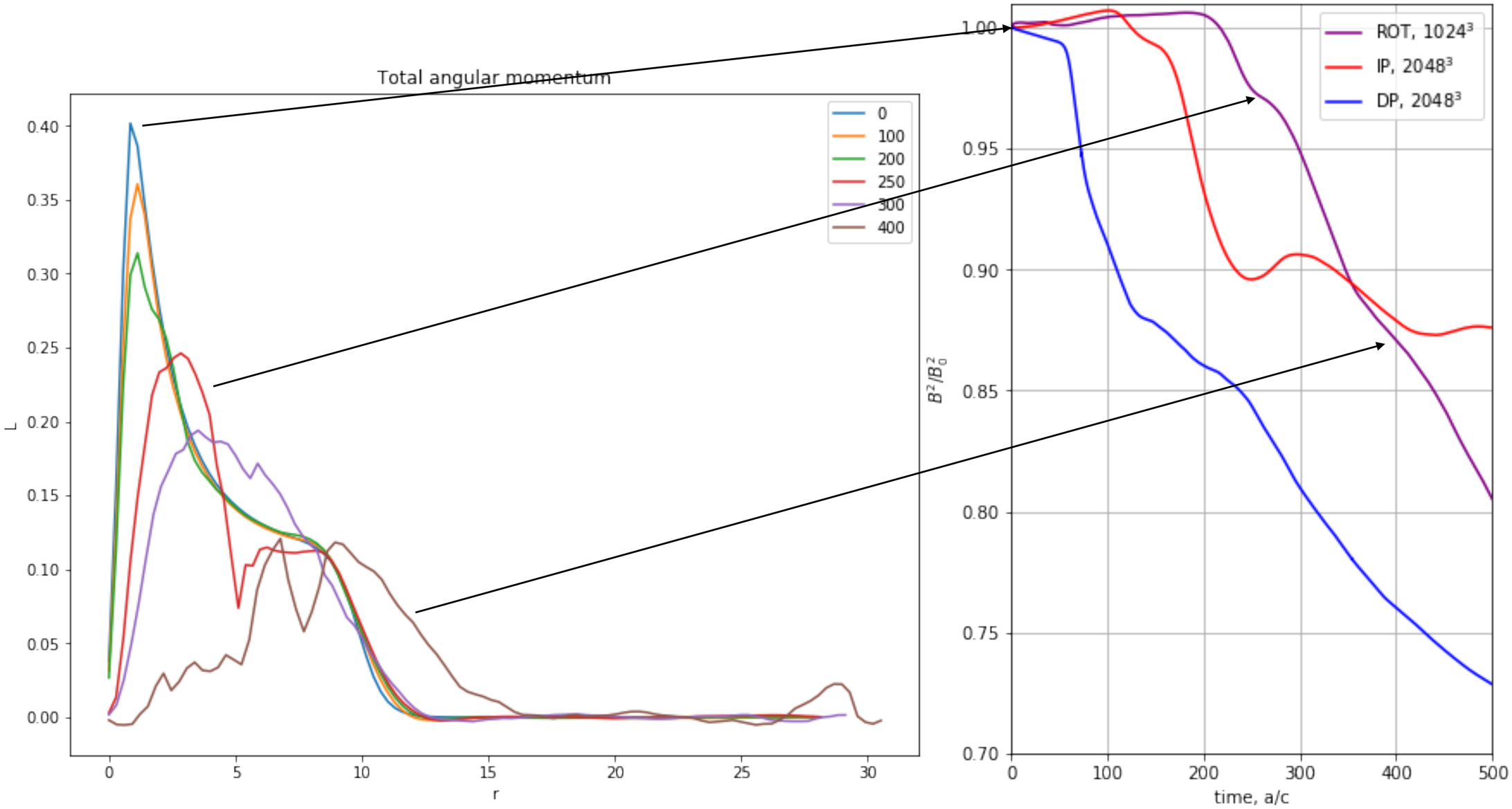
- In the rotation case the energy dissipation starts later





Kink instability

By the time when non-linear kink stage develops the angular momentum drops and energy transfers into small scales



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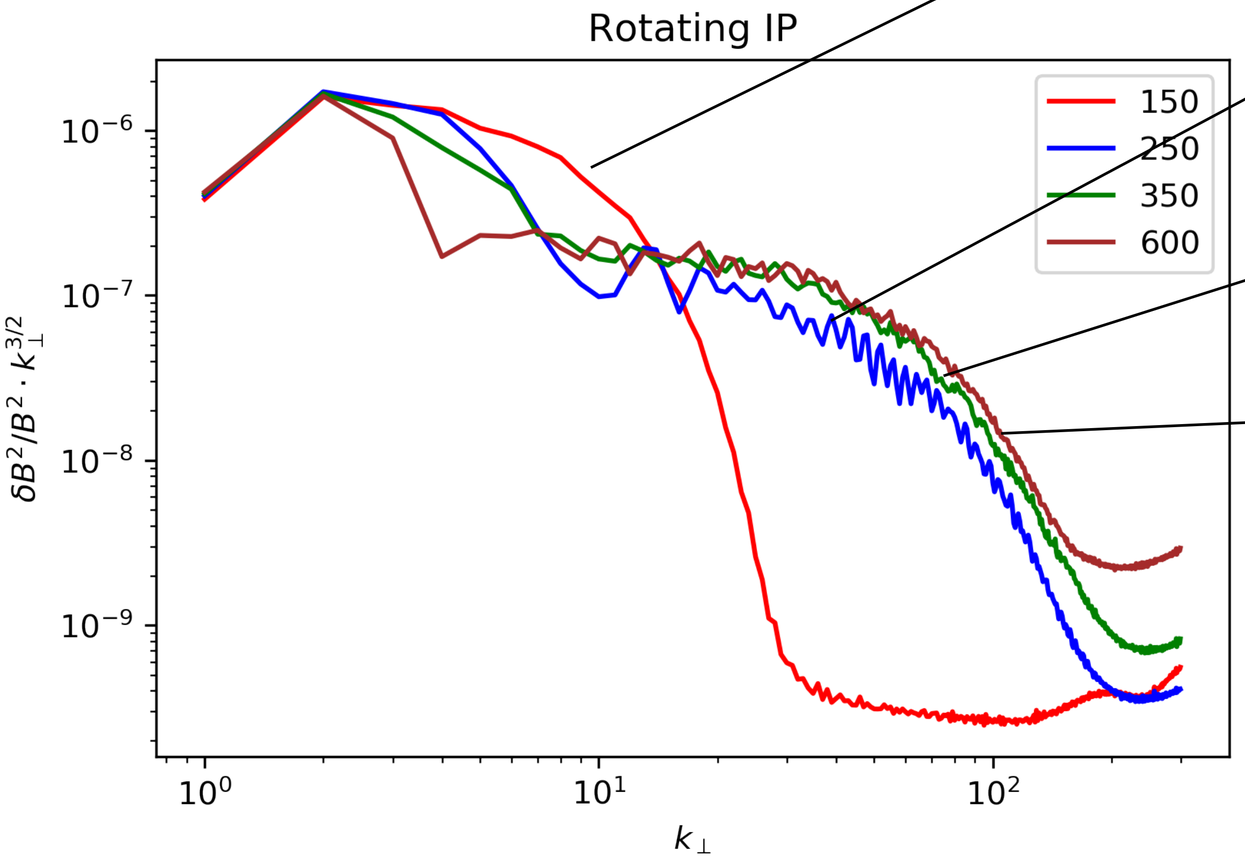
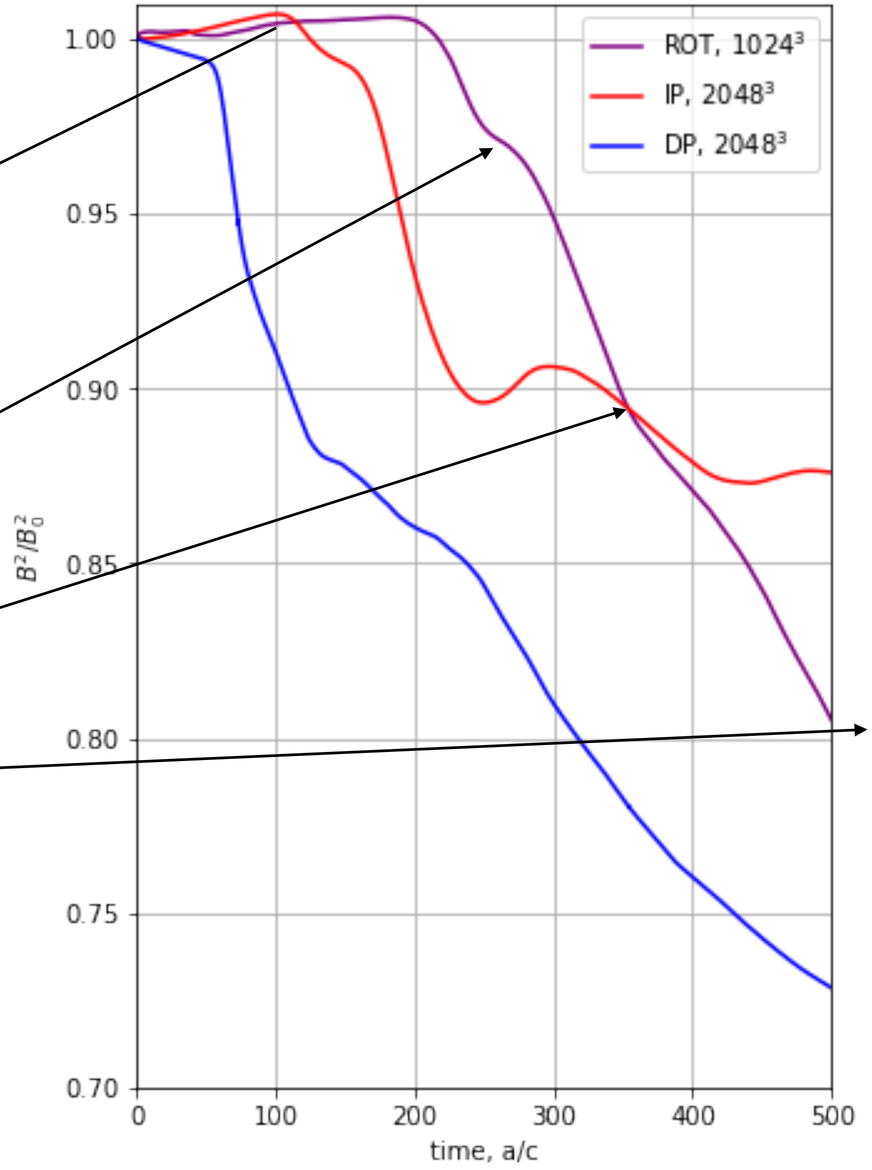
- By the time when non-linear kink stage develops the angular momentum drops and energy transfers into small scales





Summary (very preliminary)

- Energy dissipation in rotating jets starts at later time that in non-rotating
- Rotation affects linear stage of kink-instability.
- Angular momentum transfers outwards during kink phase
- Kink instability can dissipate around 1/2 of magnetic energy
- *What is the saturation criteria?*
- *How does it look like in the global simulations?*