Particle-in-cell simulations of inclined black hole magnetospheres

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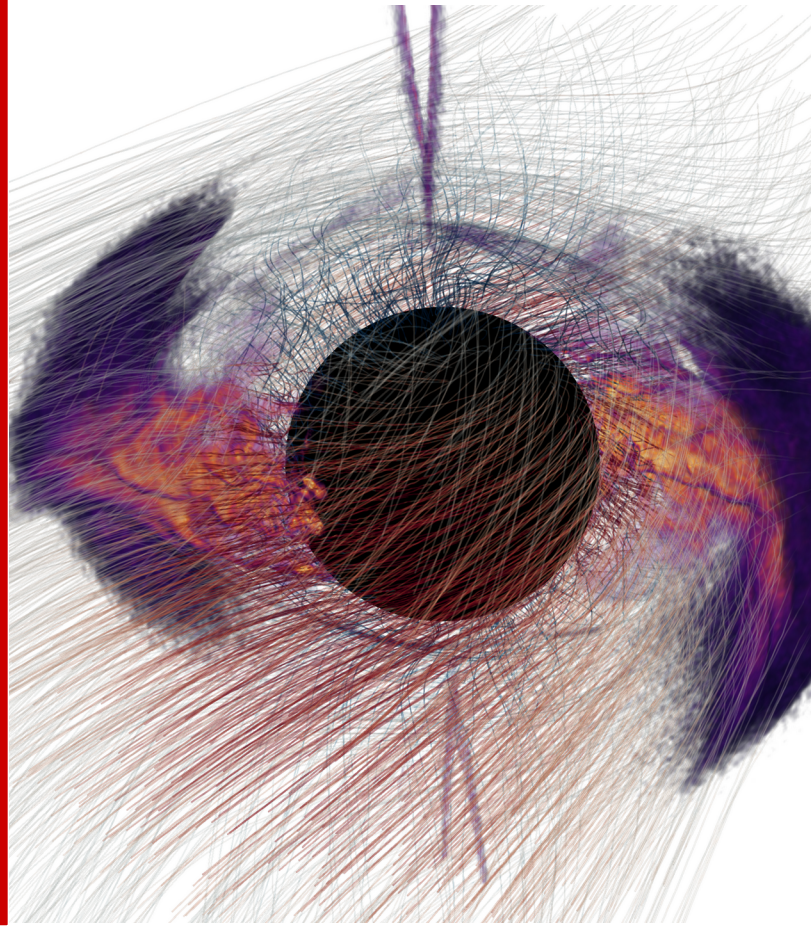

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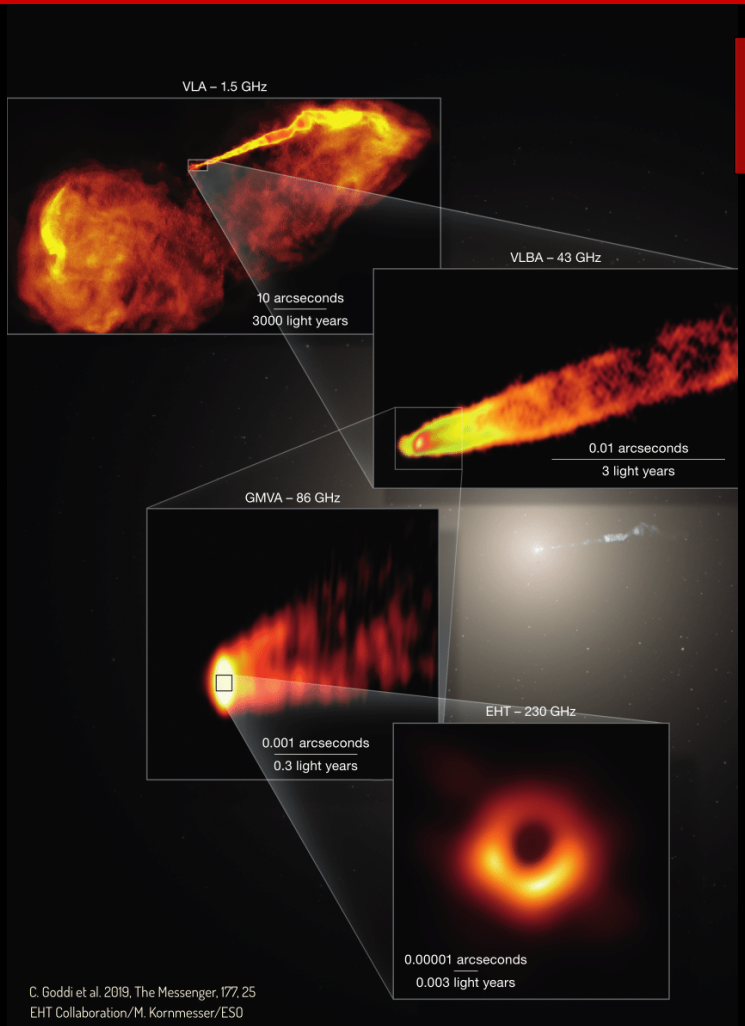
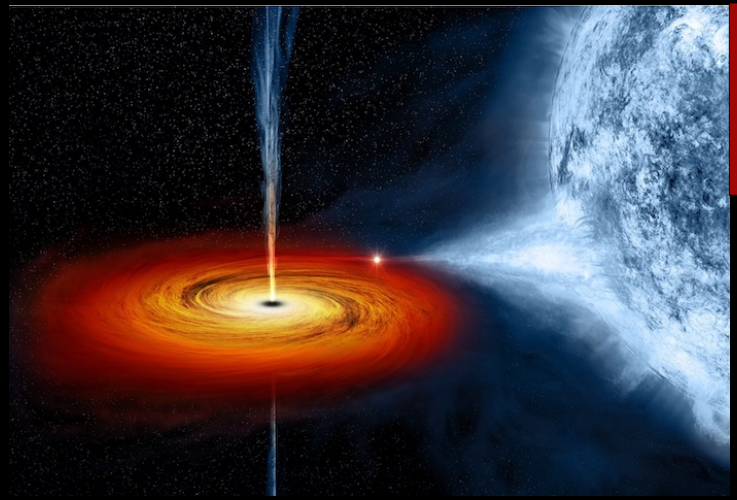
Black Holes and Jet Emission



Evidences for a connection between SMBH and galactic jets

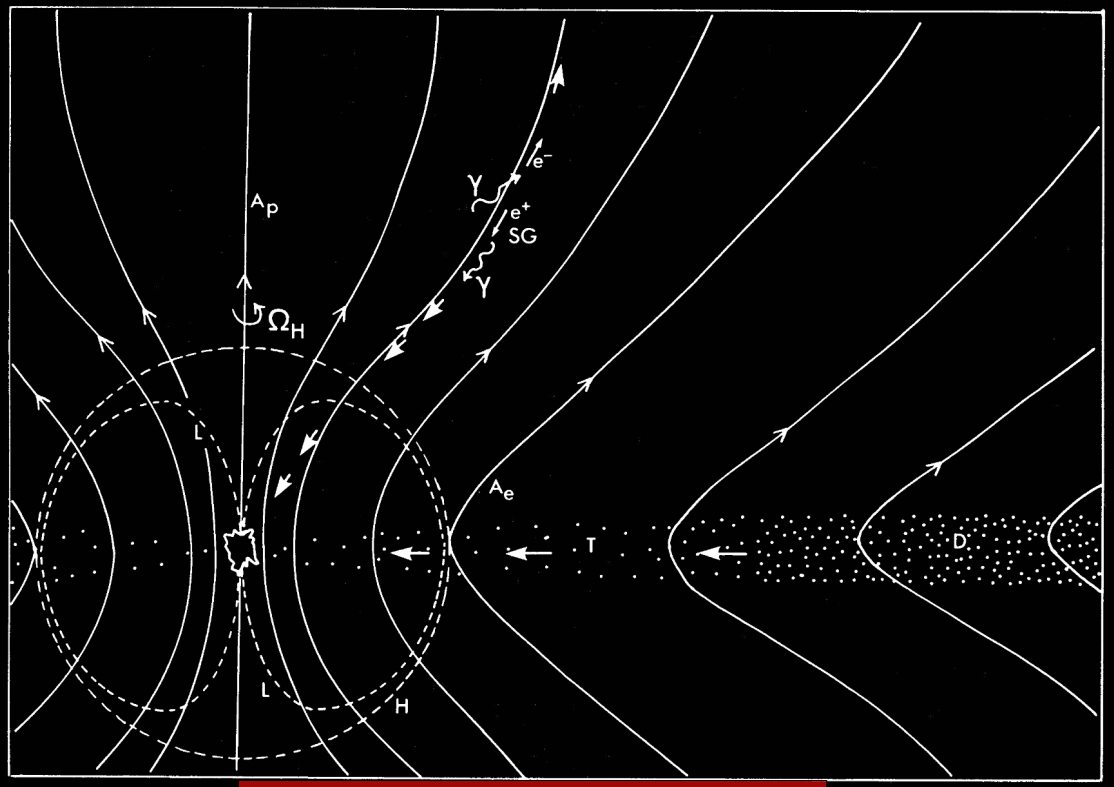


Also for stellar–mass black holes in X–ray binaries

\+

Non thermal emission → Particle acceleration

Theoretical Understanding of the Jet Emission



Blandford & Znajek, 1977

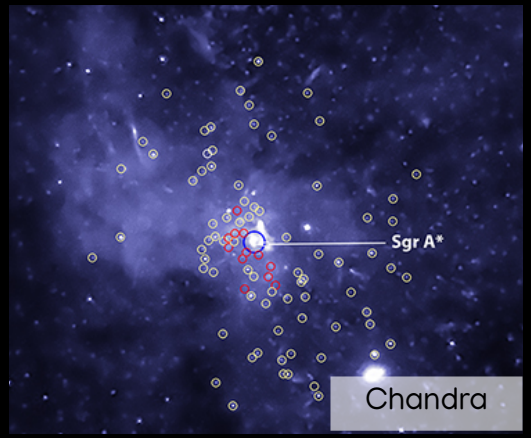
→ 2 ingredients: magnetic field and black hole spin (and plasma!)

$$L_{BZ} = \frac{1}{96} a^2 B_0^2, \; a \ll 1$$

What if we loose axisymmetry?

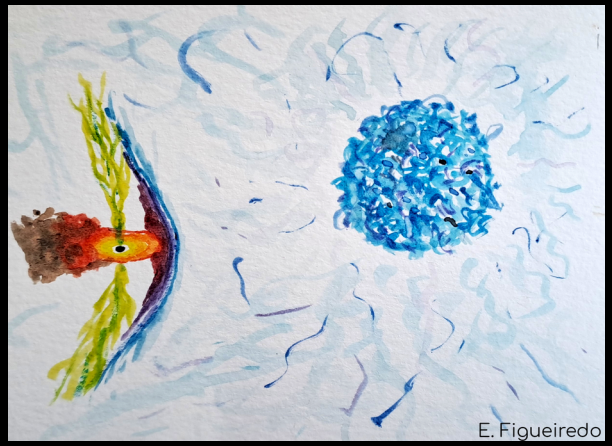
Magnetic Field Orientation

Wind-fed accretion of Sgr A* in the Galactic Center?



A black hole in a pulsar wind?

High mass X-ray binary?



Run-away black holes? Gaia black holes?

→ All those examples hint for configurations where the black hole spin and the magnetic field are not necessarily aligned

This Study: a Simple but General Setup

GRZeltron: a GRPIC code

3+1 formalism (Komissarov, 2004)

Kerr metric, KS spherical coordinates

Force-free like magnetosphere:

$$\sigma = \frac{B^2}{4\pi n m_e c^2} \gg 1$$

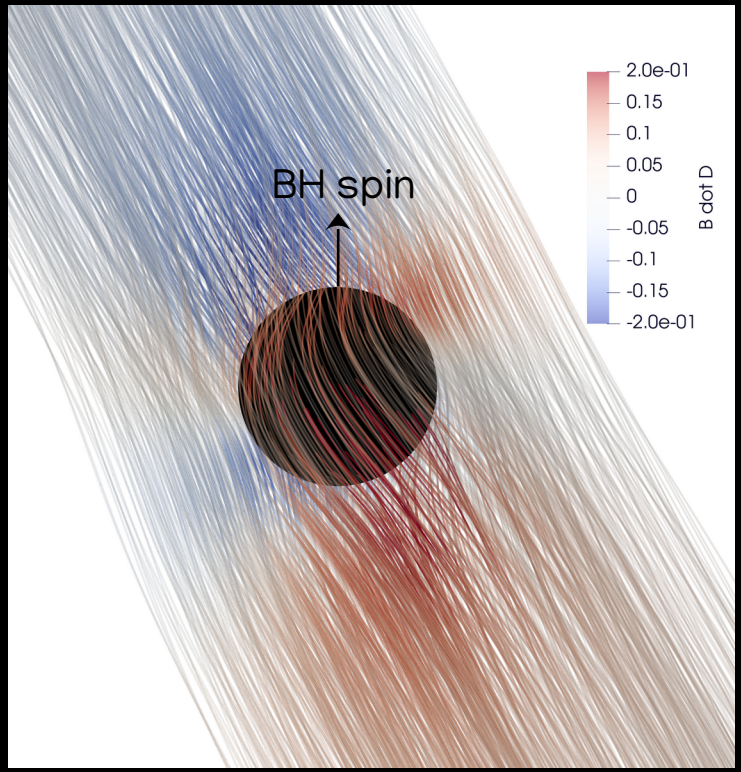
$$\kappa = \frac{n}{n_{GJ}} \gg 1 \quad n_{GJ} = \frac{\mathbf{\Omega} \cdot \mathbf{B}}{2\pi e c}$$

Ad hoc plasma injection

Injection if:

$$\sigma > \sigma_0$$

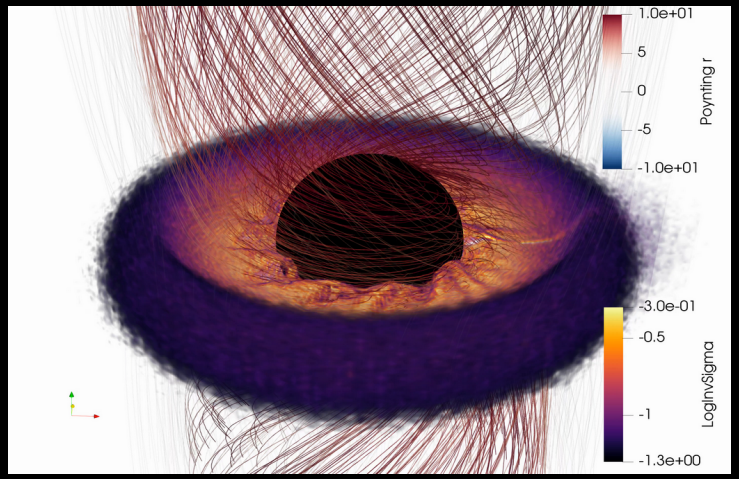
Vacuum initial state (a=0.99)



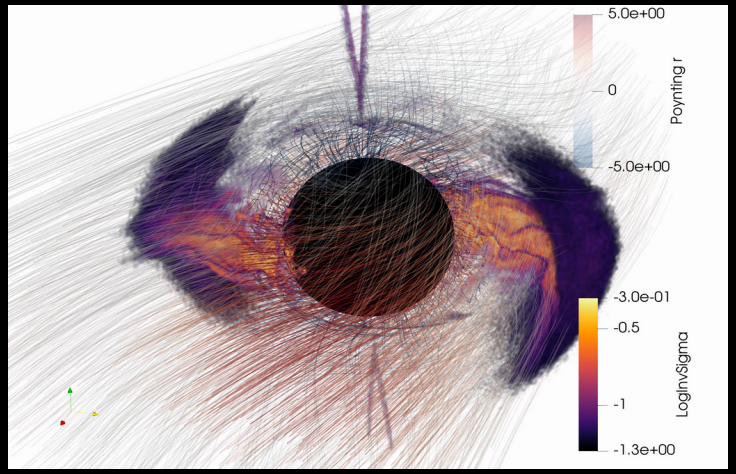
Bicak & Janis (1985)

Overview of the simulations

$\chi = 0°$



BH spin



$\chi = 85°$

$t \in [80, 84]\ t_g$

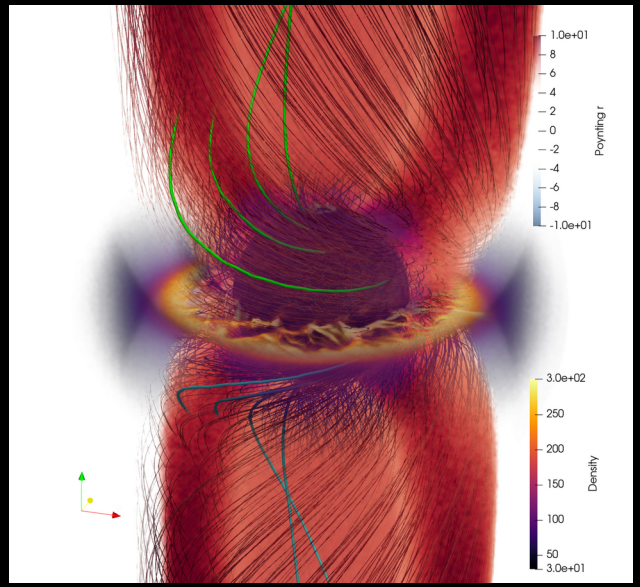
$t \in [52, 56]\ t_g$

→ The jet follows the large scale magnetic field orientation
→ A reconnecting current layer always forms

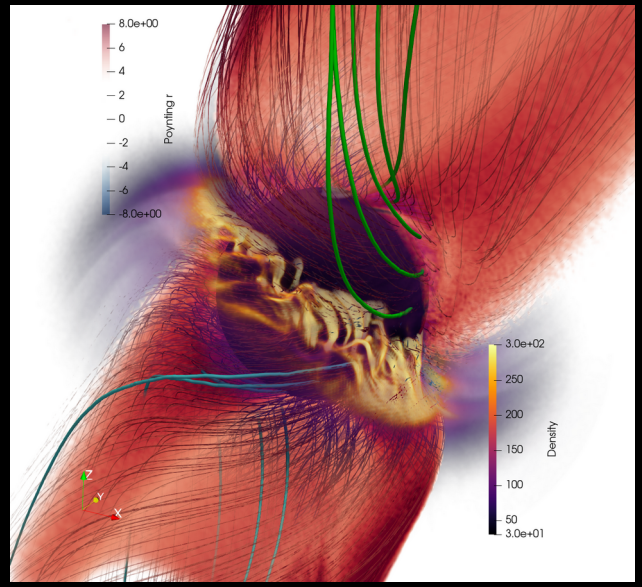
The Jet Structure Is Affected by the Inclination

BH spin

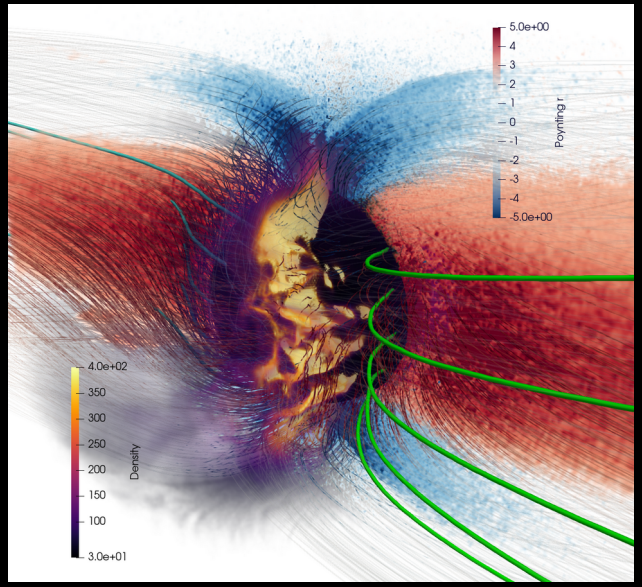
$\chi = 0°$



$\chi = 30°$



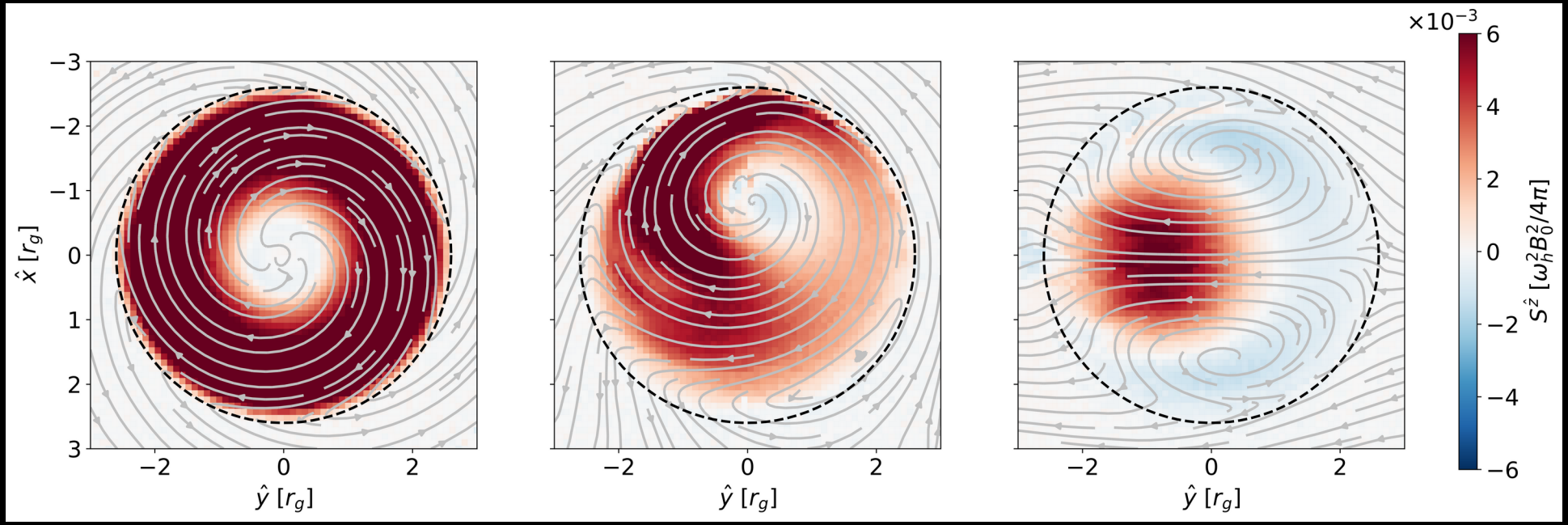
$\chi = 85°$



→ Inward EM flux at the polar regions for inclined magnetospheres
→ Outward EM flux rather comes from equatorial regions

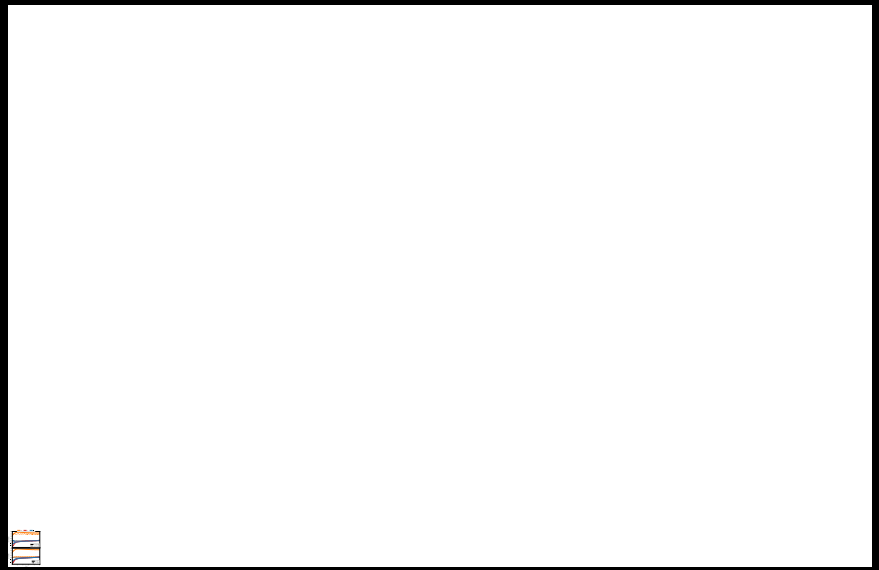
The Jet Structure Is Affected by the Inclination

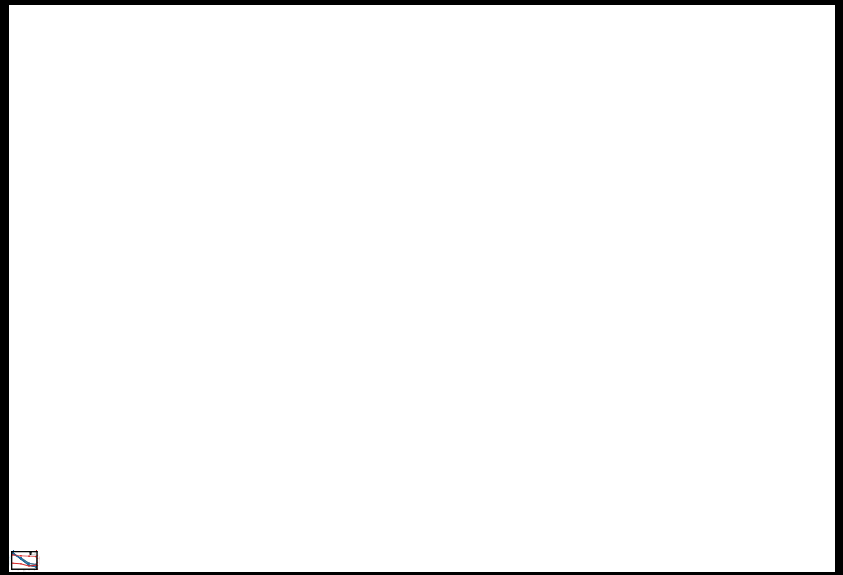
$\chi = 0°$ $\chi = 30°$ $\chi = 85°$



→ Jet power lies in the core for inclined magnetospheres
→ Magnetic structure develops 2 cells, supported by opposed currents

The jet's power weakens, but not the particles'



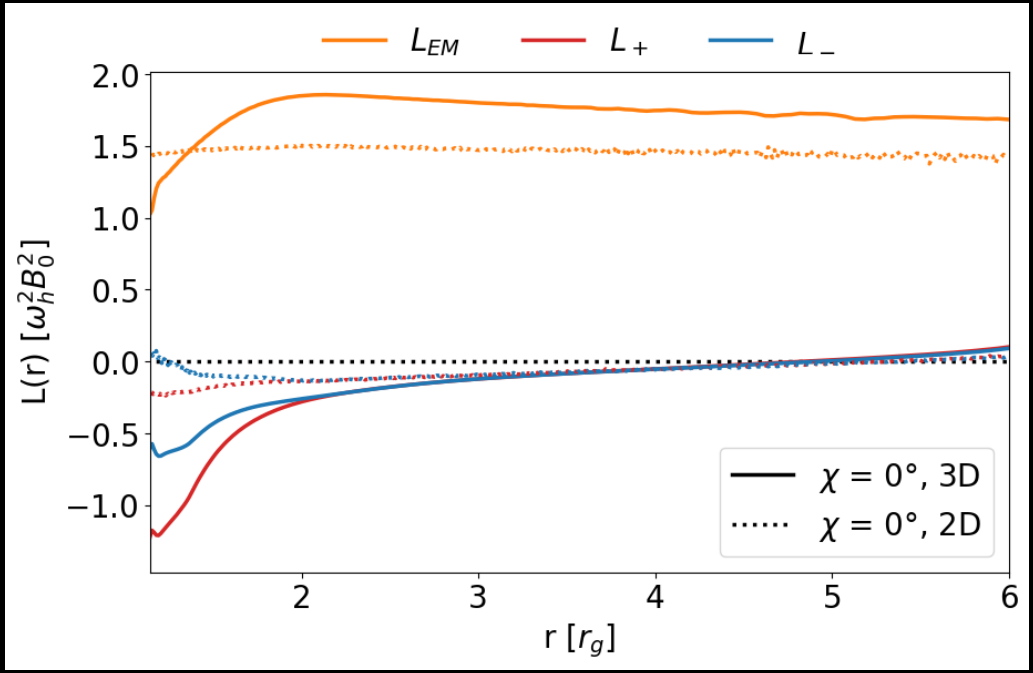


$$L_{\rm EM}(r) = \iint \sqrt{\gamma} S^r \mathrm{d}\theta \mathrm{d}\phi$$

$$L_{\pm}(r) = \iint \sqrt{\gamma} \left\langle e^{\pm}_{\infty} v^r_{\pm} \right\rangle n_{\pm} \mathrm{d}\theta \mathrm{d}\phi$$

→ Dramatic weakening of the jet power for very inclined magnetospheres
→ Non correlated with particle energization

3D is essential to capture all the dissipation



→ Much more reconnection of the toroidal magnetic field than the radial one

→ Increased electromagnetic dissipation within the ergosphere (x5)

Conclusions

– Inclination has a strong impact on the jet's shape and power

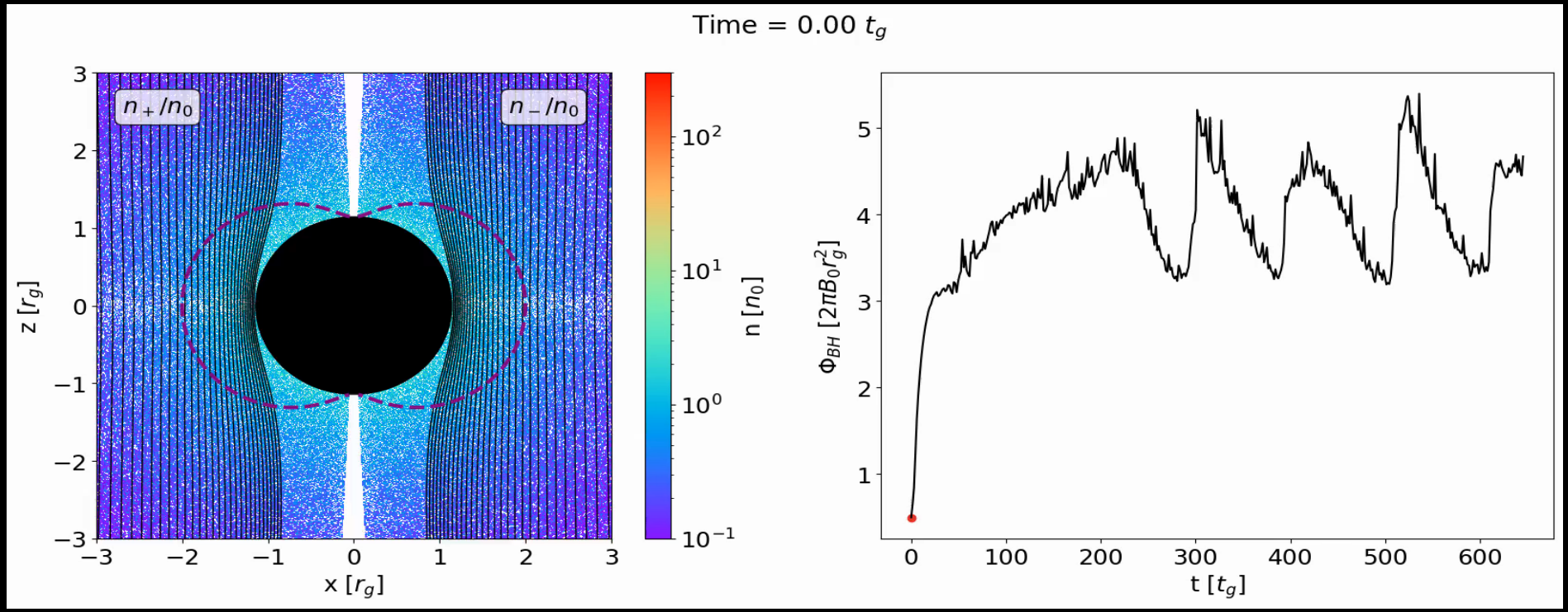
– Black hole magnetospheres are always efficient particle accelerators

– 3D simulations are essential to completely capture magnetic reconnection that does not only lie in the poloidal plane

– Crucial step into understanding of a wide range of phenomena:
wind accretion (Sg A*, …), NS–BH binaries, …

– Future work will involve more realistic pair production
→ starved magnetospheres, lightcurves, polarization, …

Bonus 1: a 2D flaring magnetosphere?



Bonus 2: a 3D flaring magnetosphere???