Relativistic structured jet

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Outline

- Motivation
- Model
- Numerical simulations
- Summary

Two component jet

Origins

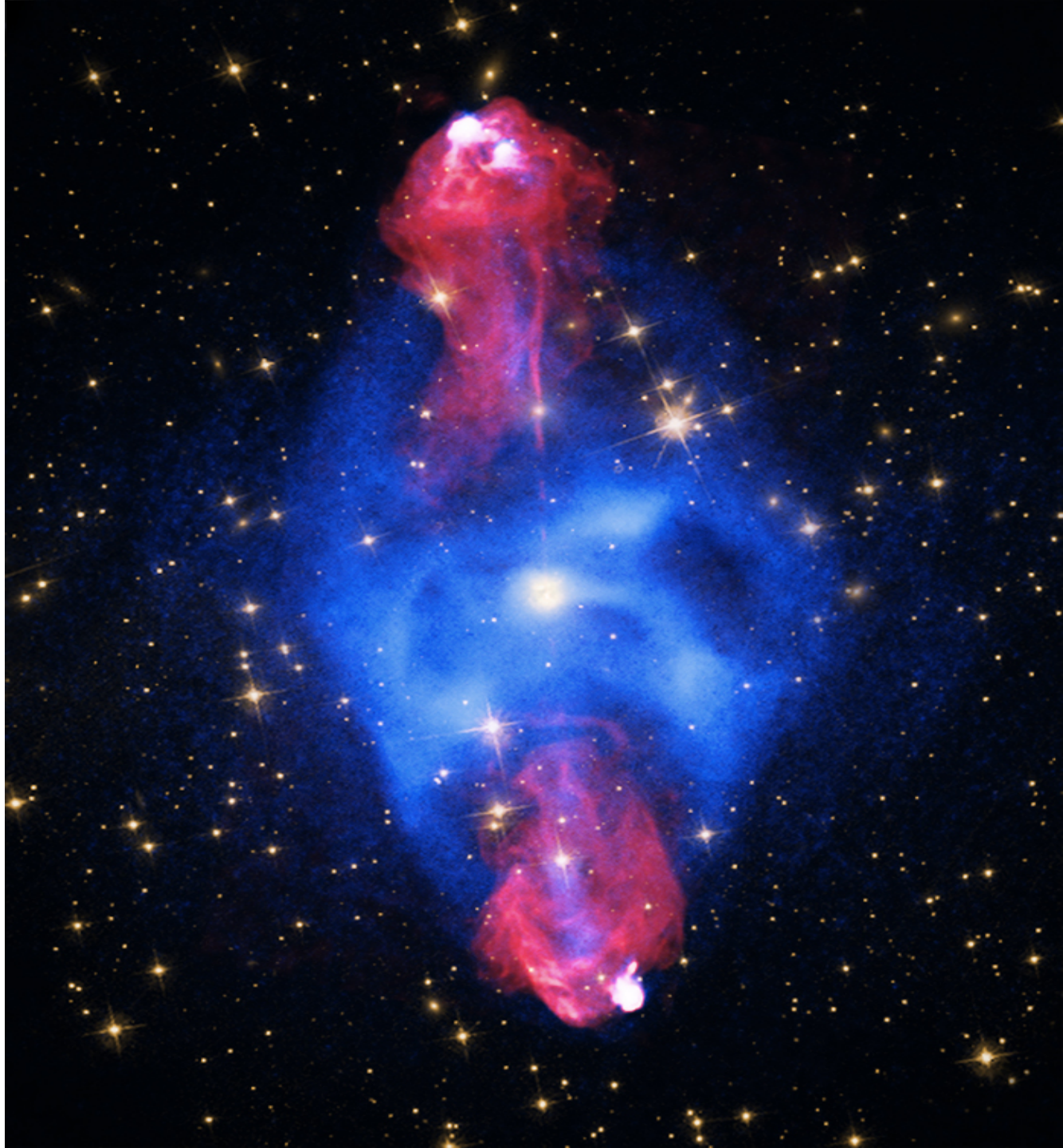
- Jet formation
- Jet propagation

Interactions

- Instabilities
- Shocks
- Current models focus on MHD

Applications

- AGN classification
- GRB light curves
- Doppler crisis
- gamma ray flares

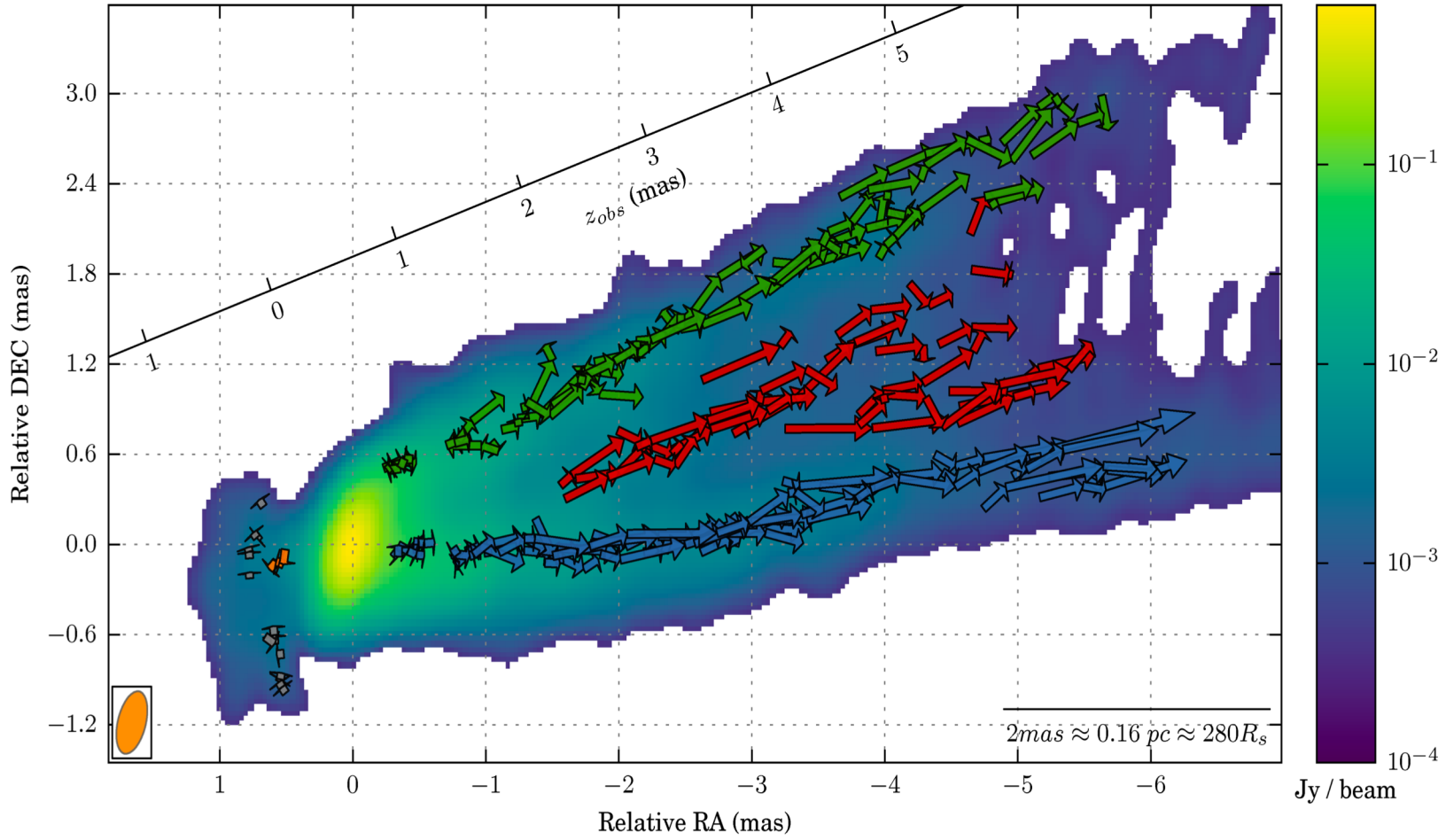


Structured jet in M87

Edge brightened jet

Central stream and limbs

Evidence for jet rotation

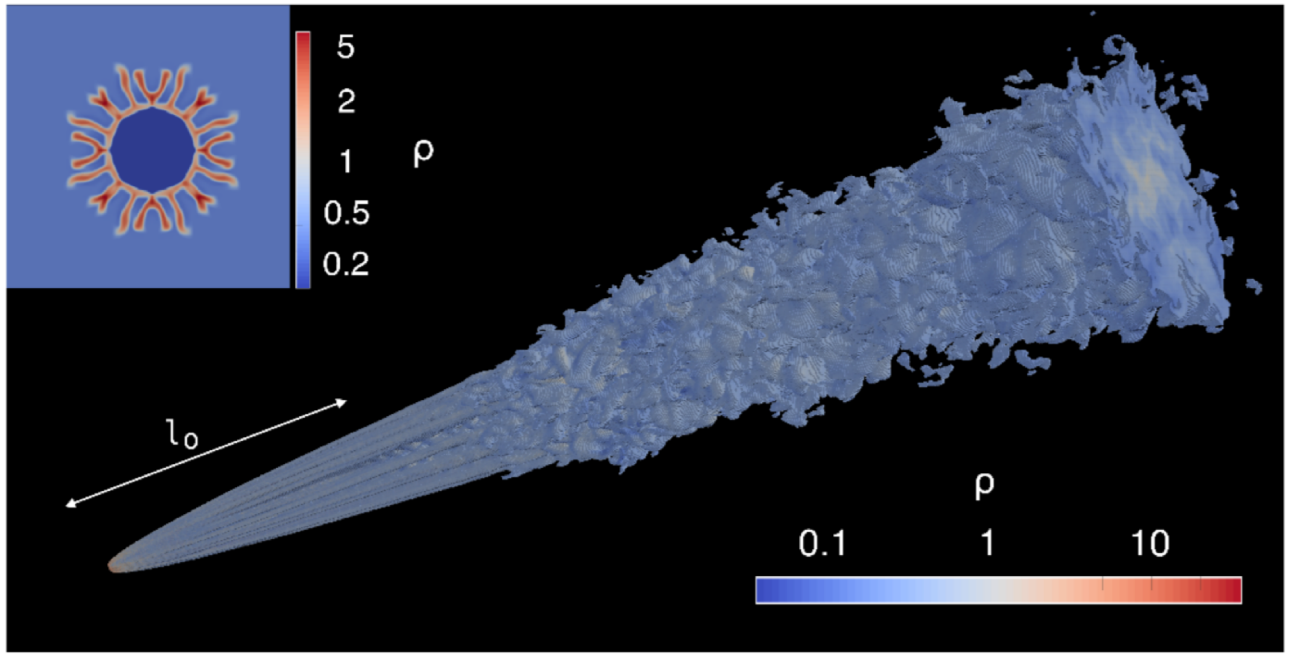


Jet de-collimation

Centrififugal RT instability de-collimation and decelerate the jet

Meliani &Keppens 2007, 2009

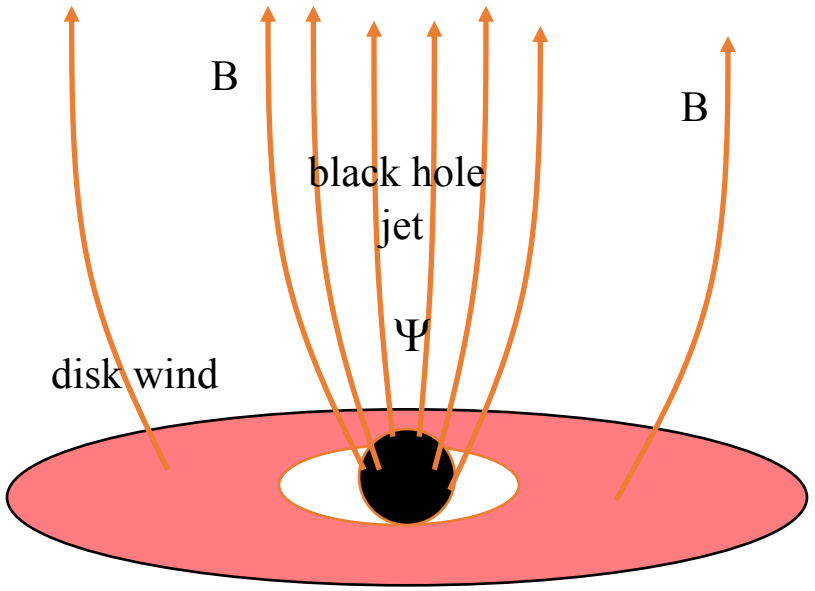
Millas, Keppens & Meliani 2018



Gourgouliatos & Komissarov 2018

Overview – Basic principle de MHD jet production

- Basic MHD mechanism: Blandford (1976); Lovelace (1976)
- Acceleration by rotating black holes (Blandford & Znajek [1977])
- Acceleration by rotating [thin] accretion disks (Blandford & Payne [1982])

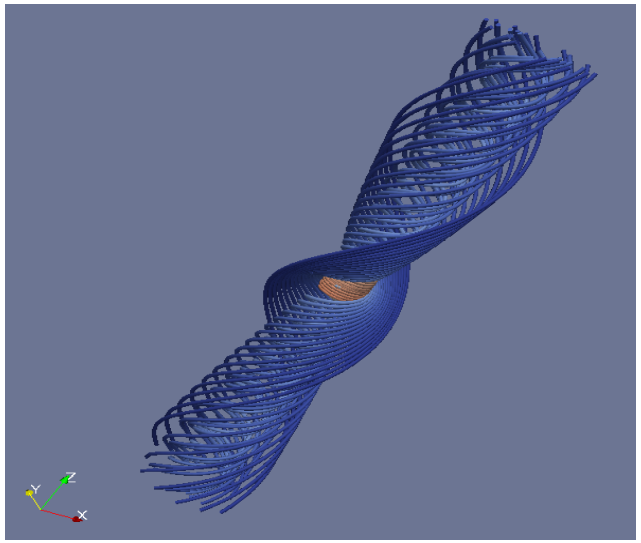


•Inertia generates toroidal field and poloidal current
•Acceleration by Lorentz-force
$j \times B + \rho_e E$
and thermal force
•Collimation due to tension in the toroidal field

Initial state in a glimpse

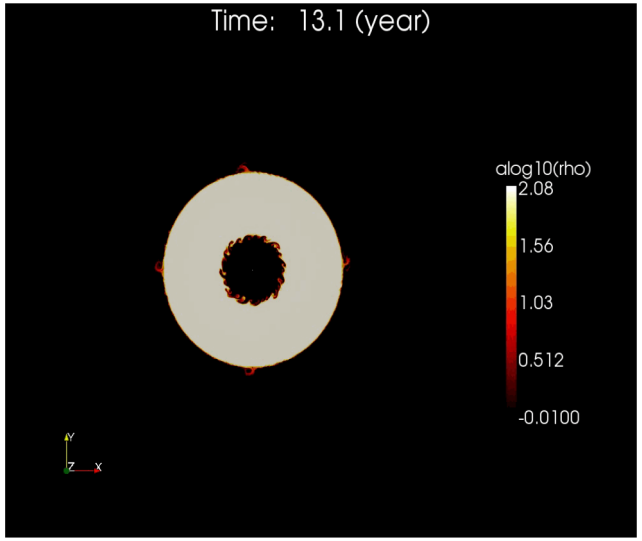
Speed profile

- Lorentz factor **~30** (inner jet), **~3** (outer jet)
- Approximately constant in each component
- No discontinuity in v_ϕ at the interface but assume differential rotation
- Typical values for AGN jets



Density profile

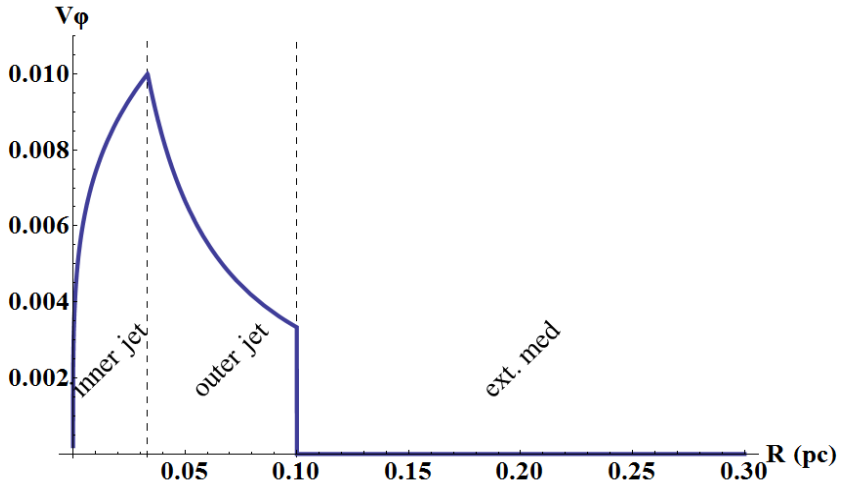
- $\rho(r)=\begin{cases} 6.92\rho_{ext}\,, & r \le r_{in} \\ 119.94 \cdot 10^2 \rho_{ext}\,, & r_{in} < r < r_{out} \\ \rho_{ext}\,, & r > r_{out} \end{cases}$

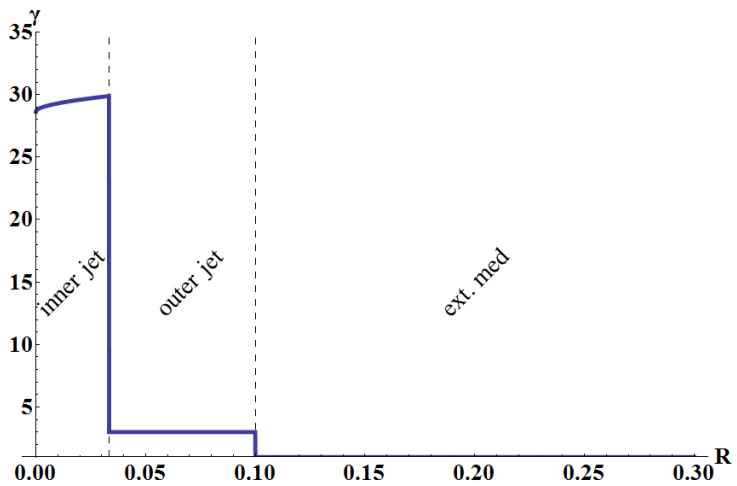


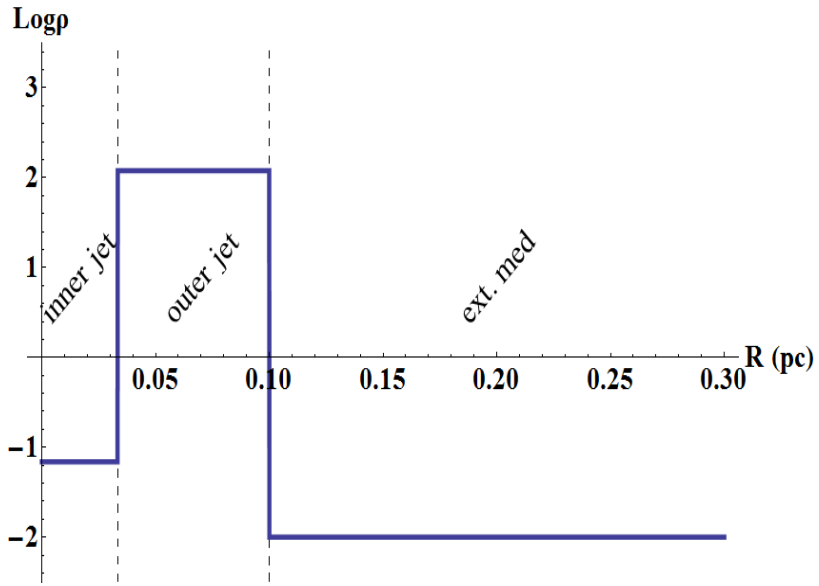
Assume a polytropic equation of state:

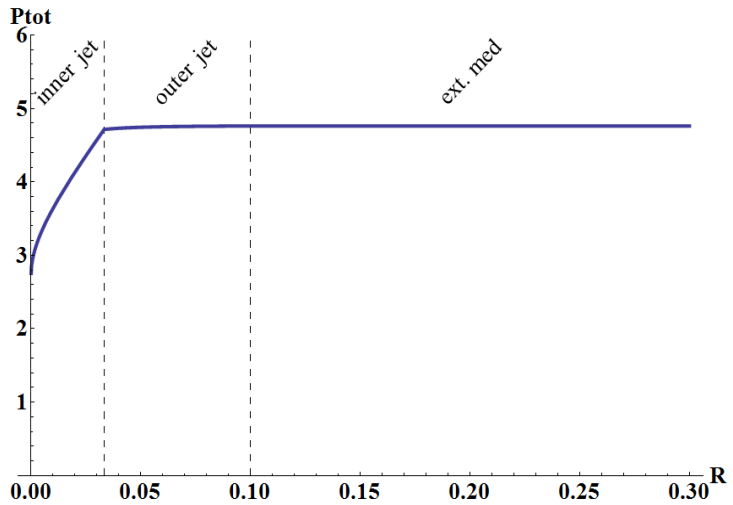
- $\Gamma_{eff,in}$= 4/3 (hot)
- $\Gamma_{eff,out}$=5/3 (cold)

Structured jet model









High energy flux outer jet

Inner wind

1/3 of jet section

Fast $\gamma_Z \approx 30$

5% of total energy

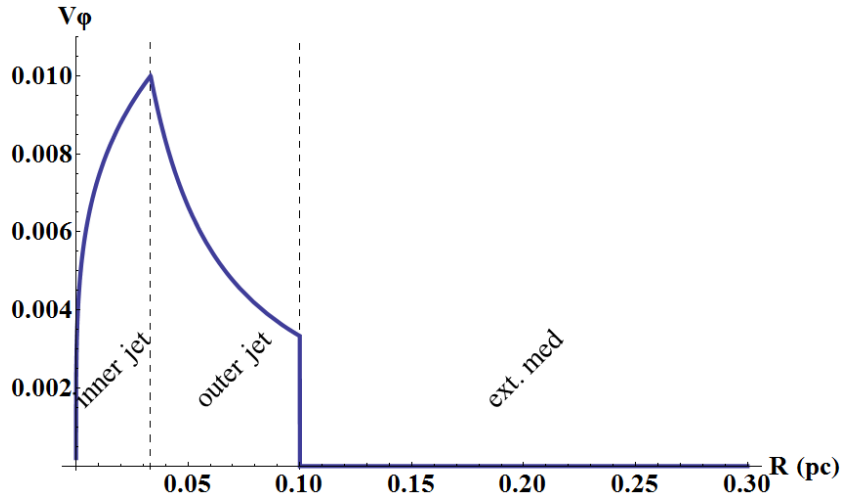
Outer jet

2/3 of jet section

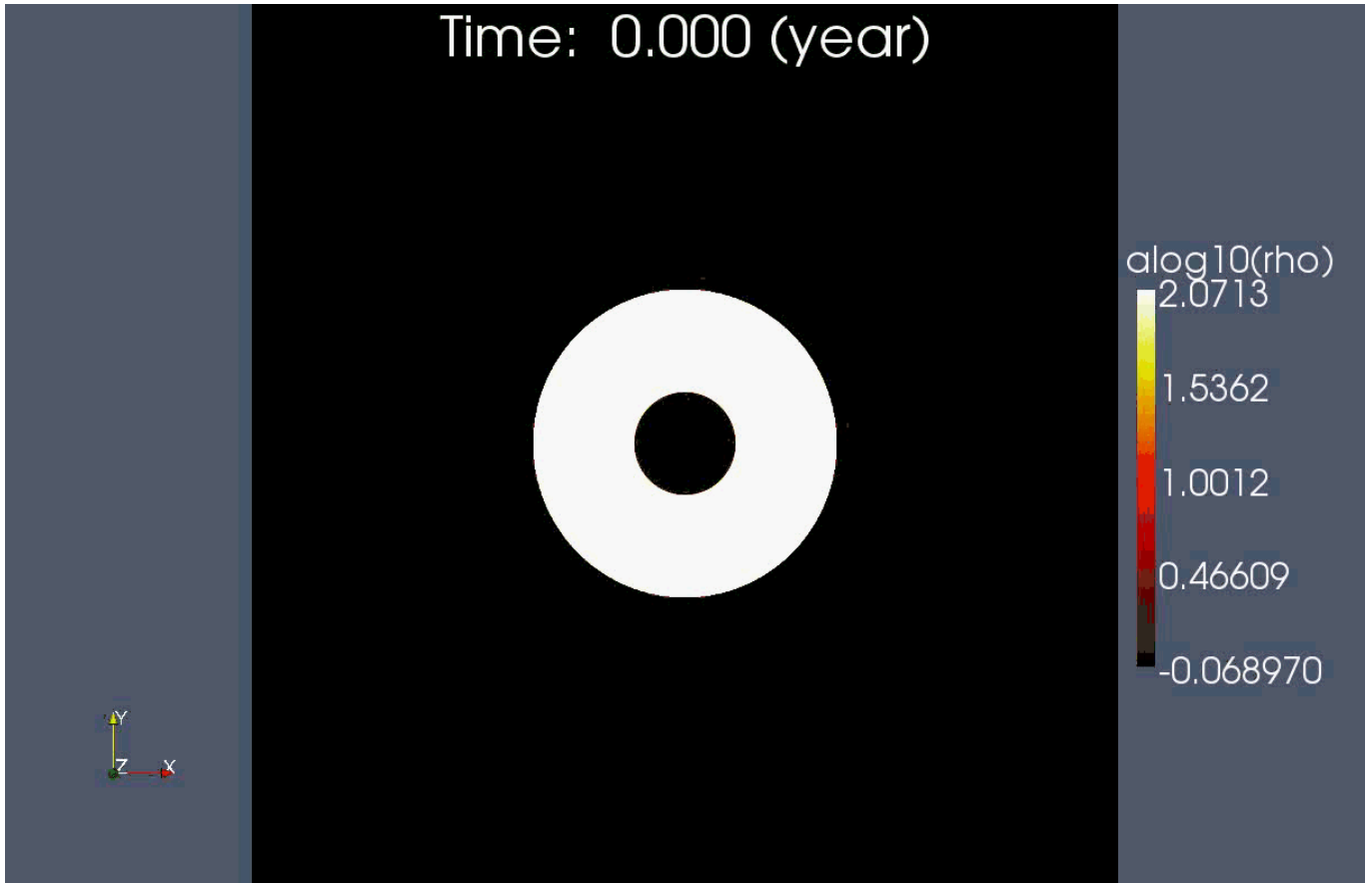
Slow $\gamma_Z \approx 3$

95% of total energy

The same amount of angular momentum is extracted by the inner wind and outer jet



High energy flux outer jet



Logarithm of the commoving frame density

Low energy flux outer jet

Inner wind

1/3 of jet section

Fast $\gamma_Z \approx 30$

30% of total energy

Outer jet

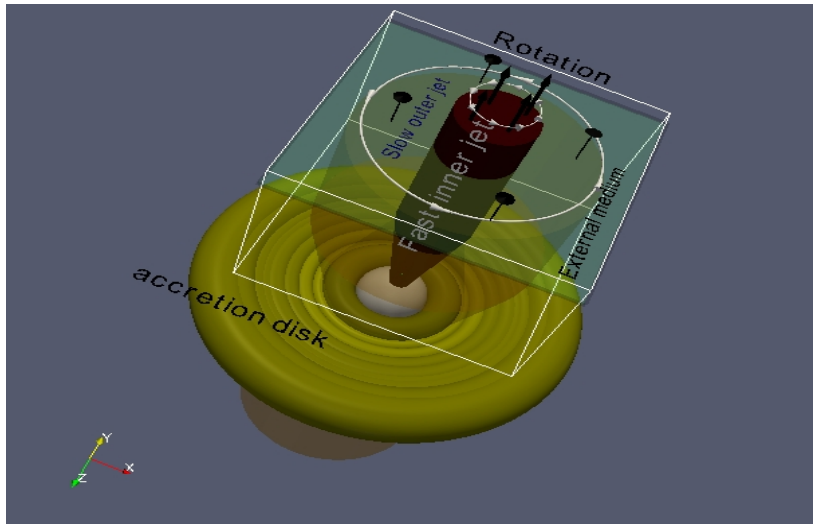
2/3 of jet section

Slow $\gamma_Z \approx 3$

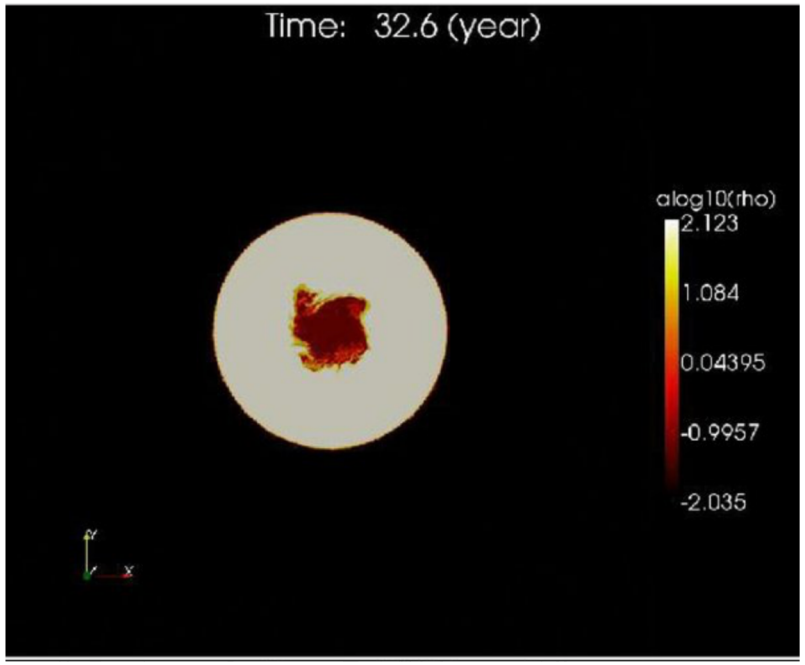
70% of total energy

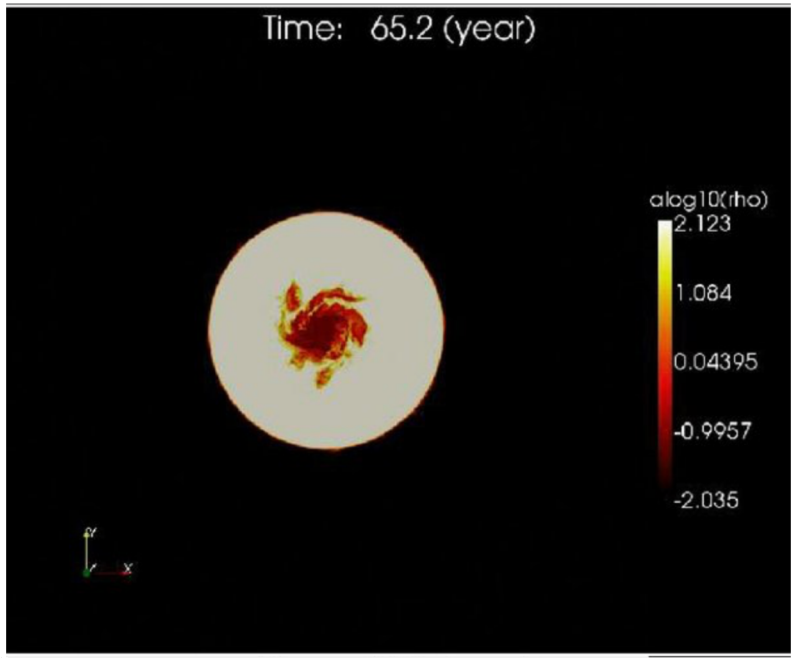
magnetize

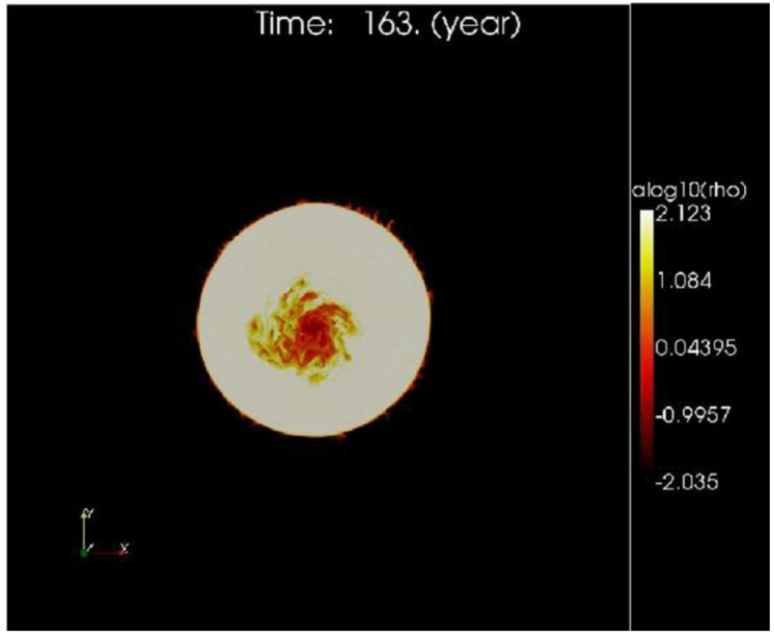
(poloidal magnetic field)



Low energy flux inner flow

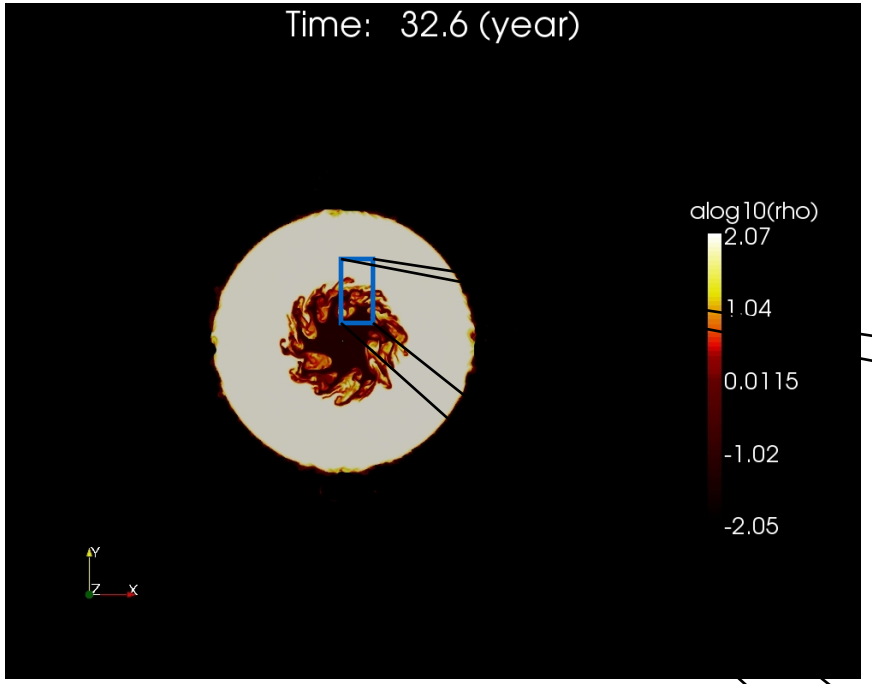






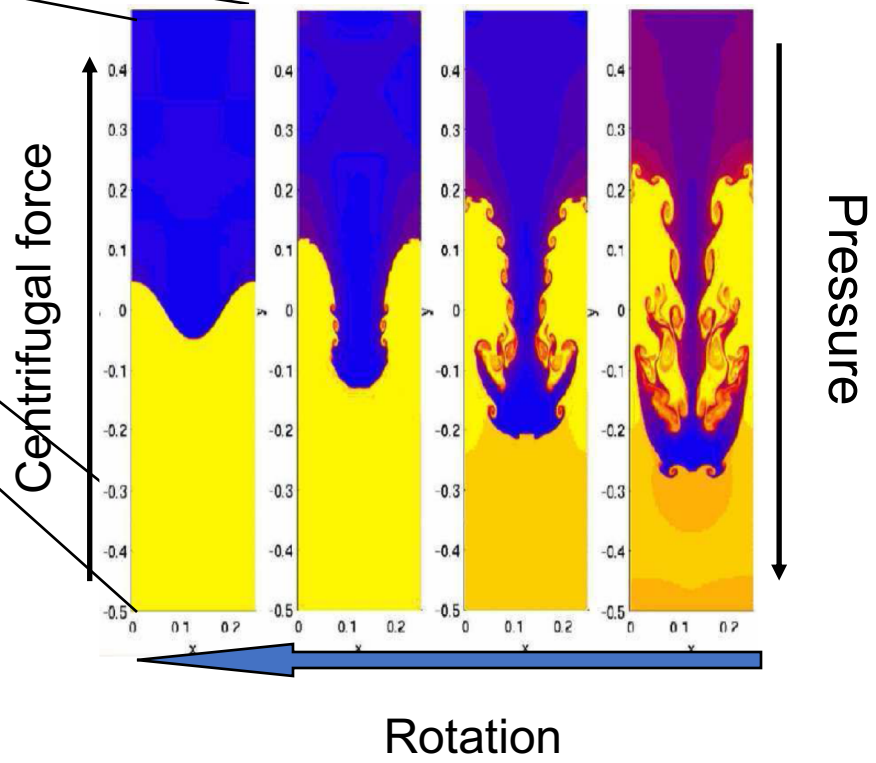
Logarithm of the commoving frame density

Interface stability



Centrifugal force - pressure equilibrium can be instable

Angular momentum extraction from the inner jet



Analogous of Rayleigh-Taylor instability

Instability criterion

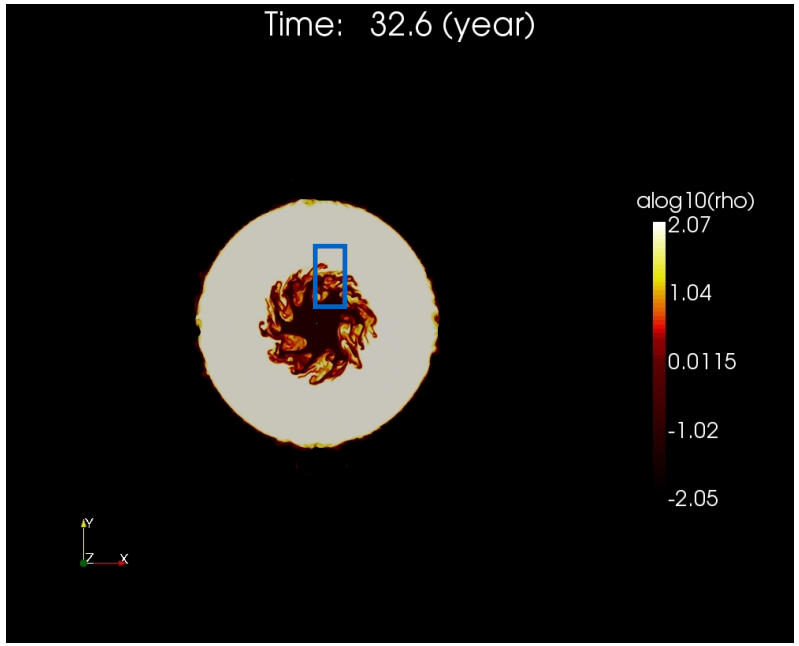
Enthalpy

Toroidal speed

$$\omega \propto k\left[\left(\gamma^2 h + B_z^2 + \gamma^2 B_\varphi^2\right)_{in} - \left(\gamma^2 h + B_z^2 + \gamma^2 B_\varphi^2\right)_{out}\right] v^\varphi$$

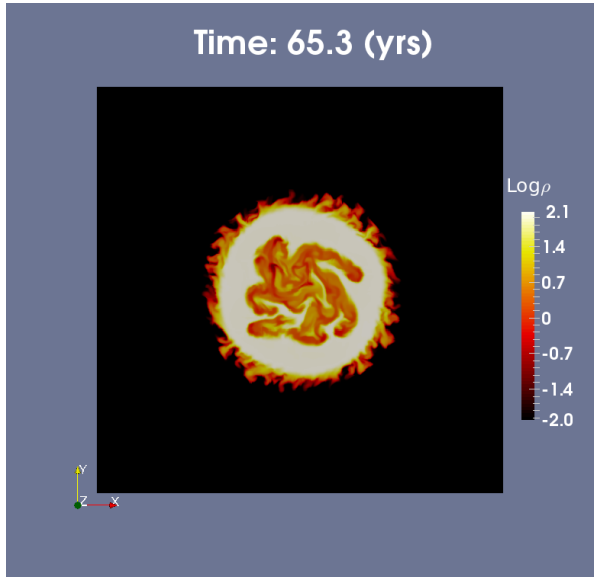
Lorentz factor

Poloidal magnetic field

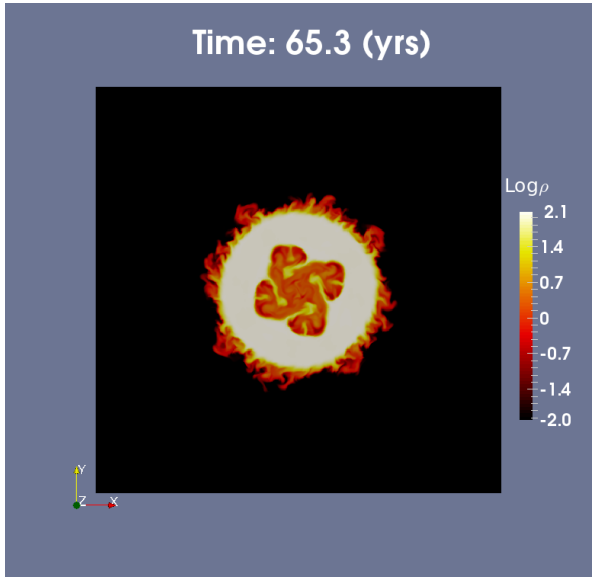


The effects of toroidal magnetic field (phase I)

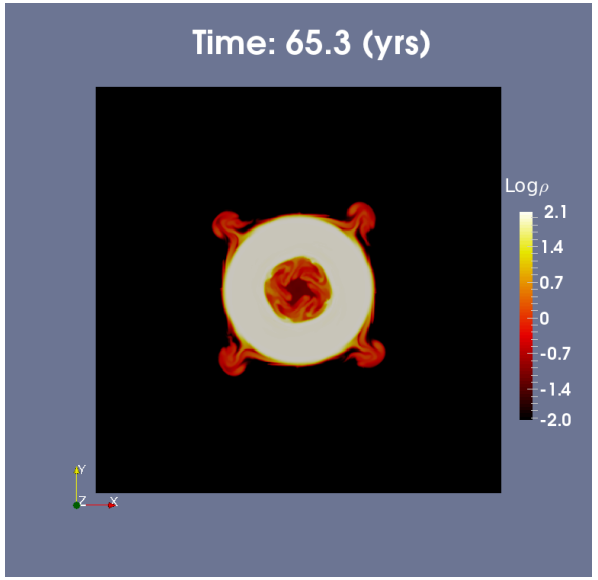
σ



σ = 0.001



σ = 0.01

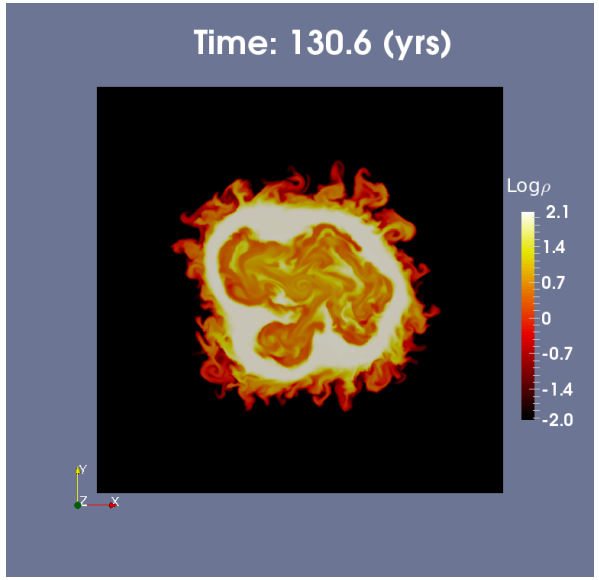


σ = 0.1

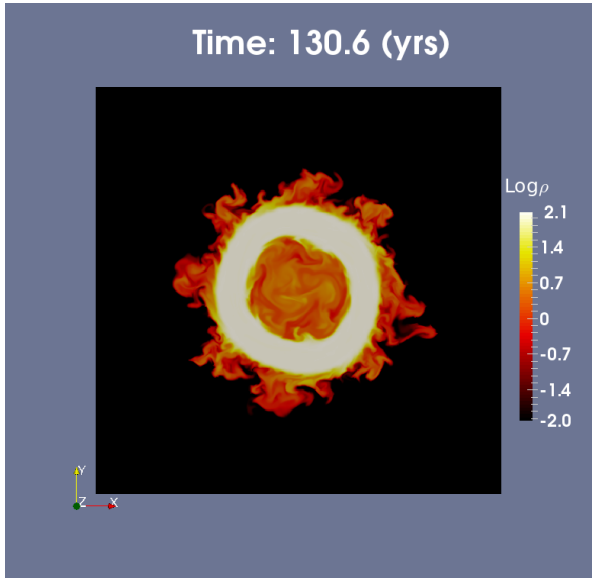
t = 1 rotation

The effects of toroidal magnetic field (phase II)

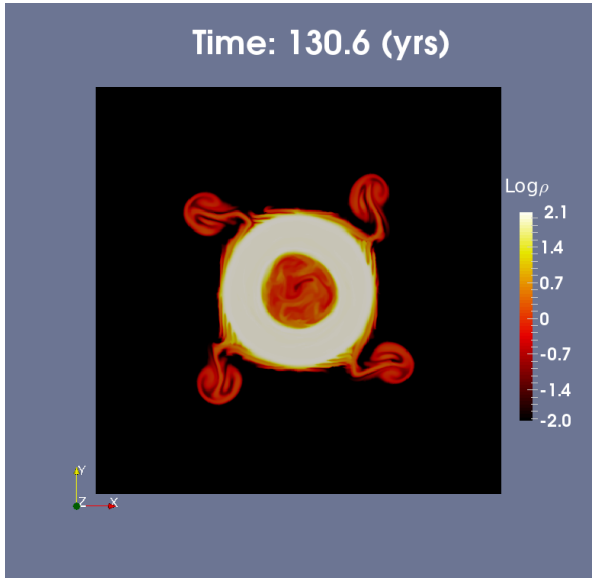
σ



σ = 0.001



σ = 0.01

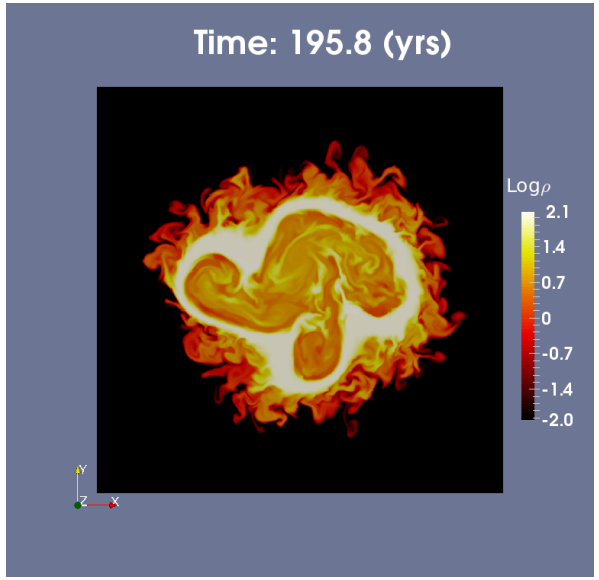


σ = 0.1

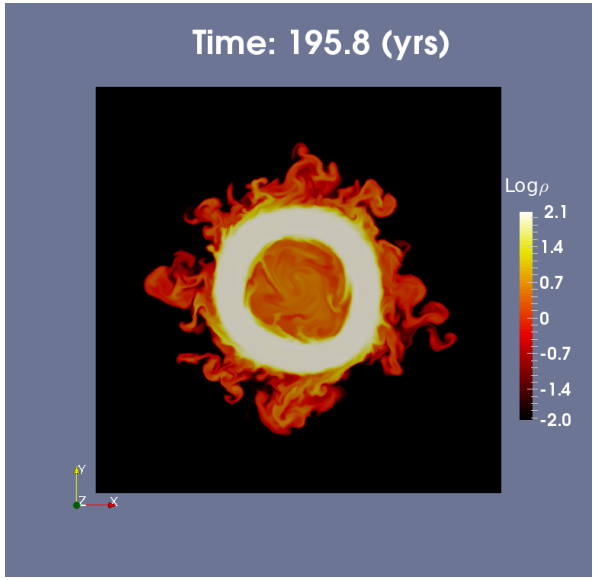
t = 2 rotations

The effects of toroidal magnetic field (phase III)

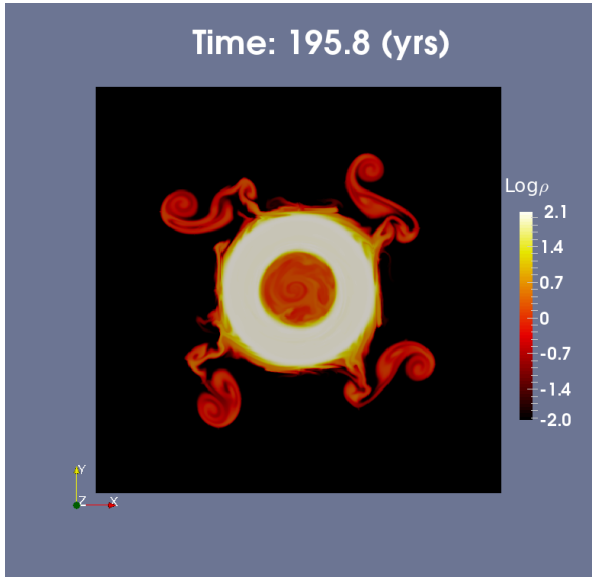
σ



σ = 0.001



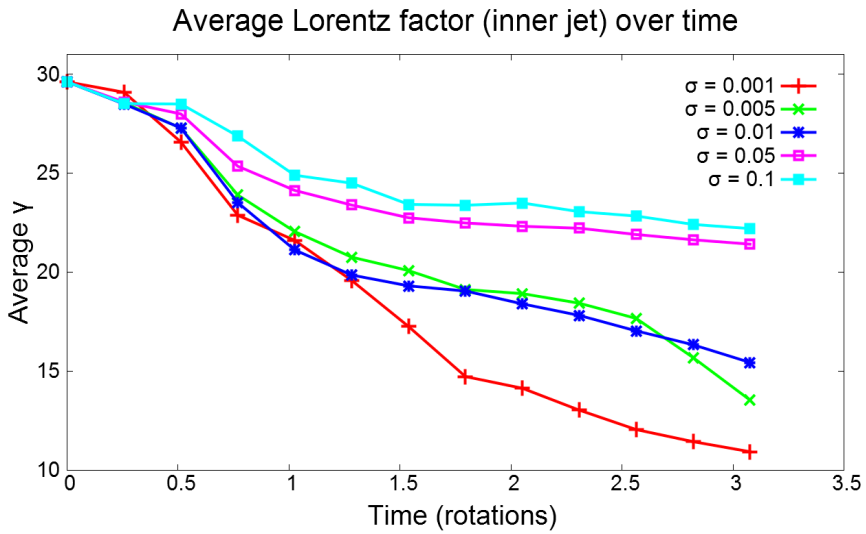
σ = 0.01

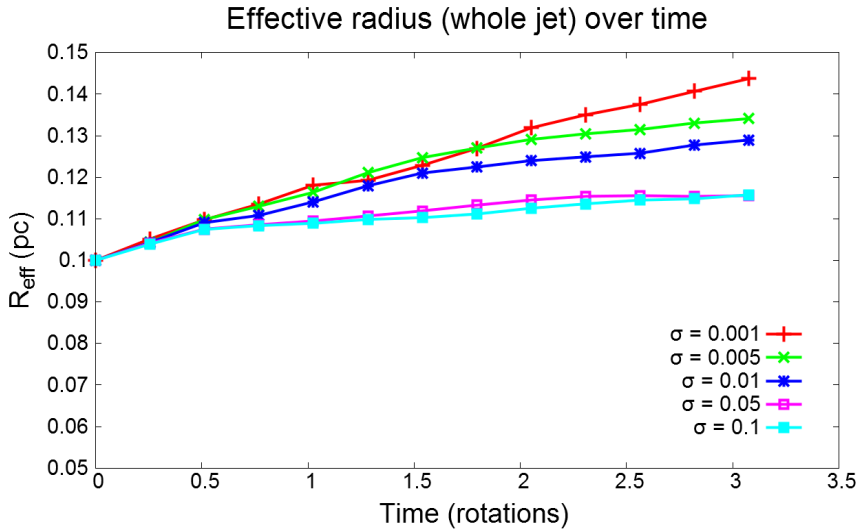


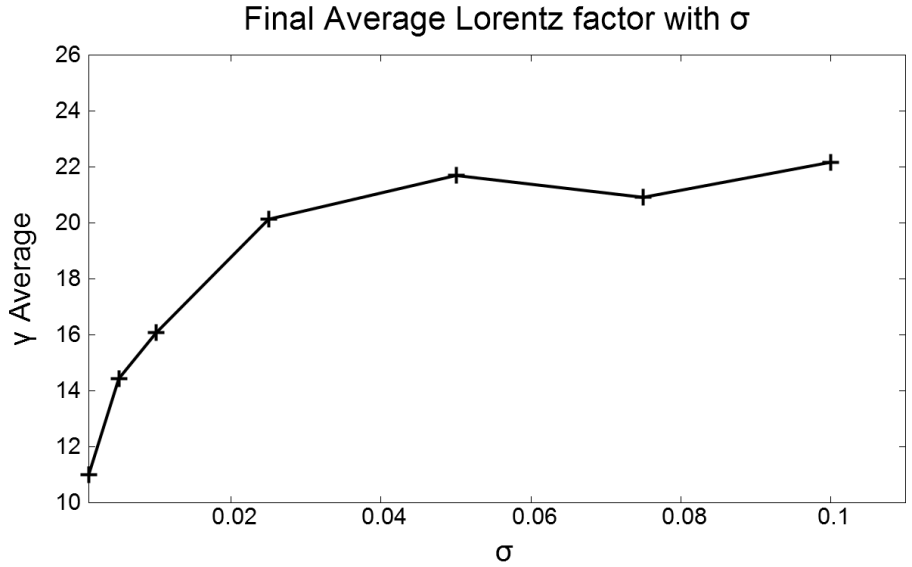
σ = 0.1

t = 3 rotations

Deceleration – de-collimation of the jet







Conclusions

Rotation of relativistic jet induces RT centrifugal instability.

Toroidal magnetic field stabilise the jet against RT instability.