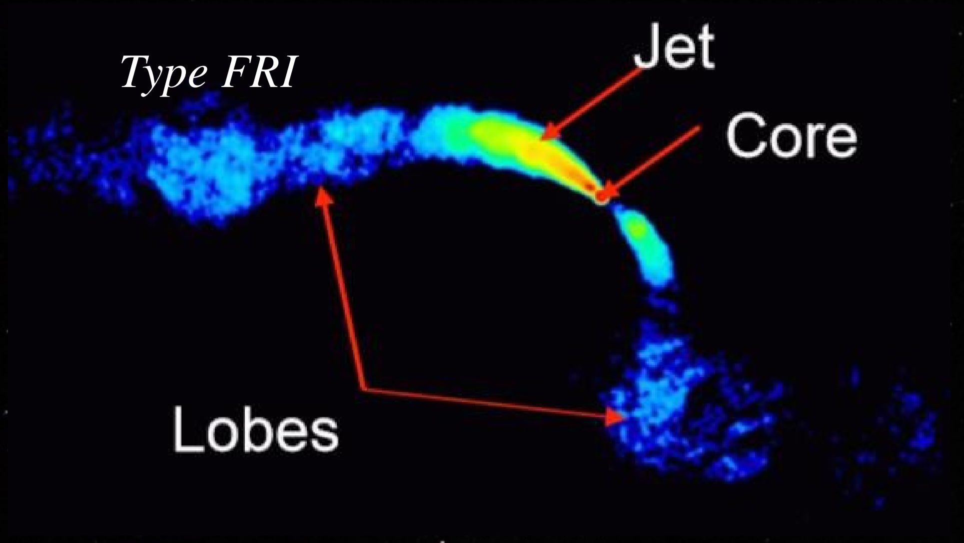
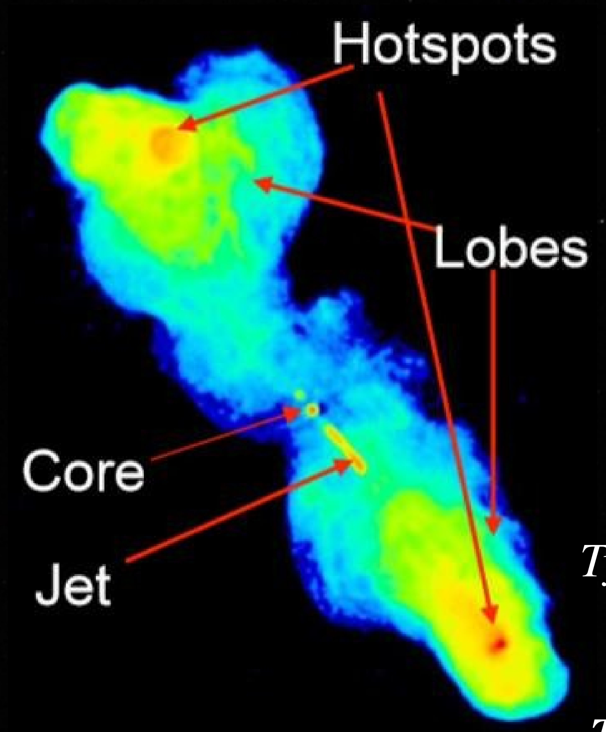
Jet asymptotic collimation : how does it depend on the source properties ?





Type FRII

Thomas Jannaud *(IPAG, Grenoble)*

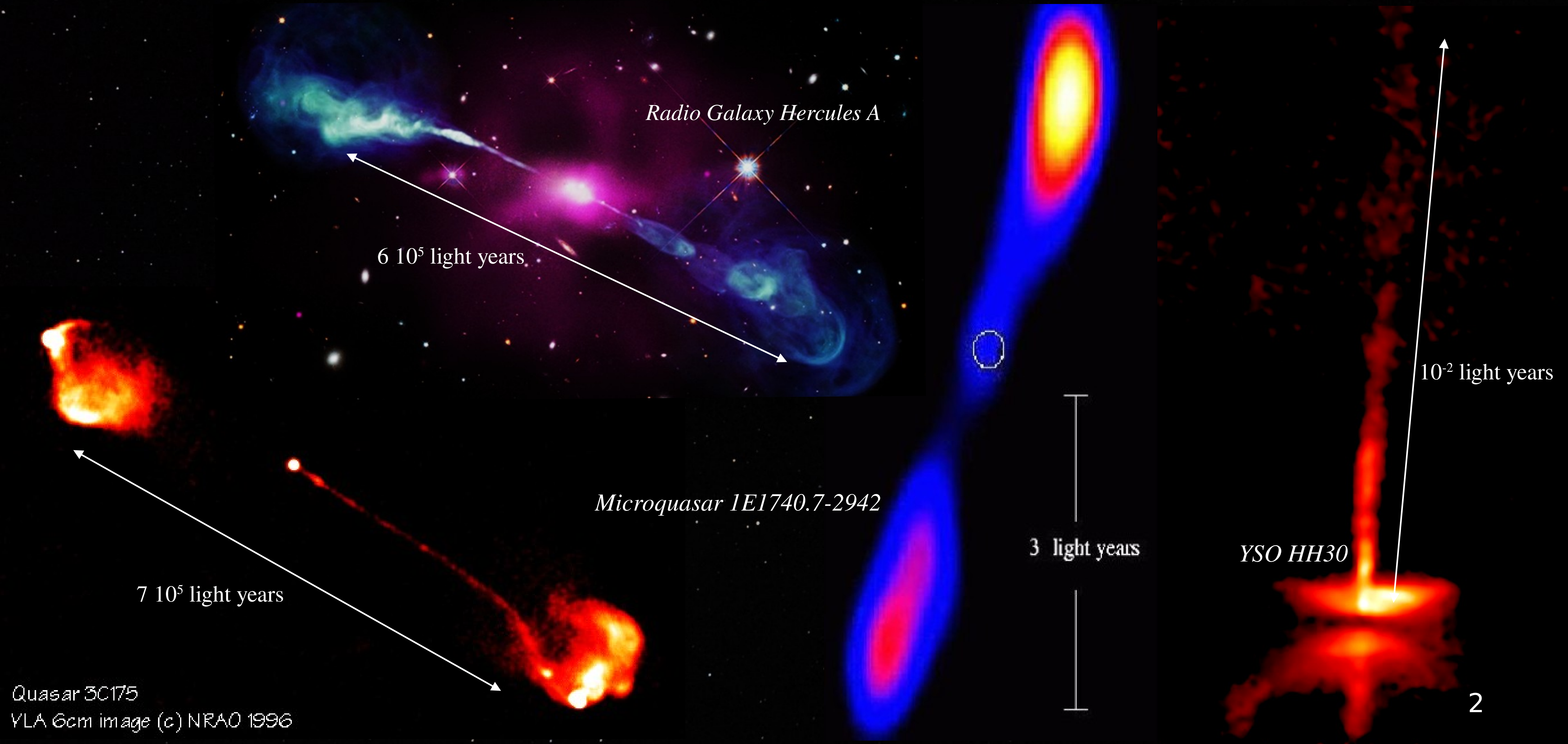
Jonathan Ferreira (IPAG, Grenoble)

Claudio Zanni (INAF, Turin)

Presentation for the 10th FERO meeting

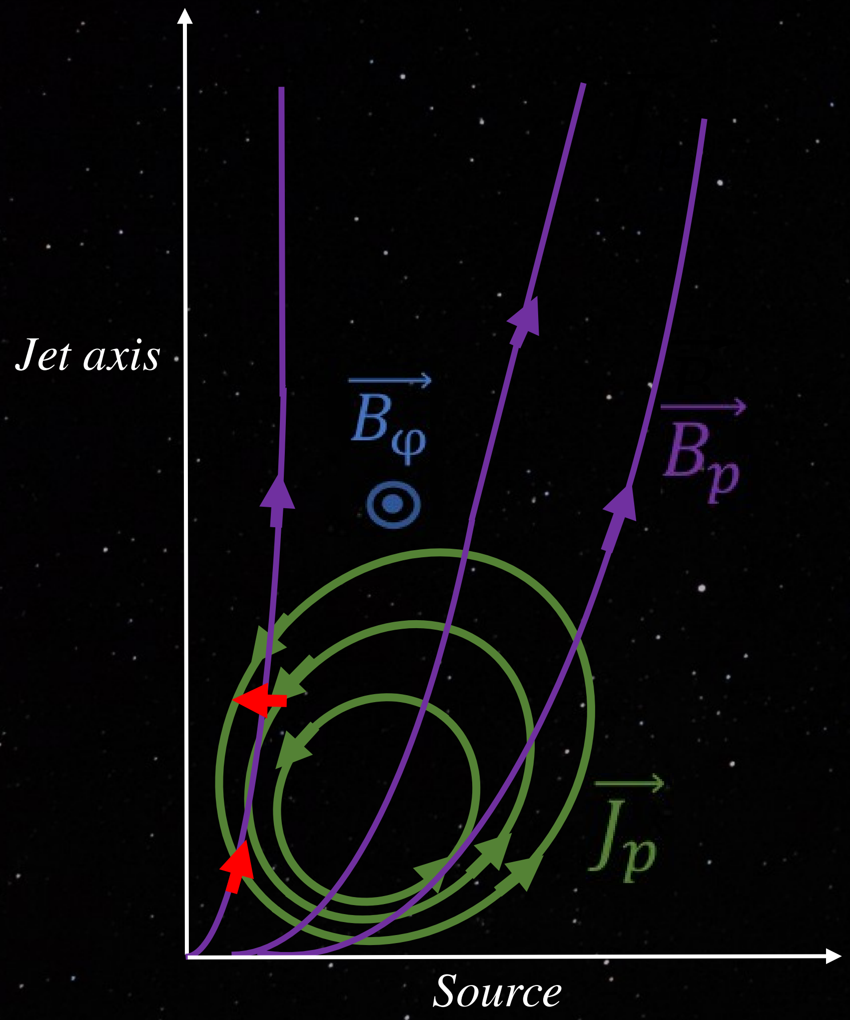
March 31, 2022

Astrophysical jets



Collimation properties

- Magnetic field and electric current ⇒ Acceleration and collimation



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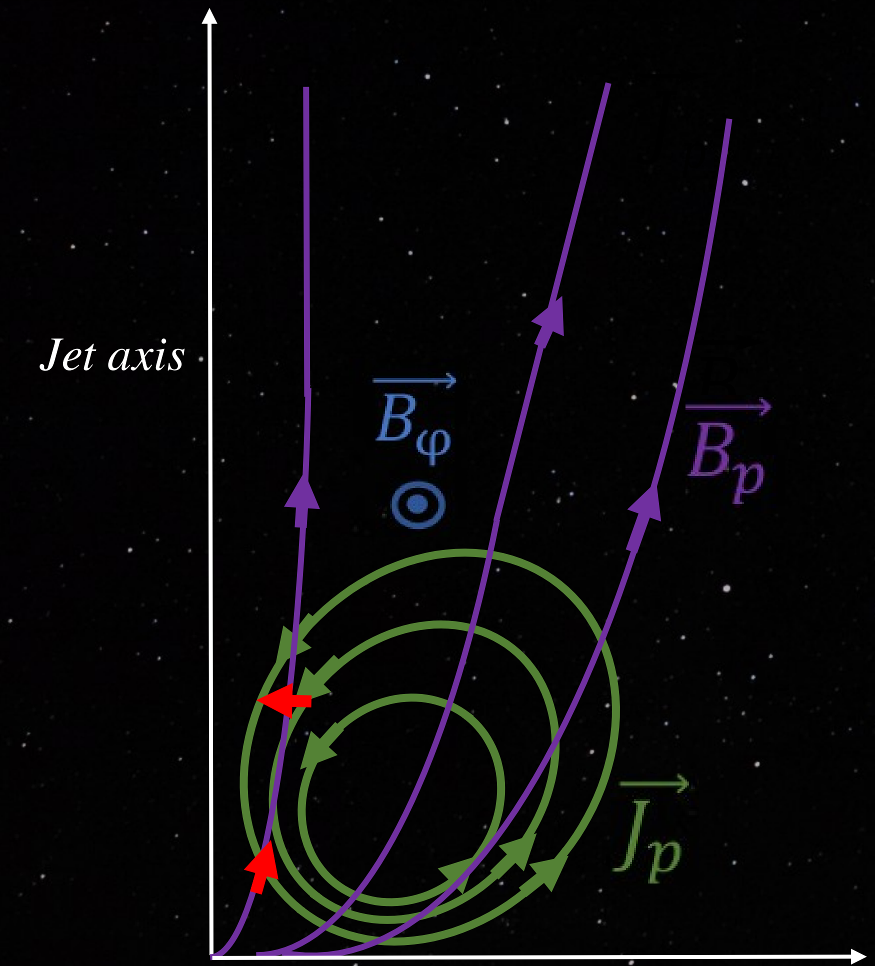
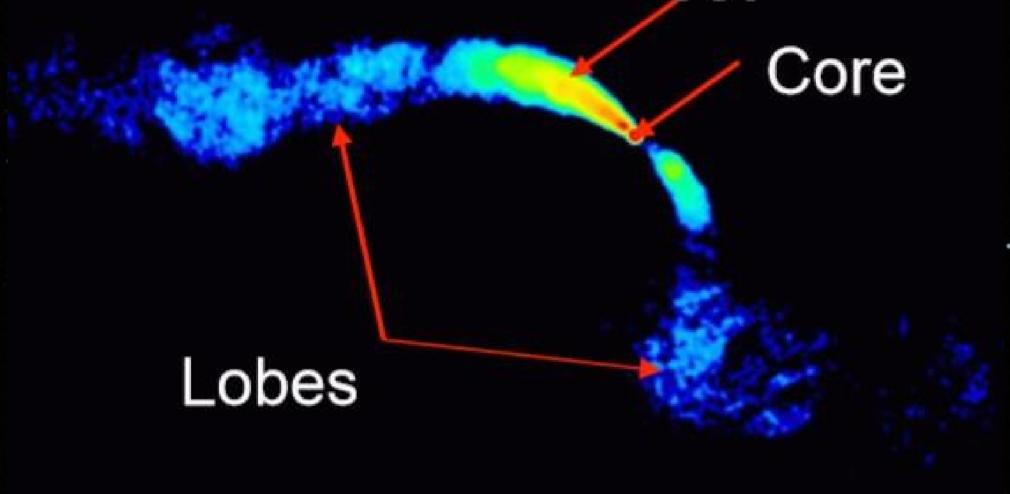
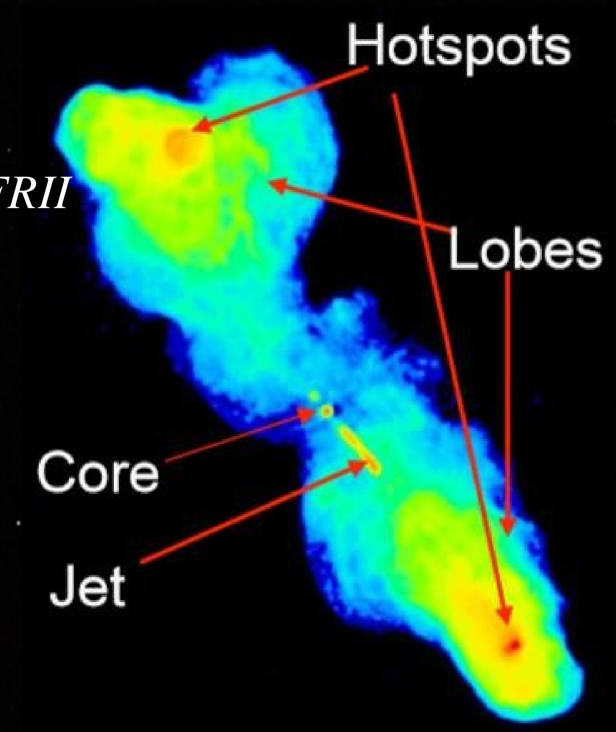


Type FRI

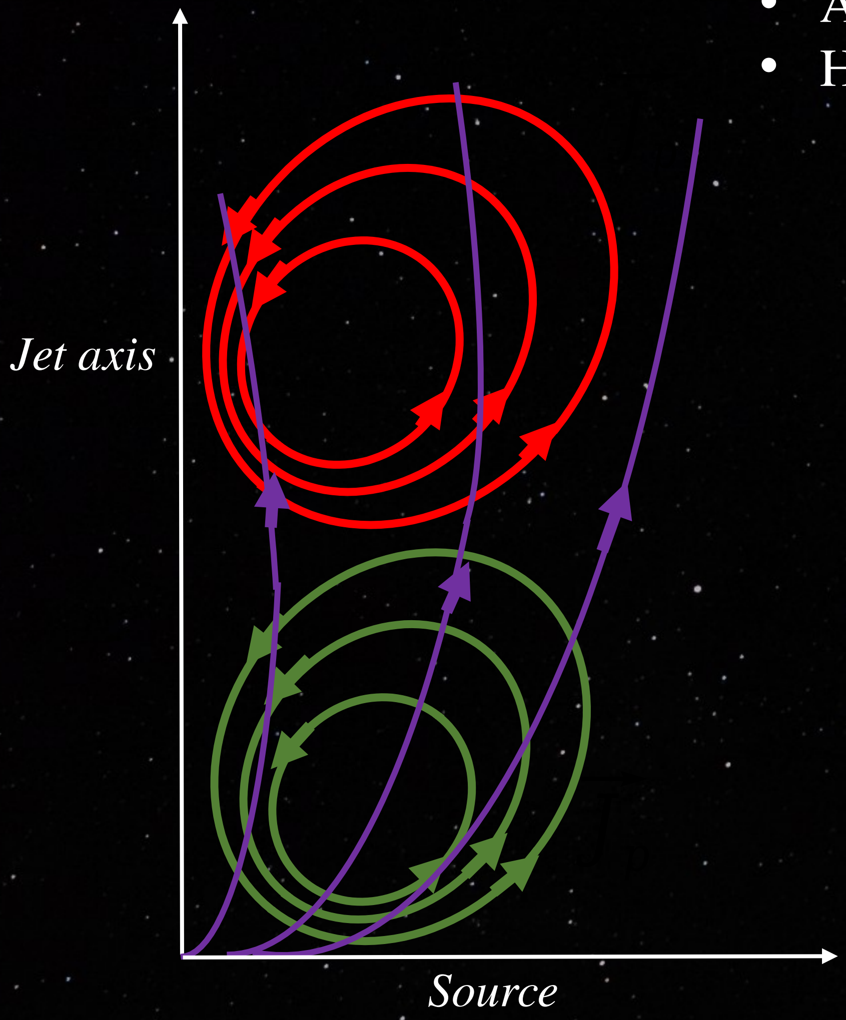


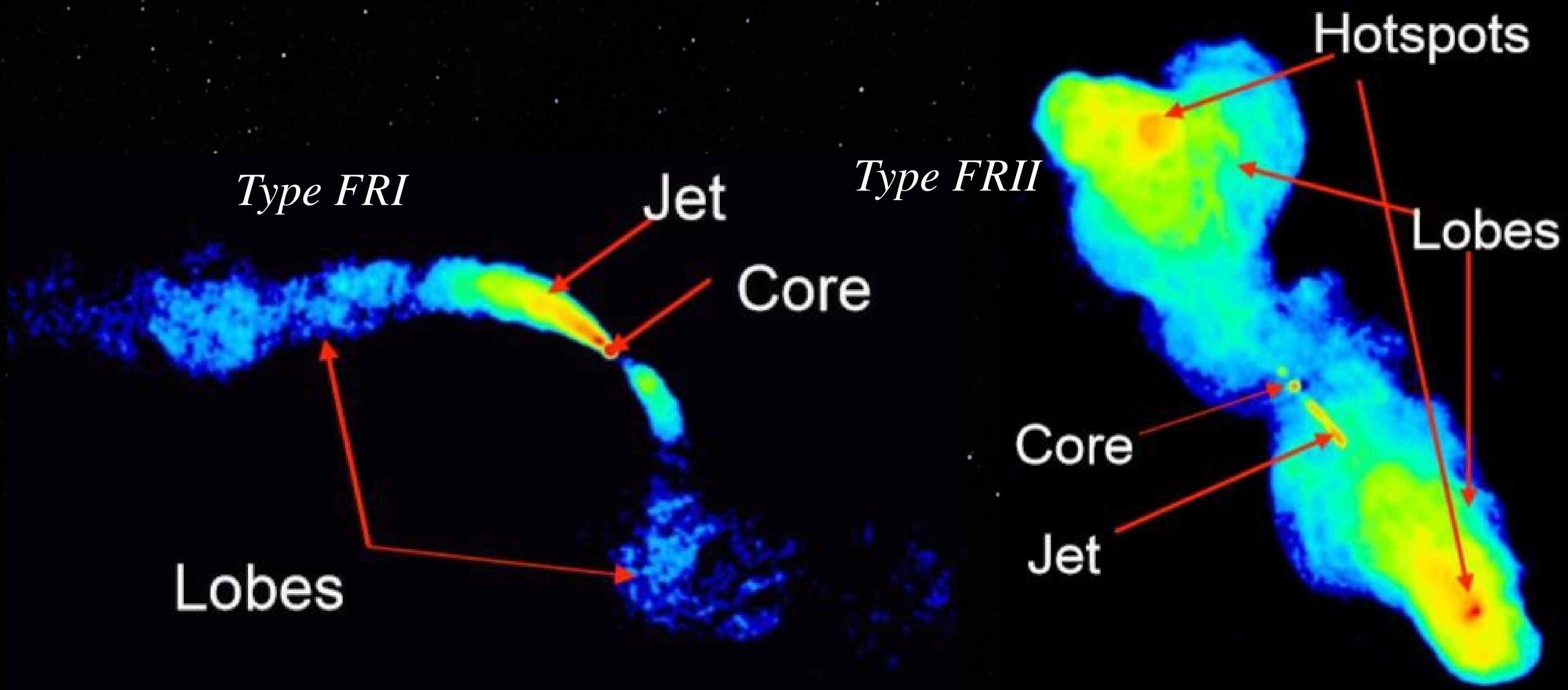
Type FRII



Collimation properties

- Magnetic field and electric current ⇒ Acceleration and collimation
- Asymptotic current ⇒ Observable shape (Heyvaerts & Norman 1989; 2003)
- How is the asymptotic current linked to the source ?





Jet source

What kind of jet source ?

- Black hole (Blandford & Znajek 1977)
- Accretion disk (Blandford & Payne 1982) ⇒ Jet-Emitting Disk (JED, Ferreira 1997)

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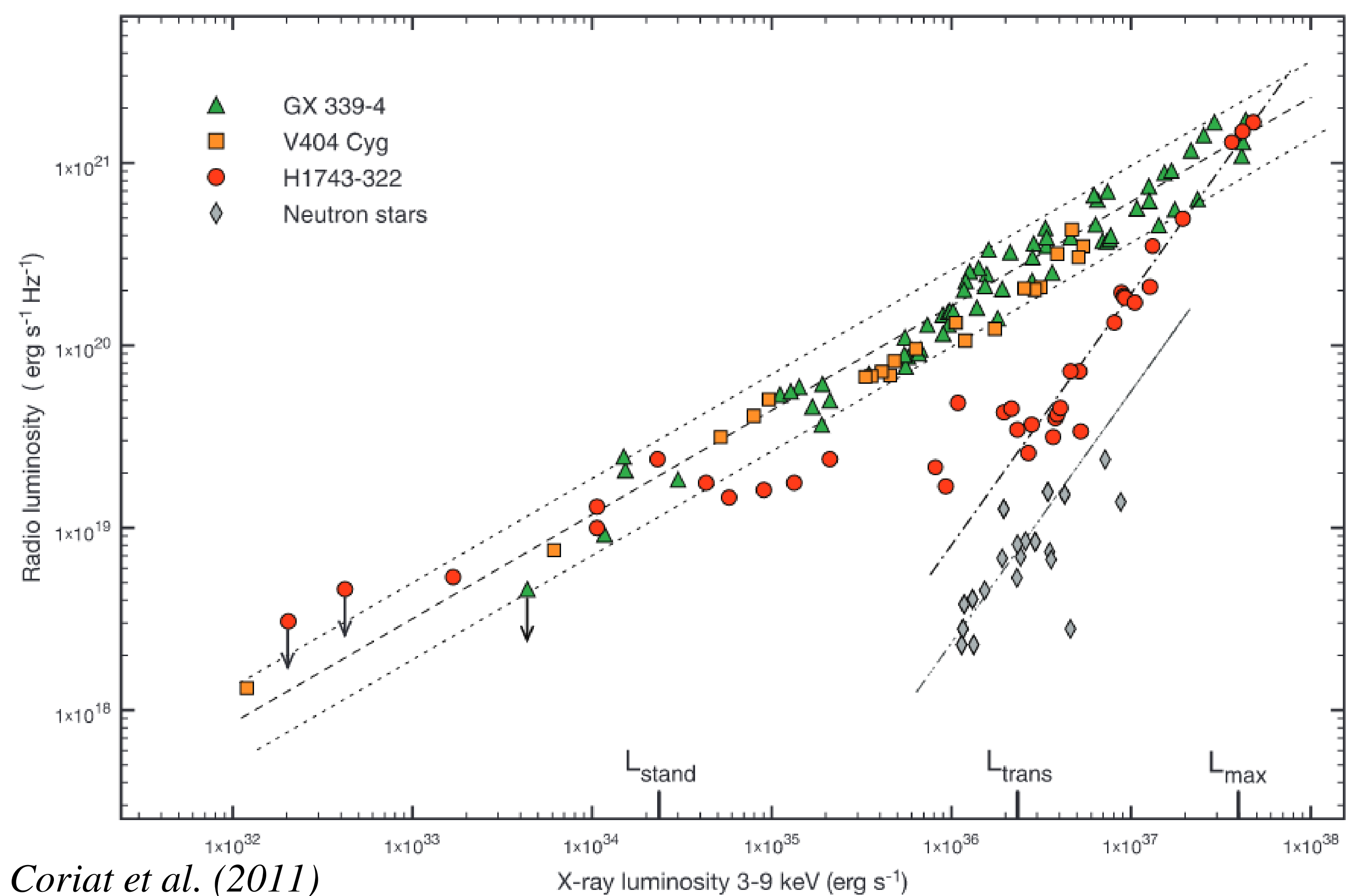

Coriat et al. (2011)

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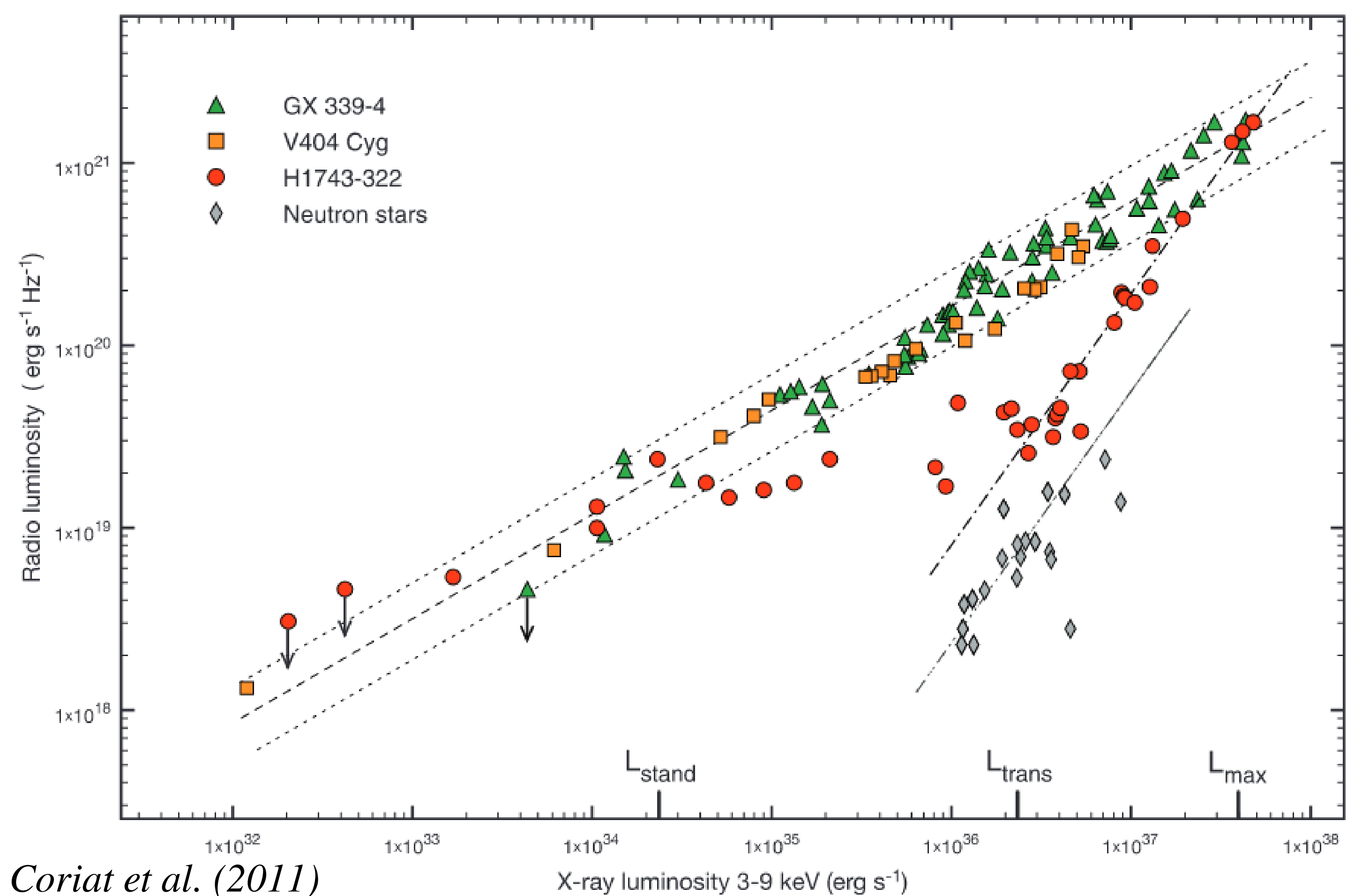
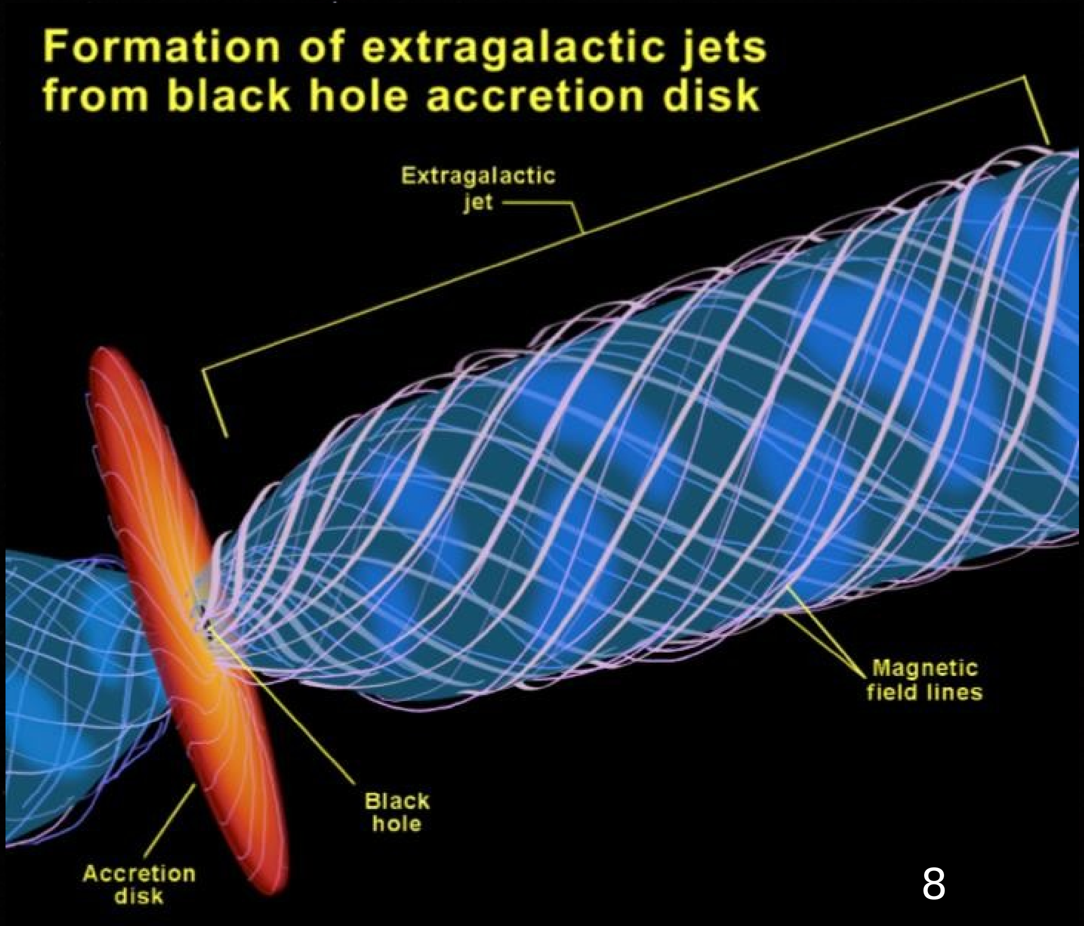
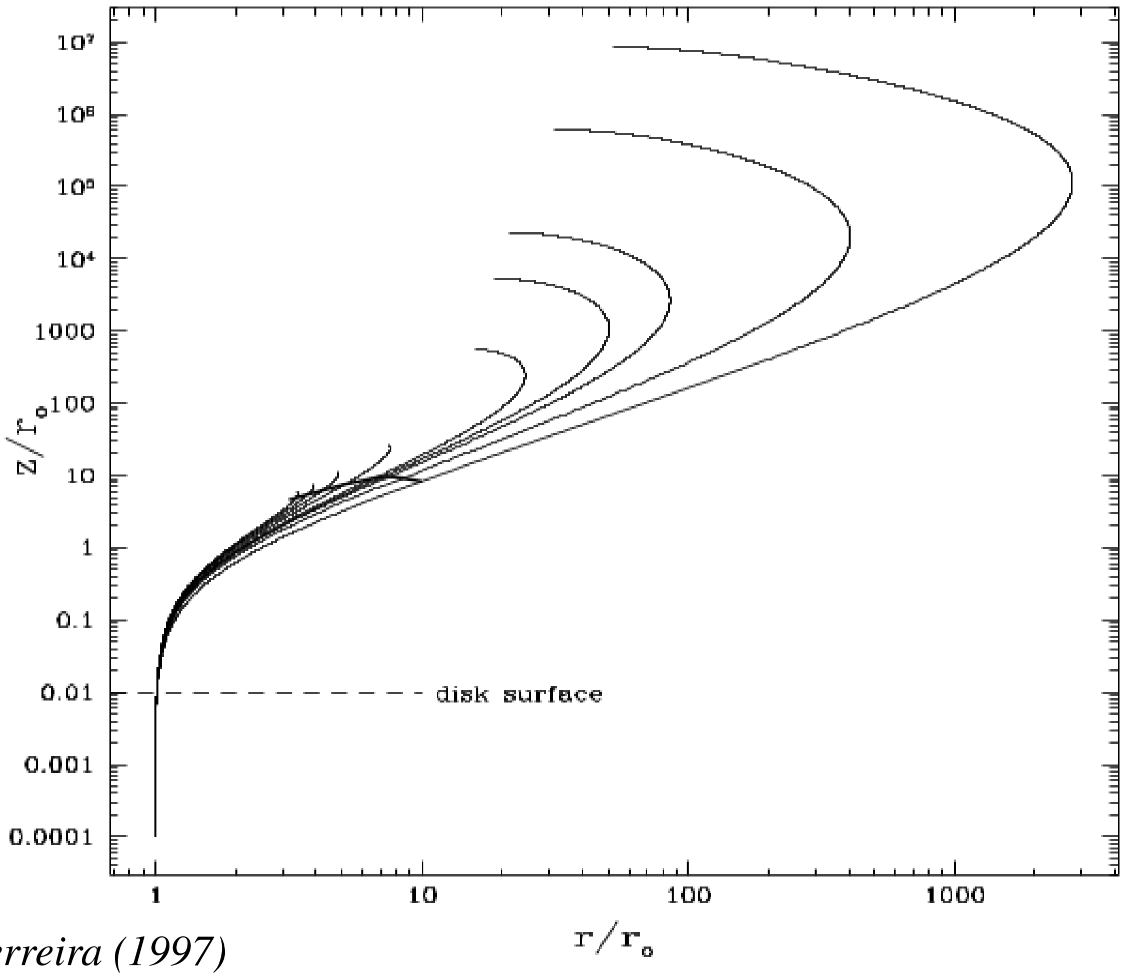


Coriat et al. (2011)



Collimation of jets emitted from JEDs

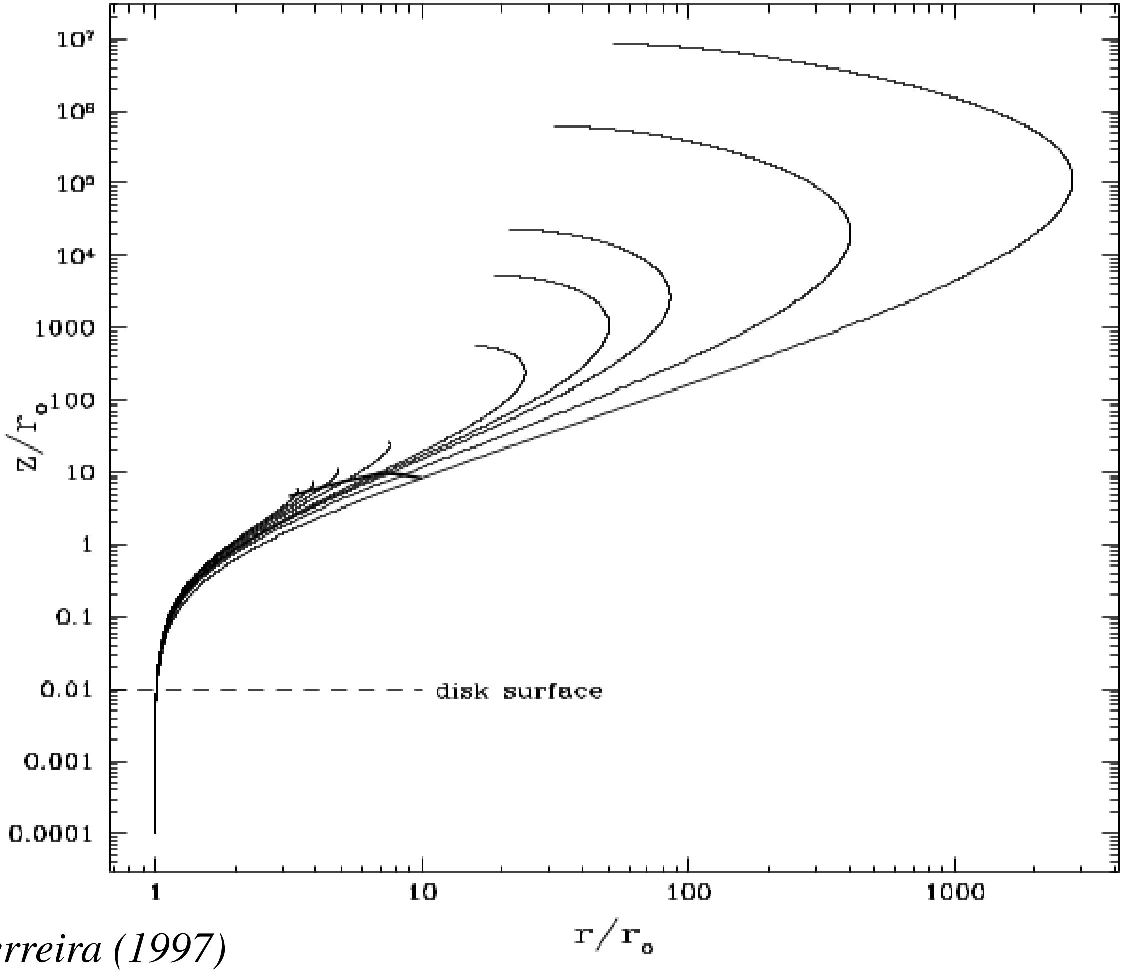
- Self-similar ansatz (Blandford & Payne 1982, Contopoulos & Lovelace 1994, Ferreira 1997)



Ferreira (1997)

Collimation of jets emitted from JEDs

- Self-similar ansatz (Blandford & Payne 1982, Contopoulos & Lovelace 1994, Ferreira 1997)
- Recollimation present ⇒ shocks expected (Ferreira 1997, Polko & al. 2010)



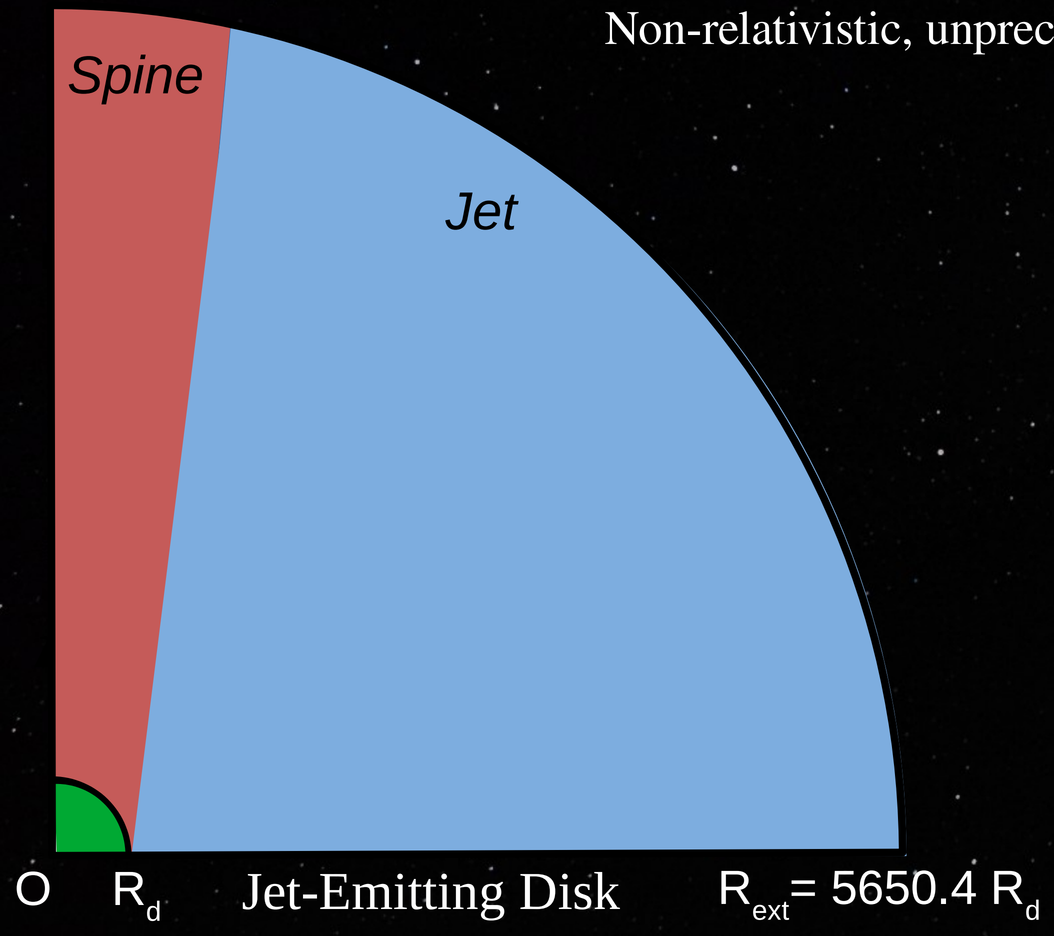
Ferreira (1997)

Numerical MHD simulations

Two-component outflow :

- Inner spine : Non-rotating central object (Schwarzchild Black Hole)
- Jet : Emission as in Ferreira 1997 (see Marcel+ 2018ab; 2019; 2020; 2021) on X-ray binaries

Non-relativistic, unprecedented scales



Numerical setup

Numerical MHD simulations

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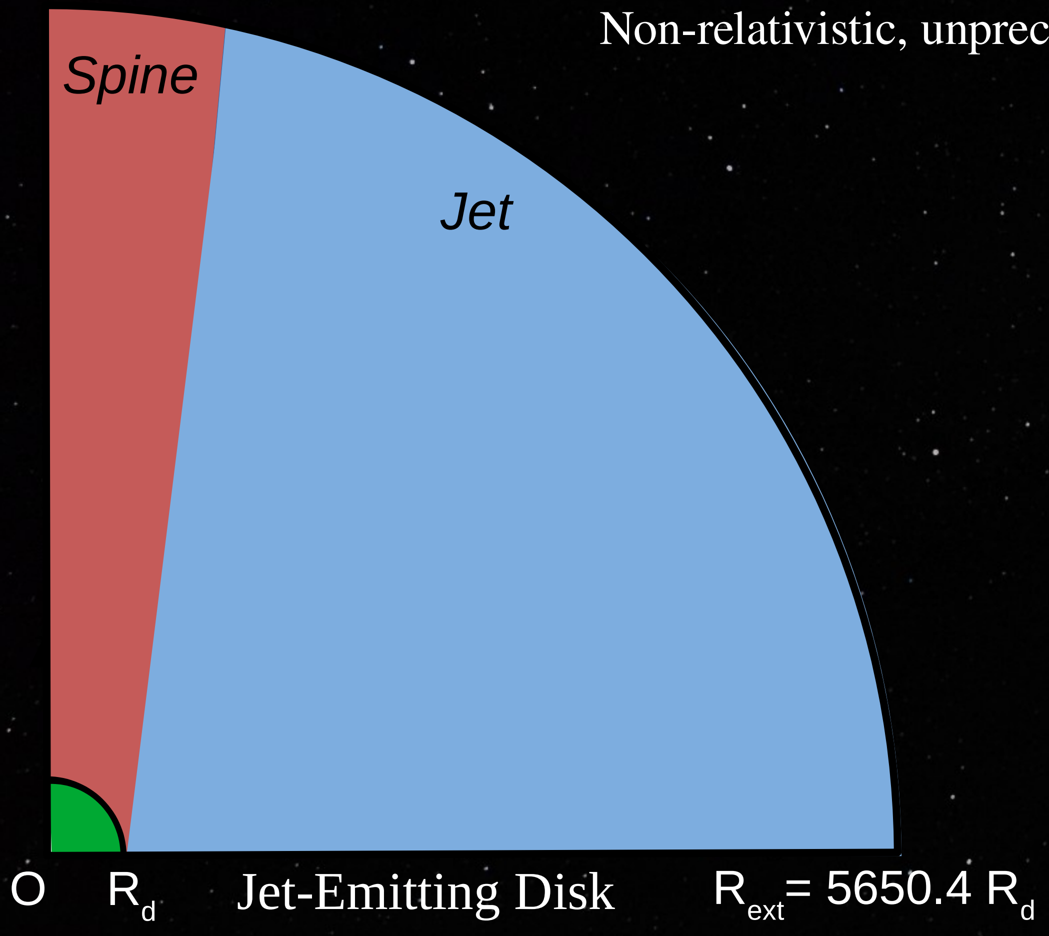


Numerical setup

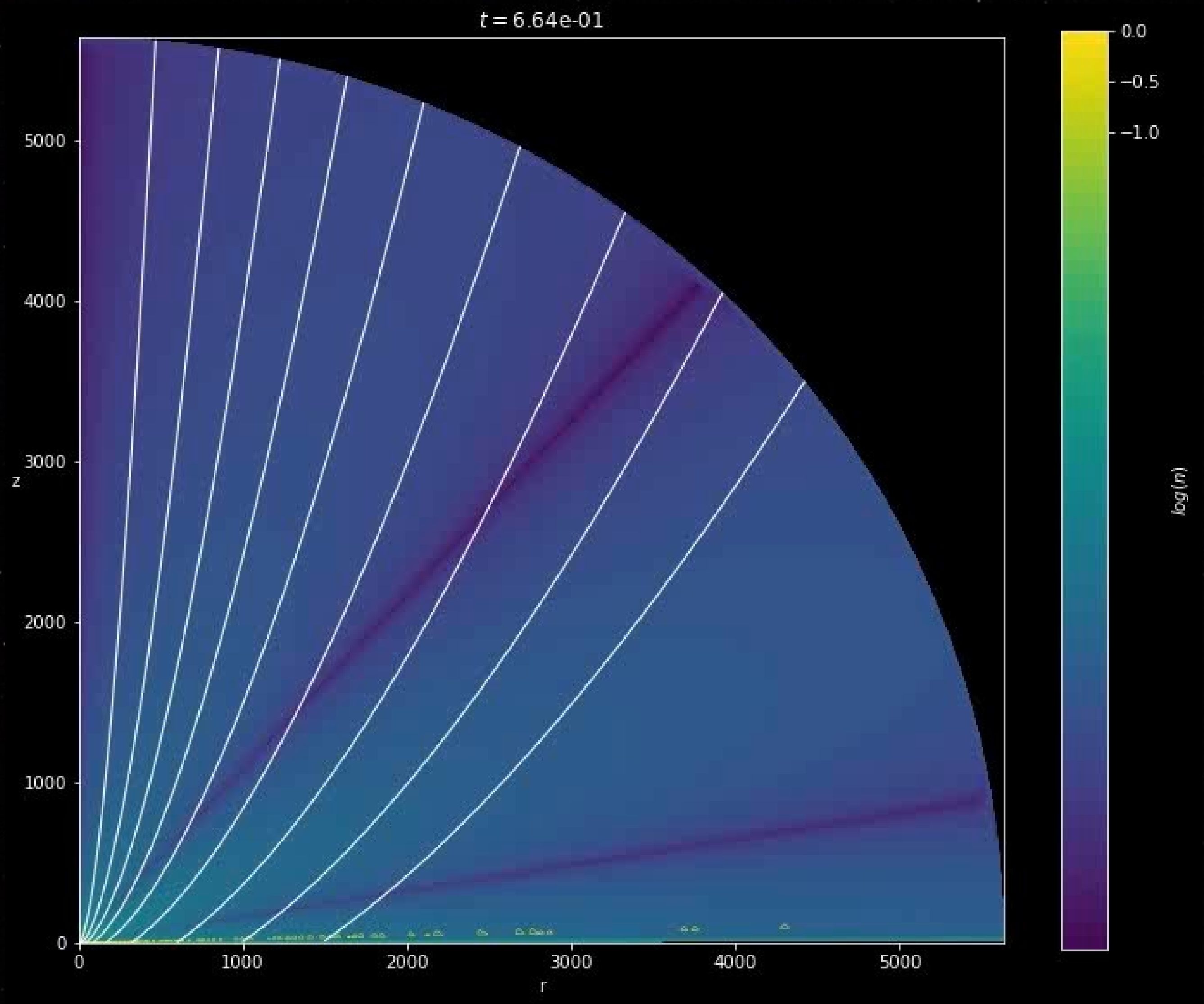
For a Schwarzschild black hole, $R_d = R_{ISCO} = 6\frac{GM}{c^2}$

For a 10^{10} $M_\odot$ black hole :

$$\mathbf{R_d = 5.10^{-3}pc}$$
$$\mathbf{R_{ext} = 30pc}$$

Radio Galaxy Hercules A

Numerical MHD simulations



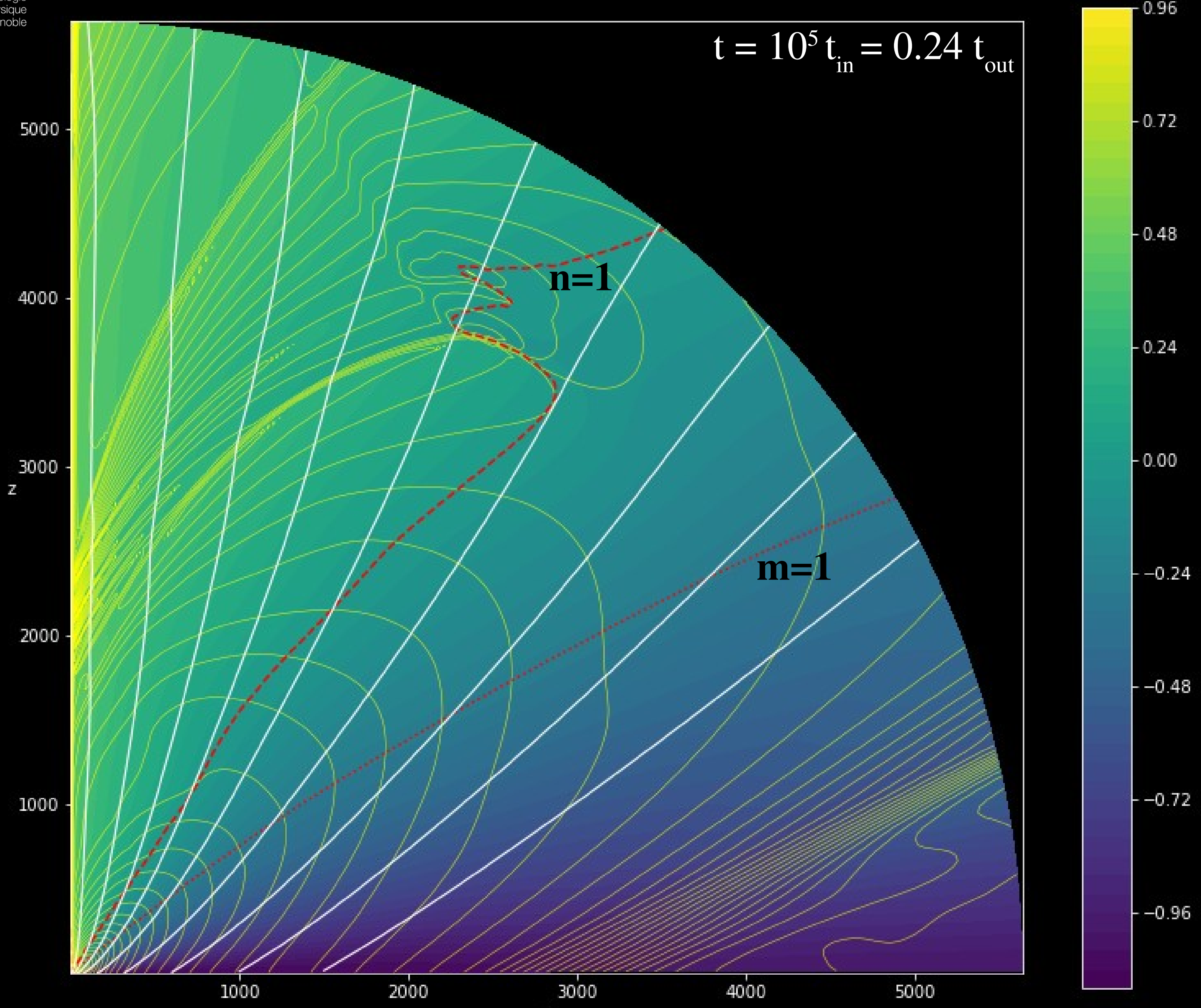
- Alfvén mach number : $m = \dfrac{u_p}{v_{A_p}}$
- Fast-magnetosonic mach number : $n = \dfrac{u_p}{v_{FM_p}}$

Electric circuits

Magnetic surfaces

Jannaud, Zanni & Ferreira, submitted to A&A

MHD recollimation shocks



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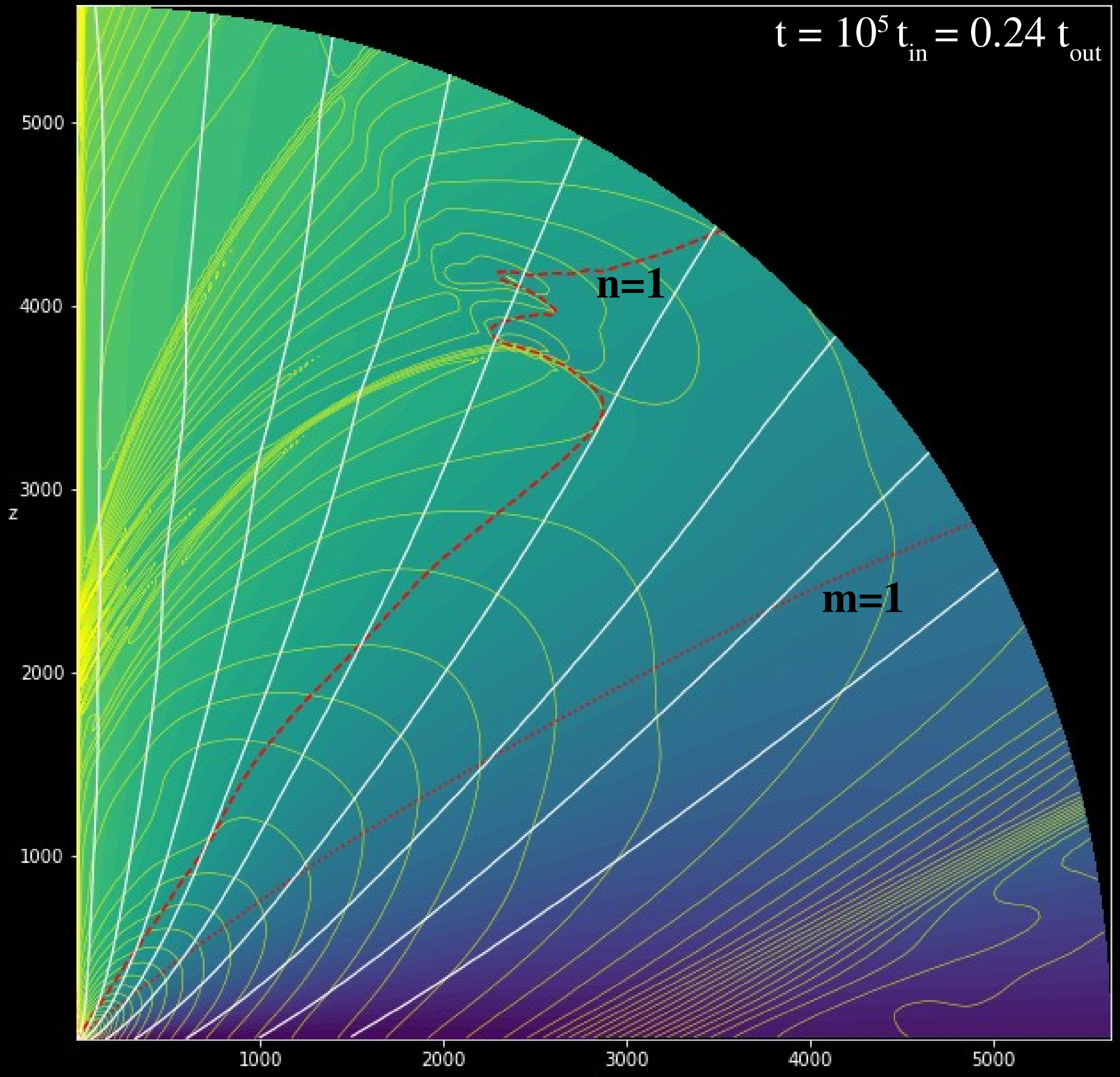
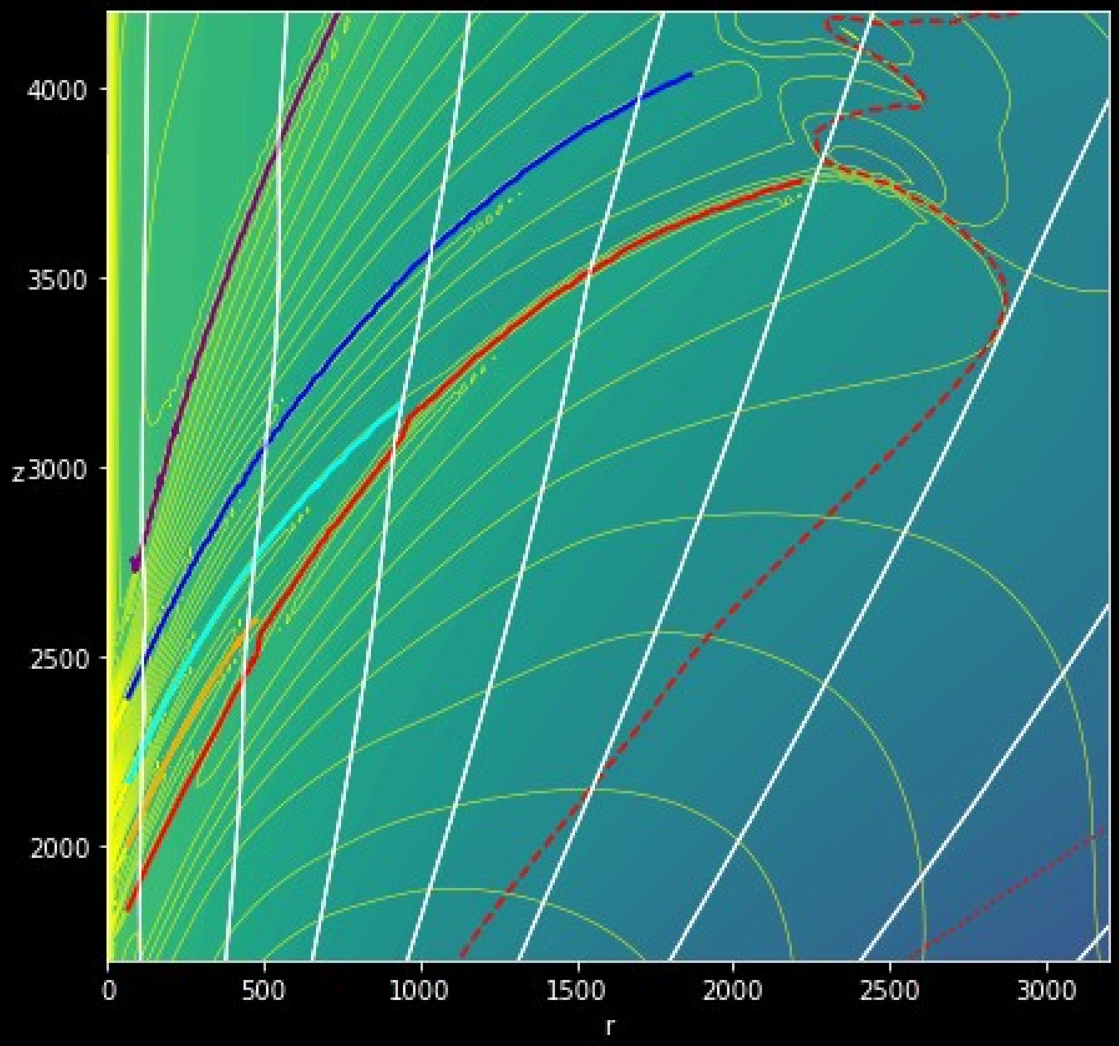


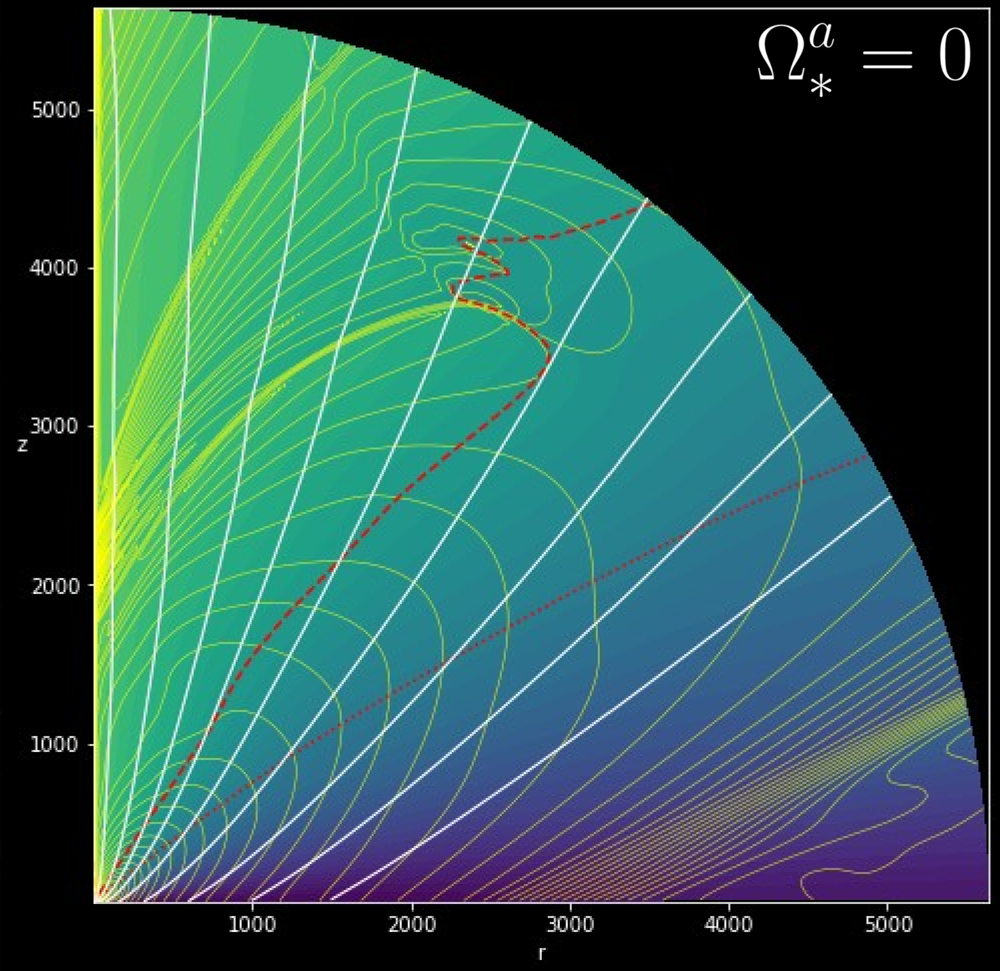


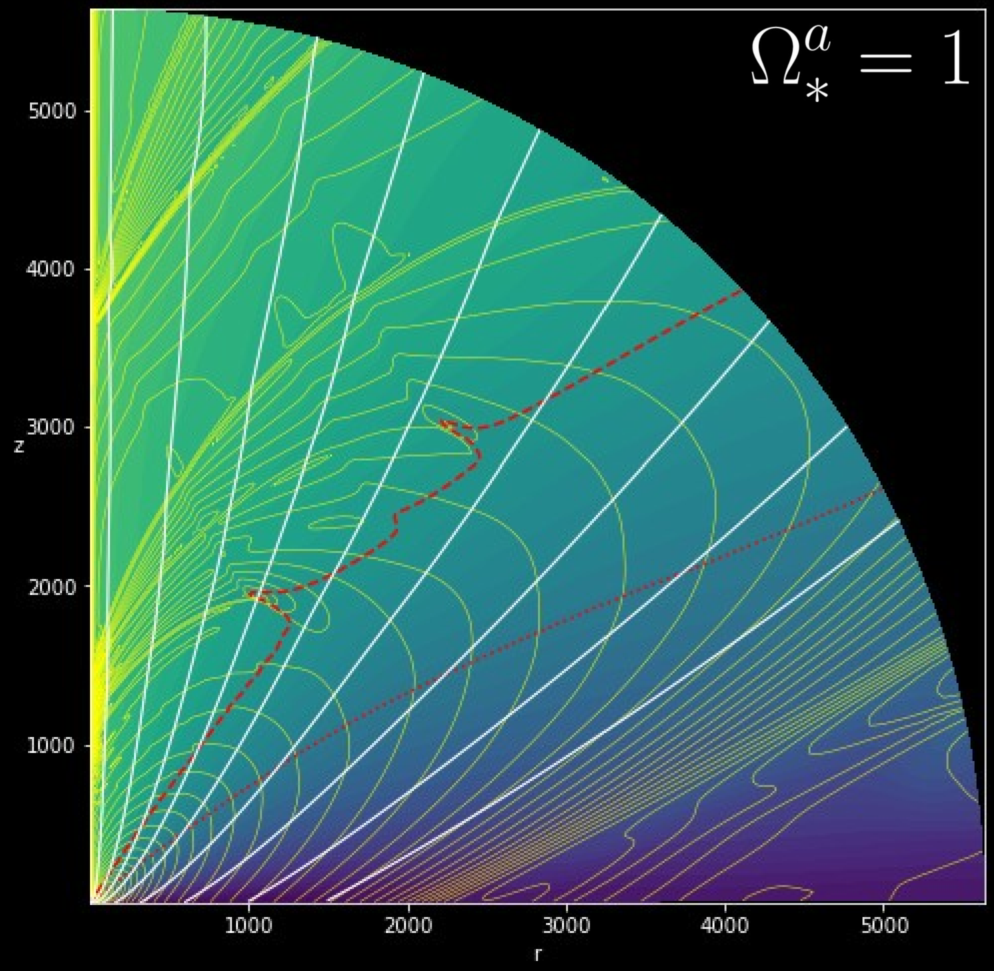
Zoom on the recollimation shocks

Jannaud, Zanni & Ferreira, submitted to A&A

Influence of the spine

- Apathic simulations with the JED parameter space
- Strong influence of the central object rotation





Jannaud, Zanni & Ferreira, submitted to A&A

Conclusion

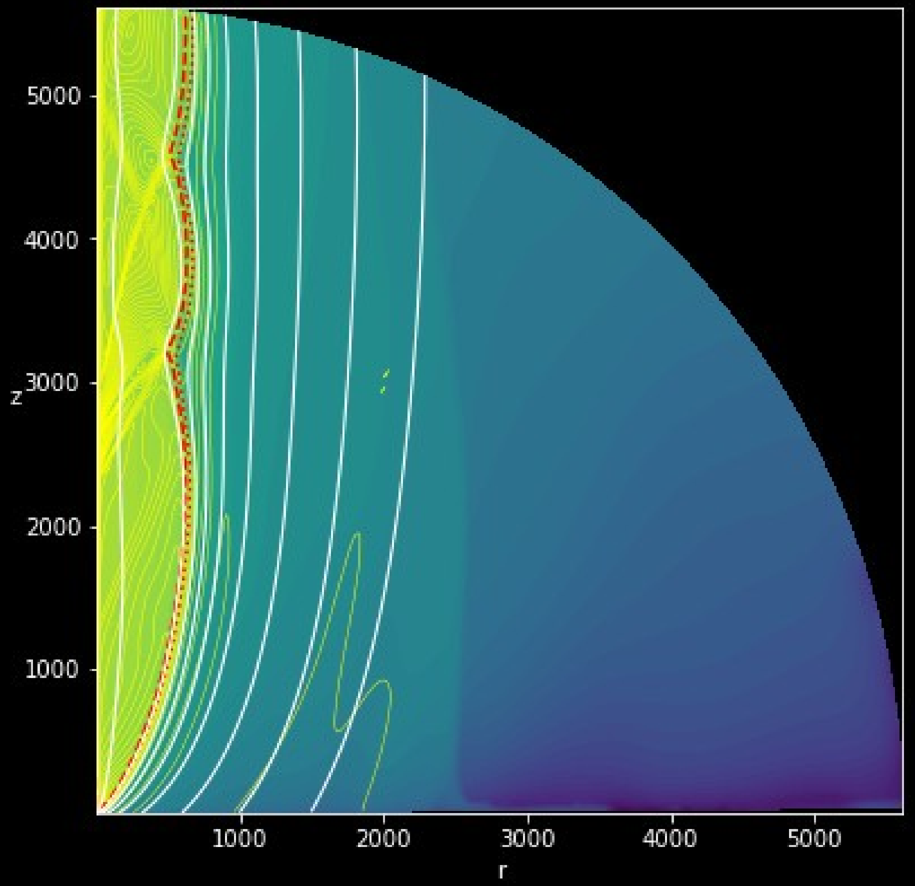
Jets emitted from JEDs of a large radial extent ⇒ Recollimation shocks

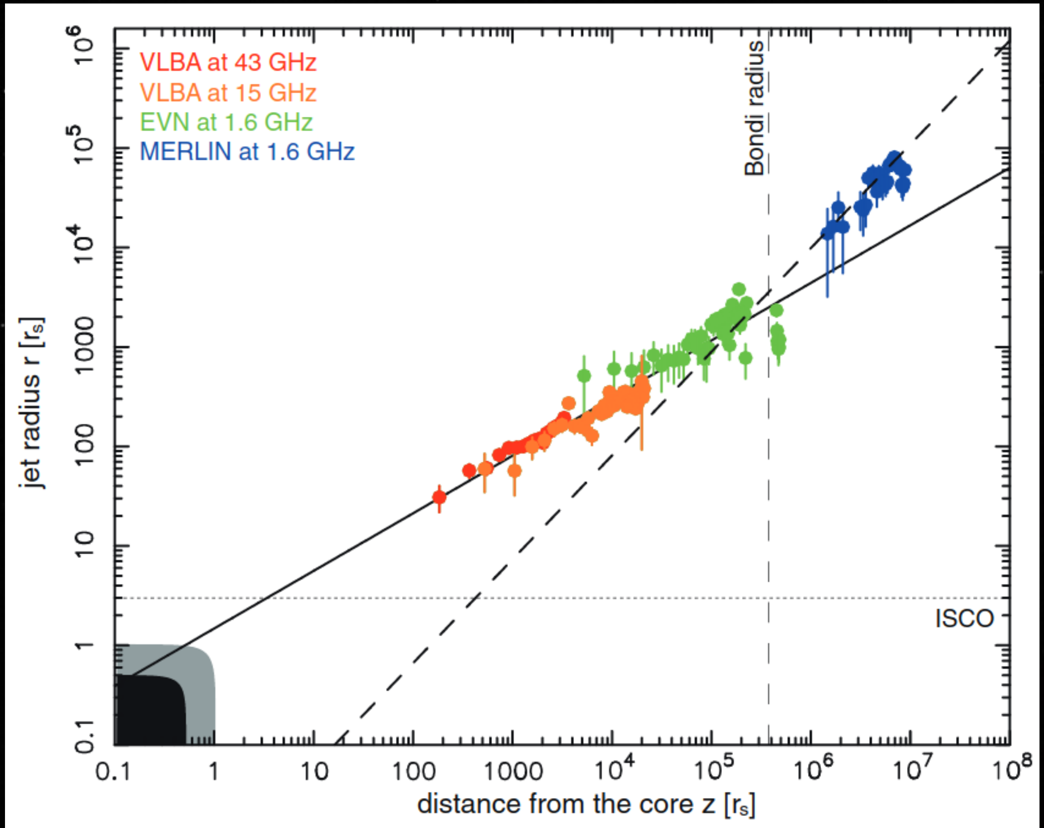
- 2D MHD simulations on unprecedented scales in space and time
- Jannaud, Zanni & Ferreira, submitted to A&A

Conclusion

Jets emitted from JEDs of a large radial extent ⇒ Recollimation shocks

- 2D MHD simulations on unprecedented scales in space and time
- Jannaud, Zanni & Ferreira, submitted to A&A
- Comparisons to observations of AGN and YSO jets ⇒ JEDs of finite size



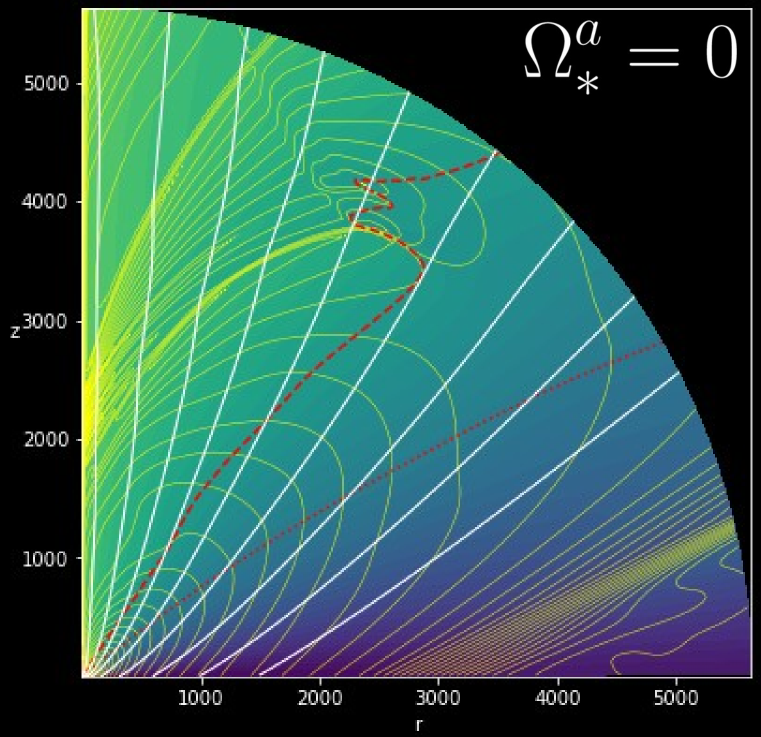


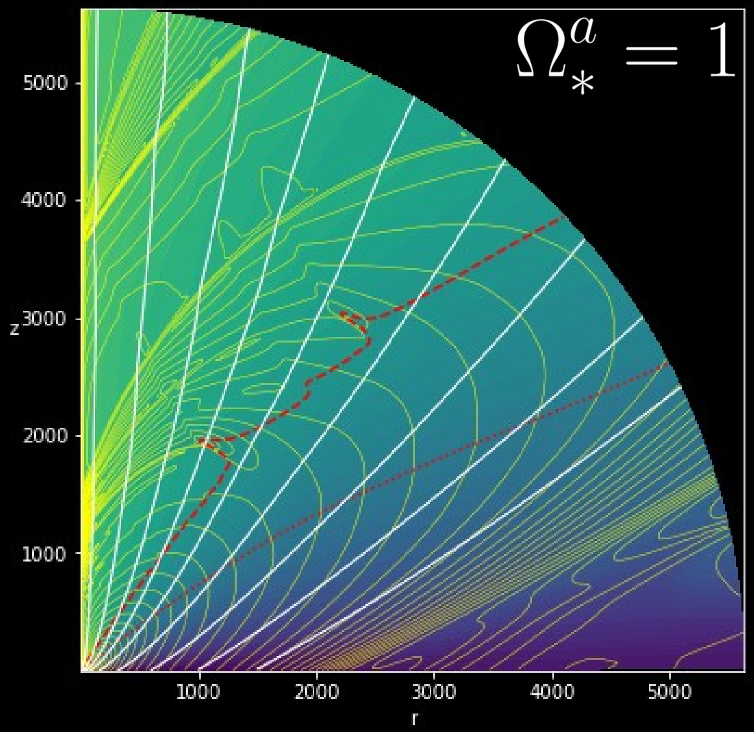
HST-1 complex in M87, Asada & Nakamura (2012)

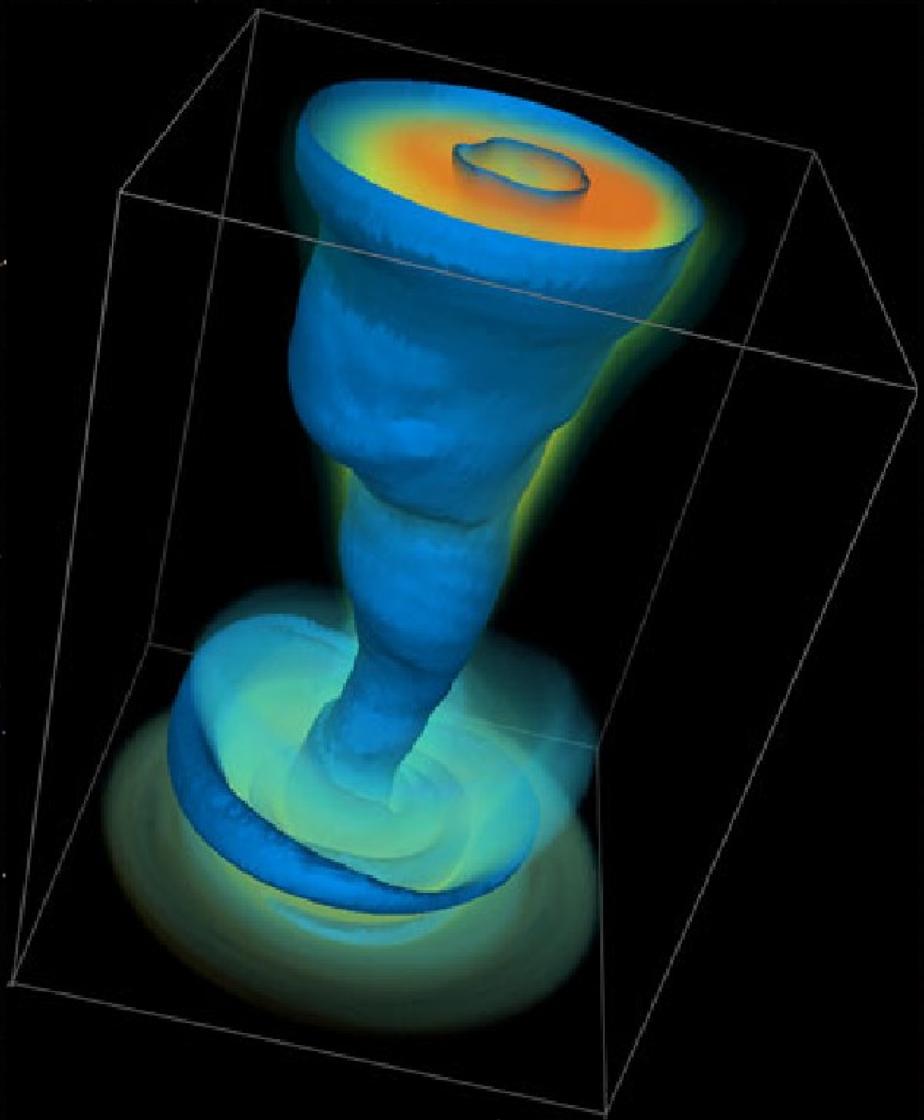
Conclusion

Strong influence of the spine on collimation

- Possible presence of a Blandford & Znajek outflow (see Barnier et al. 2021)
- Preliminary results (other simulations in the making, including in 3D)



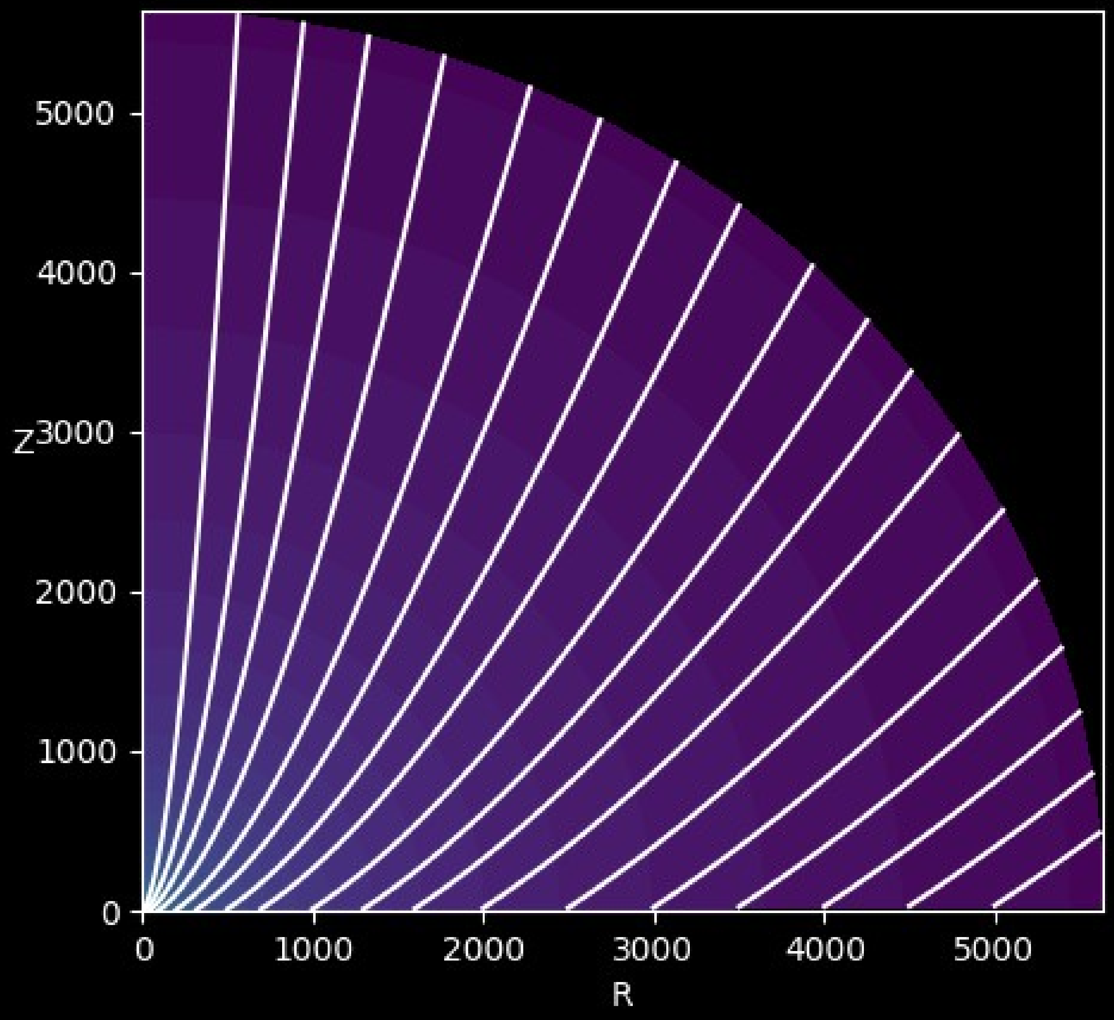




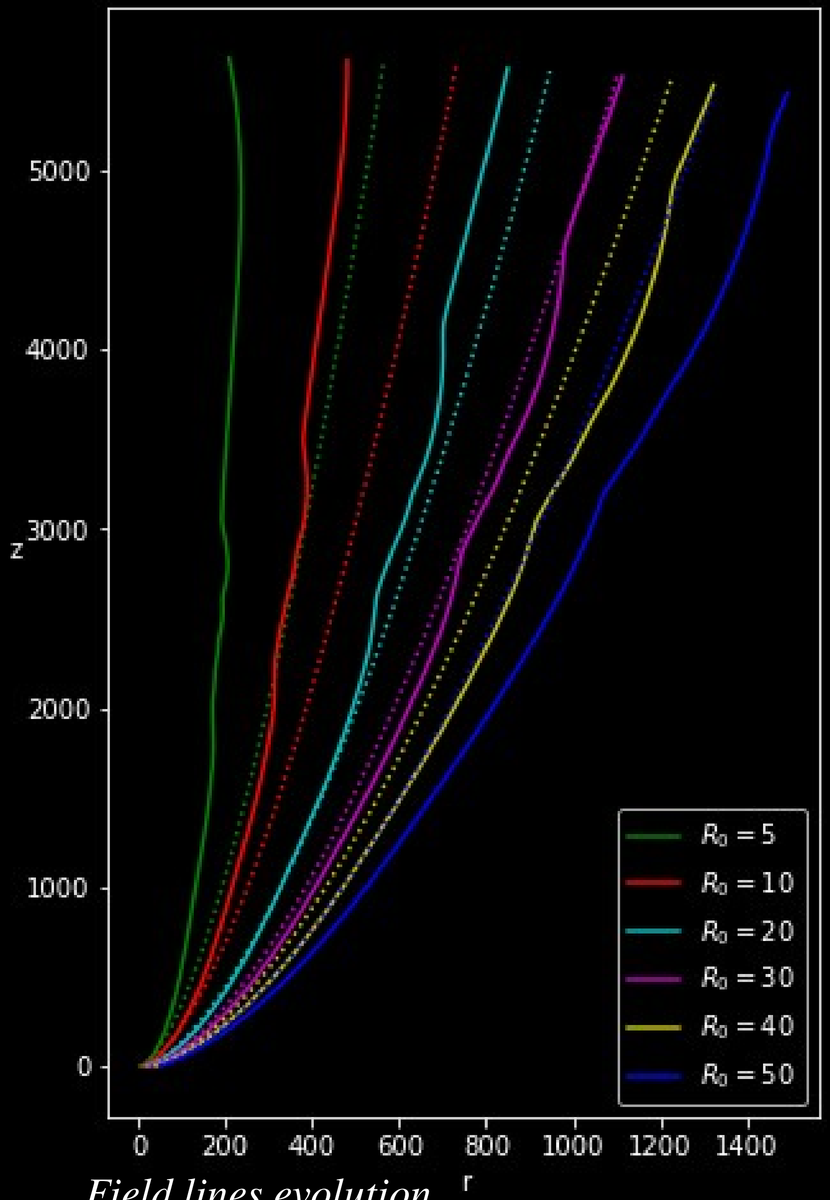
McKinney & Blandford (2009)

Jannaud, Zanni & Ferreira, submitted to A&A

Collimation of the magnetic field lines

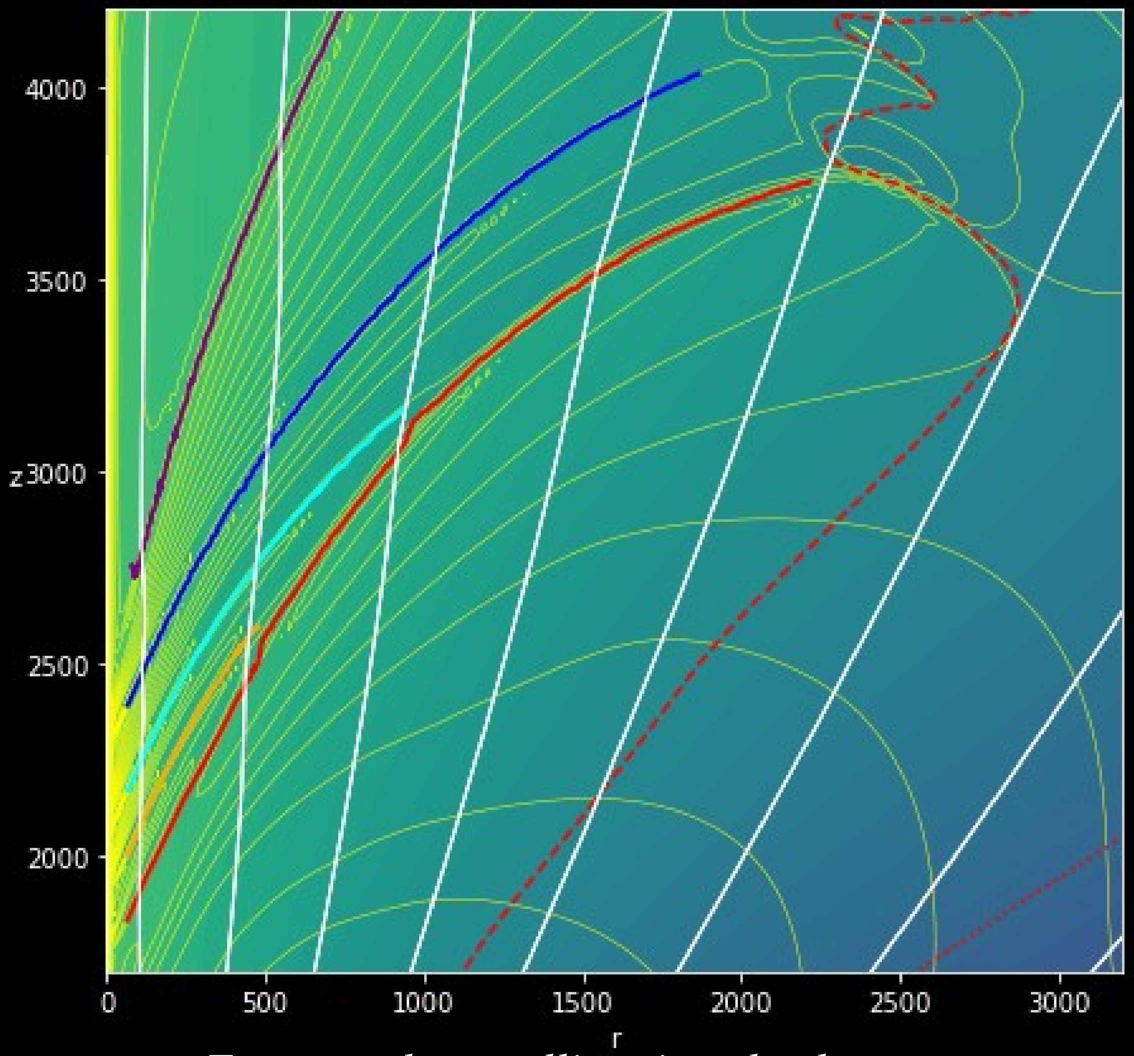


Initial conditions

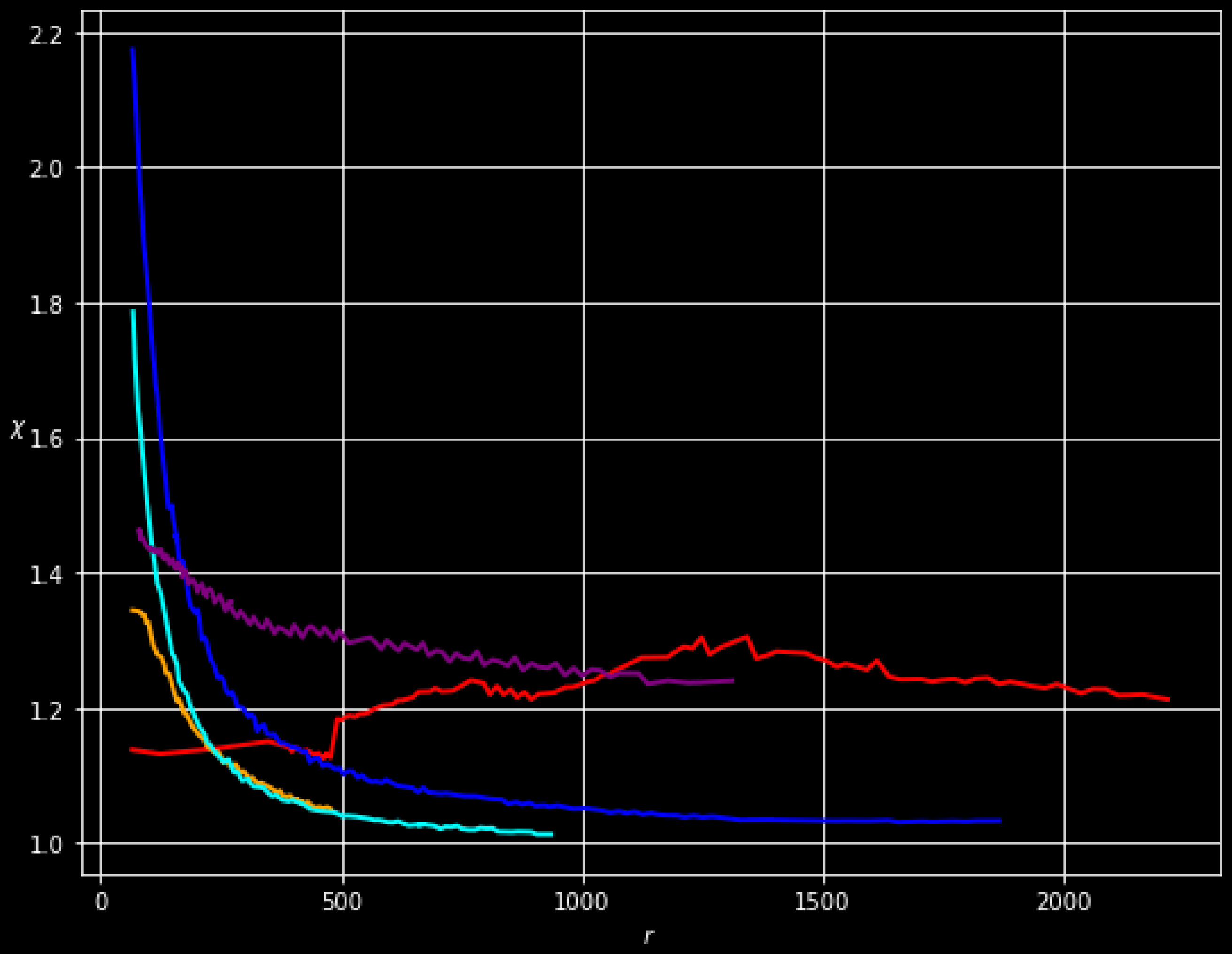


Field lines evolution

Weak and multiple recollimation shocks



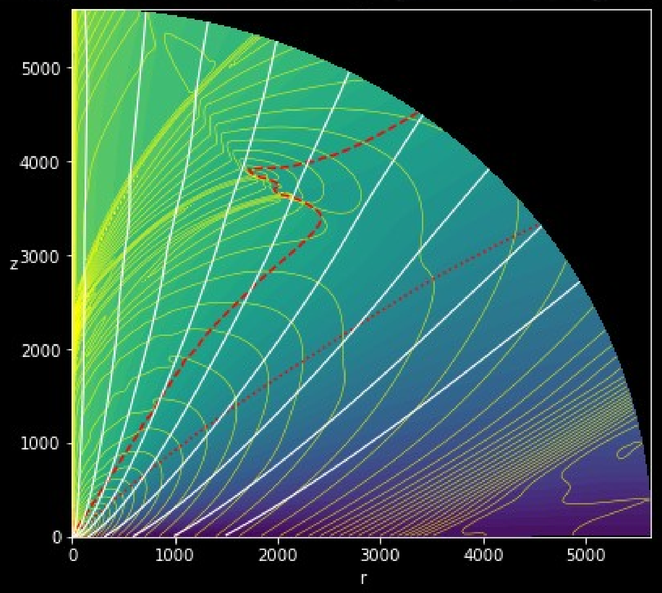
Zoom on the recollimation shocks



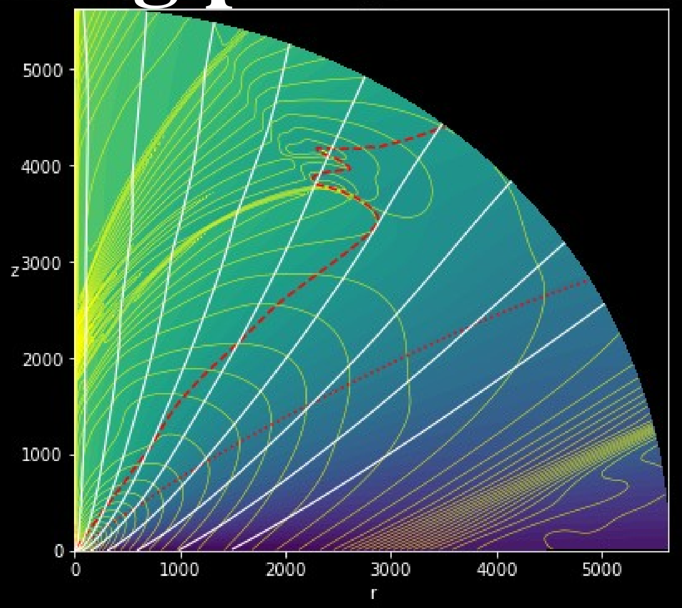
Evolution of the compression rate along the shocks

Influence of the mass loading parameter κ

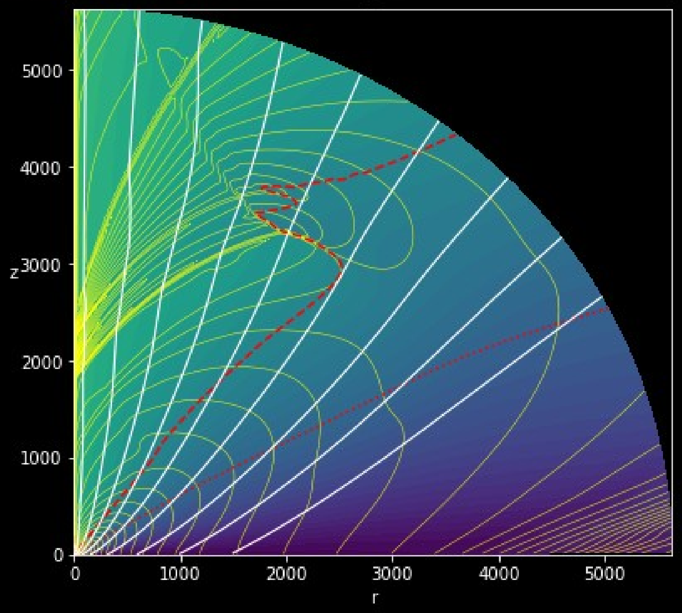
$$\kappa = \frac{v_{\theta_d} v_{k_d}}{v_{A_d}^2}$$



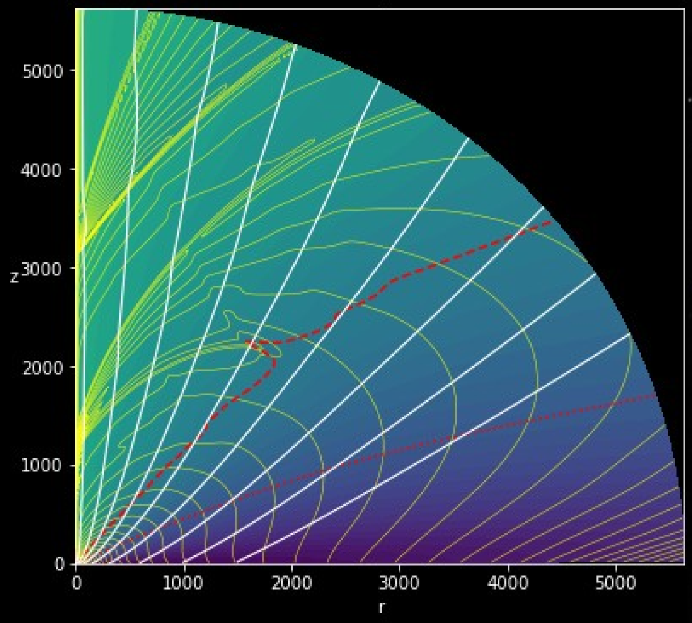
$\kappa = 0,05$



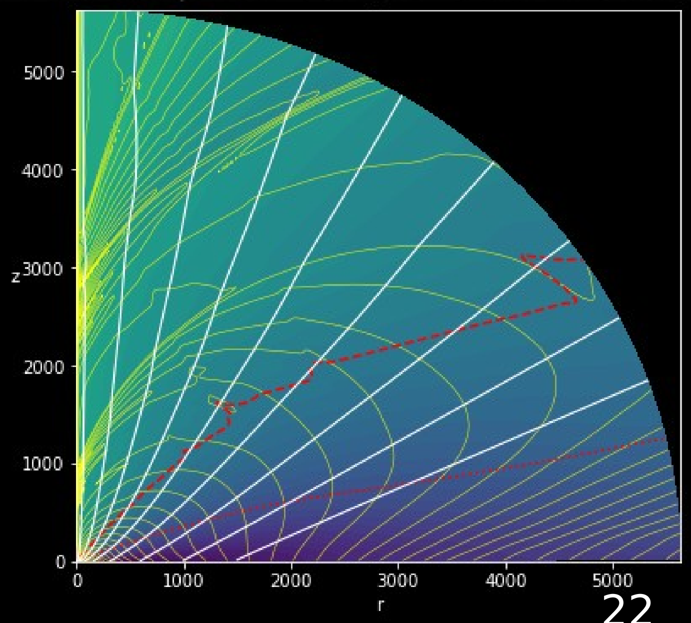
$\kappa = 0,1$



$\kappa = 0,2$



$\kappa = 0,5$



$\kappa = 1,0$

Influence of the mass loading parameter κ

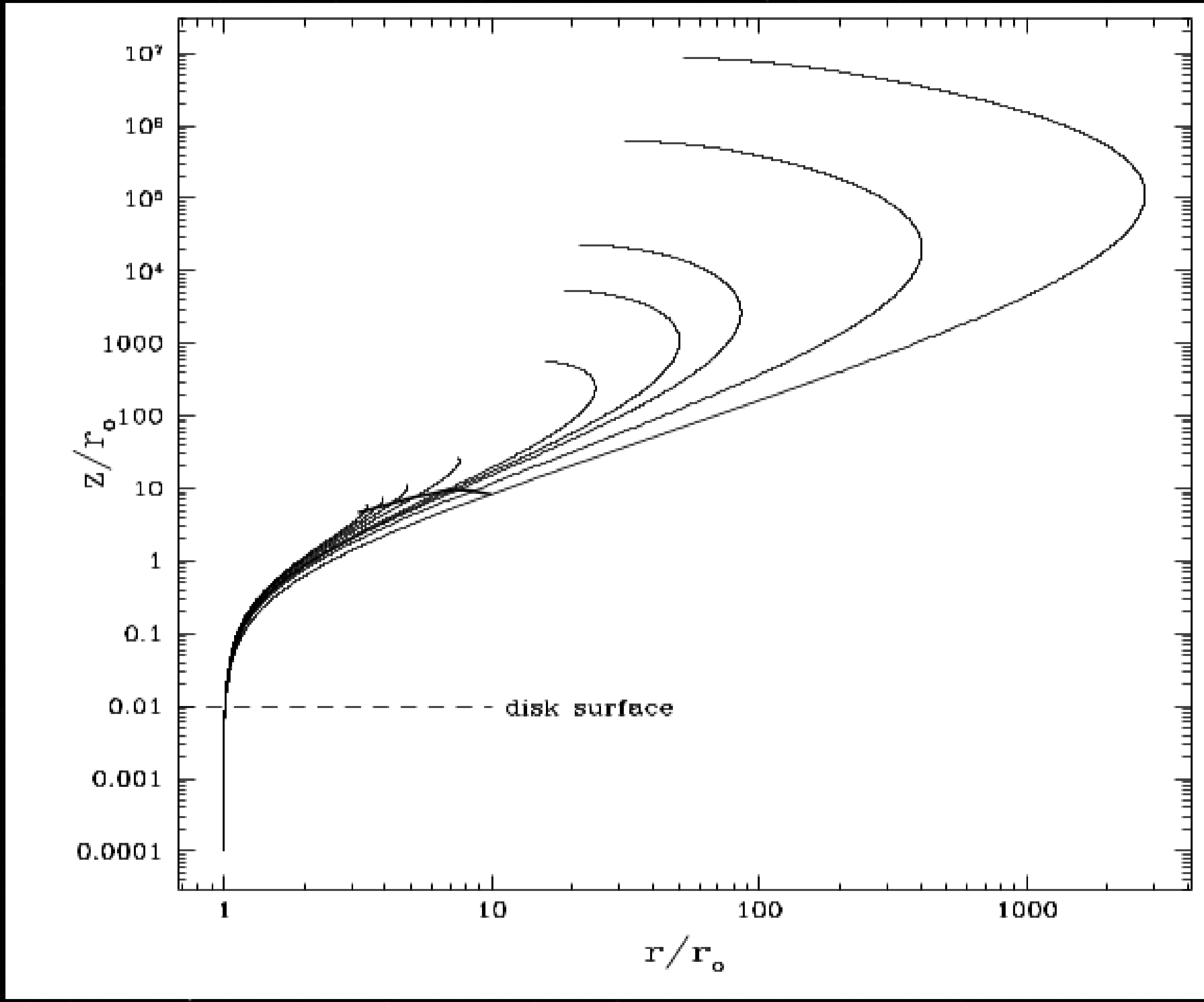
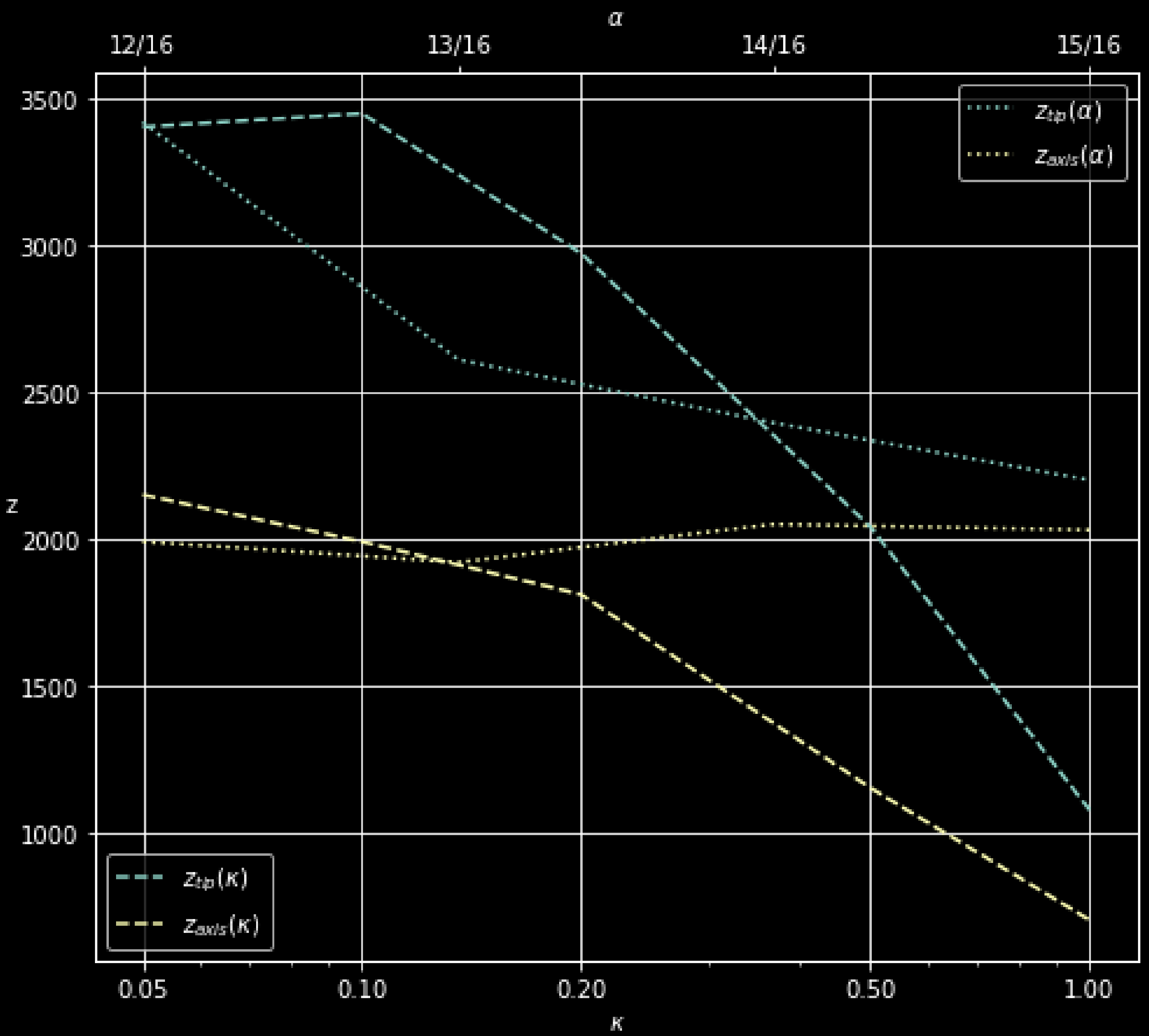
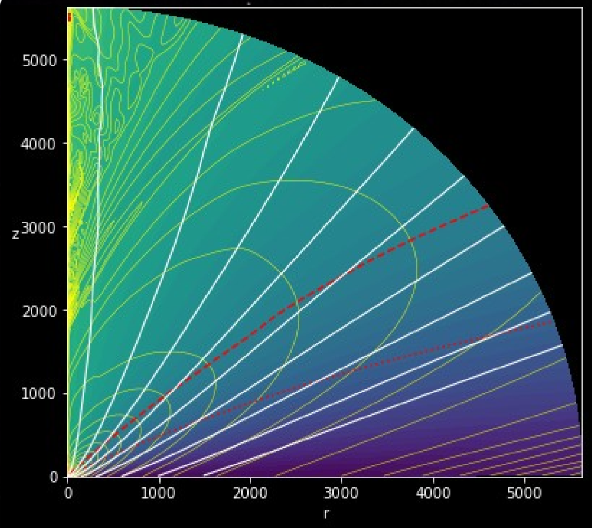


Fig.6 of Ferreira(1997) : magnetic field lines for κ from 0,005 (outermost) à 0,05 (innermost)

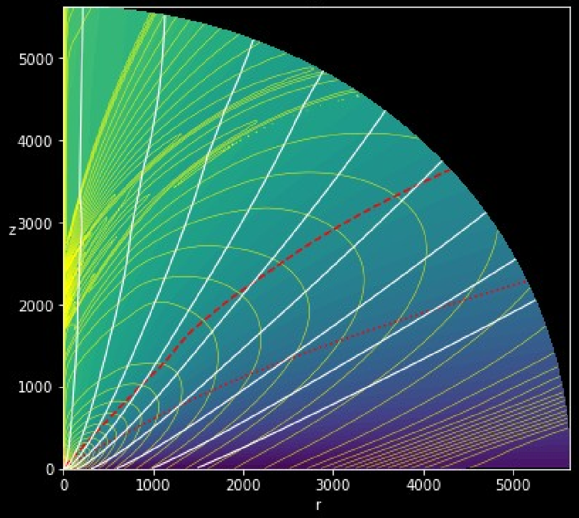


Evolution of the shock altitude Z_{shock} with κ and α

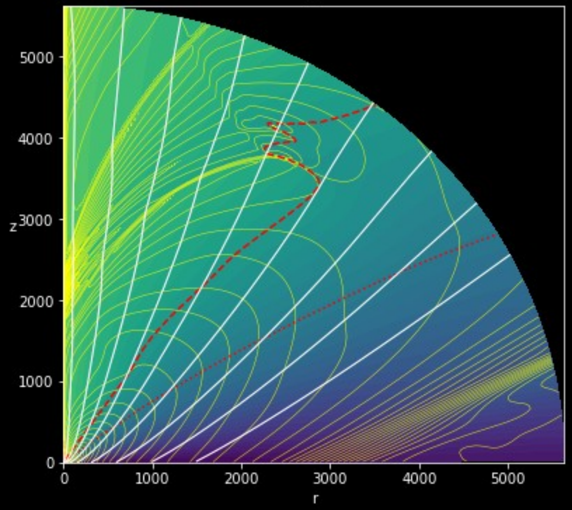
Influence of the magnetic field topology : α



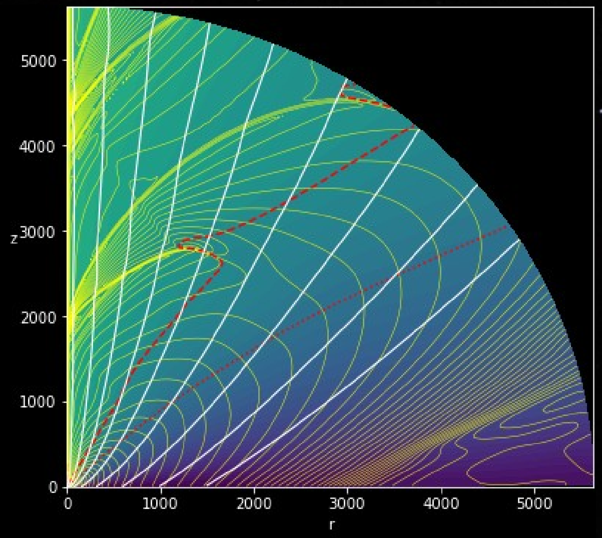
$$\alpha = \frac{10}{16}$$



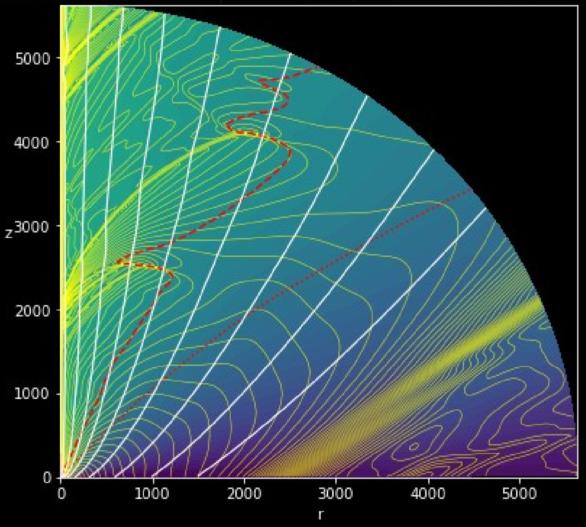
$$\alpha = \frac{11}{16}$$



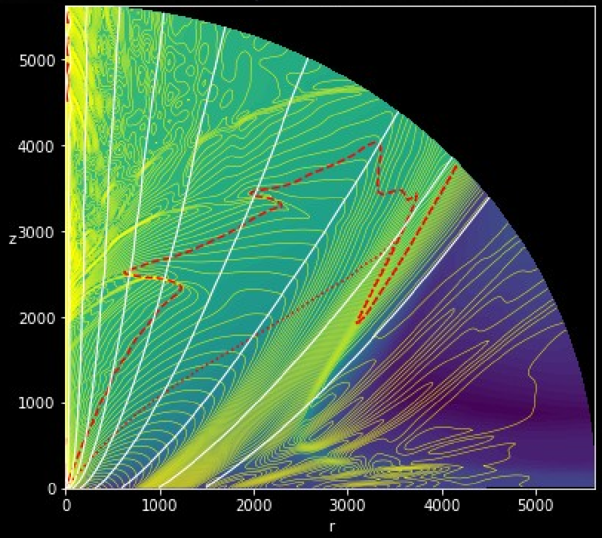
$$\alpha = \frac{12}{16}$$



$$\alpha = \frac{13}{16}$$



$$\alpha = \frac{14}{16}$$



$$\alpha = \frac{15}{16}$$

$$\rho = \rho_d \left(\frac{R}{R_d}\right)^{2\alpha-3}$$

$$P = \rho_d \frac{V_{S_d}^2}{\Gamma} \left(\frac{R}{R_d}\right)^{2\alpha-4}$$

$$B_\theta = -B_{\theta_d} \left(\frac{R}{R_d}\right)^{\alpha-2}$$

$$v_\theta = -v_{\theta_d} \left(\frac{R}{R_d}\right)^{-1/2}$$

$$v_R = v_\theta \frac{B_R}{B_\theta}$$

$$v_\phi = \sqrt{\frac{GM_\star}{R}} + v_\theta \frac{B_\phi}{B_\theta}$$

IPAG
Institut de Planétologie et d'Astrophysique de Grenoble

UGA
Université Grenoble Alpes

Influence of the magnetic field topology : α

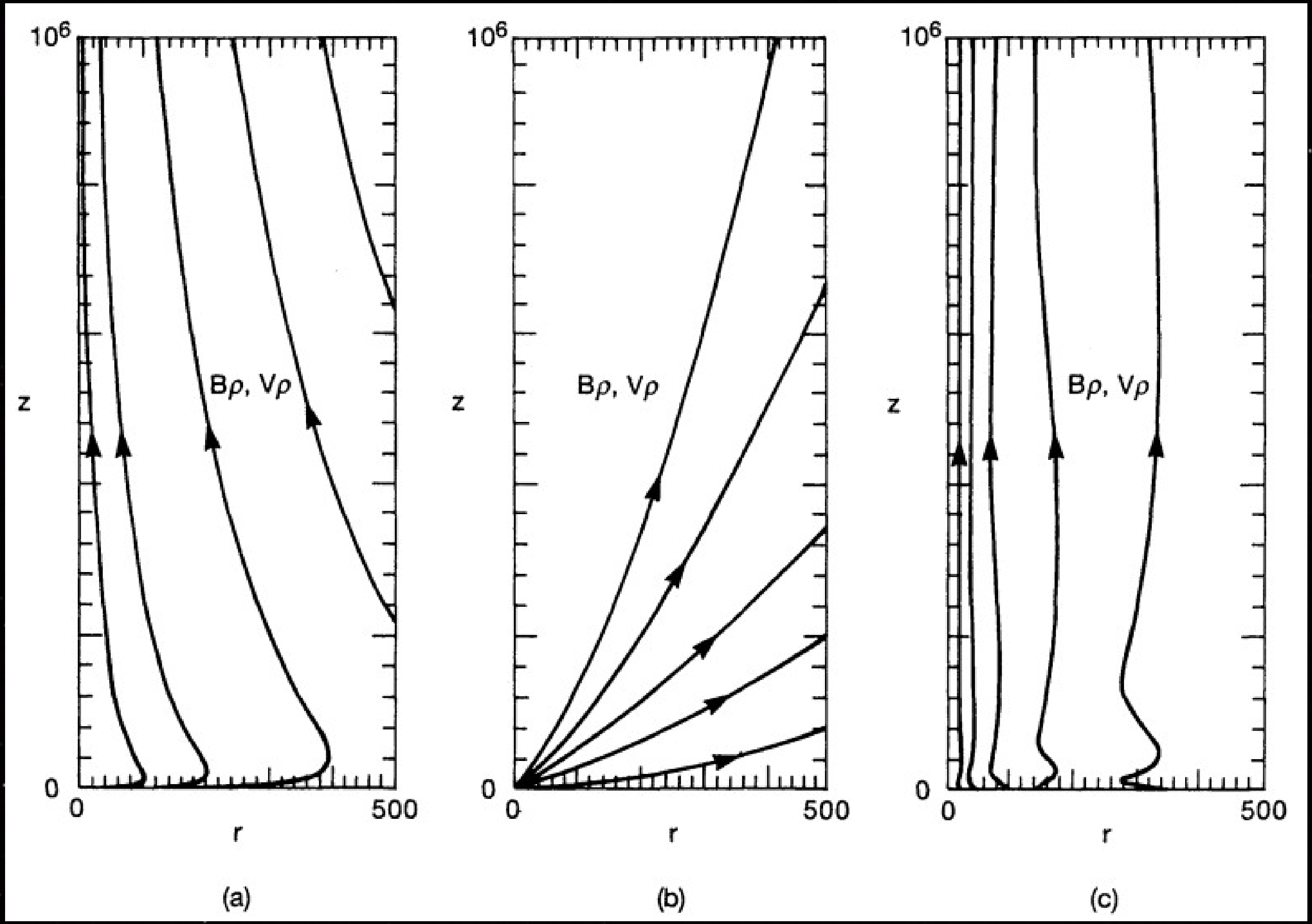
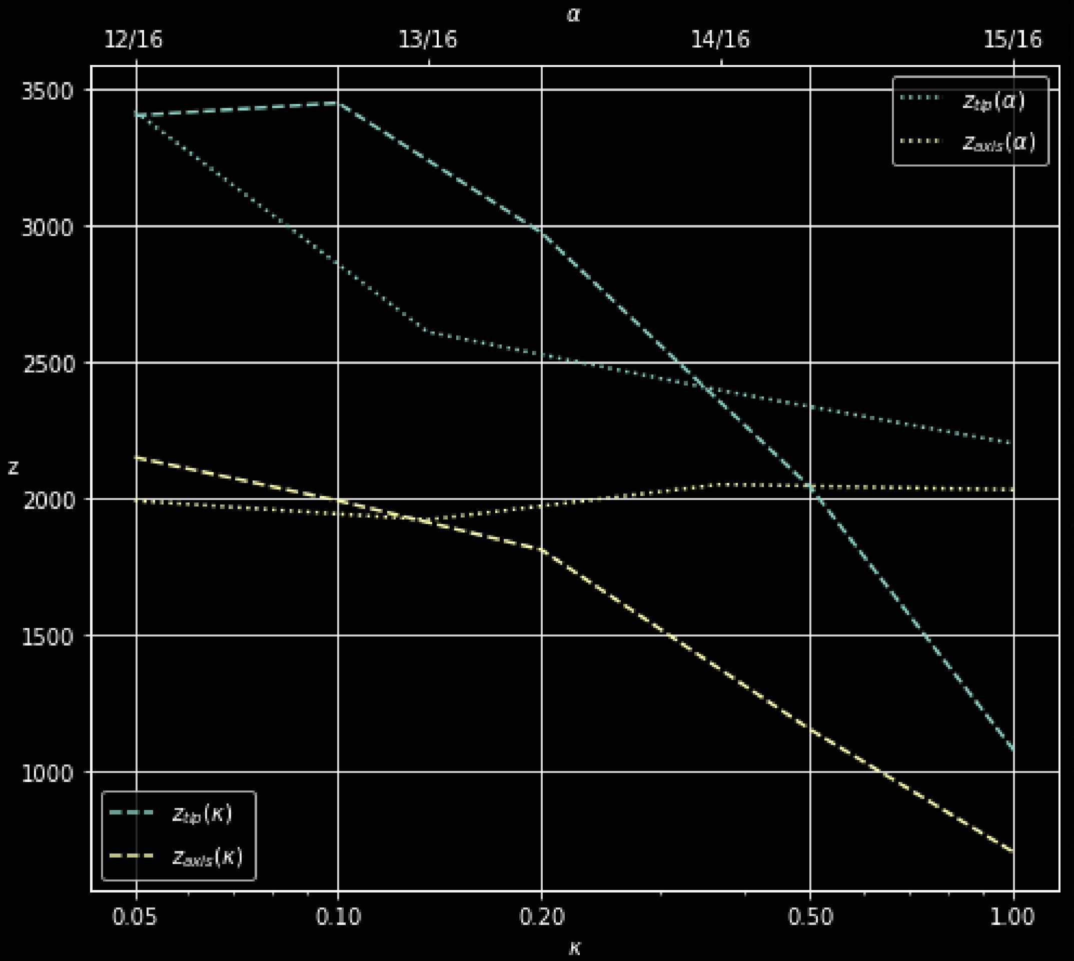
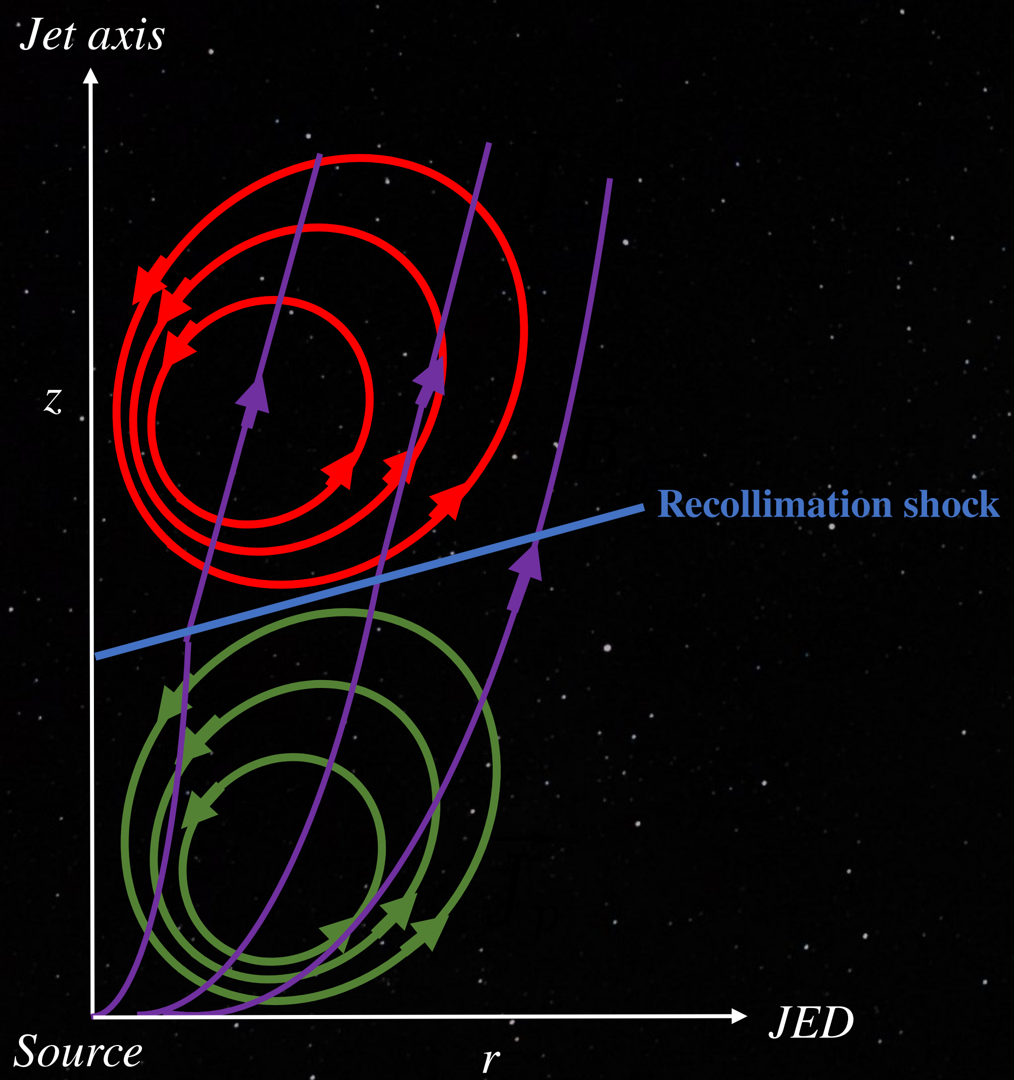


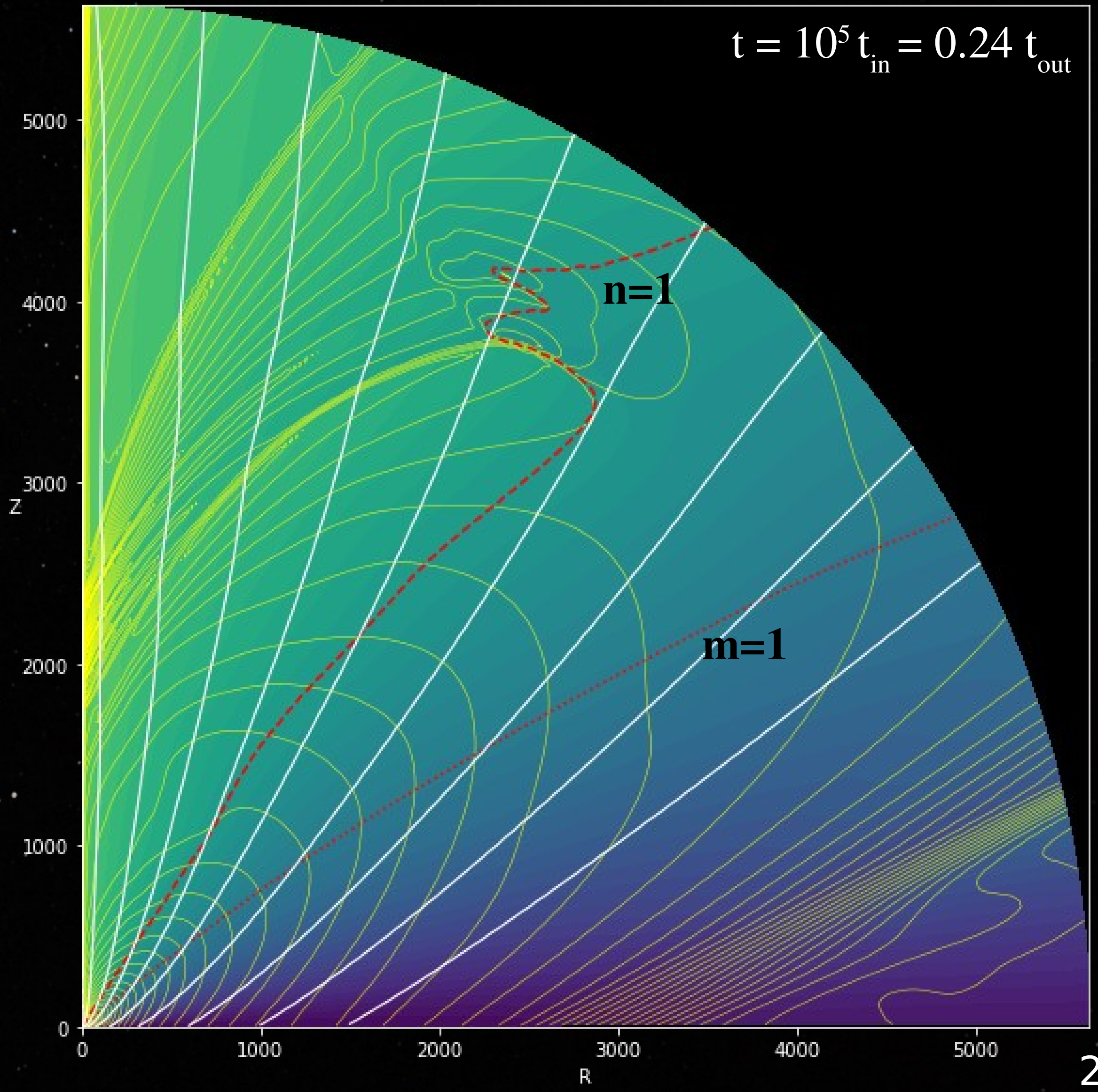
Fig.2 of Contopoulos et Lovelace(1994) : magnetic field lines for α =12,8/16 (a), α =14,4/16 (b) et α =16,3/16 (b)



Evolution of the shock altitude Z_{shock} with κ and α

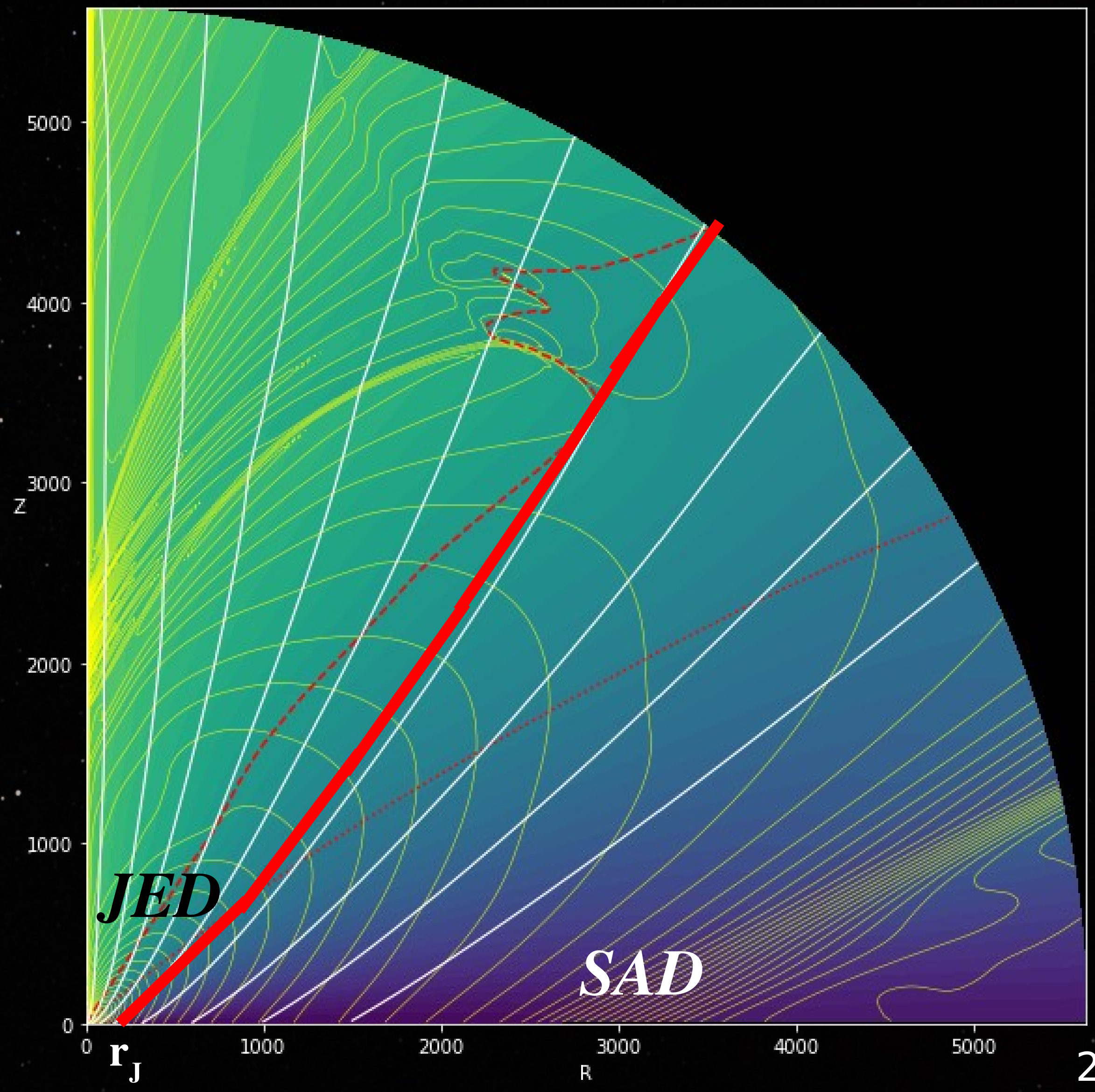
MHD recollimation shocks



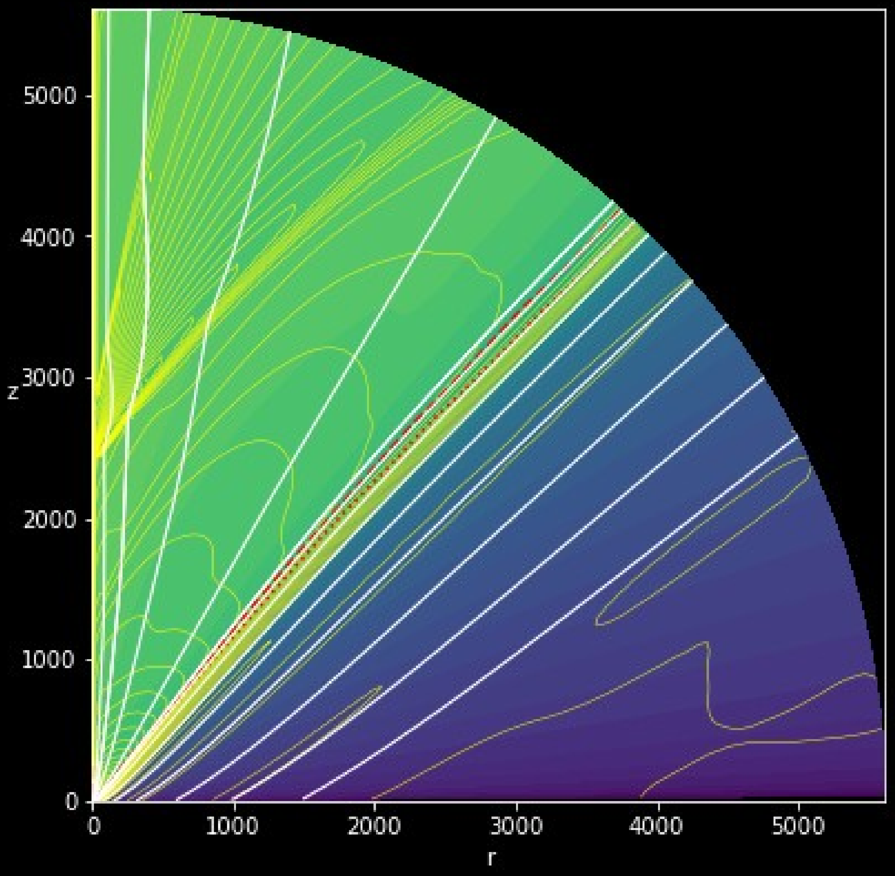


Truncated simulations

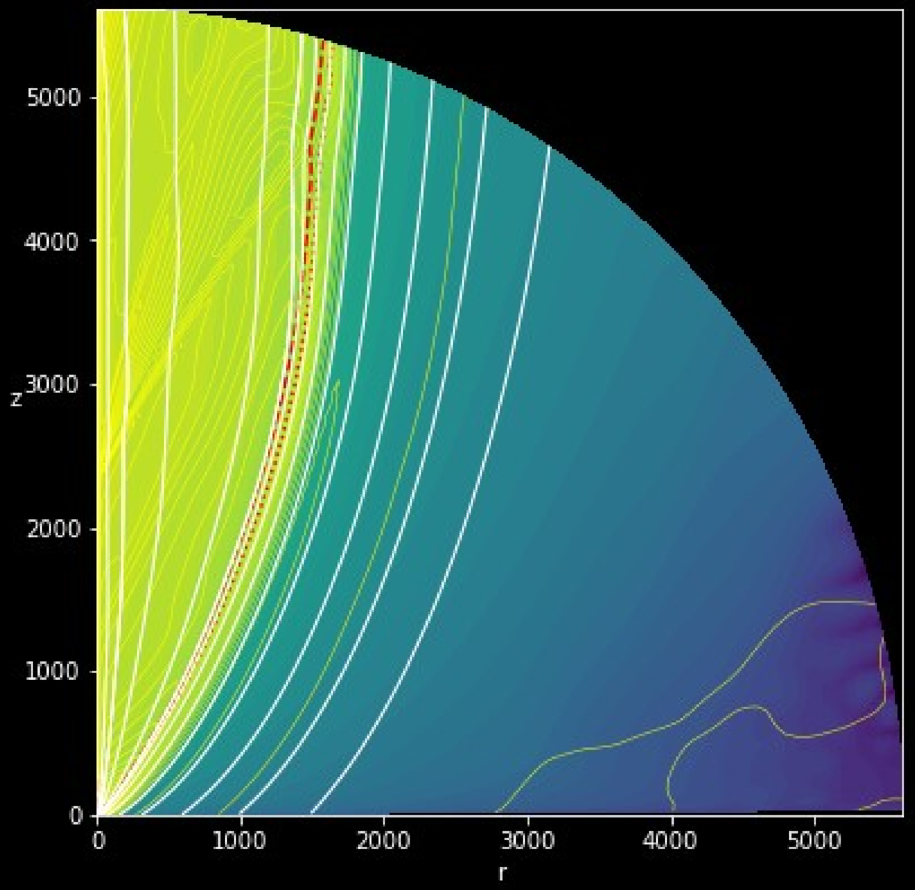
- Self-similar ejection from a finite JED
- No ejection after r_J – Standard Accretion Disk (SAD)
- Observation of shocks ? What characteristics ?



Truncated simulations



No rotation after R_0=20



Addition of a constant vertical magnetic field