Studying the accretion - ejection structure via 3D MHD simulations: jets from binary systems

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Outlines

- Background / Motivations
- Numerical setup of the model
- Single star/disk/jet setup
- Binary star/disk/jet setup
- Results and discussion

Our recent works

❖ Axisymmetric launching:

Bipolar Jets Launched from Magnetically Diffusive Accretion Disks.
I. Ejection Efficiency versus Field Strength and Diffusivity,
Sheikhnezami, S., et.al 2012, ApJ, 757, 65

❖ Bipolar jet asymmetry :

Bipolar Jets Launched from Accretion Disks. II. The Formation of Asymmetric Jets and Counter Jets,
Fendt, C. & Sheikhnezami, S. 2013, ApJ, 774, 12

❖ Including the evolution of a disk-dynamo:

Modeling MHD accretion-ejection-episodic ejections of jets triggered by a mean-field disk dynamo,
Stepanovs, D., Fendt, C., Sheikhnezami, S. 2014, APJ

Poster session, Christian Fendt

Our current study: 3D MHD jet launching

Motivations

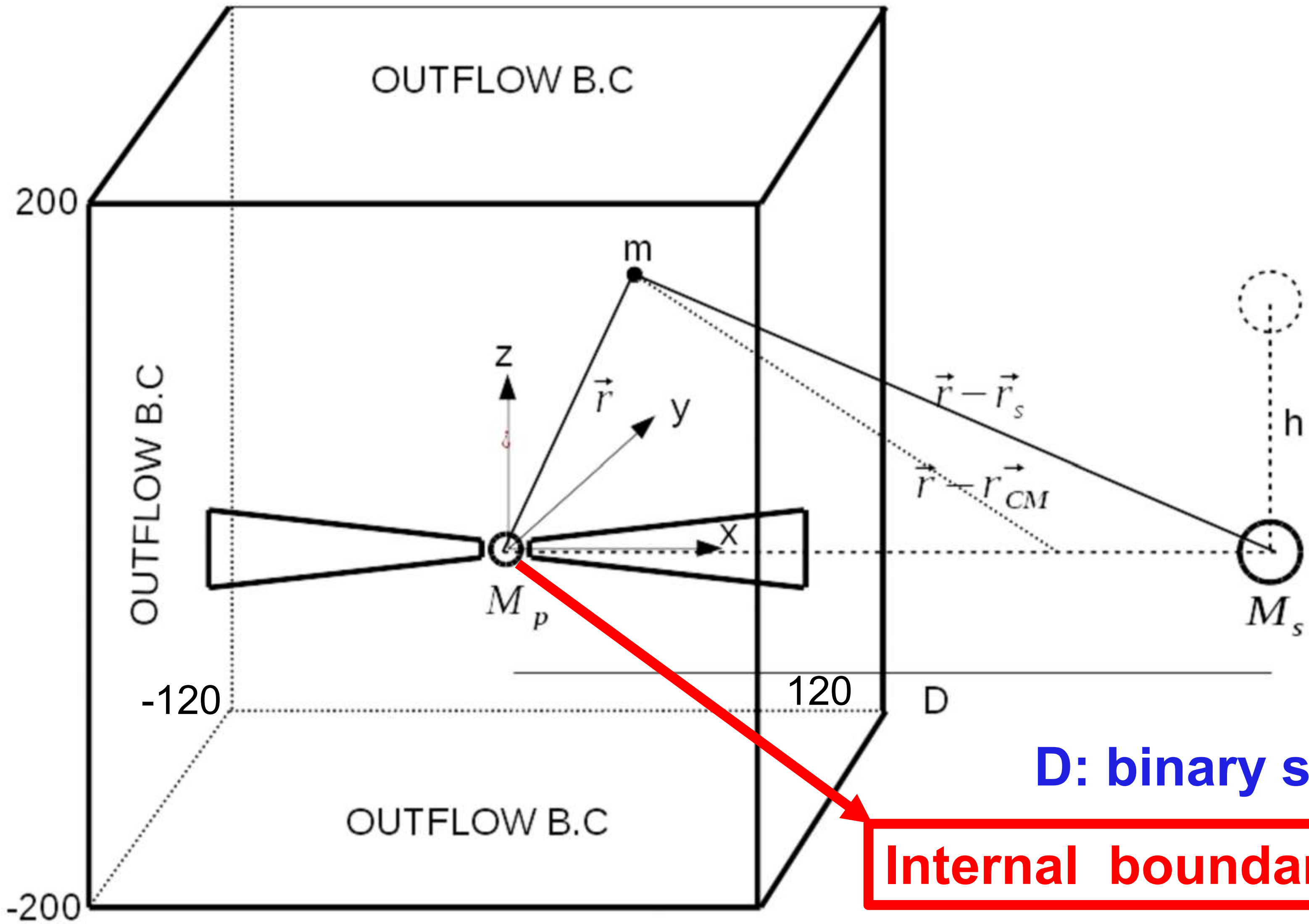
- To develop a proper model setup for jet launching in 3D
- To study the stability and symmetry of jet and counter jet
- To investigate 3D potential effects of jets launched in a binary system:

Disk warping
Disk/jet Precession

Numerical setup

Cartesian grid & **PLUTO** code (Mignone et.al 2007)

Uniform grid at $-5 < x , z , y < 5$ + Stretched grid

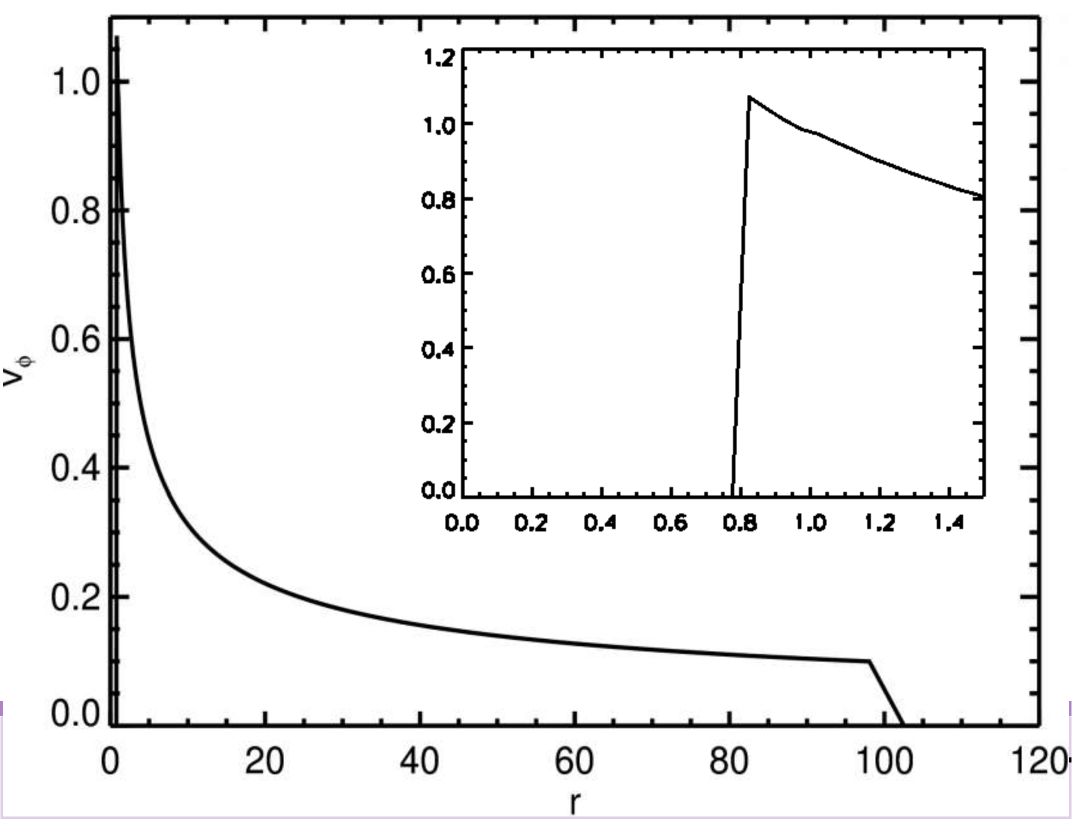


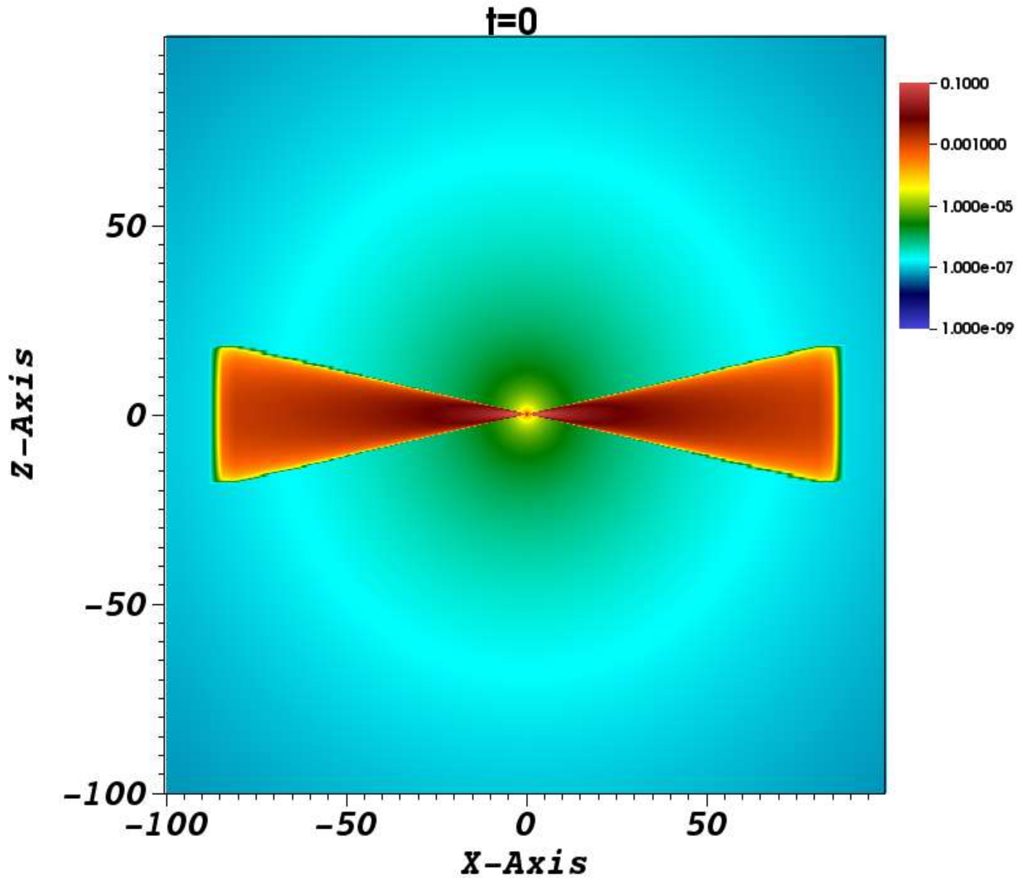
D: binary separation

Internal boundary condition

Initial rotation profile

$$V_\varphi = \sqrt{\frac{GM}{r}} \left[\begin{array}{ll} 0 & \text{Inactive zone (inside the internal boundary)} \\ \sqrt{1-5\varepsilon^2} & \text{Sub - Sub - Keplerian internal boundary} \\ \sqrt{1-2.5\varepsilon^2} & \text{Sub - Keplerian disk} \\ 0 & \text{Non rotating Corona} \end{array} \right.$$





Initial state

Axisymmetric setup - extended to three dimensions

$$\Psi = \frac{4}{3} B_{z_{0,i}} r_i^2 \left(\frac{r}{r_i}\right)^{3/4} \frac{m^{5/4}}{\left(m^2 + (z/r)^2\right)^{5/8}}$$

Magnetic flux (Zanni et.al 2007)

$$A_\varphi = \frac{\Psi}{r}$$

Magnetic vector potential

$$\eta \propto h_i(x, y, z)$$

Magnetic Diffusivity

$$h_1(x, y, z) = \exp\left(\frac{-2z^2}{H^2}\right)$$

$$h_2(x, y, z) = \exp\left(\frac{-2z^2}{H^2}\right)\left(1 + \frac{0.1}{\exp(1 - r)}\right)$$

$$h_3(x, y, z) = \eta_0 \qquad z < 10$$

Parameter runs

η : Magnetic diffusivity

q : Secondary to primary Mass ratio

D : Horizontal separation

h : Vertical separation

L_1^p : Inner Lagrange point

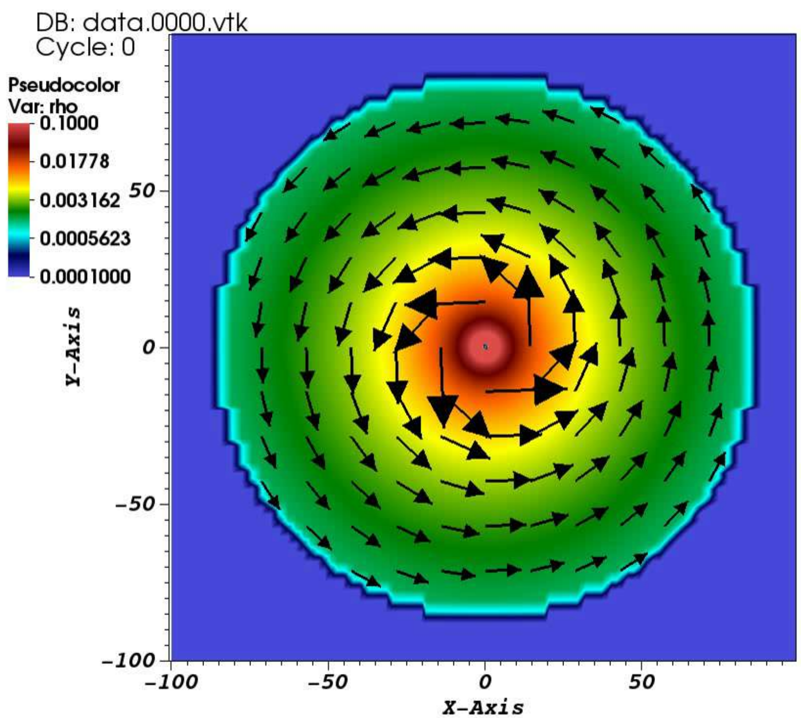
β : Gas pressure to magnetic pressure ratio

Simulation runs

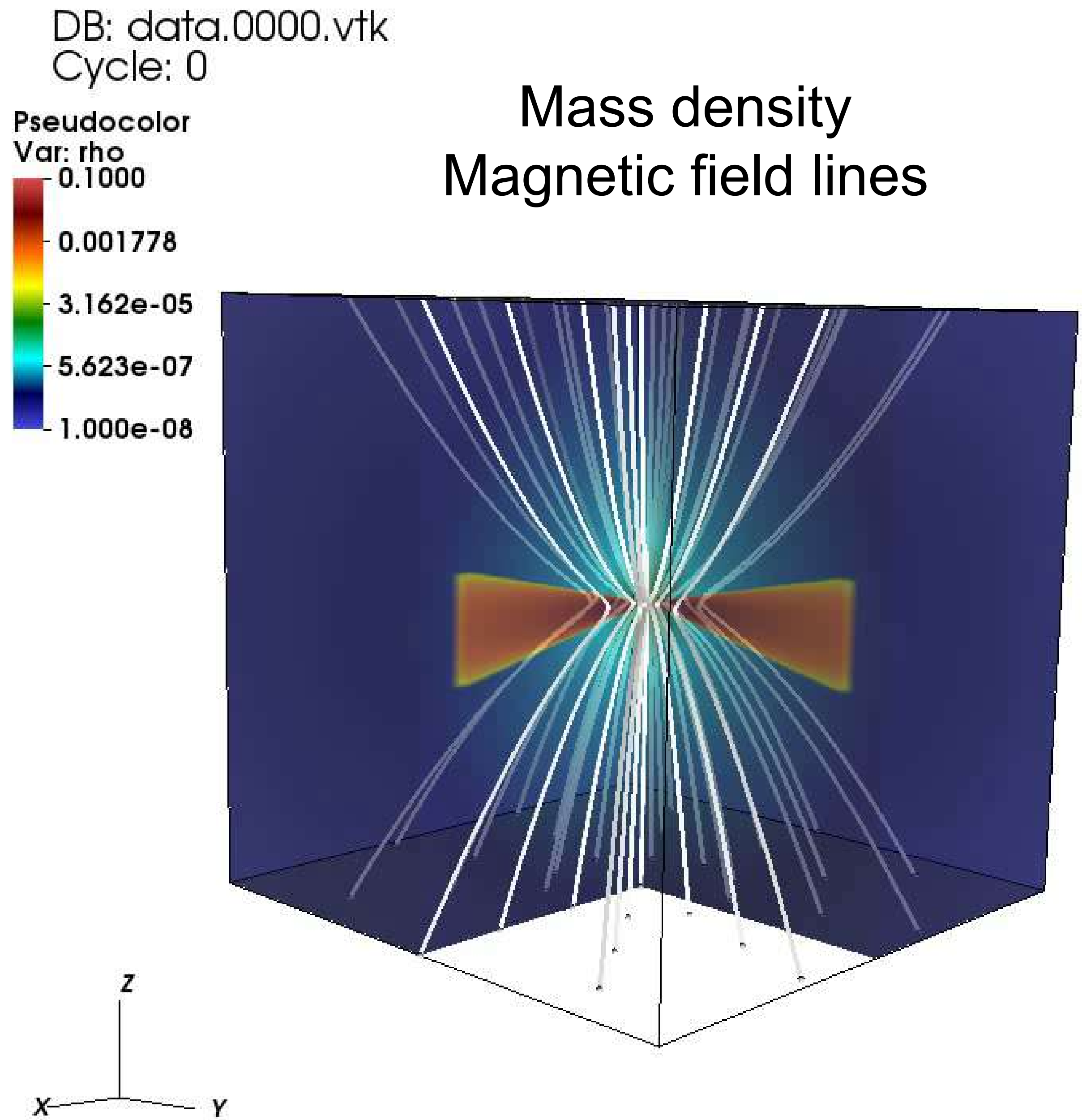
Run	η	q	h	D	β	$L_1^{\mathrm{P}}\,[x, y, z]$
Single star with jet launching disk						
scase1	0.03	-	-	-	20	-
scase2	0.03 for $z < 10$	-	-	-	20	-
scase3	$3h_2V_A$	-	-	-	20	-
scase4	$0.03h_3$	-	-	-	20	-
scase5	$0.03h_2$	-	-	-	20	-
scase6	0.03 for $z < 5$	-	-	-	20	-
Binary system with jet launching disk around primary						
bcase1	0.03 for $z < 10$	2	60	300	20	(130,0,26)
bcase2	0.03	1	60	200	20	(100,0,30)
bcase3	0.01	2	60	300	20	(130,0,26)
bcase4	0.03 for $z < 10$	2	60	200	20	(130,0,26)

3D MHD simulation of single star/disk /jet

Mass density
Velocity vectors

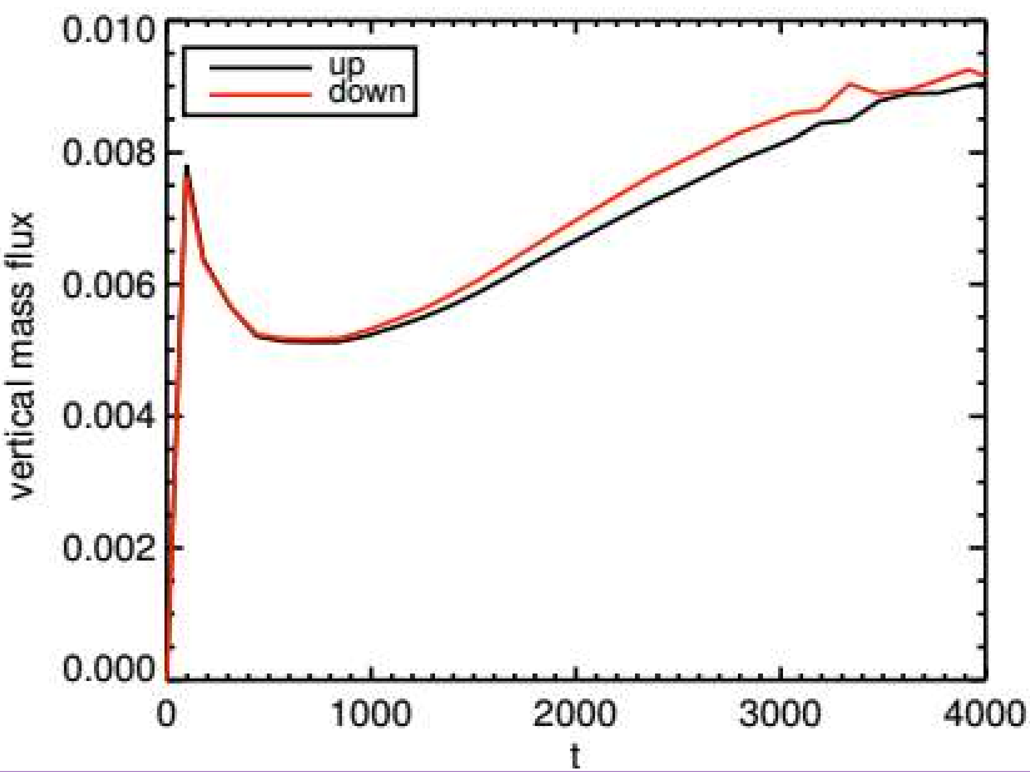


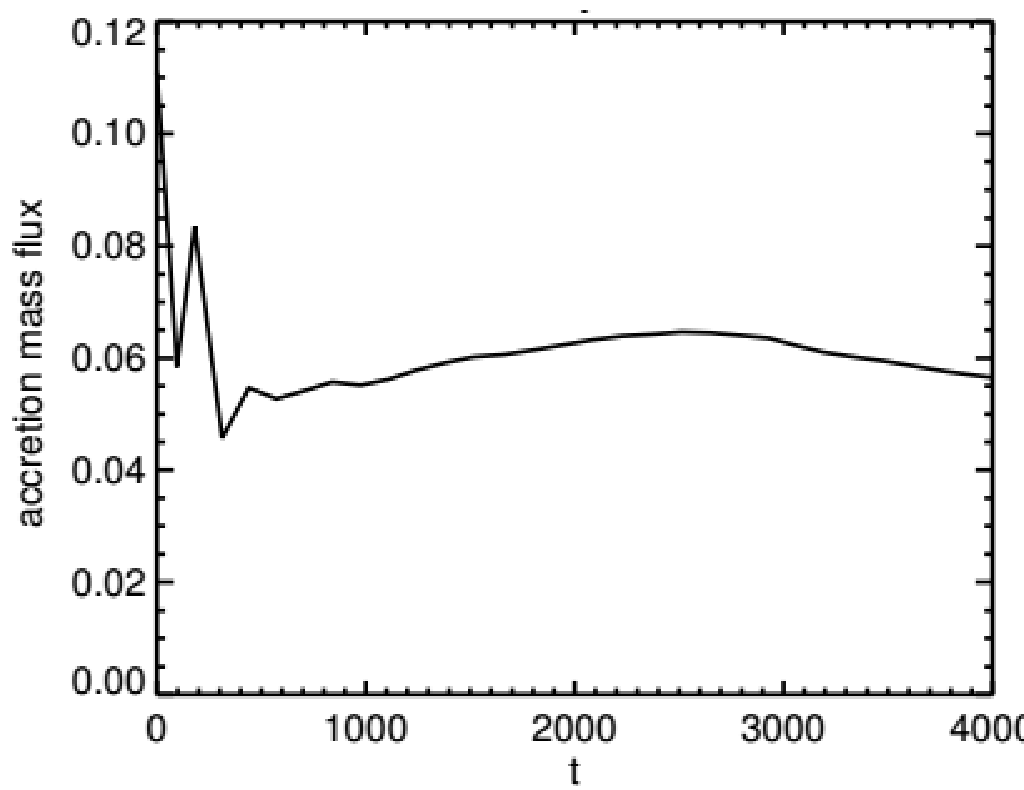
Mass density
Magnetic field lines



3D MHD simulation of single star/disk /jet

- ❖ Reference run lasts for 600 rotations at inner disk radius.
- ❖ Overall large-scale outflow keeps axial and bipolar symmetry.
- ❖ Outflow reaches super Alfvenic and super fast speed.
- ❖ Disk perturbation (instability???)





3D MHD simulation of binary star/disk /jet

Implemented 3D gravitational potential due to a secondary:

$$\boxed{\Phi = -\frac{GM_p}{|\vec{r}|} - \frac{GM_s}{|\vec{r}-\vec{r}_s|} - \frac{1}{2}\Omega^2 |\vec{r}-\vec{r}_{CM}|^2}$$

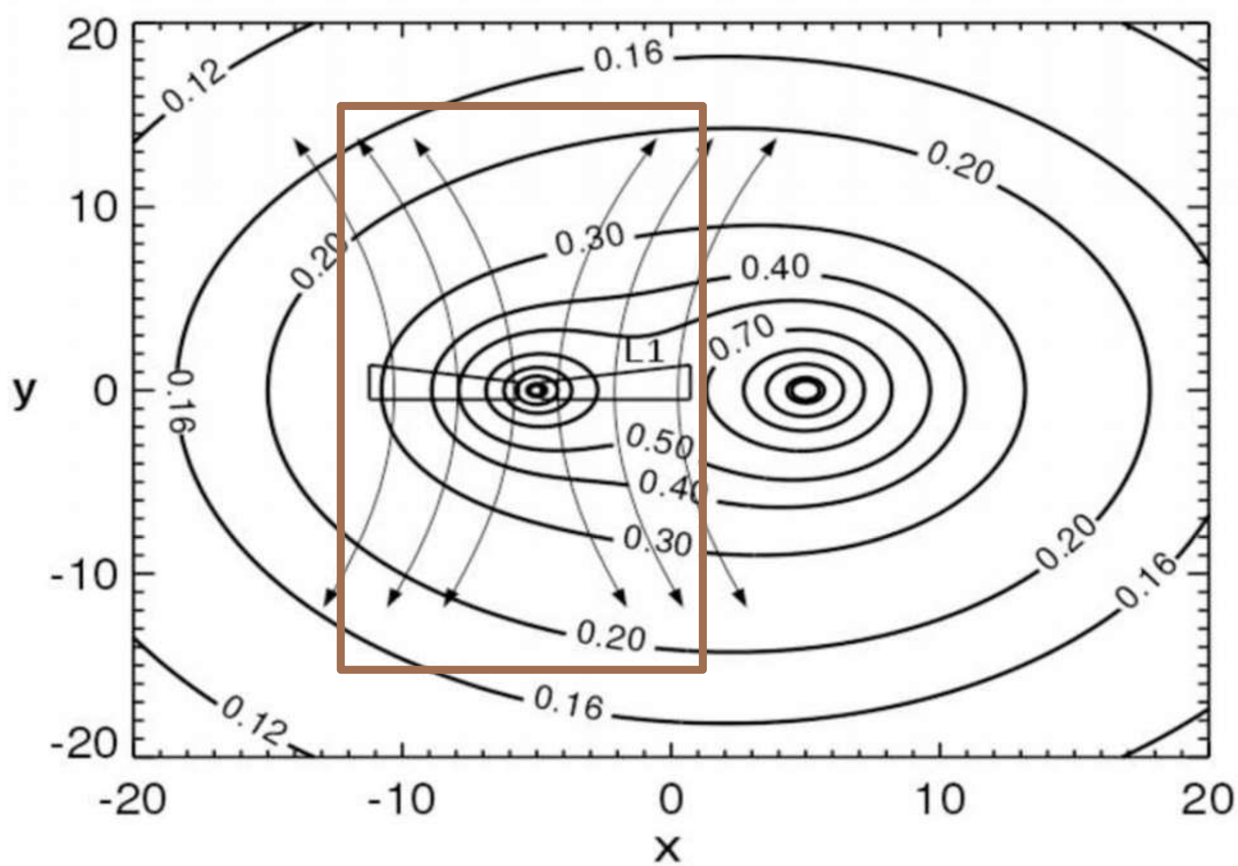
$$\Omega = \sqrt{\frac{G(M_p + M_s)}{|D+h|^3}}$$

Equipotential surfaces of

the 3D Roche potential

$$q = M_s / M_p = 2$$

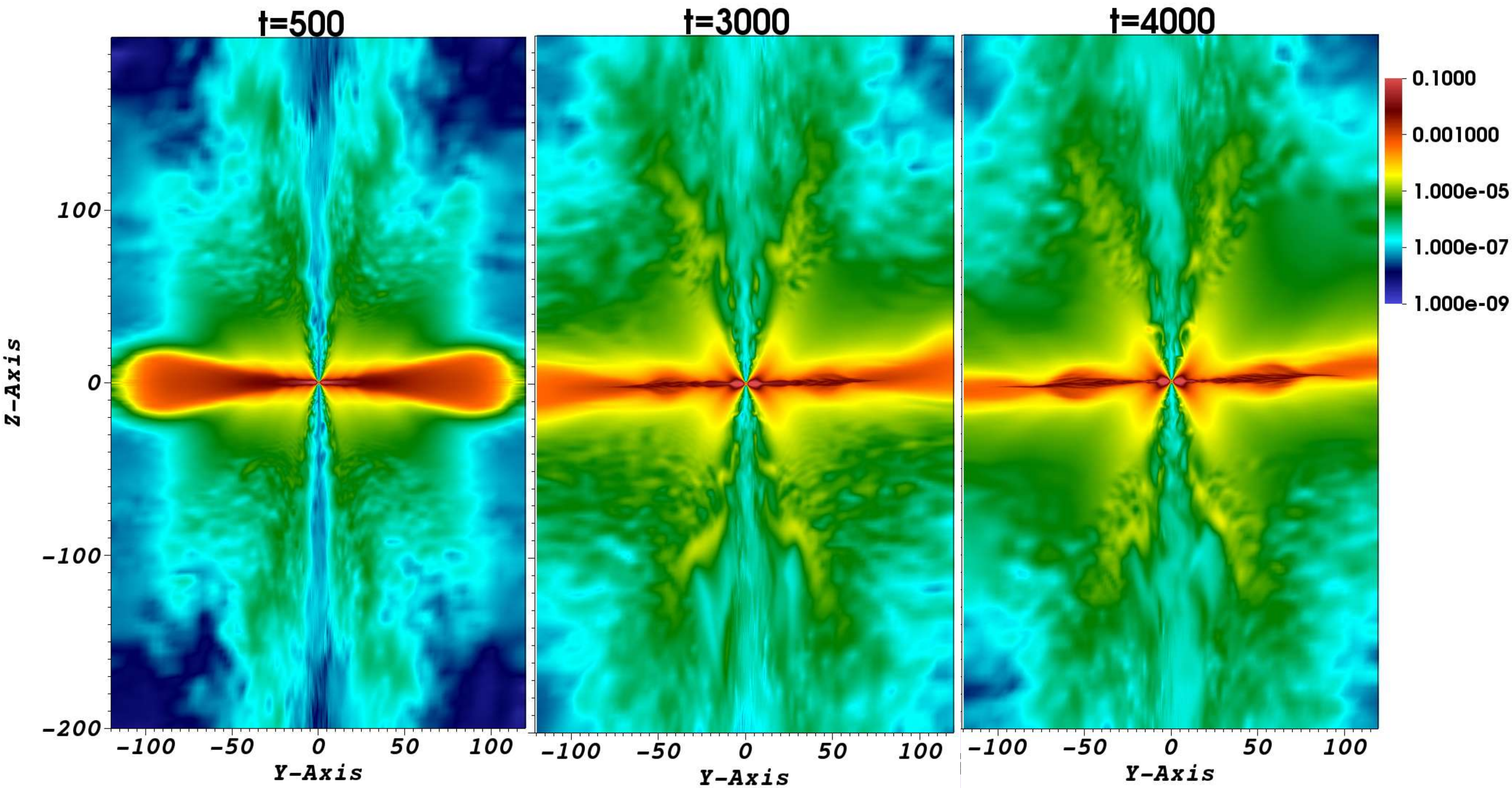
$$D = 100 r_0$$



3D MHD simulation of binary star /disk /jet

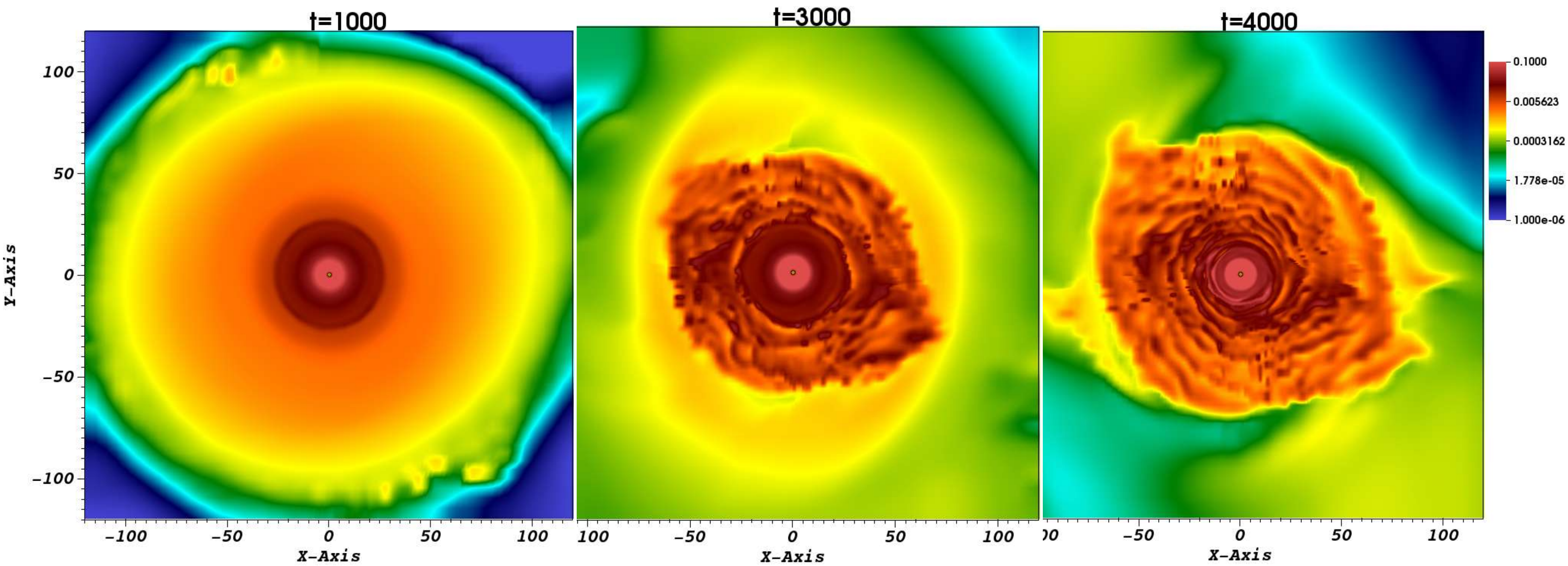
bcase1 , $D = 300 r_i$, $h = 60 r_i$, $\beta = 20$ $q = 2$

Evolution of mass density distribution , y-z plane



3D MHD simulation of binary star /disk /jet

Evolution of mass density distribution , x-y plane



3D MHD simulation of binary star /disk /jet

We observe numbers of non- axisymmetric effects:

- **Jet inclination** : Changing the disk alignment with respect to the initial mid plane

- **Spiral arms** : After dynamical time 1000 axial symmetry is broken and finally leads to a structure that looks like spiral arms.

- **Disk perturbation** : small-scale fluctuations appears in density, pressure and velocity at intermediate radii , $20r_i < r < 60r_i$ at around time 1500

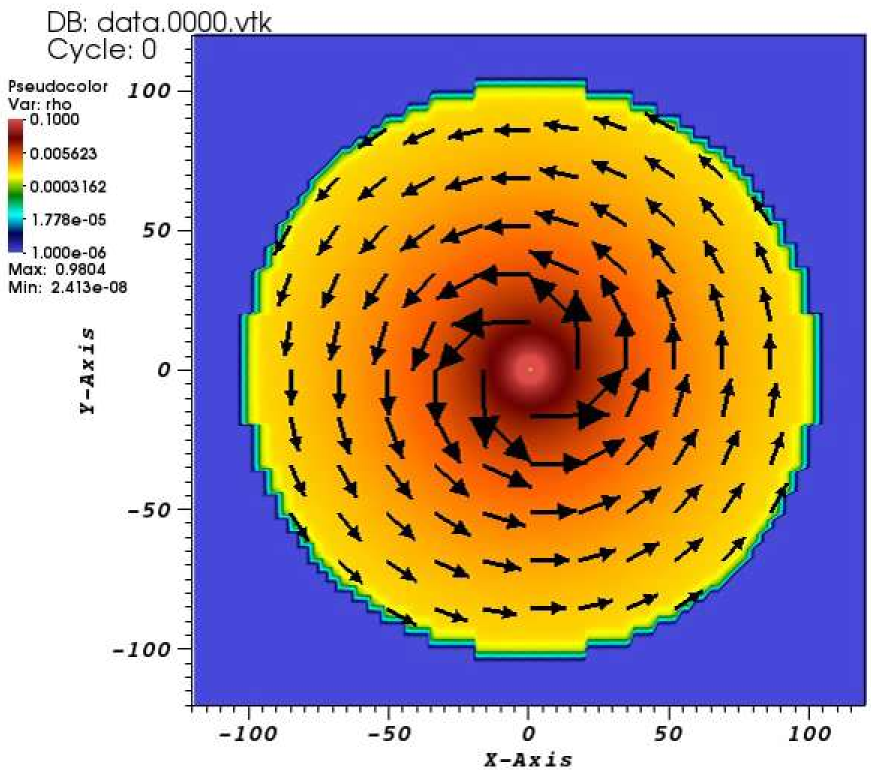
$\Downarrow$

Magneto rotational instability (MRI) !!??

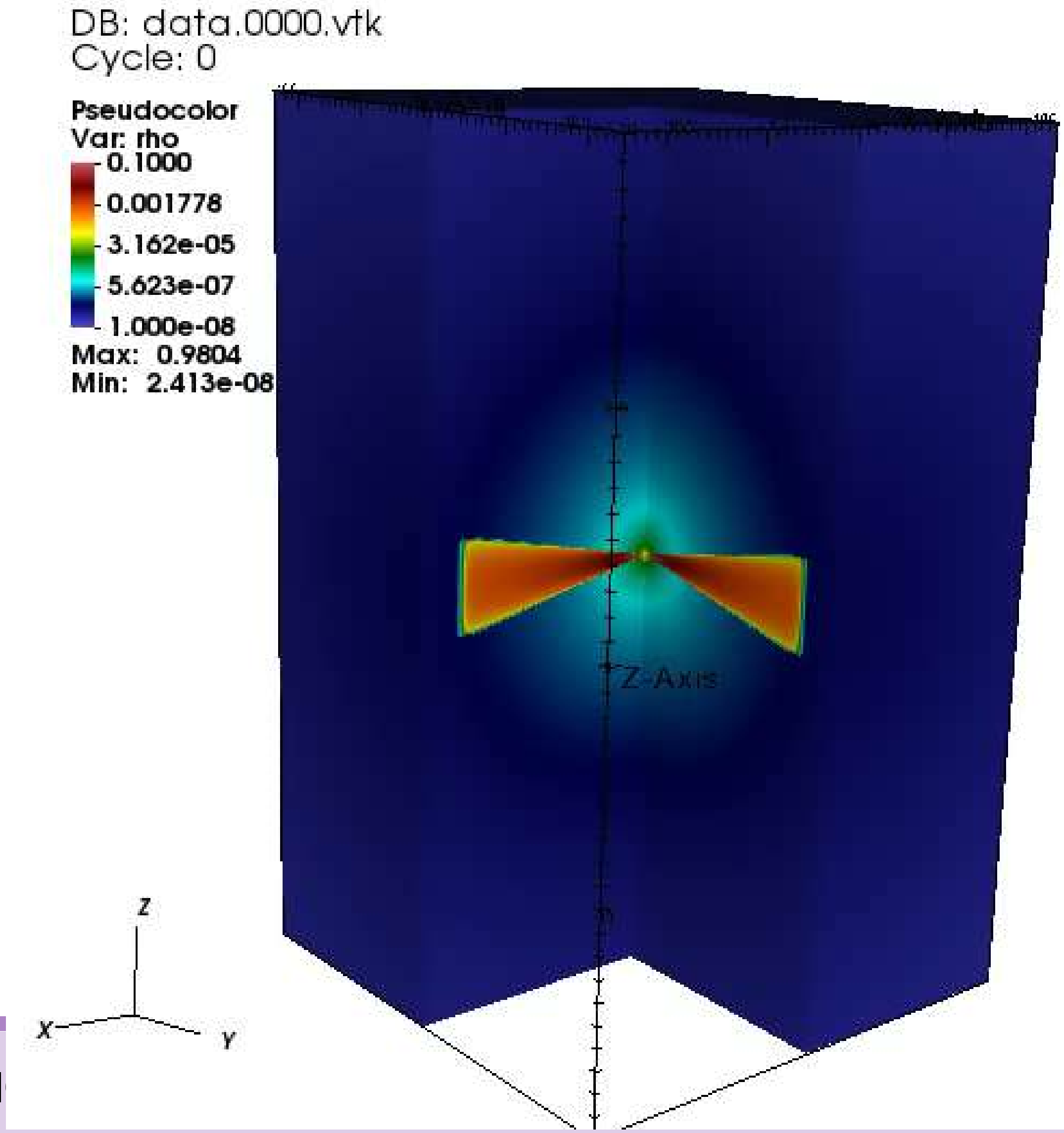
3D MHD simulation of binary star /disk /jet

"close binary system" $D = 200r_i \quad h = 60r_i \quad q = 2 \quad \beta = 20$

Mass density
Velocity vectors



Mass density

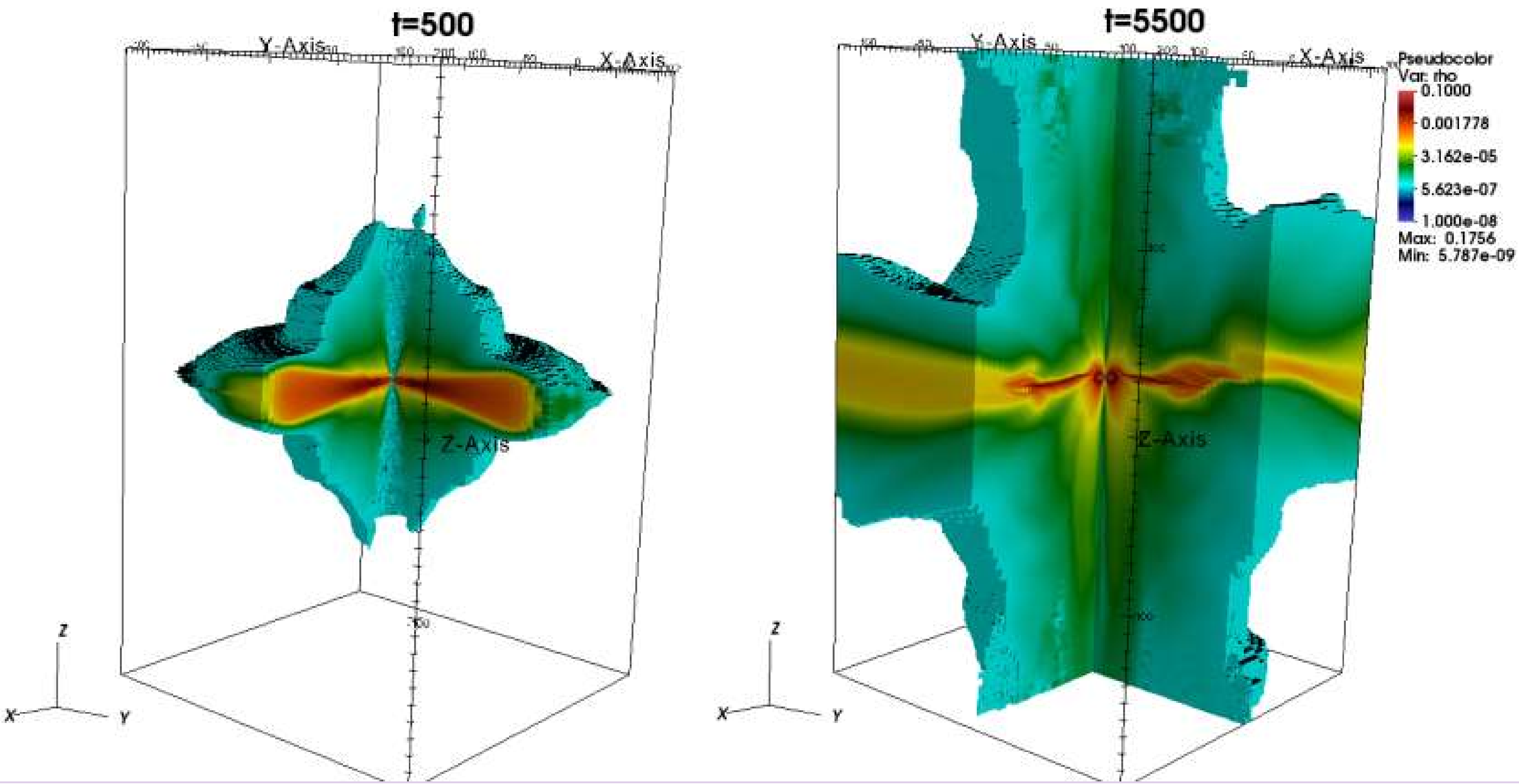


Non-axisymmetric effect: disk warping

Disk warping is induced by combination of two effects:

❖ Disk misalignment with respect to the initial mid-plane

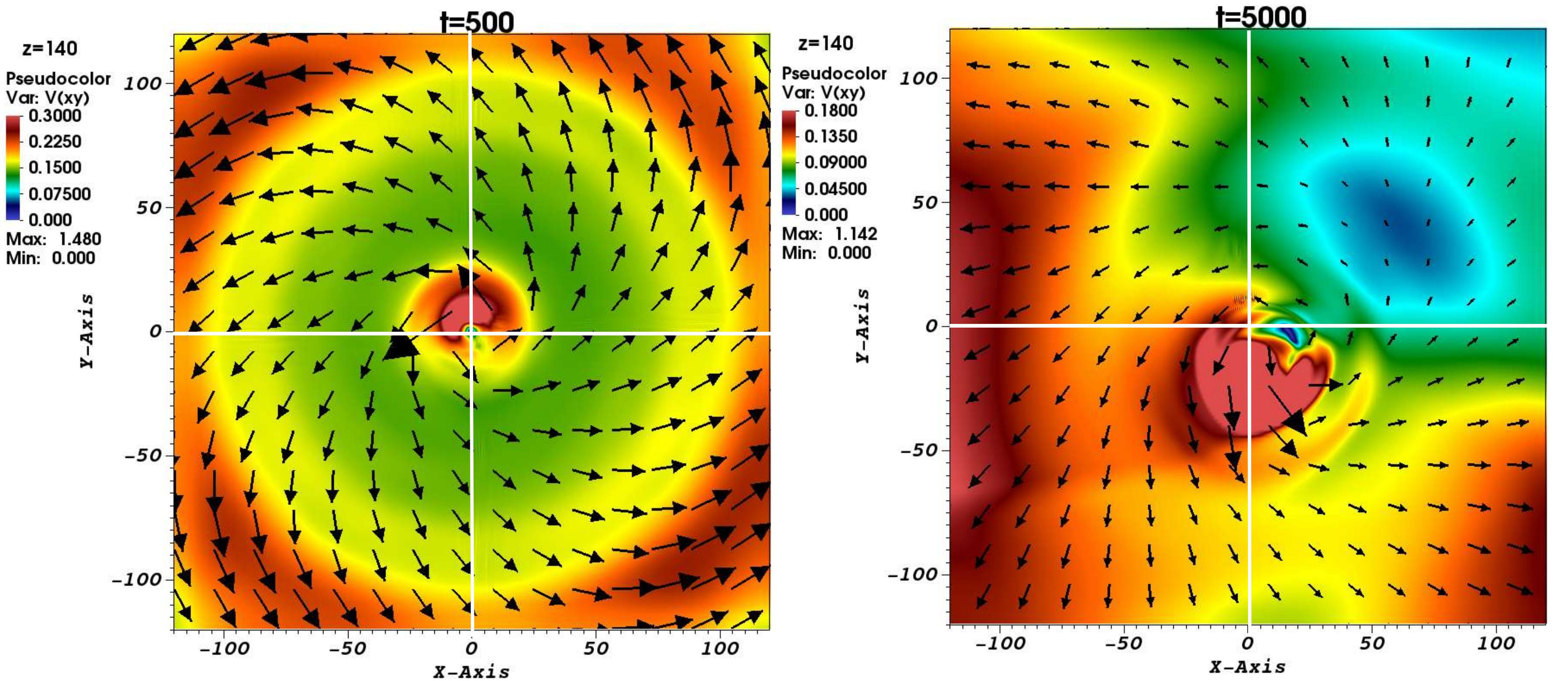
❖ Disk inflation (initiating the Roche overflow)



Non-axisymmetric effect: jet precession

Cross section of velocity in x-y plane after 5000 dynamical time steps

- ❖ Indication for onset of jet precession :
- ❖ jet axis follows the cone of 4 degree opening angle



Summary

- We have extended our previous axisymmetric setup to fully 3D

- The quality of model is confirmed with a well kept axial and bipolar symmetry of the large sacle disk-outflow in the long term simulation

- We implemented 3D gravitational potential due to a secondary.

- We are observe number of non-axisymmetric effects in binary star/disk/jet setup :
  jet inclination , disk perturbation, spiral arms

- Other non axisymmetric effects are observed in closer binary setup:
  disk warping, jet precession

Thanks For Your Attention