Large-scale 3D Simulations of Protostellar Jets: Constraining the Disk Wind Model

Jan E. Staff
Purdue University

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Collaborators:
Kai Cai (MacMaster University); see poster #13
Brian Niebergal (University of Calgary)
Rachid Ouyed (University of Calgary)
Ralph Pudritz (MacMaster University)

Overview

- Simulation setup
- Simulation results

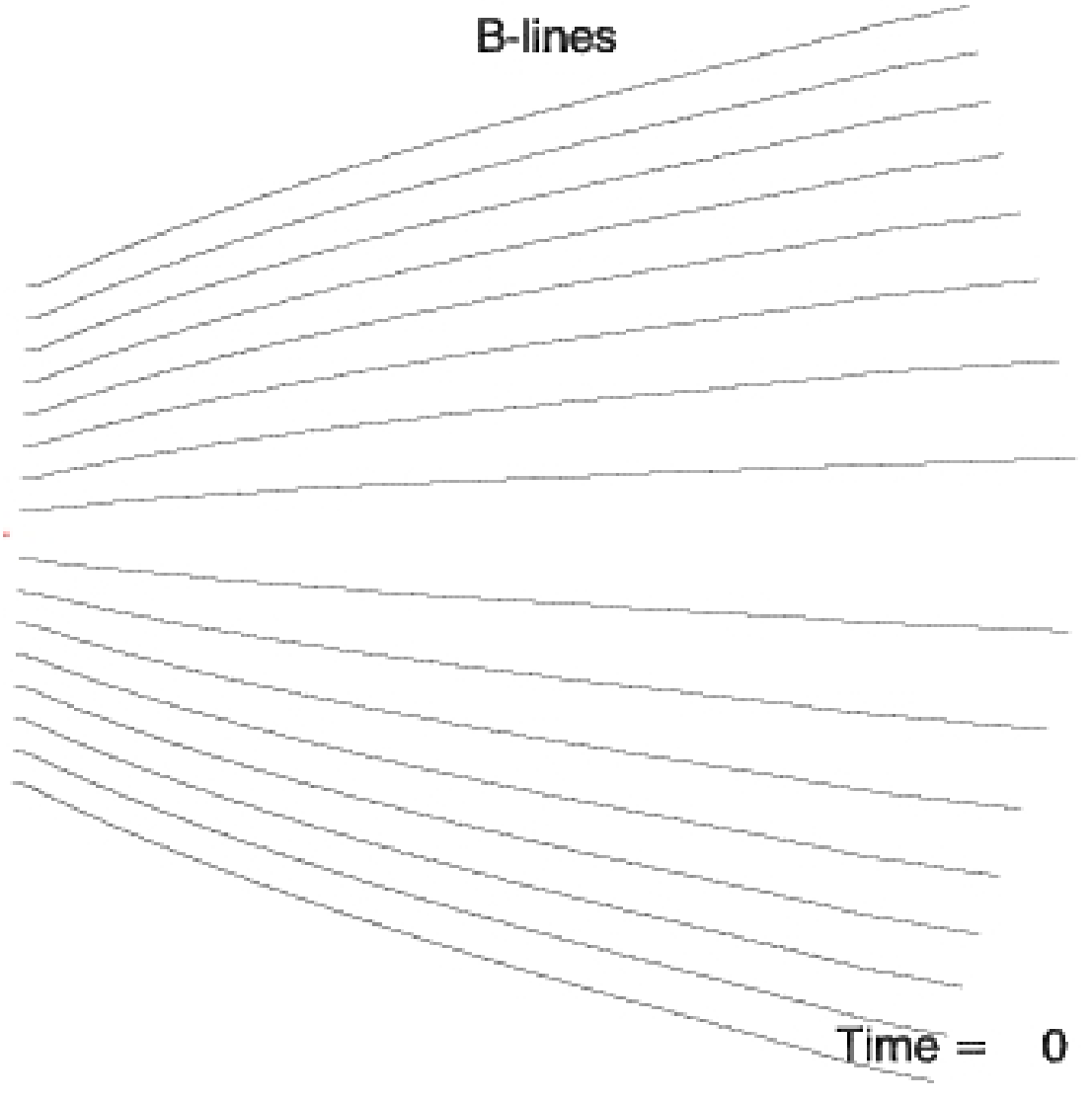
Initial setup

- Coronal density: $\rho \propto 1/R^{3/2}$
- Initial magnetic field is force free ($\mathbf{J}\times\mathbf{B} = \mathbf{0}$) and without a toroidal component.
- Setup is initialy in hydrostatic equilibrium.
- Disk as fixed boundary condition.

Disk

- Keplerian rotation.
- r_i is the inner disk radius ($r_i \approx 0.03$ AU).
- Disk truncated between $75r_i$ and $80r_i$ (~ 2.5 AU).
- Mass loading: mass injected from the disk with a velocity of 0.3% of the rotation-velocity at the inner disk radius.

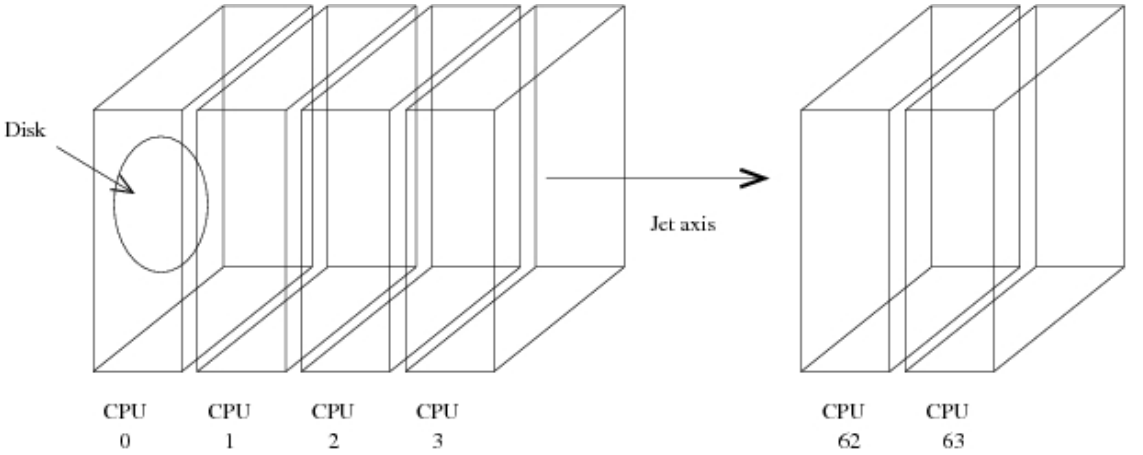
Initial magnetic field configuration



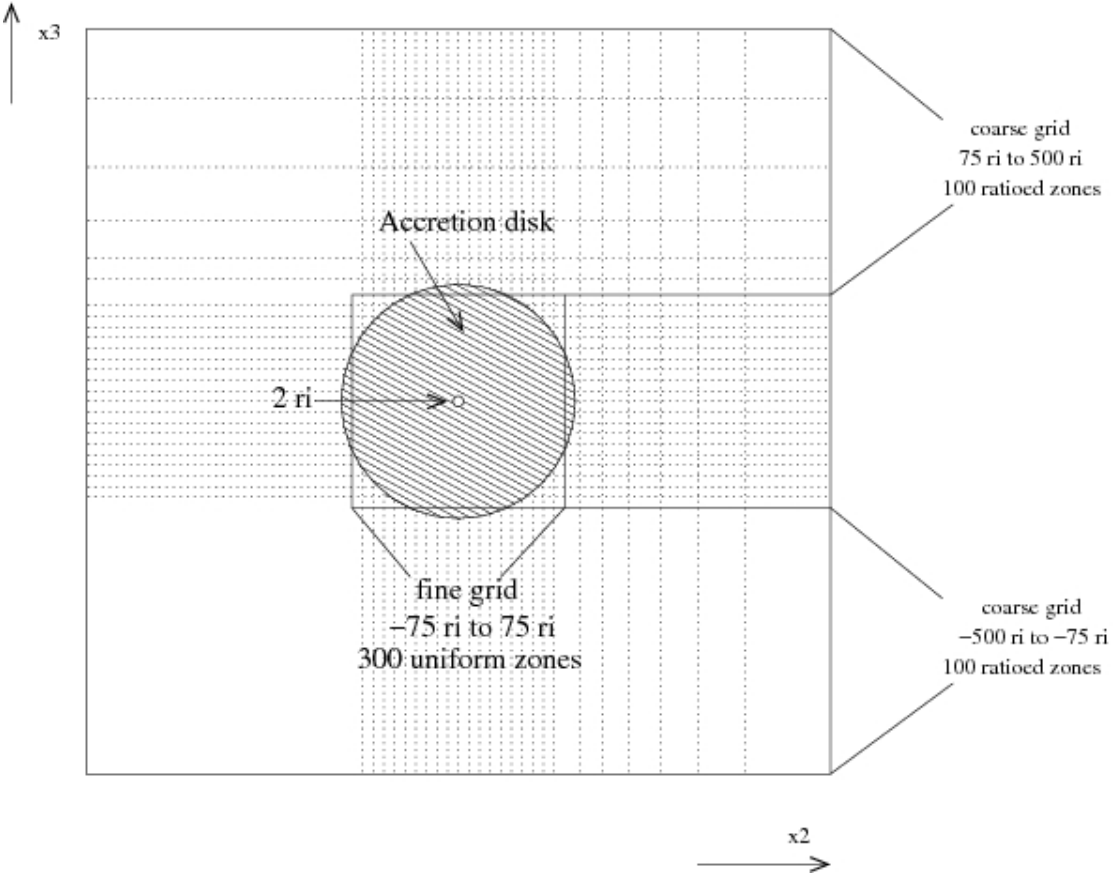
Simulation setup

- Using ZeusMP.
- Entire grid: 1536x500x500 zones, corresponding to 0 to 2000 r_i along the jet axis (0 to 60 AU), and -500 to 500 r_i in each of the two directions perpendicular to the jet axis (-15 to 15 AU).
- Fine grid: 800x300x300 zones (0 to 400 r_i along the jet axis, and -75 to 75 r_i in each of the two directions perpendicular to the jet).
- The simulation box is 60 AU long, and 30 AU wide.
- Simulation run on 64 CPUs on Sharcnet's Requin machine. Simulation was split up along the jet axis.

CPU layout



The grid


x3
coarse grid
75 ri to 500 ri
100 ratioed zones
Accretion disk
2 ri
o
fine grid
−75 ri to 75 ri
300 uniform zones
coarse grid
−500 ri to −75 ri
100 ratioed zones
x2

Basic equations

$$\frac{\partial \rho}{\partial t} + \nabla(\rho \mathbf{v}) = \mathbf{0}$$

$$\frac{\partial \mathbf{B}}{\partial t} - \nabla \times (\mathbf{v} \times \mathbf{B}) = \mathbf{0}$$

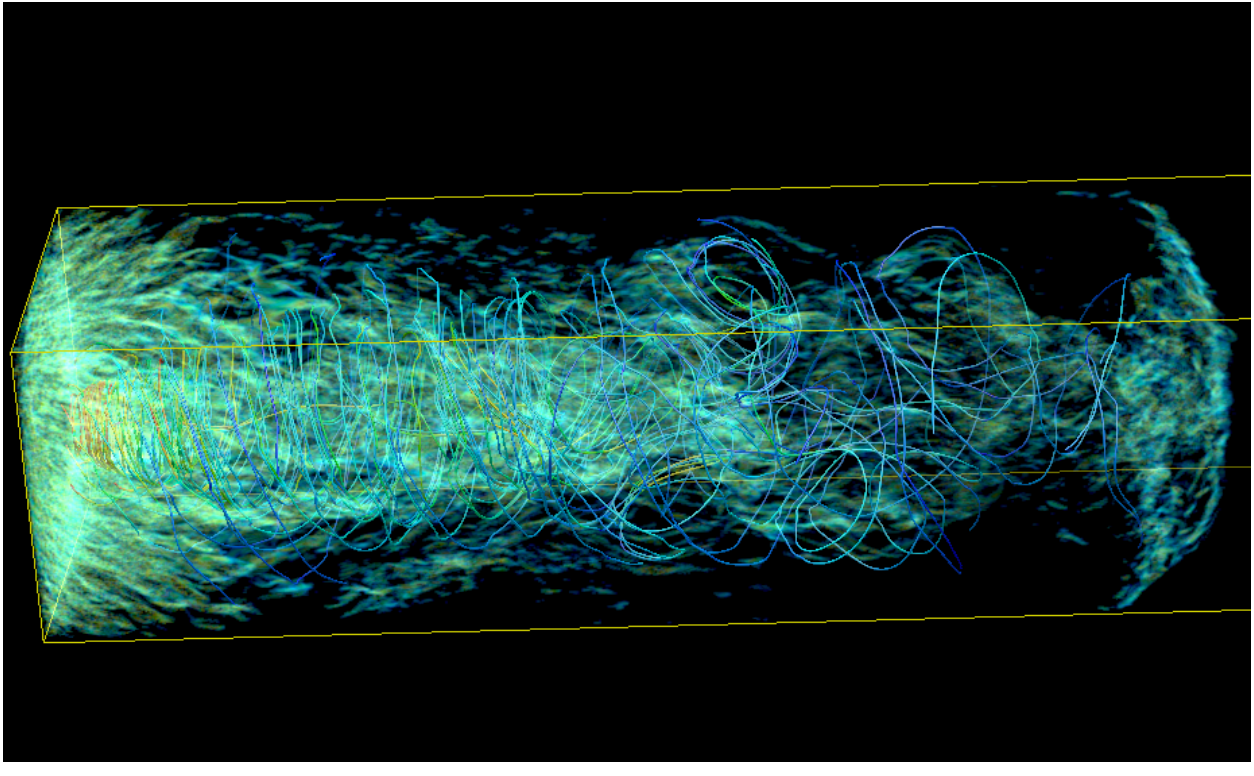
$$\rho\left[\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla)\mathbf{v}\right] + \nabla \mathbf{p} + \rho \nabla \phi - \mathbf{j} \times \mathbf{B} = \mathbf{0}$$

- Polytropic equation of state: $e = e(\rho)$.
  Internal energy is a function of density only.
- We do not solve energy equation.
- $T \propto \rho^{\gamma - 1}$; $\gamma = 5/3$.

Simulation results

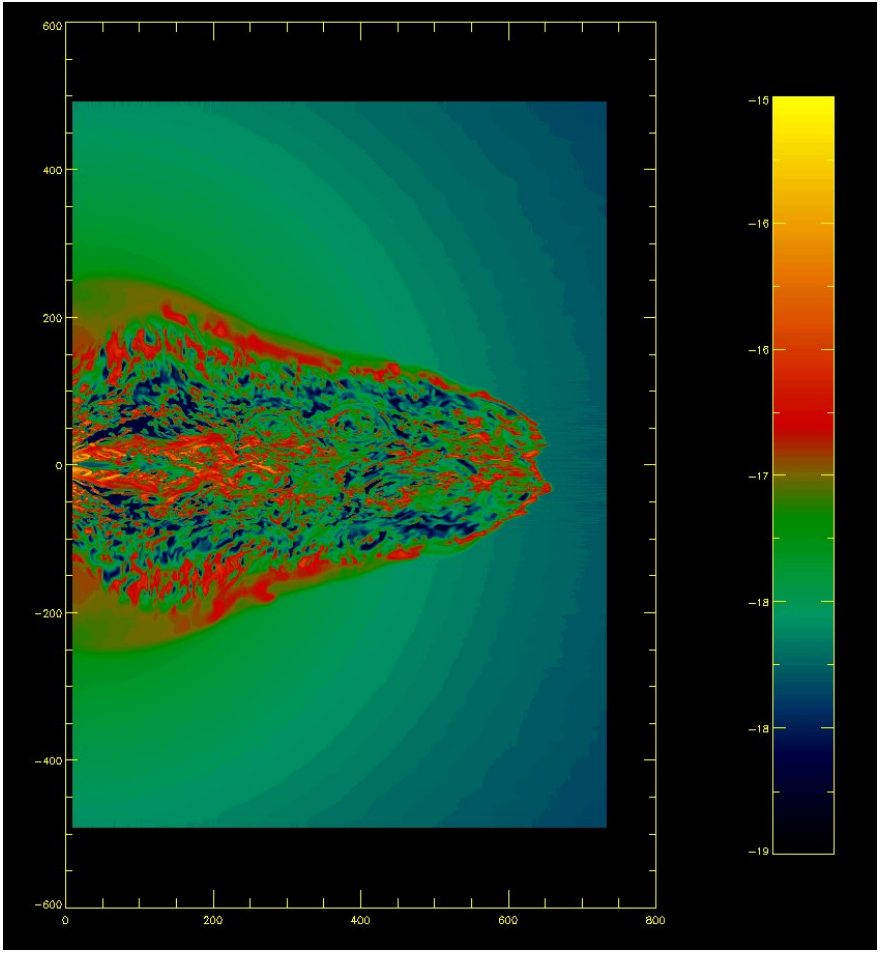
Density and B-field structure

After 1500 rotations of the inner disk:



The jet head has reached about 20 AU.

Density

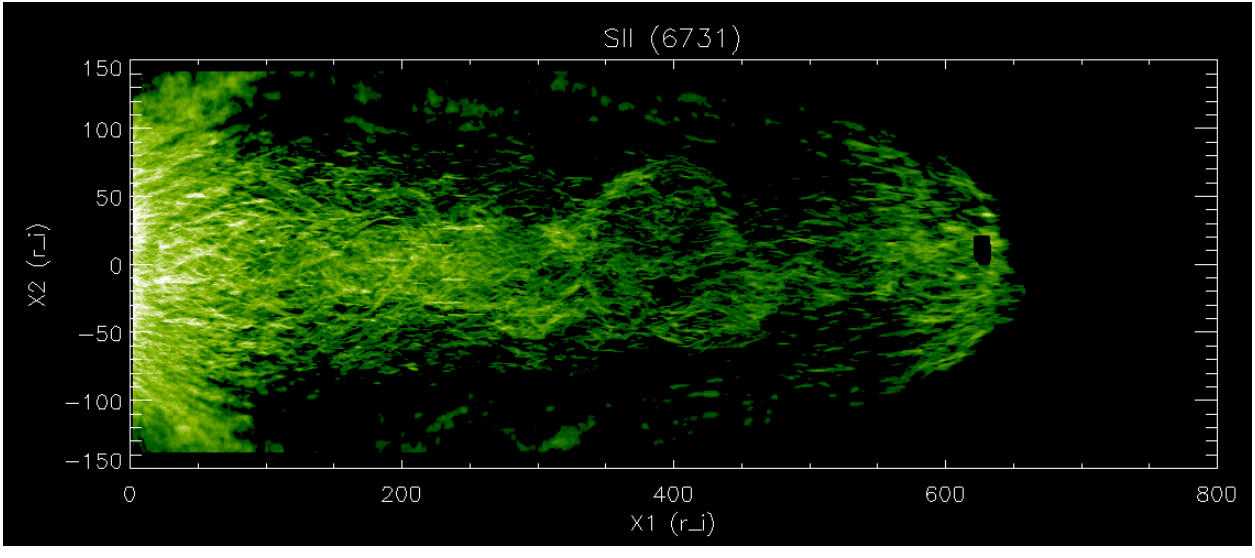


After 1500 rotations of the inner disk. The jet head has reached about 20 AU.

Emission line maps

- Found in post processing.
- Assume that emission depends on temperature (and hence density) only.
- Emission is supressed above quenching density.

SII 6731A



After 1500 rotations of the inner disk. The jet head has reached about 20 AU.

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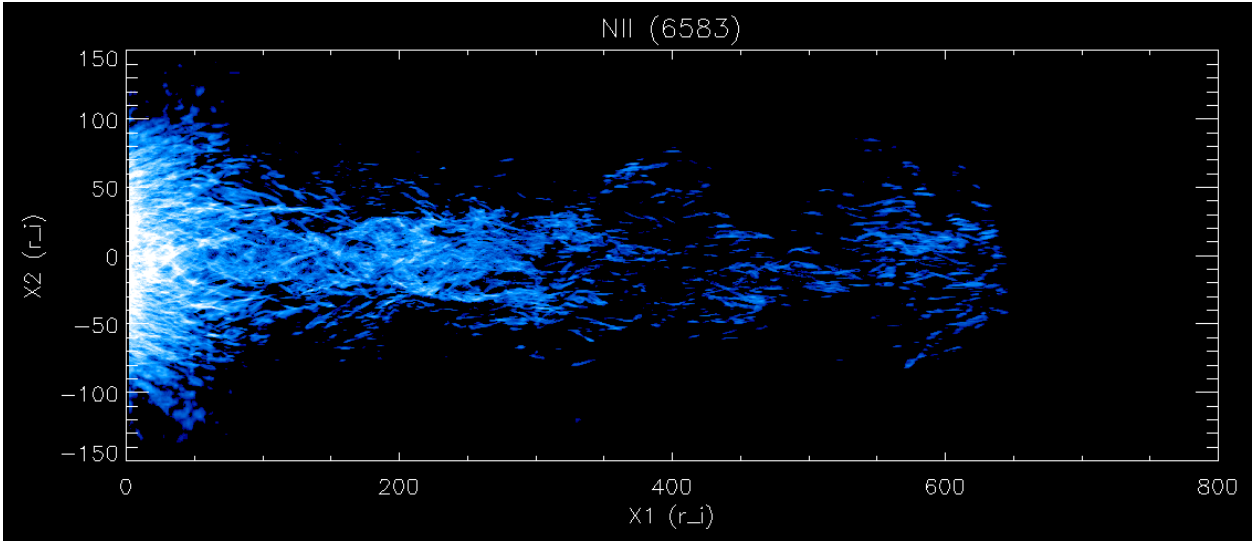
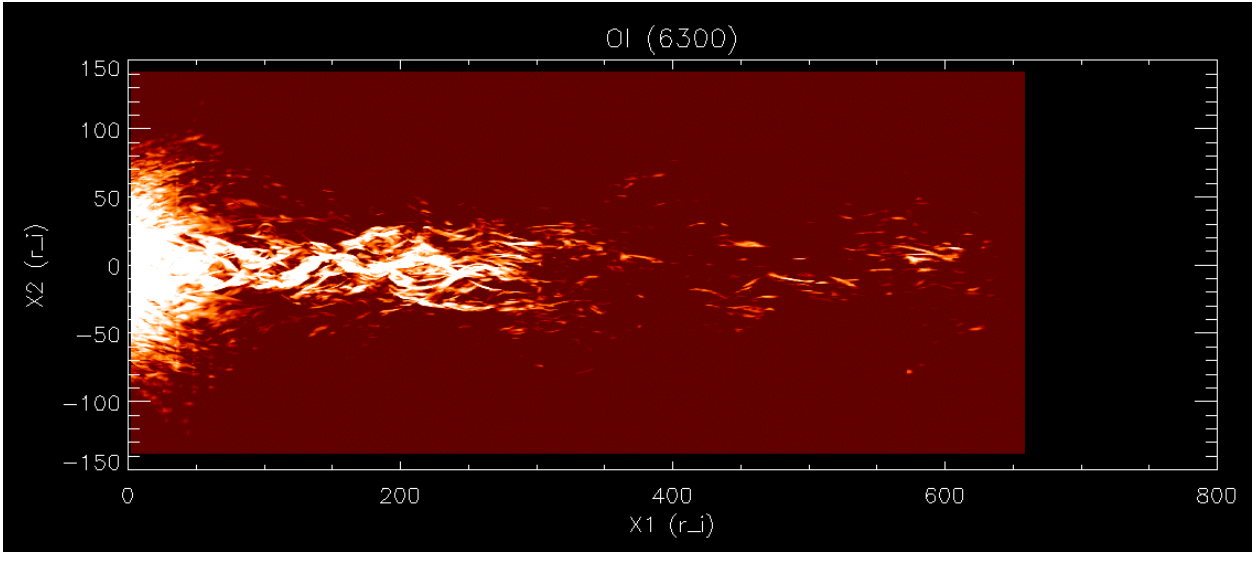


After 1500 rotations of the inner disk. The jet head has reached about 20 AU.

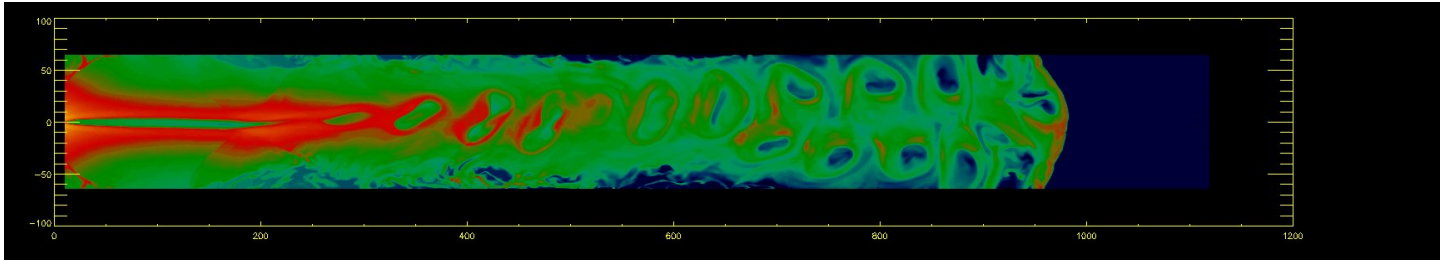
OI 6300A (logarithmic plot)



After 1500 rotations of the inner disk. The jet head has reached about 20 AU.

Higher quenching density; brighter close to source.

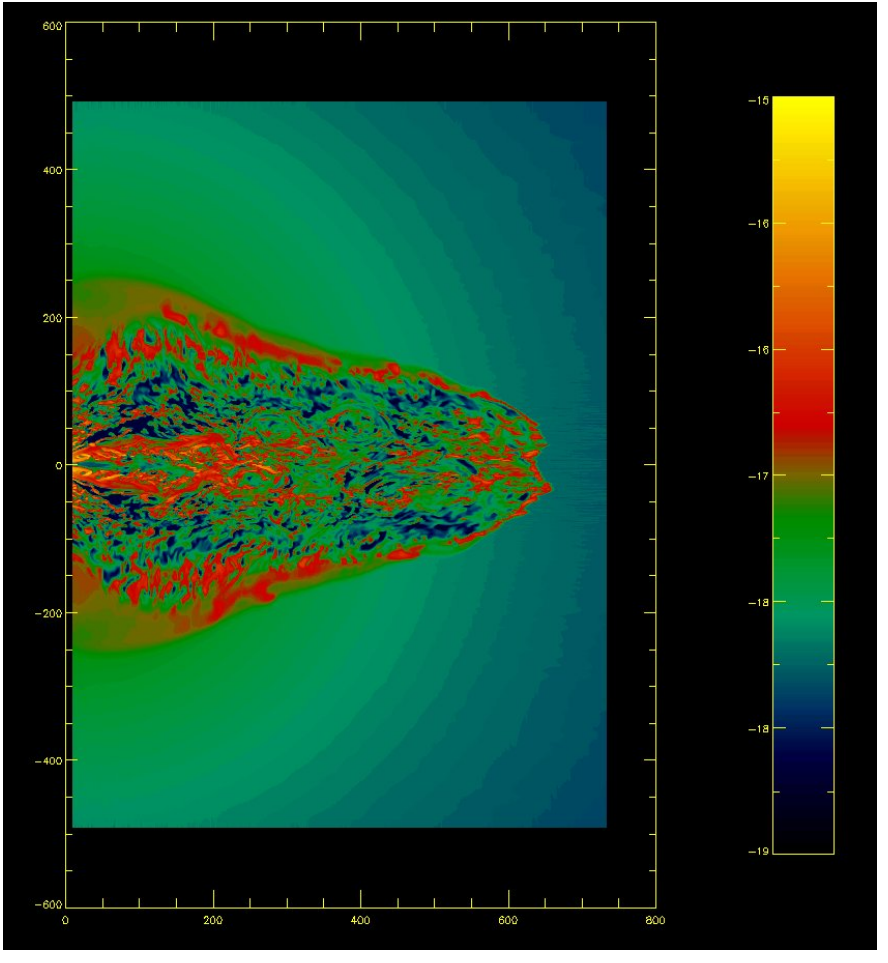
Longest run so far (narrow simulation)



After 2200 rotation of the inner disk. The jet head reached almost 30 AU.

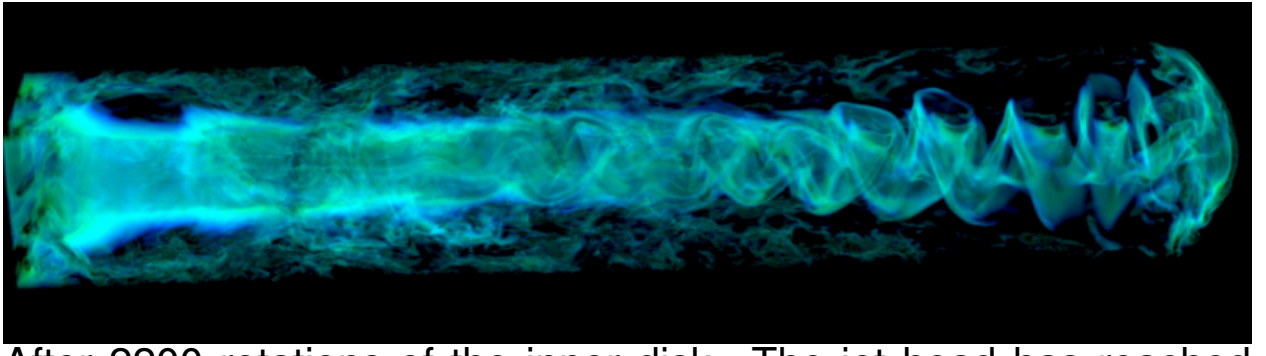
Narrower grid, about 4 AU wide. Disk radius 0.6 AU.

Density (wide simulation)



After 1500 rotations of the inner disk. The jet head has reached about 20 AU.

Density (narrow simulation)



After 2200 rotations of the inner disk. The jet head has reached almost 30 AU.

Summary

- We have extended previous simulations by Ouyed & Pudritz to 3D, and can follow the jets to scales comparable to HST observations.
- Wider box changed the jet structure.
- Self consistently created density structures.
- Created emission line maps that can be directly compared to observations.

Future

- Wait... For simulations to progress.
- Improve emission line calculations.
- Create velocity ”channel maps”.

Thank you!