From Accretion to Outflows of Massive Protostars

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Abstract

Context:
Direct observation of the formation of massive protostars and their accretion disks is observationally hindered due to their large average distance and due to the fact that they are embedded in an opaque cloud of dust.
That's why their outflows depict the best studied indirect signs of the early phases of massive star formation. Still, there are numerous open questions concerning the connection between these large-scale outflows and the underlying accretion processes. So far, these were only barely addressed in research of theoretical massive star formation.
To investigate the accretion to outflow physics in the early phases of high-mass star formation, we model the collapse of magnetized, high-density, molecular cloud cores.
In the current Simulations, we follow the evolution of a cold, magnetized molecular cloud ~2 free fall times. We observe how the in-falling envelope forms an accretion disk that twists and enhances the initially weak magnetic field to launch a jet. Afterwards we analyze the physical parameters of the steady jet and compare them to theoretical predictions and observations.

Software:
Magneto-Hydrodynamics (Pluto, Mignone et al. 2007, ApJS)
Poisson Solver for Self-Gravity (Kuiper et al. 2010, ApJ)

Current methods:
- Isothermal equation of state
- Ideal MHD

Planned extensions:
- Ideal equation of state
- Ohmic dissipation
- Ambipolar diffusion
- Radiative MHD

Aims:
We investigate the accretion process and its connection to large scale outflows in the early phases of high-mass star formation. We aim to reduce artificial constrains as much as possible while reconstructing observed and established theoretical results as closely as possible. The most important aspects of our research manifest themselves in the questions we are trying to answer:
- How is the outflow correlated to the accretion process?
- Does disk-mediated accretion and magneto-centrifugal acceleration of outflows yield velocities and mass loss rates comparable to observational data?
- What is the origin of the differences between low and high mass star formation?
- What explains the low star formation efficiency of high mass YSOs?
- Does the evolutionary sequence of early magneto-centrifugal protostellar outflows and later radiation pressure dominated outflows explain their observed broadening in time?

Results:
Here, we report on our initial results regarding the required numerical resolution of the launching region.

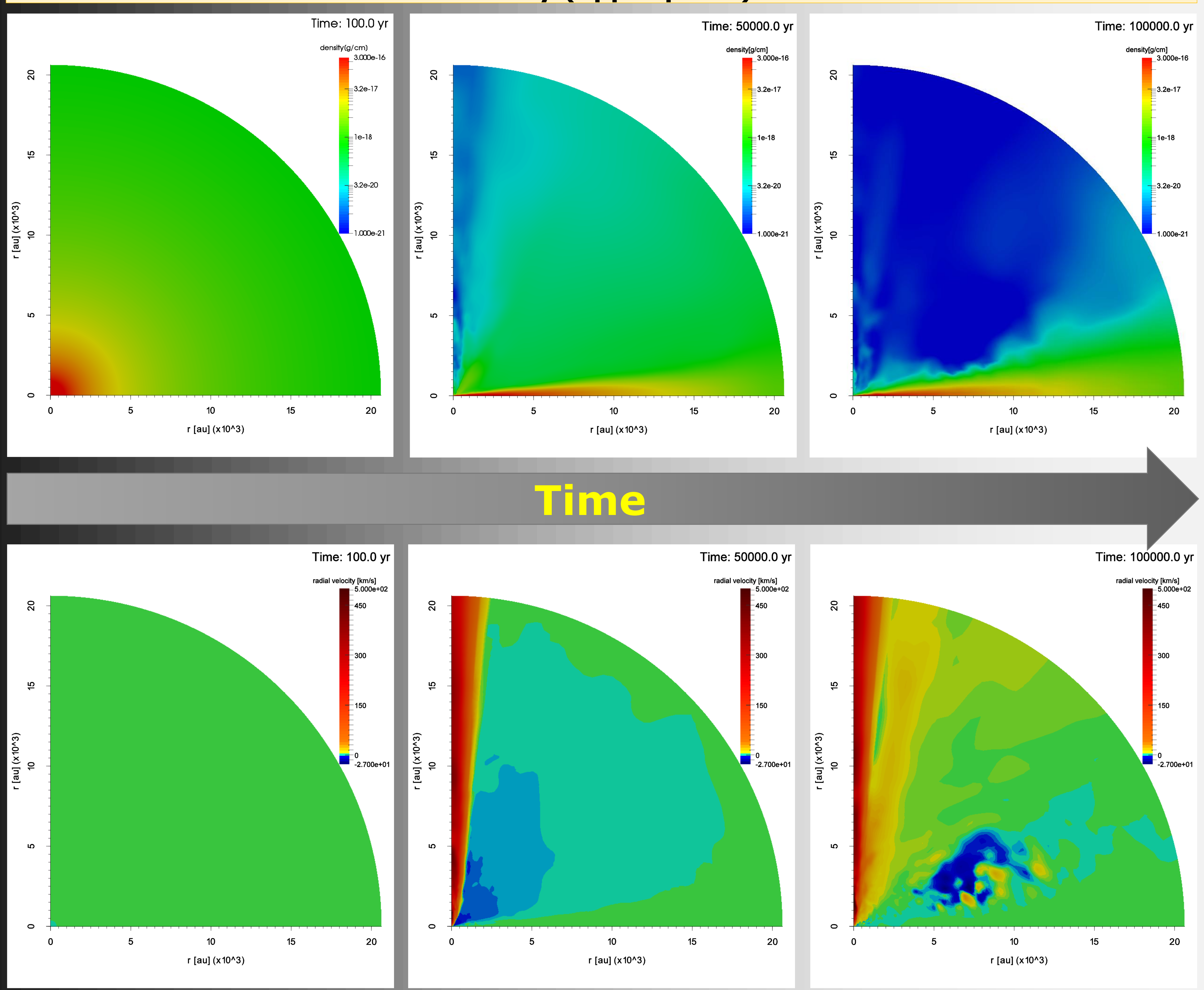
Setup

Grid:
- Spherical coordinate system
- Logarithmic radial coordinates
- 2 dimensions
- Shear viscosity
- Polar axial symmetry
- Equatorial midplane symmetry
- Angular resolution down to <1° per cell
- Resolution up to 608x104 cells total

Initial Conditions:
- Magnetized pre-stellar core: $M_{core} = 100\ M_{sol}$
- Initial magnetic field in z-direction: $\frac{M}{\phi} = 2$
- Spherical symmetric density distribution: $\rho \sim r^{-2}$
- Slow solid body rotation
- Temperature: $T_{core} = 10K$
- $R_{core}: 2\ au - 0.1\ pc$

Collapse & jet-envelope interaction

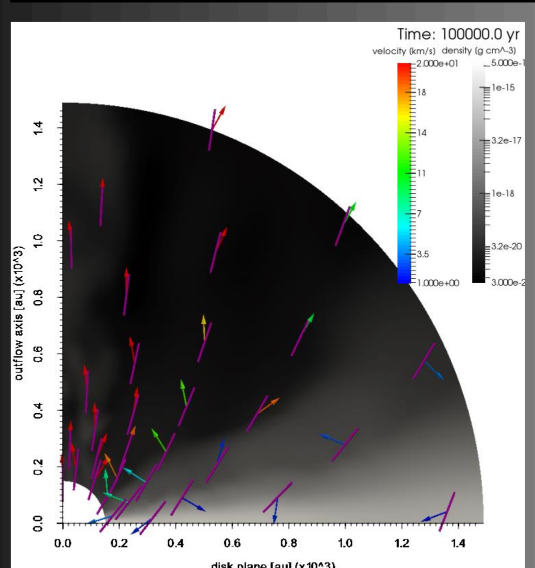
Density (upper panel)



Radial velocity (lower panel)

The evolution of a molecular gas cloud collapsing under its own gravity: initial setup with the in-falling envelope (left), disk and jet structures after ~one free fall time (center), and the nearly vanished envelope and the protostellar jet after ~two free fall times (right)

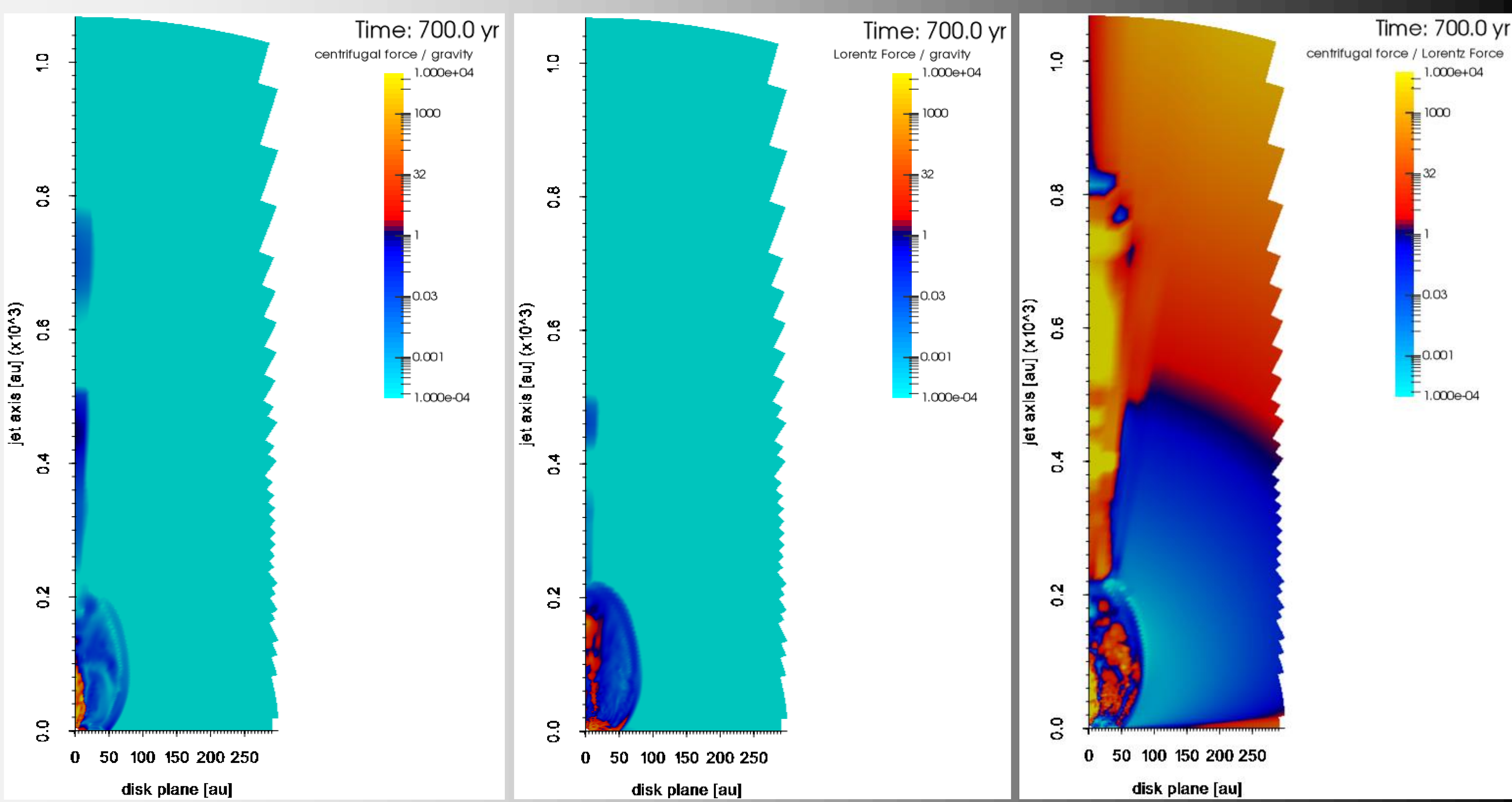
Comparison with observation



Our results can be readily compared to observations and show promising similarities with recent data. (see talk by *Alberto Sanna*)

Left: Density (background, black/white), flow velocity (arrows, color coded) and alignment of the magnetic field (violet bars) after ~2 free fall times.
(The picture shows only inner 150-1500 au of the total computational domain.)

Jet launching

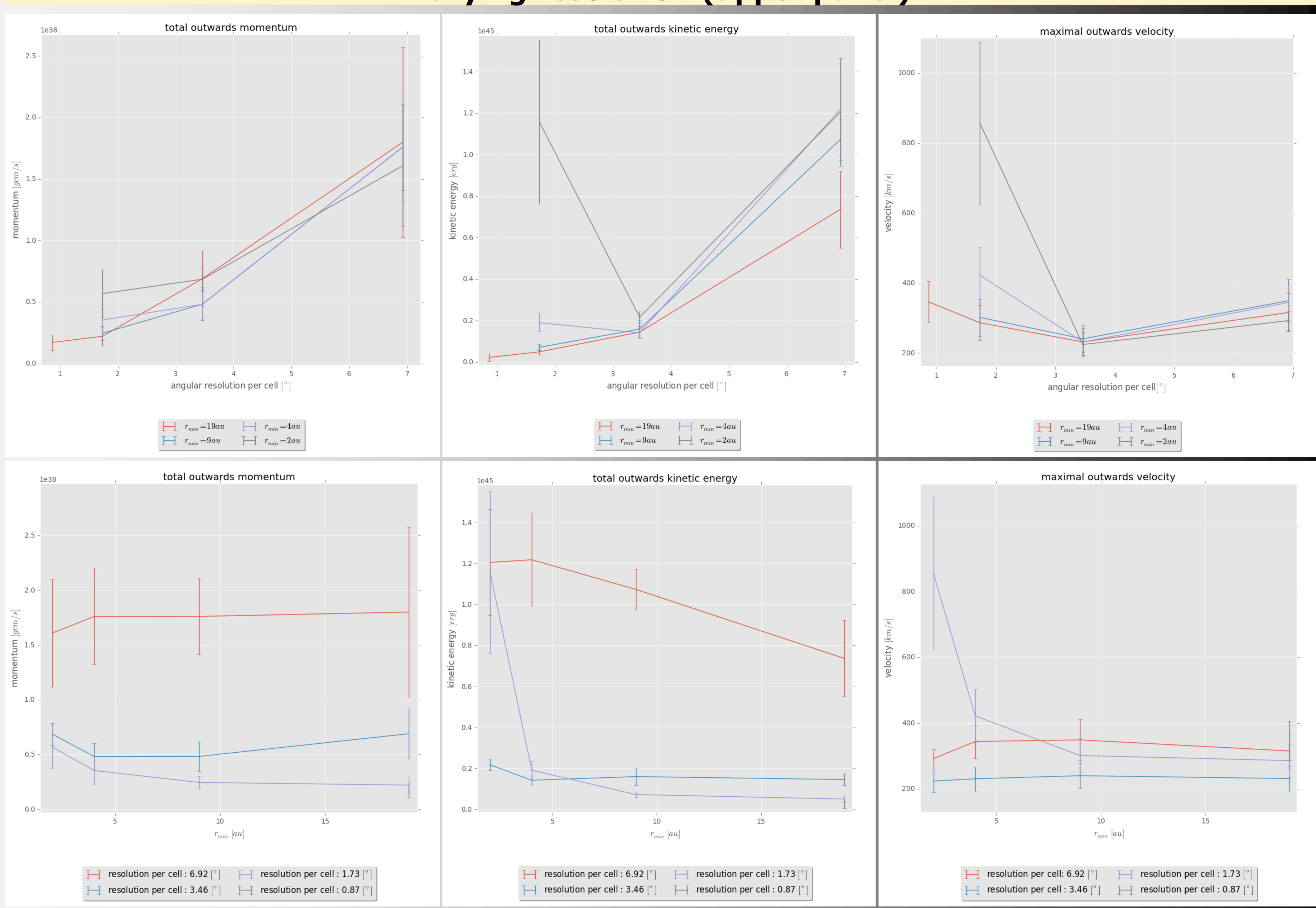


Comparison between the magnitudes of different forces in the launching process: The gravitational force governing the collapse becomes vanishingly small compared to the magnetio-rotational forces that are responsible for launching the jet.

Convergence

While our simulations show qualitatively similar results for different resolutions, important physical parameters of the jet are dependent on the chosen resolution. Therefore, we are currently conducting a convergence study to find the necessary resolution to properly resolve the physical processes involved.

Varying resolution (upper panel)



Varying radius of the inner sink cell (lower panel)

Physical properties of the jet for different resolutions and radii of the inner sink cell: the total moment carried in the jet (left), the total kinetic energy of the outflowing material (center) and the maximal velocity reached in the jet (right) (Only the angular resolution is given. The radial resolution varies accordingly.)