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From accretion to outflows of massive protostars

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Abstract. We model the long-term evolution of magnetized, massive prestellar cores from their initial gravitational collapse, through the formation of a circumstellar disks, the launching of fast collimated jets and wide angle winds, to the final cloud dispersal and outflow broadening. Our simulations resolve a high dynamic range in space and time and enable us to analyze the physical mechanisms of the jet launching process in detail, investigate feedback properties of the outflow and distinguish various effects leading to outflow broadening. We study how simulations with spherical coordinate systems, different boundaries, initial conditions and numerical parameters converge and how their properties influence disk formation and jet launching. We then compare these results with established theoretical models for stationary jets (e.g. Blandford 1982, Pelletier 1992 Lynden-Bell 2003) and with recent observations (e.g. Sanna 2015).

1. Introduction

Many details of the formation process of massive stars are still poorly understood. This is due to their large average distance from our solar system and due to the fact that their early evolutionary stages take place in an opaque cloud of gas and dust barely penetrable by our current observational capabilities. Still, we can observe a prominent feature of their evolutionary phase: their bright large-scale jets and outows. Massive stars have a significant impact on their surroundings. Their feedback mechanisms trigger further star formation and are, therefore, influences the initial mass function of their home cluster, they provide heavy elements for later generations of stars and act as giant stellar laboratories.

2. Setup

We use the modular magneto-hydrodynamics code PLUTO (Mignone 2007) with a self-gravity solver developed by Kuiper (2010). Here, a two-dimensional setup with equatorial and axis symmetry and with ohmic resistivity as a simple model for the magnetic dissipation in the dead, dense and radiatively shielded region of the disk is used. We choose an isothermal equation of state in most of our simulations but we can simulate virtually arbitrary equations of state. In combination with a spherical coordinate system and logarithmic scaling in radial direction this enables us to model a huge prestellar core up to large distances from the central object (here 0.1 pc) while sill being able to resolve the central engine that launches jets and outflows (Figure 1); here, down to $\simeq 1$ au distance from the origin.

Initially the cloud core has a radially symmetric density distribution and the rotational axis is aligned along with the direction of the magnetic field. Magnetic and rotational energies are chosen such that the core is highly supercritical and collapses immediately.

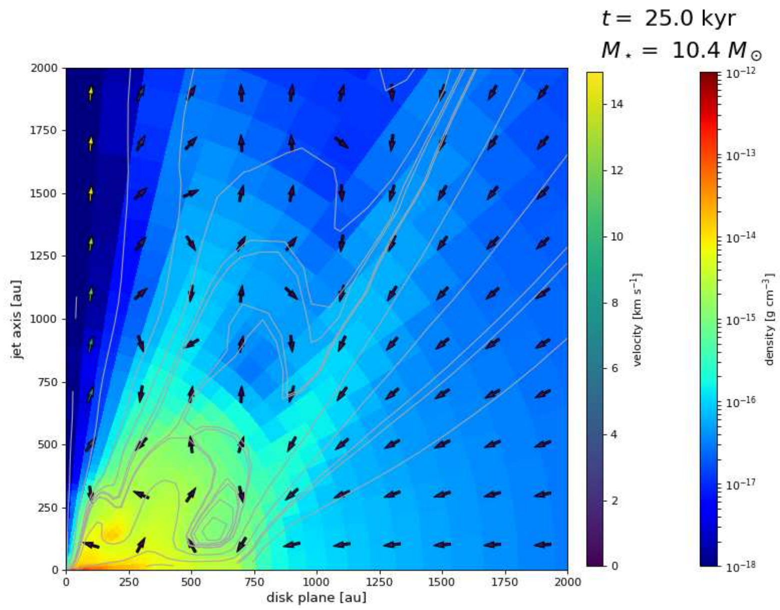

Fig. 1. The collapse of a prestellar core after $\simeq \frac{1}{2}$ free fall time: The dense envelope is infalling along the magnetic field lines (shown in grey) down to the disk's surface. It provides the disk/jet-system with material. Magnetic braking slows down the rotation of the innermost part of the accretion disk leading to steady accretion onto the protostar. A fast (300 km/s) jet is launched by magneto-centrifugal forces from the central few AU, thereby entraining some of the material of the (otherwise still infalling) envelope.

3. Discussion

While the principal mechanisms of outflow launching (magneto-centrifugal jets, magnetic tower flows, and later, radiation pressure and line-driven winds) are known, our simulations indicate that static, self-similar analytic models(Blandford 1982) are too ordered to describe the jet launching region in the inner part of a massive cloud core realistically. The jet launching regions in our simulations show a rather complex magnetic field topology and evolve rapidly on timescales of years. The extreme interplay of gravity, magnetic and centrifugal forces, and the rapidly infalling envelope prevent the development of a more static situation close to force equilibrium. Our simulations converge only with very high resolution ($\simeq$ 0.5 AU in the launching region). Such resolutions are virtually unfeasible in simulations that start from a collapsing cloud core and utilize a Cartesian grid, even with AMR. Though some physical properties, like the maximal (magneto-centrifugal) jet velocity, do not converge for different sink cell sizes (With the sink cell's radius the smallest possible launching radius shrinks as well.) The slower wider-angle magnetic tower flows are only to lesser degree influenced by the sink cell size, due to their larger distance from the sink.

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