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# Simulations of the early phases of protostellar disc evolution with radiation transfer

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**Abstract.** All protostars are surrounded by a disc like structure or proper Keplerian disc. Those discs are essential to understand the subsequent evolution of the protostar and are most probably the birthplaces of binary or multiple stellar systems, apart from being the nurseries of planets. Nevertheless, it is fairly unknown how the discs, and hence the protostars are decoupled from the infalling envelope and molecular clouds. Here we present preliminary self-consistent simulations of protostars and discs which are still embedded in an accreting envelope to track their late evolution.

## 1. Introduction

We present first 3D cloud collapse simulations employing a hybrid characteristics radiation transfer scheme (Buntemeyer et al., 2016). The solver is embedded in the magneto-hydrodynamics adaptive mesh refinement code FLASH (Fryxell et al., 2000).

We also demonstrate a star formation evolution model (Offner et al., 2009), which supports the generation of a sink particle (Federrath et al., 2010) at later collapse stages with a suitable sub-grid model.

## 2. Cloud collapse

We follow the collapse of a low mass cloud until the first hydrostatic core forms. We use a tree based self-gravity solver and the 3D radiation transfer scheme on a Cartesian grid with adaptive mesh refinement. The simulation takes place in a cubic box of size 9450 AU, which is filled with a gas of initially homogeneous density and a total mass of $M_{\mathrm{total}} = 1.96\,\mathrm{M}_{\mathrm{sol}}$. We apply outflow boundary conditions and a 10 K background radiation field. The gas is at rest initially. We run the simulation for one free fall time $\tau_{\mathrm{ff}} = 56.67$ kyr. Since the 3D setup is spherically symmetric, we show in figure 1 1D profiles of characteristic quantities at the end of the simulation.

## 3. Cloud collapse with rotation

We extend the setup of the spherically symmetric cloud collapse with an angular velocity of $\Omega = 1.886 \cdot 10^{-13}\,\mathrm{rad/s}$ with respect to the z-axis, which is added to the initial gas distribution. After 114.7 kyr the gas density distribution (figure 2) shows early disc formation, but a first hydrostatic core has not been formed yet. Still the temperature in the central dense core begins to rise.

## 4. Protostellar evolution model

At some point in a adaptive mesh refinement collapse simulation, the resolution has to be limited. To follow the star formation further

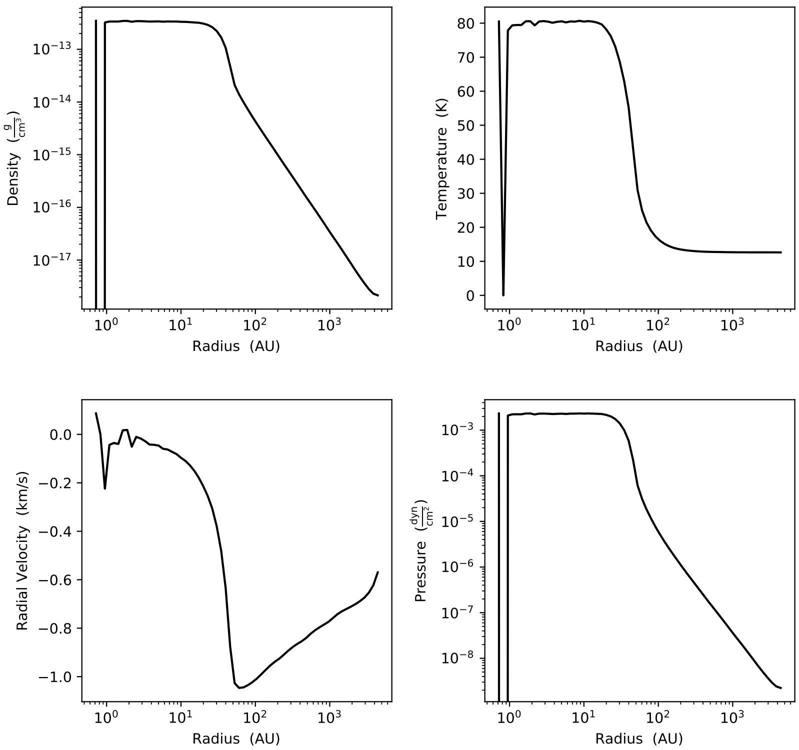


**Fig. 1.** Characteristic quantities after one free fall time of the cloud collapse simulation. Since the solution is spherically symmetric, we show 1D profiles.

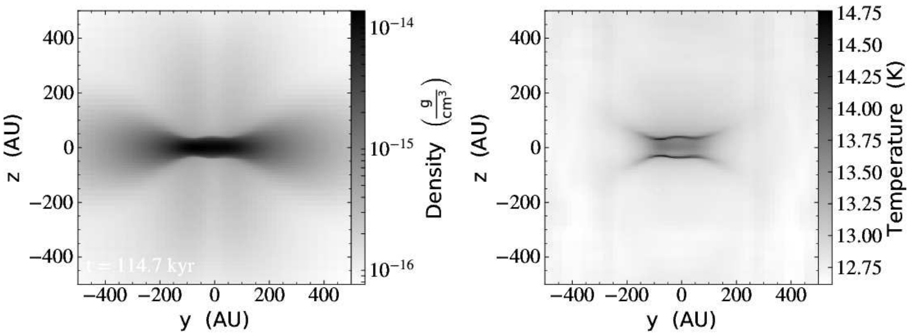


**Fig. 2.** Density and temperature maps for cuts through the mid plane of the simulation box after 114.7 kyr.

typically a sink particle is created (Klassen et al. 2016; Raskutti et al. 2016).

If we couple the accretion rate onto the sink particle with a protostellar evolution model (Offner et al. 2009; Klassen et al. 2012), we are able to assign a radius and luminosity to the sink particle, which now models a young stellar object. In figure 3 we show the stellar radius evolution for a constant accretion rate in our protostellar evolution model implementation.

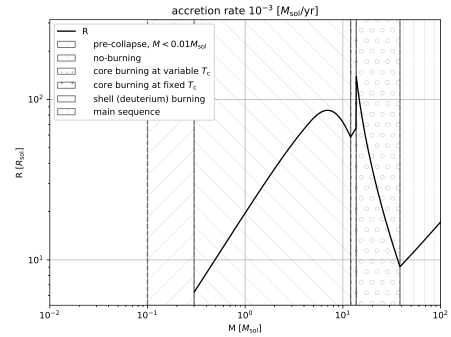


**Fig. 3.** Example of a protostellar evolution assuming a constant accretion rate of $10^{-3}$ $M_{sol}/yr$.

## 5. Conclusion

We showed successful simulations of cloud collapses with and without rotation. In the non-rotating case the cloud collapse evolution can be followed until the first hydrostatic core is formed. If an initial rotational velocity is applied, the collapse is slowed down by angular momentum conservation and early disc formation can be observed. In subsequent simulations we will follow the cloud collapse evolution until the second hydrostatic core is formed and a protostar is ignited. Therefore we implemented and tested a protostellar evolution model, which can be coupled with the radiation hydrodynamics simulations. This enables us to study the protostars radiation feedback on the disc as well as the cloud envelope.

## References

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