First core properties: from low- to high-mass star formation

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Motivation & Aim

Stars form by the gravitational collapse of dense, gaseous and dusty cores in magnetized molecular clouds. Our aims are:

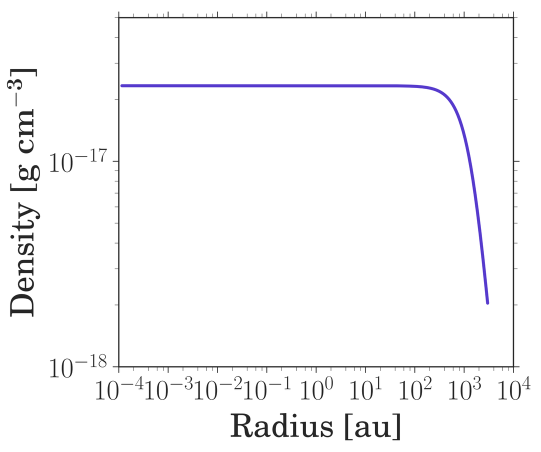
- Modeling molecular cloud core collapse to investigate the properties of Larson's[1] first and second hydrostatic cores.
- Obtaining a dependence of the first core properties on the initial cloud mass.
- Understanding these very early stages of star formation via detailed thermodynamical modeling in terms of radiation transport[2] and phase transitions[3].

Numerical simulations

- 1D spherically symmetric radiation hydrodynamic simulations using PLUTO[4].
- Gray (frequency independent) flux limited diffusion approximation.

Initial setup:

- Bonnor-Ebert[5,6] like density profile
- Uniform temperature (T = 10 K)
- Cloud mass ⇒ 0.5 $M_\odot$ - 100 $M_\odot$
- Grid size ⇒ 10^{-4} au - 3000 au (4416 grid cells)



Cloud collapse: an overview

Cold molecular cloud (T ≈ 10 K)

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Optically thin cloud collapses isothermally ($\gamma_{\rm eff}$ = 1) under its own gravity

⇓

Optical depth ≥ 1 and core contracts adiabatically ($\gamma_{\rm eff} \approx 5/3$)

⇓

First collapse phase

⇓

FIRST HYDROSTATIC CORE FORMATION (≈ 10^4 years)

⇓

Core continues to contract adiabatically ($\gamma_{\rm eff} \approx 7/5$)

⇓

When core temperature, T ≥ 2000 K, H_2 molecules begin to dissociate and $\gamma_{\rm eff} \approx 1.1$

⇓

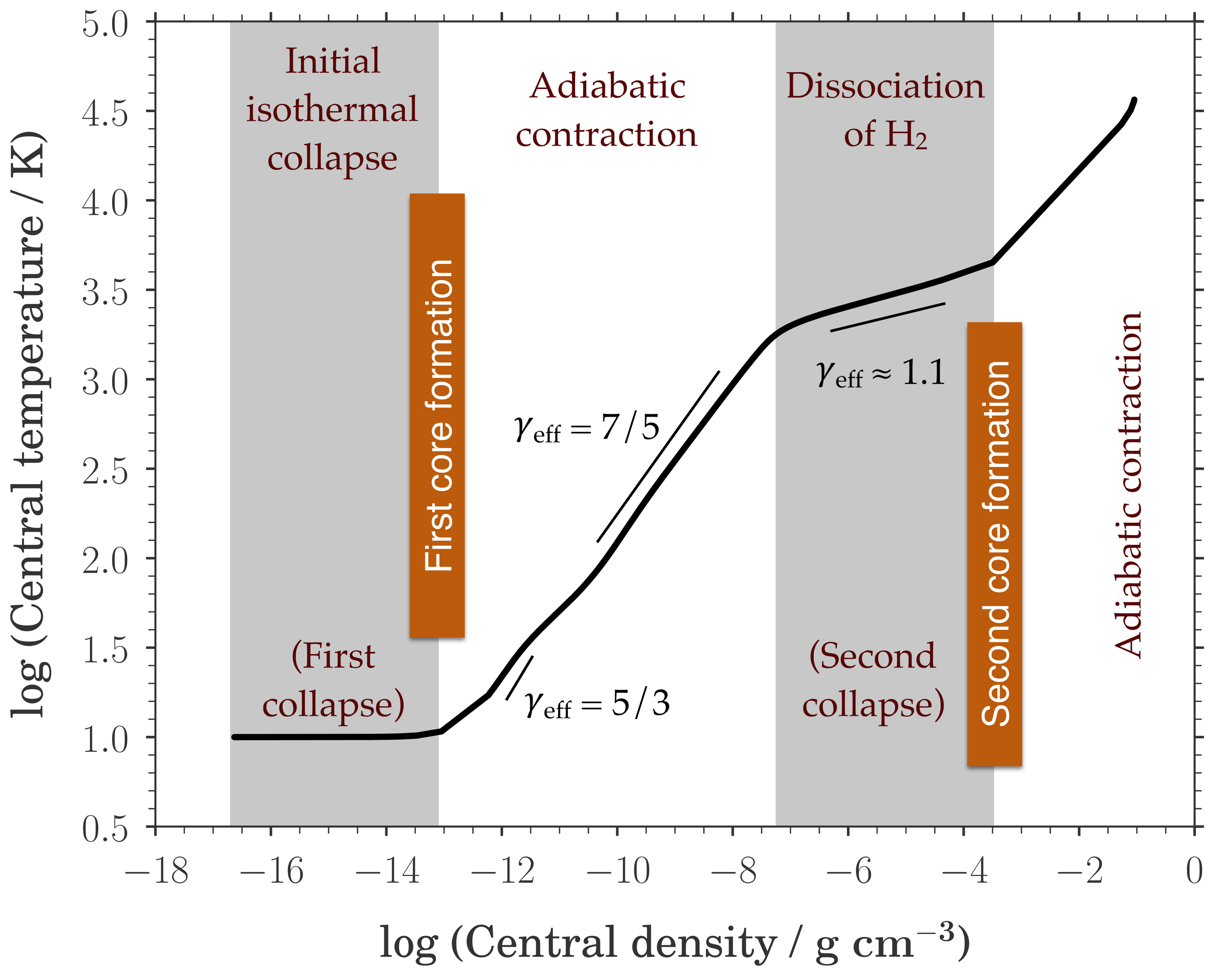
Second collapse phase

⇓

SECOND HYDROSTATIC CORE FORMATION

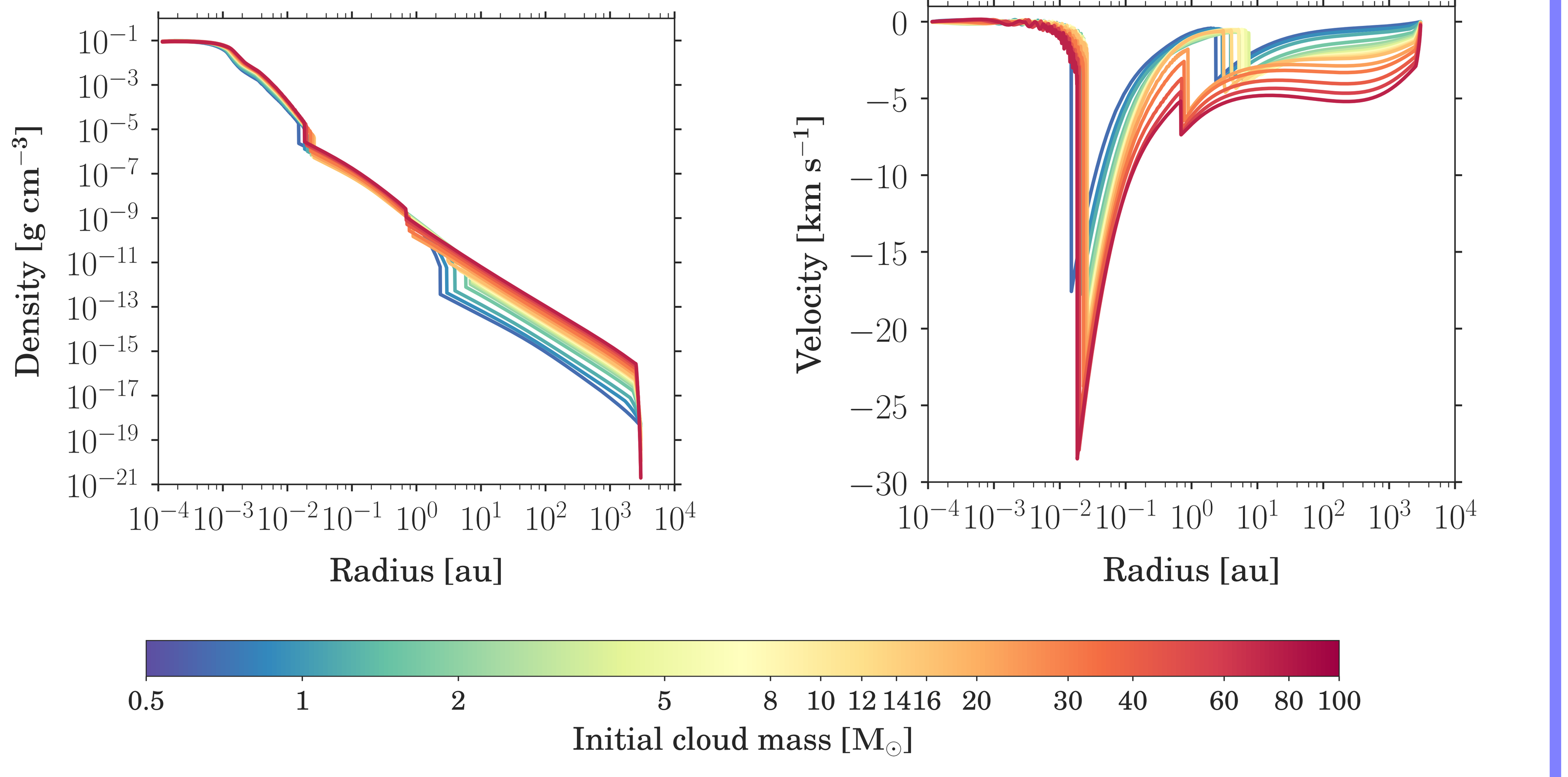
(≈ 10^5 years)

Thermodynamic profile



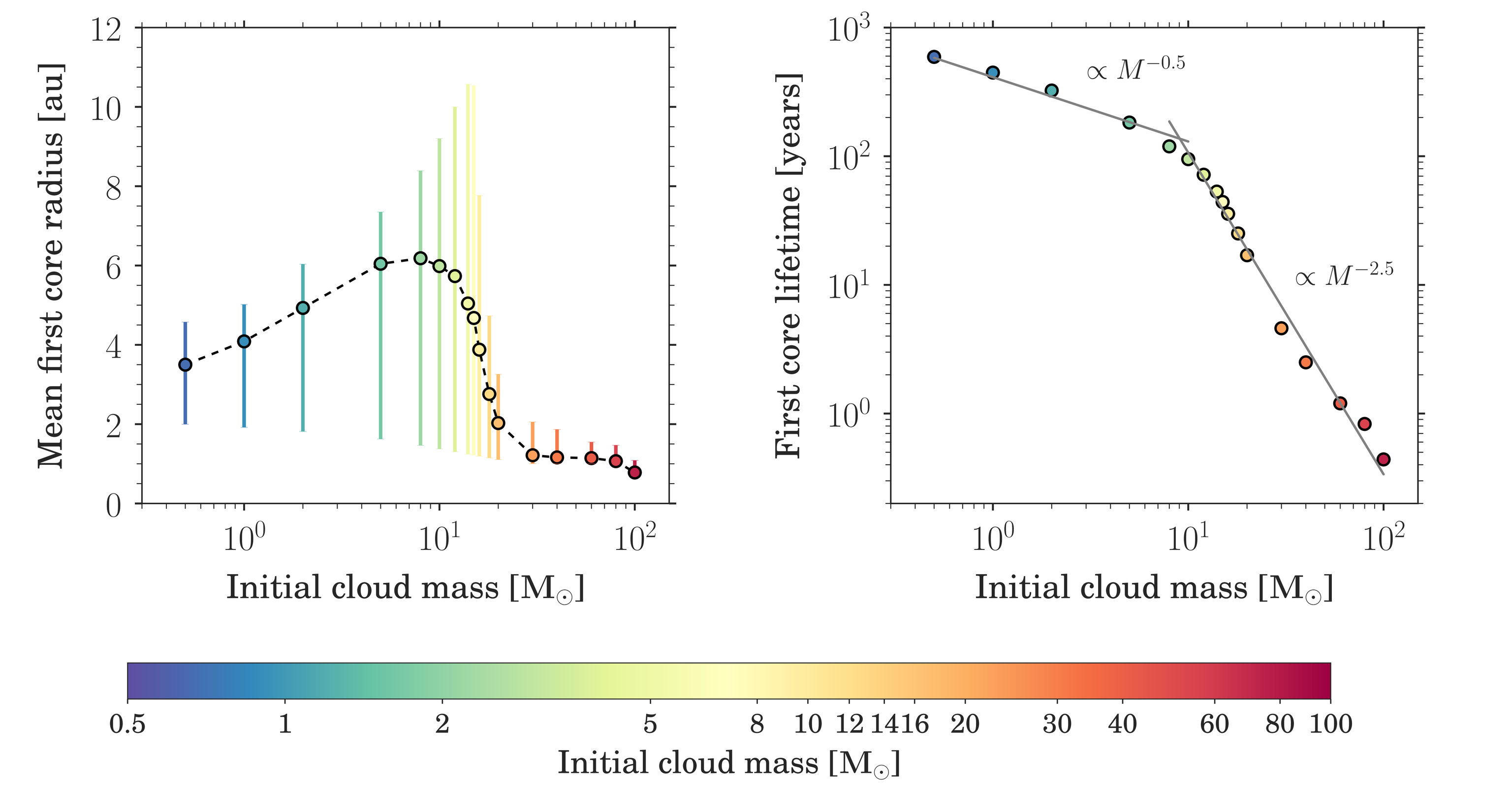
Thermal evolution showing the first and second collapse phase for a 1 $M_\odot$ cloud. The change in effective gamma $\gamma_{\rm eff}$ indicates the importance of using a realistic gas equation of state.

Core formation



Shown above are the radial density (left) and velocity profiles (right) after a non-homologous cloud collapse for different initial cloud masses (0.5 $M_\odot$ - 100 $M_\odot$).

First core properties



Dependence of the mean first core radius (left) and the first core lifetime (right) on the initial cloud mass show a transition region in the intermediate-mass regime (around 8 – 10 $M_\odot$).

Results

- The first core radius increases with initial cloud mass from the low- to intermediate-mass regime and decreases from the intermediate- to high-mass regime.
- The first core lifetime strongly decreases towards the intermediate- and high-mass regime indicating that first cores are almost non-existent in the high-mass regime.
- In a nutshell, low-mass protostars tend to evolve through two distinct stages of formation of the first and second hydrostatic cores. In contrast, in the high-mass star formation regime, the collapsing clouds rapidly evolve through the first core phase and essentially immediately form Larson's second cores.

References: [1] R. Larson, *MNRAS*, 145, 271-295, 1969. [2] R. Kuiper et al., *A&A*, 511, A81, 2010. [3] G. D'Angelo and P. Bodenheimer, *ApJ*, 778:77 (29pp), 2013. [4] A. Mignone et al., *ApJ*, 170:228–242, May 2007. [5] W. B. Bonnor, *MNRAS*, 116, 351, 1956. [6] R. Ebert, ZAp, 37, 217, 1955.