DIPSY

A new Disc Instability Population SYnthesis

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Context

Many protoplanetary discs are self-gravitating early in their lives. If they fragment under their own gravity, they form bound gaseous clumps which may evolve to become giant planets, brown dwarfs (BD) or stars.
Disc Instability (GI) is the leading formation pathway for several classes of observed giant planets: Giants on wide orbits, very young giants and giants around very low mass stars.
So far, GI has not been studied in great detail.

Aims

- Build a comprehensive model to study disc instability on a population level
- Perform an extensive population synthesis study in the disc instability paradigm
- Study the population of surviving companions
- Compare it to observations
- Assess the importance of a number of parameters (see below)

Methods

- Model evolution of discs from formation to dispersal [b]
- Include **infall** from molecular cloud core [h,i]
- Study a large range of **stellar masses** (0.05 – 5 Msol)
- Chose duration of infall phase to reproduce **IMF** (Fig. 1)

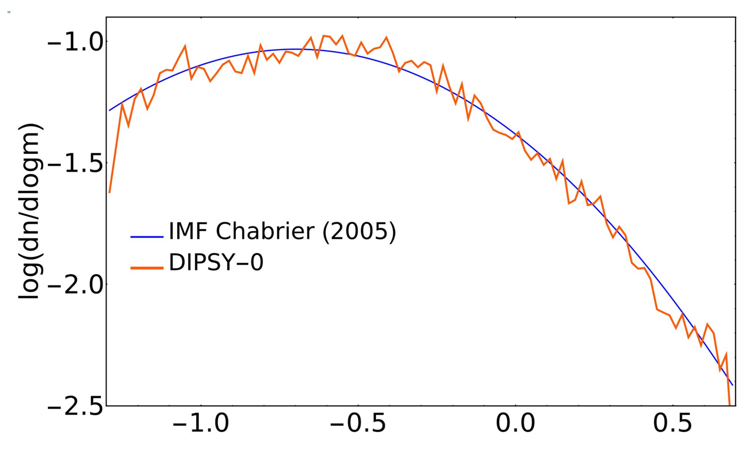

Fig. 1: Distribution of final stellar masses

- Early disc **radii** and **luminosities** consistent with observed Class 0 discs [c]
- Self-consistently include fragmentation [e,f,g,k]

$$Q_{\mathrm{Toomre}} = \frac{c_s \kappa}{\pi G \Sigma} \qquad t_{\mathrm{cool}} \lesssim \beta_c \Omega^{-1} \qquad \beta_c \approx 3$$

- Incorporate **evolution of clumps**, (many physical processes, see below)
- Model **planet-disc interaction** (gas accretion, migration, damping, [a], Fig. 2)

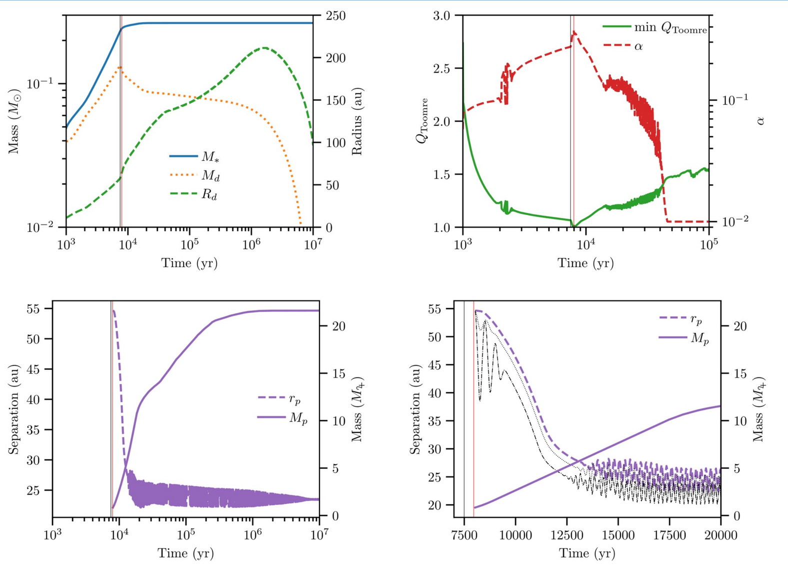

Fig. 4: Example of a system with one fragmentation event. Top left:Stellar mass, disc mass and disc size. Top right: Q_Toomre and viscosity alpha. Bottom left: Companion Mass and separation. Bottom right: Zoom view.

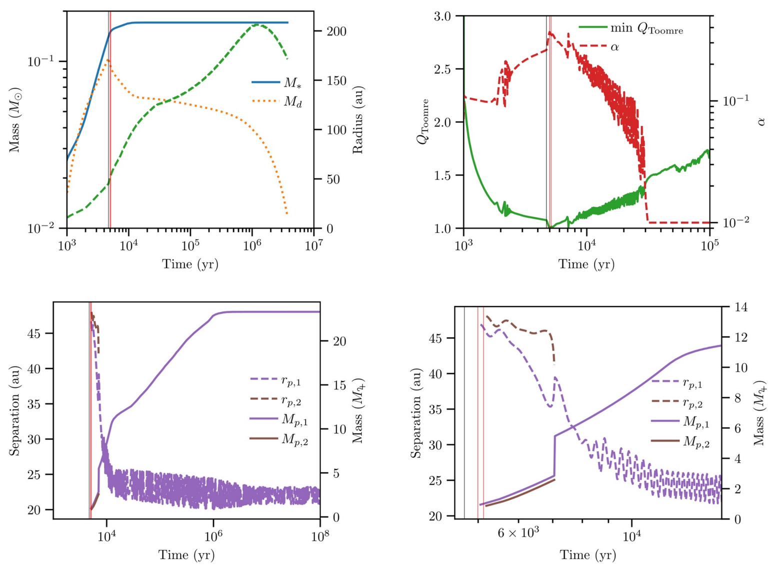

Fig. 5: Example of a system with two fragmentation events. Panels as in Fig. 4.

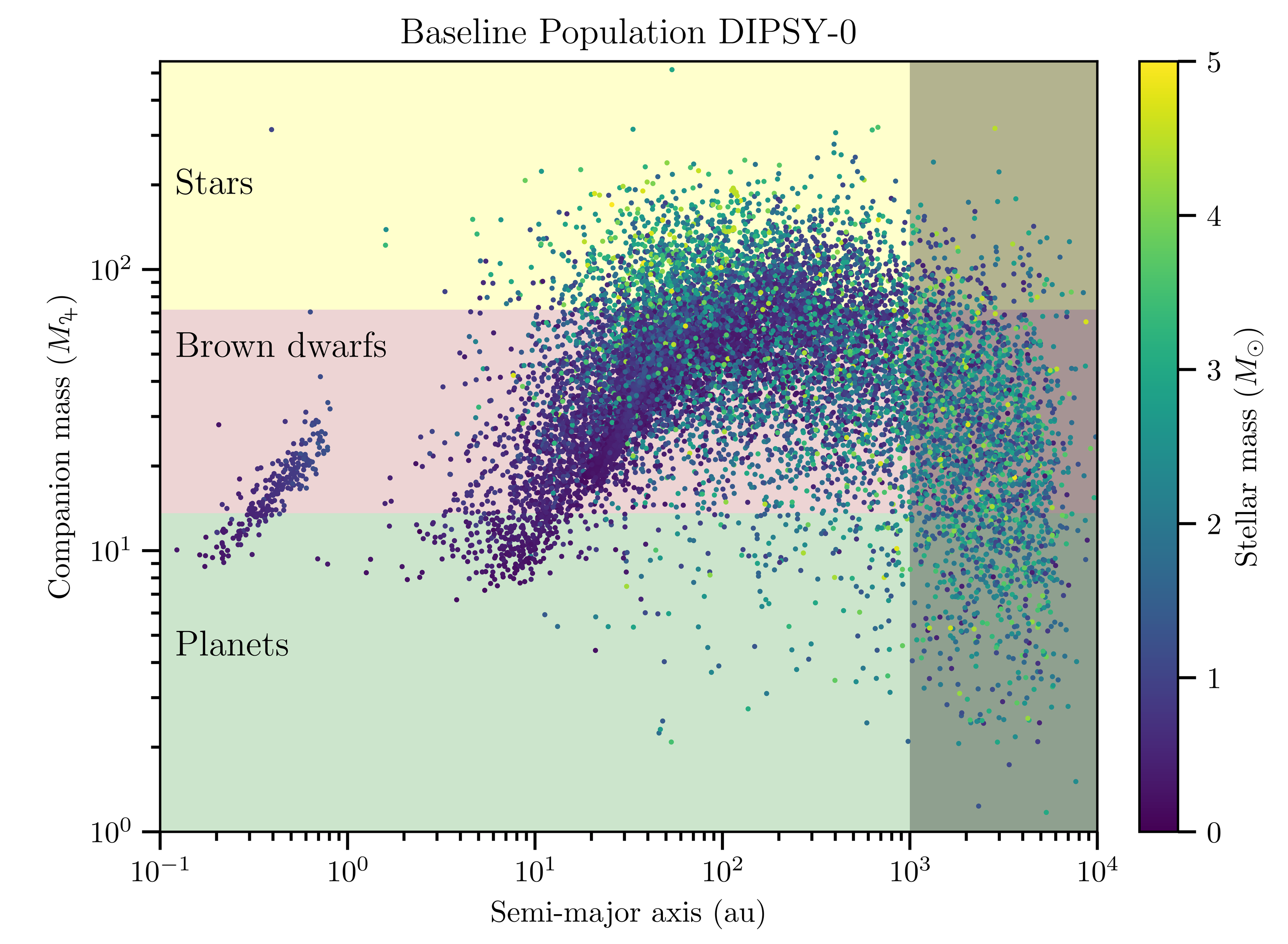

Fig. 7: Result of the baseline population: mass vs. semi-major axis of surviving clumps from 100'000 simulations with the final stellar mass in colour. The whole population is shown without accounting for the different abundances of different stellar masses.

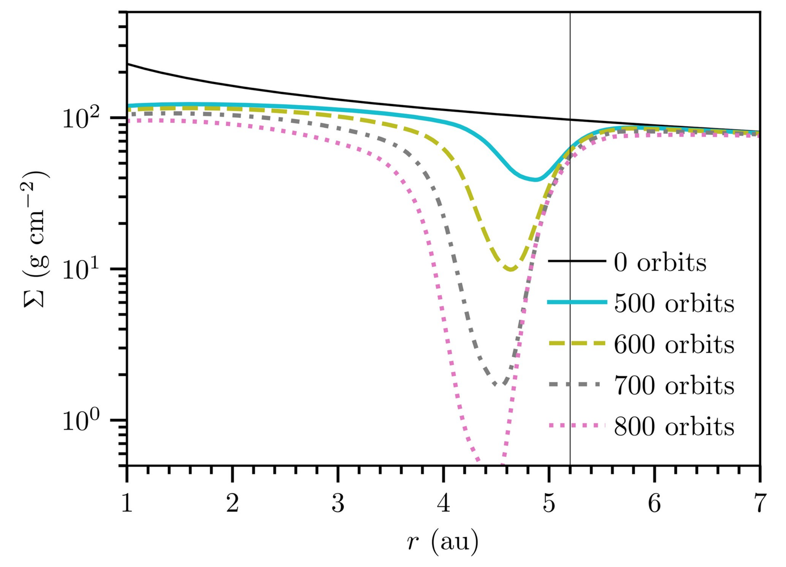

Fig. 2: Surface density evolution of a growing, migrating planet.

$$\frac{\partial \Sigma}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left[3r^{1/2}\frac{\partial}{\partial r}\left(\nu \Sigma r^{1/2}\right) - \frac{2\Lambda\Sigma}{\Omega}\right] + S$$

$$S(r,t) = S_{\mathrm{inf}} - S_{\mathrm{evap}} - S_{\mathrm{acc}} + S_{\mathrm{loss}}$$

Migration

Infall Photoevaporation Gas accretion Mass loss

- Consider gravitational interaction between objects (including collisions)

Clump evolution

The following effects are important:

- Contraction ([d], Fig. 3)
- Second collapse
- Disc irradiation
- Mass loss
- Core formation ([l], future)
- Grain growth/settling ([m], future)

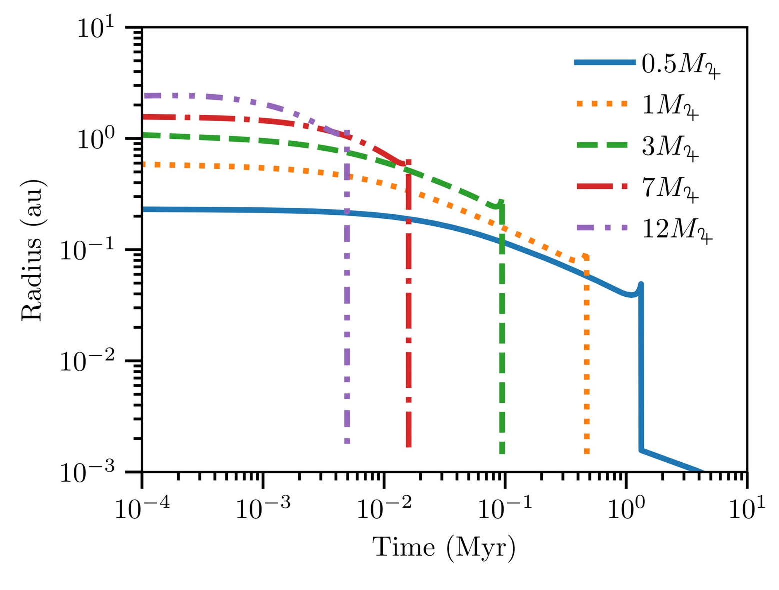

Fig. 3: Radius evolution of isolated clumps for different masses.

Conclusions

- Fragments formed in disc instability can survive and form giant planets, brown dwarfs or low-mass stars.
- This offers an explanation for the formation of some observed exoplanets.
- Gas accretion and Clump-clump interactions are crucial and might influence our results. Dedicated studies on these are necessary.
- More processes, such as episodic accretion, clump rotation, solid accretion, grain physics and core formation need to be added.

Results: Schib et al. in prep

- We present a low-dimensional model capable of simulating the concurrent formation and evolution of a star-and-disc system from formation to dispersal, including formation, evolution and interaction of clumps.
- We performed a population synthesis and find that ~10 % of systems fragment. Most of them end up as single systems, multiple systems exist (Fig. 6).

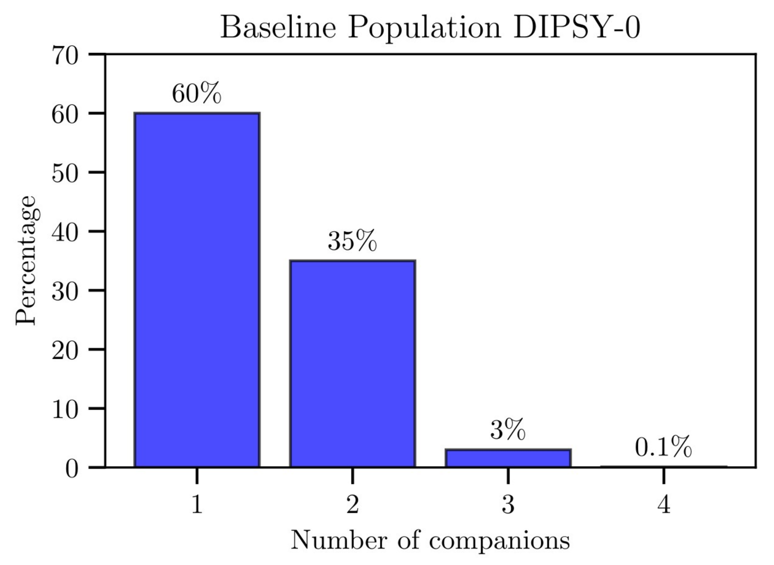

Fig. 6: Outcomes of fragmentation: number of surviving companions for all systems.

- The majority of companions inside 1000 au are in the BD range (78 %), with 4 % in the planetary mass range and another 18 % low-mass stars (Fig. 7).
- The number of surviving companions increases with stellar mass (Fig. 8).

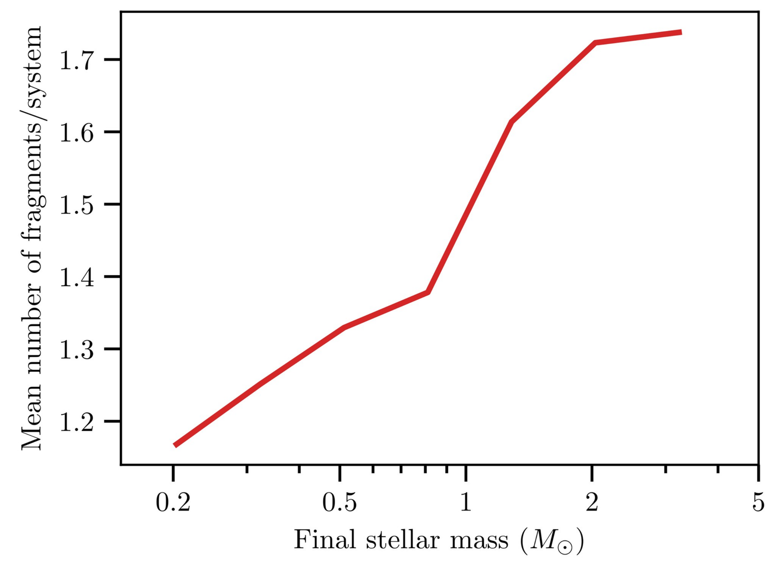

Fig. 8: Mean number of surviving companions per system as a function of final stellar mass.

- Large fraction of companions on orbits with low eccentricity, rest has a large spread
- Inclinations are low

References (selection)

[a] Schib+ 2022
[b] Schib+ 2021
[c] Schib+ 2023
[d] Humpries+ 2019
[e] Toomre 1964
[f] Gammie 2001
[g] Boley+ 2009
[h] Bate 2018
[i] Hennebelle+ 2016
[k] Deng+ 2017
[l] Helled+ 2008
[m]Helled+ 2011

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SCAN ME

Disc instability needs to be considered again!
Together with current and future observations, it will improve our understanding of planet formation greatly.
The formation of stars/brown dwarfs/(giant) planets need to be studied as interdependent processes, not separately.

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