Argelander-Institut für Astronomie
The University Of Sheffield.
Cardiff University Prifysgol Caerdydd
universität bonn

Tidally induced brown dwarf and planet formation in circumstellar discs

I. Thies (1), P. Kroupa (1), S. P. Goodwin (2), D. Stamatellos (3), A. P. Whitworth (3)
(1) Argelander-Institut für Astrophysik, Bonn, Germany; (2) University of Sheffield, UK; (3) University of Cardiff, UK

1. Introduction

Since most stars are born in clusters gravitational interactions between cluster members during encounters may significantly affect the evolution of circumstellar discs. Recent findings suggest that tidal perturbations of typical circumstellar discs due to passing stars may inhibit rather than trigger disc fragmentation in typical protoplanetary discs with radii around 40 AU and masses below 0.1 $M_\odot$. Here we show that the tidal forces during star-star encounters can trigger fragmentation between 100 AU and 200 AU in extended and massive discs ($\approx$0.5 $M_\odot$) that are observed around young stars. In our computations, otherwise non-fragmenting massive discs, once perturbed, fragment into several objects between about 0.01 and 0.1 $M_\odot$, i.e. over the whole brown dwarf mass range. Typically these orbit on highly eccentric orbits or are even ejected, and sometimes even form binaries. Our scenario provides a possible formation mechanism for brown dwarfs and very massive planets which, interestingly, leads to a mass distribution consistent with the canonical substellar IMF.

2. Model

A solar-type star with a massive, extended circumstellar disc is assumed (initial mass: 0.5 solar masses, initial radius: 400 AU). A second star (0.5 $M_\odot$ passes at $\approx$ 500 AU) at a moderate inclination ($\lesssim$ 45°). Hydrodynamical perturbations are modelled using the DRAGON SPH code with radiative transfer routines by Stamatellos et al. (2007). 100,000 and 250,000 particles are used. SPH particles exceeding 10^9 g cm^{-3} are transformed into "sink particles", i.e. are treated as gravitationally bound gas clumps.

Encounter scenarios like this are of significant probability in typical star clusters, and are highly probable in dense clusters like the ONC. In the latter case even multiple encounters are likely.

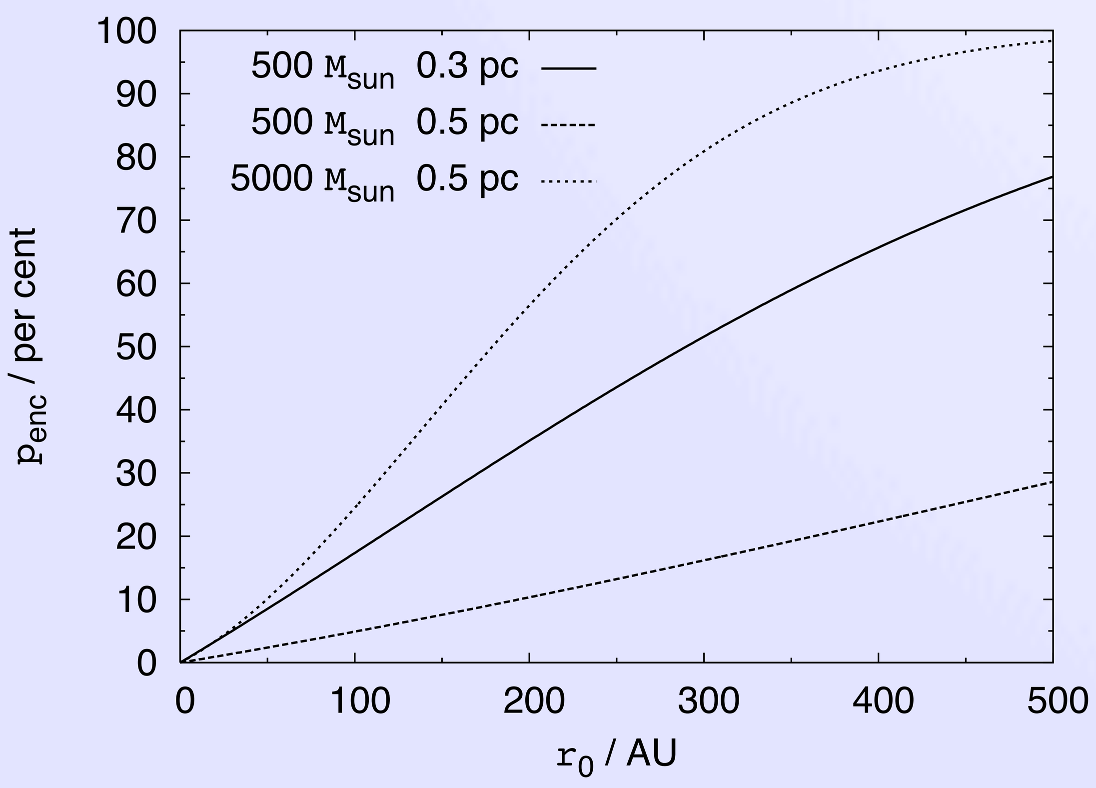


Fig. 1: The probability for at least one encounter within 6 Myr for three different cluster sizes as a function of the periastron distance (from Thies, Kroupa & Theis 2005).

3. Results

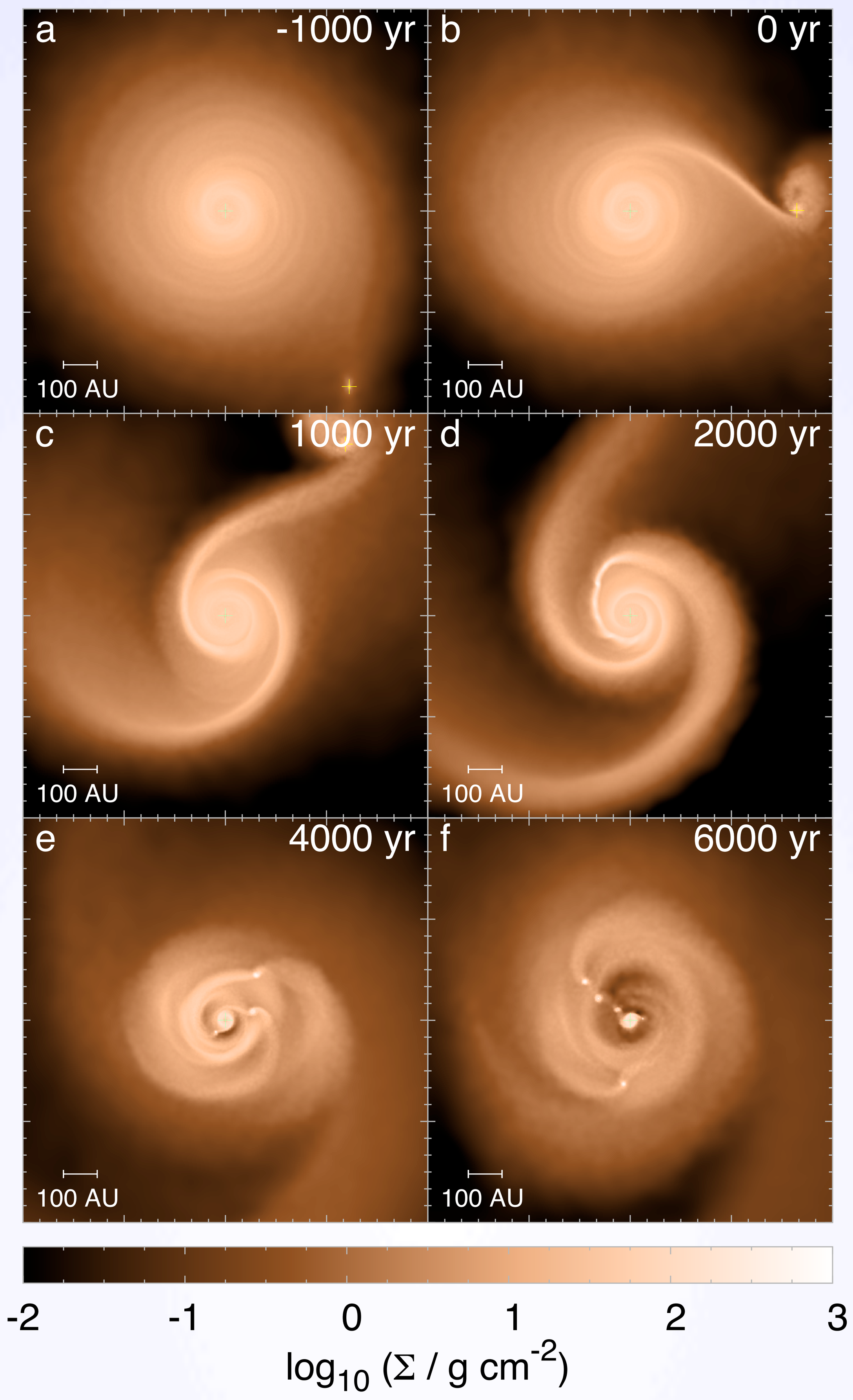


Fig. 2: Snapshots of a circumstellar disc modelled with 250,000 SPH particles, around a Sun-type star being perturbed by a close star-star encounter. The time stamp in each frame refers to the time of the encounter.

Fragmentation occurs approx. 2000–3000 years after periastron passage (t=0). Forming clumps may trigger subsequent fragmentation (Fig. 2). Typically 2–4 bodies with masses between 0.02 and 0.15 $M_\odot$ are formed per model.

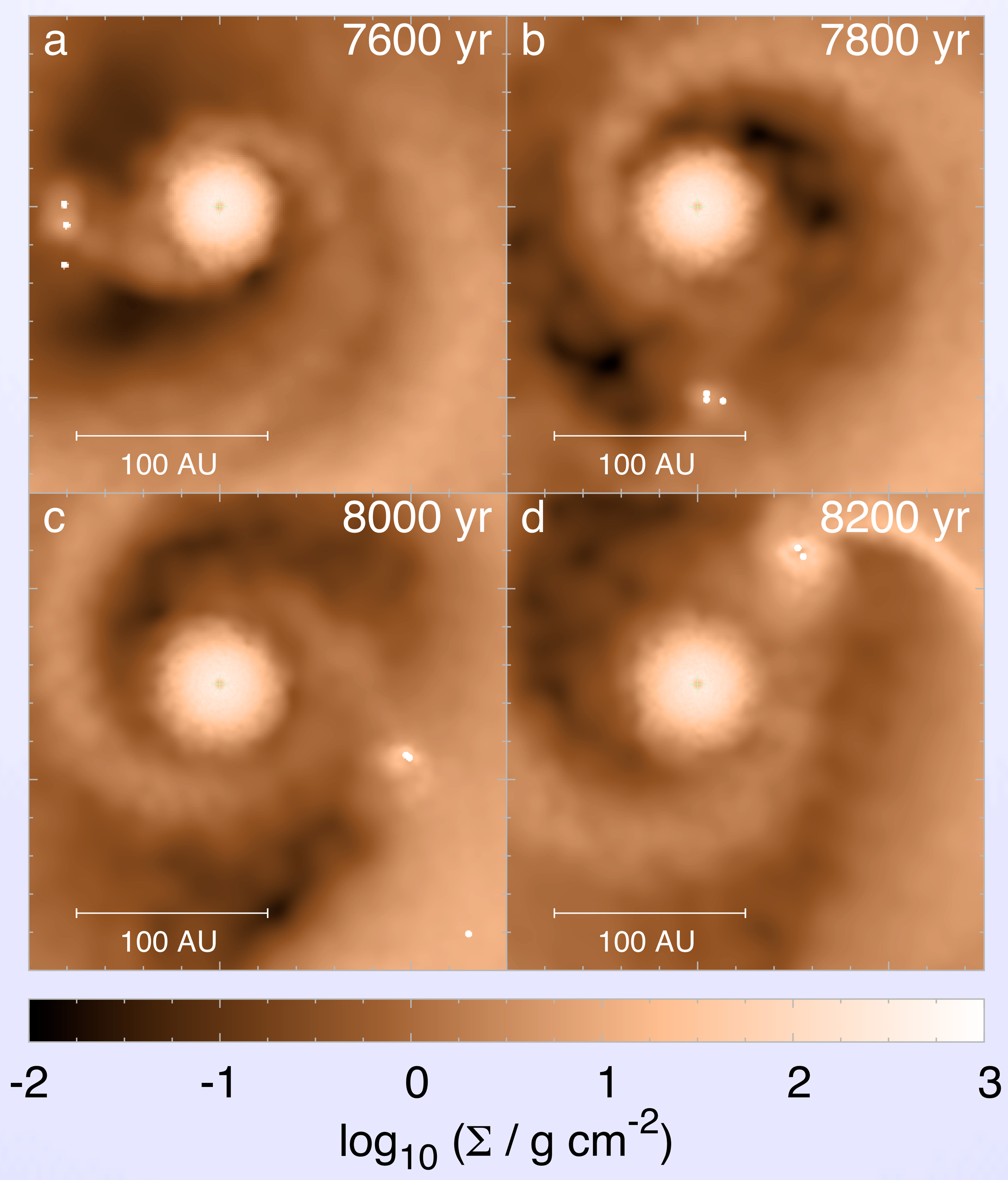
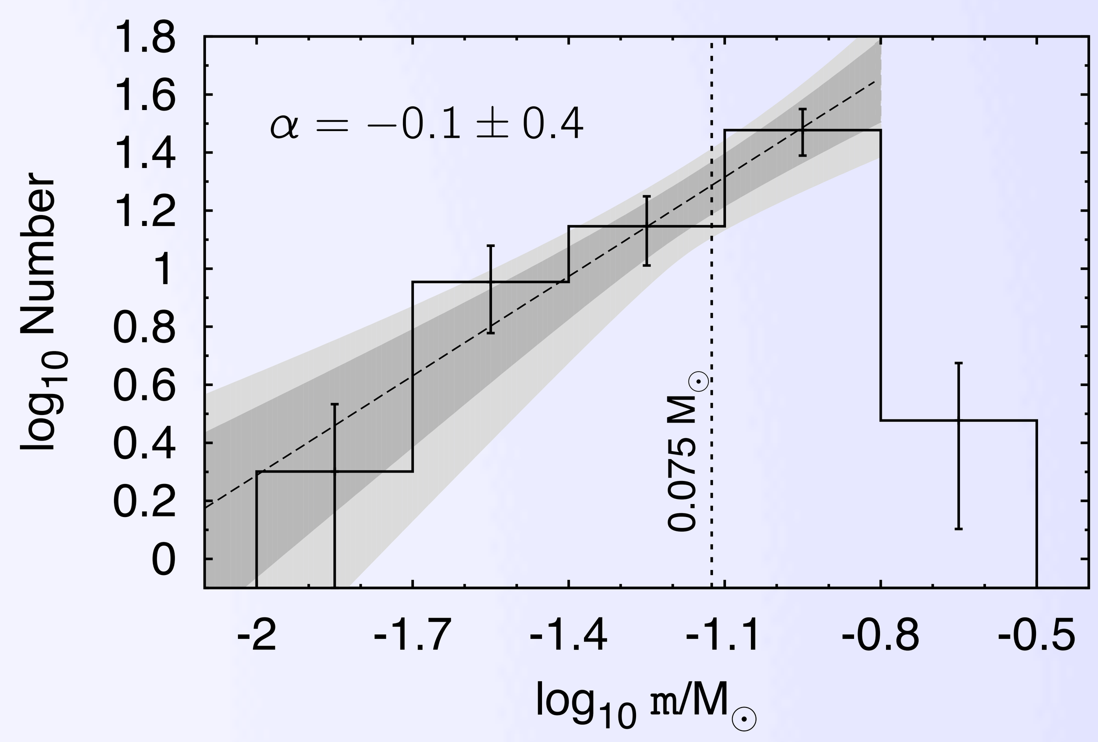


Fig. 3: Close-up of a forming binary system about 8000 years after the fly-by. The masses of the binary components are 0.09 and 0.08 Ms, the mass of the escaping body is 0.05 $M_\odot$.

4. Clues to the IMF?

We analysed the mass distribution of the outcome of 18 models showing fragmentation (10 with 100,000, 8 with 250,000 particles; 30 and 28 bodies are formed, respectively). The resulting mass function is in good agreement with the canonical substellar IMF slope (Kroupa 2001). Furthermore, the result is also consistent with results from Thies & Kroupa (2007+2008) who deduced a separate BD and VLMS IMF with truncation between 0.1 and 0.2 solar masses.



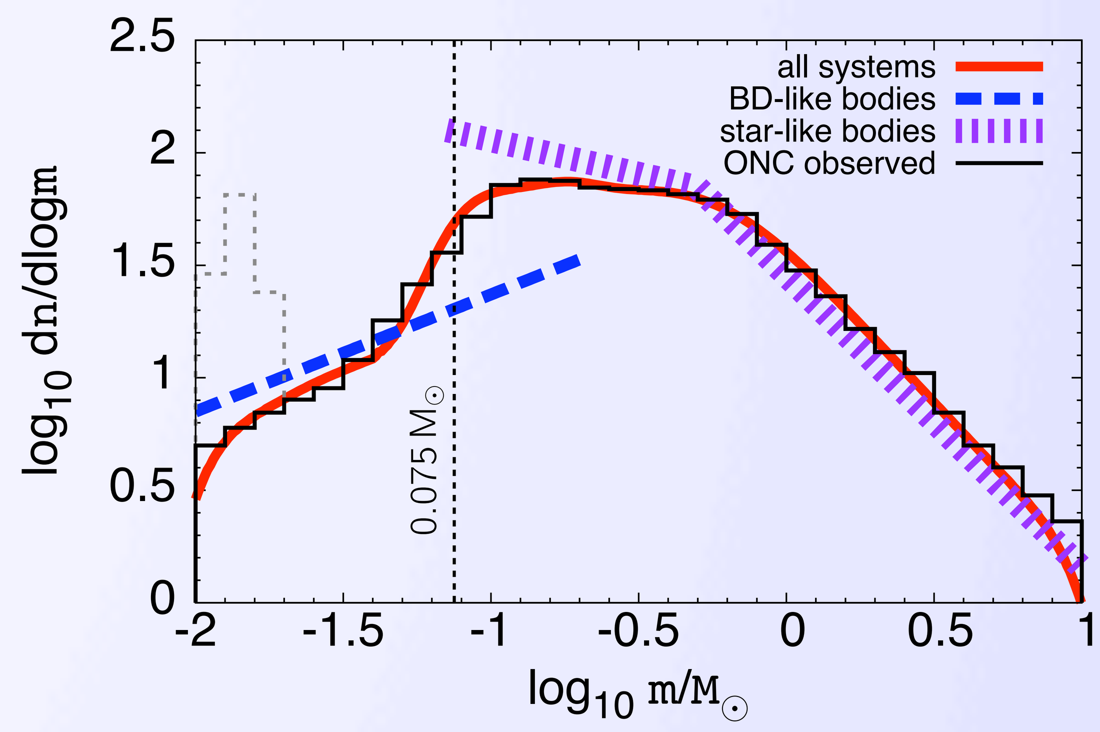


Fig. 4: Top panel: Mass distribution of 58 bodies from 18 models. The slope is in agreement with the standard BD IMF slope α = +0.3 (Kroupa 2001) as well as with a separate truncated BD-like IMF (Thies & Kroupa 2007, bottom panel).

5. Outlook

Vortices in discs may trap dust grains and enhance coagulation (Barge & Sommeria 1995). Future studies will focus at temporary gas fragments and their impact on vorticity and dust trapping.

In an ongoing project we study the accretion onto the perturbing star and its effects on a pre-existing randomly inclined circumstellar disc hosted by the perturber. Implications on planet formation and a possible isotope signature in the Solar System are to be analysed.

References

Thies et al. 2010, ApJ, 717, 577
Thies & Kroupa 2008, MNRAS, 390, 1200
Thies & Kroupa 2007, ApJ, 671, 767
Stamatellos et al. 2007, A&A, 475, 37
Thies, Kroupa & Theis 2005, MNRAS, 364, 961
Kroupa 2001, MNRAS, 322, 231
Barge & Sommeria 1995, A&A, 295 L1

Movies available on http://www.astro.uni-bonn.de/~webaiub/english/downloads.php