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The properties of planets formed by disc instability

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Abstract

Giant planets may form on a dynamical timescale due to disc instability. We perform radiative hydrodynamic simulations of gravitationally unstable discs to determine the properties of the protoplanets formed. We find that disk instability produces hot giant protoplanets on wide orbits.

1. Introduction

The properties of the observed exoplanets are quite diverse and the architecture of exoplanetary systems much different from that of our Solar System. In the last decade direct imaging surveys have established that only a small fraction ($< 10\%$) of stars host giant planets on wide orbits [1]. Nevertheless, the presence of such planets that cannot be explained satisfactorily by core accretion, opens up the possibility that the alternative mechanism of disc instability may be at play. This is further corroborated from observational evidence that planet formation may happen early on during the lifetime of a protostellar disc [5]. Discs become gravitationally unstable when gravity dominates over thermal and rotational support. An unstable disc can fragment to form bound objects when it can cool on a dynamical timescale [2]. In this paper we perform an ensemble of hydrodynamic simulations to determine the conditions for fragmentation of discs around M dwarfs and the properties of the protoplanets produced (for details see Mercer & Stamatellos, 2019).

2 Hydrodynamic simulations of fragmenting discs

We use the SPH code GANDALF to study the development of gravitational instability and subsequent planet formation in discs around M dwarfs. We start with a disc that is initially stable and slowly increase its mass until it becomes gravitationally unstable and fragments. We ensure that the disc mass does not increase by more than a few percent during an outer rotation period of the disc, so that gravitationally instability is not driven by the accretion of material onto the disc [3].

We use the radiative transfer method of [4], which is based on the method of [11]. This method uses the gas pressure scale-height of a particle to obtain the optical depth through which heating and cooling happens, and it performs well both for disc and spherical configurations [6]. The method allows us to follow the evolution of fragments that form within the disc to high densities ($\sim 10^{-3}\mathrm{g\,cm^{-1}}$) and temperatures (a few 10^4 K). We are therefore able to capture both the first and second collapse of a fragment [10] and determine the properties of the protoplanet formed. A representative snapshot of one of the simulations is presented in Figure 1.

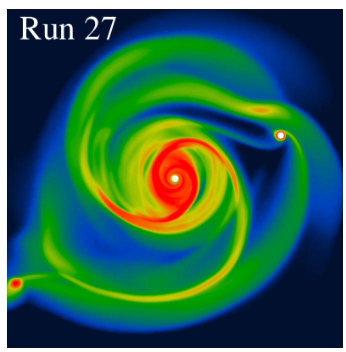

Figure 1: Fragmentation of a gravitationally unstable disc around an M dwarf. Two protoplanets form in this simulation.

3. Protoplanet properties

The discs that we study become gravitationally unstable and develop strong spiral features. The spiral arms produce fragments and we follow the evolution of the first fragment up to a density of $10^{-3}\mathrm{g\,cm^{-3}}$. As we do not use sinks in the simulation we are not able to follow the subsequent evolution of the fragment nor the disc. Once a spiral arm becomes gravitation-

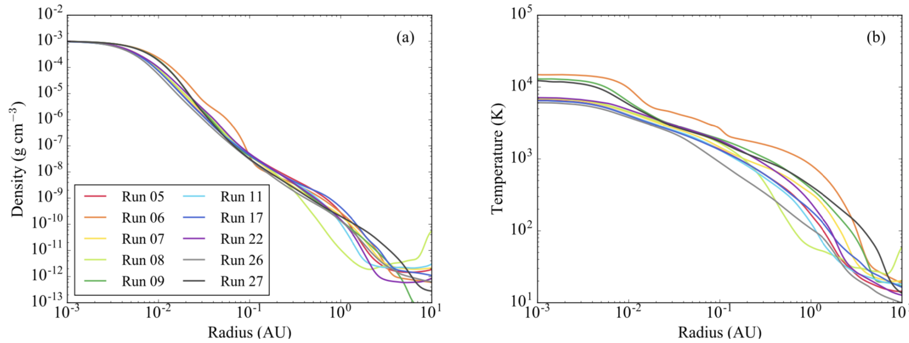

Figure 2: The properties of a selection protoplanets formed by disc instability: (a) Density profile, (b) Temperature profile.

ally ustable, a fragment forms and initially collapses fast. The collapse slows down when it becomes optically thick and the first hydrostatic core forms. Thereafter the collapse of the fragment continues on a longer timescale. The fragment contracts quasi-statically and its density and temperature rises. When the temperature reaches 2000K molecular hydrogen dissociates and the second collapse happens resulting to the formation of the second core, which we refer to as the protoplanet. Due to the fragment rotation the formation of the second core may not happen and the collapse stops while the density is still not as high. The protoplanets that form from fragments that undergo second collapse are hot; their core temperature can reach a few 10^4 K, similarly to the planets formed by core accretion [12]. We present the dentity and temperature profiles of a selection of protoplanets formed by disc instability in Figure 2. The masses of these protoplanets are on the order of a few times the mass of Jupiter and they form on wide orbits. However, their final properties may be distinctly different and will be determined by their interactions with the disc and with other fragments within the disc [9, 7, 8].

4. Discussion

Disc instability may occur during the early phases of disc formation if such discs are massive enough. The outcome of disc instability is giant protoplanets on wide orbits. These protoplanets form fast (within a few thousand years) and they are hot (a few 10^4 K). The final properties of these protoplanets will be determined by their interaction with their host disc. They may accrete too much gas and become brown dwarfs, or they may lose mass due to tidal downsizing and become terrestrial planets. They can lose angular momentum and migrate inwards, or they can gain angular momentum, by predominantly accreting gas from outside their orbit, and migrate outwards [7, 8]. Nevertheless, a fraction of them may survive as giant planets on wide orbits.

References

[1] Bowler, B. P. & Nielsen, E. L. 2018, Occurrence Rates from Direct Imaging Surveys, ed. J. Deeg, H. & Belmonte, Vol. Handbook of Exoplanets (Springer), 155

[2] Gammie, C. F. 2001, ApJ, 553, 174

[3] Lesur, G., Hennebelle, P., & Fromang, S. 2015, A&A, 582, L9

[4] Lombardi, J. C., McInally, W. G., & Faber, J. A. 2015, MNRAS, 447, 25

[5] Manara, C. F., Morbidelli, A., & Guillot, T. 2018, A&A, 618, L3

[6] Mercer, A., Stamatellos, D., & Dunhill, A. 2018, MNRAS, 478, 3478

[7] Stamatellos, D. 2015, ApJ, 810, L11

[8] Stamatellos, D. & Inutsuka, S.-i. 2018, MNRAS, 477, 3110

[9] Stamatellos, D. & Whitworth, A. P. 2009a, MNRAS, 392, 413

[10] Stamatellos, D. & Whitworth, A. P. 2009b, MNRAS, 400, 1563

[11] Stamatellos, D., Whitworth, A. P., Bisbas, T., & Goodwin, S. 2007, A&A, 475, 37

[12] Szulágyi, J., Mayer, L., & Quinn, T. 2017, MNRAS, 464, 3158