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Early tidal evolution of the TRAPPIST-1 system

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Abstract

Detection of planetary systems around ultracool dwarfs (i.e., stars with effective temperatures lower than 2 700 K) are expected to increase in the coming years [1] thanks to on-going efforts such as the TRAPPIST survey and future missions such as the project SPECULOOS. These systems can have several planets in compact orbital configurations, and they can be in or close to mean motion resonances as already observed in TRAPPIST-1 [2]. Planets arranged in this kind of set-up are surely affected by tidal effects, and the use of N-body simulation is necessary to understand both the formation and the consequent evolution of the system.

1. Introduction

In the lifetime of a system, the physical parameters governing star-planet interactions evolve quite significantly. Indeed, both stellar radius and rotation evolve during the pre-main sequence, which can last up to a few Gyr for ultracool dwarfs. In particular, this means that after the protoplanetary disk dispersal (at an age of a few Myr) due to a large stellar radius, the tide raised by the planets on the star, i.e. the stellar tide, was much stronger than today.

The dynamics governing the young TRAPPIST-1 system was therefore different than that of today. We aim at investigating these early phases of the evolution of TRAPPIST-1 to understand how the resonant chain came to evolve as what we see today.

2. Initial conditions: migration and formation within the disk

The initial conditions for the tidal simulations are outputs from planet formation models of planets embedded in the protoplanetary disk. We use two kinds of simulations for the earliest phases of the system. The first set of simulations initially took into account 29 already formed planetary embryos of 0.2 $M_\oplus$, which collided with one another and migrated in the disk. The second set of simulations reproduces more accurately the growth of the planets from small embryos through either pebble or planetesimal accretion [3].

These simulations end with the protoplanetary disk dispersal (at an age of 4 Myr) with chains of planets in resonance. However, the resonance of the inner pair is quite different to what is observed today: the simulations lead to a 3:2 resonance while the observations show a 8:5 resonance [2].

3. Tidal evolution model: post-disk evolution

In order to see if the resonances can change through tides during the early phase of the system, we use Posidonius [4]. It is a N-body code which takes into account both stellar tide and planetary tide, but also the evolution of the radius of the star [5] and its spin (accounting for contraction and stellar winds). We assume an initial stellar of spin of 2 days at an age of 4 Myr and use stellar wind parameters that allow to reproduce the $\sim$3 day spin observed today [6].

We explore several dissipation factors for the star and planets to account for the uncertainties we have on these parameters to investigate the rich dynamics of the system and also investigate how the planetary resonant chains evolve with time.

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