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Survival of satellites during the migration of a Hot Jupiter: the influence of tides

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Abstract

We explore the origin and stability of extrasolar satellites orbiting close-in gas giants, by investigating if the satellite can survive the migration of the planet in the protoplanetary disk. To accomplish this objective, we used Posidonius, a N-Body code with an integrated tidal model, which we expanded to account for the migration of the gas giant in a disk. Preliminary results suggest the survival of the satellite is rare, which would indicate that if such satellites do exist, capture is a more likely process.

1. Introduction

Satellites around Hot Jupiters were first thought to be lost by falling onto their planet over Gyr timescales (e.g. [1]). This is due to the low tidal dissipation factor of Jupiter ($Q_p \sim 10^6$, [10]), likely to be caused by the dynamical tide in the fluid enveloppe [14]. However, in the equilibrium tide regime, the tidal Q can be much higher ($Q_p \sim 10^{12}$ [7]). Using this value shows that a hot Jupiter could host even an Earth-mass satellite over Gyr timescales [4].

Today, the only evidence of such a large satellite appears to be Neptune-sized [17]. Alternatively, evidence of a much smaller satellite (Io-sized) in transit spectroscopy was recently suggested by Oza et al. 2019. It is unclear whether such a satellite would be able to form in-situ at such close-in distances due to the increased radius during gas giant formation [13]. We therefore consider the dynamical evolution of such a satellite formed at larger distance, around a Jupiter which then migrates inwards (see Fig. 1 for a schematic set up). The simulations we present should be able to yield the relative likelihood, based on our assumptions, of formation in a protoplanetary disk or satellite capture.

2. The model

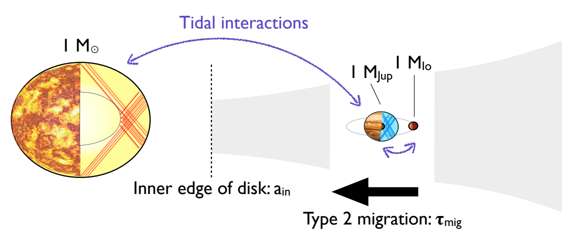

Figure 1: Schema of the simulation set up: A Io-like satellite orbits around a Jupiter-like planet with a solar-like host star.

2.1. N-body integration

We use the N-body code Posidonius [2] (Blanco-Cuaresma & Bolmont, in prep), which computes the tidal evolution of multi-planet system. It includes several evolutionary tracks for different objects such as solar-like stars ([6], with a prescription for the dynamical tide in the convective region, see [3]) and for Jupiter-mass planets ([11] with a specific prescription for tides in the planet, see next section).

Posidonius provided different integration schemes and we use here IAS15 [15]. This integrator does not assume the existence of a massive body (e.g., the host star) placed in a particular position (e.g., typically the zero reference coordinate as it is required by symplectic integrators). This allows us to setup the simulation to ensure that the tides between the star and the planet and between the planet and the satellite are both consistently computed, without any modification to the already implemented tidal model.

2.2. Tidal model

For the satellite, we use a simple equilibrium tide formalism following [9]. For the star, we use the formalism of [3], in which the frequency-averaged dissipation from tidal inertial waves in the convective envelope is calculated from stellar evolution models [6]. For the planet, we use the formalism of [8], which also accounts for the dissipation of inertial waves in the fluid envelope of Jupiter calculated from the models of [11].

2.3. Migration of the hot Jupiter

We use the prescription for the planet migration of [13]; we use the protoplanetary disk density profile from [12] and assume a simple exponential decrease to mimmic the lifetime of the disk. We assume an optically thin disk, with a power-law radially dependent temperature and a standard α viscosity disk. From there, we can get a migration timescale τ_{mig} for the Jupiter-like planet and we set the eccentricity damping and inclination damping timescales as $0.1 \times \tau_{\mathrm{mig}}$. We then infer accelerations from these evolution timescales using the prescriptions of [5] and implement them into Posidonius.

3. An unlikely survival

Preliminary results show that the survival of the satellite is difficult to ensure. If the satellite begins its evolution too far from the planet, its eccentricity increases until it get destabilized. If the satellite begins its evolution too close, the tides in the satellite (mainly) make it migrate inwards and collide with the planet. We plan to continue exploring if there could be a limited parameter space region that would allow the survival of the satellite.

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