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Tidal evolution of planets around brown dwarfs

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Abstract

The tidal evolution of planets orbiting brown dwarfs (BDs) presents an interesting case study because BDs' terrestrial planet forming region is located extremely close-in. In fact, the habitable zones of BDs range from roughly 0.001 to 0.03 AU [1] and for the lowest-mass BDs are located interior to the Roche limit.

In contrast with stars, BDs spin up as they age. Thus, the corotation distance moves inward. We study the tidal evolution of planets around BDs using a standard tidal model and test the effect of numerous parameters such as the initial semi-major axis and eccentricity, the rotation period of the BD, the masses of both star and planet, and their tidal dissipation factor. We find that the most important parameter is the initial orbital distance with respect to the corotation distance.

We find that all planets that form at or beyond the corotation distance and with initial eccentricities smaller than ~ 0.1 and are repelled from the star. Some planets initially interior to corotation can survive if their inward tidal evolution is slower than the BD's spin evolution, although most initially close-in planets fall onto the BD.

As the luminosity of BDs decreases dramatically on Gyr timescales [2], the habitable zone moves inward in time. A close-in planetary orbit can pass through the habitable zone simply due to the BD's cooling. For higher-mass BDs, planets can survive in the habitable zone for Gyr timescales.

1. Introduction

Brown dwarfs (BDs) are an interesting field of research, because contrary to most exoplanets systems which have slow rotating stars BDs spin up with time. This key difference, which is due to the inability of BDs to start the fusion of Hydrogen into Helium, has great consequences for the tidal evolution of planets orbiting BDs. For stars, the corotation distance expands as the star spins down, so close-in planets spiral inward and can merge with their stars. In contrast, the corotation distance around BDs shrinks in time such that planets should be pushed away from the BD. Here we study the tidal evolution of planets orbiting BDs.

2. Model description

The tidal model used is a re-derivation of the equilibrium tide model of Hut [3] as is done by Eggleton, Kiseleva and Hut [4]. We consider here both the tides raised by the star on the planet and by the planet on the star. We use the time lag constant model [5, 6] and use the internal dissipation constant σ as done in Hansen's paper[5], which he has calibrated for giant exoplanets and their stars.

In this work where the star is a BD, the internal dissipation factor σ_* is considered to be the same as Hansen's σ_p, because BDs and gas giants have basically the same internal structure and dissipative response. The dissipation factor is poorly constrained.

To calculate tidal evolution requires knowledge of the stellar radius and rotation period. We used the results of Baraffe's evolutionary model [7] to know the radius of the star, its moment of inertia and its luminosity.

The initial rotation period was chosen in accordance with observational data [8]. But more data points would be needed to better constrain this parameter.

3. Results

The tidal evolution of a planet is most sensitive to its initial location with respect to the corotation radius. If the planet is inside corotation, tidal forces will push the planet inward to its doom; it will either fall onto the star or be destroyed at the Roche limit. However if the planet is outside corotation, tidal forces will push the planet outward to a parameter-dependent asymptotic semi-major axis. As the corotation radius shrinks there are some intermediate cases for which the planet begins inside corotation and begins to fall, but as the BD contracts the corotation radius catches up with the planet and tides pushes the planet outward, thus saving it. The three different behaviors can be seen on Fig. 1.

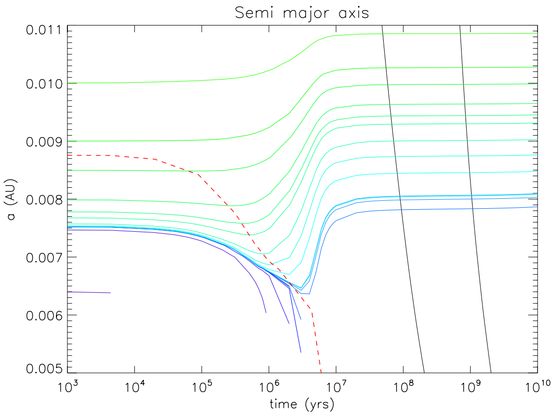

Figure 1: Semi major axis evolution vs time. The dashed line is the corotation distance, and the full lines for a 1 $M_\oplus$ planet with different initial semi-major axis. The mass of the BD is 0.04 $M_\odot$. The full black lines represent the boundaries of the habitable zone.

The study of the dependance of parameters shows the influence of the stellar tides and the planetary tides. The planetary tides are important in the beginning of the evolution to put the planet in pseudo-synchronization, then they matter only as long as the eccentricity remains non negligible and tend to push the planet inward [6]. Stellar tides contribute to push the planet outward if it is beyond the corotation radius. Given the relative importance of each of these tides, there exists a wider variety of evolutionary paths than seen in Fig. 1 for various combinations of the dissipation parameters.

4. Summary and Conclusions

The study of tidal evolution of a planet orbiting a BD is interesting from a theoretical point of view because of the variety of possible evolutions due to the spin-up of the BD and the effect of parameters like the dissipation factors. But it is also interesting from an observational point of view because planets that form close to their star have final orbital periods of less than $\sim$ 10 days. In the most favorable cases, their periods can be as short as a day. Those planets could be observed in transit around BDs.

For BDs more massive than 0.05 $M_\odot$, planets can spend a significant amount of time in the habitable zone - from 1 Gyrs to $\sim$ 10 Gyrs. Furthermore, planets with pseudo-synchronous or synchronous rotation are interesting case studies for climate modeling.

Acknowledgements

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