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Are giant planets good neighbours for habitable worlds?

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Abstract

The presence of giant planets affects potentially habitable worlds in various ways. Massive planetary neighbours can facilitate the formation of planetary cores and modify the influx of asteroids and comets towards Earth-analogs later on. Moreover, giant planets can indirectly change the climate of terrestrial worlds by gravitationally altering their orbits. In this work we present a method for quantifying how the gravitational perturbations of a giant planet can affect the capacity of a potentially habitable world to sustain liquid water on its surface. Investigating a number of well characterized extrasolar planetary systems known to date to host a main sequence star and a giant planet, we show that the presence of a 'giant neighbour' can reduce a terrestrial planet's chances to remain habitable, even if both planets have stable orbits. By providing constraints on where giant planets cease to have an adverse effect on the habitable zone size, we identify prime targets in the search for habitable worlds.

1. Introduction

The discovery of planets of similar size to that of the Earth has led to numerous interdisciplinary research activities about the potential habitability of other worlds. Previous studies suggest that the presence of a giant planet in the same exosolar planetary system can affect the formation and evolution of potentially habitable planets in various ways. For instance, during the planetary system's formation, a giant planet can act as a dynamical barrier that blocks the inward migration of proto-planetary cores [1] which in turn affects the formation of rocky planets in the inner region of the system. Even after the planetary formation phase giant planets continue to influence habitable conditions on terrestrial neighbors. While the presence of a giant planet close to the habitable zone can mean dynamical chaos and instability for Earth-like planets [2], giant planets residing within the habitable zone can be hosts to habitable Trojan planets [3] or habitable exomoons [4]. In addition, large impacts of minor bodies on terrestrial planets, may be decisive for the existence of liquid water and the evolution of life [5]. The presence of giant planets can increase the impact flux of comets and other minor bodies on terrestrial planets and hence the delivery of life enabling volatiles [6].

This work is concerned with yet another vital piece in the puzzle. The sheer presence of a giant planet in an exoplanetary system alters the orbit of a potentially habitable world over time. This will affect the amount of stellar radiation the latter receives, which is the main energy source that determines the global climate of Earth-like planets on long timescales [7]. Previous studies mainly focused on the orbital stability of the terrestrial planet assuming the habitable zone limits to be independent of the terrestrial planet's orbit. Here, we calculate the actual insolation received by a potentially habitable world by taking into consideration the orbital evolution of the terrestrial planet under the gravitational perturbations of the giant one. Having estimates of the insolation extrema and variability for any given system configuration at our disposal, we are able to determine more realistic habitable zone limits. These zones are named Dynamically Informed Habitable Zones (DIHZs) and they also take into account how the terrestrial planet atmosphere may respond to changes in the incoming radiation.

2. Method

In order to calculate the DIHZs, we combine a globally averaged radiative-convective energy balance model [7], [8], [9] with analytical results for the orbital evolution of planetary systems [10], [11]. The stability of the planetary system is also checked [12] and other dynamical effects than Newtonian gravity between point masses are also taken into consideration when required.

3. Results

We apply our method on 147 systems consisting of a star on the main sequence and a single giant planet with well-determined orbital elements and physical parameters. Assuming the presence of an additional,fictitious Earth-like planet, we investigate the effect of the giant planet on the limits of the classical habitable zone (CHZ) as defined in [7]. We calculate the extent of the CHZ and compare it to the one of the DIHZs. We find that systems with hot Jupiters exhibit the smallest shrinkages, while systems with warm or cold Jupiter show considerable shrinkage (and sometimes complete elimination) of the CHZ.

4. Summary

In this work, we have developed a general method that can assess the level at which planetary systems can sustain habitable conditions on Earth-like planets as we know them and hence provide observers with a tool to select possible targets in search for habitable worlds. More details about this work can be found in [13].

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