COLD JUPITERS AND HABITABLE PLANETS

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Abstract: Giant planets can influence potentially habitable worlds in various ways. Massive celestial neighbours can facilitate the formation of planetary cores and modify the influx of asteroids and comets towards Earth-analogs later on. Furthermore, giant planets may affect 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 have liquid water on its surface. Calculating the actual amount of radiation received by a potentially habitable planet, we are able to determine more realistic habitable zone limits than before. We show that the presence of cold Jupiters can reduce a terrestrial planet's chances to remain habitable, even if both planets have stable orbits. The method is demonstrated upon some known systems. In providing constraints on where cold Jupiters cease to affect the habitable zone size in a detrimental fashion, we identify prime targets in the search for habitable worlds.

1. Introduction

The presence of a giant planet in the same extrasolar planetary system can affect the gestation and evolution of potentially habitable planets in various ways:

- during the formation stages a giant planet can operate as a dynamical barrier that blocks the inward migration of proto-planetary core protecting the formation of terrestrial planets in the inner part of the system (e.g. Izidoro et al. 2015).

- giant planets residing within the habitable zone can be hosts to habitable Trojan planets (Schwarz et al. 2005) or habitable exomoons (Heller et al. 2014).

- giant planets can increase the impact flux of comets and other minor bodies on terrestrial planets and hence affect the delivery of life enabling volatiles (e.g. Horner & Jones 2008, 2009; Horner et al. 2010; Grazier 2016). Once life has emerged, however, impacts of asteroids and comets can trigger mass extinction events (e.g. Davis et al. 1984; Kaiho & Oshima 2017).

This work is concerned with yet another vital piece in the puzzle. For planets such as our Earth the incoming stellar radiation constitutes the main energy source that determines the global climate on long timescales (Kasting et al. 1993). The sheer presence of a giant planet in an exoplanetary system alters the orbit of a potentially habitable world over time. Planetary atmospheres can react strongly to changes in the incoming starlight, so that variations in some of the orbital elements or the obliquity of the planet constitute an important factor in assessing a planet's capacity to remain far from runaway states. By using analytical solutions for the evolution of a terrestrial planet under the gravitational perturbations of the giant planet we are able to calculate the actual radiation received by a potentially habitable world and determine more realistic habitable zone limits.

2. Methodology

The habitable zone is the region around a star where a planet with an Earthlike atmosphere on a circular orbit can support liquid water on its surface (Kasting et al. 1993). Assuming a non-Keplerian orbit for the planet, we introduce the following three **D**ynamically **I**nformed **H**abitable **Z**ones (**DIHZ**), which take into account the fact that the planetary atmospheres may react differently to incoming radiation variations:

i) the Permanently Habitable Zone (**PHZ**). This is the region where the planet always stays within habitable radiation limits. It corresponds to the classical habitable zone with the additional assumption that the planet's atmosphere reacts quasi-instantaneously to changes in the incoming stellar radiation.

ii) the Averaged Habitable Zone (**AHZ**). This is the region around the star where the stellar irradiation on the planet is on average within habitable radiation limits. It assumes that the planetary atmosphere is capable of buffering radiation changes to an unlimited degree.

iii) the Extended Habitable Zone (**EHZ**). This is the region around the star where the stellar irradiation on the planet is on average within one standard deviation from habitable radiation limits. It assumes that the planetary atmosphere is capable of buffering stellar radiation changes to a limited degree.

The calculation of the three DIHZs involves a radiative-convective cloud-free climate model (Kasting et al. 1993, Kopparapu et al. 2013, 2014), orbital stability conditions for the terrestrial planet (Petrovich 2015) and orbital evolution equations (Georgakarakos et al. 2016). Figure 1 is a graphical representation of the DIHZs.

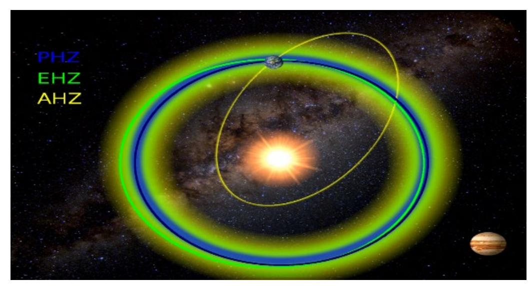

Fig.1 A graphical representation of the three DIHZs.

3. Results

As an example, we calculate DIHZs for two known exoplanetary systems consisting of a main-sequence star and a giant planet: GJ 179 and HD204149. Figure 2 presents our findings.

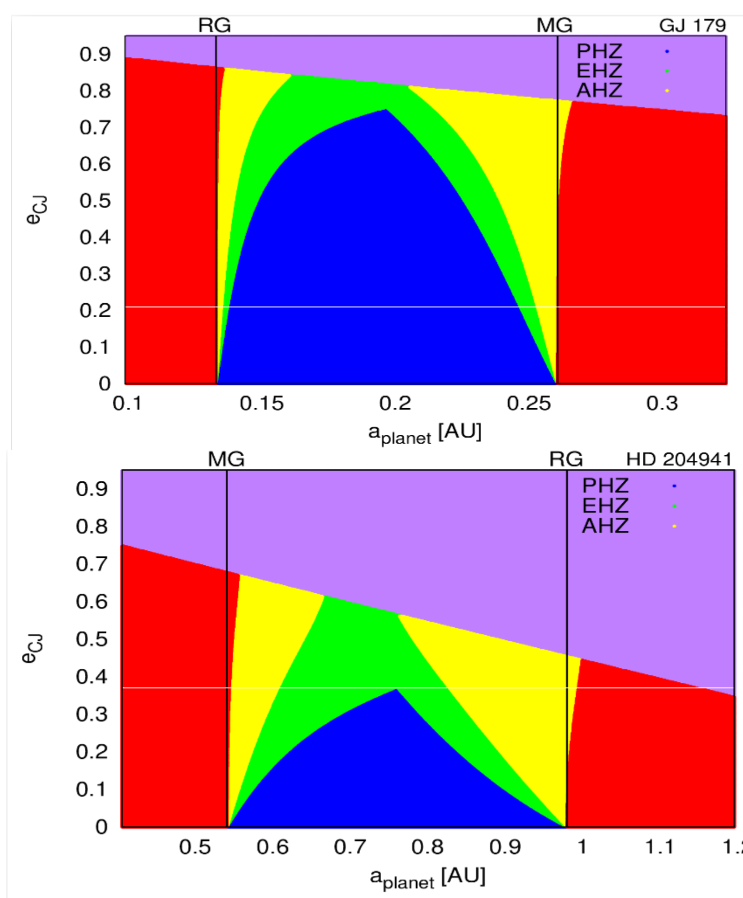

Fig.2 DIHZs for GJ 179 and HD 204941. Colours: red=uninhabitable, purple=unstable, blue=PHZ, green=EHZ, yellow=AHZ. Black lines= classical HZ limits, white line=cold Jupiter eccentricity value. System parameters for GJ 179: M_*=0.36 $M_\odot$, M_{CJ}=0.82 M_J (msini), a_{CJ}= 2.41 au, e_{CJ}= 0.21. System parameters for HD 204941: M_*=0.74 $M_\odot$, M_{CJ}=0.266 M_J (msini), a_{CJ}= 2.56 au, e_{CJ}= 0.37.

More information can be found in Georgkarakos et al. (2018), ApJ, 856, id 155

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