Dynamical Stability and Habitability of a Terrestrial Planet in HD74156 – Preliminary Results

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ABSTRACT:

The detection of extrasolar terrestrial planets located in the habitable regions of a star system is presently beyond our observational technologies. However, systems with multiple Jupiter-like extrasolar planets may prove to be candidates for supporting terrestrial planets provided that stable regions exist. The results of numerical integrations for the systems HD74156 and HD12661, each of which have two Jovian-type planets orbiting their parent star, demonstrates that a region exists in HD74156 where a terrestrial planet can remain in orbit on a timescale of 10^5 years, while HD12661 cannot support additional planets. The Swinburne Supercluster running the SWIFT computer code is used for the simulation of both massless test particles and Earth-mass planets to investigate their short-term dynamical stability. These results can be used to constrain the search region within HD74156 in which habitable terrestrial planets are most likely to be found.

Introduction

To date 119 extrasolar planets have been detected around 104 stars, with 13 of them being multiple planet systems [1]. While direct observation of these planets is not possible they can be detected indirectly, primarily with the radial velocity method which makes use of the periodic Doppler shifting of the star's spectral lines to indicate that a companion is present.

Observational evidence for the likelihood of the existence of small planets around other stars has been presented by Marcy et al. [2], who propose that it is common for rocky worlds to form around young stars. This evidence coupled with the observation by Marcy and Butler [3] that the mass distribution of planets rises steeply with decreasing mass, leads to the conclusion that up to 50% of all stars may have rocky planets.

Certain conditions must be met for a terrestrial planet to be capable of supporting life as we know it, including the presence of certain heavy elements, surficial liquid water and a range of temperatures that allow the retention of an atmosphere [4]. The region around a star where such requirements are met is referred to as the habitability zone (HZ). For a terrestrial planet to remain habitable, there is the additional dynamical requirement that other planets in the system don't gravitationally perturb the planet outside of its habitability zone [5]. When these conditions are met a system can be considered to be dynamically habitable.

In this paper numerical integrations will be used to investigate the possibilities of a terrestrial planet existing between the known planets in HD74156, and whether such a planet is likely to remain dynamically stable within the habitability zone of the system on short timescales. Should these conditions be met, the system will be considered to be dynamically habitable.

SWIFT

The SWIFT solar system integration software package [6] running on the Swinburne Supercluster [7] was used to execute the simulations in this investigation. SWIFT utilizes Wisdom Holman Mapping for N-body calculations with a dominant central mass [8], and a Regularized Mixed Variable Simpletic algorithm for the evolution of the test particles [9].

Planetary Systems

Two systems were chosen for this investigation: HD74156 (Table 1), which was found by Barnes and Raymond [10] to have a narrow stability zone between the two planets in the system; and for comparison purposes HD12661 (Table 2), which was found by Barnes and Raymond not to have a stability zone between the planets. Both of these systems were found to be dynamically inhabitable by Menou and Tabachnik [5].

HD74156 [1]		
Mass:	M_{sun} = 1.05 M_{jup} = 1099.35	
Habitability Zone:	1.07 – 2.52 AU [4]	
Planets:	**HD74156b**	**HD74156c**
M sin i:	1.56 M_{jup}	7.5 M_{jup}
Semi-Major Axis:	0.276 AU	3.47 AU
Orbital Period:	51.61 days	2300 days
Eccentricity:	0.649	0.395
Inclination	*Unknown*	*Unknown*

Table 1: The planets in HD74156 were discovered using the radial velocity method by the Geneva search team. All parameters are based on observational data, which is periodically refined and updated.

HD12661 [1]		
Mass:	M_{sun} = 1.07 M_{jup} = 1120.29	
Habitability Zone:	0.93 – 1.87 AU [4]	
Planets:	**HD12661b**	**HD12661c**
M sin i:	1.56 M_{jup}	7.5 M_{jup}
Semi-Major Axis:	0.83 AU	2.56 AU
Orbital Period:	263.6 days	1624 days
Eccentricity:	0.35	0.20
Inclination	*Unknown*	*Unknown*

Table 2: The planets in HD12661 were discovered using the radial velocity method by the California and Carnegie search team. All parameters are based on observational data, which is periodically refined and updated. Note that the radial velocity method of detection does allow determination of system inclination.

Simulations

Each system's suitability for harboring additional planets was investigated by randomly distributing massless test particles (TP's) between the two planets in the system and integrating for 10^4 years. Stability zones were defined as those areas where the TP's clumped together and remained at a constant orbital distance for the duration of the simulation (Figures 1 and 5). The TP's were replaced with an Earth-mass test planet at various semi-major axes (SMA) within the stability zone and integrated for 10^5 years.

All simulations involving a test planet were run with a co-planar Earth-mass planet and integrated for 10^5 years using a timestep of 3.56 days. In HD74156 test planets were inserted between 0.8 and 1.5AU with e=0.01 and 0.1, and at 1AU with e=0.1 and inclinations of 0°, 2.5° and 5° (Table 3). Although no stability zone was identified in HD12661, simulations were run with test planets at 0.4AU and 1.5AU with e= 0.01 and 0.1 (Table 4). A series of three simulations were run for each individual setup with the initial starting conditions randomly recalculated by SWIFT.

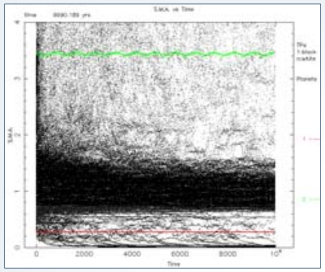

Figure 1: 1000 test particles injected in HD74156 cluster between 0.6AU and 1.4AU for the duration of the simulation, identifying this region as a stability zone.

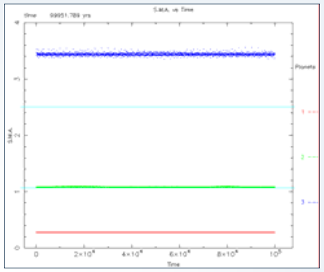

Figure 2: A planet at 1.07AU with e=0.01 in HD74156 remains bound for the duration of the integration. The HZ is defined by the turquoise lines at 1.07 and 2.52AU.

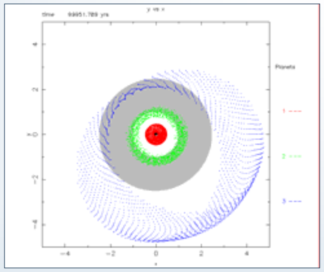

Figure 3: HD74156 with the HZ shown in gray. While a planet placed at 1.07AU with e=0.01 remains bound, it does not stay entirely within the HZ due to cyclical variations in eccentricity.

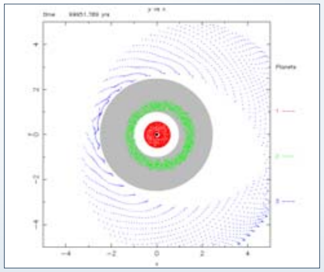

Figure 4: A planet at 1.07AU with e=0.1 in HD74156 remains bound and within the HZ in spite of its eccentricity variations.

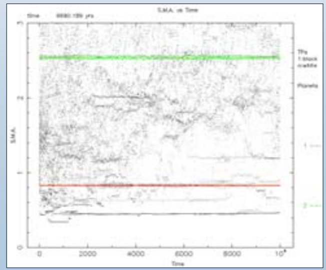

Figure 5: 100 TP's injected in HD12661 do not cluster between the two planets of the system signaling that this region is not stable, while 0.4AU appears to be.

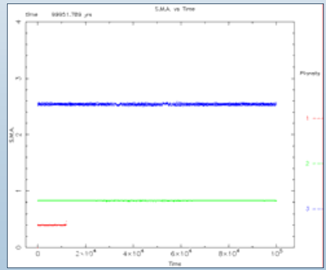

Figure 6: A planet at 0.4AU is ejected (e>1) from HD12661 early in the simulation.

Results

HD74156 was found to be capable of hosting an additional planet within the orbits of the two known planets. For a test planet placed at 1.07AU the optimal values were i=0° and both e=0.01 and 0.1 (Figure 2). With an eccentricity of 0.01, the planet does not consistently remain within the HZ (Figure 3), and therefore cannot be considered dynamically habitable. When assigned an eccentricity of 0.1, the planet does remain in the HZ (Figure 4), thus meeting the initial criterion for dynamic habitability. However, the planet exhibits an SMA excursion of roughly 0.5 AU, which may have a considerable effect on the range of temperatures on the planet. Such a temperature variation may negatively impact the evolution and sustainability of life on the planet.

HD12661 was found not to have a stability zone between the two known planets in the system, confirming the results of Barnes and Raymond [10].

HD74156 with 0.003 M_{jup} Test Planet			
Test Planet S.M.A. (AU)	**Test Planet Eccentricity**	**System Inclination (degrees)**	**Test Planet Survives Duration**
0.8	0.01	0.0	0 of 3
0.8	0.10	0.0	1 of 3
1.0	0.01	0.0	2 of 3
1.0	0.10	0.0	3 of 3
1.0	0.10	2.5	2 of 3
1.0	0.10	5.0	2 of 3
1.07	0.01	0.0	3 of 3
1.07	**0.10**	**0.0**	**3 of 3**
1.2	0.01	0.0	1 of 3
1.2	0.10	0.0	0 of 3
1.5	0.01	0.0	0 of 3
1.5	0.10	0.0	0 of 3

Table 3: Simulations with test planets placed between 0.8 and 1.5AU with varying e and i. The most stable configurations are in red, with the dynamically habitable configuration bolded.

HD12661 with 0.003 M_{jup} Test Planet			
Test Planet S.M.A. (AU)	**Test Planet Eccentricity**	**System Inclination**	**Test Planet Survives Duration**
0.4	0.01	0.0	0 of 3
0.4	0.10	0.0	0 of 3
1.5	0.01	0.0	0 of 3
1.5	0.10	0.0	0 of 3

Table 4: Simulations with test planets placed at 0.4 and 1.5AU with e=0.01 and 0.1. In each instance the test planet was ejected from the system early in the simulation.

Summary

Computer simulations using SWIFT were run to determine two extrasolar planetary systems' ability to support additional planets. HD12661 proved unable to support additional planets, while HD74156 was found to be able to support an additional planet. The breadth of the stability zone as determined by test particles was found to be ~0.8AU. However, among the test planets inserted between 0.8AU and 1.5AU, only the planets placed at 1AU and 1.07AU consistently remained bound for the duration of the integrations, suggesting that the breadth of the stability zone capable of holding a terrestrial planet is ~ 0.1AU. It was found that an Earth-mass planet inserted at 1.07AU with e=0.1 remained within the habitability zone for the duration of the 10^5 year integration, showing that in the short term HD74156 can be considered to be a dynamically habitable system capable of hosting an Earth-like planet. This work was initiated as part of a degree program at Swinburne University of Technology.

References

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Presented at the 203rd Meeting of the AAS, January 2004. Reference #899.