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A JUPITER-SATURN ANALOGUE: OGLE-06-109L

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Abstract. The far away multi-planetary system Ogle-06-109L indicates similarities with the Jupiter-Saturn pair of our Solar system – especially in mass-ratio and mutual distance. A look at the orbital parameters shows a very high inclination of the outer planet in the Ogle system. In this parameter study we show the stability of the two planets for different relative inclinations and semi-major axes of the two planets. Using the errors in semi-major axes given by the observations, the best result concerning dynamical stability has been obtained when planet b is at 2.1 AU and planet c at 5.1 AU. The worst case has been found for the closest configuration, when planet b is at 2.5 AU and planet c at 4.1 AU.

The second part of this study examines the stability of test-planets in the so-called habitable zone (HZ). Long-term stability has been found for the inner region of the HZ for all inclinations up to 50^o. Perturbations caused by the Kozai resonance for higher inclination are clearly visible in the results.

1. INTRODUCTION

Recently the far away planetary system (about 1.5 kpc from our sun) Ogle-06-109L has been discovered by Gaudi et al. (2008) using microlensing. The two planets have 0.71 (planet b) and 0.27 (planet c) Jupiter-masses and orbit the host-star (of only 0.5 M_{Sun}) in about 2.3 AU and 4.6 AU. The planetary motion seems to be low-eccentric at least for the outer planet. According to the mass-ratio, the separation ratio of the two planets and their equilibrium temperatures, this system can be considered as an analog system to the Jupiter Saturn pair of our solar system.

However, the web-site of J. Schneider (http://exoplanet.eu/catalog-microlensing.php) indicates a very high inclination of the outer planet which was taken as relative inclination of the two detected giant planets. Since we do not know all orbital parameters from the observations, the stability of this 2-planet system was studied for different positions and relative inclinations of the two planets. Following two former studies of different Jupiter-Saturn systems (see Pilat-Lohinger et al., 2008a and 2008b), the region between 0.2 and 0.4 AU was analyzed with the aid of test-planets moving in circular motion. The scanned region corresponds to the so-called habitable zone (HZ) according to the paper by Kasting et al (1993).

Table 1: Orbital elements of the gas giants of the Ogle-06-109L system

planet	a [AU]	e	inc. [deg]	mass [m_{Jup}]
b	2.3 ± 0.2	–	–	0.71 ± 0.08
c	4.6 ± 0.5	0.11	59 ± 6	0.27 ± 0.03

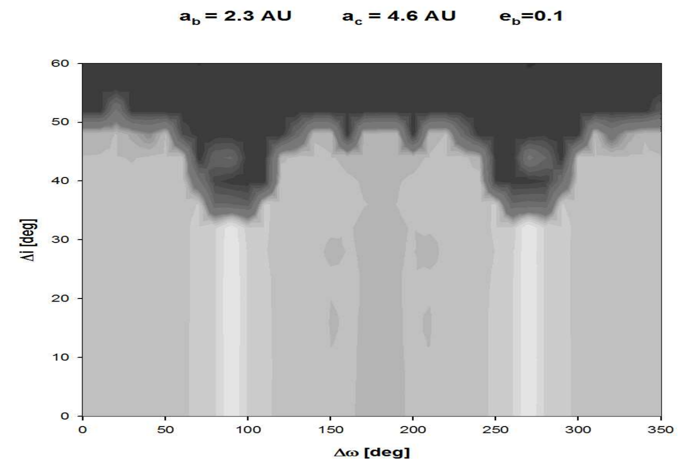


Figure 1: FLI stability map for the Ogle-06-109L system showing the stability for different configurations in $\Delta\omega$ (x-axis) and relative inclination (y-axis).

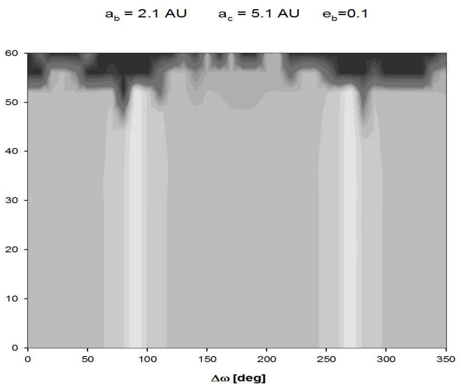
2. COMPUTATIONS

To distinguish between regular and chaotic motion we applied the Fast Lyapunov Indicator (Froeschlé et al., 1997) for our study. This chaos indicator is given by the length of the largest tangent vector $\psi(t) = \sup_i \|v_i(t)\| \qquad i = 1, \ldots n$ (n denotes the dimension of the phase space); which grows exponentially for orbits in a chaotic region. The FLI program uses the Bulirsch-Stoer integration method and the integration time was $5 \cdot 10^5$ years.

Taking the orbital parameters of the two giant planets given in Table 1, different 2-planet-configurations were analyzed concerning the long-term stability of this system using the three body problem as a dynamical model. The motion of test-planets moving in the so-called habitable zone (HZ) was studied in the restricted four body problem, where the test-planets do not influence the motion of the discovered planets.

3. RESULTS

As the observations do not provide the eccentricities for both planets we can verify the stability of such a 2-planet system in a first approximation very quickly, by using the stability maps of the "Exocat" (Sandor et al., 2007) via the Internet tool *"ExoStab" (http://www.univie.ac.at/adg/exostab)*. For the Ogle-06-109L system, we take the outer planet as already known giant planet, and get a stability map for the region of the inner planet that shows stable and chaotic orbits in the model of the restricted three body problem, where the test-planets have nearly circular motion. Even if it is only a first approximation one might get an indication whether the determined positions are in a stable region or not.



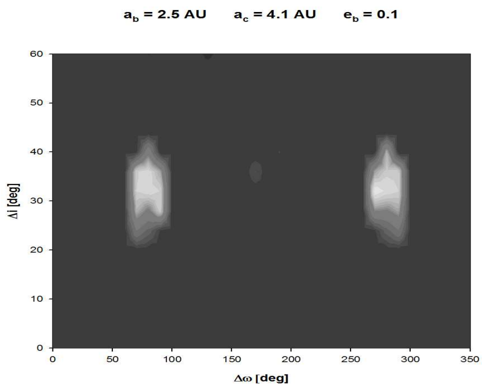


Figure 2: Same FLI stability maps like Fig. 1 where Fig. 2.a shows the best case for the Ogle-06-109L system and Fig. 2.b shows the worst case for this system.

Since we do not know the orientation of the orbits in space of the Ogle-06-109L system, it is useful to study the stability for different relative longitudes of perihelion ($\Delta\omega$). The result for this system, when the two giant planets are placed at the projected semi-major axes of 2.3 AU and 4.6 AU is given in Fig. 1. The FLI stability map shows the dynamical behavior of 576 orbits (the step in $\Delta\omega$ is 10^o and for Δi it is 4^o), where the stable motion is given by the light grey region with small FLI value. Black marks the chaotic motion connected to high FLI values. In Fig. 1 we recognize a symmetry with respect to $\Delta\omega = 180^o$, which can also be seen in other stability maps (see Figs. 2 a and b). The most stable configurations are according to Fig. 1 around $\Delta\omega = 90$ and 270 degrees (see the two vertical bright stripes up to 35 degrees in inclination). However, these configurations are the first to be chaotic if the relative inclination (Δi) of this system is larger that 35 degrees. For $\Delta i > 50^o$ all configurations are chaotic.

Similar studies using other semi-major axes of the two detected planets – according to the error in a of the observation – show the most stable result (see Fig. 2.a) when the mutual distance between the two giant planets is the largest, i.e. for semi-major axes of 2.1 and 5.1 AU. The worst case is given in Fig. 2.b, where the mutual distance of the two giant planets is the smallest, i.e. when the planets are placed at 2.5 and 4.1 AU. Like in Fig. 1 the two panels indicate stable motion by light grey regions and chaotic motion is given by black regions. It is clearly visible that the best case (Fig. 2.a) allows relative inclinations up to 60^o for special configurations (e.g. $\Delta\omega \sim 200^o$). The smallest FLI values are given for configurations with $\Delta\omega$ around 90 and 270 degrees (see the two vertical bright stripes).

In the worst case (Fig. 2.b) only two stable islands can be recognized for quite a high relative inclination around 30^o and for configurations with $\Delta\omega$ around 90 and 270 degrees. The stability mechanism for these two islands is most probably the Kozai resonance (see the presentation by Libert & Tsiganis, this volume).

In the second part of this study, we examined the stability of test-planets in the habitable zone (HZ) of the Ogle-06-109L system. According to Kasting et al. (1993) this zone is defined from 0.2 to 0.4 AU for a star of 0.5 solar masses. As stability parameter for the orbits in the HZ we used the maximum eccentricity (max-e), which

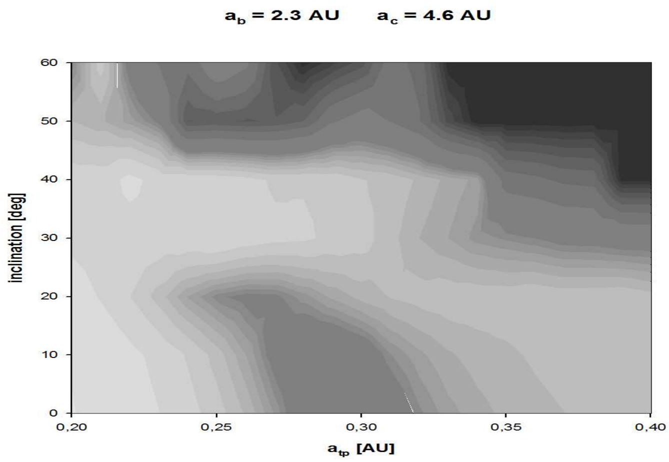


Figure 3: Max-e plot for test-planets in the habitable zone of the Ogle-06-109L system. Different gray-shades indicate different max-e values: light gray labels the lowest (< 0.2) and black the highest one (> 0.8).

indicates whether a planet remains in the HZ during its revolution or not. Fig. 3 shows the max-e for all test-planets in the HZ and different relative inclinations of the giant planets of the Ogle-06-109L system (y-axis). The max-e map was calculated for the projected semi-major axes of 2.3 and 4.6 AU, an initial eccentricity of the inner giant planet of 0.1 and $\Delta\omega = 0^o$. It is clearly visible, that the innermost region of the HZ is quite stable, while for the outer region and higher relative inclination we observe higher max-e values due to the Kozai resonance. Moreover, an island of higher eccentricity due to secular perturbations is visible around 0.3 AU for relative inclinations from 0 to 20 degrees.

In this paper, it was only possible to show some interesting results of our numerical study of the Ogle-06-109L system. A more detailed paper on this work is in preparation.

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