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STUDY OF THE *SAILBOAT* STABLE REGION FOR BINARIES SYSTEMS

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Abstract: The *sailboat* is a stable region in the Pluto-Charon system discovered by Giuliatti Winter et al. [1], who also showed this region is associated with a family "BD" of periodic orbits derived from the planar, circular, restricted three-body problem. This project is an extension of the work of Giuliatti Winter et al. [3] looking for the existence of the Sailboat region for any binary system. We analyzed through numerical simulations test particles of S-type orbits in hypothetical systems with different values of mass ratio (μ) and for several orbital configurations. Our results show the sailboat is robust and it exists for μ=[0.05,0.27] and for large intervals of argument of pericentre and inclination .

keywords: Celestial Mechanics and Dynamical Astronomy, Nonlinear Dynamics and Complex Systems, Stochastic Models.

1. INTRODUCTION

Giuliatti Winter et al. [1] studied the possibles stable regions of test particles in Pluto-Charon system before the probe New Horizons reaches there. Through numerical simulations, they analyzed particles of S-type orbits around Pluto and Charon and they detected a peculiar region (*sailboat*) located at $a = (0.5d, 0.7d)$ and $e = (0.2, 0.9)$, being a, d and e the values of semi-major axis, Pluto-Charon's distance and the eccentricity, respectively. The name is due to the shape of this region which resembles a sailboat (see their figure 1).

The *sailboat* location was unexpected, since it is located at the middle of separation distance between Pluto and Charon. It was found that the region is associated this new region with a family "BD" of periodic orbits (Broucke,R.A. [5]) derived from the planar, circular, restricted three-body problem (the gravitational effects of the moons Nix, Hidra, Kerberos e Styx are irrelevant).

To better understand this region, Giuliatti Winter et al. [3] analysed how the changes in the inclination (I) and argument of pericentre (ω) of the particles modify the *sailboat*. First they assumed the test particles were coplanar with the binary and then varied the ω, they obtain that *sailboat* survives in two narrow different intervals [$10°$,$-10°$] and [$160°$, $200°$], and its maximum size occurs when ω is $0°$ or $180°$. Later it was verified the *sailboat* exists to value of inclination up to $90°$. These results were combined in another article Giuliatti Winter et al. [4] in order to to determine safe trajectories for the New Horizons mission.

In this work we explore in details the variation of the size and shape of this region for different binaries systems and the initial conditions of the test particles. The paper is divided as follows: Section 3 describes the method applied to create the hypothetical binary systems and the numerical simulations, and in Section 4 the results are presented. In the last section we concluded our results.

2. OBJECTIVES

The purpose of this paper is to determinate the behavior of Sailboat for any binary system. We studied this region through the numerical simulation of the test particles of S-type orbits in hypothetical binary systems.

3. METHOD

We first created hypothetical systems with different mass ratio (μ) by setting the mass (m_p) and radius (r_p) of the primary body (the more massive body of binary) equals to Pluto, m_p = $1,304 \times 10^{22}$ kg, and then we determined the mass of the second body (m_s) according to the desired value of μ. In all cases the distance (d) between the binary was the same of Pluto-Charon system (19,571 km), and the secondary body is assumed to be in an equatorial and circular orbit.

We choose μ in the interval $[0.05, 0.50]$ in steps $\Delta\mu = 0.01$ and for μ in $[0.52, 0.70]$ we adopted $\Delta\mu = 0.02$. The test particles were uniformly distributed in semimajor axis in $[0.3d, 0.8d]$ with $\Delta a = 0.0008d$, the eccentricities varied from 0 to 0.99, with $\Delta e = 0.005$ and initially the argument of the pericentre and inclination was set as $\omega = I = 0°$. This results in a diagram with 133,008 initial conditions for each mass parameter.

We numerically integrated the orbits using the Radau 15 (Everhart [7]) for a total time equal to 65,000 days, equivalent to 10^4 orbital periods of the binary. Holman & Wiegert [8] and Winter & Vieira [9] have shown that all the particles which remain in the system for the whole time of integration are considered to be in stable orbits. Particles that collided with a massive body were removed from the integration.

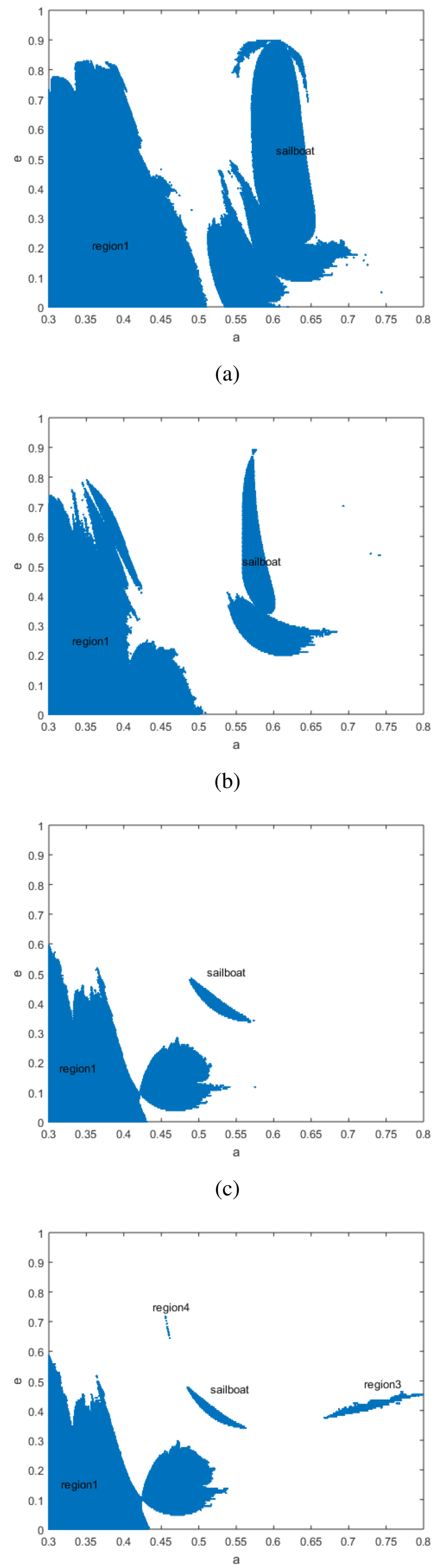
We also analyzed the behaviour of the *sailboat* according to the eccentricity (e) of the secondary body, looking for the maximum value for which the particles remain stable. A final set of simulations was performed for different values of inclinations and argument of pericenter in order to determine the extreme values for the stability.

4. RESULTS AND DISCUSSION

4.1. The hypothetical binary systems

The results of the simulations show that the existence of the sailboat is limited to $\mu = (0.05, 0.27)$. For the smallest value of μ the region comprehend an extension of $a = (0.5d, 0.75d)$ and $e = (0.0, 0.9)$, while for the other extreme ($\mu = 0.27$) the *sailboat*'s extension is $a = (0.45d, 0.6d)$ and $e = (0.3, 0.5)$.

Figure 1 presents diagrams (a, e) of the stable initial conditions for four binaries with different mass ratios: μ = 0.05, 0.11 (the closest case to the Pluto-Charon system), 0.27 and 0.28. It is possible to identify the *sailboat* approximatelly at half of separation distance between the massive bodies, as well as another region located near to the primary (region 1 hereinafter). Fig. 1c shows the latest case where is possible to distinguish the *sailboat*, and when the mass ratio of binary reaches 0.28 (figure 1d) two new stable regions emerge: one located beyond a = 0.6d up to a = 0.8d (region 3) and another region located in approximately 0.45d, but with eccentricities above 0.6 (region 4). With a small increase in μ these two regions mix with the *sailboat* and form a single region.



(a)

(b)

(c)

(d)

Figure 1: Diagram of initial conditional semi-major axis a versus eccentricity e of the stale particles for systems with (a) μ = 0.05, (b) $\mu = 0.11$, (c) $\mu = 0.27$ and (d) $\mu = 0.28$.

4.2. *Different values of initial conditions*

Once we verified the interval of mass ratio for the existence of the *sailboat*, we explore the influence of eccentricity of the second body, argument of pericenter and inclination of the test particles on the size and shape of this region.

The figure 2 shows the maximum value of eccentricity that the *sailboat* exists as a function of the each mass ratio. The almost exponential behaviour indicates that as orbit of the secondary becomes eccentricity.

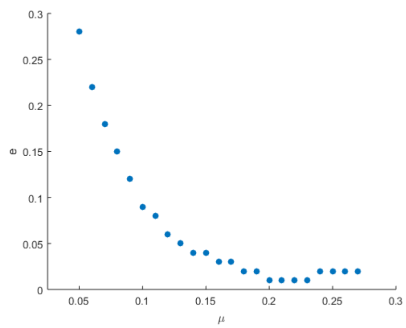


Figure 2: The excentricity of the second body in relation with mass ratio of the system.

In the other hand, the *sailboat* presents almost a linear behavior relative with the maximum inclination (I_{max}) of the test particles. It is possible to see in the figure 3 that the *sailboat* is not very sensitive to changes in this paramater, since the region exists even for retorgrade orbits.

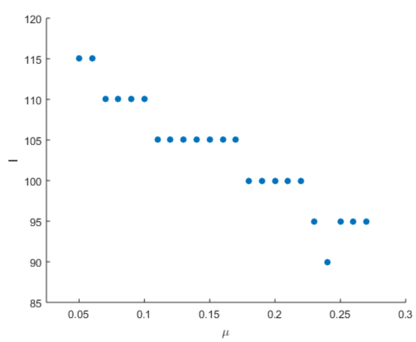


Figure 3: The maximum inclination of the test particles in relation with mass ratio of the system for which the sailboat exists.

Giuliatti Winter et al. [3] discovered that for the Pluto-Charon the sailboat exists for two narrow ranges of argument of pericentre around the its two maximum size at $0°$ and $180°$. When considering the systems with different values of μ we also found the larger extend of the sailboat at $\omega = 0°$ and $\omega = 180°$, but the size of the interval varies with the mass ratio of system.

The figures 4 and 5 show the absolute values of these two intervals of ω for each binary system, around $\omega = 0°$ (figure 4) and around $\omega = 180°$ (figure 5).

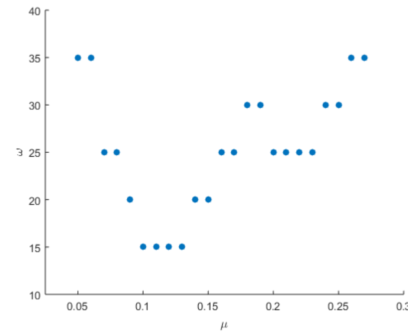


Figure 4: The absolute interval of ω of the test particle that exist the *sailboat* around $0°$ in relation with mass ratio of the system.

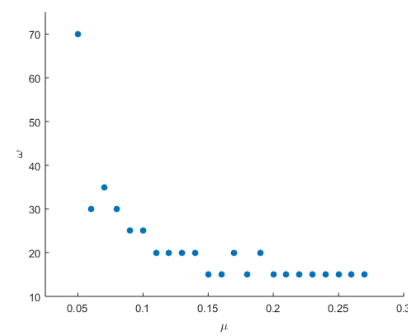


Figure 5: The absolute interval of ω of the test particle that exist the *sailboat* around $180°$ in relation with mass ratio of the system.

5. FINAL COMMENTS

The *sailboat* is a peculiar stable region of binary systems located at the middle of the distance of the massive bodies, and it is associated with a family 'BD' of periodic orbits.

Our results show that the *sailboat* is very resistant to changes in the mass ratio of the two bodies and it survives up to μ around 0.27, but small changes in the eccentricity of the secondary body are enough to decrease substancially the extend of the stable region. In respect to the orbital elements of the particles, the sailboat is more sensitive to changes in the argument of pericenter than the inclination.

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References

[1] Giuliatti Winter, S. M. and Winter, O. C. and Fernandes Guimaraes, A.H. and Silva, M.R.,Exploring S-type orbits in the Pluto Charon binary system, Monthly Notices of the Royal Astronomical Society,Vol.404, pages: 442-450, January 2010.

[2] Giuliatti Winter, S. M. and Winter, O. C. and Vieira Neto, E. and Sfair, R.,Stable regions around Pluto, Monthly Notices of the Royal Astronomical Society,Vol.430,pages: 1892-1900, April 2013.

[3] Giuliatti Winter, S. M. and Winter, O. C. and Vieira Neto, E. and Sfair, R.,A peculiar stable region around Pluto,Monthly Notices of the Royal Astronomical Society,Vol.439,pages: 3300-3307, April 2014.

[4] Giuliatti Winter, S. M. and Winter, O. C. and Vieira Neto, E. and Sfair, R., The sailboat island and the New Horizons trajectory, ICARUS , Vol.246, pages:339-344, January 201.

[5] Broucke,R.A.,Periodic orbits in the restricted three-body problem with earth-moon masses,Pasadena, Jet Propulsion Laboratory, California Institute of Technology, 1968.

[6] Murray, C.D. and Dermott, S.F.,Solar system dynamics,1999

[7] Everhart, E.,An efficient integrator that uses Gauss-Raus aucings,Dynamics of Comets: Their Origin and Evolution, Proceedings of IAU Colloq. 83, Vol.115, pages 185, 1985.

[8] Holman,M.J., Wiegert,P.A., Long-Term Stability of Planets in Binary Systems, AJ, Vol.117, pages 621-628, January 1999.

[9] Winter, O.C.and Vieira Neto,E., Time analysis for temporary gravitational capture. Stable orbits, AAP, Vol.377, pages 1119-1127, Octuber 2001.