ISSN 2176-5480

22nd International Congress of Mechanical Engineering (COBEM 2013)
November 3-7, 2013, Ribeirão Preto, SP, Brazil

A PECULIAR STABLE REGION AROUND PLUTO AND ITS ROLE ON THE NEW HORIZONS MISSION TRAJECTORY

Silvia M. Giuliatti Winter
Othon C. Winter
Ernesto Vieira Neto
Rafael Sfair

Univ. Estadual Paulista - UNESP- Faculdade de Engenharia de Guaratinguetá, Guaratinguetá, CEP 12516-410, SP, Brazil

silvia@feg.unesp.br
ocwinter@feg.unesp.br
ernesto@feg.unesp.br
rsfair@feg.unesp.br

Abstract. *Recent paper found several stable regions for a sample of particles located between the orbits of Pluto and Charon. One peculiar stable region in the space of the initial orbital elements is located at a = [0.5d, 0.65d] and e = [0.2, 0.9], where a and e are the initial semi-major axis and eccentricity of the particles, respectively, and d is the Pluto-Charon distance. This peculiar region (hereafter called sailboat region) is associated to a family of periodic orbits derived from the circular, restricted 3-body problem (Pluto-Charon-particle). We explored the extent of sailboat region by adopting different initial values of the orbital inclination and argument of the pericentre of the particles. The sailboat region is present for I= [0, 90°], and for two small intervals of ω, ω = [-10°, 10°] and ω=(160°, 200°). Since the existence and size of this stable region depend sensitively on the initial values of the orbital inclination and argument of pericentre, its extent is much smaller than the whole space of initial conditions. Therefore, we concluded that it is reduced the possibility of the New Horizons finding objects in this region during its passage through the Pluto system in July 2015.*

Keywords: *Space Missions, Periodic Orbits, Numerical Simulations, New Horizons spacecraft.*

1. INTRODUCTION

Before the launch of the New Horizons spacecraft in 2006, Pluto system was known to be formed by only two massive bodies, Pluto and Charon. These two bodies form a binary system due to its large mass ratio (0.1165) and its small separation distance, d=19570km (Buie *et al*. 2006).

Recently small satellites were discovered in the external region of the system, beyond the orbit of Charon. Nix and Hydra, detected in 2005 (Weaver *et al.* 2006), are located at about 2.5d and 3.3d, respectively, while P4, detected in 2011, is located between theirs orbits. The discovery of P4 corroborated the results described in the paper by Pires dos Santos, Giuliatti Winter & Sfair (2011). Through a sample of numerical simulations they could obtain the location and sizes of small satellites (ranging from 1 to 25km in size) which can exist without cause any change in the eccentricities of Nix and Hydra larger than 10^{-3}.

Last year another small satellite, temporarily named P5, was found interior to Nix's orbit. The discovery of these new four objects raised the question on the possibility of new satellites, or even a dust ring, exist in this binary system.

Giuliatti Winter *et al*. (2010) explored the dynamical behavior of a sample of coplanar particles located between the orbits of Pluto-Charon system for a range of eccentricities of the particles varying from 0 to 0.99. New stable regions were identified and the associated families of the periodic orbits were derived from the circular restricted three body problem, Pluto-Charon-particle. Most of their results corroborated the previous results obtained by Stern *et al.* (1994) and Nagy, Süli & Érdi (2006), except for a small region located at a = [0.5d,0.7d], a is the semimajor axis, for a large values of e.

In this work we analyse in details the origin of this peculiar small region and the variation of its size for different values of the orbital inclination of the test particles. Since the New Horizons mission will pass very close to this region it is important to understanding its origin and its extend for different values of the orbital elements of the test particles. Ours results are presented in the last section.

2. ORIGIN OF THE SMALL REGION

We numerically simulated the restricted 3-body problem which can represent a sample of small particles in orbit around Pluto (central body) gravitationally disturbed by Charon (secondary body). The eccentricity of Charon was assumed to be 0.0035 (Tholen *et al*. 2008). The gravitational effects of the four satellites P5, Nix, P4 and Hydra were neglected since they are small and too far from the internal region. The timespan of the numerical integration was adopted to be 10^4 orbital periods of the binary (T = 65000 days). Those particles which stay in the system for the whole time of integration are considered to be in stable orbits (Winter & Vieira Neto 2001).

The initial orbital elements *a* and *e* was obtained by varying the following parameters: i) the semimajor axis was uniformly distributed, about 0.5*d* from Pluto and about 0.25*d* from Charon, with step size Δa = 0.0008*d* and ii) the eccentricity was varied from 0 to 0.99 each Δe = 0.0005. The orbital inclination was assumed to be zero. A collision was computed every time the distance between the test particle and the massive body was less than the radius of this body. Figure 1 shows only the small region formed at *a*=[0.5*d*, 0.7*d*] and *e*=[0.2, 0.9], another stable regions were not shown in this figure.

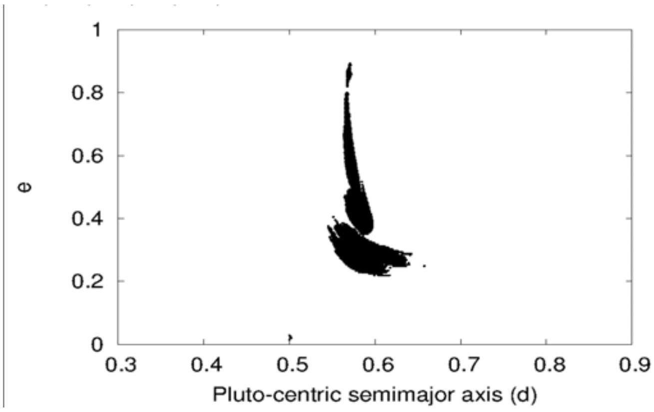

Figure 1. Diagram of *a* versus *e*. The small stable region is shown in black. The nominal parameters of the particles are: ω,= 0 and T= 0, where ω is the argument of pericentre and T is the epoch of the pericentre.

In order to identify the origin of this stable region we used the method of the Poincaré surface of section. This method permits identify chaotic and regular trajectories located in the phase space of the circular restricted 3-body problem. As pointed out before we assumed the eccentricity of Charon to be different from zero. Therefore we run the same set of initial conditions by assuming the circular restricted 3-body problem. Our results show that the small region keeps the same shape, only with a small increase in its size. Besides, many authors claimed that the eccentricity of Charon is equal to zero.

About 100 particles, uniformly distributed in the *x*-axis, generated one Poincaré surface of section for each value of C_J. The method of the Poincaré surface of section confirmed the location and size of the sailboat region: from the values of C_J and *x* at dot*x* = *y* =0 we found the osculating values of *a* and *e* in order to compare with the *a* versus *e* diagram. Winter 2000 proposed a criterion to measure the degree of the stability of a periodic orbit: the largest island surrounding the periodic orbit (shown as a point in the centre of the island) gives the size of the regular region. The small region matches the region obtained from the values of C_J = [2.766, 3.236].

Figure 2 shows a sample of Poincaré surface of sections for six different values of C_J: 2.786, 2.936, 3.016, 3.056, 3.116 and 3.224. Only the periodic and quasi periodic orbits (the islands) are shown in Figure 2, the chaotic region was removed.

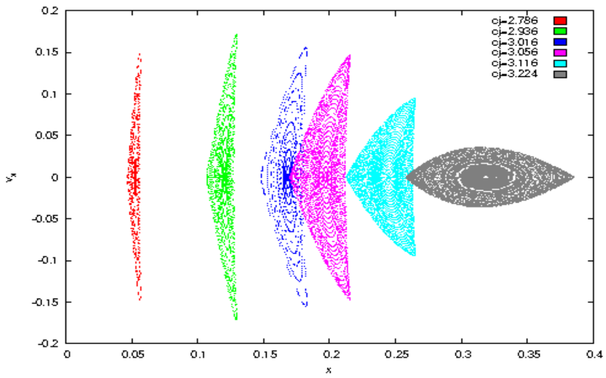

Figure 2. A sample of Poincaré surface of sections for six different values of the Jacobi Constant. In each case are shown only those points associated to the periodic and quasi-periodic orbits of the family "BD" (Broucke, 1968), which corresponds to the small region (Fig. 1).

After identifying the region, the periodic and quasi periodic orbits can be obtained. Generally, a dynamical system is periodic if after some period of time all the bodies have the same relative positions and velocities as they had before. Since the solution of the differential equations, which describe the system, is unique, the system will continue to repeat itself. The periodic orbits associated with the planar, circular, restricted 3-body problem can be classified into two types (Poincaré, 1895, Szebehely 1967): periodic orbit of the first kind and periodic orbit of the second kind. The periodic orbits of the first kind are originated from particles initially in circular orbits, while in the second kind the particles are in eccentric orbits located at the centre of the mean motion resonance.

The centre of these islands corresponds to periodic orbits of family "BD", designation given by Broucke (1968). The family "BD" is a sample of direct periodic orbits around the primary (Pluto). Broucke (1968) studied the periodic orbits for the Earth-Moon system through computational simulations of the planar, restricted 3-body problem. Despite the difference between the mass ratio of the systems, Earth-Moon and Pluto-Charon, the behavior of the periodic orbits is similar. Figure 3 shows the set of periodic orbits of family "BD" for each value of C_J presented in Figure 2.

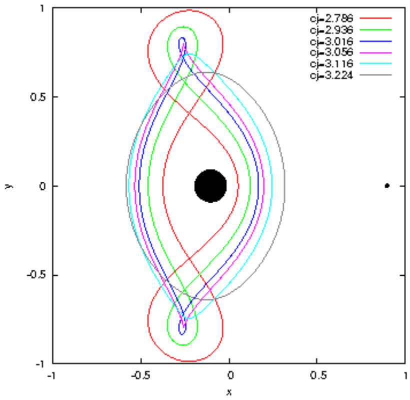

Figure 3. The set of periodic orbits, in the synodic frame, for the different values of C_J as shown in Figure 2. The barycentre is located at 0.

Figure 4 shows the period of the periodic orbits (trajectory in the synodic frame) as a function of the Jacobi constant (C_J). The period of the periodic orbits (T) is given in terms of the orbital period of Charon (T_{charon}). This figure shows that the period of the periodic orbits changes significantly according to the value of the Jacobi Constant. It shows a tendency in which T tends to be equal to the orbital period of Charon (T_{charon}) as the eccentricity grows (C_J decreases). In the case of circular orbits (higher values of C_J) it would have a period close to the 2:1 mean motion resonance with Charon (Broucke, 1968).

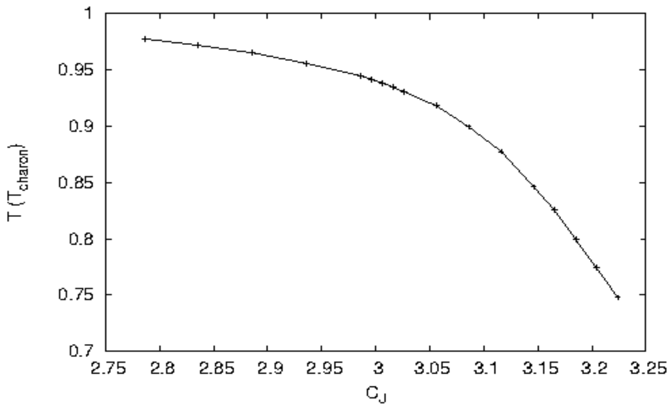

Figure 4. Orbital period of the periodic orbits, in terms of orbital periods of Charon (T_{charon}), as a function of the Jacobi constant (C_J).

3. VARIATION OF THE SIZE OF THE REGION

In this section we analyse the sailboat region for different values of ω, argument of pericentre, and I, orbital inclination, of the particles. First of all, we assumed that I=0 and varied the values of ω from 0 to 360°, each Δω= 1°. Figure 5 shows the size of sailboat region for a sample of different values of ω. The size of this region decreases from ω = 0 up to the value of ω = 10°, and start increasing from about 160° to its largest size at 180°. From our numerical

ISSN 2176-5480

simulations we found that the sailboat region exists only for two intervals of ω, ω = [-10°, 10°] and ω = (160°, 200°). The existence of the sailboat region is confined to a small interval of the initial values of the argument of pericentre. The size of such interval reveals the strength of the family of periodic orbits.

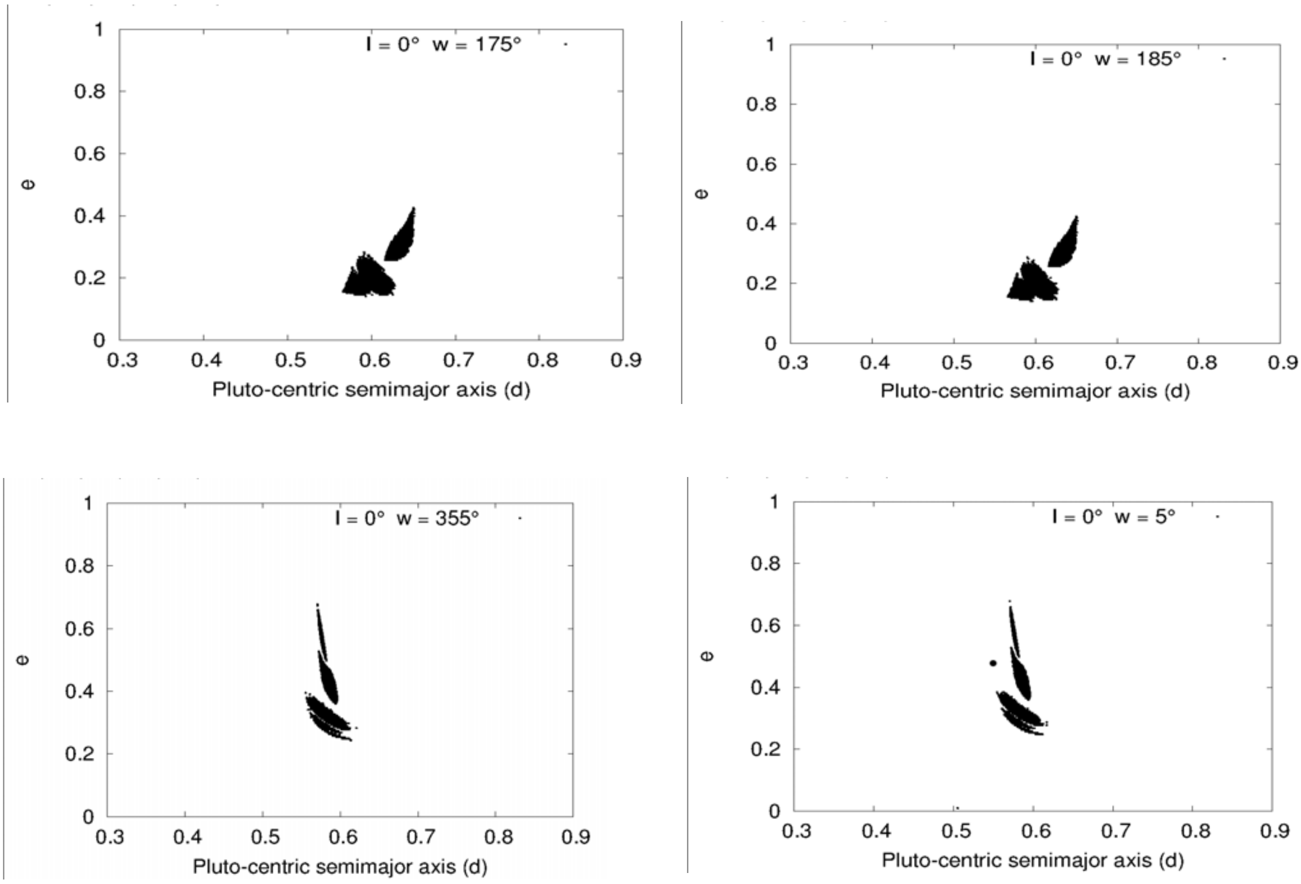

Figure 5. Diagram *a* versus *e* for different values of ω.

We also numerically integrated a set of particles for different values of *I* from 10° to 90°, each Δ I= 10°. For each value of the initial inclination we adopted two values of the argument of the pericentre, ω = 0 and ω = 180°. Sailboat region is present for all values of the inclination of the particle, regardless the value of ω is assumed to be 0 or 180°. The maximum size of the region is reached when I=0 and its minimum size is at I=90°. Figure 6 shows the size of sailboat region for different values of *I*. Sailboat region disappears for *I* > 100° as has been shown in Giuliatti Winter *et al*. (2013).

4. DISCUSSION

The searching for stable zones can help to detect debris which can pose as a harm for the New Horizons mission. In this work we explore in details one peculiar stable region located at *a*= [0.5d, 0.7d], close to the trajectory of the spacecraft. We numerically simulated the restricted 3-body problem, Pluto-Charon-particle, and neglected the gravitational effects of the four small satellites, located exterior to the Charon's orbit.

From the Poincaré surface of sections we identified the peculiar region by comparing to the *a* versus *e* diagram. From each surface of section we identify the periodic and quasi periodic orbits. Sailboat region is associated to a family of periodic orbits derived from the circular restricted 3-body problem. The centre of these islands corresponds to periodic orbits of family "BD", firstly presented by Broucke (1968) in his analysis of the Earth-Moon system.

We also explored the extent of sailboat region by adopting different values of the initial orbital inclination and the argument of the pericentre of the test particles. Since the existence and size of this stable region depend on these two initial orbital elements, its extent is smaller than the whole space of initial conditions. Therefore it is reduced the possibility of the New Horizons finding debris/objects in this region during its passage through the Pluto system.

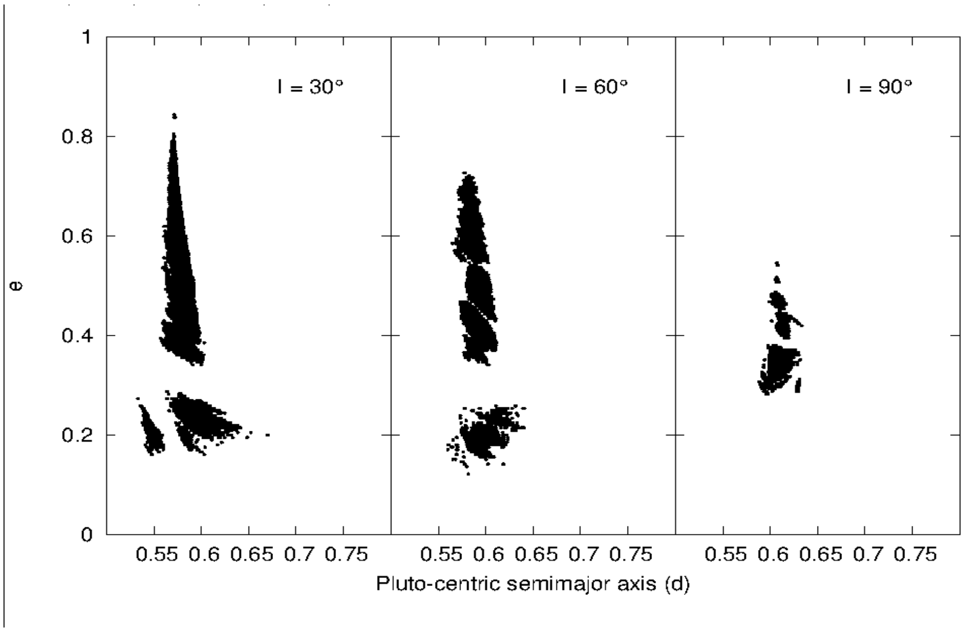

Figure 6. Diagram *a* versus *e* for different values of *I*.

5. ACKNOWLEDGEMENTS

The authors thank CNPq and Fapesp for the financial support.

6. REFERENCES

Broucke, R.A., 1968. "Periodic Orbits in the Restricted Three-Body Problem with Earth-Moon Masses". Technical Report 32-1168

Buie M., Grundy W., Young L.A. And Stern A., 2006 , "Orbits and Photometry of Pluto Satellites: Charon, S/2005 P1, and S/2005 P2", *AJ*, Vol. 132, p. 290.

Giuliatti Winter S.M., Winter O.C., Guimarães A.H.F., Silva M.R., 2010, "Exploring S-type orbits in the Pluto–Charon binary system", *MNRAS*, Vol. 404, p. 442.

Giuliatti Winter S.M., Winter O.C., Vieira Neto E., Sfair R., 2013, "Stable regions around Pluto", *MNRAS*, Vol 430, p. 1892.

Nagy, I., Sulli, Á. and Érdi, B., 2006, "A stability study of Pluto's moon system. *MNRAS*, Vol. 370, p. L19.

Pires dos Santos P.M., Giuliatti Winter S.M., Sfair, R., 2011, "Gravitational effects of Nix and Hydra in the external region of the Pluto–Charon system", *MNRAS*, Vol. 410, p. 273

Poincaré, H., 1895. Les méthodes nouvelles de la Mécanique Celeste. Gauthier-Villars, Paris

Stern S.A., Parker J.W., Duncam M.J., Snowdall J., Levison H.F., 1994, "Dynamical and observational constraints on satellites in the inner Pluto-Charon system", *Icarus*, Vol. 108, p. 234.

Szebehely,V., 1967. *Theory of Orbits. The Restricted Problem of Three Bodie*s. Academic Press Inc.

Tholen D.J., Buie M.W., Grundy N.M., Elliot G.T., 2008, "Masses of Nix and Hidra", *AJ*, Vol. 135, p. 777.

Weaver, H.A. et al., 2006. "Discovery of two new satellites of Pluto". *Nature*, Vol. 439, p. 943.

Winter, O.C., 2000, "The stability evolution of a family of simply periodic lunar orbits", *Planetary and Space Science*, Vol. 48, p. 23.

Winter, O.C., Vieira Neto, E., 2001, "Time Analysis for Temporary Gravitational Capture. Stable Orbits", *A& A*, Vol. 377, p. 1119.

7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.