Gravitational Capture and Maintenance of a Spacecraft Around Pluto

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In this work, we study gravitational captures of a spacecraft by the Pluto-Charon system, searching configurations where the loss of energy of the spacecraft to Pluto is maximized in a time interval that keeps the viability of the mission, using the three-dimensional restricted three-body problem, taking into account the perturbation of the Pluto and Charon gravitational potentials (J_2 and J_{22}), the perturbation of the Sun and the gravity of the minor satellites of Pluto (Styx, Nix, Kerberos, and Hydra). The initial conditions which lead to captures of probes that remain in orbit around Pluto for 10 years or more will be considered as stable regions. During the gravitational capture maneuvers, some aspects will be measured in order to find the best maneuver, like the minimum energy after the capture and time consumed during the process. Those variables are important in the transfer orbit selection for this phase of the mission. Using the technique of the integral of the perturbing forces, we calculate the total velocity variation received by the spacecraft, in the stable regions, due to the Sun, Charon, the small satellites of Pluto and the J_2 and J_{22} terms of the potential of Pluto and Charon. By the comparison between the velocity contribution of each disturber term and a Keplerian orbit around Pluto, we will be able to define which one of the disturbers are more significant, in order to make a decision about which forces need to be included in a model for a given accuracy and nominal orbit. We also will be able to find orbits that are less perturbed, requiring less station keeping maneuvers, and consequently orbits with good chances to become useful for a real mission, since these orbits come from captures.

Nomenclature

J_2	Polar oblateness of the body (for Pluto and Charon)
J_{22}	Equatorial ellipticity of the body (for Pluto and Charon)
G	Gravitational constant
M_P	Mass of Pluto, kg
M_j	Mass of the disturber body, kg
$\mathbf{r}$	Position vector of the spacecraft, km
$\mathbf{r}_j$	Position vector of the disturber body, km
$\mathbf{P}_P$	Accelerations due to the terms J_2 and J_{22} of the potentials of Pluto, km/s^2
$\mathbf{P}_C$	Accelerations due to the terms J_2 and J_{22} of the potentials of Charon, km/s^2
R	Mean equatorial radius of the body, km
ρ	Density of the body, gcm^{-3}
a	Semi-major axis, km
e	Eccentricity
I	Orbital inclination, deg

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ω	Argument of the perigee, deg
Ω	Longitude of the ascending node, deg
α	Approach angle, deg
E_{2C}	Two-body energy, km^2/s^2
$\mathbf{R}_p$	Position vector at the perigee, km
$\mathbf{v}_p$	Velocity vector at the perigee, km/s
x, y, z	Components of the position vector of the spacecraft, km
v_x, v_y, v_z	Components of the velocity vector of the spacecraft, km/s
$\mathbf{P}_j$	Acceleration due to a disturber j, km/s^2
p_j	Total variation of velocity caused by a disturber, m/s
T	Orbital period of the spacecraft

I. Introduction

The arrival of the spacecraft *New Horizons* at the Pluto-Charon system in July 2015 is a great opportunity to make precise measurements of physical characteristics (like shape, composition, and, consequently, the density) of this, where recently new small members were discovered.[1] Although this mission will bring to the scientific community information which will allow the improvement of the models of the formation of this system and of the Solar System itself, the spacecraft will not stay orbiting the system, it will pass by the system and will encounter objects in the Kuiper Belt. However, for the study of compared planetology (in which seasonal changes must be observed) the spacecraft must stay orbiting the system.[2] In this sense, one goal of this paper is the study of gravitational capture of probes by the Pluto-Charon system.

Studies about gravitational capture are present in the astronomy since the beginning of the XX century, and the work of T. J. J. See[3,4] is an example of this fact. In his papers, See shows that, using the Restricted Three-Body Problem model, captures in the Solar System were possible, idea contrary to the scientific thought at that time. The motivation for these studies was the discovery of natural satellites in orbits with considerable eccentricity and inclination, and high values for the semi-major axis. The first of them was Phoebe, discovered in 1899.[5] These satellites, a counterpoint to the other satellites known at the epoch (with quasi-circular and equatorial orbits, and close to the planets), had, by the most plausible explanation for their existence, the gravitational capture. With the improvement of the observational methods, the number of the eccentric satellites increased, motivating several studies in gravitational capture. Today these eccentric satellites are called irregular satellites (in opposition to the regular satellites).

In a first attempt to explain the gravitational capture, Hunter[6,7] made numerical simulations of particles in the vicinity of Jupiter, using a model of the tridimensional elliptical restricted three-body problem. The first 20 years of the study of gravitational capture, starting with the work of Hunter, are quite resumed in the work of Dvorak.[8]

The most accept theory for the formation of the natural satellites says that the regular satellites were formed form the accretion discs of their planets,[9,10] and the concept of gravitational capture continued to explain, in a satisfactory manner, the existence of the irregular satellites. In fact, temporary captures of passing bodies by planets are common,[11] and the most famous case is the collision with Jupiter, in 1997, of the comet D/Shoemaker-Levi-9. However, permanent captures of bodies that has heliocentric orbits which becomes stable planetocentric orbits require the action of non-conservatives process, like the gas drag,[11,12] which implies that the irregular satellites would have been captured while the planets still had gaseous disks around them.

The studies of gravitational captures in the astronomy basically follow two approaches: the study of the effects of the gravitational perturbations, in a determined interval of time, on a irregular satellite (real or fictitious) in orbit of a planet, and the analysis of close encounters between a body, initially in an heliocentric orbit, and a planet, in order to observe the effects of these close encounters over the orbital elements of the planet. In the astronautic area, gravitational capture can be understood as a phenomenon in which a particle, in the most of times massless, suffer a change in its two-body energy with respect to a primary body, from positive to negative.[13] This capture is always temporary and, after some time, the energy of the particle becomes positive again, and the particle leaves the neighborhood of the primary.[13] The possibility of the practical application of this phenomenon is given by the fact that, when a particle is temporarily captured by the primary, an impulse can be applied to the particle, turning permanent the capture. This turns possible the economy of fuel of a spacecraft in a transfer from a primary to the other, as in the case of a transfer between the Earth and the Moon. The application of the techniques of gravitational capture commence with Belbruno,[14] who study the insertion of an artificial satellite around the Moon, using gravitational capture.

An iconic episode involving gravitational capture and artificial satellites was the mission of the spacecraft Hiten (former MUSES-A), in which a probe (Hagomoro, former MUSES-B) loaded by the Hiten, that was released in the orbit of the Moon, stopped to send signal few minutes after the release. Then, the gravitational capture trajectories were used to allow the Hiten to enter in the lunar orbit with low fuel consumption.[15] The Japanese Space Agency put this concept in practice, which guaranteed the success of the mission. With this result, the number of studies in the area of the gravitational capture increased.[16–18] The mechanism of capture is well described by Yamakawa.[19–21]

We follow the concept of capture which takes into account the change in the signal of the two-body energy of a probe and Pluto and we are interested, like Viera-Neto and Prado,[13] in finding configurations in which the energy loss from the probe to Pluto is maximized in a time interval which allows the viability of the mission. We search for initial conditions that lead to escapes in backward integrations, which consequently, in the normal direction of integration, lead to a capture. We used the tridimensional restricted three body problem model, taking into account the perturbation of the natural satellites of Pluto (Charon, Styx, Nix, Kerberos, and Hydra), the perturbation of the Sun and the terms J_2 and J_{22} of the potentials of Pluto and Charon. A similar study, using the planar problem, was made by Brasil et al.,[22] in a study of gravitational capture of a spacecraft by Jupiter. Vieira-Neto and Winter[23] conducted a similar study of gravitational capture of satellites by Uranus.

The velocity of a spacecraft arriving in an object at the distance of Pluto, from the Earth, is high.[24]This magnitude of the incoming velocity is a technical challenge for the capture. In order to overmatch this technical barrier, we propose that the probe be composed by a main vessel, which will carry several nanosatellites that will be delivered when the probe is near the Pluto-Charon system. The nanosatellites would be captured by the system, while the main vessel would become a communication center (like a space beacon), making a communication bridge between the nanosatellites and the Earth. In this way, the mass that needs to be captured is reduced, and so the fuel consumption is smaller.

On the other hand, the stability of these probes around Pluto must to be taken into account in the choice of the orbits which would be useful for the gravitational capture. In this sense we measure the total variation of the velocity, over the probes, caused by the disturbers of the system (those mentioned previously), by using the method of the integral of the forces over the time.[25,26] The advantage of this method is that we can measure the total variation of the velocity caused by one disturber (like the Sun) without disregarding other perturbations. We show, for some values of the initial perigee radius of the orbits of the probes, which disturbing forces are more important than others. We expect that our results will be useful for a future real mission to the Pluto-Charon system, for spacecrafts that stay in orbit of Pluto.

II. Dynamical Model and Methodology

The equation of motion of the satellite can be written in the following form:

$$\ddot{\mathbf{r}} = -\frac{GM_P}{|\mathbf{r}|^3}\mathbf{r} + G\sum_{j=1}^{N-1} M_j\left(\frac{\mathbf{r}_j - \mathbf{r}}{|\mathbf{r}_j - \mathbf{r}|^3} - \frac{\mathbf{r}_j}{|\mathbf{r}_j|^3}\right) + \mathbf{P}_P + \mathbf{P}_C, \tag{1}$$

where G is the gravitational constant, M_P, M_j, and $\mathbf{r}_j$ are the mass of Pluto, the masses and vector position of the disturbing bodies (the Sun, Charon, Styx, Nix, Kerberos, and Hydra), respectively. $\mathbf{r}$ is the position vector of the spacecraft. The reference system is centered in Pluto, and the plane of reference is formed by the mean equator of Pluto, at the reference epoch. $\mathbf{P}_P$ and $\mathbf{P}_C$ are the accelerations due to the terms J_2 and J_{22} of the potentials of Pluto (subscript P) and Charon (subscript C), calculated with a modified recursive potential model,[27] adapted to Pluto and Charon. Table 1 shows some physical and orbital characteristics of the bodies considered in this work.

The equations of motion of all the bodies (similar to Eq.(1)) are integrated simultaneously with the integration of the equation of motion of the spacecraft, and the reference epoch is 2015 July 14^{th} (the arrival date of the New Horizon at the Pluto-Charon system). The initial conditions for the Sun (Pluto), Charon, Styx, Nix, Kerberos and Hydra, at the mentioned epoch, was taken from the JPL Horizons system[28] (accessed via telnet interface). The orbit of the Sun is considered as Keplerian, and the remaining bodies are disturbed by each other. Since the maximum period of integration is 10 years, we discarded the perturbation

Table 1. Physical and some orbital characteristics of the Pluto-Charon system*.

Object	Mass, kg	R, km	ρ, gcm^{-3}	a, km	e	I, deg	J_2	J_{22}
Pluto	1.304×10^{22}	1195	1.189	5.95×10^9	0.25430	126.854	9.01×10^{-4}	2.70×10^{-4}
Charon	1.520×10^{21}	605	1.72	19596	0.00005	0.0	1.14×10^{-3}	3.42×10^{-4}
Styx	1.498×10^{16}	4-14	-	42413	0.00001	0.0	-	-
Nix	5.800×10^{17}	23-70	< 1.68	48690	0.00000	0.0	-	-
Kerberos	1.648×10^{16}	7-22	-	57750	0.00000	0.4	-	-
Hydra	3.200×10^{17}	29-86	< 0.88	64721	0.00554	0.3	-	-

* The masses of Pluto, Charon, Nix, and Hydra are given in Tholen et al.;[29] the masses of Styx and Kerberos, as the values of the densities, mean equatorial radius, and mean orbital elements of Charon, Styx, Nix, Kerberos, and Hydra are given in Brozović et al.;[30] the J_2 and J_{22} coefficients are given in Beauvalet et al.;[31] the orbital elements of Pluto are given with respect to the Ecliptic at the Epoch 2015 July 14^{th}; the orbital elements of Charon, and the tiniest moons are given in the equatorial plane of Pluto, being plutocentric for Charon and barycentric for the other moons.

of the terms J_2 and J_{22} of the potentials of Pluto and Charon over the small natural satellites of Pluto. We also disregarded the effects of J_2 and J_{22} of Pluto over Charon and vice-versa.

II.A. Gravitational Capture

We consider as gravitationally captured a massless particle (like a spacecraft or a nanosatellite acting as a probe) that, arriving at the maximum approach point of Pluto, have changed the signal of the two-body energy from positive to negative. The point of maximum approach is the perigee radius (R_p), and we consider that the direction of the velocity in this point (V_p) is always normal to the perigee radius. The orbit of capture is defined by two angles: the inclination of this orbit (I) with respect to the equator of Pluto and the approach angle (α), which we define as equal to the argument of the perigee of the orbit of the spacecraft (ω). The geometry of the problem is given in Fig. (1).

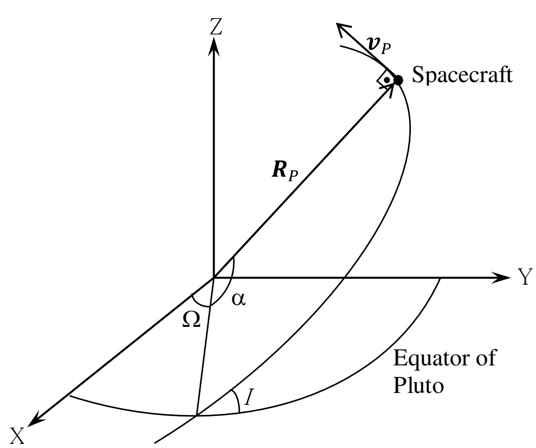


Figure 1. Geometry of the capture problem.

Following Brasil et al.,[22] we generated a series of initial conditions which leads to escape conditions in integrations in backward time (and consequently capture in a normal integration), adopting the following procedure:

1. For all the orbits, we consider the initial eccentricity (e) equal to 0.001, and the longitude of the ascending node Ω equal to zero. We fixed initial values for the perigee radius (R_p), the inclination (I), and the approach angle (α);

2. Assign the initial value of the two-body energy of the spacecraft as zero ($E_{2C} = 0$);

3. With these values, we are able to calculate the initial values of the perigee radius and the velocity vectors ($\mathbf{R}_p$ and $\mathbf{v}_p$). From Fig. (1) is easy to calculate the positions:

$$\begin{aligned} x &= |\mathbf{R}_p| \left[\cos(\alpha)\cos(\Omega) - \sin(\alpha)\sin(\Omega)\cos(I)\right], \\ y &= |\mathbf{R}_p| \left[\cos(\alpha)\sin(\Omega) + \sin(\alpha)\cos(\Omega)\cos(I)\right], \\ z &= |\mathbf{R}_p| \sin(\alpha)\sin(I), \end{aligned} \tag{2}$$

and the velocities:

$$\begin{aligned} v_x &= -|\mathbf{v}_p| \left[\sin(\alpha)\cos(\Omega) - \cos(\alpha)\sin(\Omega)\cos(I)\right], \\ v_y &= -|\mathbf{v}_p| \left[\sin(\alpha)\sin(\Omega) + \cos(\alpha)\cos(\Omega)\cos(I)\right], \\ v_z &= |\mathbf{v}_p| \cos(\alpha)\sin(I), \end{aligned} \tag{3}$$

where $|\mathbf{v}_p|$ comes from the two-body energy:

$$|\mathbf{v}_p| = \left[2\left(E_{2C} + \frac{GM_P}{|\mathbf{R}_p|}\right)\right]^{1/2}; \tag{4}$$

4. With these set of initial conditions, we integrate the equation of motion of the spacecraft (Eq. (1)) backward in time, until an escape occurs ($E_{2C} > 0$). This is the first approach. Then, for the values of (R_p), (I), and (α) where these escapes occur, we decrease the initial value of E_{2C} until we found an orbit where the escape does not occur in a time interval of 10 years. The value of the energy immediately before the one for which the escapes do not occur generates the orbit where the capture (in normal integration) occurs with the largest economy of energy ($E_{2C_{min}}$). The time of capture is the time spent by the backward integration for the spacecraft to evolve from $E_{2C_{min}}$ to $E_{2C} = 0$.

All this process is repeated for α varying from 0 to 360 degrees, for I varying from 0 to 180 degrees, and for some values of R_p. We excluded the solutions for which the spacecraft collides with the bodies of the system.

II.B. Orbital Maintenance

Since, in the previous section, we chose a desired capture orbit and test it for the generation of capture or not, for several levels of energy, we must investigate the stability and the possible maintenance of the final orbits. In order to do this, we integrate Eq.(1) for one orbital period for some values of R_p (the same of the previous section), for α varying from 0 to 360 degrees and for I varying from 0 to 180 degrees. During the integration, we store the values of the accelerations of all disturbers, including the acceleration due the perturbation of the terms J_2 and J_{22} of the potentials of Pluto and Charon.

The integration of the magnitude of the acceleration due to each disturber over the time results in the total variation of the velocity of the satellite, and we will call this variation by "p_j", where the subscript j stands for the perturbers (Sun, C for Charon, S for Styx, N for Nix, K for Kerberos, H for Hydra, J_2 and J_{22}). Then, this integral is given by:[25]

$$p_j = \int_0^T |\mathbf{P}_j|\, dt, \tag{5}$$

where T is one orbital period of the spacecraft, for each value of R_p. Notice that the method of the integral of the accelerations depends on the specific orbit of the satellite and the initial conditions of the Sun, Charon and the tiniest moons of Pluto, so we fixed the same Epoch of the capture study in this part of the work. This Epoch is also important in the definition of the initial values of the accelerations due to the potential of Pluto and Charon.

There are other possibilities to measure the effects of the accelerations acting in the trajectory of the spacecraft using the integral approach. It is possible to use the integral of the accelerations (without the modulus), the integral of the component of the accelerations in the direction of the motion, etc.

We choose the integral of the magnitude of the acceleration as a better parameter, because it measures the total acceleration given to the spacecraft by each disturber, without canceling effects with opposite signs, that may give a net result near zero, but that changes the trajectory of the satellite.[27] Furthermore, we are looking for relative results, in order to know how much a perturber is more important then other terms and by how much, as a function of (R_p), (I), and (α). Furthermore, the measure the values of the variations of velocity due to each disturber can be useful in laws of control of the spacecraft around Pluto.

If the perturbation acts above a certain limit on the trajectory of the spacecraft, it cannot be neglected in the force model. If it is periodic, and after one revolution the orbital elements of the spacecraft returned to the initial value, the trajectory was still different when compared to the one where this term was neglected. In fact, one of the advantages of the proposed method (the use of the magnitude of the accelerations) is that it measures those short periodic motions. If it is necessary to verify the behavior of orbits in the short period, it is better to use this method.

For the integration of Eq. (5) we used the Simpson 1/3 numerical method.[32] The number of the points for the numerical integration was chosen such that the precision was kept in 1×10^{-8} m/s, i. e., we take as many points as necessary to ensure this precision.

III. Results and Discussions

In all cases, Eq. (1) was numerically integrated using the RADAU integrator, a fast and precise numerical integrator.[33] The codes of the programs and routines developed for this work was written in FORTRAN language, in Linux environment.

In order to exemplify the methods proposed in this paper, we compared two cases: $R_p = 4RP$ and $R_p = 50RP$, where RP is the mean equatorial radius of Pluto (1195 km) and $R_p = |\mathbf{R}_p|$. In the first case, the orbit is between Pluto and Charon and closer to Pluto than Charon, which allow escape in integrations backward in time. Orbits below this value do not escape. In the second case, the spacecraft started the backward integration in an orbit between Kerberos and Hydra.

Figure (2) shows the energy savings for the capture of a spacecraft by Pluto as a function of the initial inclination and angle of approach (a), and the corresponding time spent during the gravitational capture (b) for $R_p = 4RP$, where each pixel of the figure means an orbit which suffers escape in a backward integration in time, leading to a capture in the normal direction of integration. The energy savings can be interpreted as an amount of energy that Pluto take from the spacecraft during the capture, which means that this energy can be discounted from the energy necessary to a gravitational capture of the spacecraft in a trajectory with velocity higher than the velocity used to generate the corresponding pixel of the figure. Since spacecrafts come from the Earth have high velocity in the approaching to Pluto, this energy saving could be decisive in the capture of a small probe (like a nanosatellite) delivery from the spacecraft. In fact, missions of this type could use a constellation of nanosatellites to explore the Pluto-Charon system in a long time mission. Then, comparing Fig. (2-a) and Fig. (2-b), we are searching for initial conditions which lead to high absolute values of the energy saving in a lower time of capture. In this case, the best solutions are polar orbits, although the initial orbits are close to Pluto, resulting in few solutions (escapes).

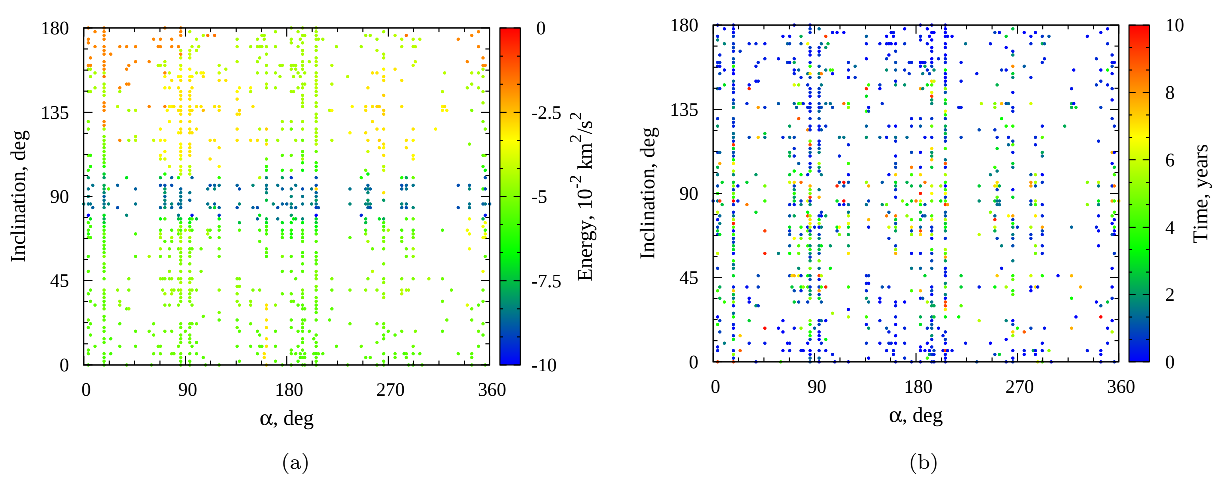


Figure 2. Energy savings for the capture of a spacecraft by Pluto as a function of the initial inclination and angle of approach (a), and the corresponding time spent during the gravitational capture (b) for $R_p = 4RP$.

In Fig. (3) the perturbation of the small satellites of Pluto leads to a larger region of escapes, although with less energy saving in comparison with $R_p = 4RP$. The white regions also, in this case, can be collisions with any body of the system. For this value of perigee radius, the best solutions are circular orbits near $\alpha = 180$ degrees. Although retrograde orbits are more stable than direct orbits,[34] retrograde orbits, in this system and at this semi-major axis, make the spacecraft to orbit in the opposite direction of the inner and outer moons near the orbit of the spacecraft, increasing the perturbations of these bodies.

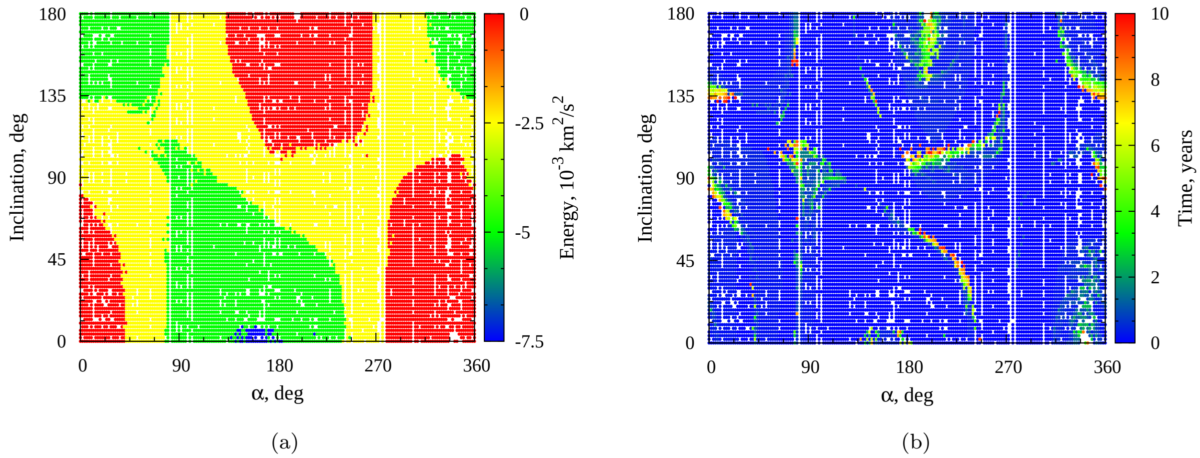
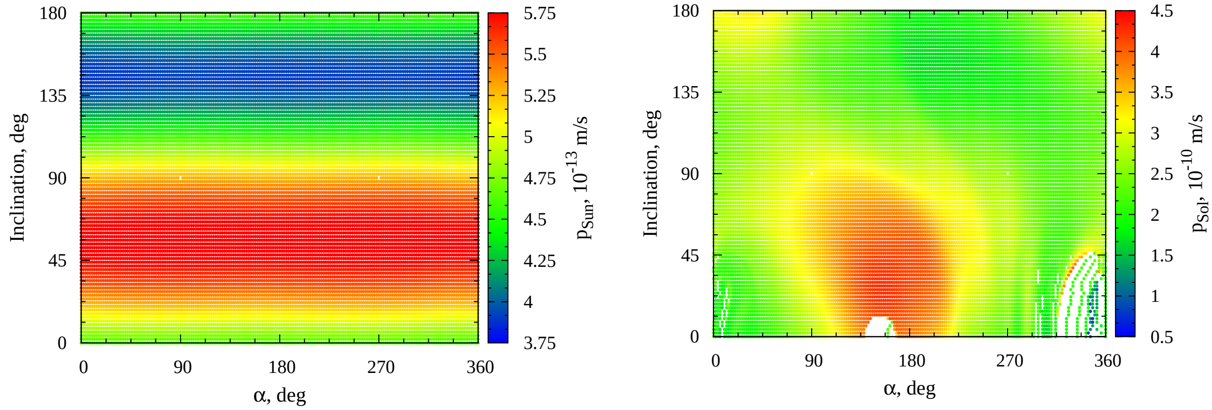


Figure 3. Energy savings for the capture of a spacecraft by Pluto as a function of the initial inclination and angle of approach (a), and the corresponding time spent during the gravitational capture (b) for $R_p = 50RP$.

By the analysis of the magnitude of the total velocity of a disturber we can find important factors which determine the stability of a spacecraft around Pluto. The first one is that, by the comparison between the influence of one perturber with other, without disregarding any perturbations in the orbit, we can determine the main perturber for a fixed value of R_p, and find initial conditions which minimize the effect of a determined perturbation, without the spend of fuel. This fact helps in the station keeping of the orbiters. The second factor is that, with the amount of velocity that a disturber apply on the spacecraft, one can made laws of control for station keeping. In a system like the Pluto-Charon system, with tiny moons, the value of the integral of the accelerations can reveal regions with high risk of collisions in a determined set of initial conditions.

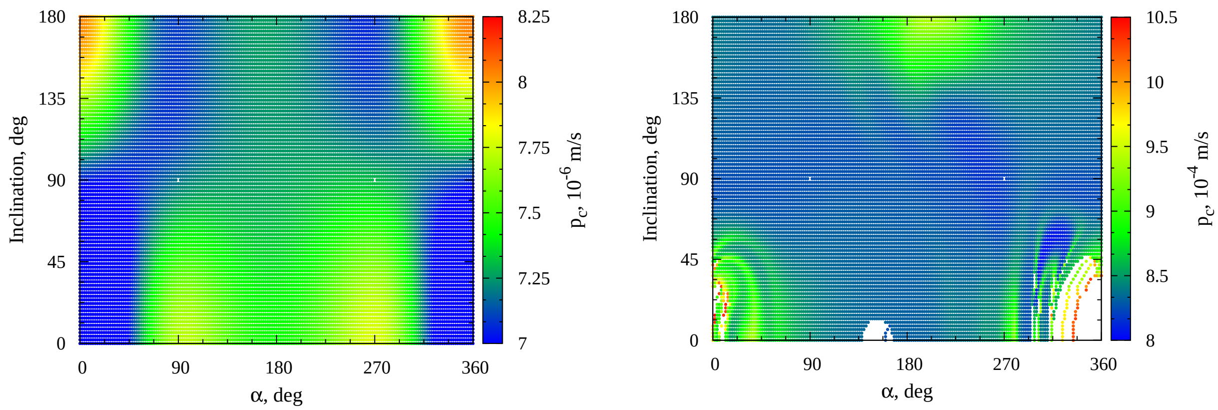
Figure 4, for example, shows the total velocity contribution due to the Sun, as a function of the initial inclination and angle of approach, for $R_p = 4RP$ (a) and $R_p = 50RP$ (b). We can note that, for $R_p = 4RP$, a well-behaved orbit (with low chance of collisions), the third-body perturbation follow the expected,[25] whereas for $R_p = 50RP$ the sinusoidal behavior of the total velocity, with respect of the inclination of the orbit, is destroyed by the effects of close approaches with the minor moons. Also, we note that, since the perturbation of the Sun has the order of magnitude, in terms of velocity variation, of 1×10^{-13}, this perturbation can be disregarded[27] in integration of orbits between Pluto and Charon. On the other hand, the increase of the total velocity due to the Sun for $R_p = 50RP$ is a result of the close approaches on the radius vector of the spacecraft, since the perturbation of the Sun depends on this quantity. This net effect will also appear in Figs. (5-13), showing the importance of considering all disturbers in this kind of study.

Crossing information between the set of figures of gravitational capture, Fig.(2) and Fig.(3), and Figs. (5-13), we can see that, even though there are few solutions for $R_p = 4RP$ in Fig.(2), the existent solutions are optimal for the values of I around 45 degrees, with approach angle around 0 degree. The abundant solutions for $R_p = 50RP$ is limited by the close approaches, but these can be easily avoided by skipping initial conditions in the white regions of Figs. (5-13). In fact, the intersection of the set of initial conditions of the blue regions in Figs. (5-13) lead to stable orbits for $R_p = 50RP$.



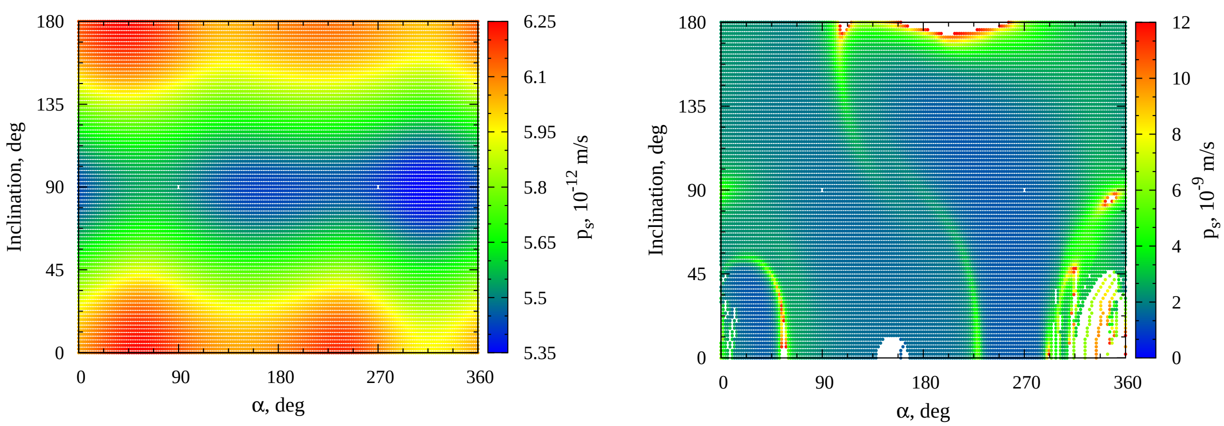
(a) (b)

Figure 4. Total velocity contribution due to the Sun, as a function of the initial inclination and angle of approach, for $R_p = 4RP$ (a) and $R_p = 50RP$ (b).



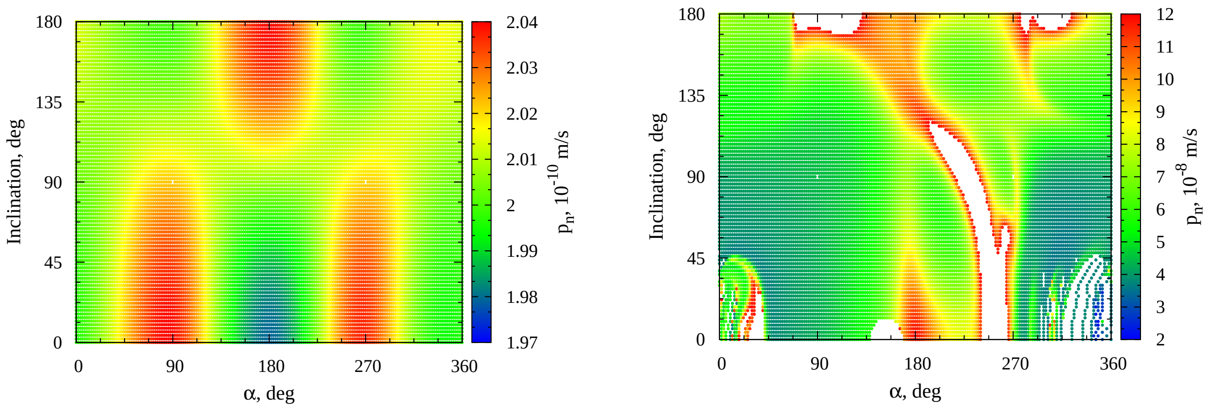
(a) (b)

Figure 5. Total velocity contribution due to Charon, as a function of the initial inclination and angle of approach, for $R_p = 4RP$ (a) and $R_p = 50RP$ (b).



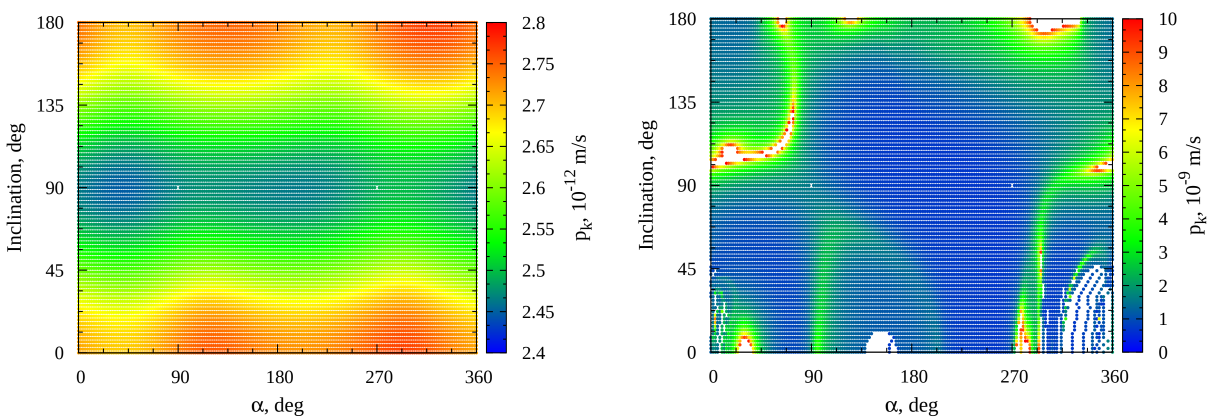
(a) (b)

Figure 6. Total velocity contribution due to Styx, as a function of the initial inclination and angle of approach, for $R_p = 4RP$ (a) and $R_p = 50RP$ (b).



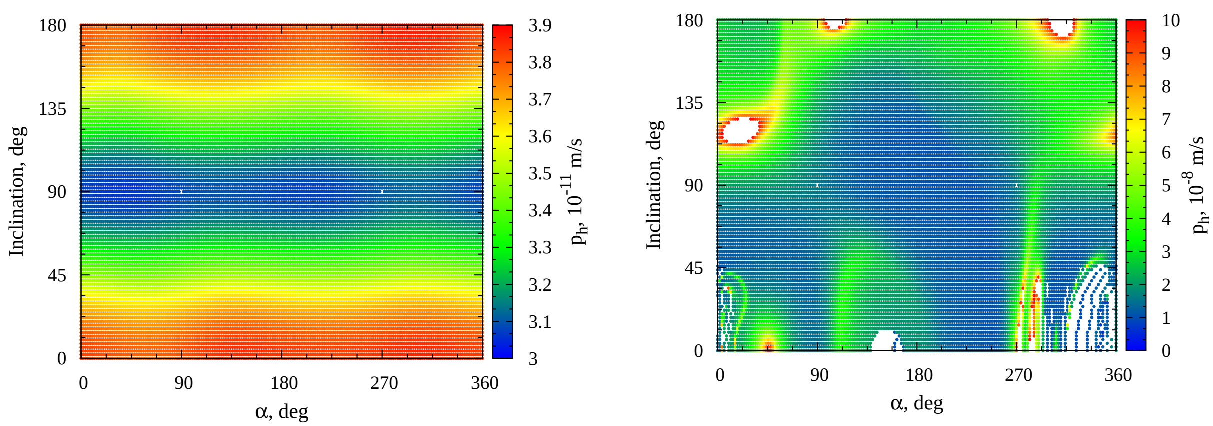
(a) (b)

Figure 7. Total velocity contribution due to Nix, as a function of the initial inclination and angle of approach, for $R_p = 4RP$ (a) and $R_p = 50RP$ (b).



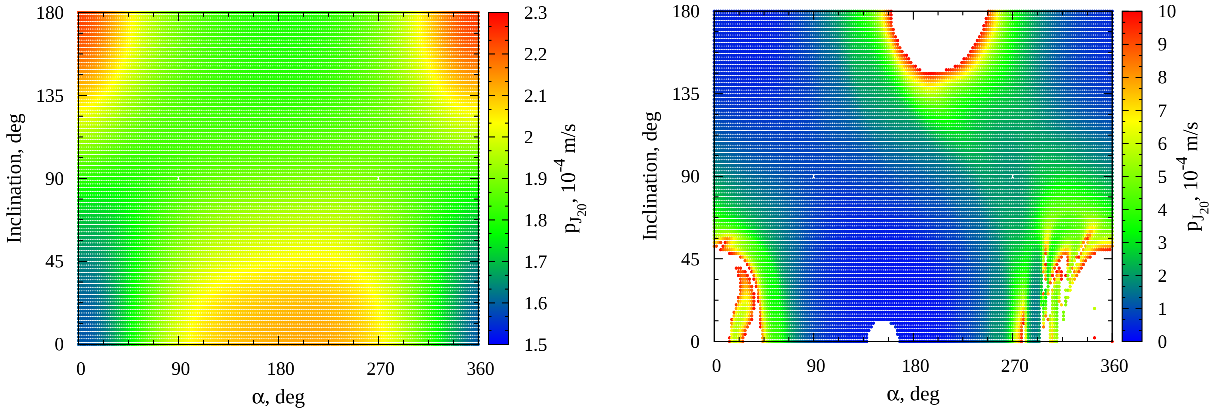
(a) (b)

Figure 8. Total velocity contribution due to Kerberos, as a function of the initial inclination and angle of approach, for $R_p = 4RP$ (a) and $R_p = 50RP$ (b).



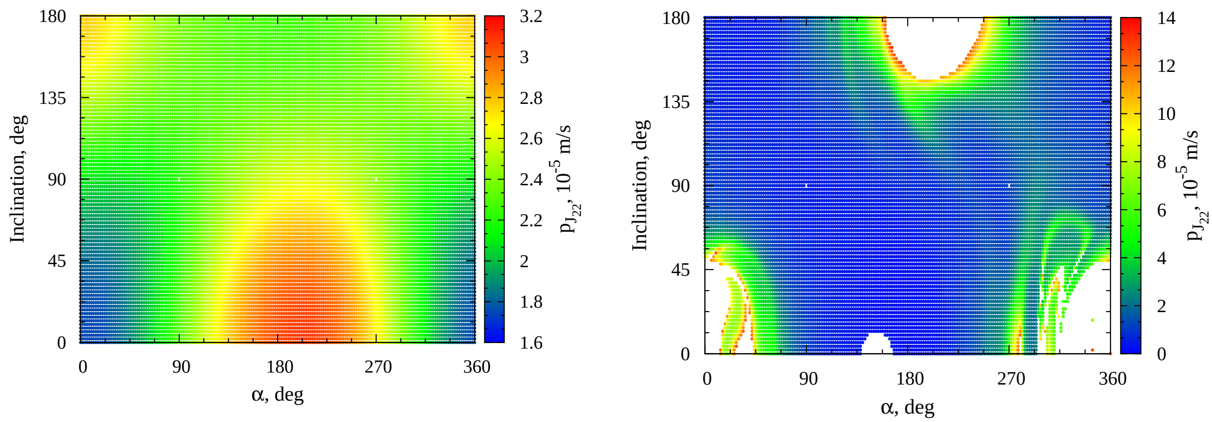
(a) (b)

Figure 9. Total velocity contribution due to Hydra, as a function of the initial inclination and angle of approach, for $R_p = 4RP$ (a) and $R_p = 50RP$ (b).



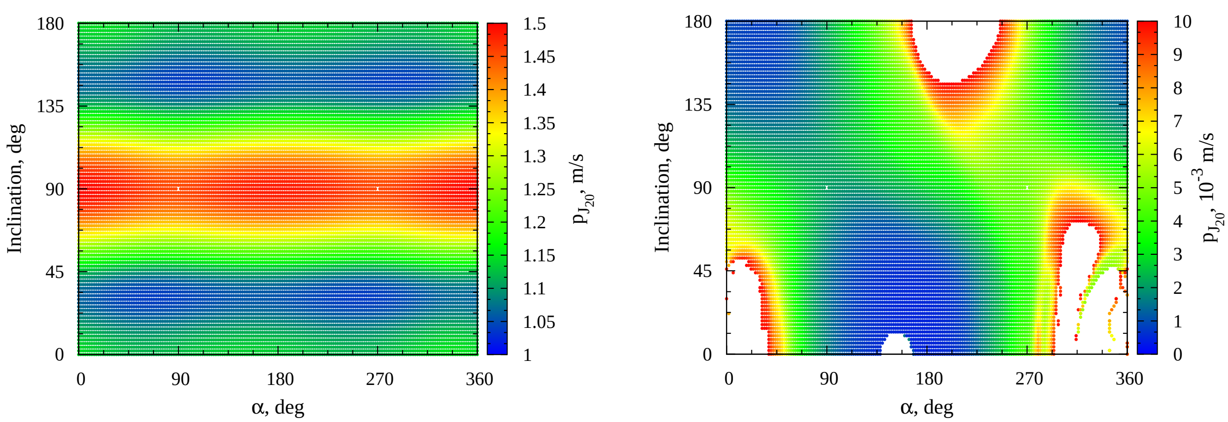
(a) (b)

Figure 10. Total velocity contribution due the term J_2 of the potential of Charon, as a function of the initial inclination and angle of approach, for $R_p = 4RP$ (a) and $R_p = 50RP$ (b).



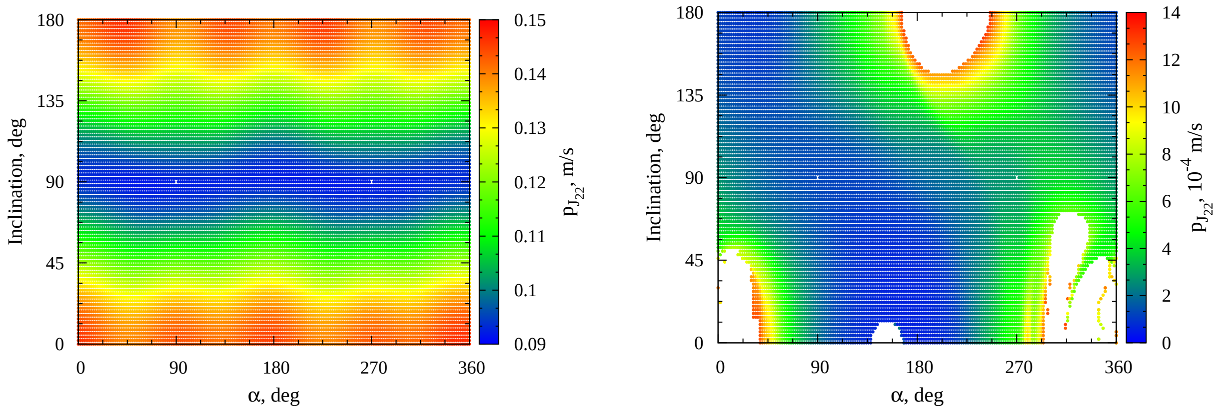
(a) (b)

Figure 11. Total velocity contribution due the term J_{22} of the potential of Charon, as a function of the initial inclination and angle of approach, for $R_p = 4RP$ (a) and $R_p = 50RP$ (b).



(a) (b)

Figure 12. Total velocity contribution due the term J_2 of the potential of Pluto, as a function of the initial inclination and angle of approach, for $R_p = 4RP$ (a) and $R_p = 50RP$ (b).



(a) (b)

Figure 13. Total velocity contribution due the term J_{22} of the potential of Pluto, as a function of the initial inclination and angle of approach, for $R_p = 4RP$ (a) and $R_p = 50RP$ (b).

IV. Conclusion

Using a thre-dimensional model of gravitational capture we found initial conditions for inclination and angle of approach (which are the inclination and the argument of the perigee of the desired orbit) which save energy during the capture of a spacecraft in the Pluto-Charon system. With the method of the integral of the acceleration we measured the total variation of velocity due to each disturber of the system Pluto-Charon. With these data, we show the net effect of one disturber over the others, including the case of close approaches. We found stable regions even for an orbit between two small moons of Pluto, and these regions are low perturbed, favoring the station keeping of small probes in the system.

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