# ASTER MISSION: STABILITY REGIONS AROUND THE TRIPLE ASTEROID 2001 SN263.

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***Abstract:*** *The celestial body 2001 SN263 is a near Earth asteroid (NEA) with semi-major axis 1.985 A.U., eccentricity 0.48 and orbital inclination 6.7 degrees. Light-curves obtained in the Observatory of Haute-Provence, in January 2008, lead to the conclusion that this asteroid was a binary system. In February 2008 the system was observed along 16 days by the radio-astronomy station of Arecibo, in Porto Rico. These observations resulted in the discovery that 2001 SN263 is a triple system [1]. The components of the system have diameters of about 2.8 km, 1.2 km and 0.5 km. With respect to the major body, the second component has a semi-major axis of about 17 km (period of 147hrs) and the third component has a semi-major axis of about 4 km (period of 46hrs) [2]. This triple system is the target of the first brazilian mission to an asteroid. In order to design a mission to explore this interesting triple asteroid system, it was made a study of the stability regions around each one of the three components and around the whole system. This system has a quite complex dynamics. The perturbations among the three components are not negligible, since the bodies are of comparable sizes. In our numerical simulations we also took into account the perturbations of the Sun, Jupiter, Mars and Earth. In this work we present the location and size of the stable regions. We used a Gauss-Radau numerical integrator [3]. Part of these results can be seen in Figure 1, where it is shown how long the trajectory survived before being ejected or collide with one of bodies. It was considered a grade o semi-major axis versus eccentricity around the two larger bodies of the system, named Asteroid 1 and Asteroid 2. Then, we will show some possible approaches to insert and keep a spacecraft exploring this system.*

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***Keywords:*** *Mission design, orbital stability, asteroids.*

## 1 Introduction.

Asteroids are primordial celestial bodies that can help us to understand the process of formation of our solar system. The importance of knowing these objects justifies the increasing number of missions that have them as target. The NEAs (Near Earth Asteroids) are especially interesting for such missions since they are bodies that approach periodically the orbit of the Earth. Besides that, the NEAs composed by two or three bodies (multiple asteroid systems) increase the range of possible observations and scientific results obtained by the mission.

Due to these advantages a growing number of missions to NEAs have been completed or are being planned by the major aerospace agencies. In May 2003, the Japan Aerospace Agency launched the Hayabusa mission to the NEA (25413) Itokawa, which was reached the target in September 2005. The same agency plans a new mission called Hayabusa 2, targeting the NEA 1999 JU3, which uses the same technology and concepts of the first mission [4]. The European Space Agency (ESA) has some studies about missions to NEAs. The program Don Quijote [5] planned to launch two spatial vehicles, one of them would collide with some NEA and the second one would catch information about the internal structure of the asteroid. The program ISHTAR [6] was planned to visit at least two NEAs and characterize all physical parameters of the asteroids such as its mass distribution, density and surface properties. The SIMONE mission [7] was planned to be composed of five micro-satellites which will study individually NEAs of different classifications. The Marco Polo mission is also part of the program of ESA missions, and its main objective is to return to Earth carrying a sample of a NEA [8]. The HERA mission is a project being developed by Arkansas Center for Planetary Science and the Jet Propulsion Laboratory. The goal is to send a probe to collect samples for 3 NEAs of these asteroids and then return to the Earth [9].

Recently, the triple system of asteroid 2001 SN263 was chosen as the target of the ASTER MISSION- First Brazilian Deep Space Mission**,** planned to be launched in 2014 [10]. . In order to design a mission to explore this interesting triple asteroid system it was made a study of the stability regions around each one of the three components and around the whole system, which we present in this paper.

The structure of this paper is such that, in section 2 we present the triple asteroid system 2001 SN263. In section 3 we discuss the methodology adopted. In section 4 we present and discuss the results. In section 5 we present the final comments with an overview of the results presented in the previous sections.

## 2. The triple system of asteroid 2001 SN263.

The asteroid 2001 SN263 was discovered in 2001 by the program LINEAR (Lincoln Near-Earth Asteroid Research) - a program developed jointly by the U.S. Air Force, NASA and the Lincoln Laboratory. Light-curves obtained in the Observatory of Haute-Provence, in January 2008, lead to the conclusion that this asteroid was a binary system. In February 2008 the system was observed along 16 days by the radio-astronomy station of Arecibo, in Porto Rico. These observations resulted in the discovery that 2001 SN263 is a triple system [1]. This system is the first triple asteroid system known that approaches the orbit of the Earth and that crosses the orbit of Mars (Amor type asteroid).

In January 2009, Becker et al. [2] presented preliminary data on the physical aspects of the asteroids. This study estimated that the asteroid primary (largest) is approximately a spheroid with principal axes of approximately 2.8 ± 0.1 km, 2.7 ± 0.1 km, 2.5 ± 0.2 km, with an estimated density of 1.3 ± 0.6 g/cm$^3$. Tab. 1 shows the physical and orbital data of the bodies. Here we call the bodies of the system as: the central body (most massive body) is called $A_1$, the second most massive body is called $A_2$ (outer) and the least massive body is called $A_3$ (inner). Fig.1 is a representation of the system.


**Figure 1 -** Representation of the triple system of asteroid 2001 SN263.

**Table 1-** Physical and Orbital datas.

| Asteroid | Orbits | a[1] | e[1] | I[1] | Period[1] | Radius[1] | Mass[2] |
|---|---|---|---|---|---|---|---|
| $A_1$ | Sun | 1.99 AU | 0.478 | 6.69º | ≈2.8 years | 1.4 km | $M_1 = 1.15x10^{13}$ kg |
| $A_2$ | $A_1$ | 17 km | * | * | ≈147 hours | 0.5 km | $M_2 \approx 7.9x10^{-2} M_1$ |
| $A_3$ | $A_1$ | 4 km | * | * | ≈46 hours | 0.2 km | $M_3 \approx 5.7x10^{-3} M_1$ |

* Not determined yet.

[1] (Nolan et.al, 2008).

[2] Calculated for density equal to 1.0 g/cm$^3$. Estimated to be between 1.3±0.6 g/cm$^3$ (Becker, 2008).

## 3. Methodology.

The goal is to determine regions of stability around each of the three bodies of the triple asteroid system 2001 SN263 in terms of orbital elements and within a given time span. The initial conditions and the methodology adopted are described in the next subsections.

### 3.1 Initial Conditions.

We consider a system composed by seven massive bodies: the three asteroids, the Sun and the planets Earth, Mars and Jupiter. We introduced in this system thousands of particles randomly distributed around the three asteroids as follow:

i) Spatial distribution: the region around the three bodies was divided into four regions. Considering the three asteroids, we calculated the Hill's radius for the problems composed by $A_1$-$A_2$ and $A_1$-$A_3$. This is an approximation since the presence of the third body will change the Hill's radius found; however, the Hill's radius computed in this way is a good parameter to spatially delimit the regions where each of these bodies is gravitationally dominant. The values found were $RHill \approx 5{,}0$ km for the primary bodies $A_1$-$A_2$ and $RHill \approx 0{,}5$ km for the primary bodies $A_1$-$A_3$. Fig. 2 is a representation of the asteroid system and of the Hill's radius found for each body. The particles are spatially distributed into those regions.

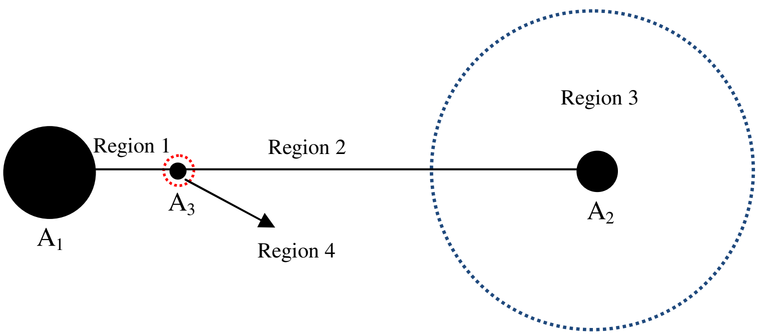


**Figure 2 –** Representation of the system 2001 SN263 and of the Hill's radii of the asteroids (blue and red circles).

ii) We considered particles starting with circular orbits ( $e = 0$ ) until eccentricities equal to 0.5, and planar cases ( $I = 0$ ).
iii) The particles were distributed with random values of true anomaly (f), argument of pericentre ($\omega$) and longitude of the ascending node ($\Omega$) .

**3.2 The Method.**

The method adopted is the numerical integration (using the Gauss-Radau numerical integrator [3]) of the problem composed by seven bodies (Sun, Mars, Earth, Jupiter and three asteroids) and by n-particles (the number of particles will change for each region), for a time span of 200 years. Throughout the integration period we monitored the particles that survive for 200 years, those that collide with any of the asteroids, and the particles ejected from the system. This information is used to define the regions of stability and instability of the system. The region of stability is defined as the region where all particles survive for 200 years while the instability region is the where no particles survive for the same time span.

**4. Results.**

Here we present the results for each of the regions described in subsection 3.1, except for region 4, which is very small and would became even smaller considering the gravitational influence due to the third body ($A_2$), besides that, the particles would orbit very close to $A_3$ increasing the collisions probability. For those reasons the region 4 was not considered on the integrations.

i) Stability in the region 1.

In this region the particles are orbiting the asteroid $A_1$ with the orbital elements: $1.5 \leq a \leq 3.5$ km, taken every 0.25 km, $0 \leq e \leq 0.5$, I=0°, and random values for $\omega$, f, and $\Omega$, as described in subsection 3.1. Such combination of values resulted in a total of 9900 particles located in region 1.

The diagram of Fig. 3 shows the result found. It was considered a grade of semi-major axis versus eccentricity, and each of the small "boxes" hold the information of 100 particles distributed angularly. On such diagram is shown how long the trajectory survived before being ejected or collides with one of the bodies. The coded color indicates the length of time in years. The color red indicates the initial conditions for what all particles survive for 200 years (stability). The color yellow indicates the particles that do not survive the same period (instability).

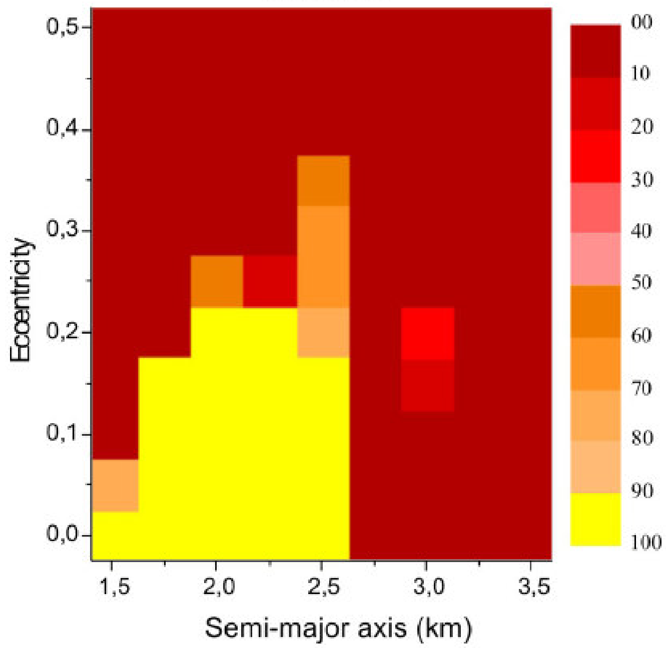


**Figure 3** - Regions of stability and instability around $A_1$ in the region 1 for a time span of 200 years. The scale goes from 0.0% of the particles that survive in that region (red) to 100% of survivors (yellow).

We see that in this region the region of stability is the region closer to $A_1$ for lower values of eccentricity. As the value of semi-major axis increases, the collisions with $A_3$ become more frequent, given origin to a region of instability. The escapes of particle are not significant. Due to their proximity with both massive asteroids ($A_1$ and $A_3$) the collisions are more frequent, as can be seen in Tab.2.

**Table 2** - Percentage of ejections, collisions and survivors in region 1.

| | |
|---|---|
| Ejections | 0.5% |
| Collisions | 75.6 % |
| Survivors | 23.9% |

ii) Stability in the region 2.

In this region the particles are orbiting the asteroid $A_1$ with semi-major axis $4.5 \leq a \leq 11.5$ km, taken every 0.7 km. The other orbital elements were chosen in the same way as before. Such combination of values resulted in a total of 12100 particles located in region 2. As the previous diagram of Fig.3, the diagram of Fig. 4 shows the region of stability found for region 2.

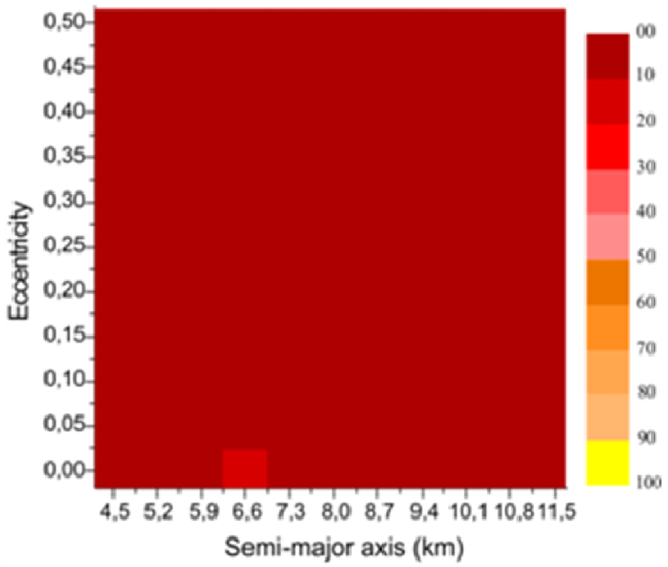


**Figure 4** - Regions of stability and instability around $A_1$ in the region 2 for a time span of 200 years.

We see that almost no particle survives 200 years in the region between the asteroids $A_3$ and $A_2$ (here called region 2), being a highly instable region. The collisions still prevail on the ejections (see Tab. 3).

**Table 3** - Percentage of ejections, collisions and survivors in region 2.

| | |
|---|---|
| Ejections | 10.7 % |
| Collisions | 89.0 % |
| Survivors | 0.3% |

iii) Stability in the region 3.

In this region the particles are orbiting the asteroid $A_2$ with semi-major axis $0.7 \leq a \leq 5.5$ km, taken every 0.6 km. The other orbital elements were chosen in the same way as before. Such combination of values resulted in a total of 9900 particles located in region 3. The diagram of Fig. 5 shows the result found.

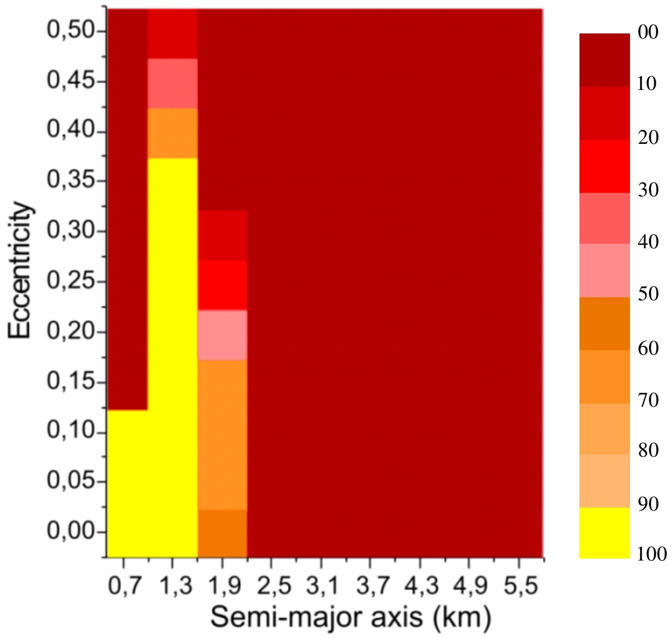


**Figure 5** - Regions of stability and instability around $A_2$ in the region 3 for a time span of 200 years.

Similar to what happens in region 1, the region of stability is that closer to the asteroid that it orbits, in this case, the asteroid $A_2$. Comparing the data from Tab.4 with Tab. 2 and Tab.3, it is clear that stability region is slightly smaller, since fewer particles survive. Furthermore, we see that in this region increases the number of ejections, which makes sense since the asteroid 2 is farthest from the central-body.

**Table 4** - Percentage of ejections, collisions and survivors in region 3.

| | |
|---|---|
| Ejections | 27.0% |
| Collisions | 57.3% |
| Survivors | 15.7% |

## 5. Final comments.

The stability regions within the system triple asteroid 2001 SN263 were determined. It was shown that the stable regions are very close to $A_1$ and $A_2$ and that out of those regions the system is instable. The regions of stability and instability that were found within the system can be visualized in a diagram like Fig.5. The diagram was made considering only particles with circular orbit. It clearly shows that the particles that survive are those that are closest to the two most massive asteroids out there and that no particles survive for 200 years.

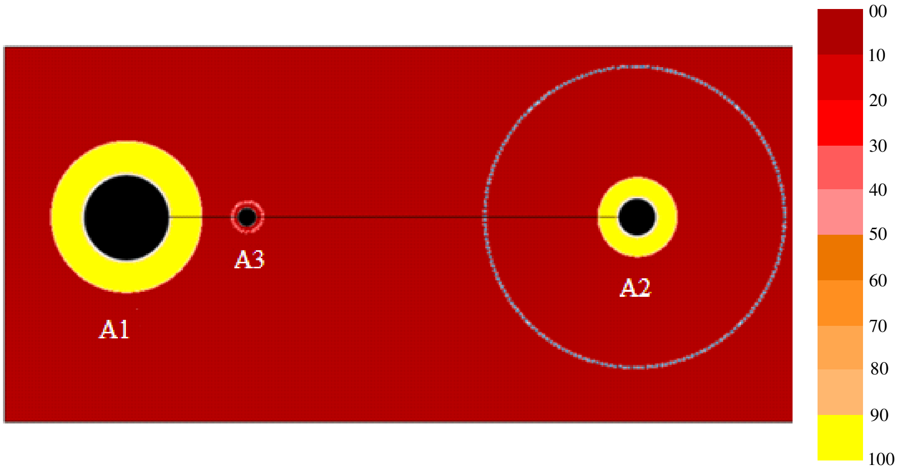


**Fig. 6:** Representation of the regions of stability and instability in the triple system of asteroid 2001 SN263 for particles with circular orbits.

The regions in yellow are the most probable place to find some debris or any ring of dust in the system. This must be considered when planning the mission that will explore the system.

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