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A Simple Method for Asteroid Deflection by Collision

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Abstract. In this work, an interception mission followed of a direct impact between a probe and a Near-Earth Asteroids (NEAs) with the objective of deflecting the orbit of this last one is analyzed. The transfer strategy adopted has as differential the reduction in the required speed increment needed for a probe escapes of the Earth-Moon system. This is possible through the blend of periodic orbits predicted by the Three-body problem and a swing-by with the Moon. The results show that within a few years the effect of a single impact between a probe and a NEA can cause a deviation in the original NEA's orbit of the order of some radii of the Earth

Keywords. Swing-by NEA, PHA, Collision, Deflection.

1 Introduction

The inner planets of our Solar system are embedded in an environment crowded of small bodies such as comets and asteroids. Those that have perihelion distance (q) less than 1.3 AU[4], are so-called of Near-Earth Objects (NEOs). In turn, NEOs are divided into two groups: Near-Earth Comets (NECs) with orbital periods less than 200 years; and Near-Earth Asteroids (NEAs) that include those asteroids whose orbits approach and/or cross the Earth's orbit. NEAs are also classified according to aphelion distance (Q) and their semi-major axes (a) by

Atiras: $a < 1.0$ AU and $Q < 0.983$ AU. Asteroids whose orbits are entirely contained within the Earth's orbit.

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[4]1 AU = 149597870.7 km.

<u>Atens</u>: $a < 1.0$ AU and $Q > 0.983$ AU. Earth-crossing NEA: NEAs whose paths crosses the Earth's orbit, but with semimajor axis less than Earth's orbit.

<u>Apollos</u>: $a > 1.0$ AU and $q < 1.017$ AU. Earth-crossing NEA: whose paths crosses the Earth's orbit, but with semimajor axis less than Earth's orbit.

<u>Amors</u>: $a > 1.0$ AU $1.017 < q < 1.3$ AU. Earth-approaching NEAs: NEAs whose path are exterior to Earth's orbit

Among the cataloged NEAs, a special group is considered potentially dangerous. They are named Potentially Hazardous Asteroids and have Earth Minimum Orbital Intersection Distance (MOID) less than 0.05 UA (≈ 7480000 km) or less and whose absolute magnitude $H \geq 22.0$ [5]. A diagram with orbital period and MOID is shown in Figure 1

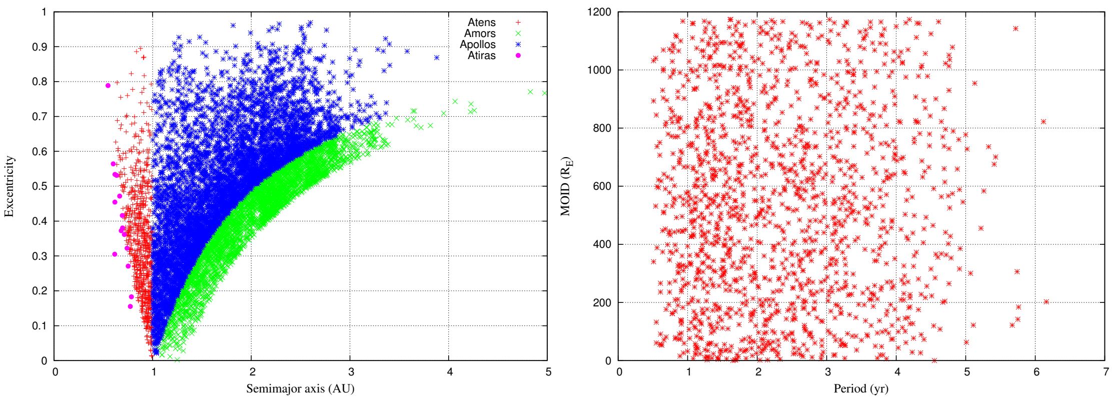

Figure 1: Diagram of semi-major axis *versus* excentricity in (a) of the NEAs separated by classes. In (b) the MOID, measured in Earth's radius ($R_E = 6370km$) *versus* the orbital period of the Potentially Hazardous Asteroids.

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Although none of the known NEOs (or NEAs) currently represents a risk of collision with the Earth in the next 100 years, the Earth's periodic proximity to these objects and a possibility of an eventual catastrophe in case of a collision is worrying [1]. Therefore, protection strategies against possible impacts will also provide strong motivation for the planning of future missions to NEAs [2–8].

In this scenary, strategies to transfer spacecrafts between the Earth and NEAs capable to provide a good relation among the time of transfer and fuel consumption must be studied. In this work, we present a study for a transfer strategy that exploits periodic orbits predicted by the Three Body Problem, a swing-by with the Moon and the effect of a collision of a probe and the asteroid.

[5] The minimum distance of orbital intersection corresponds to the distance between the points closest to the orbits of two astronomical bodies, and is often used as a parameter in the assessment of collision risk between these objects. In the case of asteroids, the absolute magnitude is a measure of the brightness that the body would present, if they were at a standard distance in 1 Astronomical Unit (AU)

2 A Route Between the Earth and the Asteroid

Escape trajectories from Earth-Moon system can be generated after a energy increases, suficient so that the probe energy, relative to the Earth, becomes positive. In this work, we use the same technique that appears in [9], were the probe is inserted into a trajectory derived from a periodic orbit of Family G [10]. These periodic orbits establish a natural way back and forth between the Earth and the Moon that can be properly perturbed in order to acomplish a close encounter with the Moon, taking advantage of its gravitational slingshot and increasing its speed.

The Figure 2 shows an example of an escape trajectory derived from a periodic orbit of Family G. A velocity increment ΔV_1, applied in a Low Earth Orbit of altitude h_0, inserts the probe into a trajectory near to a periodic orbit of Family G. After around 14 days, the probe makes a close approach with the Moon, obtaining enough energy to escape from Earth-Moon System.

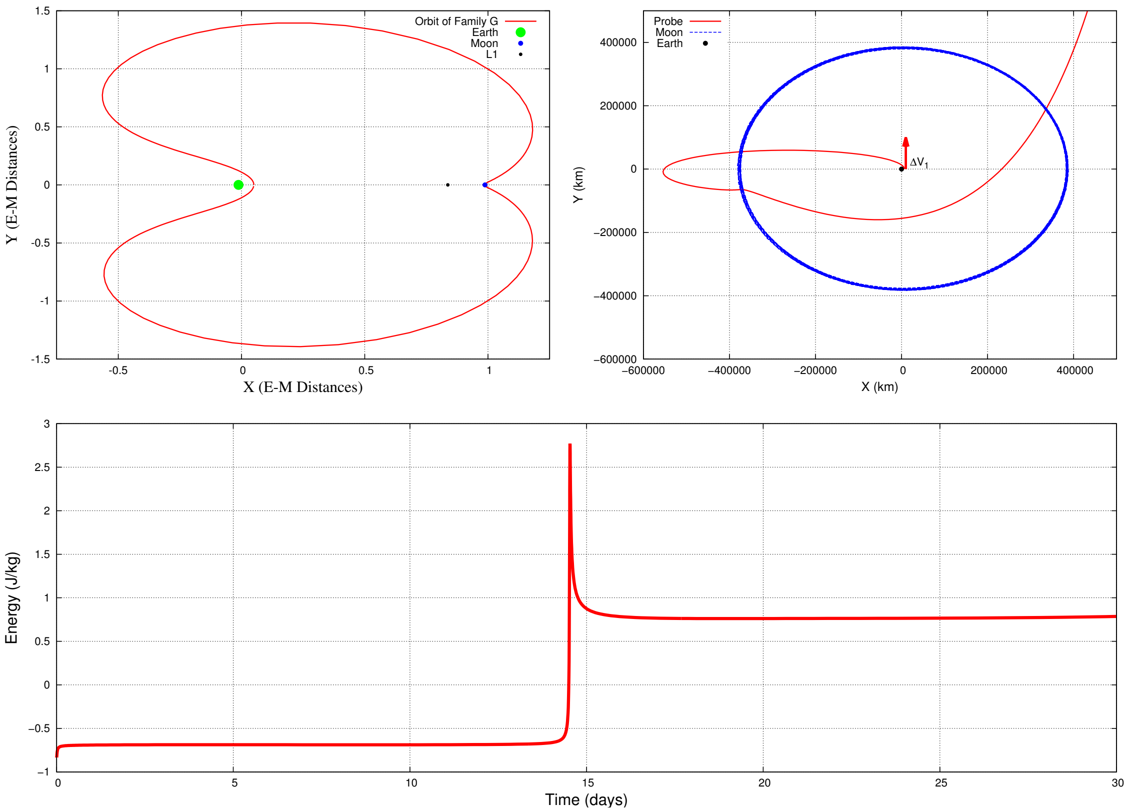

Figure 2: Periodic Orbit of Family G in (a). Escape Trajectory derived from a periodic orbit of family G in (b). Energy variation relative to Earth in (c)

After the escape, these trajectories stabilize between Earth's and Venus's orbits, or between the Earth's and Mars' orbits, or cross the Earths orbit. Since they have orbital configuration near to several NEAs, it is possible to construct a route that, after elapsed a time of flight τ_{f1}, "connects" the Earth to the NEA.

Obviously, given the size of the bodies in question, an encounter (with null distance) between a NEA and a spacecraft is unlikely considering the application of a single ΔV_1 at the departure of a LEO, followed by the swing-by with the Moon, Therefore, a second velocity increment ΔV_2, of corrective character and magnitude less than ΔV_1, should be applied at the moment that the probe passes through its aphelion, for example, in order to make the distance between it and the NEA null at the time of encounter (encounter time). This second increment of velocity is evaluated through the Gauss Problem described in [11].

3 Deviation Analysis and Results

As previously mentioned, the objective of this work is to study the effect that the collision between a probe can cause in the orbit of a NEA. To that end, we consider as dynamical system five bodies problem: Sun, Earth, Moon, probe and an asteroid, all them having mass and interacting mutated with each other. For this purpose we use an integrator with spacing Gauss-Radau [12].

Starting from a LEO with initial altitude $h_0 = 200km$, after performing the swing-by with the Moon and getting positive its energy relative to Earth, the probe will be moving in a heliocentric orbit that passes near the target NEA. Once the primary trajectory that promotes the encounter is known, the second increment $\Delta\mathbf{V}_2$ is calculated and applied at the moment the probe passes through the aphelion and its velocity reaches the lowest value, in order to promote that the distance between the probe and the NEA to be null after a time τ_{f2} corresponding to the time between the aphelion and the encounter point. Considering an inelastic collision between the probe and the NEA, the conservation of the linear momentum gives

$$m_p\mathbf{v}_p + m_n\mathbf{v}_n = m_{pn}\mathbf{v}_n^* \quad (1)$$

where $m_p = 10^3$ kg , $\mathbf{v}_s$, m_n and $\mathbf{v}_a$ are respectively the mass and velocity of the probe and the NEA just before the collision. The parameter $m_{pn} = m_p + m_n$ is the mass of the bound probe-NEA after the collision, that now, travels with velocity $\mathbf{v}_n^*$. A new system composed of four bodies (Sun, Earth, Moon and Probe+NEA) is then integrated and the deviation in the NEA's orbit is measured and analyzed.

As an application, we chose the NEA 2006 XP4 belonging to Aten class and whose main physical and orbital characteristics are presented in Table 3 and Figure 4. Using a set of real initial conditions (obtained from the ephemeris provided by the Jet Propulsion Laboratory / NASA), several launches were tested from a initial LEO and those where the encounter occurs with a high relative velocity value between the probe and the NEA were selected for collision tests.

Results obtained for departures 2017-11-29 and 2018-11-22 are shown in the Figures 5 and 6. In each one of them are the information about the transfer trajectories between the Earth and the NEA, as well as about the deflection in the orbit of the asteroid are shown in terms of the average equatorial radius of the Earth.

Figure 3: 2006 XP4
Orbital characteristics

Group: Aten Discovery data: 2006-12-14 Removed from list of PHAs in 2015-12-19	
Orbital Element	Value
m	$2,3 \times 10^8$ kg
R_{eq}	0.055km
MOID	4.16264 $\times 10^{-3}$ U.A ($\approx$ 622722.08km)
H	23.9
a	0.8726 AU
e	0.2147
i	0.5128 deg
Ω	295.045 deg
w	345.101 deg
T	297.75 d (0.82 y)
H	23.9 mag

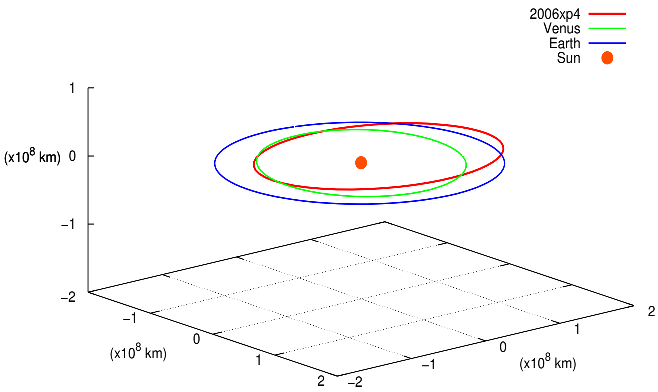

Figure 4: 2006 XP4 orbital diagram.

In a real collision, it is unlikely that the transfer of linear momentum manifests itself only in the translational motion (as shown by blue line in Figures 5 and 6). Some part of energy can be used to change the rotation of the NEA around an axis, or even dissipated as result of the NEA's own physical structure. In this perspective, a similar study was done considering that only 50% of the linear momentum of the probe is transferred to the translational motion of the NEA. This result is represented by the red lines in the Figures 5 and 6.

Departure in 29 November 2017	
ΔV_1	3.149 km/s
ΔV_2	0.499 km/s
$\Delta V_{total} = \Delta V_1 + \Delta V_2$	3.648 km/s
Time of Encounter	09/01/2021
Total time of flight	1138.08 d
Time of aplication of ΔV_2	1083.13 d
Relavite velocity at the encounter	5.213 km/s

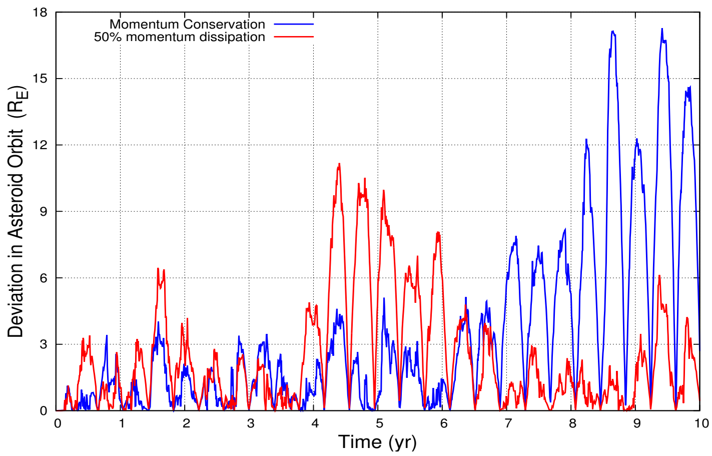

Figure 5: Deviation in the NEA's orbit
Departure in 11/29/2017

Departure in 22 November 2018	
ΔV_1	3.148 km/s
ΔV_2	0.414 km/s
$\Delta V_{total} = \Delta V_1 + \Delta V_2$	3.562 km/s
Time of Encounter	02/29/2019
Total time of flight	464.73 d
Time of aplication of ΔV_2	424.16 d
Relavite velocity at the encounter	5.898 km/s

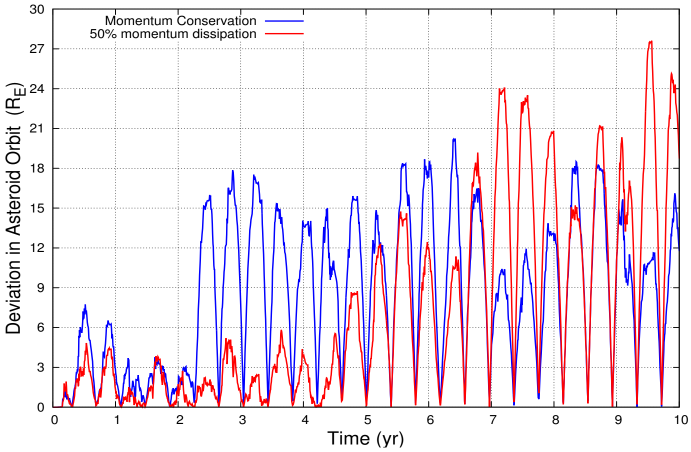

Figure 6: Deviation in the NEA's orbit
Departure in 11/22/2018

Conclusions

This work deals with the study of the effect caused in the orbit of an NEA due to the collision with a probe. The transfer strategy allows to transfer a probe from a LEO to an Near-Earth Asteroid.

As can be observed in the figures 5 and 6 to Aten 2006 XP4, in both cases, the temporal variation in the deviation caused in the NEA's orbit presents an oscillatory behavior with a period of approximately 300 days. This feature can be useful in the sense that, once a possible collision is detected, within a few years, the deviation is caused by some of the Earth's radius. The same result can be observed, to a lesser extent, even in the case of dissipation of 50% of the linear momentum at the impact. The resulting deflection, or even the reduction in linear momentum dissipation, can be optimized if, for example, successive impacts with different probes, or even the use of explosives, are considered.

The strategy presented here is, therefore, a feasible low cost transfer alternative between the Earth and an NEA. An outspread that can be further studied and of advantageous application in orbital monitoring missions is the application of a third impulse to reduce the relative velocity between the probe and the NEA as the probe approaches the sphere Influence of the NEA.

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