The Numerical Orbital Simulation for a Spacecraft to Rendezvous Two NEOs - Apophis and 2001 WN5.

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Abstract

Near the end of this decade, two Near-Earth Objects (NEOs) –99942 Apophis and 2001 WN5– will flyby the Earth with extremely close distances of 0.1 and 0.65 lunar distances, respectively. They provide a rare opportunity to investigate how the asteroids interact with the Earth during such close encounters. The aim of this work is to numerically simulate possible orbits for a single spacecraft to rendezvous both of the NEOs, which can be used to set up a future space mission. In this study, we tested two strategies for such mission, and we suggest that it is possible to visit the two NEOs by launching a spacecraft at some time near the close encounter of 2001 WN5 with the Earth. In this way, the spacecraft can flyby the NEO at a distance of 650 km. After that, it is possible for the spacecraft to use onboard thrusters to suitably adjust its orbit to rendezvous Apophis after its close encounter with the Earth.

1. Introduction

Over the last two decades, NEOs have received increasing attention due to their potential of catastrophic impacts on Earth as well as for their scientific value, such as expanding our knowledge about the early evolution and composition of the Solar System.

99942 Apophis (2004 MN4) is a well known NEO because it set the record for the highest rating on the Torino impact hazard scale with level 4 on December 27, 2004 when initial calculations indicated a possibility of 2.7% that it would impact Earth in 2029. With the subsequent improved observations of its orbit, the possibility of its impact on Earth was virtually eliminated. As calculated by the JPL Center for NEO Studies (CNEOS) and by the ESA NEODyS-2, Apophis will have a non-threatening close encounter with the Earth at 0.1 lunar distances (LD) on April 13, 2029 (JD 2462240.4).

On the other hand, about 10 months before Apophis approaches the Earth, another NEO -2001 WN5- is expected to pass within 0.65 LD from the Earth on June 26, 2028 (corresponding to JD 2461948.7). 2001 WN5 is an Apollo asteroid with H=18.3 (some 900 m size) on an eccentric (e = 0.467) orbit and a period of 818 days. Its relatively fast (4.25 hr) spin period [1] makes it an interesting target for a space mission. The extraordinary close approaches of the two NEOs with the Earth make them potential targets for spacecraft rendezvous. They provide rare opportunity for understanding how NEAs interact with the Earth during their flybys. Moreover, it is possible to establish a single orbit for a spacecraft to rendezvous those two NEOs, which has never been done in human history of asteroid space missions.

2. Methods

We conducted numerous N-body orbital simulations using the MERCURY 6.2 package [2] to find possible orbits for the spacecraft to rendezvous Apophis and 2001 WN5, using the hybrid symplectic/Bulrisch–Stoer integrator. The orbital elements of the NEOs were obtained from the JPL small-body database.

In order to use as low velocity impulse (ΔV) as possible for the mission, the spacecraft should be launched near the time when one of the NEOs is having its close encounter with the Earth. Therefore, we tested two strategies to find the best orbit fit. Since Apophis is considered to be the main target of the mission, our first strategy (hereafter S1) is to launch a total of 180000 virtual spacecraft between JD 2462240 and 2462240.8 with random ΔV less than 6 km/s pointing at random directions in the J2000 Cartesian coordinate system. Since the inclinations of the NEOs are low (<4°), we set a lower weighting factor for the velocity in the Z direction than in the X and Y directions to improve computational efficiency. After the spacecraft rendezvous with Apophis, we continue to track its orbit to see if it can also catch up with 2001 WN5. Alternatively, the second strategy (S2) is to launch 180000 virtual spacecraft between JD 2461946 and 2461948 to rendezvous 2001 WN5 first and then catch up with Apophis. The choice of the launch windows are based on preruns of 600000 spacecraft launched during different launch windows several days around the close encounter dates of the NEOs. In the simulations, the spacecraft and the NEOs are treated as massless test particles. The time step and output interval are both 0.025 days. All simulations end on the same epoch JD 2464000.

3. Results

In order to achieve high resolution images of the surface of the small size NEOs, the goal of our orbital simulations is to approach the target NEO with a closest encounter distance (D_{en}) less than a few thousand km at relative speed (V_{en}) as low as possible at the time of closest encounter. The left panel of Fig. 1 shows the D_{en} and V_{en} for every spacecraft relative to the NEOs from a subset of 60000 test particles in the S1 simulation. The red and blue dots represent the data for Apophis and 2001 WN5, respectively. As expected, this simulation produced multiple conditions for spacecraft to approach Apophis within several thousand km. However, only very few spacecraft can get close to 2001 WN5 within several hundred thousand km, with only one of them less than one hundred thousand km. An apparent feature for both Apophis and 2001 WN5 is that spacecraft having small D_{en} tend to have large V_{en}. For Apophis, spacecraft having $D_{en} < 10^4$ km will have V_{en} no less than 2 km/s.; for 2001 WN5, spacecraft with $D_{en} < 10^6$ km will have V_{en} larger than 7 km/s. The best solution we found in the S1 simulation is a spacecraft having D_{en} = 580 km to Apophis at JD 2462240.425 with V_{en} = 7.23 km/s. At this distance, the angular size of Apophis will be 2.16 arcmin. As a comparison, the New Horizons space probe took detailed images of the 18 km wide trans-Neptunian object -486958 Arrokoth- during a flyby with a distance of 3538 km [3], which corresponds to an angular size of 17.46 arcmin.

However, this spacecraft in S1 simulation can only approach 2001 WN5 with D_{en} = 36.9 LD and V_{en} = 15.64 km/s. The orbit of this spacecraft is shown in the left panel of Fig. 2. Although it is possible to use onboard thrusters after encountering Apophis to adjust the trajectory to get closer to 2001 WN5, the large and highly elliptical orbit of 2001 WN5 make it difficult to make such adjustment.

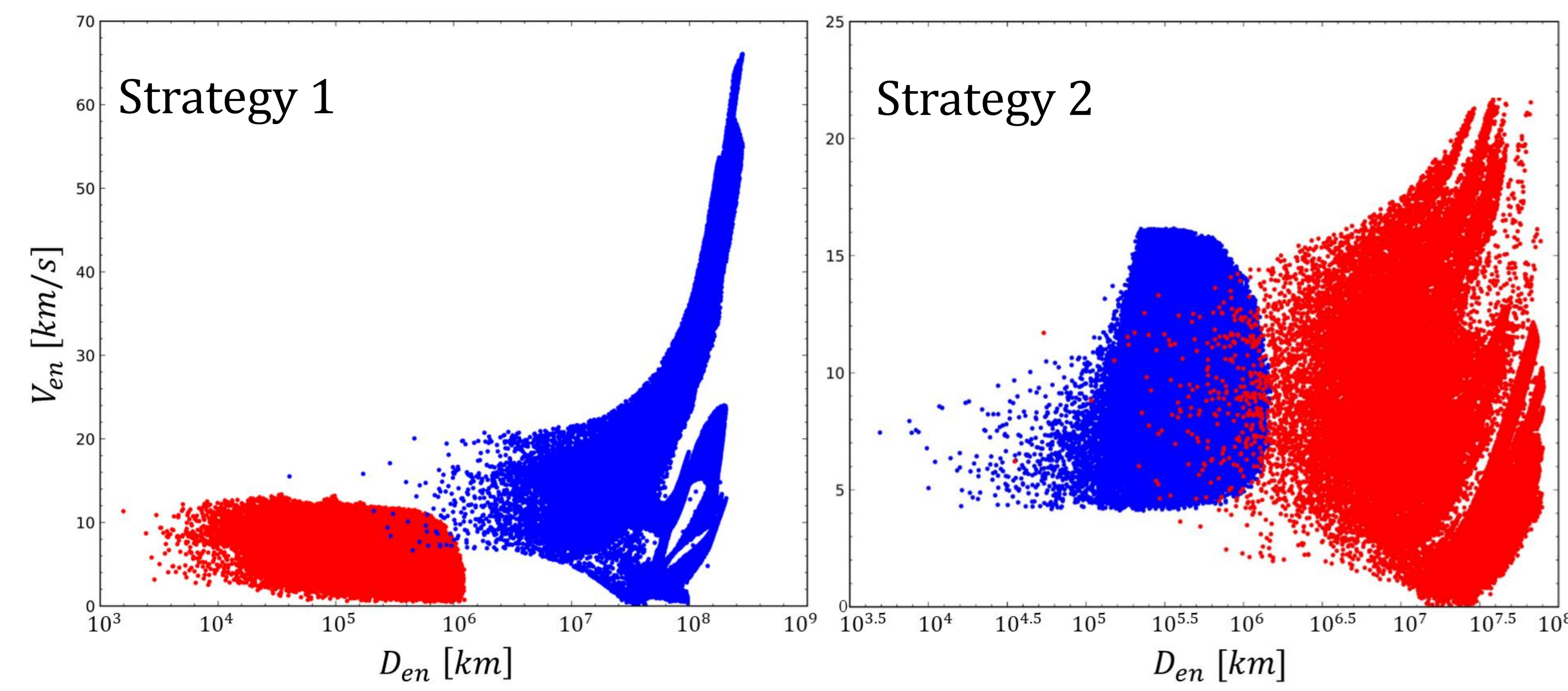

Fig. 1. Scatter plots of the spacecraft's closest encounter distance versus its speed relative to the NEOs when the encounter happens. The red dots and blue dots represent the data for Apophis and 2001 WN5, respectively. The left and right panels represent the results for S1 and S2 simulations, respectively.

For S2 simulation, as can be seen in the right panel of Fig. 1, the distribution of the red and blue dots are reversed compared to S1 simulation. We found 16 spacecraft that can approach 2001 WN5 with $D_{en} < 10^4$ km and V_{en} between 5 and 8 km/s, and there are 8 spacecraft that can approach Apophis with $D_{en} < 10^5$ km and V_{en} between 5 and 12 km/s. However, in these cases when a spacecraft has very close encounter with one of the NEOs, it will not always be able to catch up with the other NEO with any small D_{en}. The best case is that the spacecraft encounters 2001 WN5 at JD 2461950.65 with D_{en} = 650 km (corresponding to an angular size of 4.8 arcmin) and V_{en} = 4.85 km/s. The orbit of this spacecraft is shown in the right panel of Fig. 2. It is interesting that although the closest distance between this spacecraft and Apophis is very large (D_{en} = 115 LD), a significant part of their orbits overlap after Apophis has the extremely close encounter with the Earth. Therefore, it may be possible to apply onboard thrusters to adjust the trajectory to rendezvous with Apophis. For this reason, we suggest that strategy 2 may be a possible way to closely visit two NEOs with a single spacecraft.

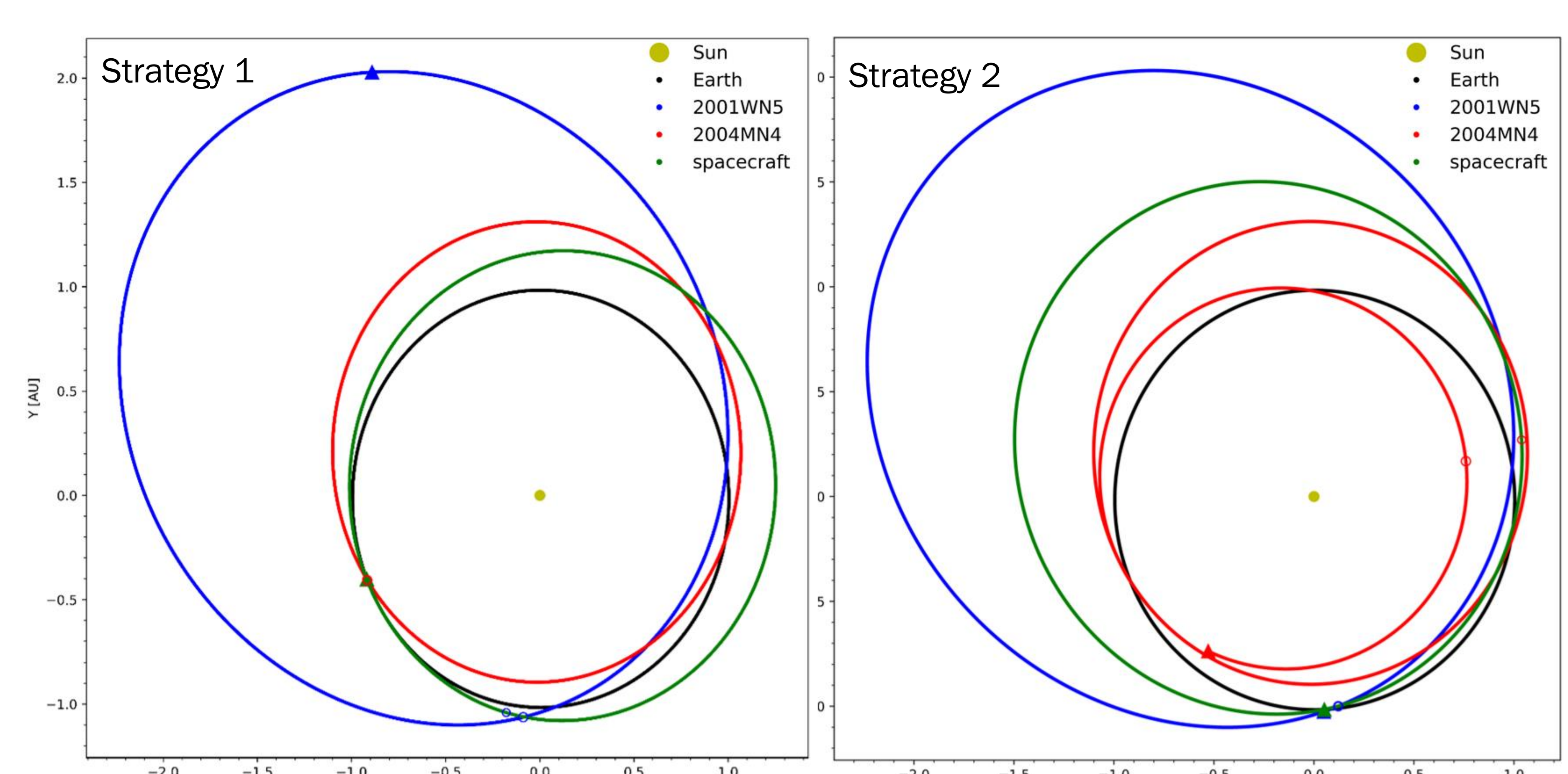

Fig. 2. Left panel: The orbit of the best case in S1, starting from the launch epoch JD 2462240.175 to JD 2464000. Right panel: The orbit of the best case in S2, starting from the launch epoch JD 2461946.85 to JD 2464000. In each panel, the triangles shows the initial positions of every objects; the hollow blue circles show the position of the spacecraft and 2001 WN5 when the closest encounter happens, likewise, the hollow red circles show the same information for Apophis.

References

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