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# Orbit Stability within a binary Near-Earth Asteroid System

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## Abstract

Using the asteroid 175706 (1996 FG3) as an example we studied the behavior of a spacecraft orbiting inside this binary system. The existence of libration points and orbital resonances helps to maneuver or maintain altitude with less usage of fuel, even in this challenging gravitational environment.

## 1. Introduction

NEOs (Near-Earth Objects) may hold important records on the origin and evolution of our planetary system. NEOs are also of interest, as they are on potential collision courses with Earth and may pose a threat to civilization and life. Binary NEOs (a system of two NEOs orbiting about their common center of mass) are abundant among the NEO population. Recent work suggests that most of them represent so-called "rubble-piles" that have split by tidal disruption after a close encounter with a planet.
Rendezvous missions to NEOs are challenging. As the NEOs are small and have odd shapes, gravity fields are complex, but weak. Effects of solar radiation pressure may significantly perturb the spacecraft orbit. In this paper, we analyze orbital motion in binary NEO systems in search off stable orbits.

### 1.1. Scientific Objectives

We focus on the NEO system 1996 FG3. In order to measure its morphology, topography and rotational parameters with optical remote sensing and laser ranging, we wish for close orbits with low eccentricity. Following up on work done by Tardivel et al.[3], we analyze different initial orbits as close as 1 - 4 km to the primary asteroid and studied their lifetimes. In the analysis we consider an orbit to be destabilized when the eccentricity reaches a value of 0.4.

## 2. Methodes

### 2.1. Model parameters

Table 1: Main characteristics of asteroid 175706 used for the simulations.

| Asteroid | 1996 FG3 | 1996 FG3 b |
|---|---|---|
| GM [$km^3/s^2$] | $1.42\times10^{-7}$ | $4.9\times10^{-9}$ |
| Radius [km] | 0.69 | 0.28 |
| $C_{2,0}$ un-normalized | - 0.14 | - |
| $C_{2,2}$ un-normalized | 0.012 | - |
| Spin period [h] | 3.5942 | - |
| Orbital period around primary [h] | - | 21.77 |

Dynamic parameters of the 1996 FG3 system, including the mass, size, shape, and rotation of the primary, mass and size of the secondary, as well as orbit of the secondary are rather well modeled in recent works. Values used for the simulation are further iterations of those used in [2] and can be seen in Table 1.
We simulate a variety of orbits with different initial conditions to display the stability regions. All the considered orbits are initially nearly circular and lie in the orbital plane of the secondary. In this plane the mechanics of Lagrangian points can negate the perturbing force of the secondary, at least in an ideal scenario.
The simulations include the gravitational field of the primary asteroid complete up to degree and order 2 with values in Table 1. The perturbing forces caused by the gravitation of Sun, Jupiter, Earth and the secondary asteroid are considered as well as the radiation pressure of the sun. The ephemeris and characteristics of perturbing bodies are drawn from SPICE-Kernels. Planetary ephemeris are provided by the DE 421 kernel [1].
Properties of the spacecraft influencing the orbit are size, shape, mass and reflectivity do to the interaction with solar radiation pressure.

## 2.2. Numerical solution of the ODE

To determine the trajectories we use a numerical integrator from previous studies [2]. It solves the equation of motion for the spacecraft, which is a second order ordinary differential equation (ODE). With all the considered forces the equation of motion takes the form:

$$\ddot{\vec{r}} = \underbrace{\ddot{\vec{r}}_{\mathrm{SRP}}(\vec{r},t)}_{\text{sol. rad. pr.}} \underbrace{-\frac{\mathrm{GM}}{r^3}\vec{r}}_{\text{mainbody}} + \underbrace{\ddot{\vec{r}}_{\mathrm{deg2}}(\vec{r},t)}_{\mathrm{C}_{2,0}\ \mathrm{C}_{2,2}} + \underbrace{\sum_{\mathrm{SB}} \ddot{\vec{r}}_{\mathrm{SB}}(\vec{r},t)}_{\text{sec. bodies}} \tag{1}$$

The numerical methods adept there order of convergence to a maximum of 8 for the Runge-Kutta-Method 'DOP853' or 12 for the implizite Adams-Method 'LSODE'. The smoothness of the differential equation meets the requirement for this order of convergence.

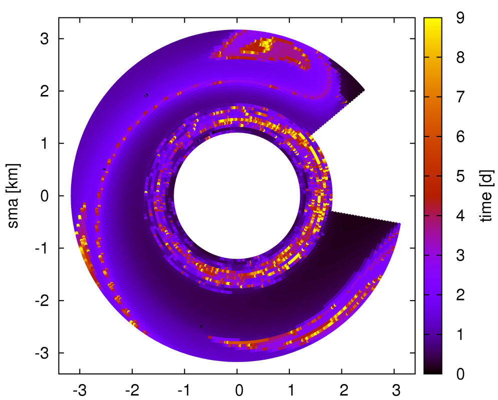


Figure 1: Stability analysis for orbits around 1996 FG3 with different initial conditions, in particular different semi-major axis and mean anomalies represented as radius and angel in polar coordinates. Colors indicate the time of stable orbiting. Initial conditions close to primary or secondary asteroid are cut out.

# 3. Results

In Figure 1 three famillies of relatively stable orbits are shown: two around the Lagrangian points L4, L5 respectively and one of lower orbits with approximately half the semi-major axis of the secondary. The lower orbits are in a 3:1 commensurability with the secondary and in a 1:2 spin-orbit coupling with the rotational period of the primary. Due to the perturbation caused by solar radiation pressure even orbits starting in these stable regions exceed an eccentricity of 0.4 after 9 days and ultimately will escape or collide.

We have also compared orbital motion in binary systems to orbits around a single NEO. Figure 2 shows that the existence of a secondary can even improve the stability of some orbits within the system.

# 4. Summary and Conclusions

Even with most obits instantly disrupted by radiation pressure and the gravitation of the secondary, we show that in the gravitational environment of binary asteroids relatively stable orbits exist near the Lagrangian points L4 and L5. Also orbits in commensurabilities with periods of the system stay longer suggesting resonances. For particular starting conditions, orbits are even more resilient to the perturbing solar radiation pressure than in the case of orbits around single NEOs. Such orbits may be useful for mapping or landing approach in future binary NEO exploration missions.

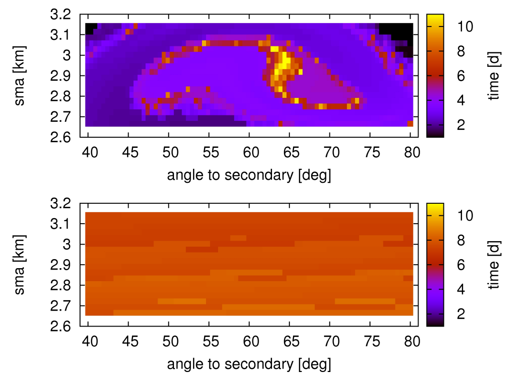


Figure 2: Stability analysis of initial conditions around L4 with (above) and without (below) the influence of the secondary. Colors indicate the time of stable orbiting.

# References


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