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Quasi-satellite orbits: a perturbative treatment

V.V. Sidorenko (1), A.I.Neishtadt (2), A.V.Artemyev (2), and L.M. Zelenyi (2)
(1) Keldysh Institute of Applied Mathematics, Moscow, Russia, (2) Space Research Institute, Moscow, Russia,
(3) Loughborough University, UK (vvsidorenko@list.ru)

Abstract

Quasi-satellite orbits (QS-orbits) are studied in the framework of restricted spatial circular three-body problem. With the use of double numerical averaging evolutionary equations are constructed that describe the long-term behavior of asteroid's orbital elements. Special attention is paid to possible transitions between the motion in QS-orbit and in another types of orbits existing at 1:1 resonance. As an example of the motion in QS-orbit the dynamics of near-Earth asteroid 2004GU9 is considered.

1. Introduction

Under the scope of three-body problem "Sun-planet-asteroid" the motion of asteroid in QS-orbit corresponds to 1:1 mean motion resonance with resonance argument $\varphi = \lambda - \lambda'$ librating around 0 (λ and λ' are the mean longitudes of the asteroid and the planet respectively). The asteroid motion in QS-orbit is bounded to the planet's neighborhood of characteristic size that can be small enough in comparison with the value of the semimajor axis a' of the planet. Nevertheless, asteroid's trajectory will never cross the planet's Hill sphere and so this asteroid can not be considered as a satellite in the usual sense.

For the first time the existence of QS-orbits was discussed probably by J.Jackson at the beginning of twentieth century [2]. The recent increase of interest to QS-orbits is inspired by the discovery of the real Earth's quasi-satellites (e.g., [1]).

Since outside the Hill sphere the gravity field of the planet is weak enough, the QS orbit can be treated as a slightly perturbed heliocentric Keplerian orbit. This offers great opportunities for analytical consideration of the motion in QS orbit. Different examples of perturbation technique application can be found in [4],[5],[6].

2. Double averaged equations describing the dynamics at 1:1 mean-motion resonance

In the case of mean-motion resonance three dynamical processes can be distinguished: "fast" process corresponds to planet and asteroid motions in orbit, "semi-fast" process is variation of the resonance argument (which describes the relative position of the planet and the asteroid in their orbital motions), and, finally, "slow" process is the secular evolution of the orbit shape (characterized by the eccentricity) and orientation (it depends on the ascending node longitude, inclination and argument of pericenter).

To study the "slow" process we constructed the evolutionary equations by means of numerical averaging over the "fast" and "semi-fast" motions. As a specific feature of these evolutionary equations we should mention that their right hand sides are not uniquely defined by values of the "slow" variables in some domains of these variables. The ambiguity appears since the averaging can be done over "semi-fast" processes with different qualitative properties - in other words, it can be done over QS-orbit, HS(horseshoe)-orbit, etc. The consideration of this ambiguity provides us an opportunity to predict whether the motions in QS- or HS-orbits are permanent or not; for non-permanent motions in QS-orbits the conditions of capture into this regime and escape from it can be established.

3.Example: dynamics of near-Earth asteroid 2004GU9

Asteroid 2004GU9 moves currently in a QS-orbit [4]; its osculating elements are presented in Table 1. We chose this asteroid among the other quasi-satellites of the Earth due to the absence of close encounters with Venus and Mars - it justifies to some extent the consideration of the secular effects in its motion on the base of evolutionary equations obtained under the scope of RC3BP (we realize that this model is insufficient for investigation of real asteroid dynamics; we want only to provide better understanding of the time scales and to illustrate some other quantitative characteristics of QS-mode of orbital motion).

The graphs in Fig. 1 demonstrate that our evolutionary equations provide an accurate description of secular evolution.

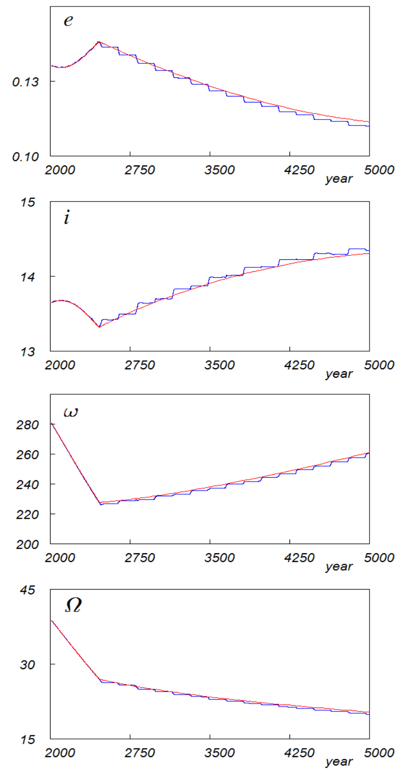

Figure 1. Evolution of 2004GU9 orbital elements. Blue lines correspond to the result of the direct integration of the motion equations, red lines characterize the secular behaviour according to evolutionary equations

Table 1: Osculating orbital elements of asteroid 2004GU9. Epoch: March 14, 2012 (JD2456000.5)

Element	Value
$a(AU)$	1.001056350821795
e	.1362904920360489
$i(^{O})$	13.64944749947083
$\Omega(^{O})$	38.74489028357296
$\omega(^{O})$	280.6255989836612
$M(^{O})$	217.2153150601352

Note. Orbital elements were taken from JPL Small-Body Database

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