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SOME DYNAMIC CHARACTERISTICS OF BINARY NEAR-EARTH ASTEROIDS

Tidal acceleration exerted by the terrestrial planets and Jupiter has been determined; orbital resonances to evaluate the motion stability in binary asteroid systems have been calculated. The radius of the Hill sphere surrounding the main component in approximation of the planetary three-body problem (the Sun-main component-satellite) has been estimated. Escape velocities from the surface of the asteroid satellites have been found and the conclusion on the possibility of substance loss has been made.

Keywords: resonance, binary NEA, and Hill sphere.

Currently, the evolution of asteroid systems as Solar system objects, as well as dynamics of individual asteroid systems are observed [1] and studied [2, 3].

Among the several thousand potentially hazardous near-Earth asteroids 59 binary and two trinary asteroids have been discovered so far [4].

The formation and evolution of binary and multiple asteroids started at the time of formation of the Solar system. Therefore, to discover and to study them, as many as possible, is important for understanding the cosmological processes in the Solar system. When approaching the planets, the asteroids can change their orbits significantly. At the same time, the motion parameters within the asteroid system can change, or the asteroid system can disintegrate either. Hence, the study of binary asteroids is important to prevent possible Earth collision with such objects.

STATEMENT OF THE PROBLEM

The asteroid systems can be influenced by three major factors that lead to the destabilization of the satellite orbits. The *first* one is the gravitational perturbations from the major planets, the *second* one is associated with the collisions within the asteroid system, and the *third* one with tidal evolution [5].

The stability of binary asteroid is determined by gravitational perturbations from the Sun and the planets. The tidal interaction between the components of binary system also has a significantly impact, especially on low-rigid celestial bodies of «rubble pile» type [6]. As the asteroids approach the planets they undergo planetary tidal influence [7]. In the course of evolution this can lead to a situation when the periods of the asteroid and the planet are multiple: the planet makes a whole number of revolutions around the sun within the time of 1, 2, 3 or 4 asteroid revolutions; in other words: motions of the asteroid and the planet may be commensurable. A typical example is the motion of Pluto and Neptune: for the period of Neptune's three revolutions around the Sun, Pluto does almost exactly two turns. According to modern research of the Solar system dynamics, the structure of the Solar system is largely determined by various resonance phenomena [8].

The aim of this research is to estimate some dynamic characteristics of binary asteroids systems currently approaching the Earth from the big planets. We have identified the largest tidal accelerations in binary asteroid systems, the Hill sphere radii for the main components of the asteroid systems, and the possibility of motion near the orbital resonances with the terrestrial planets and Jupiter.

KEY COMPUTATIONS

A convenient model for assessing the sustainability of the asteroid's satellite orbit is limited three-body problem (Sun–asteroid–satellite) [8]. The attraction between the main body and the satellite has been estimated; the orbital resonances with the terrestrial planets and Jupiter have been determined, the largest tidal accelerations in the asteroid systems from Venus, Earth, and Mars have been estimated, and the sustainability of motion on the Hill has been assessed for all known 59 binary and multiple asteroid systems.

The largest tidal accelerations are calculated using the classical formula [8]:

$$a_{\mathrm{TIDE}} = GM_{\mathrm{PLANET}}\frac{4a_s}{r^3_{\min}}, \qquad (1)$$

where G is gravity constant and $r_{\min}$ is minimum distance between the orbits of the asteroid system and the planet. This distance is estimated for each *planet – binary asteroid* pair by sequential search of distances between the orbital points. The computations are based on masses of major planets M_{PLANET} and bigger half-axes of asteroid's satellite orbits a_s taken from [4].

Having made calculations by formula (1) it is found that the largest tidal acceleration does not exceed 10^{-12} m/s^2 from Venus, 10^{-12} from Earth, 10^{-12} from Mars, and 10^{-14} from Jupiter. The tidal acceleration depends, first of all, on the minimum distance between the asteroid system and tidal planet. Therefore, the tidal acceleration created by the attraction of Jupiter is two orders of magnitude less than in the case of the terrestrial planets.

If revolution periods of two or more celestial bodies relates to each other as small whole integers, such bodies move with orbital resonance. As a result, these bodies periodically approach each other at certain points of their orbits. The resulting regular changes of gravitational acceleration can either stabilize their orbit or lead to the disintegration of the system.

To determine the ratio of the rotation periods their values should be as accurate as possible. Therefore, the asteroid systems whose periods are known with an absolute error not exceeding 0.0001 days [4]. Based on this criterion the binary near-Earth asteroids (NEA) have been selected and their orbital resonances with the terrestrial planets and Jupiter have been determined.

The orbital resonances are calculated according to the classical method [8]:

$$T_1 \times N_1 - T_2 \times N_2 \approx 0, \qquad (2)$$

where T_1 and T_2 are sidereal periods of the two objects, N_1 and N_2 are small natural numbers.

Three asteroid systems moving near orbital resonance with major planets have been found (see Table). The accuracy ranges from 0.04 (0.013%) to 1.87 (0.138%) days.

Since the heliocentric orbits of binary NEA have a considerable eccentricity, the model of planetoid three-body problem was used for the calculations [8]. To assess the stability of the satellite motion with respect to the main body, the Hill criterion was used. To this end, the radii of the Hill spheres were calculated for each asteroid system near perihelions of their orbits.

The calculation results show that the satellites in all the 59 asteroid systems are deeply inside the Hill spheres: for example, the satellite in the sys-

Orbital Resonances of Multiple Asteroids with Planets

Asteroid	Revolution period, days	Planet	Resonance	Error, days
(5646) 1990 TR	1145.17	Mars	3:5	–0.47
(5381) Sekhmet	336.85	Venus	4:6	–1.87
(363599) 2004 FG11	730.72	Earth	1:2	0.04

tem Heracles (5143) moves along the orbit with the major axis of 4 km with respect to the main body, while the Hill sphere radius is 348 km.

Further, the motion of satellites in binary systems with known axial rotation period, namely: (5381) Sekhmet, (66391) 1999 KW4, (175706) 1996 FG3, (285263) 1998 QE2, (311066) 2004 DC, (363027) 1998 ST27, (399307) 1991 RJ2, and (399774) 2005 NB7 has been studied. Having compared the centrifugal acceleration and the acceleration of gravity on the surface of these satellites assuming their spherical shape it was found that on the whole surface of asteroid's satellite, except for the poles, the former materially exceeds the latter: for example, for Sekhmet (5381) asteroid, the centrifugal acceleration exceeds 100 times the acceleration of gravity on the equator.

CONCLUSIONS

The tidal accelerations caused by the terrestrial planets and Jupiter in the binary NEA systems have been estimated for the current location of their orbits. They have been found to be negligible. Therefore, these planets cannot materially influence the motion in the asteroid systems or lead to its disintegration.

The Hill radii have been calculated for the main bodies of asteroid systems. All binary NEAs have been established to be stable in terms of the Hill criterion.

Using known radii and periods of axial rotation of asteroid satellites the centrifugal acceleration and the acceleration of gravity have been compared. In the most cases, the former exceeds the latter by one or two orders of magnitude. The matter of the satellite surface is very weakly bonded to it by forces of gravity, which may lead to loss of surficial layers.

The next stage will be to develop a numerical model of motion of dust particles leaving the surface of asteroid satellite in near-asteroid space. This would enable better understanding of the formation of dust rings around the asteroids [9].

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ДЕЯКІ ДИНАМІЧНІ ХАРАКТЕРИСТИКИ ПОДВІЙНИХ АСТЕРОЇДІВ, ЩО ЗБЛИЖУЮТЬСЯ З ЗЕМЛЕЮ

Визначені приливні прискорення з боку планет земної групи і Юпітера та обчислені орбітальні резонанси для оцінки стійкості руху в системах подвійних астероїдів. Обчислено радіус сфери Хілла, що оточує головний компонент, у наближенні планетоїдної задачі трьох небесних тіл — Сонце, головний компонент, супутник. Знайдені другі космічні швидкості з поверхні супутників астероїдів, зроблено висновок про можливість втрати речовини.

Ключові слова: резонанс, подвійні АСЗ, сфера Хілла.

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НЕКОТОРЫЕ ДИНАМИЧЕСКИЕ ХАРАКТЕРИСТИКИ ДВОЙНЫХ АСТЕРОИДОВ, СБЛИЖАЮЩИХСЯ С ЗЕМЛЕЙ

Определены приливные ускорения со стороны планет земной группы и Юпитера и вычислили орбитальные резонансы для оценки устойчивости движения в системах двойных астероидов. Вычислен радиус сферы Хилла, окружающей главный компонент, в приближении планетоидной задачи трех небесных тел – Солнце, главный компонент, спутник. Найдены скорости убегания с поверхности спутников астероидов, сделан вывод о возможности потери вещества.

Ключевые слова: резонанс, двойные АСЗ, сфера Хилла.