DOI: http://dx.doi.org/10.18524/1810-4215.2016.29.85235

RESONANCES IN ASTEROID SYSTEMS

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ABSTRACT. Today the following types of resonances in the rotation of celestial bodies in the solar system are known, namely orbital, spin-orbit and spin-spin resonances. This paper presents our computations of these types of resonances for the known binary and multiple asteroid systems.

Key words: asteroid, asteroid system, resonance.

1. Problem statement

Resonances in the solar system have been known for a long time. They are found when investigating the orbital elements of Jupiter and Saturn, Neptune and Pluto, and they exert considerable perturbations in the motion of these planets. The moon resonances have been discovered in such systems as the Jupiter, Saturn, Uranus, Neptune and Pluto systems. The asteroid belt also has resonance structure; the Kirkwood gaps are associated with asteroid resonances with Jupiter. Trans-Neptunian objects also can be in resonance with Jupiter and Neptune. The objective of the author is to show the presence of different types of resonances in the currently known asteroid systems.

Different authors have already shown the causes of occurrence and stability of resonances in the solar system (Murray and Dermot, 2010), and in particular, in near-Earth asteroids (Fang and Margot, 2012). The spin-spin resonances in the solar system have also been studied (Batygin and Morbidelli, 2015). In this paper we examine resonances in asteroid systems based on earlier results obtained by different authors.

2. Orbital resonance

If the orbital periods of two moons of an asteroid are related by a ratio of small integers, such moons are in orbital resonance.

Let us consider orbital resonances in 11 known triple asteroid systems. The asteroid moons' orbital resonance ratios computed by formula (1) within the measurement accuracy are given in Table 1. The moons of Haumea (minor-planet designation 136108 Haumea) are not in orbital resonance.

$$N_1 \cdot P_1 - N_2 \cdot P_2 \approx 0 \quad (1),$$

where N_1 and N_2 are the orbital resonance ratios of the first and second moons, respectively; P_1 and P_2 are the orbital periods of the moons. The orbital and spin periods of the asteroid moons, as well as spin periods of central asteroids were taken from Johnston's Archive: *http://www.johnstonsarchive.net/astro/asteroidmoons.html.*

Table 1. Orbital resonances of triple asteroid moons

Asteroid systems	$N_{PeriodSatelliteBeta} : N_{PeriodSatelliteGamma}$
(45) Eugenia	3:8
(87) Sylvia	3:8
(93) Minerva	6:13
(130) Elektra	1:5
(216) Kleopatra	1:2
(2577) Litva	143:1
(3749) Balam	1:44
(47171)1999 TC36	53:2
(136617) 1994 CC	7:1
(153591) 2001 SN263	1:9

Let us examine each of these asteroid systems, as well as the evolution of the asteroid moons, in more detail. For this purpose a numerical model of the moons' motion in the asteroid-centric Cartesian coordinate system was developed. The motion equations (2) were integrated by the 15th order Everhart numerical method (Bazyey and Kara, 2009); the coordinates of planets were taken from the numerical ephemerides DE431 (Folkner et al., 2014). We also accounted of the non-sphericity (i.e. the polar oblateness which is too approximate for the bodies with irregular shape – asteroids) of the central asteroid's gravity field (Troianskyi, 2015) and solar radiation pressure on the moons in these asteroid systems (Troianskyi and Bazyey, 2015):

$$\frac{d^2\vec{r}}{dt^2} = \vec{a}_U + \vec{a}_P + \vec{a}_L \quad (2),$$

where $\vec{r}$ is the radius vector; t is the time; $\vec{a}_U$ is the acceleration due to the non-sphericity of the central asteroid's gravity field; $\vec{a}_P$ is the acceleration due to the gravitational interaction with the solar system planets; $\vec{a}_L$ is the solar radiation pressure induced acceleration. To account of the acceleration due to the gravity field of the oblate central asteroid, the second zonal harmonic coefficient (J_2) should be computed using the algorithm suggested earlier (Troianskyi, 2015). The obtained coefficients J_2 for the central asteroids are given in Table 2.

Table 2. The second zonal harmonic coefficients J_2 for the selected asteroid systems

Asteroid systems	J_2	*Error*
(45) Eugenia	-0.01362	+0.00038 -0.00043
(87) Sylvia	-0.05319	+0.00003 -0.00024
(93) Minerva	0	0
(130) Elektra	-0.00946	+0.00108
(216) Kleopatra		-0.00138
(136617) 1994 CC	-0.01339	+0.00019 -0.00001
(153591) 2001 SN263	0	0

The changes in Keplerian elements of the asteroid moons were obtained by the integration of the motion equations. According to Kepler's modified third law (3) the square of the orbital period is directly proportional to the cube of the semi-major axis and only depends on this orbital element. The evolution of asteroid systems exhibits periodic changes in semi-major axes of asteroid moons; as a result, the ratios of their periods remain unaltered not affecting their resonances.

$$P = \frac{2\pi a^{3/2}}{k\left(m_A + m_{St}\right)^{1/2}} \quad (3),$$

where P is the moon's orbital period; a is the semi-major axis of the moon; k is the gravitational constant; m_A and m_{St} are the masses of the central asteroid and its moon, respectively.

3. Spin-orbit and spin-spin resonances

If the spin period of the main asteroid or its moon and the moon's orbital period are related by a ratio of small integers, then such an asteroid system is in spin-orbit resonance. A special case of the spin-orbit resonance with the ratio of 1:1 is called tidal locking or captured rotation. Table 3 presents the results of computations of the spin-orbit resonances of the moons of binary and multiple asteroids using formula (1) where P_1 is the spin period of the main asteroid or its moon; P_2 is the moon's orbital period; N_1 and N_2 are the orbital resonance ratios. It is incorrect to speak about spin-orbit resonance in the (88611) Teharonhiawako and 2003 QY90 systems as their period ratios are large and exceed 1000:1.

The type of resonance when the spin period of the main component and the spin period of its moon are related by a ratio of small integers is called spin-spin resonance. Some examples of such systems are presented here below (Table 3).

Table 3. Spin-orbit and spin-spin resonances in the selected asteroid systems

Asteroid systems	$N_{SpinSatellite} : N_{PeriodSatellite}$	$N_{SpinAsteroid} : N_{PeriodSatellite}$	$N_{SpinAsteroid} : N_{SpinSatellite}$
(90) Antiope	1:1	1:1	1:1
(809) Lundia	1:1	1:1	1:1
(939) Isberga	1:1	9:1	9:1
(1139) Atami	1:1	1:1	1:1
(2006) Polonskaya	3:1	6:1	2:1
(2478) Tokai	1:1	1:1	1:1
(2577) Litva	6:1	13:1	2:1
(3309) Brorfelde	1:1	7:1	7:1
(4868) Knushevia	1:1	4:1	4:1
(4951) Iwamoto	1:1	1:1	1:1
(5381) Sekhmet	1:1	5:1	4:1
(5426) Sharp	1:1	5:1	5:1
(7369) Gavrilin	1:1	1:1	1:1
(8474) Rettig	1:1	1:1	1:1
(15430) 1998 UR31	1:1	9:1	9:1
(16525) Shumarinaiko	1:1	6:1	6:1
(16635) 1993 QO	16:1	4:1	1:4
(18890) 2000 EV26	1:1	4:1	4:1
(27568) 2000 PT6	1:1	5:1	5:1
(66391) 1999 KW4	1:1	6:1	6:1
(69230) Hermes	1:1	1:1	1:1
(88611) Teharonhiawako	-	-	1:1
(175706) 1996 FG3	1:1	6:1	6:1
(285263) 1998 QE2	24:1	7:1	1:4
(311066) 2004 DC	3:1	9:1	3:1
(399307) 1991 RJ2	1:1	5:1	5:1
(399774) 2005 NB7	1:1	4:1	4:1
2003 QY90	-	-	2:1

If the main asteroid and its moon are in a 1:1 spin-spin resonance, it is said that the system has reached the state of completed tidal de-spinning of its components (Murray and Dermot, 2010). At the close of tidal de-spinning the main asteroid and its moon are always facing each other with the same side.

4. Results

The computations show that the moons in 10 out of 11 known triple asteroid systems are in orbital resonance. The numerical integration has shown that neither the effects of the non-sphericity of the main asteroid's gravity field nor the solar radiation pressure on the asteroid's moons can result in changes in the orbital resonances of the moons in these systems. If the asteroid systems do not approach to large planets in the solar system, such influence is of periodic nature. A case of close approach and destruction of systems was discussed in our earlier study (Troianskyi et al., 2015).

Most of the investigated binary and multiple asteroids are tidally locked. It means that the same side of a moon always faces the main asteroid. The most famous example of tidal locking in a planet-moon system is the Earth-Moon system.

Nine out of 36 studied asteroid systems are in the state of tidal de-spinning completed. An example of such a system is the Pluto-Charon system.

In the asteroid systems (66391) 1999 KW4, (88611) Teharonhiawako and (153591) 2001 SN263 the moons rotate about the central asteroid in retrograde orbit, i.e. in the opposite direction relative to the central asteroid's spinning, which results in decreasing semi-major axis of the moon as shown by Murray and Dermot in their study (Murray and Dermot, 2010). An example of such system is the Neptune-Triton system.

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