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Dynamics of the asteroid rings (10199) Chariklo

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In 2014 it was reported on opening two rings around asteroid (10199) Chariklo (Braga-Ribas F., et al., 2014, Nature, 508, 72–75) and it became the fifth object of the Solar system known to have ring system, after Jupiter, Saturn, Uranus and Neptune. The main component of the system is the biggest Centaur. This work considers the erosion time of rings in the asteroid system (10199) Chariklo, that is due to a number of effects. Also, we have calculated the mass and period of rotation of the asteroid's shepherd satellite.

ДИНАМІКА КІЛЕЦЬ АСТЕРОЇДА (10199) CHARIKLO, Троянський В.В., Базєй О.А. — У 2014 році було повідомлено (Braga-Ribas F., et al., 2014, Nature, 508, 72–75) про відкриття двох кілець навколо астероїда (10199) Chariklo; він став п'ятим об'єктом Сонячної системи, у якого виявлено система кілець, після Юпітера, Сатурна, Урана і Нептуна. Головний компонент системи є найбільшим Кентавром. У роботі розглянуто час ерозії кілець в астероїдній системі (10199) Chariklo, що відбувається через низку ефектів. Також ми визначили масу і період обертання передбачуваного супутника-пастуха даного астероїда.

ДИНАМИКА КОЛЕЦ АСТЕРОИДА (10199) CHARIKLO, Троянский В.В., Базей А.А. — В 2014 году сообщалось (Braga-Ribas F., et al., 2014, Nature, 508, 72–75) об открытии двух колец вокруг астероида (10199) Chariklo; он стал пятым объектом Солнечной системы у которого обнаружена система колец, после Юпитера, Сатурна, Урана и Нептуна. Главный компонент системы является самым крупным Кентавром. В работе рассмотрено время эрозии колец в астероидной системе (10199) Chariklo, которая происходит из-за ряда эффектов. Также мы определили массу и период обращения предполагаемого спутника-пастуха данного астероида.

Ключевые слова: кривые блеска; двойная система; HS 2231+2441.

Key words: light curves; binary system; HS 2231+2441.

1. THE ORBITAL CHARACTERISTICS OF THE ASTEROID SYSTEM (10199) CHARIKLO

Orbit of (10199) Chariklo located between the orbits of Saturn and Uranus. Its aphelion distance is greater than the perihelion distance of Uranus. Asteroid system rotates in resonance 4 : 3 (62.53 : 83.53 years) with Uranus. Table 1 summarizes the Keplerian orbital elements of asteroid system.

Table 1. Orbital data, primary asteroid (Keplerian osculating orbital elements [9]) and other data

Semimajor axis	15.754190 AU
Eccentricity	0.1715941
Inclination	23.411663°
Argument of perihelion	241.60058°
Ascending node	300.379814°
Mean anomaly	60.13111°
Epoch	2014 May 23
Diameter	248 000 ± 18 000 m [4]
Rotation period	7.004 hour [7]

The asteroid is surrounded by two narrow rings C1R and C2R width of 6600 and 3800 meters with an optical density of 0.38 and 0.06 respectively. The radius of the rings is 390 600 ± 3 300 m and 404,800 ± 3,300 m, respectively. Opened jointly by European and American astronomers in 2013 during occultation of the star UCAC4 248-108672 [2]. After the discovery a lot of other observations of this object were carried out resulting in the clarification of parameters of the system [1]. Possibility of rings disintegration as a result of the tidal effect from the planets of the Solar system [8] in the 1 million years' time interval is also considered.

2. THE CHARACTERISTIC TIME OF EROSION OF THE RINGS

Narrow and eccentric rings should be disintegrated as a result of erosion for the time much less then age of the Solar system. The fact that these rings be observed means that we live in a special epoch when such rings exist, or implies the existence of some retention mechanism that retains the properties of the rings unchanged over long periods.

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Let us consider the time of rings life, i.e. erosion of narrow rings not retained by any forces, due to a number of effects: the mutual collisions of particles of the ring, the Poynting-Robertson effect and differential precession. A detailed derivation of formulas for the erosion of the rings, considered by Murray and Dermot [3]. In the Braga-Ribas et al. [2] calculated the time of the asteroid rings erosion due to particle collisions and the Poynting-Robertson effect. We calculate the erosion time due to the third effect — differential precession of the rings.

Compression of the central asteroid causes that elongated orbits of rings particles to precess at a speeds of approximately described by the equation [3]

$$\dot{\varpi} \approx 3\pi J_2 \left(\frac{R_A}{a_{St}}\right)^2 T, \tag{1}$$

where the J_2 — the second zonal harmonic (0.014 ± 0.002), calculated by you on the previously proposed algorithm [6], R_A — radius of the asteroid, a_{St} — semi-major axis of the orbit $(400\,300 \pm 9\,700$ m), the alleged shepherd satellite, T — period of rotation (0.74 days and 0.78 days).

The difference between the values for the inner and outer edges of the eccentric rings (radial width of the ring along the major axis of its orbit are different) in semi-major axis is given by formula [3]

$$\delta\dot{\varpi} \approx -\frac{7}{2}\dot{\varpi}\frac{W}{a_{St}}, \tag{2}$$

where W — the radial width of the ring. Consequently, there must be a differential precession because the inner edge of the ring precess faster than external. Ring erosion of the characteristic time $\frac{2\pi}{|\delta\dot{\varpi}|}$, that in our calculations is 1660^{+151}_{-146} days for C1R and 2760^{+68}_{-67} days for C2R.

3. SHEPHERD SATELLITE

The discovery of narrow rings of Uranus gave impetus to the development of the theory of the ring holding, contrary to the collision of the particles, the Poynting-Robertson effect and differential precession. The presence of shepherd satellites was more plausible explanation for the stability of narrow rings. It has been suggested [3] that the narrow ring is supported by a companion.

We assume that the gap in the rings formed by the satellite of asteroid system is similar to how the Pan satellite forms the Encke gap in A ring of Saturn. Using equation (3), derived from the expression for the sphere of influence, estimate the mass of the satellite shepherd:

$$m_{St} = \frac{R^{5/2} M_A}{a_{St}^{5/2}} \approx (3.27 \pm 0.19) \cdot 10^{15} \text{ kg}, \tag{3}$$

where R — sphere of influence radius $(7100 \pm 100$ m) [5] of shepherd satellite. Mass (MA) of the asteroid (10199) Chariklo calculated using the formula:

$$M_A = \frac{4}{3}\pi a b^2 \rho \approx 7{,}82 \cdot 10^{19} \text{ kg}, \tag{4}$$

where a — semi-major axis of the ellipsoid of the asteroid (289 800 m [2]), b — minor axis of the ellipsoid of the asteroid (253 800 m [2]), ρ — the density of the asteroid (10^3 kg/m^3 [10]). From the refined Kepler's law we find the rotation period (P) shepherd satellites around the main component of the asteroid system:

$$P = \frac{2\pi a_{St}^{3/2}}{\sqrt{G(M_A + m_{St})}} \approx 6.12^{+0.23}_{-0.01} \text{ hours}, \tag{5}$$

where $G = (6{,}6740 \pm 0{,}00031) \cdot 10^{-11}$ m^3·s^{-2}·kg^{-1} — gravitational constant.

The orbital period of the system's main component around its axis is 7.004 hours [7]. Comparing this value with the resulting orbital period of alleged shepherd satellite can be seen that the system approaches to the synchronous rotation [3].

Orbital periods of C1R and C2R rings are known and are equal to 0.74 days and 0.78 days, respectively [10]. Ring are approaching to the orbital-orbital resonance 3 : 1 with shepherd satellite.

4. CONCLUSIONS

Considered in this work the phenomenon of erosion asteroid rings (10199) Chariklo, due to the differential effect of precession.

An estimate of the mass and orbital period of the satellite the alleged shepherd supporting the form of rings asteroid system.

Is shown existence of resonances between the spin of the central asteroid of the system, the orbital periods of the rings and the intended shepherd satellite.

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