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SPECIFICATION OF LIMITS OF POSSIBLE EXISTENCE OF SATELLITES IN THE GRAVITATIONAL FIELD OF PLANETS

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ABSTRACT. It is known that the satellites of the planets may exist in the area, which is bounded on one side by Rocha limit, on the other – Hill sphere. The article deals with the determination of the Rocha limits and Hill sphere of satellites of some planets in the solar system. This analysis revealed some features and identified the main factors influencing the setting of these parameters. Roche limits and Hill sphere parameters of the largest satellites of the planets of the solar system have been specified.

Key words: satellites of planets; gravitational field; Roche limit; Hill sphere; mass.

1. Introduction

Since the beginning of the study of the solar system by cosmic means up-to-date, the principal task stimulating the development of this area, in fact, remains unchanged. The new information, which comes as a result of numerous space missions, makes an important contribution in solving the fundamental problems of modern science, considering the origin and evolution of planets, their satellites and the solar system as a whole.

The application of this knowledge to understanding the natural processes that determine the development of our Solar system is equally important. A time is rapidly approaching when among the most urgent challenges will be the exploration of the satellites of the planets of the Solar system.

Today the vital question is specification of Rocha limits of the satellites of the planets in connection with obtaining new information from astronomical observations. This is the work of scholars such as K.V.Holshevnikov, A.A.Orlov, V.L.Panteleev, R.U.Ibatullin, G.I.Shyrmin, A. Philip, N.P.Pytyev, L.V.Konstantinovsky, E.L.Ruskol, L.L.Sokolov, B.P.Kondratyev, R.Barnes, R.Heller, B.Jones, P.Sleep, J.Noyola, S.Satyal and others.

Roche limit is determined by the difference between the acceleration, that is experienced from the planet nearest and farthest points of the satellite, and the gravity of the satellite; Rocha cavity – the space that surrounds each gravitation body moving along circular orbits around a common center of mass and the weight of the central body dominates the gravity of other bodies; Hill sphere – the space around a planet, in which the planet draws his satellite more than the object around which it revolves, that is the sun; sphere of attraction – the area in the form of a flattened ellipsoid of revolution around the celestial body within which the action of gravity on an object that rotates along an orbit around this body, emanating from this body, that is planets have a dominant influence on their satellites, despite the presence of much more massive, but more distant Sun (Vidmachenko & Morozhenko, 2014; Konstantinovskaya, 2002; Kholshevnikov, 2015).

2. Formulation of the problem

In other words, the Roche limit represents the shortest distance of the satellite from the planet on which it will be not be broken into pieces, and the Hill sphere determines whether the object rotates around the planet or moves to the orbit of the Sun, that is, the farthest.

Satellites of the planets deviate from the state of hydrostatic equilibrium and have shapes that vary from spherical and have asymmetries relative to the axis of rotation and the equatorial plane.

Also, in contrast to asteroids, there are objects that evolve and have: the inner core, the magnetic field, the correct form (Ruskol, 2002). It is established that the biggest planets have radius of, approximately, from 0.002 to 0.270 times the radii of the planet. Except for the satellite of Pluto – Charon. For most of the planets (except Pluto and Earth), this limit is quite low, ranging from 0.002 to 0.042 times the radius of the planet (Konstantinovskaya, 2002).

We have identified 18 largest satellites of the planets in the Solar system as a self-gravitating formation (Yasenev, 2015). All major planetary satellites are synchronized with their planets that are rotate around the planet, in the same case as a planet around the Sun (except Triton). And they have different physical characteristics (Table 1).

Table 1. Physical characteristics of planetary satellites.

№	Name	Mass, kg 10^{20}	Density, $kg \cdot m^{-3}$	Average radius, km
1	Ganymede	1 481.90	1936	2 634.10
2	Titan	1 345.20	1880	2 576.00
3	Callisto	1 077.00	1835	2 410.30
4	Io	893.19	3528	1 821.00
5	Moon	734.80	3347	1 737.10
6	Europe	480.20	3019	1 561.00
7	Triton	214.00	2061	1 354.00
8	Titania	35.27	1711	788.50
9	Oberon	30.14	1630	761.50
10	Rhea	23.07	1234	764.50
11	Iapetus	18.06	1089	735.80
12	Charon	15.80	1650	606.00
13	Ariel	13.50	1670	578.90
14	Umbriel	11.75	1405	584.30
15	Dione	10.96	1479	562.00
16	Tethys	6.18	986	531.20
17	Enceladus	1.10	1610	252.20
18	Miranda	0.71	1214	236.50

3. The main part

Modern astronomical observations carried out by ground and space means led to the discovery of a large number of satellites of the planets and their number continues to grow. Most have a small mass, but their shape and sizes are held by forces of electromagnetic interactions in the minerals from which they formed. On the other side of the planets in the solar system there are massive satellites. There are relevant research questions of satellite spacecraft that require the most serious study of their celestial-mechanical characteristics.

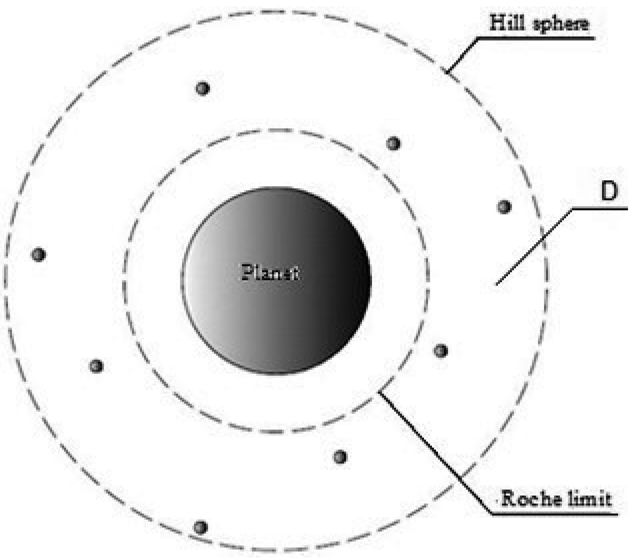

Figure 1: Field of the possible existence of satellites – the area between Roche limit and Hill sphere (D – possible existence of satellites region).

It is understood that for each of the satellites there are boundaries of their existence according to their mass and density, i.e. planets' satellites cannot be close to a planet closer than the radius of the Rocha limits and not further away than the radius of the Hill sphere (Fig. 1).

Hill sphere radius determined from the formula:

$$R_H = a(1-e)\sqrt[3]{\left(\frac{m_p}{3M_S}\right)} \qquad (1),$$

where a – major axis of the orbit of the planet around the star, e – eccentricity of the orbit, m_p – mass of the planet, M_S – mass of Sun.

Radius of Roche limits determined by the formula:

$$R_R = 2.423R\left(\frac{\rho_p}{\rho_s}\right)^{\frac{1}{3}}\left(\frac{\left(1+\frac{m_s}{3M_p}\right)+\frac{e}{3}\left(1+\frac{m_s}{M_p}\right)}{1-e}\right)^{\frac{1}{3}} \qquad (2),$$

where ρ_s – density of the satellite ρ_p – density of the planet, M_p – mass of the planet, m_s – mass of the satellite, e – polar compression of the planet. Calculate these values for some satellites of the planets (Table 2).

The orbit of the satellite can be stable at a distance of no more than 0.53 Hill sphere radius (in direct rotation) and 0.69 in the reverse. Otherwise orbit satellite will be subjected to disturbance from the Sun and other planets and satellites (Konstantinovskaya 2002, Ibatullin 2010). In other research materials, slightly different value may be given, for example (Vidmachenko &Morozhenko 2012).

All major planetary satellites in synchronization with their planets, those rotate around the planet, same as the planet around the Sun (except Triton).

It is equally clear that Roche limit is not significantly dependent on the relationship of mass of the satellite and the planet, and more dependent on the ratio of the density of the planet to the density of the satellite (Fig. 2).

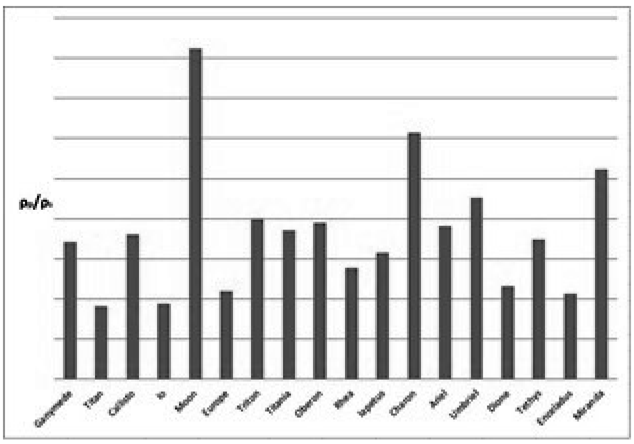

Figure 2: The ratio of density of the planet to the density of the satellite (Moon, Charon and Miranda are allocated).

Table 2. The value of Roche limits and Hill sphere for some satellites of planets in the Solar system.

№	Satellites		Planets					Roche limit, km 10^3	Hill sphere, km 10^6
	Name	**Mass, kg 10^{20}**	**Name**	**Mass, kg**	**Density, kg·m^{-3}**	**Average radius, km**	**Polar compression**		
1	Ganymede	1 481.90	Jupiter	$1.8986 \cdot 10^{27}$	1326	69 911	0.06487	153.787788	50.562718
2	Titan	1 345.20	Saturn	$5.6846 \cdot 10^{26}$	687	58 232	0.09796	105.528511	61.825270
3	Callisto	1 077.00	Jupiter	$1.8986 \cdot 10^{27}$	1326	69 911	0.06487	156.558699	50.562718
4	Io	893.19	Jupiter	$1.8986 \cdot 10^{27}$	1326	69 911	0.06487	125.905842	50.562718
5	Moon	734.80	Earth	$5.9742 \cdot 10^{24}$	5515	6 371	0.00335	18.285152	1.471698
6	Europe	480.20	Jupiter	$1.8986 \cdot 10^{27}$	1326	69 911	0.06487	132.617227	50.562718
7	Triton	214.00	Neptune	$1.0243 \cdot 10^{26}$	1638	24 622	0.01708	55.686258	114.878926
8	Titania	35.27	Uranus	$8.6832 \cdot 10^{25}$	1271	25 362	0.02293	56.229532	67.118566
9	Oberon	30.14	Uranus	$8.6832 \cdot 10^{25}$	1271	25 362	0.02293	57.145887	67.118566
10	Rhea	23.07	Saturn	$5.6846 \cdot 10^{26}$	687	58 232	0.09796	121.424253	61.825270
11	Iapetus	18.06	Saturn	$5.6846 \cdot 10^{26}$	687	58 232	0.09796	126.590511	61.825270
12	Charon	15.80	Pluto	$1.305 \cdot 10^{22}$	2030	1 184	0.01670	3.1386325	5.759526
13	Ariel	13.50	Uranus	$8.6832 \cdot 10^{25}$	1271	25 362	0.02293	56.685818	67.118566
14	Umbriel	11.75	Uranus	$8.6832 \cdot 10^{25}$	1271	25 362	0.02293	60.046501	67.118566
15	Dione	10.96	Saturn	$5.6846 \cdot 10^{26}$	687	58 232	0.09796	114.310904	61.825270
16	Tethys	6.18	Saturn	$5.6846 \cdot 10^{26}$	687	58 232	0.09796	130.853307	61.825270
17	Enceladus	1.10	Saturn	$5.6846 \cdot 10^{26}$	687	58 232	0.09796	111.122414	61.825270
18	Miranda	0.71	Uranus	$8.6832 \cdot 10^{25}$	1271	25 362	0.02293	63.043400	67.118566

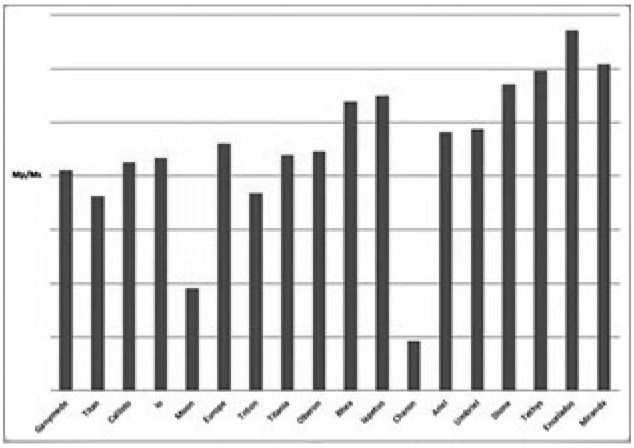

Figure 3: The ratio of the mass of the planet to the mass of the satellite (Moon and Charon are allocated) in logarithmic scale.

The calculation results show some differences in the cases of Moon and Charon, which are caused by the fact that they have large mass compared to the masses of their planets (Fig.3).

Conclusions

1. Roche limit for planetary satellites has been determined; it is less significant depending on the relationship of mass of the satellite and the planet, and more dependent on the ratio of densities.
2. The radius of Hill sphere has been specified for the planets in the Solar system, we show that its radius is the same for all satellites of the planet.
3. The calculation results show some features in the case of Moon and Charon, which are caused by the fact that they have relatively large mass compared to the masses of the planets.

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