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Study of the dynamics and evolutionary processes of near-Sun asteroids

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We consider near-Sun and near-Earth asteroids as well as dust rings existing in the inner part of the Solar System. Their distributions for orbital parameters and color indices are examined. The results obtained will allow to understand the physics of dynamic processes in both the Solar System and, as a consequence, the evolution of exoplanet systems.

Keywords: ear-Sun asteroids, near-Earth asteroids, dust rings.

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At present, the study of circumsolar asteroids (NSA) has received great development, as their study will allow us to understand the dynamics of solar activity in a new way [1]. The analysis of coronal processes is of great importance, since there is still no complete theory of the dynamics of the solar wind. In this paper, a simulation model of the dynamics of circumsolar asteroids with perihelion distances up to $q < 0.1$ au was built. The model includes the astrophysical parameters of these objects, their size distribution, and their dynamic behavior in space. The NSA digital model is designed to study their dynamics and predict them. Observations from ground-based and space systems [2] were used during the model building. As is known [3], circumsolar asteroids, according to observational selection, are divided into categories with high and low albedo. The latter can be attributed to objects that have small sizes and perihelion distances close to the Sun. For this reason, they are intensively destroyed even at a distance from the Sun [4]. This effect has become a criterion for distinguishing NSAs as objects that are either located or have recently moved in orbits with perihelion distances $q < 0.1$ au. Using the combined analysis of albedo and orbital parameters, it becomes possible to study the NSA as near-Earth asteroids [5]. The simulation model described in detail in [6] is being used. According to the model used, for objects with $q < 0.1$ au, the data for which are taken from the JPL catalog (http://ssd.jpl.nasa.gov), the orbital parameters and all possible values of the albedo and diameter parameters were simulated, since these data are mostly insufficiently determined. The simulation model makes it possible to predict the astrophysical parameters of the NSA, the distribution of their sizes, and their dynamic characteristics. It is possible to vary the simulation parameters of different NSA states and calculate their predictive trajectories. For this purpose, dynamic regression adaptive simulation is used. Simulation of changes depending on the temperature gradients of the luminosity characteristics of the orbital elements showed good agreement with the data obtained in the work [7].

In the interplanetary space there are particles of asteroid matter, which are products of their decay or products of asteroid collisions, and dust arising from the ejection of gas by comets. These particles form dust rings. In order to sustain their existence, the dust rings that are located in the inner part of the Solar System, in particular near the Earth's orbit, require constant replenishment by the small bodies of the Solar System. The dust that is released from asteroids, as well as the asteroids themselves, under the influence of the Poiting-Robertson effect, can leave the main asteroid belt and get into resonance with the Earth [8], which leads to the appearance of a circumsolar dust formation. Dust clouds are a temporary formation subject to various fluctuations, but maintained by replenishment from the main asteroid belt (MAB).

Dust rings and circumsolar asteroids in them are difficult to observe, since the Sun, due to its brightness, makes such observations difficult. Asteroids that are part of the Earth's dust ring are thought to be near-Earth objects (NEA) [9]. Some MAB asteroids have large eccentricities but small orbital perihelion points, causing them to overlap the orbits of terrestrial planets. The intersection of the orbits of the planets contributes to the collision of the NSA with them, hence such objects are dynamically short-lived.

Fig. 1 shows the dependence of the semi-major axis of the orbit of asteroids a (au) on the eccentricity e for all known near-Earth objects (NEA) (black dots) according to JPL (http://ssd.jpl.nasa.gov). The red line — is the intersection with the Earth's orbit in its inner region. Asteroids with orbits of the Atira type are located inside the Earth's orbit, in the figure they lie to the left of the red line and are located on it.

Inasmuch as objects made of more brittle matter are more susceptible to various deformations and tidal forces from the Sun and the larger planets, this leads to different stresses

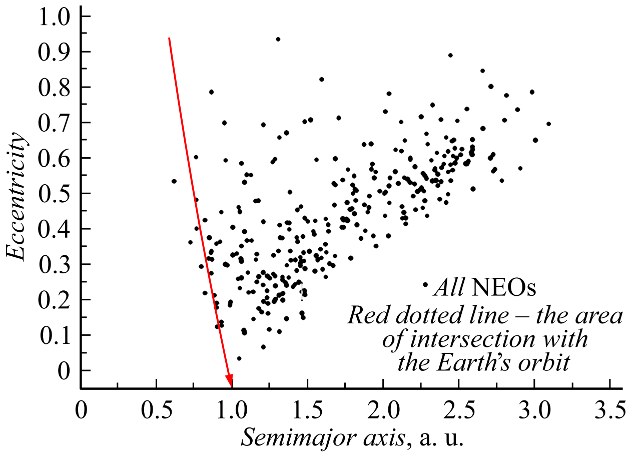

Figure 1. NSA Semi-Major Axis Dependence on Eccentricity.

within the object and its further destruction; thus, the dust rings, in particular, the dust ring near the Earth's orbit, are replenished with asteroid matter [10]. NSAs, which are resonant with the Earth's orbit, have a low eccentricity and are virtually observable in the vicinity of the Sun, as they are small in size (diameter $D \leq 1\,\mathrm{km}$), which is equivalent to about 20^m magnitude [11].

The NSA surfaces can reach temperatures that cause them to collapse due to changes in the surface of the object under the influence of a temperature gradient. As a consequence, the surface of the NSA dries out and the hydrated minerals decompose. The decay of the NSA and the resulting debris from such objects can contribute to the replenishment of the solar dust ring.

Fig. 2 shows the dependence of the isothermal spherical temperature of the blackbody (Tbb) calculated at the perihelion distance of the NSA orbit and the subsolar temperature (Tss) as a function of the magnitude of the semi-major axis of the NSA for objects having semi-major axes of the orbit smaller or comparable to the Earth's. The isothermal spherical temperature Tbb varies from 550 to 950 K, and the subsolar temperature Tss — from 750 to 1100 K. This corresponds to the temperatures at which the decomposition of hydrated minerals occurs. Experiments on the optical properties of meteorites in laboratories demonstrate that their optical properties change when heated [12]. Consequently, exceeding the temperature at which the decomposition of hydrated minerals occurs may lead to a change in the spectral properties of the reflection of objects, i.e., a change in their albedo [12,13]. In addition, the drying of the NSA surface under the influence of increased temperature can lead to thermal destruction of the object, which leads to the formation of dust and entails the replenishment of dust rings due to the dust component [14].

Based on laboratory studies of the optical properties of meteorites when heated [12], the question can be raised: is there any dependence for all NSAs on the effect of high temperatures in the perihelion region, for example, a similar color temperature for NSA? To find an answer to this question, the dependencies of the color index B-V as a function of the perihelion distance q of the NSA orbits were analyzed (Fig. 3). There is no relationship between the perihelion of the NSA orbits and the B-V color index. Similarly, the dependencies of the B-R color index as a function of perihelion (q) of the NSA orbits were analyzed. There is no relationship between the perihelion of the NSA orbits and the B-R color index. For such objects, the perihelion of the orbit q is about 1 au, and for them there would be a clear dependence of the color index B-R on distance, if there were one. In the constructed dependence of the absolute magnitude H on the perihelion of the orbit q for the NSA, no peculiarities were identified (Fig. 4). Analyzing the color dependencies of B-V and VR, it can be noted that the colors of near-solar and near-Earth objects coincide, and it is impossible to find a difference between these groups. As for the NSA, the B-V and V-R dependencies for them demonstrate that the asteroids

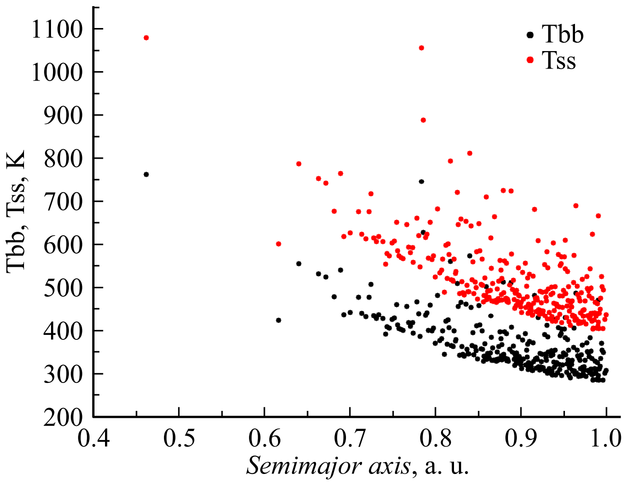

Figure 2. Dependence of NSA semi-major axis on Tbb and Tss temperatures

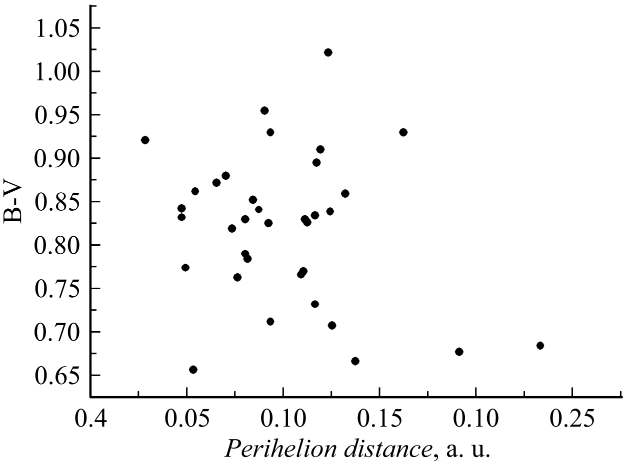

Figure 3. NSA perihelion distance vs. B-V color temperature.

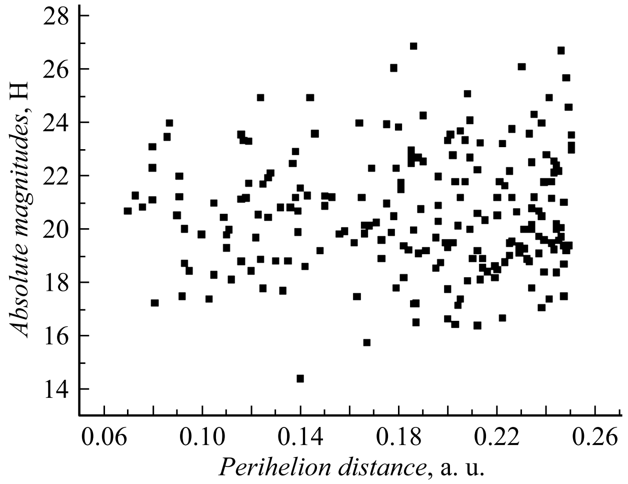

Figure 4. Dependence of NSA perihelion distance on absolute magnitude H.

correspond to the spectral types of asteroids according to the Tholen classification, which is proof that these NSA — are from the main asteroid belt. Thus, we can conclude that the color temperature does not depend on the distance to perihelion *q* or with other orbital parameters.

Summarizing all of the above, we assume that the dust rings are replenished from the MAB asteroids by gravitational and non-gravitational effects, such as solar pressure and the Poiting-Robertson effect. It can be assumed that circumsolar and near-Earth objects coincide in their dynamic characteristics, and it is difficult to separate them. This fact is confirmed by the analysis of the distributions of their orbital parameters, as well as distributions by color indices. We found no relationship between optical chromaticity and perihelion distance, nor between optical chromaticity and other orbital parameters. Thus, there is no reason to assume that objects with a small perihelion distance are affected by solar heating. The results obtained in the work can be used to assess the reliability of genetic links between meteoroids, the influence of solar radiation on the evolution of NSA [15], to study inflationary processes on the surface of asteroids [16], to develop the evolutionary theory of the Solar System and to plan new space missions and observation technologies.

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Conflict of interest

The authors declare that they have no conflict of interest.

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Translated by 123