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On the parameters of encounters of NEOs with the Earth

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Abstract. The paper presents the results of statistical modeling of the entry of near-Earth objects (NEOs) into the near-Earth space – a sphere with a radius of 0.01 AU around the Earth. The distributions of asteroids in the direction and velocity of approach to the Earth are constructed. The NEO population was modeled using the NEOMOD package and integrated for 110 years using the REBOUND package. The main results are: 1) the number of asteroids larger than 10 m in size entering to near-Earth space is approximately 1000 per year; 2) up to half of the asteroids can enter the near-Earth space from the side of the day-time-hemisphere; 3) there is anisotropy in the flux density of incoming asteroids. Typical velocity of approach to the Earth at the entrance to the near-Earth space is approximately 7.5 km/s (maximum speed can reach up to 30 km/s). These distributions can be useful in the design of a System of Observation of Day-time Asteroids (SODA).

Keywords: minor planets; asteroids: general; methods: numerical; Earth

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1 Introduction

Currently, active development of systems for detecting and monitoring dangerous celestial bodies of natural origin is underway (see, for example, Shugarov & Shustov (2022) and NASA document)[1]. To build more efficient systems, it is necessary to know the properties of the distribution of such bodies in near-Earth space. In this work, near-Earth space (NES) is defined as the space inside a sphere with a radius of 0.01 AU (which approximately equal to the radius of the Hill sphere) around the Earth. Various objects of natural origin constantly enter the NES. By definition, a near-Earth object (NEO) is an asteroid (NEA) or comet (NEC) with a perihelion distance of less than 1.3 AU. Among NEOs, there is a class of potentially hazardous objects (PHO) – these are objects larger than 140 m, the orbit of which approaches the Earth's orbit to a distance of less than 0.05 AU. However, the modern understanding of a dangerous body includes objects up to 10 m in size (Shustov et al. 2015). Although decameter-class objects do not pose a threat of global catastrophe, their fall can lead to significant local consequences. A good example is the meteorite fall near Chelyabinsk in February 2013.

The purpose of this work is to study the distribution of NEOs with a size of 10 m or larger entering NES, according to the directions of entry and the velocity of approach to the Earth. A similar study was carried out previously in the works (Shustov et al. 2013, 2017; Vereš et al. 2009; Farnocchia et al. 2012) based on the data available at that time. Over the past time, new data has appeared and new requests have appeared, especially for the safety of space activities.

2 Methodic

To solve the problem, it is necessary to trace the dynamic evolution of the NEOs population over a sufficiently large time interval (for example, several dozen characteristic periods of the NEOs), noting all entries of asteroids into the NES sphere. When using this technique, the task can be divided into two parts: 1) building a model of the population of NEOs with object sizes of 10 m or more; 2) integration of the movement of asteroids with recording of approaches to the Earth.

To build the NEO model, the open source NEOMOD software package (Nesvorný et al. 2024) was used. The package takes into account the sources of NEOs and generates distributions of NEOs in absolute magnitude H and orbital elements of the asteroids. A population with 1 million objects with $H < 28$ was generated.

[1] https://www.whitehouse.gov/wp-content/uploads/2023/04/2023-NSTC-National-Preparedness-Strategy-and-Action-Plan-for-Near-Earth-Object-Hazards-and-Planetary-Defense.pdf (Last accessed 2024-07-25)

Taking this into account, subsequent distributions will be given in normalized form (i.e. the expected number of real objects).

At the second stage, the movement of a given population of asteroids was integrated, in which approaches to the Earth were monitored. The open code REBOUND (Rein & Liu 2012) was used. The integration technique included MERCURIUS (Rein et al. 2019) and IAS15 (Rein & Spiegel 2015) numerical integrators (which are included in the REBOUND standard library). Since the integration step cannot be arbitrarily small, the asteroid was not detected exactly on a sphere with a radius of 0.01 AU, but with some delay, i.e. at a smaller distance from the Earth (but not more than 0.0008 AU from the border).

3 Results

According to the simulation results, the number of model asteroids entering the NES over the estimated time interval (110 years) was 9950. From this, an estimate can be made for the average expected frequency of asteroids entering the NES. Since the calculation was carried out for 1 million model NEOs, which is approximately 1/11.5 of the total population of NEOMOD-generated NEO population, the expected number of occurrences in the NES is $(9950/110) \cdot 11.5 \simeq 1040$ asteroids per year. Naturally, most of these entries are made by small-sized asteroids.

Figure 1 shows the velocity of entry of asteroids into the sphere of NES with respect to the Sun-Earth-asteroid angle, normalized to a unit of solid angle and a unit of time. The figure highlights the increased concentration of objects in the direction of the Sun (0° in the figure) and in the opposite direction (180°). If we conditionally highlight the region of angles smaller than 90° (corresponds to the "everyday" definition of the daytime sky), then it is easy to see that about half of the entries into the NES occurs from the daytime hemisphere. Note that the obtained distribution is close in shape to that obtained earlier in Shustov et al. (2017), obtained using the NEOPOP model with a smaller number of asteroids.

Let us now consider the distribution of the flux of incoming asteroids in all directions. On the NES-sphere under consideration, the intersection of which is fixed, we will use a modified ecliptic coordinate system that is fixed relative to the direction of the Sun (the Sun always has coordinates (0, 0)). Figure 2 shows the flux density of incoming NEOs by directions in the described coordinate system. The average number of asteroids entering the NES in a given direction per year is shown in color. The distribution shows an increased flux density near the directions toward and against the Sun, which is also reflected in Fig. 1. The region near the ecliptic plane is also distinguished. A particularly striking feature is the decreased density in the directions

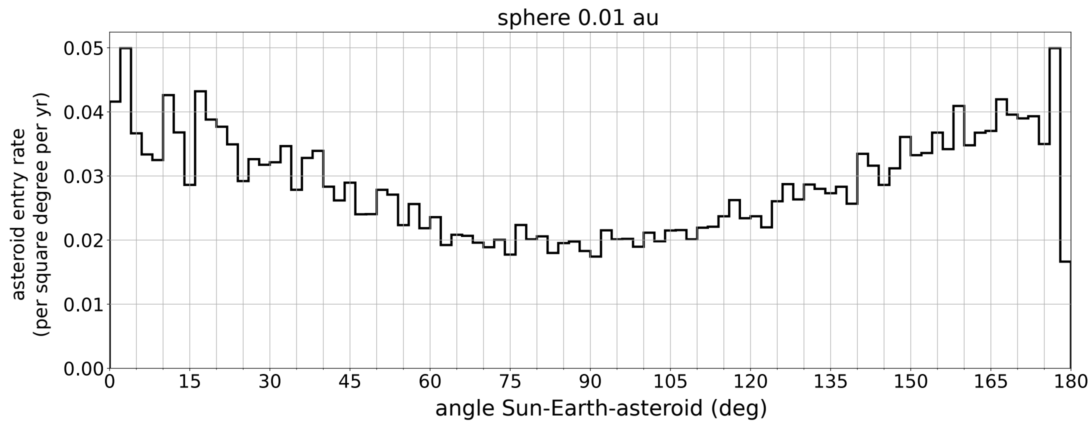

Fig. 1. Distribution of the flux density of asteroids entering the NES, by the angle between the direction to the Sun and the direction to the asteroid. 0° corresponds to the direction to the Sun.

corresponding to approximately from −120° to −60° in latitude, which corresponds to directions near the Earth's apex. Such a decrease in density is not observed in the opposite direction, near 90° in latitude. In simpler terms, there are significantly more asteroids "catching up" with the Earth than there are asteroids that the Earth "catches up" with. This is due to the structure of the NEA distribution by orbital elements.

Figure 3 shows the distribution of the velocity of approach, i.e. the rate of change of distance from an asteroid entering the NES to the Earth. The maximum of the distribution is at approximately 7.5 km/s (the value of the total spatial velocity is obviously higher). Of course, with further approach to the Earth the velocity of approach will increase. A very small proportion of asteroids entering the NES approach the Earth at a velocity of more than 30 km/s. The shape of the distribution and the position of the maximum are in qualitative agreement with the distribution constructed in Naroenkov & Shustov (2012) based on the data available at that time.

4 Summary

As a result of the calculations, an estimate was obtained for the frequency of decameter-class asteroids entering the NES, which is approximately 1000 entries per year. At the same time, there are on average about four NEOs in the NES at any given time. These are mainly relatively smaller NEAs. It should be noted that the estimate for the number of decameter and larger asteroids in the full NEO population in the NEOMOD program is approximately 11.5 million, which differs significantly from

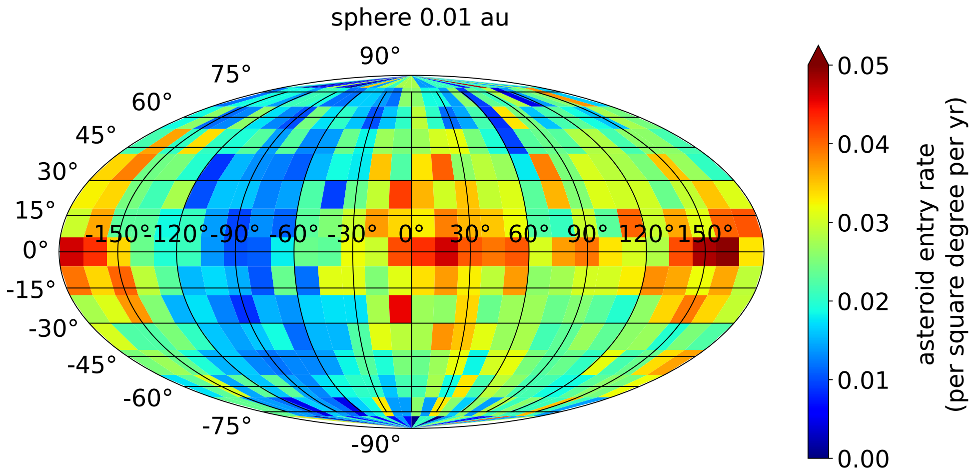

Fig. 2. Distribution of the flux density of asteroids entering the NES by directions in the modified ecliptic coordinate system.

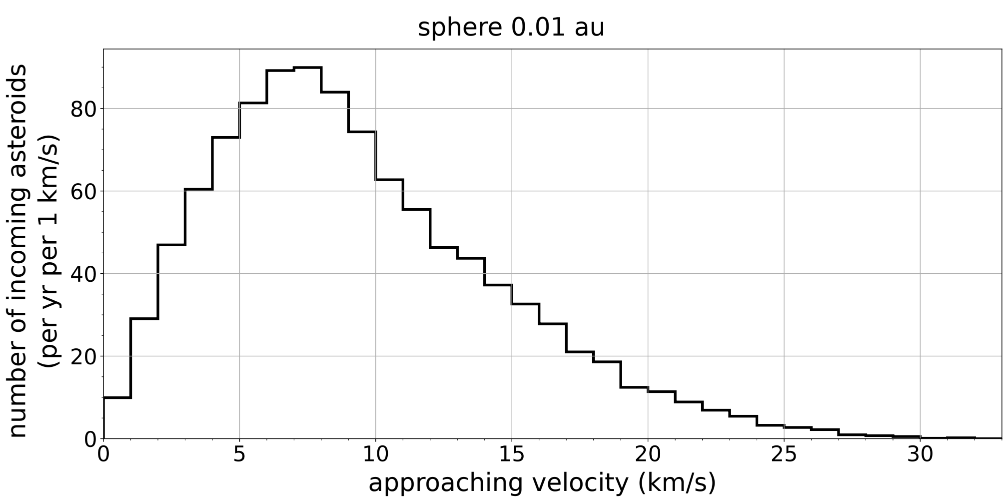

Fig. 3. Distribution of asteroids entering the NES by the velocity of approach to the Earth.

the estimate in the NEOPOP package, which predicts a population of about 65 million objects. In the above-mentioned NASA document the same estimate is about 45 million asteroids. Therefore, in order to use quantitative estimates, it is necessary to determine the expected population size and scale the expected number of approaches in accordance with the selected model.

In connection with the issues of asteroid-comet hazard, it is important to note that up to half of the asteroids enter the near-Earth space from the daytime hemisphere and cannot be detected by ground-based and near-Earth optical means.

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