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On the parameters of NEO encounters with the Earth

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Subset of near-Earth asteroids (NEAs) – potentially hazardous asteroids (PHAs) i.e. objects whose MOID does not exceed 0.05 au are obviously of practical interest. The modern interpretation of the problem of mass detection of PHAs at an acceptable level of completeness (typically 90%) includes a practically justified requirement for the detection of asteroids from 10 m in size. PHAs that may enter the near-Earth space (NES) are of particular interest. The NES refers to the space inside a near-Earth sphere with a radius of 0.01 au, which roughly corresponds to the radius of Hill's near-Earth sphere. We named such PHAs as very potentially hazardous asteroids (VPHAs) and denoted the subgroup as G_{VPHA}.

So far, there are no detection systems that meet the above completeness requirement for PHAs but work is underway to create them. To build an effective detection systems it is necessary to know the properties of the practically important distributions of PHAs (and especially those of VPHAs): special one, of their brightness and angular velocity.

For the construction and analysis of these distributions of practical importance, it is advisable to rely on the most complete sample of NEAs. One can say about the completeness of detection only for the NEAs larger than ~0.7 km. Since the completeness for the population of smaller PHAs is extremely small, models are used to study the statistical properties of this population. Here we use the generally accepted method of modeling the NEA population using the open software package NEOMOD [1].

Since NEOMOD provides only a set of parameters (*H, a, e, i*) as the output, to generate a complete set of initial conditions, the existing set was supplemented with three more parameters that allow setting the initial position and velocity of the asteroid: the longitude of the ascending node, the argument of the perihelion and the average anomaly. Among the asteroid population, these values were distributed evenly in the range [0-2π), which is consistent with the distribution of these values for the observed NEAs. Here we name this population G_{NEA}.

According to the NEOMOD a number of NEAs larger 10 m is about 11.5 million. After the initial distribution of the NEAs in size and motion parameters are set, the position and velocity of the bodies, the distribution of bodies in space, their *V* magnitudes and the geocentric angular velocities can be calculated for any time moment. We integrated asteroid motion using the REBOUND open source software package [2].

Our goal is to consider conditions for optical observations of the NEAs (PHAs and VPHAs) with ground-based telescopes, i.e. observations on the night sky. A simple illustration explaining the concept of night sky is given in Fig. 1. More detailed description of concepts of day-time sky and night sky is given in [3].

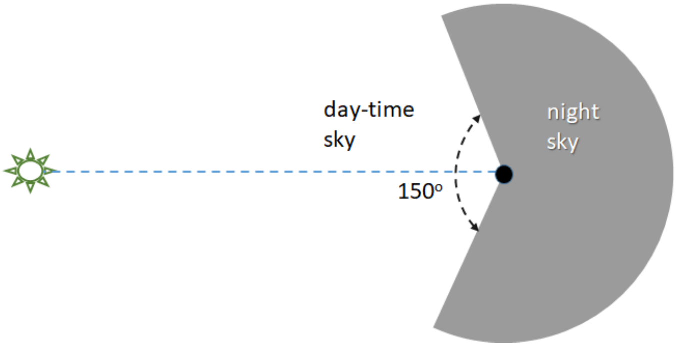

Figure 1. Night sky.

The cumulative *V*-distributions of asteroids of the G_{VPHA} and G_{NEA} ensembles calculated using formulas from [4] (albedo was assumed to be 0.15) are given at Fig. 2 for distances 0.01 au and 0.1 au. The numbers of asteroids *N* having absolute asteroid magnitude less than *H* value are given. There are few larger asteroids, so the dependence curves are not smooth.

As it follows from Fig. 2 an instrument with a limiting magnitude of ~21m is required for observations of 90% of NEAs larger than 10 m at a distance of 1.5 million km. The 140 m-sized NEAs can be confidently (> 95%) observed at a distance of 0.1 au with a telescope with a penetrating capacity of 20m. However, for larger distances mass detection of such objects becomes a difficult (almost impossible) task for visible-range telescopes.

Let us now analyze the distribution of the asteroid flux incoming the NES by directions. For this purpose, we use a coordinate system which is determined by direction to the Sun, and by ecliptic plane as the main one. We designate the coordinates on the sphere: latitude ξ and longitude ζ. The direction to the Sun always corresponds to the origin of coordinates (ξ = 0°, ζ = 0°), the direction against the Sun — (ξ = 0°, ζ = 180°). In such a coordinate

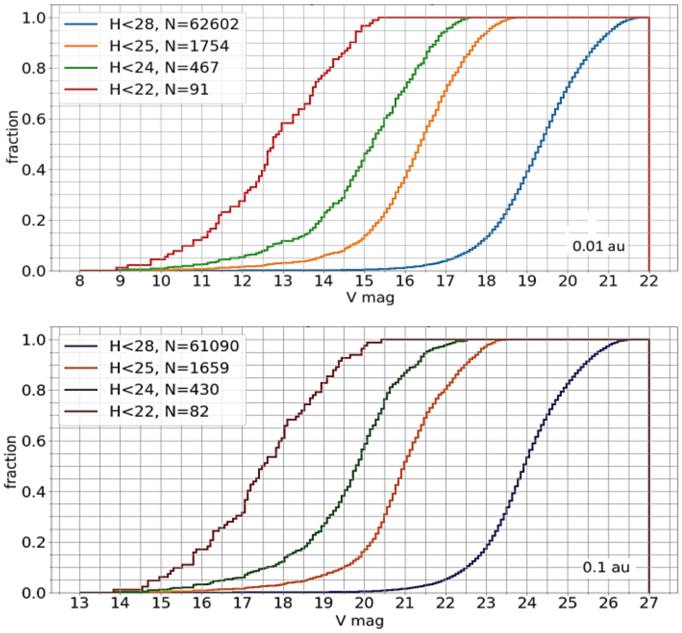

Figure 2. The fraction of the number of asteroids from having V less than the specified value at the specified distances. The numbers of asteroids N having absolute asteroid magnitude less than H value are given.

system, the direction corresponding to the direction of the Earth's velocity vector (apex) is also fixed and is given by the coordinates (0°, −90°).

Figure 3 illustrates the flux density of NEAs (here VPHAs) incoming the NES. The color shows the average number of asteroids entering the NES in a given direction per year per square degree.

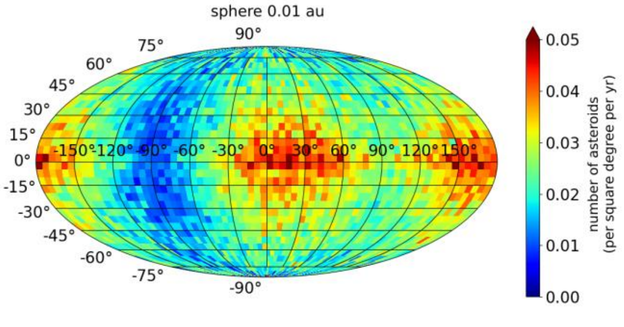

Figure 3. Distribution of the flux density of asteroids entering the NES by direction

Fig.3 demonstrates an increase in the flux density near the directions toward and against the Sun. In addition, the region near the ecliptic plane stands out. Particularly noteworthy is the decreased density in the directions corresponding to approximately $-120° < \zeta < -60°$, that is, near the Earth's apex. Such a decrease in density is not observed in the opposite direction, in the vicinity of $\zeta = 90°$. In simpler terms, there are significantly more asteroids "catching up" with the Earth than with the asteroids that the Earth "catches up" with. See for more details [5].

The angular velocity ω of the object is an important parameter too. Knowledge of ω allows us to estimate the qualification time, i.e. the minimum time interval required for the preliminary classification of the body's orbit. Knowledge of ω is also necessary to evaluate the blurring of the image of a moving object in star tracking mode. If the amount of blur in the image of a point object during exposure is greater than the pixel size, then the angular resolution deteriorates and (for weak objects) the recorded brightness decreases. For example, as shown in [6], in observations with the ATLAS telescope (the characteristic pixel size is 2") at an exposure of 30 s, the attenuation of an object moving with an angular velocity of 0.6 "/s is $\Delta V = 2.5^m$. If the angular velocity does not exceed 0.06 "/s, i.e. the image does not go beyond the pixel, then attenuation does not occur.

It is clear that the main factor influencing the angular velocity of an object is distance, since distance can vary by orders of magnitude, and spatial velocities only by several times. Dependence ω on distance is illustrated by Fig. 4.

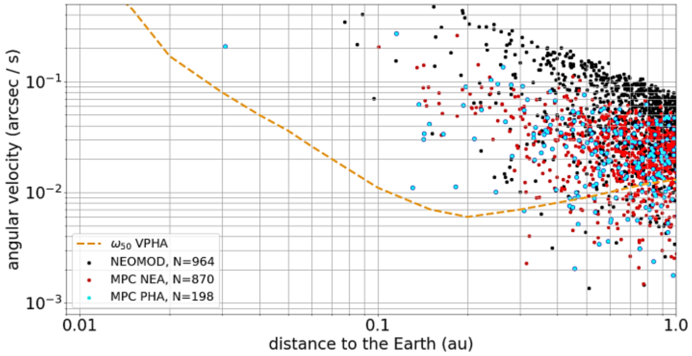

Figure 4. The positions of larger NEAs (H<22) in the angular velocity-distance diagram for May 5, 2025. Asteroids from the G_{NEA} ensemble are shown by black symbols, NEAs (not PHAs) from the Minor Planet Center data base – by red symbols, PHAs – by blue symbols. The dashed line shows the dependence of the median angular velocity ω_{50} on the distance for bodies from the G_{VPHA} ensembles.

Angular velocities for the G_{NEA} ensemble behave "as they should" and are approximately inversely proportional to the distance. For the G_{VPHA} the behavior of angular velocity is more complex. The median angular velocity ω_{50} over a distance range of 0.02–0.5 au is almost an order of magnitude less than the average for G_{NEA}. This is not a mistake, but is due to the fact that a filter was applied to the overall distribution of NEAs: only those NEAs that approach the Earth at a distance 0.01 au in 100 years were considered. It can be noted that the real PHAs (according MPC's data) are in Fig. 4 at a distance range of 0.02–0.5 au on average noticeably closer to the ω_{50} curve than the those from the G_{NEA} ensemble.

This (statistical) behavior of angular velocity is important to keep in mind when selecting an observation strategy. If we are interested in bodies that can approach the Earth at a distance of less than 0.01 AU, then we need to pay attention to objects with very low angular velocity.

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