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On the dynamical evolution of the NEO population

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We use REBOUND numerical approach to study dynamical evolution of an ensemble of small bodies of the Solar System. The goals are to improve estimates of depletion rate of the NEO population and to study the "orbital diffusion" effect – evolution of orbits in different regions of orbital parameters space. We consider a complete set of 3024 large (> 1 km) asteroids with perihelion distance q < 1.6 AU. The set includes 833 NEOs (q < 1.3 AU) which seems to be practically complete. We integrated orbits of asteroids for 10 Myr. At the start of integration the major semimajor axis – eccentricity (a-e) space was divided into 5 groups. Relative population of each group was traced during integration. We found that median lifetime of total NEO population (without any replenishment) is about 4 Myr, but strongly differs for various groups. Orbital diffusion becomes very significant at early stage of the ensemble evolution.

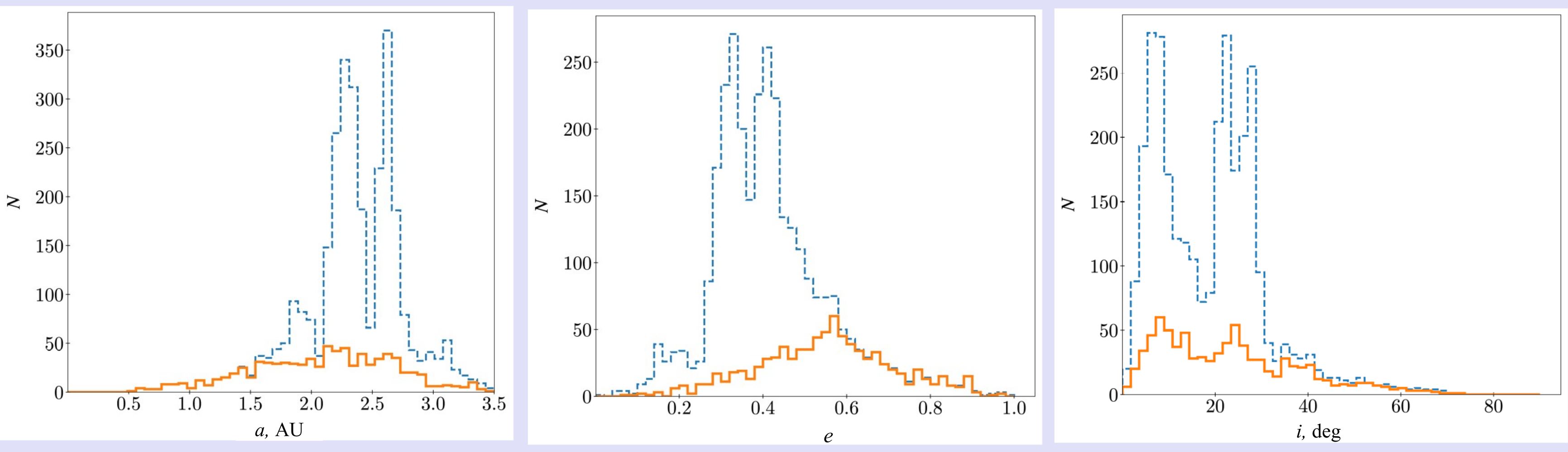
Introduction

Evolution of population of the near-Earth objects (NEOs) is an important issue both for basic studies of the evolution of the Solar system and for more applied problem of planetary protection. By definition, NEO is a minor body of the Solar System body wich perihelion distance $q < 1.3$ AU. Nowadays there known over 25 thousands objects, asteroids and comets.

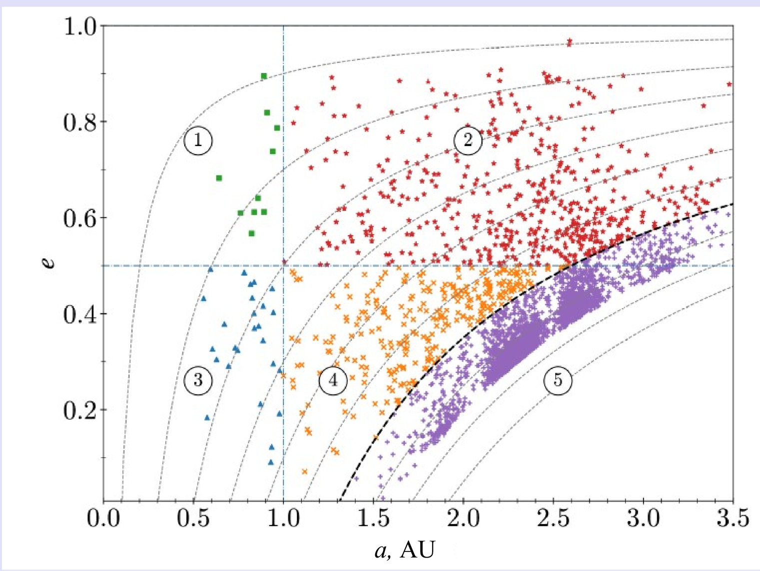
Investigations of crater-formation process on the surface of the Moon provides information about NEO population over a long period of time. According to [1], formation rate of luar impact craters larger that for 1 km did not change during last 2 Gyrs. This means that any moment of time number of NEOs was almost constant. On the other hand a given NEO population permanently decreases due to collisions with the Sun, planets or via ejection from the Solar system. Estimates of lifetime of NEO population (essentially NEOs are NEAs - near Earth asteroids, since comets are very rare) in previous works by different authors bring only rough estimates of the depletion timescale (about 10 Myr [2,3]). Thus we have a situation of dynamic equilibrium when depletion is balanced by replenishment. If we know depletion time scale we can better understand mechanisms of replenishment. To describe the depletion process one uses a scale t_{NEA} – time of twofold decrease of number of NEAs in the population (median lifetime of population). The primary goal of this work is to improve estimates of t_{NEA}.

Sampling

We sampled 3024 asteroids from Minor Planet Center database with the following filters: the perihelion distances $q < 1.6$ AU and absolute magnitude $H < 17.7^m$ (diameter $d > 1$ km). There are 833 NEAs (near Earth asteroids $q < 1.3$ AU) in this ensemble. The sample of NEAs can be considered as a representative one.



Distributions of asteroids in a, e and i: blue line – all asteroids, orange line – NEAs.



Groups of asteroids in a-e space :

1 – a < 1, e > 0.5	NEAs	
2 – a > 1, e > 0.5		
3 – a < 1, e < 0.5		
4 – a > 1, e < 0.5		
5 – q > 1.3	non-NEAs	

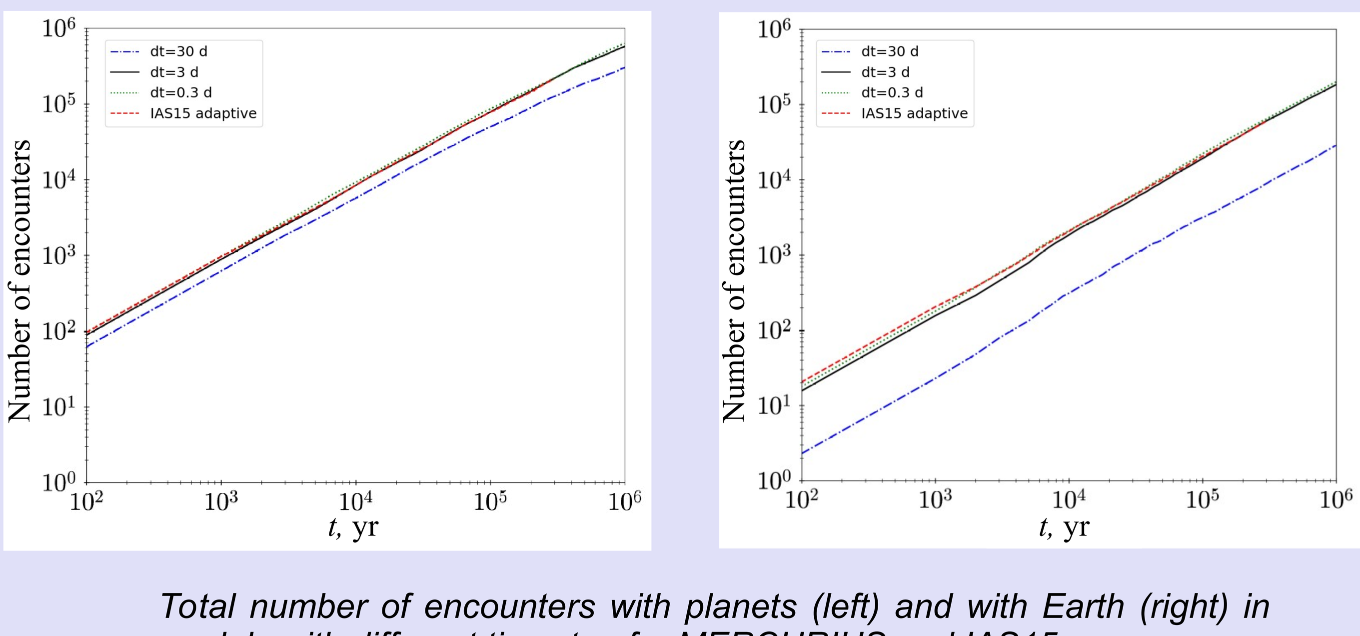
Numerical approach

Dynamical evolution of the population of asteroids was integrated for 10 Myr with REBOUND code [4]. A hybrid scheme MERCURIUS (WHFast + IAS15) [5] was used in following model:

Gravitation field by: Sun + planets (active particles)
Asteroids: passive particles in gravitational potential of active particles.

The scheme use symplectic WHFast as main integrator and switches to IAS15 with adaptive timestepping to resolve close encounters. Geometrical sizes of major bodies are used to simulate process collisions. Initial conditions was taken from NASA JPL HORIZONS database.

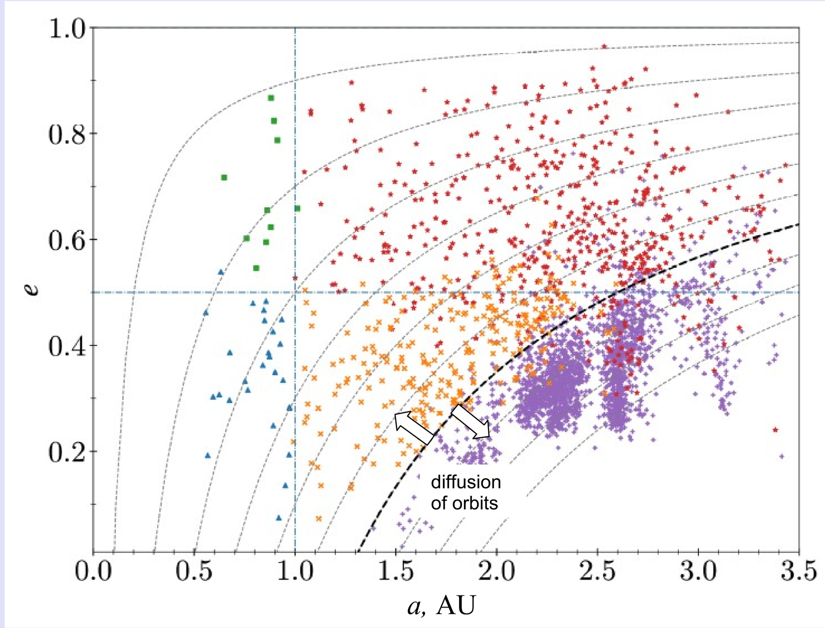
Evolution of NEAs is mostly determined by close encounters with planets. To find optimal time step for the integrator we integrated test sample with 500 NEOs generated by ESA NEOPOP [www.neo.ssa.esa.int/neo-population-generator] with different timesteps. The time step was considered as acceptable when number of encounters converges We found that 3 days is optimal.



Total number of encounters with planets (left) and with Earth (right) in models with different timestep for MERCURIUS and IAS15

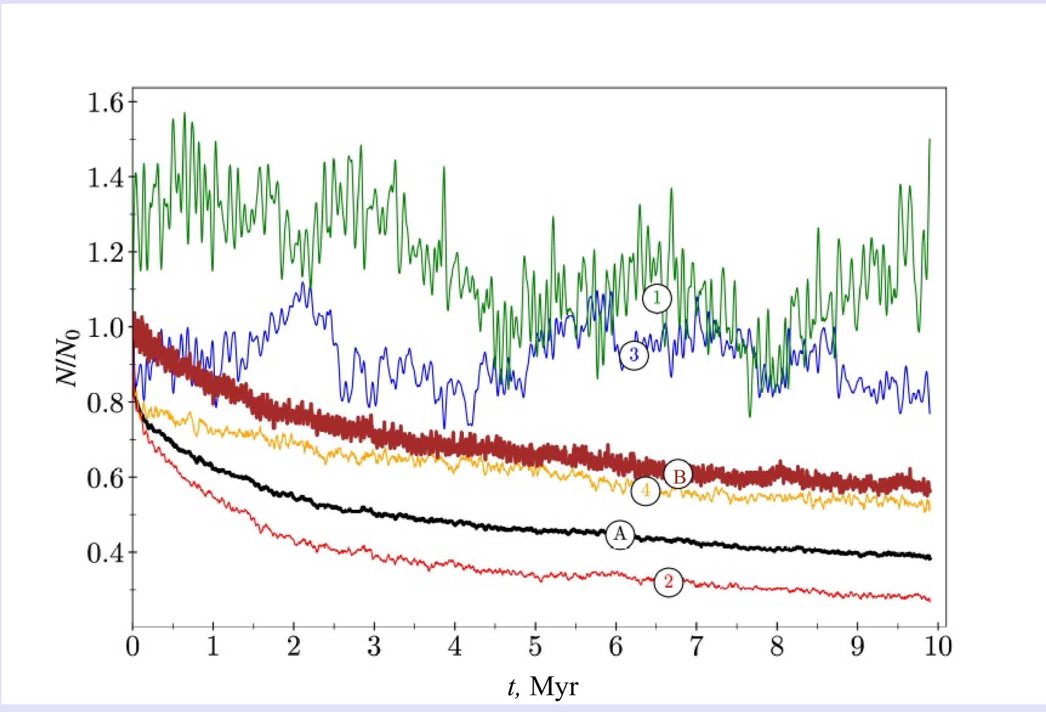
Results

Evolution of orbits is relatively fast due to close encounters with planets and many objects which initially were NEAs leave the region of $q < 1.3$ AU and vice-versa initially non-NEA objects cross the line of NEO definition and becomes NEAs. Also objects cross boundaries between groups ins the NEO-definition region.



Objects in a-e space after 3 kyr of integration. Colors and markers correspond the initial ones (see Section Sampling).

Depletion process of NEA population can be described by function N/N_o, *where N – a* current number of NEAs, N_o - initial number of NEAs.



Depletion of NEAs in time.

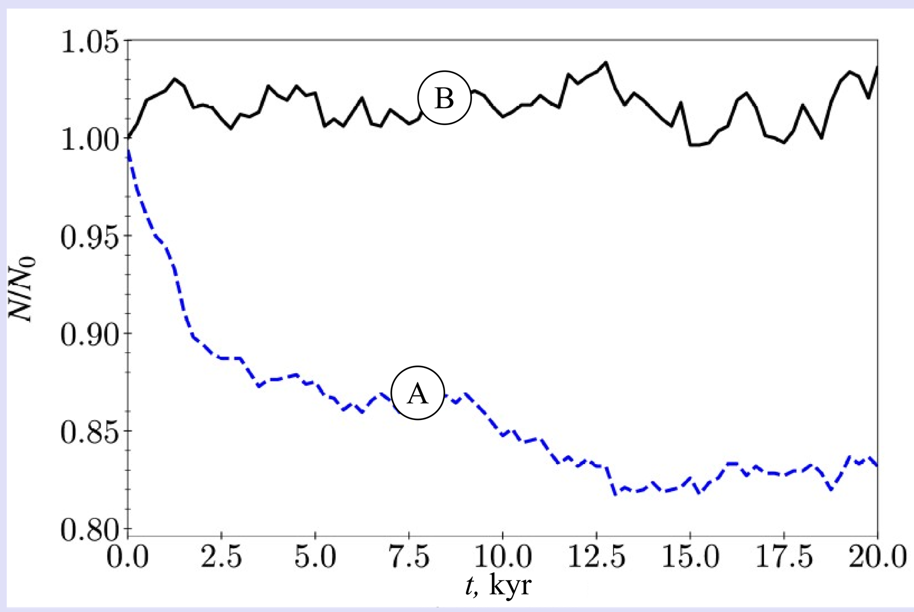
Line "A" matches the NEO-only model (if there are no group 5 in initial conditions)

Line "B" matches model with all sampled objects.

Lines marked with numbers corresponds groups in a-e space (see Section Sampling).

Objects from groups 2 and 4 are more influenced by close encounters and deplete faster than others. Line "A" reaches fraction of 0.5 at about 4 Myr, which gives estimation for t_{NEA}.

Next figure shows short-term dynamics of NEA fraction N/N_o for NEA-only ("A") and NEA+non-NEA ("B") models. For the model "A" diffusion of orbits has one-way behavior, hence NEA fraction rapidly decreases until saturation of non-NEA region. Model "B" includes objects with $q > 1.3$ as well as NEAs and illustrates two-way diffusion: one can see insignificant jumps, but general trend is constant.



Evolution of NEA fraction at first 20 kyr.

Dashed blue line "A" corresponds NEA-only model

Solid black line "B" corresponds model with all sampled objects

By analyzing dynamics of line "A" (NEA-only model), one can find an estimation for diffusion rate for NEA population:

$$\frac{d(N/N_0)}{dt} \simeq 6 \cdot 10^{-5} yr^{-1}$$

References

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See for more details: R. V. Zolotarev and B. M. Shustov, On the dynamical evolution of the near-Earth asteroids population, Astronomy Reports (in press).