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ON THE KEYHOLE POSITIONS OF APOPHIS

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ABSTRACT

The structure of initial conditions, corresponding to possible collisions of asteroid Apophis with the Earth, is very complicated (Sokolov et al., Solar System Research 2013, V. 47, N 5, P. 441-447). This structure is similar to fractal structure due to resonant returns. We discuss the case of asteroid Apophis, because its possible collisions have been carefully investigated and Apophis will be hazardous as before despite orbit refinement in 2013. Other hazardous asteroids have similar complicated structures of keyholes.

The method of approach and collision detections includes initial conditions variations using Everhart integrator and ephemerides DE405. We change only one variable (semi-major axis). Initial condition variations in the future (01.05.2035 for Apophis) were used as well in order to overcome the loss of accuracy in the case of encounter in 2029. The important characteristics of trajectories under study, including relative positions and sizes of keyholes, leading to collisions are stable with respect to small changes of motion model (Sokolov et al., Solar System Research 2012, V. 46, N 4, P. 291-300). The calculations were performed using a computer cluster of the Saint-Petersburg State University.

We derive and discuss the list of possible collisions of Apophis in XXI century. It contains many keyholes, despite Apophis orbit refinement in 2013. The only essential keyholes are presented now in the NASA website http://neo.jpl.nasa.gov/risk. In addition to 9 possible collisions in XXI century in this website, the important keyholes correspond to collisions in 2055, 2056, 2064, 2066, 2068, 2068, 2074, 2075, 2078, 2087, 2098. Only in the region of initial semi-major axes between collisions in 2060 and in 2076 (in the NASA website) are located more than 100 keyholes.

To estimate the sizes of the keyholes, the range of semi-major axes at 01.05.2035, corresponding to each collision, was calculated. An alternative method of estimation is using the range of minimum geocentric distances at 2051 for trajectories corresponding to each collision.

To avoid collision, we have to move Apophis into the region of semi-major axes without keyholes (Yeomans D.K. et al., 2009 IAA Planetary Defense Conference, Granada, Spain, 2009). We investigate the time dependence of semi-major axis regions leading to collisions and evolution with time the regions without collisions. Sizes of regions, leading to collisions as well as the regions without collisions are increasing with time. The sizes of regions of possible asteroid motion decrease with time due to the orbit refinement. After 2029, the dimensions of regions without collisions as well as the regions leading to collisions, should be multiplied by about 100000. The next significant change of dimensions takes place in 2051. The value of multiplicator depends on the minimum geocentric distance in 2051, it may be about 10000, 1000.

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