

**MINIMUM PERIHELION DISTANCES AND DWELL TIMES DURING THE DYNAMICAL EVOLUTION OF NEOs.** A. Toliou<sup>1</sup>, M. Granvik<sup>1,2</sup> and G. Tsirvoulis<sup>1</sup>, <sup>1</sup>(Asteroid Engineering Laboratory, Onboard Space Systems, Luleå University of Technology, Box 848, SE-98128 Kiruna, Sweden), <sup>2</sup>(Department of Physics, PO Box 64, 00014 University of Helsinki, Finland).

**Introduction:** The orbital history of near-Earth objects (NEOs) can be described as “chaotic”, since they are characterized by close encounters with the terrestrial planets. This means that although there are not many observed NEOs that currently exhibit orbits with low perihelion distances ( $q$ ), some members of the NEO population may have had a very different past compared to their currently observed orbits, which may include acquiring very low  $q$  values.

Meteoritic samples show signs of heating processes which, to some degree, can be a result of extreme solar irradiation. [1] explored this possibility by studying the dynamical history of NEOs and deriving their surface temperatures by using thermophysical models. In their study, they used the NEO population model by [2],[3] which was the most complete model at that time. Since then, an updated model by [4],[5],[6] has been derived, that improves upon some shortcomings of the [2],[3] model and most importantly, accounts for the disruption of NEOs close to the Sun [4].

Since the orbit of a meteorite, or a fireball in general, is expected to be similar to the orbit of its parent body, knowing the early orbital evolution of the latter is crucial in order to determine several physical properties of the former, such as the maximum temperature it has experienced, which in turn is useful in determining its composition.

The goal of our study is to construct a look-up table which can offer a probabilistic assessment of the history of the evolution of  $q$  for an asteroid with given orbital elements  $a,e,i$  and absolute magnitude  $H$ . Using the same data set as [5],[6] we will provide the probability that an asteroid, that currently has a given orbit, has at some point reached a perihelion distance below a given threshold  $q_s$ . In addition, we will calculate the cumulative time that an asteroid with that orbit has had a perihelion distance in a specific range.

**Methods:** We divided the NEO region in 42 bins of width 0.1 AU in  $0 < a < 4.2$  AU, 25 bins of width 0.25 in  $0 < e < 1$ , 45 bins of width  $4^\circ$  in  $0^\circ < i < 180^\circ$  and 40 bins of width 0.25 in  $15 < H < 25$  resulting to a grid of 1.890.000 cells. We used the same grid resolution as [6] in order to match the debiased steady-state distributions of their model. In addition, we split the  $0 < q < 1.3$  AU region in 26 bins of width 0.05 AU with each edge corresponding to the relevant  $q_s$  values.

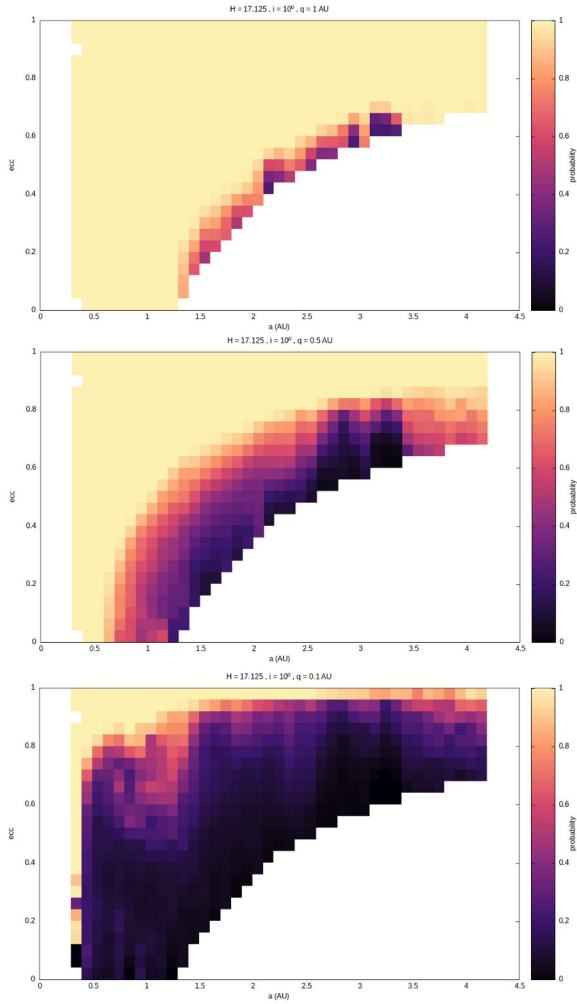
In order to calculate the probability that a test asteroid with orbital elements within the range of a cell has had a minimum perihelion distance  $q_{\min} < q_s$  during its orbital history, we conducted our study on an object by object and timestep by timestep basis. We first located the  $a,e,i$  cell the asteroid belongs to according to its orbital elements in one particular timestep and added a counter in an *event bin*. Next, we found the  $q_{\min}$  in the interval from the beginning of the test asteroid’s orbital integration, until the current timestep. We then added counters to all the  $q$ -bins that have  $q_s \geq q_{\min}$ . We follow the same procedure for all test asteroids available from integrations of [4],[5]. By adding up all the “counts” in each  $a,e,i$  cell for every  $q$ -bin that have been recorded from every asteroid and dividing them with the total number of “counts” in the *event bin* we can get the probability that an object with certain orbital elements, corresponding to each cell, has had  $q < q_s$ .

A similar process is carried out in order to derive the dwell times in each  $q$ -bin, i.e. the time an asteroid spends having  $q$  in the range of a given  $q$ -bin. At each timestep and for a single test asteroid, we find the  $a,e,i$  cell it belongs to according to its orbital elements and record the number of times  $q$  falls into any  $q$ -bin. This takes into account the orbital evolution from the beginning of the integration of this object until that point in time. The actual dwell time is found by multiplying the counts in each bin by 250 yr, which is the  $\Delta t$  of the integration output timestep. After repeating these steps for every test asteroid, we calculated the average and the median dwell time of each cell over all objects.

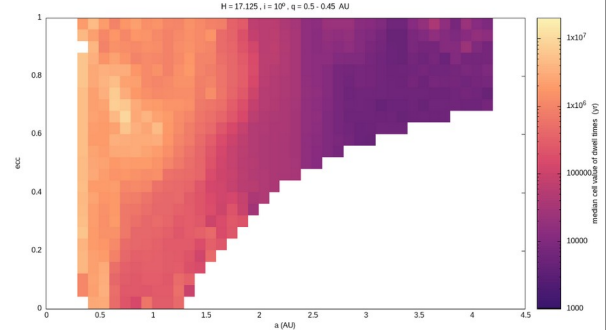
**Results:** We split the total number of test asteroids in 6 groups, according to their recorded escape routes from the main asteroid belt and calculated the source-specific  $q_{\min}$  probabilities for each cell of the grid. [6] have calculated the relative fraction of NEOs from each source region that contribute to each  $a,e,i,H$  cell,  $\beta(a,e,i,H)$ . The linear combination of the source specific  $q_{\min}$  probabilities, multiplied with the source specific  $\beta$  parameters gives us the weighted  $q_{\min}$  probabilities in each  $a,e,i,H$  cell. The same process is done for calculating the weighted average and median dwell times in each cell.

In Figure 1 we show three representative plots in the  $a-e$  plane for all cells with  $i=10^\circ$  and  $H=17.125$ . The color coding corresponds to the  $q_{\min}$  probability.

In the top panel  $q_s=1$  AU, in the middle  $q_s=0.5$  AU and in the bottom  $q_s=0.1$  AU. Figure 2 shows in the top panel the average and in the bottom panel the median dwell times for the same  $i$  and  $H$  cells and for the 0.45-0.5 AU  $q$ -bin.



**Figure 1:** distribution of the  $q_{\min}$  probability in the  $a$ - $e$  plane for cells with  $i=10^\circ$ ,  $H=17.125$  and  $q_s=1$  (top), 0.5 (middle) and 0.1 (bottom) AU.



**Figure 2:** The average (top) and median (bottom) dwell times of cells with  $i=10^\circ$ ,  $H=17.125$  in the  $a$ - $e$  plane for the  $0.45 < q < 0.5$  AU  $q$ -bin.

#### References:

- [1] S. Marchi, et al. (2009) *MNRAS*, 400, 147–153.
- [2] W.F. Bottke et al. (2000) *Science*, 288, 2190–2194.
- [3] W.F. Bottke et al. (2002) *Icarus*, 156 (2), 399–433.
- [4] M. Granvik et al. (2016) *Nature*, 530, 303–306.
- [5] M. Granvik et al. (2017) *A&A*, 598, A52.
- [6] M. Granvik et al. (2018) *Icarus*, 312, 181–207.

