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Population characteristics for natural Earth satellites

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Abstract

We provide estimates for various population characteristics—such as the steady-state size-frequency distribution (SFD) and residence-time distributions—for natural Earth satellites (NES). These objects are temporarily captured from the near-Earth-object (NEO) population due to purely gravitational interactions between mainly three massive bodies, that is, the Sun, the Earth, and the Moon, and an NEO with negligible mass. We carry out orbital integrations to estimate the capture probability of NESs from the near-Earth space as a function of orbital elements, and combine it with the current best estimates for the SFD and orbital distribution of NEOs. The resulting NES model predicts that there is, on average, one one-meter-diameter NEO temporarily orbiting the Earth at any given time.

1. Introduction

The currently known NEO population contains two objects that have certainly been temporarily-captured natural Earth satellites—1991 VG and 2006 RH_{120}. Whereas the natural origin of the previous can be debated, the latter is certainly natural with an absolute magnitude of about $H = 29.9$ [1]. To the best of our knowledge there are no other estimates of the characteristics of the steady-state population of these objects.

2. Results

We integrate a swarm of test particles through the Earth-Moon system to estimate the capture probability as a function of orbital elements. We define a particle a *temporarily-captured orbiter* (TCO) if it makes more than one revolution about the Earth in a co-rotating frame while having a negative Kepler energy with respect to the Earth and a geocentric distance less than 0.03 AU (Fig. 1).

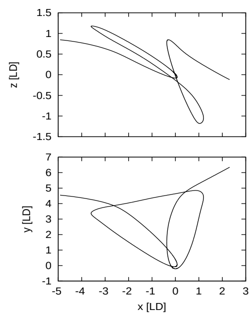

Figure 1: The orbital path of an average TCO in geocentric, inertial Cartesian coordinates. The TP is captured for 280 days and during that time it makes 2.94 retrograde revolutions around the Earth in a co-rotating frame. The distance scale is given in lunar distances ($1\,\mathrm{LD} \approx 0.00256\,\mathrm{AU}$).

Considering that only one confirmed NES captured from the NEO population (2006 RH_{120}) has ever been detected and that that object has an equivalent diameter of a few meters, our prediction that the largest member always present in the steady-state population of NESs should be approximately one meter in diameter (see Fig. 2) agrees with the single, verified data point available. We stress that knowledge of 2006 RH_{120} is not used in the modeling. Furthermore, if one postulates that 1991 VG is natural and an NEO, the time between these captures would have been about 15 years. Our model predicts that objects with, say, $H \sim 29$ should be captured on average every few tens of years which would again be in good agreement with the data at hand.

The residence-time distribution has a spike at ($a \sim 0.001\,\mathrm{AU}, \iota \sim 35\,\mathrm{deg}$) which is due to only a handful of objects that have a lifetime up to 10^3 longer than the average TCO (Fig. 3). It turns

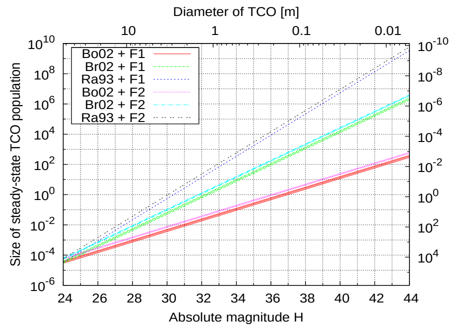

Figure 2: The steady-state SFD for TCOs by using three different NEO SFDs [2, 3, 4] and two different methods of calculating the flux of TCOs (F1 and F2). We consider the TCO SFD corresponding to Br02+F1 — calculated using the Earth-impactor SFD [3] — to provide the best estimate which means that the maximum size at which at least one object is captured at any given time is $H \sim 32$ (or a diameter of approximately 1 m), and that the frequency of TCOs with $H \sim 30$ is about one every quarter century. The uncertainty envelopes correspond to the 1-σ uncertainties for the size of the steady-state population. The conversion from H magnitude to diameter assumes a geometric albedo of 0.15.

out that the long-lived TCOs evolve into orbits with apocentra within the Moon's orbit and/or are also affected by the Kozai resonance to a varying degree. These orbital features prevent them from having frequent close encounters with the Moon and thus from being ejected from the Earth-Moon system on short timescales.

3. Summary and Conclusions

We predict that there is one one-meter-diameter or larger NEO temporarily orbiting the Earth at any given time assuming that the current best NEO orbit-density distribution and SFD are fairly accurate for meter-scale objects. The long-lived TCOs have orbits stable enough that may allow successful searches for objects on similar orbits to be carried out in specific regions of the sky instead of relying on all-sky surveys such as PS1 and LSST.

The NEO model is currently the main factor limiting the accuracy of our predictions. It will

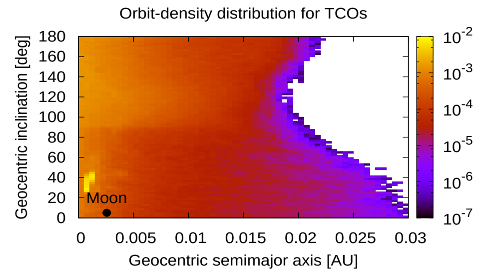

Figure 3: Residence-time distribution for TCOs in geocentric (a, ι) space.

be straightforward to update the predictions presented in this paper when improved estimates for the NEO size-frequency and orbit distributions become available. We estimate that our NES population model is correct to within about an order of magnitude based on its consistency with the 1–2 known NESs.

Acknowledgments

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