Near-Earth Objects In Earthlike Orbits

A useful situational awareness exercise is to occasionally survey all known near-Earth objects (NEOs) in orbits similar to Earth's as catalogued by the Jet Propulsion Laboratory's (JPL's) Small Bodies Database (SBDB). Orbits with osculating semi-major axis a near 1 AU, osculating eccentricity e near zero, and osculating ecliptic inclination i also near zero tend to be the most accessible for human space flight (HSF) over time intervals of years to decades. These NEO orbits also tend to pose the greatest threat of Earth impact, particularly if the NEO is sufficiently large or monolithic.

Results from the present survey of Earthlike NEO orbits are plotted in Figure 1 as points in (a, e) coordinates, generally for $i < 5°$. Many of these points are annotated with NEO HSF Accessible Targets Study (NHATS, pronounced "gnats") rankings. The metric for these rankings is n, a tally of NHATS-compliant missions with launch dates in years 2015 through 2040. The NEO ranked #1 in Figure 1 is 2000 SG_{344} at (a, e) coordinates (0.978 AU, 0.067) with n = 3,302,718. Criteria for NHATS-compliant missions are as follows.

1) Total change-in-velocity $\Delta v_{TOT} \leq 12$ km/s. In NHATS software, Δv_{TOT} is computed as the sum of impulses required to depart a circular Earth orbit at 400 km height targeting NEO intercept, achieve NEO rendezvous, perform NEO departure targeting Earth return, and ensure Earth's atmosphere is entered at a speed of 12.0 km/s if this value would otherwise be exceeded.

2) Roundtrip mission duration ≤ 450 d.

3) Post-rendezvous NEO loiter time ≥ 8 d.

Additional NHATS viability criteria optionally exclude any NEO whose absolute magnitude is too faint or whose orbit prediction uncertainty is too great. These criteria are inhibited in computing NHATS rankings to annotate Figure 1.

Osculating orbit elements in the SBDB are dynamic on occasion due to NEO planetary encounters. These elements also change to reflect updates from new observations. Rankings under the NHATS n metric can change as these new observations are incorporated into the SBDB and as additional NEOs are discovered. Data and annotations in Figure 1 reflect downloads from the SBDB browser at http://ssd.jpl.nasa.gov/sbdb.cgi and from the interactive NHATS table at http://neo.jpl.nasa.gov/cgi-bin/nhats performed on 11 March 2013 UT.

Each (a, e) marker plotted in Figure 1 has an appearance indicating the corresponding NEO's membership in one of four possible orbit groups. Blue diamond markers correspond to the Amor group, whose members have orbits completely exterior to Earth's. Green triangles indicate members of the Apollo group, whose orbits cross Earth's (in the sense perihelion is less than Earth's aphelion) and have periods exceeding Earth's. Red squares correspond to members of the Aten group, whose orbits cross Earth's (in the sense aphelion is greater than Earth's perihelion) and have periods less than Earth's. Atira group members have orbits completely interior to Earth's. No cataloged Atira has (a, e) coordinates within Figure 1 limits.

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As noted in the Figure 1 legend, multiple loci are co-plotted with NEO (a, e) points. Two vertical "25y tS" lines are plotted, one "inferior" (interior) to Earth's orbit at a = 0.974 AU, and one "superior" (exterior) to Earth's orbit at a = 1.028 AU. Together, these lines denote a rectangular region in Figure 1 within which a plotted NEO (a, e) point is associated with a synodic period exceeding 25 years. Thus, it is possible for a NEO in this region to be on the other side of the solar system from Earth during years 2015 through 2040 and not tally a single NHATS-compliant mission. Notable examples of this outcome are 2003 YN_{107}, at the most Earthlike (a, e) = (0.989 AU, 0.014) catalogued, and 2006 QQ_{56} at (a, e) = (0.985 AU, 0.046). These are the only NEO annotations in Figure 1 not accompanied by #m suffixes indicating their NHATS n rankings.

The "ZePHA" locus referenced in Figure 1's legend is a mnemonic for <u>Ze</u>ro <u>P</u>erigee <u>H</u>eliocentric <u>A</u>psis. This V-shaped locus contains (a, e) points capable of very close Earth encounters near perihelion (for NEO members of the Apollo orbit group) or near aphelion (for NEO members of the Aten orbit group). Such close approaches possess low heliocentric radial velocity enhancing NHATS-compliant mission opportunities and n. At a given e coordinate, note Figure 1 plots no NEO inferior to the inferior ZePHA branch (locus points with a < 1 AU). This dearth of NEOs at the left of Figure 1 is almost certainly a consequence of always observing these relatively small and faint objects from locations close to Earth's surface, where members of the Aten and Atira orbit groups never stray far from the Sun's glare.

A second V-shaped locus appearing in Figure 1 is dubbed "GReMS", a mnemonic for <u>G</u>eocentric <u>Re</u>lative <u>M</u>otion <u>S</u>tall conditions. Any (a, e) point on this locus corresponds to an orbit whose speed with respect to Earth would fall to nearly zero around perihelion (for NEO members of the Apollo orbit group) or around aphelion (for NEO members of the Aten orbit group). If a GReMS condition were to develop at a location near the Sun-Earth line, favorable mission opportunities and enhanced n could be expected for the associated NEO in that timeframe.

A third V-shaped locus in Figure 1 lies between the ZePHA and GReMS loci and corresponds to Tisserand's parameter T = 3 with respect to the Sun-Earth system. Notional loci for T = 2.975 and T = 3.01 also appear in Figure 1. Because of the V-shaped symmetry about a = 1 AU in Figure 1, this graphic is informally referred to as a "V-plot".

Within Figure 1 (a, e) limits, the general intent is to annotate every NEO whose n ranking is #50 or less. Notes and exceptions relating to this intent are as follows.

1) Two members of the Aten orbit group meet the n ranking ≤ #50 criterion, but their e coordinates exceed the plot maximum of 0.2 and therefore do not appear in Figure 1. These exceptions are 2009 HE_{60} at (a, e) = (0.996 AU, 0.266) with n ranking #21 and 2011 CF_{66} at (a, e) = (0.997 AU, 0.270) with n ranking #50.

2) Two NEOs meet the n ranking ≤ #50 criterion and fall within Figure 1 axis limits, but they exceed the i < 5° criterion by a small amount. These exceptions are 2001 FR_{85} at (a, e, i) = (0.983 AU, 0.028, 5.245°) with n ranking #5 and 2006 DQ_{14} at (a, e, i) = (1.028 AU, 0.053, 6.296°) with n ranking #45. Both of these NEOs are plotted in Figure 1 with unfilled markers.

3) Every NEO with $e < 0.1$ plotted inside Figure 1's $T = 3.01$ envelope is annotated, even if its n ranking exceeds 50.

4) Due to perennial interest in its Earth collision possibilities, (99942) Apophis is annotated at $(a, e) = (0.922 \text{ AU}, 0.191)$ with n ranking #136.

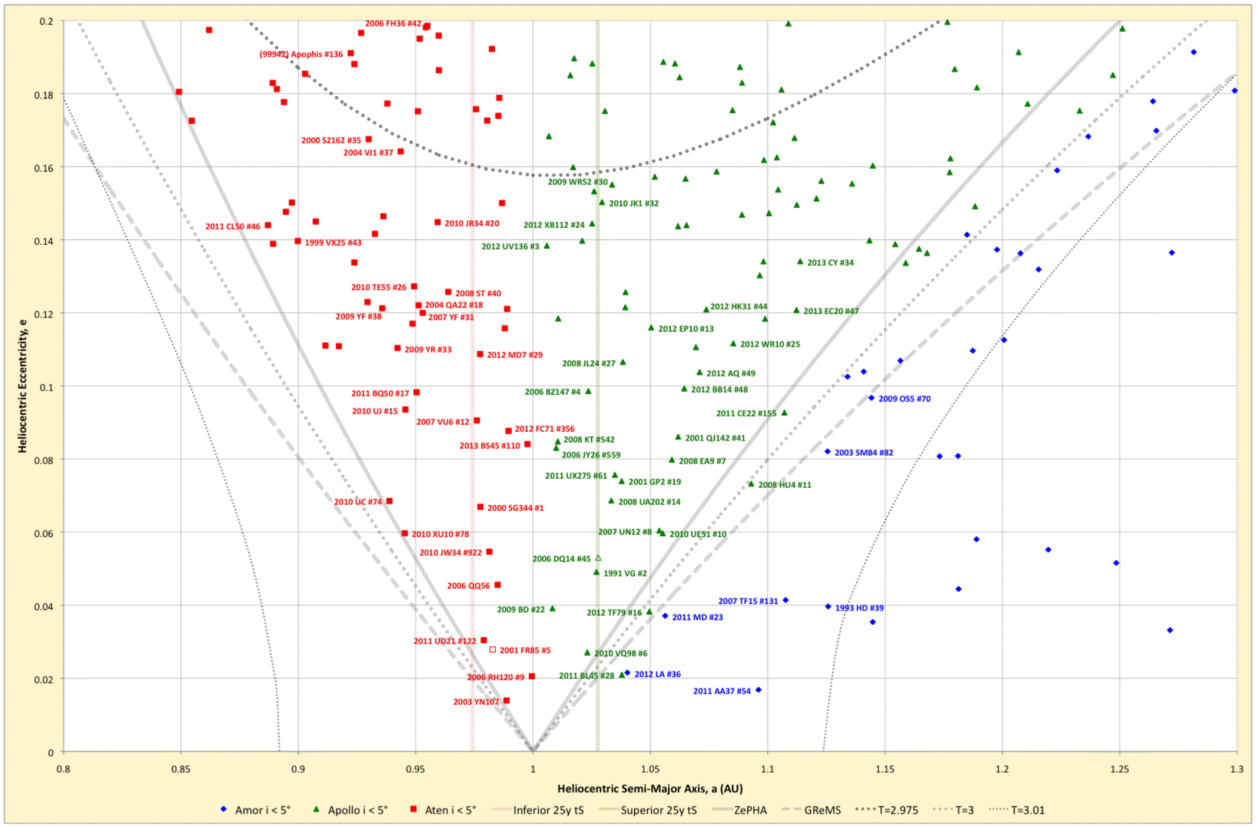

Figure 1. All NEOs catalogued in the SBDB with 0.8 AU < *a* < 1.3 AU, *e* < 0.2, and *i* < 5° are plotted according to their (*a*, *e*) coordinates. Those NEOs ranking in the top 50 according to the NHATS metric *n* are annotated with their SBDB designation, followed by their #*m* rank. Exceptions to these plotting and annotation rules are noted in the foregoing narrative along with the significance of loci plotted in gray. Supporting SBDB and NHATS data are time-sensitive and reflect downloads on 11 March 2013 UT.