Draft version February 14, 2024
Typeset using LaTeX **RNAAS** style in AASTeX631

Baked Before Breaking into Bits: Evidence for Atira-type Asteroid Splits

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ABSTRACT

Current near-Earth asteroid orbital models cannot reproduce the observed populations close to the Sun. Supercatastrophic and tidal disruptions may explain the differences between theoretical models and observational data. Here, we explore the distributions of mutual nodal distances and the angular separation of perihelia of the known Atiras looking for evidence of past splittings. We find a number of pairs, trios, and one quartet of Atiras with mutual nodal distances as short as 0.001 au at the orbits of Mercury and Venus. The smallest of these highly correlated objects is 2023 WK_3. Fragmentation or binary disruption may have triggered the recent formation of the unusual pair made of 594913 'Aylo'chaxnim (2020 AV_2) and 2012 VE_{46} with both mutual nodal distance and angular separation of perihelia in the first percentile of the distribution, making 2012 VE_{46} a robust candidate to being a former moon or piece of 'Aylo'chaxnim.

Keywords: Near-Earth Asteroids

INTRODUCTION

Granvik & Walsh (2023) pointed out that current near-Earth asteroid orbital models cannot reproduce the observed populations close to the Sun. Supercatastrophic (Granvik et al. 2016) and tidal (Granvik & Walsh 2023) disruptions have been suggested as processes that may help to explain the differences between theoretical expectations and observational data. Small bodies moving in eccentric orbits and confined inside the path of Earth are the most vulnerable to these processes as they are subjected to high temperatures and strong solar wind irradiation in addition to experiencing close encounters with Mercury and Venus. Such objects are called Atiras or Interior Earth Objects (IEOs) and have aphelion distances <0.983 au. Here, we show that the distributions of mutual nodal distances and the angular separation of perihelia of the 32 known IEOs include highly correlated sets of objects, which is suggestive of ongoing asteroid splits.

ATIRAS: DATA

Here, we use publicly available input data from Jet Propulsion Laboratory's Solar System Dynamics Group Small-Body Database (SBDB)[1] and horizons[2] on-line solar system data and ephemeris computation service (Giorgini 2015), which use the new DE440/441 solution (Park et al. 2021). Data retrieval from SBDB used the Python package Astroquery (Ginsburg et al. 2019) and its HorizonsClass[3] and SBDBClass[4] classes. The data collected are referred to epoch JD 2460200.5 (2023-Sep-13.0) TDB (Barycentric Dynamical Time, J2000.0 ecliptic and equinox). There are 32 known Atiras, the most recent discovery was 2023 WK_3 (Duszanowicz et al. 2023).

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[1] https://ssd.jpl.nasa.gov/sbdb.cgi
[2] https://ssd.jpl.nasa.gov/?horizons
[3] https://astroquery.readthedocs.io/en/latest/jplhorizons/jplhorizons.html
[4] https://astroquery.readthedocs.io/en/latest/jplsbdb/jplsbdb.html

CORRELATED SETS

In order to uncover evidence for past asteroid splits among the Atira population, we focus on the study of the distributions of two orbital correlation parameters: the mutual nodal distances between pairs of Atiras ($\Delta_{\pm}$, + ascending node, − descending node) computed as described by Saillenfest et al. (2017) and the angular separation between their directions of perihelia (α_q) evaluated as shown in de la Fuente Marcos & de la Fuente Marcos (2018). The propagation of the orbital uncertainties onto the computed values of $\Delta_{\pm}$ and α_q was studied by generating sets of orbital elements using data from SBDB as described in de la Fuente Marcos & de la Fuente Marcos (2021). As most probable value, we computed the median out of 10^4 pairs of virtual Atiras for each actual pair; the 16th and 84th percentiles were adopted as a measure of the associated dispersion.

Figure 1 shows the results of our statistical analyses. The top panel shows that out of 496 pairs, 10 have $\Delta_{\pm}$ <0.004 au that is the first percentile of the distribution (the outliers). They are strongly correlated with the orbital locations of Mercury and Venus. The analysis of the pairs shows several instances of trios in which one object has $\Delta_{\pm} < 0.004$ au with two others simultaneously and even one quartet. The quartet is made of the pairs: 2010 XB_{11}–2017 YH ($\Delta_- = 0.0029$ au), 2017 YH–2021 PH_{27} ($\Delta_+ = 0.0028$ au), and 2017 YH–2023 WK_3 ($\Delta_- = 0.0012$ au). The first trio is made of the pairs: 413563 (2005 TG_{45})–2023 WK_3 ($\Delta_- = 0.0026$ au) and 2017 YH–2023 WK_3. The second trio is made of the pairs: 418265 (2008 EA_{323})–481817 (2008 UL_{90}) ($\Delta_+ = 0.0014$ au) and 418265–2021 VR_3 ($\Delta_+ = 0.0029$ au). The third trio is made of the pairs: 594913 'Aylo'chaxnim (2020 AV_2)–2012 VE_{46} ($\Delta_- = 0.0013$ au) and 613676 (2006 WE_4)–2012 VE_{46} ($\Delta_+ = 0.00021$ au). The fourth trio is made of the pairs: 2010 XB_{11}–2017 YH and 2010 XB_{11}–2021 BS_1 ($\Delta_+ = 0.0011$ au). The pair 613676–2012 VE_{46} has the smallest value of $\Delta_{\pm}$.

Figure 1 shows that one pair, 'Aylo'chaxnim–2012 VE_{46}, is highly remarkable as it has $\Delta_- = 0.0013$ au and α_q=5$^\circ\!\!.$46 (the first percentile is 8$^\circ\!\!.$41, see bottom panel). This may be indicative of a very recent separation in the form of fragmentation (Granvik & Walsh 2023) or perhaps binary disruption (de la Fuente Marcos et al. 2017) assisted by Mercury.

DISCUSSION AND CONCLUSIONS

In the solar system, the dynamical evolution in the near-Sun region is the fastest (Ribeiro et al. 2016; de la Fuente Marcos & de la Fuente Marcos 2020; Greenstreet 2020; Lai & Ip 2022). Most Atiras orbit the Sun once every few months and may experience several planetary encounters per year. This increases the probability of disruptive episodes that are also favored by the extreme physical conditions characteristic of this region. Only a few Atiras have been characterized spectroscopically, one of them is 'Aylo'chaxnim that is a Sa-type asteroid (Popescu et al. 2020). Additional spectroscopic characterizations of members of this class may help to confirm the tentative connections between some of them discussed here.

This work was partially supported by the Spanish 'Agencia Estatal de Investigación (Ministerio de Ciencia e Innovación)' under grant PID2020-116726RB-I00 /AEI/10.13039/501100011033.

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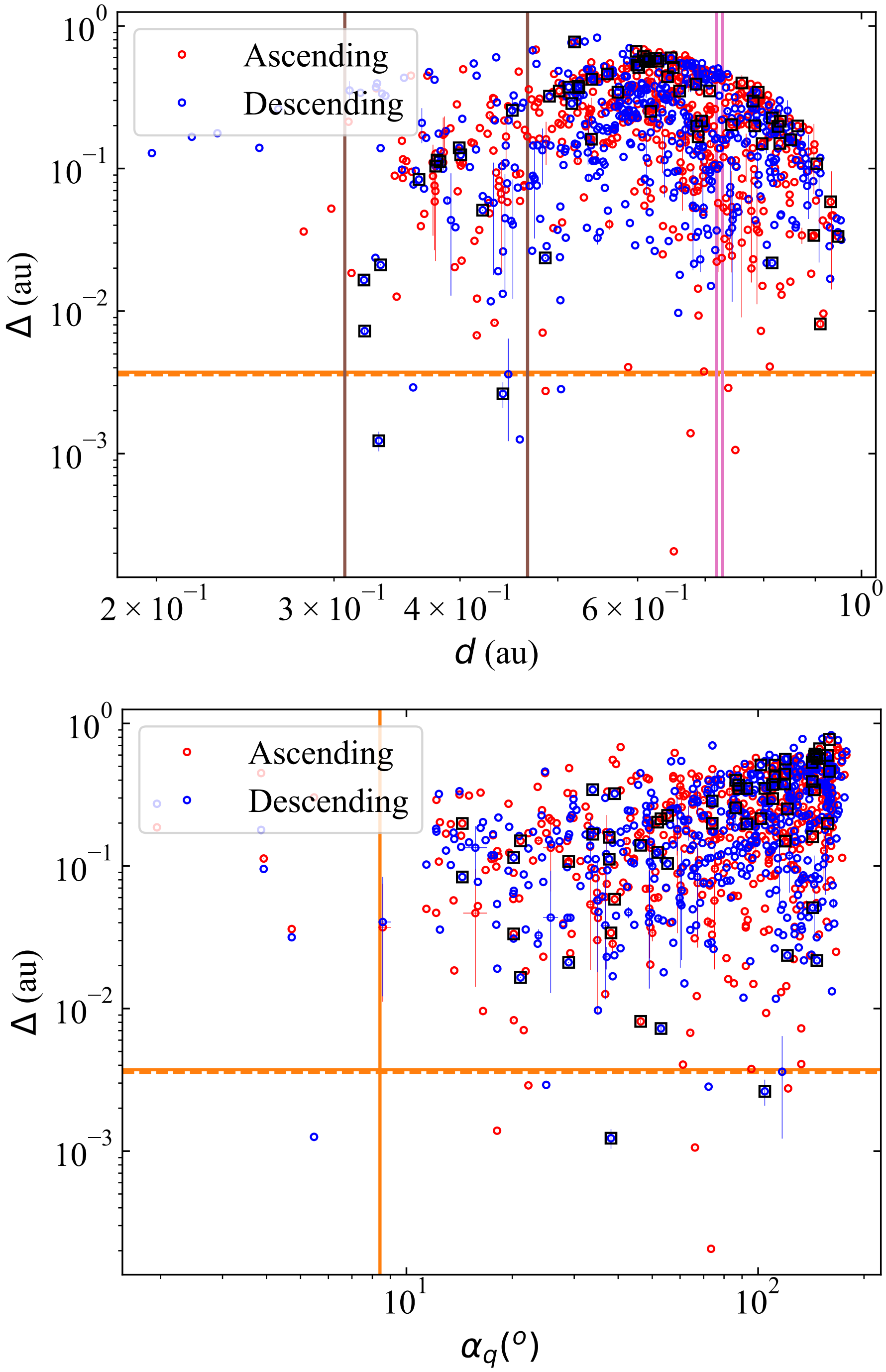

Figure 1. Mutual nodal distances as a function of the distance to the node (top panel) and as a function of the angular separation of the perihelia (bottom panel) for the 32 known Atiras. The first percentil of the distribution is shown as an orange line (solid or dashed). The pink vertical bars show Venus' perihelion and aphelion, the brown vertical bars display those of Mercury (top panel). The error bars are the result of the evaluation of 10^4 sets of synthetic elements compatible with the uncertainties and generated using a Monte Carlo process. The black squares in the panels correspond to pairs that include 2023 WK_3.

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