Temporal Earth Coorbital Types of Asteroid 2016 HO3

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Abstract. A newly discovered asteroid 2016 HO3 has coorbital type of retrograde (or quasi) satellite with respect to Earth. The discovery enlarges number of known retrograde satellites of Earth. In this work numerical studies have been performed to investigate orbital dynamics of the asteroid by including all planets and the Moon as perturbers. Hypothetical asteroids were also generated to assess its general dynamics. Results show that since several hundreds thousands years ago the asteroid has been trapped in alternating coorbital types of retrograde satellite (RS) and horseshoe (HS). The RS and HS types, respectively, have taken place for some hundreds and some thousands years, and so those for the future. Long term orbital evolution for one million years predicts that about a few hundreds thousands years from the epoch the asteroid will completely escape its coorbital configuration with Earth. Orbit of the asteroid does not follow Kozai resonance state, and by this study it is found that asteroid 2016 HO3 may behave a coorbital pair with asteroid 2000 WN10.

1. Introduction
A coorbital asteroid has almost same orbital period with that of the corresponding celestial object (planet or another asteroid). This is an orbital 1:1 mean-motion resonance. With respect to rotating coordinate system, there are three basic coorbital types of such orbit, i.e. Tadpole or Trojan (T), Horseshoe (HS), and Retrograde (or quasi) Satellite (RS). Moreover, there are transient coorbital types which are a mixture of two out of the three types [1]. It has been known that Earth harbours asteroids whose orbits belong to all the three types. It has been reported elsewhere, e.g. [2], that Earth has at least four RS companions, i.e. 2004 GU9, 2006 FV35, 2013 LX28, and 2014 OL339. A recent discovered RS companion, asteroid 2016 HO3 (Fig. 1), enlarges this number.

![Figure 1. Orbit of a retrograde satellite 2016 HO3 (encircling Earth) in the Sun-Earth rotating coordinate system.](image)
may be trapped in Kozai resonance state; and the asteroid may probably belong to coorbital pair such as the well-known Janus and Epimetheus in Saturnian system.

2. Orbital Elements and Integration Scheme
Orbital elements of asteroid 2016 HO3 (see Table 1) and all planets (including the Moon) are available at the JPL-NASA Solar System Dynamics (http://ssd.jpl.nasa.gov/horizons.cgi). Recent available epoch was MJD 57600 (2016 July 31, 00:00:00 UT).

| Table 1. Orbital elements of asteroid 2016 HO3 for MJD 57600. |
|---------------------------------------------------------------|
| Elements                      | Value                                      |
|--------------------------------|---------------------------------------------|
| Semimajor axis (a)           | 1.001229935 ± 2.76E-9 au                   |
| Eccentricity (e)             | 0.1041429 ± 4.80E-7                        |
| Inclination (i)              | 7.77140 ± 3.62E-5 deg                      |
| Longitude of ascending node (Ω) | 66.51326 ± 4.33E-5 deg                     |
| Argument of pericenter (ω)   | 307.22765 ± 6.68E-5 deg                    |
| Mean anomaly (M)             | 297.53211 ± 9.70E-5 deg                    |

There are two derived parameters to analyze coorbital motion. First, the relative distance $\alpha = (a - a_E)/a_E$, and second, the libration angle $\theta = \lambda - \lambda_E$, with $\lambda = (\Omega + \omega + M)$; subscript $E$ denotes Earth. Because of the 1:1 mean-motion resonance, value of $\alpha$ should be small. On the other hand, RS companion follows $\theta \approx 0^\circ$, which is a complement of HS type ($\theta \neq 0^\circ$), and T type stays for $\theta \approx \pm 60^\circ$.

Two integration packages were used in this work. Mercury package [3] was applied for short term backward and forward integrations of some tens thousands years. The other package, Swift [4] ver. 4 (released in year 2012), was employed for long term integrations of one million years, including integrations for hypothetical asteroids. Hypothetical asteroids were generated by combining available uncertainties of the asteroid’s six orbital elements to finally yield $3^6 (= 729)$ objects. The hypothetical objects represent a collection of possible orbits of the asteroid. Step of the integrations were chosen to be 1/100 (short term) and 1/200 (long term) year, which are believed to be sufficient. All planets and the Moon behave perturbers for orbit of the ‘massless’ asteroid/objects along the integrations.

3. Results and Discussion
3.1. Short term integrations
Figure 2 shows results for short term backward and forward integrations, respectively, of twenty thousands years. It is obvious that asteroid 2016 HO3 has temporal RS and HS coorbital types with relatively short time (several hundreds years) as RS companion.
3.2. Long term integrations and Kozai resonance state

Long term orbital integrations show that for several hundreds thousands years from the epoch, orbit of asteroid 2016 HO3 will shrink into inner Earth region (for example, see top panel of Figure 3). More than 60% orbits of the hypothetical asteroids demonstrate roughly the same trend. In line with this, the asteroid will depart from its coorbital configuration after that time because of the cumulative gravitational attractions of the perturbers.

![Figure 3](image)

**Figure 3.** An example of long term integration of asteroid 2016 HO3. No long libration type has been arisen in panel $\omega$ (second panel from the bottom).

Regarding long term integrations, it is suitable to investigate Kozai (Kozai-Lidov) resonance state of asteroid 2016 HO3. Orbit of an asteroid is expected to be in Kozai resonance state if the orbit has steady semimajor axis and falls to some criteria at once: i. The Kozai parameter $((1 - e^2)^{1/2} \cos i)$ does not vary appropriately for an order of $10^5 – 10^6$ years; ii. There is a coupled oscillation of $e$ and $i$; iii. Librations of $\omega$ occur at $\pm 60^\circ$ or $0^\circ/180^\circ$. Regarding these criteria it is clear that orbit of asteroid 2016 HO3 does not follow Kozai resonance state. This is in accordance with a new published result [2].

![Figure 4](image)

**Figure 4.** A possible play of two coorbital asteroids as a pair. Each of the change of coorbital type in orbit of 2016 HO3, the corresponding change (marked by vertical dashed lines for clarity) is also happened in orbit of 2000 WN10.
3.3. Earth coorbital pair?
It is interesting to search a coorbital pair among the known Earth coorbital asteroids. A coorbital pair is a pair of two asteroids that show a coupled of two coorbital types. A famous example of this phenomenon is an orbital ‘dancing’ between Janus and Epimetheus in Saturnian system. Figure 4 illustrates this possibility that the changes of RS-HS types of 2016 HO3 are coincidence in time with those of 2000 WN10 that comprise all coorbital types, including the transient one (a mixture of HSRs). This finding needs a deeper inspection to a bulk of possible orbits of both asteroids.

3.4. New Earth RS-HS coorbital asteroid
By this study we find another (possibly) Earth coorbital asteroid (2016 CA138) that shows alternating RS-HS pattern (Fig. 5) in its orbital dynamics. To our knowledge this may be the fourth asteroid belongs to that pattern of orbit; the other three are 2004 GU9, 2015 SO2, and 2016 HO3.

4. Conclusions
- Asteroid 2016 HO3 will completely escape its coorbital configuration after some hundreds thousands years. The asteroid shows that RS-HS coorbital types occur, respectively, in hundreds and thousands years.
- Orbit of asteroid 2016 HO3 does not in Kozai resonance state.
- Asteroid 2016 HO3 may be a coorbital pair with asteroid 2000 WN10 for at least twenty thousands years.

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