Near the Edge of the Atira Orbital Realm: Short-Term Dynamical Evolution of 2020 HA₁₀ and 2020 OV₁

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ABSTRACT

Atiras or Interior Earth Objects (IEOs) have their orbits contained entirely within the orbit of Earth. The first IEO, 1998 DK₃₆, was found in 1998; 15 out of the 23 known Atiras have been discovered during the last decade. Here, we provide a preliminary assessment of the current dynamical status and short-term orbital evolution of 2020 HA₁₀ and 2020 OV₁, two recently discovered Atiras. Our calculations indicate that 2020 HA₁₀ periodically switches between the Aten and Atira orbital realms, and although it is almost certainly a present-day Atira, it spends most of the time following Aten-type orbits. In contrast, 2020 OV₁ is well entrenched within the Atira orbital realm, but it might have arrived there relatively recently.

Keywords: Solar system, Minor planets, Small solar system bodies, Asteroids

Until 1998, we had no data on possible populations of minor bodies going around the Sun following orbits contained entirely within the orbit of Earth, i.e. with aphelion distances, Q , < 0.983 au. Such bodies are now known as Atiras or Interior Earth Objects (IEOs, [Greenstreet et al. 2012](#)). The first IEO candidate, 1998 DK₃₆, was only observed four times, spanning one day, and it is currently considered a lost minor planet. The second IEO discovered was 2003 CP₂₀ that eventually became (163693) Atira and gave name to the entire dynamical class. This large binary asteroid may have a primary of 4.8 ± 0.5 km in diameter ([Rivera-Valentin et al. 2017](#)). Out of the 23 known Atiras (as of 2020-July-24), 15 of them have been discovered during the last decade, including the first Vatira ($Q < 0.718$ au, [Greenstreet et al. 2012](#)), 2020 AV₂ ([Bolin et al. 2020](#)), that has been recently characterized, both dynamically ([Greenstreet 2020](#); [de la Fuente Marcos & de la Fuente Marcos 2020](#)) and physically ([Popescu et al. 2020](#)). The two most recent discoveries, 2020 HA₁₀ and 2020 OV₁, further confirm that the Solar System inside the orbit of the Earth hosts a non-negligible fraction of dynamically interesting minor bodies ([Ribeiro et al. 2016](#)). Here, we provide a preliminary assessment of the current dynamical status and short-term orbital evolution of 2020 HA₁₀ and 2020 OV₁. Our analyses are based on data publicly available from JPL’s Small-Body Database ([Giorgini 2015](#)) and N -body simulations. Our methodology has been described in [de la Fuente Marcos & de la Fuente Marcos \(2019a, 2020\)](#).

Asteroid 2020 HA₁₀ was discovered on 2020-April-28 by Mt. Lemmon Survey using the 0.5-m reflector + 10K CCD ([Leonard et al. 2020](#)). Its heliocentric orbit determination as of 2020-May-3 is: semimajor axis, $a = 0.8204 \pm 0.0010$ au, eccentricity, $e = 0.1544 \pm 0.0009$, inclination, $i = 49^\circ 66' \pm 0^\circ 11'$, longitude of the ascending node, $\Omega = 103^\circ 46' \pm 0^\circ 05'$, and argument of perihelion, $\omega = 27^\circ 1' \pm 0^\circ 3'$;¹ this solution is based on 23 observations for a data-arc span of 5 days. Although the orbit determination is rather poor, it is however good enough to perform a preliminary assessment of its current dynamical status and an initial exploration of its past and future orbital evolution. The value of $Q = 0.9471 \pm 0.0012$ au places 2020 HA₁₀ within 3σ from the Atira boundary, but inside it (see above). Figure 1,

left-hand side panels, shows the evolution of relevant orbital parameters for representative orbits of 2020 HA₁₀. The top, left-hand side panel of Figure 1 shows that although 2020 HA₁₀ is almost certainly a present-day Atira, it spends most of the time following Aten-type orbits, periodically switching between the Aten and Atira orbital realms. As many other Atiras (de la Fuente Marcos & de la Fuente Marcos 2018, 2019a,b, 2020), it displays (see second to top and second to bottom, left-hand side panels of Figure 1) an anti-coupled oscillation of the values of eccentricity and inclination, but no oscillations (perhaps with the exception of the $+9\sigma$ orbit) of the value of the argument of perihelion (see bottom, left-hand side panel of Figure 1). The analysis of the behavior of 2020 HA₁₀ shows that some present-day Atiras may be spending just a small fraction of their lives within the Atira orbital realm; a dynamically robust Atira must spend all or a very significant amount of its time at $Q < 0.983$ au.

Asteroid 2020 OV₁ was discovered on 2020-July-19 (Melnikov et al. 2020) by the Zwicky Transient Facility (ZTF) observing system (Graham et al. 2019; Ye et al. 2019) at Palomar Mountain. Its heliocentric orbit determination as of 2020-July-23 is: $a = 0.637 \pm 0.002$ au, $e = 0.253 \pm 0.008$, $i = 32^\circ.8 \pm 0^\circ.7$, $\Omega = 296^\circ.2 \pm 0^\circ.6$, and $\omega = 190^\circ.1 \pm 0^\circ.3$;² this solution is based on 29 observations for a data-arc span of 3 days. The value of $Q = 0.798 \pm 0.002$ au places 2020 OV₁ well within the Atira boundary (see the top, right-hand side panel of Figure 1). As in the case of 2020 HA₁₀ and many other Atiras, when the value of the eccentricity reaches its maximum, the inclination reaches its minimum and vice versa (see second to top and second to bottom, right-hand side panels of Figure 1). Although a concurrent oscillation of the value of the argument of perihelion is not observed for all orbits, that of $+9\sigma$ displays a distinctive but temporary libration in the value of ω (see bottom, right-hand side panels of Figure 1) that hints at the activation of the von Zeipel-Lidov-Kozai mechanism (Kozai 1962; Lidov 1962; Ito & Ohtsuka 2019; de la Fuente Marcos & de la Fuente Marcos 2019a, 2020).

Although 2020 HA₁₀ is a hybrid Aten-Atira that spends significantly more time pursuing Aten-type orbits than Atira-type ones, 2020 OV₁ is comfortably entrenched within the Atira orbital realm, but it might have arrived there relatively recently (see results for the $+9\sigma$ control orbit in the top, right-hand side panel of Figure 1) in astronomical terms. The behavior observed for 2020 HA₁₀ is also shared by other known Atiras (those with the highest values of Q) and it shows that Atira-type and Aten-type orbits can evolve into each other. The dynamical evolution of 2020 HA₁₀ is more stable than that of 2020 OV₁ because the latter experience closer and more frequent encounters with Venus. In addition, 2020 HA₁₀ and 2020 OV₁ are not currently engaged in mean-motion resonance with any planet (but 2020 HA₁₀ is close to the 16:1 mean-motion resonance with Jupiter). Although our picture of the Solar System inside the orbit of Earth is better now than it was prior to the discovery of the Atiras, it is still far from satisfactory and more focused surveys like those being carried out by ZTF (Ye et al. 2020) or EURONEAR (Vaduvescu et al. 2018) should add more pieces to this puzzle in the near future.

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REFERENCES

Bolin, B. T., Masci, F. J., Ye, Q.-Z., et al. 2020, Minor Planet Electronic Circulars, 2020-A99 de la Fuente Marcos, C. & de la Fuente Marcos, R. 2018, Research Notes of the American Astronomical Society, 2, 46 de la Fuente Marcos, C. & de la Fuente Marcos, R. 2019a, MNRAS, 487, 2742	de la Fuente Marcos, C. & de la Fuente Marcos, R. 2019b, Research Notes of the American Astronomical Society, 3, 106 de la Fuente Marcos, C. & de la Fuente Marcos, R. 2020, MNRAS, 494, L6 Giorgini, J. D. 2015, IAU General Assembly, 22, 2256293 Graham, M. J., Kulkarni, S. R., Bellm, E. C., et al. 2019, PASP, 131, 078001 Greenstreet, S. 2020, MNRAS, 493, L129 Greenstreet, S., Ngo, H., & Gladman, B. 2012, Icarus, 217, 355
- ² Epoch 2459051.5 (2020-July-21.0) TDB

Figure 1. Evolution of the values of the aphelion distance (Q , top panel), eccentricity (e , second to top panel), inclination (i , second to bottom panel), and argument of perihelion (ω , bottom panel) for the nominal orbit (in black) of 2020 HA₁₀ (left-hand side panels) and 2020 OV₁ (right-hand side panels) and those of control orbits with Cartesian vectors separated $+3\sigma$ (in green), -3σ (in cyan), $+9\sigma$ (in red), and -9σ (in pink) from the nominal values. The aphelion distance of Earth is shown in violet and that of Venus in blue (top panel).

Ito, T. & Ohtsuka, K. 2019, *Monographs on Environment, Earth and Planets*, 7, 1
 Kozai, Y. 1962, *AJ*, 67, 591
 Leonard, G. J., Christensen, E. J., Farneth, G. A., et al. 2020, *Minor Planet Electronic Circulars*, 2020-J11
 Lidov, M. L. 1962, *Planet. Space Sci.*, 9, 719
 Melnikov, S., Stecklum, B., Bolin, B. T., et al. 2020, *Minor Planet Electronic Circulars*, 2020-O66
 Popescu, M., de León, J., de la Fuente Marcos, C., et al. 2020, *MNRAS*, 496, 3572

Ribeiro, A. O., Roig, F., De Prá, M. N., Carvano, J. M., & DeSouza, S. R. 2016, *MNRAS*, 458, 4471
 Rivera-Valentin, E. G., Taylor, P. A., Virkki, A., et al. 2017, *Central Bureau Electronic Telegrams*, 4347
 Vaduvescu, O., Hudin, L., Mocnik, T., et al. 2018, *A&A*, 609, A105
 Ye, Q., Masci, F. J., Lin, H. W., et al. 2019, *PASP*, 131, 078002
 Ye, Q., Masci, F. J., Ip, W.-H., et al. 2020, *AJ*, 159, 70