The Second Earth Trojan 2020 XL₅

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Abstract

The Earth Trojans are coorbitals librating around the Lagrange points L₄ or L₅ of the Sun–Earth system. Although many numerical studies suggest that they can maintain their dynamical status and be stable on timescales up to a few tens of thousands of years or even longer, they remain an elusive population. Thus far only one transient member (2010 TK₇) has been discovered serendipitously. Here, we present a dynamical study of asteroid 2020 XL₅. With our meticulous follow-up astrometric observations of the object, we confirmed that it is a new Earth Trojan. However, its eccentric orbit brings it close encounters with Venus on a frequent basis. Based on our N-body integration, we found that the asteroid was captured into the current Earth Trojan status in the fifteenth century, and then it has a likelihood of 99.5% to leave the L₄ region within the next ∼10 kyr. Therefore, it is most likely that 2020 XL₅ is dynamically unstable over this timescale.

Unified Astronomy Thesaurus concepts: Asteroids (72); Near-Earth objects (1092); Trojan asteroids (1715)

1. Introduction

Trojans are small bodies in 1:1 mean-motion resonance (MMR) with a planet, librating around the Lagrange points L₄ or L₅ of the Sun–planet system. Numerous researchers (e.g., Rabe 1967; Mikkola & Innanen 1992; Tabachnik & Evans 2000; Brasser & Lebto 2002; Cuk et al. 2012; Christou & Georgakarakos 2021; Marzari & Scholl 2013; Zhou et al. 2019, and many more) have performed theoretical and numerical studies on dynamical stability of Trojans and other types of coorbitals of solar system planets.

In the past century, over 10,000 Trojans have been recognized, the vast majority of which belong to Jupiter. In contrast, only one Earth Trojan (asteroid 2010 TK₇) has been identified, the discovery of which was in a serendipitous way by the Wide-field Infrared Survey Explorer mission in space (Connors et al. 2011). Ironically, all dedicated Earth Trojan surveys have found nothing (e.g., Whiteley & Tholen 1998; Markwardt et al. 2020; Liset et al. 2021), owing to the fact that the observing circumstances of these objects are never ideal for ground-based telescopes, because they are always at small solar elongations. Moreover, such a survey will have to cover a huge sky area where Earth Trojans are potentially residing because of their proximity to Earth and libration around the Lagrange points (Wiegert et al. 2000).

Dynamical studies (e.g., Marzari & Scholl 2013; Zhou et al. 2019) indicate that low-inclination Earth Trojans have the potential to survive the age of the solar system, and therefore these long-term stable members could be primordial planetaryesimal remnants formed in situ near the Earth–Moon system in the protoplanetary disk. However, none of this subgroup of Earth Trojans has been discovered yet. In comparison, Mars has several Trojans that are dynamically stable over the age of the solar system (e.g., Scholl et al. 2005; de La Fuente Marcos & de La Fuente Marcos 2013). The only known Earth Trojan 2010 TK₇ is dynamically stable in the 1:1 MMR with Earth for merely ∼25 Myr, and therefore it was most likely captured from elsewhere as a near-Earth asteroid (Dvorak et al. 2012).

Recently, asteroid 2020 XL₅ was discovered by the Panoramic Survey Telescope and Rapid Response System (Pan-STARRS 1) telescope at Haleakala Observatory, Hawai‘i, on 2020 December 12, and was suspected to be a potential candidate of the Earth Trojan population (de la Fuente Marcos & de la Fuente Marcos 2021). Thanks to our follow-up astrometric observations, we report our conclusive identification of asteroid 2020 XL₅ as the second transient Earth Trojan, confirming the study by de la Fuente Marcos & de la Fuente Marcos (2021) based upon a much shorter observing arc of the object. We describe our follow-up observations in Section 2 and present a dynamical analysis of the asteroid in Section 3.

2. Observation

We obtained follow-up observations of 2020 XL₄ using the University of Hawai‘i (UH) 2.2 m telescope atop Maunakea, Hawai‘i, on UT 2021 January 8, and September 12 and 13. In the first observing night, the observations were acquired through the Tektronix CCD in the on-chip 2 × 2 binning mode, rendering us an angular resolution of 0″44 pixel⁻¹ with a field of view (FOV) of 7″.5 × 7″.5. In the remaining observing nights, we employed the STAcam CCD, which has been in use since 2021 April. To achieve critically sampling the typical seeing on Maunakea, the STAcam images were 5 × 5 binned, resulting in a pixel scale of 0″.41 and an image dimension of 2112 × 2112 pixels. Individual images from 2021 January 8 have exposures of 60 and 90 s, while those from 2021 September have a common exposure of 8 minutes. In order to maximize collecting photons from the asteroid, we did not employ any filter, and the telescope was tracked nonsidereally at the apparent motion rate of the target. During our observations, the weather remained totally clear.

We performed astrometric measurements for our follow-up observations. Since our observations were tracked nonsidereally, all of the field stars in the same FOV alongside the target...
were obviously trailed in the data, making conventional simple centroiding techniques inapplicable. To accommodate this, we treated each star trail as a trapezoid and Gaussian in the along-track and cross-track directions, respectively. In such a profile model, there are six free parameters in total to be fitted using the least-squares method, including the centroid's pixel coordinates, length, width, and position angle of the trail, and the peak pixel value of the trail profile model. The parameters were solved iteratively with determination of the sky background with adjacent pill-shaped annuli centered on the best-fit pixel coordinates of the centroids. With the obtained pixel coordinates of the centroids, we had to adopt the weighting scheme described in detail by Vereš et al. (2017) for them. Moreover, the observations were also debiased in accordance with Farnocchia et al. (2015). We then refined the orbital elements of 2020 XL₅ using the orbit determination package EXORB8 written by A. Vitagliano, in which the planetary and lunar ephemerides DE431 (Folkner et al. 2014) are utilized and perturbations from the eight major planets, Pluto, the Moon, and the 16 most massive asteroids as well as post-Newtonian corrections are all incorporated. We summarize our best-fit orbital elements for 2020 XL₅ as well as the associated 1σ formal errors, which were calculated from the obtained covariance matrix propagated from the astrometric measurement uncertainties, in Table 2. In the solution, all of the observations were found to have astrometric residuals within the assigned or measured error bars, indicating that our adoption of the weighting scheme is reasonable. We show the astrometric residuals of our follow-up observations in the best-fit solution in Table 1.

We then created 1000 Monte Carlo (MC) orbital clones for 2020 XL₅ based on the obtained covariance matrix of the orbital elements according to the Cholesky decomposition method, which were subsequently integrated by SOLEX12, an N-body integration standalone package accompanied by EXORB8. To maintain consistency, the exact same force model was applied. We thereby obtained the geometric heliocentric state vectors of the nominal orbit, orbital clones, major planets, the Moon, Pluto, and the 16 most massive asteroids referenced to the J2000 ecliptic as functions of different epochs. Since here we only care about whether 2020 XL₅ is a new Earth Trojan or not, we first computed the heliocentric Cartesian coordinates of the target in a nonuniformly rotating frame in which the Earth–Moon system barycenter (EMB) always lies on the x-axis, and the z-axis is defined by the normal of the heliocentric orbital plane of the EMB:

\[
\begin{pmatrix}
x
\end{pmatrix} = \begin{pmatrix}
r \\
\hat{r}_{\text{EMB}} \\
(r \cdot \hat{\mathbf{n}}_{\text{EMB}}) \hat{\mathbf{n}}_{\text{EMB}} - (r \cdot \hat{\mathbf{r}}_{\text{EMB}}) \hat{\mathbf{r}}_{\text{EMB}}
\end{pmatrix},
\]

Note. The orbital elements are referred to an osculation epoch of Barycentric Dynamical Time (TDB) 2020 November 26.5 = JD 2,459,180.0. The reported uncertainties (noted in the parentheses for concision) are all 1σ formal errors propagated from the astrometric measurement uncertainties.

### Table 1

| Observation Time (UTC) | R.A. (°) | Decl. (°) | 1σ Uncertainty (°) | O–C Residuals (°) |
|------------------------|---------|-----------|--------------------|-------------------|
| 2021 Jan 08.661324     | 14 33 49.544 | −19 59 19.23 | 0.075              | +0.028            |
| 2021 Jan 08.666890     | 14 33 51.824 | −19 59 21.33 | 0.071              | −0.020            |
| 2021 Sep 12.610790     | 07 07 42.372 | +09 42 55.34 | 0.066              | +0.015            |
| 2021 Sep 12.616674     | 07 07 43.246 | +09 42 52.64 | 0.095              | −0.039            |
| 2021 Sep 12.622738     | 07 07 44.143 | +09 42 49.72 | 0.066              | −0.067            |
| 2021 Sep 13.617119     | 07 10 13.089 | +09 34 46.08 | 0.045              | +0.018            |
| 2021 Sep 13.623808     | 07 10 13.974 | +09 34 43.20 | 0.054              | +0.046            |

Notes. The coordinates are referred to the Earth mean equator and equinox of J2000 system. Technically the uncertainty and residuals in the R.A. direction are essentially in the east–west (E–W) direction on the corresponding great circle in the celestial sphere.

### Table 2

| Quantity | Value |
|----------|-------|
| Semimajor axis (au) | a = 1.00076222(54) |
| Eccentricity | e = 0.3871541(17) |
| Inclination (°) | i = 13.846827(10) |
| Longitude of ascending node (°) | Ω = 153.598852(87) |
| Argument of perihelion (°) | ω = 87.984486(98) |
| Mean Anomaly (°) | M = 262.41609(13) |

Note. The orbital elements are referred to an osculation epoch of Barycentric Dynamical Time (TDB) 2020 November 26.5 = JD 2,459,180.0. The reported uncertainties (noted in the parentheses for concision) are all 1σ formal errors propagated from the astrometric measurement uncertainties.

In order to investigate the dynamical status of 2020 XL₅, we updated its orbit with our astrometry together with astrometric measurements by other observers, including the Catalina Sky Surveys, Pan-STARRS 1, and a few others. These observations were obtained through querying the Minor Planet Center (MPC) Database. Since there is no available information regarding the astrometric measurement uncertainties from these observers, we had to adopt the weighting scheme described in detail by Vereš et al. (2017) for them. Moreover, the observations were also debiased in accordance with Farnocchia et al. (2015). We then refined the orbital elements of 2020 XL₅ using the orbit determination package EXORB8 written by A. Vitagliano, in which the planetary and lunar ephemerides DE431 (Folkner et al. 2014) are utilized and perturbations from the eight major planets, Pluto, the Moon, and the 16 most massive asteroids as well as post-Newtonian corrections are all incorporated. We summarize our best-fit orbital elements for 2020 XL₅ as well as the associated 1σ formal errors, which were calculated from the obtained covariance matrix propagated from the astrometric measurement uncertainties, in Table 2. In the solution, all of the observations were found to have astrometric residuals within the assigned or measured error bars, indicating that our adoption of the weighting scheme is reasonable. We show the astrometric residuals of our follow-up observations in the best-fit solution in Table 1.

We then created 1000 Monte Carlo (MC) orbital clones for 2020 XL₅ based on the obtained covariance matrix of the orbital elements according to the Cholesky decomposition method, which were subsequently integrated by SOLEX12, an N-body integration standalone package accompanied by EXORB8. To maintain consistency, the exact same force model was applied. We thereby obtained the geometric heliocentric state vectors of the nominal orbit, orbital clones, major planets, the Moon, Pluto, and the 16 most massive asteroids referenced to the J2000 ecliptic as functions of different epochs. Since here we only care about whether 2020 XL₅ is a new Earth Trojan or not, we first computed the heliocentric Cartesian coordinates of the target in a nonuniformly rotating frame in which the Earth–Moon system barycenter (EMB) always lies on the x-axis, and the z-axis is defined by the normal of the heliocentric orbital plane of the EMB:

\[
\begin{pmatrix}
x \\
y \\
z
\end{pmatrix} = \begin{pmatrix}
r \\
r \cdot \hat{r}_{\text{EMB}} \\
(r \cdot \hat{\mathbf{n}}_{\text{EMB}}) \hat{\mathbf{n}}_{\text{EMB}} - (r \cdot \hat{\mathbf{r}}_{\text{EMB}}) \hat{\mathbf{r}}_{\text{EMB}}
\end{pmatrix},
\]
Here, \( r = (X, Y, Z)^T \) is the heliocentric position vector of 2020 XL5, and \( \mathbf{r}_{\text{EMB}} \) and \( \mathbf{\dot{r}}_{\text{EMB}} \) are respectively the unit radial vector and normal of the heliocentric orbital plane of the EMB, all expressed in the heliocentric J2000 ecliptic reference frame. In the rotating reference frame, \( L_4 \) and \( L_5 \) points are at \((1/2, \sqrt{3}/2, 0)^T\) and \((1/2, -\sqrt{3}/2, 0)^T\) au, respectively. We visually tracked the motion of the nominal and MC clones both backward and forward for 500 yr with a time step of 1 day in the \( xy \)-plane of the rotating reference frame, finding that all of them are moving around the \( L_4 \) point, which is indicative of 2020 XL5 being a potential Earth Trojan (Figure 1).

However, such visualization alone does not provide us with any conclusive answer, because other coorbitals may behave similarly. So next, we converted the state vectors in the heliocentric J2000 ecliptic reference frame to heliocentric osculating orbital elements and computed the resonant argument in the 1:1 MMR configuration

\[
\varphi \equiv \lambda - \lambda_{\text{EMB}} = (\varpi + M) - (\varpi_{\text{EMB}} + M_{\text{EMB}})
\]

where \( \lambda \), \( \varpi \), and \( M \) are respectively the mean longitude, longitude of perihelion, and mean anomaly of the asteroid, and the quantities with the subscript “EMB” refer to those of the EMB system. For Trojans around the \( L_4 \) point their resonant arguments oscillate around 60°, and those around the \( L_5 \) point will librate around \( \varphi = -60^\circ \), whereas other types of coorbitals have \( \varphi \) oscillating around 0° if they are quasi-satellites, or around 180° for horseshoe coorbitals. We show the evolution of the resonant argument of 10 of the clones alongside the nominal orbit from 5 kyr in the past to 10 kyr in the future in Figure 2, where we can see that, since the fifteenth century or thereabouts, 2020 XL5 has been in the current dynamical status. Its resonant argument indeed oscillates close to but not about \( \varphi = 60^\circ \) in a libration period of \( \sim 170 \) yr. We calculated the libration period using the formula by Murray & Dermott (2000):

\[
T_L = \frac{4\pi}{3} \sqrt{\frac{a_{\text{EMB}}^3}{3GM_{\text{EMB}}}}.
\]

Here, \( a_{\text{EMB}} \approx 1 \) au and \( M_{\text{EMB}} \approx 6 \times 10^{24} \) are respectively the semimajor axis of the heliocentric orbit and total mass of the EMB system, and \( G = 6.67 \times 10^{-11} \) m$^3$kg$^{-1}$s$^{-2}$ is the gravitational constant. Inserting numbers, we found \( T_L \approx 220 \) yr, which is slightly longer than the observed period.

In order to understand the reason why the current libration of asteroid 2020 XL5 is not about \( \varphi = 60^\circ \), we calculated its ponderomotive (effective) potential (Namouni et al. 1999)

\[
\Psi = \frac{1}{2\pi} \int_{-\pi}^{\pi} \left( \frac{1}{|\mathbf{r} - \mathbf{r}_{\text{EMB}}|} - \mathbf{r} \cdot \mathbf{\dot{r}}_{\text{EMB}} \right) d\lambda,
\]

where the position vectors are both expressed in au. Using the osculating orbital elements in Table 2, we plot the effective potential of the asteroid as the red curve in Figure 3, in comparison to that of the first Earth Trojan 2010 TK$_7$ in blue, whereupon we can observe that, while the minima of the latter are located basically around the Lagrange points \( L_4 \) and \( L_5 \), those of 2020 XL5 are clearly shifted to larger resonant arguments in magnitude, due to the nontrivial orbital inclination and eccentricity. Therefore, we are now confident that 2020 XL5 is currently in a tadpole orbit librating near the \( L_4 \) point, thus being the second known Earth Trojan after 2010 TK$_7$.

We proceed to investigate the orbital stability of 2020 XL5. Unfortunately, chaos in its orbit prevents us from finding a conclusive answer pertinent to the exact history of 2020 XL5 before its current dynamical status as an \( L_4 \) Earth Trojan. We calculated the Lyapunov timescale of the asteroid to be only a few hundred years by means of the tangent map method by Mikkola & Innanen (1999). Therefore, statistics from backward...
introduction of the clones for timespans much longer than the Lyapunov timescale are likely physically meaningless, because this may well cause a manifest increase in entropy of the system with time reversal, which clearly violates the second law of thermodynamics. Indeed, orbital evolution of the MC clones and the nominal orbit in our backward integration prior to CE $\sim 1000$ is drastically different (for instance, in terms of the resonant argument, see Figure 2).

It is most likely that 2020 XL5 will maintain its current Earth Trojan state for the next four millennia, whereafter its evolution becomes unclear again due to chaos in its orbit. Following Connors et al. (2011) and Dvorak et al. (2012), we visually examined the phase portraits of the nominal orbit and the MC orbital clones of 2020 XL5 in the semimajor axis versus resonant argument space. Here, for clarity, only 10 of the MC clones alongside the nominal orbit are shown in Figure 4, where we can observe that while some of the clones remain in the current dynamical status as an $L_4$ Earth Trojan, others may become an $L_5$ Earth Trojan, quasi-satellite, or even leave the 1:1 MMR with the EMB. During this period, the nominal clone is gradually moving toward the $L_5$ point, as is also evidenced in Figure 2.

In order to better characterize the timescale on which 2020 XL5 remains as an Earth Trojan at the $L_4$ point, we tracked the nominal orbit and its 1000 MC orbital clones at each output time step (0.2 yr) in our numerical integration. In the forward simulation, whenever the resonant argument of a clone exceeds 180° for the very first time, we marked the corresponding epoch as the moment at which it has left the $L_4$ point. In the backward simulation, the latest epoch at which the clone has $\varphi \leq 180^\circ$ was treated as the time when it started to be trapped in the $L_4$ region. The results are plotted in Figure 5. We found that 2020 XL5 has been an $L_4$ Earth Trojan since CE $\sim 1444.7 \pm 1.1$, and $\sim 99.5\%$ of the clones (996 out of 1001 clones, including the nominal orbit) will leave the $L_4$ libration region within the next 10 kyr. We found the mean epoch when the clones exit the $L_4$ region to be $4.86 \pm 0.51$ kyr from J2000, where the uncertainty is the standard deviation. Therefore, it is highly likely that the 2020 XL5 is dynamically unstable over the investigated period ($\sim 10$ kyr), thus being the second transient Earth Trojan after 2010 TK7. The latter became an $L_4$ Earth Trojan $\sim 2$ kyr ago and will maintain its current dynamical status for $\sim 15$ kyr before becoming a horseshoe
coorbital or jumping into the neighborhood of the $L_5$ point (Dvorak et al. 2012).

The short lifetime of 2020 XL$_5$ being on an Earth Trojan orbit is not unexpected, because its nontrivial eccentricity plus the relatively small orbital inclination makes it susceptible to the gravitational pulls of other terrestrial planets, in particular Venus, with which close encounters were found to occur on a common basis. Our finding agrees with the analysis by de la Fuente Marcos & de la Fuente Marcos (2021) based upon a much shorter observed arc of the object. With SOLEX12 we made use of the 1000 MC orbital clones in addition to the nominal orbit and searched for close encounters between the asteroid and various massive bodies in our force model described earlier in this section having mutual close approach distances $d_{\text{min}} \leq 0.1 \text{ au}$ from Barycentric Dynamical Time (TDB) 1900 January 1.0 to 2200 January 1.0. The results are summarized in Table 3, where we can see that in the examined three centuries, Venus is the only massive body that had and will continue having 10 close encounters with the Earth Trojan at mutual distances $\leq 0.1 \text{ au}$ in our search.

In the following, we use order-of-magnitude calculation to estimate the timescale on which 2020 XL$_5$ will leave the 1:1 MMR with Earth solely due to the perturbation from Venus. We only consider close encounters between the two bodies at $d_{\text{min}} \leq 0.1 \text{ au}$. During one such close approach to Venus, the change in the orbital energy of 2020 XL$_5$ is due to the influence of the Venusian gravitational potential

$$|\Delta E| = G \frac{M_V M}{d_{\text{min}}},$$  

(5)

where $M_V$ and $M$ are respectively the masses of Venus and 2020 XL$_5$, and $d_{\text{min}} \leq 0.1 \text{ au}$ is the close approach distance between the two bodies. In the two-body problem, the heliocentric orbital energy of 2020 XL$_5$ is given by

$$E = -G \frac{M_\odot M}{2a}.$$  

(6)

Here, $M_\odot$ is the mass of the Sun. Differentiating both sides, and equating the change in the orbital energy to the one by Equation (5), we find the change in the semimajor axis in the heliocentric orbit of 2020 XL$_5$ is

$$\Delta a = \frac{2a^2}{d_{\text{min}}} \left(\frac{M_V}{M_\odot}\right).$$  

(7)

whereby we obtain that after a close encounter with Venus at $d_{\text{min}} \leq 0.1 \text{ au}$, the Earth Trojan experiences a change of $\geq 5 \times 10^{-5} \text{ au}$ in semimajor axis in his heliocentric orbit. We approximate that 2020 XL$_5$ will stop being trapped in the 1:1 MMR with Earth once its semimajor axis differs from the one of Earth by over the Hill radius of the latter, which is $R_H \approx 0.01 \text{ au}$. Despite that we did not check close encounters
between the asteroid and Venus outside the timespan from 1900 to 2200, we do not expect that the frequency of such encounters while 2020 XL₅ is still in the 1:1 MMR with Earth is significantly different. Accordingly, we estimate that a total number of 200 such close encounters with Venus will accumulatively destabilize the orbit of the Earth Trojan and gradually nudge it outside the 1:1 MMR with Earth. Given the expected occurrence frequency, the whole process will take merely 6 kyr, which agrees rather well with our N-body numerical simulation, demonstrating that Venus is the primary perturbation source that influence the coorbital status of 2020 XL₅ with Earth.

Note that in our analysis, we have completely omitted the Yarkovsky effect of the Earth Trojan due to anisotropic solar heating. However, we argue that our conclusions are not likely altered considerably even if there is such an effect. Following Farnocchia et al. (2013) and Hui & Jewitt (2017), we compute the expected drift rate in the semimajor axis of the heliocentric orbit of the asteroid by comparing to asteroid (101955) Bennu, in which way we will need a size estimate for 2020 XL₅. Using our photometry and that from the MPC, assuming a typical asteroidal phase slope of \( \alpha = 0.15 \) in the model by Bowell et al. (1989), we find the absolute magnitude of Earth Trojan to be \( H = 20.4 \pm 0.5 \) in the \( G \) band of the Gaia DR2 catalog. We further simply assume a typical geometric albedo of 0.1 for the asteroid, thus obtaining its nucleus radius to be \( 1.6 \pm 0.4 \) \( \times \) 10⁸ m. Accordingly, we find the change rate in the semimajor axis of 2020 XL₅ is then \( 3 \times 10^{-3} \) au Myr⁻¹, which is by no means comparable to the corresponding change rate in the semimajor axis of the heliocentric orbit due to the perturbation by Venus. Therefore, we conclude that our omission of the Yarkovsky effect will not introduce any noticeable deviation from the reality.

### 4. Summary

The key conclusions of our study are listed as follows:

1. With our follow-up astrometric observations, we confirmed that 2020 XL₅ is a new Earth Trojan after 2010 TK₇.
2. 2020 XL₅ is only a transient Earth Trojan, as it has been librating around the \( L₄ \) point only since the fifteenth century, and its orbit is unstable on a \( \sim 10 \) kyr timescale primarily due to frequent close approaches to Venus at mutual distances of \( \lesssim 0.1 \) au.
3. The minima of its current effective potential are clearly shifted away from \( 60° \) to a larger angle in the resonant argument because of its nontrivial orbital inclination and eccentricity.

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**Software:** EXORB8, IDL, SOLEX12.

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### Table 3

| Time (TDB) | Body | Close Approach Distance (au) | Relative Speed (km s⁻¹) |
|------------|------|-------------------------------|------------------------|
| 1979 Feb 01.8877 ± 0.0014 | Venus | 0.094141 ± 0.000013 | 11.23909 ± 0.00048 |
| 1987 Jan 28.6599 ± 0.0043 | Venus | 0.054339 ± 0.000065 | 12.7084 ± 0.0028 |
| 1995 Jan 27.4661 ± 0.0066 | Venus | 0.050302 ± 0.000090 | 12.8850 ± 0.0040 |
| 2003 Jan 29.0713 ± 0.0081 | Venus | 0.082103 ± 0.000092 | 11.6470 ± 0.0033 |
| 2054 Feb 12.7629 ± 0.0065 | Venus | 0.06122 ± 0.00013 | 16.7320 ± 0.0060 |
| 2062 Feb 12.5494 ± 0.0032 | Venus | 0.049010 ± 0.000058 | 16.1344 ± 0.0028 |
| 2070 Feb 10.5425 ± 0.0020 | Venus | 0.070863 ± 0.000041 | 17.1707 ± 0.0020 |
| 2179 Apr 04.878 ± 0.014 | Venus | 0.098895 ± 0.000022 | 13.891 ± 0.017 |
| 2190 Jan 30.540 ± 0.023 | Venus | 0.04856 ± 0.00040 | 16.001 ± 0.021 |
| 2198 Feb 01.512 ± 0.018 | Venus | 0.037676 ± 0.00019 | 13.676 ± 0.013 |

**Notes.** Our search for close encounters between asteroid 2020 XL₅ and the massive bodies in our force model was confined to a maximum close approach distance of 0.1 au. Under such configuration, Venus is the only planet that showed up in our search. The reported uncertainties are all standard deviations computed from the 1000 MC clones plus the nominal orbit.

a The corresponding uncertainties are in days.

**Software:** EXORB8, IDL, SOLEX12.
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