A Revisit From Near-Earth Object (NEO) 2012 TC_4

Eight days after its discovery, near-Earth object (NEO) 2012 TC_4 approached our planet to within 95,000 km, or 25% of the Moon's distance, when it reached perigee at 05:29 UT on 12 October 2012. In this close flyby, 2012 TC_4 crossed Earth's orbit travelling inbound toward perihelion on 25.0 November 2012 UT, when it was about 91% of our distance from the Sun.

Even in the Earth's night sky before perigee, 2012 TC_4 was difficult to observe. Its absolute magnitude $H = 26.525$ placed its diameter somewhere in the 7.5-30 m range, depending on its unknown surface reflectivity, making observations possible only at very close range. Upon entering Earth's daytime sky as it passed through perigee, 2012 TC_4's orbit condition code (OCC) stood at 4 thanks to 281 visible light telescopic observations spanning a 7-day arc. At OCC = 4, 2012 TC_4 along-track heliocentric position uncertainty would increase at rates up to 382 arc-seconds per decade.[1]

Predicted position precision, together with knowledge of 2012 TC_4's size and shape, can be vastly improved with radar observations. Although observations were attempted with the Goldstone, California DSS-14 planetary radar in 2012, no echoes were obtained before pointing uncertainties quickly exceeded the precision required to detect 2012 TC_4.

As it was lost to further observations in 2012, Earth gravity perturbations to 2012 TC_4 had increased the NEO's heliocentric orbit period from 1.455 years to 1.667 years. This increased period, remarkably close to 5/3 years, indicated 2012 TC_4 would make its next 3 revolutions of the Sun in very nearly the same time Earth made 5 such revolutions.[2]

Thus, even as 2012 TC_4 was effectively lost a week after its discovery, there was hope it could be recovered 5 years later as it crossed Earth's orbit circa 12 October 2017. Half a decade later, searching for this faint NEO would not be easy. Due to its OCC = 4 pedigree, 2012 TC_4 along-track heliocentric position uncertainty at that time would be up to 191 arc-seconds, equivalent to 139,000 km near Earth's heliocentric orbit. An OCC-based uncertainty estimate has order-of-magnitude precision and can be improved in this case with a linear propagation of the October 2012 covariance matrix to 2017's Earth encounter. This propagation has a 3-sigma along-track heliocentric position uncertainty equivalent to ±13.4 hours of geocentric motion, producing 2012 TC_4 closest approach distances to Earth ranging from 460,000 km down to 13,000 km.

At a distance of 56 million km, 2012 TC_4 was recovered with the European Southern Observatory's 8.2-m telescopes at the Very Large Telescope Observatory in the Atacama Desert of Northern Chile from images obtained on 27 July, 31 July, and 5 August 2017.[3] By early September 2017, with observations then spanning nearly 5 years, OCC for 2012 TC_4 dropped to 0 (along-track heliocentric position uncertainty increasing at up to 1.0 arc-second per decade).

Up to this point, 2012 TC_4 motion had been modeled using only gravity accelerations. When non-gravity effects modeling began on 11 September 2017, OCC temporarily increased to 2

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[1] Reference http://www.minorplanetcenter.net/iau/info/UValue.html (accessed 24 September 2017), where the uncertainty parameter U is equivalent to OCC. Orbit data and their uncertainty statistics supplied for 2012 TC_4 are obtained from JPL's *Horizons* ephemeris server via https://ssd.jpl.nasa.gov/?horizons (accessed 24 September 2017).

[2] In astrodynamics terminology, 2012 TC_4 is said to be in a 3 : 5 mean motion resonance with Earth under these conditions. Encounters giving rise to such resonances each entail flying through a restricted and unique region in space about a planetary body called a *keyhole*.

[3] Reference https://www.jpl.nasa.gov/news/news.php?feature=6906 (accessed 24 September 2017).

(along-track heliocentric position uncertainty increasing at up to 19.6 arc-seconds per decade). On 22 September, with OCC reduced back to 1 (along-track heliocentric position uncertainty increasing at up to 4.4 arc-seconds per decade), perigee had converged to 05:41 UT on 12 October 2017 with a distance of 50,100 km. Geocentric motion during this Earth flyby is plotted in Figure 1.

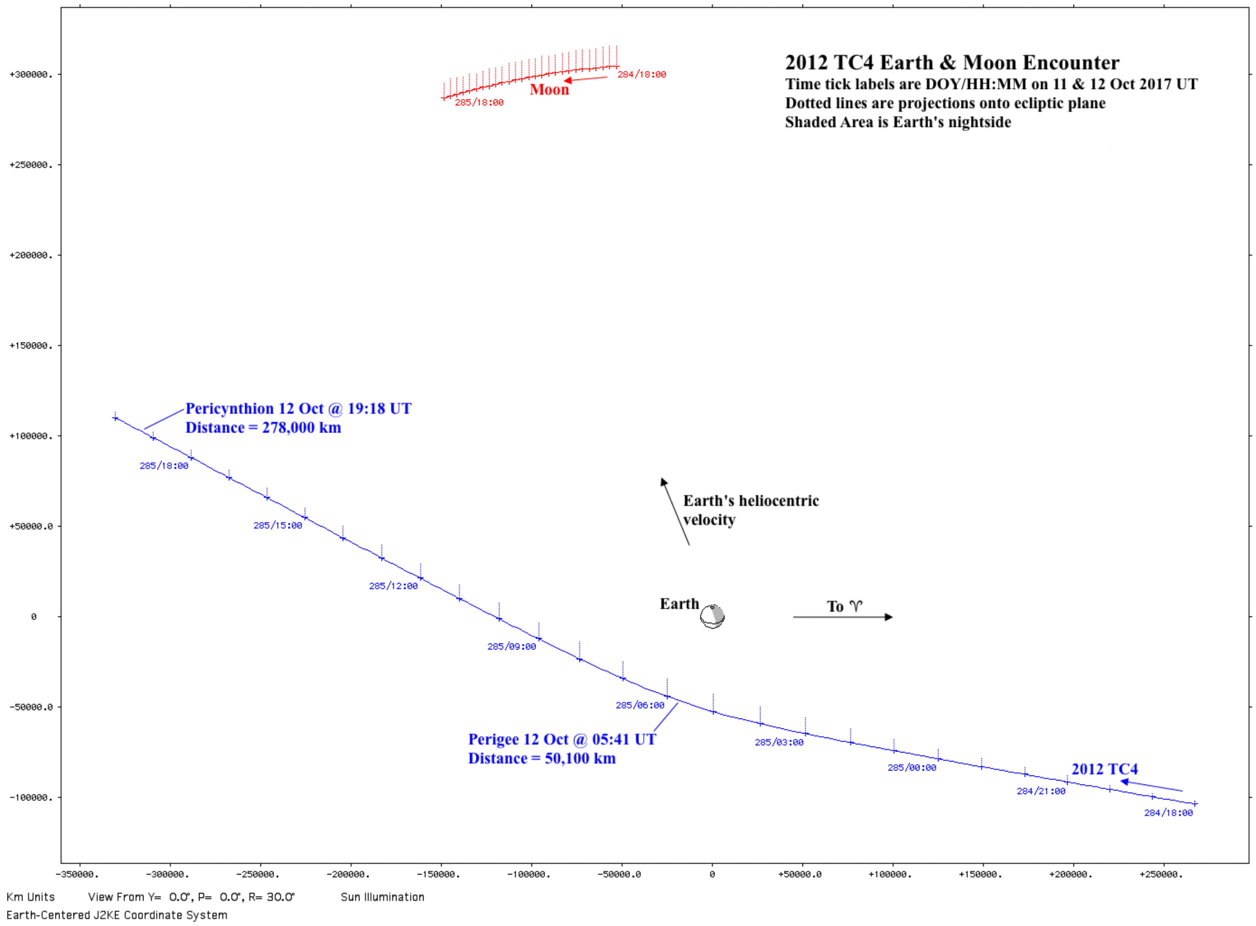

Figure 1. Geocentric motion of 2012 TC$_4$ (blue) and the Moon (red) are plotted during 11-12 October 2017 UT. Plot perspective is from 60° north of the ecliptic plane.

With OCC approaching 0, even while non-gravity effects are modeled, prospects for obtaining 2012 TC$_4$ radar observations in 2017 greatly improve with respect to 2012's Earth encounter. The Goldstone planetary radar is scheduled to attempt 2012 TC$_4$ observations from 9 to 14 October.[4] If recovery from Hurricane Maria damage permits, the Arecibo, Puerto Rico planetary radar will attempt additional observations.

On the Goldstone radar schedule extending from 2017 seven years into the future, 2012 TC$_4$ is by far the faintest upcoming target as reckoned by *H*. The Goldstone radar beam will illuminate about half of 2012 TC$_4$, so any imagery obtained will likely span just one to four pixels in a specific direction. The smallest NEO detected by Goldstone to date is 2012 XB$_{112}$, with H = 29.9 and diameter of 2.5 m. Since this diminutive NEO's "imagery" was limited to one pixel when observed in December 2012, its shape remains unknown.

[4] Reference https://echo.jpl.nasa.gov/asteroids/goldstone_asteroid_schedule.html (accessed 25 September 2017).

Just as in the 2012 Earth encounter, 2012 TC$_4$'s perigee location in 2017 is over Earth's trailing hemisphere as denoted by the "Earth's heliocentric velocity" annotation in Figure 1.[5] Consequently, the 2017 encounter also increases 2012 TC$_4$'s heliocentric orbit period. But in this case, the post-flyby period of 2.062 years has no short-term mean motion resonance with Earth's heliocentric orbit. The next 2012 TC$_4$ close approach to our planet will be circa 17 October 2050 UT. The shift from 12 October for this event is due to 2012 TC$_4$ close encounters with Mars on 30 September 2034 UT and on 29 July 2050 UT. Effects of Earth gravity perturbations in 2017 on 2012 TC$_4$'s heliocentric orbit are illustrated in Figure 2.

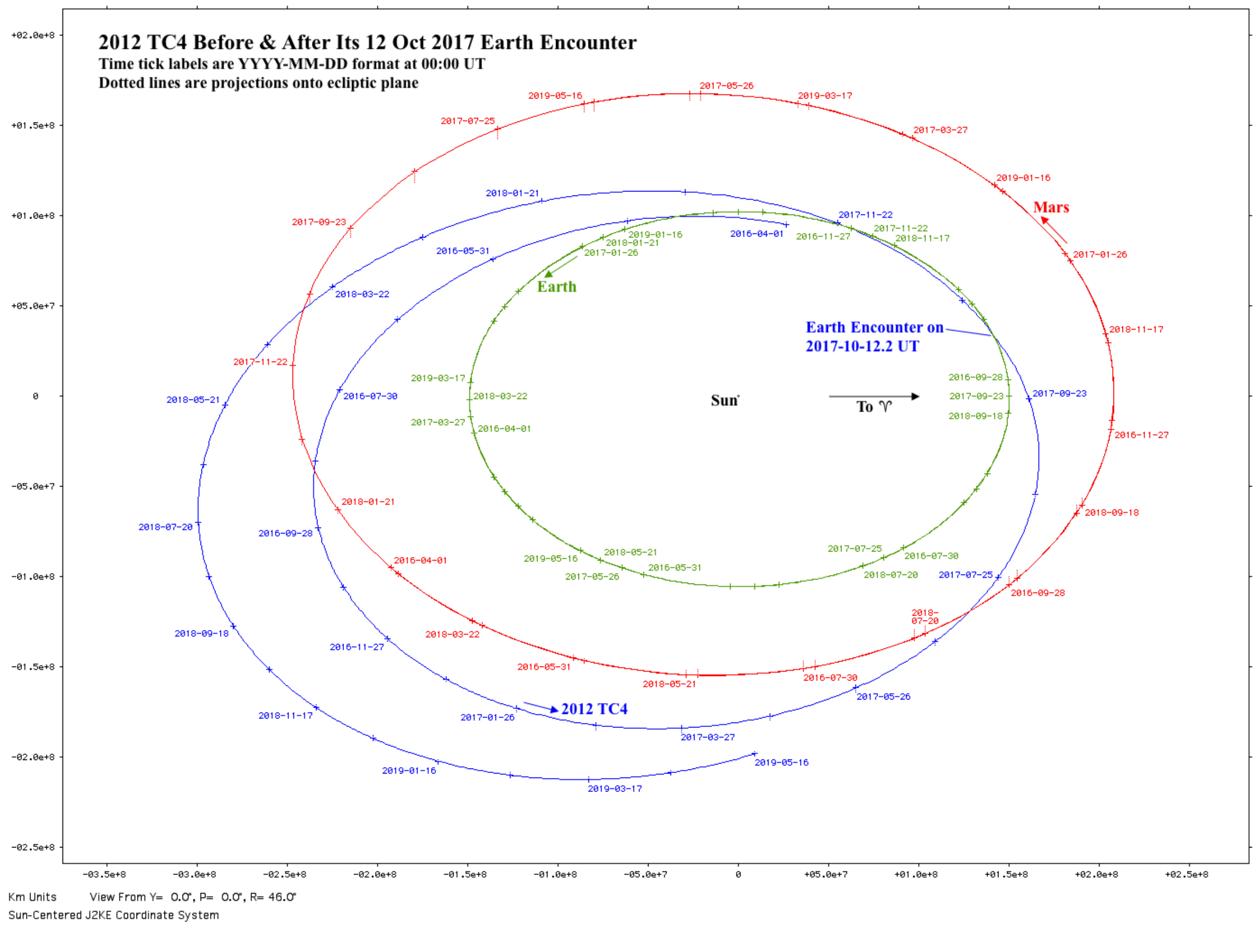

Figure 2. Heliocentric motion of 2012 TC$_4$ (blue), the Earth (green), and Mars (red) are plotted from early April 2016 until mid-May 2019 to illustrate effects of the NEO's Earth encounter on 12 October 2017. Plot perspective is from 44° north of the ecliptic plane.

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[5] As in 2012, this Earth flyby occurs with 2012 TC$_4$ moving inbound toward perihelion. This solar closest approach will occur on 4.0 November 2017 UT at about 97% of Earth's distance from the Sun.