A 2012 TC_4 Gravity Assist From Earth

Yet another recently discovered near-Earth object (NEO) glided past Earth on 12 October 2012, approaching to about 25% of the Moon's distance when it reached perigee at 05:29 UT. Dubbed 2012 TC_4 shortly after it was first detected on 4 October, this NEO is a member of the Apollo group whose orbits cross Earth's and whose orbit periods exceed Earth's.

In the case of this close flyby, 2012 TC_4 crosses Earth's orbit travelling inbound toward perihelion on 25.0 November 2012 UT, when it will be about 91% of Earth's distance from the Sun. As illustrated by the shaded nighttime hemisphere in Figure 1, this inbound geometry places 2012 TC_4 in Earth's night sky before its flyby, facilitating discovery with optical telescopes. After perigee, however, 2012 TC_4 rapidly moves into Earth's daytime sky, and optical observations will become all but impossible. An attempt was made to track 2012 TC_4 prior to perigee with the DSS-14 planetary radar antenna at Goldstone, CA, but it appears no useful data were obtained.

Consequently, the diameter of 2012 TC_4 must be estimated from its absolute magnitude H = 26.525. Most NEOs range in albedo (reflectivity) from 0.60 to 0.03. Assuming this range places the diameter of 2012 TC_4 anywhere from 8.5 m up to 38 m. Depending to some degree on 2012 TC_4 shape and composition, this size range spans a sobering spectrum of potential Earth collision hazards. Such a collision might be just a "boom in the sky", possibly followed by a harmless shower of gravel, or it could resemble an event which leveled 2000 km^2 of Siberian forest in 1908 (reference http://science.nasa.gov/science-news/science-at-nasa/2008/30jun_tunguska/).

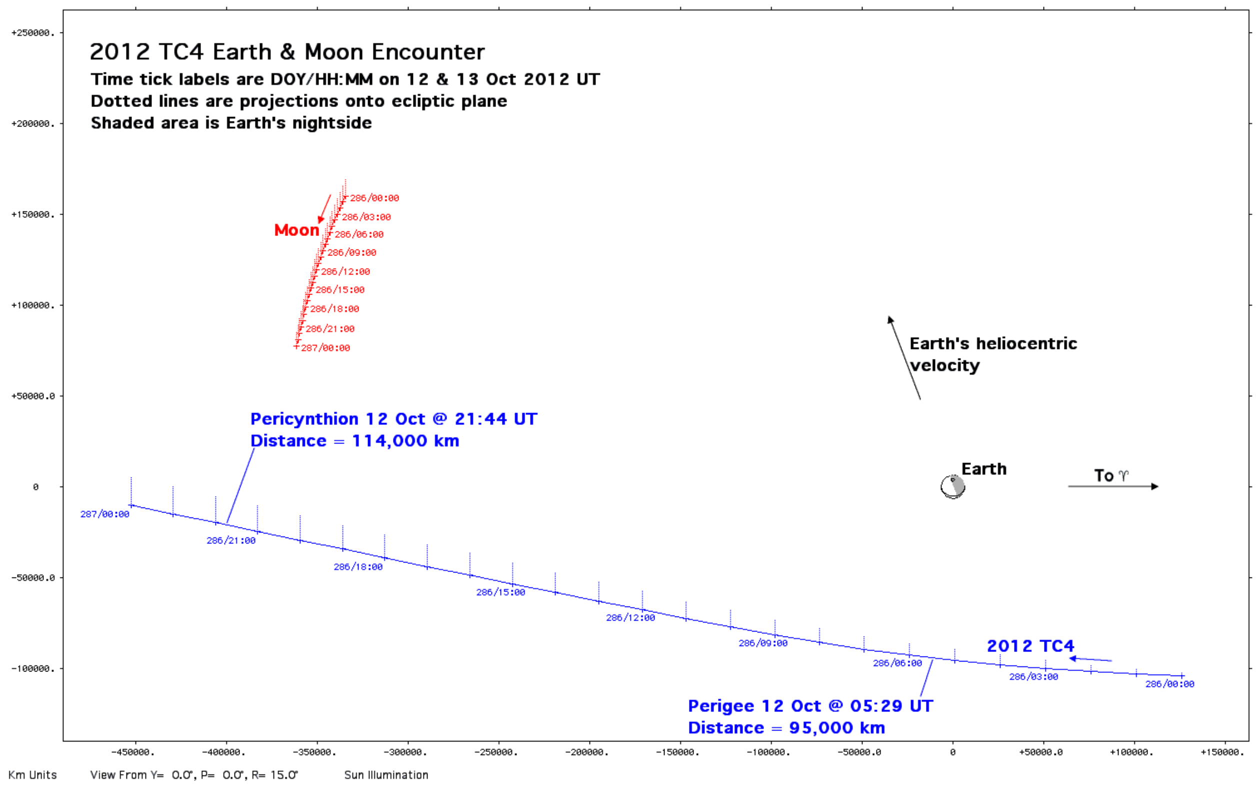

Figure 1. Geocentric motion of 2012 TC_4 and the Moon are plotted during 12 October 2012 UT. Plot perspective is from 75° north of the ecliptic plane.

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The direction of Earth's heliocentric motion is annotated in Figure 1. Because 2012 TC_4 reaches perigee at a point behind Earth in its heliocentric orbit, the NEO receives a gravity assist in the direction of Earth's heliocentric motion. This perturbation is evident in Figure 1 as a slight upward bend in the geocentric path taken by 2012 TC_4. Since 2012 TC_4 is moving about the Sun in generally the same direction as Earth on 12 October 2012, the gravity assist it receives increases its heliocentric speed slightly. This also increases the orbit period of 2012 TC_4, ensuring it remains in the Apollo group.

Effects of the 12 October 2012 Earth gravity assist on 2012 TC_4's heliocentric orbit are evident in Figure 2. This plot begins in late May 2011 and ends in late January 2014. A significant increase in 2012 TC_4 aphelion is evident when the portion of its orbit beyond that of Mars is compared before and after 12 October 2012's Earth encounter.

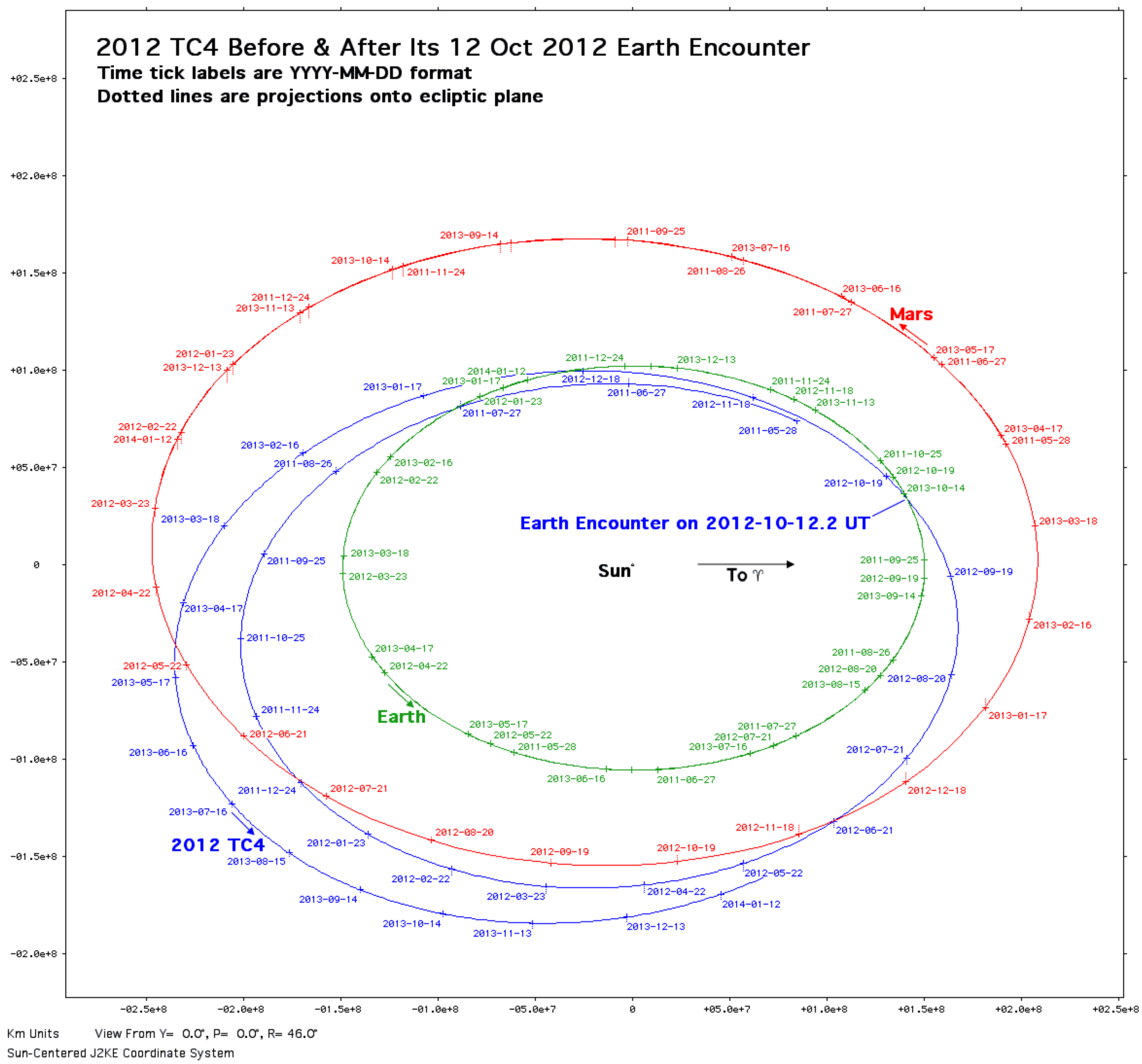

Figure 2. Heliocentric motion of 2012 TC_4, the Earth, and Mars are plotted from late May 2011 until late January 2014 to illustrate effects of the NEO's Earth encounter on 12 October 2012. Plot perspective is from 44° north of the ecliptic plane.

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Earth-crossing NEOs whose orbit periods are less than Earth's are members of the Aten group. How closely Apollos and Atens approach Earth is typically a critical matter of timing. In the case illustrated by Figure 1, an Earth collision would have occurred if 2012 TC_4 had crossed Earth's orbit approximately $95{,}000/v_E$ seconds earlier, where $v_E = 29.8$ km/s is Earth's heliocentric speed. This approximation assumes 2012 TC_4 geocentric motion is transverse to Earth's heliocentric motion, a condition roughly applicable to Figure 1 geometry. The approximate time skew required for collision is therefore 3190 s = 53.1 min earlier. If 2012 TC_4 had crossed Earth's orbit slightly earlier than the time skew necessary for collision, perigee would have been above Earth's leading hemisphere with respect to its heliocentric motion. The resulting gravity assist would then have *reduced* 2012 TC_4 heliocentric speed and orbit period. In this manner, 2012 TC_4 could be transformed from an Apollo to an Aten.

Transformations between Apollos and Atens can occur with surprisingly high frequency. For example, consider a linear analysis of 2012 TC_4 position uncertainty in the recent past based on its JPL#17 orbit elements as obtained from the *Horizons* ephemeris server at http://ssd.jpl.nasa.gov/?horizons on 13 October 2012. Working backward in time, 2012 TC_4 position uncertainty increments at a greater rate before Mars is encountered on 24 January 2011 at a periapsis distance near 13 million km. This encounter occurs near the 2012 TC_4 aphelion before Figure 2's plot begins. As a consequence of 2011's Mars encounter, the previous 2012 TC_4 Earth encounter on 12 October 1996 has a 3-standard-deviations (3σ) perigee distance ranging from 4000 km (a statistical collision we know did <u>not</u> occur) to 2.35 million km. Not surprisingly, the time of perigee associated with this Earth encounter has a 3σ uncertainty of ±3085.1 min (±2.14 *days*). Prior to 12 October 1996, 2012 TC_4 might have been an Apollo or an Aten.

Finally, we must all be grateful for any knowledge of 2012 TC_4. An object this small approaching Earth *after* perihelion is not observable until after perigee and can easily escape detection as it recedes into interplanetary space and dims beyond reach of instrumentation confined to Earth or its vicinity.