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IMPROVED NEO ASTROMETRY WITH THE GAIA CATALOG: APPLICATION TO APOPHIS

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ABSTRACT

(99942) Apophis is frequently referred to as the “Poster Child for Killer Asteroids”. This distinction was earned in 2004, when the probability of an Earth impact in 2029 briefly reached about 3 percent. Now with over a decade of observations with which to compute its orbit, we know that the object will miss the Earth by less than 40000 km on 2029 April 13. However, future impacts cannot yet be ruled out, one potentially occurring as early as 2068. Standing in the way of improved impact predictions is, in part, the Yarkovsky effect. The quality of the currently available optical astrometry is insufficient to detect the size of this effect. The recently released Gaia-DR1 catalog provides an opportunity to improve NEO astrometry in general, and that of Apophis in particular.

Our earliest observations of Apophis utilized the USNO-B1.0 catalog. It soon became clear that significant systematic errors were present in this catalog, with the declination residuals showing an offset of nearly 0.2 arcsec to the north. A more recent re-reduction using the 2MASS catalog reduced the bias significantly, but the

absence of proper motions in the 2MASS catalog produced a growing systematic error with time. Our most recent observations of Apophis have been reduced using the PPMXL catalog, but the random and systematic errors in it are still the limiting factor.

In 2016 September, the Gaia-DR1 catalog was released, and over 200 observations of Apophis acquired within 2 years of that catalog's reference epoch of 2015.0 have been reduced against it. With PPMXL, it took aggressive outlier rejection to bring the RMS residual of the astrometric solution down to roughly 0.15 arcsec. With Gaia-DR1, the RMS residual is closer to 0.05 arcsec without such aggressive rejection procedures. To be sure, outlier rejection is still necessary, as the centroids of reference stars can be corrupted by overlapping trails, bad CCD columns, cosmic ray hits, etc. But the noise contributed by the astrometric solution is usually negligible compared to that of measuring the object itself.

Systematic error has also been dramatically improved. The worst case identified in the PPMXL-reduced data was a set of five observations taken on 2013 December 25 UT, in which the average residual in right ascension was -0.29 arcsec, greatly in excess of the computed uncertainty of 0.05 arcsec. With Gaia-DR1 as the reference, the average residual in right ascension for these observations is +0.04 arcsec. We have limited evidence to suggest that the absence of proper motions for the vast majority of stars in Gaia-DR1 is detectable in our data, as fields with a larger range of proper motions, as indicated by the PPMXL catalog, have larger reduced chi-squared statistics for the astrometric solutions. A complete re-reduction of all our Apophis astrometry, spanning 2004 to 2015 must therefore wait for Gaia-DR2, due out by the end of 2017.

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