Predicting the Earth Encounters of Apophis in 2029 and 2036. J. D. Giorgini[1], L.A.M. Benner[1], S. J. Ostro[1], M. C. Nolan[2], M. W. Busch[3], [1]JPL/Caltech, MS 301-150, 4800 Oak Grove Drive, Pasadena, CA 91109-8099, USA, (Jon.D.Giorgini@jpl.nasa.gov), [2]Arecibo Observatory, NAIC, HC03 Box 53995, Arecibo, PR 00612, USA, [3]Division of Geological Sciences, Caltech, Pasadena, CA, 91123, USA.

Arecibo Doppler measurements (2380-MHz, 12.6-cm) of asteroid 99942 Apophis, obtained in August 2005 and May 2006, have been combined with optical astrometry reported through August 2006 to produce a new orbit solution. This has reduced the volume of the uncertainty ellipsoid entering the April 13, 2029 Earth encounter an additional 87% relative to knowledge available after the initial delay-Doppler measurements in January of 2005. Apophis is predicted to encounter the Earth at a minimum geocentric distance within the interval [5.62,6.30] Earth-radii, considering both astrometric and physical parameter uncertainties. There is a potential Earth encounter in 2036 (Fig. 1).

Trajectory predictions and impact hazard assessments for asteroids such as Apophis are usually based on a Standard Dynamical Model. The SDM considers *n*-body relativistic gravitational influences of the Sun, planets, Moon, and Ceres, Pallas and Vesta. We find that approximations within the SDM are sufficient to obscure the difference between a predicted Earth impact and a distant miss in 2036 by altering the dynamics leading into the 2029 encounter. Normal impact probability assessments become problematic without knowledge of the object's physical properties; impact could be excluded while the actual dynamics still permit it.

No statistically significant deviation from the Standard Dynamical Model is yet observed in the reported astrometry. However, such deviations are expected in the 2011-2021 interval as a result of at least solar energy related accelerations and other factors (Fig. 2). Solar energy can cause 82-4720 Earth radii of change relative to the SDM by 2036, depending on the physical properties of Apophis. Planetary ephemeris uncertainties can cause up to 23 Earth-radii of uncertainty, Earth gravitational harmonics up to 2.9 Earth-radii of change, and unmodelled asteroid perturbers up to 2.3 Earth-radii (Fig. 3). Offsets are almost entirely along-track.

Depending on their as yet unknown true magnitudes, such issues will affect trajectory prediction, hazard assessment, and mitigation feasibility not only for Apophis' potential encounter with Earth in 2036, but for a growing number of objects, as new surveys increase the rate of discovery.

References: Giorgini J.D., Benner L.A.M., Ostro S.J., Nolan M.C., Busch M.W. (2008) *Icarus, 193,* 1-19.

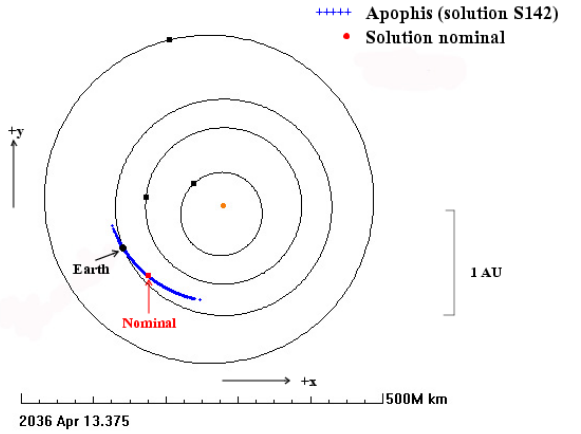

Fig. 1 Current SDM 3σ Monte-Carlo region for the 2036 Earth encounter.

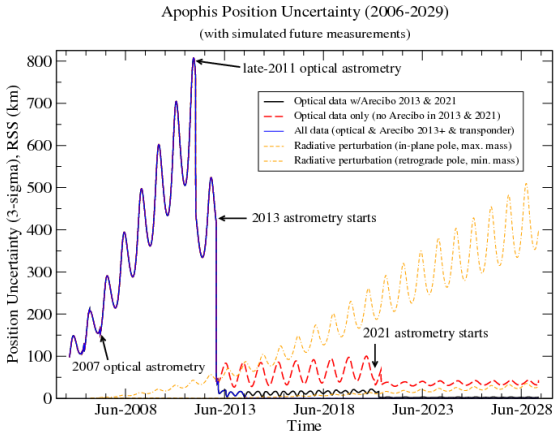

Fig. 2 Apophis 3σ SDM uncertainty during 2006-2029 for optical data only, optical+Arecibo, and optical+Arecibo+transponder. Also shown are min./max. radiation perturbations not included in the SDM.

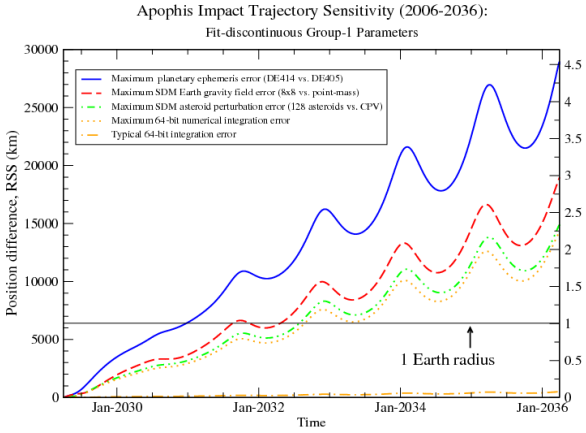

Fig. 3 Maximum SDM trajectory prediction error accumulation 2006 - 2036 (only post-2029 is shown) due to non-SDM parameters.