**APOPHIS IMPACT HAZARD ASSESSMENT AND SENSITIVITY TO SPACECRAFT CONTACT.** S. R. Chesley[1,2] and D. Farnocchioa[1], [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California 91109, USA, [2]steve.chesley@jpl.nasa.gov.

**Introduction:** The near-Earth asteroid (99942) Apophis has been the subject of significant scientific and public attention ever since it was re-discovered in Dec. 2004 by Gordon Garradd at Siding Spring Observatory [1], at which point it became clear that the asteroid would see an extraordinarily close approach to Earth in April 2029. Initially, an Earth collision in 2029 could not be ruled out, and the impact probability for 2029 rose as high as 2.7% before dropping to zero by late December when precovery observations from Spacewatch dating to March 2004 were reported [2].

As the orbit continued to be refined with additional observations, the 2029 encounter time and distance became clear, with current estimates showing a distance of 37,700 ± 700 km from the geocenter at 2029-Apr-13 21:46 TDB. This is less than 5 Earth radii from the surface, lower than the altitude of geosynchronous satellites. Such a close approach will cause a significant orbital deflection due to Earth's gravitational perturbation. For Apophis, the semimajor axis will increase from 0.92 au before the 2029 Earth encounter to 1.10 au after, thus Apophis will transition from an Aten to an Apollo type asteroid through this encounter.

**Resonant Returns:** Besides changing the orbit itself, such a close approach invariably injects increased uncertainty into post-encounter trajectory predictions, and in particular a broader range of possible orbital periods are possible after the encounter. If certain resonant orbital periods are within the post-encounter uncertainty then Apophis can return to the encounter position a number of years later at the same time that the Earth is there, setting up a possible resonant return collision [3]. After the 2029 collision was ruled out, the most interesting potential impact return was in 2036, seven years and six Apophis revolutions later. This return was also ruled out with additional observations, at which point the focus turned to a resonant return in April 2068 [4], which currently carries an impact probability of $6.7\times10^{-6}$ [5].

**Yarkovsky Effect:** An important element of the Apophis impact hazard assessment is the Yarkovsky effect, a subtle nongravitational acceleration related to the anisotropic emission of thermal radiation [6]. The Yarkovsky effect leads to a slow drift in the semimajor axis that is a significant element of the future impact hazard assessment, and yet so far we have only a weak direct measurement of the Yarkovsky effect acting on Apophis [5,7]. However, one can use forward modeling of the known or estimated physical properties of Apophis to derive an estimate of the Yarkovsky effect and an associated uncertainty, which can then be fully accounted for in the impact hazard assessment [3].

**Spacecraft Perturbations:** The 2029 Earth encounter of Apophis represents a unique opportunity to investigate a relatively large asteroid at an extraordinarily close distance to Earth. Some mission concepts may call for contacting Apophis with a spacecraft, whether it be for the purpose of landing, sample collection or an experimental impact. However, any contact will inevitably lead to a small perturbation that might not lead to an ignorable effect in the impact hazard assessment. In other words, spacecraft contact could potentially cause Apophis to be deflected onto an impact trajectory, though it is just as likely that it would deflect an impact trajectory onto a safe trajectory. Either of these scenarios has a low probability, but it is important to note that any contact taking place pre-perigee in 2029 will be greatly amplified by the 2029 encounter, while those taking place post-perigee will have a dramatically reduced effect on the trajectory. As a part of this presentation we will characterize the effect of small perturbations to the orbit, such as might be induced by spacecraft landings or cubesat impacts, and the implications for the trajectory in the out years when impacts are possible.

**References:** [1] MPEC 2004-Y25 (2004). [2] MPEC 2004-Y70 (2004). [3] A. Milani, S. R. Chesley, and G. B. Valsecchi (1999) *Astron. Astrophys. 346*, L65–L68. [4] Farnocchia et al. (2013) *Icarus, 224,* 192–200. [5] Vokrouhlický et al. (2015) *Icarus, 252,* 277–283. [6] Vokrouhlický et al. (2015) *Asteroids IV*, 509. [7] Brozović et al. (2018) *Icarus, 300*, 115–128.