THE ABRUPT ALTERATION OF APOPHIS' SPIN STATE AND ITS IMPLICATIONS. D. J. Scheeres[1a], C. Benson[1b], M. Brozović[2c], S. Chesley[2d], P. Pravec[3e], and P. Scheirich[3f], [1]University of Colorado Boulder, UCB 429, Boulder, Colorado, 80309, USA, [a]scheeres@colorado.edu, [b]conor.j.benson@colorado.edu, [2]Jet Propulsion Laboratory, [c]marina.brozovic@jpl.nasa.gov, [d]steven.chesley@jpl.nasa.gov, [3]Astronomical Institute of the Academy of Sciences of the Czech Republic, [e]petr.pravec@asu.cas.cz, [f]petr.scheirich@gmail.com

Introduction: On April 13, 2029 the asteroid Apophis will make a close approach to the Earth, coming within 6 Earth radii. This flyby offers many opportunities for remote and in situ observations, and is an event that will drive much planning and analysis over the next decade. The close approach will have a significant impact on two aspects of Apophis' dynamic state, its orbit and its rotation. In this paper we revisit a detailed analysis we performed over a decade ago in 2005 that studied the range of possible spin states the asteroid could have following its close approach flyby [1]. In our current analysis we will take advantage of the many observations of this object that have occurred since that time to develop a more precise range of predictions of what effect the flyby will have on the Apophis spin state and any related geophysical perturbations that may arise from it. Specifically, we will draw from a much richer knowledge of its rotation state that was published in 2014 [2]. In addition, recent radar measurements have also enabled improved understanding of its shape model [3]. The addition of these important items greatly improves the modeling of the effects of its closest approach to the Earth, and will provide a realistic range of post-flyby situations that may be expected.

Motivation: This analysis supports two important scientific aspects. First, from these results we will be able to predict the range of surface accelerations and global stresses that will be placed across the body during its closest approach. These predictions may enable for more precise designs of any measurements that may be performed by visiting spacecraft. Second, assuming further improvements in its shape and spin state, the flyby will also provide some insight into the moments of inertia of the body based on the observed changes in its rotation state through the flyby.

Approach: Modeling Apophis using a second degree and order gravity field (derived from its estimated moments of inertia) and a point mass earth, we numerically integrate the asteroid's coupled orbit and attitude dynamics over four days centered on the 2029 encounter. The Apophis spin state and shape model solutions provided by [2] and [3] are both considered. Monte Carlo runs are used to account for current uncertainty in the asteroid's tumbling periods.

Conclusions: For both the solutions from [2] and [3], Apophis' spin state will be significantly altered due to the 2029 encounter. The resulting evolution is very sensitive to the asteroid's closest approach attitude and mass distribution. Sensitivity to the latter will aid in refining the asteroid's moments of inertia through pre and post flyby tracking. Peak accelerations obtained from the flyby simulations indicate that resurfacing and internal distortion are unlikely. Nevertheless, if Apophis is a contact binary, the components could potentially shift at closest approach. This deformation may be detectable through remote and in situ observation.

References: [1] Scheeres D. et al., (2005) Abrupt alteration of Asteroid 2004 MN4's spin state during its 2029 Earth flyby, *Icarus*, *178*, 281–283. [2] Pravec P. et al., (2014) The tumbling spin state of (99942) Apophis, *Icarus*, *233*, 48–60. [3] Brozović M. et al., (2018) Goldstone and Arecibo radar observations of (99942) Apophis in 2012–2013, *Icarus*, *300*, 115–128.