Impact of Yarkovsky Effect Modification Due to 2029 Fly-by on the Close Approach Structure of 99942 Apophis. Tam Do[1], Aaron Boley [1], [1]Department of Physics and Astronomy, University of British Columbia, 6224 Agricultural Road, Vancouver, British Columbia, Canada, V6T 1Z1

Abstract: The 2029 close approach of 99942 Apophis has prompted a thorough investigation into its Earth impact risk, including any potential passage of the asteroid through a keyhole in the 2029 b-plane [1]. Recent observations during the 2021 close approach have enabled further analysis to rule out an impact over the next century [2]. However, the strong gravitational interaction between the asteroid and Earth during the 2029 flyby could lead to changes in dynamically relevant properties of Apophis. Examples include changing Apophis's spin state [3] or albedo (due to resurfacing). These in turn could increase or decrease the strength of the Yarkovsky effect. This work conducts a preliminary investigation into how such changes would affect the long-term dynamics of the asteroid, with attention to any changes in the asteroid's long-term Earth impact risk.

We use Rebound/ReboundX [4][5] to simulate the orbital evolution of Apophis. A sudden change in the strength of the Yarkovsky effect is included in the integration following the 2029 close approach. We first explore a 10% increase in the Yarkovsky effect's strength, which is based on the predicted maximum change in asteroid's obliquity as discussed in [3]. Second, we explore an extreme scenario in which the Yarkovsky effect becomes negligible due to a steep increase in albedo from asteroid resurfacing. With these changes, we examine the keyhole structure on the 2036 b-plane, which shows the closest approach the asteroid has with Earth for 100 yr following the 2036 flyby, as a function of b-plane location. Fig. 1 shows the resulting b-plane structure for Apophis in the two modified Yarkovsky scenarios compared with the nominal case.

Differences between simulation results are small and the modifications to Apophis's orbit following the 2029 flyby, as investigated here, do not lead to an increased impact risk. The difference in the expected 2036 ζ between the nominal and the 10% increase Yarkovsky scenario is about -19 km. For the case without the Yarkovsky effect, the difference is about 190 km. The largest variations in the close approach structure occur within the keyhole complexes, which are far from the nominal and modified solutions.

References: [1] Chodas, P. W. (2006) *IAUS* 229, 215. [2] Satpathy, A., Mainzer, A., Masiero, J., et al. (2021) *AAS/DPS* 53, 7-306.06 [3] Souchay, J., Lhotka, C., Heron, G., et al. (2018) *A&A* 617, A74. [4] Rein, H. and Liu, S. (2012) *A&A* 537, A128 [5] Tamayo, D., Rein, H., Shi, P., and Hernandez, D. M. (2020) *MNRAS* 491, 2-2885

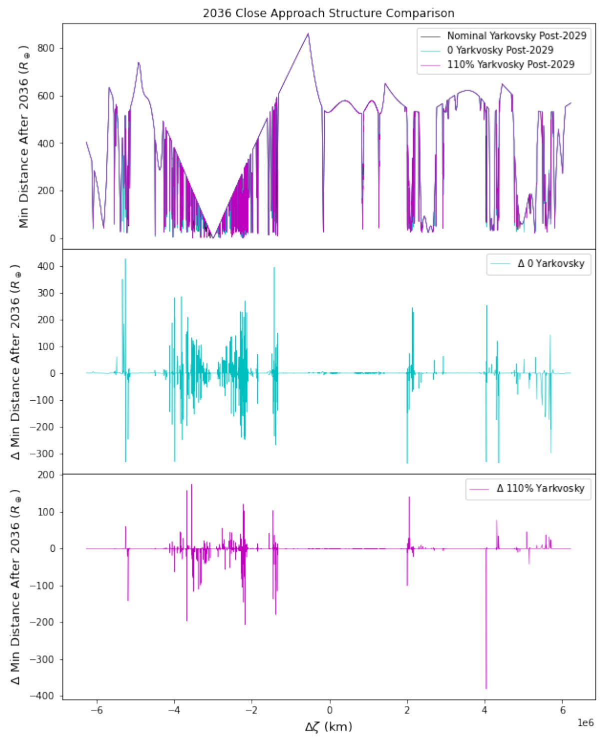

Figure 1: Close approach structure for Apophis under two modified Yarkovsky scenarios as compared with the nominal case (top). The differences between the close approach structures are shown in the middle and bottom panels. The current Horizons orbit solution is used for initial conditions and we use $\zeta_{2036} = -4.6985841 \times 10^7$km as the nominal 2036 b-plane location. All $\Delta\zeta$ values are referenced to this location. For these simulations, we explore the parameter space in the b-plane by giving 10 000 virtual Apophis particles an instantaneous velocity perturbation. Each virtual particle has its own Δv, which is either along or against track. The perturbation for each new virtual particle is incremented to a maximum Δv of $\pm$1cm. In addition, the 3-σ uncertainty ellipsoid is evenly sampled by virtual particles to provide higher resolution within the uncertainty ellipsoid. For each of the modified Yarkovsky cases, we instantaneously scale the Yarkovsky effect parameter at the time of the 2029 close approach.