PDC 2025
Stellenbosch, Cape Town, South Africa

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3D shape model and spin state of 99942 Apophis estimated from 2013 radar and lightcurve data

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Keywords: 99942 Apophis, radar, lightcurves, characterization

99942 Apophis was a target of intense optical and radar observing campaigns during the 2012–2013 apparition when the asteroid approached Earth within 0.097 au. Radar observations were obtained on 19 days between 2012 December 21 to 2013 March 16 [1] and lightcurve observations were obtained on 49 days between December 23 and April 15 [2]. Brozović et al. [1] and Pravec et al. [2] estimated the shape and spin state based on separate studies of radar and optical data. The Brozović et al. [1] model was estimated from radar data with coarse resolution relative to the size of Apophis, incomplete rotation coverage, and weak signal-to-noise ratios, and did not include lightcurves in the modeling, so we knew that the model could be improved and was not unique. Here we combine the 2012–2013 radar and lightcurve data for the first time and report new estimates of the shape and spin state. Based on the lightcurves, Pravec et al. [2] reported that Apophis is a slow rotator in a tumbling spin state. The long axis precesses around the angular momentum vector with a period of 30.56 h and the asteroid oscillates (i.e., rolls) about the long axis with a period of about 11 days. Pravec et al. reported a convex shape model with axis ratios of $a/c = 1.64 \pm 0.9$ and $b/c = 1.14^{+0.04}_{-0.08}$. The spin state derived from the lightcurves reproduces the orientations and shapes of the delay-Doppler echoes (Brozovic et al. 2018). The radar data showed evidence of bifurcation that does not appear in the convex shape model estimated from lightcurves. In the new analysis discussed here we fit a contact binary shape to the 2012–2013 lightcurve and radar data, and we find that the data are not very selective with respect to various degrees of bifurcation. Minor adjustments to the Pravec et al. [2] spin state and moderate increases in the elongation of the 3D radar model from Brozović et al. [1] significantly improve the fits to the combined radar and lightcurve data. We will summarize the shape constraints that we can derive at this point and discuss plans for propagating the spin state from 2013 to the radar and optical data

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obtained in 2021. The next opportunities to observe Apophis with lightcurves will be in early 2028 and again from late 2028-April 2029. The next opportunity for radar observations begins about one month prior to the closest approach in April, 2029.
Comments: *(Oral or Poster)*

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