

Apophis T-4 Years

## Spin state of Apophis – predicting its orientation during and after the 2029 flyby

Josef Ďurech<sup>a,\*</sup>, Petr Pravec<sup>b</sup>, David Vokrouhlický<sup>a</sup>, Kamil Hornoch<sup>b</sup>, Peter Kušnirák<sup>b</sup>, Petr Fatka<sup>b</sup>,  
Hana Kučáková<sup>a,b</sup>

<sup>a</sup>Astronomical Institute, Charles University, V Holešovičkách 2, 180 00 Prague 8, Czech Republic

<sup>b</sup>Astronomical Institute of the Czech Academy of Sciences, Fričova 298, 251 65 Ondřejov, Czech Republic

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Asteroid Apophis rotates in an excited rotation state described by two periods, rotation and precession, with the values of 263 h and 27.38 h, respectively. Together with other spin parameters and a convex shape model, these periods were derived by [1] from photometric observations carried out in 2012/13. Radar observations are consistent with the spin state derived from light curves, and the derived shape model is nonconvex [2].

We carried out photometric observations of Apophis with the Danish 1.5m telescope at La Silla, ESO, between November 2020 and May 2021 to use them with old photometric data to determine its precise spin state. Due to the long time interval of eight years between observations, the rotation parameters could be determined precisely, which would enable us to (i) predict its orientation before and during the close approach in 2029 and (ii) estimate the change of its spin state caused by the Earth's gravitation torque during the encounter.

However, when applying the light curve inversion method [3], we realized that the spin state cannot be determined uniquely. Different spin parameters provided about the same quality of the fit to the data. Fortunately, because of the same 8-year separation between 2012/13, 2020/21, and 2029, all acceptable spin solutions that fit the data from 2012/13 and 2020/21 phase together again in 2029, which means we can predict the attitude of Apophis during its close approach with the Earth on 13 April 2029. However, our simulations show that the way Earth's gravitation torque affects Apophis' spin during the flyby is so sensitive to the precise orientation of Apophis (affected by the YORP effect and model uncertainties) that the spin state after the approach is uncertain.

Observations from 2027 and 2028 are crucial to uniquely determining Apophis' spin state; photometry from 2029 will not be sufficient.

### References

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\*Corresponding author

Email address: durech@sirrah.troja.mff.cuni.cz (Josef Ďurech)