A once in a lifetime experiment: SLR observations of the Apophis encounter Friday, April 13, 2029

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Abstract

On Friday, 13 April 2029 close to 21:00 UTC, the asteroid 99942 Apophis and the Earth will have a very close encounter. Apophis will pass inside the geostationary belt. During that period, Apophis's minimum range distance to European SLR stations will be around 32000-35000 km.
The closest encounter period will occur during local night conditions in Europe.
A general overview of the visibility conditions for Europe is presented. The Apophis sky elevation for the European SLR stations will be in the same range as that for regular SLR observations.
Given the current SLR state-of-the-art on laser ranging to passive objects (space debris), mainly among the EUROLAS SLR stations, and considering the expected technological advances in the next seven years. It is the time to start a preliminary discussion about organizing a European-wide SLR Apophis laser ranging campaign based on the multistatic space debris mode SLR ranging. The analysis presented here did not include the possibility of landing an SLR reflector on the Apophis surface.
This SLR precise distances data set that could be obtained will complement a wide array of observations planned or proposed and help to determine the Apophis post encounter orbit and other parameters of interest.
Initial ideas are presented about how to organize such a campaign.

1. Introduction: Apophis discovery and current knowledge.

The asteroid 99942 (Apophis) was discovered on June 19, 2004 by R. Tucker, D. J. Tholen and F. Bernardi at Kitt Peak Observatory. The fact that the discovery orbit indicated a 2.7% impact probability on April 13th, 2029, or later in 2036, generated a large amount of additional observations needed to refine Apophis's orbit and the impact probability. The new observations and orbital analysis, using post & prediscovery images, photometric data, and radar observations, eliminated the probability of an Earth impact for the next 100 years.
At the same time, several asteroid parameters were determined with high reliability. The current calculated orbit has a positional error of ~2 km during the 2029 close encounter and confirmed that Apophis will pass inside the geostationary belt.
The 2029 close encounter will change Apophis orbit from 0.7461 x 1.0993 AU to 0.894 x 1.310 AU. If the geology of the asteroid is the typical for this type of asteroids, it is expected that Earth's tidal forces will resurface Apophis' regolith, changing its albedo and color index.
The known parameters are as follows:

- Size: 450 x 170 m. (using radar), mean radius ~185 m.
- Albedo: 0.23 (from ESA Kepler observations)
- Rotation period: 30.56 h (photometric period) Tumbling on a short axis
- Precession period: 27.38 ± 0.07 h

- Rotation 263 ± 6 h

2. Modeling the Apophis range/visibility encounter conditions for the European SLR stations network.

In order to evaluate the Apophis observing conditions for the European SLR stations during the April 13th encounter, we decided to calculate the Apophis visibility only for the SLR stations situated at the extremes of longitude and latitude in continental Europe and added Izaña in Tenerife, Canary Islands, Spain (Fig. 1). All other European SLR station have parameters in between these extremes.[1]

Using the Horizons NASA/JPL JPL's On-line solar system data service available at: https://ssd.jpl.nasa.gov/horizons/app.html#/ (J. Giorgini et al.), we calculated the Apophis parameters of interest for each selected SLR station with 12 minutes time resolution. Two cut-off parameters were used: An elevation cut-off of 5° above the horizon and the daylight cut-off. In this way, the local observation conditions are similar to any regular SLR night/twilight observation run.

The time scale used in this paper is UTC.

The SLR stations plots showing the Apophis local elevation, range and stellar magnitude are shown in Figs. 2, 3, 4 and 5.

It can be concluded that from the viewpoint of pointing to and fine visual guidance – including twilight conditions-, tracking Apophis should not present any problem.

3. Apophis SLR observations using the multistatic space debris mode.

In 1962 were reported laser observations to the Moon using the lunar surface backscatter (see L. D. Smullin). Since then, the laser ranging capabilities has advanced by orders of magnitude. While other general proposals for asteroids SLR ranging has been presented before (see M. Ābele), if the Apophis observations are carried out, it will be the first time in more than 65 years that laser ranging to a non-cooperative solar system object will be done.

The multistatic space debris methodology has been described elsewhere (see Kirchner et al.). As remarked in several related papers, one of the limiting factors for regular multistatic space debris observations is the need to have simultaneous clear weather on (almost) all participating SLR stations. The clear weather condition is fundamental for the transmitting SLR station operation.

In the case of the European-wide Apophis single opportunity encounter observations, it is of the utmost importance to have at least 2 or 3 active SLR system widely distributed in Europe to diminish the chance of cloudy weather on April 13th 2029. See Fig. 1 for the current (2022) European SLR geographical distribution.

4. Qualitative, order of magnitude, analysis of the expected return signal from Apophis.

To evaluate whether it is physically possible to get a usable return signal from Apophis, we decided to use a qualitative comparison with successful multistatic debris space debris observations, by applying the SLR link equation:

In its full form, the SLR link equation is (equation 1):

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[1] We should had selected Metsähovi, but being the authors from Latvia, we choose Riga.
The Johannes Kepler and the NyÅlesund SLR stations are not included on Fig 1.

$n_s = (E_t/h_v)\ \eta_t\ (2/\pi(\theta_d R)^2)\ \exp[-2\ (\Delta\theta_p/\theta_d)^2]\ [1/(1+(\Delta\theta/\theta_d))][\sigma A_r/\pi(\theta_d R)^2]\ \eta_r\eta_c T_a^2 T_c^2$

Here our parameters of interest are:

n_s = detected satellite photoelectrons per laser pulse.
σ = optical cross-section.
R = Slant-range station satellite.
A_r=Telescope Receiving Area.
(See J. Degnan for a full parameter description).

In our case, since we are comparing the possible Apophis observations against successful SLR multistatic debris observations, we can reduce the SLR link equation to the symbolic form of:

sufficient photoelectrons! = [parameters* A_r]*(σ/R^4)

Allowing to carry out a *qualitative* comparative analysis. If we calculate the (σ/R^4) parameters for a given observed object, the possibility of getting successful returns from Apophis using the same experimental conditions can be evaluated, at least at the order-of-magnitude level.

We assume that there will not be a several orders of magnitude increase of the laser pulse power in relation to the space debris lasers in use now. And we assumed that the return signal will be at the single-photon level.

Using the space debris information taken from Kirchner et al.:

Debris Object	OCS σ (m²)	Slant Range R(m)	(σ/R^4) 1/m²
Envisat	19.49	10^6	$1.9\ 10^{-23}$
SL-16 R/B	11.22	10^6	$1.1\ 10^{-23}$
ARIANE 1 DEB 39014	7.7	10^6	$0.8\ 10^{-23}$

in the case of Apophis, the (σ/R^4) value is, using the values presented in this paper:

Object	OCS σ (m²)	Slant Range R(m)	(σ/R^4) 1/m²
Apophis	$2.5\ 10^4$ [2]	$3.2\ 10^7$	$1.7\ 10^{-26}$ [3]

The Apophis (σ/R^4) parameter is 3 orders of magnitude less than for the reported space debris observations made using technology and hardware from the 2010s.

New SLR stations with added capabilities.

Recently, two new European SLR space-debris capable systems started operations: ESA's Izaña in Tenerife, Spain and DLR's Johannes Kepler SLR in Empfingen, Germany. The DLR system is oriented mainly towards space debris surveillance [4].

If we calculate (σ/R^4) for objects using the Johannes Kepler reported minimum debris size initial capabilities:

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[2] (π x mean radius² x albedo)
[3] Value range using the extreme values from the 450 x 170 m profile: $0.5\text{-}1.3\ 10^{-26}$ 1/m²
[4] see https://www.evwind.es/2022/07/20/laser-based-detection-of-space-debris/87056

Johannes Kepler SLR	OCS σ (m²)	Slant Range R(m)	(σ/R^4) 1/m²
Minimal debris size	0,01	10^6	1 10^{-26}

The Johannes Kepler SLR system is, in principle, able to get returns from Apophis operating in the single SLR space debris observation mode and could serve as one of the active systems for a multistatic European SLR Apophis campaign.

The Izaña SLR system has in its development program, the future installation of high power space debris lasers capable of orbit modification.

Apophis observation partners using the SLR Johannes Kepler as active system.

In equation (1) it is assumed that the same telescope is used for sending and receiving the laser photons. In the multistatic mode we should consider the different transmitter and receiver telescope areas. As in 2022, Grasse MEO (d=1.54m), Matera (d=1.50 m), Riga and Zimmerwald (d=1.00 m) have telescopes with diameters comparable to the Johannes Kepler 1.75 m telescope the equivalent A_r will be of the same order.

5. Complementary non-SLR observations during close encounter.

It is expected that an European Apophis classical astronomy observation campaign will be carried out, covering fields as astrometry, photometry and including radar ranging/imaging observations. In the last decade, several SLR stations working on the space debris field have introduced photometric capabilities, in some cases sampling up to 100 kHz (see D. Kucharski).

The possibility of regolith resurfacing phenomena during the encounter, causing albedo and color index changes, has been raised. This encounter albedo and color index time evolution could give information about the asteroid's regolith mechanical and geological properties. If several SLR stations can make photometric observations in parallel with the SLR ranging, coordinating the photometric observations with the European "classical" astronomical community will enhance the value of the obtained data.

6. A proposed timetable

Before discussing a timetable for an observing program in 2029, there are technical questions that have to be studied in detail before committing to an observation program.

The possibility of getting returns from Apophis's surface, given the expected SLR state-of-art in 2029 has to be evaluated in detail. A full numerical evaluation of the SLR link equation is needed for each participating SLR station; this evaluation should also include the asteroid earth-facing cross-section time evolution during the encounter. Any information about the cloud cover statistics at the SLR stations will be useful.

If possible, given the expected range accuracy and precision, can the SLR range data have a positive impact on the Apophis post encounter orbit determination?

How to test in advance the Apophis multistation observation setup? One possible idea would be to use old satellites currently in the geostationary graveyard orbit. This test, if feasible, could be an interesting application on itself.

A possible timetable:

- 2022-2027: Regular contacts between the groups involved, including analysis centers and with specialized astronomical groups. A possible informal steering group could be created.

- 2026-2027: Reach a consensus for a Go-No Go decision to do the experiment. If a positive agreement is reached, then apply for funding (if needed). This will include a rehearsal test at the Geostationary Graveyard.
- 2028 April or September: Rehearsal test at the Geostationary Graveyard, if needed. The time periods are selected to have a solar declination and illuminating conditions similar to the Apophis encounter.
- 2029, April 13: Apophis observations.
- After April 13, 2029: Publications & Meetings.

Fig. 1 Reference SLR stations used in this paper.

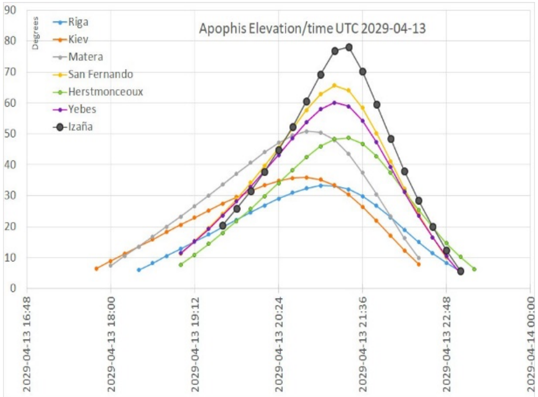

Fig. 2 Elevation for the reference SLR stations

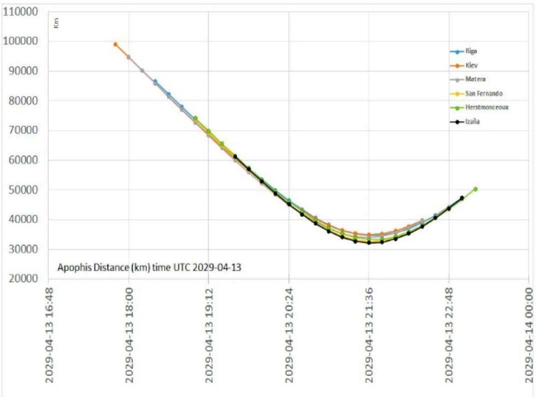

Fig. 3 Range to Apophis for the reference SLR stations during the full encounter

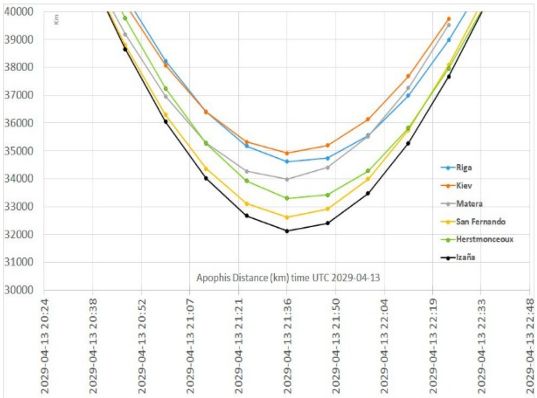

Fig. 4 Range to Apophis during close approach period for the reference SLR stations

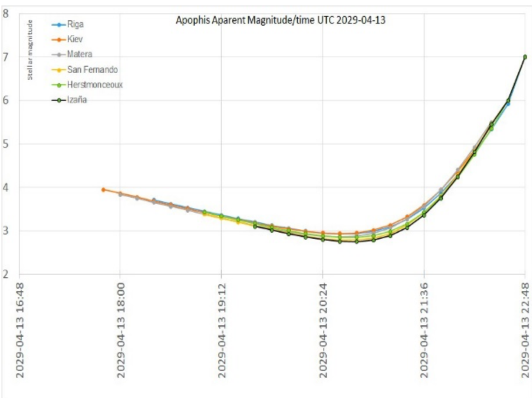

Fig. 5 Apophis apparent stellar magnitude for the reference SLR stations

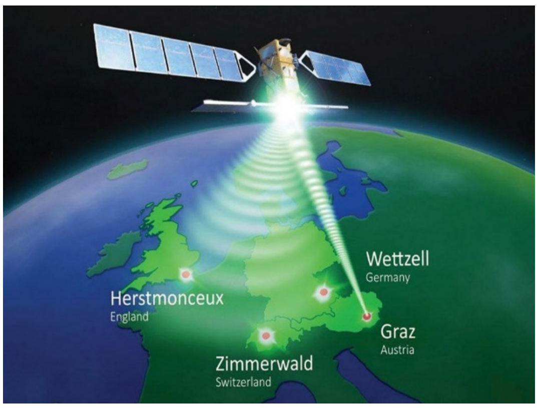

Fig. 6 Example of multistatic space debris SLR observations (Kirchner et al.)

7. Conclusions

Given the current SLR status of art and the foreseen developments for the next few years, there is no physical impossibility to carry out SLR observations during the Apophis close encounter in April 13th 2029.

Its realization heavily depends on the scientific values of the observation results and the willingness (and funding) of the European SLR stations to carry out the observation program.

Note: On November 12th 2022, the ESA Space Safety Division announced that they will propose an Apophis Mission Study.

If the mission is approved and includes a lander with SLR on board, it will increase the success of an Apophis SLR observation campaign, because ‘classical’ single station SLR ranging will also be possible to selected SLR stations.

References

M. Brozović, et al., Goldstone and Arecibo radar observations of (99942) Apophis in 2012–2013, Icarus 300 (2018) 115–128, 2017, DOI:10.1016/J.ICARUS.2017.08.032

L. D. Smullin, G. Fiocco, Optical Echoes from the Moon, Letters to the Editor, Astrophysics, Nature, Vol 194, pp 1267, 1962.

J. Degnan, Millimeter Accuracy Satellite Laser Ranging: A Review of Contributions of Space Geodesy to Geodynamics: Technology Geodynamics, 25, pp. 133-162, 1993.

M. Ābele, L Osipova, Possibility of the Near Earth Objects Distance Measurement with Laser Ranging Device, 15th International Workshop on Laser Ranging Instrumentation, Canberra, Australia, October 15-20, 2006.

G. Kirchner et al., Multistatic Laser Ranging to Space Debris Targets: Tests and Results, 18th International Workshop on Laser Ranging, Fujiyoshida, Japan, November 11-15, 2013.

D. Kucharski et al, High-definition Photometry - a new tool for space debris characterization, 21th International Workshop on Laser Ranging, Canberra, Australia, November 4-9, 2018.

G. Kirchner et al., Light Curve Measurements with Single Photon Counters at Graz SLR, 2015 ILRS Technical Workshop, Matera, Italy October 26 – 30, 2015.

J. Giorgini, D. Yeomans, A. Chamberlin, P. Chodas, R. Jacobson, M. Keesey, J. Lieske, S. Ostro, E. Standish, R. Wimberly, JPL's On-line solar system data service. Bulletin of the American Astronomical Society, 28. 1158., 1996.