GROUND-BASED OBSERVATION CAMPAIGN FOR (99942) APOPHIS: 2020-21 APPARITION

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Scientific backgrounds

- (99942) Apophis is an S-type Aten NEA with an estimated size of 350 m.
- After the discovery, Apophis triggered concerns for impacts with the Earth; maximum impact probability of 2.7% was predicted for April 13, 2029.
- Coordinated follow-up obs. with ground-based VIS and radio telescopes provided improved predictions over the subsequent years; the possibility of impact in 2029 was removed.
- Apophis will approach the Earth to come within the GEO orbit during the 2029 encounter, thus expected to offer a unique chance for detailed studies.

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Visibility during 2020-2021 apparition

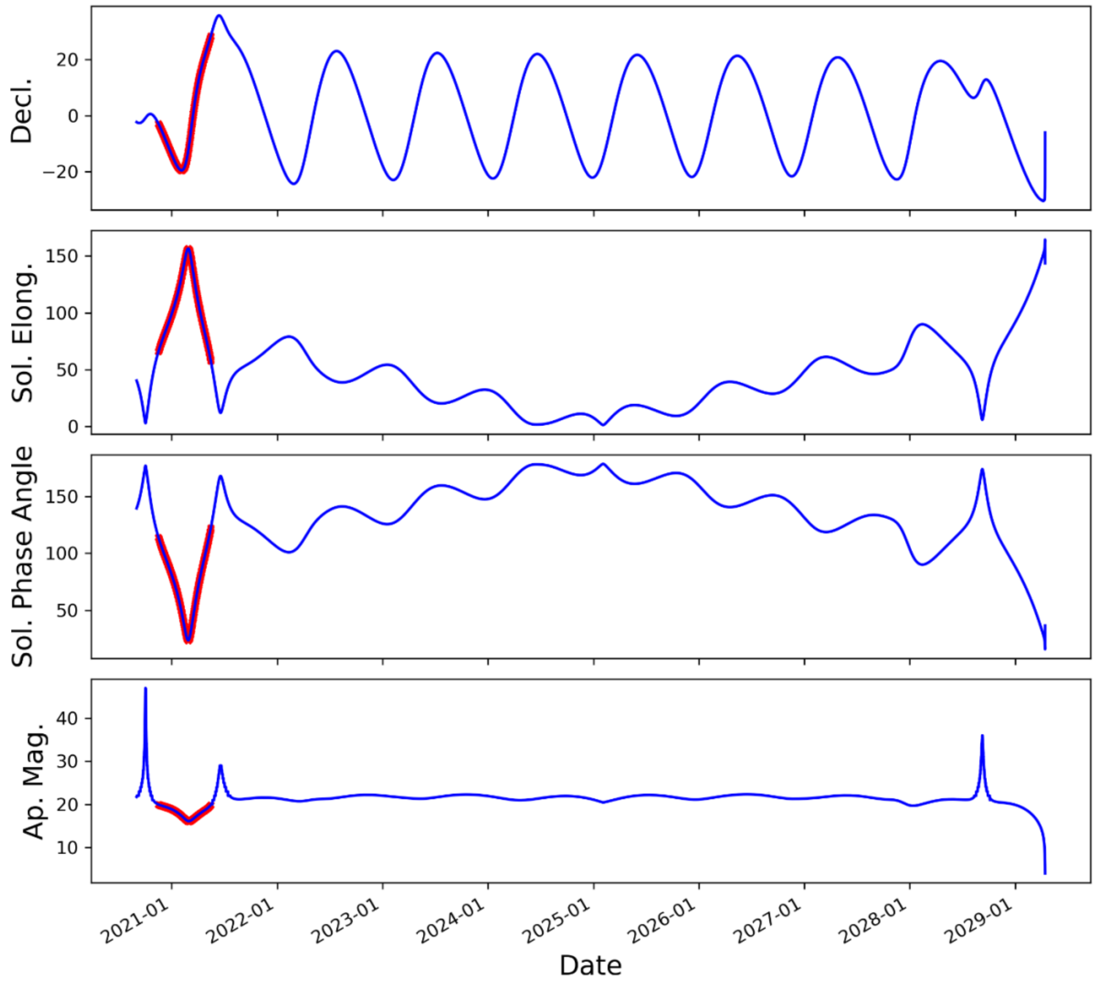
November 2020 – April 2021

: **Last chance** before 2029 encounter

Observable in both hemispheres

: **V_max:** ~16.1 mag

: **phase angle:** 21 – 115 degrees



Prepared by H.-J. Lee

Observation campaign

Refine shape model and spin states

- **Previous result:** Physical model (Pravec + 14) based on LC inversion w/ 2012-13 apparition data
- **Our plan:** High temporal resolution time-series photometric observation w/ three KMTNet telescopes, BOAO 1.8 m, LOAO 1 m and other telescopes in Korea and abroad

Check surface composition variations

- **Previous result:** NIR-spectroscopy (Reddy + 18) suggested probable surface variegation
- **Our plan:** Higher temporal resolution time-series spectroscopy w/ BOAO 1.8 m + the Long-slit Spectrograph and other telescopes + instruments in abroad

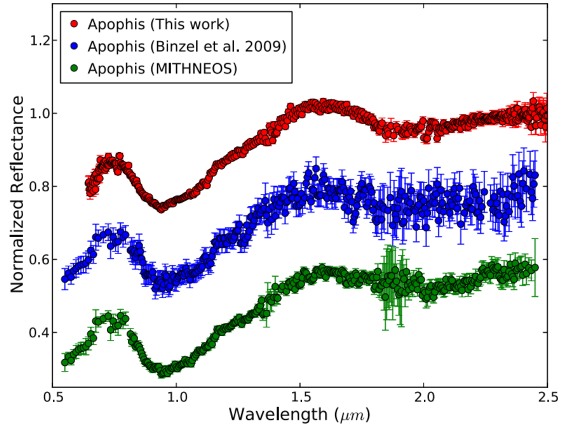
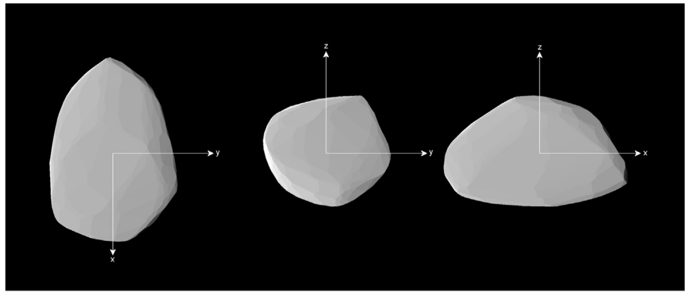


Figure 2. Comparison between the NIR spectra of Apophis obtained as part of this work (red), Binzel et al. (2009) (blue), and the spectrum obtained by MITHNEOS (green) file a099942.sp117.txt. All spectra are normalized to unity at ~1.5 μm and are offset vertically for clarity.

Table 2
Parameters of the Apophis model with their estimated admissible uncertainties (corresponding to 3σ confidence level).

Fitted parameters	
λ_L (°)	250[a]
β_L (°)	−75
ϕ_0 (°)	152^{+173}_{-64}
ψ_0 (°)	14^{+44}_{-11}
P_ψ (h)	263 ± 6
P_ϕ (h)	27.38 ± 0.07
$I_a \equiv I_1/I_3$	$0.61^{+0.11}_{-0.08}$
$I_b \equiv I_2/I_3$	$0.965^{+0.009}_{-0.015}$
Derived parameters	
$\left(P_\phi^{-1} - P_\psi^{-1}\right)^{-1} = P_1$ (h)	30.56 ± 0.01
θ_{min} (°)	12 ± 4
θ_{max} (°)	55^{+9}_{-20}
θ_{aver} (°)	37^{+6}_{-14}
a_{dyn}/c_{dyn}	1.51 ± 0.18
b_{dyn}/c_{dyn}	1.06 ± 0.02
a_{shp}/c_{shp}	1.64 ± 0.09
b_{shp}/c_{shp}	$1.14^{+0.04}_{-0.08}$
E/E_0	1.024 ± 0.013

The angles ϕ_0 and ψ_0 are for the epoch JD 2456284.676388 (=2012 December 23.176388 UT), light-travel time corrected (i.e., asterocentric).
E/E_0 is a ratio of the rotational kinetic energy and the lowest energy for given angular momentum, defined as $E_0 = L^2/(2I_3)$.
[a] The major and minor semiaxes of the uncertainty area of the direction of $\vec{L}$ are 27° and 14°, respectively, see Fig. 4.



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Ex) Physical modeling for a tumbler

(5247) Krylov: 1st physical model for an MBA – Apophis also shows tumbling motion!

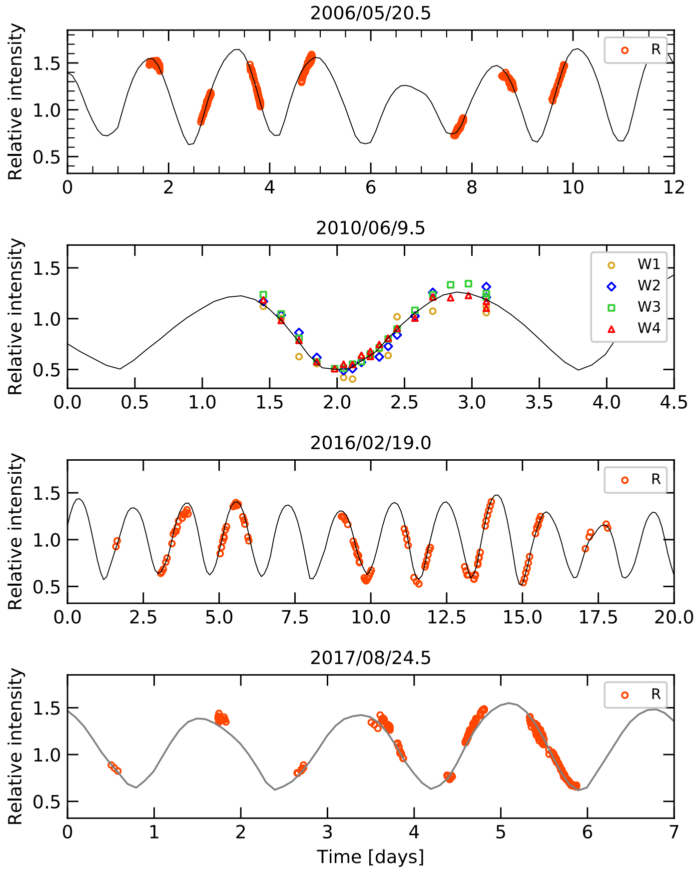
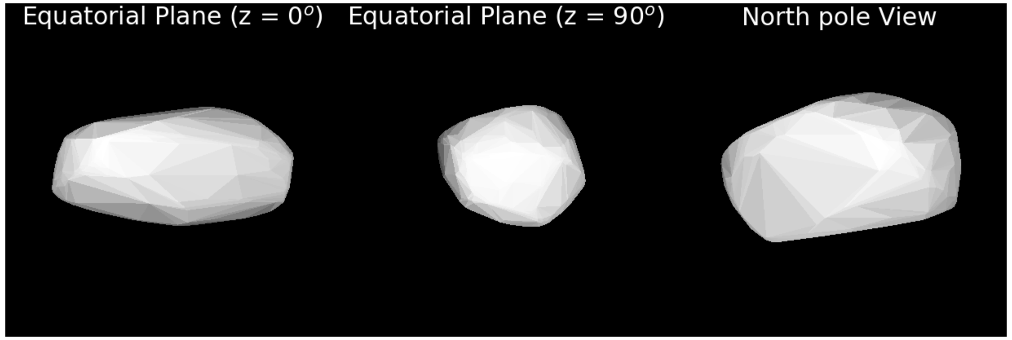


Table 2. Physical model of Krylov

Physical parameter	Value
Fitted parameters	
λ_L [deg]	298 ± 37
β_L [deg]	−58 ± 12
P_ψ [hr]	368.7 ± 0.2
P_ϕ [hr]	67.27 ± 0.01
ψ_0 [deg]	5 ± 28
ϕ_0 [deg]	126 ± 14
t_0 [day]	2453877.618993
I_a/I_c	0.36 ± 0.02
I_b/I_c	0.96 ± 0.01
Derived parameters	
$(P_\phi^{-1} - P_\psi^{-1})^{-1} = P_1$ [hr]	82.28 ± 0.04
θ_{aver} [deg]	30 ± 10
θ_{min} [deg]	6 ± 5
θ_{max} [deg]	45 ± 20
a_{dyn}/c_{dyn}	2.2 ± 0.1
b_{dyn}/c_{dyn}	1.12 ± 0.02
a_{shape}/c_{shape}	2.1 ± 0.4
b_{shape}/c_{shape}	1.13 ± 0.2
E/E_0	1.023 ± 0.001

Notes. θ_{aver}, θ_{min}, and θ_{max} : the average, minimum, and maximum value of θ over one cycle; a_{dyn}/c_{dyn} and b_{dyn}/c_{dyn} : the axial ratio of a dynamically equivalent ellipsoid; a_{shape}/c_{shape} and c_{shape}/c_{shape} : the axial ratio of a convex shape model; E/E_0 : the ratio of the rotational kinetic energy to the lowest energy for the given angular momentum.



Lee + 2020

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Ex) Surface homogeneity confirmation

(3200) Phaethon:

JAXA's DESTINY+ mission target

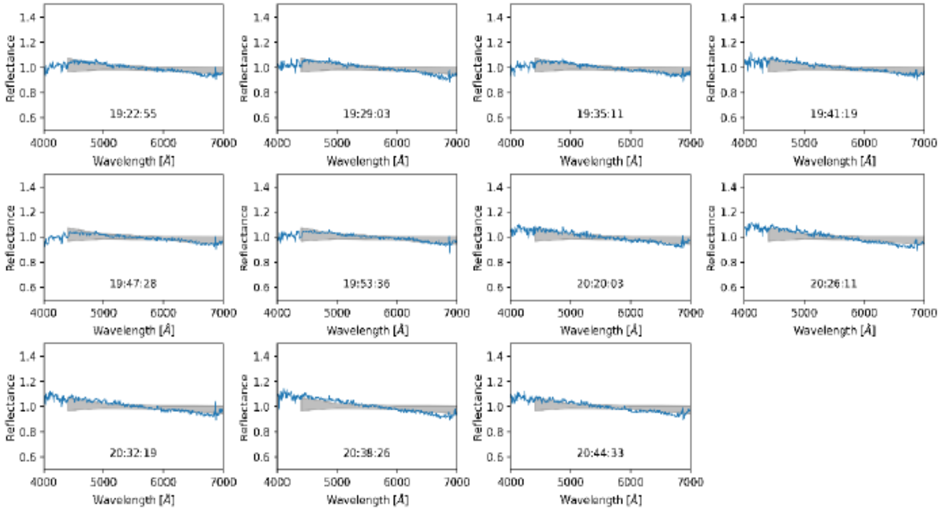
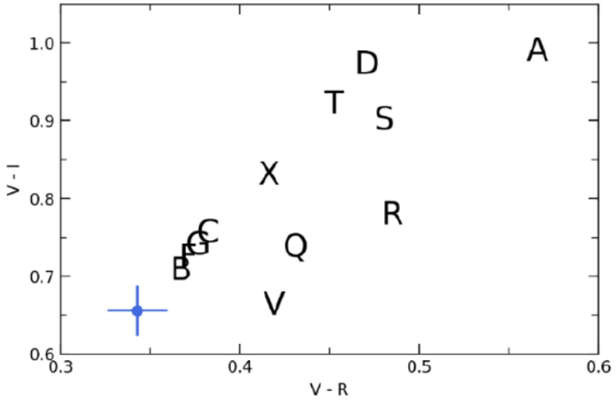


Figure 3. The spectra of Phaeton taken on Dec. 07 2017. The gray area corresponds to the range of B-type asteroid spectra (Bus & Binzel, 2002).



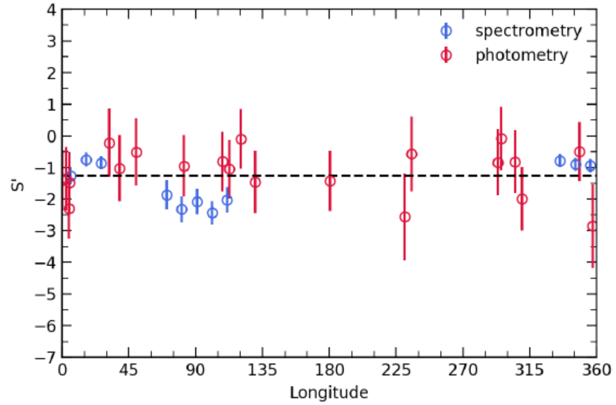


Figure 4. Spectral gradient S' according to the longitude of Phaeton. The dots indicate S' determined on the observation data, and the dashed lines represent the mean values of S'. The errors in the slope S' for spectroscopy were estimated considering the noise in the spectra.

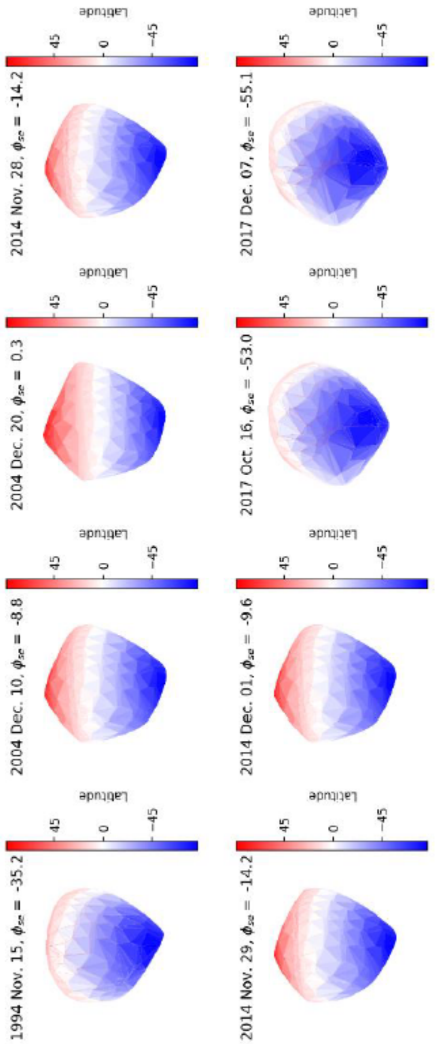


Figure 5. The aspects of Phaethon at the time of spectral observation.

Kim + 2018, Lee + 2019

Summary and suggestions

- KASI organizes high temporal resolution VIS time-series photometric observation campaign and data analysis to have a better physical model for Apophis.
- KASI also organizes high temporal resolution VIS-NIR time–series spectroscopic observation campaign and data analysis to check if Apophis has a homogeneous surface.
- We propose an IAWN-led global observation campaign for Apophis during 2020-2021 encounter.