Observation Campaign of (99942) Apophis in the 2021 apparition. H.-J. Lee[1], M.-J. Kim[1], Y.-J. Lee[2], A. Marciniak[3], S., Urakawa[4], D.-H. Kim[1,5], H.-K. Moon[1], Y.-J. Choi[1,6], D. Kuroda[7], S. Okumura[4], S. Zoła[8], J. Chatelain[9], T. A. Lister[9], E. Gomez[10], S. Greenstreet[11], A. Pál[12], R. Szakáts[12], N. Erasmus[13], R. Lees[14], P. Janse van Rensburg[13,14], W. Ogłoza[15], M. Dróżdż[15], M. Żejmo[16], K. Kamiński[3], M. K. Kamińska[3], R. Duffard[17], D.-G. Roh[1], H.-S. Yim[1], T. Kim[18], S. Mottola[19], F. Yoshida[20,21], D. E. Reichart[22], E. Sonbas[23], D. B. Caton[24], M. Kaplan[25], O. Erece[25,26], and H. Yang[1], [1]Korea Astronomy and Space Science Institute (e-mail: hjlee@kasi.re.kr), [2]Technische Universität Berlin, [3]Astronomical Observatory Institute, [4]Japan Spaceguard Association, Bisei Spaceguard Center, [5]Chungbuk National University, [6]University of Science and Technology, [7]Okayama Observatory, Kyoto University, [8]Astronomical Observatory, Jagiellonian University, [9]Las Cumbres Observatory, [10]Las Cumbres Observatory, School of Physics and Astronomy, Cardiff University, [11]Department of Astronomy and the DIRAC Institute, University of Washington, [12]Konkoly Observatory, Research Centre for Astronomy and Earth Sciences, Eőtvős Loránd Research Network (ELKH), [13]South African Astronomical Observatory, [14]Department of Astronomy, University of Cape Town, [15]Mt. Suhora Observatory, Pedagogical University, [16]Kepler Institute of Astronomy, University of Zielona Góra, [17]Departamento de Sistema Solar, Instituto de Astrofísica de Andalucía (CSIC), [18]National Youth Space Center, [19]Deutsches Zentrum für Luft- und Raumfahrt (DLR), Institute of Planetary Research, [20]University of Occupational and Environmental Health, [21]Planetary Exploration Research Center, Chiba Institute of Technology, [22]University of North Carolina at Chapel Hill, [23]Department of Physics, Adiyaman University, [24]Dark Sky Observatory, Dept. of Physics and Astronomy, Appalachian State University, [25]Akdeniz University, Department of Space Sciences and Technologies, [26]TÜB ITAK National Observatory, Akdeniz University Campus.

Introduction: The potentially hazardous asteroid (PHA) (99942) Apophis is an Sq-type asteroid [1,2], that will approach within Earth's geosynchronous orbit in April 2029. Apophis' Earth approach in 2029 will be an excellent opportunity to examine how the physical properties of the asteroid could be changed due to the Earth's gravitational perturbation. To do so, we need to understand the physical properties of Apophis before its 2029 Earth encounter.

Observation Campaign: On March 6, 2021, Apophis made a close approach to the Earth at a minimum distance of 0.11 AU whit the apparent magnitude reaching up to V~16. This was the most favorable condition to observe this asteroid until its 2029 encounter. Thus, we performed an extensive and long-term photometric and spectroscopic observation campaign during this 2021 apparition. The telescopes used for observation campaign of Apophis is listed in Table 1.

Photometric Campaign: We conducted photometric observations from January to April in 2021 for a total of 218 nights among 47 observers from 14 different countries using thirty-six 1 to 2-m class facilities. The main goals of our photometric campaign were to refine the spin state and convex shape model of Apophis.

Spectroscopic Campaign: We observed Apophis with CAHA/CAFOS and SEIMEI/KOOLS-IFU (Visible), IRTF/SpeX and Gemini-North/GNIRS (NIR) to check the surface composition variations. In this campaign, five visible and eight near-infrared spectra of Apophis were obtained. Each spectrum was obtained at different rotation phases of Apophis.

Convex Shape model and Spin State: The refinement of the convex shape model and spin state of Apophis was conducted employing light curve inversion technique for non-principal axis rotator [3],[4],[5]. Our model for Apophis is listed in Table 2 and the convex shape model of this asteroid is shown in Figure 1. We found that Apophis is rotating in a short axis mode and the shape of this asteroid can be approximated by an elongated prolate ellipsoid.

Surface Inhomogeneities: We found different taxonomic signatures in different phases based on the near-infrared spectra (Figure 2). Some of the reflectance spectra of Apophis were shown to be typical for an Sq-type asteroid, as was previously known. However, most of them appear as the unweathered spectra of Q-type asteroid. These differences in the near-infrared spectra of Apophis would be caused by a local resurfacing event, inhomogeneous surface composition, or differences in particle size. Additionally, radar observations have suggested that this asteroid has a bifurcated shape [7]. Thus, we are cautious that this difference may have been caused by Apophis's contact binary.

References: [1] Binzel, R. P. et al. (2009) *Icarus*, 200, 480- 485. [2] Reddy et al. (2018) *AJ*, 155, 140. [3] Kaasalainen, M. (2001), *A&A*, 376, 302-309. [4] Kaasalainen, M. and Torppa, J. (2001). *Icarus*, 183, 24-36. [5] Kaasalainen, M. et al. (2001) *Icarus*, 153, 37-51. [6] DeMeo et al. (2009) *Icarus*, 202, 160-180. [7] Brozović M. et al. (2018) *Icarus*, 300, 115-128.

Table 1. List of telescopes for the observation campaign.

Telescope	Country	Telescope	Country
- Photometric observation -			
Adiyaman Observatory 0.6 m	Turkey	AMU Winer, RBT 0.7m	Arizona, USA
ATLAS HKO 0.5 m	Hawaii, USA	ATLAS MLO 0.5 m	Hawaii, USA
BOAO 1.8 m	Korea	CAHA 1.23 m	Spain
CAHA 2.2 m	Spain	DOAO 1.0 m	Korea
Kawabe Cosmic Park 1.0 m	Japan	KMTNet CTIO 1.6 m	Chile
KMTNet SAAO 1.6 m	South Africa	KMTNet SSO 1.6 m	Australia
Krakow-CDK500 0.5 m	Poland	LCO CTIO A 1.0 m	Chile
LCO CTIO B 1.0 m	Chile	LCO McDonald A 1.0 m	Arizona, USA
LCO McDonald B 1.0 m	Arizona, USA	LCO SAAO A 1.0 m	South Africa
LCO SAAO B 1.0 m	South Africa	LCO SAAO C 1.0 m	South Africa
LCO SSO A 1.0 m	Australia	LCO SSO B 1.0 m	Australia
LOAO 1.0 m	Arizona, USA	OWL Mitzpeh Ramon 0.5 m	Israel
OWL Oukaimeden 0.5 m	Morocco	OWL Tucson 0.5 m	Arizona, USA
OWL Yeongcheon 0.5 m	Korea	SAAO Lesedi 1.0 m	South Africa
Skynet DSO-14 0.4 m	Northern California, USA	Skynet Prompt5 0.4 m	Chile
Skynet Prompt6 0.4 m	Chile	Skynet Prompt MO 1 0.4 m	Chile
Skynet RRRT 0.6 m	Virginia, USA	SOAO 0.6 m	Korea
Suhora Observatory Zeiss-60	Poland	TUG 1.0 m	Turkey
TESS 0.1 m	Space-based		
- Spectroscopic observation -			
Gemini-North Telescope 8.1 m	Hawaii, USA	IRTF 3.2 m	Hawaii, USA
Seimei Telescope 3.8m	Japan	CAHA 2.2 m	Spain

Notes. AMU: Adam Mickiewicz University, RBT: Roman Baranowski Telescope, ATLAS: Asteroid Terrestrial-impact Last Alert System, HKO: Haleakala Observatory, MLO: Mauna Loa Observatory, BOAO: Bohyunsan Optical Astronomy Observatory, DOAO: Deokheung Optical Astronomy Observatory, CAHA: Calar Alto Observatory, KMTNet: Korea Microlensing Telescope, CTIO: Cerro Tololo Inter-American Observatory, SAAO: South African Astronomical Observatory, SSO:Siding Spring Observatory, LCO: Las Cumbres Observatory, LOAO: Lemonsan Optical Astronomy Observatory, CDK: Corrected Dall-Kirkham, OWL: Optical Wide-field patroL Network, DSO: Dark Sky Observatory, MO: Meckering Observatory, RRRT: Rapid Response Robotic Telescope, SOAO: Sobaeksan Optical Astronomy Observatory, TUG: TÜBİTAK National observatory, TESS: Transiting Exoplanet Survey Satellite, IRTF: NASA Infrared Telescope Facility

Table 2. Parameters of the Apophis model.

Physical parameter	Value
λ_L [deg.]	278^{+9}_{-8}
β_L [deg.]	-86^{+5}_{-4}
P_ϕ [hr]	27.3885 ± 0.003
P_ψ [hr]	264.18 ± 0.03
ϕ_0 [deg.]	183^{+7}_{-4}
ψ_0 [deg.]	3^{+5}_{-1}
I_a	$0.64^{+0.02}_{-0.09}$
I_b	$0.962^{+0.023}_{-0.002}$

Notes. λ_L, β_L are the ecliptic coordinates of the angular momentum vector $\vec{L}$; P_ψ, P_ϕ are the periods of rotation and precession; ϕ_0, ψ_0 are the standard Euler angles at t_0; I_a, I_b are the principal moments of inertia. They are normalized by I_c [5]. The epoch JD_0 for the standard Euler angles is 2456284.676388 (2012-12-23.176388).

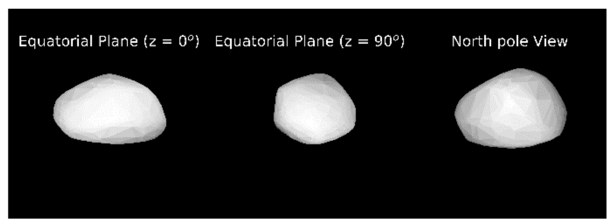

Figure 1. Convex shape model of Apophis.

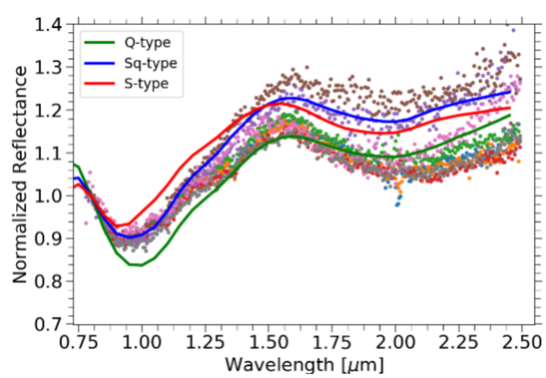

Figure 2. Reflectance spectra of Apophis in the near-infrared region. The colored solid lines are the reference spectra of Q-type (green), Sq-type (blue), and S-type(red) asteroids [6].