SCIENCE AND EXPLORATION IN THE SOLAR POWER SAIL OKEANOS MISSION TO A JUPITER TROJAN ASTEROID.

T. Okada[1,2], T. Iwata[1], J. Matsumoto[1], T. Chujo[1], Y. Kebukawa[3], J. Aoki[4], Y. Kawai[4], S. Yokota[4], Y. Saito[1], K. Terada[4], M. Toyoda[4], M. Ito[5], H. Yabuta[6], H. Yurimoto[7,1], C. Okamoto[8], S. Matsuura[9], K. Tsumura[10], D. Yonetoku[11], T. Mihara[12], A. Matsuoka[1], R. Nomura[1], H. Yano[1], T. Hirai[13], R. Nakamura[14], S. Ulamec[15], R. Jaumann[15], J.-P. Bibring[16], N. Grand[17], C. Szopa[18], E. Palomba[19], J. Helbert[15], A. Herique[20], M. Grott[15], H. U. Auster[21], G. Klingelhoefer[22], T. Saiki[1], H. Kato[1], O. Mori[1], J. Kawaguchi[1], [1]Institute of Space and Astronautical Science (ISAS), Japan Aerospace Exploration Agency (JAXA), 3-1-1 Yoshinodai, Chuo-ku, Sagamihara, Japan, [2]University of Tokyo, Japan, [3]Yokohama National University, Japan, [4]Osaka University, Japan, [5]Kochi Institute for Core Sample Research, Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Japan, [6]Hiroshima University, Japan, [7]Hokkaido University, Japan, [8]Hosei University, Japan, [9]Kwansei Gakuin University, Japan, [10]Tohoku University, Japan, [11]Kanazawa University, Japan, [12]RIKEN, Japan, [13]Chiba Institute of Technology, Japan, [14]National Institute of Advanced Industrial Science and Technology (AIST), Japan, [15]German Aerospace Center (DLR), Germany, [16]Institut d'Astrophysique Spatiale (IAS), Orsay, France, [17]LISA, Univ-Paris-XII, France, [18]ISPL LATMOS, France, [19]INAF-IAPS, Italy, [20]IPAG, France, [21]TU Braunschweig, Germany, [22]Leibniz Universität Hannover, Germany. Email: okada@planeta.sci.isas.jaxa.jp.

Introduction: The SPS-OKEANOS (Outsized Kitecraft for Exploration and AstroNautics in the Outer Solar system) is under study in Japan to rendezvous with and land on a Jupiter Trojan asteroid [1]. It is primarily an engineering mission to demonstrate advanced space technology but also to conduct key science for understanding the solar system origin and evolution by conducting in-depth measurements there. The concept is complementary to LUCY [2], multi-flybys to six Jupiter Trojans, that was selected as a Discovery class mission, aiming at understanding the variation and diversity of Jupiter Trojans. The SPS-OKEANOS mission is jointly studied between engineers and scientists both from Japan and Europe [3]. The scientific objectives and the strawman payloads for this mission are described here.

Jupiter Trojan Asteroids: Jupiter Trojan asteroids are located around the Sun-Jupiter Lagrange points (L4 or L5), and most of them are classified as D- or P-types in taxonomic class, which are considered as volatile rich materials with silicates, water ices, and organics. But, their origin and evolution, composition and physical state remain unknown, since they might be moved after formation by gravity scatterings due to migration of giant planets [4]. Jupiter Trojans are a missing link of materials that originate from the inner or the outer solar system. Those bodies to be explored should have a diameter from 20 to 30 km (large enough to classify their taxonomy by ground-based observations but small enough for safe landing on the surface), so that they may undergo aqueous and thermal alteration. They should be the key targets to understand the solar system evolution processes and the radial distribution of chemical and isotopic composition in the early solar system.

Spacecraft Design: The spacecraft consists of a spin-stabilized main orbiter with a large area solar power sail which rotates at 0.1 rpm and a 3-axis controlled lander to be deployed from the main spacecraft. Its total wet mass is ca. 1,400 kg. The lander is designed within the wet mass of 100 kg, with its body size within φ650 x 400 mm to be mounted on the main spacecraft, with the extensible legs and sampling devices. The lander is designed to work on the asteroid for 20 hours or longer, using a primary battery of 600 W-Hours allocated for the mission. The main spacecraft will be thrusted using the hybrid propulsion system combined with a large area (40 x 40 m^2 in size) thin-film solar-power sail (SPS) inherited from the IKAROS mission and an advanced ion engine inherited from the Hayabusa and Hayabusa2 missions, enabling to explore the outer solar system without using a radioisotope thermoelectric generator (RTG).

Mission Design: The spacecraft will be launched by a H-IIA launch vehicle (or its successor) in mid-2020s, accelerated by gravity assists of Earth and Jupiter. It will arrive at the target asteroid in the Jupiter Trojans after a thirteen-year long space journey.

The mission design after launch is scheduled as shown in Table 1, for the launch in Dec 2024, Jan 2026, and Feb 2027. Plan-A denotes a one-way trip to the target Jupiter Trojan asteroid, and Plan-A' adds another asteroid rendezvous if the spacecraft is still healthy after a 1.5-year long asteroid proximity mission is completed. Plan-B is a return trip from a Jupiter Trojan asteroid to Earth. Their technical feasibility is now studied for the final decision which plan should be taken. During the long-time cruise, the downlink bitrate is designed higher than 1 Kbps using a HGA with a 2-axis gimbal for enabling the fruitful cruising science. During the most of asteroid phase, the downlink bitrate is designed 4 Kbps or higher. The bitrate from the lander to the main spacecraft is as high as 1 Mbps to transfer more than 500 Mbytes of data.

Science Mission and Payloads: Mission payloads should be within 30 kg on the main spacecraft and within 20 kg on the lander. The masses on the film-type dust detector on the sail and the magnetometers in the corner mass to expand the sail are not counted. The imagers and LIDAR for the optical navigation and the radio science using ranging and doppler measurements are also used for scientific purpose.

***Cruising Science*:** During the 1.5-year long test phase after the launch to the Earth swing by, and the 2.5-year long cruise from Earth to Jupiter, and the 8.5-year long cruise from Jupiter to the target body, many science experiments will be carried out using the main spacecraft as a deep-space platform, with the instruments shown in Table 2-1.

Continuous measurements of interplanetary dusts and magnetic fields from the inner to the outer solar system will be conducted to monitor their radial distribution, and also detect sudden events. Gamma-ray polarimeter will continuously monitor the gamma-ray events for precise positioning of gamma-ray burst sources by use of the Earth to spacecraft very long baseline. Visible to near-infrared telescope will map the zodiacal lights from the inner solar system, and will observe the deep sky from the outer solar system outside the orbit of dusty asteroid main belt (free from thermal radiation backgrounds by zodiacal lights). The instruments for Trojan science will be also used for calibration during Earth and Jupiter swing-bys.

Trojan Science: Physical, mineralogical, and isotopic studies of surface materials and volatile compounds could provide a clue to understanding the origin and evolution processes of the target body, as well as the solar system formation. To achieve these goals, *in situ* surface experiments with the lander as well as global mapping from the main spacecraft are required.

After arriving there, the target asteroid will be globally investigated through remote sensing for the scientific purposes (asteroid shape, rotation state, gravity, geologic features, mineralogy, thermo-physical properties, dielectric and magnetic properties, subsurface physical state, degree of hydration, and current activities), and for the landing site selection, with the instruments shown in Table 2-2. The asteroid will be characterized and investigated such as high-resolved surface global mapping by using an optical telescopic imager, as well as the surface mineralogy and the degree of hydration mapping by a near-infrared and a thermal-infrared hyperspectral imager (1 to 4 μm, 7 to 14 μm), with spatial resolution of higher than several tens of meters.

A lander will be deployed from the main spacecraft to land on the asteroid to observe the surface materials and physical properties (geologic context) of the surrounding area, and to conduct *in situ* analysis (hyperspectral microscopy for grains, and high-res. mass spectrometry for volatiles) for the materials sampled from asteroid surface and subsurface (up to 1 m depth), with the instruments shown in Table 2-3. Collected samples will be viewed with a visible to infrared microscope (covering 1 to 4 μm) with a spatial resolution of ca. 20 μm per pixel to identify and classify each grain. Those samples will be heated by step-wise heating, pyrolysis, and gas-chromatography for high resolution mass spectrometry (HRMS). Mass resolution $m/\Delta m > 30{,}000$ is required to investigate isotopic ratios of D/H, $^{15}N/^{14}N$, and $^{18}O/^{16}O$ (M=1~30), as well as molecules from organic matters (M = 10 to 300).

In addition, technical feasibility and science requests of sample return are discussed for the Plan-B, especially in thermal design of sample box in thr reentry capsule [5].

References: [1] Okada T. et al. (2017) Lunar Planet. Sci. Conf., 48, #1828. [2] Levison H.F. et al. (2016) Lunar Planet. Sci. Conf., 47, #2061. [3] CE Study Report (2015) DLR-RY-CE-R019-2015-4. [4] Morbidelli A. et al. (2005) *Nature 435*, 462-466. [5] Kebukawa Y. (2017) Lunar Planet. Sci. Conf., 48, #2221.

Table 1: SPS-OKEANOS mission schedule

Phase	Events	1: 2009SK27 2: 1996PS1	1: 1998WR10 2: 2005LB37 or 2009UW26	1: 2005YJ15 2: 2010XE81
Before arrival	Launch	2024/12/18	2026/01/20	2027/02/28
	Earth SWB	2026/09/27	2027/11/03	2028/12/17
	Jupiter SWB	2029/05/16	2030/08/15	2032/03/19
	Arv: Ast1	2037/12/18	2039/01/20	2040/02/28
Plan-A’	Dep: Ast1	2039/06/18	2040/07/20	2041/-8/28
	Arv: Ast2	2047/06/18	2048/07/20	2046/09/28
Plan-B	Dep: Ast1	2039/06/18	2040/07/20	2041/08/28
	Jupiter SWB	2053/02/03	2054/05/06	2055/12/11
	Ret: Earth	2055/10/08	2057/12/19	2059/-1/15

Table 2-1: Instruments for Cruising science

#	Characteristics	Mass
EXZIT	Visible to NIR telescope	< 12 kg
GAP2	Gamma-ray polarimeter	< 5 kg
ALDN2	PVDF large area dust detector	< 2kg
MGF2	Flux-gate 3-axis magnetometer	< 2kg (na)

Table 2-2: Instruments for Trojan science on the main spacecraft

#	Characteristics	Mass
MASTER	NIR imaging spectrometer	< 6 kg
TROTIS	TIR multiband imager/radiometer	< 3 kg
Radar	HF ground penetration radar	< 3kg
ONC-T/W	Optical navigation camera	na (AOCS)
LIDAR	Laser ranger	na (AOCS)
Radio science	Ranging and doppler shift	na (COM)

Table 2-3: Instruments for Trojan science on the lander

#	Characteristics	Mass
Sampler	Surface and subsurface sampler	12 kg
HRMS	Mass spectrometer (R>30000)	↑
Microscope	Hyperspectral Microscope	3.5 kg
Panorama	Hyperspectral panoramic imager	↑
Camera	Optical navigation camera	< 0.5 kg
Mini-RAD	Laser ranger	< 0.3 kg
MAG	Fluxgate 3-axis magnetometer	< 0.3 kg
APXS	PIXE and XRF for composition	< 0.5 kg
Others	(monitor camera, booms)	< 2 kg