OKEANOS –A Solar Power Sail Mission to a Jupiter Trojan Asteroid and Its Updated Science Mission Proposal. T. Okada[1,2], T. Iwata[1], J. Matsumoto[1], T. Chujo[1], Y. Kebukawa[3], M. Ito[4], J. Aoki[5], Y. Kawai[5], S. Yokota[5], Y. Saito[1], K. Terada[5], M. Toyoda[5], H. Yabuta[6], H. Yurimoto[7,1], S. Matsuura[8], K. Tsumura[9], D. Yonetoku[10], T. Mihara[11], A. Matsuoka[1], R. Nomura[12], H. Yano[1], T. Hirai[13], A. Kumamoto[9], 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], F. Yoshida[13], M. Yoshikawa[1], M. Matsushita[1], 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]Kochi Institute for Core Sample Research, Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Japan, [5]Osaka University, Japan, [6]Hiroshima University, Japan, [7]Hokkaido University, Japan, [8]Kwansei Gakuin University, Japan, [9]Tohoku University, Japan, [10]Kanazawa University, Japan, [11]RIKEN, Japan, [12]National Astronomical Observatory of Japan (NAOJ), 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 OKEANOS (Oversize Kite-craft for Exploration and AstroNautics in the Outer Solar system) is a mission under study to rendezvous with and land on a Jupiter Trojan asteroid [1]. It is primarily an engineering mission to demonstrate advanced technologies to explore the outer solar system with a small to medium sized spacecraft and limited cost, but also to conduct key science for understanding the origin and evolution of the solar system and life by performing in-depth scientific measurements. The concept is complementary to the Lucy mission [2], multi-flybys to six Jupiter Trojans, that was selected as a NASA Discovery class mission, aiming at understanding of variation and diversity of Jupiter Trojans. The OKEANOS is jointly studied between engineers and scientists both from Japan and Europe [3].

The OKEANOS is one of two candidates for the next medium class space science mission in Japan, waiting for the final selection. The scientific objectives, the latest science mission scenarios and the strawman payloads 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 asteroid taxonomy, considered to contain materials enriched in volatiles (ices, organics). They might have experienced almost no or only a low degree of aqueous and thermal alteration. Their origin and evolution, as well as the current surface composition and physical state still remain unknown. Jupiter Trojans should be a missing link of materials that originate from the inner or the outer solar system since they might have moved from their originated regions by gravity scattering due to migration of giant planets [4]. Thus they are key targets to understand solar system evolution and the radial distribution of elements and isotopes in the early solar system.

There are two constraints to select the target body amongst the Jupiter Trojans: It must belong to D- or P-type by ground-based or space-based observations. And it must have a diameter of 30 km or smaller due to the constraint on fuel consumption during the release of the lander to the asteroid surface.

Mission Design: The OKEANOS mission design has been downscaled due to the severe cost cap, including the reduction of ion engines from 3 to 2 units, downsizing the lander from 100 to 40 kg class, and rejection of the sample return option. However, main success criteria and requirements for the mission remain unchanged.

The spacecraft will be launched by a H-2A launch vehicle (or its successor H-3) in 2027 or later, accelerated by gravity assists of Earth and Jupiter. It will arrive at the target asteroid among the Jupiter Trojans after a thirteen-year long space journey.

During the cruise, the downlink rate is designed to 1 Kbps or higher using X-band HGA with 2-axis gimbals for enabling fruitful science. During the asteroid proximity phase, the downlink rate is designed to 4 Kbps or higher. Telemetry rate from the lander to the main spacecraft is at 1 Mbps to transfer more than 500 Mbytes of data.

Spacecraft Design: The spacecraft consists of a spin-stabilized main spacecraft with a large area solar power sail which rotates at 0.1 rpm, and a Mascot-like small lander. The total wet mass is within 1,400 kg.

The main spacecraft will be thrusted during the cruise and position-stabilized during the asteroid rendezvous using the hybrid propulsion system combined with a large area (40 x 40 m^2 in size) thin-film type solar power sail inherited from the IKAROS mission, and an advanced ion engine inherited from the Hayabusa and the Hayabusa2 missions. The OKEANOS uses this fuel-efficient thrusting system, enabling to explore the outer solar system without a radioisotope thermoelectric generator (RTG) and within a severe cost cap. A mass allocation of 30 kg is reserved for science instruments, 12 kg of which is for the international collaboration for Trojan science.

The lander is within 40 kg, and like Mascot, without any attitude and orbit control system, fuel, or landing legs, but with attitude detection and uprighting capability on the asteroid surface. The tentative design is box-shaped with 500 x 500 x 334 mm size. The primary battery has a total energy supply of 1090 Wh for 25 hours mission lifetime, and 360 Wh are allocated for science activities. A mass of 12 kg is allocated for science instruments.

Science Mission and Payloads: Mission payloads are limited to 30 kg on the main spacecraft and to 12 kg on the lander. Masses of the film-type dust detector on the sail and the magnetometers in the corner mass to expand the sail are not counted. Bus instruments such as the optical navigation cameras (ONC-T and -W) , LIDAR, and radio science using ranging and doppler measurements are also used for scientific purposes. The science mission proposal [5] is updated as shown below.

***Cruising Science*:** During the 1.5-year long EDVEGA phase after the launch to the Earth swing by, 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" (see Table 1). Continuous measurements of interplanetary dust and magnetic fields will monitor their radial distribution from the inner to the outer solar system and detect sudden events. The gamma-ray polarimeter will monitor the gamma-ray events for precise positioning of gamma-ray burst sources using the Earth to spacecraft very long baseline. The 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 dusty asteroid main belt.

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

Global mapping is carried out to characterize the asteroid and select the landing site. The shape, size, rotation state, and geologic features of the asteroid are determined by optical imaging. Gravity and altitude is measured by radio tracking and laser raging. Visible multi-band and near-infrared spectroscopy (1.8 to 3.6 μm) characterizes red or less red patterns, the degree of hydration, mineralogy, and abundance of ices, organics, and brines. Thermal infrared multi-bands (7 to 15 μm) inform on thermo-physical properties, mineralogy and amorphous phases. A radar probes the surface physical state and also contributes to altimetry (see Table 2). The global mapping is mainly conducted from the Home Position at an altitude of 250 to 350 km (depending on the actual size and mass of the asteroid). Occasional higher resolution mapping at lower altitudes of 50 to 100 km is foreseen. The descent operations to 1 km altitude are carried out for the lander release and its rehearsal, during which highest resolution data will be obtained.

In situ experiments with the lander will start with imaging and spectroscopy (1 to 3.6 μm) of the footprint and surrounding area, followed by measurements of mineralogical, elemental, and organic composition as well as physical, thermal, and magnetic properties at the site. Then the asteroid sample (at least 1 mg per analysis) is collected with the contamination-free air-gun and the horn-shape collector to perform high-resolution mass spectroscopy (HRMS), especially to determine the isotopic ratios of δD and $\delta^{15}N$ and the volatile species contained in the sample (see Table 3). Mass resolution $m/\Delta m > 30{,}000$ for the isotopic ratios (mass range M/Z = 2~30) and molecules from organic matters (M/Z = 10~300) is required for the HRMS, so that the MULTUM system (infi-TOF type mass spectrometer [6]) with stepwise heating and pyrolysis capability will be used.

Regarding downscaling of the mission design, the mass allocation for mission payloads aboard the now 40 kg class lander had to be reduced from 20 to 12 kg. The subsurface sampling is rejected because of its large size for the new lander design and high cost. A gas-chromatograph for the HRMS is given up because of the mass limitation. The hyperspectral microscope is rejected but its function is retained as the down-looking view of the hyperspectral imager.

The Trojan science experiments of the OKEANOS mission still have significance as they are complementary to the multiple flybys of Jupiter Trojans by the NASA Lucy mission. Detailed discussions on the payloads are planned during the Critical Joint Study in 2019.

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Table 1: Instruments for Cruising science

#	Characteristics	Mass
EXZIT	Visible to NIR telescope	12 kg
GAP2	Gamma-ray polarimeter	5 kg
ALADDIN2	PVDF large area dust detector	1.4 kg
MGF	Flux-gate 3-axis magnetometer	10 kg ($)

($: mass replaced from the corner mass)

Table 2: Instruments for Trojan science on the MS

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

Table 3: Instruments for Trojan science on the lander

#	Characteristics	Mass
Sampler	Surface sampler by air-gun	8~9 kg
HRMS	Mass spectrometer (R>30000)	↑
MacrOmega	Panoramic & surface hyperspectral Imager	2.5 kg
Camera	Surface imager with 4 color LED	0.5 kg
Mini-RAD	Multi-band radiometer	0.2 kg
MAG	Fluxgate 3-axis magnetometer	0.2 kg
APXS	PIXE and XRF for composition	0.5 kg
Others	(monitor camera, accelerometer)	< 1 kg