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Science exploration and instrumentation of the OKEANOS mission to a Jupiter Trojan asteroid using the solar power sail

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A B S T R A C T

An engineering mission OKEANOS to explore a Jupiter Trojan asteroid, using a Solar Power Sail is currently under study. After a decade-long cruise, it will rendezvous with the target asteroid, conduct global mapping of the asteroid from the spacecraft, and *in situ* measurements on the surface, using a lander. Science goals and enabling instruments of the mission are introduced, as the results of the joint study between the scientists and engineers from Japan and Europe.

1. Introduction

Jupiter Trojan asteroids are located in the long-term stable orbits around the Sun-Jupiter Lagrange points (L4 or L5) Most of them are classified as D- or P-types in taxonomy (DeMeo and Carry, 2014), considered as volatile rich, composed of rocks (silicates), water ices, and organics. They might be missing links of materials that originate from the inner or the outer solar system due to planetary migration (Morbidelli et al., 2005; Walsh et al., 2011; Levison et al., 2009), and might have undergone some degree of aqueous and thermal alteration process in the outer solar system. They are key target bodies to be explored for understanding the solar system formation process, the chemical radial distribution in the solar system, and the degree of alteration in the outer solar system. Certain Trojans are believed to have formed together with Jupiter, containing material that is inaccessible at the gas giant (Emery et al., 2458). It is also important to verify the possibility with isotopic ratios such as D/H and $^{15}N/^{14}N$ (Marty, 2012), if the materials trapped at the Jupiter Trojan are of the same origin as the sources of terrestrial ocean water and life.

Lucy (Levison et al., 2017), a Jupiter Trojan multi-flyby mission, has been selected as a NASA Discovery class mission, which aims for understanding the variation and diversity of Jupiter Trojans. Complementary to the Lucy mission, an engineering mission using a large-area solar power sail (Mori et al., 2015) is being studied to rendezvous with and land on a Jupiter Trojan asteroid, and optionally even return samples for in-depth studies. After its arrival, the asteroid will be investigated by remote sensing, both for the purposes of scientific observations and landing site selection. A lander will be deployed to land on the asteroid surface and conduct *in situ* experiments. Science goals and the enabling instruments have been jointly studied between engineers and scientists both from Japan and Europe (Trojan Study, 2015). This mission, originally referred to as SPS (Solar Power Sail) is now named OKEANOS (Oversize Kite-craft for Exploration and Astro-Nautics in the Outer Solar system), from the Greek god of ocean at the far end of the world. We will present here the key scientific objectives and the strawman payload for the OKEANOS mission.

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2. OKEANOS mission concept

The OKEANOS mission is one of two candidates of the next medium class space science mission in Japan, and its Phase-A1 study is organized by the Institute of Space and Astronautical Science (ISAS), Japan Aerospace Exploration Agency (JAXA). This mission is primarily proposed as a technology mission including a solar power sail. This solar power sail is a hybrid propulsion system using a large-area (ca. 40 m × 40 m) thin-film solar panel which generates the power to activate the advanced ion engine system even at the Jupiter distance from the Sun. The solar power sail technology is inherited from the IKAROS (Mori et al., 2009) mission (the first interplanetary "kite craft"), and the ion engine system is inherited from Hayabusa (Kawaguchi et al., 2003) and Hayabusa2 (Tsuda et al., 2016) missions (the first sample return from an asteroid and its successor). The hybrid propulsion system enables us to visit and explore the outer solar system without using a radioisotope thermoelectric generator (RTG).

The OKEANOS spacecraft consists of a spin-stabilized main spacecraft, which rotates at 0.1 rpm, and a 3-axis controlled lander. The total wet mass is ca. 1400 kg, able to be launched directly to the deep space by a H-2A launch vehicle. The lander is designed within the mass of 100 kg. Its main body mounted inside of the main spacecraft must be within 650 mm diameter by 400 mm height, and the sampling devices are equipped at the center of the base panel of the lander. The overall payload of the lander will be 20 kg in total, including science payloads, sampling package, including their electronics, as well as the sample container and sample transfer system in case of the optional sample return (Mori et al., 2015). All the science operations of the lander must be carried out on the asteroid within 20 h with a 600 Wh energy allocation of primary batteries.

3. OKEANOS mission profile

In the current proposal (Mori et al., 2015; Trojan Study, 2015), the OKEANOS spacecraft will be launched with an H-2A (or H-3) Launch Vehicle in January 2026 as a nominal case. Three options are now considered. Plan-A is a one-way trip to a Jupiter Trojan asteroid, Plan-A' is that a second Jupiter Trojan asteroid rendezvous is added, and Plan-B is a round-trip mission to a Jupiter Trojan asteroid, returning samples to Earth. The trajectories of the spacecraft are illustrated in Fig. 1.

After launch, the spacecraft will use the ion engine system for thrust and change trajectory using gravity assist maneuvers at Earth and Jupiter. It will rendezvous with the target Jupiter Trojan asteroid approximately 11 years or longer after launch (Saiki et al., 2015). During the first two years spacecraft operations are dominated by use of the ion engine for the trajectory correction maneuver before the Earth swing-by. After the swing-by, the spacecraft will travel from the Earth to Jupiter. That period will be an ideal opportunity to make observations continuously from the interplanetary platform, such as dust and magnetic field distribution in the outer solar system. During the second half period of the cruise phase, from Jupiter to a Trojan asteroid, the spacecraft will cruise outside of the asteroid main belt. This phase will be ideal to conduct astronomical observations under almost dust-free conditions without infrared radiation background, and to carry out gamma-ray interferometry using a very long baseline from Earth to spacecraft.

The target asteroid will be selected both under scientific and engineering viewpoints. D- or P-type asteroids are dominated in Jupiter Trojans and desired as target bodies, but no taxonomic data has been reported for those Jupiter Trojans smaller than 20 km size range by ground-based or space-based observations (DeMeo and Carry, 2014). On the other hand, smaller surface gravity eases safe landing on the asteroid and reduces fuel consumption (Mori et al., 2018). The maximum size of

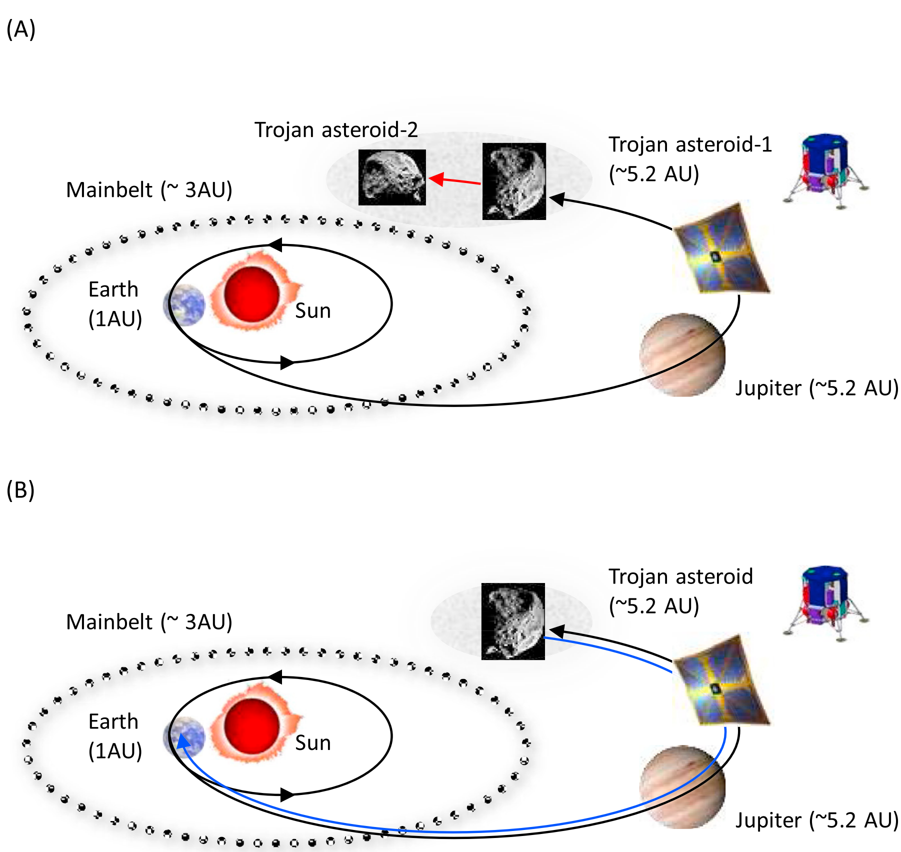

Fig. 1. The trajectories of the OKEANOS spacecraft are illustrated: (A) a one-way trip to a Jupiter Trojan asteroid (Plan-A) and an extra rendezvous to the second asteroid (Plan-A′), (B) round-trip to a Jupiter Trojan asteroid for sample return (Plan-B). After the Earth swing-by 2 years after the launch, the spacecraft will travel from the Earth to Jupiter and observe the along-the-track radial distribution of dusts and magnetic fields and their mutual interactions in the solar system. After the Jupiter swing-by, the spacecraft will travel to the Jupiter Trojans outside of the "dusty" main belt, where infrared astronomy will be performed under extremely low abundance of dusts or low infrared backgrounds. Gamma-ray polarimetric interferometry will be also carried out, using the very long baseline between the Earth and the spacecraft. After the arrival at the Trojan asteroid, the remote sensing from the main spacecraft and *in situ* observations using the lander will be planned.