IN-SITU ANALYSIS OF SURFACE AND SUBSURFACE SAMPLES FROM A JUPITER TROJAN ASTEROID USING A HIGH RESOLUTION MASS SPECTROMETER IN THE SOLAR POWER SAIL MISSION. Y. Kebukawa[1], M. Ito[2], J. Aoki[3], T. Okada[4,5], Y. Kawai[3], J. Matsumoto[4], R. Nakamura[6], H. Yano[4], K. Terada[3], M. Toyoda[3], H. Yabuta[7], N. Grand[8], H. Cottin[8], A. Buch[9], C. Briois[10], L. Thirkell[10], O. Mori[4], and J. Kawaguchi[4], [1]Yokohama National University, Japan (kebukawa@ynu.ac.jp), [2]Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Japan, [3]Osaka University, Japan, [4]Institute of Space and Astronautical Science (ISAS), Japan Aerospace Exploration Agency (JAXA), Japan, [5]University of Tokyo, Japan, [6]National Institute of Advanced Industrial Science and Technology (AIST), Japan, [7]Hiroshima University, Japan, [8]LISA, Université Paris-Est Créteil, Paris Diderot, France, [9]Ecole Centrale Paris, France, [10]LPC2E, Université d'Orléans, France.

Introduction: The Solar Power Sail (SPS) mission is one of candidates of the upcoming strategic middle-class space exploration to demonstrate the first outer Solar System journey of Japan. The mission concept includes unique instruments of in-situ high resolution mass spectrometry (HRMS) and possible sample return capability as well as remote sensing instruments. The current mission sequence proposes the launch in late 2020s, and rendezvous to a D or P type Trojan asteroid of ~20-30 km in diameter in 2030s after Jupiter flyby. The overview of this mission is presented by Okada et al. in this meeting [1].

Here we present specific scientific goals of in-situ analysis with a HRMS and sample return from the surface and subsurface (up to 1 m) materials of a Jupiter Trojan asteroid.

Scientific Goals: The key questions for the Jupiter Trojan asteroid exploration are: (1) constraining planet formation/migration theories, (2) evolution and distribution of volatiles (water and organics) in the Solar System, (3) origin of Earth's water, and (4) surface processes of Jupiter Trojan asteroids.

(1) Constraining planet formation/migration theories. The classic model for the Solar System formation suggests that the Trojan asteroids are mainly survivors of building blocks of the Jupiter system [2], while recently proposed planetary migration models (e.g., Nice model) claim that they are intruders from outer regions after the planetary migration of the giant gas planets settled [3]. Thus, origin of Jupiter Trojans potentially contains a key to understand the planetary formation and migration. We can roughly consider that in the case of the former scenario, the Trojans have similar composition to primitive main belt asteroids (e.g., C, D, or P type), and the later scenario, the Trojans have similar composition to comets (Kuiper belt objects, KBOs). The apparent differences between primitive asteroids and comets are, in general, comets have not aqueously altered, and enriched in heavy isotopes (D and ^{15}N) than primitive asteroids due to isotopic fractionations in cold environments (e.g., molecular clouds and the outer protosolar disk) [4].

(2) Evolution and distribution of volatiles in the Solar System. It is first opportunity to in-situ investigation and sample return of D/P type asteroid, and it could be a *Missing link between comets and asteroids*. Since the only known D/P type asteroid sample is the Tagish Lake meteorite (an ungrouped carbonaceous chondrite), our knowledge of these types of asteroids is very limited by observational studies. Consistent with aqueously-altered nature of the Tagish Lake, main belt D type asteroids show 3 μm bands which indicates phyllosilicate OH, but Jupiter Trojans do not show the 3 μm band [5]. Thus, we might expect the very early stage of aqueous alteration and/or water ice (at subsurface) from the Trojan samples.

What was origin and evolutional processes of extraterrestrial organic matter? Comets contain larger amount of volatile simple molecules than primitive asteroids, i.e., carbonaceous chondrites. Alexander et al. [6] hypothesized that insoluble organic matter (IOM) in various chondrites and possibly cometary refractory organics evolved from a common precursor, which has high H/C ratios and high δD. We might be able to confirm that theory with the analysis of a Trojan asteroid.

Finally, the stable isotopic compositions of H, C, N and O for volatiles in the Trojans give us an important insight into circulation, distributions and evolution of gas and solid materials within the Solar System.

(3) Origin of Earth's water. D/H ratio of water in the Solar System objects is interesting, with regards of origin of Earth's water. Oort cloud comets have higher δD than Earth's water, a Jupiter family comet (JFC) 103/P Hartley 2 shows similar δD to the Earth's water but recent result from Rosetta mission shows that water in 67P/Churyumov-Gerasimenko (a JFC) has much high δD [7]. While, water in chondrites are estimated to lower than the Earth's water [8]. How about the Trojan asteroid?

(4) Surface processes of Jupiter Trojan asteroids. Samplings from both surface and subsurface are good opportunity to study space weathering and surface evolution of the Jupiter Trojan asteroid. Noble gas isotopes are sensitive indicators to elucidate a history of irradiation from cosmic rays and/or solar wind on its surface, as shown by the Itokawa particles by the Hayabusa mission [9].

In-situ analytical sequences: We plan to analyze volatile materials on the Jupitar Trojan, for their isotopic and elemental compositions using a HRMS with a combination of pyrolysis ovens and gas chromatography (GC) columns. This HRMS system allows to measure H, N, C, O isotopic compositions and elemental compositions of molecules prepared by various pre-MS procedures including stepwise heating up to 600ºC, pyrolysis-GC, and high-temperature pyrolysis with catalyst in order to decompose the samples into simple gaseous molecules (e.g., H_2, CO, and N_2). The required mass resolution should be at least 30,000 for analyzing isotopic ratios (e.g., $H_2{}^{16}O$, $HD^{16}O$ and $H_2{}^{18}O$ for H and O isotopic measurements) for simple gaseous molecules. For elemental compositions of molecules/ions, mass accuracy of ~10 ppm is required to determine elemental compositions for molecules with *m/z* up to 300 (as well as compound specific isotopic compositions for smaller molecules). Our planned analytical sequences consist of three runs for both surface and subsurface samples (Fig. 1). In addition, 'sniff mode' which simply introduces environmental gaseous molecules into a HRMS will be done by the system. The details of the analytical methods and apparatus are under developments.

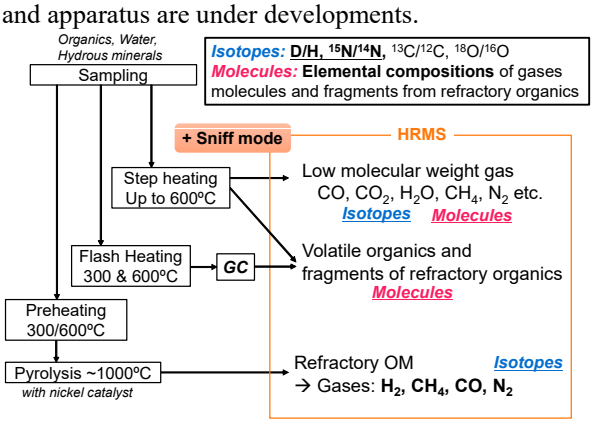

Fig 1: In-situ analytical sequences of surface and subsurface samples of a Jupiter Trojan asteroid using a high resolution mass spectrometer (HRMS).

The sample return from the Trojan asteroid: Analyses of returned samples from Moon [10], asteroid [11] and comet [12] were essential to understand their origin and nature as well as increasing our knowledge about the Solar System. The most recent returned sample was from the S-type asteroid Itokawa by Hayabusa mission in 2010. The results by series of analyses provided new insights for the connection to meteorite researches, space weathering processes, small asteroidal body formation in the Solar System [e.g., 11]. JAXA Hayabusa 2 and NASA Osiris-REx are both current sample return missions from the organic-rich asteroids, Ryugu (C-type) and Bennu (B-type), respectively [13,14]. Both missions have complementary scientific goals that are to understand the Solar System evolution in the point of view of organics, water and associated minerals. We, therefore, are working on the possibility of the sample return from Trojan asteroid that is expected to contain primordial chemical information at the very beginning of Solar System formation.

D/P-type Jupiter Trojan asteroids likely consist of dominant of organics (carbonaceous materials) and anhydrous silicates (hydrated silicates cannot be excluded), possibly with water (ice) in its interiors [15]. Beside in-situ HRMS analysis of isotopic ratios, elements and molecules in surface and subsurface samples on the Trojan asteroid, analysis of returned samples containing non-volatile materials (organics and minerals) as well as water (ice) will open a new insight of the detailed scientific objectives for the Solar System evolution. Since, in-situ analysis is limited in terms of sample preparations, lack of relationship among components, and mineralogical/petrological contexts, the state-of-the-art microanalysis techniques on the Earth will provide these additional information such as isotopic ratios of individual component (organics and associated minerals), trace amount of gaseous species (e.g., Noble gases, CO, CO_2, NH_3, CH_4 in the ice), and organic compounds that are hard to be detected under the current in-situ HRMS system (e.g., amino acids).

The details of the sample return capsule is not yet fixed but a cryo-system is highly encouraged. Thus, we will receive "extraterrestrial ice (water)" that has a pristine water at the Solar System which contains the information of nebular gas, formation of ice, reservoir of volatiles (water and organics), and the origin of the Earth's water.

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