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Japanese mission plan for Jupiter system: The Jupiter magnetospheric orbiter and the Trojan asteroid explorer

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Abstract

In the future Jupiter system study, Coordinated observation of Jovian magnetosphere is one of the important targets of the mission in addition to icy satellites, atmosphere, and interior of Jupiter. JAXA will take a role on the magnetosphere spinner JMO (Jupiter Magnetospheric Orbiter), in addition to JGO (Jupiter Ganymede Orbiter) by ESA and JEO (Jupiter Europa Orbiter) by NASA. We will combine JMO with a proposed solar sail mission of JAXA for Jupiter and one of Trojan asteroids. Since Trojan asteroids could be representing raw solid materials of Jupiter or at least outer solar system bodies, involvement of Trojan observation should enhance the quality of Jupiter system exploration.

1. Introduction

Jupiter is the largest planet in the solar system. It is a rapidly rotating gaseous body with main composition is hydrogen and helium. Jupiter has various satellites, four of which were discovered by Galileo in 400 years ago. Jupiter has the strongest planetary magnetosphere in the solar system [2]. And recent discoveries of exoplanets, especially hot jupiters, show that Jupiter should represent a body not only in the solar system but in the universe[1)].

The Jupiter System, with Jupiter and its satellites, can be considered as a small planetary system. However, data amount from Galileo spacecraft was very limited due to the malfunction of high-gain antenna. We now have more information on the Saturn System (being provided by Cassini) than that on the Jupiter system.

EJSM (Europa Jupiter System Mission) is a planned Jovian system mission with three spacecraft aiming at coordinated observations of the Jovian satellites especially Europa and the magnetosphere, atmosphere and interior of Jupiter [2]. In order to investigate the 3D structure of magnetosphere, multi-spacecraft mission is desirable. From the beginning, JAXA and Japanese members committed with the mission planning. The initial plan was that JAXA will make JMO (Jupiter Magnetosphere Orbiter) and JMO would be launched and transported together with ESA's orbiter, similar to BepiColombo. However, due to the increase in the resource and mass of JGO, JAXA is requested to launch JMO by its vehicle. We seek a possibility to combine JMO with a proposed solar sail mission for Jupiter and one of Trojan asteroids. ESA will take charge of JGO (Jupiter Ganymede Orbiter) and NASA will be responsible for JEO (Jupiter Europa Orbiter).

JAXA already started a study of a solar power sail for deep space explorations in early 2000s. It evaluated a mission proposal for a new engineering verification spacecraft, which is called the solar power sail, a hybrid propulsion system of solar sail and ion engines, to demonstrate technologies necessary to explore the outer planet region in the solar system [5]. Together with a solar sail (photon propulsion), it will have very efficient ion engines where electric power is produced by very thin solar panels within the sail. JAXA has already experience ion engine in the successful HAYABUSA mission[4)].

2. Jovian magnetosphere

The Jovian magnetosphere is driven by the fast rotation of Jupiter and populated by ions coming mainly its satellites. It is the gateway to the astro-plasma world. Explosive phenomena require ideal-MHD to break down. How this can be done in an astro-plasma situation where the basic scale length is much larger than the non-MHD characteristic scales (ion and electron scales) is not clear at all, which would require in-situ observation.

The regarding astrophysical processes that can be investigated in Jovian magnetosphere are (i) dynamics of a magnetodisk, with different mechanisms of angular momentum exchange and dissipation of rotational energy (ii) electro-dynamical coupling between a central body and its satellites and, (iii) global and continuous acceleration of particles. Electrodynamic interactions of the Jovian system include generation of plasma at the Io torus, magnetosphere / satellites interactions, dynamics of a giant plasma disc coupled to Jupiter's rotation by the auroral current system, generation of Jupiter's intense radiation belts [3].

The Jovian magnetosphere is the most intense particle accelerator in the planetary system. Sulfur ions that came out of Io at the energy of less than 1 eV are somehow energized up to > 10 MeV within the magnetosphere. It is obvious that turbulence driven by the fast rotation of the planet and magnetic reconnection in the magnetodisk are playing crucial roles. Ganymede has an intrinsic magnetic field and occupies a small magnetosphere in the huge Jovian magnetosphere[5). Interaction of Jovian particles and Ganymedean magnetosphere is another intriguing target of plasma science. It is desirable that JMO shall monitor the Jovian magnetosphere while JGO is observing Ganymedean environment. During the initial stage of orbital maneuver, JMO by itself will flyby with Ganymede and observe its plasma and magnetic environment.

During the initial periods, the Jovian magnetosphere is investigated by the three spacecraft. JMO will take the largest periapsis (> 100R_J: R_J being the radius of Jupiter). After JEO and JGO enter orbits around Europa and Ganymede, respectively, JMO will take equatorial orbits with periapsis at Europa or Ganymede's orbit and apoapsis around 100R_J. JMO will determine the outer boundary condition.

In the final stage, we can increase the orbital inclination of JMO to observe off-equatorial characteristic of magnetosphere and polar regions of Jupiter. Preliminary estimates by S. Campagnola show that using multiple gravity assists by Callisto the inclination of JMO can be enhanced up to 35deg in a half year and 55deg in two years. High inclination enables JMO to observe polar region of Jupiter and off-equatorial region of Jovian magnetosphere.

JMO will have energetic particle instruments package including low-energy plasma spectrometers (< a few keV), medium energy particle detectors (1 – 80keV), energetic particle detectors (50keV – 1MeV), very high energetic particle detectors (>1MeV) and DC electric field / magnetic field and plasma wave instrument package including a magnetometer and plasma/wave instrument. JMO will also have remote sensing instruments such as an ENA imager, an EUV spectrometer, and a camera for the observation of Jupiter, Io torus, and magnetosphere. JMO will have a dust detector.

3. Trojan asteroids by solar sail

At present, there are two models for the origin of Trojan asteroids [4]. One is that they are leftovers of planetesimals that formed the Jovian systems. Another is so-called Nice Model that Trojan asteroids are captured when Jupiter and Saturn entered 1:2 resonance orbits [4]. They should derive from outer solar system, probably some of Kuiper Belt objects.

Most of Jovian L4 Trojan asteroids are D-type asteroids [1], poorly understood taxonomic types from neither ground observation spectroscopy nor meteorite analyses due to the lack of possible analog chondrites discovered on the Earth. One advocates that D-type asteroids are remnants of short-period cometary nucleus. If detailed observation revealed the connection between Trojan and cometary nucleus, this would support Kuiper belt origin model.

An engineering mission IKAROS (Interplanetary Kite-craft Accelerated by Radiation Of the Sun) was launched in 2010 together with Venus Climate Orbiter PLANET-C. IKAROS was operated successfully and utilized the solar radiation pressure for the navigation. A mission with a large (100m-scale) solar power sail can transfer large payload mass to Jovian system. Currently we are studying a mission to Jupiter and one (or two) of Trojan asteroids, which are primitive bodies with information of the early solar system as well as raw solid materials of Jovian system. JMO will be released and inserted to the orbit around Jupiter using a chemical thruster, before the main spacecraft flies by Jupiter to direct Trojan asteroid using gravity assist. Apoapsis of JMO around Jupiter will be decreased by a chemical thruster and gravity assists by satellites. The main spacecraft will cruise for about 5 years to one of Trojan asteroids.

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