Jupiter System Observatory at Sun-Jupiter Lagrangian Point One

Contact: Hsiang-Wen Hsu, LASP, University of Colorado Boulder (sean.hsu@lasp.colorado.edu)

The Jupiter L1 Observatory is a Discovery class mission concept - an observatory located at the Sun-Jupiter Lagrangian point L1 (~0.35 au from Jupiter) focusing on time-domain sciences of the Jupiter system [1]. The science scope includes the weather system monitoring and the interior structure of Jupiter, activities of Galilean moons, ionosphere-magnetosphere-solar wind coupling, and impact flashes on Jupiter. This conceptual observatory also allows unique advantages to study jovian irregular satellites, upstream solar wind, interplanetary/interstellar dust populations, and other minor bodies that are critical to understand the current and past interactions between the jovian system and the solar system. Considered instruments include telescopes covering wavelength range from Ultraviolet to Near-Infrared with spectral information, a Doppler Spectro-Imager [2], as well as field-and-particle instruments. Developments of autonomous on-board processing data pipelines and flexible observation planning scheme are also essential. The proposed interplanetary observatory focusing on time-domain sciences will provide strategic values to future missions to Jupiter with scientific synergies connecting solar system research, exoplanets, and astrophysics studies.

1. Science Theme

Emphasizing observation **continuity, longevity, and simultaneity**, the proposed observatory will focus on observing objects within or interacting with the jovian system presented by the following three science themes.

1.1 Jupiter – The Exoplanet at Our Front Door

Jupiter's weather layer is a manifestation of its internal energy through chemical and physical processes in the top fluid envelope, which provides the ground truth for investigation of distant exoplanets and brown dwarfs. Continuous and high-cadence monitoring of the weather system and ionospheric / magnetospheric activities from visible light to radio emission is the key to address the dynamic nature of a gas giant planet and the hierarchy of processes involved. The stable observation geometry provided by the Jupiter L1 Observatory will also serve as an ideal platform for a Doppler Spectro-Imager to characterize Jupiter's interior structure at depth beyond current measurements and help addressing the formation process of Jupiter.

1.2 A Song of Ice and Fire – Geological Activities of Io and Europa

Monitoring the surface changes and atmospheric and auroral activities of Galilean moons at multiple wavelengths is another major science objective. The L1 libration orbit provides observation opportunities at various phases, including in eclipse, which is useful to address the interactions between the surface deposits, volcanic plumes, and the global atmosphere of Io. The L1 observatory can also serve as the ultimate "Europa plume hunter" with unmatchable temporal coverage at various wavelengths. The continuous "bird-eye" view on the Galilean moons will provide synergistic information enhancing the science return of future missions, such as the Europa Clipper and JUICE.

1.3 Time Capsules of the Solar System – Irregular Satellites and Minor Bodies

Irregular satellites are objects in eccentric orbits within 0.5 Hill radius of the host planet. Their capture is believed to occur during the early stage of the solar system. These objects therefore offer a unique window to examine the conditions in the early solar system along the path of Jupiter's migration. The L1 Observatory has significant advantages over Earth-based observations of irregular satellites considering their small sizes (<100km, mostly a few km) and proximity to the bright Jupiter. Light curves, color and spectral information, and ephemeris derived from the L1 Observatory will provide critical information to investigate the compositional and physical properties as well as the evolution history of Jupiter's irregular satellites. Monitoring impact flash on Jupiter and Galilean moons will provide critical constraints about the current distribution of meteoroid populations around Jupiter.

2. Mission Platform and Architecture

A viable transfer option to send a spacecraft to orbit about the Sun-Jupiter L1 point with reasonably low C3 has been identified and discussed in the white paper [1]. Except during the Jupiter Orbit Insertion phase, the envisioned observatory will remain in the solar wind upstream from Jupiter. Once in orbit about L1, the mission will conduct small stationkeeping maneuvers every 1-2 years, which should require very little fuel. The spacecraft distance to Jupiter oscillates about 54 million kilometers (~755 Jupiter radii) and each revolution about the L1 takes approximately six years. The baseline mission duration is two revolutions to cover an entire Jovian year.

Remote sensing observations can be carried out by a main telescope with additional small telescope(s) for specific needs. A derivative of the HiRISE telescope imager [3] on the Mars Reconnaissance Orbiter (MRO) mission is a feasible option for the main telescope, providing a spatial resolution of ~100 km for jovian system bodies, corresponding to an 8-meter telescope on Earth. Imaging sensors with color information and focal plane sharing options for multiple small back-end instruments can be adapted to accommodate observation needs, such as a Spectro-Doppler Imager and an UV-NIR spectrometer. Alternatively, a wide-field design (e.g., the one for the Kepler mission) or the Multiple Instrument Distributed Aperture Sensor (MIDAS) design [4] may also be suitable. Additional gimbaled small telescopes may be considered for specific observation requirements, e.g., an EUV instrument for Io Plasma Torus monitoring.

Four field-and-particle instruments were considered: (a) upstream Solar Wind Ion and Magnetic Field Monitor; (b) Dust Analyzer capable of mass spectrometry to monitor Iogenic nanodust, interplanetary, and interstellar dust populations; (c) Energetic Neutral Atom instrument to monitor the Io Plasma Torus; (d) Radio Wave Instrument to study jovian auroral and magnetospheric radio emission and plasma waves in the solar wind.

3. Technology Challenges

Considering the time-domain sciences as the essence of the proposed mission concept, the most challenging tasks to overcome are:

(1) to develop a balanced telescope option to provide competitive data products sufficient to address science requirements: the spatial resolution of the selected telescope in the desired wavelength range should be comparable or better than the best existing ground-based telescopes.

(2) to design a practical yet flexible observation planning scheme to reduce operation cost: the planning scheme should be simple yet allow Target-of-Opportunity Observation implementation.

(3) to establish a data processing pipeline to generate higher-order data sets in a timely fashion and reduce data volume: the data processing pipeline should minimize the need of human operation and reduce data volume to enable a long-term monitoring mission.

4. Reference

[1] Hsu et al., Bulletin of AAS, 53, 4, e-id. 358, 2021. [2] Soulat et al., 2011, doi: 10.1117/12.896710.
[3] McEwen et al., JGR, 112, E05S02, 2007, doi: doi:10.1029/2005JE002605.
[4] Pitman et al., 2004, doi: 10.1117/12.565710.