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Neptune Orbital Survey and TRiton Orbiter MissiOn (NOSTROMO): A Mission Concept to Explore the Neptune-Triton System.

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Introduction

The Neptune Orbital Survey and TRiton Orbiter MissiOn (NOSTROMO) is a mission concept aimed to explore the ice giant Neptune and its icy moon Triton, with the goal to advance our understanding of ice giant systems and their role in planetary formation both within and beyond our Solar System. Aligned with ESA's Voyage 2050 plan, NOSTROMO aims to reveal the processes that formed the outer Solar System, provide insights for interpreting the mini-Neptunes exoplanets and enhance our understanding on potential habitable zones beyond Earth.

Science Objectives

The main goal of the NOSTROMO mission is to conduct an exploration of Neptune and its moon Triton, aimed to enhance our understanding on the planetary system formation and evolution of ice giants and their moons. This is done by studying Neptune's atmospheric dynamics, magnetic field, and interior structure, as well as Triton's surface composition, interior dynamics and possibility of possessing a subsurface ocean. NOSTROMO plans to also investigate the moon's potential for habitability. In general, the mission aims to enhance our understanding of the outer Solar System and provide insights into interpreting mini-Neptune-like exoplanets.

The three primary scientific questions that NOSTROMO will address are the following:

SQ-1: *How did Neptune and other ice giants form and evolve, and what can they reveal about planetary system formation, including exoplanets?*

SQ-2: *What is Triton's origin and geological evolution, and how does it inform us about captured*

KBOs and early Solar System history?

SQ-3: *Could Triton support habitability, and what do its plumes and subsurface features suggest about habitable zones beyond Earth?*

Payload

The NOSTROMO spacecraft (*Fig.1*) is equipped with a suite of seven scientific instruments to explore Neptune and its icy moon Triton. Each instrument has been carefully selected and adapted from proven heritage systems to operate in the extreme environments of the outer Solar System, addressing key scientific questions about planetary formation, atmospheric dynamics, magnetospheric interactions, composition, and potential habitability.

The payload includes a Magnetometer in a dual fluxgate and scalar sensor configuration, derived from JUICE J-MAG, to investigate Neptune's unique magnetic field and probe Triton's internal conductivity for signs of subsurface oceans. A Particle Suite, adapted partially from JUICE PEP, features a mass spectrometer, ion and electron detectors, and an Energetic Neutral Atom (ENA) camera to study plasma environments and particle composition around Neptune and Triton in high resolution.

For visual observations, a set of Optical Cameras; a Narrow Angle Camera (NAC) and Wide-Angle Camera (WAC), based on Rosetta heritage, will image Triton's surface and Neptune's dynamic atmosphere. A Radio Science instrument will use Doppler tracking to map the gravity fields and internal structures of both bodies.

An UltraViolet imaging Spectrometer (UVS), with heritage from Europa Clipper and Cassini, will enable studies of aurorae, lightning, and plume activity, while also conducting stellar and solar occultations for atmospheric analysis. A VIS-NIR Spectrometer derived from OSIRIS-REx will perform chemical mapping of Neptune's atmosphere and Triton's surface and plume deposits, with different observation modes and high spectral resolution.

Finally, a Thermal Infrared Imaging Spectrometer, inspired by BepiColombo's MERTIS, will deliver global thermal and emissivity maps of Triton, enabling the identification of thermal anomalies, surface activity, composition and potential cryovolcanic features.

Mission and spacecraft overview

The interplanetary mission follows an EEJN (Earth-Earth-Jupiter-Neptune) transfer sequence, with the primary launch window targeted for March 2041 and a backup opportunity in April 2042. After launch, the spacecraft will perform a deep space maneuver, followed by an Earth swing-by in 2043 and a Jupiter gravity assist in 2045. Arrival at Neptune is scheduled for September 2061, following a 20.5 year journey.

Upon arrival, the spacecraft will enter a highly elliptical retrograde orbit around Neptune with an eccentricity of 0.98 and a periapsis of 1000 km above the 1 bar reference of Neptune's atmosphere. Subsequently, the apoapsis is lowered to achieve an eccentricity of 0.88 enabling global observations of Neptune's surface, atmosphere, and magnetic field close to periapsis. This science phase will image 20% of Neptune's surface, covering up to 20° of latitude north and south of the equator, and enhanced coverage in select areas.

Following the Neptune science phase, the spacecraft transfers into a Triton orbit using Tisserand leveraging maneuvers. The spacecraft will settle into a near-circular, 200 km altitude orbit with an 87° inclination. This configuration will allow a 3.16 year science campaign to achieve 90% surface coverage of Triton, including detailed observations of its smaller and possibly active surface features such as cryoplumes.

At the end of its operational life, the spacecraft will transfer to a 700 km graveyard orbit using an additional 120 m/s of Δv . Alternatively, a more stable Neptune-centered disposal orbit may be

considered, at the cost of 625 m/s of Δv . The total mission Δv budget is estimated at 3957 m/s.

Operating in the remote environment of Neptune imposes several constraints that drive the spacecraft design. These include significant travel time, extremely low solar irradiance, and limited communication capabilities. Most significantly, the low solar flux at the Neptune system makes using solar power impractical. Therefore, americium-241 radioisotope thermoelectric generators (RTGs) were selected as nuclear power sources. Due to the low development stage of these RTGs in particular, and the high cost of RTGs in general, mission cost reduction was another design driver. The significant travel distance necessitates a very large fuel load, resulting in a mass of 8.1 t when the spacecraft is fully fueled and a mass of 2.3 t without fuel. Given the long development timeline and the estimated mission cost, including risk margin, of 1.42 billion euros, this mission concept falls into the ESA Large-class. This further aligns with the ESA Voyage 2050 senior committee final recommendations, where a Large-class mission is recommended to address the "Moons of the Giant Planets" theme.

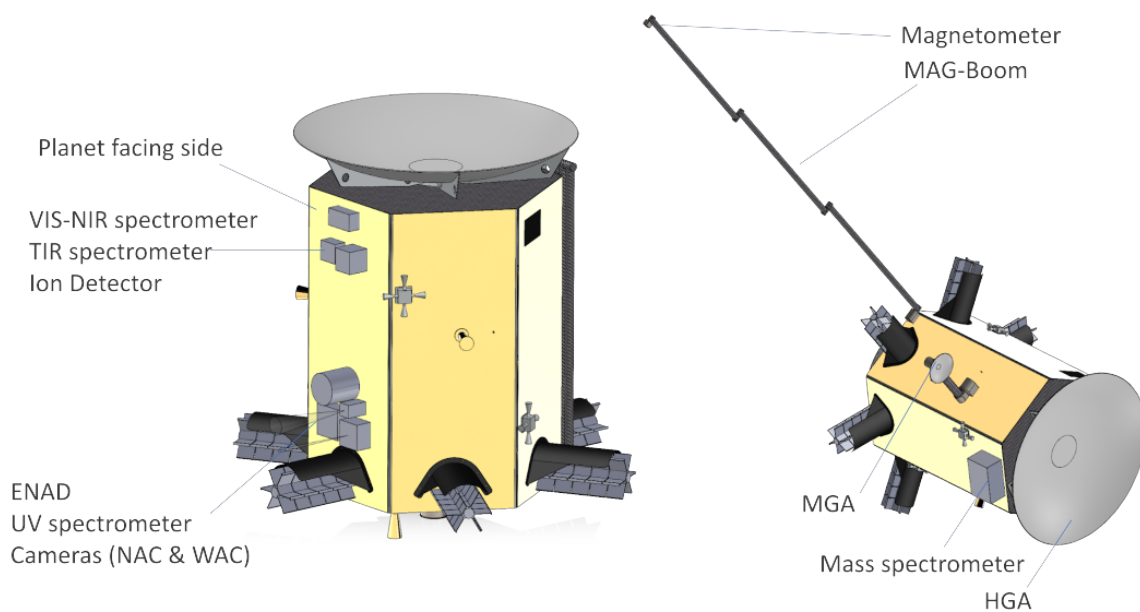


Figure 1: NOSTROMO spacecraft design with annotated instrumentation: NOSTROMO spacecraft upright (left) and as it would appear in orbit (right), with the planet-facing side directed downward and the MAG boom deployed. Height: 4.5 m, Diameter incl. RTGs: 2.9 m.