Exploring Neptune: Atmosphere, Magnetosphere and Topography L. A. Siegfried[1] and B. H. Foing[2],
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Introduction: Neptune is the eighth planet in our solar system and it has a radius of almost 25'000 km, which makes it a giant planet [1]. It's also the densest of the solar system's giants, additionally to being considered an ice giant. This is the case, as Neptune contains a large amount of ammonia, methane and water, which are referred to as "icy" [2]. Since it's the farthest known planet from the sun, our knowledge about Neptune is severely limited. Past observations of the planet reveal that, interestingly, parts of its atmosphere are at higher temperatures than expected from a planet 30 AU away from the sun. This is just one example of the many phenomena that shall be explored by a specialized science payload.

This report discusses a hypothetical science mission to Neptune using an L-class spacecraft, which carries at least eight science instruments. These instruments will conduct measurements on the planet's atmosphere, magnetosphere and topography using different technologies.

Based on heritage missions, a science payload is put together and the basic system for the spacecraft is creates, that will allow the payload to be carried to Neptune. This is done within the scope of the EPFL Space System Design Engineering course.

Mission Design: The mission is to explore Neptune with a variation of science instruments and to set a precedent for future long-term interplanetary missions. Collecting data on an ice giant such as Neptune will be an important step in understanding our solar system and the universe.

Every scientific institution shall have access to the collected data as the mission is executed in the name of peaceful, collaborative exploration. The science objectives will be detailed in a later paragraph.

The majority of the design choices and instruments will be based on heritage missions such as Cassini, Galileo, New Horizons and BepiColombo.

The complete mission is going to span over three decades. The spacecraft will be thoroughly tested. In order to reduce risk, many instruments will have a very high TRL.

The spacecraft will be launched into Earth escape orbit and then travel to Neptune, where its propulsion system will insert the spacecraft into its final science orbit, which will be circular and polar. This allows a maximum coverage of the planet's surface.

The spacecraft will spend ten years (with a possible extension of five years) observing the planet and relaying the data back to Earth for scientists to analyse. At EOL, the orbit will no longer be maintained to the spacecraft will eventually enter Neptune's atmosphere. If possible, the instruments will take some final measurements, though this would be a bonus, not an obligatory part of the mission.

Spacecraft: A concept has been developed for the subsystems of the spacecraft. However, this is not the focal point of this abstract, so they are only described very briefly and in relation to the payload.

Telecommunication Subsystem. Data is communicated via the DSN's 70 m parabolic antenna using X- and Ka-Band. The challenge will be to time the TM and TC exchange, as the travelling time of the signal is non-negligible. In fact, it takes the signal roughly four hours for one way. To make it as efficient as possible, the science data will only be downlinked after certain intervals, e.g. 16 orbits.

Electrical Power Subsystem. The power source will be made up of four GPHS-RTGs since it is practically infeasible to use solar power at 30 AUs from the Sun. This allows keeping the instruments on whenever their pointing requirements are met.

Command and Data Handling. Roughly 200 kbps of science data is generated (fig. 2) which needs to be handled additionally to the house-keeping data.

Thermal Subsystem. So far from the sun, it's very important to properly heat the system. The excess power of the EPS will be distributed in the form of heat to keep the other systems operational. Especially science instruments tend to be more vulnerable to temperature fluctuations and extremes.

Concepts for the Structure and Configuration, ADCS and Propulsion Subsystem are developed, but not detailed here.

Science Objectives: The science objectives are to take images of Neptune and its moons, mainly Triton, on the visible, IR and UV spectrum. Moreover, science instruments will analyse the composition of the atmosphere and measure the magnetic field.

One part is to observe the planet's atmosphere. As other giant planets, it has very strong winds and large circular patterns (such as the "Great Dark Spot"). Neptune has the highest ratio of emitted internal heat and absorbed sunlight. The goal is to confirm existing models and to learn how sunlight and internal heat affect atmospheric structures [3].

Another part is to study the strong tilt and offset of the magnetosphere with respect to its rotational axis and whether this is the result of its sideways rotation or due to the movements of fluids in the planet's interior.

Lastly, as Neptune has no solid surface, there is no "topography" as there is for rocky planets. However, since the pressure of the atmosphere increases towards the planet's core, a "surface" can still be analysed.

Science Payload: The science objectives are to be fulfilled by eight main science instruments (fig. 1), which are all based on heritage instruments.

Instrument	Heritage Instrument	Heritage Mission
Magnetometer	MESSENGER MAG	MESSENEGR
Imaging Science Subsystem	ISS	Cassini
Visible-Near Infrared Imaging Spectrometer	Ralph	New Horizons
Ion and Neutral Mass Spectrometer	INMS	Cassini
Laser Altimeter	Mercury Laser Altimeter	MESSENGER
Radio and Plasma Wave Science	RPWS	Cassini
UV Imaging Spectrometer	Alice	Rosetta
Ice Penetrating Radar	MARSIS	Mars Express

Figure 1: Science Instruments

Magnetometer. A magnetometer is used to measure Neptune's magnetic field with the goal of mapping its unusual magnetosphere in three dimensions [4].

Imaging Science Subsystem. Map the surface and the atmosphere movements (i.e. storms, aurorae) of the planet by repeatedly taking images of the planet [5].

IR Imaging Spectrometer. Map the planet surface geology and temperature, and the thermal patterns of the atmosphere [6].

Mass Spectrometer. Measure composition (mass of ions) of Neptune's atmosphere and magnetosphere [7].

Laser Altimeter. Map Neptune's surface topography and morphology by continuously sending light pulses at 10-30 Hz [8].

Radio and Plasma Wave Science. The PRWS instrument is used to detect radio and plasma waves in Neptune's magnetosphere [9].

UV Imaging Spectrometer. Analyse the composition of Neptune's surface and its atmosphere [10].

RADAR. Map Neptune's surface topography by continuously sending RF pulses [11].

Instrument	Mass $[kg]$	Power $[W]$	Bit rate $[kbps]$
Magnetometer	4.4	2	0.014
ISS	57.83	30	115.2
IR Imaging Spectrometer	10.5	7.1	0.200 (TBD)
INM Spectrometer	6	15	1
Laser Altimeter	7.4	20	0.046
RPWS	6.8	7	0.9
UV Imaging Spectrometer	3.1	2.9	0.142 (TBC)
Radar	12 (TBC)	5 (TBC)	18-75
Total	**108.03**	**89**	**192.502**

Figure 2: Science Instruments Properties

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References:

[1] Dr. D. R. Williams, NASA. *Neptune Fact Sheet* (https://nssdc.gsfc.nasa.gov/planetary/factsheet/neptunefact.html)

[2] Mark Marley, The Planetary Society (2019), *Not a Heart of Ice* (https://www.planetary.org/articles/not-a-heart-of-ice)

[3] Mark Hofstadter (2011), *The Atmospheres of the Ice Giants, Uranus and Neptune*, I. Overview, p.1.

[4] NASA. *MESSENGER: Magnetometer (MAG)* (https://nssdc.gsfc.nasa.gov/nmc/experiment/display.action?id=1997-061A-07).

[5] NASA. *Cassini: Imaging Science Subsystem* (https://nssdc.gsfc.nasa.gov/nmc/experiment/display.action?id=1997-061A-02).

[6] Dennis C. Reuter et al. (2008) *Ralph: A Visible/Infrared Imager for the New Horizons Pluto/Kuiper Belt Mission*.

[7] NASA. *Cassini: Ion and Neutral Mass Spectrometer (INMS)* (https://nssdc.gsfc.nasa.gov/nmc/experiment/display.action?id=1997-061A-12).

[8] NASA. *MESSENGER: Mercury Laser Altimeter (MLA)* (https://nssdc.gsfc.nasa.gov/nmc/experiment/display.action?id=2004-030A-05).

[9] NASA. *Cassini: Radio and Plasma Wave Science (RPWS)* (https://nssdc.gsfc.nasa.gov/nmc/experiment/display.action?id=1997-061A-07).

[10] S. A. Stern et al. (1998) *Alice—An ultraviolet imaging spectrometer for the Rosetta Orbiter*, Advances in Space Research 21.11, pp. 1517–1525.

[11] ESA. *MARSIS: Mars Advanced Radar For Subsurface And Ionosphere Sounding* (https://sci.esa.int/web/mars-express/-/34826-design?section=marsis-mars-advanced-radar-for-subsurface-and-ionosphere-sounding).

Abbreviations:

- TRL: Technology Readiness Level
- TM: Telemetry
- TC: Telecommand
- DSN: Deep Space Network
- EOL: End Of Life
- IR: Infrared
- UV: Ultraviolet
- EPS: Electrical Power System
- GPHS: General-Purpose Heat Source
- RTG: Radioisotope Thermoelectric Generator
- ADCS: Attitude Determination and Control System
- IRIS: IR Imaging Spectrometer
- RPWS: Radio and Plasma Wave Science
- UVIS: UV Imaging Spectrometer