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EXODUS: A mission to explore exoplanet evolution through understanding atmospheric escape

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EXODUS is a proposed mission to study the largely unexplored range of sub-Neptune to Jupiter-sized exoplanets with orbital periods longer than 100 days. The focus of the mission lies in the detection of these planets and characterisation of atmospheric escape to constrain their evolutionary pathways. Further, the activity of the host star is monitored in the ultra-violet (UV) wavelengths to distinguish between two mechanisms of atmospheric escape: UV-driven mass loss and core-powered mass loss. The proposed mission design consists of a space telescope which requires a Lissajous orbit around L2. The primary instrument consists of an Integral Field Unit (IFU) optimised for direct imaging of exoplanetary systems in the near-infrared (NIR) domain. Simultaneous monitoring of the parent star is conducted via photometric observations of the H_alpha emission. The correlation between atmospheric escape and stellar activity is studied to determine the responsible mechanism.

Science objectives

Understanding the variety of system architectures and formation histories of planetary systems remains a major challenge. Current detection methods are strongly biased towards short-period bodies, leaving a gap in the exoplanet population demographics. A mission capable of detecting and characterising exoplanets with orbital periods longer than 100 days would address these biases and add to the population demographic. Measurements of exoplanet properties have established the existence of a bimodal distribution of planetary radii, creating the so-called radius valley. This radius valley is thought to stem from planetary size evolution produced by atmospheric escape, a mass-loss phenomenon that can be core-driven or UV-driven. This process can be detected via observations of the He triplet at 1083 nm in reflected light. The EXODUS mission aims to answer the following science questions:

- How does atmospheric escape shape the evolution of long orbital period exoplanets?
- What proportion of the exoplanet population do exoplanets with long orbital periods represent?
- How does the Solar System architecture compare to that of exoplanetary systems?

Payload

To answer these questions, EXODUS aims at observing a core sample of 2000 exoplanets. The payload includes two telescopes, one for NIR observations of the planet and the other for UV monitoring of stellar activity. The NIR observations are conducted with a 2.4 m diameter telescope in a Cassegrain configuration. The main target observations are performed with the MARY instrument, consisting of a high contrast coronograph and an integral field unit (IFU) equipped with a NIR detector. The configuration allows to obtain a contrast of 1E-9. The IFU is used to obtain spatially resolved full-frame spectra of the exoplanets in the 1000-2000 nm range with a 1nm spectral resolution. A secondary instrument (VISVIS) composed of three detectors is used for the fine guidance system and for monitoring of the host star with an H_alpha filter. The UV monitoring of the star is performed with a smaller secondary Cassegrain telescope, featuring a 9.3 cm primary mirror. A UV photometer measures the flux of the parent star to correlate stellar activity with atmospheric escape.

Spacecraft design

The spacecraft design is driven by the strict thermal requirement imposed by the instrument temperature constraints and the pointing requirements to achieve the desired observation contrast. The spacecraft design assesses these requirements.

To fulfill the thermal requirements, a segmented design with hot and cold sections is chosen. The spacecraft comprises four main modules: (1) the payload module with the primary mirror on top, separated by a thermally isolating structure from (2) the service module, (3) the secondary mirror's support fixed to the payload module, and (4) the sunshield support, which protects the instruments from solar radiation.

The communication subsystem consists of a combination of a High Gain antenna system devised for science downlink and a Low Gain antenna system for telemetry and telecommand, though both are available for either operation in case of emergency, at the expense of a longer downlink time for the Low Gain system. The power subsystem design is based on three main components: solar panels for power generation, batteries for power storage, and a Power Control and Distribution Unit (PCDU) for power management throughout the spacecraft. The propulsion subsystem consists of bipropellant thrusters which use the same fuel as the Attitude Determination and Control System (ADCS). A design for the tank and fluid supply system is proposed such that either hydrazine or LMP, a green propellant that is currently being researched, can be used.

The ADCS subsystem design is driven by the required pointing accuracy of the coronagraph and the reaction wheel desaturation needed in between science measurements. For the fine pointing of the instrument, a system consisting of a Fine Steering Mirror, a Fine Guidance Sensor (FGS), which is the VISVIS instrument, and a FGS Control Unit is used. For the rough pointing and stabilisation of the spacecraft, eight mono-propellant thrusters and four reaction wheels are connected via a control unit to a system with six sun sensors, a gyroscope and two star-trackers.

The thermal control subsystem design is driven by the required temperature of the payload to avoid thermal noise in the detector. The primary objective of the sunshield is to maintain the payload operating environment at the required temperature, while avoiding an active cooling system for the payload. This reduces the complexity and enhances the reliability of the thermal system. To this end, a seven-layered sunshield was designed to reduce the temperature to the level required by the instrument at the innermost layer. To manage overall heat rejection on the spacecraft, surface coatings such as black paint and aluminized kapton are applied. Meanwhile, targeted heating and dissipation is provided with heaters, radiators, insulators and thermal couplings throughout the spacecraft.