SAMPLE RETURN FROM A RELIC OCEAN WORLD: THE *CALATHUS* MISSION TO OCCATOR CRATER, CERES.

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Introduction: The *Cosmic Vision* programme for 2015–2025 is the current cycle of the European Space Agency's long-term plan for space science missions [1]. One of the programme's main objectives concerns the search for habitability and life within the Solar System, as well as the formation and composition of small bodies. Here we present *Calathus*, a mission concept that seeks to return a sample of Ceres' Occator Crater to Earth in pursuit of these aims.

Occator Crater, as revealed by NASA's *Dawn* orbiter, is 92 km in diameter and contains two distinct bright regions – called *faculae* – composed of salt-rich carbonates believed to be the solid residue of brines erupted from a cryo-magmatic chamber [2]. These carbonates are likely younger than 2 Myr in age, and smaller, darker faculae across Ceres may be older remnants of deposits formed similarly [3].

Planetary evolution models [3] suggest the source of these deposits could be a localised brine reservoir below Occator [4], the remnant of a once possibly planet-wide ocean. To understand the composition and evolution of Occator's faculae, accordingly, is to understand the inner workings of a relic and potentially extant ocean world [5]. In-depth analysis of Occator could be a window inside not only Ceres but a wider class of ice-rich, small bodies including Europa, Ganymede, and perhaps Kuiper Belt Objects such as Pluto.

Sample return: *Dawn*'s discovery of Occator created as many questions as it answered:

1) Astrobiology: Ceres appears to contain the three vital prerequisites for life: sources of water, carbon, and energy. Do ice-rich bodies like Ceres represent a widespread, astrobiologically-favourable niche?

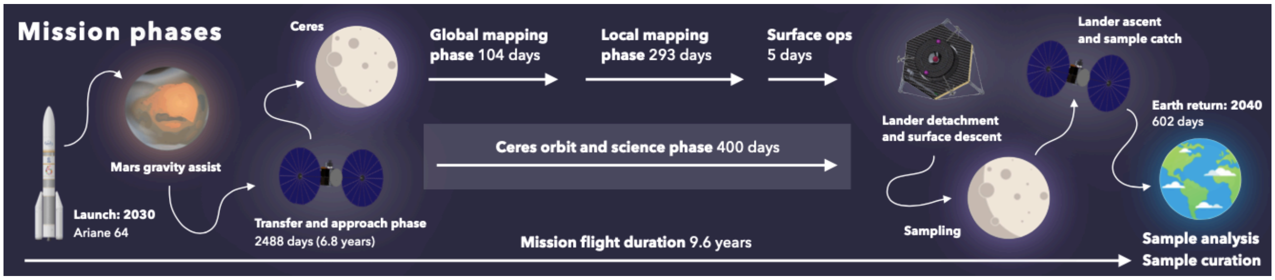
2) Origins: Ceres' spectral features do not match any known meteorite group [6], nor can the location of its formation be pinpointed to a specific region. Where and how did Ceres form, and did asteroids of similar composition play any role in the delivery of water/organics to the proto-Earth?

The chemical composition of Occator's bright material is a complex mix of carbonates and other salts, with possible evidence for organics [7]. A thorough chemical analysis can only be achieved by employing high-precision techniques on Earth, whose instruments are too large to be accommodated by spacecraft unless a compromise in resolution is accepted. Meticulous sample analysis is necessary to unravel the exact composition of the crater, its faculae, and its subsurface; to evaluate the role of possible aqueous and thermal processes; and to better understand the evolutionary history of Ceres itself and its relation to the wider Solar System.

A return mission to Ceres to sample material from Occator Crater would provide invaluable insight into these questions, as well as further the study of a world fascinating in its own right.

Science objectives: The *Calathus* mission will return a mass of 4 cm^3 of the Occator Crater faculae to Earth. In addition, the surface of Ceres will be globally mapped, with higher resolution mapping focused on Occator and the landing site. This will be achieved

Figure 1: *The Calathus mission timeline from launch in 2030 to re-entry in 2040. The orbiter and lander schematics, including their full instrument suites, are explored in greater detail in the poster.*



with both an optical camera and an IR to UV mapper to build context for the returned samples and provide compositional information. *Calathus* will also probe the Cerean near-subsurface to a depth of 100 m using radar, to elucidate whether particular geological structures or reservoirs may have enabled these exceptional faculae. For sampling, a lander module will descend to the surface equipped with cameras to select the safest and most scientifically advantageous sites. Finally, the *Calathus* lander is also equipped with a gas chromatography mass spectrometer (GCMS) to perform preliminary compositional analysis whilst upon the surface.

Mission payload: The spacecraft is composed of three main constituents: the orbiter, lander, and ascending module. To address the complexity of a sample return mission, we have conducted a system engineering run-through via the concurrent design software OCDT at ESA's ESEC-Galaxia base in Belgium [8]. The duration of the mission is 9.6 years from a launch date in 2030, returning in 2040.

The orbiter: The main driver of the orbiter design is the use of low thrust ion engines, whose employment is state-of-the-art for interplanetary missions to small bodies [9, 10, 11]. This drive limits the propellant mass and avoids multiple flybys, but requires substantial solar panels to provide power. All engineering subsystems have been developed considering the technology readiness level to obtain a feasible and competitive design.

The lander: The lander is used to fulfil the sample collection goal of *Calathus*. This will be released from the orbiter at a low altitude, as with the *Rosetta-Philae* and *Hayabusa2* missions, and will reduce its velocity using hydrazine thrusters. Once upon the surface, a ground-in-the-loop process will select the most gainful sampling sites, and the lander will then perform the sampling and sample storing. The sampling subsystem is composed of a manipulator arm with cameras, a grinding device to minimise hydrazine contamination, and a hammering drill with five sample holding bits. In the nominal scenario, four samples will be collected for return while one will be analysed within the onboard GCMS.

The ascent module: Subsequently, samples will be sent to orbit via the ascending module, as in plans for the Mars Sample Return Mission [12] or in the current Airbus DS lunar sample return mission design [13]. The on-orbit catching subsystem aims at relative navigation between the spacecrafts. At large range, optical navigation and three-way radar ranging will be used to perform cooperative localisation between the orbiter and the ascending module. At close range, the canister will be released and non-cooperative catching will be performed using laser ranging, visual navigation and beacon-radar data. As with the *Hayabusa2* artificial marker [14], the canister will be covered with LEDs and mirrors to increase visual and laser navigation, respectively.

Return to Earth: Ceres is a Class V restricted body, necessitating the strict enforcement of forward and backward protective measures. The spacecraft will be thoroughly sterilised prior to launch, and approval will be given from a planetary protection officer for launch from Earth, from Ceres, and the re-entry to Earth. Any returning hardware must also be contained or sterilised for re-entry.

Conclusions: Given the high priority of exploring as-yet technologically unreachable worlds such as Europa for their astrobiological interest, and given complimentary missions such as NASA's *OSIRIS-REx* and JAXA's *Hayabusa2* to similarly C-type bodies, a return mission to Ceres would provide insight into both these categories of interest.

As the class of extinct and extant ocean-bearing worlds across the Solar System grows, this in-depth study of one such body could reveal a previously unconsidered niche of habitability, one that extends not only around our star but potentially others. Closer to home, Ceres also provides a study of our own origins as beings of water and complex organic matter, both delivered to Earth by non-terrestrial bodies including worlds like Ceres.

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