Low-Cost Mission Opportunities Using Re-Purposed Artemis European Service Modules. C. A. Raymond(1) L. Fesq(1), J. E. C. Scully(1), J. T. Keane(1), D. Bearden(1), S. Ulamec (2), J-B. Vincent(2), C. J. Renggli(3), N. Krupp(3), T. Kleine(3), M. Winter(4), K. Wünnemann(5), W. F. Bottke(6), P. K. Byrne(7), (1 Jet Propulsion Laboratory/California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109, carol.a.raymond@jpl.nasa.gov; (2)DLR, Linder Höhe, 51147 Köln, Germany; (3)Max Planck Institute for Solar System Research, Justus-von-Liebig-Weg 3, 37077 Göttingen, Germany; (4)Airbus Defence and Space GmbH, Airbus-Allee 1, D–28199 Bremen, Germany; (5)Museum für Naturkunde, Leibniz-Institut für Evolutions und Biodiversitätsforschung, Invalidenstraße 43, 10115 Berlin, Germany; (6)Southwest Research Institute, 1301 Walnut St., Boulder, CO 80302; (7)Washington University in St. Louis, 1 Brookings Drive, St. Louis, Mo 63130.

Introduction: The European Service Module (ESM) is the element of NASA's Artemis Program that returns the Orion Crew Module to Earth (Fig. 1). After separation of the Crew Module, the current plan is to destroy the ESMs by burning them up in Earth's atmosphere. However, the ESM is a capable spacecraft, complete with propulsion, power generation, conditioning and distribution, attitude control, thermal control, and payload support. By leveraging the propulsive capabilities that remain following Crew Module separation, the ESMs have the potential to provide near-term, low-cost opportunities on a notionally yearly cadence to achieve valuable science across an array of extended mission types [1].

JPL hosted a scientific workshop in summer 2024, with US and European participants, to discuss potential ESM extended mission targets and types. During the workshop, the participants jointly assessed the benefits that could be derived from repurposing the ESM for scientific use after it completes its primary mission. The concepts considered were divided into categories requiring: 1) no augmentation of the ESM; 2) minimal augmentation; and 3) low-to-moderate augmentation. Target accessibility was determined by realistic trajectory analyses. The participants generated over thirty concepts that offered significant value in planetary science, planetary defense, and cosmology. The mission types are illustrated in Figure 2.

The ESM currently relies on the Crew Module for several functions including communications, computing, and attitude control sensors; thus, several spacecraft functions would need to be added for the minimum capability needed in an extended mission. The current ESM design does not include scientific instruments, but the mass margins allow accommodation of a scientific payload, opening the possibility to expand the prime mission for additional science objectives.

The minimally augmented case favors missions where the ESM impacts a target and is observed by ground or space-based observing systems. Targets of interest include asteroids, the Moon, Phobos and Deimos.

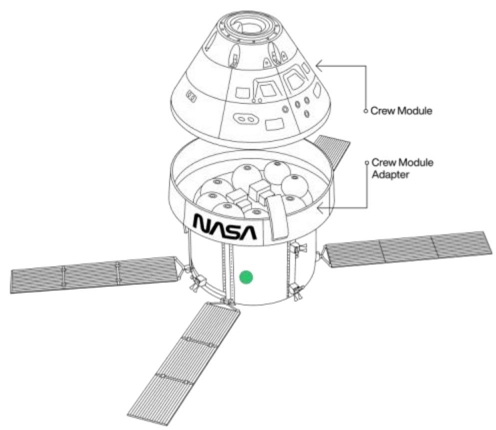

Figure 1. The ESM (labelled with green dot) will have propulsive capabilities post Orion Command Module separation that offer near-term, low-cost opportunities to achieve high value science goals across an array of mission types.

Augmented mission concepts that would carry up to 300 kg of additional payload include impactor missions with instrumented observer spacecraft, single or multiple asteroid flybys, asteroid landers, and Near-Earth asteroid rendezvous. The exploration of Near-Earth Objects (NEOs) figured prominently as there are many diverse, unexplored classes of near-Earth and main belt asteroids that could be reached with the ESM after its primary mission. Some of these bodies are associated with water (e.g., 24 Themis), others with metals (e.g., 216 Kleopatra), and others may present impact hazards in the future. The ESM, in principle, could tour several diverse asteroids, rapidly accelerating our understanding of these worlds. Another concept highlighted the capability to use the ESM as a large kinetic impactor, sending it to impact a suitable NEO. ESM has a dry mass seven times larger than the spacecraft used on the successful DART mission.

An exciting possibility is to send ESM back to the Moon for a targeted impact into a Permanently

Shadowed Region to excavate subsurface material, potentially including H_2O. ESM has twice the mass of LCROSS. The plume from the impact could be observed from Earth or from other spacecraft, and the creation of a fresh impact crater in the Artemis exploration zone could provide an exciting target for subsequent crewed exploration.

The delta-V available for an ESM extended mission may even allow it to reach Mercury or the Jupiter system with minimal additional payload. This capability raises the possibility of flybys to observe craters that were created by the disposal of the BepiColombo and MESSENGER spacecraft at Mercury and the Juice and Europa Clipper spacecraft at Ganymede. Doing so would provide observations of the fresh material exposed by the cratering process as well as mapping of the crater morphology and ejecta distribution for an impact of known impactor mass and kinetic energy. Another option would be to send two ESM spacecraft to these targets, using one to observe the crater made by the impact of its companion into the target.

In the recently published VEXAG Venus Exploration Strategy [2], a long-term communications asset in Venus orbit was identified as a high-priority need to replicate the success of the Mars Relay Network. Interestingly, an ESM equipped with a software radio such as the Electra package and placed into a high-altitude orbit at Venus would be a powerfully enabling infrastructure for future in situ aerial- and surface-based missions to the second planet.

Of course, the highest priority for each ESM mission is to accomplish the primary mission objectives within the Artemis program. Although the ESM has the potential to deliver additional scientific value well beyond its current scope, the scientific value added will have to be weighed against programmatic considerations and carefully analyzed within the ESM's programmatic framework and its stakeholders. Acknowledging this, we invite the community to explore the possibilities to achieve tantalizing, opportunistic science at a lower cost than a comparative stand-alone mission.

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References: [1] Freeman, A. et al. (2024) *Acta Astronautica*, *224*, 122-126. [2] VEXAG Venus Exploration Strategy (2024) arxiv.org/pdf/2412.06830.

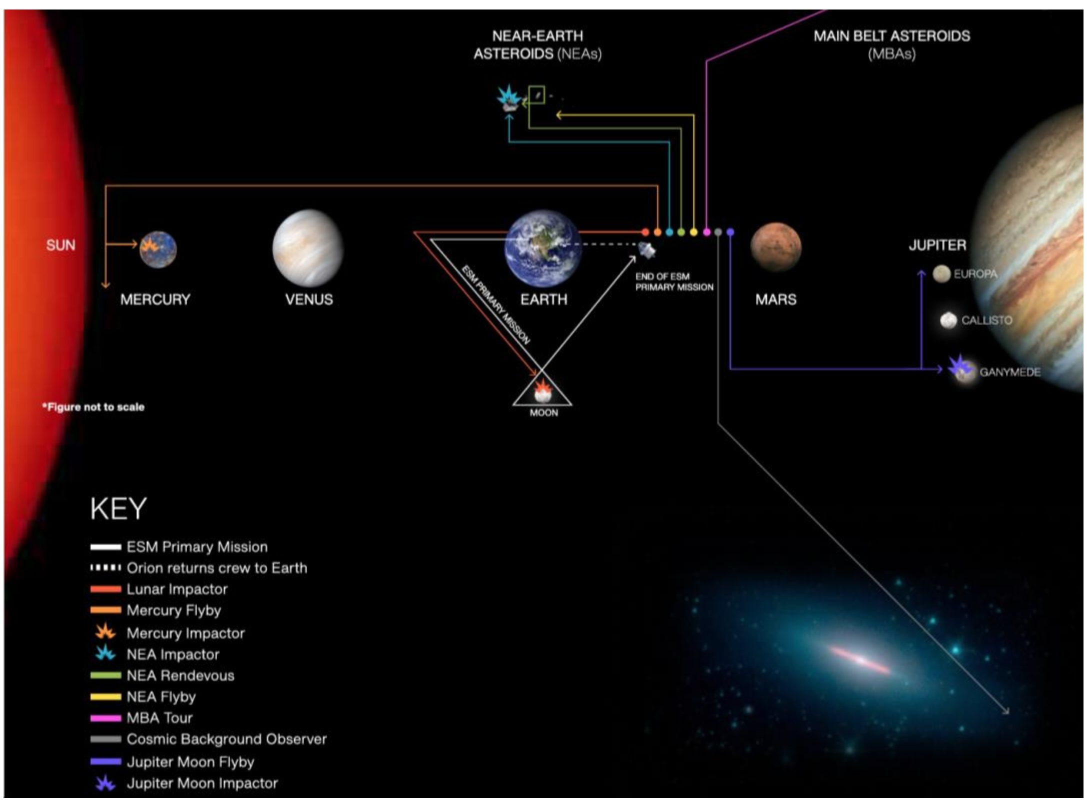

Figure 2. A summary of the range of mission types that were evaluated as candidates for ESM extended missions.