A Mercury Lander Mission Concept Study.

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Introduction: As an end-member of terrestrial planet formation, Mercury holds unique clues about the original distribution of elements in the earliest stages of solar system development and how planets and exoplanets form and evolve in close proximity to their host stars. This Mercury Lander mission concept enables in situ surface measurements that address several fundamental science questions raised by MESSENGER's pioneering exploration of Mercury. Such measurements are needed to understand Mercury's unique mineralogy and geochemistry; to characterize the proportionally massive core's structure; to measure the planet's active and ancient magnetic fields at the surface; to investigate the processes that alter the surface and produce the exosphere; and to provide ground truth for current and future remote datasets.

A study [1] was completed as a part of NASA's Planetary Mission Concept Studies program to evaluate the feasibility of accomplishing transformative science through a New-Frontiers-class, landed mission to Mercury in the next decade. The resulting mission concept [1,2] achieves one full Mercury year (~88 Earth days) of surface operations with an ambitious, high-heritage, landed science payload (Figure 1).

Science Goals: Four overarching and fundamental science goals were identified to guide this Mercury Lander mission concept study:

- Goal 1: Investigate the highly chemically reduced, unexpectedly volatile-rich mineralogy and chemistry of Mercury's surface, to understand the earliest evolution of this end-member of rocky planet formation;
- Goal 2: Investigate Mercury's interior structure and magnetic field, to unravel the planet's differentiation and evolutionary history and to understand the magnetic field at the surface;
- Goal 3: Investigate the active processes that produce Mercury's exosphere and alter its regolith, to understand planetary processes on rocky airless bodies, including the Moon;
- Goal 4: Characterize the landing site, to understand the processes that have shaped its evolution, to place in situ measurements in context, and to enable ground truth for global interpretations of Mercury.

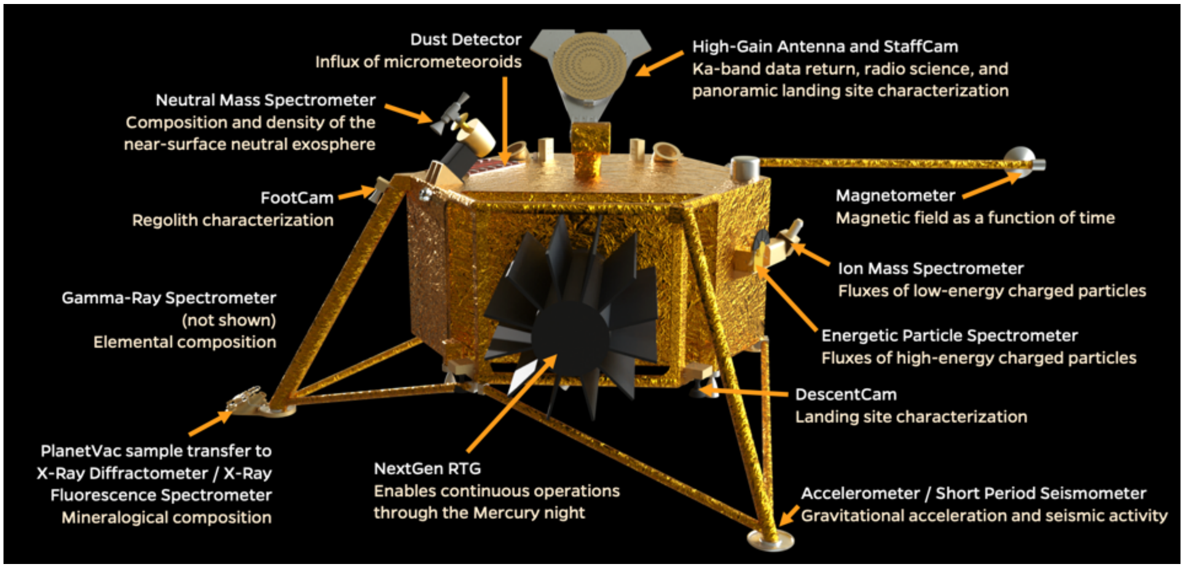

Figure 1. The Mercury Lander spacecraft concept in its landed configuration. The placement of the 11-instrument payload, radioisotope thermoelectric generator (RTG), and high-gain antenna (HGA) are shown. Figure from [2].

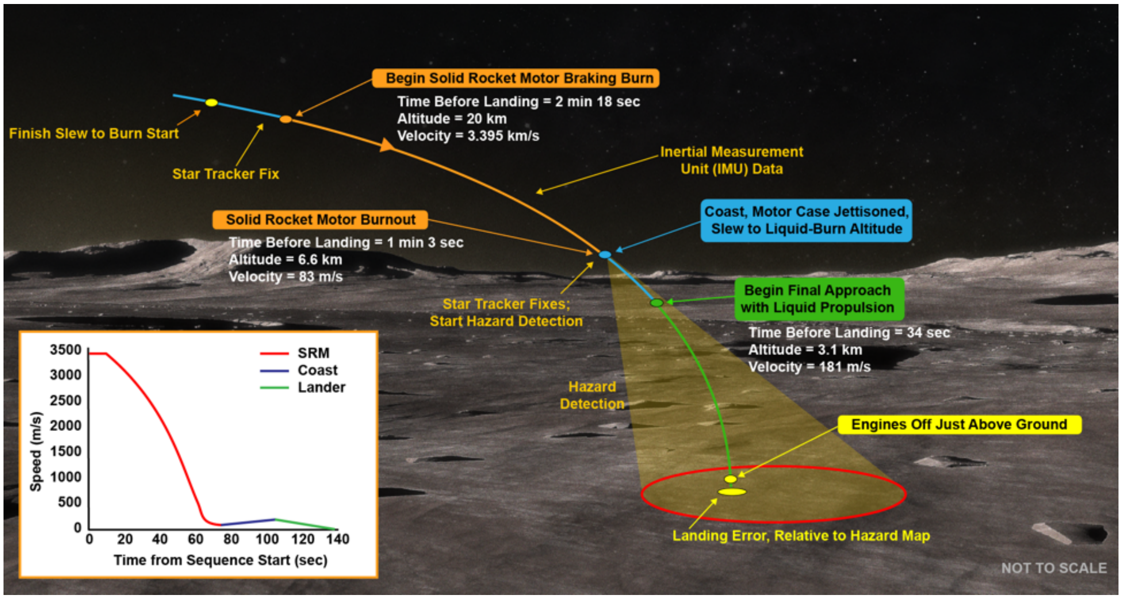

Figure 2. The descent and landing sequence. The sequence begins with a 75-s braking burn executed by the SRM, which reduces most of the orbital energy, decelerating the lander from a high incoming horizontal speed to a nearly vertical speed at the end of the burn. Landing uses continuous LIDAR operations post-SRM burn to support hazard detection. Figure from [2].

Mission Concept: An 11-instrument science payload is delivered to a landing site within Mercury's widely distributed low-reflectance material, and addresses science goals and objectives encompassing geochemistry, geophysics, the Mercury space environment, and surface geology. This mission concept was meant to be representative of any scientific landed mission to Mercury; alternate payload implementations and landing locations would be viable and compelling for a future landed Mercury mission.

The Mercury Lander flight system launches from Cape Canaveral Space Force Station on a fully expendable Falcon Heavy in 2035 with a backup launch period in 2036. The four-stage system uses a solar electric propulsion cruise stage to reach Mercury in 2045. The cruise stage is jettisoned after orbit-matching with Mercury, and the orbital stage uses its bipropellant propulsion system first to bring the remaining three stages into a thermally safe orbit, then to perform apoherm- and periherm-lowering maneuvers to prepare for descent. During the 2.5-month orbital phase, a narrow-angle camera acquires images, at ~1 m pixel scale, for down selecting a low-hazard landing zone. The orbital stage is jettisoned just prior to initiation of the landing sequence (Figure 2) by the descent stage, a solid rocket motor (SRM). The SRM begins the braking burn just over two minutes before landing. The descent stage is jettisoned after SRM burnout, and the Lander executes the final landing with a bipropellant liquid propulsion system. Landing uses continuous LIDAR operations to support hazard detection and safely deliver the payload to the surface.

Landing occurs at dusk to meet thermal requirements, permitting ~30 hours of sunlight for initial observations. The RTG-powered Lander continues surface operations through the Mercury night. Direct-to-Earth (DTE) communication is possible for the initial three weeks of the landed mission, followed by a six-week period with no Earth communication. DTE communication resumes for the remaining four weeks of nighttime operations. Thermal conditions exceed Lander operating temperatures shortly after sunrise, ending operations. A total of ~11 GB of data are returned to Earth.

Mercury Lander in the Decadal Survey: This mission concept was judged to have exceptional scientific merit and considered as a candidate flagship mission by the Planetary Science and Astrobiology Decadal Survey 2023–2032 [3]. The report suggested that "The Mercury Lander concept would benefit from development work to enable enhanced spacecraft thermal control and high-temperature subsystems that would allow for longer duration surface operations and cost-effective circular and low-altitude orbits. Further, mission concept development to broaden the science goals, e.g., to enable characterization of isotopic composition, would be valuable."

References: [1] Ernst, C.M. et al. (2020) arXiv:2107.06795. [2] Ernst, C.M. et al. (2022) PSJ, 3:68. [3] National Academies of Sciences, Engineering, and Medicine. 2022. Origins, Worlds, Life: A Decadal Strategy for Planetary Science and Astrobiology 2023–2032.