The Mercury Lander Mission Concept Study: Enabling Transformative Science from the Surface of the Innermost Planet. C. M. Ernst[1], N. L. Chabot[1], R. L. Klima[1], S. Kubota[1], G. Rogers[1], P. K. Byrne[2], S. A. Hauck, II[3], K. E. Vander Kaaden[4], R. J. Vervack, Jr.[1], S. Besse[5], D. T. Blewett[1], B. W. Denevi[1], S. Goossens[6,7], S. J. Indyk[8], N. R. Izenberg[1], C. L. Johnson[9,10], L. M. Jozwiak[1], H. Korth[1], R. L. McNutt, Jr.[1], S. L. Murchie[1], P. N. Peplowski[1], J. M. Raines[11], E. B. Rampe[12], M. S. Thompson[13], S. Z. Weider[14,15]. [1]Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland. [2]North Carolina State Univ., Raleigh, NC. [3]Case Western Reserve Univ., Cleveland, OH. [4]Jacobs, NASA JSC, Houston, TX. [5]ESA/ESAC, Madrid, Spain. [6]Univ. of Maryland Baltimore County, Baltimore, MD. [7]NASA GSFC, Greenbelt, MD. [8]Honeybee Robotics, Altadena, CA. [9]Univ. of British Columbia, Vancouver, British Columbia, Canada. [10]Planetary Science Institute, Tucson, AZ. [11]Univ. of Michigan, Ann Arbor, MI. [12]NASA JSC, Houston, TX. [13]Purdue Univ., West Lafayette, IN. [14]Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, DC. [15]NASA HQ, Washington, DC. (carolyn.ernst@jhuapl.edu)

Introduction: As an end-member of rocky planet formation, Mercury holds unique clues about the original distribution of elements in the earliest stages of Solar System development, as well as how planets form and evolve in close proximity to their host stars generally. 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 structure of the planet's 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.

Mission concept: NASA's Planetary Mission Concept Studies (PMCS) program selected this study in 2019 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 achieves one full Mercury year (~88 Earth days) of surface operations with an ambitious, high-heritage, landed science payload, corresponding well with the New Frontiers mission cost framework.

The 11-instrument science payload (Figure 1) 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 is meant to be *representative* of any scientific landed mission to Mercury; alternate payload implementations and landing locations are equally viable and compelling for a future landed Mercury mission.

The study was performed as a Concept Maturity Level 4 preferred point design. The Mercury Lander flight system launches from Cape Canaveral on a fully expendable SpaceX Falcon Heavy in 2035 with a

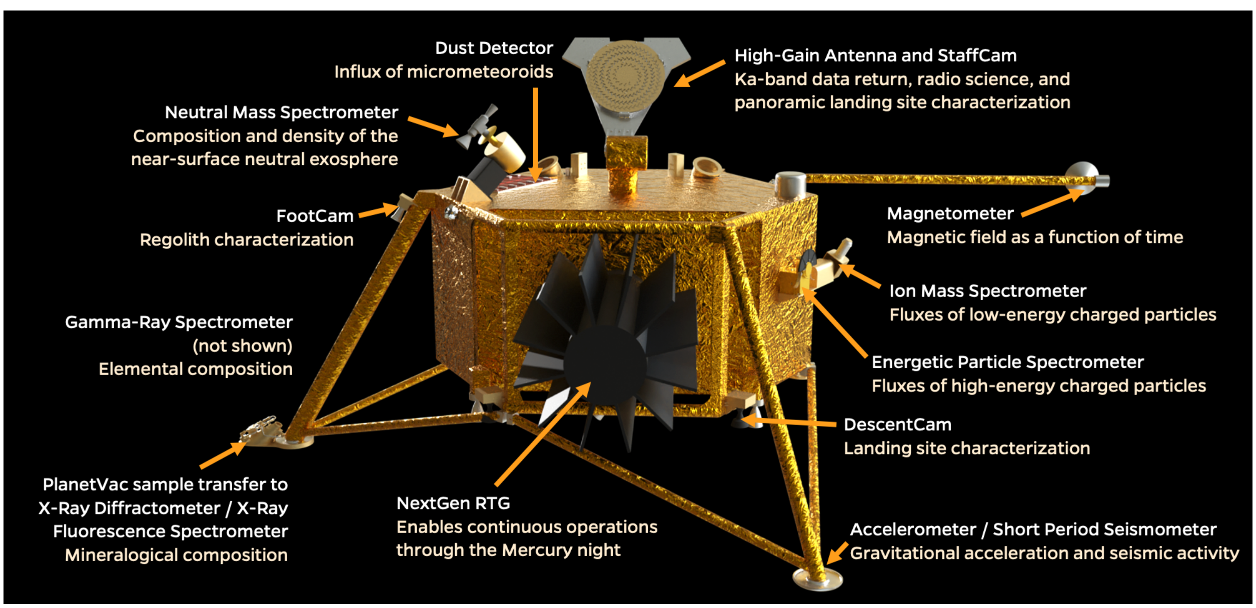

Figure 1. Mercury Lander in its landed configuration. The placement of the 11-instrument payload, RTG, and HGA are shown.

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 downselecting a low-hazard landing zone. The orbital stage is jettisoned just prior to initiation of the landing sequence 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. The Lander uses continuous LIDAR operations to support hazard detection and safely deliver the payload to the surface.

Figure 2 summarizes the timeline of landed operations. Landing occurs at dusk to meet thermal requirements, permitting ~30 hours of sunlight for initial observations. The radioisotope thermoelectric generator (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 surface operations. A total of ~11 GB of data are returned to Earth.

The Phase A–D mission cost estimate (which, per the PMCS rules, features 50% unencumbered reserves, excluding the launch vehicle) with the 11-instrument payload is $1.2 B (FY25$), comparing favorably with past New Frontiers missions, as well as to the cost cap prescribed in the New Frontiers 4 AO (~$1.1B FY25$). This cost estimate demonstrates that a Mercury Lander mission is feasible and compelling as a New Frontiers-class mission in the coming decade.

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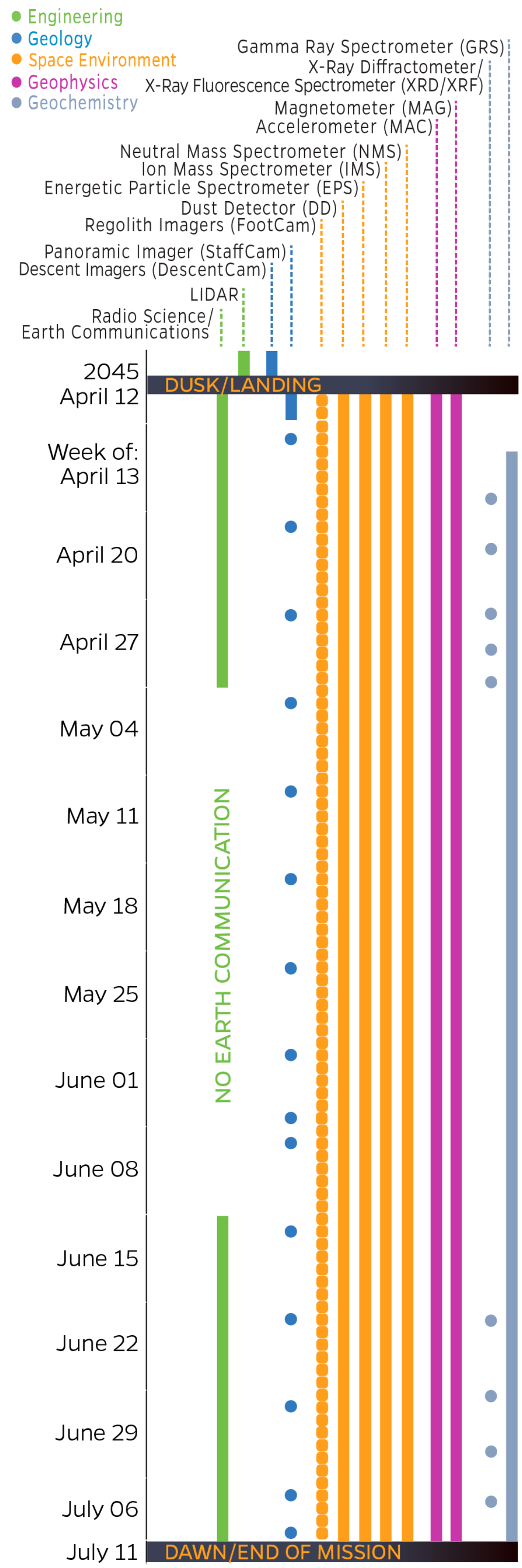

Figure 2. Timeline of landed operations.