

SUN RUN RELAY: REFINING SCIENCE AND TRAVERSE FEASIBILITY FOR A MERCURY ROVER ALONG THE TERMINATOR. M. Murillo¹ and P. G. Lucey¹, ¹Hawaii Institute of Geophysics and Planetology, University of Hawaii at Manoa; 1680 East-West Road, Honolulu, HI 96822, USA; mari713@hawaii.edu

Introduction: Mercury is the only terrestrial planet in the Solar System that remains unexplored by a landed spacecraft, despite its many geologically unique environments that could shed light on longstanding questions in planetary science. Mercury presents one of the most challenging surface environments in the Solar System for landed exploration. Extreme temperature variations, driven by the planet's slow rotation and proximity to the Sun, result in surface temperatures approaching ~700 K under direct illumination and dropping below ~100 K on the unlit side [1]. These conditions have historically limited Mercury exploration to orbital missions, despite the planet's exceptional geologic features and its importance for understanding terrestrial planet formation, differentiation, and volatile retention.

In a narrow region near the terminator, however, temperate conditions would allow a rover to run on solar power and collect data and samples on the surface without the need to withstand extreme thermal cycling. This region offers a unique opportunity for sustained surface operations in temperate conditions. Our 2025 LPSC abstract "Run with the Sun" presented a mission concept for a terminator-tracing rover on Mercury [2]. This abstract revisits and refines the feasibility of this rover mission concept. We incorporate updated considerations of rover velocity requirements, candidate traverse regions, and navigability constraints informed by existing orbital datasets, while outlining scientific objectives enabled by terminator-based mobility.

Terminator Dynamics & Rover Velocity Constraints: To remain within the temperate region surrounding the terminator, a rover must traverse longitudinally at a rate comparable to the apparent motion of the Sun across Mercury's surface. The velocity of the terminator varies with latitude and is governed by Mercury's 3:2 spin-orbit resonance and orbital eccentricity [3]. At the equator, the terminator reaches its maximum velocity, approximately 6 km/hr, decreasing as a function of the cosine of latitude. At $\pm 45^\circ$, the maximum terminator velocity is reduced to ~4.25 km/hr.

We estimate terminator motion using orbital ephemeris data from NASA JPL's Horizons system by tracking changes in subsolar longitude over 24-hour intervals. Because the terminator is located 90° east and west of the subsolar longitude, this approach enables direct estimation of terminator movement

across Mercury's surface. These calculations demonstrate that maintaining position within a defined longitudinal band around the terminator does not require exact velocity matching, but rather sustained motion sufficient to remain within thermally permissible limits.

Calculated rover velocity requirements are compared to historical and contemporary surface vehicles, including the Apollo Lunar Roving Vehicle (maximum ~15 km/hr), Lunokhod 2 (~2 km/hr), and modern Mars rovers such as Perseverance (average ~0.1 km/hr) [4, 5, 6]. While terminator-tracing on Mercury demands higher sustained speeds than typical Mars operations, the required velocities are within the demonstrated capabilities of existing and near-term rover technologies, particularly in the context of advancements in autonomous navigation and hazard avoidance.

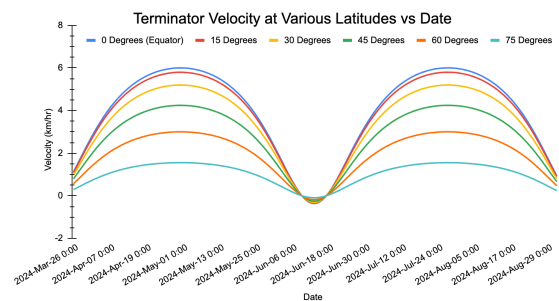


Figure 1. Terminator velocity is a function of the cosine of latitude, and phases in accordance with Mercury's 3:2 spin-orbit resonance.

Scientific Objectives: Mercury's surface preserves a record of processes that challenge prevailing models of terrestrial planet evolution, including its large iron core, reduced mantle composition, widespread volcanism, and hollows—volatile-rich, shallow depressions unique to Mercury that are often found in bright, high-albedo regions, including on the rays of young craters. A rover operating near the terminator uniquely enables in-situ investigation of these processes across a variety of geologic terrains.

Scientific objectives for a terminator-tracing Mercury rover include morphologic and mineralogical characterization of hollows, volcanic deposits, contractional tectonic features, and low-albedo patches potentially linked to carbon-rich or space-weathered materials [7, 8, 9]. Fresh impact craters provide access

to subsurface materials and offer additional opportunities for sampling various lithologies within a single traverse.

In-situ measurements obtained using techniques such as Ground Penetrating Radar; X-ray, neutron, and gamma-ray spectrometry; and thermal infrared and VNIR spectroscopy would enable direct investigation of Mercury's mineralogy, morphology, and dynamics. These measurements would complement orbital observations from MESSENGER and BepiColombo by providing ground-truth constraints on surface materials and processes that cannot be fully resolved remotely.

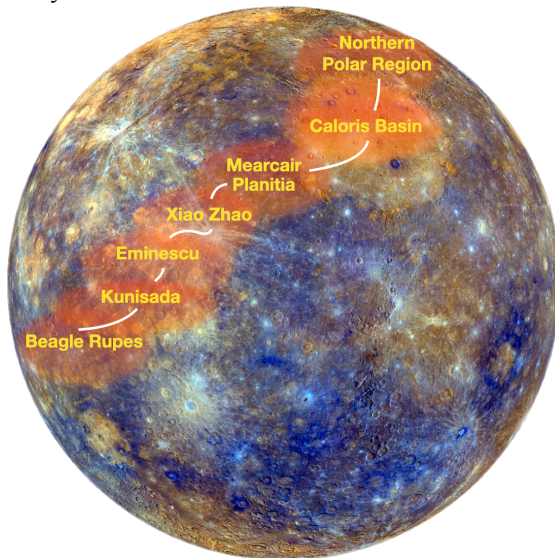


Figure 2. A proposed traverse maximizes scientific interest while considering efficiency and navigability.

Proposed Route of Traverse: This work identifies candidate traverse regions that balance scientific value with rover mobility constraints. High-resolution MESSENGER MDIS imagery is used to identify geologically different terrains near the terminator, including smooth volcanic plains, hollow-bearing craters, and tectonically deformed regions.

Planned evaluation of rover navigability incorporates topographic and slope constraints derived from MLA altimetry and stereo-derived digital elevation models. Slope maps provide a framework for identifying traversable routes, avoiding high-relief terrain, and constraining rover mobility limits along proposed paths. These constraints inform both traverse planning and science target prioritization, enabling realistic assessment of achievable science return within the designated operational framework.

A conceptual traverse begins at a polar landing site at a lull in the terminator velocity cycle, allowing for a period of acclimation to the terrain. The traverse

progresses along the terminator toward the equator. This strategy enables extended dwell times near high-priority science targets while maintaining thermal and power constraints.

Mission Feasibility & Future Work: Preliminary analysis demonstrates that a terminator-tracing rover mission on Mercury is feasible using existing and near-term technologies, provided that we address key challenges, including low-Sun-angle power generation, energy storage, and autonomous navigation. Scientific objectives are optimized against rover mobility and measurement capabilities, providing a preliminary framework for future science traceability and mission design studies.

This refined mission concept highlights the scientific potential of mobile Mercury surface exploration and motivates continued development of traverse-based mission architectures. By leveraging existing orbital datasets and focusing on realistic mobility constraints, a terminator-tracing rover represents a compelling pathway for advancing Mercury surface science in the era of BepiColombo and future inner Solar System missions.

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