MERLIN: MARS-MOON EXPLORATION, RECONNAISSANCE AND LANDED INVESTIGATION.

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Background: Although Mars' moons, Phobos and Deimos, were discovered over a century ago, their compositions, origins, and geologic history remain poorly understood today. Their presence in Mars' orbit is surprising; their albedo, spectra and density resemble D-type bodies, a class of objects common in the outer solar system but rare in the inner solar system [1-3]. Yet viable methods for capturing outer solar system objects into Mars orbit are dynamically difficult [4]. D-type objects are widely considered "ultraprimitive", rich in organics and volatiles, and a possible source of prebiotic materials to the early terrestrial planets [5], but their true composition is uncertain and volatile-poor compositions are also consistent with existing remote measurements [6]. Phobos and Deimos, with their accessible location in Mars orbit, offer a unique opportunity to investigate D-type objects, as well as the origin of the martian moons, with a high science payoff, low-risk inner solar system mission. The most recent spectroscopic measurements of the two moons, by MRO/CRISM, suggest a composition containing Fe-phyllosilicate and that at least some primitive, volatile-bearing material is present on both moons [7,8].

Mission Concept: The Mars-Moon Exploration, Reconnaissance and Landed Investigation (MERLIN), a Discovery-class mission concept, targets Deimos, an ideal choice for a landed investigation of a D-type body. Deimos is more accessible than any other D-type body that is larger than a few hundred meters in diameter, and its surface is smooth and relatively safe for landing. Current knowledge of Deimos enables a high-fidelity investigation plan to be developed *a priori*. MERLIN would begin landed robotic exploration of Mars' moons and of D-type bodies, and collect information on Deimos' surface valuable to the planning of future human exploration of the Mars system.

MERLIN addresses NASA science goals through straightforward measurements, first obtained during an orbital reconnaissance phase followed by a landed phase when a MER-like arm deploys contact instruments to the surface. Landed measurements distinguish among the models for Deimos origin and provide *in situ* information on characteristics of a D-type body (Table 1). The orbital measurements put the landed science into context and investigate the processes that have shaped small, D-type bodies. MERLIN unravels the origin of the martian moons, addressing the major NASA science theme of understanding the first billion years of solar system history and the initial stages of planet and satellite formation. MERLIN determines the inventory of prebiotic materials on Deimos, addressing NASA's major science questions about the history and distribution of volatiles and organics across the solar system. MERLIN characterizes the geology, surface regolith and internal structure of Deimos, addressing NASA's goals and objectives to understand the processes that shape planetary bodies and how those processes operate and interact.

Mission Overview: An innovative interplanetary trajectory lessens propulsion requirements, so MERLIN is launched on an Atlas V 401. Following Mars Orbit Insertion (MOI) MERLIN executes trajectory correction maneuvers to fly nearly in formation with Deimos, completing about 5 months of global mapping and radio science measurements (Fig. 2). A landing site on fresh material exposed in an albedo streamer is characterized and certified as safe for landing. The spacecraft descends to the surface and completes approximately 90 days of landed measurements.

Instrumentation: The instrument complement and operations largely derive from hardware and ground systems proven on MER, MRO and MESSENGER, reducing development cost and technical risk (Fig. 3). During the orbital phase, a multispectral wide-angle camera (WAC) and high-resolution narrow-angle camera (NAC) based on MESSENGER/MDIS determine Deimos' geology, surface properties, and shape, while radio science probes the interior. After landing, a MER-like arm accurately deploys an alpha particle X-ray spectrometer to measure elemental composition, a Raman spectrometer [9] to measure mineralogic composition, and a color microscopic imager to determine regolith texture. An operational stereo camera (OpsCam) and a terrain-imaging camera (TerrainCam), based on MER's Hazcam and Navcam, support tactical planning of landed measurements and characterize geology of the landing site. MERLIN is implemented by the Applied Physics Laboratory, together with its partner institutions the Jet Propulsion Laboratory and Washington University in St. Louis.

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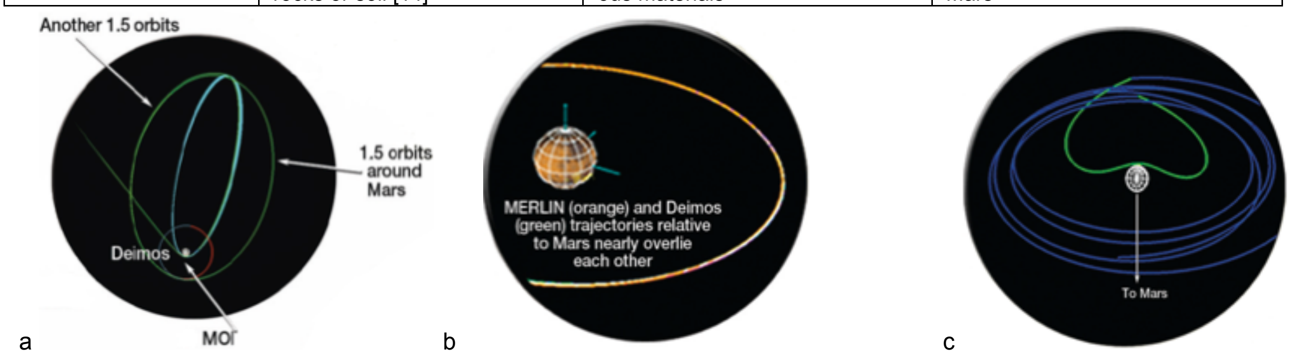
Table 1: MERLIN's landed measurements differentiate among hypothesis for Deimos' origin.

Origin Hypothesis	**Composition Predicted**	**Elemental Abundance Results**	**Mineral Abundance Results**
Capture of organic- and water-rich outer solar system body	Ultra-primitive D-type composition; Tagish Lake is the best known analog [10]	High C; high Zn/Mn; high S; composition possibly unique from known meteorites	Abundant phyllosilicates; carbonates and organic phases; anhydrous silicate phases rare
Capture of organic and water-poor outer solar system body	D-type composition matched by anhydrous silicates plus elemental C [6,11]	High C; Mg/Fe ratio ~2–4; bulk composition unlike any meteorite analogs	Anhydrous, med. Fe (20–40%) pyroxene; abundant amorphous C or graphite?
Capture of inner solar system body	Composition like common meteorites (e.g., carbonaceous or ordinary chondrites) [12]	Mg/Si ~0.8–1, Al/Si ~0.05–0.1; Zn/Mn and Al/Mn ratios separate known meteorites; low C	Low carbonates, phyllosilicates; pyroxene, olivine probably in range of known meteorites
Co-accretion with Mars	Bulk Mars; similar to ordinary chondrites but specific SNC-derived composition [13]	Mg/Si, Al/Si, Fe/Si indicative of bulk Mars; low C; Zn/Mn, Al/ Mn like ordinary chondrites	Anhydrous silicates with Fe, Mg expected for bulk Mars; low abundance of C-bearing phases
Giant impact on Mars	Evolved martian crust or mantle, like SNC meteorites, Mars rocks or soil [14]	High Al/Si, Ca/Si, lower Fe/Si, Mg/Si indicative of evolved igneous materials	Evolved, basaltic mineralogy consistent with many datasets for Mars



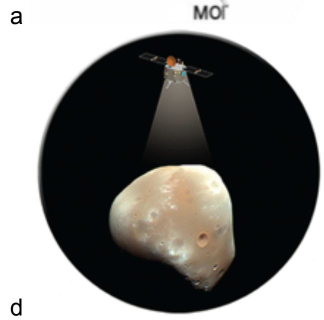


Fig. 1. Mission profile. (a) During 1.5 elliptical orbits after MOI, OpNav images refine Deimos' ephemeris. Two more maneuvers, separated by another 1.5 orbits, circularize MERLIN's orbit at Deimos. (b) MERLIN and Deimos are then nearly co-orbital; the spacecraft flies in formation with the moon and acquires color and stereo images, and mass/volume measurements. (c) 1- to 2-km altitude flyovers certify the landing site with color and morphology imaging and terrain modeling. (d) MERLIN is delivered to a point above Deimos, then navigates to landing using onboard closed-loop processing of descent images.

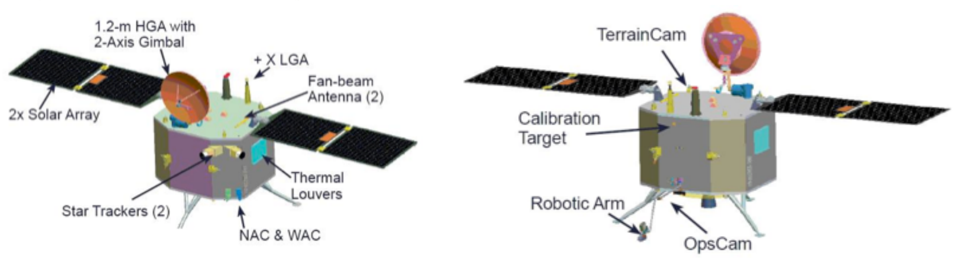


Fig. 2. MERLIN spacecraft configuration showing accommodation of science instrumentation.