PADME (Phobos And Deimos & Mars Environment): A Proposed NASA Discovery Mission to Investigate the Two Moons of Mars. Pascal Lee[1,2,3], Mehdi Benna[4], Daniel Britt[5], Anthony Colaprete[1], Warren Davis[1], Greg Delory[6], Richard Elphic[1], Ejner Fulsang[1], Anthony Genova[1], Daniel Glavin[4], William Grundy[7], William Harris[8], Brendan Hermalyn[1,2], Butler Hine[1], Mihaly Horanyi[9], Douglas Hamilton[10], Robert Johnson[11], Thomas Jones[12], Sasha Kempf[9], Brian Lewis[1], Lucy Lim[4], Paul Mahaffy[4], John Marshall[2], Patrick Michel[13], David Mittlefehldt[8], Sam Montez[1], Yung Nguyen[1], Brandon Owens[1], Maurizio Pajola[14], Ryan Park[15], Cynthia Phillips[2], Laura Plice[1], Andrew Poppe[6], Joseph "Ed" Riedel[15], Attilo Rivoldini[16], Pascal Rosenblatt[16], Micah Schaible[11], Mark Showalter[2], Heather Smith[1], Zoltan Sternovsky[9], Peter Thomas[17], Hajime Yano[18], and Michael Zolensky[8]. [1]NASA Ames Research Center, MS 245-3, Moffett Field, CA 94035-1000, USA, [2]SETI Institute, [3]Mars Institute, pascal.lee@marsinstitute.net. [4]NASA Goddard Space Flight Center, [5]U. of Central Florida, [6]UC Berkeley, [7]Lowell Observatory, [8]NASAJohnson Space Center, [9]LASP, U. of Colorado, Boulder, [10]U. of Maryland, [11]U. of Virginia, [12]Institute for Human and Machine Cognition, [13]Obs. de la Cote d'Azur, [14]U. of Padua, [15]NASA Jet Propulsion Laboratory,[16]Royal Observatory, Belgium, [17]Cornell U., Ithaca, NY, USA, [18]JAXA (Japan Aerospace Exploration Agency).

Summary: PADME is a proposed NASA Discovery mission to investigate the origin of two remarkable and enigmatic small bodies, Phobos and Deimos, the two moons of Mars.

Introduction: After 40 years of solar system exploration by spacecraft, the origin of Mars's satellites, remains vexingly unknown [1]. There are three prevailing hypotheses concerning their origin: H1: They are captured small bodies from the outer main belt or beyond; H2: They are reaccreted Mars impact ejecta; H3: They are remnants of Mars' formation. There are many variants of these hypotheses, but as stated, these three capture the key ideas and constraints on their nature. So far, data and modeling have not allowed any one of these hypotheses to be verified or excluded. Each one of these hypotheses has important implications for the evolution of the solar system, the formation and evolution of planets and satellites, and the delivery of water and organics to Early Mars and Early Earth. Determining the origin of Phobos and Deimos is identified by the NASA and the NRC Decadal Survey as the most important science goal at these bodies [1].

PADME Science Goals and Objectives: The PADME mission has two distinct goals: 1) Determine the origin of Phobos; 2) Determine the origin of Deimos. To meet these goals, PADME will test the above three hypotheses at both Phobos and Deimos. At each moon, PADME has three objectives: A) Determine the composition of surface and near-surface materials; B) Constrain the internal structure; C) Characterize the dynamics of surface materials. While Objective A addresses composition and is therefore key to constraining origin, Objectives B and C allow an assessment of the extent to which surface and near-surface compositions may be extrapolated to the *bulk* of these moons.

Objective B will constrain whether the interior of each body is close to homogenous, or significantly heterogeneous. If the internal structure is close to homogenous, then surface and near-surface compositions may be more confidently applied to the whole body. If, on the other hand, the interior is significantly heterogenous, then extrapolating surface and near-surface compositions to the interior will be fraught with uncertainty.

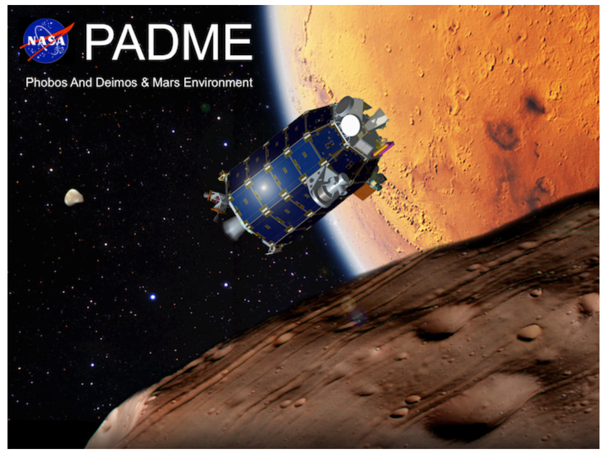

Figure 1: PADME will conduct multiple close flybys of Phobos & Deimos to elucidate their origin. PADME builds on substantial heritage from NASA's successful LADEE mission. It is low cost, low risk, and timely.

Objective C will characterize whether and how surface materials (e.g., dust) might be transported across the surface of each moon, and from one moon to the other (in particular from Deimos to Phobos). Characterizing the latter is critical to understanding the meaning of Phobos' spectrally "Redder" and "Bluer" Units as revealed by the *Phobos 2* spacecraft in the visible and near-IR. Are these units indicative of a heterogeneous body throughout, or is the "Redder Unit", which is spectrally similar to Deimos' spectrum and akin to that of D-type asteroids, merely a veneer of material imported from Deimos? In the former case, Phobos would be a heterogeneous body with spectrally distinct bulk constituants. In the latter case, only the "Bluer Unit" would represent the true Phobos with respect to the body's origin; the "Redder" Unit would be an exogenous coating.

PADME Science Strategy and Instruments: PADME will be able to meet all its science objectives by being just an orbiter of Mars conducting multiple close flybys of each Phobos and Deimos. No rendevous or landing is required. Each one of PADME's objectives is met by a two-pronged approach: composition is addressed by a combination of neutron spectrometry and mass spectrometery; internal structure is investigated via a combination of radio science and imaging; surface material dynamics is addressed by imaging, and also via dust detection.

PADME carries four science instruments (Table 1). A fifth experiment is radio science (led at JPL), with no dedicated instrument required.

Table 1: PADME Instruments

Instrument	Source
NS: Neutron Spectrometer	NASA ARC/LM
NMS-E: Neutral gas Mass Spectrometer - Enhanced	NASA GSFC
OIS: Optical Imaging System	NASA JPL
MDEX: Mars Dust Experiment	LASP

NS determines the H abundance and bulk elemental composition of near-surface materials (top 1 m of the regolith). NMS-E independently constrains the composition of surface materials by analyzing the atoms, molecules, and ions sputtered off the surface by solar wind impingement. (With NMS-E, PADME will be the first mission to explore the exosphere of a small body.) Bulk elemental compositions derived via NS and NMS-E will then be compared to major meteorite class compositions to identify best fits for Phobos and Deimos. OIS is a triple optically mounted camera system (including a 45^o FOV WAC, a 16^o MAC, and a 2.2^o NAC) that will image Phobos and Deimos globally, regionally, and locally in RGB color down to a spatial resolution of ~ 10 cm/pxl. OIS imaging will support internal structure studies (measurements of Phobos' gravity coefficients C_{20} and C_{22}, and of Phobos' libration amplitude θ), and also geological investigations of surface color relationships and material transport. In addition, OIS will support PADME's high precision optical navigation. MDEX will measure dust particle size, energy, and density distributions in the immediate vicinity of Phobos and Deimos, and in the circum-Martian environment, to characterize dust transport on, and between, these moons.

PADME Mission: The PADME spacecraft is based on NASA Ames Research Center's (ARC) proven LADEE spacecraft bus. PADME may be launched on a Falcon-9-class rocket. Following launch in Aug 2020, PADME will reach Mars seven months later, in late Feb-Mar 2021.

Once in Mars orbit, PADME will carry out 16 flybys of Phobos, followed by 9 flybys of Deimos. Most fybys will be at an altitude of ~2 km AGL. Flybys velocities will be in a highly desirable "sweet spot" range (0.8 to 2.2 km/s for Phobos; 0.6 to 1.2 km/s for Deimos): slow enough for neutron spectrometry, mass spectrometry (NMS-E's open source ion mode), radio science, and imaging; fast enough for dust detection.

PADME's primary mission will end in June 2022, at which point the spacecraft will depart the Martian system and retire in heliocentric orbit.

Science Enhancement and Tech Demo Options: The PADME team welcomes, and will support NASA in hosting, a vigorous Participating Scientist program. Also, during its primary mission, PADME will collect data opportunistically to search for the long-hypothesized dust rings, and any undiscovered moonlets, around Mars. If sufficient delta-v is left, PADME will be targeted to flyby a NEO. PADME will also support a laser communications technology demonstration experiment.

PADME Team & Management: PADME is a PI-led mission. The Science Team includes Co-Investigators (including Experiment Leads from NASA ARC, GSFC, JPL, LASP, and the SETI Institute) and Collaborators from across the US. PADME's Science Team also includes International Co-Investigators from Belgium, France, Italy, and Japan.

NASA ARC will design, develop, build, and test the PADME spacecraft, manage science instruments, and manage mission operations. PADME will use the same Modular Common Spacecraft Bus (MCSB) as NASA's LADEE. This MCSB, developed at NASA ARC, is an innovative way of transitioning away from custom designed spacecraft and toward multi-use designs and assembly-line production, thus reducing spacecraft development costs drastically. NASA KSC will be responsible for launch vehicle integration, launch services, and launch range operations. NASA JPL will be responsible for Nav (in particular OpNav) and Deep Space Network (DSN) support.

Conclusion: PADME is an exciting proposed NASA Discovery mission to explore two inner solar system bodies that have remained enigmas for too long. In addition to its high scientific merit, PADME is of high programmatic value for NASA, as it is an ideal precursor to more complex and higher risk landed missions to Phobos and Deimos, e.g., sample return or human precursor missions. Through its science mission, PADME also fills strategic knowledge gaps regarding Phobos, Deimos, and Mars's orbital environment. PADME is low cost, low risk, and timely.

References: [1] Lee, P. (2009). Mars Inst. Tech. Pub. 2009-001, Mars Inst., Moffett Field, CA, 57pp.