MARS NANO ORBITER: A CUBESAT FOR MARS SYSTEM SCIENCE. B.L. Ehlmann[1,2], A. Klesh[2], T. Alsedairy[3], R. Dekany[4], J. Dickson[1], C. Edwards[5], F. Forget[6], A. Fraeman[2], D. McCleese[7], S. Murchie[8], T. Usui[9], S. Sugita[10], K Yoshioka[10], J.Baker[2] [1]Div. of Geological & Planetary Sciences, California Institute of Technology, [2]Jet Propulsion Laboratory, California Institute of Technology, [3]King Abulaziz City for Science and Technology, [4]Caltech Optical Observatories, Div. of Physics, Mathematics, and Astronomy, California Institute of Technology, [5]Northern Arizona University, [6]Laboratoire de Météorologie Dynamique, [7]Synoptic Science, [8]Johns Hopkins Applied Physics Laboratory [9]Earth & Life Science Institute, Tokyo Institute of Technology, [10]Univeristy of Tokyo

Summary: Our proposal mission submitted to NASA in November 2017, the Mars Nano Orbiter (MNO), consists of two identical 12U CubeSat spacecraft, launched simultaneously as secondary payloads on a larger planetary mission launch, and deployed to Earth-escape, as early as with Mars 2020. The nominal mission will last for 1 year, during which time the craft will independently navigate to Mars, enter into a 5.1-sol elliptical orbit in 33:1 resonance with Phobos, and achieve close flybys of Phobos and Deimos, obtaining unprecedented coverage of each moon (Fig. 1, 2). The craft will additionally provide high temporal resolution images of Mars clouds and atmospheric phenomena at multiple times of day (Fig. 3). Two spacecraft provide redundancy to reduce the risk in meeting the science objectives at the Mars moons and to provide enhanced coverage of the dynamic Mars atmosphere.

This mission is enabled by recent advances in commercial CubeSat propulsion technology, attitude control systems, guidance, navigation and control, and radio for deep space communication (Fig. 4). MNO builds directly on the systems heritage of the MarCO mission, scheduled to launch with the 2018 Discovery mission Insight. Our MNO team is led and managed

Fig. 1. MNO would make measurements of Mars' moons at high spatial resolution and monitor Mars at high temporal resolution.

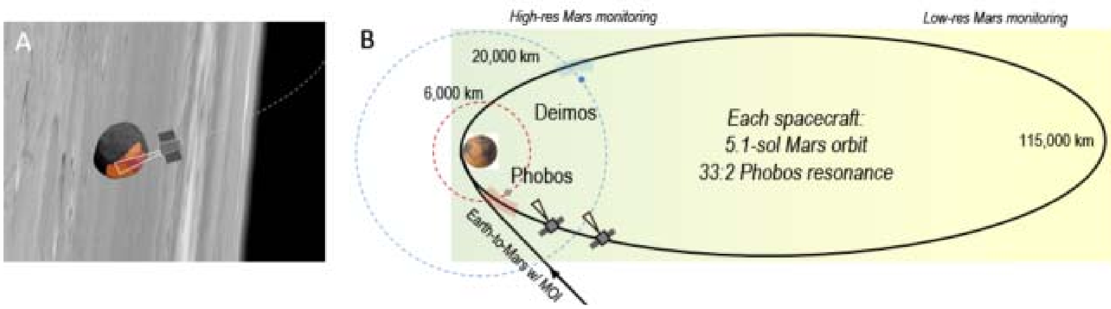

Figure 2. Footprint of an MNO-MSI image with 4 filters, showing in yellow the footprint of a resultant sub-framed multispectral image group (yellow; 24.6 m by 6.1 m at closest flyby) shown on moon shape models [Wilner et al., 2014].

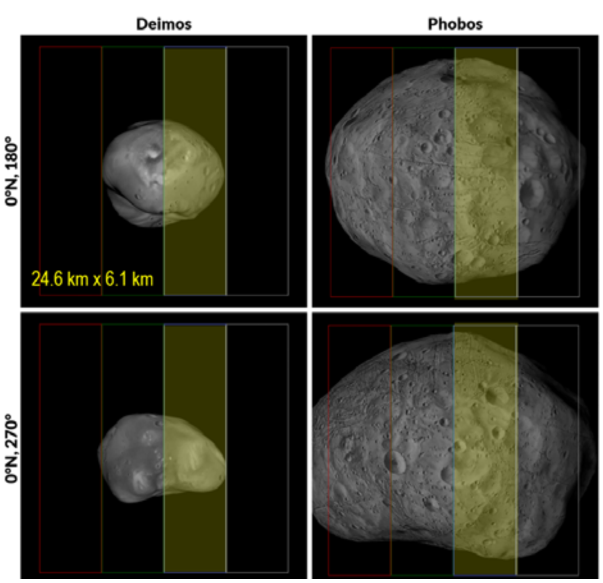

Figure 3. MNO would observe at multiple times of day and continuously over >2 hr timescales dynamic atmospheric phenomena that are regional to hemispheric in scale, including clouds, fogs, frosts, and dust storms

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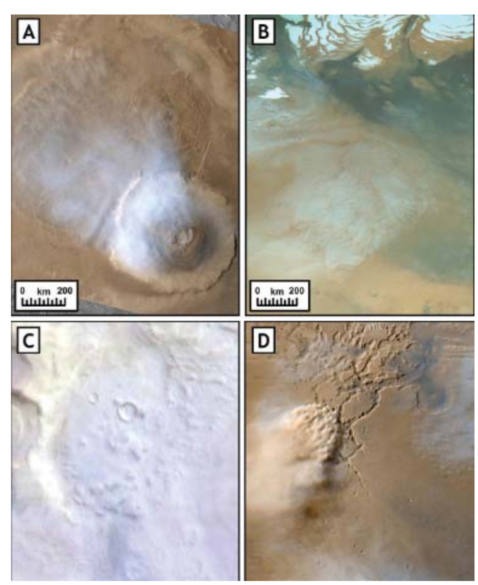


from the California Institute of Technology (Caltech). The proposal benefits from the capabilities of three of Caltech's Divisions: science and mission leadership from the Division of Geological & Planetary Sciences, camera design and delivery by Caltech Optical Observatories within the Division of Physics, Mathematics, and Astronomy, and the spacecraft assembly facilities in the Guggenheim Aeronautical Laboratory of the Division of Engineering and Applied Science. Caltech will lead spacecraft assembly, working with U.S. commercial vendors and an international partner, the King Abdulaziz City for Science and Technology (KACST). The Jet Propulsion Laboratory (JPL) will provide systems engineering and mission management. The international science team includes world experts on small bodies and Mars weather from the U.S., France, and Japan

Science Goals: MNO science supports Decadal Survey Objectives and the scientific goals of the MEPAG and SBAG programs as well as supplies crucial information and technology demonstrations needed for further Mars system exploration

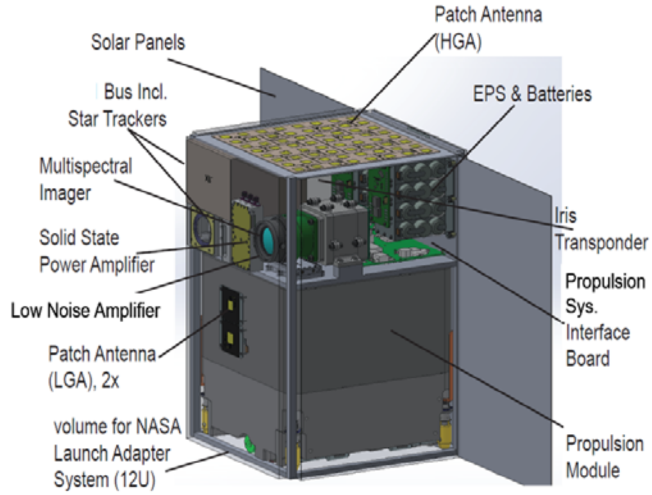
Goal 1. What are the origin, evolution, and properties of Mars' Moons? MNO would (A) Map completely Phobos and Deimos at high spatial resolution (≤30 m/pixel) and study landforms that provide insight into the internal composition and geologic history of both moons (B) Determine definitively the density of Deimos to understand its composition, internal structure, and similarity to Phobos and (C) Map the spectral properties of Phobos and Deimos surfaces to search for atypical phases, Mars-like compositions, changes since prior imaging, and variation in regolith properties relevant to future exploration, such as JAXA's MMX and other Mars moon landed missions.

Goal 2. What drives Mars' dynamic weather? MNO would (A) Monitor diurnal evolution of clouds, largely unexplored by suitably instrumented but sun-synchronous missions that have flown to date, and the initiation and growth of dust storms at high temporal resolution to understand why some storms are regional and others become global events (B) Monitor dynamic Mars volatiles (frosts and fogs) with high temporal resolution, revealing new insights into phenomena like Valles Marineris water-ice fogs, water-ice defrosting of the mid-latitudes, and the transport of ice aerosols.

Technology Objectives: In addition to its science investigations, MNO serves as a trailblazer for future planetary science small satellite missions through (i) demonstration of Mars orbit insertion by a CubeSat, (ii) demonstration of repeated small body flybys, and (iii) a CubeSat autonavigation software demonstration.

Payload: MNO's science goals are achieved using the high-heritage, high resolution MNO visible/near-infrared multispectral imager. The MNO imager is a pushframe camera delivered by Caltech Optical Observatories and incorporates a detector assembly from JPL's high heritage camera line (MSL/EECAM, OCO-3, NEAScout). The multispectral imager has no moving parts. Filters are mounted above the detector, and multispectral image cubes are built up by the motion of the spacecraft. The 500-1000 nm wavelength range enables MNO to detect major spectral features relevant to understanding Phobos' and Deimos' origins: the continuum that distinguished 'red' vs. 'blue' units, the 0.65-um absorption feature, and 0.9-um absorption features that would be due to mafic minerals. Coverage in visible and near-infrared light is well-suited for distinguishing clouds, fogs, and frosts from the Martian surface (e.g. MARCI, HiRISE).

Figure 4. CAD model of the components of the MNO spacecraft. The structure and solar panels are provided by KACST. Commercial vendors supply the propulsion system, avionics, and deep space radio. Integration and test occurs at Caltech.



A Phase A/B trade after propulsion system volume is fixed will evaluate the inclusion of a second science instrument focused on thermal imaging, solar winds, or Phobos surface impactor to excavate fresh material.

Summary: The Mars Nano Orbiters (MNO) mission would make groundbreaking discoveries in the Mars system, advancing both small bodies research and Mars science. MNO would provide the first complete stereo multispectral color images of Phobos and Deimos at high resolution. It would provide a never previously observed high time resolution view of dynamic Mars phenomena. The Planetary Science Division's commitment to carrying secondary payloads on future planetary launches represents a key force multiplier in our ability to make significant discoveries in the scientific exploration of the solar system.