SECONDARY NANOSPACECRAFT SURVEY OF THE MARTIAN MOONS. A. T. Klesh[1] and J. C. Castillo-Rogez[1], [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Blvd, Pasadena, CA 91109, *andrew.t.klesh@jpl.nasa.gov*.

Introduction: CubeSats have become widely popular for low-cost Earth orbit science and technology missions, in part due to the large availability of launch slots as secondary payloads. Multi-spacecraft missions are now being funded to provide diverse and distributed experiments across LEO for minimal cost. This same architecture, with the use of NanoSats leveraging the CubeSat experience, provides a distributed sensing network on the Martian moons, with targeted custom experiments from multiple investigators. By using a simple standard, individual investigators can propose a mission that maintains low risk to the primary vehicle, yet high science return, just as CubeSats have begun to demonstrate on Earth. Such investigations provide community-driven science without the so-called “Christmas-tree” effect of large missions, and also supports future exploration endeavors. We propose the development and deployment of multiple NanoSats at Phobos with an ESPA-ring class mothership to provide a massive spectrum of investigations at a very low cost.

Mission Architecture:

Single unit (10x10x10 cm) CubeSats can now be launched with 90% volume available for payloads – this includes deployable antennas, power systems, batteries, C&DH, and UHF radios capable of communicating to nearby spacecraft. All of this within a cost of a few tens of $K. Larger volumes, such as the so-called 3U (10x10x30cm) are also widely available by university, government, and industry labs. With UHF radios capable of transmitting 1000s of kilometers (tested on multiple CubeSat missions in LEO), the mother spacecraft, which previously served as a deployer, can now work as a relay, passing on data to Earth through an Electra or other standard radio.

Each CubeSat module (up to 3U) deploys separately, creating a simple method of distributed deployment: individual deployers open as the mothership moves through the Martian system. With either primary batteries (creating a lifetime of a few days at most), or deployable solar arrays (current CubeSat technology provides up to 30W at Mars), these smaller systems should be optimized for the mission at hand.

Current CubeSat GNC capability allows pointing with an accuracy of less than 1 degree This is a major advantage offered by CubeSats over other forms of deployables: the capability to access and point at specific regions of interest, some of which may be in extreme environments (e.g., steep slopes like in the Stickney crater).

Mothership: The mothership vehicle would likely be an ESPA-ring class spacecraft – similar to LCROSS in that the ring should be augmented with propulsion, communications and required flight equipment. By utilizing available spacecraft hardware, the overall cost would be minimized – in fact, the only major modification would be in the propulsive stage (likely electric propulsion to allow for Martian capture with minimal volume).

Engineering: Radiation, power generation, and capability are often listed as primary concerns. Yet with the deployment module shielded, and a demonstrated LEO orbit duration of up to 9 years, CubeSat technology has been shown to be robust, and would be protected from the deep-space environment during the entire cruise. Additional efforts, including using rad-hard CubeSat processors (available from some vendors), shielding the invididual avionics boxes, or simply planning for multiple spacecraft with the same instruments (redundant low-cost copies) allow for use at Mars.

Deployment:

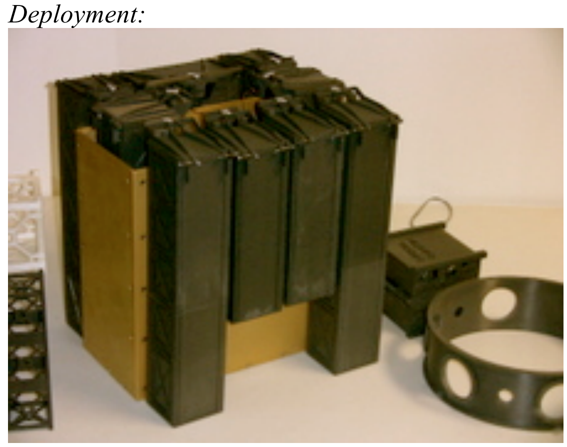

Figure 1 - Example of mass NanoSat deployer, NPS-Cul, built by the Naval Postgraduate School (24U launcher).

Instrumentation: Figure 2 illustrates the wide variety of sensors that conceivably fit within a 1-3U CubeSat formfactor without large changes. These instruments provide for a wide range of science applications, from radio science and geology, to chemistry and astrobiology. One can envision that CubeSats could easily access the surface and turn into landers to perform analytical measurements. Distributed sampling across the surface through the use of many probes may well provide a better picture than any single large lander or orbiter could provide – in-situ measurements.

Traceability to NASA: Applications envisioned for these Cubesats address key objectives of the planetary science decadal survey and of the Human Exploration program.

Reconnaissance: e.g., high-resolution mapping (cm/px) with assets hovering just a few tens of meters above the surface; high-resolution gravity measurements of specific areas identified as scientific interesting or as potential landing sites.

Surface Science: imaging gives constraints on soil mechanical properties at the 10-100 cm scale; asset landing provides information on surface mechanics.

Environmental Science: measurement of dust dynamics by using asset as sacrificial element when assessing dust levitation, electrostatic charging; radiation measurements; in situ asset determines grain size using dust instruments herited from Rosetta (e.g., MIDAS).

System Science: multiple assets deployed in the Martian system help track the flux of dust between Phobos, Deimos, and Mars, and its composition; depending on cost cap, assets may be deployed at both Phobos and Deimos.

In situ Resources: specific color filters yield basic but key constraints on composition (e.g., presence or absence of hydrated silicates).

Astrobiology: besides volatiles, search for the signature of organics (e.g. Raman spectroscopy).

Addressing MEPAG IV Objectives: High-resolution imaging should help prove (or disprove) Murray et al. [4] suggestion that Phobos' grooves formed by blocks ejected by impact at Mars. This implies that Martian meteorites should be closely associated with these grooves. Systematic search for such blocks would be key to identify potential future landing sites for a Human crew.

EPO/Public Involvement: CubeSats started as educational products and have benefited from the creativity and innovation of junior explorers. These platforms are now ready to be exploited by the planetary science community, which will benefit from years of development leading to highly mature platforms. Future student involvement in CubeSat-based deep space exploration is a natural development and one that is likely to create a lot of excitement and attract students to STEM.

Challenges Addressed: CubeSats, due to their low-cost nature, could easily benefit larger missions by serving as disposable probes, something unobtainable by larger spacecraft that are restricted by the traditional low-risk mission approach. These probes provide high-risk / high science results that multiply mission return, but programmatic adoption must yet be studied. Likewise, studying the cost scaling with the number of assets must be understood.

Development and Timeline: We recommend that the mission concept selected for the 2018 opportunity includes the utilization of a CubeSat as a technology demonstration experiment. Such a CubeSat would carry a descent camera (for high-resolution imaging) as well as a TRL-6 instruments to be also validated for deep space during that experiment. Such a mission would represent a milestone in the development of CubeSat-based exploration and potentially pave the way for the 2022 mission opportunity.

This work is being carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract to NASA. Government sponsorship acknowledged.

References: [1] Muylaert, J. et al. (2009) QB50 Workshop. [2] Schultz, P.H., et al. (2010) Science Magazine. [3] Puig-Suari, (2001) IEEE Aerospace. [4] Murray, J. B. (2011) EPSC-DPS Joint Meeting, #1003.

INSTRUMENT	GEOPHYSICS	CHEMISTRY	HABITABILITY	HERITAGE	MASS (ESTIMATED)
Seismometer	●		○	OPTIMISM/Mars 96/InSIGHT	50-500 g
PanCam	●	○	○	CIVA/Rosetta; Phobos 11	100-1000 g
Radiation dose	●		○	RADOM/Chandrayaan-1	100g
Gravimeter	●		○	GRAS/Phobos 11	250g
Tiltometer	●		○	Huygens	250g
Optical microscope	●	●	○	Beagle-2; Phobos 11	100-300g
Magnetometer	●	○	○	MMO Bepi Colombo	770g
XRF	○	●	○	APXS/Rosetta	640g

Figure 2 – Examples of 1U CubeSat-sized instruments with description and estimated mass (Source: Zelenyi 2011)