ESPA-Based Multiple Satellite Architecture for Mars Science and Exploration.
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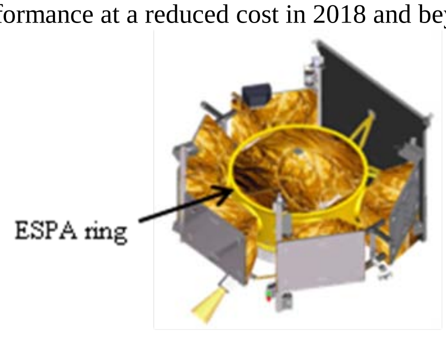
Introduction: Budget cuts to the NASA Planetary Science Division, and in particular to the Mars Exploration Program, have constrained NASA's future Planetary Exploration program. This abstract outlines an innovative exploration approach that maximizes the science return of each launch to Mars in the current cost contrained environment.

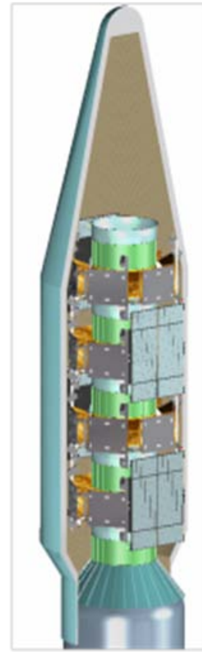
We propose a flexible architecture that has the capability to cost-effectively enable multiple science and exploration missions. This "MCROSS" architecture is based on the successful, rapid development LCROSS (Lunar CRater Observation and Sensing Satellite) approach, which was enabled by its innovative use of the ESPA (EELV Secondary Payload Adaptor) ring. Exploiting this architecture for an MCROSS mission can recapture the 2018 and/or 2020 Mars launch opportunities with multiple satellites that can support the wide range of NASA's science and exploration goals.

LCROSS: One of the key features of LCROSS was the use of the ESPA ring, originally designed to carry six separate small satellites underneath a primary mission in a launch vehicle. LCROSS's use of the ESPA ring had a dual purpose: it was the primary structure of the spacecraft subsystems bolted to the six ports, and it also carried the LRO (Lunar Reconnaissance Orbiter) satellite inside the launch vehicle. The figure below shows the LCROSS spacecraft with the ESPA ring in yellow. Application of the LCROSS architecture and mission design to Mars mission(s) can provide the key innovation needed to achieve excellent mission performance at a reduced cost in 2018 and beyond.



The ESPA-based LCROSS spacecraft

MCROSS Mission Architecture: The fundamental discriminator of an ESPA-based satellite is the inherent ability to stack multiple spacecraft in a single launch vehicle, creating a constellation. The MCROSS architecture can position up to 4 "ESPA-sats" into different orbits around Mars, providing up to 4 platforms and orbit geometries in a single launch.



4 ESPA-sats stacked in an EELV

Like LCROSS, each ESPA-sats will have at least one panel and the interior of the ESPA ring available for science instruments and can be configured to accommodate a diverse set of science instruments. The nominal ESPA-sat dry mass is 522 kg; allocating 50 kg for science and 100 m/s of fuel brings the total mass of an ESPA-sat to ~590 kg.

The constellation of ESPA-sats will launch, cruise, and perform orbit insertion at Mars as a single unit. One constellation option is a "mothership" that contains the major communication and propulsion equipment, and function as the Martian relay satellite for the other ESPA-sats. After orbit insertion, the ESPA-sats separate and use their own on-board fuel to move to different orbits or perform other maneuvers.

The 2018 launch opportunity has a best-case C3 of 7.8 km^2/s^2. With an EELV class launch vehicle, this allows 1307-2989 kg, or 2-4 ESPA-sats to be placed into orbit around Mars with aerobraking assist. Table 1 shows the mass capabilities of NASA launch vehicles. Columns labeled "direct" indicate the orbital mass using direct injection into Martian orbit. Columns labled "aero" indicate orbital mass injected with aerobraking, where the insertion ΔV has been reduced by 48%.

Table 1: Orbit mass around Mars with direct inject or aerobraking, for the best and worse case C3 during the 2018 launch opportunity.

Orbit mass	**C3 = 10.5 km^2/s^2**		**C3 = 7.8 km^2/s^2**	
(kg)	**direct**	**aero**	**direct**	**aero**
Falcon 9	828	1207	897	1307
Atlas V 401	1100	1603	1164	1696
Atlas V 411	1447	2108	1527	2225
Atlas V 421	1734	2527	1821	2654
Atlas V 431	1953	2846	2051	2989

MCROSS Mission Concepts: The ESPA-sat architecture is very flexible and can accommodate a wide variety of missions. We highlight a few here. Note that the figures show fixed arrays for simplicity but the mass of solar array drives have been accounted for.

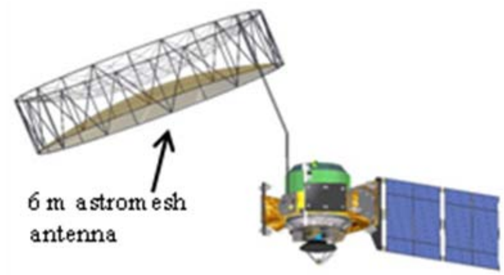
Mars Impact Water Plume Measurement: In this concept, some of the ESPA-sats carry a suite of penetrators that will target polar regions known to have subsurface water ice. Using data from the Gamma Ray Spectrometer onboard Mars Odyssey, Boynton et al. [1] showed that ice may be nearly ubiquitous in the Martian soil and, at high latitudes, may be only 10-100 cm below the surface. The Phoenix Lander confirmed that ice was located only 5 cm below the surface at its landing site near 68º N 234º E. In this LCROSS-style mission, the penetrators will create a plume upon impact. Options include carrying several 100 kg class penetrators to potentially excavate deeper than 1m, or carry many 10 kg class penetrators to excavate small craters where ice may be shallow.

An ESPA-sat carrying multiple spheres (in red) used as projectiles to excavate subsurface ice.

Spectral measurement of the plume material will reveal the quantity and composition of the subsurface material, including the amount of subsurface ice. These observations can be obtained from a limb-viewing angle by either another orbiting ESPA-sat that carry e.g. a high resolution hyperspectral imagers or by other in-situ Mars-orbiting satellites such as ExoMars.

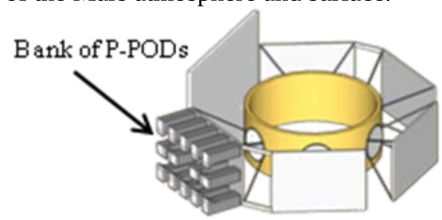
Mars Monitoring and Telecomm Network: Here, the ESPA-sat fleet is dispersed in various elliptical orbits to provide (sparse) global coverage of the surface. The instrument payload provides global environmental and surface remote sensing and could monitor e.g. the wind structure, the dust cycle and storms, or the carbon dioxide and water cycles. Additionally, the fleet can provide a GPS-like system around Mars to enable precision tracking of existing and future Mars surface assets, as well as a communications relay system to ensure the daily availability of high-speed communications with Earth from any location on Mars.

This infrastructure provides the support necessary for future landed or exploration missions and reduces those mission costs by offloading their communications payloads. On-board storage and forward capabilities in each ESPA-sat ensures that all Mars science data is forwarded as long as the DSN is available. A variation of this concept places sophisticated science payloads on all but one of the ESPA-sats in the fleet, with the final ESPA-sat "mothership" as the relay communications systems between the science satellites and Earth.



Communications equipment on a relay ESPA-sat

Mars CubeSat Network: A Mars-orbiting constellation can be augmented by having each ESPA-sat host a large number of CubeSats. These CubeSats will be deployed once the ESPA-sat is in orbit around Mars. The resulting constellation will have very dense coverage of the Mars atmosphere and surface.



At 1 kg each, CubeSats can be a versatile way to perform simultaneous in situ measurements.

Each CubeSat would carry a single science instrument, with identical copies of 1-3 instruments employed throughout the constellation, and the dense constellation would provide high spatial and temporal resolution monitoring of the dust/CO_2/H_2O cycles. In this scenario, the parent ESPA-sats serve as the data relay from the CubeSats to Earth.

Conclusion: A constellation of stacked ESPA-sats presents an innovative way of maximizing the science return for NASA. Launches to Mars require the use of EELVs to obtain sufficient C3; at the relatively low cost of additional launch vehicle boosters, the architecture proposed here can put in place much of the infrastructure NASA has been planning for Mars exploration. With a production line of ESPA-sats, the spacecraft cost will be a small fraction of the overall mission cost, allowing NASA the ability to carry more complex science and exploration instruments. This upcoming Mars 2018 opportunity is a perfect gateway for NASA to realize the potential of secondary launches and put in a place a program to utlize this archecture.

References: [1] Boynton, W. V., W. C. Feldman, S. W. Squyres, T. H. Prettyman, et al. (2002) *Science, 297,* 81-85.