PCROSS – Phobos Close Rendevous Observation Sensing Satellite A.Colaprete[1], J. Bellerose[1] and D. Andrews[1], [1]NASA Ames Research Center, Moffett Field, Mountain View, CA 94035, Anthony.colaprete-1@nasa.gov.

Introduction: PCROSS is a robotic pre-cursor mission consisting of a rebuild of the ESPA-based LCROSS spacecraft, tailored to interplanetary destinations. PCROSS aims to be a very low cost, innovative mission to address both science (e.g., MEPAG and Decadal Survey) and exploration needs (e.g., Mars Strategic Knowledge Gaps for human exporation). Specifically, PCROSS will obtain measurements at 10km, 5km, and close proximity via visible and thermal imaging, radio tracking, UV-visible and NIR spectroscopy, and surface probes ("Thumpers"). An "enhanced" payload could carry Synthetic Apperature Radar (SAR) or ground penetration radar. Proximity operations at Phobos are designed to refine shape and gravity field models, and surface properties through imaging, feature identification, bulk density, thermal properties, and mineral composition, and to obtain subsurface properties (e.g., strength and restitution), micro-structure, and mechano-electro properties (electric fields and charging).

PCROSS seeks to apply LCROSS capabilities-driven, design-to-cost, risk-tolerant approaches to an inexpensive scouting mission around $150M (not including launch vehicle). The LCROSS-heritage hardware has been simplified, and the avionics footprint shrunk and made more robust with options for selective redundancy appropriate for longer duration missions. There is an available ESPA port to accommodate auxiliary payloads or microsats/cubesats or probes targeted toward Mars, if launch vehicle mass constraints permit. PCROSS spacecraft propulsion makes use of a COTS-based Solar Electric Propulsion (SEP) system to accommodate a variety of launch options. PCROSS is designed to be a flexible secondary payload to make use of many opportunities of existing missions, possibly SLS demonstrations, or dedicated launches as desired.

PCROSS milestone-driven, streamlined project management approaches strike the right balance to drive rapid development, playing to the natural skills of this experienced team. PCROSS balances heritage reuse of existing systems to keep cost and technical risk in check, while demonstrating new capabilities such as onboard S/C management and terrain relative navigation via our partner, Draper Lab. These capabilities have utility to multiple NASA mission directorates, including HEOMD precursor activities and SMD science missions.

Technical Approach: The PCROSS mission goal is to return the information essential to a human visit to either of the moons of Mars, but for this presentation is specific to Phobos. NCROSS is a simple space vehicle, shortening design period from ATP to CDR; by using a simple ESPA ring AI&T time is reduced, shortening the CDR-to-shipment period; and by limiting cost, the mission can fit inside tighter budgets.

The baseline mission design takes advantage of the ESPA ring to rideshare launch with another mission. If PCROSS were to launch as a secondary payload to a primary mission, the SEP system enables PCROSS to orbit Mars and rendevous with Phobos for any initial departure condition of C3 between 10 and 25 km^2/m^2 . Given this initial launch condition PCROSS could reach Mars in 1-3 years, depending on the specific launch date and begin a 3-6 month mission (see Table 1). Other secondary opportunities with a greater initial C3 or a dedicated launch could improve on this timeline. Initially PCROSS enters into orbit around Mars and then maneuvers to rendezvous with Phobos. As it approaches Phobos PCROSS switches from Mars-centric to target-centric navigation with gated Rendezvous & Proximity Operations (RPO). At 10 km, PCROSS will begin a high-resolution mapping campaign of Phobos through partial orbit and hovering, characterizes debris fields and surface roughness through identification of surface features. Following this period of "global" mapping, PCROSS maneuvers to come as close as 5km from Phobos, further refining the characterization of the moon with studies of specific areas of interest. After this period of targeted observations, PCROSS will move to within 5 km of the moon's surface to perform extremely detailed surface mapping and release low-speed impactors called 'Thumpers' allowing surface/subsurface characterization.

The long range visible camera is the flight spare for the DAWN mission, and is used to locate the moon from long range and provide global mapping at resolutions of 2m/pixel at a range of 10 km. The camera eight-position filter wheel returns a panchromatic and seven spectral bands imaging for preliminary composition investigation.

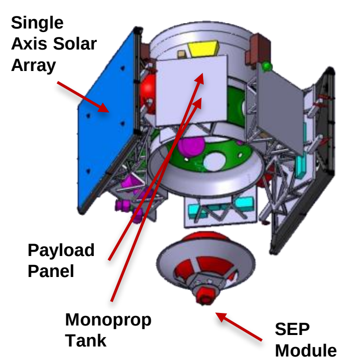

Figure 1. The PCROSS spacecraft builds on the LCROSS spacecraft design, tailored to interplanetary destinations. The ESPA design allows for PCROSS to be included as a secondary payload on EELV-type launch vehicalsl.

The short range visible and mid-IR cameras support the RPO, augmenting proximity operation capabilities by correlating surface features in both visible and infrared, and

Table 1: PCROSS SEP trajectory analysis for Dry Mass Margin (DMM) including propellant for rendezvous at Mars, spiraling in to Phobos after Mars insertion, and 20 kg for proximity operations at Phobos.

Launch	C3 (km2/s2)	Arrival	DMM %
Jul-15	19.1	Jun-18	36%
Aug-15	11.6	May-18	37%
Sep-15	10.1	Jun-18	38%
Nov-15	22.1	Jun-18	36%
Sep-17	8.9	Oct-20	36%
Oct-17	8.5	Jun-20	36%
Nov-17	13.7	Sep-20	34%
Jul-18	18.3	Jul-20	34%
Aug-19	10.4	May-22	31%
Sep-19	8.4	Jun-22	32%
Nov-19	7.6	Jul-22	32%

are keys to addressing navigation and operation SKGs such as morphology and topography. At a range of 5 km these cameras have resolutions of 0.3 and 2 m/pixel respectively. The UV-Visible Spectrometer (0.23-0.81 um) looks for the dust or debris field surrounding the target and any disturbing activity, maps composition, and can perform exosphere observations. The NIR Spectrometer (1.8-3.4 um) is focused on volatile identifican, including bound OH/H2O, but also allows for the identification of minerology. The Thumpers provide ground truth of surface and subsurface properties with onboard sensors, accelerometers, electrostatic probes, and a 'Crashcam' to capture surface details pre- and post Thumper impact. The Thumpers will also excave to a shallow depth (depending on impact speed and surface properties), revealing subsurface materials for observation by the remote sensing instruments. An enhanced payload includes a SAR to support detailed surface and subsurface morphology, near surface stability and composition.

The PCROSS leans heavily on LCROSS architecture to enable interplanetary missions from a cheap rideshare or dedicated launch. The propulsion subsystem baseline uses two small Busek Hall Effect Thrusters, 2kW of single axis solar arrays, and a rebuild of the DAWN Xenon tank. Optional PCROSS solutions include Arcjet lower cost where the Mission ∂V requirement is lower. On arrival, the SEP and Arcjet versions use a small monoprop system based on LCROSS to support 6 DoF maneuvering about the target.

PCROSS reuses the LCROSS avionics with the RPO components incorporated in the payload Data Handling Unit (DHU), simplifying the camera to RPO interface. The RPO system uses angles only navigation during the 100 to 10km approach and terrain relative navigation once the target has been characterized.

PCROSS carries a gimbaled 4ft X-Band HGA, and a 50W TWTA for data return, supporting a data rate of 60kbps from the target to the 34m DSN ground stations, and 30kbps to the 30m DLR ground station

The PCROSS baseline mission duration can vary from 1 to 3.5 years, depending on launch parameters. During this time PCROSS is controlled out of the Multi-Mission Operations Center (MMOC) at Ames Research Center, which verifies and uploads spacecraft commands and receives raw spacecraft telemetry. The MMOC links directly to the DSN, and is supported by Remote Operations Center(s) (ROC) that enables cost-efficient backroom support on RPO and spacecraft operations. Ground interaction from the MMOC/ROC while at Phobos will include RPO gate decisions as the mission moves closer to the moon.

During cruise phase, orbit determination and trajectory prediction are carried out using DSN tracking data obtained every few days with cost effective tone beacon monitoring between contacts.

Management and Cost: The PCROSS project philosophy utilizes proven approaches of the on-time, on-cost LCROSS project. PCROSS is not about maximizing performance, but containing cost within a clean set of requirements. The Project is staffed with a lean-team to maximize value of the mission. The approach presumes that the team works principally on the Mission with lightweight extraneous reporting.

PCROSS cost was developed based on grass-roots estimates tied to heritage experience. A complete WBS has been established and is the basis for both the Life Cycle Cost Estimate (LCCE) and the project Integrated Master Schedule (IMS). Much of the PCROSS costs are tied to the SEP spacecraft as expected. The spacecraft bus is very similar to LCROSS and the SEP propulsion system is heritage Busek. The Aerospace Corp rules of thumb on relative WBS cost weighting are in good alignment for PCROSS. Total PCROSS cost is about $150M (without launch vehicle) with 50% of that for spacecraft and 10% for the baseline payloads.

The NCROSS spacecraft development schedule is 35 months, which is 5-months longer than LCROSS to accommodate the differences between the two spacecraft, including the SEP propulsion system. Five months funded schedule reserve (FSR – 15% of development time) is allocated to spacecraft development which shares the critical path with mission operations. Mission operations development and training is cleverly organized for Just-In-Time (JIT) delivery making efficient use of labor costs. Given the potentially long cruise phase to Mars, the project staffing will be streamlined with the bulk of the team going away, returning 6-months before Mars arrival to write procedures and train for the final phase of the mission. This approach dramatically reduces the redundant (and costly) activities associated with long cruise-phase missions.