INNOVATIVE STRATEGIES FOR ASTEROID PRECURSOR EXPLORATION.
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Introduction: Our ambitions for space exploration have outpaced our ability to afford frequent visits to targets of interest. Launch costs and development times continue to increase for getting large space craft to deep space. This particularly affects workforce development and imperils opportunities for new development starts. A new paradigm for planetary exploration is clearly needed. The time has come to leverage technology advances (including advances in autonomous operation and propulsion technology) to reduce the cost and increase the flight rate of planetary missions, while actively developing a scientific and engineering workforce to achieve national space objectives.

Background: As demonstrated by the 1994 Clementine mission, planetary exploration missions maximizing off-the-shelf components to obtain a focused set of measurement objectives can make meaningful contributions to advancing the frontiers of space exploration by achieving numerous science and exploration objectives. Near-Earth Objects [NEOs] are interesting candidates for missions of this nature. While results from recent missions (i.e., Hayabusa, NEAR) have dramatically increased our understanding of asteroids, important questions remain. For example, characterizing the properties of asteroid regolith is an important consideration for understanding telescopic observations of asteroids, as well as preparing for future asteroid human exploration.

Mission Overview: Many possible targets exist for future NEO exploration; since very few NEOs have been explored by spacecraft, many exploration opportunities exist. For this mission concept, we assume that the target is one of two C-type asteroids that are potential human exploration targets due to their size (greater than 250 m in diameter). C-type asteroids are of both great scientific interest because they offer the opportunity to investigate primordial Solar System materials and gain insights into the origin and evolution of the early Solar System and exploration interest, because the presumed high volatile content offer interesting possibilities for in-situ resource utilization.

The first candidate, with a launch opportunity of July 2021, is 1993 JU3. This asteroid was a possible target for the Hayabusa -2 mission. The other candidate, with a launch opportunity of June 2017, is 1989 UQ. Both of these asteroids are cited as potential targets for the Marco Polo mission, ESA's concept for a NEO sample return. We selected the earlier opportunity, 1989 UQ, because it is more difficult. The same SEP system can also do the July 2021 launch to 1993 JU3.

Traditional missions of this type would build a small 1-2 kW conventionally propelled spacecraft and launch it into a C3=0 trajectory using a large launch vehicle. Higher power electrically propelled spacecraft were generally not considered because the size, mass, and cost of the solar array and electric propulsion system did not allow a significant savings in total costs.

We made the decision to leverage the recent advances in next generation gridded ion thrusters seen by the NEXT propulsion team at GRC, along with the advancements we've seen on two USG and Boeing funded technology initiatives: The AFRL IBIS (Integrated Blanket/Interconnect System) and the DARPA FAST (Fast Access Spacecraft Testbed) Programs. These programs both pushed the state of the art for solar power generation system power density from ~ 35 w/kg levels to upwards of 135 w/kg via the use of innovative deployment structures, 33% IMM Solar cells, and high voltage (200V) power management and distribution technologies. These arrays also package into much smaller volumes than a conventional array.

Leveraging these two new technologies allowed us create a small spacecraft with a very high total impulse. This in turn allowed us to offload most of the impulse required to get to C3=0 from the launch vehicle to the spacecraft, resulting in the smallest launch vehicle that could accommodate the spacecraft, in this case a Minotaur IV. The Minotaur IV, along with leveraging of the NEXT, FAST and IBIS programs results in a significant cost savings over a conventional approach to this mission.

Given these assumptions, a 20kWe SEP spacecraft is about 1600 kg with a tank capacity of 425 Kg of Xenon. Selecting the Minotaur IV launch vehicle for LEO insertion is the lowest cost option that has sufficient fairing size and throw mass capability. It is important to select the correct orbit insertion altitude because of the stability of the large arrays. It was determined that a 400 km altitude reduces the aerodynamic drag and gravity torques to acceptable levels of control. The performance of the Minotaur IV is 1650 kg to a 400 km orbit.

Mission Objectives: The measurement objectives described here would enable an outstanding scientific yield while obtaining the necessary data to enable future human asteroid activity. These objectives include:

1) Characterization of the radiation environment in the vicinity of a near-Earth object

Science: Solar physics and space weather

Human Exploration: Countermeasure design, life support requirements

2) Determine the surface mineralogy and geochemistry of the asteroid surface

Science: Meteorite/Asteroid connections

Human Exploration: In-situ resource utilization

3) Disambiguate physical properties of the asteroid regolith

Science: Spectroscopic interpretation, impact processes

Human Exploration: Human health and safety, hardware design, in-situ resource utilization industrial process definition

4) Map the topography of the asteroid surface

Science: Asteroid geophysics, morphology, impact processes,

Human Exploration: Landing site selection, operational simulations, autonomous descent preparation.

Payload Elements: The instrument suite consists of:

• A medium-to-high resolution imaging system to provide visible-light images of the asteroid for scientific and navigational purposes. This would be nearly an off-the-shelf instrument.

• An ultraviolet/visible/near-infrared spectrometer in order to apply principles of reflectance spectroscopy to map the composition of the asteroid's surface over the 0.5 micron to 2.5 micron wavelength range. This is the most commonly-used and well-understood current method of investigating asteroid surface composition remotely.

• A laser rangefinder/altimeter to map the shape and topography of the asteroid. We note the possibility that the Laser Altimeter could be combined with the remote Raman system described below, an exciting concept that is worthy of further investigation as this effort moves forward.

• A radiation environment sensor in order to measure and quantify the effects of radiation on tissue-equivalent plastic.

• An orbital Raman system (ORS) to provide definitive information about the composition and physical properties of the asteroid surface. An ORS would provide a unique opportunity to study the composition and physical properties of a planetary surface. Raman spectroscopy provides some definite advantages over other spectroscopic techniques including the unique identification of a wide range of chemical substances and minerals, including organics, gases, and ice. Raman systems generally have the following components: a laser, transmitting optics to collimate the laser light, receiving optics, and a (preferably gated) detector with photo-multiplication.

Mission Concept of Operations: Two NEXT thrusters operate at full power during the planetocentric and heliocentric phases of the mission, with the extra power shunted back to the array.

Planetocentric Phase: Meeting the Launch vehicle performance constraints does require some help for the heliocentric transfer. The solar arrays consist of two identical wings producing a total power of 20 kWe. Since we are limited in tank capacity, the HEO orbit provides a lunar Swing-by, enabling heliocentric departure energy of 2 Km2/sec2.

Heliocentric Phase: After the lunar swing-by the SEP bus departs with a positive energy on a heliocentric transfer to 1989. The total flight time is 281.5 days, and the SEP system uses 118.5 kg of fuel. The overall mission takes 555 days to rendezvous with the target asteroid with the first two mission phases roughly equal.

Asteroid Phase: Once asteroid rendezvous is achieved, our current baseline concept of operations is a 6-month primary exploration mission with an option to continue for longer if supported by the hardware.

First 2 months: This mission phase involves an initial characterization of the asteroid.

Month 2-6: Orbiter continues mapping mission, in a slightly lower elliptical orbit. This gives the science team a chance to do discovery-driven science on the asteroid surface and obtain more Raman observations, using the orbiter to follow up on any interesting science results.

Primary mission ends at 6 months: If fuel reserves and hardware continue to be operational, we anticipate that the asteroid science investigation could be extended or if fuel reserves permit and energetically favorable flyby opportunities exist the spacecraft could be retargeted to another NEO.

Conclusion: Our concept closes significantly below the current Discovery Mission Cost cap of $425 million and includes the Minotaur IV launch vehicle. Our parametric cost estimates also include a 30% margin on top of the standard reserve assumptions for mass and LV contingencies. This concept further sets the stage for human exploration by doing the type of science exploration needed as a precursor to a human visit to a NEO and flight demonstrating enabling technology advances (high power generation, SEP) for human deep space missions.