THE ASTEROID BELT CYCLER (ABC) CONCEPT: A COMPREHENSIVE ASTEROID BELT SAMPLE RETURN CAMPAIGN ENABLED BY CREWED PRESENCE IN CISLUNAR SPACE.

M. Fries[1], L. Graham[1], K. John[1], J. Hamilton[1], F. McCubbin[1], P. Niles[1], E. Stansbery[1], L. Welzenbach[2]. [1]Astromaterials Research and Exploration Science (ARES), NASA Johnson Space Center, Houston, Texas 77058, [2]Planetary Science Institute, Tucson, Arizona 85719. Author email: marc.d.fries@nasa.gov

Introduction: The Asteroid Belt Cycler* (ABC) is a mission concept that capitalizes upon a crewed presence in cislunar space to comprehensively sample the asteroid belt using robotic sample return (SR) spacecraft. In place of current single-use SR spacecraft, ABC spacecraft would be re-usable and would visit the asteroid belt to collect samples and contextual scientific data from selected bodies and then return the sample(s) to a crewed platform in cislunar space (e.g. the Earth-Moon L1 Lagrangian point). The astronaut crew would refit and refuel the ABC spacecraft to sample another target, and would then carry the sample to Earth inside the crewed vehicle. This system allows comprehensive sampling of the Asteroid Belt, re-use of the SR spacecraft, and improved protection of samples from thermal effects of re-entry than are possible in a small sample return capsule (SRC). The ABC concept may also have important technological and operations parallels with future efforts to obtain resources from Asteroid Belt sources, and the sample suite obtained would be useful for resource identification towards that end.

It is important to note that ABC is not intended as a cost-savings activity versus single-use SR, but rather it leverages a future crewed presence in cislunar space to enable comprehensive scientific exploration of the entire Asteroid Belt. ABC targets might also include Near-Earth Objects (NEOs) and Jupiter-family comets (JFC). The basic concept might also facilititate SR missions to bodies requiring especially distant apihelia (due to reduced spacecraft mass versus single-use SR) and/or stringent Planetary Protection requirements (through crewed interaction with samples prior to Earth return).

*The word "Cycler" as used here is intended as shorthand for a re-usable spacecraft that makes repeated trips between cislunar space and Asteroid Belt targets.

Nominal ABC Mission Architecture:

1) A SR spacecraft visits a target in the Asteroid Belt (or NEO, or JFC, etc.) and collects sample(s) and contextual science data.
2) The SR spacecraft then delivers samples to a crewed platform in cislunar space. The astronauts' Earth return capsule would accept the samples, carry them internally, and provide refrigeration if necessary.
3) Astronauts service the SR spacecraft, refueling and refitting it. Refit would include emplacement of clean sample collection hardware and may include addition/subtraction of scientific instruments, addition of small solid rockets for post-sampling escape from larger bodies (e.g. Ceres), replacement of ion engine electrodes, etc.
4) The SR spacecraft departs to sample its next target body.
5) The crewed spacecraft returns the sample(s) to Earth protected inside the capsule, as was performed in the Apollo program.
6) Repeat steps 1-5.

Scientific Rationale: Sample return from asteroids is a very important means of understanding the early history of the Solar System. The Asteroid Belt is composed of 26 classes of asteroids, as defined by the Small Main-Belt Asteroid Spectroscopic Survey (SMASS) [1]. This is material left over from the early assembly of the Solar System but it was spared incorporation into large planets and so retains much of the chemical, mineralogical, morphological, and isotopic signatures of the young Solar System. The asteroids range from silicate-rich "S" type bodies in the inner Asteroid Belt to carbonaceous "C"-type bodies which predominate at the reaches of the Belt closest to Jupiter. While inferred matches can be surmised between asteroid spectral classes and meteorite types, only SR can establish definitive ground truth that a given asteroid spectral class is appropriately assigned to a meteorite type.

Once an asteroid is matched to a given meteorite, NASA's and the scientific community's investment in the chemical, mineralogical, morphological, isotopic, and other research into meteorites can be directly applied to known asteroid bod(ies). This provides the parent-body context that is largely missing in meteorite studies, improving our ability to describe the processes that formed our present-day solar system. Gaining the ability to tie research on a given meteorite to a known parent body immediately and dramatically expands our understanding of the parent body and its asteroid spectral class. To date, only one asteroid has been definitively matched to a meteorite type by SR; S-type asteroid 25143 Itokawa which JAXA's Hayabusa-1 mission paired with the LL ordinary chondrites [2,3]. The OSIRIS-REx and Hayabusa 2 SR missions may also provide a meteorite type match for their respective targets 101955 Bennu of asteroid class B and 162173

Ryugu of asteroid class Cg. Currently, twenty-four asteroid reflectance classes are unpaired with known meteorite types, comprising the vast majority of the Belt in both mass and number of bodies.

In addition to the 26 reflectance classes of bodies in the Asteroid Belt, there are a number of individual targets of special scientific interest to include Ceres, Psyche, Vesta, etc. which could be specific targets of ABC sorties. NEO and JFC bodies may also be targets depending on mission architecture considerations.

Operations/Architecture Rationale:

Mass/Complexity Considerations: Current NASA SR missions focus on a single target and include all the SRC hardware necessary to return sample(s) through the Earth's atmosphere to a waiting Curation facility. The ABC concept removes the SRC mass and components from the SR spacecraft design, decreasing SR mass and complexity. The use of replaceable sample collection hardware also allows re-use of the expensive SR spacecraft for multiple SR missions. Visits to multiple bodies are currently possible, as demonstrated by the Stardust-NExT extended mission to comet Tempel-1 after the primary Stardust mission ended [5], visits to both Vesta and Ceres by the Dawn mission [6], and visits to both Pluto and 2014 MU69 (in January of 2019) by New Horizons [7].

Delta-Velocity Considerations: Since the SR spacecraft does not have to decelerate to a velocity survivable for SRC entry but only to within capture velocity for cislunar space, higher return velocities might be permissible. This may translate into higher allowable aphelion distances for SR missions and may support SR from outer Solar System objects.

Cold Sample Handling Considerations: In the case where mission science goals require cold or cryogenic SR, hardware must currently be included to protect the samples from the thermal pulse introduced by Earth atmospheric entry. This produces the ironic condition where the mission must carry relatively complex hardware through the entire mission just to deal with effects that occur after the samples that are returned to Earth (but before they are collected). Experience with the Apollo mission shows that returning samples in a large, crewed capsule offers significantly greater thermal protection than small SRCs such as those used in the Genesis and Stardust missions. By passing off the requirement for end-stage thermal protection from the SR spacecraft to the crewed vehicle, risk to the samples is reduced and the complexity/cost of the SR spacecraft is reduced significantly. This may prove to be an important enabling technology for returning cold samples.

Cost Considerations: The ABC concept draws its value not from cost savings but from leveraging a future crewed presence in cislunar space to enable comprehensive sampling of the Asteroid Belt and other inner solar system bodies. SR mass savings, sample thermal protection, and cislunar entry velocity aspects of ABC may also facilitate SR missions to bodies that are beyond current capabilities. In terms of general cost considerations, however, costs would be reduced by re-use of SR spacecraft for multiple missions and elimination of the launches needed for single-use SR missions. Costs would be increased if dedicated crewed missions were required.

Additional Missions: It is worth noting that the core concept of utilizing a crewed presence in cislunar space to facilitate farther, more capable SR missions is not restricted to the ABC concept. One-off SR missions to distant or difficult targets such as Saturn's rings (McCubbin F. et al, this meeting) or Mars sample return (Lewis R. et al, this meeting) could be enabled by passing off some traditional SR spacecraft functions (Earth atmosphere entry, Planetary Protection functions, etc.) to an astronaut crew.

Relevance to the Planetary Science Vision 2050 Workshop: This abstract most directly serves several themes of the workshop, namely Origins, Life, and Threats/Resources.

Origins: Obtaining a comprehensive suite of Asteroid Belt samples will substantially improve our understanding of the formation and evolution of the inner solar system through both direct sample analysis and by facilitating matching asteroid spectral classes with meteorite types.

Life: Obtaining a comprehensive suite of Asteroid Belt samples will assist in constraining the type and quantity of volatiles delivered to the early Earth from Asteroid Belt sources.

Threats and Resources: The comprehensive sample suite ABC provides would inform resource prospecting in the Asteroid Belt. ABC missions to NEOs would also directly serve understanding of the composition and structure of hazardous bodies.

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