Poor Man's Asteroid Sample Return Missions. R. Landis[1] and L. Graham[1], [1]NASA Johnson Space Center, 2101 NASA Parkway, Houston, Texas 77058, rob.r.landis@nasa.gov

Introduction: A cislunar platform at a Near-Rectilinear [Halo] Orbit (NRO)[1] in the vicinity of the Moon could provide an opportunity for a small near-Earth asteroid (NEA) sample return mission at relatively low cost. There are a couple potential small (0.1-1m) object target dynamical groups for this mission including:

1. small Earth orbiting, transient "mini moons" or quasi-satellites in temporarily captured orbits such as asteroids 2006 RH_{120}, 2016 HO_3, 2003 YN_{107}, etc. [1]
2. potential Earth Trojans in Sun-Earth Lagrangian point 4 (SEL_4) or Earth-Sun Lagrangian point 5 (SEL_5), such as 2010 TK_7. [2]

Concept of Operations: Utilizing telescopic assets to locate these low-Δv targets is the key essential first step., Once identified a small robotic spacecraft in NRO can perform rendezvous and proximity operations to examine, capture and return these small natural objects to the Deep Space Gateway (DSG) in NRO.

Mission Vehicle: The mission vehicle has a mass of (an estimated) 700 kg with a Δv capability of ~4 km/s) enabling RPO with either a minimoon, a retrograde, elliptical Earth orbiting object, or a Trojan at SEL_4. Sample return canisters would be limited to approximately 1kg sample mass. A limited sampling acquisition capability would also exist on the mission vehicle in the event that the orbiting object was too large to fit within the 1kg mass capability. In all three target family capture scenarios, the vehicle would use electric propulsion systems.

Detection and Rapid Response: A few of these objects have been detected from ground surveys. The key to finding these; however, is a space-based survey optimized in the infrared, away from the vicinity of the Earth, such as NEOCam [3]. Once such a relatively easily accessible NEA is detected, the existing DSG-based on-orbit asset is necessary to quickly respond to a mission opportunity due to the relatively transient nature of these objects in orbit and the potential mission duration timelines using electric propulsion.

[1] NROs are a subset of L_1 and L_2 halo orbit families. NRO is a possible candidate orbit for the DSG.

Planetary Protection: Depending on the compositional type, the scientific consensus is that asteroids are not likely to support life and therefore do not present a risk to humans [4], and therefore no special handling or containment restrictions need be provided at the DSG for the returned samples. A few exceptions do exist and would warrant an appropriate curation process to ensure no contamination from the vehicle or to the crew of the DSG. [5]

Mini moons: Small asteroids may routinely be captured by the Earth's gravitational field for limited durations in time and thus become temporary natural satellites. Entering into dynamic Earth orbits (pulled by gravity from Earth, the Moon and the Sun), they may only stay for a month, a year, or decades and then depart Earth's vicinity. 2006 RH_{120}, 2016 HO_3, 2003 YN_{107} mentioned above are examples of such bodies and there are several others.[2]

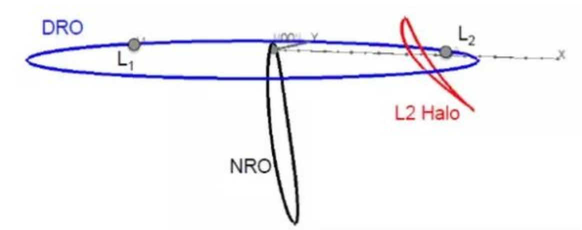

Figure 1: Depiction of NRO with respect to Deep Retrograde (DRO) and L_2 (EML_2) Halo orbits about the Moon

Earth Trojans: In 2011, the NEOWISE spacecraft identified the first (and, so far only) Earth Trojan, 2010 TK_7. [2] Such objects can be captured at Lagrangian points of stability where the gravitational effects from two larger objects (in this case, the Sun and the Earth) will hold a small object in a stable orbit. Two of these points (SEL_4 and SEL_5) are located either 60º ahead or behind the Earth in it's orbital plane, as shown in Figure 2. 2010 TK_7 precedes the Earth at the SEL_4 location and is approximately 300 meters in size, oscillating about SEL_4. At closest approach, 2010 TK_7

[2] Other quasi-satellites include: 2004 GU_9, 2006 FV_{35}, 2013 LX_{28}, 2014 OL_{339}. These bodies are not gravitationally bound to the Earth. There are also more bodies in horseshoe type orbits; again, loosely and temporarily semi-bound. These asteroids migrate from horeshoe orbits to quasi-satellites and back again.

is approximately 20 million kilometers from the Earth and at a high inclination of 20.9° to the ecliptic and thus requires 9.4 km/s Δv_{total} to reach it. This represents a difficult (but not impossible) sampling target to reach with existing propulsion systems.

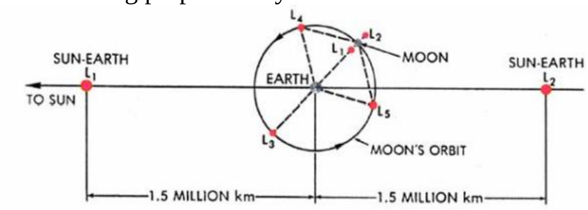

Figure 2: Earth-Moon Lagrange locations (with respect to SEL_1 and SEL_2 locations)

There may be other Trojans yet-to-be discovered. Several studies have been done to estimate the probability of finding more of these Earth Trojan asteroids [6, 7]. Dvorak *et al*. used analytical mapping and numerical methods in dynamical models. By taking into account clone orbits, the capture and escape of Trojans, and the stability region of the Lagrange points, they predict that other Trojan asteroids exist at Earth's stable Lagrange points [6]. Mikkola and Innanen (1990) performed numerical integrations to demonstrate that there exists stable, 1:1 resonance, asteroidal orbits for Earth [7]

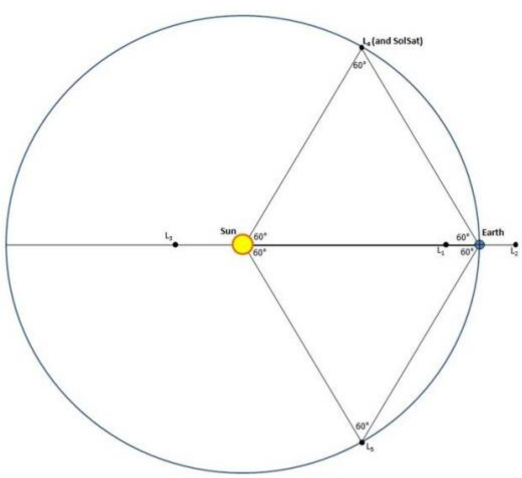

Figure 3: Sun-Earth Lagrange Locations

Conclusion: It is feasible that a small, relatively inexpensive sample gathering spacecraft can be based at the DSG and be able to transit to different locations to obtain NEA (or lunar ejecta samples). Searching for these objects in the course of regular NEA survey efforts (via ground- and space-based assets) might yield other opporotunties for sample return. *In situ* characterization of these samples could lead to cultivating immediate benefits in science, exploration, and resource utilization.

References:

[1] M. Chyba, T. Haberkorn, R. Jedicke. (2016) *Minimum fuel round trip from a L 2 Earth-Moon Halo orbit to Asteroid 2006 RH 120*. B. Bonnard, M. Chyba. Recent Advances in Celestial and Space Mechanics, Springer, Recent Advances in Celestial and Space Mechanics, <10.1007/978-3-319-27464-5>. <hal-01207088>

[2] K. John, L. Graham, P. Abell. (2015) *Investigating Trojan Asteroids at the L4/L5 Sun-Earth Lagrange Points*, 46th Lunar Planetary Science Conference (#2845), Houston, TX. https://www.hou.usra.edu/meetings/lpsc2015/pdf/2845.pdf,

[3] A. Mainzer. (2009) NEOCam https://www.lpi.usra.edu/sbag/meetings/sbag2/presentations/Mainzer_SBAG2009_NEOCam.pdf

[4]Task Group on Sample Return from Small Solar System Bodies, (1998) *Evaluating the Biological Potential in Samples Returned from Planetary Satellites and Small Solar System Bodies*, National Academy Press.,

[5] NASA Procedural Requirements (NPR) 8020.12.

[6] R. Dvorak, C. Lhotka, & L. Zhou, (2012) *The orbit of 2010 TK7. Possible regions of stability for other Earth Trojan asteroids*, Astronomy & Astrophysics.

[7] S. Mikkola, & K. Innanen (1990) *Studies on solar system dynamics. II - The stability of earth's Trojans*, Vol. 100 n. 1, The Astronomical Journal.