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Science Context: MiniMoons are near Earth asteroids that travel 'weak stability boundary' trajectories, entering and exiting cislunar space through Lagrange point regions and remaining in geocentric orbits for periods ranging from months to years [1] . They range in size from tens of centimeters to tens of meters. These objects are relatively difficult to observe from Earth, although less so now with increased sensitivity and availability of ground-based assets to look for NEOs over the last ten years. Statistical analyses based on these limited observations indicate that at any given time up to a dozen of the smaller of these objects are in cislunar space, entering through Lagrange points at the rate of about one a month. In fact, these small objects, a subset of which become MiniMoons for the Earth and other planets, may represent one of the largest populations of objects in the solar system. Why do MiniMoons matter? Asteroids are 'rosetta stones' of solar system formational history. Growing evidence indicates that they are far more heterogeneous in composition and formational history and far more numerous than previously assumed. Asteroids passing close to and potentially striking the Earth represent not only a potential threat, but a potential source of resources (volatiles, organic material, metals) for use in space exploration. Characterizing them (determining bulk and variation in elemental and mineral composition, density, surface properties, dust distribution, as well as interaction with surrounding particle and field environment), tagging, and even sampling these asteroids, and systematically testing the technology that could be applied to other asteroid populations, could create the basis of a breakthrough in our understanding not only of asteroids, but of solar system processes and resources. We are exploring the MiniMoon mission concept as a cubesat applicaiton which could be performed economically while maximizing science and technology gain.

Mission Concept: The MiniMoon Orbiting Lagrange Observatory (MOLO) is an operationally complex, multi-platform Cubesat concept proposed as an inter-center collaborative project between GSFC and JPL. The MiniMoon concept envisions 'targets-of-opportunity' encounters with incoming minimoons, via multi-body (dynamical) processes to support close encounters with small asteroids temporarily captured in the Earth-Moon region. The point of access would be Lagrange points, where cubesat platforms equipped with sensors for characterizing asteroids would remain in halo orbits, acting as an observatory. Once incoming objects were detected and trajectories determined, the 'closest' cubesat could, with minimal delta V, be launched on a rendezvous trajectory. Earth-based observatories would play a role by observing in the direction of Lagrange points, to provide 'early warning' of incoming objects.

Current Status: The MOLO working group leverages GSFC expertise in multi-body trajectory analysis in cislunar space, the asteroid proximity operations analysis for OSIRIS-Rex, and recent work in deep space science-requirements driven Cubesat instrument and bus design, development, at GSFC and JPL, as well as JPL's connection to an extensive ground-based observatory network (to expand knowledge and statistics of the MiniMoon population) as part of the intercenter collaboration effort.

Development Plan: We are in the process of developing science requirements which have implications for investigations involving approaching and in situ measurements, contact or sampling strategies and mechanisms.

Our next steps include modeling and exploring options for Cubesat transportation (chemical, sails, electrical propulsion) to these MiniMoons and as well as the extent ground observational support is needed for their advanced detection. We also plan to model rendezvous trajectory designs from Lagrange points via multi-body trajectories, associated Lagrange point orbits, and the proximity operations at asteroids in the Earth-Moon (EM) region, as well as support the modeling of the trajectory transport mechanisms (EM capture and expulsion) of this asteroid population.

Inputs from the flight dynamics and proximity operations analysis will allow analysis of: 1) based on propulsion requirements and available mass and volume, what payloads could be carried (including cameras, mechanical and electrostatic property 'touch' sensors, dust analyzers); 2) based on proximity operations analysis, the nature of traverses and in situ sampling that could be performed (number of 'touches', number and length of traverses); 3) based on proximity operations analysis, the potential for tagging and dust collection for in situ analysis.

References: [1] Lo M. (2001), http://www.gg.caltech.edu/~mwl/publications/papers/IPSAndOrigins.pdf