ROADMAP TO THE SOLAR SYSTEM - TRANSASTRA'S PLANS FOR ACHIEVING PRACTICAL ASTEROID ISRU THROUGH INCREMENTAL TECHNOLOGY DEVELOPMENT

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Introduction: TransAstra Corporation has developed a roadmap of technology development, ground test, in-orbit experiments, and demonstrations that will pave the way for near Earth Asteroid (NEO) resource extraction and utilization. The Sutter compound matched filter (CMF) telescope technology will first be demonstrated using a 30 cm ground telescope, then in LEO also using a single 30 cm telescope on a cubesat platform to verify in space performance, culminating in the launch of 3 Sutter Ultra Spacecraft, each with 100 30 cm telescopes, into a novel pseudo-geocentric orbit that will provide unmatched detection, tracking, and characterization (prospecting) of 1,000s of small NEOs that are currently undetectable by any existing or planned ground or space-based system [1]. The Apis™ family of spacecraft use inflatable reflectors to concentrate solar power for both propulsion (using the Omnivore™ thruster capable of using water from Earth or volatiles (primarily water) extracted directly from NEOs as propellant), and as the means for extracting the resources from the candidate small asteroids. Initial ground demonstrations are planned of theinflatable reflectors to insure adequate optical performance. The first in-space demonstration will be the Mini Bee which will capture and process a half meter diameter simulated asteroid in Low Earth Orbit to show end-to-end proof of concept. This will lead to the launching of the initial Honey Bee class spacecraft, capable of processing NEOs up to 10 meters in diameter and returning the extracted volatiles to a convenient location in the cis-lunar system where it can be further processed for use by NASA or commercial firms to provide propellant for other spacecraft and/or consumables for human use. A further scaled up Queen Bee will eventually be developed, capable of processing NEOs up to 40 meters in diameter. This roadmap will lead the way to a "gold rush" in space and make space exploration, commercialization, and colonization feasible and affordable.

Sutter™ Roadmap: We propose a new type of low cost, high performance, *aggregated* imaging system, a Compound Telescopes with Matched Filter (CTMF) system, for a series of space missions that we call Sutter™, named after the Sutter's Mill discovery which led to the California gold rush. Like its namesake, Sutter™ Ultra will discover and characterize valuable resources that will lead to an economic *rush*: this one in space. The baseline deployment of the Sutter™ Ultra operational mission involves a constellation of three spacecraft in an innovative, Pseudo Geocentric Distant Retrograde Orbit (PRO) to achieve high survey volume coverage and find new small asteroids passing close to Earth.

While the Sutter™ system's PHO performance statistics are impressive, the system's superiority is demonstrated when considering the objects that they are specifically designed to assay: small ISRU and human exploration targets. For comparison, the JPL NHATS website lists a total of about 2,000 objects that require a $\Delta V<12$ km/s for a round trip journey from Earth. That still leaves the return leg with up to 12 km/s of entry speed into Earth's atmosphere. In 2016 all the ground-based surveys discovered about 300 objects that meet these criteria, but Sutter™ would discover nearly 3× as many objects on an annual basis that meet a much more stringent criteria of $\Delta V<3$ km/s to return resources to cislunar space. Of the ~200 low ΔV objects discovered annually by Sutter™ Ultra, about 50 will be objects with high water content suitable for H_20 mining. Sutter™ Ultra will discover water bearing objects at an average of one every week.

We have used two independent cost models ([2]Hamaker 2016 and [3] Claybaugh 2016) which agree and validate that this entire constellation can be developed for less than $400M using private sector methods. This cost includes first unit costs for design and development of the spacecraft at $126M, $101M for the second spacecraft, and $80M for the third spacecraft. Nonrecurring development of the telescope unit is estimated to be $8M. Average telescope production cost is $140K based on an 80% learning curve. Operations system development cost is projected to be $13M and flight operations for 3 years is $25M. The Falcon 9 launch cost is ~$62M.

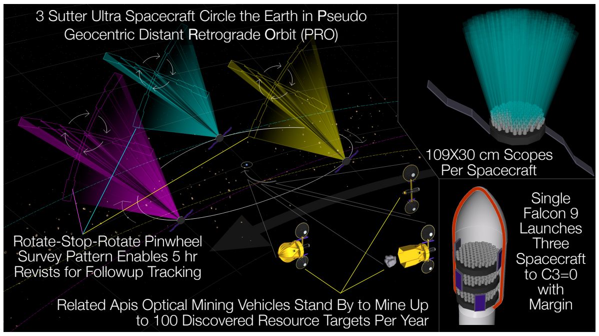

Figure 1 – Elements of the Sutter Ultra Mission

Apis ™ Roadmap: Apis™ is a breakthrough mission and flight system architecture designed to revolutionize NASA's human exploration of deep space and to enable massive space industrialization and human settlement. Apis™ is enabled by Public Private Partnership (PPP) and a series of inventions and innovations including the Optical Mining™ method of asteroid resource harvesting, the Omnivore™ solar thermal thruster, and a spacecraft architecture that uses highly concentrated sunlight as a far lighter, less expensive, and higher performing alternative to electric power in space. Mission and business analysis funded by a combination of private, NIAC, Emerging Space, and SBIR sources shows $300B in savings for NASA HEOMB while enabling affordable cis-lunar tourism and space industries.

The Apis™ spacecraft design and mission architecture for asteroid In-Situ Resource Utilization (ISRU), the Omnivore™ solar thermal thruster, and the Optical Mining™ technique have been the subject of multiple privately funded efforts at TransAstra along with a collection of low TRL NIAC and SBIR contracts and grants to advance the innovative and interconnected technologies required to implement the exciting missions contained in our roadmap that will make the benefits of asteroid ISRU available to NASA and commercial firms.

These Innovations include:

- The ability to extract resources from candidate asteroids using concentrated light via Optical Mining™,
- The use of thermal energy from concentrated sunlight to provide propulsion using water as a propellant with the solar thermal Omnivore™ thruster, and
- The Apis™ spacecraft design to support the rendezvous, extraction, and return of resources to the cis-lunar system for use.

These innovations, along with the innovative Apis™ spacecraft and mission design, all combine to provide their maximum benefit as part of the overall Apis™ mission architecture and roadmap. Each consists in elevating the technology readiness level of the entire Apis™ spacecraft design and mission architecture to the point that the initial Mini-Bee™ mission can be proposed for flight development and demonstration in low Earth orbit. Its success establishes the commercial potential of the Honey Bee and Queen Bee designs for harvesting NEO resources and returning them to the cis-lunar vicinity for use by NASA or other commercial firms at a fraction of the cost of launching them from Earth. Mission and business analysis funded by a combination of private, NIAC, Emerging Space, and SBIR sources shows $300B in savings for NASA HEOMB while enabling affordable cis-lunar tourism and space industries.[4,5]

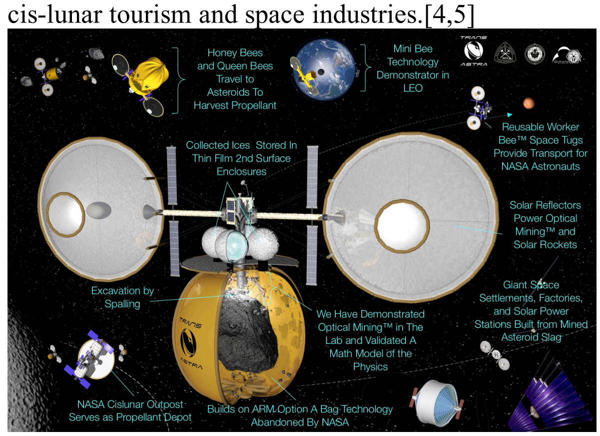

Figure 2: Apis™ Roadmap Elements

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