GEOPHYSICAL RECONNAISSANCE ASTEROID SURFACE PROBE SCIENCE OBJECTIVES.

Kieran A. Carroll[1], Henry Spencer[2], Robert E. Zee[3], Martin Connors[4], [1]Gedex Systems Inc., 407 Matheson Blvd. East, Mississauga, Ontario, Canada L4Z 2H2, kieran.carroll@gedex.com, [2]SP Systems, [3]University of Toronto Space Flight Laboratory, [4]Athabasca University.

Introduction: Here we describe a small (12U cubesat) sized spacecraft designed to make geophysical measurements on the surface of an asteroid, and the asteroid science objectives which can be addressed using those measurements. Gedex and the Space Flight Laboratory (SFL) are developing the "Geophysical Reconnaissance Asteroid Surface Probe" (GRASP) spacecraft (Figure 1) to be a low-cost means for conducting fundamental asteroid science, as well as for exploring for possible natural resource deposits in asteroids [1]. To that end, GRASP's design is based on the "Microspace" approach that SFL has used on many successful, very low-cost and high-capability nanosats and microsats in low Earth orbit (LEO). In particular, by following this design approach, GRASP is by design robust against operational failures seen in some previous small deep-space missions.

Science Objectives: The Canadian Space Agency recently commissioned members of the Canadian planetary science community to establish science objectives in several areas of planetary science, to guide CSA's decision-making regarding future planetary exploration activities; the results are documented in [1]. A planetary geosciences team compiled six "Planetary Geology, Geophysics, and Prospecting" objectives, in order of priority:

- PGGP-01 Document the geological record and processes that have shaped the surface of the terrestrial planets their moons icy satellites and asteroids;
- PGGP-02 Determine the Resource Potential of the Moon Mars and Asteroids;
- PGGP-03 Understand the origin and distribution of volatiles on the terrestrial planets and their moons asteroids and comets;
- PGGP-04 Determine the interior structure and properties of the terrestrial planets and their moons icy satellites and asteroids;
- PGGP-05 Understand the impact threat and hazards posed by impact events on the Earth and other solar system bodies;
- PGGP-06: Understand surface modification processes on airless bodies.

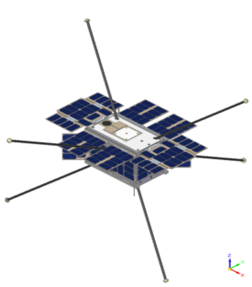

Figure 1: GRASP Asteroid Lander/Rover

The GRASP mission can support science investigations which address objectives PGGP-01 through PGGP-05.

Asteroid Surface Geophysics: Previous and current asteroid missions have carried various instruments, most of which have been used to measure asteroid surface properties. For example, imagers measure the shape of the surface, its reflectivity and in some cases its colour; imaging spectrometers can be used to infer mineral composition of the surface layer; radiation detectors can be used to estimate elemental compositions, and from that infer mineralogy. In geoscience terms, these are used for determining *geomorphology* and *surface geochemistry*. These have told us a great deal about the bodies that have been visited, but surface observations alone leave many important questions unanswered.

One category of such questions has to do with the composition and structure of the *interiors* of asteroids and comets; answering these questions will shed further light on the evolution of the Solar system. To the extent to which the interiors of these bodies are not completely reflected in their surface composition, techniques which can "see" interior properties can help address such questions. Such techniques will also be valuable in any future asteroid resource-prospecting endeavours, in places where bulk composition varies significantly from proximate surface composition.

Geophysics is the branch of geoscience that uses instruments that are sensitive to subsurface properties (including gravimetry, magnetometry, seismometry, heat flow and interaction with electromagnetic waves), and analyzes data from those instruments to make inferences about subsurface composition and structure. Previous asteroid missions have made *some* geophysical measurements — primarily radio tracking of spacecraft near an asteroid in order to infer asteroid mass, and in some cases a few of the higher-order terms of the asteroid's gravity field. However, the application of geophysical techniques has been limited by the fact that most previous missions have been fly-bys and orbiters, rather than landers.

In general, higher-quality geophysical measurements can be made when instruments are closer to the target, particularly so when actually *on* its surface. And, such techniques return much more useful results if measurements can be made at multiple locations on the surface. The aim of GRASP is to make high-quality surface gravimetry and magnetometry measurements at multiple stations distributed across the surface of a target asteroid.

Class of Target Asteroids: Asteroids come in a wide range of sizes, with different approaches needed for such things as landing and surface mobility, for large versus small asteroids; GRASP is designed to be able to land and move about small asteroids, of sizes in the range 100 to 1000 m, with bulk densities between 400 and 8000 kg/m^3 (although not all possible combinations of these), with more-restricted (local, not global) operations possible on larger bodies (e.g., Phobos). Asteroids also inhabit a wide variety of orbits; GRASP is designed to operate on asteroids whose orbits range in distance from the Sun between 0.85 and 1.5 AU, close enough to Earth to be inexpensively accessible, to have moderate thermal environments and adequate Sunlight for power generation, and to be interesting potential asteroid mining targets. There are currently more than 50 potential GRASP target asteroids encompassed by these parameters.

Asteroid Surface Gravimetry Investigation: GRASP's primary science investigation involves making gravimetry measurements at multiple locations spread around the asteroid's surface, using a novel absolute gravimeter instrument (Gedex's Vector Gravimeter/Accelerometer, or VEGA), with a measurement accuracy goal of 1-10 microGal. This instrument is at an advanced state of development, and will soon be ready for test-flying in space. VEGA's measurements will be processed to estimate the asteroid's internal density distribution, with a spatial resolution goal of 10-100 m [3]. They will also allow a very high-accuracy (< 1%) estimate to be made of the asteroid's total mass.

The estimated inhomogeneity of the asteroid's density will allow the following science questions to be addressed:

- What is the nature of porosity within the asteroid? Is large-scale macroporosity detectable?
- Is there evidence of significant compositional inhomogeneity within the asteroid? To what extent does this constrain the composition of different parts of the asteroid?
- Is there evidence of internal geological structure to the asteroid, say from differentiation due to early melting?

The answers to these questions will allow primary questions about the origin, formation and evolution of the asteroid, and hence of the Solar system, to be addressed:

- Did this particular small asteroid form directly from accreted chondrules, in which case homogeneous, low density might be expected?
- Or is the asteroid a rubble-pile, formed of higher-density metamorphosed material arising from parent asteroid melting/differentiation, with subsequent impact-driven fragmentation followed by assembly into the present body?
- If the latter, were the rubble-pile fragments derived from a *single* differentiated body that was fragmented in a catastrophic collision and then subsequently re-assembled? Or from fragments of *multiple* asteroids? If the latter, is there evidence of those various parent asteroids forming at different distances from the Sun?

Asteroid Surface Magnetometry Investigation: We are in the early stages of defining science objectives for a potential secondary science instrument — a set of magnetometers to measure surface magnetic properties. These can be used to seek evidence of magnetized fragments on the asteroid's surface, perhaps collected over the asteroid's lifetime by accreting debris ejected from other asteroids by impact processes. Such fragments could represent crust or core material from asteroids large enough to have melted, differentiated and frozen-in a remanent magnetic field, perhaps from a Solar-system-wide magnetic field, or from a dynamo in an asteroid's melted core [4]. Locating the magnetometers at the end of GRASP's legs will distance them from magnetic disturbances due to electrical equipment in GRASP's bus. By making measurements in very close proximity to the surface, even a low-sensitivity magnetometer may make useful measurements of remanent magnetization of asteroid surface rocks. Statistical analysis of this data could shed light on the extent to which remanent magnetization in the population of known meteorites is representative of that for the overall asteroid population.

References: [1] Carroll et al. (2016) "An Asteroid Lander/Rover for Asteroid Surface Gravity Surveying", AIAA/USU Conf. on Small Satellites, paper No. SSC16-XI-08. [2] CSA (2017) "Topical Teams Reports on Planetary Exploration 2017". [3] Carroll (2014) LPSC Abstract #2352. [4] Elkins-Tanton et al. (2011) *Earth & Planet. Sci. Lett., 305(1-2)* pp.1-10.