Geophysical Reconnaissance Asteroid Surface Probe Science Objectives

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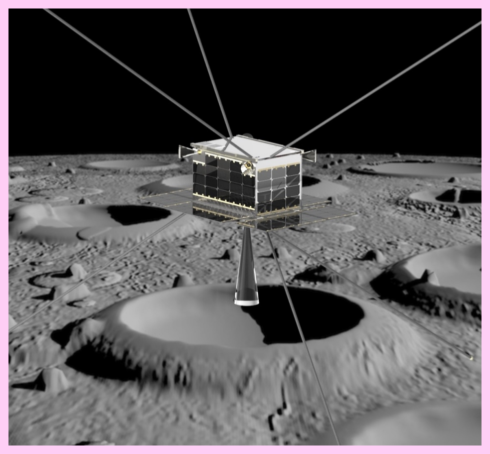
GRASP Mission

Mission Concept :

- The GRASP mission involves developing a very small asteroid lander/rover spacecraft based on SFL's world-class nanosat heritage and experience, and hitching a ride to a small (1 km in diameter or smaller) near-Earth asteroid aboard a host Mothership spacecraft, which will drop GRASP onto the asteroid's surface.
- GRASP will carry two main geophysics instruments, a gravimeter located in GRASP's central bus structure, and a set of magnetometers located in GRASP's feet.
- GRASP will use its rockets to hop from one location to another, eventually covering the entire surface of the asteroid, making science measurements at 100 or more surface locations.
- The data will be sent back to Earth, using the Mothership as a communications relay.
- GRASP will also take many images and movies using its numerous on-board cameras during its travels around the asteroid, and will also send some of those home to Earth for analysis.



Main Scientific and Technical Innovations :

- GRASP is an innovative mission, both scientifically and technically.
- The gravity science is enabled by Gedex's "Vector Gravimeter/Accelerometer" (VEGA), a new-technology miniature space instrument with unprecedented accuracy, whose development has been co-funded by Gedex and the Canadian Space Agency.
- The field of science for the primary investigation, **Asteroid Surface Gravimetry**, is a new field of scientific investigation, enabled by the VEGA instrument's absolute vector gravimetry capability.
- The **Asteroid Surface Magnetometry** investigation will also break new ground.
- The design of the GRASP spacecraft itself is an incremental yet very significant technological step forward for SFL's already world-class spacecraft development capabilities.

GRASP Science Investigations

Context: Canadian Space Agency's recent Space Exploration Science programmatic documents, specifying Canadian planetary science priorities :

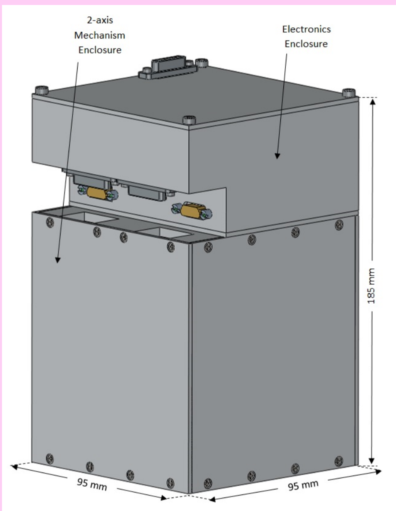
- 2016 Canadian Space Exploration Workshop (CSEW 2016) --- Canadian science community consultation (similar to US Decadal Study prioritization)
- Topical Teams Reports on Planetary Exploration 2017
- 2017 CSA Space Exploration Request for Proposals For Concept Studies for Planetary Secondary Payloads and Nanomissions
  - GRASP meets CSA's Space Exploration Program Requirements and Objectives for Secondary Payloads, meeting Canadian science priorities, and being Canadian-led, with a mass < 24 kg, and a development cost < $20M.
  - The GRASP spacecraft is simultaneously a nanosat, a landed package and a nanorover.

CSA Exploration Science Objectives Addressed (cf. 2016 CSEW report):

- *Objective SN-8, "Determine the interior structure and properties of the terrestrial planets and their moons, icy satellites, and asteroids",* by determining the interior density distribution of an asteroid, with far greater spatial resolution and accuracy than ever before.
- *Objective SN-7, "Understand the origin and distribution of volatiles on the terrestrial planets and their moons, asteroids, and comets."* If the asteroid on which GRASP is deployed contains significantly large amounts of volatile materials (e.g., water ice), and if those are segregated into large blocks inside the asteroid, then the lower density of such volatiles could allow GRASP to detect their presence, and quantify them.
- *Objective SN-6, "Determine the Resource Potential of the Moon, Mars, and asteroids."* Some resources, for example water ice and nickel-iron, have densities that are markedly different from the expected average density of their parent asteroid. GRASP's gravity survey could detect such deposits; its magnetometry survey could detect nickel-iron deposits.
- *Objective SN-5, "Document the geological record and processes that have shaped the surface of the terrestrial planets, their moons, icy satellites, and asteroids,"* by measuring statistical variations in remanent magnetic fields in rock fragments at various locations on the asteroid's surface. These measurements will provide clues as to the sources of the fragments from which the asteroid accreted over its lifetime.

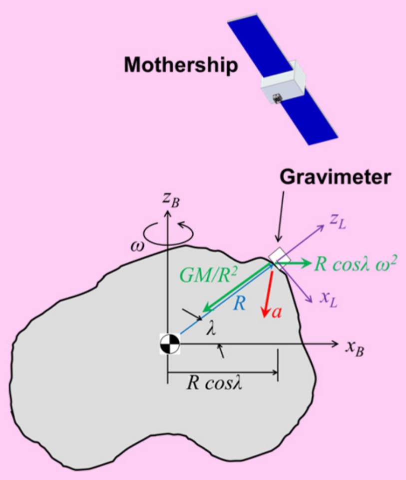
Primary Investigation: Asteroid Surface Gravimetry

- To date, instruments carried on asteroid missions have mainly investigated the ***outer surfaces*** of asteroids,(the top few centimetres), via imagers, spectrometers, radiation detectors, etc.
- Knowledge of the ***interiors*** of asteroids could lead to better understanding of the formation and evolution of asteroids, and of the Solar system in general.
- For example, a small asteroid could be a left-over from the original formations of planetesimals, never having undergone enough heating to melt and differentiate, and have a homogeneous chondritic interior.
- Alternately, a small asteroid could be a rubble-pile composed of large, structurally-competent fragments from collisions of differentiated asteroids, with internal blocks coming from different source asteroids, or from multiple depths in a single differentiate source asteroid, and hence have varying composition, also possibly with large void spaces.
- ***Conjecture:*** small asteroids could possess internal density variations large enough to result in detectable variations in surface gravity.
- For ***large*** asteroids (>> 1 km diameter), mass is easy to determine via radio tracking from Earth of spacecraft flying-by or orbiting. Some higher-order terms of the spherical harmonic expansion of the gravity field can also be (and have been) determined in such cases.
- However, this technique works less well for ***smaller*** asteroids
  - Partly due to reduced S/N
  - Partly due to interference from solar radiation pressure, out-gassing, etc.
- A ***single*** surface gravimetry measurement can provide a much more accurate mass estimate for smaller bodies.
- Must compensate for asteroid rotation (and in some cases tumbling).



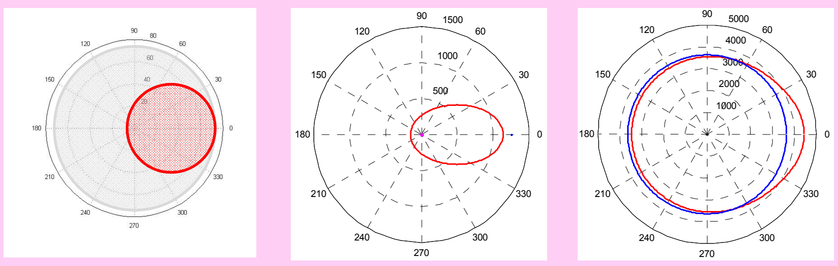
VEGA Space Gravimeter Instrument

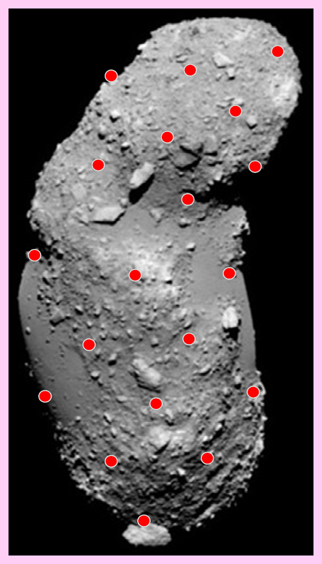
- Measures ***absolute gravity vector magnitude and direction,*** with no bias
- ***Accuracy:*** 1-10 nanoG on a small asteroid
- ***Bandwidth:*** 1-10 mHz
- ***Size:*** 9.5 x 9.5 x 18.5 cm
- ***Mass:*** 2.1 kg
- ***Power consumption:*** 6-12 W (depending on spacecraft temperature)

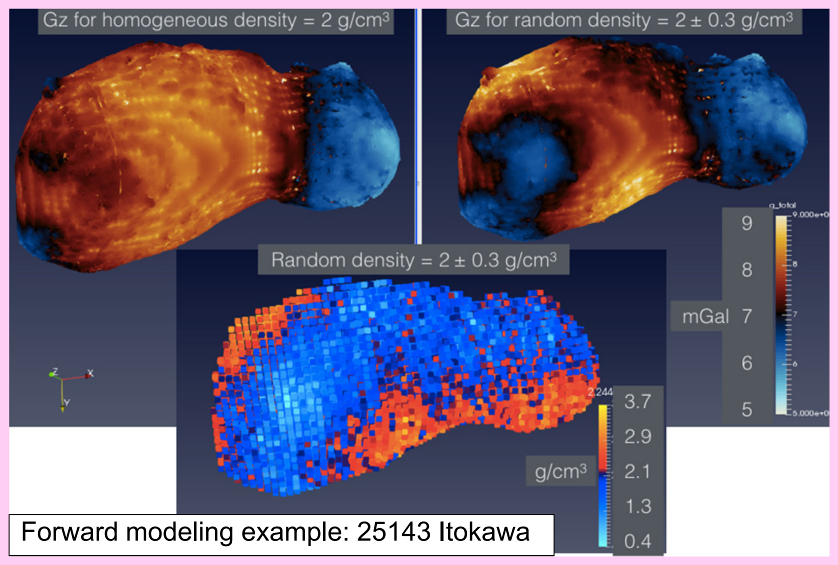


- Simple models of asteroid internal density inhomogeneity illustrate the nature and magnitude of the surface anomalous gravity signal.
- Below, a sphere-shaped density anomaly of 80m diameter, of density 1000 kg/m3 higher than the surrounding asteroid material, is "planted" just below the surface of a 150m diameter spherical asteroid.
- A gravity high of 1200 microG is present on the surface above it.
- VEGA could measure that with an S/N of about 1000.

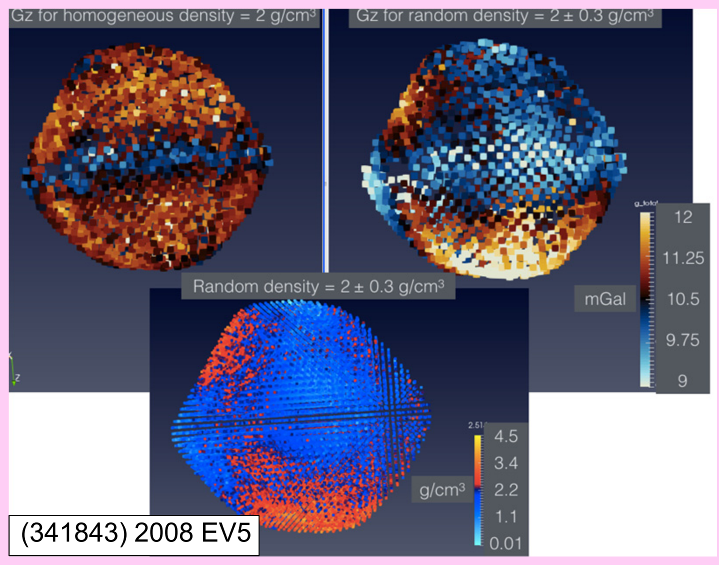
- ***Investigation Concept:*** Conduct a global surface gravimetry survey, with measurement stations spread across the surface of a small asteroid.
- Similar to a typical gravity survey on Earth, with many distributed survey points.
- In this case, the survey plan is extremely 3D, rather than approximately planar.
- Use geophysical inversion to estimate the internal density distribution.
- From this, constrain the asteroid's internal structure and composition.







Forward modeling example: 25143 Itokawa



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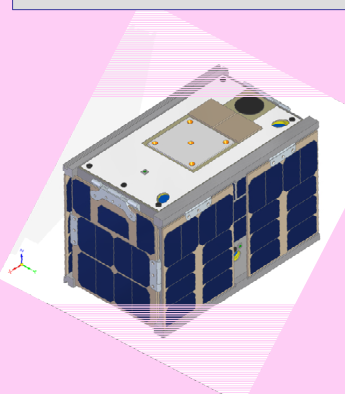
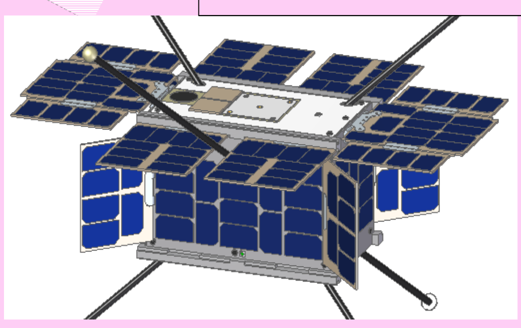
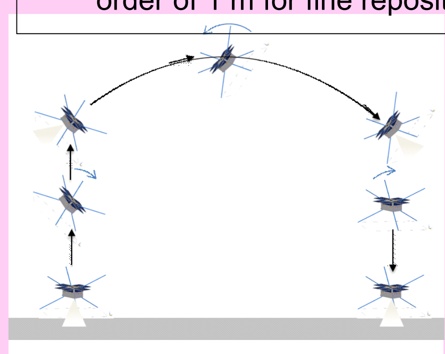
GRASP Spacecraft

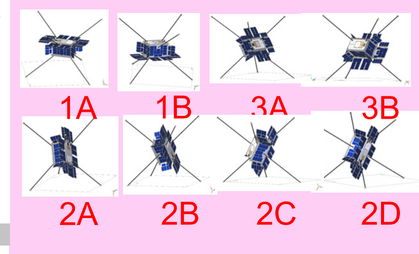


- Stows as a 12U cubesat
- Target mass: 12.5 kg
- Deploys six ***Legs*** (each 1.7m long) and ***Photovoltaic Arrays*** after release from mothership
- Mothership relays communications to/from Earth
- Can survive for months to years on an asteroid's surface



- Designed for a wide range of asteroid targets
- ***Asteroid diameter:*** 100-1000m
- ***Asteroid density:*** 400-8000 kg/m^3
- ***Surface gravity:*** 10-100 microG
- ***Distance from the Sun:*** 0.85 to 1.5 AU
  - Currently >40 known NEAs in this range, with condition code <2 and H<25
- Full 3-axis attitude control subsystem
  - Reaction wheels, cold-gas thrusters, star tracker, angular rate sensors
- 150 m/s ΔV propulsion subsystem enables ***propulsive mobility***
  - Minimizes dependence favourable soil mechanics to enable reliable roving
  - Sized to perform surveys with over 100 measurement stations
  - Long hops up to hundreds of metres, short hops on the order of 1 m for fine repositioning





- Equipped with six symmetrically disposed legs
- Results in eight stable orientations on asteroid surface
- Reaction wheels can be used to experiment with ***"tumbling" mobility***

Secondary Investigation: Asteroid Surface Magnetometry

- Many meteorites posses remanent magnetization
- However, with several asteroids sampled to date, none have shown global magnetic fields.
  - For example, [Acuña et al., 2002] found no magnetic field associated with the asteroid 433 Eros, even after the NEAR Shoemaker spacecraft landed on the asteroid, leaving its magnetometer only about 2 m above the surface.
- ***Conjecture:*** that small (dm-sized) rock fragments with meteorite-like remanent magnetization might exist on an asteroid's surface, but in random orientations, so that their magnetic fields mostly cancel out, even at a distance of only 2 m away.
- ***Investigation concept:*** Getting a magnetometer closer than that to the surface might allow such remanent fields to be detected. Doing this in multiple locations will provide statistics which can be compared with those for magnetized meteorites. Potentially global magnetic fields might also be discerned.
- ***Instrument concept:*** Miniature fluxgate magnetometers, located in several of GRASP's feet.
  - *Advantage:* location results in magnetometers approaching to within a few cm of the asteroid's surface. This maximizes the chance of detecting any remanent magnetization in surface rocks near the feet.
  - *Advantage:* GRASP will relocate many times, providing many opportunities to sample surface magnetization.
  - *Challenge:* Out at the end of GRASP's legs, the magnetometers will be subject to a wide temperature range, -150C during local night-time, to +150C in daytime. Requires magnetometers with a wide survival and operating temperature range, and temperature sensing and calibration to allow compensation for magnetometer output variation with temperature.
- A relatively low-resolution magnetometer should suffice to make useful measurements.
  - A candidate miniature magnetometer has been identified, that has a suitably wide temperature range.
  - Initial tests of meteorites with remanent magnetization produced measurements of 50-100 nT at distances of a few cm for carbonaceous chondrite meteorite samples, and several thousand nT for iron meteorites, which were easily within the magnetometer's sensitivity .
- By measuring magnetometer signals while landing and taking off, effects of bias drift can be compensated, eliminating need for magnetometer to have high accuracy.