IN SITU PROSPECTING SCIENCE AS APPLIED TO SOLAR SYSTEM SMALL BODIES.

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Introduction: DSI intends to fly several mission types to Near Earth Asteroids. These include fast flybys, rendezvous missions, and rendezvous with sample return.

The designs which DSI is pursuing are cubesat-based (to allow piggyback launch and to drive down costs) and thus there will be serious budget limitations in terms of mass, power, and bandwidth, applying to the spacecraft as a whole and to the science instrumentation choices.

DSI seeks to develop a ‘science instruments kit’ for these missions that will best address the information gaps relevant to two over-riding issues, namely (a) information relevant to Earth-Impactor deflection methodologies; and (b) information relevant to asteroidal resource extraction and recovery.

The Need: Scientists want every possible instrument included, while the mission designers insist on minimal mass budgets and are understandably wary of close approaches not to mention actual contact with an uncooperative asteroid. Decision makers need a considered ‘science suite’, ranked by simplicity, criticality (value), mass-budget, power-budget, proximity and bandwidth requirements for the instruments to be carried on first-generation asteroid flyby and surface-science spacecraft.

What can be accomplished varies with the type of mission.

Fast Flyby Missions:

- Measurement of asteroid dimensions
- Estimate of surface characteristics (monolith or rubble pile)
- Accurate albedo (and thus refine mass to with a factor of two or so)
- Spin axis and rate, existence of tumble
- Existence of satellites (if so, precise measure of mass)
- Crude to modest spectra (thus likely composition)
- Refinement of orbit (and possibly precise impact coordinates)

Slow Pass / Loiter Missions:

- Precise measure of asteroid dimensions.
- Detailed surface mapping (if loiter time greater than asteroid period)
- Detailed ir-vis-uv spectrum (sub meter resolution) yielding mineralogy map
- Visual Structural investigation (monolith, rubble pile, or jumble/contact binary)
- Presence of satellites (which will reveal mass and possible complications)
- Spin/tumble axis
- Accurate albedo
- Presence of regolith (very fine particles)
- A LIDAR may give sufficiently precise relative velocity to infer mass

Orbit or Very Slow Close-Pass Missions:

- LIBS (gives precise elemental surface composition, instantly, one point at a time)
- Gamma Ray Spectroscopy (gives precise average bulk elemental composition to about 20 cms depth, assuming long integration times)
- X-ray spectra (gives detailed surface mineralogy map)
- A LIDAR will reveal mass, and with multiple slow orbits, variations in gravity (mascons) and thus internal structure.
- A series of penetrators, launched into the asteroid, would reveal the strength (see touchdown stick below) of the surface down to (potentially) tens of centimeters.
- Achieving an orbit measures the asteroid mass (this is difficult, largely because of the difficulty of applying sufficiently tiny impulses and measuring low tangential velocity vectors from a distance).

Touchdown / Docking Missions:

- Visual sub-millimetre resolution (may reveal chondrules, CAIs, pores, fractures, nanodiamonds, metal grains)

- Reflection Seismology (pinger and microphone) can reveal structural integrity and possibly provide a measure of the number of large fragments, and macro-porosity, ; multiple listening points combined with impactors or thumpers can provide detailed structural information
- Magnetic measurements can determine the fraction of iron and/or ferromagnetic minerals such as magnetite. For a monolith, this yields ability to dock using nothing more than an electromagnet. For a rubble pile, it yields ability to extract boulders using nothing more than an electromagnet. For regolith or gravel, it yields equivalent ability to excavate using only an electromagnet.
- Touchdown stick: thrusting a simple rod into the asteroid (using a known impulse) yields the cm-scale strength of the asteroid (UCS, friability) by measuring the depth of penetration. This indicates ease of extracting a portion of the asteroid (ie, breaking or slicing it in two).
- Pulling it out reveals cohesion (and thus the ability to anchor, or retrieve a boulder using a harpoon).
- The touchdown stick (if removable) may be poked into the surface at multiple locations.
- If a boulder may be moved, it exposes less-weathered material for additional science.
- Docking, then thrusting toward the asteroid can instantly provide an independent measure of mass (assuming accurate accelerometer).
- Permanently docking (or dropping a transponder and/or retro-reflectors) greatly simplifies subsequent rendezvous missions.

Note that if docking is possible via harpoon or electromagnet, these are the simplest ways to dock. Orbital (and escape) velocities are so low that it is difficult to approach and touch down without bouncing.

Conclusions: There exists a wide variety of instruments with applicability to various missions and which have disparate resource requirements (mass, power, and bandwidth to name a few) as well as overlapping values. This paper provides a framework for evaluating these instruments according to mission-specific criteria, science needs, and spacecraft capabilities.