Orbital seismology by laser Doppler vibrometry

Paul Sava
psava@mines.edu

Erik Asphaug
asphaug@lpl.arizona.edu

The interior structure of small planetary bodies holds clues about their origin and evolution, from which we can derive an understanding of the solar system formation. High resolution interior imaging of small bodies can use either radar waves for dielectric properties, or seismic waves for elastic properties. Radar investigation is efficiently done from orbiters, but conventional seismic investigation requires landed instruments (seismographs, geophones) mechanically coupled to the body. However, radar waves cannot always penetrate deep in the interior of a small body, unlike seismic waves.

A good understanding of the interior structure of a small planetary body requires observations from multiple directions, as in medical tomography. 3D seismic imaging is well-developed in terrestrial environments and takes advantage of two main opportunities: instruments are coupled to the ground, and seismometers form dense networks (antennas). Neither condition can be satisfied with conventional instruments on a small planetary body. Various mission concepts employ seismometers on the surface. Anchoring a seismology package to a small body requires robust technology that does not yet exist. The complexity of a landed package raises the cost of a mission and increases its risk. Strong seismic waves may even dislodge the payload from the surface. These challenges led to complex methods for embedding seismic payloads on a small body, with large thermal, power, mechanical and communications issues.

Our method removes the need for instrument surface deployment by employing Laser Doppler Vibrometers. LDVs can effectively record ground motion of a small body surface and are advantageous over conventional seismometers because they:
1. Measure ground motion from orbit;
2. Do not require landing and anchoring;
3. Do not use mechanical components;
4. Are mobile and can relocate around the body;
5. Operate from stable orbital platforms.

Seismology from a remote sensing platform enables a new class of geophysics missions that avoid the complexity and mass of landed payloads on small bodies and can facilitate detailed 3D seismic imaging of their internal structure. Dense global seismic acquisition enables imaging by high resolution wavefield imaging developed in the context of terrestrial seismology. Migration identifies and positions the interior reflectors by time reversal. Tomography constrains the elastic properties in-between the interfaces. These techniques benefit from dense data acquired by the LDV system at the surface, and from knowledge of small body shape. In both cases, a complex body shape, such as a comet or asteroid, contributes to increased wave-path diversity in its interior, and leads to high (sub-wavelength) imaging resolution.

Acknowledgment: This work is supported by the NASA Planetary Instrument Concepts for the Advancement of Solar System Observations (PICASSO) program (NNH16ZDA001N).

Seismograph

<table>
<thead>
<tr>
<th>Seismograph</th>
<th>Laser Doppler Vibrometer</th>
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<tbody>
<tr>
<td>Landing</td>
<td>Difficult and requires expensive and complex operations; disrupts surface and orbiter.</td>
</tr>
<tr>
<td>Coupling</td>
<td>Difficult on rough surfaces; requires complex anchoring in micro-g environments; requires leveling.</td>
</tr>
<tr>
<td>Mobility</td>
<td>Not possible without complex, costly and risky near-surface maneuvers.</td>
</tr>
<tr>
<td>Protection</td>
<td>Environment protection (thermal, radiation) increases complexity of landed instrument.</td>
</tr>
<tr>
<td>Power</td>
<td>Communications and operations increases the size and complexity of the lander.</td>
</tr>
</tbody>
</table>

Lander

- Difficult and requires expensive and complex operations; disrupts surface and orbiter.
- Not needed.
- Not needed.
- Full body coverage from orbiter.
- Provided by orbiter.