Seismology on Comets

Martin Knapmeyer, for the SESAME Team of Rosetta
SESAME - CASSE

[Diagram of SESAME-CASSE with labels for Leg 1, Leg 2, Leg 3, +Y Foot, -Y Foot, MUPUS, +X Foot, and coordinate axes.]
### Receiver Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor Type</td>
<td>Piezo-Electric Accelerometer</td>
</tr>
<tr>
<td>Model</td>
<td>Bruel &amp; Kjaer OrthoShear 4506</td>
</tr>
<tr>
<td>Channels</td>
<td>3</td>
</tr>
<tr>
<td>Mass</td>
<td>approx. 20 g</td>
</tr>
<tr>
<td>Size</td>
<td>17 by 17 by 17 mm$^3$</td>
</tr>
<tr>
<td>Amplitude Range</td>
<td>0.0054 ... 230 ms$^{-2}$</td>
</tr>
<tr>
<td>Frequency Range</td>
<td>1 Hz ... 3.5 kHz (vertical: 6 kHz)</td>
</tr>
<tr>
<td>Sampling Rate</td>
<td>0.1 ... 16 kHz (usually 2 - 5 kHz)</td>
</tr>
<tr>
<td>ADC</td>
<td>7 Bit + sign, log compression</td>
</tr>
<tr>
<td>FIFO RAM</td>
<td>128 kB</td>
</tr>
</tbody>
</table>
Touchdown in Agilkia

ROLIS, 9 m above ground
Touchdown in Agilkia

ROLIS, 9 m above ground
Touchdown in Agilkia

ROLIS, 9 m above ground
Preliminary results for Agilkia:

- Young's modulus: few 10 MPa
- Compressional strength: ca. 10 kPa
MUPUS Listening at Abydos
MUPUS Listening at Abydos
MUPUS Listening at Abyc
MUPUS Listening at Abyd
MUPUS Listening at Abydos

Measure Travel Time

Unknown Topography at Abydos: Underestimate Distance

→ Underestimate Velocity!
MUPUS Hammering Mechanism

- Coil gun principle: Capacitor discharge via coil accelerates hammer mass
- All active components within MUPUS head
- Stroke times not known precisely

<table>
<thead>
<tr>
<th>Stroke Level</th>
<th>Energy [J]</th>
<th>Charge Time [s]</th>
<th>4-Stroke Delay [s]</th>
<th># of Strokes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.5</td>
<td>1.4</td>
<td>14.5</td>
<td>12</td>
</tr>
<tr>
<td>1</td>
<td>1.6</td>
<td>4.9</td>
<td>28.4</td>
<td>16</td>
</tr>
<tr>
<td>2</td>
<td>2.2</td>
<td>6.2</td>
<td>33.5</td>
<td>32</td>
</tr>
<tr>
<td>3</td>
<td>4.2</td>
<td>12.2</td>
<td>57.9</td>
<td>249</td>
</tr>
</tbody>
</table>
Sample Data

- 14 hammer strokes recorded
- Signal dominated by Rayleigh wave
- 8 of these visible on more than one foot
- +Y foot typically the best
- -Y foot typically the weakest
- 65 arrival times extracted
- Lower bound of shear wave velocity of 83 m/s results
Layering

- Frequencies below ca. 250 Hz arrive approx 10 ms later than higher frequencies.

This translates into:
- An upper layer $\geq 10\,cm$ thick.
- Velocity in top layer is increased 30% or more compared to deeper material.
**Layering**

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This translates into:
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- Velocity in top layer is increased 30% or more compared to deeper material.

Velocity $v_R \geq 79 \text{ m/s}$

- $E \geq 4 \text{ MPa}$
- More "fluffy" $z \geq 10 \text{ cm}$
Natural sources
Natural sources

Impact Crater?
Natural sources

Natural sources


Tea Kettle Whistle?
Natural sources
Natural sources

- upcoming cliff collapse
- debris from previous collapses
Natural sources
Natural sources

neck breakup
We conducted the first active seismic experiment on a comet, at 500 Mill. km distance from Earth: the farthest-out seismic experiment ever.

Specific technical challenges due to distance, spacecraft size, and environment.

Industrial triaxial accelerometers as seismic sensors.

Usable signals from touchdown and hammering of MUPUS.

Touchdown evaluation suggests a Young's modulus of a few 10 MPa.

MUPUS hammering suggests shear modulus of at least 3.6 MPa, and probably less than 331 MPa for a top layer of few decimeters thickness.

Below, shear modulus is reduced by 30 % or more.

Comets appear to offer a variety of potential natural sources, like impacts, a possible tea-kettle-like whistling in active regions, cliff collapse and mass wasting, and comet breakup.
Seismisches Experiment auf 67P/C-G

Würzburg, Oktober 2015

Lecture > M. Knapmeyer, Seismology on Comets

ISSI Beijing, January 2017

DLR.de • Chart 29

Ellipse: ESA/Rosetta/Philae/CONSERT

Image: ESA/Rosetta/MPS for OSIRIS Team MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA

CONSERT ellipse
Agilkia Touchdown: Scenarios