EPSC Abstracts
Vol. 10, EPSC2015-595, 2015
European Planetary Science Congress 2015

SESAME/CASSE listening to the insertion of the MUPUS PEN at Abydos site, 67P/Churyumov-Gerasimenko

M. Knapmeyer (1) Fischer, H.-H. (2), Knollenberg, J. (2), Seidensticker, K.J. (2), Thiel, K. (3), Arnold, W. (4), Faber, C. (2), Möhlmann, D. (2)
(1) DLR, Germany (martin.knapmeyer@dlr.de) (2) DLR, Germany, (3) Cologne University, Germany (4) Saarland University and Göttingen University, Germany

1. Introduction

SESAME is a suite of three instruments (the *Comet Acoustic Surface Sounding Experiment* CASSE, the *Dust Impact Monitor* DIM, and the electrical *Permittivity Probe* PP) that have sensors and transmitters distributed all over the Philae lander, but share common electronics for commanding and processing. SESAME is conducted by a consortium of DLR, the Max Planck Institute for Solar System Research (Göttingen), and the Finnish Meteorological Institute (Helsinki, [1]).

The Multi-Purpose Sensor MUPUS, run also by DLR, combines a thermal conductivity and heat flow experiment with a mechanical properties experiment associated with the anchoring harpoons of the lander ([2]).

It was recognized early in the preparation of both the SESAME and MUPUS experiments that the hammering mechanism of the latter, which drives the thermal probe into the ground, might as well serve as source of elastic waves for the CASSE experiment. To support the CASSE experiment, the MUPUS flight software provides information on its hammering process in a shared memory of the lander data management system.

CASSE listening to the MUPUS PEN hammer mechanism proved to be the first active seismic experiment conducted on a celestial body other than Earth since the Lunar Seismic Profiling Experiment, which was carried out on the Moon by the Apollo 17 astronauts in 1972 (e.g. [3]).

2. Experiment Setup

The experiment was conducted at the Abydos site on comet 67P/Churyumov-Gerasimenko, which is the place where the Philae lander finally came to rest after repeated bouncing. At the time of writing, the exact location of Abydos on the comet is still unknown, although constrained to an area of a few hundred square meters on the "head" of the comet by the CONSERT instrument ([4]). Contrary to the nominal landing site Agilkia, which is a relatively flat terrain, Abydos shows steep walls at least as tall as the lander itself and partly less than 1 *m* away [5]. Moreover, it is not obvious from existing imagery which direction is "down", i.e. what the orientation of Philae with respect to local gravity is.

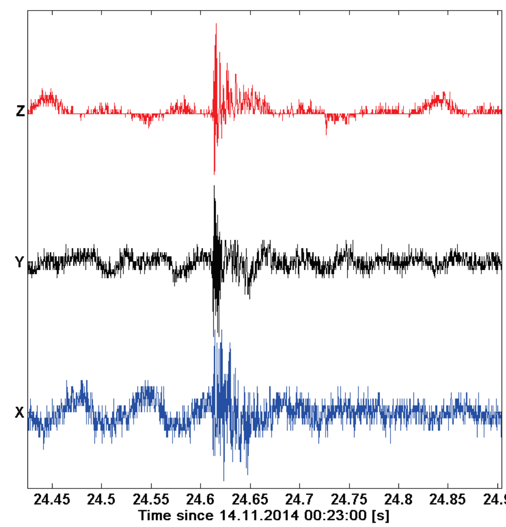

Fig. 1: An early MUPUS hammer stroke as recorded by CASSE on the +Y foot. All channels normalized to unit amplitude individually to emphasize wave train shape. Actual amplitude is of the order of 0.1 m/s^2. Note that in the manufacturer's nomenclature, the "x" channel is vertical, while "y" and "z" are horizontal, i.e. in the plane of the lander feet.

The MUPUS PEN consists of a glass fiber rod with a metal tip. Its hammering mechanism is accommodated in a cylindrical housing on top of this rod. The working principle is that of a coil gun: a capacitor is short-circuited via a coil, thus generating a magnetic field that accelerates the hammer head onto the rod. Strokes may be executed at four different energy levels which are set automatically in order to penetrate materials of different strength [2].

The receiving sensors of CASSE are piezo electrical accelerometers (Bruel & Kjaer 4506 Ortho-Shear) capable of recording three orthogonal components of acceleration. Three of these sensors are housed in the landing feet of the Philae lander. Two principal operational modes were foreseen to listen to MUPUS: a triggered mode, where a threshold trigger starts storing data from a ring buffer memory as soon as a certain amplitude threshold is exceeded on selected sensor channels, and a listening mode which simply records for a certain amount of time whenever it is commanded.

3. Results

SESAME was active during the MUPUS PEN insertion phase for more than two hours, starting at 14.11.2014, 00:12:07 UTC and ending at 02:28:00 UTC. During this time, 5 listening mode measurements, 14 triggered mode measurements and several soundings using the CASSE piezo transmitters were conducted. Sampling rates ranged from 2 *kHz* to 5 *kHz*, since sampling rate, number of recording channels, and recording duration needed to be traded against each other. A total of 231 time series with durations from 40 *ms* to 15 *s* were recorded during the MUPUS PEN insertion phase. An example is shown in figure 1. All sensors and transmitters are fully functional; the bumpy landing caused no damage whatsoever.

During the first five recordings, all three accelerometers show more or less continuous vibrations at frequencies between 10 *Hz* and 30 *Hz*, that are often much stronger in amplitude than the signals interpreted as actual hammer strokes, although there is evidence that these vibrations are also sustained by the hammering of MUPUS. Since only a few discrete frequencies are observed, we conclude that these vibrations represent eigenmodes of the Philae landing gear, excited via the deployment boom of MUPUS, which was connected to MUPUS during the entire experiment.

The actual hammer strokes of MUPUS are transient, broad-banded signals with decay times of a few tens of milliseconds. Typically the +Y foot received the strongest signals and triggered the recording, although the –Y foot is closer to the nominal position of MUPUS. In one case, the strongest signal was received by the +X foot. Signal quality varies between recordings, but the measurements nevertheless support that all three feet are in contact with the comet. One recording contains signals from two adjacent strokes with a time delay perfectly fitting to the nominal stroke sequence of MUPUS at that time.

4. Discussion and Conclusions

Two pathways for elastic waves must be considered in the evaluation of the presented data: unwanted acoustic crosstalk through the structure of the lander and the desired sounding of the comet subsurface. The presence of (1) low frequency vibrations in only the first few recordings, (2) the changes of relative and absolute signal strength between recordings of hammer strokes, (3) the broad banded frequency content allowing for sharp onsets of the transient signals, as well as (4) the perfectly fitting time delay in the recording containing two strokes all support our interpretation that we do indeed see signals from subsurface sounding rather than crosstalk. Finally, we expect crosstalk signals to arrive synchronously at all feet, while subsurface sounding should reflect differences in path length.

In most cases, time series require careful individual processing to make further evaluation possible. Thus the evaluation and geological interpretation of the data is still ongoing at the time of writing this abstract.

References

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