Rosetta Lander – Philae: Operations on 67P/Churyumov-Gerasimenko. Stephan Ulamec[1], Jens Biele[1], Barbara Cozzoni[1], Cedric Delmas[2], Cinzia Fantinati[1], Koen Geurts[1], Sven Jansen[1], Eric Jurado[2], Oliver Küchemann[1], Valentina Lommatsch[1], Michael Maibaum[1], , Laurence O'Rourke[3], (1) DLR, German Aerospace Center, Cologne, Germany, (2) CNES French National Center for Space Studies, Toulouse, France, (3) ESAC European Space Agency, Madrid, Spain

Introduction: Philae is a comet Lander, part of Rosetta which is a Cornerstone Mission of the ESA Horizon 2000 programme. Philae successfully landed on comet 67P/Churyumov-Gerasimenko on November 12th, 2014 and performed a First Scientific Sequence, based on the energy stored in it's on board batteries. All ten instruments of the payload have been operated at least once. Due to the fact that the final landing site (after several bounces) was poorly illuminated, Philae went into hibernation on November 15th, and the teams hoped for a wake-up at closer heliocentric distances [1].

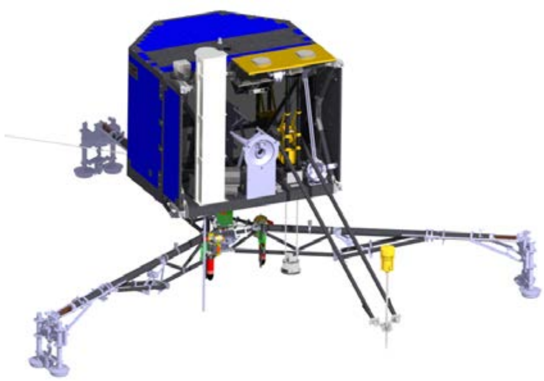

Figure: Illustration of Philae with deployed landing gear and instruments [1]

Operations responsibilities: Philae is operated by the Lander Control Centre (LCC) at the German Aerospace Center, DLR, in Cologne and the Science Operations and Navigation Centre (SONC) at the Centre national d'études spatiales, CNES, in Toulouse. Commanding is sent via the Rosetta Orbiter which is controlled by the Rosetta Mission Operations Center, RMOC at the European Spacecraft Operations Centre (ESOC) in Darmstadt. The scientific lead is at the Max Planck Institute for Solar System Science, MPS, in Göttingen, Germany, and the Institut d'Astrophysique Spatiale, IAS, in Paris, France [2].

Rosetta is an ESA mission with contributions from its member states and NASA. Rosetta's Philae lander is provided by a consortium led by DLR, MPS, CNES and ASI with additional contributions from Hungary, UK, Finland, Ireland and Austria.

Scientific and technological background: Comets are believed to be the primitive leftover of the Solar System formation process. Thus, they contain information on the compositional mixture from which the planets formed about 4.6 billion years ago. They carry records of the Solar System's very early phase and are, thus, a key for our understanding of its origin and development (e.g. [3]).

In addition, comets may have played an important role for the origin of life, since they transported organic matter to the early Earth [4].

In addition to being of important scientific interest, the first landing on a comet was also a technological challenge, with 67P being an almost unknown object at the time of development [1].

Separation - Descent - Landing: After careful selection of an appropriate landing site for Philae, when an area later called "Agilkia" was chosen [5] the exact descent strategy was planned [6]. The final Rosetta pre-delivery manoeuvre was performed on November 12th at 06:06 UTC.

The Lander was separated from the main spacecraft, as planned, at 08:35 UTC [1,7]. Descent to the comet surface took seven hours. The Touch-Down signal was generated at 15:34 UTC.

Unfortunately, an active descent (cold gas) system, ADS, did not operate and the anchoring harpoons did not fire. This led to a bounce; Philae only came to final rest about two hours later at an area about 1km from the originally targeted site [7].

First Science Sequence: The unexpected bounce at touch down and the lack of anchoring required major adaptation of the originally planned activities, following the landing and based on energy stored in the onboard batteries. Eventually, all instruments were activated at least once, producing a wealth of scientific data from the surface of a comet. The sequence of instrument operations is described in [1,8]. Philae´s final landing site turned out to be poorly illuminated and only very little power was generated by the solar generator. Philae was put into a configuration that would allow it to re-establish contact with the orbiter, when closer to the sun, as soon as sufficient power was available (and the temperatures high enough to operate the Lander [1].

Attempted Long Term Science Operations: And indeed, signals from the Lander were received on June 13th when 67P was at a distance of about 1.4 AU from the Sun. Housekeeping values showed that Philae has already been active earlier, but no RF contact with the mothership could be established. Seven more times, signals from Philae were received, the last ones on July 9th, 2015. With these contacts established, significant work was made by the ESA RMOC and RSGS teams to redesign the trajectory being flown by the Orbiter to allow the same communication conditions (latitude of comet) to be repeated in the weeks after. However, unfortunately, no reliable or predictable links could be achieved.

Various attempts have been undertaken, not only "listening" for signals from the Lander but also to command it "into the blind" in a so-called telecommand backup mode (TCBM), without two-way communications link. This way, science operations could have been performed, even if the transmitter aboard Philae had problems in operating nominally.

Conclusions and Outlook: Philae provided the historic first scientific data from the surface of a comet. Despite the problems during landing, including the bounce to an unforeseen, badly illuminated area, spectacular science could be generated during a first scientific sequence. Attempts to perform Long Term Science during 2015 were not successful, despite a few contacts with Philae in June and July.

Although Philae does not provide data anymore and will not be able to get active at the increasing heliocentric distances, Rosetta is very active. It is expected to obtain images of the Lander from the orbiter cameras (OSIRIS NAC) that shall clarify the environment of Philae, its exact orientation towards local terrain and help to better interpret the data obtained.

References: [1] Ulamec S. *et al.* (2015) *Acta Astron*, http://dx.doi.org/10.1016/j.actaastro.2015.11.029i [2] Ulamec S. *et al.* (2012) *Acta Astron*. 81, pp.151–159; [3] Ciesla F.J. and Charnley S. (2006) University Arizona Press; [4] Ehrenfreund P. *et al.* (2002) *Rep. Prog. Phys*. 65, pp. 1427–1487; [5] Ulamec S. *et al*. (2015) *Acta Astronaut*. 107 pp.79–86. [6] Accomazzo A. *et al*. (2016) submitted to *Acta Astron*. [7] Biele J. *et al.* (2015) *Science* 349, aaa9816. [8] Moussi A. (2016) submitted to *Acta Astron.*