PHILAE – FIRST LANDING ON A COMET. S. Ulamec[1], J. Biele[1], P. Gaudon[2], M. Salatti[3], M. Maibaum[1], K. Geurts[1], C. Fantinati[1], V. Lommatsch[1], E. Jurado[2], A. Moussi-Soffys[2]. [1]German Aerospace Center, DLR, Cologne, Germany (stephan.ulamec@dlr.de, as corresponding author), [2]Centre National d'Études Spatiales, CNES, Toulouse, France, [3]Agenzia Spaziale Italiana, ASI, Rome, Italy.

Introduction: Rosetta is a Cornerstone Mission of the ESA Horizon 2000 programme [1,2]. In August 2014 it did rendezvous with comet 67P/Churyumov-Gerasimenko (CG) after a 10 year cruise. Both its nucleus and coma have been studied allowing the selection of a landing site for Philae, the lander provided by an international consortium with major contributions from DLR, CNES and ASI [3]. Philae was separated from the Rosetta main spacecraft on November 12, 2014 and touched the comet surface after seven hours of descent. However, the lander bounced off again and only came to rest after a leap of about 2 hours, approximately one km from the originally targeted site. Philae was operational for almost 64 hours after separation and provided unique information from the surface of the comet. All ten instruments aboard could be operated at least once.

Descent and Landing: Shortly before separation the final preparations for the Lander were performed. Unfortunately the nitrogen tank for the cold gas thruster (supposed to push the lander onto the surface after touchdown) could not be opened. However, it was decided to proceed with the sequence, since there was little hope the tank could successfully be opened at a later time. After injection of the Rosetta spacecraft into the delivery orbit, Philae was ejected with a separation velocity of 18,76 cm/s on November 12th, 2014 at 8:35 UTC. This maneuver was performed perfectly, leading to a touch-down, about 7 hours later, at 15:34:04, only 51 seconds (!) before the precalculated landing time. The touch-down signal was received, the lander switched into the "on-comet mode" and started its first scientific sequence. However, the anchoring harpoons have not been fired.

Due to the lack of hold down thrust and no anchoring, Philae bounced off the surface and was ballistically drifting above the comet surface. During this time some of the scientific instruments (CONSERT, ROMAP, COSAC) performed as if resting on the surface. Only after 1:50 hours Philae came to its final rest, after two more surface contacts. The Lander is now at a poorly illuminated location, the solar generator provided power for only 1:20 hours per comet rotation. Fortunately communications link with the Orbiter was possible very similar to the predicted time-slots.

Localization of Lander: In the following hours and days, great effort was taken to localize the final landing spot of the Lander. Information was obtained by using the radar instrument CONSERT for ranging, detection of attitude (and surface contacts) with the magnetometer ROMAP and analyzing OSIRIS and NAVCAM images, showing the Lander and even the footprints of the first touch-down.

The following subsystems and instruments were used for the search of the lander and in order to reconstruct the trajectory and bouncing:

- Analysis of OSIRIS images (some of them showing the lander, shadow or footprints.)
- CONSERT ranging
- RF link pattern and signal strength
- Landing gear HK and mechanical simulation
- Power on solar generator
- ROMAP (3 axis magnetometer) data
- MUPUS TM (thermal mapper) data
- ROLIS (downlooking camera)
- SESAME (acoustic sensors in feet)

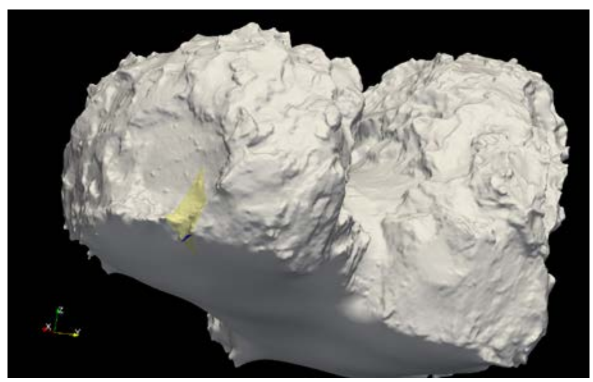

Figure 1: Estimated Lander position as derived from CONSERT data (small blue wedge in yellow area).

Modified First Scientific Sequence: Since Philae was not safely anchored and the actual state of the Lander on the cometary surface was unclear, the originally foreseen sequence to operate the instruments and downlink data could not be used. In particular any mechanical actuation (like deploying MUPUS-PEN, or drilling) could only be commanded after careful evaluation.

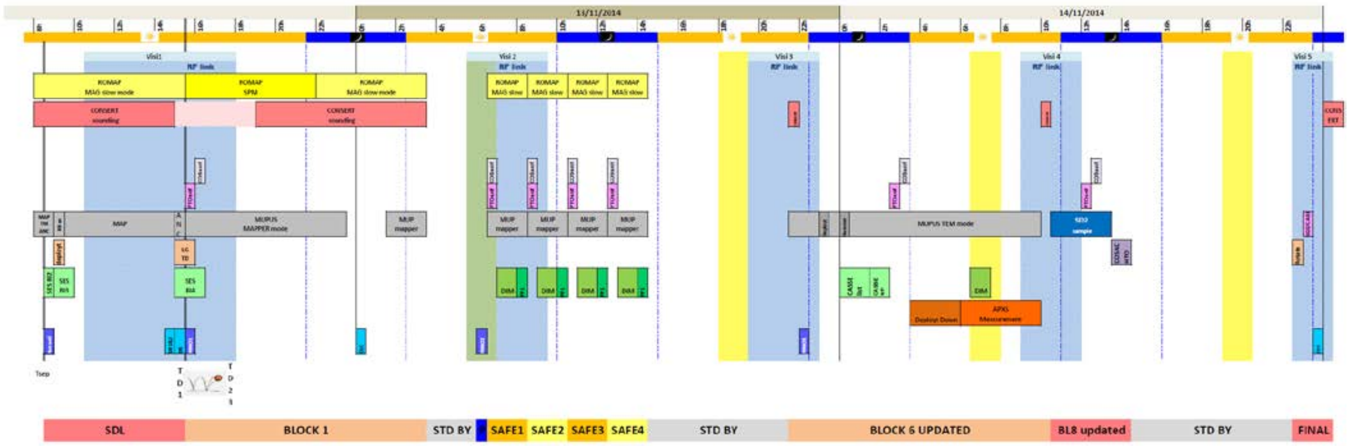

Figure 2: Timeline of Philae operations during descent and first scientific sequence (the blue background indicating RF link with the orbiter)

Figure 2 shows the timeline as performed between separation and preliminary end of operations. Note that all instruments were activated at least once. SD² attempted to take a sub-surface sample and deliver it to an oven, feeding COSAC. It is still to be evaluated how much material eventually was in the oven.

Philaes batteries ceased to provide power November 15th at 0:36 (UTC, on ground), 63.7 h after separation.

Long Term Science and chances for re-activation of Philae: Philae is currently at a location with limited illumination; too short to enter long term science immediately after the first sequence. Thus, the Lander is currently in a hibernation state, with insufficient power to boot the CDMS or establish communications link with the orbiter.

The situation, however improves, the closer comet and Lander get to the sun. Current estimates indicate that re-boot of Philae´s CDMS and RF link with Rosetta should be possible around May/June 2015 at a heliocentric distance around 1.6 to 1.4 AU. Re-charging of the secondary battery (and consequently more demanding science operations) is expected to be possible July to September 2015 (1.4 to 1.25 AU).

Conclusions: Philae successfully performed the first-ever landing on a cometary surface. Outstanding results could be obtained at or nearby the surface. High resolution images, measurements of the physical properties of the surface, radio sounding through the nucleus and in-situ chemical analyses were performed which could not have been obtained remotely. There results significantly enhance the overall scientific output of the Rosetta mission.

Acknowledgements: 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.

The authors would like to thank the teams of Rosetta and Philae for realizing the project. Special thanks go to ESA for its strong support to prepare and realize the landing of Philae.

References: [1] Glaßmeier, K.-H., Böhnhardt, H., Koschny, D., Kührt, E. and Richter I., (2007) *Space Science Rev*. 128, pp. 1-21. [2] Biele, J. and Ulamec, S. (2008) *Space Science Rev*. 138, 275-289. [3] Ulamec, S. *et al*. (2015) *Acta Astron*., Vol. 107, pp. 79-86.