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The final year of the Rosetta mission

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ABSTRACT

The International Rosetta Mission was launched on 2nd March 2004 on its 10 year journey to rendezvous with comet 67P Churyumov-Gerasimenko. Rosetta performed comet orbit insertion on the 6th of August 2014, after which it characterised the nucleus and orbited it at altitudes as low as a few kilometres. In November 2014 Rosetta delivered the lander Philae to perform the first soft landing ever on the surface of a comet. After this critical operation, Rosetta began the escort phase of the comet in its journey in the Solar System heading to the perihelion, reached in August 2015. Originally foreseen till the end of 2015, the mission was extended for another nine months to follow the comet on its outbound arc of the orbit. In view of the acquired experience and of the approaching end of mission the spacecraft was flown at much closer distances from the nucleus so that the scientific instruments had the chance to perform unique measurements. Following this phase of very close orbits, on the 30th of September 2016 Rosetta was set on a collision course trajectory with the comet to terminate the mission with a controlled impact.

This paper describes the details of the extended mission phase and the issues encountered during these months. It also includes the changes implemented on the spacecraft and in the operations concept to optimise the remaining mission time. The paper also includes the lessons learned from this unique and complex mission phase.

1. Introduction

Rosetta is a cornerstone scientific mission of the European Space Agency [1–3], launched on 2nd March 2004 on an Ariane 5 G+ rocket. Its main scientific objective was to rendezvous with the nucleus of comet 67/P Churyumov-Gerasimenko in 2014, to orbit it for about 1.5 years and to deliver onto the nucleus' surface a landing module named Philae. Seven years of active cruise, in which several planet gravity assist manoeuvres and two asteroid fly-bys were carried out [4–10], were followed by the final part of the cruise, where Rosetta (Fig. 1) had to fly at distances from the Sun that had never been reached before by a solar-powered spacecraft (aphelion was reached on 3rd October 2012 at about 5.3 AU distance) [11]. Notwithstanding the large solar array (64 m ^{2}), in order to survive at such Sun distances, the spacecraft had to be almost fully deactivated from June 2011 to January 2014 [12,13] to drastically reduce the power consumption and survive this mission phase. After reactivation, the final mission phase was flown towards its target, which was reached early August 2014; a full comet mapping and characterisation phase was then carried out [14], leading to the landing of the lander Philae [15–17]. The mission continued then its nominal plan by following the comet in its orbit around the Sun and beyond perihelion [18].

Section II of this paper describes the operations conducted after the perihelion passage in August 2015 including the mission extension phase. All the optimisation activities carried out during this phase to make sure the last months of the mission would be fully exploited are described in section III. Section IV describes the end of mission phase when Rosetta was flown very close to the nucleus and finally set on a collision course to the comet to terminate it with a soft touchdown, after having retrieved unique scientific data. Lessons learned and conclusions are addressed in sections V and VI respectively.

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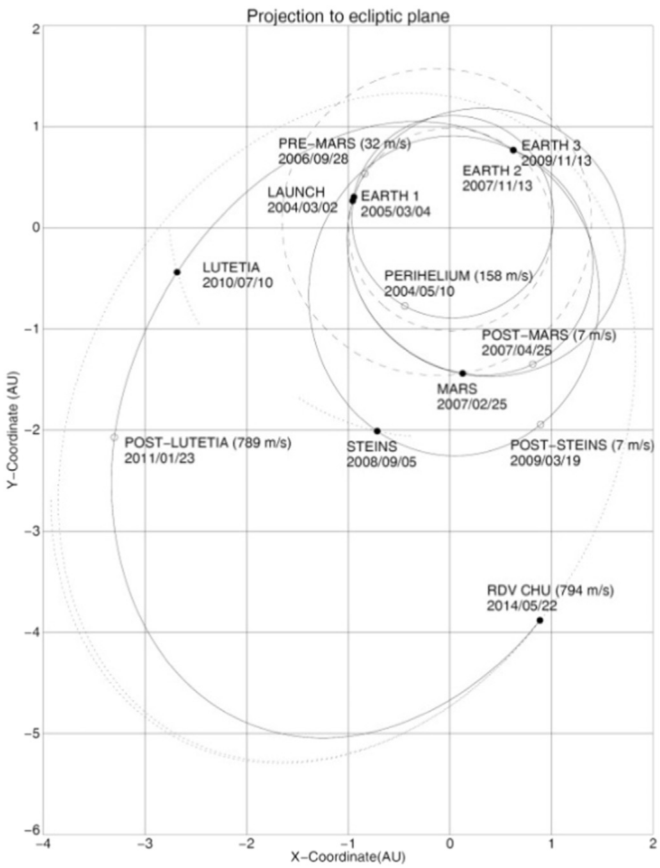

Fig. 1. Rosetta interplanetary trajectory.

2. The post-perihelion and mission extension phases

The peak of comet activity was reached in the weeks following the perihelion in August 2015. During this period Rosetta was flying at distances on the order of a few hundreds of kilometres in order to prevent the star sensor to be affected by the extreme dust environment surrounding the comet. This condition was taken as an opportunity to conduct a far excursion to ca. 1500 km from the comet nucleus so that the plasma instrument package could complete its set of observations regarding the interaction with the solar wind (see Fig. 2).

It was only in early November 2015 that the environmental conditions allowed the operations team to gradually perform a second approach phase and operations in proximity of the nucleus. This was also the last chance to listen for a possible radio signal from Philae before the concerned comet region would enter the autumn and then winter seasons again, thereby deteriorating the illumination conditions of the Lander to the point that it could not reactivate itself anymore. Specific listening campaigns were conducted between December 2015 and January 2016 (see Fig. 3) but no signal could be detected.

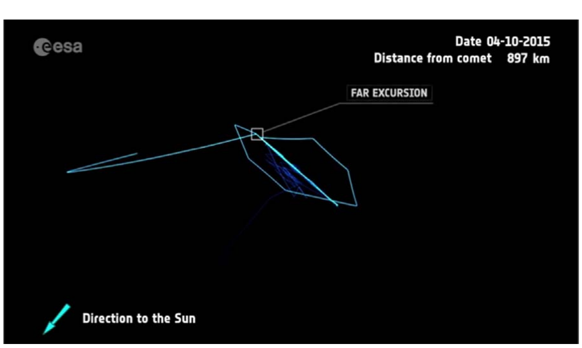

Fig. 2. Far excursion.

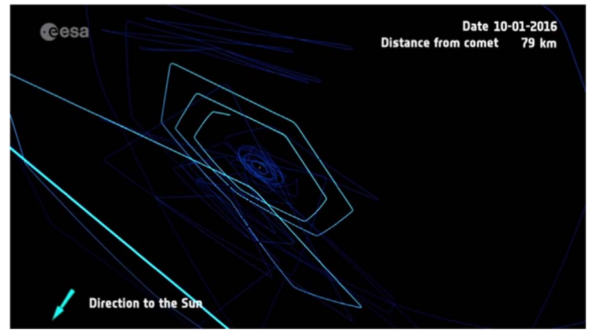

Fig. 3. Last listening opportunities for Philae.

During this phase it was possible to monitor the effects of the changed comet activity not only because of the more benign environment, but also from other observables like the rotation period of the comet itself. Upon arrival at the comet in 2014 a slight increase of the rotation period (up to 50 s/month) could be observed due to the outgassing from the surface and imparted torques to the body.

With the seasonal changes occurring around the perihelion phase (equinoxes in May 2015 and March 2016, solstice in September 2015), the increased comet activity (thus torques), and the illumination of the Southern hemisphere it was possible to see how the rotation period first significantly decreased, with the change rate that reached peak values of 350–400 s/month just after the perihelion/solstice phase, to then return to negligible changes shortly after. Fig. 4 shows how the comet rotation period (red line) changed from ca. 12 h 25 min to 12 h 03 min in the observed time frame.

The effects of the outgassing and the induced torques were also visible in the direction of the estimated spin axis of the comet; Fig. 5 shows its evolution in inertial frame (Earth Mean Equator 2000) from September 2014 to June 2016(uncertainty of estimation below 0.1 deg). Note that, for this declination, one degree of right ascension corresponds to an angular direction difference of only about half a degree. Start (September 2014) is at the bottom left of the image and end (June 2016) at the top left: the right ascension went up then down while the declination went mainly up. During the same period the comet mass decrease due to the emissions of gas and dust was estimated by the ESOC Flight Dynamics team to be ca. 0.1%, corresponding to 100 million tons.

With the mission extension approved beyond the original date of December 2015, the operations team was also confronted with the decision on how to terminate the mission. The main constraint for this decision was the heliocentric distance, which would reach the prohibitive threshold of 4.5 AU in January 2017, thus preventing any safe

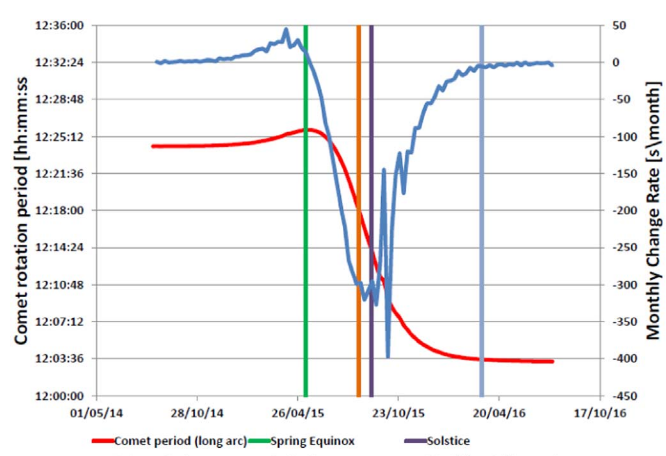

Fig. 4. Rotation period.