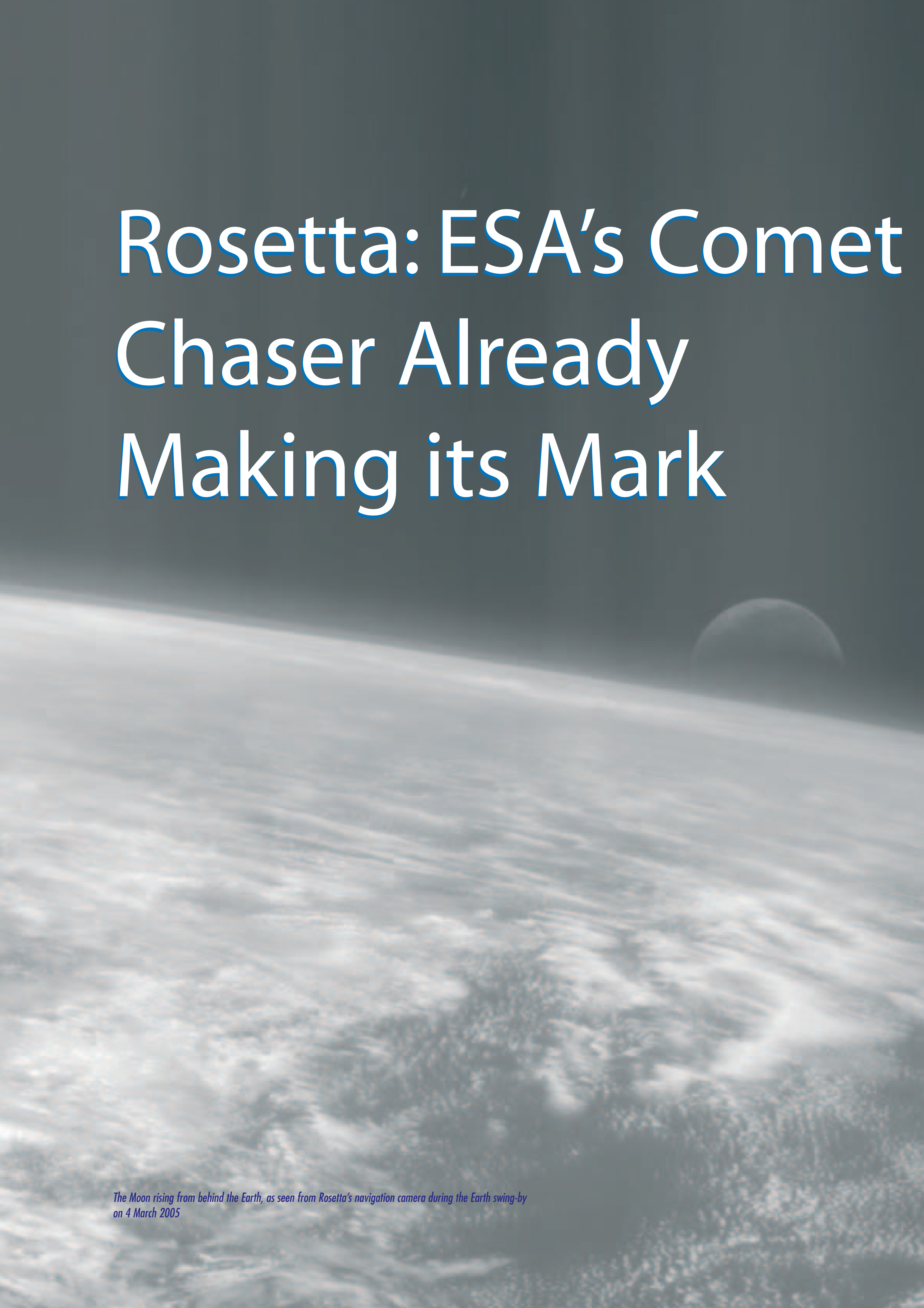
Rosetta: ESA's Comet Chaser Already Making its Mark



The Moon rising from behind the Earth, as seen from Rosetta's navigation camera during the Earth swing-by on 4 March 2005

Paolo Ferri
ESA Directorate of Operations and Infrastructure, ESOC, Darmstadt, Germany

Gerhard Schwehm
ESA Directorate of Scientific Programmes, ESTEC, Noordwijk, the Netherlands

Rosetta, the first planetary cornerstone mission of the ESA Scientific Programme, was launched on 2 March 2004 on its ten-year journey to rendezvous with comet 67P/Churyumov-Gerasimenko. In summer 2014, Rosetta will go into orbit around the comet's nucleus, approaching to within a few kilometres of its surface, will deliver a Lander called 'Philae' onto its surface to make in-situ measurements, and will then accompany the comet on its onward journey for about 1.5 years.

The launch and the first 1.5 years of flight operations have been very smooth, with the spacecraft, its payload and the ground segment performing almost perfectly, with no major anomalies and all parameters well within specification. All planned mission activities have gone according to schedule, and additional 'bonus' scientific and technological operations were even added to the intense operations schedule of the first few months.

Among the mission events to date were the observations of the NASA Deep Impact probe's encounter in July 2005 with comet 9P/Tempel-1, from a 'privileged' position in space just 80 million kilometres away.

The Mission's Launch and Early Orbit Phases

Rosetta's 21-day launch window opened on 26 February 2004, but the first launch attempt had to interrupted 20 minutes before lift-off due to unfavourable wind conditions. It was re-scheduled for the following day, but in the early morning of 27 February a routine inspection of the Ariane-5 launcher on the pad indicated that one or more thermal-insulation tiles had become detached from the cryogenic first stage. This caused cancellation of the second launch attempt and a delay of three days, as the launcher had to be rolled back into the Final Assembly Building for repair. Finally, on the morning of 2 March the launch took place with a perfect injection of the spacecraft into escape orbit, after about 2 hours of ascent and coasting on top of the Ariane-5 launcher.

The early-orbit phase went very smoothly and was completed in less than 72 hours, after which the spacecraft-commissioning activities were started.

Earth seen with Rosetta's Navigation Camera after the swing-by, from a distance of about 250 000 km

Satellite Commissioning

After about a week of subsystem checkout, the commissioning of the payload instruments began. The instruments were activated one at a time, with experts from the instrument teams present at ESOC during daily ground contact with the spacecraft via the New Norcia ground station in Western Australia, usually lasting 10 hours per day. All of the planned payload-checkout and satellite-commissioning activities could be carried out within the foreseen three-month time slot, and were therefore successfully completed by the beginning of June 2004. The correct functioning of all 10 instruments onboard the Rosetta spacecraft and the Philae lander was thoroughly checked during this phase.

Thanks to the smooth execution of the planned operations and the healthy status of the spacecraft, it was possible to include in this phase previously unplanned operations, such as complex spacecraft pointing profiles to allow boresight direction calibration of the remote-sensing instruments on board. On two occasions between the end of April and the beginning of May 2004, some scientific observations of comet C/2002 T7(Linear) were even carried out.

On 25 May, still during the commissioning phase, the spacecraft reached its closest point to the Sun (for this first revolution) of 0.886 Astronomical Units (AU), about 132 million km. The first deep-space manoeuvre of the mission was also carried out during the commissioning phase. The spacecraft's thrusters were fired for more than 3.5 hours, to achieve a total acceleration of about 153 m/s. The precision of this manoeuvre was outstanding, with an error of just 5 mm/s.

After the completion of the commissioning phase, the spacecraft was configured for a quiet cruise phase. Some further subsystem tests were also carried out, mainly to check the spacecraft's thermal behaviour when in the vicinity of the Sun. Other tests analysed the pointing accuracy of the star-trackers in specific parts of the sky.

The most critical post-launch activity took place in July 2004, with the uplinking and activation of the new version of the onboard avionics software. The uplinking activities began on 15 July and, after a week of software patching and verification, the 'reboot' command that would activate the new software was given on 22 July.

From the beginning of June, the number of ground station acquisitions was gradually reduced from one pass per day to two passes per week around mid-July. After the new software had been validated in the second half of July, the spacecraft was configured into 'quiet-cruise' mode and only one ground-station pass per week was used for monitoring purposes.

The second and last payload-commissioning phase was carried out in the period September-October 2004, involving the parallel activation of all onboard instruments and special pointing activities mainly to calibrate the remote-sensing payload.

After two small trajectory correction manoeuvres in November 2004 and February 2005, preparations for the first Earth swing-by began. The spacecraft's closest approach to Earth occurred on 4 March 2005, during the so-called 'swing-by' or 'gravitational-assist' manoeuvre, with Rosetta passing within 1954 km of the Earth's surface. Several payload instruments were activated to perform calibration activities during this phase, taking advantage of the known environment of the Earth and using the Earth-Moon system as targets for the remote-sensing instruments. The Moon also provided a unique opportunity to validate the spacecraft mode that will be used for attitude control during the two asteroid fly-by phases in 2008 and 2010. In this special mode, Rosetta makes use of the Navigation Camera to steer the spacecraft in such a way that the payload platform is kept pointed towards the asteroid – represented in the test by the Moon. The test was very successful, demonstrating exceptional performance in terms of attitude stability, which will be key in providing optimal support to the scientific operations during the real asteroid fly-bys.

After completing the Earth swing-by, Rosetta began its second orbit around the Sun, traveling this time towards planet Mars, which it will reach for a second swing-by manoeuvre in February 2007. At the beginning of this cruise phase, a long in-flight commissioning of the Near-Sun Hibernation Mode took place. This is a special mode that will enable the spacecraft to operate with minimum hardware for periods of up to six months during the long quiet-cruise phases, with ground contact typically taking place just once per month.

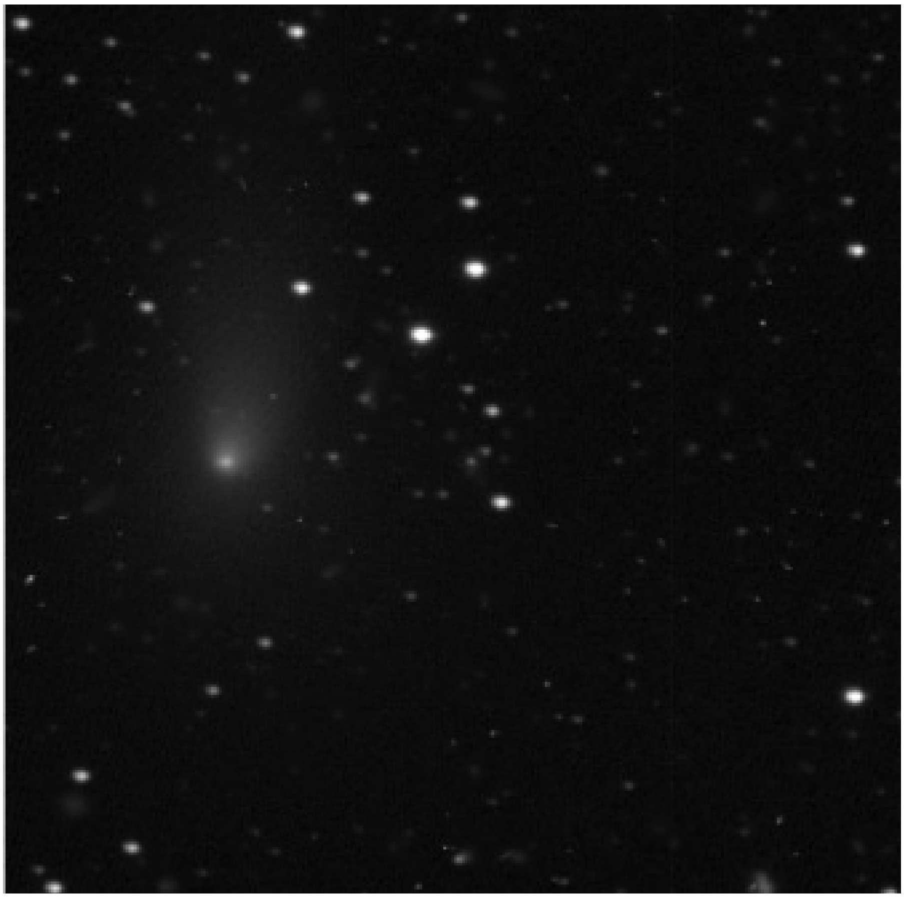


Image of comet Tempel-1 taken by Rosetta's OSIRIS NAC camera in June, prior to the Deep Impact event (copyright 2005 ESA-MPS for OSIRIS Team)

The 'Deep Impact' Observations

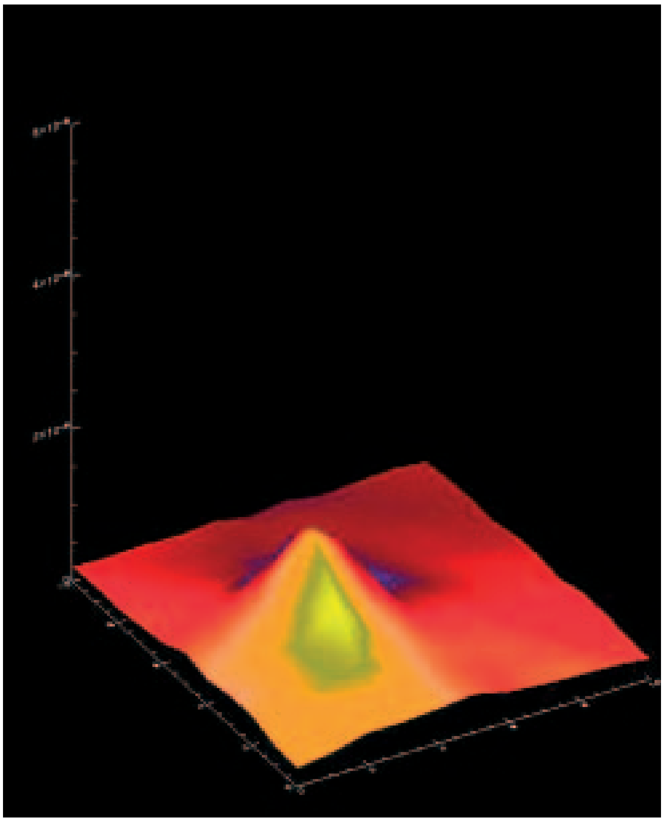
Before entering its Near-Sun Hibernation Mode, in July 2005 Rosetta was commanded to point at comet Tempel-1 during the final phase of NASA's Deep Impact mission, and its four remote-sensing scientific instruments were used to observe the probe's impact with the comet's nucleus on 4 July.

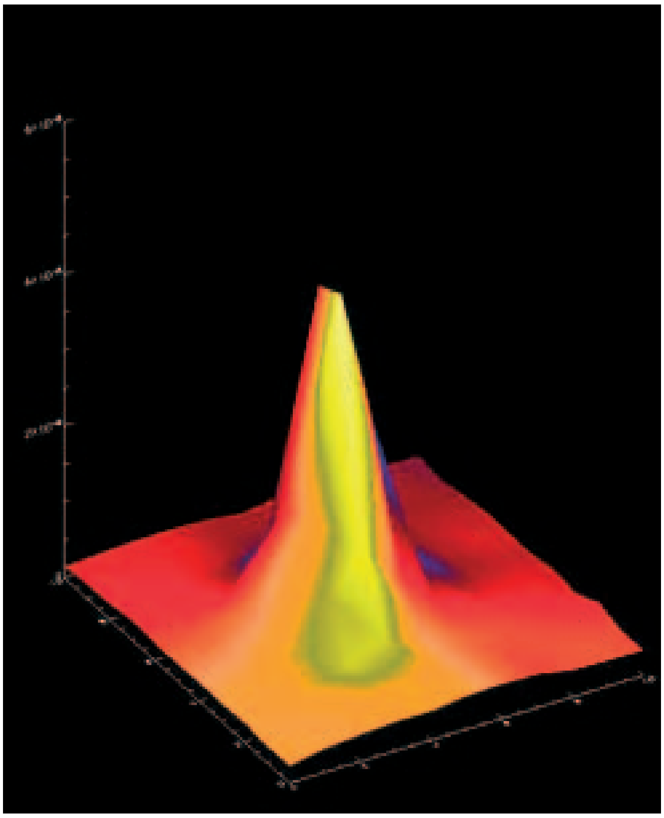
At NASA's request, Rosetta's entry into quiet-cruise mode had been postponed by a few months to allow the spacecraft to pointed to observe the collision. Rosetta happened to be in a good observing position, about 80 million kilometres from the comet, with an ideal angle of 90 degrees between the Sun and comet directions, which provided optimum observing conditions. Rosetta was first pointed towards comet Tempel-1 on 29 June and kept tracking it until 14 July. Its four remote-sensing instruments - Miro, Alice, Virtis and Osiris - were operated in parallel using a complex pointing profile to gather the best scientific data with all four instruments.

The NASA impactor hit the nucleus of Tempel-1 as planned at 05:52 UTC on 4 July. The impactor itself and the Deep Impact spacecraft delivered impressive pictures of the impact on the comet's surface. At the same time, observatories around the world pointed their instruments at the comet to register the electromagnetic radiation generated at infrared, visible and ultraviolet wavelengths. Thanks to the absence of an atmosphere between its instruments and the comet, Rosetta could monitor the event continuously as, unlike the ground-based telescopes, it did not have to cope with the Earth's rotation.

The scale of the impact was such that the event was clearly recorded by Rosetta's instruments. Observations continued for about 10 days after the impact, providing a wealth of data on its evolution and effects. Over the 18 days of its observations, Rosetta delivered an average of 60 Mbytes of data per day. The scientific processing and evaluation of these data is still in progress, but it has already provided indications of the high quality of the data and of the possible results.

The Deep Impact observations have demonstrated that the Rosetta spacecraft is not only extremely reliable, but also versatile and flexible. The planning of this complex activity took only a few weeks from the formal decision to go ahead, to





Brightness of comet Tempel-1 in OSIRIS camera images before and after being struck by the Deep Impact probe (copyright 2004 ESA-MPS for the OSIRIS Team)

the actual execution of the operation. The scientific instruments worked flawlessly and the pointing performance of the spacecraft was accurate beyond all specifications. In addition to constituting a unique and precious scientific opportunity, the Deep Impact observations are also an example of how efficient and cost-effective inter-agency cooperation between ESA and NASA can be.

The Long Journey Continues

Following the Deep Impact scientific operations, Rosetta has finally been put into Passive-Cruise mode, in which it will remain for most of the rest of its journey to Mars. After the Mars fly-by, there will be two more Earth fly-bys, two fly-bys of asteroids Steins (2008) and Lutetia (2010), a long deep-space cruise phase in which the spacecraft will be spun-up and almost completely deactivated, and finally the rendezvous with comet Churyumov-Gerasimenko in 2014, with the soft landing by Philae on the nucleus's surface planned for the last quarter of the year. The end of the mission is currently foreseen for December 2015, a few months after the comet's perihelion passage.

Conclusion

The Rosetta mission has begun in the best possible way: a perfect orbital injection and excellent performance from both the spacecraft platform and the instrument payload. This is a very good but also necessary beginning for such a long-duration mission, during which hardware-obsolescence problems can sometimes occur.

The level of ground activity has been higher than expected, due to the intense use of the spacecraft for in-flight testing, the additional unforeseen scientific observations, and instrument characterisation efforts. Intense use of the spacecraft engineering model at ESOC has contributed greatly to the success of mission operations so far, but at the expense of a high workload for the flight-control personnel. This has, however, been rewarded in the end by the smooth operation and excellent performance of the spacecraft.

During Rosetta's first 18 months in space, therefore, both the Mission Operations Team and the Science Operations Team have certainly demonstrated that they are more than able to operate both the spacecraft and the payload in the most efficient way possible and thereby optimise the scientific harvest from this exciting mission.