Rosetta Mission Description

***Editor’s note:*** *This document was reformatted from the “DESCRIPTION” text of the last version of the PDS3 Mission Catalog File delivered to the Planetary Data System (PDS) Small Bodies Node (SBN). Obvious typos were corrected; UK English spell-checking was applied; some verb tenses were modified for uniformity with the surrounding text; the PDS3 REFERENCE\_KEY\_ID values inserted into the text were replaced with inline citations in the usual journal format; a* Reference *section was added to list the associated references as they were provided to SBN; and DOIs were added for references to the published literature, as retrieved from the Astrophysics Data System database.*

*Readers should be aware that this file was never completed. Specifically, there are “TBD” and similar notations found in some tables and descriptive sections, and two sections corresponding to the final two mission phases were never provided. The Rosetta technical reports cited in the text and listed in the references were not submitted for archiving and do not appear to be available in any public, digital form now (August 2024) – nor where they during the active mission.*

# ROSETTA Mission Overview

The ROSETTA mission is an interplanetary mission whose main objectives are the rendezvous and *in situ* measurements of the comet 67P/Churyumov-Gerasimenko, scheduled for 2014/2015. The spacecraft carries a Rosetta Lander, named Philae, to the nucleus and deploys it onto its surface.

A brief description of the mission and its objectives can be found in Glassmeier, et al. (2007a). A detailed description of the mission analysis can be found in the ROSETTA User Manual (RO-DSS-MA-1001), and the flight Operations Plan (RO-ESC-PL-5000).

On its long way to the comet nucleus after a Launch by Ariane 5 P1+ in March 2004, the ROSETTA spacecraft orbited the Sun for one year until it returned to Earth for the first swing-by. The planet Mars was reached in February 2007, about 3 years after launch. In November 2007 a second Earth swing-by took place and a third one in November 2009. Two asteroid flybys (2867 Steins and 21 Lutetia) were performed on the way to the comet. These two asteroids had been selected at the Science Working Team meeting on 11th March 2004 among all the available candidate asteroids, depending on the scientific interest and the propellant required for the correction manoeuvre. Around the aphelion of its orbit, which is 5.3 AU from the Sun, the spacecraft has been in a spinning hibernation mode for about 2.5 years.

Rosetta rendezvoused with comet 67P/Churyumov-Gerasimenko in August 2014. The Philae lander was deployed to the surface of the comet on 12 November 2014.

The end of the nominal mission was planned for December 2015 but was extended to 30th September 2016. On that date the Rosetta orbiter performed a hard landing on the 67P nucleus, in the Ma’at region.

The Mission Phase Schedule can be found below based on the official mission calendar. For archive purposes, we used a slightly updated calendar splitting the escort and extension phases.

Below we summarise the phases used by the team for archive purposes:

|  |  |  |  |
| --- | --- | --- | --- |
| **MISSION\_PHASE\_NAME** | **Abbreviation** | **Start date** | **End date** |
| GROUND | GRND | \*\*\* | 2019-09-30 |
| LAUNCH | LEOP | 2004-03-03 | 2004-03-04 |
| COMMISSIONING 1 | CVP1 | 2004-03-05 | 2004-06-06 |
| CRUISE 1 | CR1 | 2004-06-07 | 2004-09-05 |
| COMMISSIONING 2 | CVP2 | 2004-09-06 | 2004-10-16 |
| EARTH SWING-BY 1 | EAR1 | 2004-10-17 | 2005-04-04 |
| CRUISE 2 | CR2 | 2005-04-05 | 2006-07-28 |
| MARS SWING-BY | MARS | 2006-07-29 | 2007-05-28 |
| CRUISE 3 | CR3 | 2007-05-29 | 2007-09-12 |
| EARTH SWING-BY 2 | EAR2 | 2007-09-13 | 2008-01-27 |
| CRUISE 4-1 | CR4A | 2008-01-28 | 2008-08-03 |
| STEINS FLY-BY | AST1 | 2008-08-04 | 2008-10-05 |
| CRUISE 4-2 | CR4B | 2008-10-06 | 2009-09-13 |
| EARTH SWING-BY 3 | EAR3 | 2009-09-14 | 2009-12-13 |
| CRUISE 5 | CR5 | 2009-12-14 | 2010-05-16 |
| LUTETIA FLY-BY | AST2 | 2010-05-17 | 2010-09-03 |
| RENDEZVOUS MANOEUVRE 1 | RVM1 | 2010-09-04 | 2011-06-07 |
| CRUISE 6 | CR6 | 2011-06-08 | 2014-01-20 |
| PRELANDING | PRL | 2014-01-21 | 2014-11-19 |
| COMET ESCORT 1 | ESC1 | 2014-11-20 | 2015-03-10 |
| COMET ESCORT 2 | ESC2 | 2015-03-11 | 2015-06-30 |
| COMET ESCORT 3 | ESC3 | 2015-07-01 | 2015-10-21 |
| COMET ESCORT 4 | ESC4 | 2015-10-22 | 2015-12-31 |
| ROSETTA EXTENSION 1 | EXT1 | 2016-01-01 | 2016-04-05 |
| ROSETTA EXTENSION 2 | EXT2 | 2016-04-06 | 2016-06-30 |
| ROSETTA EXTENSION 3 | EXT3 | 2016-07-01 | 2016-09-30 |

For the Lander, the Cruise Phase data sets followed the same file naming but the Comet phase has been split differently:

|  |  |  |  |
| --- | --- | --- | --- |
| **MISSION\_PHASE\_NAME** | **Abbn** | **Start date** | **End date** |
| POST HIBERNATION COMMISSIONING | PHC | 2014-04-09T08:15:25 | 2014-04-23T15:45:13 |
| PRE DELIVERY CALIB SCIENCE | PDCS | 2014-07-13T14:42:56 | 2014-10-17T20:31:20 |
| SEPARATION DESCENT LANDING | SDL | 2014-11-12T08:35:02 | 2014-11-12T15:34:04 |
| REBOUNDS | RBD | 2014-11-12T15:34:05 | 2014-11-12T17:30:20 |
| FIRST SCIENCE SEQUENCE | FSS | 2014-11-12T17:30:21 | 2014-11-15T01:00:00 |

Please note:

The ROSETTA spacecraft was originally designed for a mission to the comet 46 P/Wirtanen to be launched in January 2003. Due to a delay of the launch a new comet (67P/Churyumov-Gerasimenko) had been selected by the Science Working Team on 3rd-4th April 2003. The compliance of the design was checked and where necessary adapted for this new mission. Therefore, in the following all the details and characteristics for this new mission are used.

# ROSETTA Mission Objectives

The scientific objectives of the ROSETTA mission can be considered from three main viewpoints:

First of all, comets and asteroids are fully-fledged members of our solar system, which means, that they are objects of intrinsic interest to planetary scientists. The level of investigations conducted on these bodies is therefore far below that achieved for the other objects of the solar system. The study of the small solar-system bodies arguably represents the last major gap in the tremendous worldwide effort that has been made to reveal our planetary neighbours to us.

The most important scientific rationale for studying small solar- system bodies is the key role-play in helping us to understand the formation of the solar system. Comets and asteroids have a close genetic relationship with the planetesimals, which formed from the solar nebula 4.57 billion years ago. Most of our present understanding of these processes has been obtained by studying meteorites, which constitute a biased sample of asteroidal material, and micrometeoroids, which may represent cometary grains processed by solar radiation and atmospheric entry. There is therefore a strong scientific case of studying cometary material *in situ*, as it is surely more primitive than extraterrestrial samples.

A third scientific aspect is the study of the physio-chemical processes, which are specific to comets and asteroids. In this respect, asteroids can provide information on impact phenomena, particularly on very large scale. However, the increase in cometary activity as these bodies approach the Sun undoubtedly represents one of the most complex and fascinating processes to be observed in the solar system.

## Science Objectives

The prime scientific objectives as defined in the Announcement of Opportunity [RO-EST-AO-0001] by the Rosetta Science Team can be summarized as:

* Global characterisation of the nucleus, determination of dynamic properties, surface morphology and composition
* Chemical, mineralogical and isotropic compositions of volatiles and refractories in a cometary nucleus
* Physical properties and interrelation of volatiles and refractories in a cometary nucleus
* Study of the development of cometary activity and the processes in the surface layer of the nucleus and in the inner coma (dust-gas interaction)
* Origin of comets, relationship between cometary and interstellar material
* Implications for the origin of the solar system
* Global characterisation of the asteroid, determination of dynamic properties, surface morphology and composition

# Mission Profile

The ROSETTA mission profile results from the orbit of the target comet 67P/Churyumov-Gerasimenko, which has a perihelion close to 1.2 AU and an aphelion of about 5.7 AU, resulting in a period of about 6.5 years. A detailed description of the Mission Profile can be found in the Rosetta Mission Calendar [RO-ESC-PL-5026] and in the RSOC Design Specification [RO-EST-PL-2010].

The injection of the spacecraft by a single Ariane 5 Launch with the so-called 'delayed ignition' of the upper stage, was not directly into the trajectory to the comet, because of the high spacecraft wet mass. Therefore, the spacecraft had to be accelerated by a sequence of gravity assist manoeuvres at Mars and the Earth, in order to catch up with the comet's velocity at perihelion.

The initially large distance to the comet at the perihelion of its trajectory has been slowly decreasing after the third Earth swing-by. At the intersection of both orbits, the difference in orbit inclination and the residual relative velocity were diminished by the comet orbit matching manoeuvre at around 4.0 AU Sun distance. The range of the spacecraft-to-Sun distance was between 0.88 and 5.33 AU, defined by the minimum Sun distance during the first five years of the mission with the swing-bys at Earth, and the maximum Sun distance close to the aphelion of the comet's orbit. The evolution of the spacecraft distance to Earth over the mission time followed the profile of the Sun distance superimposed by an oscillation with an amplitude of 2 AU (+1,-1) and a period of about one year due to the Earth's motion around the Sun. This resulted in a range from 0 AU (Earth Departure and Swing-by) to 6.3 AU during the superior solar conjunction close to the spacecraft's aphelion (see [Solar Conjunctions](#_Solar_Conjunctions/Oppositions) section below).

After the second and third Earth swing-by ROSETTA crossed the asteroid main belt, which gave the opportunity of two asteroid flybys. The asteroids 2867 Steins and 21 Lutetia were encountered on 5 September 2008 and 10 July 2010 respectively. These two asteroids had been selected at the Science Working Team meeting on 11th March 2004 among all the available candidate asteroids, depending on the scientific interests and the propellant required for the correction manoeuvre.

Between the major mission events, up to the comet rendezvous manoeuvre, the spacecraft performed long interplanetary cruise phases (up to 2.5 years) with several solar conjunctions (see Solar Conjunctions section below) and the power critical aphelion passage (last cruise phase). In order to reduce the ground segment costs and the wear and tear of spacecraft equipment during these phases, the spacecraft was put in “Hibernation Mode”.

Two types of hibernation modes were planned to be used:

1. *Deep Space Hibernation Mode* above 4.5 AU: Inertial spin mode with a spin rate of 4 deg/sec. The spacecraft was almost entirely passive, except of receivers/ decoders, power supply, heaters and two Processor Modules with one RTU.
2. *Near Sun Hibernation Mode* below 4.5 AU: 3-axes stabilised mode with the solar arrays Sun-pointing and the +X-axis Earth-pointing. Attitude control was performed with thrusters and star trackers, based on ephemerides; occasional solar array adjustments and ground contacts via the medium gain antenna (MGA).

The final approach to the comet into its sphere of influence was prepared by the rendezvous manoeuvre (RVM-2), that matched the spacecraft orbit with the comet orbit.

A subsequent sequence of approach manoeuvres, supported by optical navigation, took the spacecraft closer and closer to the comet. After determination of the physical model of the comet by Doppler and optical measurements, the spacecraft was inserted into a global mapping orbit around the comet.

The “Duck-shape” of the comet was a surprise and a challenge for the Flight Dynamics team. Three activity cases had been planned to orbit the comet, respectively at 30, 20 or 10km. Finally, it was chosen to go to 10km.

Meanwhile, a board was selecting 5 and then 2 landing sites. The chosen landing sites were located on the “head” of the Duck Shape comet.

The delivery of the Lander or Surface Science Package (SSP) was achieved from an eccentric orbit, which took the spacecraft to a low altitude above the selected landing site. The Lander release was fully automatic according to a predefined schedule and led to a first touchdown with minimum vertical and horizontal velocities relative to the local rotating surface.

The first touchdown reached the foreseen landing site within 50m accuracy. However, the Lander did not succeed in harpooning and bounced twice. It was stopped by cliff walls, which unluckily hid the Lander from the Sun.

The Lander, Philae, had the time to operate all instruments on board during a phase named the FSS, First Science Sequence, before going to sleep on November 15th at 00:36 UTC. Upon the landing of the Lander, the spacecraft provided uplink and downlink data relay between the Lander and the Earth.

After the Lander delivery the ROSETTA spacecraft escorted the comet until the perihelion passage (13th August 2015) and outwards again, until a Sun distance of 2 AU was reached at end of the year 2015. The main scientific objective during this phase was the monitoring of the features of the active comet.

The mission was extended from 1st January 2016 to 30th September 2016. Rosetta ended its journey on September 30th by a controlled impact onto the comet from an altitude of about 19km.

# Mission Phases Overview

This section gives an overview of the major mission phases and main events in scheduled tables. A description of the individual phases is given in the following section. More detailed information can be found in the Rosetta Mission Calendar [RO-ESC-PL-5026] and the RSOC Design Specification [RO-EST-PL-2010]

## Mission Phase Schedule

The following table shows a schedule of the mission phases, with start-end times (dd/mm/yyyy), duration (days) and distance to the sun (Astronomical Units). Some of the most important events within the mission phases are marked with an arrow (à). Further description of each mission phase is given below.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Phase | Start Date | Main Event | End Date | Dur (days) | Sun Dist  (AU) |
| LEOP | 02/03/2004 |  | 04/03/2004 | 3 |  |
| Commissioning1 | 05/03/2004 |  | 06/06/2004 | 94 | 0.89-0.99 |
| àDSM1 |  | 11/05/2004 |  |  |  |
| àDSM1 Touch-up |  | 16/05/2004 |  |  |  |
| Cruise 1 | 07/06/2004 |  | 05/09/2004 | 91 | 0.89-1.04 |
| Commissioning2 | 06/09/2004 |  | 16/10/2004 | 41 | 1.04-1.09 |
| Earth Swing-by1 | 17/10/2004 |  | 04/04/2005 | 170 | 0.99-1.11 |
| àEarth |  | 04/03/2005 |  |  |  |
| Cruise 2 | 05/04/2005 |  | 28/07/2006 | 480 | 1.04-1.76 |
| àDeep Impact |  | 04/07/2005 |  |  |  |
| Mars Swing-by | 29/07/2006 |  | 28/05/2007 | 304 | 0.99-1.59 |
| àDSM2 |  | 29/09/2006 |  |  |  |
| àMars |  | 25/02/2007 |  |  |  |
| àDSM3 |  | 29/04/2007 |  |  |  |
| Cruise 3 | 29/05/2007 |  | 12/09/2007 | 107 | 1.32-1.58 |
| Earth Swing-by2 | 13/09/2007 |  | 27/01/2008 | 137 | 0.91-1.32 |
| àEarth |  | 13/11/2007 |  |  |  |
| Cruise 4-1 | 28/01/2008 |  | 03/08/2008 | 189 | 1.02-2.03 |
| Steins Flyby | 04/08/2008 |  | 05/10/2008 | 63 | 2.03-2.19 |
| àSteins |  | 05/09/2008 |  |  |  |
| Cruise 4-2 | 06/10/2008 |  | 13/09/2009 | 343 | 1.35-2.26 |
| àDSM4 |  | 19/03/2009 |  |  |  |
| Earth Swing-by3 | 14/09/2009 |  | 13/12/2009 | 92 | 0.98-1.35 |
| àEarth |  | 13/11/2009 |  |  |  |
| Cruise 5 | 14/12/2009 |  | 16/05/2010 | 154 | 1.03-2.45 |
| Lutetia Flyby | 17/05/2010 |  | 03/09/2010 | 111 | 2.45-3.14 |
| àLutetia |  | 10/07/2010 |  |  |  |
| Rendez-vousMan1 | 04/09/2010 |  | 13/07/2011 | 313 | 3.15-4.58 |
| àRVM1 |  | 23/01/2011 |  |  |  |
| Cruise 6 (DSHM) | 14/07/2011 |  | 20/01/2014 | 917 | 4.46-5.29 |
| Rendez-vousMan2 | 21/01/2014 |  | 17/08/2014 | 206 | 3.40-4.49 |
| àRVM2 1st burn |  | 21/05/2014 |  |  |  |
| Global Mapping and Close Observation | 18/08/2014 |  | 19/10/2014 | 63 | 3.15-3.53 |
| Lander Delivery | 20/10/2014 |  | 16/11/2014 | 28 | 2.97-3.15 |
| àLander Delivery |  | 12/11/2014 |  |  |  |
| Comet Escort | 17/11/2014 |  | 31/12/2015 | 410 | 1.24-2.96 |
| Extension | 31/12/2015 |  | 30/09/2016 | 274 | 2.01-3.83 |

## Payload Checkouts

Payload checkouts were scenarios designed to allow Rosetta payload to make regular health checks, to activate mechanisms and to monitor trends through calibration tests. They were allocated in the mission calendar at regular 6-month periods during the first 10 years of the mission cruise phase. They were split into passive and active payload checkouts. Passive payload checkouts were entirely non-interactive. Conditions for the passive checkout were that it would: a) not require any real time monitoring, b) run entirely off of MTL, c) not require s/c specific pointing other than to maintain listed constraints, d) produce minimal science data. Active payload checkout operations were executed both interactively and non-interactively. Conditions for the active checkout were that it would: a) limit the requirement for real time monitoring, b) run mostly from MTL, c) limit the requirement for s/c specific pointing beyond maintaining listed constraints, d) produce minimal science data. There was more flexibility during active checkouts and in addition payloads used interactive passes to make any necessary memory patches and tests.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Name | Type | Begin | End | Mission Phase |
| P/L Checkout 0 | Passive | 27/03/2005 | 31/03/2005 | Earth Swing-by 1 |
| P/L Checkout 1 | Passive | 30/09/2005 | 05/10/2005 | Cruise 2 |
| P/L Checkout 2 | Passive | 03/03/2006 | 08/03/2006 | Cruise 2 |
| P/L Checkout 3 | Passive | 25/08/2006 | 30/08/2006 | Mars Swing-by |
| P/L Checkout 4 | Active | 23/11/2006 | 22/12/2006 | Mars Swing-by |
| P/L Checkout 5 | Passive | 18/05/2007 | 23/05/2007 | Mars Swing-by |
| P/L Checkout 6 | Active | 13/09/2007 | 29/09/2007 | Earth Swing-by 2 |
| P/L Checkout 7 | Passive | 04/01/2008 | 09/01/2008 | Earth Swing-by 2 |
| P/L Checkout 8 | Active | 19/07/2008 | 24/07/2008 | Cruise 4-1 |
| P/L Checkout 9 | Passive | 28/01/2009 | 02/02/2009 | Cruise 4-2 |
| P/L Checkout 10 | Active | 18/09/2009 | 08/10/2009 | Earth Swing-by 3 |
| P/L Checkout 12 | Passive | 22/04/2010 | 15/05/2010 | Cruise 5 |
| P/L Checkout 13 | Passive | 01/12/2010 | 15/12/2010 | RVM1 |

## Solar Conjunctions/Oppositions

Other mission phases, which resulted from the orbit geometry and interfered with the above operational phases, were the solar conjunctions.

Two types of conjunctions occurred throughout the mission:

1. Solar Oppositions: The Earth was between spacecraft and Sun, resulting in a degradation of the command link to the spacecraft.
2. Superior Solar Conjunctions: Sun was between spacecraft and Earth, resulting in a degradation of the command and telemetry link to/from the spacecraft.

Table below shows the solar conjunction phases throughout the mission with type, begin and duration of the conjunction and corresponding mission phase. The phases are defined as the periods, during which the Sun-SpaceCraft-Earth (SSCE) angle is below 5 degrees.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Type | Duration | Begin | End | Mission Phase |
| Conjunction 1 | 48d | 21/03/2006 | 07/05/2006 | Cruise 2 |
| Conjunction 2 | 39d | 08/12/2008 | 15/01/2009 | Cruise 4-2 |
| Conjunction 3 | 50d | 22/09/2010 | 10/11/2010 | RV Manoeuvre 1 |
| Opposition 1 | 37d | 13/04/2011 | 19/05/2011 | RV Manoeuvre 1 |
| Conjunction 4 | 64d | 15/10/2011 | 17/12/2011 | Cruise 6 |
| Opposition 2 | 47d | 30/04/2012 | 15/06/2012 | Cruise 6 |
| Conjunction 5 | 67d | 31/10/2012 | 05/01/2013 | Cruise 6 |
| Opposition 3 | 46d | 20/05/2013 | 04/07/2013 | Cruise 6 |
| Conjunction 6 | 60d | 24/11/2013 | 22/01/2014 | Cruise 6 |
| Opposition 4 | 28d | 25/06/2014 | 22/07/2014 | RV Manoeuvre 2 |
| Conjunction 7 | 41d | 21/01/2015 | 02/03/2015 | Comet Escort |

It can be noted that for archive purposes and because of the non-expected landing, which included rebounds, the Lander team provided the data sets from wake up to the First Science Sequence (FSS) in 5 data sets with sub mission phases that differ from the official ones. The table below lists these sub phases:

|  |  |  |  |
| --- | --- | --- | --- |
| **PHC** | Post Hibernation Commissioning | 2014-04-09T08:15:25 | 2014-04-23T15:45:13 |
| **PDCS** | Pre-Delivery Calib Science | 2014-07-13T14:42:56 | 2014-10-17T20:31:20 |
| **SDL** | Separation Descent Landing | 2014-11-12T08:35:02 | 2014-11-12T15:34:04 |
| **RBD** | Rebounds | 2014-11-12T15:34:05 | 2014-11-12T17:30:20 |
| **FSS** | First Science Sequence | 2014-11-12T17:30:21 | 2014-11-15T01:00:00 |

The Orbiter instruments used the phase Prelanding (PRL) to deliver the data from wake-up to FSS.

# Mission Phases Description

## Launch and Early Orbit phase (LEOP)

Rosetta was launched by an Ariane 5/G+ in a dedicated flight (single launch configuration) from Kourou at 07:17:51 UTC 2 March 2004. After burnout of the lower composite, the upper stage together with the spacecraft remained in an eccentric coast arc for nearly 2 hours. Then the upper stage performed delayed ignition and injected the Rosetta spacecraft into the required escape hyperbola.

After spacecraft separation from the upper stage, Rosetta acquired its three axes stabilised Sun pointing attitude and deployed the solar arrays autonomously. Ground operations acquired the downlink in S-band using the ESA network and controlled the spacecraft to a fine- pointing attitude with the HGA pointing towards Earth using X-band telemetry. Tracking and orbit determination were performed, the departure trajectory was verified and corrected by the on-board propulsion system of the spacecraft.

The launch locks of the Lander Philae were released at the end of the first ground station pass. Philae remained firmly attached to the spacecraft by the cruise latches until its release at the comet.

## Commissioning phase

Commissioning started three days after launch following the first trajectory correction manoeuvre. A Deep Space Manoeuvre (DSM1) of 173 m/s was executed at perihelion. All spacecraft functions needed during the cruise to the comet, in particular for hibernation, were checked and the scientific payload was commissioned.

Commissioning was done in two parts, as the New Norcia ground station must have been shared with Mars Express and could not be used by Rosetta from June to mid-September 2004.

For more information refer to the following reports:

* [RO-EST-RP-3293] Consolidated Rosetta Payload Report of the Mission Commissioning Results Review
* [RO-EST-RP-3307] RSOC\_Commissioning\_Results\_Report\_2005Dec19.pdf
* [RO-EST-RP-3343] Interference Scenario Report

## Cruise phase 1

Almost all the scientific instruments, except ALICE were switched off while ground contact was practically not available. No payload operations were done during this phase.

## Earth swing-by 1

The actual Earth swing-by took place on 4-Mar-05. The phase ended one month after the swing-by and the spacecraft was prepared for the next cruise phase to Mars.

One passive Payload Checkout was scheduled end of March 2005. Immediately after this flyby an Asteroid Flyby Mode Simulation was performed using the Moon as a target. Some limited payload operations were permitted shortly before during and shortly after this Earth Flyby. Rosetta payload teams were given the opportunity to conduct scientific investigation that included close approach of both the Earth and the Moon and the AFM simulation. Any activities that did not require the Earth-Moon system i.e. continued instrument commissioning, were considered for later in the Mission, such as during the next active checkout.

The instrument objectives are listed below.

### ORBITER

#### ALICE

* Flat field calibration
* Extended object scattered light calibration (Moon as the target)
* Absolute solar calibration
* Absolute flux and wavelength calibration (wide part of the slit to take in the Moon)
* Door performance test due to anomalies raised during commissioning

#### MIRO

* Asteroid Flyby Simulation test
* H2O lines in Earth (high quality data obtained but analysis not complete)
* Radiometric calibration of the Moon

#### RPC

* Sensor calibration
* Magnetospheric physics
* Verification of the science operations modes for the Mars flyby

#### RSI

* HGA to Earth around closest approach to Moon

#### OSIRIS

Because of technical issues OSIRIS was not operated during the Earth Swing-By itself.

#### VIRTIS

* Co-alignment M/H
* Aldebaran target in IR (failed, boresight did not detect the target)
* Absolute calibration using the Moon
* Full disc Earth imaging including exosphere over one rotation

### LANDER

#### CIVA

* Earth Picture with Camera #2 or 4

#### ROMAP with RPC MAG

* Magnetic axes alignment of sensors with Earth magnetic field
* Checking of scaled values with known Earth values
* Solar wind values comparison with other s/c

### Problems

#### RPC

* Loss of LAP science data for 41.5 hours (2005-03-01 19:00 -- 2005-04-03 12:30).

For more information refer to the following reports:

* [RO-EST-RP-3318] Payload Passive Checkout 0 Report
* [RO-EST-RP-3321] Rosetta Earth-Swingby #1 Payload Operations Report

## Cruise phase 2 (and Deep Impact)

After leaving the Earth, the spacecraft made one revolution around the Sun, and in the second arc from perihelion to aphelion made a swing-by of Mars.

There was a solar conjunction for more than one month in April 2006 (see [Solar Conjunctions](#_Solar_Conjunctions/Oppositions_1) section above). Two passive check-outs with non-interactive instrument operations for about 5 days were scheduled during the cruise to Mars. PC1 occurred from 5/09/2005 to 5/10/2005. PC2 took place from 3/03/2006 to 8/03/2006.

The NASA Deep Impact mission encountered comet 9P/Tempel 1 on 4 July 2005, which fell into the Cruise 2 mission phase. At around 06:00 UTC, the mother probe sent a 362 kg impactor into the nucleus with a relative speed of 10.2 km/s. Rosetta was in a privileged position for its remote sensing instruments to observe the event (80 million km distance, 90 degrees angle respect to the sun). Rosetta monitored Tempel 1 continuously (i.e. 24 hrs per day) over an extended period from 7 days before the deep impact to 11 days afterwards (27Jun-15Jul 2005). The first 2 days ALICE observed the stars for calibration. From the 28th June to the 15th July, OSIRIS, ALICE, and MIRO operated observing comet 9P/Tempel 1 continuously. VIRTIS was on only several hours around the impact. Maintenance activities were carried out for COSIMA, ROSINA, ALICE.

### Deep Impact Subphase

During the Deep Impact subphase, the instruments had the following objectives:

#### ORBITER

##### ALICE

* Baseline pre-impact spectrum. Comparison with near- and long-term post impact spectra. The comet was detected in all spectra.
* Strong atomic lines of neutral H and O were detected throughout the observation period.
* Two weak lines of neutral C detected on some dates. No change detected by ALICE in comet's UV spectrum as a result of impact except for possible enhancement in C emission.
* No evidence of Ar, S, N, CO.
* Water production rates. Results TBC.
* Dark histograms.
* Calibration star before the encounter. Spectra of calibration star was used for calibration of the Deep Impact spectra and instrument sensitivity. The data was also used to look for any flux variations due to pointing/jitter (initial results did not show any evidence of significant fluctuations in the stellar count rate).
* Memory patch (time synchronisation issue).

##### MIRO

* Changes in the coma composition induced by the impact.
* Upper limit on the water production rate in the pre-impact phase of the experiment. Water production rate and albeit with low signal-to-noise measured in the post impact phase. The water production rate was less than had been anticipated based on models.
* Detection of carbon monoxide: the analysis was not complete but so far no CO was detected.
* Estimate of Doppler velocity.

##### OSIRIS

* Accurate photometry of the unresolved nucleus (no atmosphere in between) with complete time coverage. The time resolution was better than a minute around the impact and could draw conclusion about the evolution of the impact cloud during the first hour. The long-term monitoring allowed determination of the composition and evolution of the impact cloud (water production and dust/ice ratio)
* UV coverage that allowed imaging of the OH emission at 308nm (estimate of the water production by the impact)
* Imaging of the coma out to at least 150000km from the nucleus. The effect of the impact could be seen in the images for approximately a week (stereo reconstruction of coma, impact cloud).

##### VIRTIS

* Coma and ejecta composition and temporal evolution. But the outburst due to the impact was not energetic enough to reach the minimum sensitivity required.

#### Conclusions of the Deep Impact Observations:

The science objectives of the Deep Impact Observations scenario were met. The brightness increase of Tempel 1 produced by the impact was lower than we had hoped for, and as a result the comet was too weak to be detected by VIRTIS. For ALICE and MIRO the signal was just above the sensitivity limit, but nevertheless important measurements could be achieved. The results of OSIRIS even exceeded the expectations, and the first scientific publications were widely cited. The data collected by the experiments on board Rosetta are unique because Tempel 1 was monitored continuously over an extended period of time (no day-and-night cycle in contrast to ground-based telescopes) and in the absence of an absorbing atmosphere.

### Passive Checkout 1

The following operations were done during the Passive checkout 1:

#### ORBITER

##### ALICE

* Electronic and software
* Test pattern and stim test
* Memory check
* Dark exposures

There were no instrument anomalies. The door performance test showed nominal behaviour.

##### CONSERT

* Consert Orbiter verification
* Consert Lander verification
* Consert Orbiter/Lander time synchronisation

##### COSIMA

* Self check
* Target manipulator unit maintenance
* Ion emitter maintenance

##### GIADA

* Run mechanisms - cover operations
* Health check (all subsystems, electronics, noise and contamination monitoring, performances estimation)

##### MIDAS

* Exercising of all mechanisms (shutter, approach mechanism, linear stage, wheel, scanner)

The test was successful and MIDAS is fully operable.

##### MIRO

* Regular exercise and health check of all commands in all modes
* Regular dump of EEPROM memory to check for radiation damage.

All objectives were met. There was no radiation damage of the EEPROM.

##### RPC

* MAG: instrument calibration. Undisturbed solar wind was measured to calibrate the offsets of the MAG instrument in quiet conditions (Hedgecock method).
* LAP: instrument calibration.
* MIP: Instrument checkout
* IES: measurement in the undisturbed solar wind for calibration of its sensors and cross calibration with LAP.

The PC operations were completed successfully with no change in instrument performance for MAG and IES.

##### RSI

Two frequency downlink driven by the USO and a ground station that could receive the X and S band signals.

* Investigate the stability of the USO
* Verify interaction with the ground

Investigations of the USO data from PC#0 revealed that the behaviour of the USO was obviously not as good as it had been during the last USO test in October.

##### OSIRIS

* Exercise the instrument mechanisms
* Verify the sanity of the CCD
* Verify the focus

No anomaly occurred.

#### LANDER

Test of the Lander Platform overall performance

Secondary battery monitoring

Lander extended AFT

CDMS EEPROM dump

functional test for

* PTOLEMY
* CONSERT

### Passive Checkout 2

The following operations have been done during the Passive checkout 2:

#### ORBITER

##### ALICE

* same health tests as PC1. Tests successful.

##### CONSERT

* same as PC1. Tests generally successful (see report)

##### COSIMA

* self-check of all hardware sub-systems on operational voltage levels
* target manipulator unit checkout
* maintenance COSISCOPE checkout
* emitter maintenance

Tests generally successful.

##### GIADA

* Same as PC1 plus monitoring of MBS coating evolution.

The cover operations went fine. There was no further contamination of the microbalances. GDS is not fully tested for light conditions. IS seems nominal. All HK values were as expected.

##### MIDAS

* same as PC1. Tests were successful.

##### MIRO

* Same as PC1. Overall success.

##### RPC

* Same as PC1. All performances checked were nominal.

##### RSI

* Same as PC1. The USO behaved very good, USO drift satisfactory.

##### OSIRIS

* Same as PC1. Generally successful. For solar elongation angles < 90 degrees OSIRIS got substantial scattered light through the nominally closed doors. The scattered light observed during PC2 was unfortunately enough that parts of the CCD surface was saturated. This happened in spite of the large exposure time reduction that was made after PC1.

##### VIRTIS

* The check done were performed properly.

#### LANDER

Same as PC1 plus functional tests for

* MUPUS
* CONSERT

For more information refer to the following reports:

* [RO-EST-RP-3341] Deep Impact Observations, Payload Operations Report
* [RO-EST-RP-3342] Passive Payload Checkout 1 Report
* [RO-EST-RP-3418] Passive Payload Checkout 2 Report

## Mars swing-by

The mission phase began two months before DSM2 of 65 m/s, which was performed near perihelion. The actual Mars swing-by took place on 25-Feb-07. The minimum altitude with respect to the Martian surface was 200 km. The relative approach and departure velocity was 8.8 km/s. During the swing-by a communications black-out of approximately 14 min was expected due to occultation of the spacecraft by Mars. Furthermore, the spacecraft was expected to be in eclipse for about 24 min. The phase ended one month after DSM3. DSM3 of 129 m/s was scheduled near the aphelion of this arc in order to obtain the proper arrival conditions at the Earth. Two passive payload check-outs of about 5 days and an active longer one of 25 days were scheduled during the phase (PC3, PC4, PC5).

### Payload Checkout 3

PC3 started on 25th August 2006 and ended 30th August 2006. The following operations were planed during PC3. GIADA and ROSINA did not take part in this PC.

#### ORBITER

##### ALICE

* Electronics & software verification, test pattern and stim test, Memory Check, Aperture Door, Performance Test.

All operations were executed as expected.

##### CONSERT

* Consert Orbiter verification, Consert Lander verification, Consert Orbiter/Lander time Synchronisation.

##### COSIMA

* self check of all hardware sub-systems on operational voltage levels, target manipulator unit checkout and maintenance emitter maintenance

##### MIDAS

* Regular health check and exercising of all mechanisms (shutter, approach mechanism, linear stage, wheel, scanner)

##### MIRO

* Regular exercise and health check of all commands in all modes.
* Regular dump of EEPROM memory to check for radiation damage.

All operations were successful.

##### RPC

* MAG: Instrument calibration. Undisturbed solar wind measurement.

Such data will be used to calibrate the offsets of the MAG instrument in quiet conditions (Hedgecock method).

* LAP: Instrument calibration.
* MIP: Instrument checkout.
* IES: measurements in the undisturbed solar wind for calibration of its sensors and crosscalibration with LAP.

##### RSI

* Investigate the stability of the USO and verify interaction with the ground.

The PC3 results were very promising and the behaviour of the USO was as good as expected. The stability of the USO was still one order of magnitude better than anticipated before launch.

##### OSIRIS

* Instrument mechanisms, verify the sanity of the CCD, verify the focus of the instrument.

##### VIRTIS

* Both VIRTIS M and H were working as expected.
* PC3 was used to verify the upload of a new pixel map for VIRTIS-H to be used during the forthcoming PC4 (pixel map allowed to drastically reduce the data volume).

#### LANDER

* Test of the Lander platform to check the overall performance and Secondary Battery Status
* Lander Extended AFT with short function tests of some units and EEPROM
* checks for all ComDPU units
* Secondary Battery Monitoring
* CDMS EEPROM dump
* Separate short functional tests for MUPUS and CONSERT

### Payload Checkout 4

PC4 was an active checkout. It started on Nov. 23rd and ended on Dec. 22nd, 2006. All Rosetta payload instruments took part in this scenario.

#### ALICE

* Passive Check out
* Optics Decontamination
* HV and detector tests
* Calibrations, performance
* Stare observations of Saturn and Vega

#### CONSERT

* Passive 6 months Status Check

#### NAVCAM

* Calibration

#### COSIMA

* Maintenance Procedure
* Cosiscope operation

#### GIADA

* Passive 6 months status check
* Settings test

#### LANDER

* Lander interactive and non-interactive operations

#### MIDAS

* Check out and mechanism activation
* s/w upload and functional check out
* Calibration
* High resolution image of a dust collector facet

#### MIRO

* Passive Status Check

#### ROSINA

* DPU s/w Patch
* COPS microtips
* DFMS cover and modes
* RTOF delta commissioning

#### RPC

* Passive Check out and calibrations
* IES noisy channels test, upload patches and tables
* LDL failure investigation
* Upload new LAP macros
* MIP new seq test
* Mars Swing By rehearsal
* ROMAP/RPC co operation
* MAG continuous operation
* Upload temporary patch for directional resolution improvement

#### RSI

* Passive two frequency downlink

#### SREM

* Continuous operation

#### OSIRIS

* Passive 6 months Check
* Bias, darks, charge transfer efficiency with doors closed
* Patch s/w
* Staring observations
* Calibration and Mars Fly By preparation

#### VIRTIS

* H and M calibrations

Although several open issues were resolved in this checkout, several issues remain open and new anomaly reports were generated. 75% of the planned operations were successful. The 25% loss was mainly due to OSIRIS that lost the majority of its operations.

### Payload Checkout 5

PC5 is a Passive Check Out that started on May, 18th and ended on May, 23rd 2007. The instruments that took part in this PC are listed below: ALICE, CONSERT, COSIMA, GIADA, LANDER, MIDAS, MIRO, RPC, RSI, OSIRIS. VIRTIS was NOGO and did not operate.

Main objectives of the scenario have been met with no issues.

Payload checkout reports:

* [RO-SGS-RP-0001] Rosetta\_Passive\_Payload\_Checkout\_3\_Report\_2007Jun27.pdf
* [RO-EST-RP-3464] Rosetta\_Report\_Active\_Payload\_Checkout\_4\_2006Apr13.pdf
* [RO-SGS-RP-0002] Rosetta\_Passive\_Payload\_Checkout\_5\_Report\_2007June27.pdf

## Cruise phase 3

No check-outs were scheduled during the short cruise to Earth.

## Earth swing-by 2

Daily operations started again around two months before Rosetta reached Earth with tracking and navigation manoeuvres. The actual Earth swing-by took place on 13-Nov-07. The perigee altitude was 13890 km. The relative approach and departure velocity was 9.3 km/s. The phase ended one month after the LGA strobing phase. In this phase the spacecraft got very close to the sun (min distance 0.91AU). One 15-day payload checkout and one 5 day payload checkout were also scheduled in this phase (PC6 and PC7).

Payload Checkout 6 (PC6) was an active checkout where a target independent opportunity to perform interactive operations and to request spacecraft pointing was given to all Rosetta payload teams. The active payload checkout 6 ran for 15 consecutive days starting on the 13th September 2007 until the 29th September 2006. All Rosetta payloads took part in this scenario. Operations ranged from a repeat of established passive checkout operations to extensive software patching and calibration campaigns. Four instruments required active spacecraft pointing during the scenario with nine different targets observed. Pointing types were 7 stares, 2 slew scans, 2 raster scans giving a total of around 176 hours of dedicated spacecraft pointing. These were mostly for calibration purposes. Overall operations went smoothly. Although several open issues were resolved in this checkout several issues remained open and new ones have been generated.

Payload Checkout 7 (PC7) was a passive checkout run form 4th January 2008 to 9th January 2008. Main objectives have been met with no issue apart from GD. This issue was due to higher operating temperatures resulting from the short Sun-Spacecraft distance.

The Payload checkout reports are:

* [RO-SGS-RP-0004] Rosetta\_Report\_Active\_Payload\_Checkout\_6\_2007Oct30.doc
* [RO-SGS-RP-0005] Rosetta\_Passive\_Payload\_Checkout\_7\_Report\_2008Jun24.pdf.

## Cruise phase 4 (split into 4-1 and 4-2)

In this phase the spacecraft made one revolution around the Sun. A solar conjunction took place in January 2009 (see [Solar Conjunctions](#_Solar_Conjunctions/Oppositions_1) section above), together with another two conjunctions of the Earth- spacecraft- Sun angle (Sun-Earth conjunction as seen from the spacecraft). In this phase the spacecraft got very close to the sun (min distance 0.91AU). This Cruise phase was split into two parts after the selection of the first Asteroid flyby which fell in the middle of this phase. Cruise 4-1 was before the flyby phase, and 4-2 was right after. Two passive check-outs were scheduled, one during Cruise 4-1 and the second one during Cruise 4-2.

During CR4, Passive Checkout 9 and Active Checkout 8 were planned.

Payload Checkout 8 (PC8) was an active checkout where a target independent opportunity to perform interactive operations and to request spacecraft pointing was given to all Rosetta payload teams. All Rosetta payloads took part in this scenario. The Active Payload Checkout 8 ran for 2 days (05-06 July 2008) plus 26 consecutive days starting on the 9th July 2008 until the 1st August 2008.

Three instruments required active spacecraft pointing during the scenario with 9 different targets observed. Pointing types were 14 stares and 3 raster scans. These were mostly for calibration purposes.

Payload Checkout 9(PC9) was a passive checkout executed between 28th January and 2nd February 2009. An RSI passive checkout was also completed on 09th February. All but 2 of the Rosetta payload instruments participated in the scenario, the exceptions being Rosina and Virtis. Operations were limited to instrument health checks and passive checkouts, as is the case for nominal Passive Checkout scenarios. All of the operations planned and executed in the PC09 scenario were successful (as detailed in Section 3). Minor issues were observed by 2 instruments (CN and RS) but none of these prevented the successful completion of the corresponding operations.

The Payload checkout reports are:

* [RO-SGS-RP-0019] Rosetta\_Report\_Active\_Payload\_Checkout\_8\_2011Jul25.pdf
* [RO-SGS-RP-0030] Rosetta\_Report\_Passive\_Payload\_Checkout\_9\_2011Jul20.pdf

## Steins flyby

Asteroid Steins was the first dedicated scientific target of the Rosetta mission. Closest approach was on 5 September 2008 at 18:38:22 UTC. Rosetta flew at 800 km from asteroid Steins. For the first time a European spacecraft flew next to an asteroid, performed an optical navigation campaign, and autonomously tracked the asteroid by means of its on board camera.

The 2867 Steins E-type asteroid had been discovered on 4 November 1969 by N. Chernykh. Its dimensions have been estimated by Keller, et al. (2010) to 6.67 x 5.81 x 4.47 km3, corresponding to a spherical equivalent radius of 2.65 km. Its sidereal rotation period has been estimated to 6.04681 +/- 0.00002h, its pole direction in ecliptic coordinates to approximately Lambda = 250 deg and Beta = -89 deg with an error of about 5 degrees Lamy, et al. (2008). Its albedo has been estimated to 0.3 in the visible and 0.4 in the infrared, both by Keller, et al (2010) and Lamy, et al. (2008).

The two asteroids Rosetta flew by are secondary science targets of the Rosetta mission, with comet 67P/Churyumov-Gerasimenko being the primary science target. Therefore, scientific measurements of Asteroid (2867) Steins had highest priority. Some calibrations were also performed during the flyby phase.

The flyby geometry necessitated a flip in the spacecraft attitude before closest approach. As a compromise between the incompatible requirements to minimize the illumination of the -X and +-Y panels of the spacecraft (flip as late as possible) and to minimize the impact on the science observations (flip as early as possible), the spacecraft flip was performed between 40 and 20 minutes before closest approach. Rosetta's relative speed with respect to Steins was 8.6km/s.

The heliocentric and geocentric distances of Rosetta during the Steins flyby were 2.14 AU and 2.41 AU, respectively. The one-way light travel time was 20 minutes.

The estimated accuracy of the determination of the position of Steins in the plane perpendicular to the flight direction during the navigation campaign was +/-2 kms for navigation with OSIRIS and +/-16 kms for navigation with the NAVCAMs (from navigation slot on Sept. 4). For the targeted passage through phase angle 0 at a distance of 1280 kms from Steins, a positional offset of 2 kms would correspond to a minimum phase angle of 0.1 degree.

The following table shows an overview of the Steins Flyby scenario:

|  |  |  |
| --- | --- | --- |
| **Start Date** | **End Date** | **Operation** |
| 04/08/2008 | 04/09/2008 | Navigation campaign (astrometry) using NAVCAM and OSIRIS NAC |
| 01/09/2008 | 10/09/2008 | Scientific operations targeting the asteroid |
| 07/09/2008 | 04/10/2008 | Observation of gravitational microlensing events in the galactic bulge by OSIRIS |

The following table shows the observation results per instrument:

|  |  |  |  |
| --- | --- | --- | --- |
| Instrument | Title | Success | Comments |
| ALICE 01 | Alice optics decontamination | Yes | at the beginning and end of all scenarios |
| ALICE 02 | Standard stellar flux calibration using the AL narrow centre boresight | Yes | During major scenarios |
| ALICE 03 | Standard stellar flux calibration using the AL +X wide bottom boresight | Yes | During major scenarios |
| ALICE 04 | Dark exposures | Yes | Regular calibration |
| ALICE 05 | Search for evidence of exosphere/coma around Steins | Yes | No exosphere or coma found |
| ALICE 06 | Point at Steins to obtain an FUV spectrum | Yes | First Spectrum of an asteroid below 200nm |
| ALICE 07 | Point to the Steins RA and Dec at the midpoint of AL 06 observation | Yes |  |
| ALICE 08 | Point to the Steins RA and Dec at the midpoint of AL 05 observation | Yes |  |
| ALICE 09 | Standard stellar flux calibration using the AL -X wide top boresight | Yes | During major scenarios |
| COSIMA 01 | Image and expose D8 substrate | No | TMU error |
| COSIMA 02 | Image all D8 substrates substrate | No | Cancelled after failure of CS 01 |
| GIADA 01 | non nominal operational configuration, i.e. only impact sensor on and cover closed | Yes |  |
| LANDER 01 | Run MUPUS TEM mode during periods with pronounced temperature changes | Yes |  |
| LANDER 02 | Operate ROMAP in slow mode and fast mode during CA +/-30min | Yes | Interference from MUPUS detected |
| LANDER 03 | CASSE measurements during WOL with SW FM-2 | Yes |  |
| LANDER 04 | Thermal test of SESAME soles | Yes |  |
| LANDER 05 | Operation of CASSE and DIM in a dusty environment | Yes |  |
| MIRO 01 | Observation of Steins during approach | Yes |  |
| MIRO 02 | Run Asteroid Mode sequence at closest approach to Steins | Yes | Pointing inaccuracy during Asteroid Flyby mode affects scientific output |
| MIRO 03 | Observation of Steins during Recession | Yes |  |
| ROSINA 01 | Outgassing | Yes |  |
| ROSINA 02 | Single mass measurement sequence | Yes | Contamination issue due to s/c flip. Sw instability caused temporary switch-off of detector |
| ROSINA 03 | Pressure monitoring | Yes | Contamination issue due to s/c flip |
| RPC 01 | Steins Fly by | Mostly | ICA did not produce scientifically useful data due to a commanding error. Interference from MUPUS detected |
| RSI 01 | Coherent measurement with Xup/Xdown or Xup/ Sdown received by a groundstation capable of receiving X- and S- band Doppler and Ranging Signals | TBD | TBD |
| SREM 01 | SREM standard accumulation | YES | No Steins specific operations, general particle flux monitoring |
| OSIRIS 01 | Vega Stare | Yes | Stellar calibrations repeated during major scenarios |
| OSIRIS 02 | 16 Cyg Stare | Yes | Stellar calibrations repeated during major scenarios |
| OSIRIS 03 | Steins Lightcurve at CA-2 weeks | Yes | TBD |
| OSIRIS 04 | Steins Lightcurve at CA-24 hours | Mostly | WAC data compromised by overexposure |
| OSIRIS 05 | Steins observation at CA | Mostly | NAC went into Safe mode due to shutter issues about 10 min before CA |
| OSIRIS 06 | Fast imaging sequence around the time of phase angle 0 | Yes | observation merged with OSIRIS 05 |
| OSIRIS 07 | Characterization of solar straylight for same orientation as the one the s/c had when the OSIRIS hill sphere dust search was performed | Yes | TBD |
| VIRTIS 01 | VIRTIS-M lightcurve of Steins | Yes | TBD |
| VIRTIS 02 | V-M and V-H operating; s/c stare at target Nadir looking; continuous acquisition in pushbroom mode | Yes | Operations were affected by inaccuracy of s/c pointing |
| VIRTIS 03 | V-M and V-H continuous observation of Steins for 1 hour after VR02; V-M in image mode (10 lines scan) | Yes | TBD |

The Rosetta first asteroid flyby was a success. The navigation campaign produced highly accurate predictions of the Steins position, and during the flyby most instruments worked without serious problems. Asteroid flyby mode worked well, although with somewhat lower tracking accuracy than expected.

Summary results per instrument during closest approach can be found in the operation report:

* [RO-SGS-RP-0020] Science Operations Report for the Steins FlyBy

## Earth swing-by 3

Operations were essentially the same as for the Earth swing-by 2. The actual Earth swing-by took place in Nov-09. The perigee altitude was 300 km. The relative approach and departure velocity was 9.9 km/s. Phase started 3 months before the swing-by and ends 1 month later. Two short payload checkouts of about 5 days each were scheduled during this phase.

The phase contained the Active Payload Checkout 10 (PC10). The section first describes PC 10 and then the Earth Flyby.

### PC10

The Active PC10 ran for 18 consecutive days from 18th September 2009 to 4th October 2009. It represented a target independent opportunity to perform interactive operations and to request spacecraft pointing. All payloads took part in this scenario, as interactive or non-interactive operations. There were approximately 425 hours of non-interactive and 68 hours of interactive operations. Four instruments required active s/c pointing with 15 targets observed (111 hours of dedicated s/c pointing). These were mostly for calibration purposes.

More details on the results can be found in the report:

* [RO-SGS-RP-0022] Payload Report Active PC10

### Earth flyby 3 (EAR3)

This was the last of the three gravity assists from the Earth, after which Rosetta increased its orbital energy, enough to allow the scheduled encounter with the asteroid 21 Lutetia and the rendezvous with Churyumov-Gerasimenko. From an operational point of view, the swing-by spacecraft operations were of highest priority, and both science observations and payload operations were only allowed on a non-interference basis with those. Keeping this in mind, Rosetta had the opportunity to perform special scientific observations of the Earth-Moon system, instrument calibrations using Earth and/or Moon and public relations observations.

The criticality of the spacecraft operations left payload operations in a second place, provided that Earth is not a scientific target for Rosetta and that potential trajectory correction manoeuvres would force the cancellation of all of them. This is reflected in the fact that only six instruments took part in the operations: ALICE, MIRO, OSIRIS, RPC, VIRTIS and SREM.

Operation scheduling was centred on Earth Closest Approach, which took place on 13 Nov. 2009 at 07:45:40 UTC, and overall operations went smoothly, despite some scattered events. According to the available reports, the EAR3 can be considered as fully successful.

EAR3 results are described in:

* [RO-SGS-RP-0023]

## Cruise phase 5

One Active checkout (12) was scheduled during this cruise phase. It can be noted that Passive Checkout 11 were cancelled since there was not enough time to include it between PC10 and PC12. PC 11 was supposed to be passive meaning that it is mainly instrument health check operations. PC 10 and 12 are active and more important to preserve.

Payload Checkout 12 (PC12) was an active checkout that ran for 23 consecutive days starting on the 22nd April 2010 until the 14th May 2010. All Rosetta payloads took part in this scenario. Operations ranged from a repeat of established passive checkout operations to extensive software patching and calibration campaigns.

Overall operations went smoothly. Numerous open issues were resolved in this checkout, whilst several issues remain open and new ones have been generated. There was a particularly noticeable and positive increase in the success rate of payload operations, when compared to previous Scenarios.

All results can be read in [RO-SGS-RP-0027] report.

## Lutetia flyby (17/05/2010 - 03/09/2010)

The second of the flybys took place on 10 July 2010 to the asteroid 21 Lutetia, discovered on 15 November 1852 by H. Goldschmidt. Its classification into a specific asteroid type had turned out to be ambiguous and included the possibilities of a C-type or an M-type asteroid. This contradiction made it an interesting object for close inspection.

Closest Approach (CA) occurred at 15:45 UT at a distance of 3168.2km. The relative fly-by velocity was of 15 km/s. The fly-by strategy allowed continuous observations of Lutetia before, during and for 30 minutes after CA.

Images obtained by OSIRIS revealed that Lutetia has a complex geology and one of the highest asteroid densities measured so far, 3.4+/-0.3g/cm3. Its geologically complex surface, ancient surface age and high density suggest that Lutetia is most likely a primordial planetesimal.

This is the second of the two asteroids selected at the Science Working Team meeting on 11th March 2004 among all the available candidate asteroids, depending on the scientific interests and the propellant required for the correction manoeuvre.

The following operations took place around the Lutetia fly-by:

* 21 May 2010 - 9 July 2010: Navigation campaign (astrometry) using the OSIRIS NAC and NAVCAM.
* 5 July 2010- 14 July 2010: scientific operations targeting the asteroid.

The Lutetia fly-by was a success. The navigation campaign produced highly accurate predictions of the position of Lutetia and during the fly-by most instruments worked without serious problems (except Rosina, RPC IES and RPC ICA). Asteroid fly-by mode worked excellently.

The objectives summarised below have been addressed by the instrument measurements:

* Physical and thermal properties, mineralogy and geomorphology of Lutetia from spatially resolved multi-wavelengths remote-sensing observations between the extreme UV and the mm-range.
* Determination of the mass of the asteroid from Doppler measurements of the spacecraft trajectory.
* Global shape parameters from light curves taken days before CA.
* Search for satellite/dust particles.
* Search for an asteroid magnetic field.
* Particle and field measurements.

Results of the Lutetia Fly By can be found in [RO-SGS-RP-0028].

## Rendez-Vous Manoeuvre 1 (04/09/2010 - 13/07/2011)

The deep space manoeuvre was carried out when the spacecraft reached a distance from the Sun around 4.5 AU on 23-Jan-11. One passive check -out (13) was scheduled during this phase. One solar conjunction of 50 days and one solar opposition of 37 days happened during this phase. (see [Solar Conjunctions](#_Solar_Conjunctions/Oppositions_1) section above).

### PC 13 (1st-9th Dec 2010 + 14th Dec)

This was the final Cruise Phase Checkout. A number of additional payload operations were also executed, to close out pending and essential requirements, and/or to configure instruments for the upcoming Deep Space Hibernation Phase. Only OSIRIS did not participate in PC 13. PC13 ran for 9 consecutive days between 1st and 9th December 2010.

An RSI passive checkout was also completed on 14th December.

All of the operations planned and executed were successful. Minor issues were observed by 4 instruments (Consert, Philae, Rosina, RPC).

Alice performed successfully some instrument checkout.

Cosima did periodical maintenance and check its status.

Giada checked successfully its status.

Midas performed a normal passive check-out and an additional modified one for Deep Space Hibernation Preparation.

Miro performed a normal and successful passive check-out.

Osiris did not participate in the PC13 timeframe. However, on 23-26th March 2011 - post RVM1 - specific OSIRIS operations were performed in order to prepare and configure the instrument for the Rosetta Deep Space Hibernation.

The Lander performed some operations and Consert performed a unit functional test; both were partially successful.

Rosina did not participate in the nominal PC13 scenario, but conducted several specific operations immediately following completion of the nominal PC13 timeline. A spacecraft slew was executed with RTOF monitoring, to further investigate data observed during Lutetia fly-by.

RPC PIU, IES, LAP, ICA performed checkout with some errors/anomalies reported, which were considered as no problem for the instrument.

Virtis performed the checkout successfully.

RSI measurements during PC13 showed some disturbances. The cause is unknown at the time being.

SREM performed a successful checkout.

More detailed results can be found in [RO-SGS-RP-0029].

## Cruise phase 6 (8 Jun 2011 - 20 Jan 2014)

The whole period was spent in Deep-Space Hibernation Mode (DSHM). Maximum distances to Sun and Earth are encountered during this period, i.e. 5.3 AU (aphelion) and 6.3 AU, respectively. During this phase, 3 superior solar conjunctions and 2 solar oppositions occurred (see table above). This phase ended with the Spacecraft wake-up on the 20th of January 2014.

## Rendez-Vous Manoeuvre 2 (21 Jan 2014 - 9 Sep 2014)

The RVM2 started after Spacecraft wake-up and until September 2014, when the Global Mapping phase started. It contained the Near Comet Drift (NCD), the Far Approach Trajectory (FAT) and the Close Approach Trajectory (CAT). It ended with the transition to Global Mapping.

During this phase, Rosetta did a series of ten OCMs, starting on the 7 May to reduce its speed with respect to comet 67P/C-G by about 775 m/s. The first, producing just 20 m/s delta-v (change in velocity), was done as a small test burn, as it was the first use of the spacecraft’s propulsion system after wake-up.

## Near comet drift (NCD) phase (21 May 2014 - 2 July 2014)

The following three OCMs form the Near Comet Drift (NCD) phase. They took place every two weeks starting 21 May. They delivered 289.6, 269.5 and 88.7 m/s in delta-v, respectively.

## Approach Phase

### Far Approach Trajectory (FAT) (2 July - 3 August 2014)

The FAT contained the next four burns. The four FAT burns were carried out weekly during July, and all proceeded nominally. The approach manoeuvre sequence reduced the relative velocity in stages down to 3 m/s.

During this phase, the first images of the comet were obtained with the optical measurement system (NAVCAM, OSIRIS). After detection, knowledge of the comet ephemeris was drastically improved by processing the on-board observations. Image processing on the ground derived a coarse estimation of comet size, shape and rotation. The first landmarks were identified.

The FAT ended at the Approach Transition Point (ATP), which is located in the Sun direction at about 1000 comet nucleus radii from the nucleus.

Find below a list of burns with delta-v reduction and duration

|  |  |  |
| --- | --- | --- |
| Date | Delta-V  m/s | Dur.  mins |
| 7 May | 20 | 41 |
| 21 May | 290 | 441 |
| 4 Jun | 270 | 406 |
| 18 Jun | 91 | 140 |
| 2 Jul | 59 | 94 |
| 9 Jul | 26 | 46 |
| 16 Jul | 11 | 26 |
| 23 Jul | 5 | 17 |
| 3 Aug | 3 | 13 |
| 6 Aug | 1 | 7 |

### Close Approach Trajectory (CAT)

Close approach trajectory operations started at ATP. The spacecraft distance to the comet was decreased to 20 nucleus radii and the relative velocity fell below 1 m/s. The final point of this phase was the Orbit Insertion Point (OIP), the point where the spacecraft started orbiting the comet.

During the CAT, 5 landing sites were selected by the Landing team. Details of the final manoeuvres to prepare insertion:

**6 August:** Rosetta was commanded to conduct a 1-m/s thruster burn (which ran 7 min) to change its direction and enter onto the first arc (of three arcs) of two triangular (really, tetrahedral) orbits about the comet.

It is important to note Rosetta has not been captured by 67P/C-G gravity, and the continuing series of thruster burns were necessary to keep the spacecraft at the comet.

Rosetta executed two of these triangular orbits, one large, at about 100km closest pass-by distance (Big CAT) and the second at about 50km (Little CAT).

**10 August:** CAT Change 1 burn - a 6min:25sec, 0.88-m/s burn that pushed Rosetta onto the next arc (100km pass-by height).

**13 August:** CAT Change 2 burn - a 6min:22sec, 0.87-m/s burn that pushed Rosetta onto the next arc (100km pass-by height).

**17 August:** CAT Change 3 burn - a 6min:19sec, 0.85-m/s burn that pushed Rosetta onto a transfer arc, down to about 80 km height achieved on 20 Aug (CAT 4).

Finally, with the next two burns on 24 and 27 August, the distance was lowered to 50km.

### Transition to Global Mapping (TGM)

On 31 August, Rosetta began the third and last arc of Little CAT and Rosetta entered the TGM, a set of two manoeuvres. The phase ended at 10 nucleus radii with ta relative velocity of 0.3 m/s.

Global Mapping and Close Observations (10 Sep 2014 - 28 Oct 2014) The Global Mapping phase ran 10 September to 15 October. During this phase, Rosetta went down to 29 km distance, a point when the spacecraft became actively captured by the comet gravity, and its orbit became circular.

At the beginning of this phase, the Lander team down selected 2 landing sites: the nominal and the backup.

A series of manoeuvres reduced Rosetta distance from 18.6 km orbit (taking 7 days) to an intermediate orbit approximately 18.6 x 9.8 km (with a period of 5 days). From there the orbit was circularised at about 9.8 km radius, with a period of approximately 66 hours on 15 October, and the mission entered the Close Observation Phase (COP). This phase provided even higher resolution images of the landing site in order to best prepare for Philae's challenging touch-down. The new orbit also allowed a number of Rosetta's science instruments to collect dust and measure the composition of gases closer to the nucleus.

On the 28 October, Rosetta conducted a thruster burn (82 sec from 12:59 UTC) that delivered a delta-v of 0.081 meters/sec. This pushed the spacecraft to leave the 10-km-altitude circular orbit (following the terminator line) and the COP. Rosetta started its transition to the pre-lander-delivery orbit.

On 31 October, the mission control team performed another manoeuvre to enter onto the pre-delivery orbit proper.

## Lander delivery

On 31 October, Rosetta entered a pre-delivery elliptical orbit at approximately 30 km distance from the comet centre. This orbit was maintained until delivery on 12 November.

The orbiter performed its pre-separation manoeuvre at 6:04 on 12 November, which placed it on the trajectory required for separation. The separation occurred at 08:35 UTC (the confirmation signal arrived on Earth at 09:03 UTC). At 10:34 UTC the Lander activated its transmitters and started forwarding its telemetry to the orbiter. At 11:08 UTC, this telemetry was received on ground. Touchdown was confirmed for Philae at 16:03 UTC.

While Lander telemetry kept flowing towards the Orbiter, the RF link between the two crafts was regularly interrupted, which was not consistent with a stable landing. Other Lander telemetry gave indication that the Lander had bounced after initial touch-down. The link between Orbiter and Lander was broken at 17:59 UTC one hour earlier than expected for the targeted landing site.

On 13 November Lander telemetry was received on ground at 6:01 UTC, very close to the expected time.

During the descent, ROLIS acquired an image at 14:38:41 UT, from a distance of approximately 3 km from the surface. The landing site was imaged with a resolution of about 3m per pixel.

After separation, Orbiter operations focus on maximising visibility with the Lander and acquiring data to reconstruct the Lander descent trajectory and support Orbiter Navigation. NAVCAM and OSIRIS, once in Lander pointing, acquired every hour until touch-down + 2 hours. After that, NAVCAM observed every 2 hours for navigation.

The following Orbiter instruments were operated: ALICE, CONSERT, MIRO, OSIRIS, ROSINA, RPC.

The post-delivery manoeuvre executed on 12 November 2014 started at 09:14:58.1 UTC and a nominal end time at 09:19:53.7 UTC. Rosetta was then on a 50 km orbit.

On 13 November at 19:23 UTC Philae started transferring data to Rosetta. Link was lost at 23:08 UTC on 13 November, 40 minutes before predicted time.

During this slot were commanded:

* ranging measurements by CONSERT (Lander Search)
* CIVA images
* MUPUS boom deployment and hammering
* APXS deployment and measurement

On 14 November at 9:01, Philae data were received on-board Rosetta and immediately transmitted to ground, 48 minutes after expected time. The visibility period finished at 11:47 UTC on 14 November, 50 minutes earlier than predicted.

During this period were commanded:

* APXS released but measured copper thus revealing that the door had not opened.
* MUPUS deployment was successful, hammering took place, SESAME detected it
* Drill activation for sample return to COSAC
* PTOLEMY/COSAC spectra acquisitions
* CIVA image but dark.................................................
* Consert ranging

The fourth and last Philae visibility period started on 14 November at 22:15 UTC ground time. The Lander bus voltage appeared to decrease rapidly. On November 15 at 00:07, the link between Orbiter and Lander broke.

Among the Lander operations carried out during the fourth visibility period was a rotation of the Lander to increase the illumination of its solar arrays.

After the planned Touch Down, the Lander did not anchor and bounced. We estimated that the first TD was:

**Time UTC:** 15:34:06

**Comet-fixed coordinates:** [2.129171, -0.961358, 0.498268] km

The NAVCAM image, the NAC image and the first TD as the starting point gave the following impact point at:

**Time UTC:** 16:26:23

**Comet-fixed coordinates:** [2.450, -0.511, -0.242] km

This point has an uncertainty of 7 minutes. The position is also uncertain. By using three WAC images, the second TD can be deduced:

**Time UTC:** 17:31:10

**Comet-fixed coordinates:** [2.275, 0.249, -0.444] km

Consert Ranging estimated a final landing site at Comet-fixed coordinates: [2.446, -0.055, -0.360] km

After Touch Down, began the First Science Sequence (FSS) where all Lander instruments operated on the primary battery. The operations did not go as planned due to the several TDs but occurred as listed above. The Long Term Science Phase should have started after the primary battery died, but the final TD left the Lander in a location where the illumination condition could not allow battery charging. Contact was lost on 15 November 2014 at 00:07, ending the FSS, and the Lander went to sleep.

## Escort phase

Planning period during the comet phase were approximately monthly and allowed changes in trajectory types every two weeks. The table below summarises the trajectory followed by Rosetta after the Landing:

|  |  |
| --- | --- |
| 21 Nov - 3 Dec 2014 | Bound Orbits at 30 km |
| 3 Dec - 6 Dec 2014 | Transition |
| 6 Dec - 19 Dec 2014 | Bound Orbit at 20 km |
| 19 Dec - 24 Dec 2014 | Transition |
| 24 Dec - 4 Feb 2015 | Bound Orbit at 28 km |
| 4 Feb - 21 Feb 2015 | Close FlyBy CA on 14 Feb at 8km Leg up to 143km |
| 21 Feb - 10 Mar 2015 | Arcs around 80 km |
| Apr 2015 | Fly bys: CA of 90 km and maximum distanceof 180km |
| May 2015 | Fly bys: first from 125km to 180 km then from 200km to 325km |
| June 2015 | Fly bys: from 200 to 240km then CA to 160km Sub s/c point located North for Lander com. |
| July 2015 | Fly bys: CA at 150 km |
| Aug 2015 | Fly bys: CA increased to 180 km (star tracker issues. |
| Sept 2015 | Fly bys: between 400 and 460km first then reduced to 300-330 km |
| Oct 2015 | Far excursion at 1500 km |
| Nov 2015 | Fly bys from 420 to 140km |
| Dec 2015 | Fly bys (75-150km) |
| Jan 2016 | Fly bys (45-95km) |
| Feb 2016 | Fly bys (32-52km) |
| Mar 2016 | Terminator orbit (17 to 12km) - night side excursion - far excursion at 1000km - hyperbolic arcs at 200km |
| Apr 2016 | Far Flyby arcs at 200km in terminator - Flyby arcs at 80 km at 80 deg - Close Flyby at 30km Outbound arc (140 to 70km) at terminator - insertion into bound orbits at 19km dist. |
| May 2016 | Bound orbits in terminator plane: first elliptical 19kmx10km - circular 10km - circular 7km - mapping orbit at 17km. |
| Jun 2016 | Mapping orbit at 17km - at 30 km - 2 day-side half orbit at 45 deg phase angle – elliptical 28x14km at terminator |
| Jul 2016 | 2.5 elliptical orbit 26x9km at terminator - circular orbit at 10 km at terminator |
| 26 Jul - 9 Aug 2016 | 4 elliptical orbits 14x8km with 70-110 deg phase angles |
| 9 Aug - 2 Sep 2016 | elliptical orbits (70-110 deg phase angles). Pericentre gradually reduced and apocentre increased while constant orbital period of 3 days 13.7km, 7.5km, 13.7km, 6.7km, 14.4km, 6.0km, 15.1km, 5.5km, 15.5km, 5.0km, 15.9km, 4.6km, 16.2km, 4.4km, 16.4km |
| 2 Sep - 26 Sep 2016 | elliptical orbits (70-110 deg phase angles). Pericentre gradually reduced and apocentre increased while constant orbital period of 3 days 4.0km, 17.1km, 3.9km, 17.1km, 4.1km, 16.1km, 4.1km, 16.8km, 4.1km, 16.0km, 4.1km, 17.0km, 4.1km, 16.7km, 4.1km, 17.2km |
| 26 Sep - 30 Sep 2016 | exit from elliptical orbits - hyperbolic arcs with dist from 17 to 23km - final descent to the comet nucleus. |

## Near perihelion phase

[*No information was provided for this phase by the mission. –Ed.*]

## Extended mission

[*No information was provided for this phase by the mission. -Ed.*]

# Orbiter Experiments

## ALICE

ALICE, an Ultraviolet Imaging Spectrometer, will characterise the composition of the nucleus and coma, and the nucleus/coma coupling of comet 67 P/Churyumov-Gerasimenko. This will be accomplished through the observation of spectral features in the extreme and far ultraviolet (EUV/FUV) spectral regions from 70 to 205 nm.

ALICE will make measurements of noble gas abundances in the coma, the atomic budget in the coma, and major ion abundances in the tail and in the region where solar wind particles interact with the ionosphere of the comet. ALICE will determine the production rates, variability, and structure of H2O and CO, and CO2 gas surrounding the nucleus and the far-UV properties of solid grains in the coma.

ALICE studied Mars and the Rosetta asteroid flyby targets while *en route* to Churyumov- Gerasimenko. ALICE also mapped the cometary nucleus in the FUV.

Instrument Reference: Stern, et al. (2007)

## CONSERT

CONSERT (Comet Nucleus Sounding Experiment by Radio wave Transmission) is an experiment that will perform tomography of the comet nucleus revealing its internal structure. CONSERT operates as a time domain transponder between the Lander on the comet surface and the Orbiter. A radio signal passes from the orbiting component of the instrument to the component on the comet surface and is then immediately transmitted back to its source, the idea being to establish a radio link that passes through the comet nucleus. The varying propagation delay as the radio waves pass through different parts of the cometary nucleus is used to determine the dielectric properties of the nuclear material. Many properties of the comet nucleus are examined, such as its overall structural homogeneity, the average size of the sub-structures (Cometesimals) and the number and thickness of the various layers beneath the surface.

Instrument References: Kofman, et al. (2007)

## COSIMA

The Cometary Secondary Ion Mass Analyser is a secondary ion mass spectrometer equipped with a dust collector, a primary ion gun, and an optical microscope for target characterization. Dust from the near comet environment is collected on a target. The target is then moved under a microscope where the positions of any dust particles are determined. The cometary dust particles are then bombarded with pulses of indium ions from the primary ion gun. The resulting secondary ions are extracted into the time-of-flight mass spectrometer.

Instrument References: Kissell, et al. (2007)

## GIADA

The Grain Impact Analyser and Dust Accumulator measures the scalar velocity, size and momentum of dust particles in the coma of the comet using an optical grain detection system and a mechanical grain impact sensor. Five microbalances measure the amount of dust collected as the spacecraft orbits the comet.

Instrument References: Colangeli, et al. (2007)

## MIDAS

The Micro-Imaging Dust Analysis System is intended for the microtextural and statistical analysis of cometary dust particles. The instrument is based on the technique of atomic force microscopy. This technique, under the conditions prevailing at the Rosetta Orbiter permits textural and other analysis of dust particles to be performed down to a spatial resolution of 4nm.

Instrument References: Riedler, et al. (2007)

## MIRO

MIRO (Microwave Instrument for the Rosetta Orbiter) is composed of a millimetre wave mixer receiver and a submillimetre heterodyne receiver. The submillimetre wave receiver provides both broad band continuum and high-resolution spectroscopic data, whereas the millimetre wave receiver provides continuum data only.

MIRO measures the near surface temperature of the comet, allowing estimation of the thermal and electrical properties of the surface. In addition, the spectrometer portion of MIRO allows measurements of water, carbon monoxide, ammonia, and methanol in the comet coma.

Instrument References: Gulkis, et al. (2007)

## OSIRIS

OSIRIS (Optical, Spectroscopic, and Infrared Remote Imaging System) is a dual camera imaging system operating in the visible, near infrared and near ultraviolet wavelength ranges. OSIRIS consists of two independent camera systems sharing common electronics. The narrow angle camera is designed to produce high spatial resolution images of the nucleus of the target comet. The wide-angle camera has a wide field of view and high straylight rejection to image the dust and gas directly above the surface of the nucleus of the target comet. Each camera is equipped with filter wheels to allow selection of imaging wavelengths for various purposes. The spectroscopic and wider band infrared imaging capabilities originally proposed and incorporated in the instrument name were descoped during development.

Instrument References: Keller, et al. (2007)

## ROSINA

ROSINA (Rosetta Orbiter Spectrometer for Ion and Neutral Analysis) consists of two mass spectrometers, since no one technique is able to achieve the resolution and accuracy required to fulfil the ROSETTA mission goals over the range of molecular masses under analysis. In addition, two pressure gauges provide density and velocity data for the cometary gas.

The two mass analysers are:

1. A double focusing magnetic mass spectrometer with a mass range of 1 - 100 amu and a mass resolution of 3000 at 1 % peak height, optimised for very high mass resolution and large dynamic range
2. A reflectron type time-of-flight mass spectrometer with a mass range of 1 -300 amu and a mass resolution better than 500 at 1 % peak height, optimised for high sensitivity over a very broad mass range

Instrument References: Balsiger, et al. (2007)

## RPC

RPC (Rosetta Plasma Consortium) is a set of five sensors sharing a common electrical and data interface with the Rosetta orbiter. The RPC sensors are designed to make complementary measurements of the plasma environment around the comet 67P/Churyumov-Gerasimenko.

The RPC sensors are:

* ICA: an Ion Composition Analyser, which measures the three-dimensional velocity distribution and mass distribution of positive ions;
* IES: an Ion and Electron Sensor, which simultaneously measures the flux of electrons and ions in the plasma surrounding the comet;
* LAP: a Langmuir Probe, which measures the density, temperature and flow velocity of the cometary plasma;
* MAG: a Fluxgate Magnetometer, which measures the magnetic field in the region where the solar wind plasma interacts with the comet;

Instrument References: Glassmeier, et al. (2007b)

* MIP: a Mutual Impedance Probe, which derives the electron plasma density, and can sometimes constrain other plasma parameters of the inner coma of the comet.

Instrument References: Carr, et al. (2007)

## RSI

RSI (Radio Science Investigation) makes use of the communication system that the Rosetta spacecraft uses to communicate with the ground stations on Earth. Either one-way or two-way radio links can be used for the investigations. In the one-way case, a signal generated by an ultra-stable oscillator on the spacecraft is received on earth for analysis. In the two-way case, a signal transmitted from the ground station is transmitted back to Earth by the spacecraft. In either case, the downlink may be performed in either X-band or both X -band and S-band.

RSI investigates the nondispersive frequency shifts (classical Doppler) and dispersive frequency shifts (due to the ionised propagation medium), the signal power and the polarization of the radio carrier waves. Variations in these parameters yields information on the motion of the spacecraft, the perturbing forces acting on the spacecraft and the propagation medium.

Instrument References: Paetzold, et al. (2007)

## VIRTIS

VIRTIS (Visible and Infrared Thermal Imaging Spectrometer) is an imaging spectrometer that combines three data channels in one instrument. Two of the data channels are committed to spectral mapping and are housed in the Mapper optical subsystem. The third channel is devoted solely to spectroscopy and is housed in the High-Resolution optical subsystem.

The mapping channel optical system is a Shafer telescope consisting of five aluminium mirrors mounted on an aluminium optical bench. The mapping channel uses a silicon charge coupled device (CCD) to detect wavelengths from 0.25 micron to 1 micron and a mercury cadmium telluride (HgCdTe) infrared focal plane array (IRFPA) to detect from 0.95 micron to 5 microns.

The high-resolution channel is an echelle spectrometer. The incident light is collected by an off-axis parabolic mirror and then collimated by another off-axis parabola before entering a cross- dispersion prism. After exiting the prism, the light is diffracted by a flat reflection grating, which disperses the light in a direction perpendicular to the prism dispersion. The high-resolution channel employs a HgCdTe IRFPA to perform detection from 2 to 5 microns.

Instrument References: Coradini, et al. (2007)

## SREM

The Standard Radiation Environment Monitor (SREM) is a monitor-class instrument intended for space radiation environment characterisation and radiation housekeeping purposes. SREM provides continuous directional, temporal, and spectral data of high-energy electron, proton, and cosmic ray fluxes encountered along the orbit of the spacecraft, as well as measurements of the total accumulated radiation dose absorbed by SREM itself.

This instrument is a facility monitor flown on several ESA spacecrafts. It is not considered as a PI (Principal Investigator) instrument.

Instrument References: Mohammadzade, et al. (2003)

# LANDER (PHILAE)

The 100 kg Rosetta Lander, named Philae, is the first spacecraft ever to make a soft landing on the surface of a comet nucleus. The Lander is provided by a European consortium under the leadership of the German Aerospace Research Institute (DLR) and the French Space Research Centre (CNES). Other members of the consortium are ESA and institutes from Austria, Finland, France, Hungary, Ireland, Italy and the UK. A description of the Lander can be found in [RO-EST-RS-3020].

The box-shaped Lander was carried in piggyback fashion on the side of the Orbiter until it arrived at Comet 67P/Churyumov-Gerasimenko. Once the Orbiter was aligned correctly, the ground station commanded the Lander to self-eject from the main spacecraft and unfold its three legs, ready for a gentle touch down at the end of the ballistic descent. The Landing is described above.

Immediately after touchdown, a harpoon was supposed to fire to anchor the Lander to the ground and prevent it escaping from the comet's extremely weak gravity. The system did not work and the Lander bounced several times.

## Science Objectives

It is the general aim of the scientific experiments carried and operated by the Rosetta Lander to obtain a first *in situ* composition analysis of primitive material from the early solar system, to study the composition and structure of a cometary nucleus, reflecting growth processes in the early solar system, to provide ground truth data for the Rosetta Orbiter experiments and to investigate dynamic processes leading to changes in cometary activity.

The primary objective of the Rosetta Lander mission is the *in situ* investigation of the elemental, isotopic, molecular and mineralogic composition and the morphology of early solar system material as it is preserved in the cometary nucleus. Measurement of the absorption and phase shift of electromagnetic waves penetrating the comet nucleus will help to determine its internal structure. Seismometry and magnetometry will also be used to investigate the interior of the comet.

The scientific objectives of the Rosetta Lander can be listed according to their priority as follows:

1. Determination of the composition of cometary surface and subsurface matter: bulk elemental abundances, isotopic ratios, minerals, ices, carbonaceous compounds, organics, volatiles - also in dependence on time and insolation.
2. Investigation of the structure and physical properties of the cometary surface: topography, texture, roughness, regolith scales, mechanical, electrical, optical, and thermal properties, temperatures. Characterization of the near surface plasma environment.
3. Investigation of the global internal structure.
4. Investigation of the comet/plasma interaction.

The *in situ* measurements performed by the Rosetta Lander instruments will also provide local ground truth to calibrate Orbiter instruments.

## Lander Experiments

Following is a description of all the instruments of the Lander:

### APXS: Alpha-p-X-ray spectrometer

The goal of the Rosetta APXS experiment is the determination of the chemical composition of the landing site and its potential alteration during the comet's approach to the Sun. The data obtained is used to characterize the surface of the comet, to determine the chemical composition of the dust component, and to compare the dust with known meteorite types.

Instrument References: Klinglehofer, et al. (2007)

### CIVA: Panoramic and microscopic imaging system

The Cometary Infrared and Visible Analyser (CIVA) is an integrated set of imaging instruments, designed to characterize the landing and sampling site, the 360 deg panorama as seen from the Rosetta Lander, all samples collected and delivered by the Drill Sample and Distribution System, and the stratigraphy within the boreholes. It is constituted by a panoramic stereo camera (CIVA-P), and a microscope coupled to an IR spectrometer (CIVA-M). CIVA is sharing a common Imaging Main Electronics (CIVA/ROLIS/IME) with ROLIS. CIVA-P will characterize the landing site, from the landing legs to the local horizon. The camera is composed of 6 identical micro-cameras, mounted on the Lander sides, with their optical axes separated by 60 deg. In addition, stereoscopic capability is provided by one additional micro-camera, identical to and co-aligned with one of the panoramic micro-cameras, with its optical axis 10 cm apart.

CIVA-M combines in separated boxes, two ultra-compact and miniaturized channels, one visible microscope CIVA-M/V and one IR spectrometer CIVA-M/I, to characterize, by non-destructive analyses, the texture, albedo, mineralogical and molecular composition of each of the samples collected and distributed by the Drill Sample and Distribution System.

Instrument References: Bibring, et al. (2007)

### CONSERT: Radio sounding, nucleus tomography

The Comet Nucleus Sounding Experiment by Radio wave Transmission (CONSERT) is a complex experiment that performs tomography of the comet nucleus revealing its internal structure. CONSERT operates as a time domain transponder between the Lander, on the comet surface and the Orbiter orbiting the comet. A radio signal passes from the orbiting component of the instrument to the component on the comet surface and is then immediately transmitted back to its source, the idea being to establish a radio link that passes through the comet nucleus. The varying propagation delay as the radio waves pass through different parts of the cometary nucleus is used to determine the dielectric properties of the nuclear material. Many properties of the comet nucleus is examined as its overall structural homogeneity, the average size of the sub-structures (Cometesimals) and the number and thickness of the various layers beneath the surface.

Instrument References: Kofman, et al. (2007)

### COSAC: Evolved gas analyser - elemental and molecular composition

The COmetary SAmpling and Composition experiment COSAC is one of the two 'evolved gas analysers' (EGAs) on board the Rosetta-Lander. Whereas the other EGA, Ptolemy, aims mainly at accurately measuring isotopic ratios of light elements, the COSAC is specialised on detection and identification of complex organic molecules. The instrument can be described as an effort to analyse *in situ*, mainly with respect to the composition of the volatile fraction, cometary matter nearly as well and accurately as could be done in a laboratory on Earth. Due to the Rosetta Lander rotatability, the instrument can conduct analyses and investigations at different spots of the landing site and, aided by the drill, take samples for analysis from a depth up to at least 0.2 m.

Instrument References: Goesmann, et al. (2007)

### PTOLEMY: Evolved gas analyser - isotopic composition

The size of a small shoe box and weighing less than 5 kg, Ptolemy uses gas chromatography / mass spectrometry (GCMS) techniques to investigate the comet surface & subsurface. The instrument concept is termed 'MODULUS' which is taken to mean Methods Of Determining and Understanding Light elements from Unequivocal Stable isotope compositions. The scientific goal of the PTOLEMY is to understand the geochemistry of light elements, such as hydrogen, carbon, nitrogen and oxygen, by determining their nature, distribution and stable isotopic compositions.

Instrument References: Wright, et al. (2007)

### MUPUS: Measurements of surface and subsurface properties

The Multi-Purpose Sensor Experiment actually consists of three parts:

1. A penetrator, approximately 40 cm long, is hammered into the ground about 1m apart from the Lander for measuring during the penetration process the mechanical strength of the material by means of a depth sensor and a densitometer. The penetrator is equipped with a series of temperature sensors and heaters for determining the temperature as a function of depth and insolation.

2. An accelerometer and a temperature sensor accommodated in the harpoon(s)

3. A four-channel infrared radiometer measures surface temperatures in the vicinity of the Lander. Density of the near surface (down to 20cm) material is determined by measuring the absorption of gamma-rays emitted from a radioactive isotope mounted at the tip of the penetrator.

Instrument References: Spohn, et al. (2007)

### ROLIS: Descent & Down-Looking Imaging

The ROLIS Camera (Rosetta Lander Imaging System) delivered first close-ups of the environment of the landing place of comet 67P/Churyumov-Gerasimenko during the descent. After landing ROLIS made high-resolved investigations to study the structure (morphology) and mineralogy of the surface.

Instrument References: Mottola, et al. (2007)

### ROMAP: Magnetometer and plasma monitor

The Rosetta Lander Magnetometer and Plasma Monitor ROMAP is a multi- sensor experiment. The magnetic field is measured with a fluxgate magnetometer. An electrostatic analyser with integrated Faraday cup measures ions and electrons. The local pressure is measured with Pirani and Penning sensors. The sensors are situated on a short boom. The deployment on the surface of a cometary nucleus demanded the development of a special digital magnetometer of little weight and small power requirements. For the first time a magnetic sensor is operated from within a plasma sensor. A prototype of the magnetometer, named SPRUTMAG, was flown on space station MIR.

Instrument References: Auster, et al. (2007)

### SD2: Sampling, Drilling and Distribution Subsystem

The Rosetta-Lander is equipped with a Sample Drill & Distribution (SD2) subsystem which is in charge to collect cometary surface samples at given depth and distribute them to the following instruments: CIVA-M (microscope (MS) & Infrared Spectrometer (IS)), the ovens, serving COSAC and PTOLEMY.

Comet sample from pre-determined and/or known (measured) depth are collected and transported by SD2 to well defined locations:

* MS & IS viewing place
* ovens for high temperature (800 deg C) heating
* ovens for medium temperature (130 deg C) heating.
* ovens with a window, where samples can be investigated by CIVA-M

The sampling, drilling and distribution (SD2) subsystem provides microscopes and advanced gas analysers with samples collected at different depths below the surface of the comet. Specifically, SD2 can bore up to 250 mm into the surface of the comet and collect samples of material at predetermined and/or known depths. It then transports each sample to a carousel which feeds samples to different instrument stations: a spectrometer, a volume check plug, ovens for high and medium temperatures and a cleaning station. SD2 is accommodated on the flat ground-plate of the Rosetta, where it is exposed to the cometary environment.

Instrument References: Ercoli-Finzi, et al. (2007)

### SESAME: Surface electrical, acoustic and dust impact monitoring

The SESAME (Surface Electrical, Seismic and Acoustic Monitoring Experiments) electronics board and the integration of the components are managed by the German Aerospace Centre (DLR), Institute of Space Simulation, Cologne.

The results of SESAME help in understanding how comets, have formed and thus, how the solar system, including the Earth, was born.

Instrument References: Seidensticker, et al. (2007)

# Ground Segment

This section summarizes the roles and responsibilities for the Rosetta Ground Segment.

The primary responsibility for developing the payload operations strategy for the Rosetta Scientific Mission is the Rosetta Science Working Team. The Rosetta Science Working Team (SWT) monitors and advises on all aspects of Rosetta which affect its scientific performance.

## Rosetta Ground Segment

The Rosetta ground segment consists of two major elements: the Rosetta Mission Operations Centre (RMOC) and the Rosetta Science Ground Segment (RSGS).

### Rosetta Science Ground Segment

The Rosetta Science Ground Segment (RSGS) is located at the European Space Astronomy Centre (ESAC) in Spain. The main task is to support the Rosetta Project Scientist in the planning of the science operations schedule and in the generation of coordinated operational sequences, the payload command sequences for all Rosetta instruments and their onward transmission to the Rosetta Mission Operations Centre (RMOC). In addition, the RSGS prepares the trajectory during the comet escort phase.

### Rosetta Mission Operations Centre

The Rosetta Mission Operations Centre (RMOC) is located at the European Space Operations Centre (ESOC) in Darmstadt, Germany. The RMOC is responsible for the Spacecraft operations and all real time contacts with the spacecraft and payload, the overall mission planning, flight dynamics and spacecraft and payload data distribution.

## Rosetta Lander Ground Segment

The Rosetta Lander Ground Segment (RLGS) is made up of two operational teams. When CNES joined the DLR consortium for developing the Lander, it was decided to divide the RLGS into 2 centres (see Lander Project Plan [RL-PL-DLR-97002]).

These teams are responsible for the success of the Lander operations, to ensure that the Lander performs the science with regards to its status, and to give the data to the PI's and suppliers.

### Lander Control Centre

The Lander Control Centre (LCC), located at DLR/MUSC in Koeln (Germany), in charge of Rosetta Lander operations during the flight segment definition, design, realization, assembly and tests.

### Science Operations and Navigation Centre

The Science Operations and Navigation Centre is under CNES responsibility, located in Toulouse (France). It is responsible for the navigation and mission analysis aspects, including separation, landing and descent strategies and generation of the scientific sequences.

## Rosetta Scientific Data Archive

All scientific data obtained during the full mission duration remains proprietary of the PI teams and the Lander teams for a maximum period of 6 months after they have been received from ESOC. After this period, the scientific data products from the mission have to be submitted to RSOC in a reduced and calibrated form such that they can be used by the scientific community. The Archive Scientist prepares the release of Rosetta Scientific Data Archive after reception from the individual Rosetta instruments and after the 6 months proprietary period.

# References

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# Acronyms

For more acronyms refer to Rosetta Project Glossary [RO-EST-LI-5012]

|  |  |
| --- | --- |
| ATTC | Absolute Time Telecommand |
| AU | Astronomical Unit |
| CA | Closest Approach |
| CAP | Comet Acquisition Point |
| CAT | Close Approach Trajectory |
| CNES | Centre National d'Etudes Spatiales |
| COP | Close Observation Phase |
| DLR | German Aerospace Center |
| DSM | Deep Space Manoeuver |
| ESA | European Space Agency |
| ESAC | European Space Astronomy Centre |
| ESOC | European Space Operations Center |
| ESTEC | European Space Research and Technology Center |
| EUV | Extreme UltraViolet |
| FAT | Far approach trajectory |
| FSS | First Science Sequence |
| FUV | Far UltraViolet |
| GCMS | Gas Chromatography / Mass Spectrometry |
| GMP | Global Mapping Phase |
| HGA | High Gain Antenna |
| HgCdTe | Mercury Cadmium Telluride |
| HIGH | High Activity Phase (Escort Phase) |
| HK | HouseKeeping |
| IRAS | InfraRed Astronomical Satellite |
| IRFPA | Infrared Focal Plane Array |
| IS | Infrared Spectrometer |
| LCC | Lander Control Center |
| LDL | Long Debye Length |
| LEOP | Launch and Early Orbit Phase |
| LOW | Low Activity Phase (Escort Phase) |
| LTE | Local Thermodynamic Equilibrium |
| MINC | Moderate Increase Phase (Escort Phase) |
| MGA | Medium Gain Antenna |
| MLI | Multi Layer Insulation |
| MS | Microscope |
| NNO | New Norcia ground station |
| OCM | Orbit Correction Manoeuvres |
| OIP | Orbit Insertion Point |
| PI | Principal Investigator |
| P/L | PayLoad |
| PC | Payload Checkout |
| PDHC | Pre Delivery Calib Science |
| PHC | Post Hibernation Commissioning |
| PRL | Prelanding |
| RBD | Rebounds |
| RF | Radio Frequency |
| RMOC | Rosetta Mission Operations Center |
| RLGS | Rosetta Lander Ground Segment |
| RL | Rosetta Lander |
| RO | Rosetta Orbiter |
| RSGS | Rosetta Science Ground Segment |
| RVM | Rendez-vous Manoeuver |
| S/C | SpaceCraft |
| SDL | Separation Descent and Landing |
| SINC | Sharp Increase Phase (Escort Phase) |
| SONC | Science Operations and Navigation Center |
| SSP | Surface Science Package |
| STR | Star TRacker |
| SWT | Science Working Team |
| TGM | Transition to global mapping |