



## Research paper

## The science planning process on the Rosetta mission



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## ABSTRACT

The Rosetta mission arrived at comet 67 P/Churyumov-Gerasimenko in Summer 2014, after more than 10 years in space. All previous mission encounters with a comet have provided a snapshot of the cometary activity at a given heliocentric distance. In contrast, Rosetta has escorted the comet nucleus for an extended period (> 2 years) at a large range of cometo-centric and heliocentric distances, which has provided exceptional and unprecedented observing conditions to study, analyse and monitor 67 P during its passage to, through and away from perihelion.

One of the biggest challenges of this mission is the development of an observation plan that adequately addresses the mission's science objectives while coping with a largely unknown and continuously evolving environment that constantly modifies the planning constraints.

The Rosetta Science Ground Segment (RSGS), in support of the Project Scientist and the Science Working Team, is in charge of translating the high level mission science objectives into a low level pointing and operations plan.

We present here the high-level science planning process adopted during the comet escort phase. We describe the main science objectives addressed along the mission lifetime, the different groups involved in the science planning, and the approach followed to translate those requirements into a viable and scientifically valid operations plan. Finally, we describe how the science planning scheme has evolved since arrival at the comet to react to the unexpected environment, largely reducing the planning lead times.

## 1. Rosetta mission

The European Space Agency's (ESA) Rosetta mission is carrying out a true exploration of an unknown world: It is the first rendezvous with and landing on a comet. This has led to a break-through in cometary science and unprecedented public attention for a space mission to a minor body, but it also required new challenges to be overcome for science and operations planning. The properties (including its shape) of the nucleus were not well known before Rosetta arrived, and the gas and dust activity of comet 67 P/Churyumov-Gerasimenko could only be investigated when the spacecraft was already within the coma. Throughout the mission, the spacecraft has to deal with a large range of

environmental conditions.

Specific challenges relevant to the area of science planning are:

- Environmental constraints: Rosetta is the first spacecraft to navigate within close range (tens to hundreds of kilometers) of a comet for an extended period. In addition to the gravity of the comet (the deviation from point source gravity due to the non-spherical shape is significant at close distance) and the one of the Sun, the drag force from the gas streaming away from the nucleus and solar radiation pressure also has to be considered. In particular gas drag limits the predictability of short-term trajectories and of the trajectory types that can be flown on the long-term. In addition, the dust particles

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emitted by the nucleus can pose a hazard for the spacecraft and instruments and further limit the trajectory options.

- Spacecraft constraints: Rosetta operates between 0.9 AU and 4.5 AU from the sun. At large heliocentric distance operations are constrained by limited power availability, while at lower distances thermal constraints limit the possible spacecraft attitudes. Attitude limitations in turn feed back into trajectory constraints through the need of regularly pointing the navigation cameras to the nucleus.
- Lander support: One of the great achievements of the Rosetta mission is the first landing on a cometary nucleus with the Rosetta lander Philae. At the same time, there was little time available between orbit insertion and landing, and consequently the early phase of the mission focussed on preparation for and implementation of the landing. This meant that the mission related operations were prioritised over science. However, in most cases the requirements for landing site selection and related operations also supported significant scientific observations.
- The scientific objectives of the mission change while the target comet is explored based on science and operational changes. A major example of that is the impact of changes driven by the dust environment on the operation of the spacecraft in the vicinity of the nucleus.
- The diverse groups of international participants and instruments, some of which have divergent pointing and distance requirements, presented the need to find compromises in mission planning and data collection strategies.

Due to such constraint evolution and the experience gained, the science planning process also evolved during the mission. Before lander delivery, the trajectory and high priority observations of Rosetta orbiter instruments were pre-defined based on the needs of Philae (May – December 2014). Purely scientific observations were then added as far as resources allowed. For the phase after landing and at moderate comet activity, trajectories were planned several months in advance based on scientific requirements and predictions of activity of the comet, and observations were distributed according to scientific disciplines (December 2014 – March 2015). From April 2015 on, the operations scheme has been modified to deal with unpredictability of the comet activity and to increase flexibility in adapting to new conditions: trajectories are selected only days in advance, and chosen based on scientific high level criteria. As much as possible operations are adapted to the trajectories actually flown.

The present paper focuses on the science planning activities in the scientific phase (post lander delivery) of the mission. It is organized as follows: In [Section 2](#) the science goals of Rosetta and their distribution over the mission are described. [Section 3](#) describes the overall science operations planning concept and the groups involved in the science planning steps. [Section 4](#) details the science planning process. [Section 5](#) explains the evolution to the current planning scheme. We conclude in [Section 6](#) with a discussion of the benefits and limitations of both schemes (before and after March 2015).

## 2. Master science plan

The Rosetta mission science planning follows a scientific roadmap or Master Science Plan (MSP), created by the Science Working Team (SWT, see below), and based on the high level goals outlined in the Rosetta Science Management Plan [1]. The MSP provides guidance for the prioritisation of investigation types or instrument operations by mission phase and also tracks the completion of the mission's top level science objectives.

The overarching science goal of Rosetta is to understand the physical and chemical processes that drive the cometary activity. In particular, to disentangle which constituents and characteristics originate from the formation of the comet and which ones have developed throughout the comet's history in the solar system. Such an under-

standing can be gained only by monitoring a certain number of physical properties of the comet as function of the heliocentric distance over a full activity cycle (from 'dormant' inactive state to the maximum of activity and back to dormant).

The MSP is divided into three main steps: 'First Time', 'Observing the Development of Cometary Activity' and 'Comparison with Pre-Perihelion Conditions'. Additionally, the MSP also includes an 'Extension' phase. We summarize in the next paragraphs the main characteristics and scientific content of each phase.

### 2.1. First time

During this phase, Rosetta was 'getting acquainted' with the comet and fundamental measurements were performed for the first time. The 'First Time' phase has been conducted during December 2014 until March 2015, at a distance range of 2.95 to 2.1 Astronomical Units (AU) and while the Northern hemisphere of the nucleus was illuminated.

It is important to note that fundamental properties of the nucleus had been derived during the pre-landing phase, as part of the operational support for the Philae landing [2]. Before the 'First Times' science phase, initial values of the comet rotation period, mass, volume, density and interior structure had been derived, as well as the shape of the illuminated regions characterized to a < 50 cm scale resolution.

The overarching aspect of the 'First Times' science objectives was the characterisation of the relatively inactive nucleus and its environment as a basis for comparison to the later changes, after large scale activity onset. We list below the science objectives addressed during this 'First Time' phase (although some continue into other phases). Note that the First Times phase of the orbiter science plan included observation campaigns in direct collaboration, or complemented by, the First Science Sequence of the Philae lander.

- What is the distribution of minerals, organics and ice on the comet's surface? ['Ground-truth' provided by the measurement of Philae for investigated surface elements]
- What are the di-electrical surface properties of the nucleus? ['Ground-truth' provided by the measurement of Philae for investigated surface elements]
- What are the thermal properties/energy balance of the surface material? ['Ground-truth' provided by the measurement of Philae for investigated surface elements]
- What is the composition of the dust and gas around the nucleus at very low activity level (including isotopes)?
- Are there any icy grains outside the snow line?
- Characterise the dynamics of dust, and the dust physical properties around the nucleus at very low activity level
- Search for icy patches on the nucleus and search for any sign of activity onset
- Quantify the relative contribution of H<sub>2</sub>O, CO<sub>2</sub> and CO to the low activity regime
- Observe the interaction of the solar wind with the nucleus surface (sputtering)

### 2.2. Observing the development of cometary activity

This second main phase of the Rosetta MSP covers a distance range from around 2.1 AU down to the perihelion at 1.25 AU, corresponding to the time between April-August 2015. During this phase, the comet activity increased and the nucleus began to become shielded from the solar wind environment as the coma fully developed. This period also coincides with the Southern equinox (May 2015) where the Southern hemisphere of the nucleus started to get illuminated after a long winter.

The main science objectives of this phase are listed below.

- Evolution of nucleus geomorphology and surface composition and

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