THE ROSETTA MISSION: FLYING TOWARDS THE ORIGIN OF THE SOLAR SYSTEM

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Abstract. The ROSETTA Mission, the Planetary Cornerstone Mission in the European Space Agency's long-term programme Horizon 2000, will rendezvous in 2014 with comet 67P/Churyumov-Gerasimenko close to its aphelion and will study the physical and chemical properties of the nucleus, the evolution of the coma during the comet's approach to the Sun, and the development of the interaction region of the solar wind and the comet, for more than one year until it reaches perihelion. In addition to the investigations performed by the scientific instruments on board the orbiter, the ROSETTA lander PHILAE will be deployed onto the surface of the nucleus. On its way to comet 67P/Churyumov-Gerasimenko, ROSETTA will fly by and study the two asteroids 2867 Steins and 21 Lutetia.

Keywords: ROSETTA, solar system, comets, asteroids

1. Introduction

The International ROSETTA Mission, approved in November 1993 by the Science Programme Committee of the European Space Agency (ESA), is the planetary cornerstone mission in ESA's long-term programme Horizon 2000 (Bonnet, 1985). The ROSETTA mission is a logical follow-up mission of ESA's very successful first mission, GIOTTO, to comet 1P/Halley (Reinhard, 1986). The prime scientific objectives of the ROSETTA mission are to investigate the origin of our solar system by studying the origin of comets (e.g. Schwehm and Schulz, 1999). Originally planned as a comet nucleus sample return mission (e.g. Huber and Schwehm, 1991), it consists of two mission elements, the ROSETTA orbiter and the ROSETTA lander PHILAE. The ROSETTA mission is a cooperative project between ESA, various European national space agencies, and NASA, and is comprised of twenty-five experiments, making it unprecedented in scale. The mission is named after a plate of volcanic basalt currently in the British Museum in London, called the Rosetta

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Stone. This plate was the key to unravel the civilization of ancient Egypt. Just as the Rosetta Stone provided the key to an ancient civilization, the scientific instruments onboard the ROSETTA spacecraft are designed to unlock the mysteries of the oldest building blocks of our solar system, the comets.

Why a cometary mission as a planetary cornerstone? Comets are widely considered to contain the least processed material in our solar system since their condensation from the proto-solar nebula. Most likely even pre-solar grains have been preserved in these bodies. The physical and compositional properties of comets may therefore be a key to their formation and evolution, hence to the formation of the solar system. Direct evidence on cometary material, in particular on the composition of cometary volatiles, is however extremely difficult to obtain. Until the first spacecraft missions to comet 21P/Giacobini-Zinner, 1P/Halley, and 26P/Grigg-Skjellerup only ground-based spectroscopic evidence about the compositional character of comets could be used to hypothesize on the properties of comets. These early ground-based observations led to the popular view of a comet as being a "dirty snowball" (Whipple, 1950, 1951).

In-situ measurements of the named cometary missions and their successors, the Deep-Space 1 mission to comet 19P/Borrelly (Boice *et al.*, 2002), the Stardust mission to 81P/Wild2 (Tsou *et al.*, 2004), and the Deep Impact mission to 9P/Tempel1 (Sunshine *et al.*, 2006; Belton *et al.*, 2006), led to a major revision of our current understanding of cometary nuclei. Major results of previous missions are: Cometary activity is rather localized at the nucleus surface with only minor parts being active and the activity being highly constant in short time scales. However, sometimes outbursts with dramatic increase of activity but unclear genesis occur. The dominant component is not water ice and a more proper characterization of the nucleus would be as an "icy dirtball". Organic material, that is CHON particles, have been observed, and some isotopic ratios and most elemental abundance differ from solar ones. Their surfaces can be evolved with very different landforms visible; impact structures have been observed. The Deep Impact results even suggest a layered structure with different physical characteristics, which led to the development of a layered pile model (Belton *et al.*, 2006). Furthermore, some minerals must have been processed in hot (T about 2000 K) environment near the Sun or other stars. All the present results indicate that cometary nuclei are unique, have their own history, and are not entirely pristine.

Many physicochemical processes, like sublimation, (photo)chemical reactions, and interactions with the solar wind and the high energy radiation in space alter the material originally present in the nucleus. The species observable from Earth and even in situ during flyby missions are consequently not representing the immediate molecular composition of the nucleus from formation times, although the currently available information already demonstrates the low level of evolution of cometary material. To retrieve information about the composition of a cometary nucleus and the processes altering it, the nucleus and the near-nucleus environment of a comet needs to be monitored in situ by very sensitive analytical investigations, including also the ionized gas or plasma environment of the comet whose evolution during perihelion approach is not fully understood (e.g. Neugebauer, 1990; Ip, 2004; Hansen *et al.*, this issue). The measurement goals of the ROSETTA mission therefore include (Schwehm and Schulz, 1999):

– a global characterization of the nucleus,
– the determination of its dynamic properties,
– the surface morphology and composition,
– the determination of chemical, mineralogical and isotopic compositions of volatiles and refractories in the cometary nucleus,
– the determination of the physical properties and interrelation of volatiles and refractories in the cometary nucleus,
– studies of the development of cometary activity and the processes in the surface layer of the nucleus and inner coma, that is dust/gas interaction,
– studies of the evolution of the interaction region of the solar wind and the outgassing comet during perihelion approach.

To achieve these goals ROSETTA will study in detail the properties of the nucleus, the physicochemical evolution of the cometary coma, and the plasma environment of comet 67P/Churyumov-Gerasimenko from onset of activity at large solar distances (possibly around 3 AU) through perihelion at 1.2 AU. Table I provides an overview of the different mission phases. ROSETTA's payload comprises 12 scientific instruments and instrument groups on board the orbiter (see Table II) and 10 on the Surface Science Package, the Rosetta lander PHILAE (see Table III), details of which are described in the respective instrument papers of the special ROSETTA issue introduced here.

ROSETTA combines two strategies for characterizing the properties of a cometary nucleus. On one hand, the comet's evolution along the orbit with decreasing heliocentric distance will be investigated with the orbiter instruments by monitoring the physical and chemical properties of the nucleus and in situ analysis of the near-nucleus environment. On the other hand, the ROSETTA lander PHILAE will provide ground truth by analyzing the nucleus material directly.

2. Mission Overview

The original target of the ROSETTA mission was comet 46P/Wirtanen. A failure of an Ariane rocket in December 2002 forced ESA to postpone the initially scheduled January 2003 launch and to re-target ROSETTA, now heading for comet 67P/Churyumov-Gerasimenko. ROSETTA was finally launched by an Ariane-5 G+ launch vehicle from the Guyana Space Center in Kourou, French Guyana, on March 2, 2004 (Figure 1). During a circuitous ten-year trek across our solar system, ROSETTA will travel the distance Sun-Earth five times, and will pass through the

TABLE I
Milestones of the ROSETTA mission.

Mission event	Nominal date
Launch	March 2, 2004
First Earth Gravity Assist	March 4, 2005
Mars Gravity Assist	February 25, 2007
Second Earth Gravity Assist	November 13, 2007
2867 Steins Flyby	September 5, 2008
Third Earth Gravity Assist	November 13, 2009
21 Lutetia Flyby	July 10, 2010
Rendezvous Manoeuvre 1	January 23, 2011
Start of Hibernation	July, 2011
Hibernation Wake Up	January, 2014
Rendezvous Manoeuvre 2 Between 4.5 and 4.0 AU	May 22, 2014
Start of Near-Nucleus Operations at 3.25 AU	August 22, 2014
PHILAE Delivery	November 10, 2014
Start of Comet Escort	November 16, 2014
Perihelion Passage	August, 2015
End of Nominal Mission	December 31, 2015

asteroid belt into deep space beyond 5 AU solar distance before it reaches its destination, the periodic comet 67P/Churyumov-Gerasimenko.

On its way to 67P/Churyumov-Gerasimenko the spacecraft will employ four planetary gravity assist manoeuvres (Earth-Mars-Earth-Earth) to acquire sufficient energy to reach the comet (Figure 2). In between the last two Earth swingbys ROSETTA will fly by the main belt asteroid 2867 Steins at a distance of 1700 km and at a relative velocity of 9 km/s on September 5, 2008. After the third Earth swingby ROSETTA will enter the main asteroid belt again and fly by the main belt asteroid 21 Lutetia at a distance of 3000 km and a speed of 15 km/s on July 10, 2010. The spacecraft will enter a hibernation phase in July of 2011. In January 2014 Rosetta will come out of hibernation and begin a series of rendezvous manoeuvres for comet 67P/Churyumov-Gerasimenko in May 2014.

The rendezvous manoeuvre 2 at $\approx$4.5 AU from the Sun will lower the spacecraft velocity relative to that of the comet to about 25 m/s and put it into the near comet drift phase, starting May 22, 2014 until the distance is about 10,000 km from the comet (Figure 3). It will be performed on the basis of a ground-based determination of the orbit from dedicated astrometric observations, before the comet is detected by the on-board cameras. The final point of the near-comet drift phase, the comet acquisition point (CAP), is reached at a Sun distance of less than 4 AU. As soon as

TABLE II
The Payload of the ROSETTA Mission

Instrument Name	Scientific Objectives	Principal Investigator
OSIRIS	Multi-Colour Imaging with a Narrow and a Wide Angle Camera	Horst-Uwe Keller MPS, Lindau Germany
ALICE	UV-Spectroscopy (70 nm - 205 nm)	Alan Stern SRI, Boulder, USA
VIRTIS	VIS and IR Mapping Spectroscopy (0.25 - 5 μm)	Angioletta Coradini IAS-CNR, Rome, Italy
MIRO	Microwave Spectroscopy (1.3 mm and 0.5 mm)	Sam Gulkis JPL, Pasadena, USA
ROSINA	Neutral Gas and Ion Mass Spectroscopy DFMS: 12-200 AMU $M/\Delta M \approx 3000$ RTOF: 12-350 AMU $M/\Delta M > 1000$ incl. Gas Pressure Sensor	Hans Balsiger Universität Bern Switzerland
COSIMA	Dust Mass Spectrometer (SIMS, $m/\mu m \approx 2000$)	Martin Hilchenbach (formerly Jochen Kissel) MPS, Lindau Germany
MIDAS	Grain Morphology with an Atomic Force Microscope at nm Resolution	Willi Riedler IWF, Graz, Austria
CONSERT	Radio Sounding and Nucleus Tomography	Wlodek Kofman LPG, CNRS/UJF, Grenoble France
GIADA	Dust Velocity and Impact Momentum Measurement, Contamination Monitor	Luigi Colangelo INAF, Naples, Italy
RPC	Langmuir Probe (LAP)	Anders Eriksson (formerly Rolf Boström) IRF Uppsala, Sweden
	Ion and Electron Sensor (IES)	Jim Burch SRI, San Antonio, USA
	Flux Gate Magnetometer (MAG) Germany	Karl-Heinz Glassmeier IGEP, Braunschweig, D

(*Continued on next page*)

TABLE II
(*Continued*)

Instrument Name	Scientific Objectives	Principal Investigator
	Ion Composition Analyser (ICA)	Rickard Lundin IRF, Kiruna, Sweden
	Mutual Impedance Probe (MIP)	Jean-Gabriele Trotignon LPCE/CNRS, Orleans France
	Plasma Interface Unit (PIU)	Chris Carr Imperial College, London England
RSI	Radio Science Experiment	Martin Pätzold Universität Köln Germany
SREM	Standard Radiation Environment Monitor	

the solar arrays provide enough power to bring the spacecraft into a suitable status, images of the comet will be acquired with the on-board navigation camera. The comet ephemeris will be updated from the on-board observations.

The far approach trajectory phase will start as soon as CAP has been reached. At the end of this ≈30 day phase, the relative velocity between ROSETTA and the comet will have been reduced to about 1.5 m/s, at a distance of about 300 comet nucleus radii. At this point landmarks and radiometric measurements are used to make a precise determination of the spacecraft and the comet relative positions, their relative velocity, and the rotation and gravity of the comet nucleus to fine-tune the approach. This information is used to start orbit insertion and close approach operations at about 60 comet radii distance at a few cm/s. At about 25 comet radii a capture manoeuvre will close the orbit. Polar orbits at 5 to 25 comet nucleus radii will be used for mapping the nucleus; this global mapping will start August 22, 2014. After global studies of the nucleus are completed, about five areas (500×500 m^2) will be selected for close observation at a distance down to 1 nucleus radius. Ideally all the orbiter payload instruments are operating during this phase. Due to the large geocentric distance and the low downlink data rate of about 14 kbits/s on board pre-processing and intermediate storage of data in the on-board solid state mass memory will be required.

At the end of the close observation phase, the landing site for PHILAE will be selected on the basis of the collected data. The lander will be delivered from an eccentric orbit (pericenter altitude as low as possible) with a pericenter passage near the desired landing site. An ejection mechanism will separate the lander from

TABLE III

The payload of the ROSETTA lander PHILAE lead investigators: Jean-Pierre Bibring and Hermann Boehnhardt.

Instrument Name	Scientific Objectives	Principal Investigator
APXS	α-p-X-Ray Spectrometer	Göstar Klingelhöfer (formerly Rudi Rieder) Universität Mainz Germany
COSAC	Evolved Gas Analyser: elemental and molecular composition	Fred Goesmann (formerly Helmut Rosenbauer) MPS, Lindau Germany
PTOLEMY	Evolved Gas Analyser: isotopic composition	Ian P. Wright Open University Milton Keynes, UK
CIVA	Panoramic Camera IR microscope	Jean-Pierre Bibring IAS, Orsay, France
ROLIS	Descent Camera	Stefano Mottola DLR Berlin, Germany
SESAME	Comet Acoustic Surface Sounding Experiment (CASSE)	Klaus J. Seidensticker (formerly Dirk Möhlmann) DLR Cologne, Germany
	Dust Impact Monitor (DIM)	Istvan Apathy KFKI, Budapest, Hungary
	Permittivity Probe (PP)	Walter Schmidt (formerly Harri Laakso) FMI, Helsinki, Finland
MUPUS	Multi-Purpose Sensor for Surface and Sub-Surface Science	Tilman Spohn DLR Berlin, Germany
ROMAP	RoLand Magnetometer (ROMAG)	Hans-Ulrich Auster IGEP, TU Braunschweig Germany
	Plasma Monitor (SPM)	Istvan Apathy KFKI, Budapest, Hungary
CONSERT	Comet Nucleus Sounding	Wlodek Kofman LPG, CNRS/UJF, Grenoble France
SD-2	Drill, Sample, and Distribution System	Amalia Ercoli-Finzi Politechnico di Milano Milano, Italy

Figure 1. Lift-off of the Ariane-5 G+ rocket on March 2, 2004, 07:17 UTC carrying the ROSETTA spacecraft into space. Figure by courtesy of ESA.

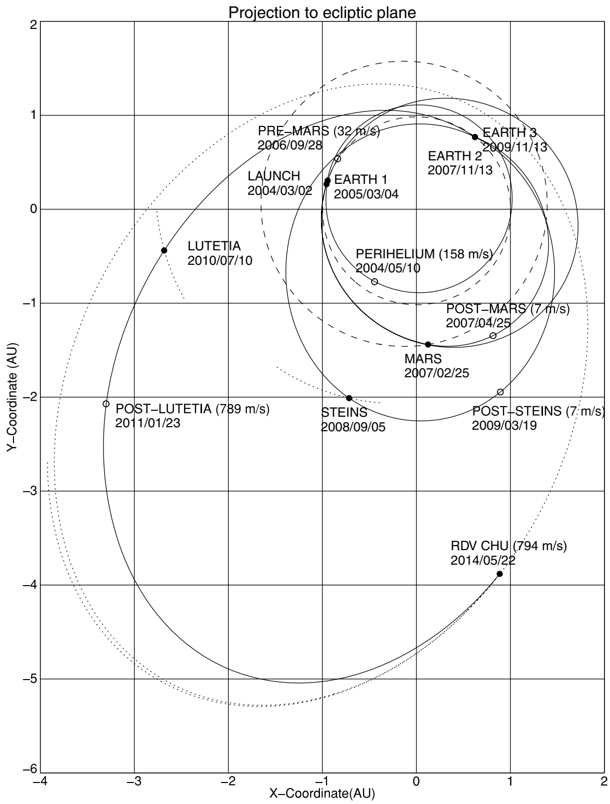

Figure 2. ROSETTA's journey to 67P/Churyumov-Gerasimenko. Figure by courtesy of ESA.

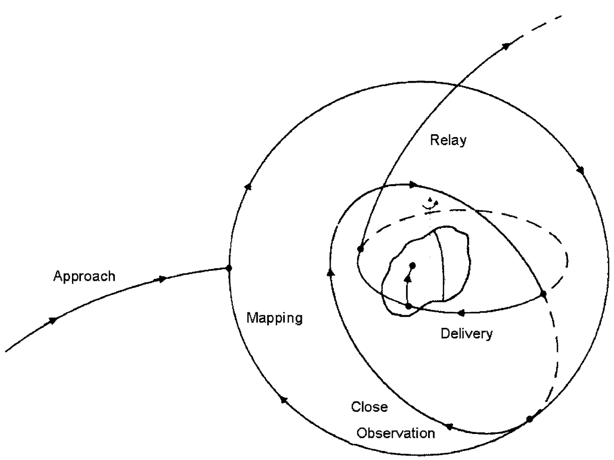

Figure 3. Schematic showing the spacecraft manoeuvres close to comet 67P/Churyumov-Gerasimenko. Figure by courtesy of ESA.

the spacecraft with a maximum relative velocity of about 1 m/s. The time and direction of the ROSETTA-PHILAE separation will be chosen such that the landing package arrives with minimum vertical and horizontal velocities relative to the local (rotating) surface. After delivery of the lander on November 10, 2014 at a solar distance of 3 AU, the spacecraft will be injected into an orbit which is optimized for receiving the data transmitted from the lander and to relay them to the Earth. To adjust the payload operations sequences, the lander can be commanded via the orbiter.

The initial prime PHILAE activities will last for 5 days with a longer operation period not excluded. After this the orbiter will spend at least 200 days in orbit in close vicinity of the comet nucleus until perihelion passage, still collecting data from the lander at regular intervals as long it remains operational. The objective of this comet escort phase is to monitor the nucleus (active regions), dust and gas jets, and to analyze gas, dust and plasma in the inner coma from the onset to peak activity. Orbital design will depend on safety considerations and scientific goals, taking into account that the communication relay service has to be provided for the long-life ROSETTA lander. Mission planning will depend on the results of previous observations, such as the activity pattern of the comet. Extended monitoring of different regions in the vicinity of the nucleus could be performed by successive quasi-hyperbolic flybys configuring petal-like trajectories.

It should be noted that the ROSETTA orbits will be highly perturbed by e.g. the Sun's gravitation and cometary gas and dust, that is they are very different from spacecraft orbits around planets. To keep the spacecraft on the required trajectory involves highly demanding spacecraft operations.

ROSETTA will remain in orbit around the comet past perihelion passage in August 2015 until the nominal end of mission on December 31, 2015. Depending on spacecraft condition and possibilities further operations such as a near-comet tail excursion are not excluded. The major mission events are summarized in Table I.

3. The ROSETTA Orbiter and its Payload

ROSETTA's design is based on a cuboid central frame, 2.8 m × 2.1 m × 2.0 m, with an aluminum honeycomb main platform. Total launch mass is 2900 kg including the 100 kg lander and 165 kg of scientific instruments (see Table IV). Two solar panels, 32 square meters each, extend outward from opposite sides of the cuboid, spanning 32 m tip-to-tip (Figure 4). The spacecraft consists of two primary modules, the Payload Support Module, which holds the scientific instrumentation and two payload boom deployment mechanisms in the top part of the frame, and the Bus Support Module, which holds the spacecraft subsystems in the lower part. A steerable 2.2 m diameter high-gain parabolic dish antenna is attached to one side, and the lander PHILAE is mounted on the opposite side (Figures 5 and 6).

TABLE IV
Spacecraft properties.

Size: main structure	$2.8 \times 2.1 \times 2.0$ m^3
Span of solar arrays	32 m
Launch mass:	
Total	2900 kg
Propellant	1720 kg
Science payload	165 kg
Lander PHILAE	100 kg
Solar array output	850 W at 3.40 AU
	395 W at 5.25 AU
Propulsion subsystem	24 bipropellant
	10 N thrusters
Operational life time	12 years
Prime contractor	EADS Astrium, Friedrichshafen

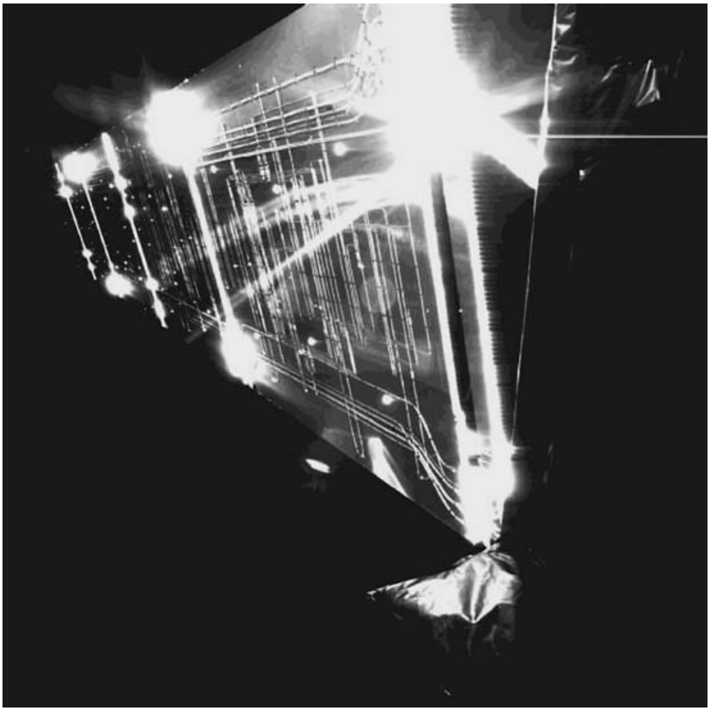

Figure 4. One of ROSETTA's solar panels as seen in-flight in May 2004 from the PHILAE lander camera CIVA. The back of one of the solar panels can be seen, with contours on the panel illuminated by sunlight and surfaces of the spacecraft main body recognizable in the lower right. For further details see Bibring *et al*. (this issue b). Figure by courtesy of CIVA/PHILAE/ESA.

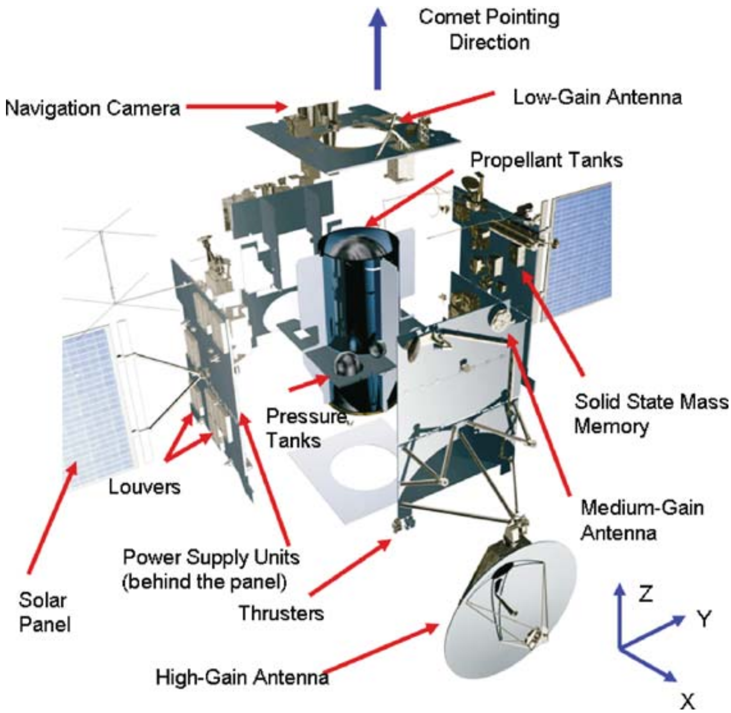

Figure 5. The ROSETTA spacecraft – an exploded view. The tripod in the lower right corner gives the spacecraft coordinate system. Figure by courtesy of ESA, with modifications.

The science instrument panel is mounted on the top and designed to be facing the comet continuously during orbit while the antenna and solar panels face the Earth and Sun, respectively. Radiators and louvers are mounted on the back and side panels which face away from the Sun and comet. In the center of the spacecraft protruding from the bottom is a vertical thrust tube made of corrugated aluminum with strengthening rings (Figure 5).

The thrust tube provides the propulsion for primary manoeuvres and contains two 1106-liter propellant tanks, the upper one containing propellant and the lower one oxidizer. A total of 660 kg of propellant (bipropellant monomethyl hydrazine) and 1060 kg of oxidizer (nitrogen tetroxide) is necessary to provide 2200 m/s ΔV over the course of the mission. The launch mass of ROSETTA including fuel is 2900 kg. There are also four 35-liter pressurant tanks. The orbiter scientific payload mass is 165 kg, PHILAE's mass is 100 kg.

The spacecraft is three-axis stabilized and the orientation controlled by 24 thrusters of 10 N each. Attitude is maintained by four reaction wheels as well as using two star trackers, Sun sensors, navigation cameras, and three laser gyro packages. Power is supplied by the solar arrays. The solar cells employed are 200 μm Si solar cells of low intensity, low temperature (LILT) type sized 37.75 mm

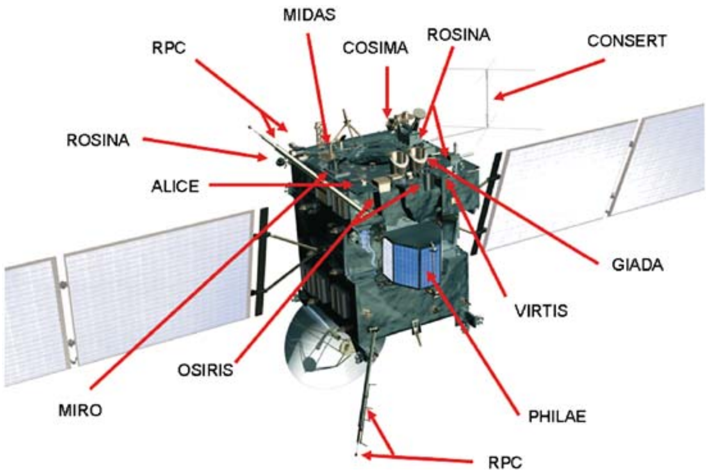

Figure 6. The ROSETTA spacecraft and its scientific payload. Figure by courtesy of ESA, with modifications.

in width and 61.95 mm in length. The cover-glass is 100 μm thick ceria doped micro-sheet designated curb mount glass (CMG). The cover-glass covers the solar cell completely. The solar arrays will provide 395 W at 5.25 AU and 850 W at 3.4 AU, when comet operations begin. Power is stored in four 10 Ah NiCd batteries which supply the 28 V bus power. Communications is maintained via the high-gain antenna, a fixed 0.8 meter medium-gain antenna, and two omnidirectional low gain antennas. ROSETTA utilizes an S-band telecommand uplink and S- and X-band telemetry and science-data downlinks, with data transmission rates from 5 to 20 kbits/s. Communication equipment includes a 28 W RF X-band traveling wave tube amplifier and a dual 5 W RF S/X band transponder. On-board heaters keep the instrumentation from freezing during the period the spacecraft is far from the Sun.

The orbiter's scientific payload includes 12 experiments, in addition to the lander. Scientific consortia from institutes across Europe and the United States have provided these state-of-the-art instruments. An ultraviolet imaging spectrometer – ALICE - will analyze gases in the coma and the tail, and it measures the comet's production rates of water and carbon monoxide or dioxide. It will also provide information on the surface composition of the nucleus. The comet nucleus sounding experiment – CONSERT – will probe the comet's interior by studying radio waves that will penetrate the nucleus. A cometary secondary ion mass analyzer – COSIMA – will analyze the characteristics of dust grains emitted by the comet, such as their composition and whether they are organic or inorganic. The grain impact analyzer and dust accumulator – GIADA – will measure the number, mass, momentum and velocity distribution of dust grains coming from the comet nucleus. A micro-imaging dust analysis system – MIDAS – will study the dust environment around the comet and provide information on particle population, size, volume and shape. The microwave instrument onboard the ROSETTA orbiter – MIRO – will determine the abundances of selected major gases, the surface outgassing rate and the nucleus sub-surface temperature. The optical, spectroscopic, and infrared remote imaging system – OSIRIS – consists of a wide-angle and a narrow-angle camera to obtain high-resolution images of the comet's nucleus. The orbiter spectrometer for ion and neutral species analysis – ROSINA – will determine the composition of the comet's atmosphere and ionosphere, the velocities of ionized gas particles and reactions in which they take part. The five instruments and the plasma interface unit of ROSETTA's plasma consortium – RPC – are designed to study structure and dynamics of the comet-solar wind interaction during the comet's approach to the Sun. RPC will also examine the physical properties of the nucleus. And during the cruise phase the RPC instruments also provide scientific measurements about possible encounters of cometary ion tails and dust trails. A radio science investigation – RSI – uses shifts in the spacecraft's radio signals to measure e.g. the mass, density, and gravity of the nucleus. A visible and infrared mapping spectrometer – VIRTIS – will map and study the nature of the solids and the temperature on the surface of the nucleus. VIRTIS will also identify comet gases, characterize the physical conditions of the coma and help to identify the best landing sites. Further details about the science objectives and the performances of the above mentioned experiments are presented in the accompanying instrument descriptions of this special issue.

In addition to these scientific experiments the orbiter is also equipped with a standard radiation environment monitor – SREM – to monitor the high energetic, ionizing particle environment aboard the spacecraft. The objective of SREM is to provide a continuous, almost uninterrupted measurement of the high energetic particles encountered by Rosetta and provide this information for mission analysis purposes.

4. The ROSETTA Lander PHILAE

The ROSETTA lander PHILAE can be considered a scientific spacecraft of its own that is carried and delivered by the ROSETTA orbiter to the comet (Figure 7). Upon proposal by various scientists, lead by Helmut Rosenbauer from the Max-Planck-Institut für Sonnensystemforschung in Katlenburg-Lindau, the 10 scientific instruments and the various spacecraft subsystems are provided by a consortium of spaceflight agencies and research institutes from 6 European countries and by ESA. A full description of the PHILAE lander system can be found in Bibring *et al.* (this issue a).

The nucleus mapping phase and close-up investigations of a few potential nucleus regions that are considered scientifically most interesting and safe enough for landing will set the stage for the release of the PHILAE sub-spacecraft from the orbiter. The final landing site is selected by the lander project team and ESA for lander touch-down in November 2014, when the comet is about 3 AU from the Sun.

Figure 7. ROSETTA and PHILAE – the lander is attached to the orbiter during integration of the spacecraft. Figure by courtesy of ESA.

The lander will be – literally – dropped on the cometary surface from a distance of about 1–2 nucleus radii and at a speed of up to 1 m/s. Sophisticated touch-down and anchoring equipment, a harpoon, will assure safe landing even under more extreme conditions like very hard or very soft and inclined surface layers.

During descent to the nucleus, images of the surface will be taken by the CIVA and ROLIS camera systems. Immediately after touch-down the scientific measurement program of the on-board instrumentation will be started. This analysis will involve all lander experiments (see Table III) and will be powered by the on-board batteries for about 5 days: CIVA and ROLIS will continue the imaging of the surface and its environment around the landing site (landscape, activity, close-up view of the surface structure). SESAME will perform electric and acoustic sounding of the surface and monitor dust impacts from cometary activity. The lander equipment of the CONSERT experiment will be switched on and receive and transmit the radio sounding signals from the orbiter counterpart of the instrument, thus allowing to explore the interior of the comet and the global constitution of the nucleus as a whole. The magnetic and plasma environment of the landing site and its interaction with the solar wind is explored by the ROMAP instrument on-board PHILAE. The APXS spectrometer and the MUPUS instrument will be deployed to the surface to measure the elemental composition of the surface material and the physical properties of the subsurface layers, respectively. The combined activities of the drill and sampling acquisition system SD-2 and of the mass spectrometers and gas chromatographs PTOLEMY and COSAC will collect and analyze surface and subsurface samples of the nucleus for isotopic and molecular composition and their chirality. A camera and infrared spectrometer of the CIVA instrument allow to image and measure SD-2 sample before vaporization in the PTOLEMY and COSAC ovens.

The initial measurements will be performed through a pre-programmed command sequence stored in the on-board computer of the lander. The measurements will be relayed via the ROSETTA orbiter to Earth, and after quick-look analysis refined and modified measurement schemes can be commanded – again via the orbiter – to the lander spacecraft for execution. After the intense measurement phase of the first 5 days the lander will switch to the long-term exploration of the comet, now monitoring the temporal (diurnal, orbital) evolution of nuclear activity and environmental phenomena, taking further nucleus samples at different locations around the landing site and continuing the exploration of the cometary interior (through CONSERT measurements). The long-term program is powered by the secondary battery that can be recharged by the solar generator onboard PHILAE, and relies on regular RxTx contact with the orbiter for data and command transmission to/from Earth. It is expected that the lander will survive the harsh environment at the cometary surface for a few months up to at least 2 AU solar distance.

Further details about the science objectives and the performances of the above mentioned PHILAE experiments are presented in the accompanying PHILAE instrument descriptions of this special issue.

5. The Main ROSETTA Target: 67P/Churyumov-Gerasimenko

Comet 67P/Churyumov-Gerasimenko (Figure 8) is a short-periodic comet from the class of the Jupiter Family comets (JFC) (Lamy *et al.*, this issue). It was discovered on September 9, 1969 – by chance – by Klim Ivanovic Churyumov and Svetlana Ivanovna Gerasimenko on photographic plates taken for comet 35P/Comas-Sola with the 50 cm Maksutov telescope of the Alma Ata Observatory, Tadchik Republic.

JFCs are believed to originate from the Kuiper Belt. Since the size distribution in the Kuiper Belt is collision-dominated for bodies smaller than about 50 km, JFCs

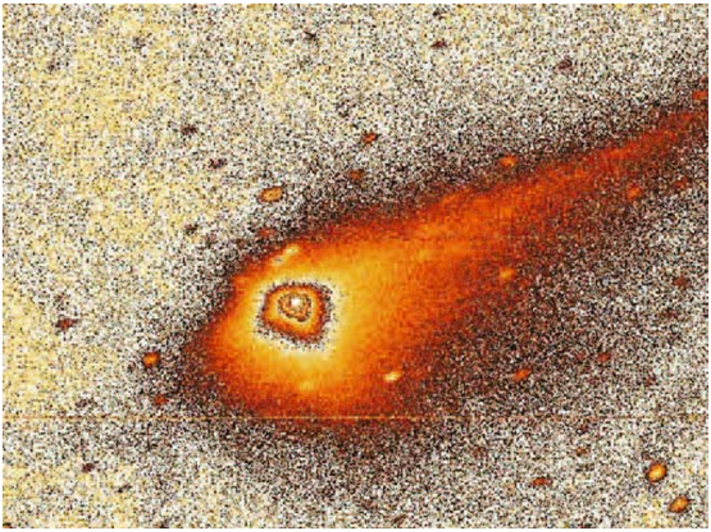

Figure 8. Comet 67P/Churyumov-Gerasimenko at 2.49 AU from the Sun, imaged on March 9, 2004 through broadband R filter with the EFOSC2 instrument at the 3.6 m telescope of the European Southern Observatory in La Silla/Chile. Non-circular isophotes in the coma indicate asymmetric material emission from the nucleus. The tail and neck-line structure extends beyond the edge of the field of view at PA $\approx 295°$. North is up and East to the left. The field of view is 70,000 $\times$ 50,000 km^2 at the distance of the comet. Figure by courtesy of Hermann Boehnhardt and ESO.

may actually represent the low-mass fragments from collision events in the belt. They were ejected from the Kuiper Belt region by Neptune. Repeated gravitational scattering at the outer major planets let them cascade inward, where they were finally captured by Jupiter into a short-periodic, near-ecliptic orbit around the Sun (Morbidelli and Brown, 2004; Duncan *et al*., 2004). Hence, their formation region was the icy outskirt environment of the planetary system, and due to their low body temperature, they preserved in their interior the most pristine material from the formation period of the solar system.

As JFC, nowadays, the orbit evolution of 67P/Churyumov-Gerasimenko is controlled by Jupiter. Backward calculations have revealed several encounters with the gas giant over the past 200 years with the one on February 4, 1959 (more than 10 years before discovery) being the closest one at just 0.052AU (about 109 Jupiter radii) distance from the planet (Belyaev *et al*., 1986). This close encounter has significantly changed the orbit of the comet, for instance the perihelion distance from 2.744 AU before to 1.280 AU after, bringing the comet within reach for the ROSETTA mission. The current orbital elements of the comet are listed in Table V and will remain widely unchanged well beyond the ROSETTA mission duration.

Intense physical characterization of the comet by Earth-based observations started only with the launch of ROSETTA in 2004. 67P/Churyumov-Gerasimenko is a small size body of about 2 km radius with likely low albedo and asymmetric

TABLE V
Orbital elements of the ROSETTA target comet.

	67P/Churyumov-Gerasimenko
Perihelion distance (AU)	1.28931109
Eccentricity	0.631935597
Ascending node (deg)	50.923016
Perihelion argument (deg)	11.367883
Inclination (deg)	7.1272258
Perihelion date	2002-Aug-18.23754

body shape (Lamy *et al*., this issue). It is thus the smallest comet that will be visited by a man-made spacecraft. The water production rate at perihelion is slightly below 10^{28} molecules/s and the coma gas chemistry seems to be carbon-depleted (A'Hearn *et al*., 1995; Schulz *et al*., 2004). Coma structures indicate the existence of 2–3 active regions on the nucleus – at least during its 2003–2004 return (see Figure 8). During the past perihelion passage the comet showed an interesting neck-line structure which may be due to – still to be confirmed – distant dust activity of the nucleus (Fulle *et al*., 2004). The comet is also well-known to produce a dust trail of heavy grains along its orbit (Sykes and Walker, 1992). Compared to the original ROSETTA target comet, 46P/Wirtanen, comet 67P/Churyumov-Gerasimenko is a larger representative with characteristics of an evolved object and the prospect for the mission to allow in-situ exploration of the overall nucleus structure and the global "comet machine" as well as a number of rare cometary phenomena. The papers of Agarwal *et al*. (this issue), Hansen *et al*. (this issue), and Lamy *et al*. (this issue) summarize the current knowledge on the prime target of the ROSETTA mission.

6. The ROSETTA Fly-by Targets: Asteroids 2867 Steins and 21 Lutetia

During cruise to its main target (see Section 5) the ROSETTA spacecraft will also visit – during short flybys at a few thousand km distance – two asteroids, namely 2867 Steins and 21 Lutetia. Both objects are main belt asteroids. Asteroids are considered as planetesimals of the inner planetary formation disk and as such they are important for understanding the formation of the terrestrial planets. 2867 Steins was discovered in 1969 (preliminary designation 1969VC). The asteroid is an asymmetric body of a few km size and its taxonomic type is still not firmly determined. 21 Lutetia is observed since 1866. The object is about 120 km in size and it belongs to the taxonomic class X, i.e. it is spectrally similar to E, M, and P-type asteroids that are usually considered as evolved objects. After 1 Ceres and 4 Vesta that will be visited by NASA's DAWN mission (Russell *et al*., 2004), 21

TABLE VI
Orbital elements of the ROSETTA target asteroids.

	2867 Steins	21 Lutetia
Perihelion distance (AU)	2.019181	2.044912
Eccentricity	0.1457363	0.1608390
Ascending node (deg)	55.53703	81.02638
Perihelion argument (deg)	250.51986	249.85812
Inclination (deg)	9.9457	3.06938
Perihelion date	2005-Jun-23.34057	1989-Jan-27.12771

Lutetia will be the third largest asteroids closely analyzed by a spacecraft. Table VI summarizes the orbital elements of the two asteroids. The chapter of Barucci *et al.* (this issue) provides detailed and up-to-date information on the physical properties of these ROSETTA targets.

7. Summary and Conclusions

The ROSETTA mission with its orbiter and lander elements is a challenging project providing a first-class scientific opportunity of historic proportions and some straight technical firsts. ROSETTA will be the first spacecraft to orbit a cometary nucleus and the first spacecraft to fly alongside a comet as it heads towards the inner Solar System. This allows for an unprecedented opportunity to examine from close proximity how a comet, coming from deep space, is transformed while heated by the Sun. The lander PHILAE will perform the first controlled touchdown of a robotic lander on a comet nucleus, and therefore the mission will provide the first images taken from the cometary surface and the first in situ analysis results of cometary material. The ROSETTA mission also comprises the first flybys of two main-belt asteroids.

ROSETTA is also the first spacecraft to fly close to the Jovian orbit using solar cells as its main power source. This is due to its large solar panels and the use of specially optimized low intensity low temperature (LILT) technology (e.g. Strobl *et al.*, 1995). In order to limit consumption of power and fuel, the spacecraft will be placed in hibernation, with most electrical systems turned off, for several years when it is in deep space cruise. The ROSETTA spacecraft had to be designed for a high level of reliability as the main scientific mission is starting more than 10 years after launch, and also for a high level of availability during the early years of the mission cruise, which also contains many key technical and scientifically valuable events including three Earth swingbys, one Mars swingby, two asteroid flybys, several deep space trajectory correction manoeuvres, and regularly scheduled on-board system and payload checkouts.

These outstanding efforts will assure that ROSETTA will contribute significantly to answer open questions in solar system research such as: How pristine are comets? How does cometary activity work? Are the craters on comets from impacts or from other processes? What is the internal structure of cometary nuclei? How does cometary material look like and what is it made of? Are there internal heat sources that trigger normal activity and outbursts? What are the main physical and chemical processes in the coma? How does solar wind – comet interaction change at the different activity levels from 3 AU to perihelion? Are comets candidates that delivered prebiotic molecules and water to Earth?

Comets remain the poorest understood solar system objects. The future measurements of Rosetta orbiting around a comet for several months and delivering a lander to the surface will open a whole new field of research. And ROSETTA will provide a much better understanding of comets and solar system formation, much as the Rosetta Stone did in our understanding of the Egyptian culture.

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