ROSETTA SPACE MISSION TO COMET 67P/CHURYUMOV–GERASIMENKO

K. I. Churyumov

Astronomical Observatory, National Taras Shevchenko University of Kyiv
3 Observatorna Str., 04053 Kyiv, Ukraine
e-mail: `klim.churyumov@observ.univ.kiev.ua`

On March 2, 2004 Rosetta space mission successfully started from the Kourou cosmodrom to Comet 67P/Churyumov–Gerasimenko. Upon entering orbit around the nucleus observations will be made as the comet becomes more active as it journeys towards the Sun. A lander, named Philae, will be deployed and attempt to make the first ever controlled landing on a comet. On its 10 year journey Rosetta will fly-by two asteroids, namely, 2867 Steins in September 2008 and 21 Lutethia in July 2010. Rosetta will be the first spacecraft to orbit a comet's nucleus. It will be the first spacecraft to fly alongside a comet as it heads towards the inner Solar System. Rosetta will be the first spacecraft to examine from close proximity how a frozen comet is transformed by the warmth of the Sun. Shortly after its arrival at Comet 67P/Churyumov–Gerasimenko, the Rosetta orbiter will despatch a robotic lander for the first controlled touchdown on a comet nucleus. The Rosetta lander's instruments will obtain the first images from a comet's surface and make the first in situ analysis of the relict matter of the Solar System.

INTRODUCTION

The European Space Agency's unprecedented mission of cometary exploration is named after the famous "Rosetta Stone". This slab of volcanic basalt – now in the British Museum in London – was the key to unravelling the civilization of ancient Egypt.

French soldiers discovered the unique Stone in 1799, as they prepared to demolish a wall near the village of Rashid (Rosetta) in Egypt's Nile delta. The carved inscriptions on the Stone included hieroglyphics – the written language of ancient Egypt – and Greek, which was readily understood. After the French surrender in 1801, the 762-kilogram stone was handed over to the British.

By comparing the inscriptions on the stone, historians were able to begin deciphering the mysterious carved figures. Most of the pioneering work was carried out by the English physician and physicist Thomas Young, and the French scholar Jean François Champollion. As a result of their breakthroughs, scholars were at last able to piece together the history of a long-lost culture.

Just as the Rosetta Stone provided the key to an ancient civilization, so ESA's Rosetta spacecraft will unlock the mysteries of the oldest building blocks of our Solar System – the nucleus of Comet 67P/Churyumov–Gerasimenko, which will be play a role of "Rosetta Stone". As the worthy successor of Champollion and Young, the valuable data, receiving by Rosetta will allow scientists to look back 4 600 million years to an epoch when no planets existed and only a vast swarm of asteroids and comets surrounded the young Sun.

COMET 67P/CHURYUMOV–GERASIMENKO, THE MAIN TARGET OF THE ROSETTA MISSION

Comet 67P/Churyumov–Gerasimenko is a large dirty snowball that orbits the Sun once every 6.6 years.

During this time, it commutes between the orbits of Jupiter and the Earth. However, little is known about it, despite its regular visits to the inner Solar System. Physical and orbital parameters of Comet 67P/Churyumov–Gerasimenko are the following:

diameter of nucleus	4 km,
orbital period	6.6 yr,
minimum distance from the Sun	186 million km,
maximum distance from the Sun	857 million km,
orbital eccentricity	0.6,
orbital inclination	7.1°,
date of discovery	October 2, 1969,
discoverers	Klim Churyumov (National Taras Shevchenko University of Kyiv, Ukraine), Svetlana Gerasimenko (Institute of Astrophysics, Dushanbe, Tajikistan).

Over an entire year, as it approaches the Sun, Rosetta will orbit the comet. As its ices evaporate, instruments on board the orbiter will study gas and dust particles which surround the comet and trail behind it as streaming system.

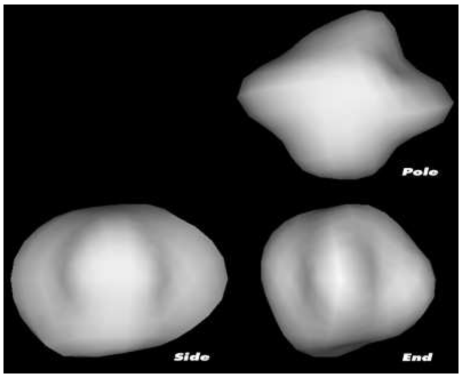

Figure 1. The shape and sizes of the nucleus of Comet 67P/Churyumov–Gerasimenko

THE MAIN GOALS OF THE ROSETTA MISSION

The main goal of the Rosetta mission is to study the origin of comets, the relationship between cometary and interstellar material and its implications with regard to the origin of the Solar System [1]. The measurements to be made to achieve this are the following:

– global characterization of the nucleus, determination of dynamic properties, surface morphology and composition;
– determination of the chemical, mineralogical and isotopic compositions of volatiles and refractories in a cometary nucleus;
– determination of the 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 the inner coma (dust/gas interaction);
– global characterization of asteroids, including determination of dynamic properties, surface morphology and composition.

SPACECRAFT: ROSETTA AND LANDER

The Rosetta spacecraft measures $2.8\times 2.1\times 2.0$ metres, on which all subsystems and payload equipment are mounted. There are two 14-metre solar panels with a total area of 64 square metres. At launch, the vehicle weighs approximately 3000 kg (fully fuelled) including 1670 kg of propellant, 165 kg of scientific payload for the orbiter, and 100 kg for the lander Philae.

The large number of complex scientific instruments needs to be accommodated on one side of the spacecraft, which must permanently face the comet during the operational phase of the mission. Until its release, the lander is carried on the opposite side of the orbiter to the large high-gain antenna dish.

As it arrives on the comet, the Rosetta lander Philae uses three different techniques (self-adjusting landing gear, harpoons, and a drill) to ensure that once it has arrived on the surface of the comet, it stays there.

As soon as it touches down, two harpoons will anchor the probe to the surface, the self-adjusting landing gear will ensure that it stays upright, even on a slope and then the lander's feet will drill into the ground. These devices will help counteract the fact that there is very low gravity on a comet. The lander will focus on the study of the composition and structure of the comet nucleus material. Goals include the determination of the elements that exist, traces of minerals and isotopic composition of the comet's surface and immediate subsurface. The comet's surface strength, density, texture, porosity, ice phases and thermal properties will also be studied. Texture investigations will include microscopic studies of individual grains.

The Rosetta Orbiter's scientific payload includes 11 experiments, in addition to the lander. Scientific consortia from institutes across Europe and the United States have provided these state-of-the-art instruments. All of them are located on the side of the spacecraft that will permanently face the comet during the main scientific phase of the mission. ALICE (Ultraviolet Imaging Spectrometer) analyses gases in the coma and tail and measures the comet's production rates of water and carbon monoxide/dioxide. It also provides information on the surface composition of the nucleus.

CONSERT (Comet Nucleus Sounding Experiment by Radiowave Transmission) probes the comet's interior by studying radio waves that are reflected and scattered by the nucleus.

COSIMA (Cometary Secondary Ion Mass Analyser) will analyse the characteristics of dust grains emitted by the comet, including their composition and whether they are organic or inorganic.

GIADA (Grain Impact Analyser and Dust Accumulator) measures the number, mass, momentum and velocity distribution of dust grains coming from the nucleus and from other directions (reflected by solar radiation pressure).

MIDAS (Micro-Imaging Dust Analysis System) studies the dust environment around the asteroids and comet. It provides information on particle population, size, volume and shape.

MIRO (Microwave Instrument for the Rosetta Orbiter) is used to determine the abundances of major gases, the surface outgassing rate and the nucleus subsurface temperature. It will also measure the subsurface temperatures of Steins and Lutetia, and search for gas around them.

OSIRIS (Optical, Spectroscopic, and Infrared Remote Imaging System) is a wide-angle camera and a narrow-angle camera to obtain high-resolution images of the comet's nucleus and the asteroids that Rosetta passes on its voyage to Comet 67P/Churyumov–Gerasimenko. It will help in identifying the best landing sites.

ROSINA (Rosetta Orbiter Spectrometer for Ion and Neutral Analysis) contains two sensors which will determine the composition of the comet's atmosphere and ionosphere, the velocities of electrified gas particles, and reactions in which they take part. It will also investigate possible asteroid outgassing.

RPC (Rosetta Plasma Consortium). In this instrument, five sensors measure the physical properties of the nucleus, examine the structure of the inner coma, monitor cometary activity, and study the comet's interaction with the solar wind.

RSI (Radio Science Investigation). Shifts in the spacecraft's radio signals are used to measure the mass, density and gravity of the nucleus, to define the comet's orbit, and to study the inner coma. RSI will also be used to measure the mass and density of Siwa, and to study the solar corona during the periods when the spacecraft, as seen from the Earth, is passing behind the Sun.

VIRTIS (Visible and Infrared Thermal Imaging Spectrometer) maps and studies the nature of the solids and the temperature on the surface of the nucleus. Also identifies comet gases, characterizes the physical conditions of the coma and helps to identify the best landing sites.

The 100-kilogram Rosetta lander is provided by a European consortium under the leadership of the German Aerospace Research Institute (DLR). Other members of the consortium are ESA and institutes from Austria, Finland, France, Hungary, Ireland, Italy, and the UK.

The box-shaped lander is carried on the side of the orbiter until it arrives at Comet 67P/Churyumov–Gerasimenko. Once the orbiter is aligned correctly, the lander is commanded to self-eject from the main spacecraft and unfold its three legs, ready for a gentle touchdown at the end of the ballistic descent.

On landing, the legs damp out most of the kinetic energy to reduce the chance of bouncing, and they can rotate, lift or tilt to return the lander to an upright position.

Immediately after touchdown, a harpoon is fired to anchor the lander to the ground and prevent it escaping from the comet's extremely weak gravity. The minimum mission target is one week, but surface operations may continue for many months.

The main instruments of the Rosetta lander Philae and their purposes are: APXS (Alpha X-ray Spectrometer) is lowered to within 4 cm of the ground, it detects alpha-particles and X-rays, which provide information on the elemental composition of the comet's surface.

CIVA: six identical micro-cameras take panoramic pictures of the surface. A spectrometer studies the composition, texture and albedo (reflectivity) of samples collected from the surface.

CONSERT (Comet Nucleus Sounding Experiment by Radiowave Transmission) probes the internal structure of the nucleus. Radio waves from the CONSERT experiment on the Orbiter travel through the nucleus and are returned by a transponder on the lander.

COSAC (Cometary Sampling and Composition experiment) is one of two evolved gas analysers, it detects and identifies complex organic molecules from their elemental and molecular composition.

MODULUS PTOLEMY is an evolved gas analyser, which obtains accurate measurements of isotopic ratios of light elements.

MUPUS (Multi-Purpose Sensors for Surface and Subsurface Science) uses sensors on the Lander's anchor, probe and exterior to measure the density, thermal and mechanical properties of the surface.

ROLIS (Rosetta Lander Imaging System) is a CCD camera to obtain high-resolution images during descent and stereo panoramic images of areas sampled by other instruments.

ROMAP (Rosetta Lander Magnetometer and Plasma Monitor) is a magnetometer and plasma monitor to study the local magnetic field and the comet/solar-wind interaction.

SD2 (Sample and Distribution Device) drills more than 20 cm into the surface, collects samples and delivers them to different ovens or for microscope inspection.

SESAME (Surface Electrical, Seismic and Acoustic Monitoring Experiments). Three instruments measure properties of the comet's outer layers. The Cometary Acoustic Sounding Surface Experiment measures the way in which sound travels through the surface. The Permittivity Probe investigates its electrical characteristics, and the Dust Impact Monitor measures dust falling back to the surface.

THE PHASES OF THE ROSETTA FLIGHT

The mission falls into several distinct phases:

launch	March 2, 2004,
first Earth gravity assist	March 2005,
mars gravity assist	March 2007,
second Earth gravity assist	November 2007,
fly-by the binary asteroid Steins (2867)	September 2008,
third Earth gravity assist	November 2009,
fly-by the big asteroid Lutethia (21)	July 2010,
enter hibernation	July 2011,
exit hibernation	January 2014,
rendezvous manoeuvre	May 2014,
global mapping	August 2014,
lander delivery	November 2014,
perihelion passage	August 2015,
end of mission	December 2015.

ROSETTA'S SCIENTIFIC "FIRST" OBSERVATIONS IN 2004

ESA's comet-chaser Rosetta, whose 10-year journey to its final target Comet 67P/Churyumov–Gerasimenko started on March 2, 2004 is well on its way. The first phase of commissioning is close to completion and Rosetta has successfully performed its first scientific activity, observations of Comet C/2002 T7 (Linear).

The commissioning activities, which started a couple of days after launch, included the individual activation of all instruments aboard the Rosetta orbiter and the Philae lander. This first check-out worked flawlessly and showed that the spacecraft and all instruments are functioning well and in excellent shape.

The commissioning tests also paved the way for Rosetta's first scientific activity: observation of Comet C/2002 T7 (LINEAR), which is currently travelling for the first and only time through the inner Solar System and offered Rosetta an excellent opportunity to make its first scientific observations.

On April 30, 2004 the OSIRIS camera system, which was scheduled for commissioning on that date, took images of this unique cometary visitor – Comet C/2002 T7 (LINEAR). Later that day, three more instruments aboard Rosetta (ALICE, MIRO, and VIRTIS) were activated in parallel to take measurements of the comet.

The first data from the remote-sensing observations confirm the excellent performance of the instruments. The four instruments took images and spectra of Comet C/2002 T7 (LINEAR) to study its coma and tail

Figure 2. Comet C/2002 T7 (LINEAR) from a distance of about 95 million kilometres (OSIRIS camera of Rosetta)

in different wavelengths, from ultraviolet to microwave. Rosetta successfully measured the presence of water molecules in the tenuous atmosphere around the comet. The OSIRIS camera produced high-resolution images of Comet C/2002 T7 (LINEAR) from a distance of about 95 million kilometres.

The image (above) showing a pronounced nucleus and a section of the tenuous tail extending over about 2 million kilometres was obtained by OSIRIS in blue light.

After Rosetta's first deep-space manoeuvres were carried out on May 10 and 15, 2004 with the highest accuracy, the first phase of commissioning is set to be completed in the first week of June 2004. Rosetta was then into a quiet "cruise mode" until September 2004, when the second phase of commissioning was scheduled to start. These activities, including the interference and pointing campaign, were last until December 2004.

So, the Rosetta spacecraft is well under way on its historic 10-year voyage, to do what has never before been attempted – orbiting and landing on the nucleus of Comet 67P/Churyumov–Gerasimenko.

On June 18, 2004 ESA's Rosetta comet-chaser has photographed itself in space at a distance of 35 million kilometres from the Earth. The CIVA imaging camera system on the Philae lander returned this image as part of its testing in May 2004.

Figure 3. Image of the Earth and Moon made by the Rosetta CIVA imaging camera

Figure 3 shows the image of the Earth–Moon system, taken by ESA's Rosetta comet-chaser spacecraft from a distance of 70 million kilometres. This image was taken by the Navigation Camera System (NAVCAM) aboard the Rosetta spacecraft, activated for the first time on July 25, 2004. This system, comprising two separate independent camera units (for back-up), will help to navigate the spacecraft near the comet nucleus. The cameras perform both as imaging cameras and star sensors, and switch functions by means of a refocusing system in front of the first lens.

At the comet, extremely high-precision measurements of the relative distance and velocity (between spacecraft and nucleus) will be needed. These are not achievable with the ground-based methods normally used with all other spacecraft or for normal Rosetta trajectory determinations.

In the meantime though, the cameras can also be used to automatically track the two asteroids that Rosetta will be visiting during its long cruise, Steins and Lutetia.

The successful observation of Comet Linear was a first positive test for Rosetta's ultimate goal, Comet 67P/Churyumov–Gerasimenko, which will be reached in 2014. Rosetta will be the first mission to undertake a long-term exploration of a comet at close quarters whilst accompanying it on its way towards the Sun. The unprecedented in-depth study conducted by the Rosetta orbiter and its Philae lander will help scientists decipher the formation of our Solar System around 4600 million years ago and provide them with clues of how comets may have contributed to the beginning of life on the Earth.

[1] The new Rosetta targets: Proc. of the Capri-2003 Conf. / Eds L. Colangelli *et al.*–Kluwer Acad. Publ., 2004.–392 p.