DEPARTMENT OF
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ROSETTA: COMET CHASER

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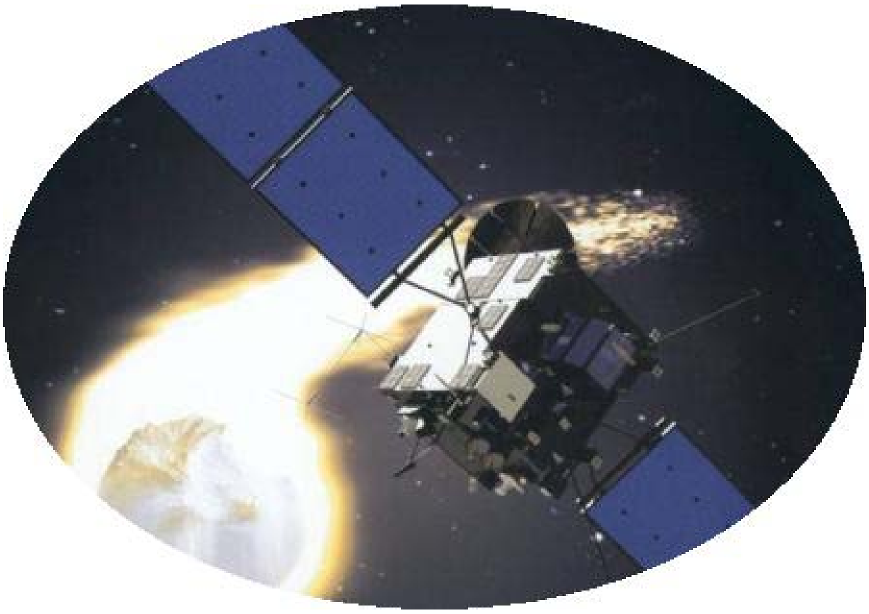

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Intended Readers:

This report has been written for the head of an astronomy research group from University College London interested in the formation of the solar system. It is intended as a description of the experiments aboard the Rosetta spacecraft, the type of results expected and the scientific benefits achievable by the mission.

Abstract

The purpose of this report is to outline the scientific benefits of the Rosetta mission to comet 46P/Wirtanen. The design of the experiments aboard both the Orbiter and the Lander is discussed also the method, by which the objectives of the mission will be met, are outlined. It is concluded that the mission will provide a great deal of data which can be used in studies of the origin of the solar system.

1 Breaking News

On 14th January 2003, ESA together with Arianespace announced that due to a complete systems review of the rocket Ariane5, the Rosetta spacecraft would be grounded until February 2003 at the earliest. This means Rosetta will not reach its target in time. The mission will have to be re-designed with a new target and a new flight path; they are predicting a launch date of Jan 2004 at the earliest. Despite this postponement, this report will be written as if the mission launched as planned on the 12th January 2003, the science and technology will still be unaffected, only the objects to be studied.
(*European Space Agency – Rosetta Home Page*).

2 Introduction

2.1 Mission overview

The Rosetta mission was approved by ESA in November 1993. Its aim is to rendezvous with, and land on the comet 46P/Wirtanen. After 10 years of preparation, the spacecraft was launched on January 12th 2003. It will reach the comet in 2011 where it will perform 18 experiments via a Lander and an Orbiter. The experiment will end in 2013 when the comet enters perihelion. On its long journey out to the comet, Rosetta will fly-by two asteroids, Otawara (July 2006) and Sewa (July 2008) (*Schwehm, 2001*).

2.2 Background

-Why are comets of interest?

Comets, like asteroids, planets and planetesimals were created out the early solar nebula around 5 billion years ago. Since cometary material has succumb to the lowest level of processing, much of that material is as it was when it formed. To look inside a comet is to look at the isotopic, chemical, mineralogical and textural features of the primordial matter of the solar nebula (*Riedler et al. 1998*). Although samples of cometary dust have been collected on earth, the organic and volatile composition will not be the same as its parent comet. Even with the results of ESAs Giotto mission, our knowledge of comets is low.

2.3 Scientific Objectives

The main objective is to study the origin of comets, the relationship between cometary and interstellar material and its implication as regards to the origin of the solar system (*Schwehm, 2001*). A few of the questions to be answered by Rosetta are:

-What is the bulk density of a comet's nucleus?

The OSRIS experiment on the orbiter will give accurate measurements of the volume and mass of the cometary nucleus (*Schwehm, 2001*).

-Is the comet a dirty snowball or an icy dirtball?

The SD^2 experiment on the Lander will analyse samples taken from depths of 25cm (*Biele et al. 2002*). The MUPUS experiment also on the Lander, will, with the use of a penetrator, take thermal and mechanical measurements 32cm below the surface of the comet (*Keller & Spohn, 2002*).

-*Why is the nucleus of a comet so dark?*

The Lander will be able to characterise the surface and the interior in terms of chemistry (*Biele et al. 2002*), while the VITRIS experiment on the Orbiter will analyse the spectral signature of the surface (*Coradini et al. 1999*).

-*Why are the active regions localised?*

Spectral analysis of the emitted gasses and measurements of emitted dust grains by the GIADA experiment on the Orbiter (*Bussoletti et al. 1999*) as well as radio images of the interior, taken by the CONSERT experiment on both the Orbiter and the Lander will address this issue (*Barbin et al. 1999*).

-*Is a comet one piece or a composite of many?*

Radio images of the interior taken by CONSERT will answer this question (*Barbin et al. 1999*).

-*What is a comet's exact composition?*

The ROSINA experiment on the Orbiter will determine the elemental, isotopic and molecular composition of the atmosphere and ionosphere of the comet (*Balsiger 1998*). COSAC, on the Lander, will analyse the chemical and isotopic composition of the gasses evolving from the surface (*Rosenbauer, 1999*). SD^2, on the Lander, will collect samples, from beneath the surface of the comet, for analysis by ÇIVA (*Pozzi et al 1997 & Biele et al. 2002*).

2.4 Flight Path

The journey to the comet is very complicated and will take approximately 8 years. The reason for this is that Rosetta is equipped only with solar panels, so it needs multiple gravity assists. The plan is to use Mars then Earth, this will then put it in an orbit allowing a flyby of the Otawara asteroid. There will then be a final Earth assist putting the spacecraft in an orbit to catch up with the Wirtanen comet. On it way, it will fl-by the asteroid Siwa.

2.5 46P/Wirtanen

Comet 46P Wirtanen.

This comet was chosen because it is short period (5.5 yrs) and is a member of the Jupiter family, which means that it is observable throughout its entire orbit. The comet's radius is between 600 and 700m (assunming an albedo of 0.04). It has a gas production rate of 10^{28} molecules/s at perihelion, which is 100 times less than 1P/Haley (*Schewhm, 2001*).

3 The Orbiter

The Orbiter consists of 11 separate experiments and a Lander (see below). The type of measurements being carried out can be categorised as follows: remote sensing; composition analysis; nucleus large-scale structure; comet plasma environment and solar wind interaction (*European Space Agency Website – Rosetta Home Page*).

3.1 Remote Sensing

There are 4 experiments - OSIRIS (Optical, Spectroscopic, and Infrared Remote Imaging System), ALICE (Ultraviolet Imaging Spectrometer), VIRTIS (Visible and Infrared Thermal Imaging Spectrometer) and MIRO (Microwave Instrument for the Rosetta Orbiter).

3.1.1 OSIRIS

OSRIS comprises of two separate cameras, and narrow angle camera (NAC) and a wide-angle camera (WAC). The NAC is designed for imaging the nucleus while the WAC is designed for imaging the dust and gas around the nucleus. OSRIS will determine the bulk properties of the nucleus, such as volume, density, surface gravity fields and inhomogeneities. It will also identify surface features, study the regolith, map surface ices, investigate the colour and mineralogy of the surface. As regards the dust and gas emission, OSRIS will determine the special distribution of dust and gas near to the surface, the sources of emission, the production rates and the gas-dust ratio (*Max-Planck-Institut für Aeronomie – OSRIS Homepage*).

3.1.2 ALICE

ALICE is an ultraviolet imaging spectrometer for the Rosetta orbiter. Its main scientific aim is to detect and measure noble gasses, atomic abundances in the coma, major ion abundances in the tail and production rates, variability and structure of H_2O and CO/CO_2 molecules that generate cometary activity (*Stern et al. 1998*). Although the instrument was designed for planetary atmospheres it has been optimised for the Rosetta mission and will give an increased sensitivity, instantaneous field-of-view and wavelength coverage. The instrument will be active throughout the comet rendezvous (*Stern et al. 1998*).

In more detail the scientific benefits of this instrument are:

(1) *It will help determine a thermal history of the comet.* The frosts of inert gasses observed on the nucleus surface are both chemically inert and extremely volatile. This means the trapping of noble gasses is temperature dependent, therefore the abundances of trapped noble gasses can be used as a sensitive thermometer. ALICE will measure the abundances of He, Ne, Ar and Kr at 584 Å, 736/744 Å, 1048/1067 Å and 1236 Å respectively (*Stern et al.*).

(2) *It will allow the direct observation of the nucleus/coma coupling.* The nucleus outgassing is directly linked to the sublimation of H_2O, CO and CO_2. ALICE will be able to determine the production rates of these key molecules, plus their special distributions near the nucleus. This will enable the mapping of the outgassing regions which will yield data on the depths of the various icy reservoirs from which these molecules come from (*Stern et al. 1998*).

(3) *It will investigate the ionisation mechanisms and the interaction of the solar wind in the coma.* The O^+ (834 Å) and C^+ (1335 Å) ions are differently affected by the solar winds, the O^+ has the strongest resonance line at 834 Å, this will allow the investigation of the solar wind interaction. The C^+ ion will provide complementary information on the competing ionisation processes (photoionisation vs. electron impact). ALICE will measure the emission strengths of each ion (*Stern et al. 1998*).

(4) *It will study the onset of nuclear activity*. As the comet gets closer to the sun, successively 'harder volatiles' evaporate off the surface (turn on). This 'turning on' effect is to be monitored by ALICE. The expected observations include N_2, CO_2 and H_2O in absorption, Noble Gasses, CO, S (as a tracer for H_2S and CS_2) in emission (*Stern et al. 1998*).

3.1.3 VIRTIS

VIRTIS is a visible and infrared imaging spectrograph for the Orbiter. It comprises of 2 channels, one with a high spatial resolution, and large field of view designed for spectral mapping (VIRTIS-M), the other has a high spectral resolution designed purely for spectroscopy (*Coradini et al. 1999 & Istituto di Astrofisica Spaziale e Fisica Cosmica – VIRTIS Homepage*). These channels will be used together to determine the nature of the composition of the ices, dust and organic molecules on the surface of the nucleus. Also to identify and monitor near-nuclear gasses and their distribution, to characterise the conditions of the coma and to measure the temperature of the nucleus (*Coradini et al. 1999*).

3.1.4 MIRO

MIRO is a dual-frequency heterodyne receiver, operating at 190GHz (~1.6mm) for continuum and 562GHz (~0.5mm) for spectroscopy. MIRO will be used to determine the near-surface temperature of the comet. It will also study, over time and with the use of the spectrometer, the sublimation of H_2O, CO, NH_3 (ammonia) and CH_3OH (methanol). The spectrometer part of MIRO has been pre-tuned to these molecular transitions (*JPL NASA – MIRO Homepage*).

3.2 Composition Analysis

There are 3 experiments – ROSINA (Rosetta Orbiter Spectrometer for Ion and Neutral Analysis), COSIMA (Cometary Secondary Ion Mass Analyser) and MIDAS (Micro-Imaging Dust Analysis System).

3.2.1 ROSINA

ROSINA consists of three sensors: The Double Focusing Magnetic Mass Spectrometer (DFMS) with a high resolution (3000) and a range of 1-100 amu, the DFMS is designed for gas and ion analysis. The second sensor is the Reflectron Type Time Of Flight mass spectrometer (RTOF) with a range of 1-300 amu and a very high sensitivity, the RTOF is designed to compliment DFMS by providing a higher mass range and increased sensitivity. The third sensor is the Neutral Ion and Dynamics Monitor (NIDM) with three pressure gauges providing information velocity and temperature measurements of the cometary gas (*Balsiger et al. 1998*).

The main objectives of ROSINA are:

-To determine the composition and character of the nucleus in terms of molecular, elemental and ionic content.

-To determine and map over time and space, the processes by which the cometary atmosphere and ionosphere are formed.

This, together with studies of the asteroids will help to establish the relationship between comets and asteroids, and also the implications for the origin of the solar system (*Balsiger et al. 1998*).

3.2.2 COSIMA

COSIMA consists of 2 components, a Time-of-Flight Secondary Ion Mass Spectrometer (TOF-SIMS) with a resolution of 2000, and an ion gun for cleaning and probing the samples (*Finland Metrological Institute, GEO – COSIMA Homepage*).

The main objectives of COSIMA are to study the composition and chemistry of the expelled cometary particles and to identify and analyse and organic material present in the particles. This will help to establish more precise models of cometary and solar system evolution. COSIMA will also help to establish whether there is any exobiological significance of the organic matter found on comets, i.e. what role do comets play (if any) in the introduction of organic molecules to planets (*Finland Metrological Institute, GEO – COSIMA Homepage*).

3.2.3 MIDAS

MIDAS is designed to collect and image dust particles in the nanometer – micrometer range. It comprises of a collector wheel with ~200 facets, each with hundreds of scanning areas (50x50µm), and an Atomic Force Microscope (AFM) – a type of scanning microprobe capable of three-dimensional imaging. This will be the first use of an AFM in a space environment (*Riedler et al. 1998*).

The particles collected by MIDAS originally formed the regolith covering the cometary surface. These particles represent a modified version of the original cometary, thus solar nebular material (*Riedler et al. 1998*).

MIDAS will collect morphological and statistical information on the texture, shape, size and flux of dust particles. From this, information about the history of the particles can be formed – were they molten? Are they crystalline (indicating slow cooling)? Are they porous (indicating loss of volatiles)? Are they composites of finer grains? MIDAS will also ascertain whether the size distribution of cometary particles matches that of interstellar dust (*Riedler et al. 1998*).

3.3 Nucleus Large-Scale Structure

There are 2 experiments – CONSERT (Comet Nucleus Sounding Experiment by Radiowave Transmission) and GIADA (Grain Impact Analyser and Dust Accumulator).

3.3.1 CONSERT

CONSERT will obtain radio images of the nucleus of the comet. This will be achieved by transmitting a radio signal from the orbiter, through the comet, to be received by the Lander. Many of the experiments on board both the Lander and the orbiter will look at the surface, sub-surface, coma and surrounding plasma, but none are able to look deep into the surface. This is why CONSERT is an essential part of the mission.

The aim is to probe the interior of the comet in order to see any inhomogeneities, layers or agglomerations of chunks of material. It will detect these inhomogeneities or structural transitions through the refraction, or scattering of the wave front. The transmitting and receiving of radio waves will be repeated for many combinations of orbiter, comet, Lander. (*Barbin et al. 1999*).

3.3.2 GIADA

GAIDA will study the cometary dust flux evolution and grain dynamic properties. It includes a grain detection system, an impact sensor and five microbalance systems pointing in different directions. GAIDA will detect both direct dust from the comet surface and indirect dust from deflections due to solar radiation pressure. This will enable the evolution of both populations as a function of time, to be studied.

GIADA will measure the size distribution of dust from the nucleus; this will help with calculating the mass loss rates. The velocity of the ejected dust grains will also be measured, as a function of time and of mass; this will enable ejection velocities and masses to be derived.The dust flux variations observed by GIADA will highlight the active regions detected by other experiments aboard Rosetta (*Bussoletti et al.1999*).

3.4 Comet Plasma Environment and Solar Wind Interaction

There 2 experiments – RPC (Rosetta Plasma Consortium) and RSI (Radio Science Investigation).

3.4.1 RPC

RPC is a consortium of five sensors capable of complementary measurements of the plasma environment around the comet (*Imperial College – RPC Homepage*). The five experiments are as follows:

-The Langmuir Probe (LAP), to study the plasma density, temperature and flow velocity.

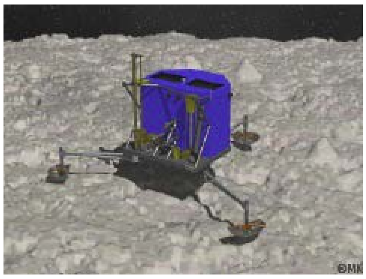
-The Ion and Electron Sensor (IES), to measure the ions and electrons of the solar wind, ions and electrons in the cometary coma, and sputtered ions and photoelectrons generated on the cometary nucleus.

-The Ion Composition Analyser (ICA), to measure the distribution function of positive ions.
-The Fluxgate Magnetometer (MAG), to measure the magnetic field in the interaction region between the solar wind plasma and the comet.
-The Mutual Impedance Probe (MIP), to measure the aeronomical parameters, electron density and temperature, as well as plasma flow velocity in the inner coma.
(*Imperial College – RPC Homepage*).
The scientific objectives of RPC are as follows:
-To study the physical properties of the nucleus by measuring the onset of activity via ion detection and by analysing electromagnetic activity.
-To study the solar wind interaction by analysing the contact surface, the coma and the boundaries in the lpasma.
-To study the formation and evolution of the plasma tail by analysing the structures, formation regions and the disconnection event.
(*Imperial College – RPC Homepage*).

3.4.2 RSI

RSI does not have a dedicated instrument on the Rosetta spacecraft but makes use of the onboard radio subsystem which is responsible for communication between the spacecraft and the ground stations on Earth (*Hagermann et al. 2002*).
RSI will make measurements such as mass and bulk density of the nucleus, its gravity field as well as non-gravitational forces, nucleus size and shape, internal structure, composition and roughness of the nucleus surface, the abundance of large dust grains, the plasma content in the coma and the combined dust and gas mass flux (*Hagermann et al. 2002*).

4 The Lander



RoLand: Rosetta Lander

In October of 2012, the Rosetta Lander will detach from the Orbiter and begin a gentle decent to a pre-determined location on the surface of the comet. From then until 120 hours after touchdown, the short-term experiments will be completed, including sample collection and analysis. After the minimum science requirements have been fulfilled, the long-term monitoring experiments will begin, this will last between distances of 3 and 2 A.U from the sun (a period of ~3 months). The Lander mission is likely to end in February 2013 when the comet reaches a distance of ~1-2 A.U and the Lander overheats (Biele et al. 2002).

4.1 Short-term Experiments

4.1.1 APX

(Alpha Proton X-ray Spectrometer)
APX will be used for the analysis of all major elements except H and He). It will fire alpha particles at the surface of the nucleus and detect the backscattered alpha particles and alpha-induced X-ray radiation (*Biele et al. 2002*). Because of solar illumination of the surfaces monitored by APX, non-volatile material will be more easily detected. APX will be able to study the day/night changes in composition of the surface material, due to frosts of recondensated volatiles. (*Biele et al. 2002*).

4.1.2 ÇIVA

(Comet Nucleus Infrared and Visible Analyser)
ÇIVA is an integrated set of imaging instruments consisting of a panoramic and

stereo camera set (5 identical cameras + a stereo pair of micro-cameras) and a microscope camera coupled with an IR spectrometer (*Biele et al. 2002*).

The panoramic cameras will be used to map the surface topography and albeco around the landing site, it will identify structures and erosion features and it will create a 3D simulation of the local surface (*Biele et al. 2002*).

The microscope camera will analyse the texture, albedo, mineralogical and molecular composition of the samples collected by SD^2 (*Biele et al. 2002*).

4.1.3 ROLIS

(Rosetta Lander Imaging System)

ROLIS will be used to characterise the landing site before and after the Lander lands. ROLIS includes a down looking camera, far field and near field capabilities, RGB and IR illumination and stereo imaging (*Rosetta Lander Homepage*).

4.1.4 SD^2

(Sample Drill and Distribution)

SD^2 will collect samples from measured depths up to 30cm, these samples will then be delivered to COSAC, MODULUS, ÇIVA and ROLIS via containment ovens. (*Rosetta Lander Homepage*).

4.2 Long-term Experiments

4.2.1 CORSAC

(Cometary Sampling and Composition Experiment)

CORSAC will use pyrolysis, chromatography, and mass spectrometry to analyse the chemical and isotopic composition of the volatiles in the cometary material, atmosphere and pyrolytically generated gas. This will include the identification of organic molecules which may have been the spark for life on earth. (*Rosenbauer et al. 1999*)

The pyrolyser will heat the samples provided by the SD^2 tool, in a stepwise manner, the gases given off will then be analysed by the GC or MR, or a combination of both.

The GC is able to identify organic and inorganic gases, by the characteristic travelling speeds through capillary columns.

The MS determines mass per charge of ionised gas molecules, by firing them through a potential drop, and measuring their flight time. (*Rosenbauer et al. 1999*)

4.2.2 MODULUS

(Method Of Determining and Understanding Light elements from Unequivocal Stable isotope compositions)

MODULUS uses both gas chromatography and mass spectrometry to understand the geochemistry of light elements such as hydrogen, carbon, nitrogen and oxygen. This will be done by determining their nature, distribution and stable isotopic compositions (*Open University – MODULUS Homepage*).

4.2.3 MUPUS

(Multi-Purpose Sensors for Surface and Sub-Surface Science)

MUPUS uses the science of penetrometry to assess the mechanical and thermal properties of the surface and sub-surface layers. It will achieve this by using a penetrator, a thermal mapper and sensors attached to the Lander's anchor (*Keller & Spohn 2002*).

The penetrator will be deployed ~1m away from the Lander, it will reach a depth of ~32cm. its main function will be as a thermal probe. It contains 16 titanium resistor cells printed on one kapton foil; the cells will be used as temperatures sensors and heaters, in order to measure the thermal diffusivity and thermal conductivity of the sub-surface material.

The thermal mapper is a small 4 channel thermal sensor mounted on the Lander to measure the temperature of the surface around the Lander.

The anchor is primarily used to keep the Lander in place after it lands on the low gravity surface. This provides the perfect opportunity to measure the strength of the surface layers. The anchor is mounted with piezoelectric shock accelerometer and temperature sensor designed to measure the deceleration of the anchor (*Keller & Spohn 2002*).

4.2.4 ROMAP

(Rosetta Lander Magnetometer and Plasmamonitor)

ROMAP will study the interaction of the solar wind with the comet as a function of distance from the sun, using a magnetometer (MAG) and a plasma monitor (SPM). With these two sensors it will be possible to measure the density, speed, temperature, flow direction and magnetic field vector of the solar wind (*Technische Universität, Braunschweig, Germany – ROMAP website*)

The main objectives are to study the cometary activity as a function of time, to measure the remnant magnetisation of the nucleus and to characterise the electrical conductivity of the nucleus (*Technische Universität, Braunschweig, Germany – ROMAP website*).

4.2.5 SESAME

(Surface Electrical, Seismic and Acoustic Monitoring Experiment)

SESAME consists of three separate experiments, CASSE ('Cometary Acoustic Sounding Surface Experiment), PP ('Permittivity Probe) and DIM (Dust Impact Monitor). CASSE will measure mechanic and elastic properties of the cometary surface using piezo-acoustic transmitters and sensors, PP will investigate the surface through geo-electric methods and DIM will determine dust impacts and production rate. (*DLR, Cologne, Germany – SESAME Homepage*).

5 Conclusion

The Rosetta mission is definitely a groundbreaking mission, in terms of both scientific return and technological application. The benefits of this mission go further than just a better understanding of comets; it will give more clues as to the formation of the solar system. In studying the comet's structure and composition, the formation process becomes clearer. If we know how comets were formed, we can apply this to models of solar system formation, thereby understanding how planets were created. In studying the chemistry of the dust and ice found on comets, information about their formation in the solar system will gained, this will provide insight into as to how planets acquired water. In studying the organic molecules found on comets, the question of whether comets sparked life on Earth may be answered. The mission will also provide a wealth of knowledge about comets themselves, how they form, how they work, how they change over time and how they die. This will provide groundwork for future studies into comets, asteroids, plants and solar system formation.

Overall, this mission will provide a great deal of useful data, which will be used by many people for many applications.

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Technische Universität, Braunschweig, Germany – ROMAP website (*http://www.tu-bs.de/institute/geophysik/forschung/projekte/roslan/romap/index.html*).