ROSETTA: ESA's Comet Orbiter and Lander Mission

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ROSETTA in a Nutshell

Science goal: Understanding the origin of the solar system by exploring a primitive body, comet 67P/Churyumov-Gerasimenko

Spacecraft: Orbiter (ROSETTA) & Lander (PHILAE)

Instruments: 20=10+10 remote & in-situ type

Mission: Launch 2004 - arrival 2014
4 planet & 2 asteroid flybys
orbiting & landing at 67P
longterm exploring comet for 1 ½ year

Project: >20 years ESA Cornerstone Mission
<table>
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<tr>
<th>Instrument Name</th>
<th>Instrument Type</th>
<th>Wavelength</th>
<th>Science Objective</th>
<th>Object Component</th>
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<tr>
<td>OSIRIS</td>
<td>Imager</td>
<td>Visible</td>
<td>Morphology Composition</td>
<td>Nucleus Surface</td>
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<td></td>
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<td>Gas + Dust</td>
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<tr>
<td>ALICE</td>
<td>Imaging spectrometer</td>
<td>UV</td>
<td>Composition Mineralogy</td>
<td>Gas + Dust</td>
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<tr>
<td>VIRTIS</td>
<td>Imaging spectrometer</td>
<td>Visible+NIR</td>
<td>Composition Mineralogy</td>
<td>Gas + Dust</td>
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<tr>
<td>MIRO</td>
<td>Microwave sounder</td>
<td>GHz</td>
<td>Composition Phys. properties</td>
<td>Gas</td>
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<tr>
<td>RSI</td>
<td>Radio science</td>
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<td>Phys. properties</td>
<td>Nucleus</td>
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<tr>
<td>CONCERT</td>
<td>Radio sounder</td>
<td>MHz</td>
<td>Internal structure</td>
<td>Nucleus</td>
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<tr>
<td>ROSINA</td>
<td>Mass spectrometer</td>
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<td>Composition Phys. properties</td>
<td>Gas</td>
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<td>COSIMA</td>
<td>Mass spectrometer</td>
<td></td>
<td>Composition Phys. properties</td>
<td>Dust grains</td>
</tr>
<tr>
<td>MIDAS</td>
<td>Atomic force microscope</td>
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<td>Phys. properties</td>
<td>Dust grains</td>
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<tr>
<td>GIADA</td>
<td>Impact analyser</td>
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<td>Phys. properties</td>
<td>Dust grains</td>
</tr>
<tr>
<td>RPC</td>
<td>Magnetometer Plasma analyzer</td>
<td></td>
<td>Phys. properties</td>
<td>Nucleus Plasma</td>
</tr>
</tbody>
</table>
CONSERT

**Radio sounder @ 90 MHz**

- Orbiter and Lander used for 'Send – Repeat – Receive' ops
- Simultaneous operation on 2 S/C in opposite hemispheres

**Future alternatives:**
Penetrating radar on orbiter

COSIMA

**TOF dust particle analyzer using SIMS**

- Dust collector in flight S/C direction
- Microscope for grain identification
- Position grain in SIMS beam (In ions)
- TOF spectrometer for measuring positive/negative ions
  ==> analysis of compositional structure of individual dust grains

**Future improvements & alternatives:**
Laser device as 'grain vaporizer' for bulk composition analysis
Raman spectroscopist for mineralogy
PHILAE Lander

Science goal: Surface science of a cometary nucleus

Instruments: 10, remote (3) & in-situ type (7) (27kg out of 111kg total mass)

Mission: Landing on the cometary surface
Sampling of surface & subsurface
Longterm in-situ exploration of the surface and its environment

Concept:
- Passive landing (no GNC)
  (single attempt only with mediocre targeting accuracy)
- Anchoring (no release from surface)
  (harpoons, ice screws, ADS)
- Autonomous 'survival' and operation in environment of cometary activity
  (day-night, secular)
- Relay through orbiter (commanding & data transfer)
- Single site exploration
- Surface & subsurface (drill) sampling
- Automated combined inst, operation
  SD2-CIVA-COSAC/PTOLEMY-ROLIS
  SESAME-APXS/MUPUS/SD2
  CONSERT orbiter+lander
PHILAE Instrument Location
<table>
<thead>
<tr>
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<th>Science Objective</th>
<th>Object Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>CIVA</td>
<td>Imager Microscope Spectrometer</td>
<td>Visible IR</td>
<td>Morphology Composition</td>
<td>Regolith</td>
</tr>
<tr>
<td>ROLIS</td>
<td>Microscope</td>
<td>Visible</td>
<td>Morphology Mineralogy</td>
<td>Regolith</td>
</tr>
<tr>
<td>CONSER</td>
<td>Radio sounder (repeat)</td>
<td>MHz</td>
<td>Internal structure</td>
<td>Nucleus</td>
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<tr>
<td>APXS</td>
<td>Alpha &amp; x-ray spectrometer</td>
<td></td>
<td>Elemental comp.</td>
<td>Solids</td>
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<tr>
<td>MUPUS</td>
<td>Hammer Thermoprobe</td>
<td></td>
<td>Mechanical prop. Thermal prop.</td>
<td>Surface</td>
</tr>
<tr>
<td>ROMAP</td>
<td>Magnetometer Plasma analyzer</td>
<td></td>
<td>Magnetic prop. Physical prop. Composition</td>
<td>Surface Plasma</td>
</tr>
<tr>
<td>SD2</td>
<td>Drill &amp; sampler</td>
<td></td>
<td>Mechanical prop.</td>
<td>Surface</td>
</tr>
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</table>
SD2

Sampler, drill & distribution system

- Subsurface drilling (30cm) at $\geq 1$ sampling site
- Sample collection
- Sample delivery to oven
- Sample deposition
- Move oven to inst. docking station

MUPUS

Hammer & temperature sensors

- Slide hammer to selected surface
- Hammer MUPUS into ground (30cm)
- 16 PT100 sensors at different height
- Thermal IR probe to measure surface temperature at hammering area
- Device retrieval not foreseen
CIVA
- Pre-imaging of sampling site (if not yet existing)

ROLIS
- Rotate lander to sampling area
  - pre-sampling color imaging of sampling area:
    - surface structure, grain morphology & comp.

SD2
- Drill hole and take sample: mechanical properties
- Deliver sample to instrument oven (few mm$^3$)
- Rotate oven to analysis port

CIVA
- Imaging of oven sample: grain morphology
- Spectroscopy of oven sample: composition

COSAC or PTOLEMY
- Controlled heating of oven to release volatiles
- Distribute gas to GC/MS
- Gas chromatography of volatile
- Mass spectroscopy of volatile:
  - elemental & molecular composition
  Special: PTOLEMY - light elements, isotopy
  COSAC – chirality of compounds
  Both – coma composition, pressure

ROLIS
- Post-sampling color imaging of sampling area

Optional: APXS analysis of sampling area: elemental comp.
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<th>PHILAE Lander Instrument</th>
<th>Coupled Science Goals</th>
<th>ROSETTA Orbiter Instrument</th>
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<tr>
<td>Composition of cometary material</td>
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<tr>
<td>APXS</td>
<td>Elemental composition</td>
<td>ALICE</td>
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<tr>
<td>CIVA-M</td>
<td>Mineralogy, molecular composition</td>
<td>COSIMA</td>
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<tr>
<td>COSAC</td>
<td>Isotopy, elemental composition, chirality</td>
<td>ROSINA</td>
</tr>
<tr>
<td>PTOLEMY</td>
<td>CHON chemistry, stable isotopes</td>
<td>VIRTIS</td>
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<tr>
<td>Physical properties of cometary material</td>
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<td></td>
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<tr>
<td>MUPUS</td>
<td>Temperature, density, porosity</td>
<td>MIDAS</td>
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<tr>
<td>SESAME</td>
<td>Electrical &amp; acoustic surface properties</td>
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<tr>
<td>CIVA-M</td>
<td>Microscopic structure</td>
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<td>Largescale structure of the comet</td>
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<td>ROMAP</td>
<td>Exosphere plasma &amp; magnetic fields</td>
<td>RPC</td>
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<td>SESAME</td>
<td>Dust environment</td>
<td>GIADA</td>
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<td>ROLIS, CIVA-P</td>
<td>Surface structure</td>
<td>OSIRIS</td>
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<tr>
<td>CONsert</td>
<td>Nucleus interior</td>
<td>CONsert</td>
</tr>
<tr>
<td>Cometary activity</td>
<td>All</td>
<td>All</td>
</tr>
</tbody>
</table>

**Note:** The table above outlines the coupled science goals for the PHILAE Lander and ROSETTA Orbiter instruments. Each instrument has specific goals related to the composition, physical properties, and activity of cometary material.
Improvements from ROSETTA towards Future Small Bodies Mission – A Wish List

Remote sensing
• M3-type instrument for vis-NIR spectral imaging
• MIR spectral imager for thermal emission analysis
• Penetrating radar imager for analysis of body interior

In-situ instrumentation
• Raman microscope for mineralogy of surface
• Imaging electron microscope for elemental analysis of surface
• Laser evaporation for compositional analysis of surface

S/C technology and operations
• GNC for accurate landing
• Surface hopping for multi-site visits
• Deeper subsurface sampling for regolith, icy and rocky surfaces
• Multi-body visits

Methodology
• Accurate calibration to 1 percent level and below for UV-vis-NIR-MIR imagers and spectrometers
• Adequate modeling of light scattering on surfaces over wide wavelength range
• Curing the 'the forest and the trees' phenomenon: lab experiments (involving lab & S/C equipment) and modelling
• Understanding space organics and its secure detection/identification
• Systematic approach for astrobiological investigation of small bodies
Towards The Final Goal

Multi-Site and Multi-Body Sample Return with Educated Site Selection and Exploration and Versatile Sampling Techniques