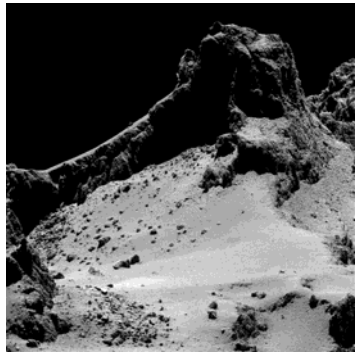
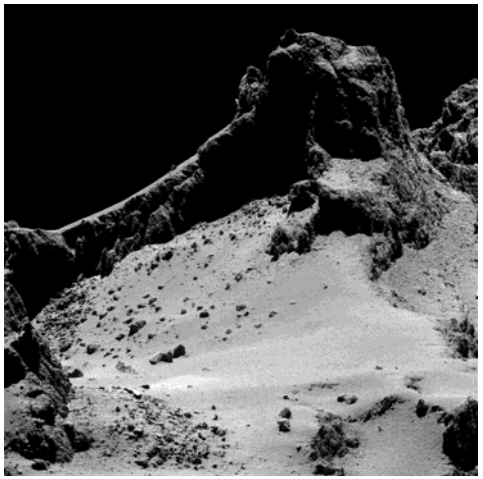
Light: a Bridge between Earth and Space: Winter College on Optics

Study of comets: the Rosetta mission

Giampaolo Preti
Selex ES Space LoB



Content



- Why studying comets
- Rosetta : building up the spacecraft
- … some secrets of the instruments
- Rosetta mission, from the very beginning up to today
- Close view of the comet
- … 3 , 2, 1 … zero = landing
- Science: the latest results

Comets: what we knew in the past time

The first scientific image of a comet id due to Giotto. The comet has been painted in Padua, Cappella degli Scrovegni, in 1305; three years before Giotto had seen the comet.

… fatti non foste a viver come bruti,
ma per seguir virtute e canoscenza

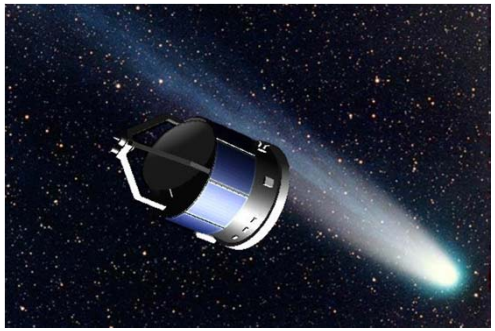
≈ 1300

≈ ??

1600/1700

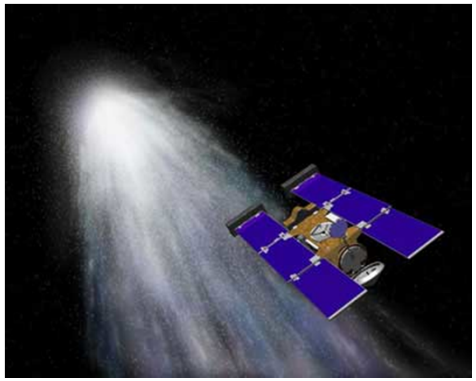
1952

Missions to a comet



Comet Halley
Giotto, 1986

Comet Borrelly
Deep Space 1, 2001



Comet Wild 2
Stardust, 2004

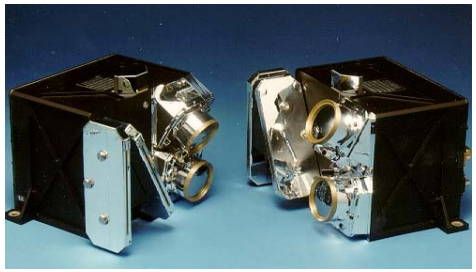
Comet Tempel 1
Deep Impact, 2005

Giotto mission

Giotto Mission (1985) from ESA has given the first short distance image of a comet;
Selex ES provided some hardware to this mission

1992

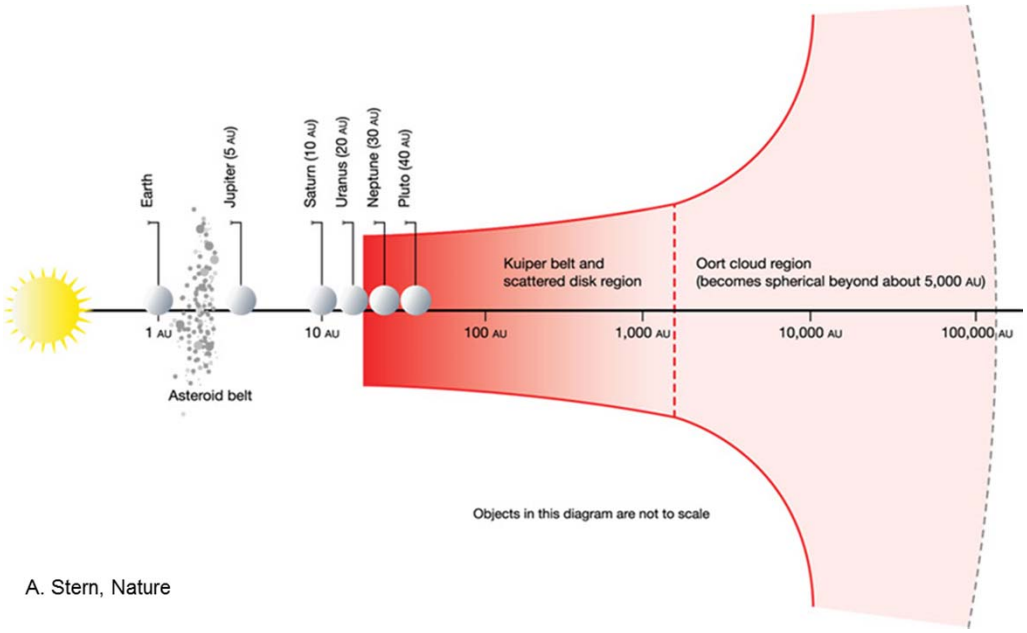
Selex ES: scan mirror and baffle



Selex ES: attitude sensors

Why are we interested in comets?

- They are made of primordial material. Comets are heterogeneous aggregates of dust (crystalline and glassy silicates, iron oxides), organic compounds (CHON particles), ices and trapped volatiles.
- They formed early in the Solar System history and have spent most of their life in a cold environment; are unlikely to be deeply thermally altered.
- They transport material from one side to another in the Solar System. Do they transport material from a star to another star?
- Can be the Rosetta stones to the understanding of the solar system formation.



A. Stern, Nature

How many comets do exist?
Billions !

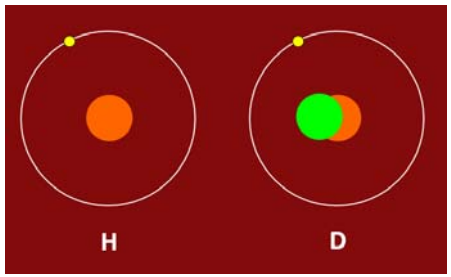
Why are we interested in comets?

Earth's bulk composition similar to Enstatite Chondrites suggests a dry proto-Earth with subsequent delivery of volatiles. Who carried them? Comets, asteroids, meteorites.

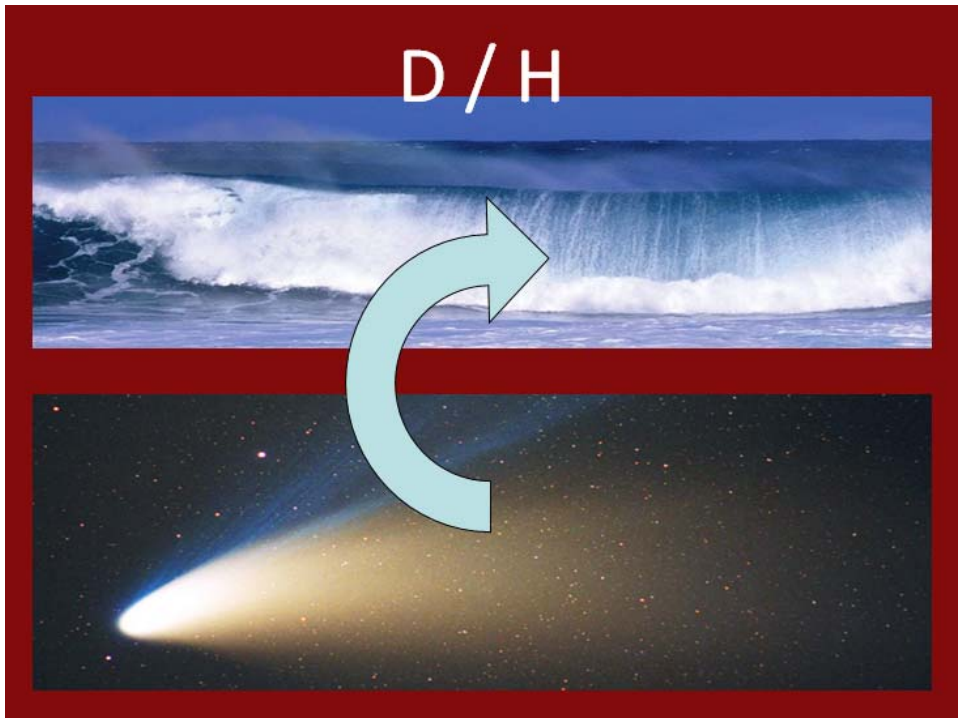
The Earth undergo an intense meteorites bombardment between 4,5 to 3,5 billion years ago.

40,000 tons/year of extra-terrestrial material are falling on the Earth

Why are we interested in comets?

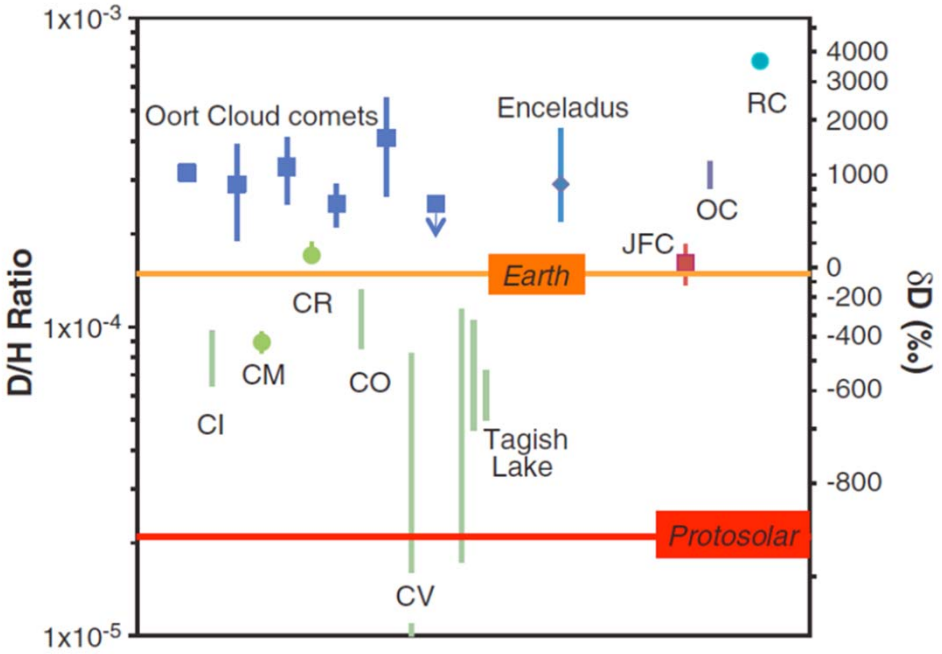


If the water has been delivered to the Earth by the comets, we must find in the comets the same D/H relationship as in our oceans.



Why are we interested in comets?

- Comets show very large spread of D/H values.
- D/H ratio in the Jupiter-family comet 103P/Hartley 2, originated in the Kuiper belt, is compatible with Earth value (Hartogh et al, Nature 2011).
- However, D/H tends to increase with heliocentric distance. Water ice would have been heavily enriched in deuterium via a series of ion-molecule reactions during the pre-stellar to protoplanetary disk phases.
- The emerging picture is that of a complex dynamical evolution of the early Solar System with extensive radial mixing of cometesimals.



The Rosetta mission

ESA Rosetta, named *"Comet Hunter"* , is the first space mission to perform a close exploration of a comet.

After orbiting the comet 67P / Churyumov-Gerasimenko (since August 2014), Rosetta released its small lander Philae on the icy nucleus (November 2014).

Rosetta will orbit around the comet for a whole year (2015). Rosetta and the comet will run together towards the Sun; after the perielium (minimum distance from the Sun), Rosetta will continue orbiting around the comet for a further year and a half, while the comet will run again towards Jupiter orbit.

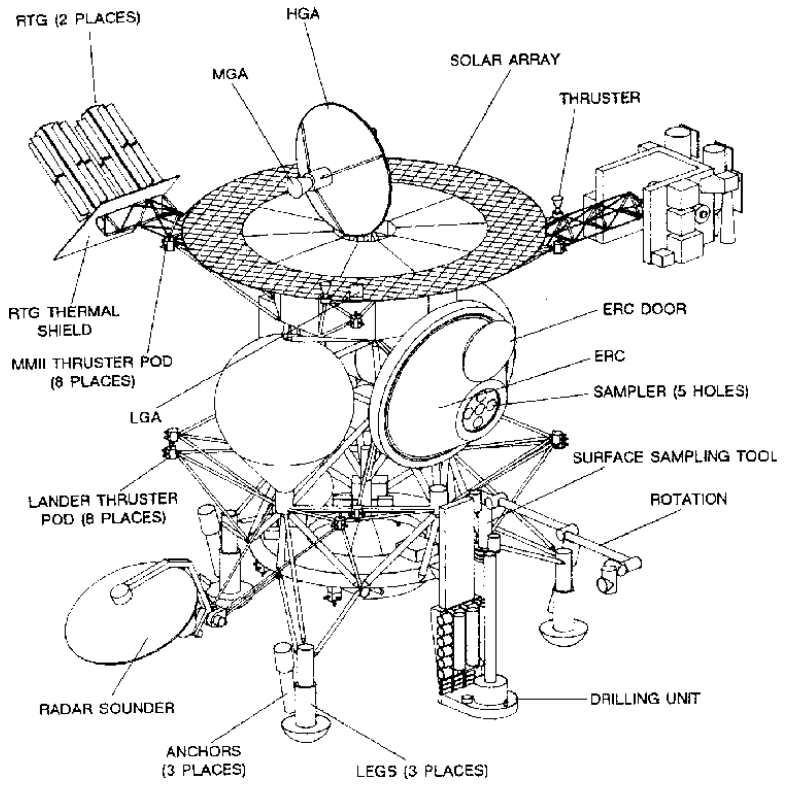
Like Rosetta stone helped scientists to decript the hieroglyphs, we hope that Rosetta will provide help in solving the mysteries of the Solar System evolution.

Firsts of Rosetta mission

Rosetta firsts in the space exploration:

- First mission to **orbit around a comet and land on it**
- First **laboratory for «in-situ» analysis** with the Philae lander
- First mission **for comet long term investigation**, including both coma and tail, and **short distance investigation** of comet behaviour when being close to the Sun.

The first idea for a comet mission (CNSR)



Credits: ESA

Take samples or make in-situ science?

The mission CNSR:
Comet (Nucleous) Sample Return

First ideas are dated end ’70es; in 1985 the mission was selected by ESA as a ″Cornerstone″.

Very ambitious mission, with collection of samples and the following shipping to the Earth; cooperation between NASA / ESA.

After NASA de-selection, the mission was reviewed: the **Rosetta mission was borning**.

The mission in pills

The industrial Team:

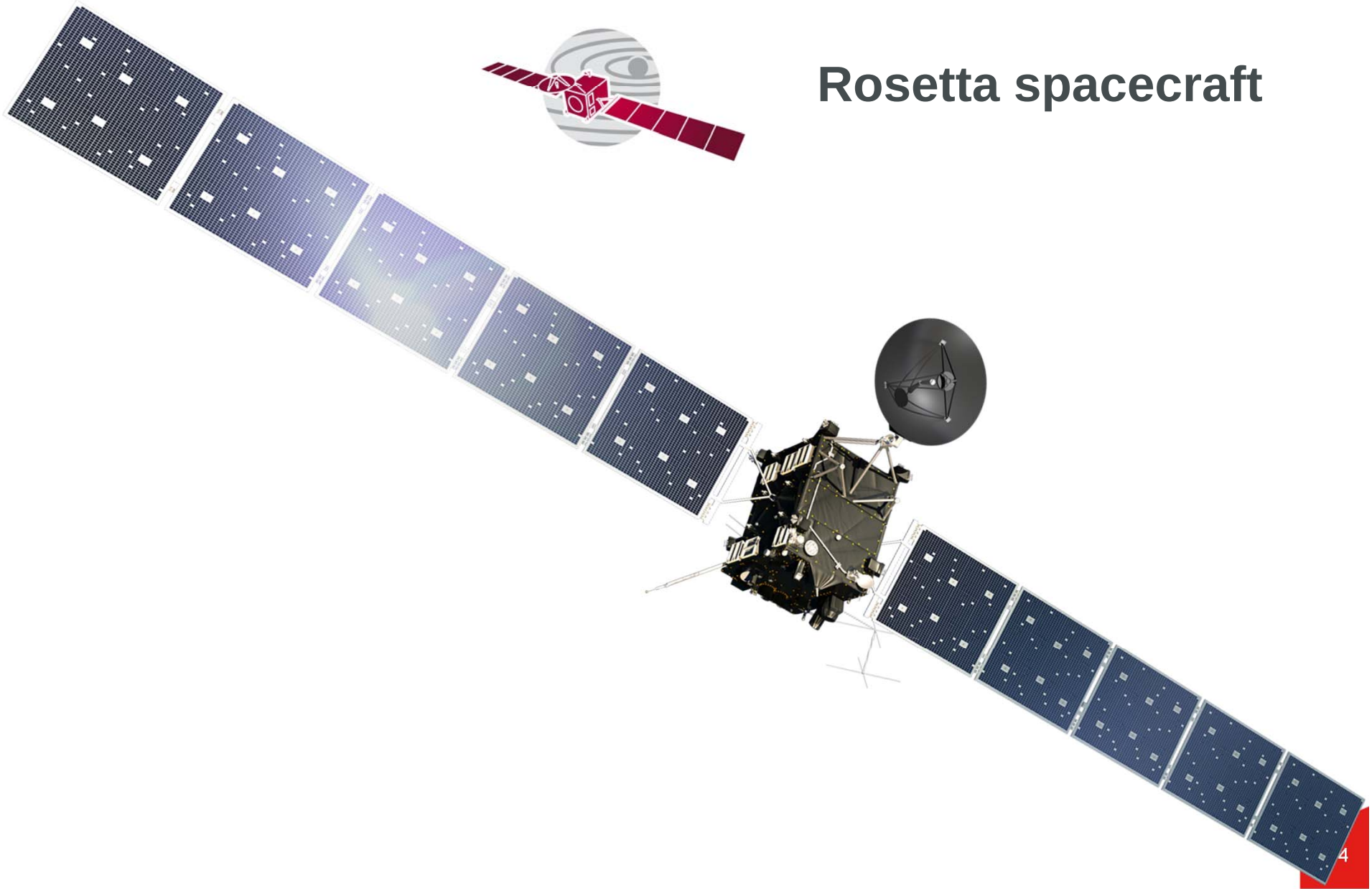
- Rosetta Prime Contractor: Airbus Defence and Space GmbH Friedrichshafen, Germany (at that time was Astrium GmbH).
- Industrial Team: more than **50 companies from 14 european countries plus USA and Canada**.
- About **1000 technicians** involved in the development of Rosetta.

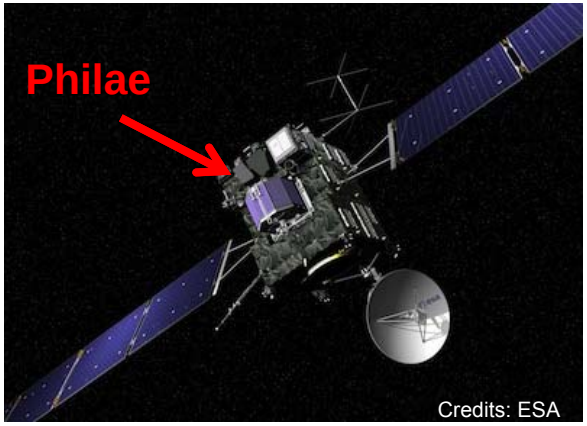
Overall cost: 1400 M€ for 20 years work (1996 – 2015 as a minimum), including the spacecraft, the launch, the payload, the mission control and the scientific research. It means: **3,5 € for each european citizen.**

Launch: Rosetta has been launched on March 2nd 2004 with an Ariane-5 from Kourou (French Guiana).

Lenght of the mission: at least 12 years (December 2015).

Rosetta spacecraft





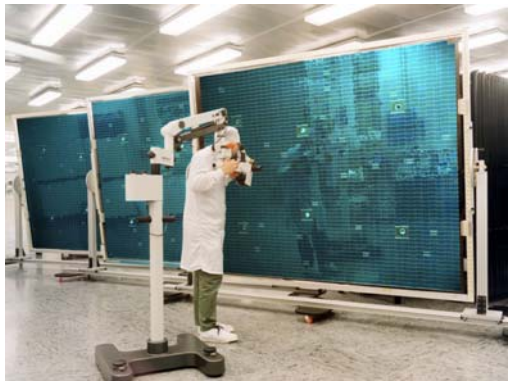
The spacecraft in brief

The spacecraft is made by:

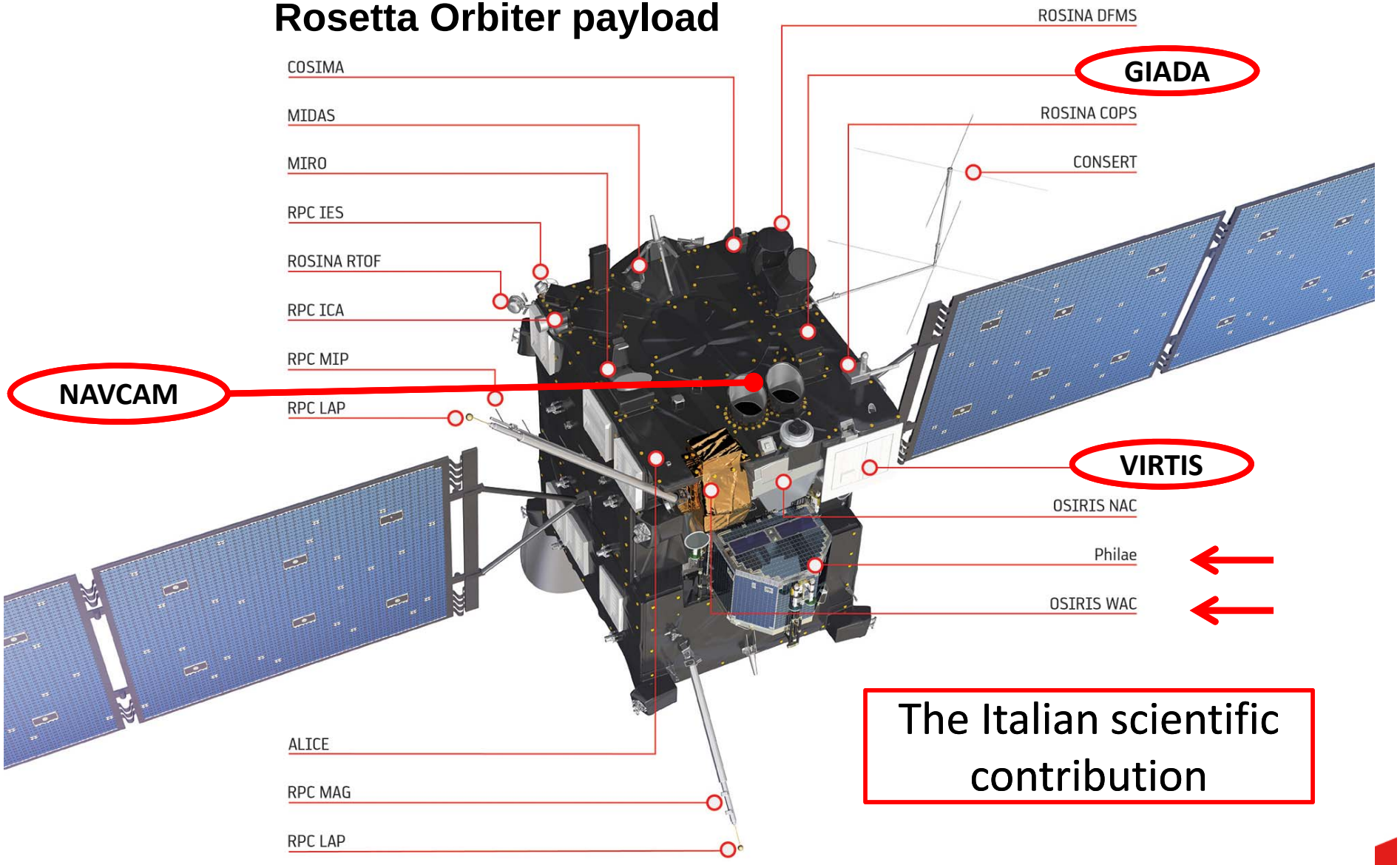
- ✓ **Orbiter**, with 11 scientific instruments
- ✓ **Lander**, named "**Philae" ,** with 10 additional instruments for in-situ analysis of the comet

The spacecraft:

- ✓ Rosetta looks a black parallelepiped, with dimensions **2.8 x 2.1 x 2.0 m**
- ✓ The scientific instruments are assembled on the outer part of the S/C
- ✓ Rosetta has a parabolic antenna **2.2 m diameter** for TLC with the Earth Terra
- ✓ Two large solar panels, with a total area as large as **64 m2** can be oriented (± 180° to maximize the energy collected. The lenght of each panel is 14 m
- ✓ Mass: about **3000 kg** of which 1670 kg of propellent, **165 kg for scientific instruments and 100 kg for the Lander itself**



Rosetta Orbiter payload



The Italian scientific contribution

Rosetta remote sensing from Orbiter

OSIRIS *(H. Sierks, DE)* (WAC Co-PI *C. Barbieri, I*)	Camera (250–1000nm) Wide-angle (12° FOV, 125μrad res) Narrow angle (2.5° FOV, 12.5μrad)
ALICE *(A. Stern, US)*	UV spectrometer (70–205nm)
VIRTIS *(F. Capaccioni, I)*	VIS -IR spectrometer (250–5000 μm) VR-Mapper 250μrad res VR-HighRes 2-5 μm, λ/Δλ@3 μm = 3000
MIRO *(S. Gulkis, US)*	Microwave spectrometer; thermal radiometer

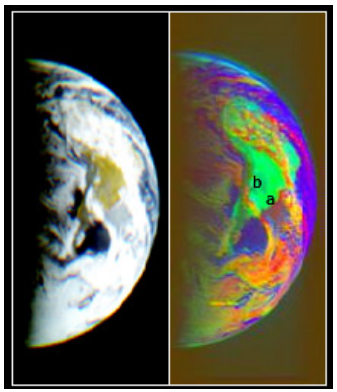
Selex ES for Rosetta mission

Rosetta Mission

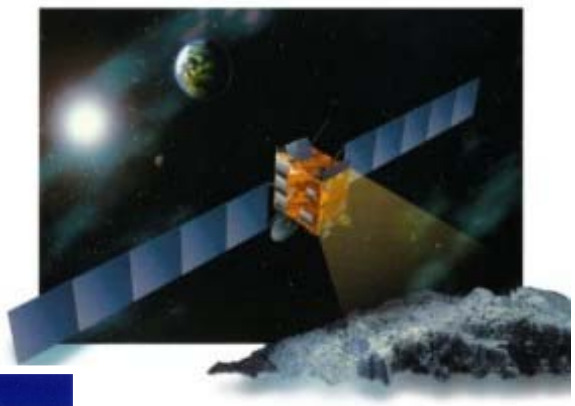
ESA planetary mission to the comet 67P/Churyumov-Gerasimenko, launched in 2004

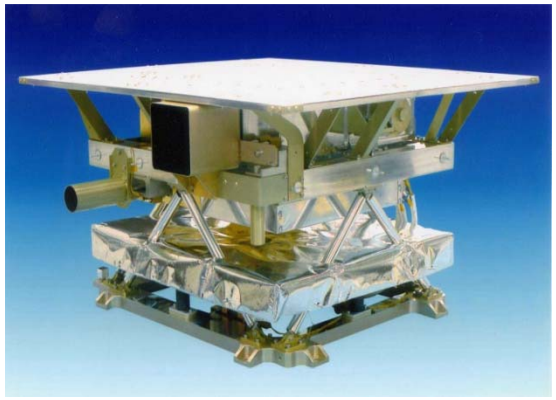
Selex ES contribution:

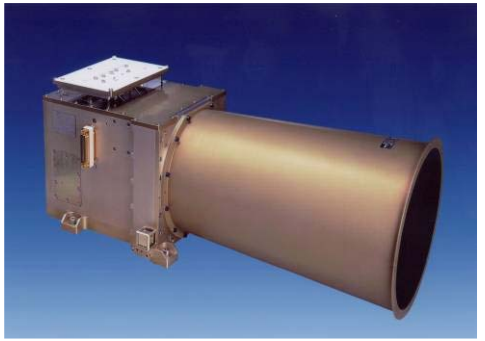
- **VIRTIS** imaging spectrometer for VIS/NIR remote sensing (with INAF-IASF RM)
- **GIADA** dust analyser (with INAF-OAC NA)
- **SD2** drill, comet sample acquisition and distribution system (with Politecnico MI)
- **Navigation camera** and **star tracker** for satellite attitude control
- **Solar panels** for Orbiter & Lander



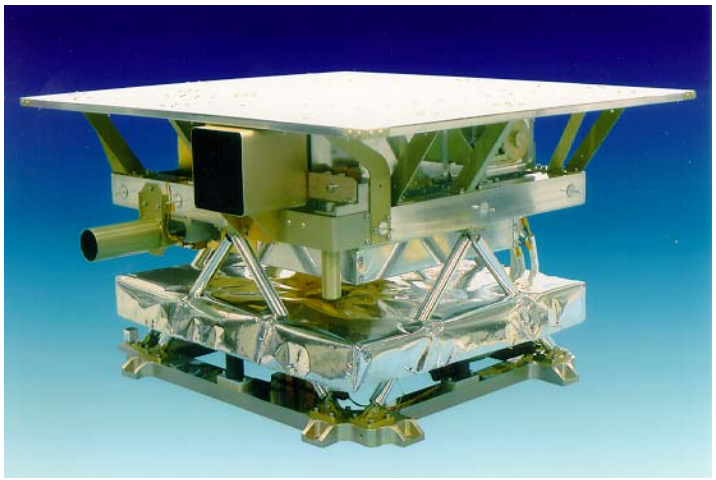
The Earth seen by VIRTIS (credits: ASI/ESA/INAF)







Selex ES for Rosetta: VIRTIS spectrometer



VIRTIS

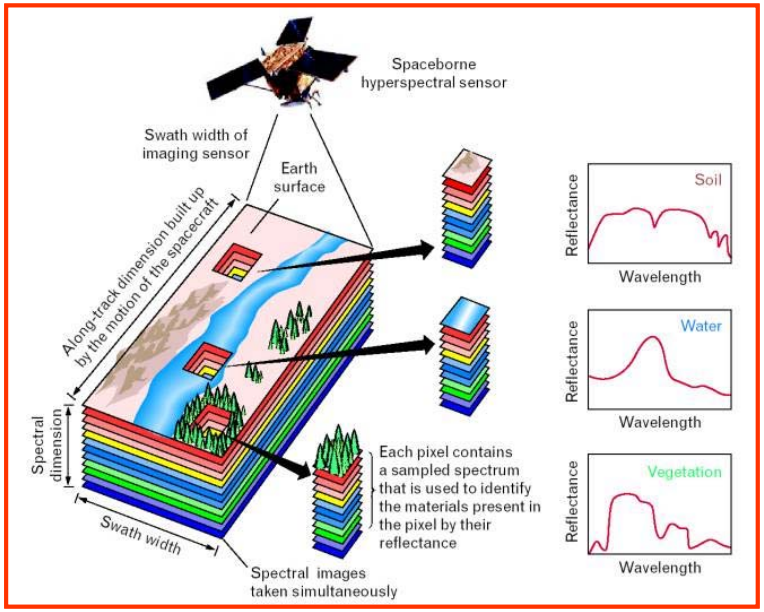
Visible IR Thermal Imaging Spectrometer
(Spectrometer from VIS to 5 μm)
Principal Investigator from INAF-IAPS

Scientific Objectives

- Nucleus and comet environment study
- Surface solid components analysis
- Volatile components identification
- Coma physics characterization
- Surface temperature measurement

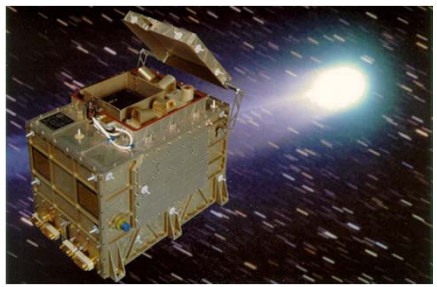
The Instrument

- VIRTIS M: 2 ch (250-5000 nm) hyperspectral Imaging
- VITIS H: (2000-5000 nm) spectrometer
- Cryogenically cooled detectors
- Optical head mass: 20 kg
- Flying on Rosetta and flown on Venus Express



hyperspectral Imaging concept

Selex ES for Rosetta: GIADA



GIADA

Grain Impact Analyser and Dust Accumulator
Principal Investigator from UniNA Parthenope

Scientific Objectives

- Dust flux measurement
- Dust speed distribution analysis
- Dust emission from coma: study of the evolution
- Dust variable emission wrt nucleus evolution
- Dust versus gas emission relationship

The instrument

Is made by two measurement sytems:

- An electro-optical system for dust speed measurement
- A piezo-mechanic system for dust flow measurement
- Can detect particles up to 30 μm diameter

Selex ES: the Attitude Sensor

A-STR (Star Tracker)

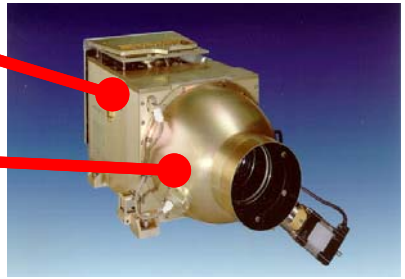
(Autonomus Star Tracker)

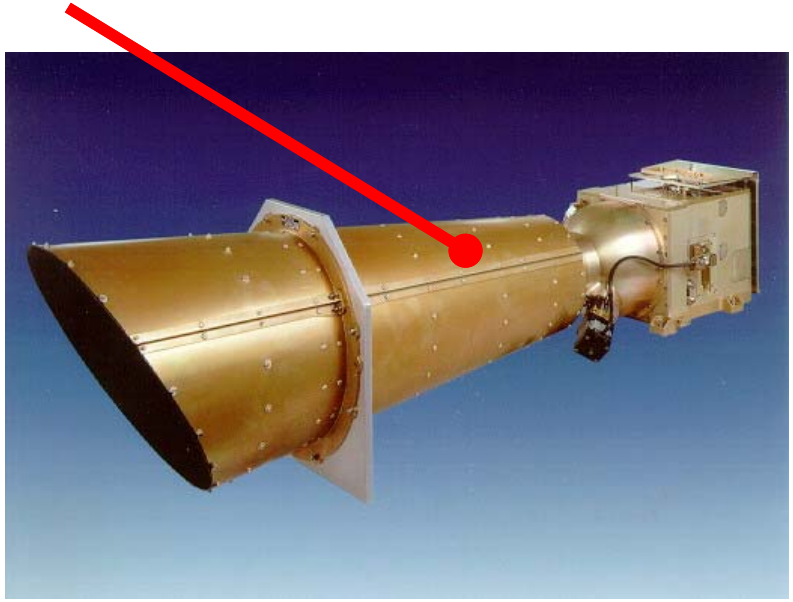
Technical Objectives

Determination of satellite absolute positioning in space

Field of view		16.47° x 16.47°
Revisit frequency (track mode)		2.5 Hz
Number of stars		Up to 9 concurrently
Accuracy		
	Axes X_T & Y_T	About 10 arcsec
	Axis Z_T (Roll)	About 60 arcsec
Power (OH)		14.3 – 16.8 W in the operating range
Mass		OH+Baffle = 5.2 Kg EU = 2.2 Kg
Dimension [mm]		OH: 515(L) x 222(H) x 239(W) EU: 265(L) x 75(H) x 185(W)

Selex ES: the Navigation Camera





NAVCAM

Navigation Camera

Technical Objectives

- Determination of satellite absolute positioning in space (Attitude Sensor task)
- Measurement of satellite position wrt a “relatively near” object (Navigation Camera task)

The instrument

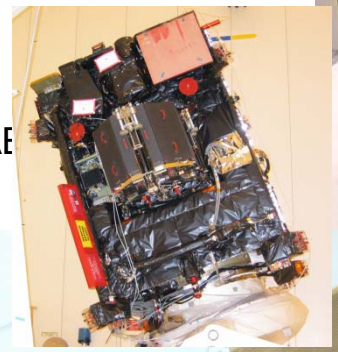
The instrument proposed by Selex ES can perform two functions, working as Attitude Sensors and Navigation Camera thanks to a special mechanism which acts on the instrument optics.

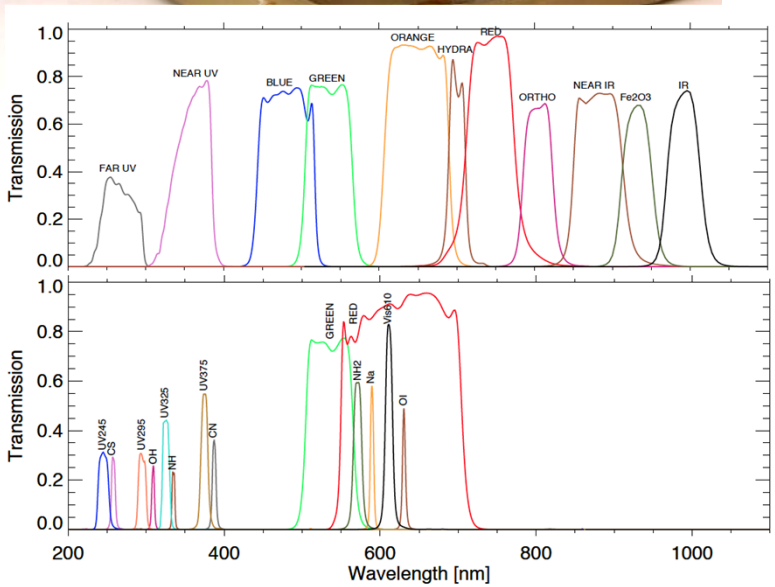
Officine Galileo *Space Business Unit*	ROSETTA AVIONICS NAVIGATION CAMERA & STAR TRACKER COMBINED PROPOSAL EXECUTIVE SUMMARY	DIS/PT/205-b Mar. 1998

OSIRIS - Scientific Camera System

NAC – Narrow Angle Camera
FOV 2.2° , IFOV 18.6 µrad/px
SiC, 2k x 2k BI E2V CCD, AB
3-mirror off-axis, f/8, 717mm

WAC – Wide Angle Camera
FOV 12° , IFOV 101 µrad/px
Al bench, 2k x 2k BI E2V CCD, AB
2-mirror off-axis, f/5.6, 140mm

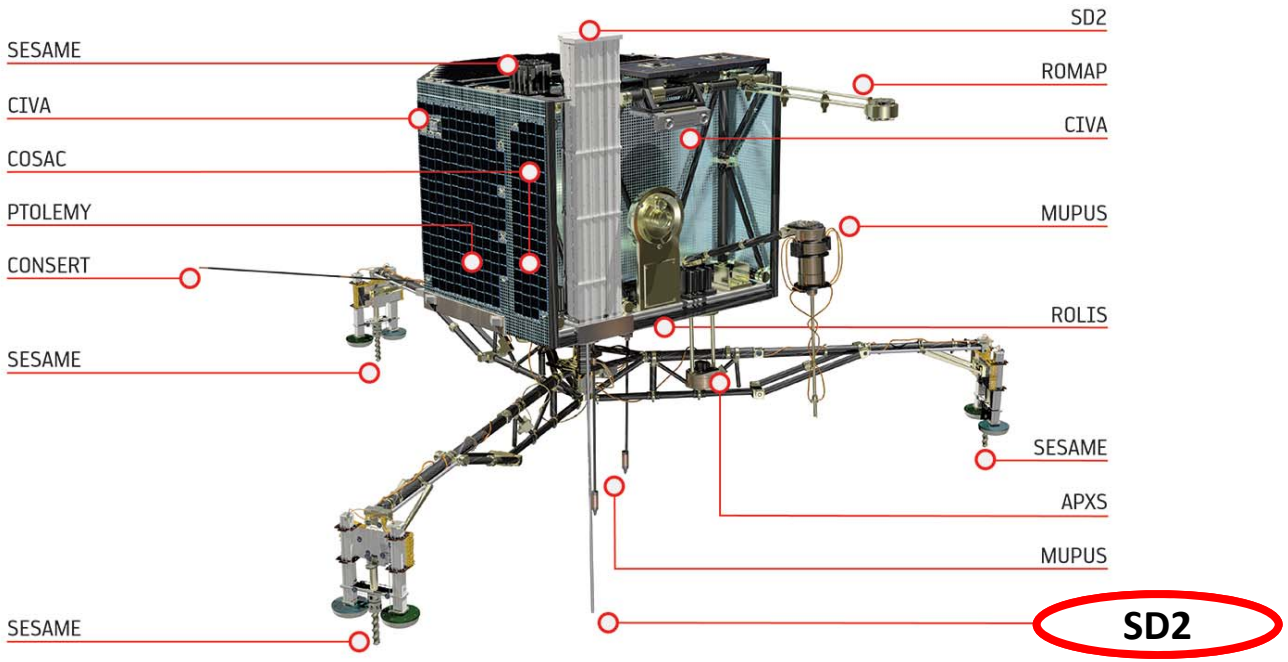




ROSINA *(K. Altwegg, CH)*	Neutral gas- and ion mass spectrometer Chemical composition of gas in coma
COSIMA *(M. Hilchenbach, DE)*	Solid mass spectrometer Chemical composition of coma dust
MIDAS *(M. Bentley, AT)*	Atomic force microscope Shape and size of dust grains
GIADA *(A. Rotundi, I)*	Grain impact analyzer and dust collector
CONSERT *(W. Kofmann, FR)*	Radio transmitter on lander and receiver on orbiter Tomography of nucleus
RPC *(Several PI's)*	Rosetta plasma consortium Five plasma instruments
RSI *(M. Pätzold, DE)*	Radio science investigation

Rosetta orbiter in-situ instruments

Rosetta Lander instruments



Rosetta science from the Lander Philae

Remote Sensing Experiments:
CIVA: Panoramic imaging and microscopy (VIS and NIR)
ROLIS: Downward imaging
APXS: X-ray spectroscopy

Composition Analysis:

COSAC: Molecular composition and chirality

PTOLEMY: Isotopic composition

Large Scale Structure:

SESAME: Dust environment (impacts)

ROMAP: Magnetic field

CONSERT: (lander unit)

Physical Properties:

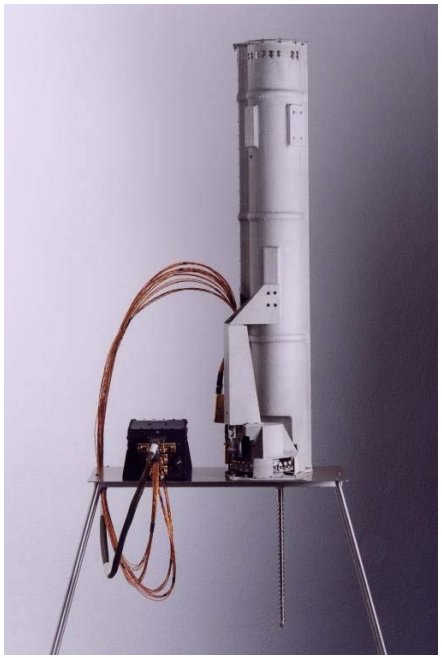
MUPUS: Porosity, Density, Thermal

SESAME: Seismic and acoustic properties

SAMPLER SD2: Drill to 20cm depth and transfer of samples to P/L

(A. Ercoli Finzi, IT)

Selex ES for Rosetta: SD2 (drilling and sampling system)



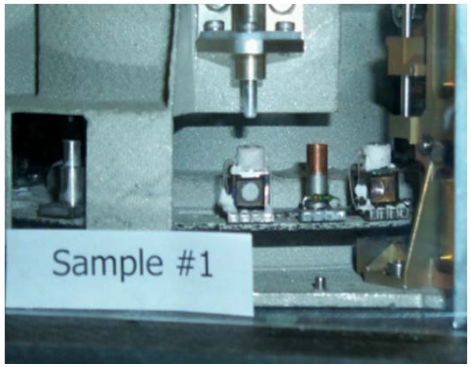
SD2

Sample and Distribution Device
PI-ship from POLIMI

How much power for SD2 ??

Scientific Objectives

- Drill the comet up to 230 mm
- Take comet samples at different depths
- Bring the samples in front of several instruments on the lander



A sample holder

Philae and SD2
credits: ESA / ASI

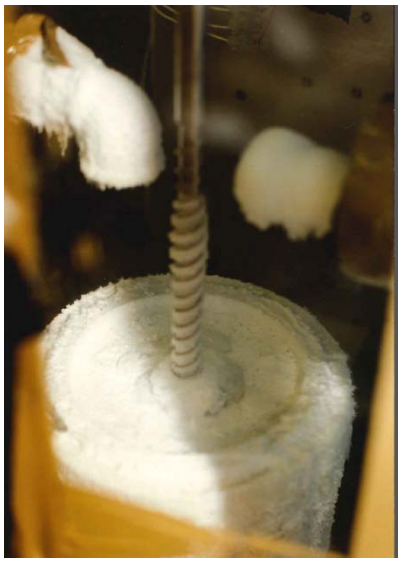
The instrument

- Integrated system for drilling, sample collection and distribution
- Sample holders: 26 holders with heaters
- Mass: 5.1 kg (including electronics)
- Power: 1 W standby, 4 -12 W during drilling
- Operating Temperature: -160 °C a +40 °C

Selex ES for Rosetta: SD2 sampling system

SD2 tip in drilling configuration

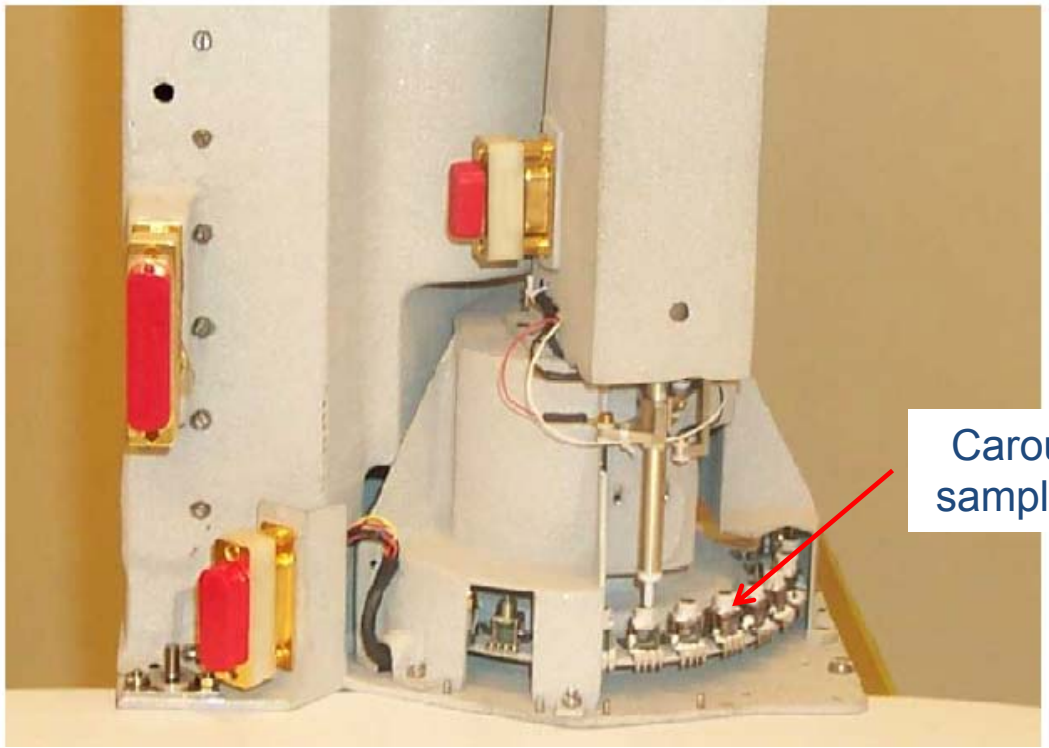
SD2 tip in sampling configuration



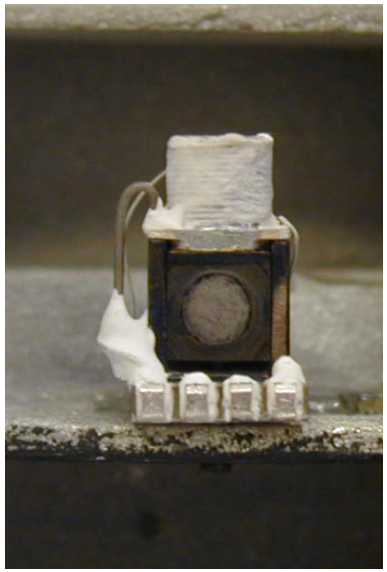
SD2 makes use of a single drilling tip (lenght about 600 mm) equipped with a special mechanism for sample collection

Selex ES for Rosetta: SD2 sampling system

Rotating Sample distribution system



Carousel with sample holders



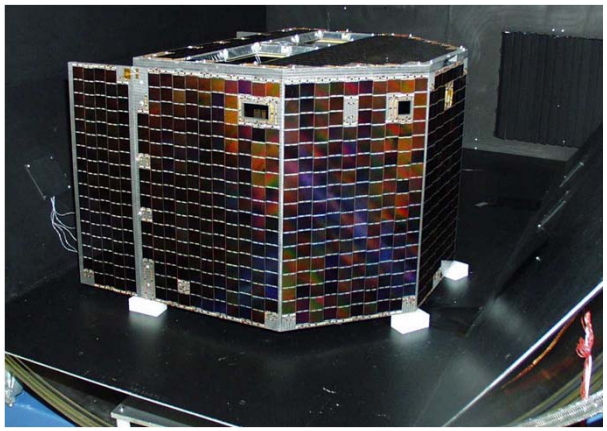
Selex ES for Rosetta: solar panels

Why solar panels?

Solar Panels

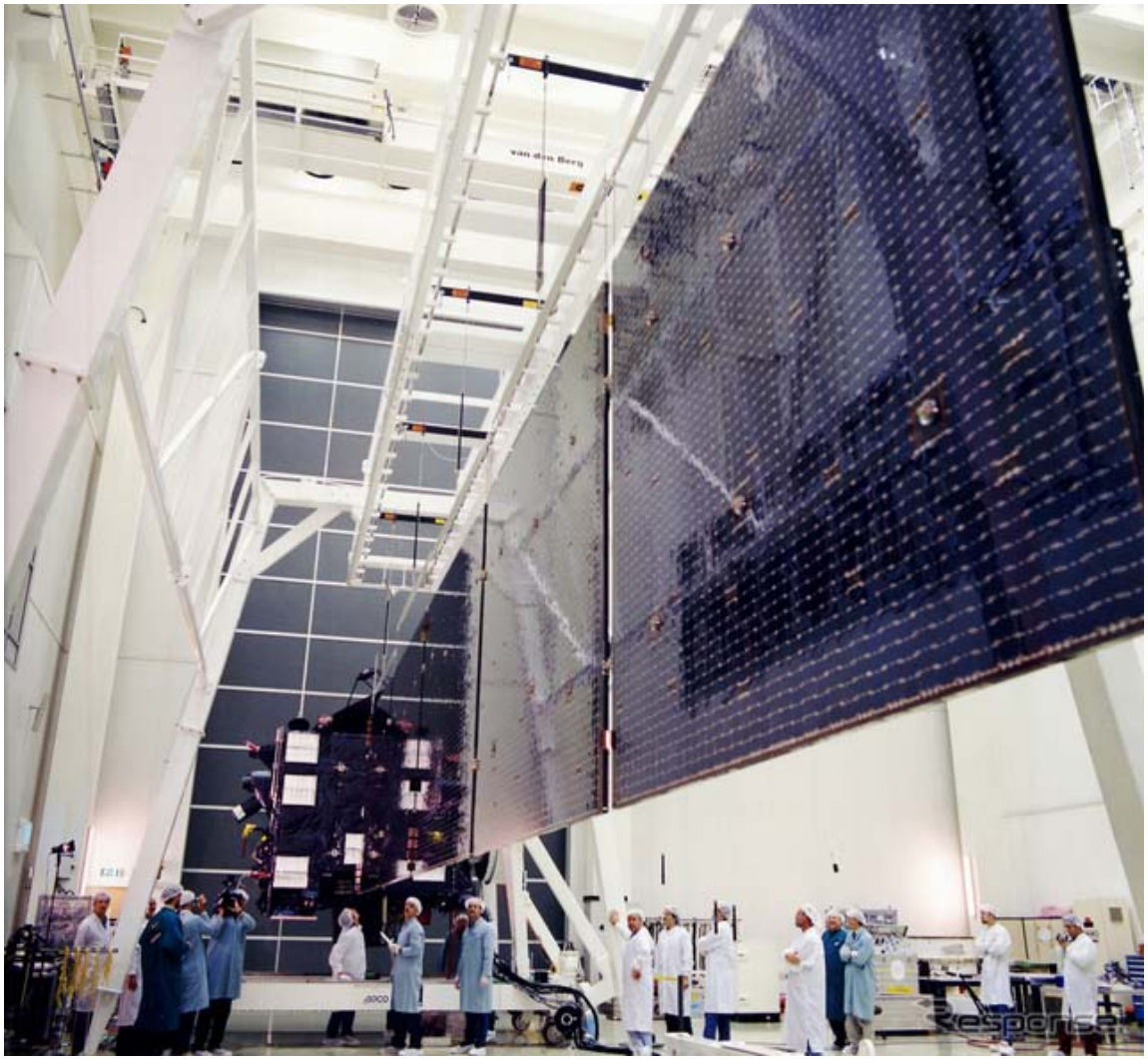
Selex ES has manufactured the SP for the whole mission, both for the Lander and for the Orbiter.

These last, having an **area of 64 m²** are the largest SP ever built for an interplanetary mission.



When Rosetta was @ **800 million km** from the Sun, the power delivered by the solar panels was **400W**.

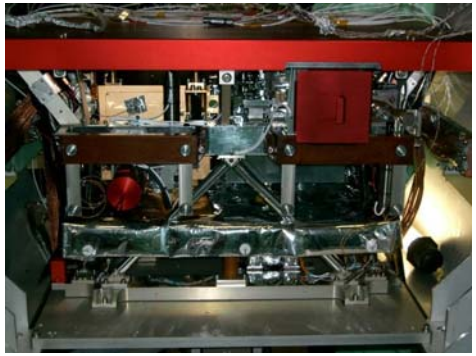
Selex ES for Rosetta: Solar Panels

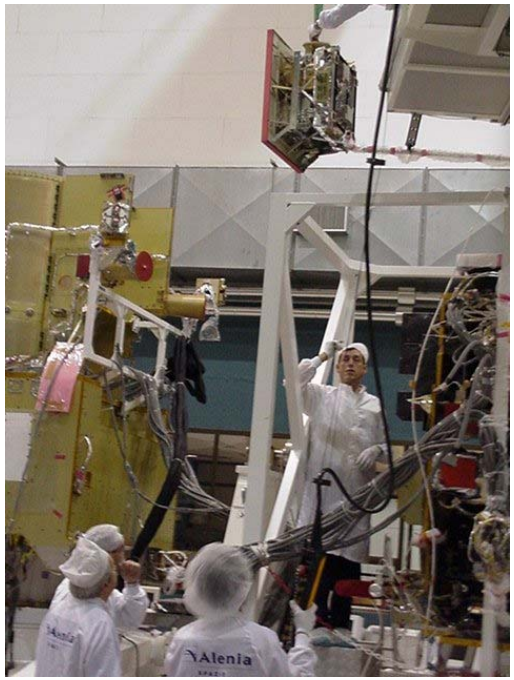


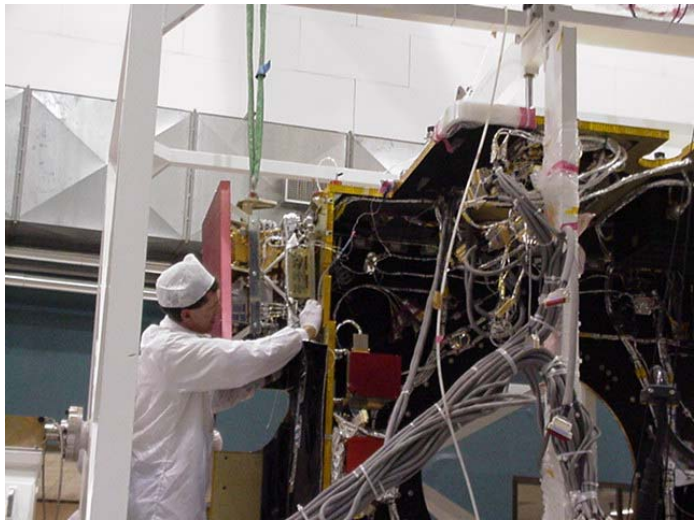
Rosetta Solar Panels unfolding just before fairing integration

(credits ESA)

Rosetta under development: VIRTIS integration

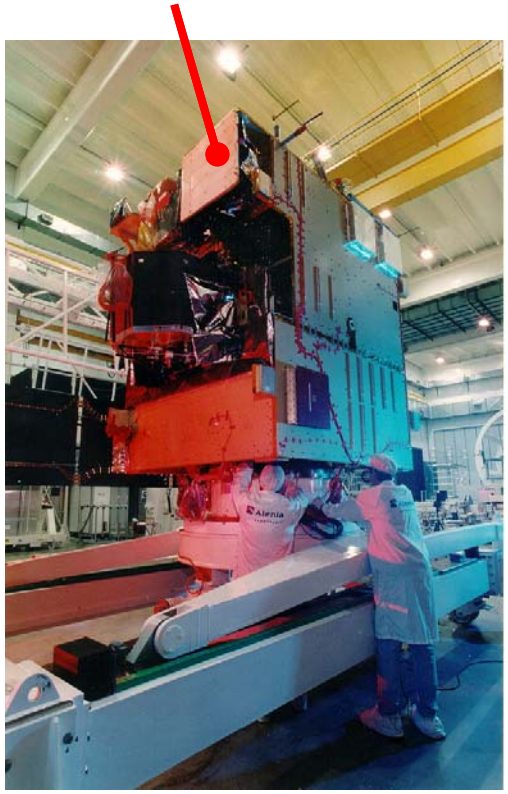


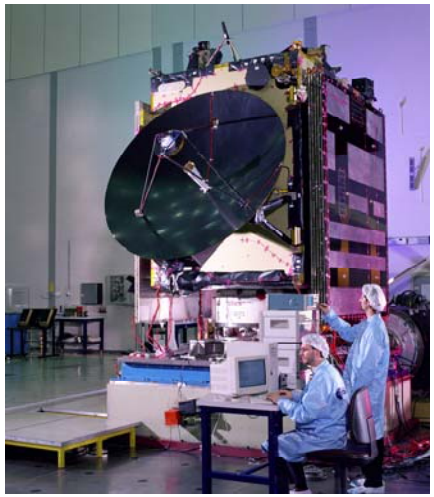


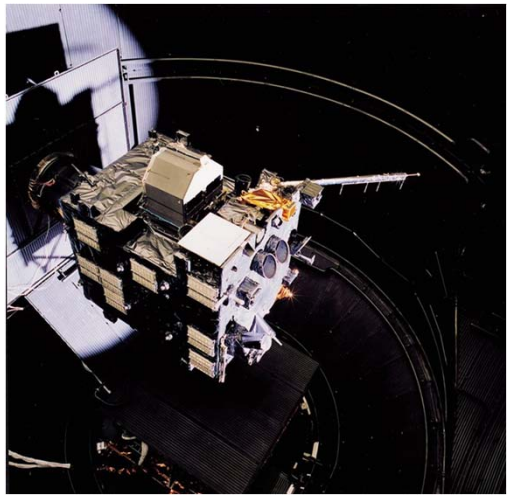


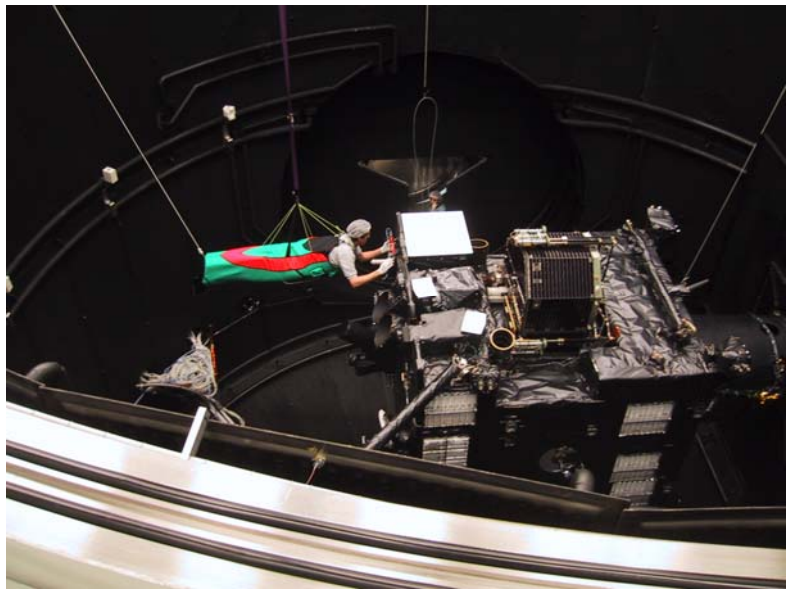
Rosetta integration

VIRTIS by Selex ES









Images: credits ESA

Final integration of Rosetta

Rosetta last view before integration in the fairing credits ESA

Rosetta fairing credits ESA

Rosetta on the fairing credits ESA CNES Arianespace

First launch … postponed !!!

The launch of Rosetta was foreseen on **January 2003**, on an Ariane-5. The target of Rosetta was the comet **46P / Wirtanen**, with an encounter foreseen in 2011.

Following the failure of the first Ariane 5 ECA (December 2002), **ESA and Arianespace decided not to launch Rosetta** to perform additional tests on the Ariane 5 launcher.

January 2003 was the only launch window available: **the mission to comet 46P / Wirtanen had to be abandoned.**.

First Ariane 5 launch (Dec 2002)

Second launch: March 2004 : ok !!!

In May 2003 a «new» comet was selected; a new mission was planned, with a new launch date.

The new comet, 67P, had a larger mass and a different orbital period.

Rosetta was launched in **March 2004**; after a ten years trip, in' **August 2014,** Rosette met his new target, the comet

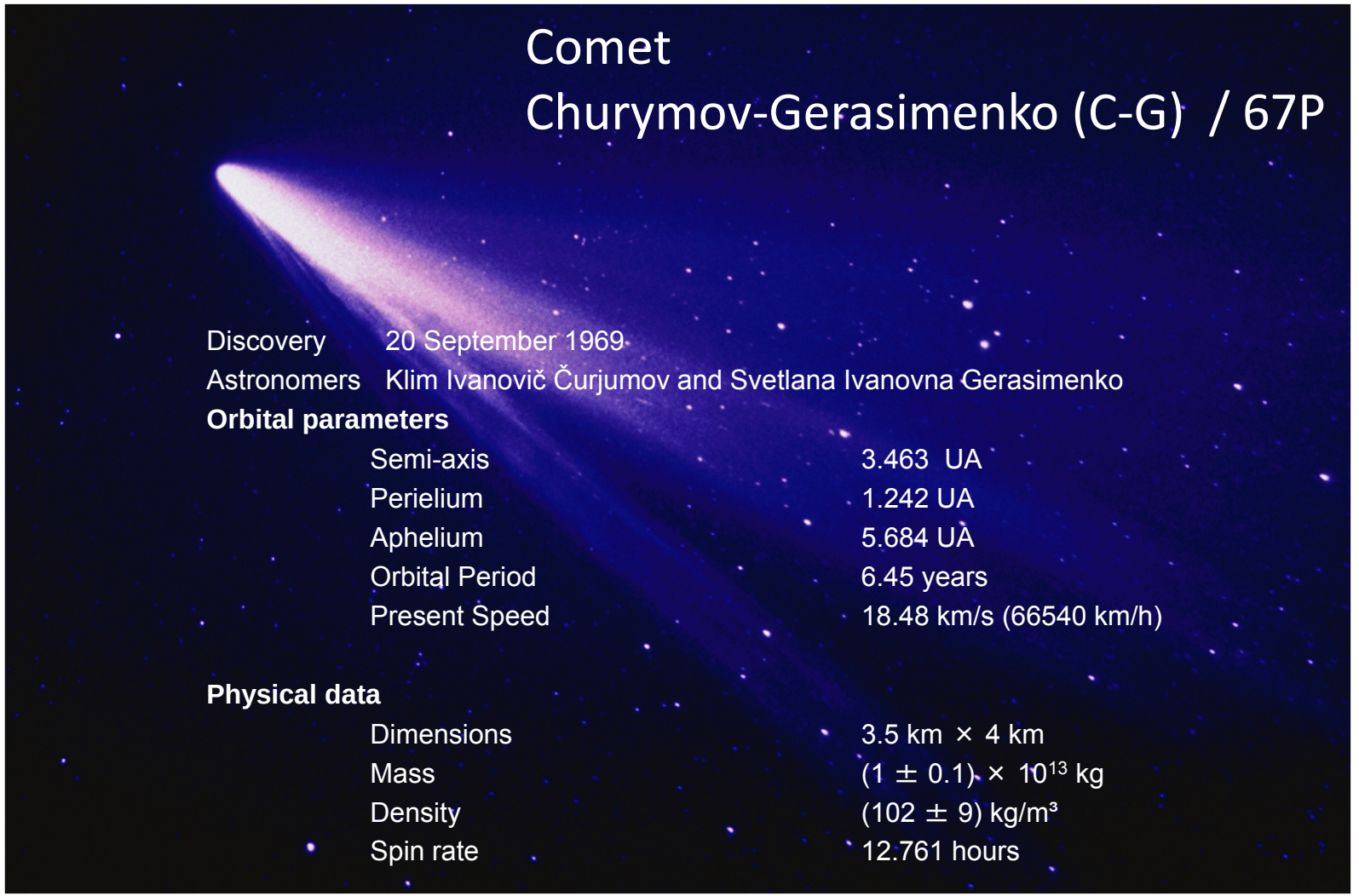
67P / Churyumov-Gerasimenko

The comet

Why selecting comet CG?

- Observed several times (since 1969), with perielion 6.5 years
- Its orbit is close to the ecliptic
- The orbit is mostly in the inner solar system
- The time to cover one orbit is compatible with Rosetta timing

The comet


Comet
Churymov-Gerasimenko (C-G) / 67P
Discovery 20 September 1969
Astronomers Klim Ivanovič Čurjumov and Svetlana Ivanovna Gerasimenko
Orbital parameters
Semi-axis 3.463 UA
Perielium 1.242 UA
Aphelium 5.684 UA
Orbital Period 6.45 years
Present Speed 18.48 km/s (66540 km/h)
Physical data
Dimensions 3.5 km × 4 km
Mass (1 ± 0.1) × 10^13 kg
Density (102 ± 9) kg/m³
Spin rate 12.761 hours

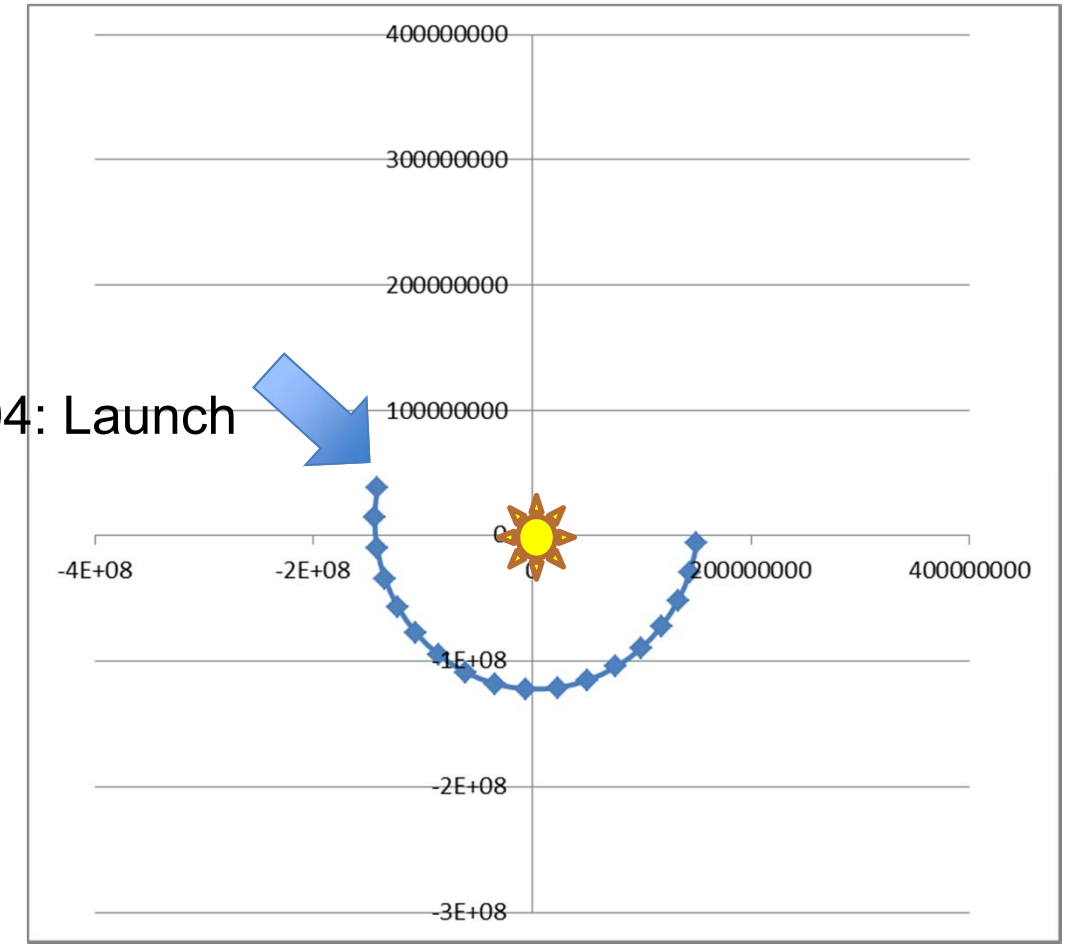
Mission timeline

4 fly-by

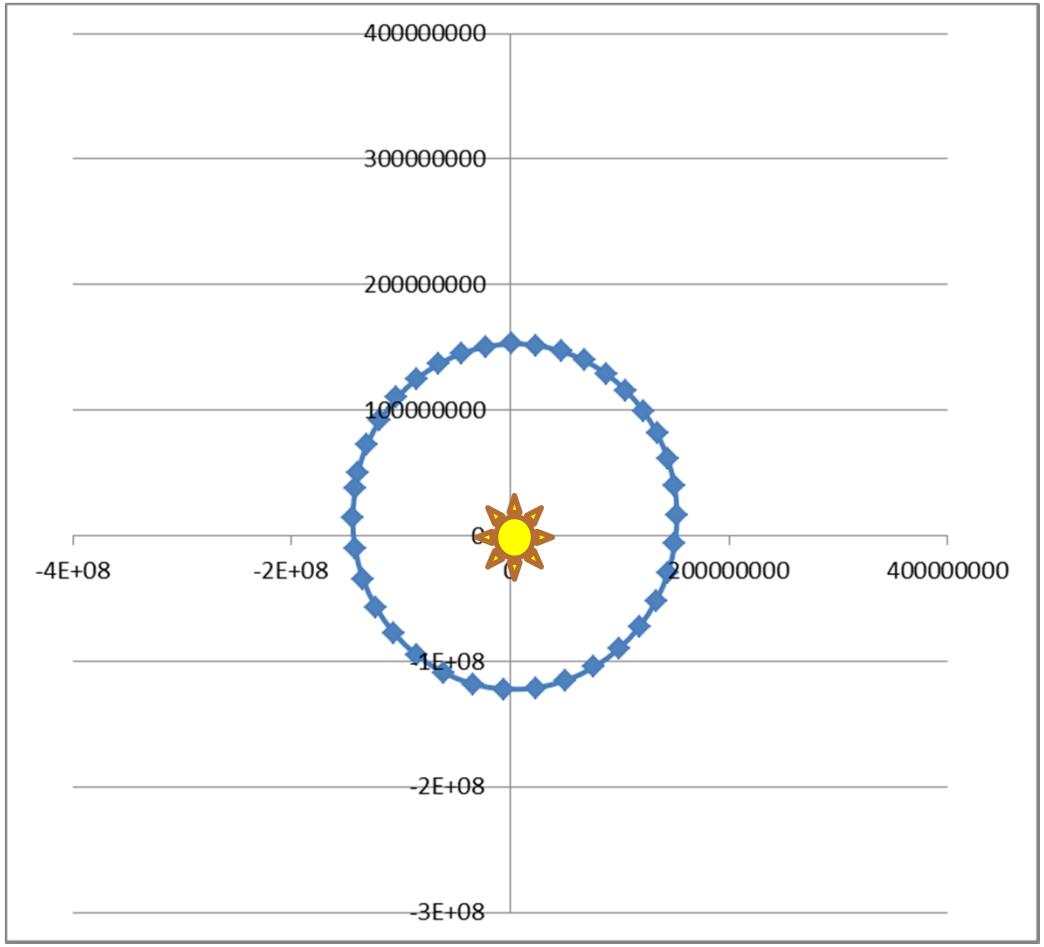
Launch:	2 March 2004	
1st Earth swingby:	4 March 2005	(distance from Earth: 1955 km)
Mars swingby:	25 February 2007	(distance from Mars: 250 km)
2nd Earth swingby:	13 November 2007	(distance from Earth: 5301 km)
Steins flyby:	5 September 2008	(distance from Steins: 802.6 km)
3rd Earth swingby:	13 November 2009	(distance from Earth: 2480 km)
Lutetia flyby:	10 July 2010	(distance from Lutetia: 3162 km)
Enter deep space hibernation:	8 June 2011	
Exit deep space hibernation:	20 January 2014	
Comet rendezvous manoeuvres:	May - August 2014	(distance from comet: 600,000–100,000km)
Arrival at comet:	6 August 2014	
Philae lander delivery:	November 2014	(distance from comet: 3 km)
Comet escort phase:	From Dec 2014	
End of mission:	December 2015	

The trip 2004

02/03/2004: Launch

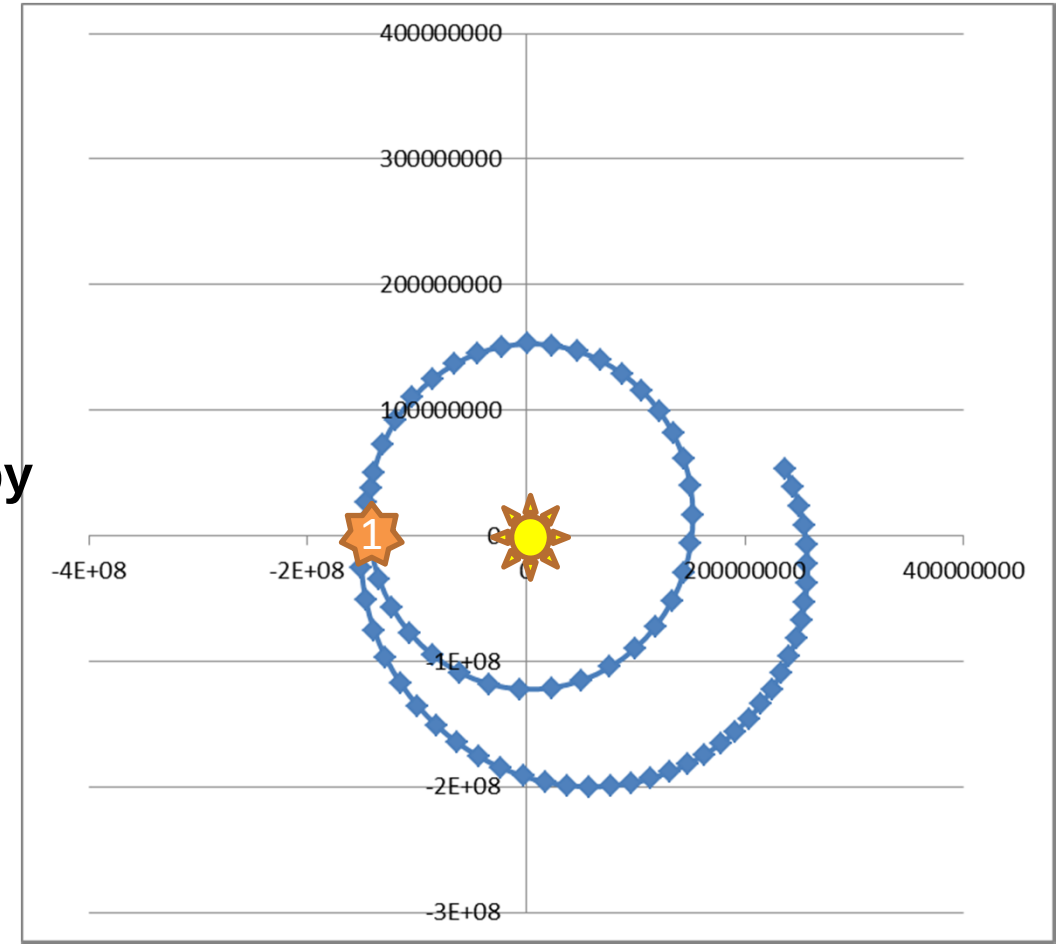


The trip 2005

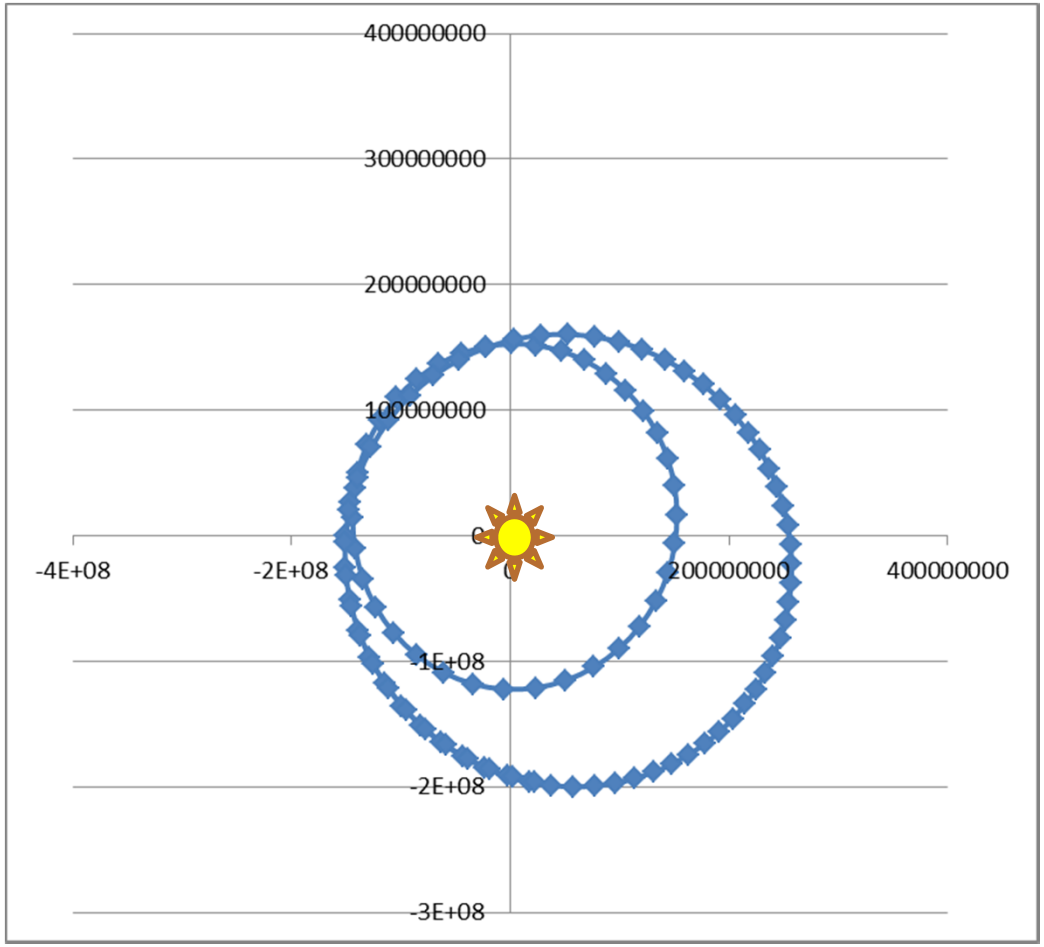


The trip 2005 - 2006

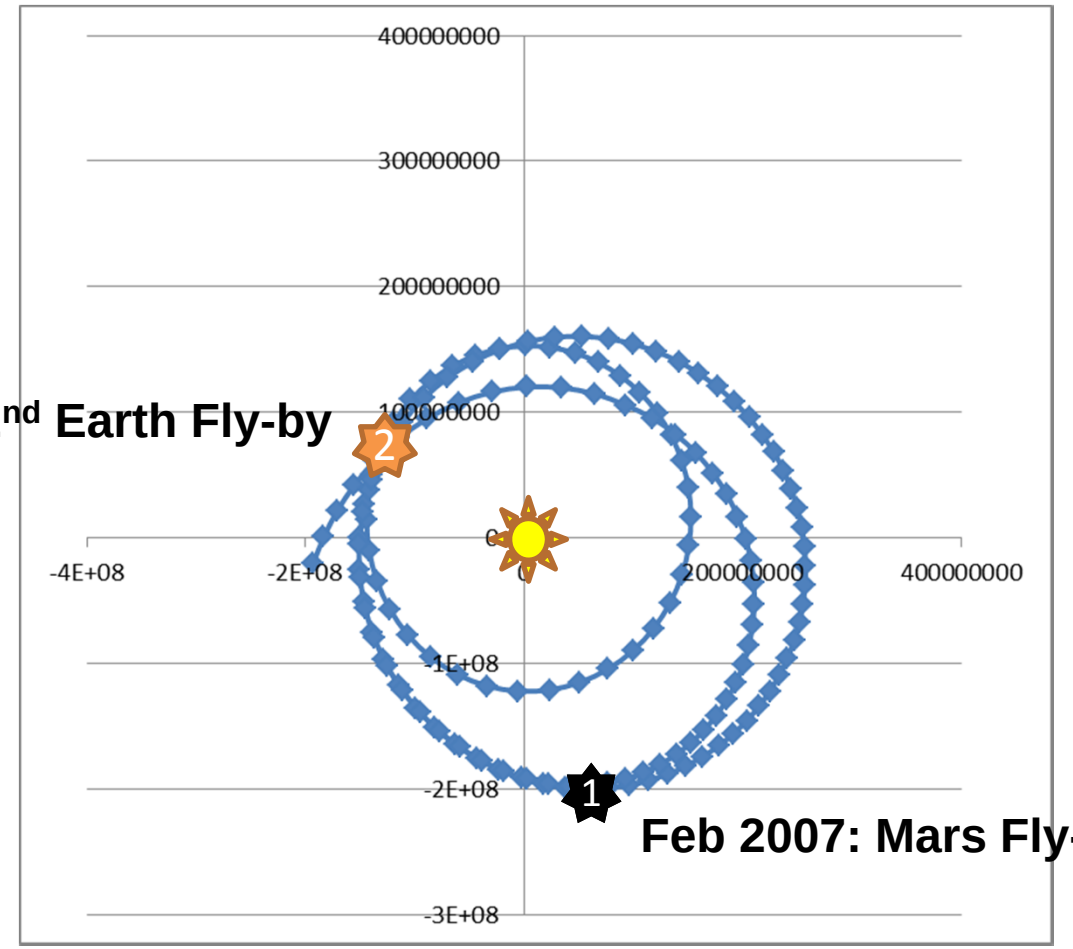
March 2005:
1st Earth Fly-by



The trip: 2007



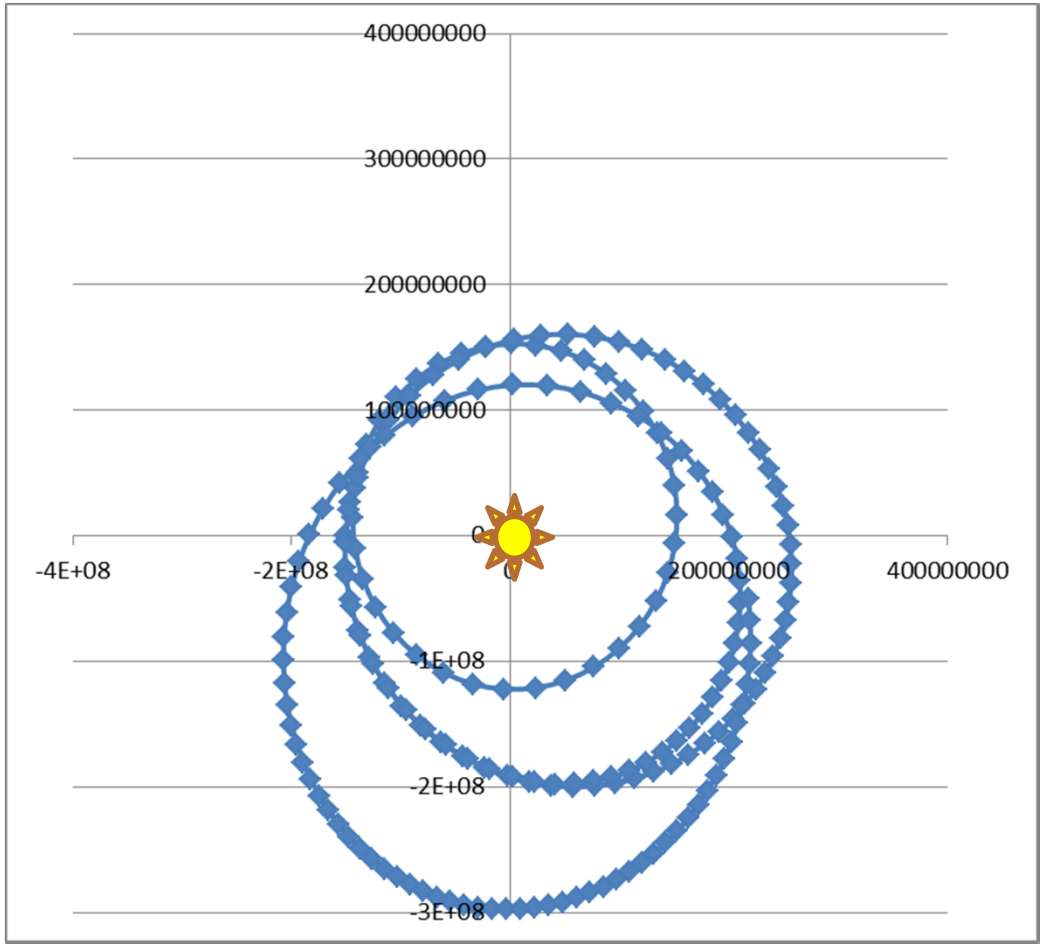
The trip: 2007



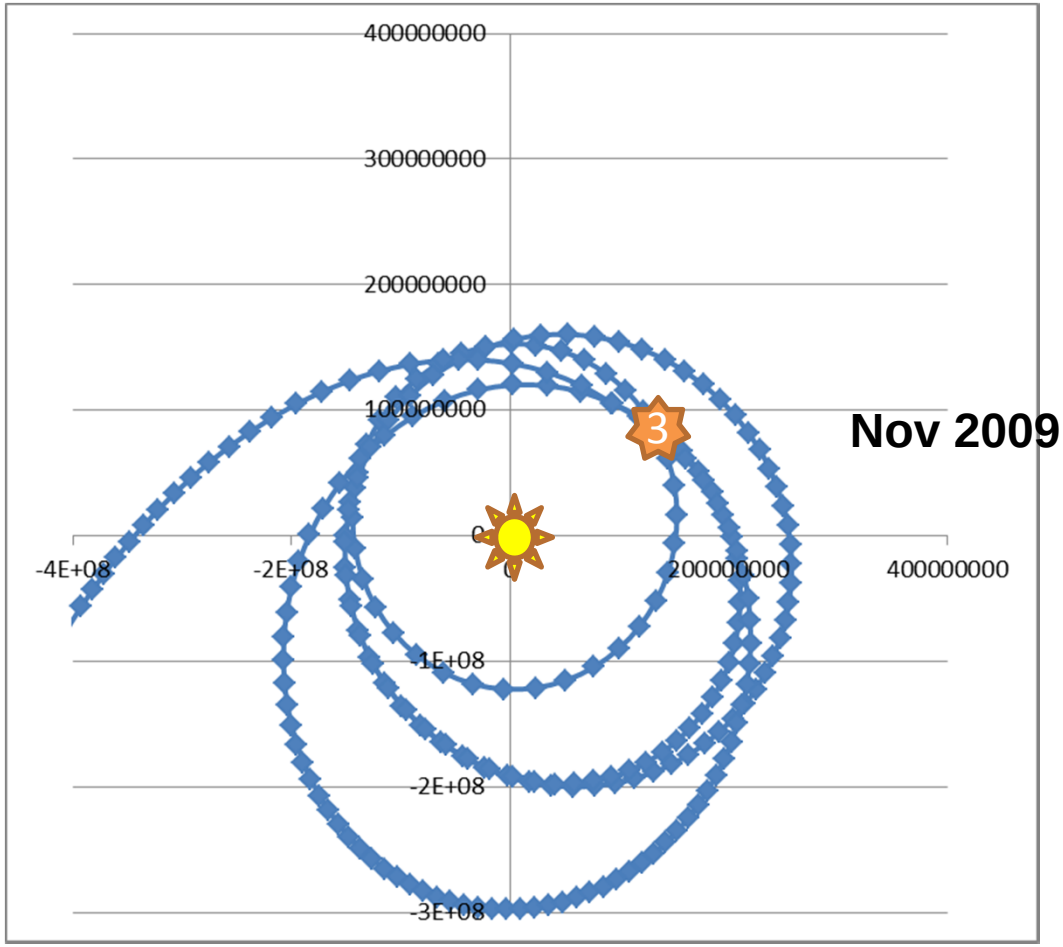
Nov 2007: 2nd Earth Fly-by

Feb 2007: Mars Fly-by

The trip: 2008

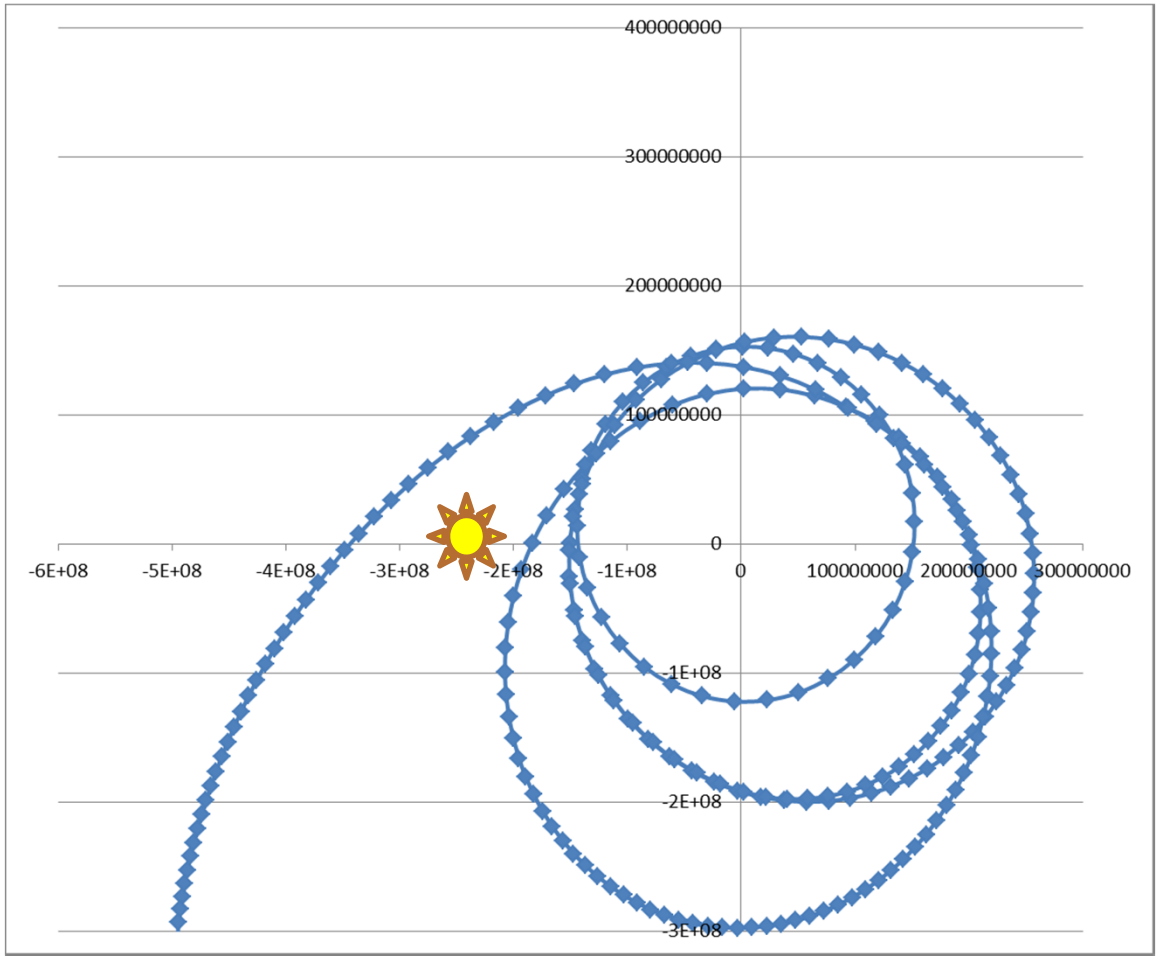


The trip: 2009



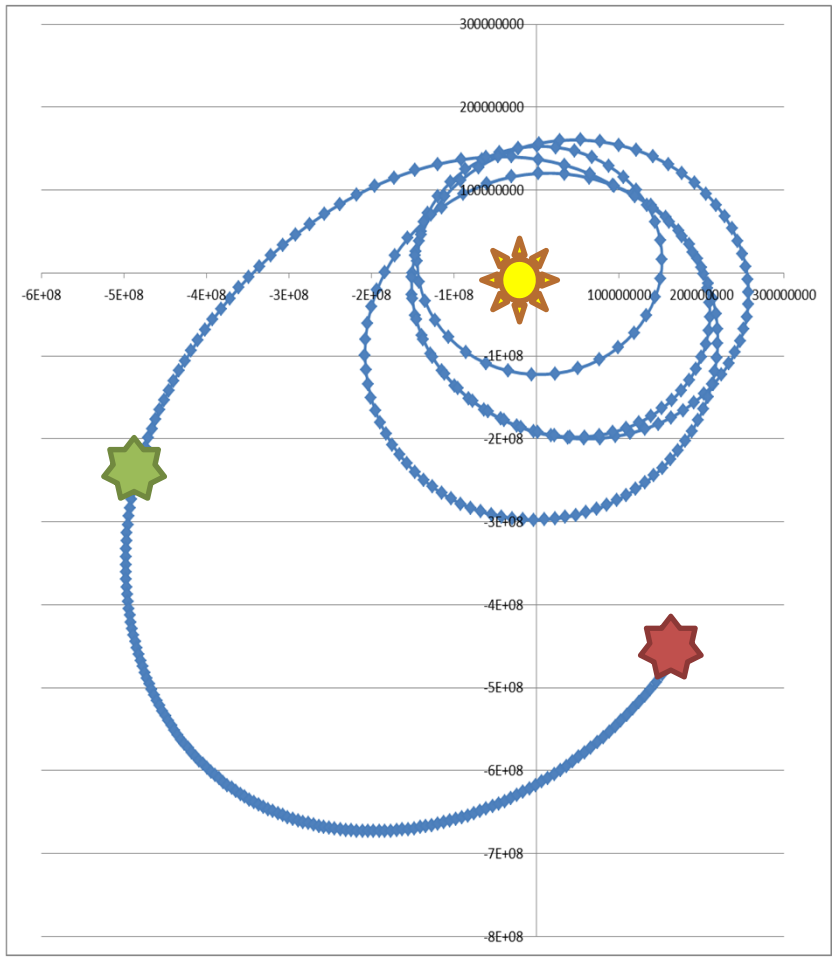
Nov 2009: 3rd Earth Fly-by

The trip 2010-2011



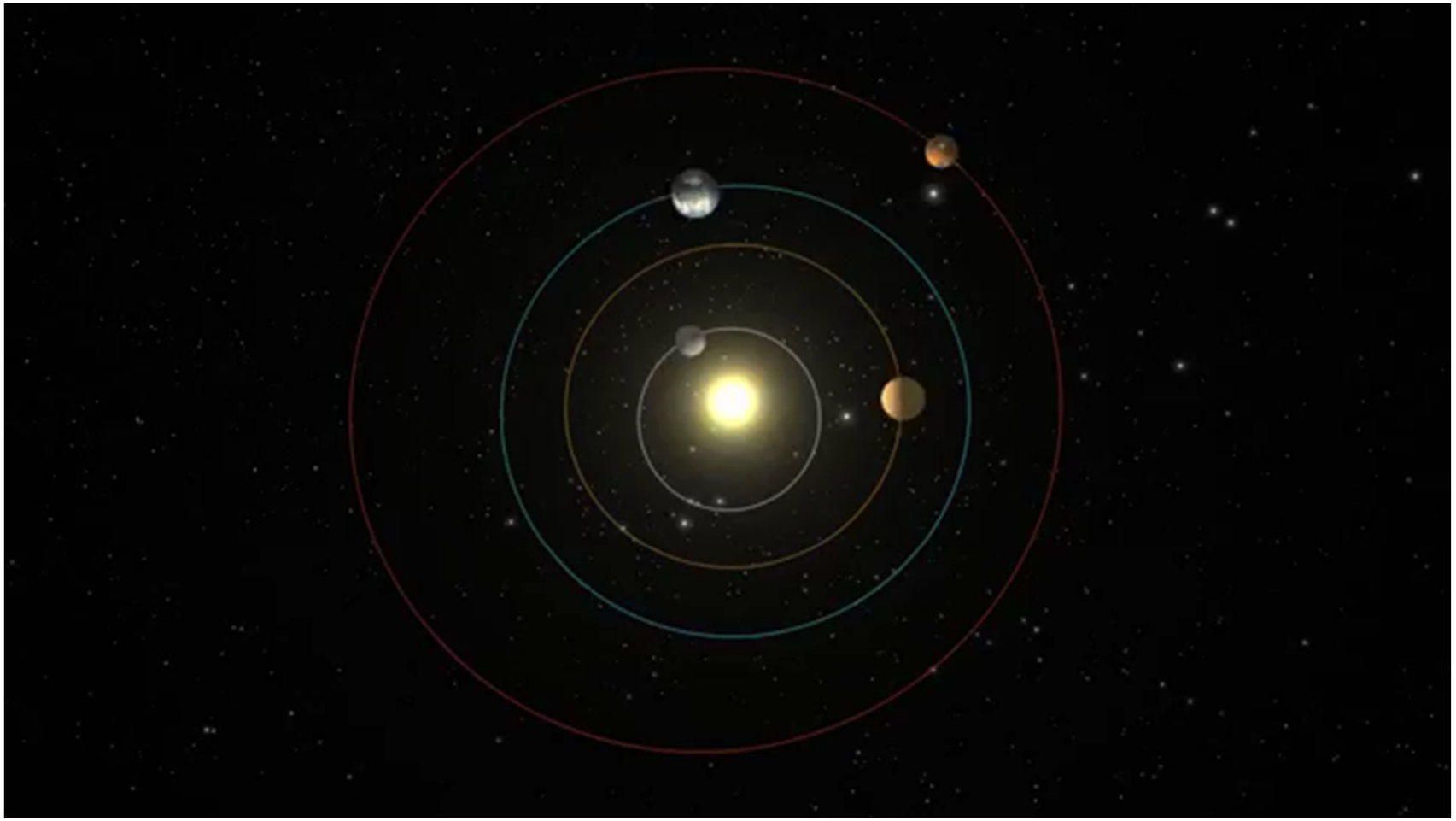
The trip: 2011 - 2014

May 2011
Hybernation



20/01/2014
Wake-up

The whole trip: reply



Hybernation

On June 8th 2011 Rosetta has been put into hybernation for **31 months**.

Rosetta was too far from the Sun (between 660 and 800 million Km from the Sun). The received energy by the panels is very low, not enough to power the satellite.

All on board systems have been switched off, including tele-communication and attitude control systems.

Only active systems: **on board computer (with its clock!) and some heaters.**

Before hybernation, Rosetta has oriented its solar panels to the Sun and the satellite has been put in spin mode.

Signals from Rosetta need 45 m to get to the Earth

The wake up

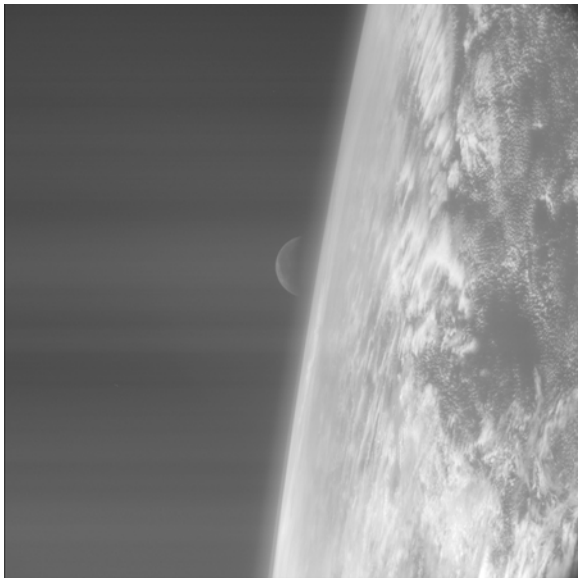
Wake up was possible when Rosetta's orbit only when the satellite was closer to the Sun: "only" 673 million km from the Sun.

Rosetta was still 9 mililon km far from the cometa, when it was waked up.

Key action has been performed by the **attitude sensors developed by Selex ES**: they provided the exact position amd orientation in space to allow Rosetta exactly pointing its antenna towards the Earth, which was 807 million km far. As you know, **this difficult task has been fully successful**.

During the trip

Rosetta at its 2° Fly-by has been classified as a NEO!



1° Earth Fly-by (2005)

<=

The Earth and the Moon seen by NAVCAM
(credits ESA/Selex ES)

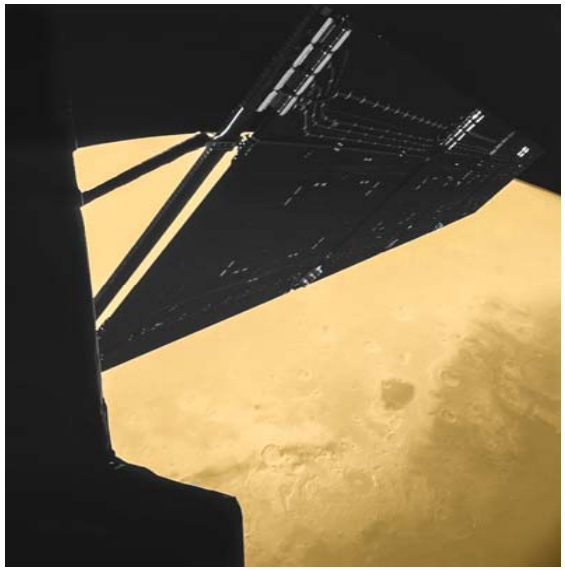
2° Earth Fly-by (2007)

=>

The Earth seen by OSIRIS
(credits ESA/OSIRIS)

Mars Fly-by (2007)

=>

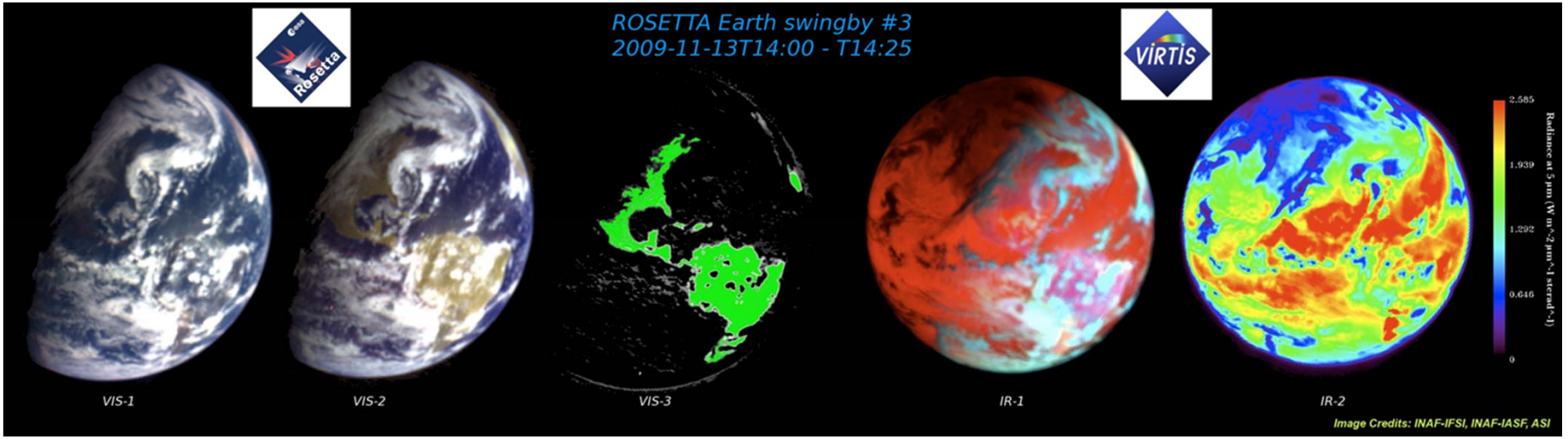


Rosetta selfie during Mars fly-by (credits ESA)

Science during the trip…

3rd Earth Fly-by (2009): The Earth as seen by VIRTIS

(credits ESA/ASI/VIRTIS/INAF-IAPS)



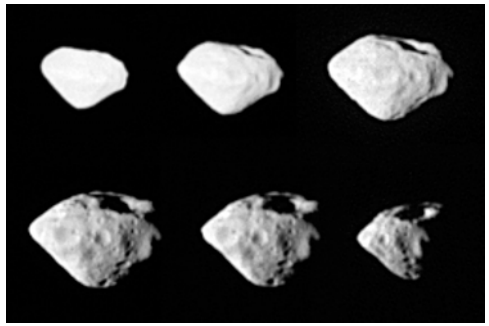
- Fig1. VIS channel; spatial resolution of about 50 km. RGB imaging (0.44, 0.55, 0.7μm).
- Fig 2 VIS Channel; contrast enhanced image (0.474μm, 0.785μm, 1.0μm).
- Fig 3 VIS Channel; contrast enhancement of chlorophyll absorption feature.
- Fig 4 IR Channel; B @1.20μm, G@2.25μm and R@4.92μm. Radiation emitted from the night side clearly shows up in this image. The cyan spots are high altitude clouds, while Oceans appears in red having a thermal emission and inertia larger than the landforms (in pink).
- Fig 5. Thermal emission region at 5.0 μm; the Earth looks fairly uniform on the day and night side. The northern American continent (in the top-left quadrant of the image), mainly at night and during the winter season, appears as the coldest area of this image (in blue).

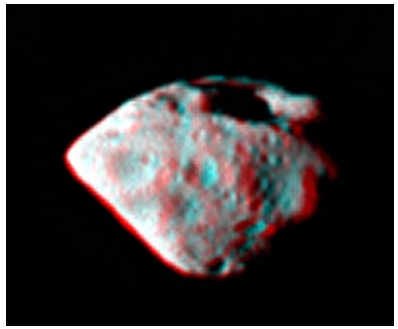
During the trip: the asteroid Steins

During its trip, Rosetta has been programmed to met two asteroids orbiting between Mars and Jupiter orbits. The first encounter has been with (2867) **Steins**.

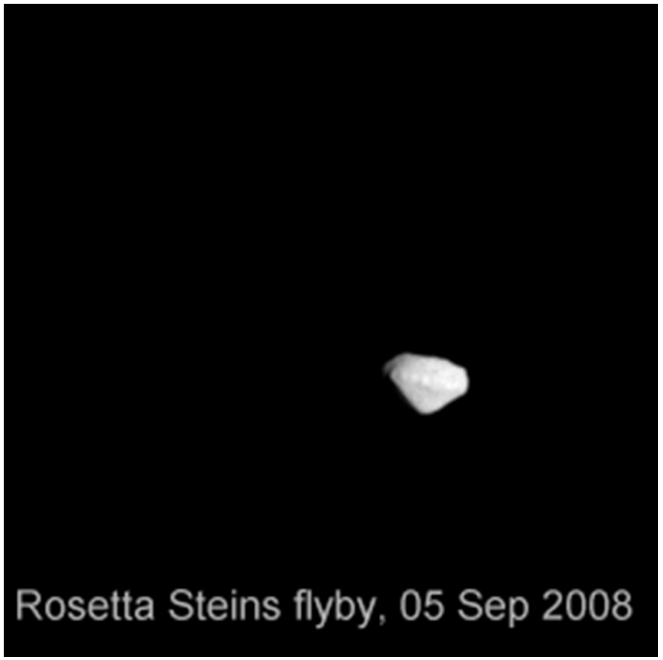
The Steins fly-by started on August 4, 2008, by leaving the satellite setting autonomously its traiettoria under **optical** navigation (i.e. by using the data from the navigation camera); this approach has never been tested by ESA before Rosetta.

Closest encounter on September 5, 2008, when Steins was at 2.14 UA from Sun and 2.41 UA from Earth. Relative speed was 8,62 km/s and minimum distance 802,6 km.





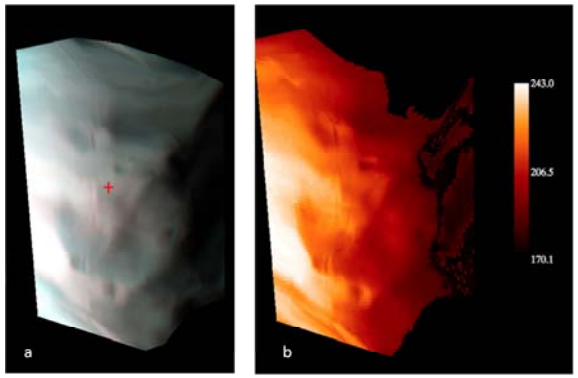
Immagini di Steins
(credits ESA/OSIRIS)



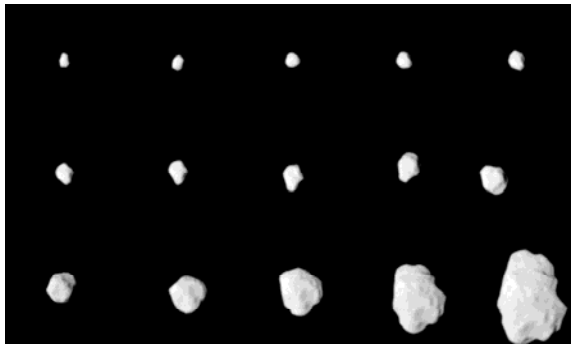
During the trip: the asteroid Lutetia

On July 2010 Rosetta meet his second asteroid: (21) **Lutetia**, a large asteroid (dimensions: 126 km x 103 km x 95 km – ten times more than Steins).

Spectacular fly-by, at a distance of 3162 km and relative speed 15 km/s. Lutetia seems very old (4,5 billion years), due to the many impact craters seen on it.

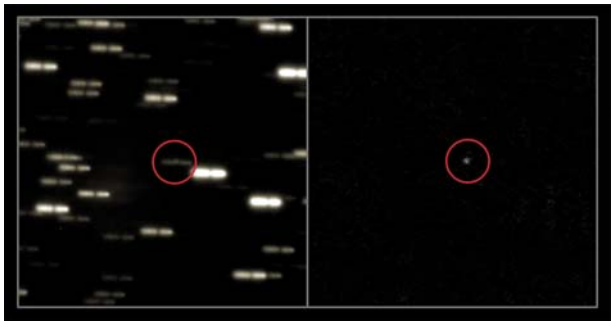


Images of Lutetia (credits ESA/INAF-IAPS/VIRTIS)



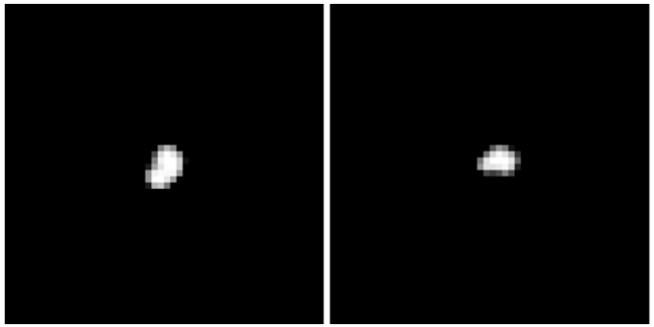
Images of Lutetia (credits ESA/OSIRIS)

Recent history: the comet as seen on …

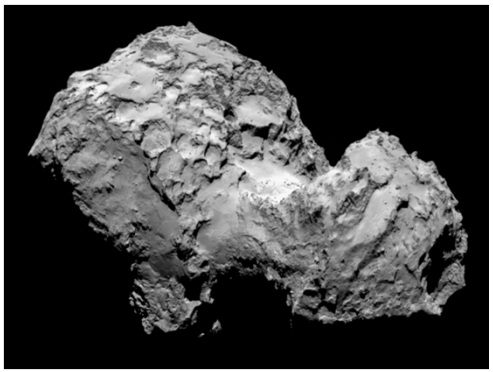


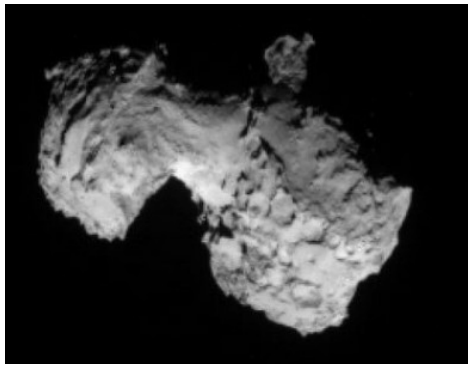
2 February

4 May



4 July





3 August

All images credits: ESA/OSIRIS

Images of the comet on …

August 19th 2014 – NAVCAM ~79 km

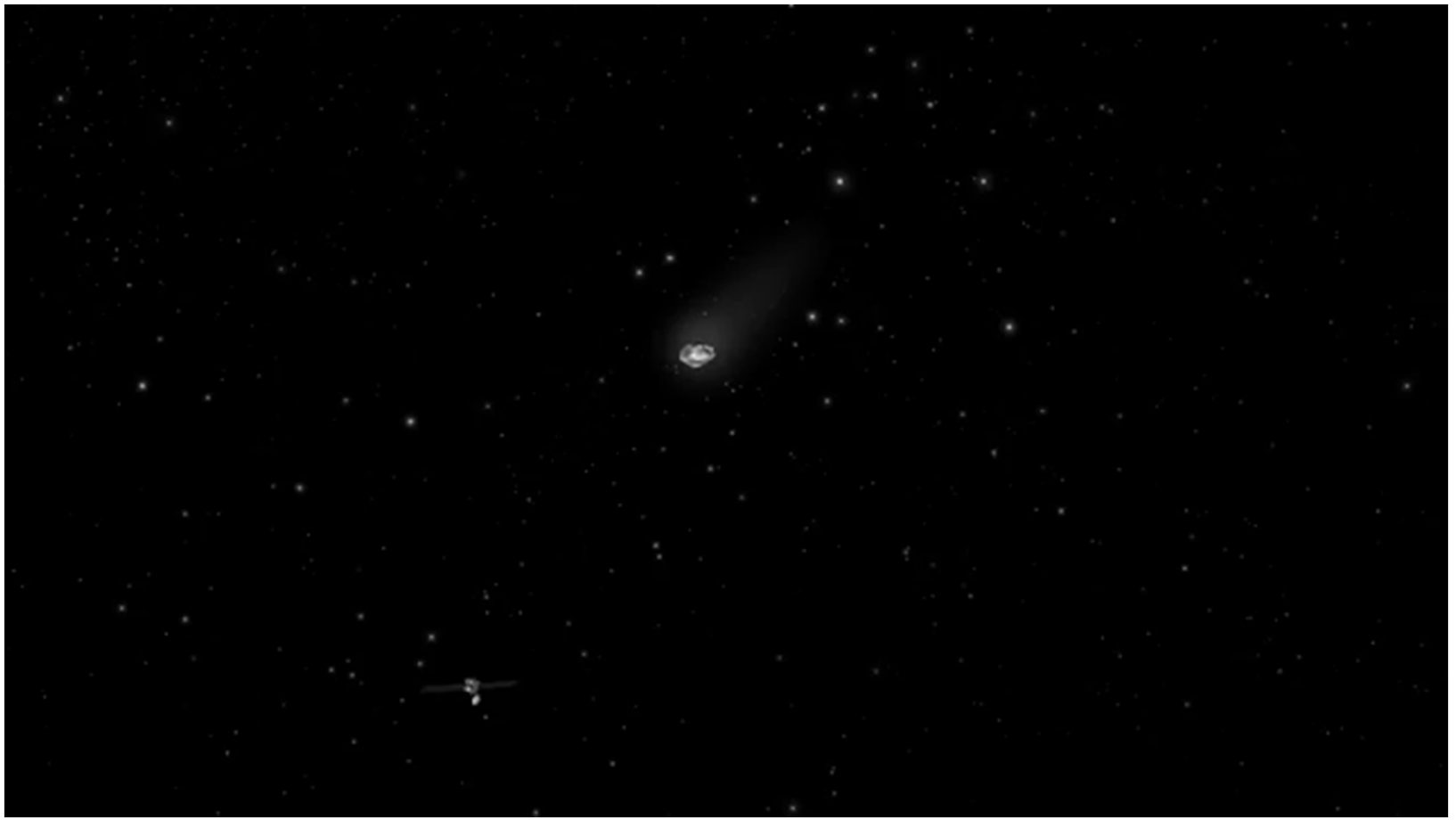
August 21st 2014 – NAVCAM ~ 69 km

Credit: ESA/Rosetta/NAVCAM

Comet speed wrt Sun: 55.000 km/h

The "orbiting" phase

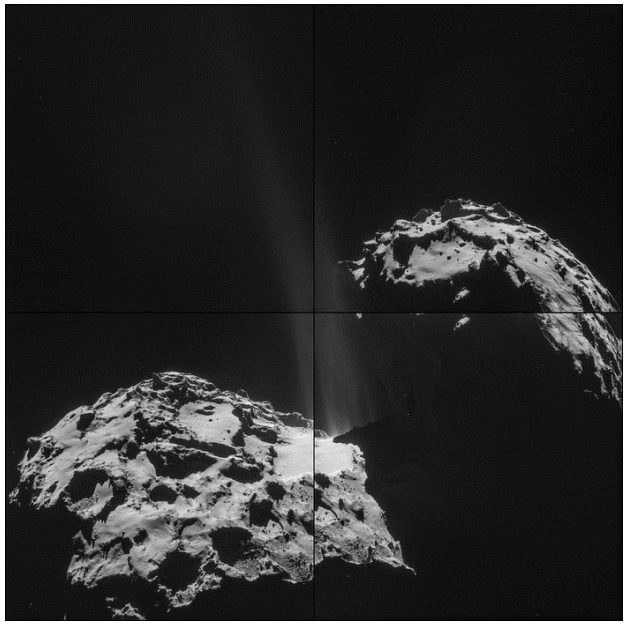
Comet to Rosetta speed: few cm/s



ESA: orbiting the comet

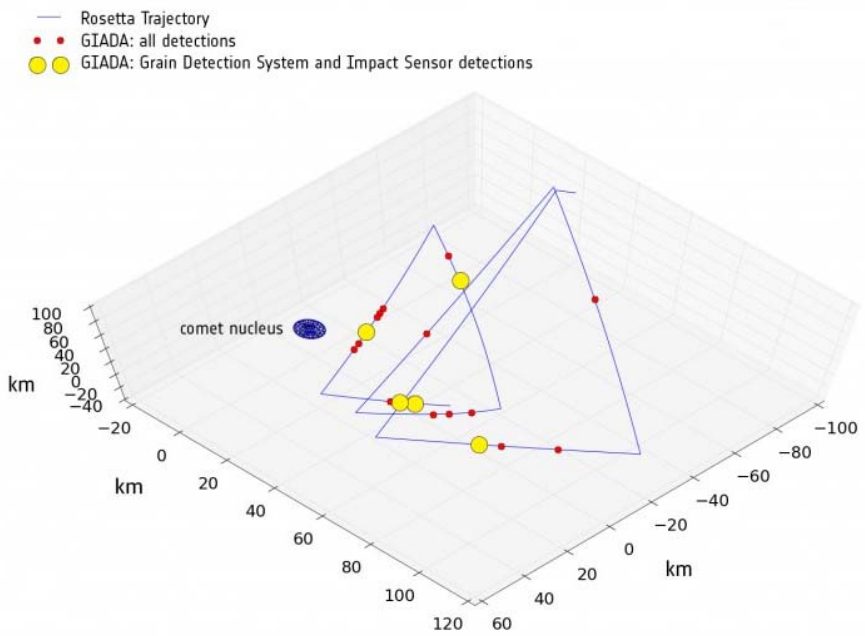
Preliminary scientific results (1)

Image from **NAVCAM** (Selex ES) showing the jets emitted from the comet



credits ESA/NAVCAM

Dust position wrt comet as seen by **GIADA** (Selex ES) during August



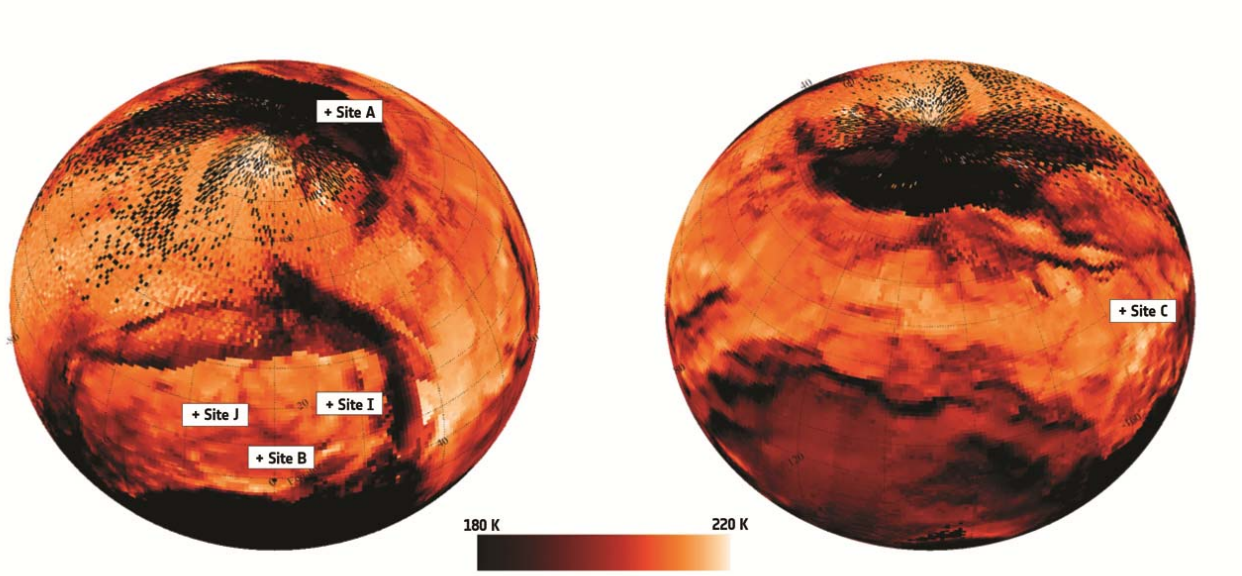
credits: ESA/Rosetta/GIADA/Univ Parthenope NA/INAF-OAC/IAA/INAF-IAPS

Dust grains deetected by GIADA:
first grain @ 800million km, 9 grains @ 90 km, 17 grains @ 50 km

Scientific results from VIRTIS (2)

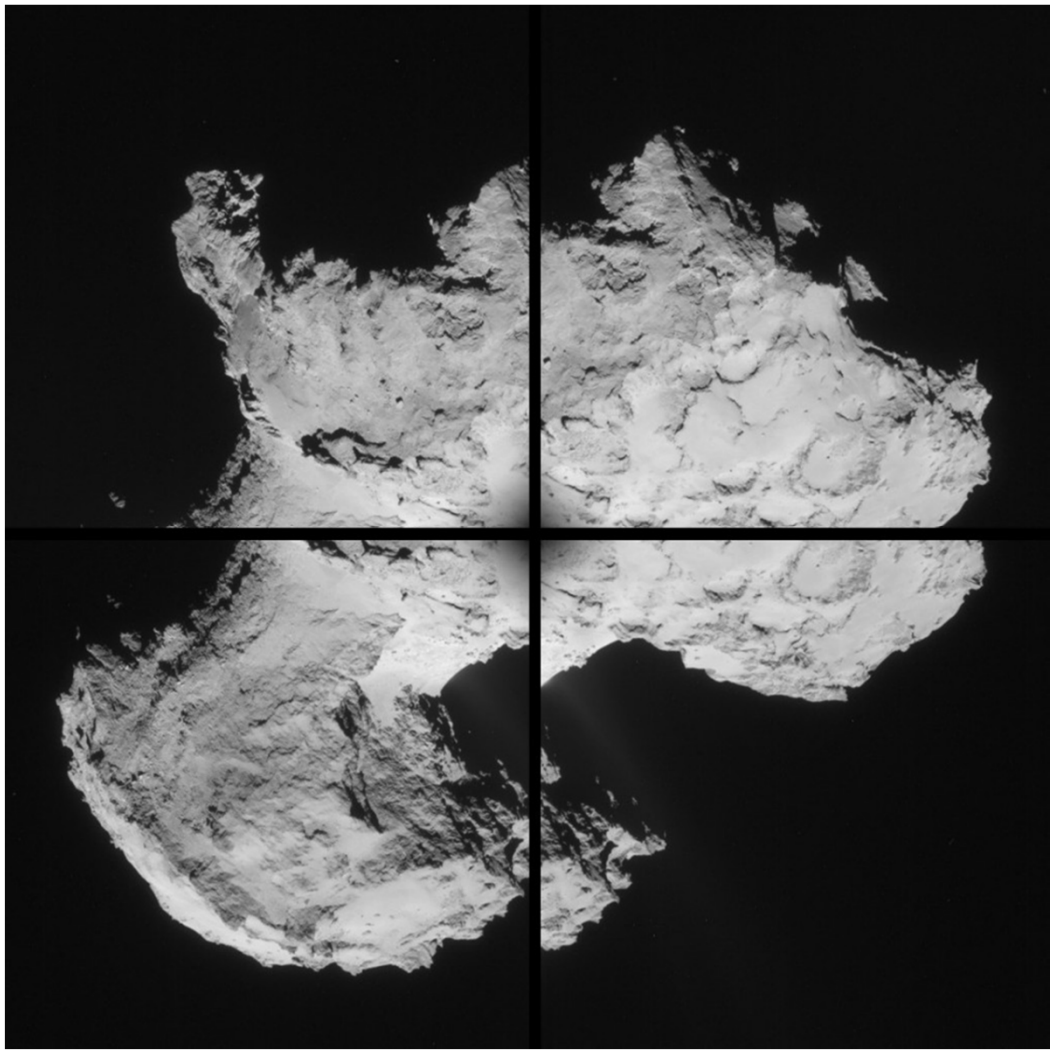
The scientific team of **VIRTIS** (Selex ES) has measured the comet surface temperature, finding remarkable temperature variations.
Mean surface temperature is around 200 K.

The spectrometer has detected on the surface de-idrated material (dust) and Carbon composites (organic).



Credit: ESA/Rosetta/VIRTIS/INAF-IAPS/OBS DE PARIS-LESIA/DLR

Scientific results from **NAVCAM (3)**

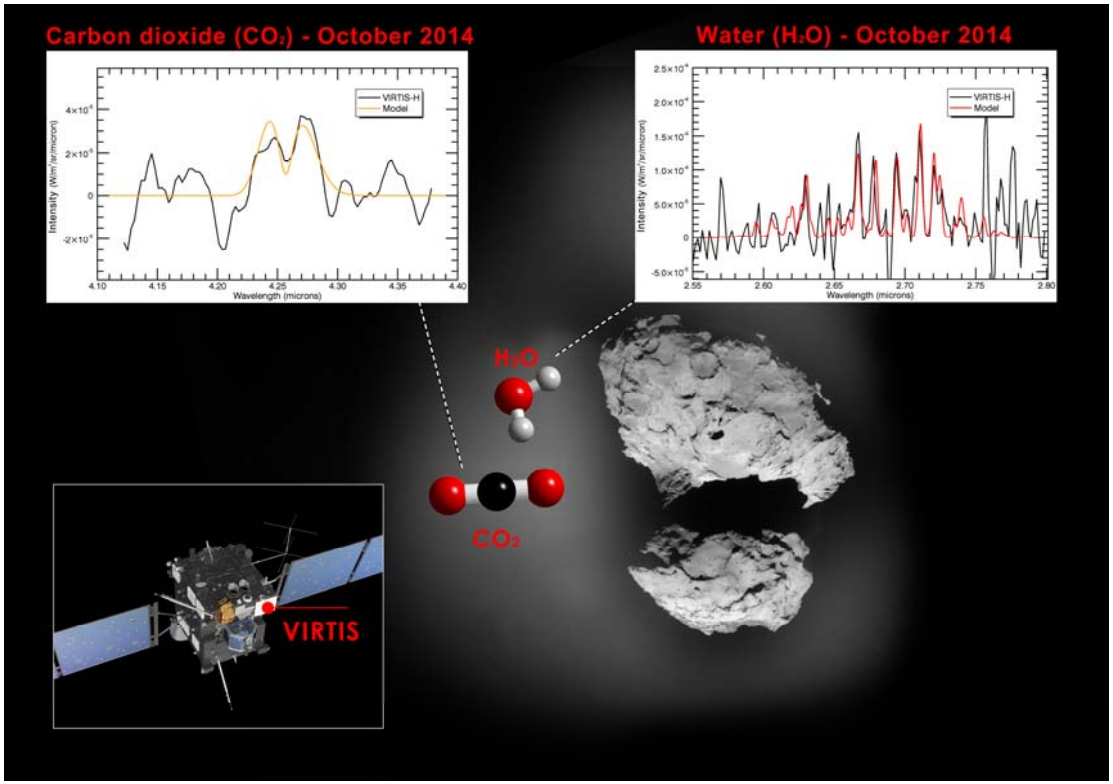


Credits:ESA/SELEX ES

NAVCAM images
October 26th 2014

Distance: 7.7 km
Resolution: 65 cm/pixel

Scientific results from VIRTIS (4)

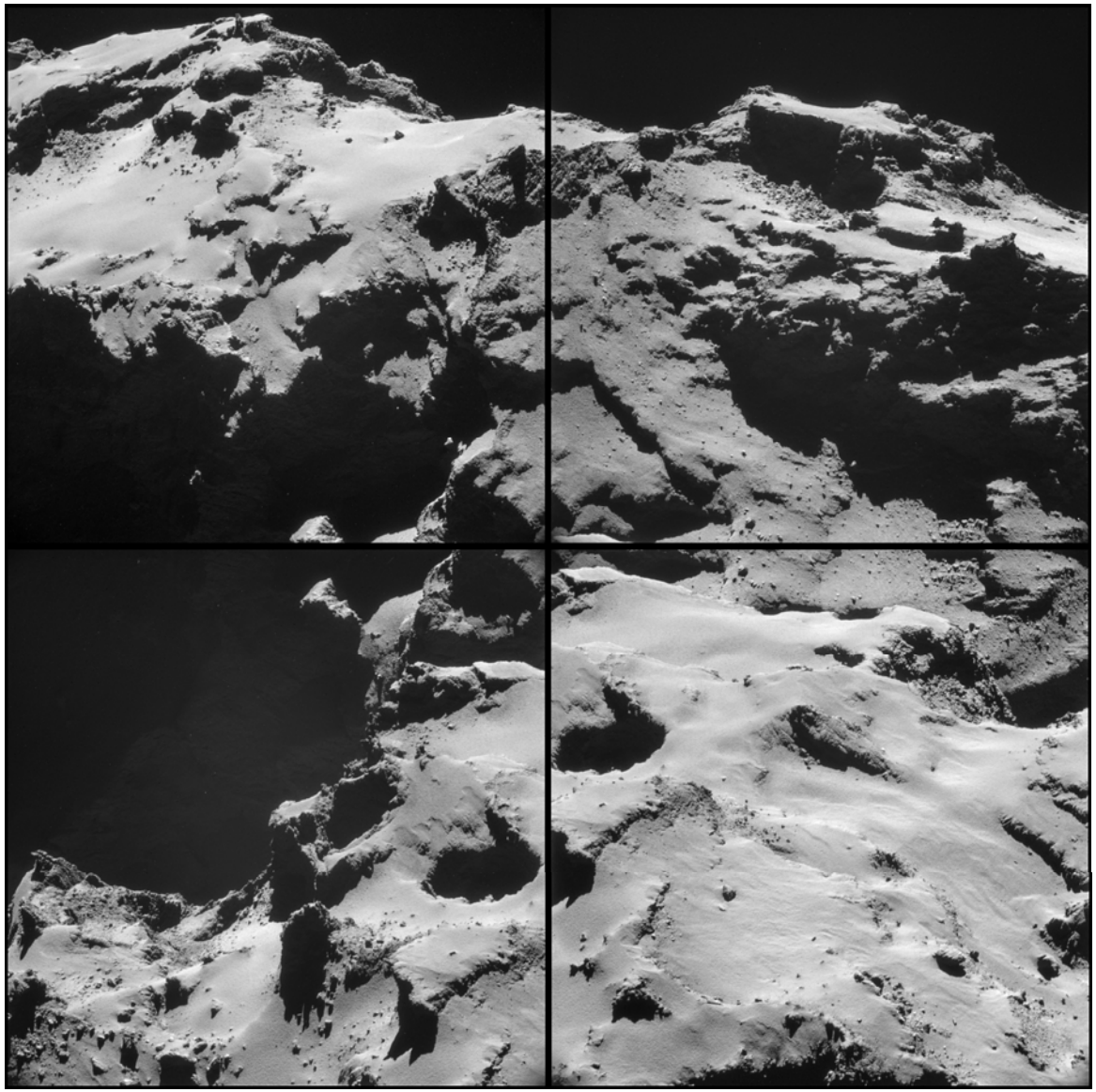


The coma is analyzed by VIRTIS: verified presence of water and CO2

In summary:

- Instrument VIRTIS-H
- Other volatiles detected
- Measured temperatures (October):
  on the surface = -70 °C
  on the coma (1 km) = -183 °C

Credits: ESA/Rosetta/VIRTIS/INAF-IAPS/OBS DE PARIS-LESIA/DLR

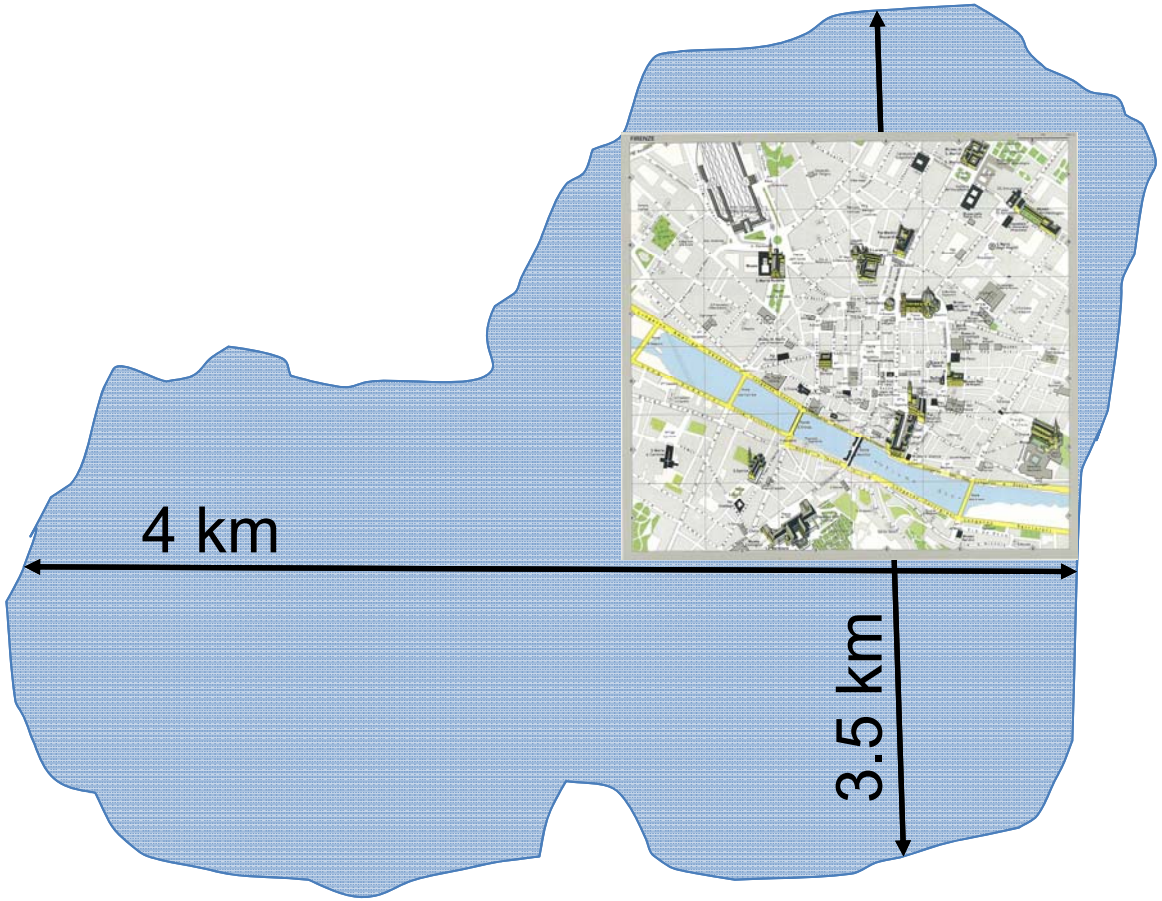


Orbiting around the comet

Comet 67P on 15 October 2014
Distance: 9.9 km from centre of comet
Mosaic image – NavCam
Total area: 1300 m x 1300 m (0.63 m/pixel)

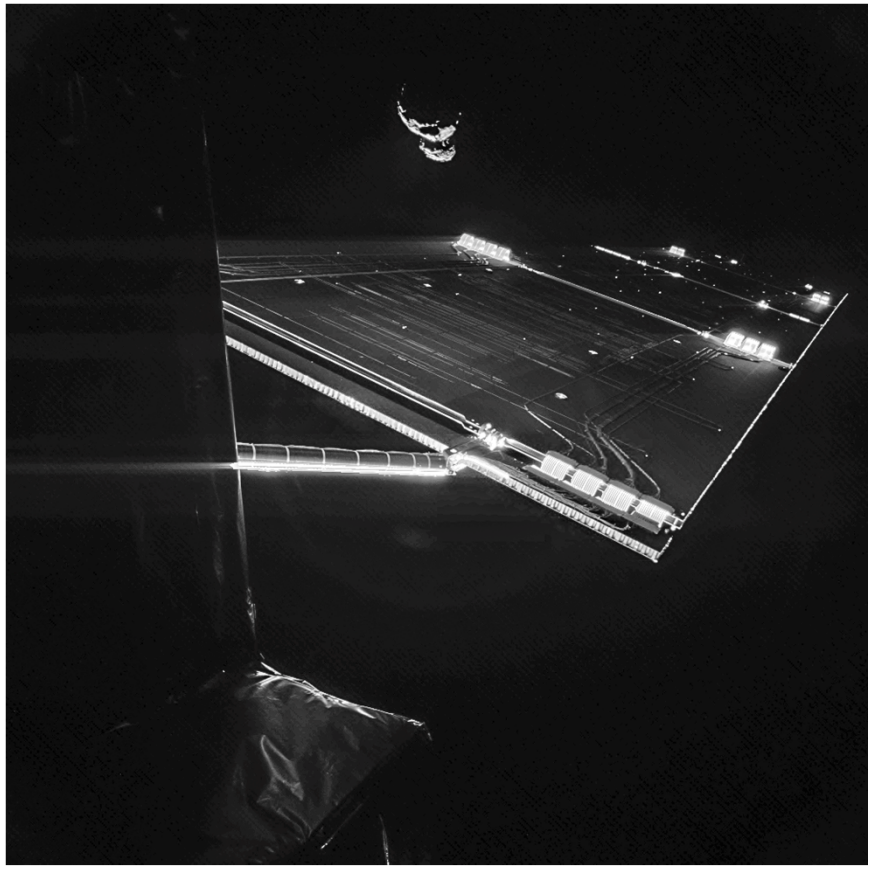
Credit: ESA/Rosetta/NAVCAM

How large is the comet



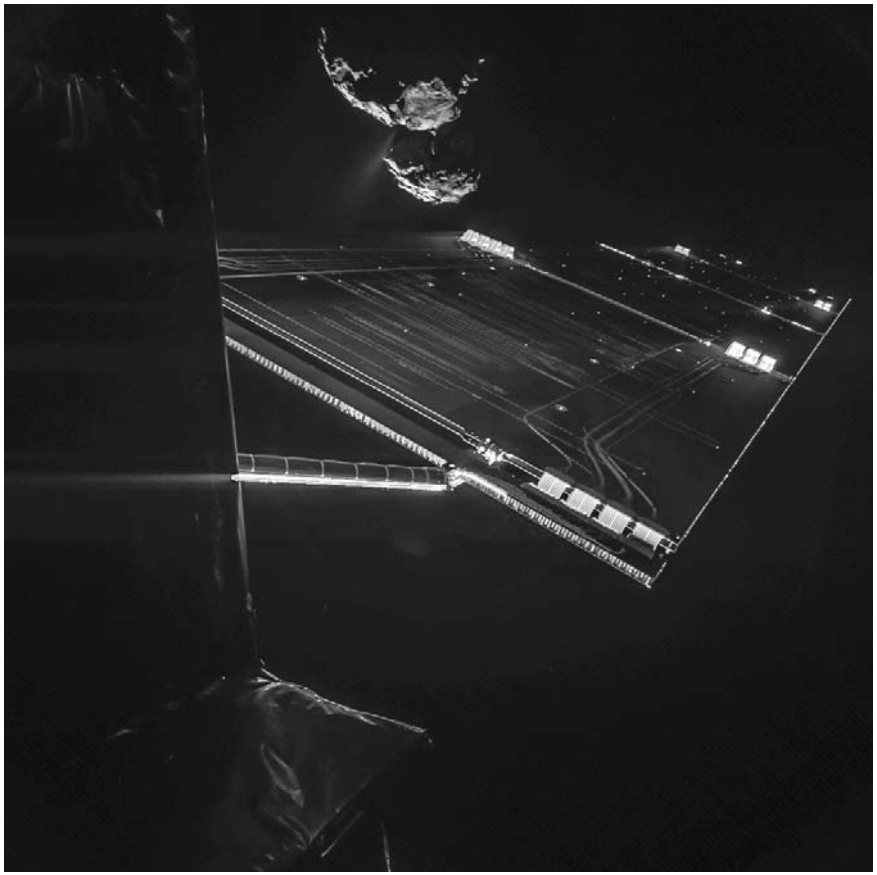
Firenze is much smaller than the comet!!!

Orbiting around the comet



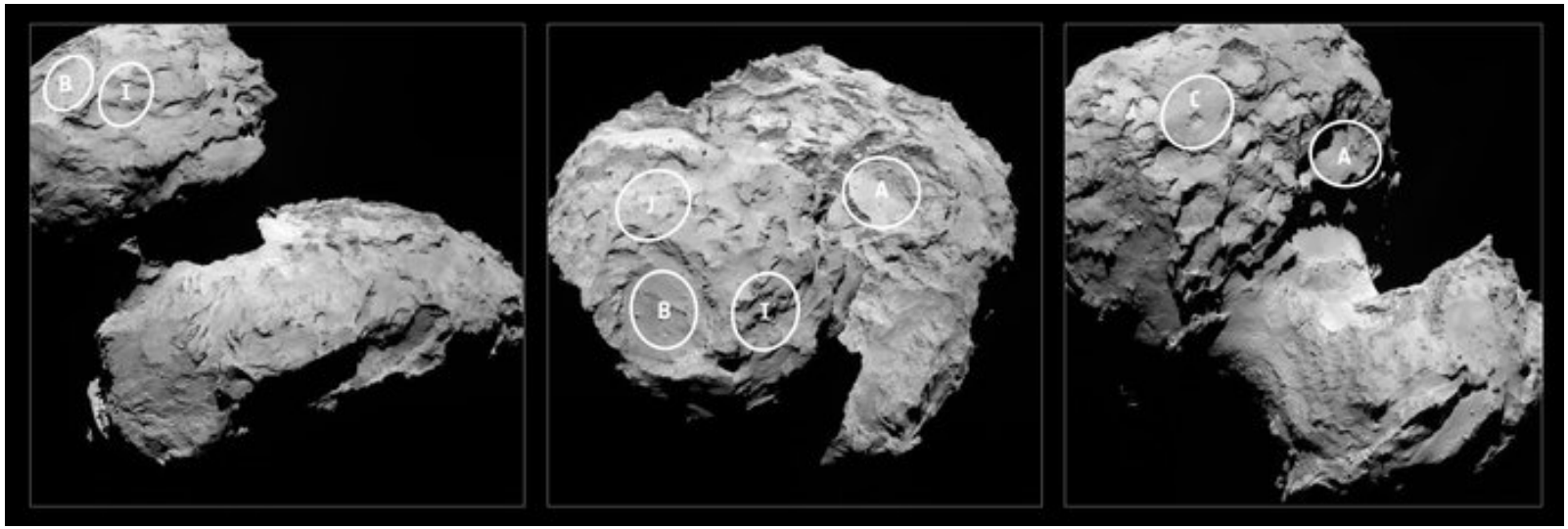
7 Sept 2014 Rosetta selfie at 50 km

Credit: ESA/Rosetta/Philae/CIVA



7 Oct 2014 Rosetta selfie at 16 km

The choice of the landing area″



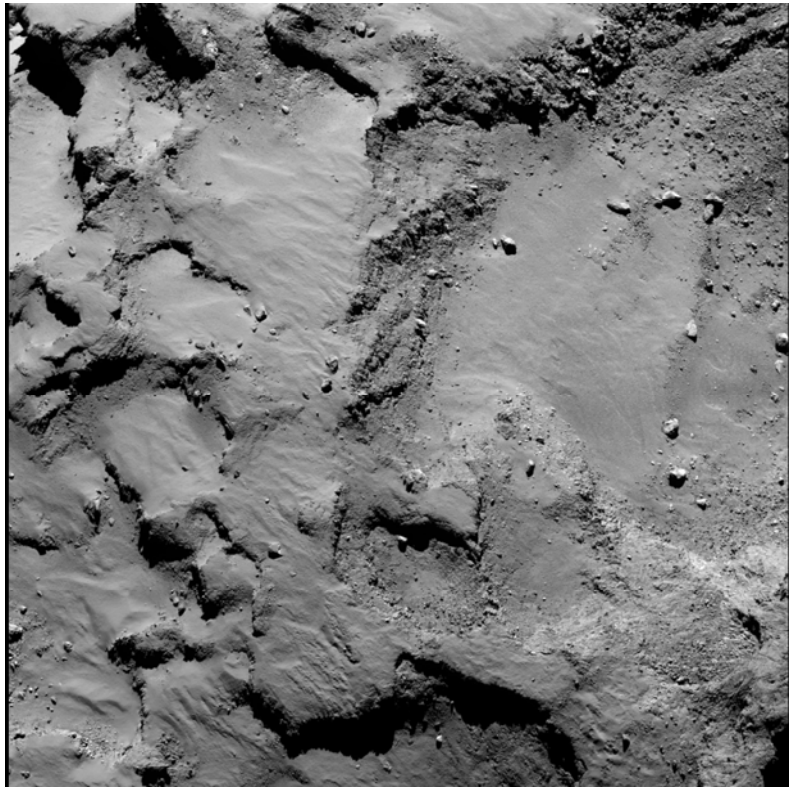
Credits ESA/Rosetta/MPS for OSIRIS Team

17 September: selected the site ″J″, named Agilkia

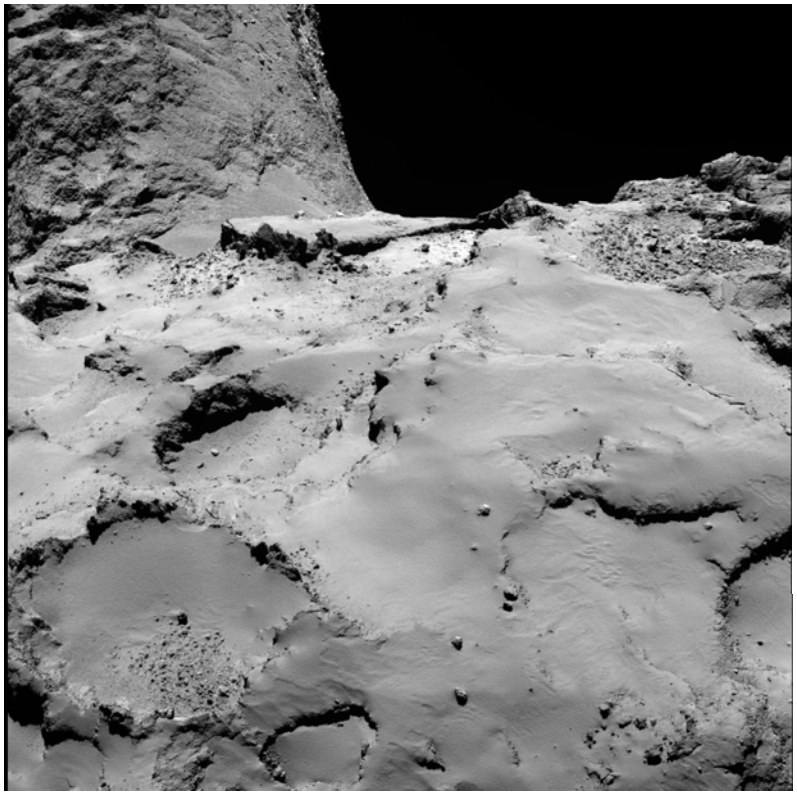
Besides being interesting for scientists, the landing area must have many additional features:

- To allow regular communications between lander / orbiter
- The surface must be regular, without craters and with reduced slopes
- The area must have a good visibility of the Sun; this will allow good scientific observations and, even more important, a good charging of lander batteries (only 64 h autonomy)

The selected landing area



Philae's primary landing site from 30 km

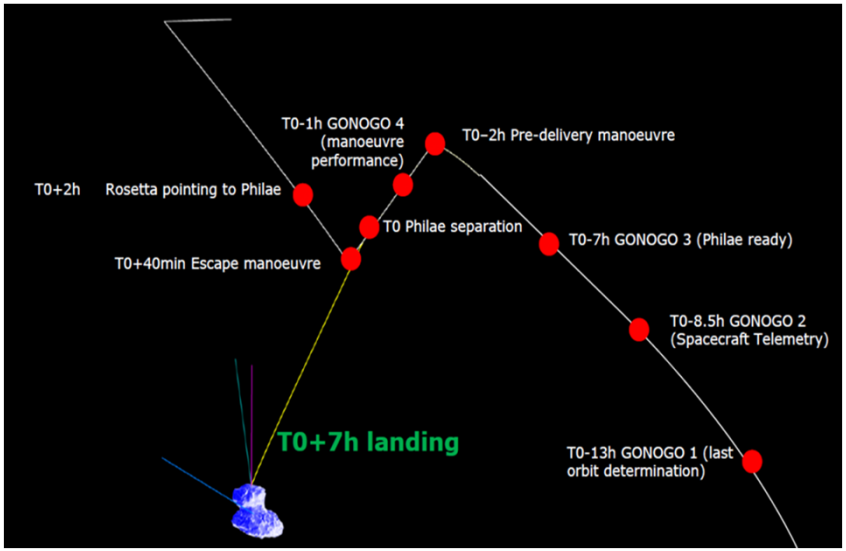


Philae's backup landing site from 30 km

Credits: ESA/Rosetta/MPS for OSIRIS Team MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA

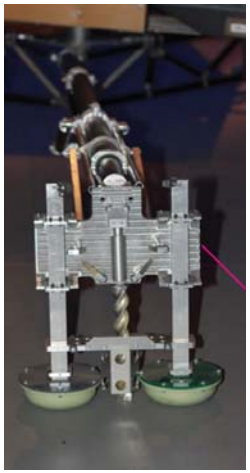
Landing in a nutshel

ESA: Philae with the SD2 Drill by Selex ES



- Distance from Sun: 450 million km
- Distance from Earth: 511 million km
- Lander released from: **5 km**
- Relative speed Rosetta / comet: few cm/s
- Landing phase: **length of 22 km flown in 7 hours**
- After separation, the lander fly in a ballistic way: no active control is available
- Descent speed at contact time: **1 m/s** (3,6 km/h)
- Time needed by radio signals from 67P to the Earth: 28 min

What is the set-up for landing?

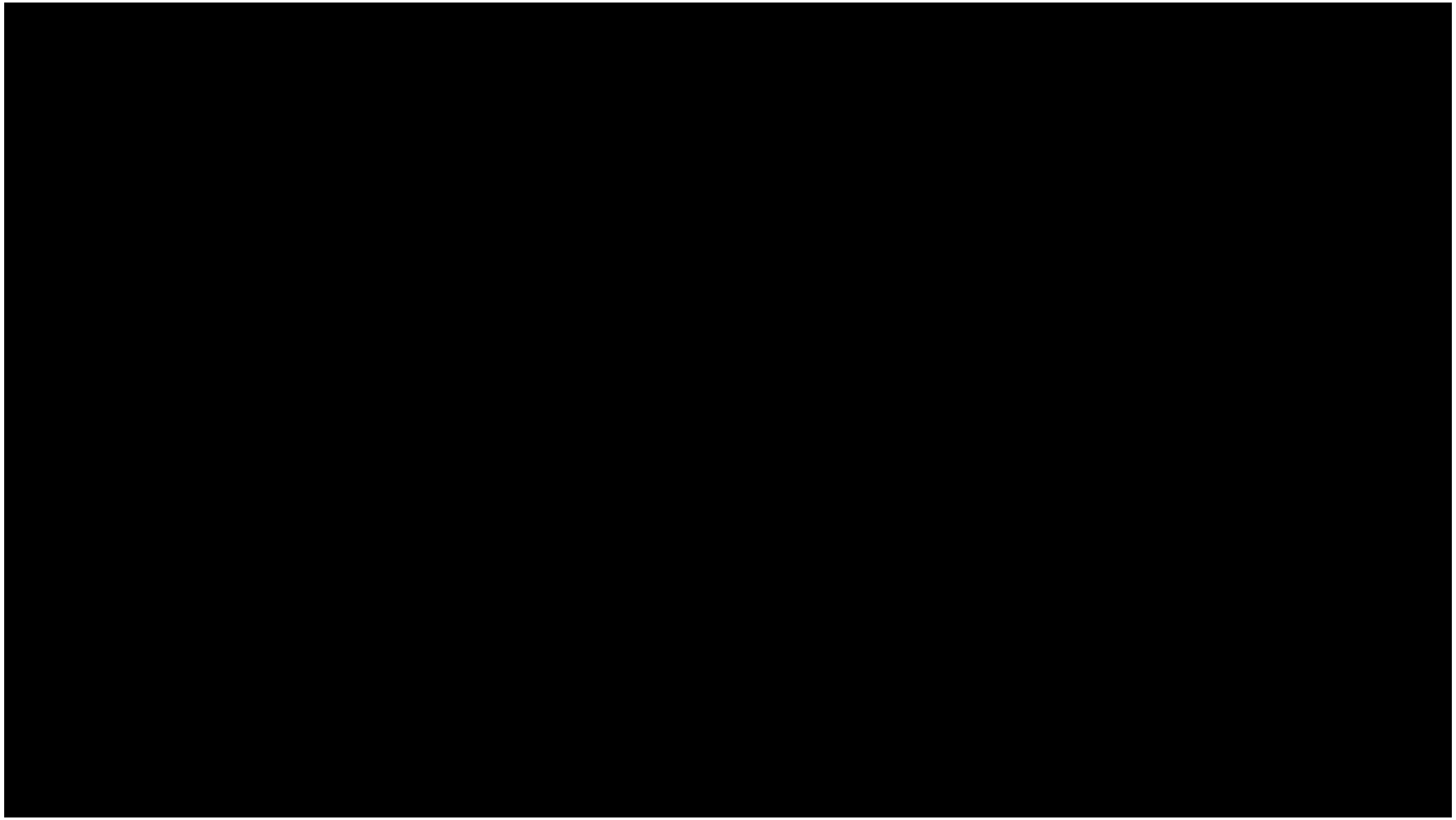


Credits ESA Bulletin

Final phase

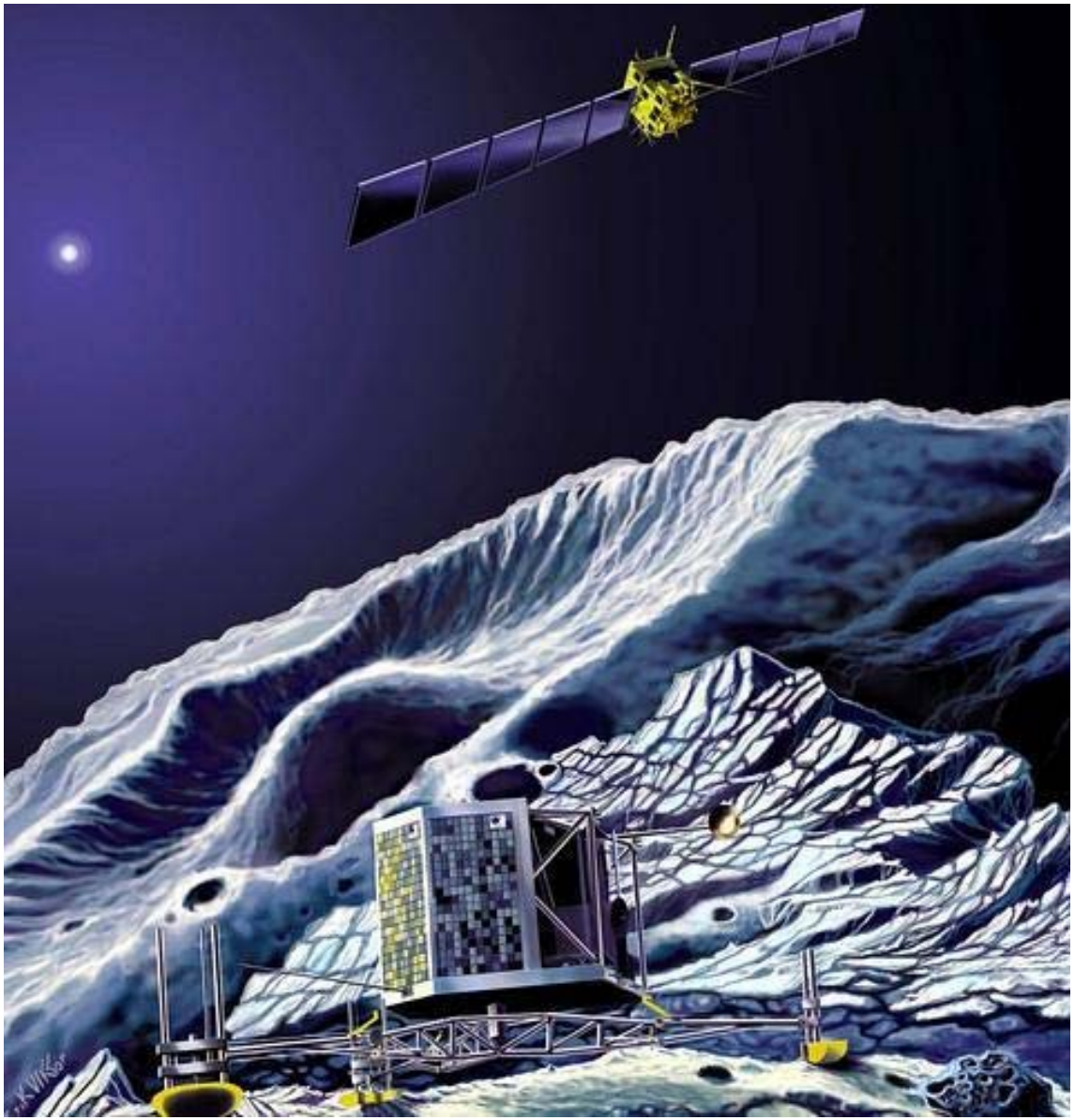
- Gravity on 67P is very low: hundred thousands times less than on Earth => an anchoring system is necessary
- Sequence:
  - ✓ A **propulsion system** will push Philae on the comet
  - ✓ A **special screw** in is present in each leg
  - ✓ Two **harpoons** will be fired by the lower part of Philae

Flight procedures for landing



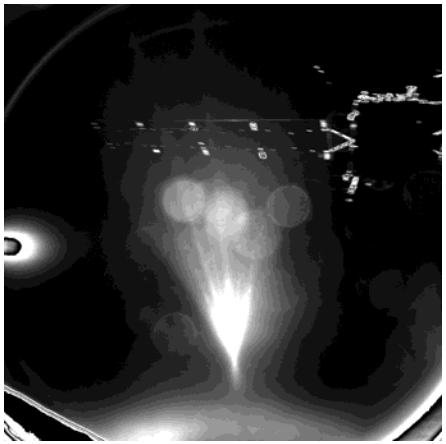
Study of comets: the Rosetta mission

Light: a Bridge between Earth and Space: Winter College on Optics



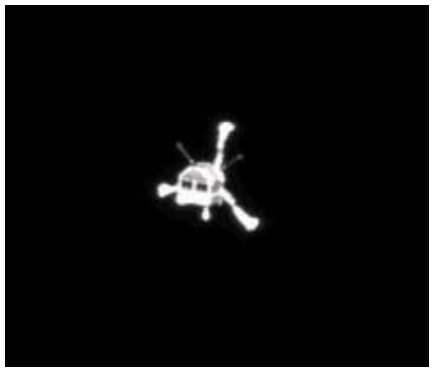
Philae is leaving Rosetta

11 November: checks on Philae are finished, there are problems but landing is started any way GO!. Distance between the Earth and 67P: 511 milioni km = 28 min delay for radio



credits ESA Rosetta Philae CIVA

Bye bye Rosetta



12 November 2014
10:03: Philae is launched
17:03: Philae is on the comet

3 Km to the comet …

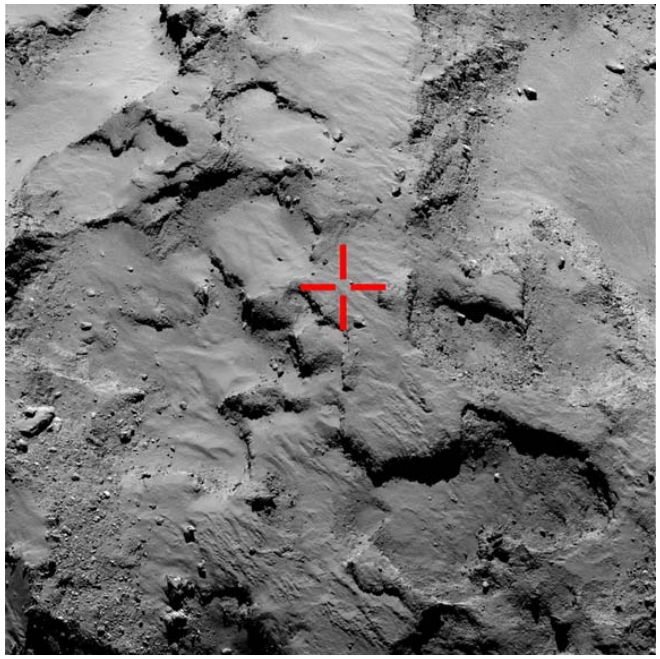
credits ESA Rosetta Philae ROLIS DLR

ROLIS image of 67P at 40 m height

credits ESA Rosetta Philae ROLIS DLR

Philae landed … yes … no … yes

The landing point



credits ESA Rosetta MPS

Philae on 67/P

Exit speed from 67/P: 0.5 m/s

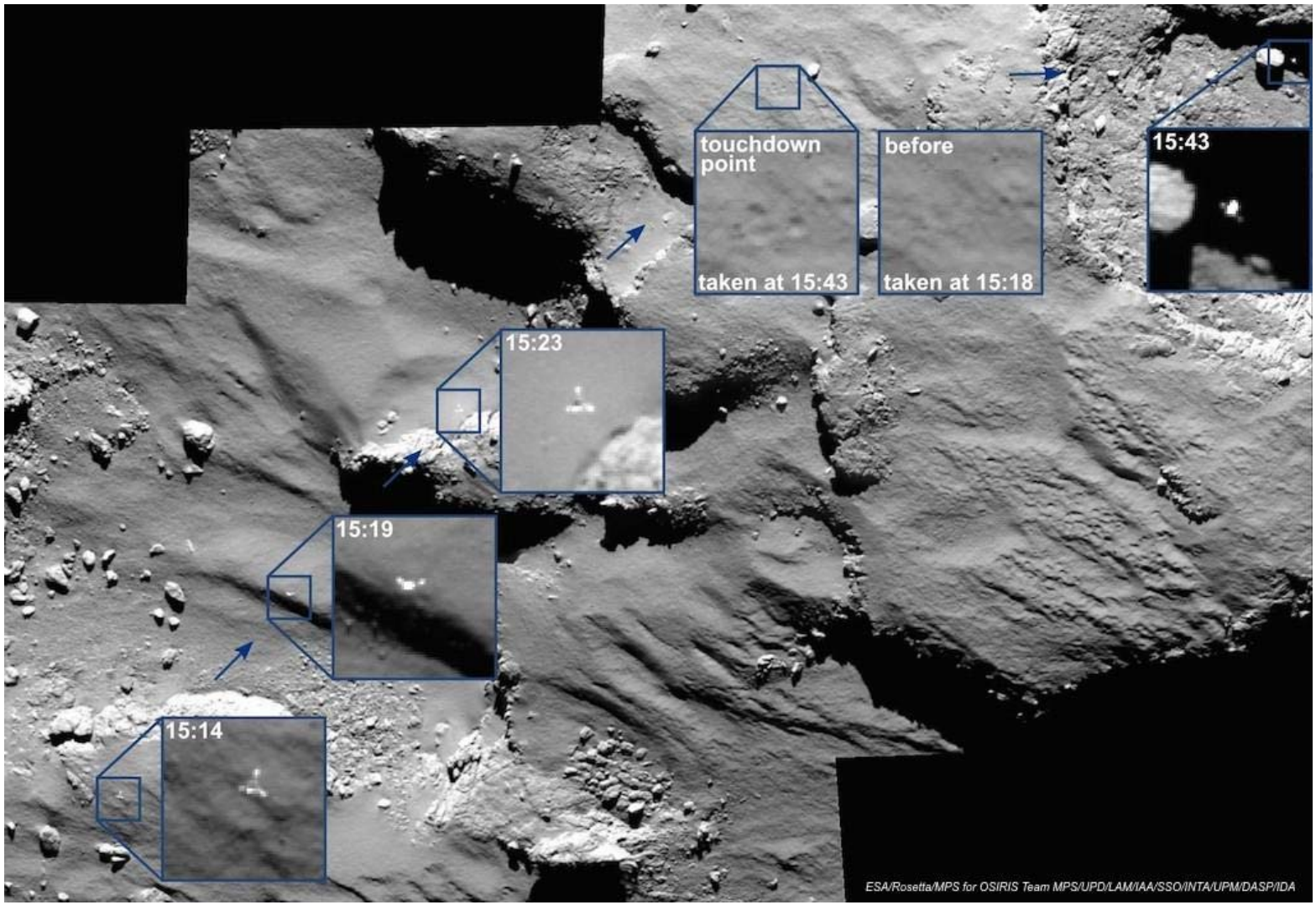
- The jets failed …
- The harpoons have not been fired …
- **Philae does not land and bounces**

Philae bounches twice

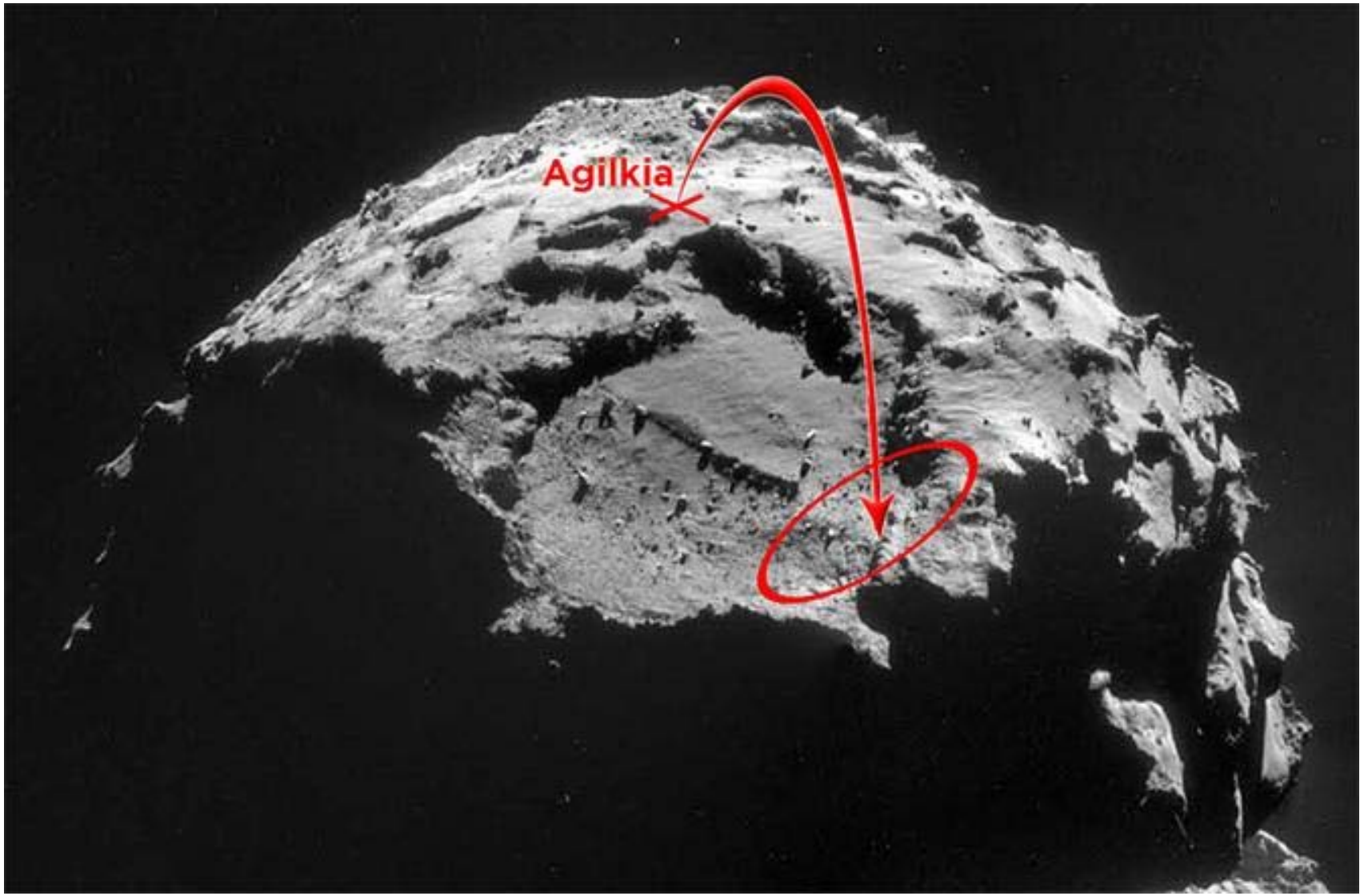
After first bounce, Philae has flown 1 h and 50 min travelling about one Km; after that another bounce lasted 7 min . **Where is Philae?**

At the time of the first bounce, all instruments thought: «landed!» and started operating according to the foreseen protocol. We have been lucky …

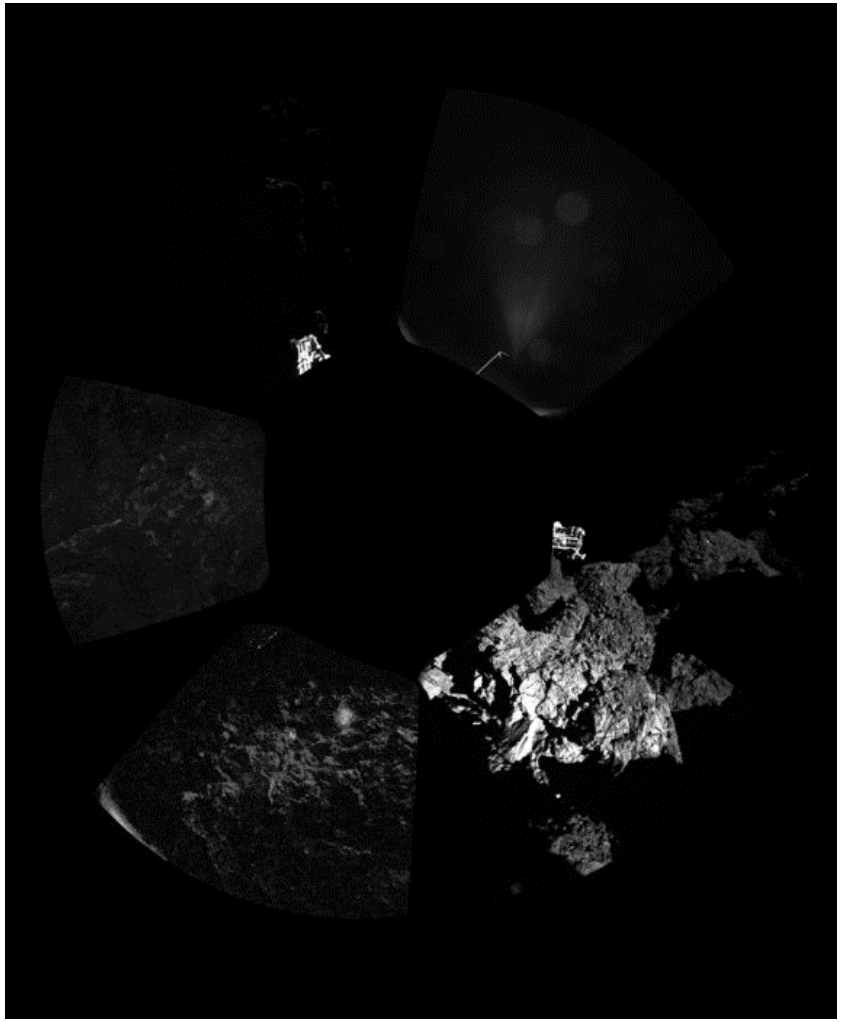
Osiris Camera spotting Philae during descent to comet

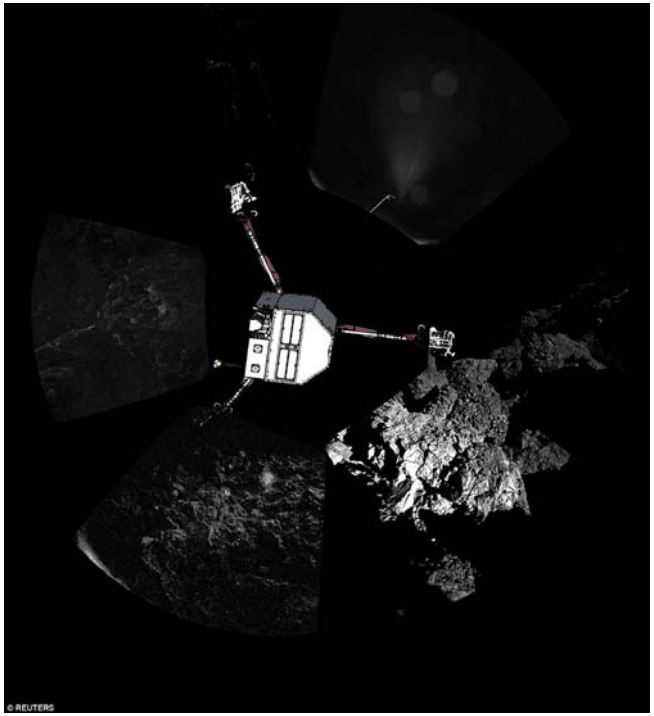


(Credit: ESA/Rosetta/MPS for OSIRIS Team MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA)


Agilkia

… shortly before sleeping

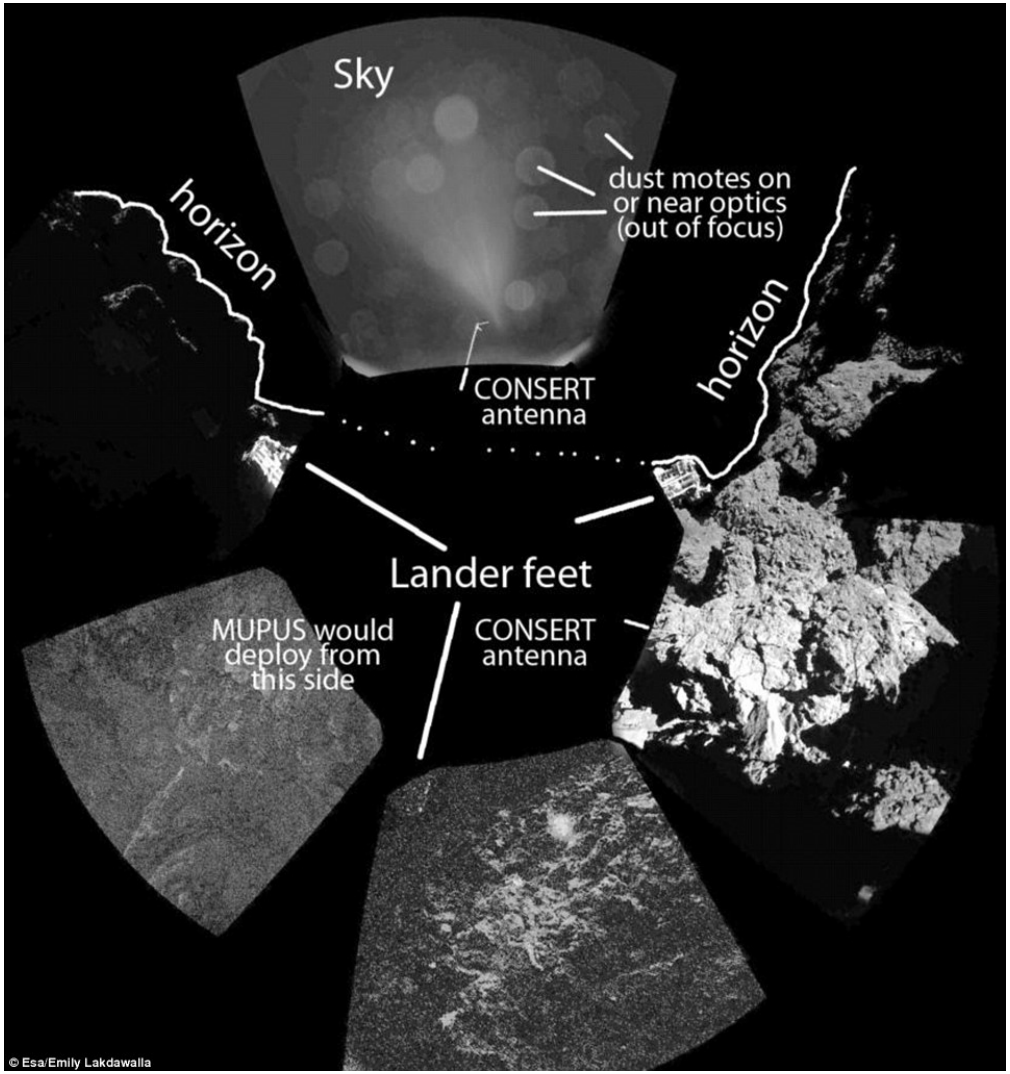




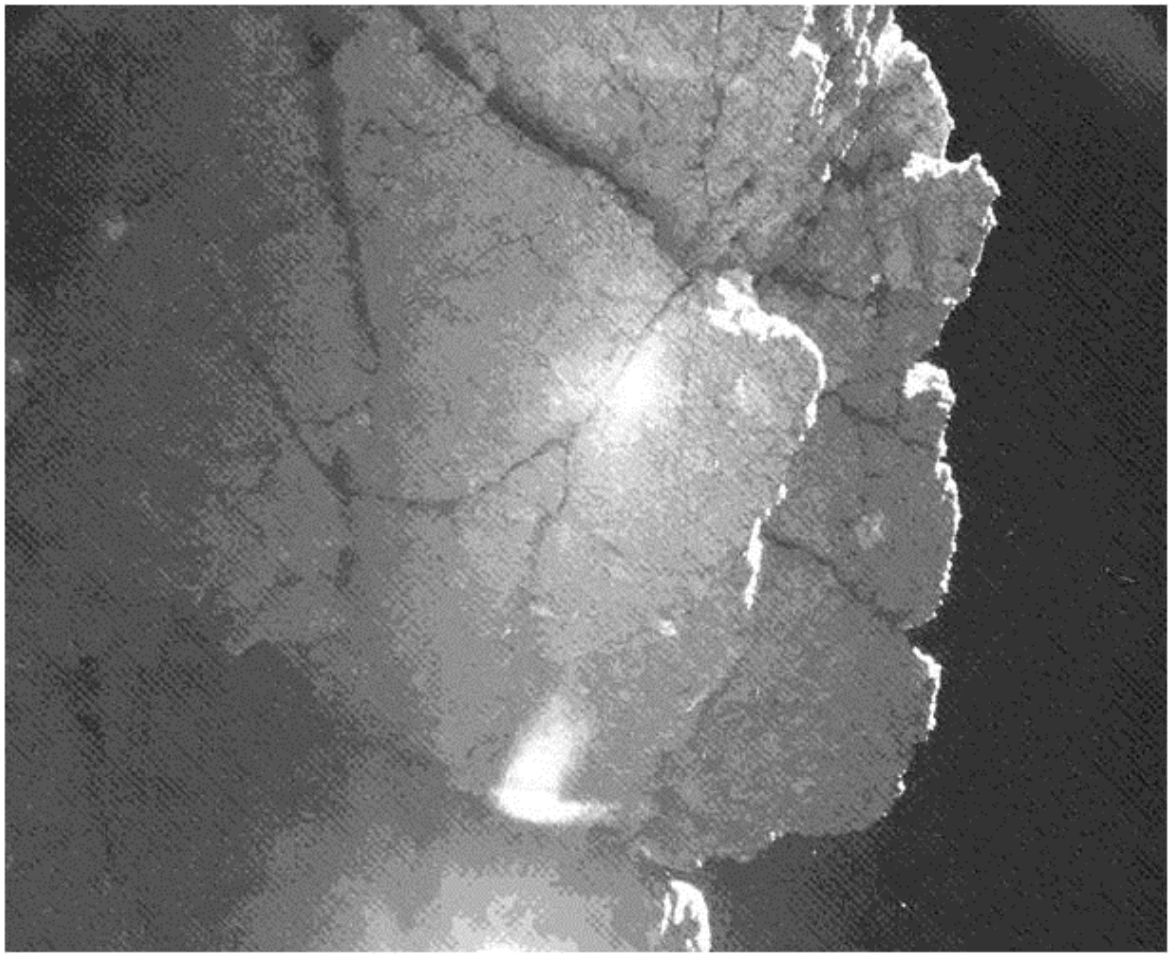
credits ESA Rosetta Philae CIVA

November 15, time 1.36 GMT:
Batteries on Philae are over !!

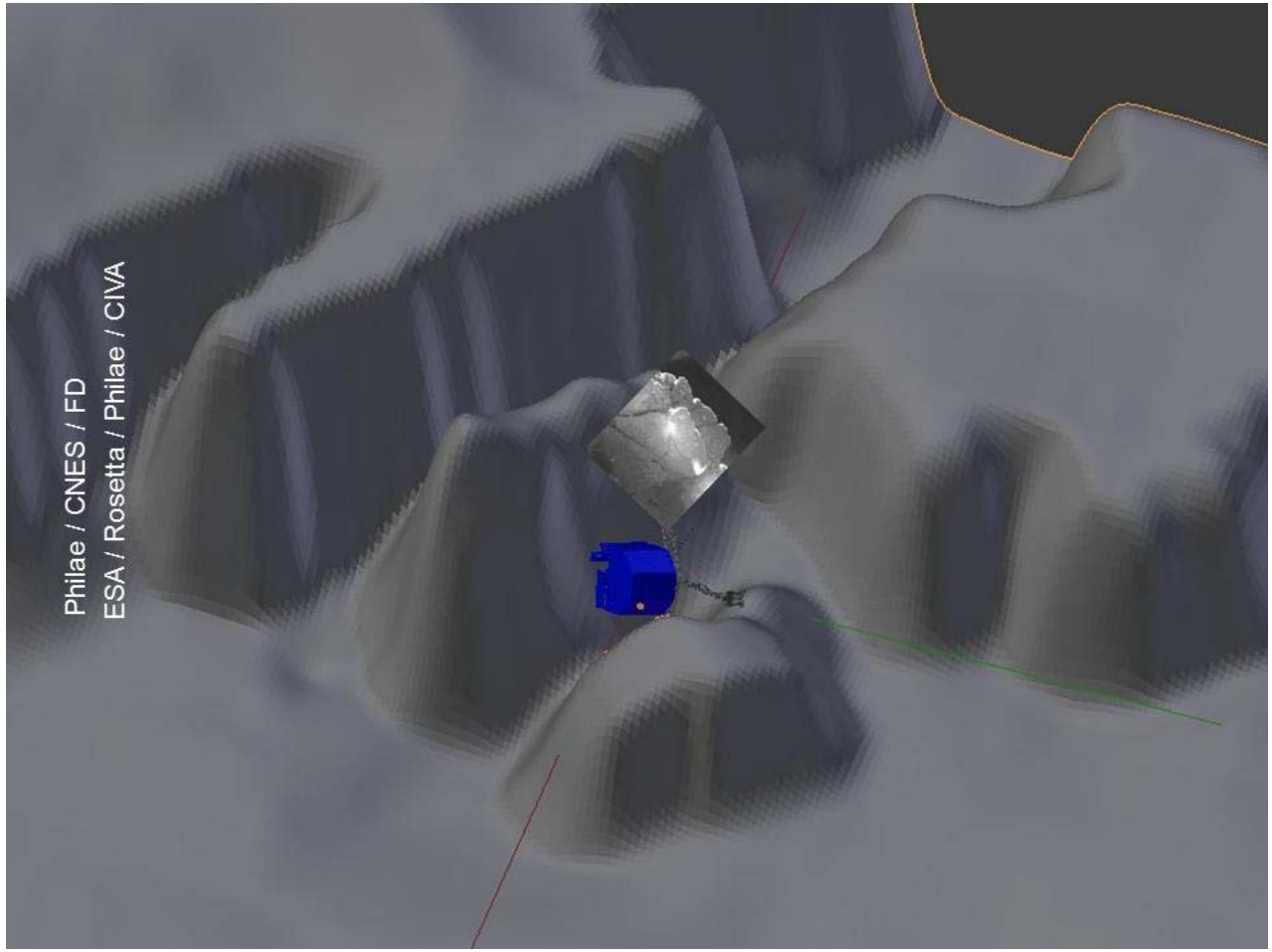
Collection of views from Philae



Where is Philae?



Philae possible location



Rosetta Philae results

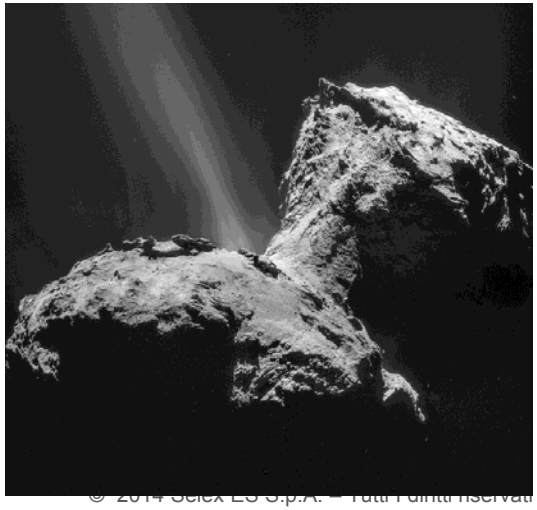
- MUPUS: Penetrator stopped at max power (broken). 10-20cm soft layer, very hard ice layers below.
- SESAME experiment (Surface Electrical, Seismic and Acoustic Monitoring Experiment) : cometary activity at landing site is low, presence of a large amount of water ice under the lander.
- SD2 (Drill): it performed all the steps: drilling, sampling and delivering to ovens. But no information yet if materials has been collected or not.
- CIVA and Rolis collected images. Rolis extended its operation to two landing sites.

- Presently only 1.5hr of Solar Panel illumination; minimum 6hr are necessary
- Potential for future operation, in spring, when illumination conditions could improve

Rosetta escort phase 2015

Rosetta is using its **Navigation Camera** for the navigation, with orbits that could reach, if necessary, a distance of few Km from the comet. During distant and close fly-byes, Rosetta will:

- Monitor nucleus topography and composition changes
- Monitor changes in thermal and physical properties of nucleus materials
- Monitor coma composition, flux changes in gas and dust
- Monitor the evolution of the physical properties of the dust
- Monitor interaction between dust and gas in acceleration regions
- Investigate Nucleus-Inner Coma relationships
- Monitor jets activities through coordinated campaigns



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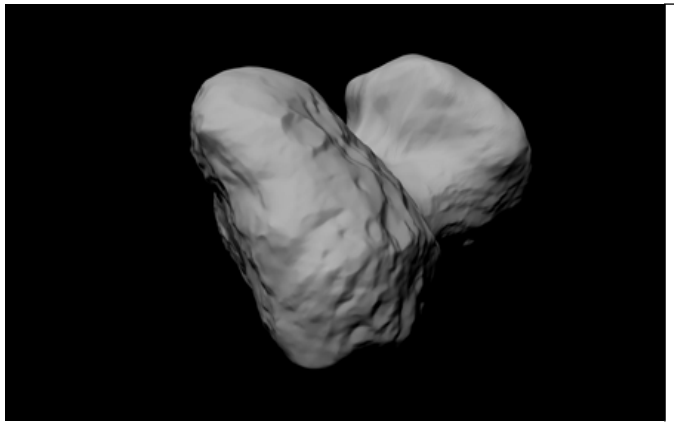
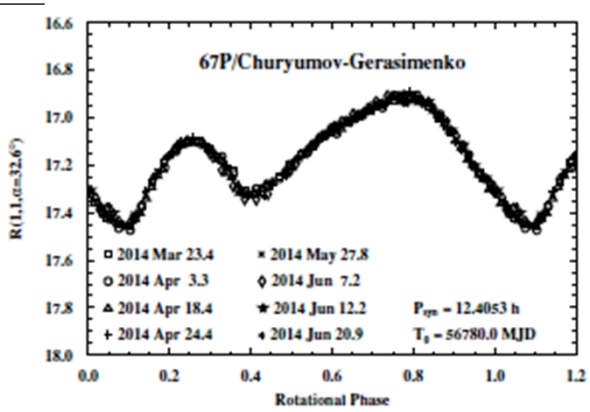
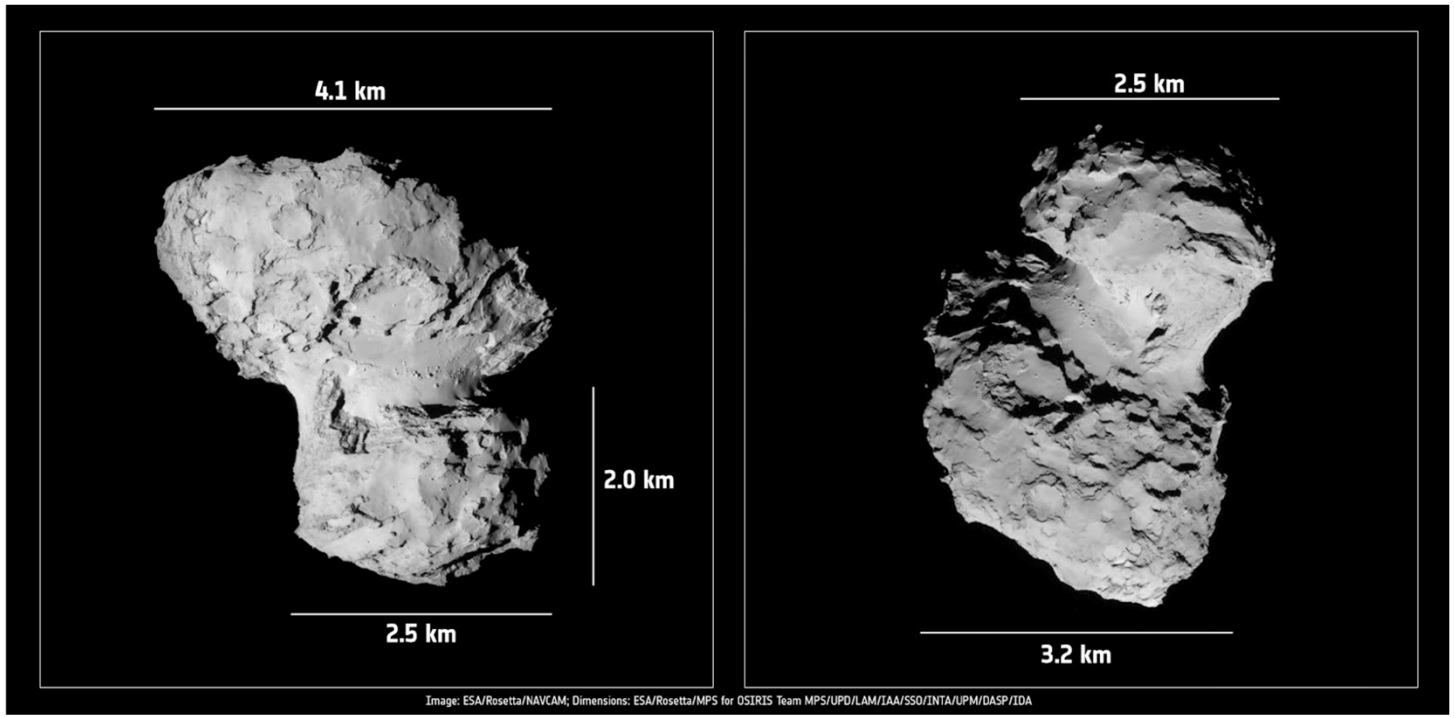
The real comet 67P/Churyumov-Gerasimenko





Mass ~ 10^{13} kg
Volume ~ 25 km^3
Density ~ 0.4g/cm^3
Rotation ~ 12.4 hour

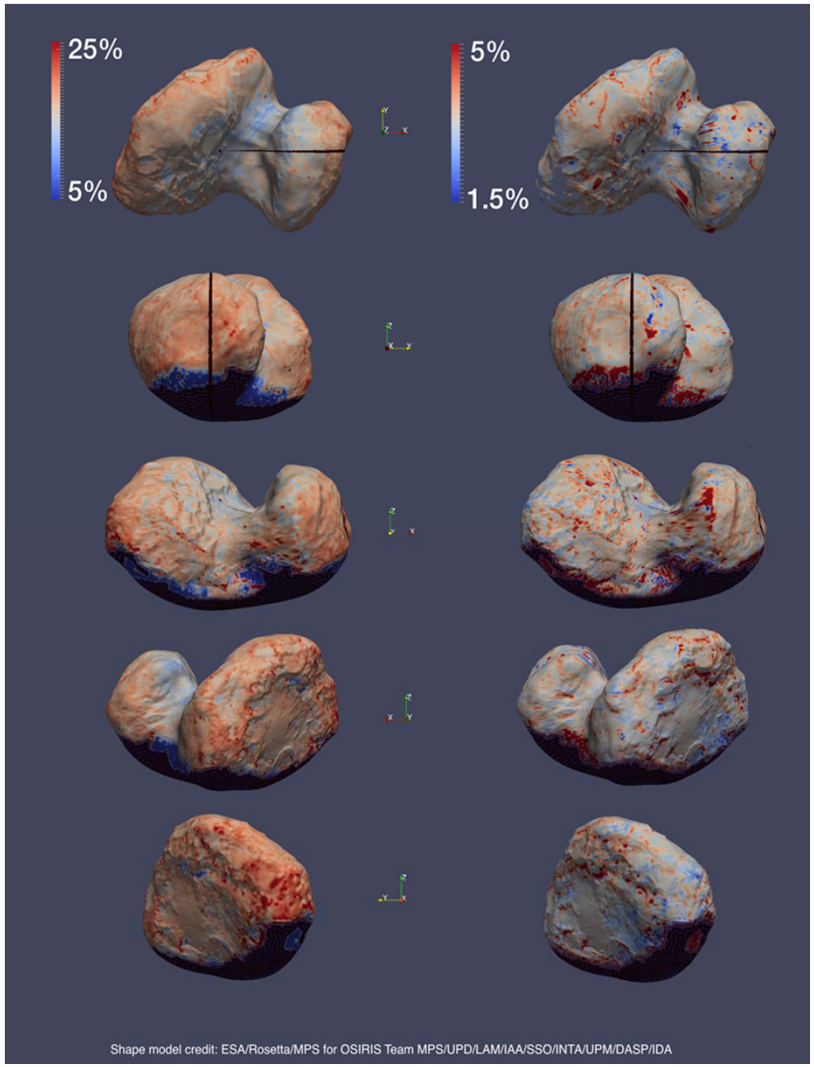


Different albedo values ….

Study of comets: the Rosetta mission

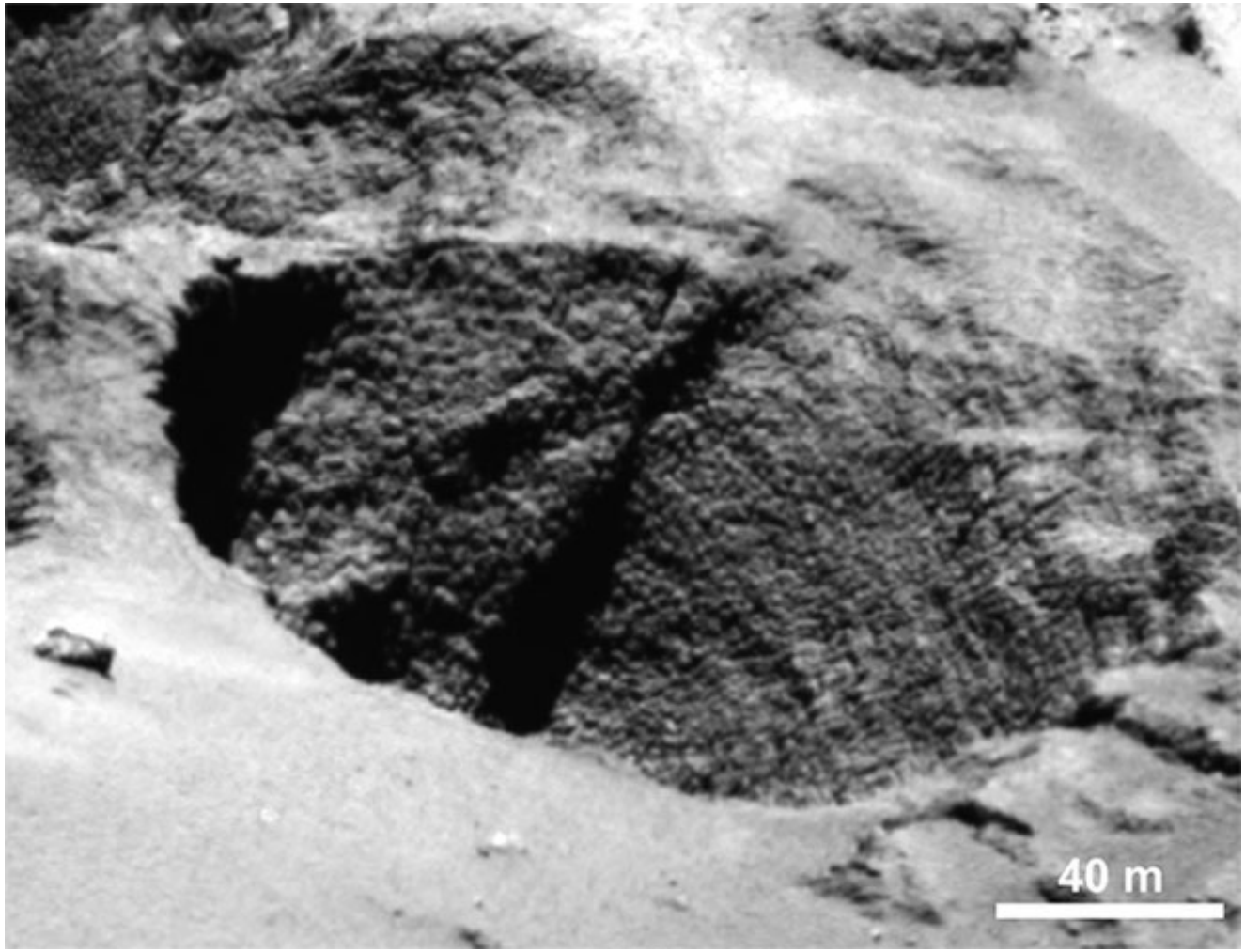
Light: a Bridge between Earth and Space: Winter College on Optics

VIRTIS: spectral slopes

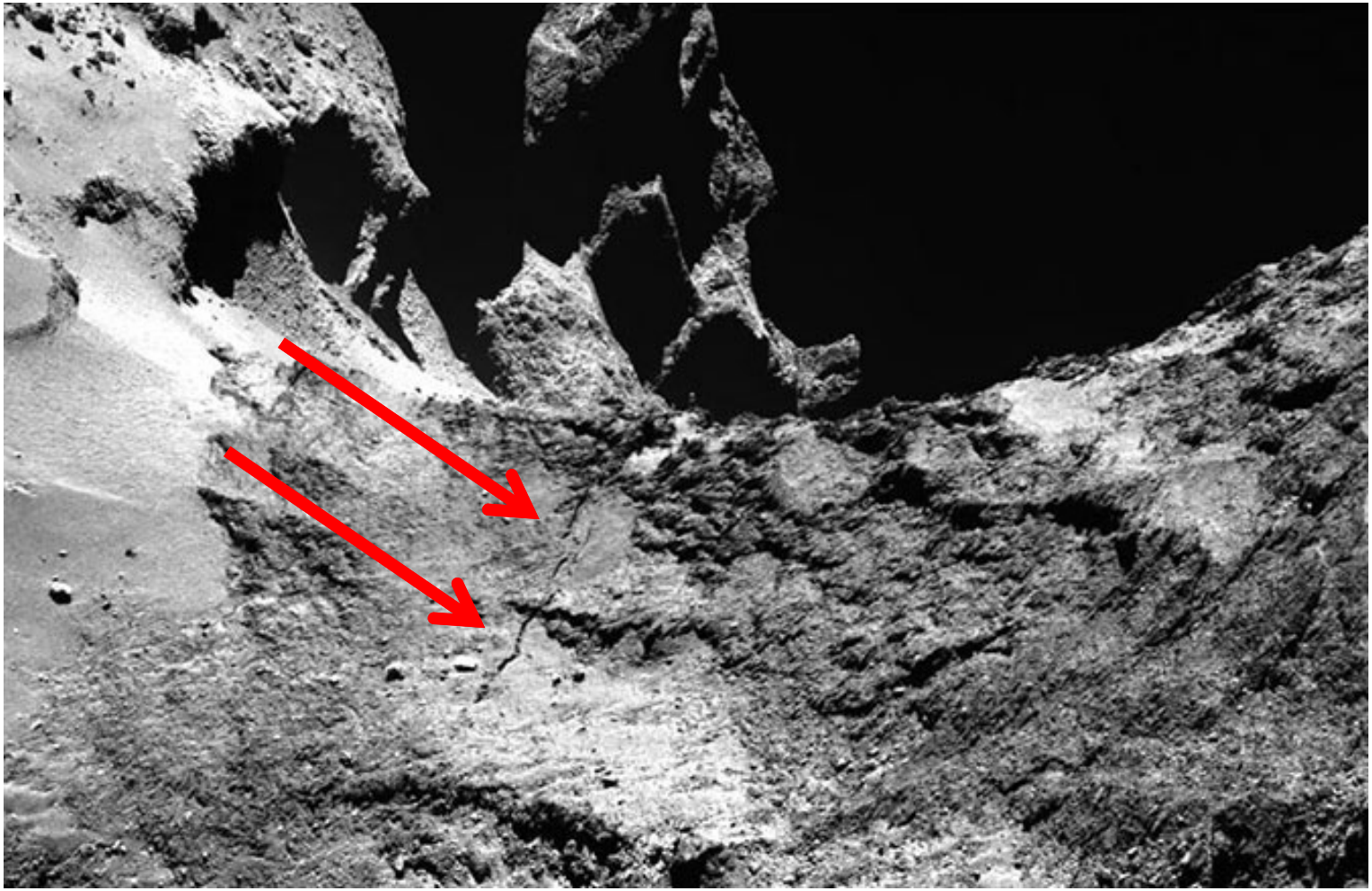


- Variability of the VIS (0.5-0.8 μm, left column) and IR (1-2.5 μm, right column) spectral slopes across the nucleus.
- Data were acquired from 7th Aug 2014 to 2nd Sep 2014;
- Slopes are averages calculated on illuminated points having incidence and emission angles below 80° .
- Slopes in VIS 5 times larger than in the IR
- In the VIS range, spectra are clearly bluer in the region of the neck
- Presence of water or smaller grain sizes

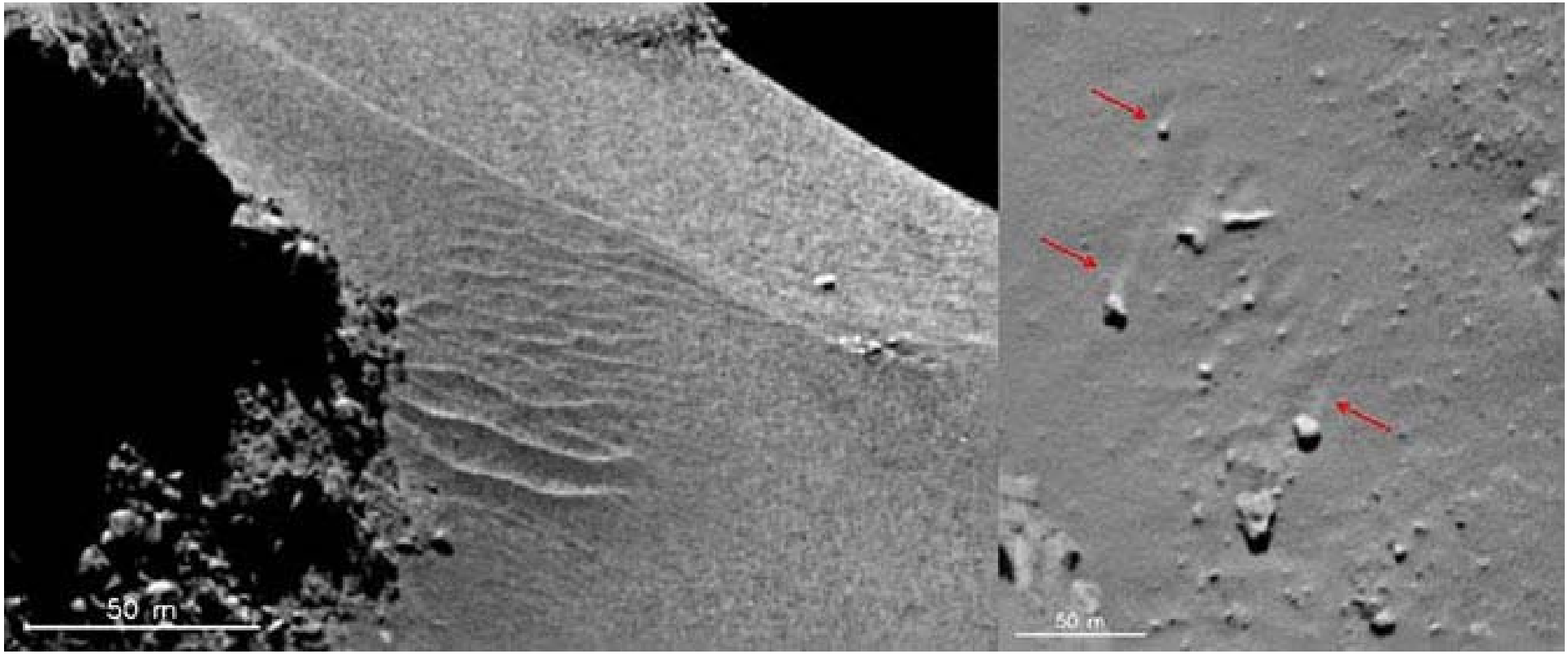
Wells and eggs



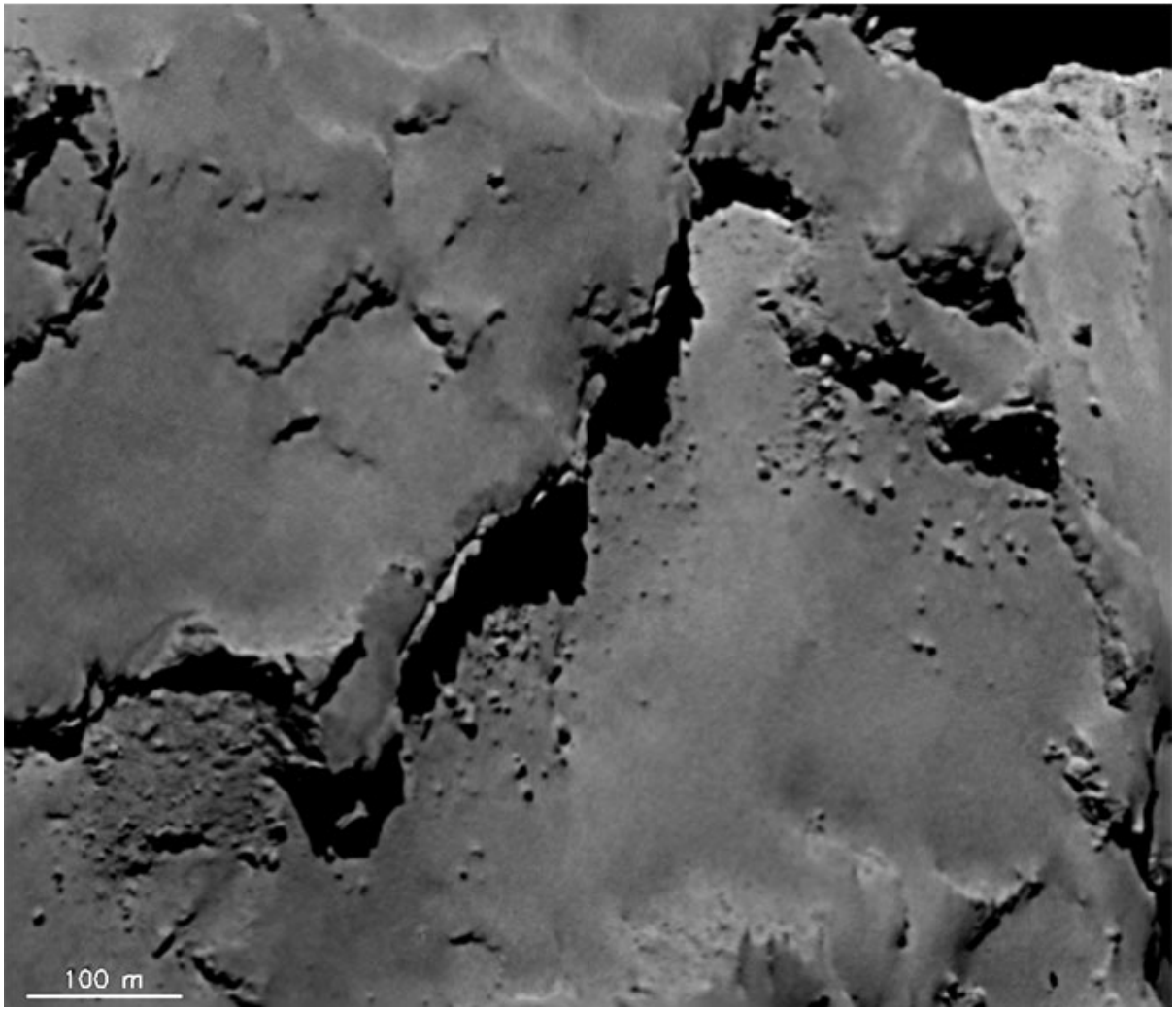
Cracks



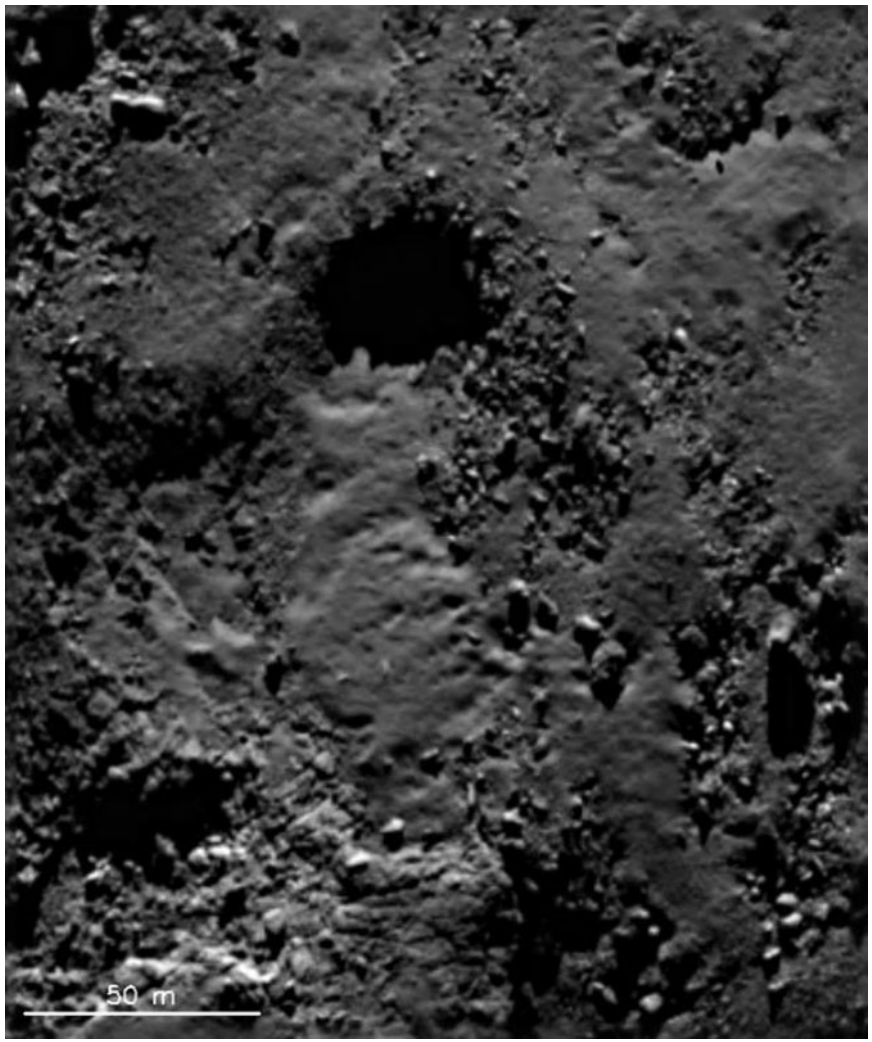
Effect of the wind?



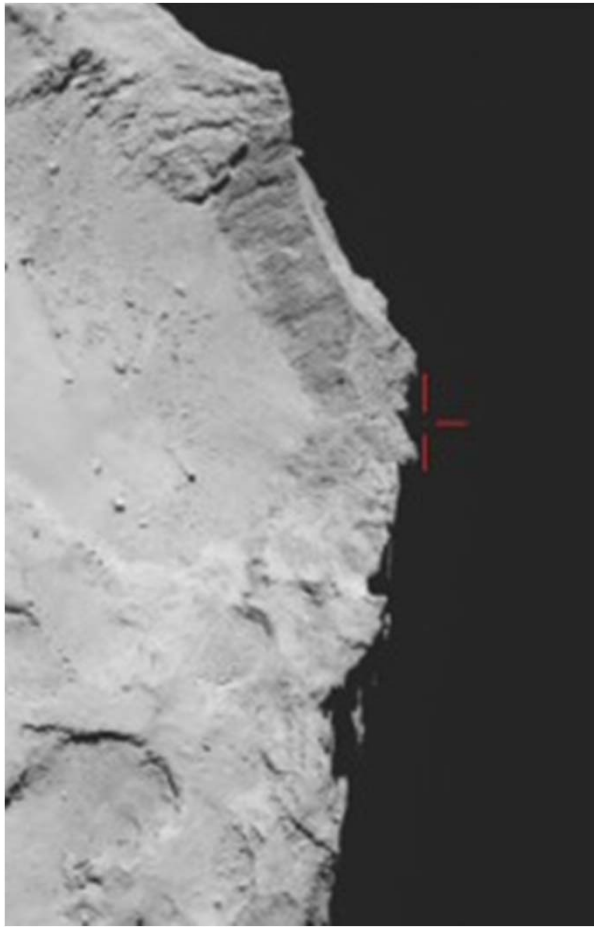
Landslides



Comet erupted material



What happens tomorrow, Feb 14th ?



Tomorrow, **Feb 14th**, Rosetta is going to orbit at only **6 Km from the comet**; the orbit has been designed to have the Sun on the back for the best comet visibility without any shadow.

Objectives of this close fly-by:

- Further search of Philae
- Possibility to perform excellent observations

Rosetta mission: print echoes

Celebrating the first ever landing on a comet. Congratulations to the European Space Agency

Rosetta sulla cometa
«Missione compiuta»
Centrato un traguardo storico grazie alla tecnologia italiana

Sulla **COMETA**
per «capire» la vita

Telecamera, trivella, capo missione
Lassù c'è (anche) la scienza italiana

Sd2, il «trapano» italiano che scaverà la superficie

«Missione Rosetta»
l'Italia sulla cometa
Dalla sonda spaziale europea si è sganciato il lander «Philae» che ha toccato il corpo celeste

SPAZIO. La sonda europea ha sganciato Philae
Un passo storico: Rosetta (e l'Italia) sulla cometa
Ora è caccia ai misteri della vita
L'apporto della nostra tecnologia

Quanta Italia è arrivata sulla cometa
Il successo di Rosetta è nato in gran parte nel nostro Paese, grazie al rapporto tra industria e università

«Il viaggio della Selex, sulla cometa con Rosetta»
Sensori, telecamere, macchina fotografica realizzati a Campi. «Missione iniziata 20 anni fa»

Così è fatta una cometa
Le rocce viste da vicino nelle prime immagini della sonda Philae
L'imprevisto: si è posata su un terreno instabile, non potrà trivellare

Spazio Il lander sull'orlo di un cratere
Scatta l'ipotesi dell'ibernazione

La navicella è in bilico
«Philae» sull'orlo di un burrone
e l'ancoraggio è impossibile

FONDAMENTALE IL RUOLO DEL NOSTRO PAESE
Missione che parla italiano, tra università ed enti di ricerca

"Second" Firsts of Rosetta mission

Engineers had to fix a number of other key issues for Rosetta mission:

- ESA had to set-up a ground TLC network suitable for planetary distances as Rosetta was requiring; this has been done as a cooperation with JPL;
- Hybernation had never been tried before
- Ground station and scientific team: they both had to remain operational for a very long time, 22 years
- Optical navigation (NAVCAM); never tried before. Absolutely necessary, thinking that before entering into 67P orbit, the position of the comet was known with an error of 10,000 Km
- Power generation and control; due to the large solar panels, the power ranges from 8 Kw (orbit around the Earth) to only 400 w @ 5 AU
- Problem of landing on a body with extremely low gravity

In the first years of the mission, engineers had to face several problems:

- High temperatures (up to 90 Celsius), during Earth fly-by
- Some SW glitches
- When setting the new mission, an eclips (24 min) due to Mars was forgotten
- A leak of Helium in the tanks (reduced cruise time)

Rosetta has demonstrated how important is a strong cooperation between scientists and engineers for the whole mission lenght.

Aknowledgments

Angioletta Coradini

For planetary exploration a very few played a major and critical role. Angioletta is among them. We miss her work and her smile.

Special thanks to :

Fabrizio Capaccioni (Istituto di Astrofisica e Planetologia Spaziali – INAF)

Emanuele Pace (Osservatorio Polifunzionale del Chianti , University of Florence – Dep.Physics and Astronomy)

who strongly supported me and;

thanks to many colleagues from Selex ES (previously Officine Galileo) who built and tested the instruments and subsystems that are now flying on Rosetta.