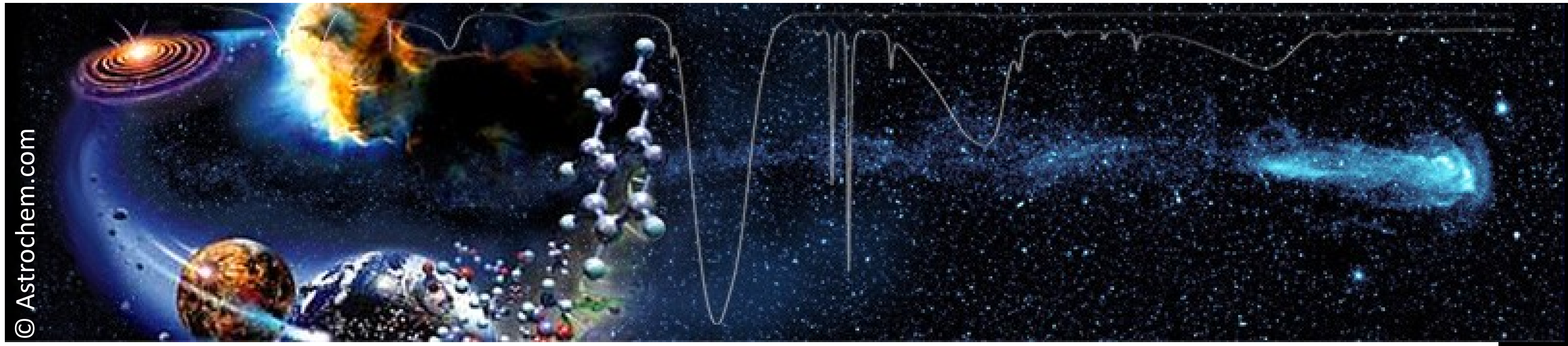

Astrochemistry and Astrobiology of the Small Bodies in the Solar System

- *The challenges of the Rosetta mission*
- *The astrobiological legacy of Rosetta*
- *Astrochemistry of the small bodies of the Solar System*
- *Astrobiology challenged by Astrobiowashing*

Hervé COTTIN

LISA, Laboratoire Interuniversitaire des Systèmes Atmosphériques
Université Paris Est Créteil (UPEC), Université Paris Cité (UPC),UMR CNRS 7583

@hcottin

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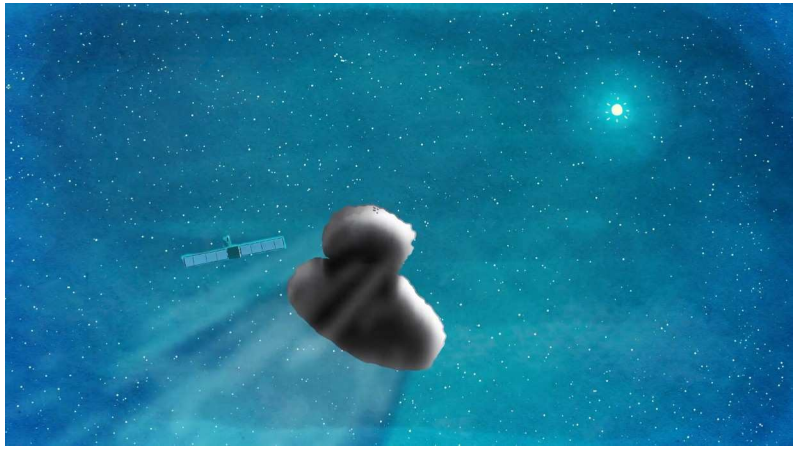
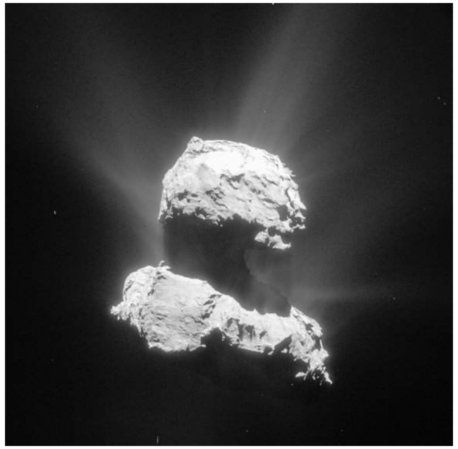
UPEC
UNIVERSITÉ PARIS-EST CRÉTEIL VAL DE MARNE
Connaissance - Action

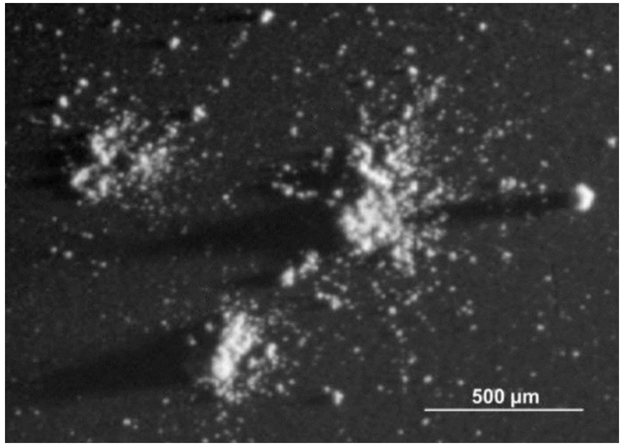
lisa
Laboratoire Inter-universitaire des Systèmes Atmosphériques

The challenges of the Rosetta mission

Hervé COTTIN

LISA, Laboratoire Interuniversitaire des Systèmes Atmosphériques
Université Paris Est Créteil (UPEC), Université Paris Cité (UPC),UMR CNRS 7583



@hcottin

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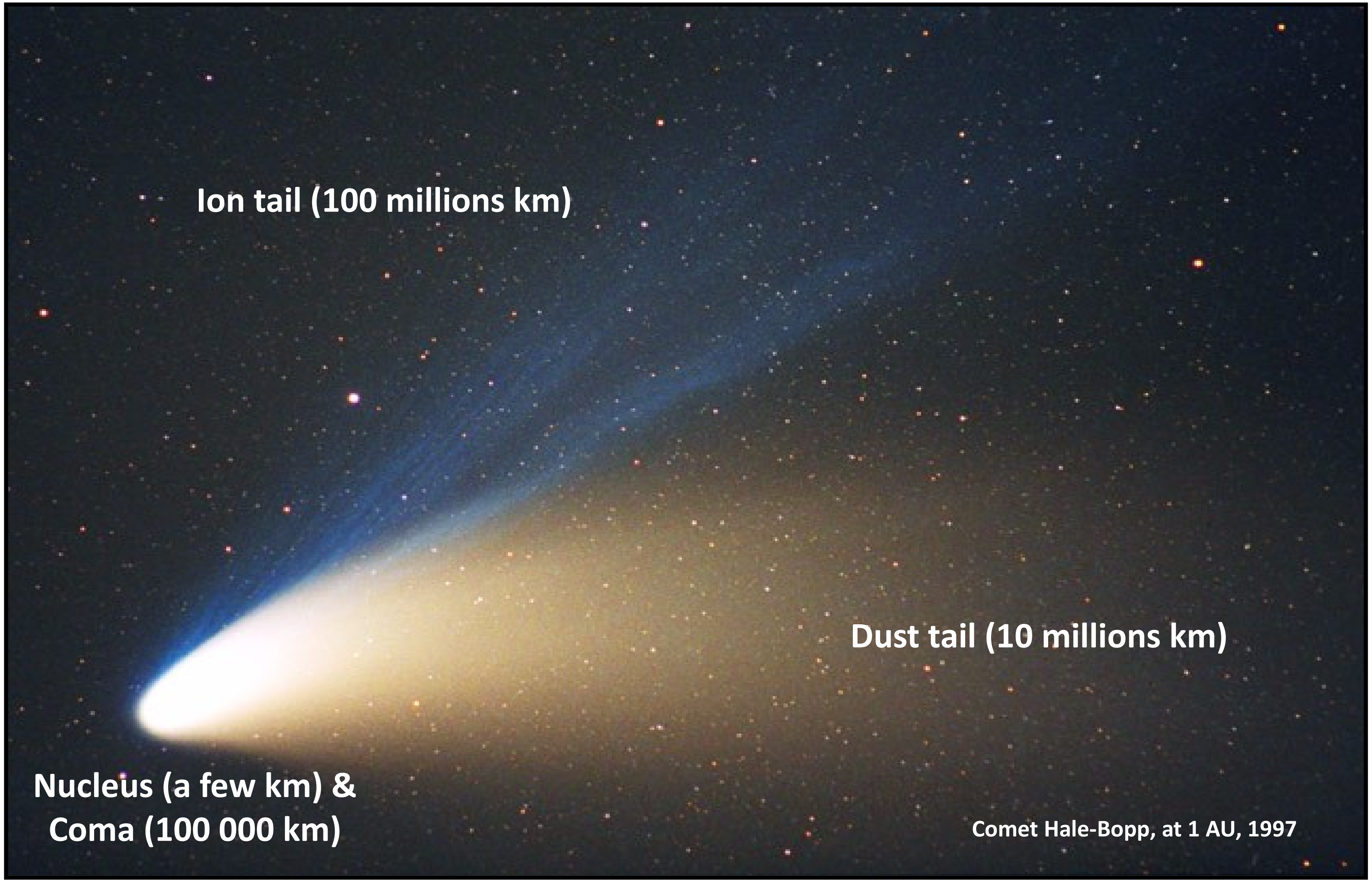
UPEC UNIVERSITÉ PARIS-EST CRÉTEIL VAL DE MARNE
Connaissance - Action

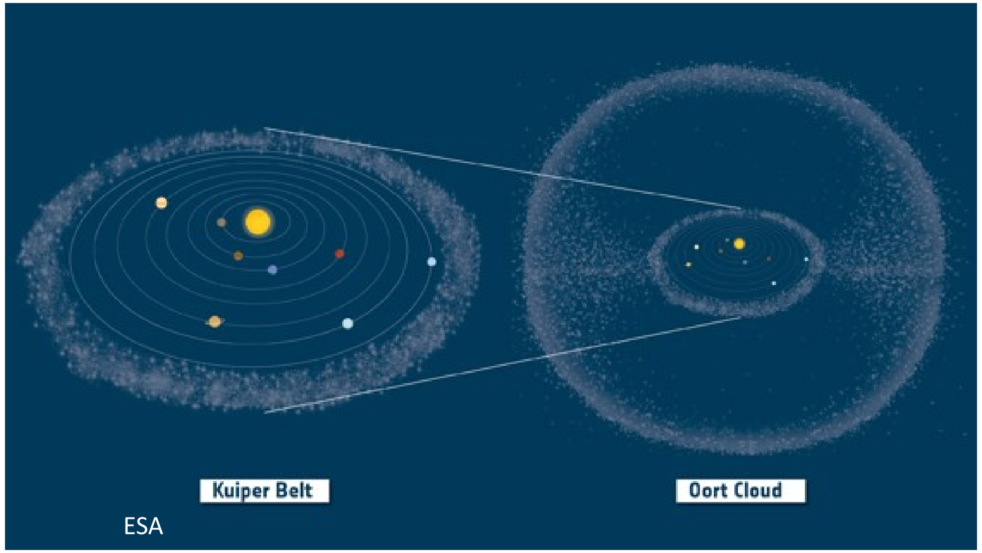
lisa Laboratoire Inter-universitaire des Systèmes Atmosphériques

What is a comet ?

A small body of the Solar System
made of ices and dust



Where do they come from ?



Two main reservoirs

The Kuiper Belt

The Oort Cloud

An excentric orbit

For 67 P

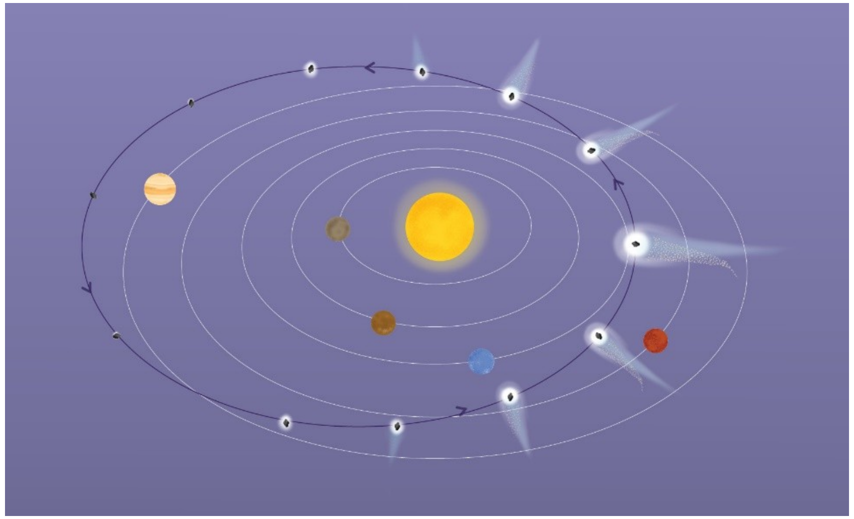
Perihelion : 1,2432 au

Aphelion : 5,6829 au

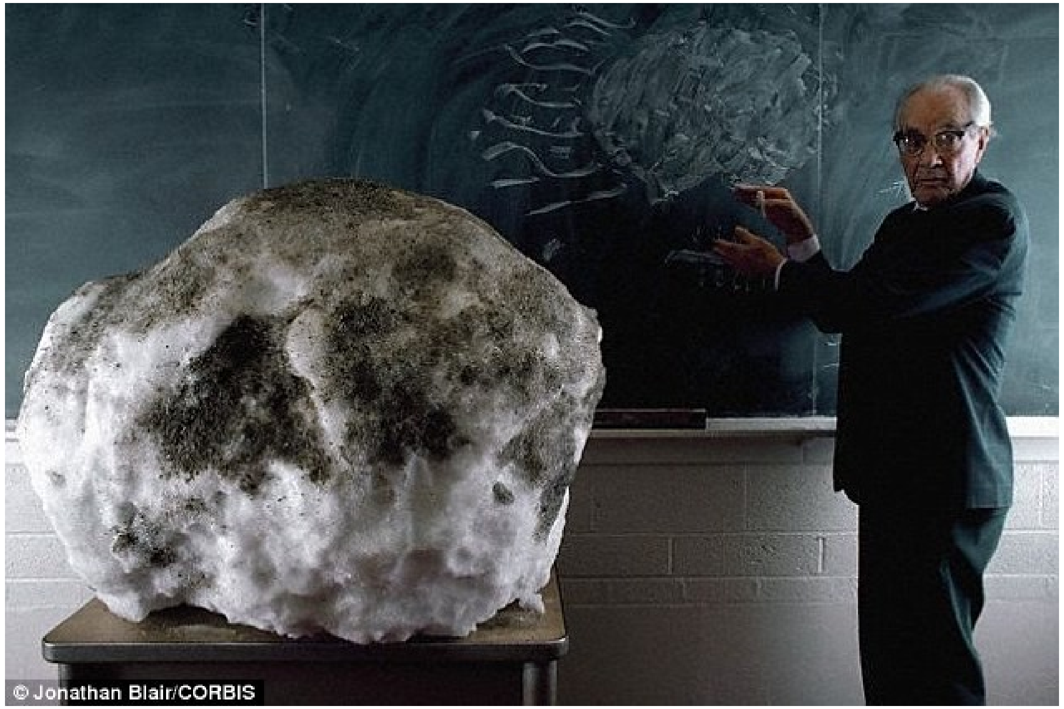
Orbit : 6,44 y

au : astronomical unit

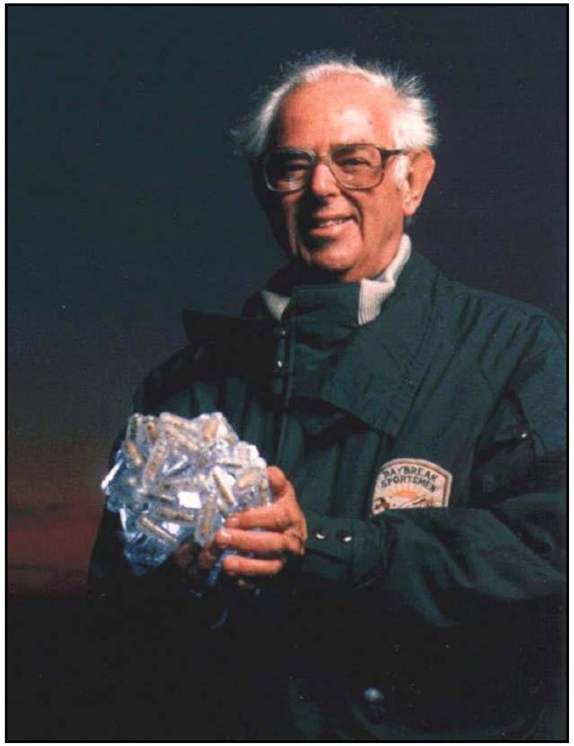
Sun-Earth distance: 150 10^6 km



Making a comet nucleus



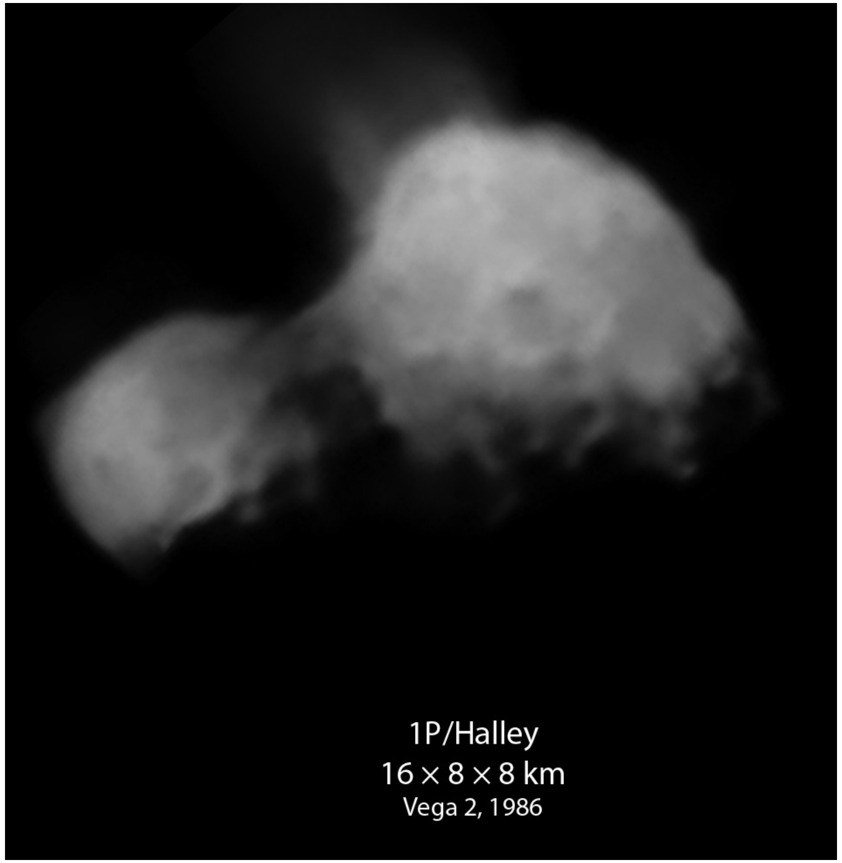
A dusty snowball ?
(Whipple, 1950)



An interstellar aggregate ?
(Greenberg, 1982)

What do they look like ?

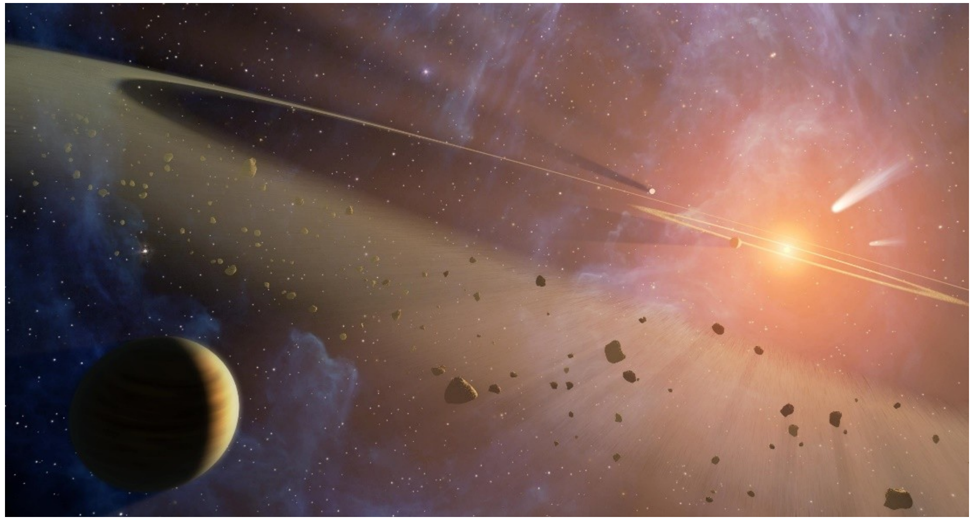
1P/Halley
March 14th 1986, from 2000 km
Giotto



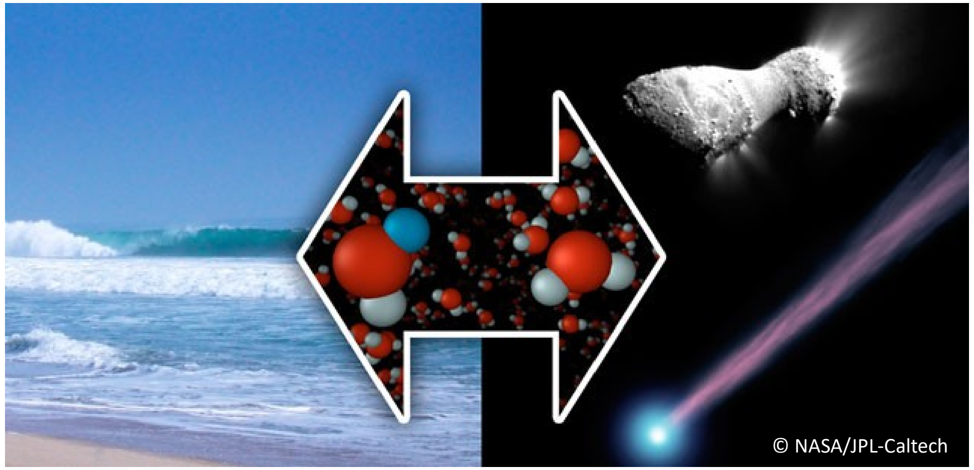
1P/Halley
16 × 8 × 8 km
Vega 2, 1986

What do they look like ?

Why study comets ?

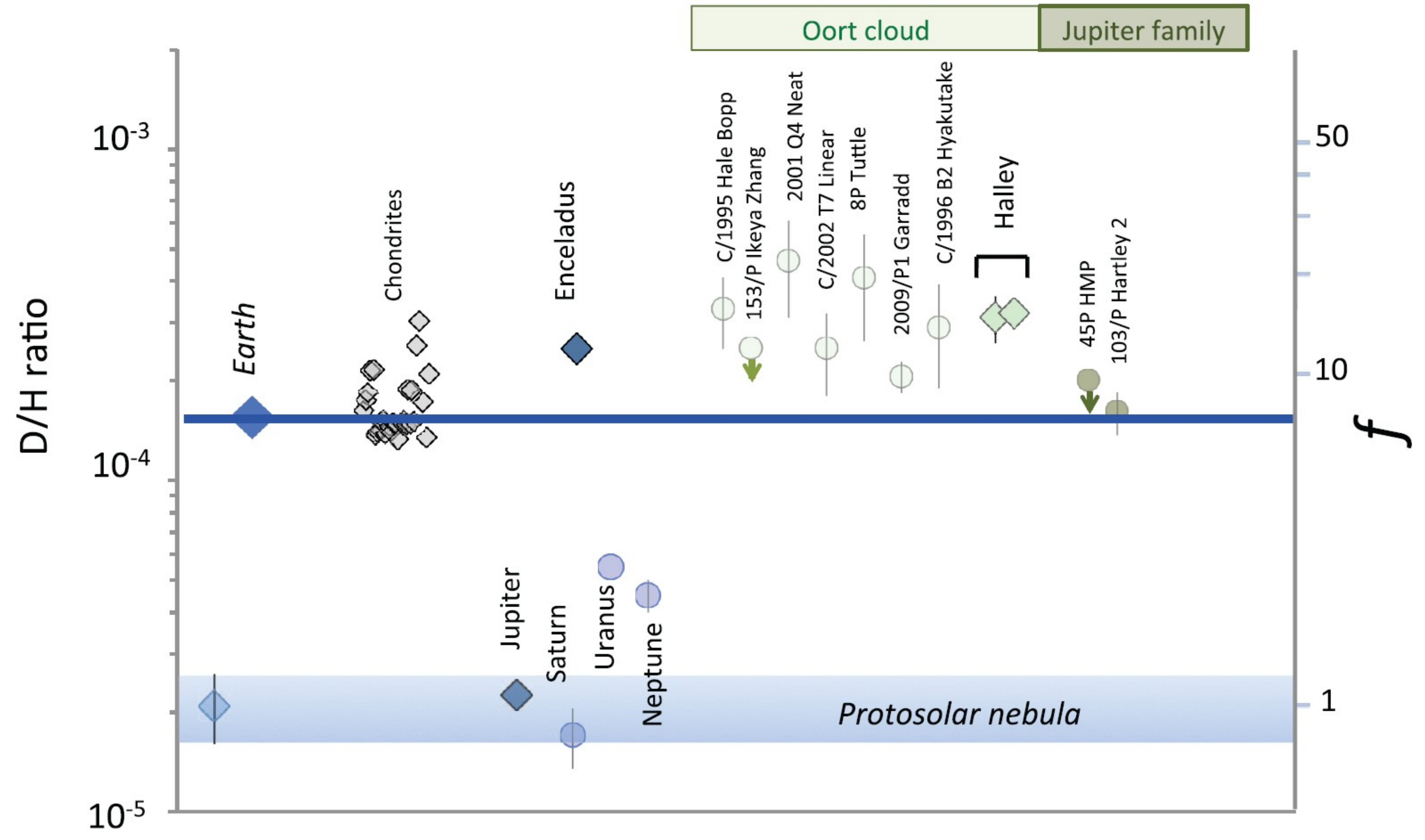


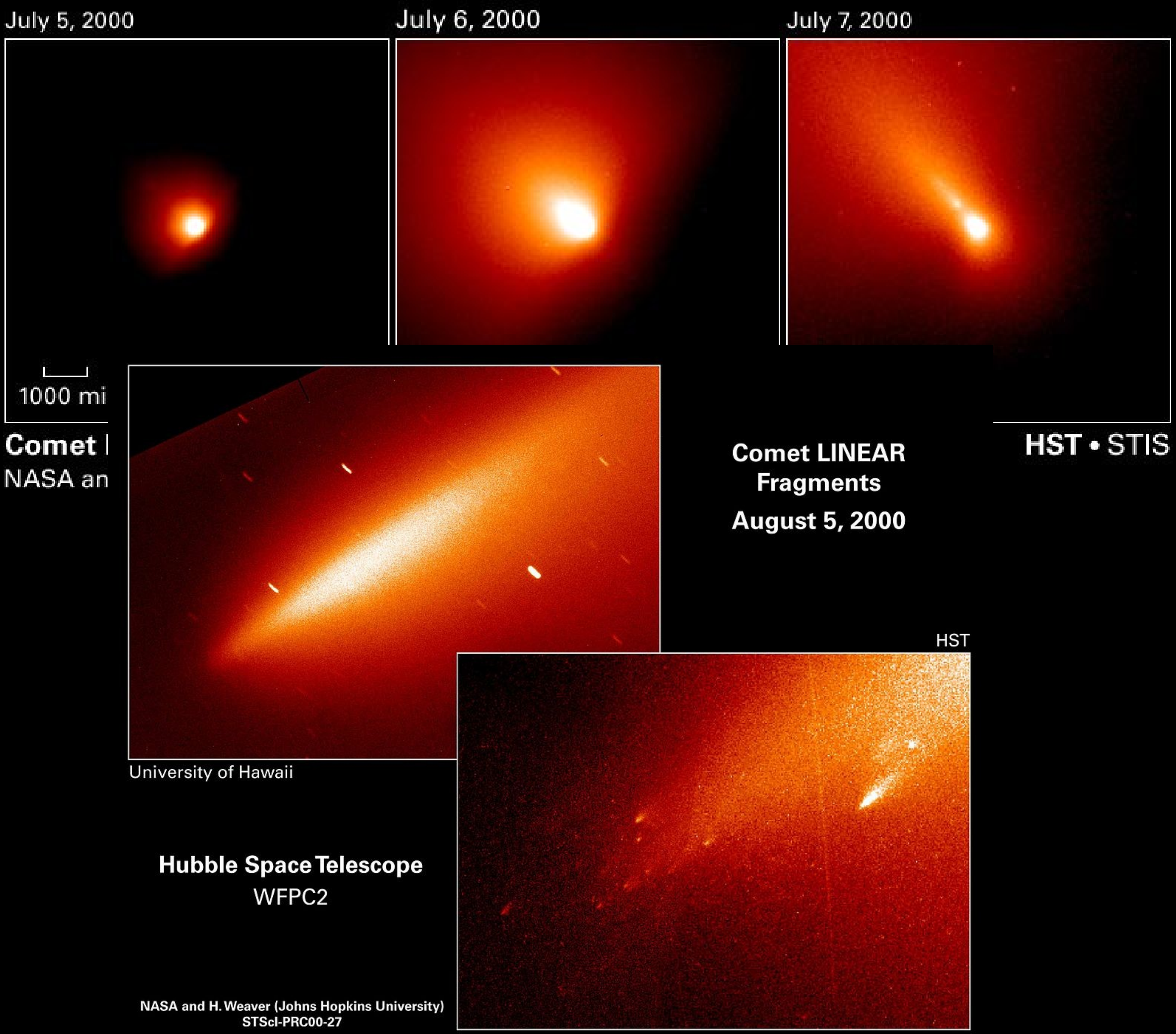
A reservoir of
primitive material



A role in the origin of life ?
(water and organic compounds)

Why study comets ?




July 5, 2000
July 6, 2000
July 7, 2000
1000 mi
HST • STIS
Comet LINEAR Fragments
August 5, 2000
University of Hawaii
HST
Hubble Space Telescope
WFPC2
NASA and H. Weaver (Johns Hopkins University)
STScI-PRC00-27


Comet Machholz, 12/2004


Comet Mc Naught
01/2007

Comet C/2020 F3 (NEOWISE) , 12 Juillet 2020 © THIERRY LEGAULT

Deciding ROSETTA

After the surprises by Halley's Comet, the logical step for NASA and ESA is to bring back a cometary sample for analysis on Earth.

↓

1986-1992 CNSR Mission(*Comet Nucleus Sample Return*) : NASA / ESA

↓ NASA withdraw: sample return impossible. Laboratory to the comet instead!

1993 ROSETTA mission : ESA

↓ 2 landers

Champollion (JPL/CNES) Roland (MP + DLR)

JPL withdraw in 1994

↓

Philae (DLR/CNES/ASI)

Deciding ROSETTA

Launch initially planned for January 2003

Target: comet 46P/Wirtanen (~700 m)

But the failure of a launch of the Ariane 5 rocket on December 11, 2002 postponed the launch and led to a change of target.

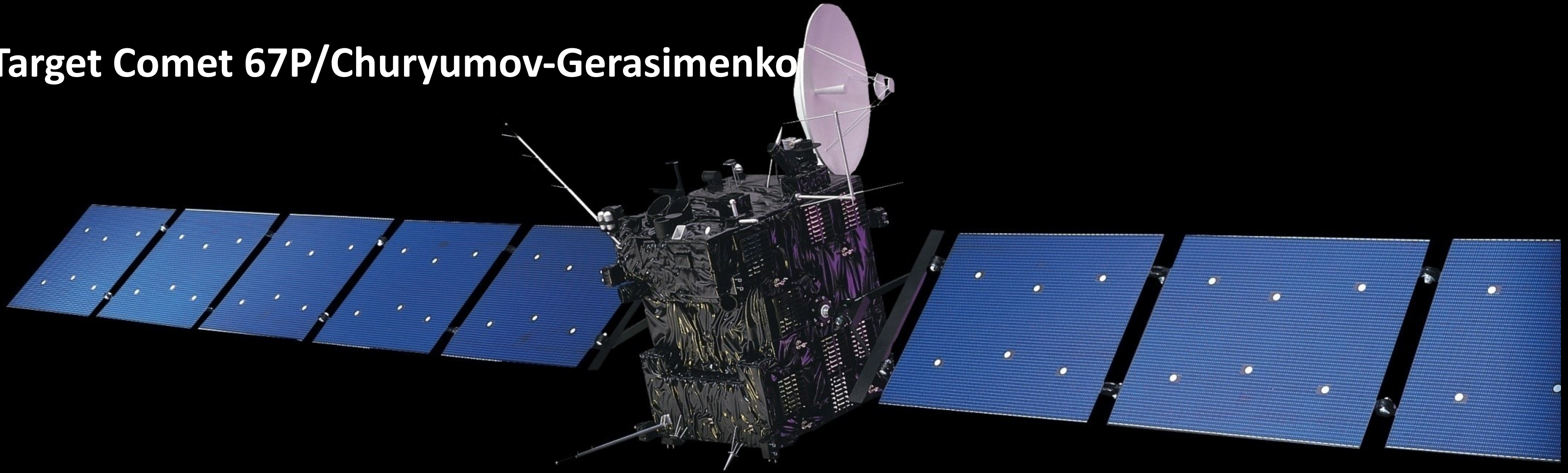
Launched March 2, 2004

New target:
comet
67P/Churyumov-Gerasimenko
(~4km
30 times more massive than 46P)

Rosetta: Outlooks

Launch : March 2nd, 2004

Target Comet 67P/Churyumov-Gerasimenko



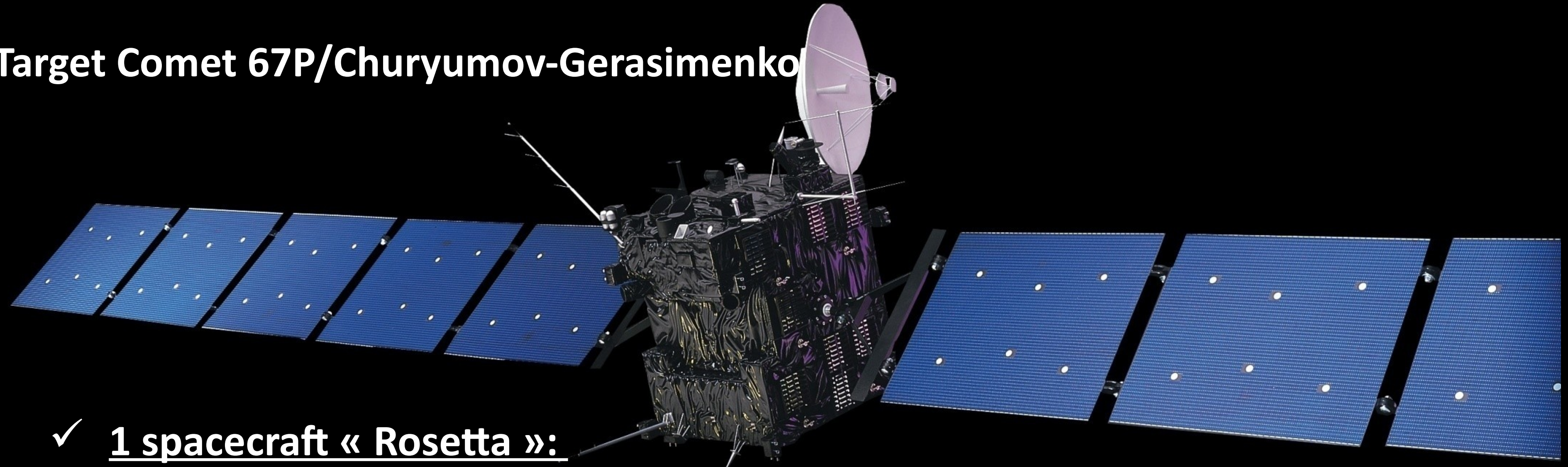
- ✓ **1st spacecraft « orbiting » around a comet**
- ✓ **1st in-situ analyses of a comet beyond 2 AU**
- ✓ **1st landing on a cometary nucleus**

⇨ A tremendously ambitious mission

Rosetta: Outlooks

Launch : March 2nd, 2004

Target Comet 67P/Churyumov-Gerasimenko



- ✓ **<u>1 spacecraft « Rosetta »:</u>**
  - ✓ **2.8 x 2.1 x 2 m + 2 solar pannels of 15 m (64 m^2)**
  - ✓ **2 970 kg (1 300 kg without fuel)**
  - ✓ **11 instruments (165 kg)**

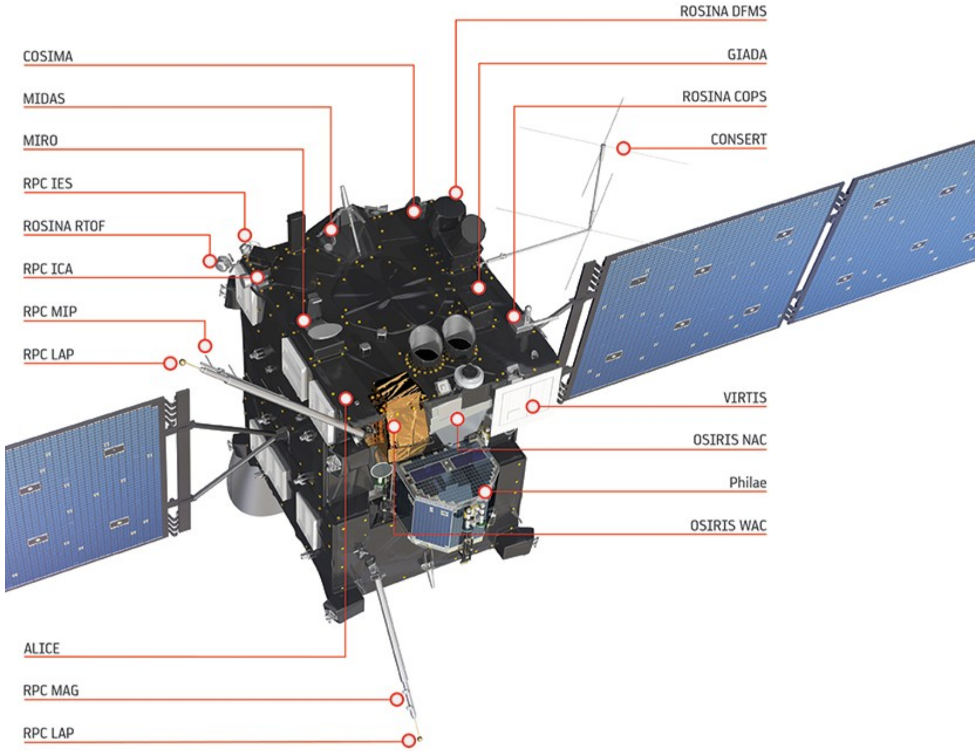
- ✓ **<u>1 lander « Philae »:</u>**
  - ✓ **1 x 1 x 0.8 m**
  - ✓ **100 kg**
  - ✓ **10 instruments (21 kg)**

INSTRUMENTS onboard ROSETTA spacecraft

Bring the lab to the comet !
UV, Vis, IR, Radio spetrometers
AFM
Cameras
Radar
Mass spectrometers….

All instruments must be :
- Small
- Light
- Low power consumption
- Reliable after launch (vibrations and chocks), 10 years in space (cold, radiations), can't be fixed if broken !
- And ready for unexpected things

Instruments	
ALICE	UV Spectrometer (70nm-205nm)
CONSERT	COmet Nucleus Sounding Experiment by Radiowave Transmission
COSIMA	COmetary Secondary Ion Mass Analyser
GIADA	Grain Impact Analyser and Dust Accumulator
MIDAS	Micro-Imaging Dust Analysis System
MIRO	Microwave Instrument for the Rosetta Orbiter
OSIRIS	the Optical Spectroscopic and Infrared Remote Imaging System
ROSINA	Rosetta Orbiter Spectrometer for Ion and Neutral Analysis
RPC	The Rosetta Plasma Consortium : - Langmuir Probe (LAP) - Ion and Electron Sensor (IES) - Flux Gate Magnetometer (MAG) - Ion Composition analyser (ICA) - Mutual Impedance Probe (MIP) - Plasma Interface Experiment (PIU)
RSI	Radio Science Experiment
VIRTIS	Visual IR therla Imaging spectrometer



Spectroscopy

✓ Ultraviolet : ALICE

-- 70-205 nm

✓ Visible : OSIRIS

-- NAC – 250 – 1000 nm (12 filtres)

-- WAC – 240-720 nm (14 filtres)

✓ Infrarouge : VIRTIS

-- plusieurs canaux 0.25 – 5 µm

✓ Mm & sub-mm : MIRO

-- 188 Ghz (1.6 mm) (continuum data only)

-- 562 Ghz (0.5 mm) (continuum & high resolution)

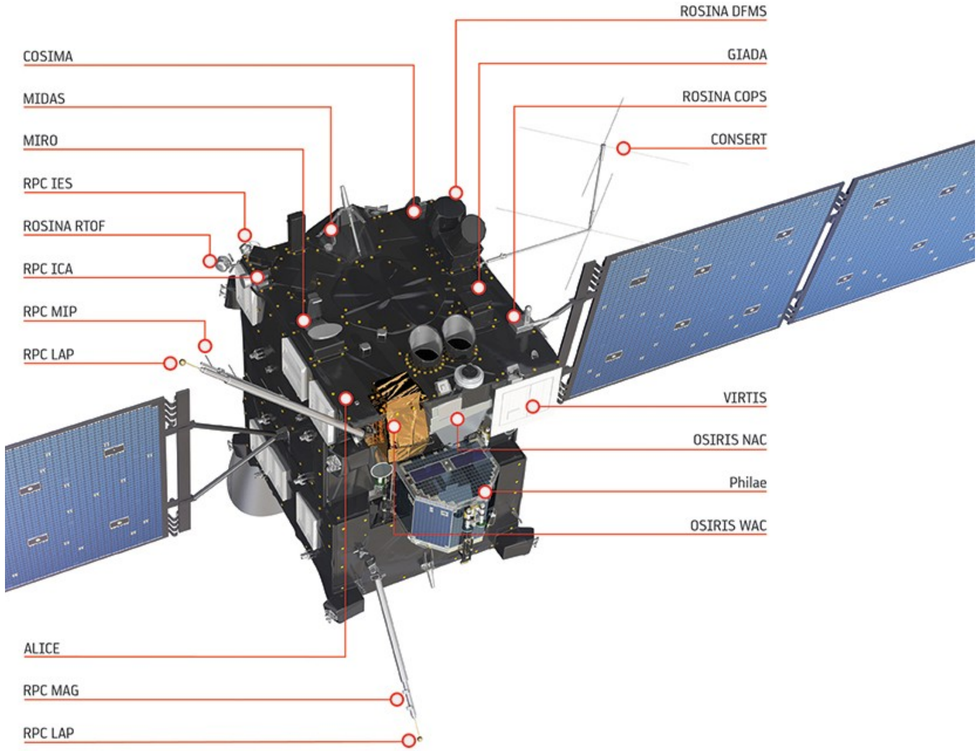
Virtis main characteristics and requirements

	VIRTIS-M Visible	VIRTIS-M InfraRed	VIRTIS-H
Spectral Range (nm)	220.1–1046.0	952.8–5059.2	*Order* 0 4.05–5.03 *Order* 1 3.47–4.32 *Order* 2 3.04–3.78 *Order* 3 2.70–3.37 *Order* 4 2.43–3.03 *Order* 5 2.21–2.76 *Order* 6 2.03–2.53 *Order* 7 1.88–2.33
Spectral Resolution $\lambda/\Delta\lambda\lambda$	100–380	70–360	1300–3000
Spectral Sampling (nm) (1)	1.89	9.44	0.6
Field of View (mrad × mrad)	63.6 (slit) × 64.2 (scan)	63.6 (slit) × 64.2 (scan)	0.49 × 1.47
Max Spatial Resolution (μrad)	248.6 (slit) × 250.8 (scan)		

TABLE I

Rosetta-ALICE characteristics, spacecraft resource requirements, and measured performance summary (Ground cal and Flight results)

Parameter	Proposed/Specified performance	Measured performance
Passband:	700–2050 Å	680–2060 Å (Flight)
Spectral	4–8 Å (point source)	4–8 Å (Ground Cal); 4–9 Å (Flight)
Resolution:	10–12 Å (extended source)	8–12 Å (Ground Cal and Flight)
Spatial resolution:	0.05° × 0.6° (Nyquist sampled)	0.05° × 0.6° (Nyquist sampled)
Active FOV:	0.1° × 6.0° (Proposed FOV)	0.05° × 2.0° + 0.1° × 2.0° + 0.1° × 1.5° (final design)



Imaging & spatial resolution

- ✓ OSIRIS :

WAC 5 m.pixel^{-1} à 100 km
NAC 1.86 m.pixel^{-1} à 100 km

- ✓ COSIMA :

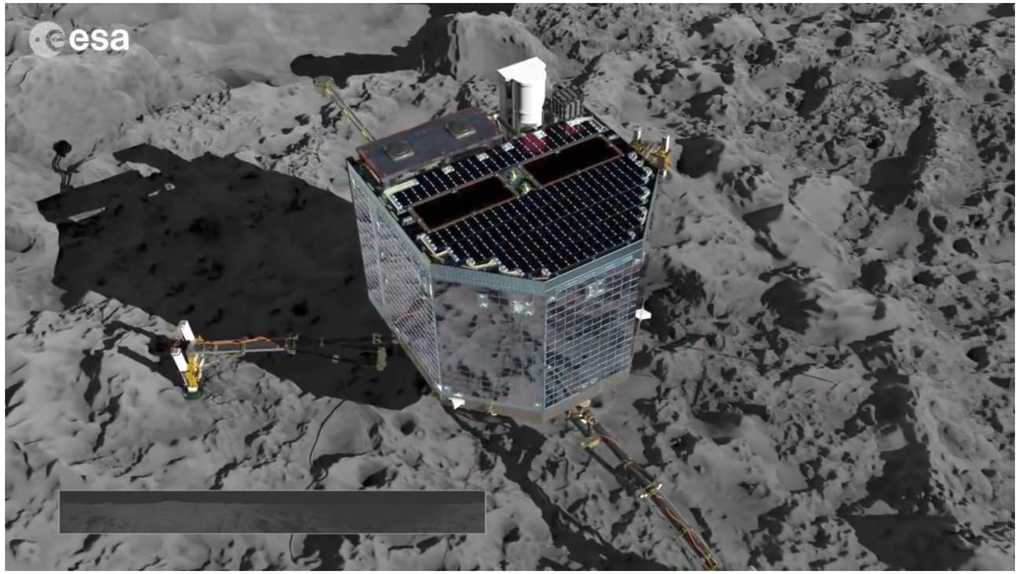
14 µm.pixel^{-1}

- ✓ MIDAS :

4 nm.pixel^{-1}

INSTRUMENTS onboard PHILAE lander

Instruments	
APXS	Alpha Particle X-Ray Spectrometer
CIVA	Panoramic Camera & IR microscope
CONSERT	Comet nucleus sounding
COSAC	Evolved Gas Analyser : elemental and molecular composition
MUPUS	Multi-Purpose Sensors for Surface and Subsurface Science
PTOLEMY	Evolved Gas Analyser : isotopic composition
ROLIS	Rosetta Lander Imaging System
ROMAP	Rosetta Lander Magnetometer and Plasma Monitor
SESAME	Surface Electrical, Seismic and Acoustic Monitoring Experiments
SD-2	Sample and Distribution Device

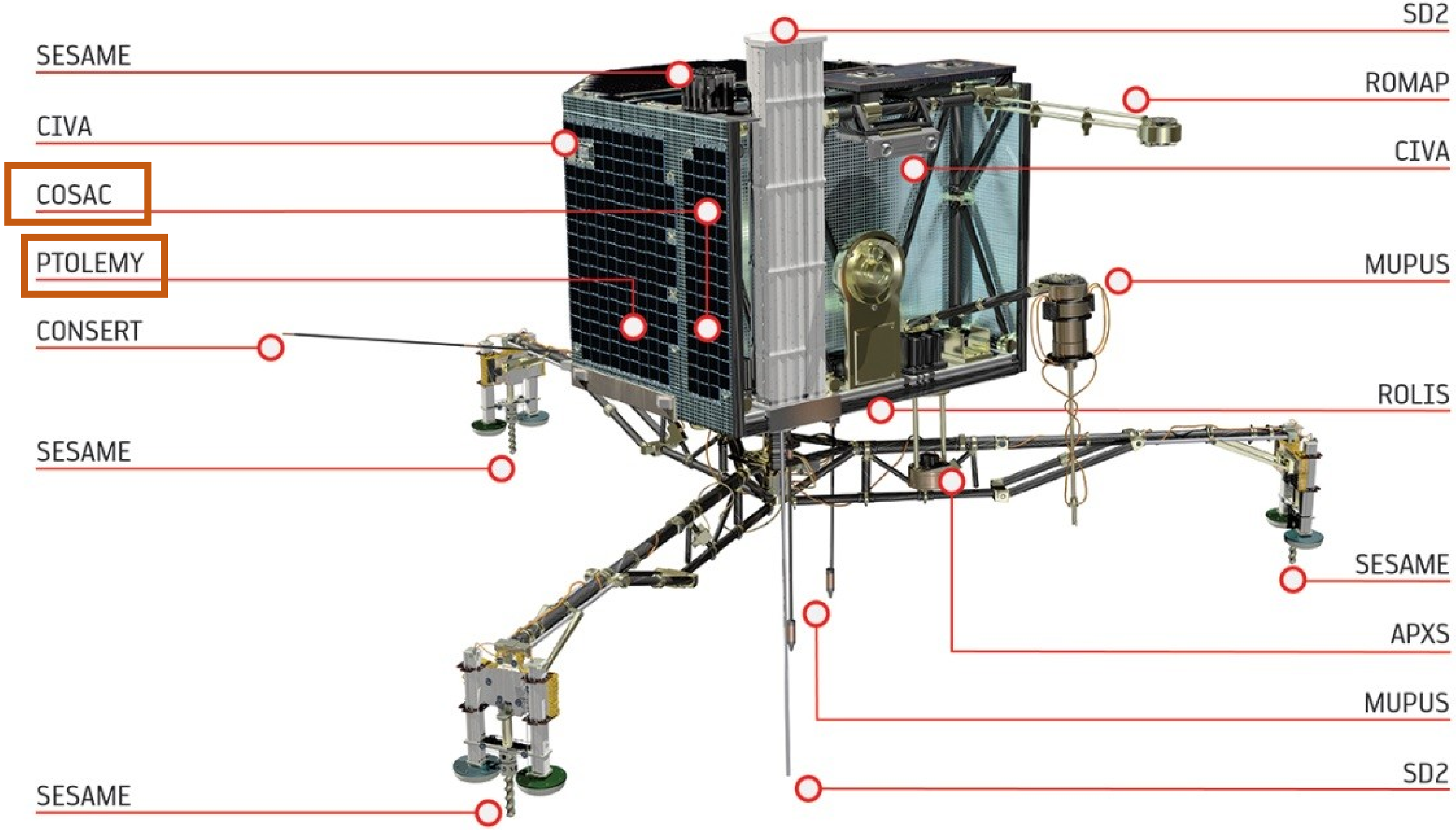


A race against time

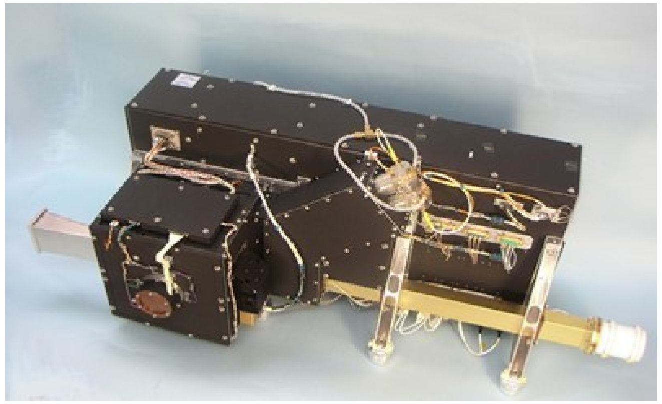
SDL : Separation, Descent, Landing
Nov 12th, 7h from 22.5 km to comet

FSS : First Science Sequence : 2.25 days
(50 to 56h)

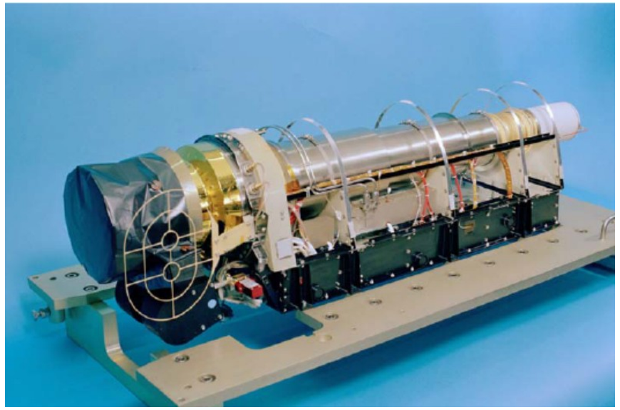
LTS : Long Term Sequence : mid Nov
2014- March 2015


SD2
SESAME
ROMAP
CIVA
CIVA
COSAC
PTOLEMY
MUPUS
CONSERT
ROLIS
SESAME
SESAME
APXS
MUPUS
SESAME
SD2

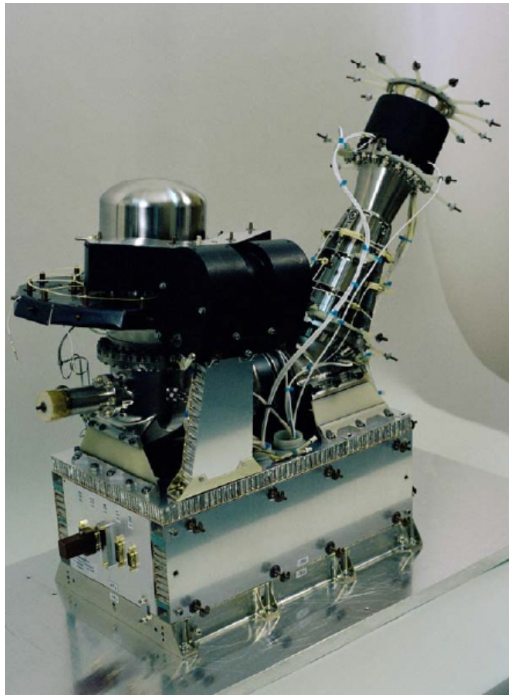
5 mass spectrometers at the comet



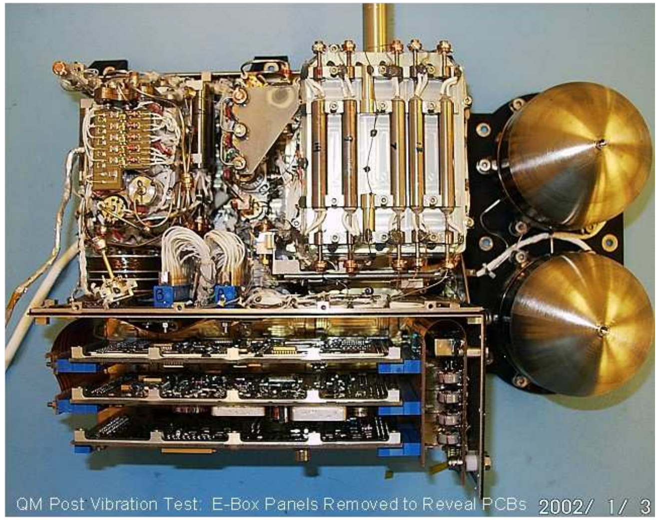
COSIMA (TOF-SIMS)



ROSINA RTOF



ROSINA DFMS



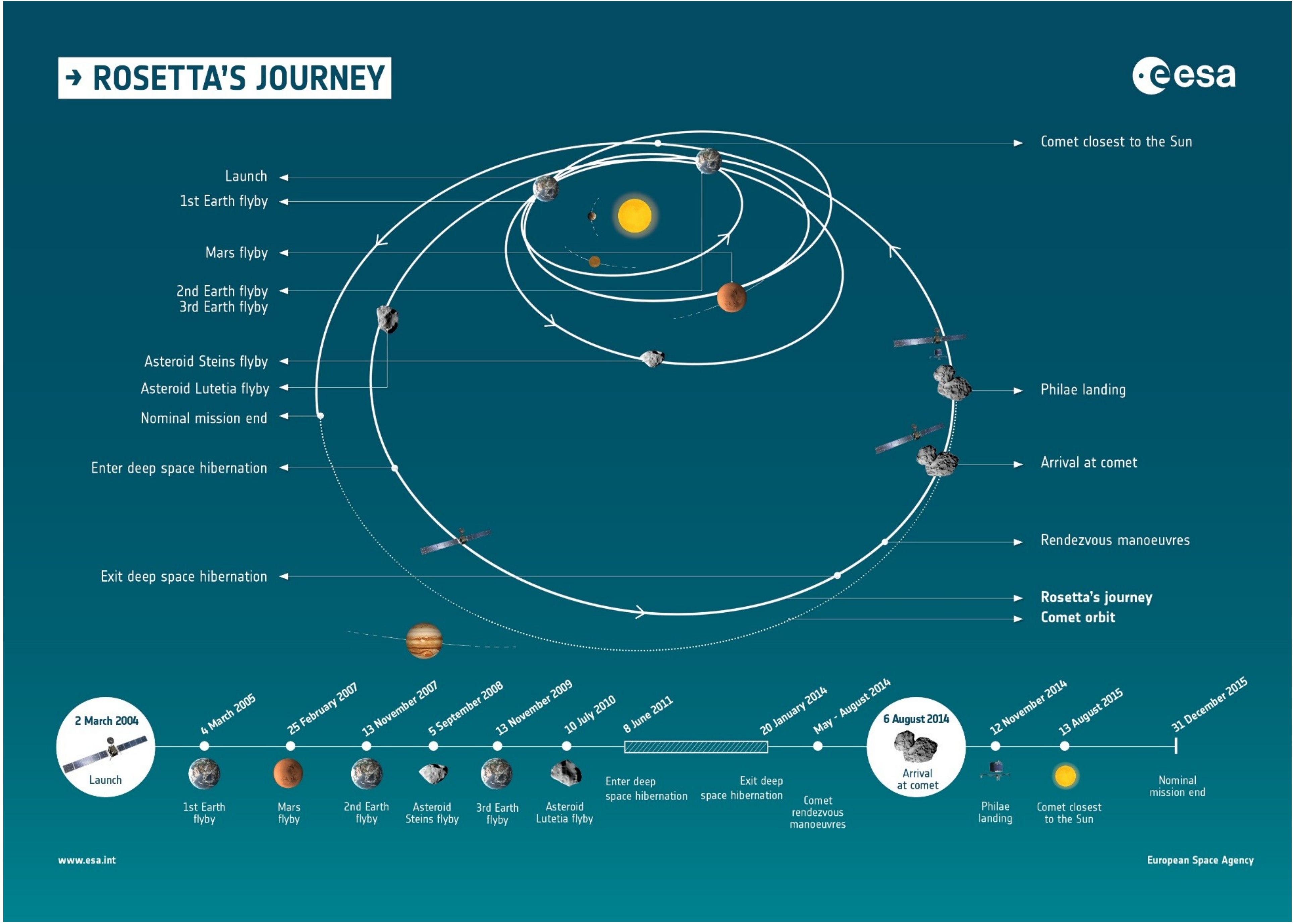
PTOLEMY
(GC - Ion Trap)

COSAC
(GC - TOF)

Mass spectrometers at the comet

	Instrument	Instrument Characteristics				
		Sample	**Ionisation**	**Analyseur**	**Resolution**	**Mass Range (Da)**
Rosetta	COSIMA	Particles	SIMS	RTOF	1200 FWHM at 100 Da	1-3500
Rosetta	ROSINA	Gas	EI	DFMS	3000 at 1%	12-150
				RTOF	500 à 1%	1->300
Philae	COSAC	Nucleus + Gas	EI	Linear TOF	350 at 70	1-1500
Philae	PTOLEMY	Nucleus + Gas	Field Effect	Ion Trap	70 FWHM at mass 44	12-150

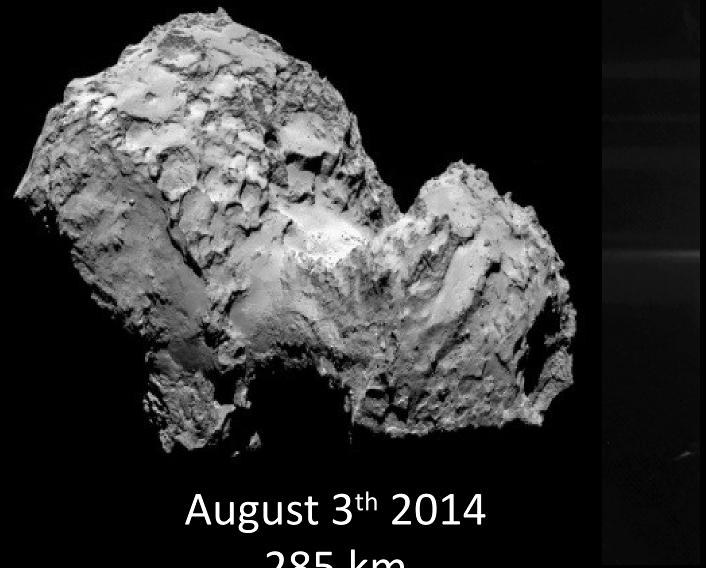
Balsiger, H. *et al. Rosina – Rosetta Orbiter Spectrometer for Ion and Neutral Analysis. Space Science Reviews 128, 745-801 (2007).*
Goesmann, F. *et al. Cosac, The Cometary Sampling and Composition Experiment on Philae. Space Science Reviews 128, 257-280 (2007).*
Kissel, J. *et al. COSIMA, a High Resolution Time of Flight Spectrometer for Secondary Ion Mass Spectroscopy of Cometary Dust Particles. Space Science Reviews 128, 823-867 (2007).*
Wright, I. P. *et al. Ptolemy – an Instrument to Measure Stable Isotopic Ratios of Key Volatiles on a Cometary Nucleus. Space Science Reviews 128, 363-381, (2007).*



End of mission : September 30th 2016

June 28th 2014
86 000 km

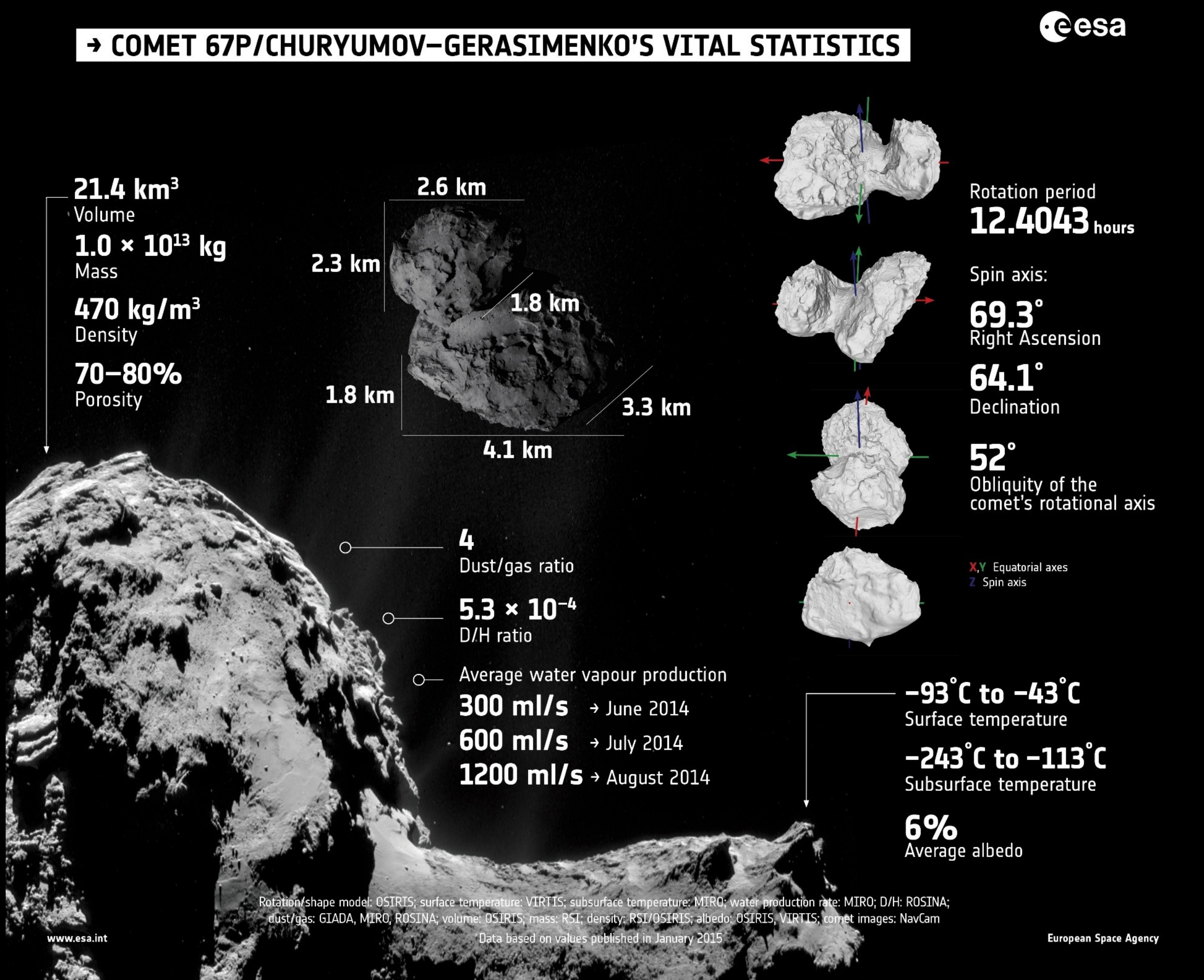
July 14th 2014
12 000 km

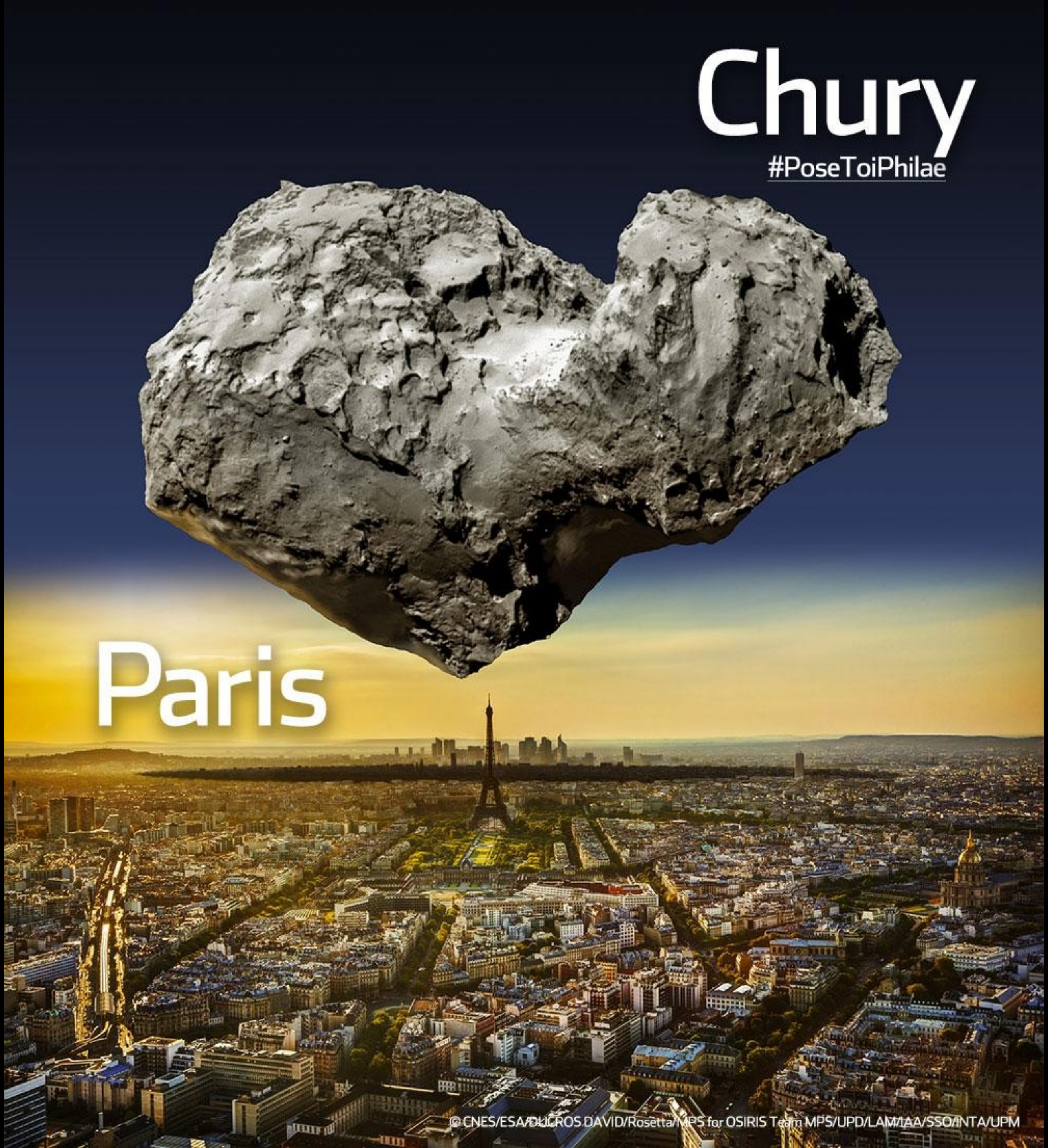


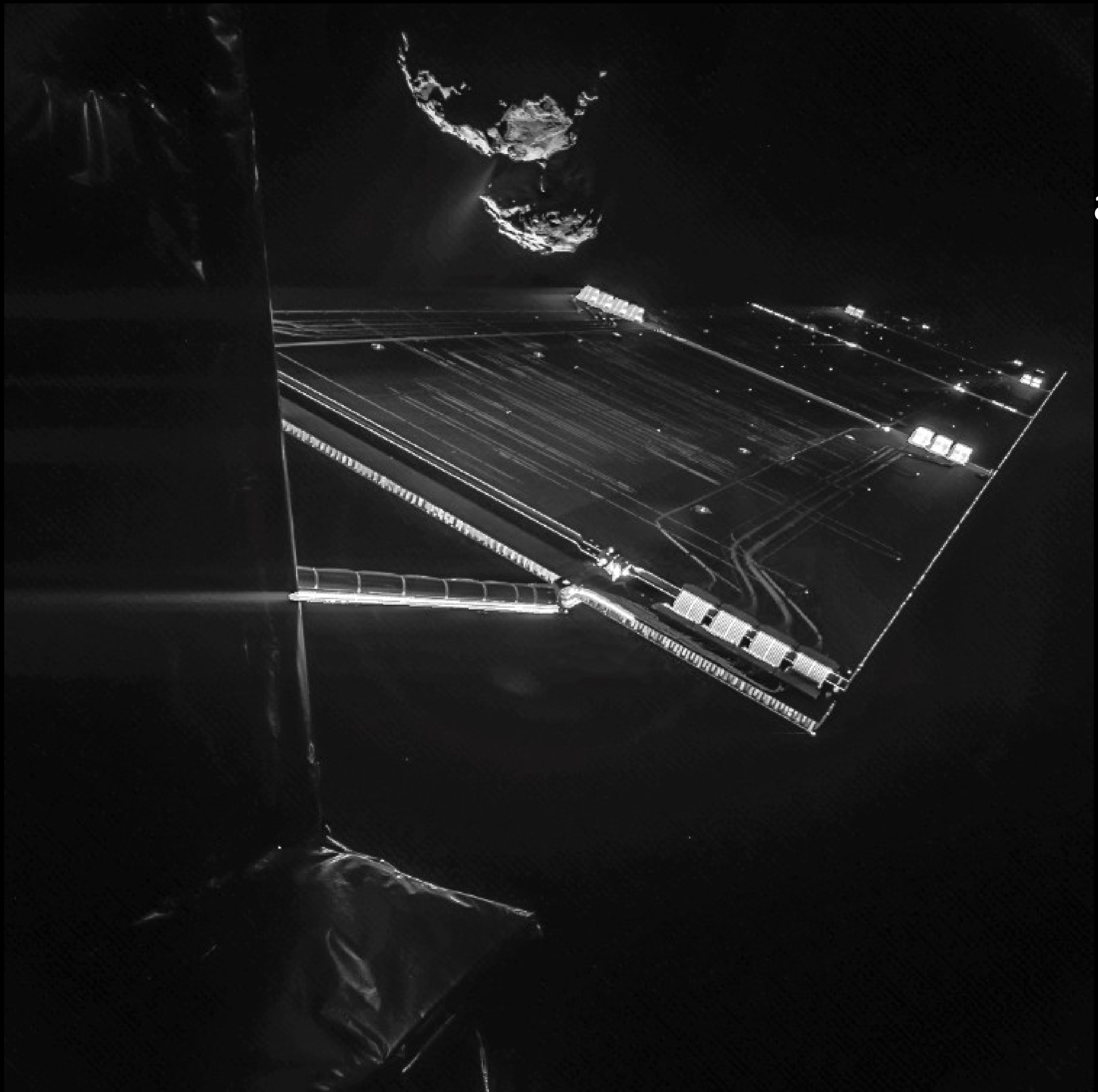
August 3th 2014
285 km

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

August 18th 2016
6 km

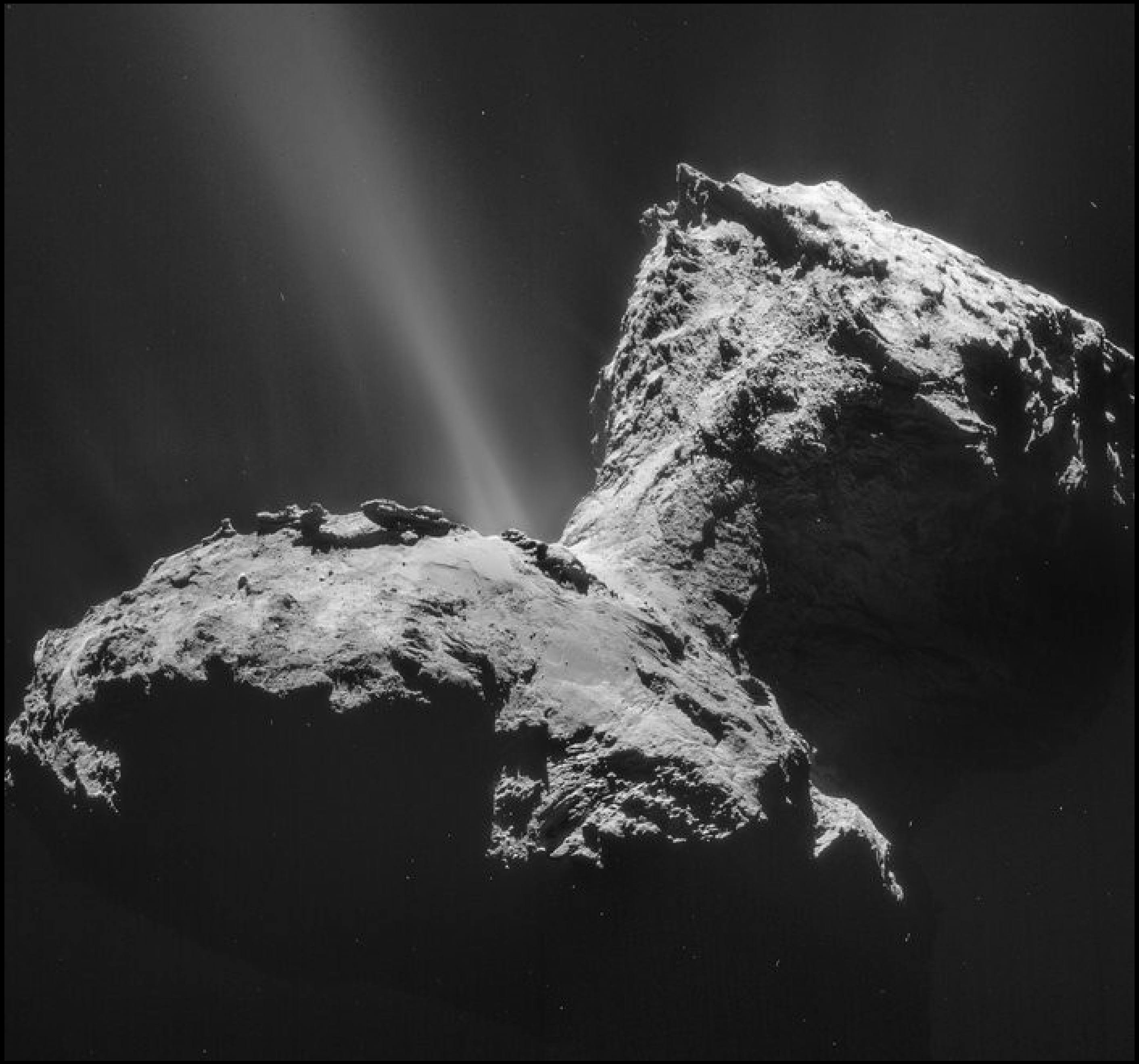

→ COMET 67P/CHURYUMOV–GERASIMENKO'S VITAL STATISTICS
esa
21.4 km³
Volume
1.0 × 10¹³ kg
Mass
470 kg/m³
Density
70–80%
Porosity
2.6 km
2.3 km
1.8 km
1.8 km
3.3 km
4.1 km
Rotation period
12.4043 hours
Spin axis:
69.3°
Right Ascension
64.1°
Declination
52°
Obliquity of the comet's rotational axis
X,Y Equatorial axes
Z Spin axis
4
Dust/gas ratio
5.3 × 10⁻⁴
D/H ratio
Average water vapour production
300 ml/s → June 2014
600 ml/s → July 2014
1200 ml/s → August 2014
–93°C to –43°C
Surface temperature
–243°C to –113°C
Subsurface temperature
6%
Average albedo
Rotation/shape model: OSIRIS; surface temperature: VIRTIS; subsurface temperature: MIRO; water production rate: MIRO; D/H: ROSINA; dust/gas: GIADA, MIRO, ROSINA; volume: OSIRIS; mass: RSI; density: RSI/OSIRIS; albedo: OSIRIS, VIRTIS; comet images: NavCam
www.esa.int
Data based on values published in January 2015
European Space Agency


Chury
#PoseToiPhilae
Paris
© CNES/ESA/DUCROS DAVID/Rosetta/MPS for OSIRIS Team MPS/UPD/LAM/IAA/SSO/INTA/UPM



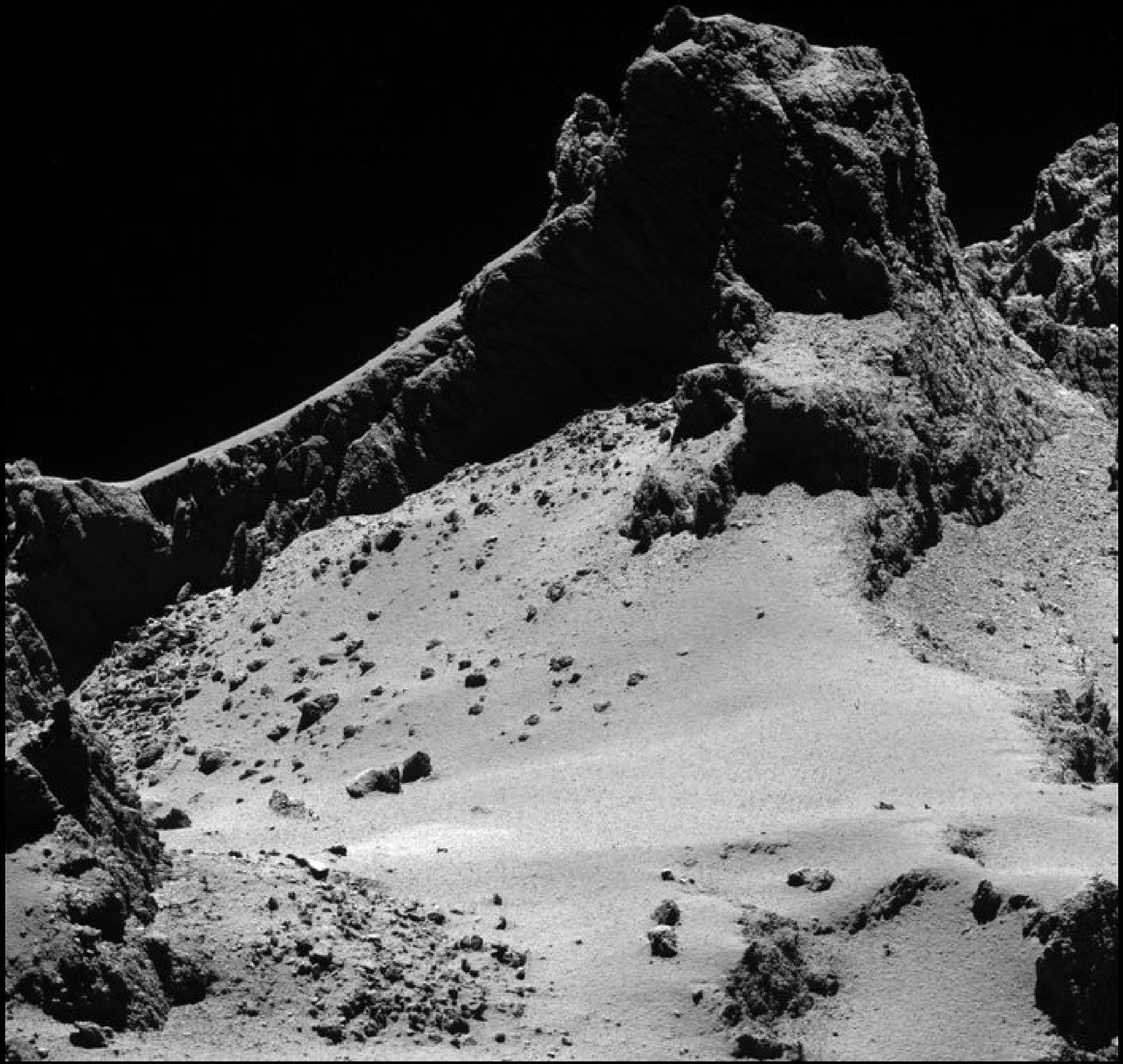
A selfie
at 16 km from nucleus
14/10/2014

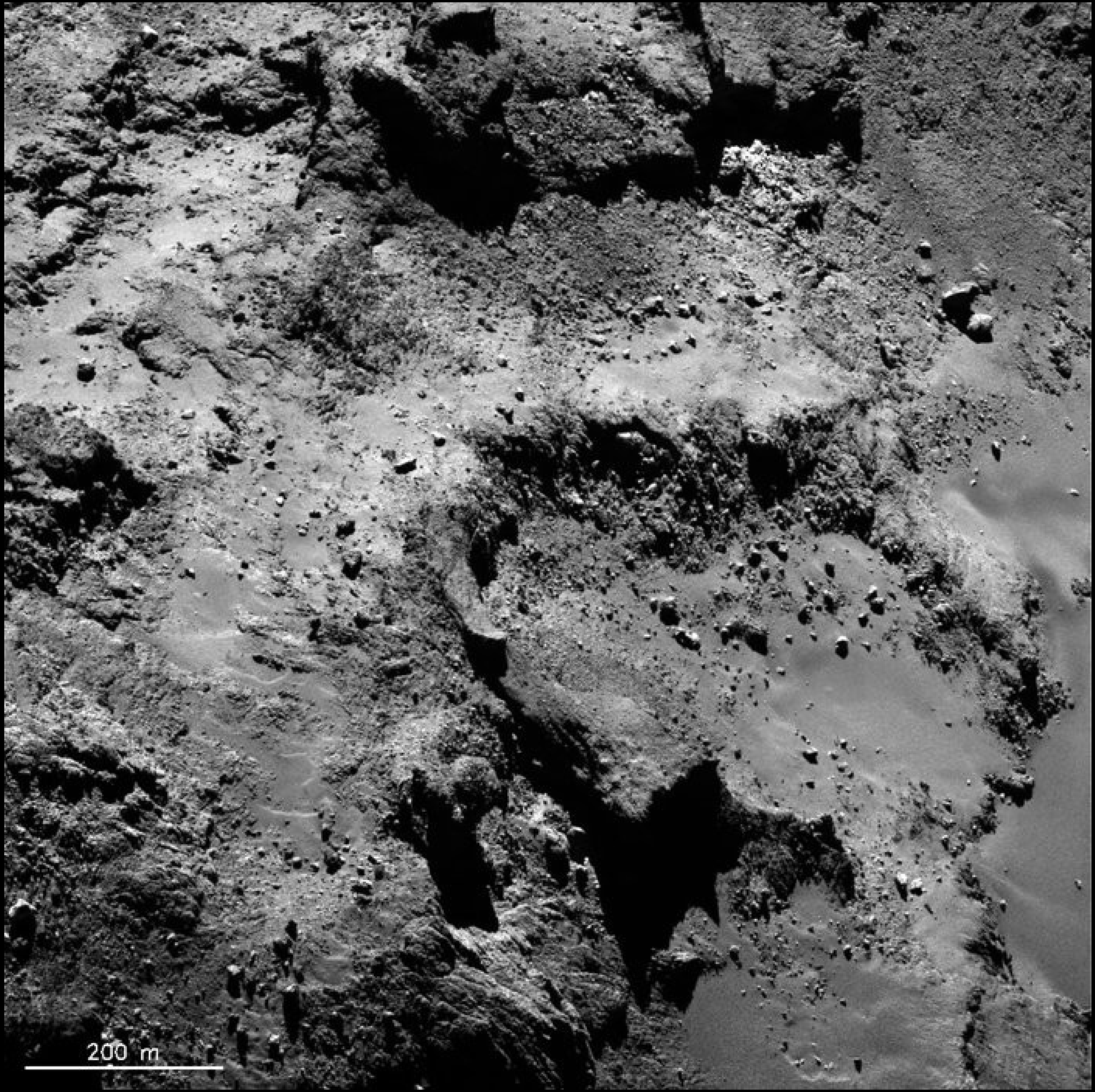
ESA/Rosetta/Philae/CIVA



From a distance of 28.0 km from the centre of Comet 67P/Churyumov-Gerasimenko on 31 January 2015. The image resolution is 2.4 m/pixel

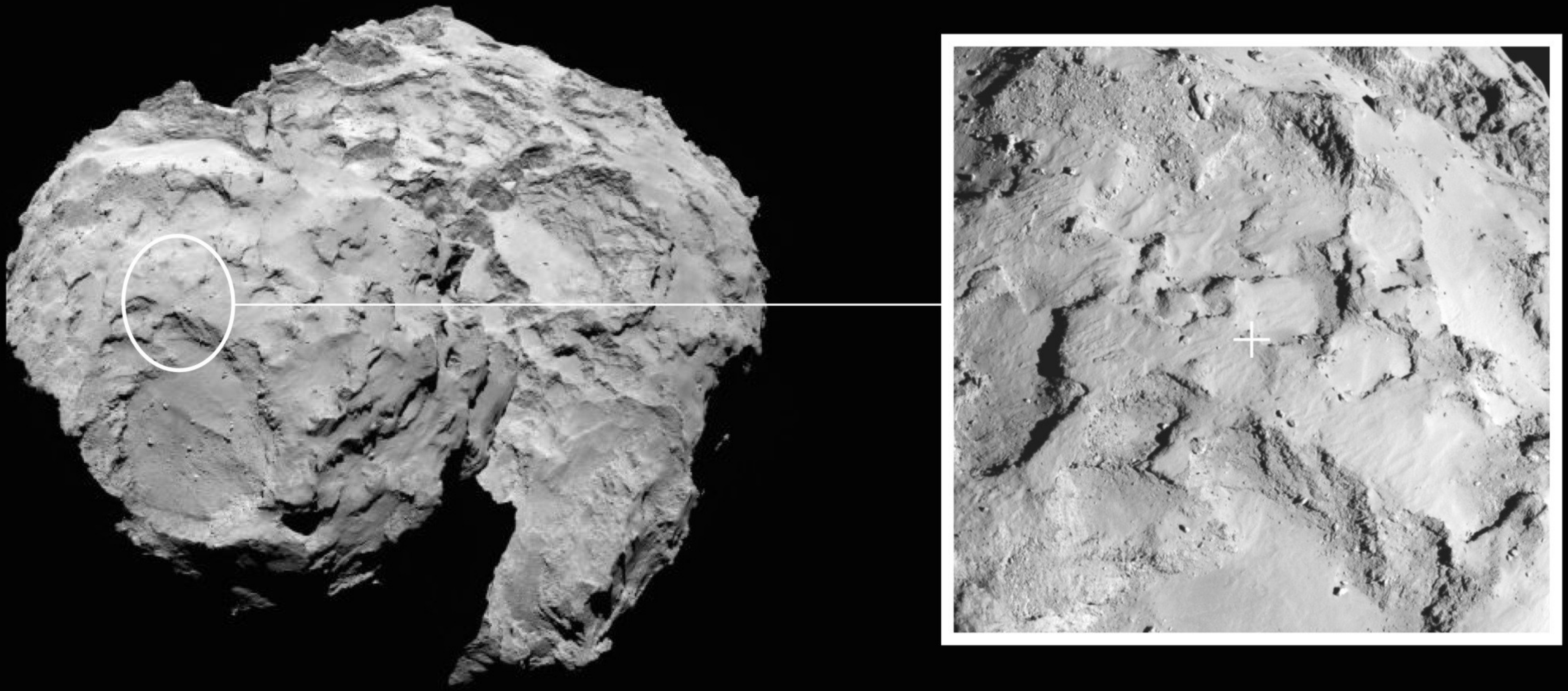
Credits: ESA/Rosetta/NAVCAM



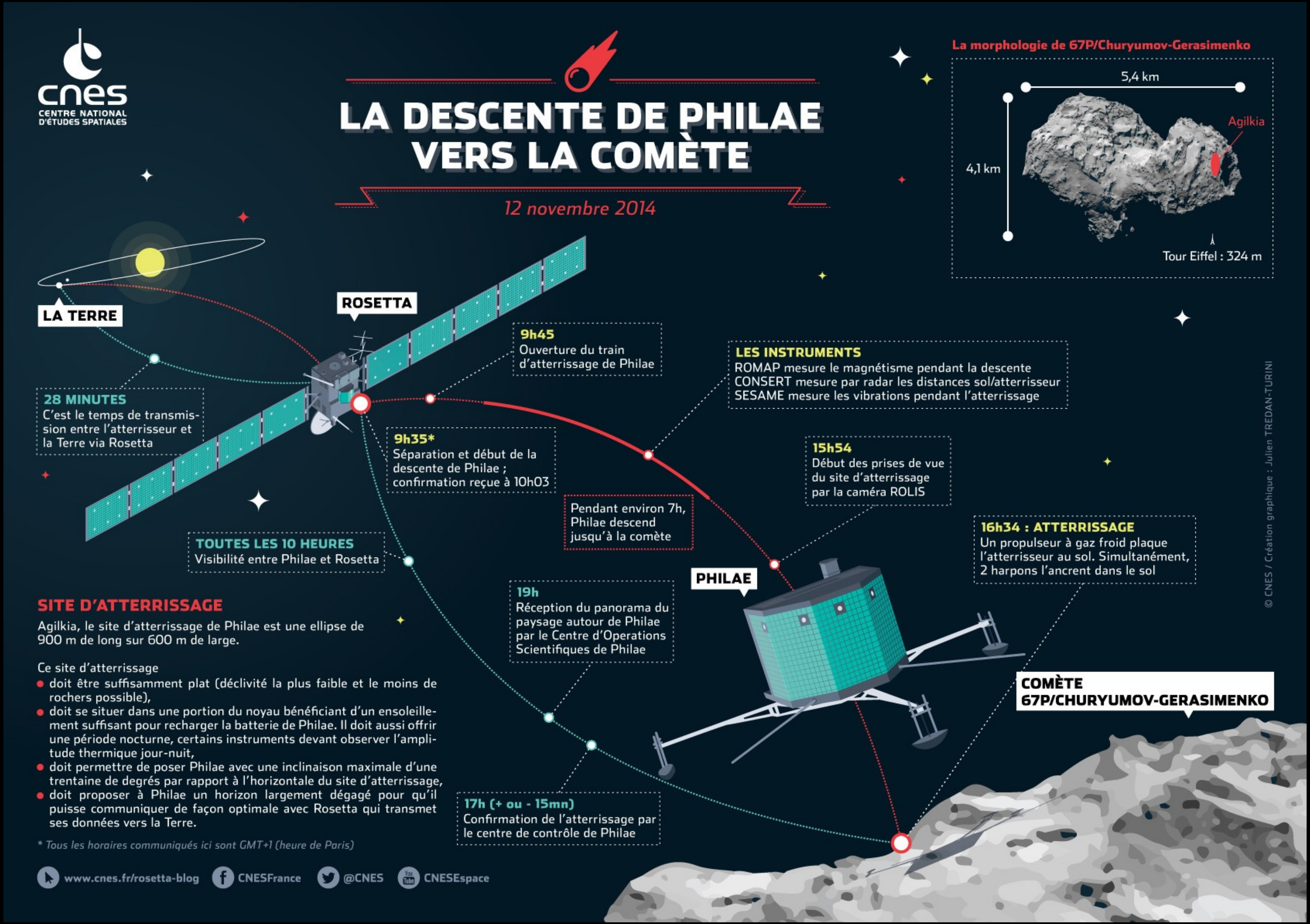

200 m

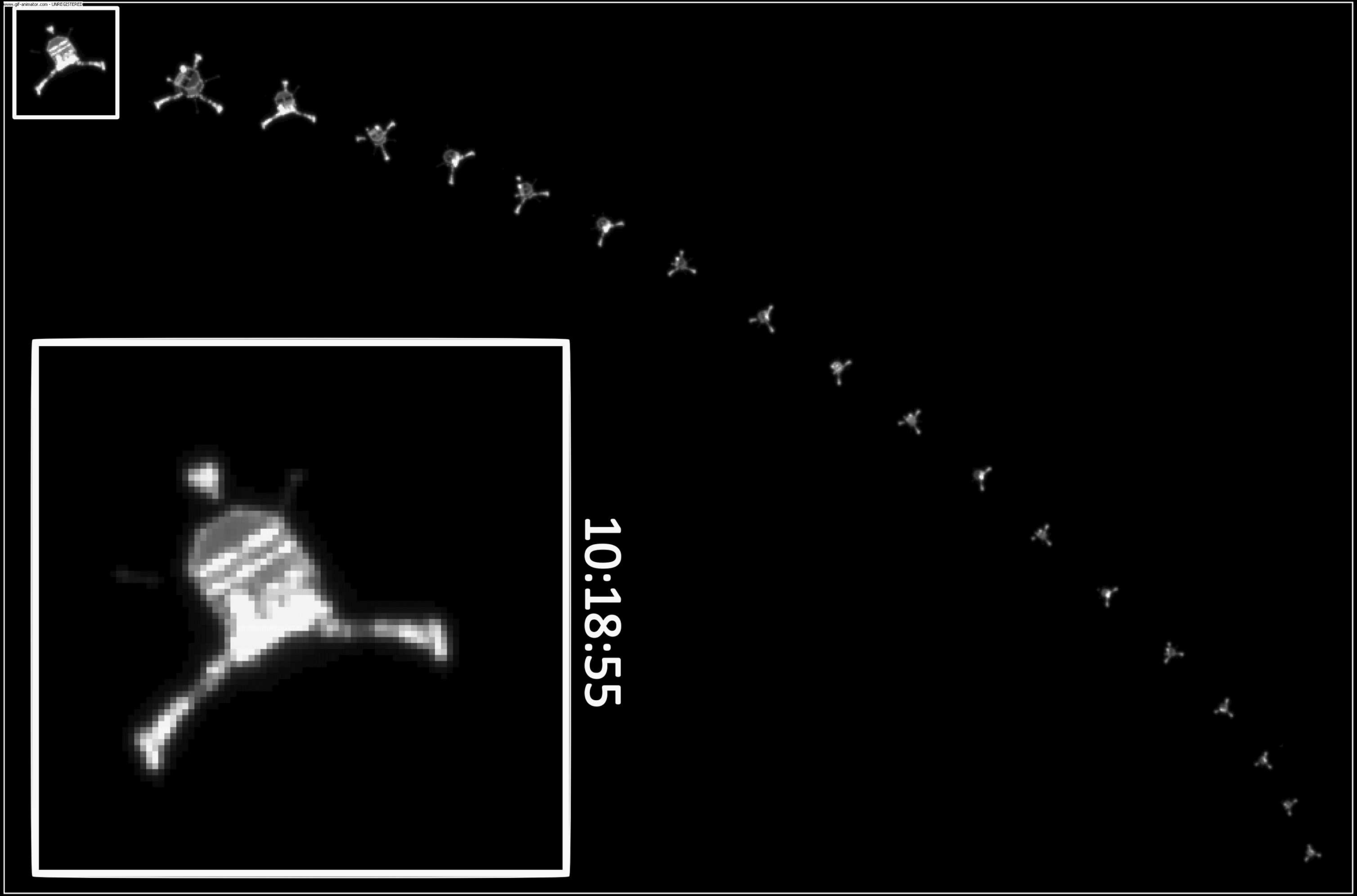
Complete journey at comet 67P : 08/2014 – 09/2016

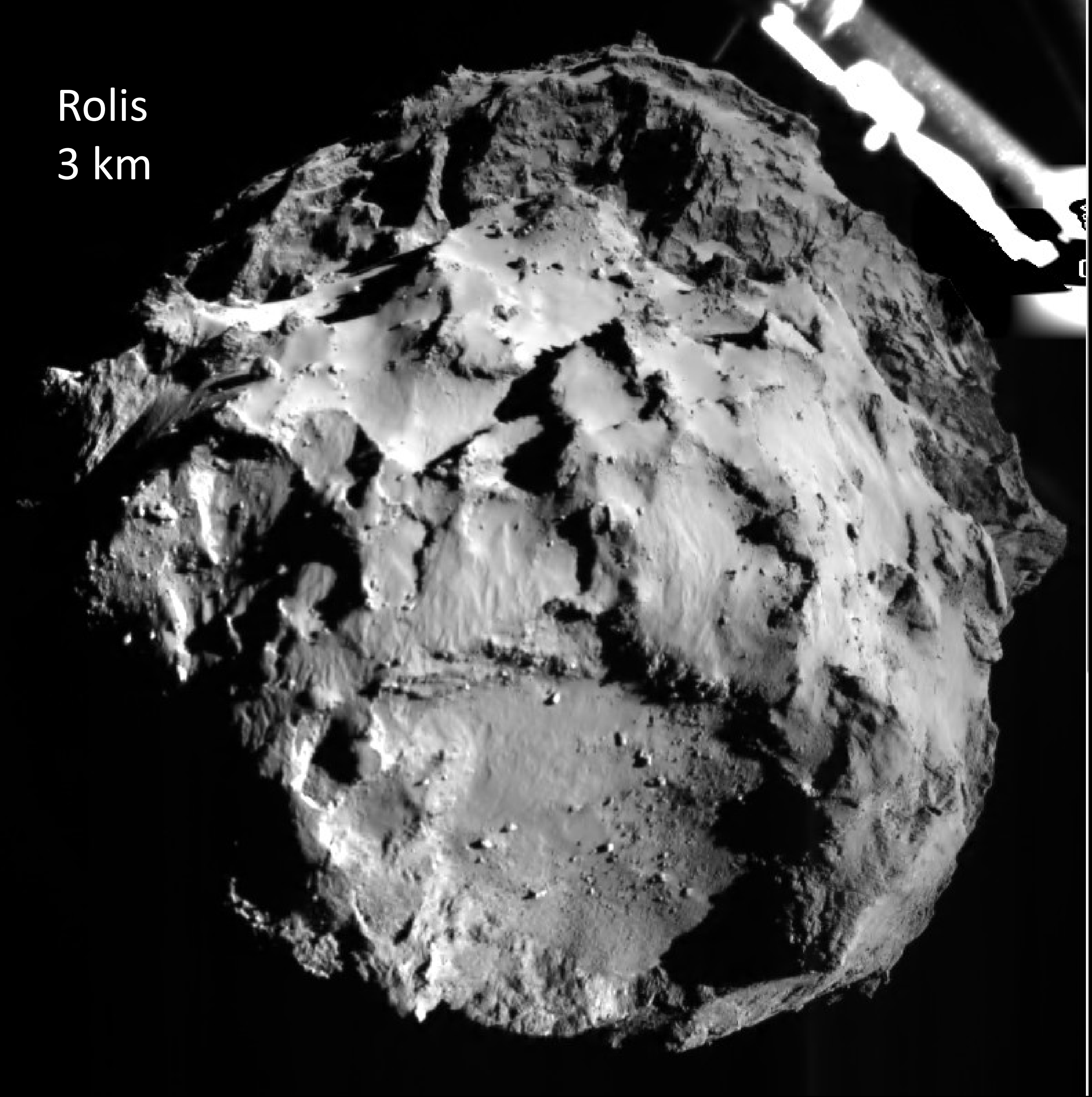
➔ PHILAE'S LANDING SITE

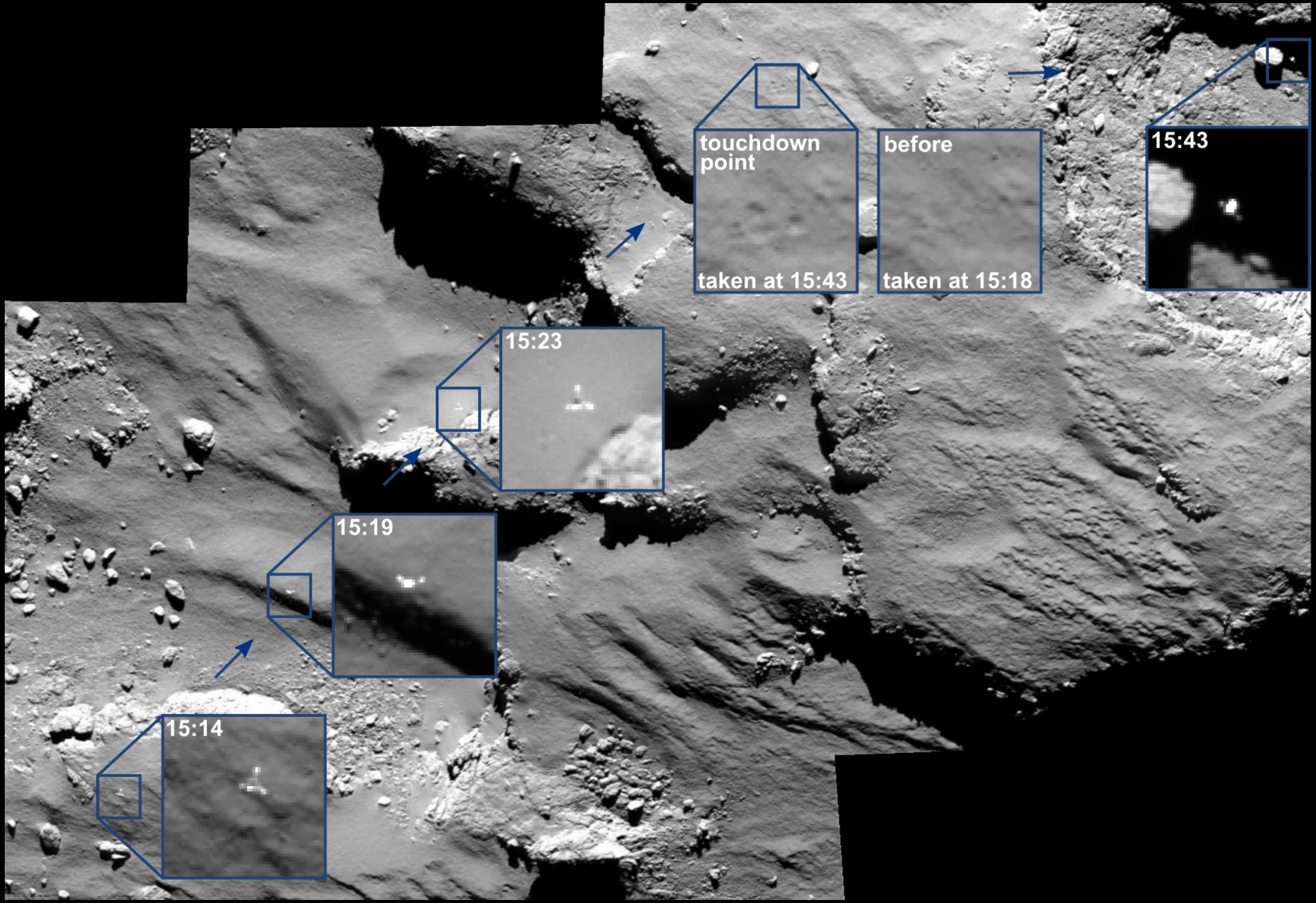


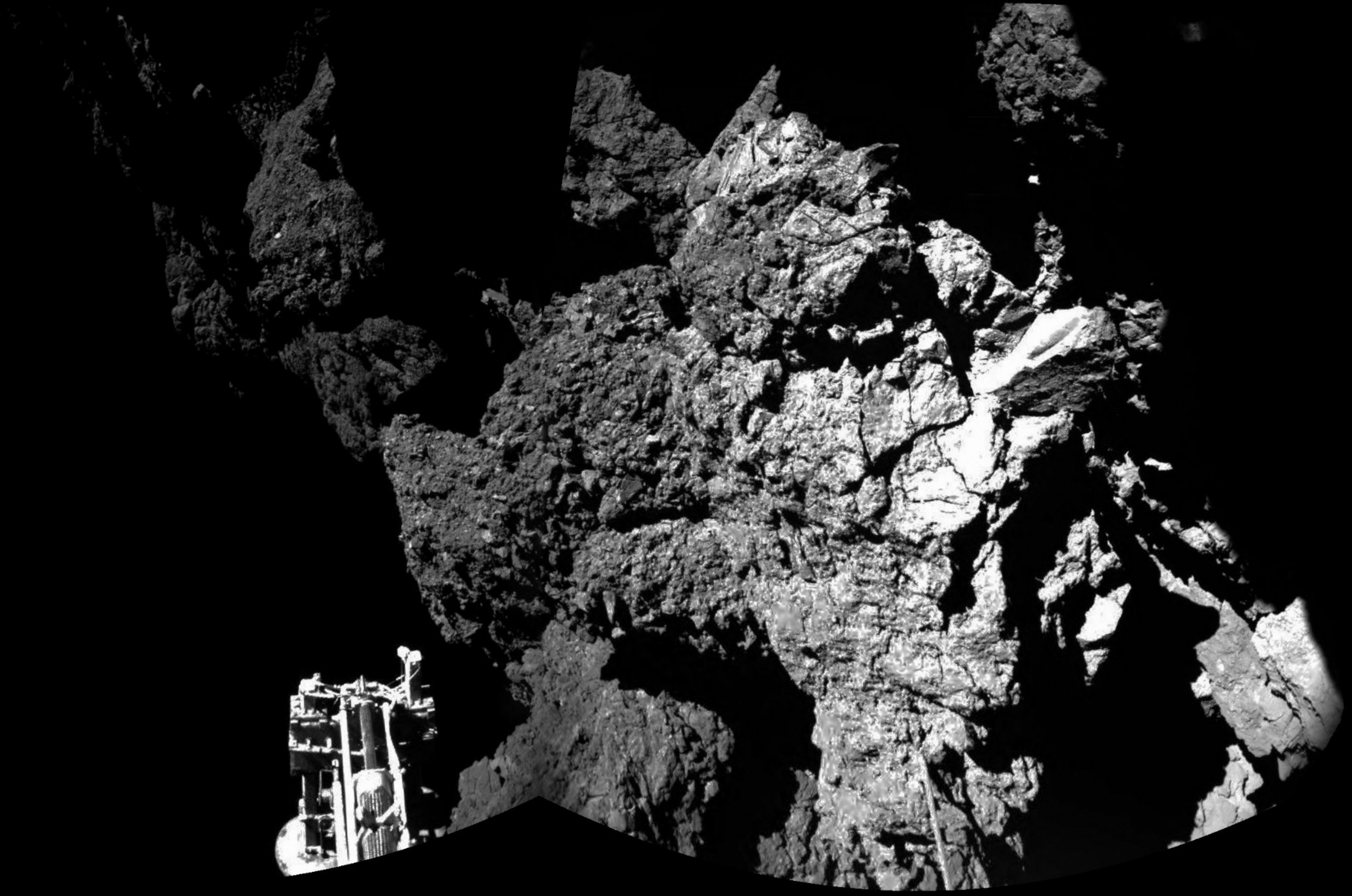
Atterrissage le 12 Novembre 2014

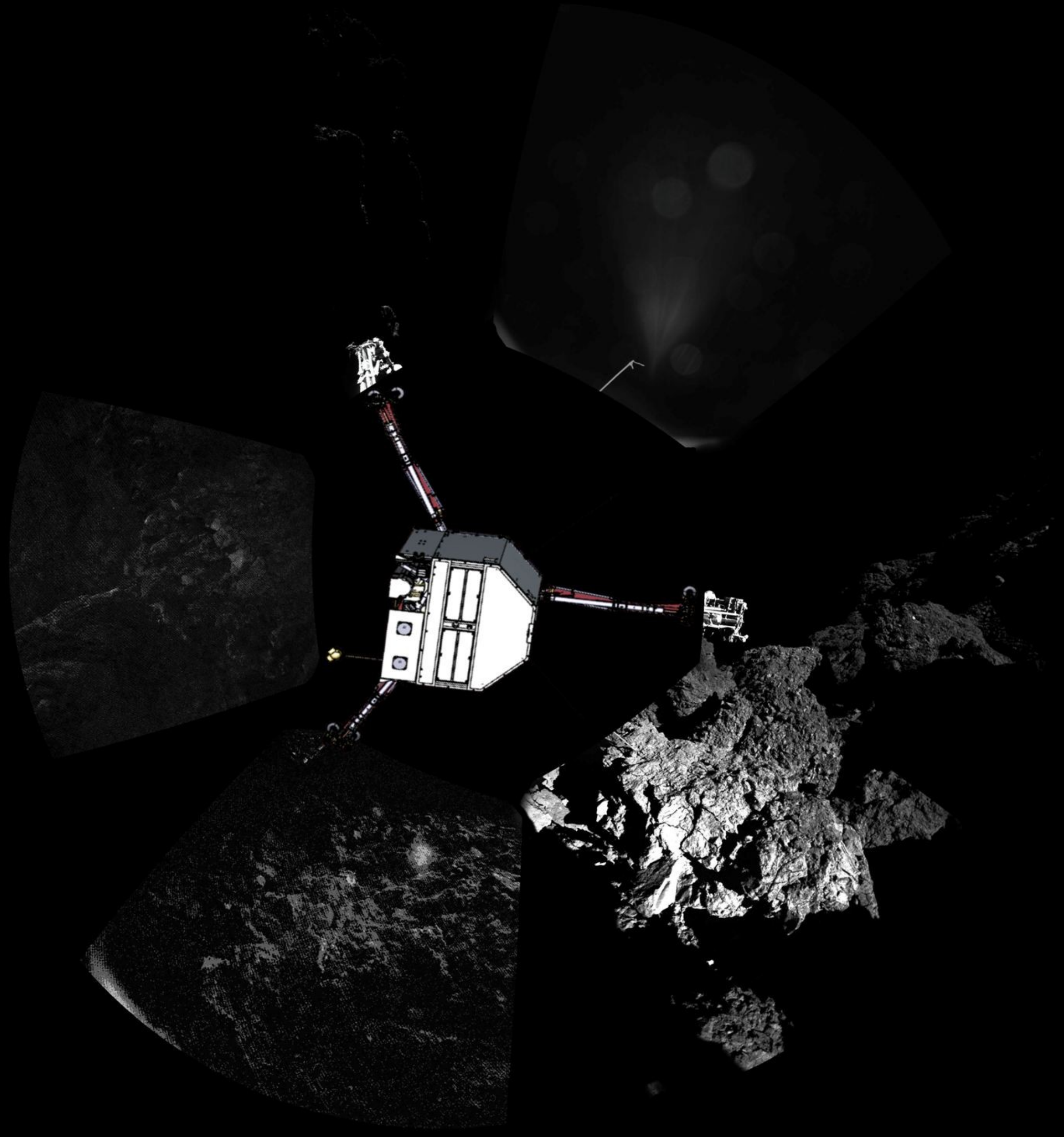

cnes
CENTRE NATIONAL D'ÉTUDES SPATIALES
LA DESCENTE DE PHILAE VERS LA COMÈTE
12 novembre 2014
La morphologie de 67P/Churyumov-Gerasimenko
5,4 km
4,1 km
Agilkia
Tour Eiffel : 324 m
LA TERRE
ROSETTA
9h45
Ouverture du train d'atterrissage de Philae
LES INSTRUMENTS
ROMAP mesure le magnétisme pendant la descente
CONSERT mesure par radar les distances sol/atterrisseur
SESAME mesure les vibrations pendant l'atterrissage
28 MINUTES
C'est le temps de transmission entre l'atterrisseur et la Terre via Rosetta
9h35*
Séparation et début de la descente de Philae ; confirmation reçue à 10h03
Pendant environ 7h, Philae descend jusqu'à la comète
15h54
Début des prises de vue du site d'atterrissage par la caméra ROLIS
16h34 : ATTERRISSAGE
Un propulseur à gaz froid plaque l'atterrisseur au sol. Simultanément, 2 harpons l'ancrent dans le sol
TOUTES LES 10 HEURES
Visibilité entre Philae et Rosetta
PHILAE
19h
Réception du panorama du paysage autour de Philae par le Centre d'Operations Scientifiques de Philae
COMÈTE 67P/CHURYUMOV-GERASIMENKO
SITE D'ATTERRISSAGE
Agilkia, le site d'atterrissage de Philae est une ellipse de 900 m de long sur 600 m de large.
Ce site d'atterrissage
• doit être suffisamment plat (déclivité la plus faible et le moins de rochers possible),
• doit se situer dans une portion du noyau bénéficiant d'un ensoleillement suffisant pour recharger la batterie de Philae. Il doit aussi offrir une période nocturne, certains instruments devant observer l'amplitude thermique jour-nuit,
• doit permettre de poser Philae avec une inclinaison maximale d'une trentaine de degrés par rapport à l'horizontale du site d'atterrissage,
• doit proposer à Philae un horizon largement dégagé pour qu'il puisse communiquer de façon optimale avec Rosetta qui transmet ses données vers la Terre.
17h (+ ou - 15mn)
Confirmation de l'atterrissage par le centre de contrôle de Philae
* Tous les horaires communiqués ici sont GMT+1 (heure de Paris)
www.cnes.fr/rosetta-blog
CNESFrance
@CNES
CNESEspace
© CNES / Création graphique : Julien TREDAN-TURINI

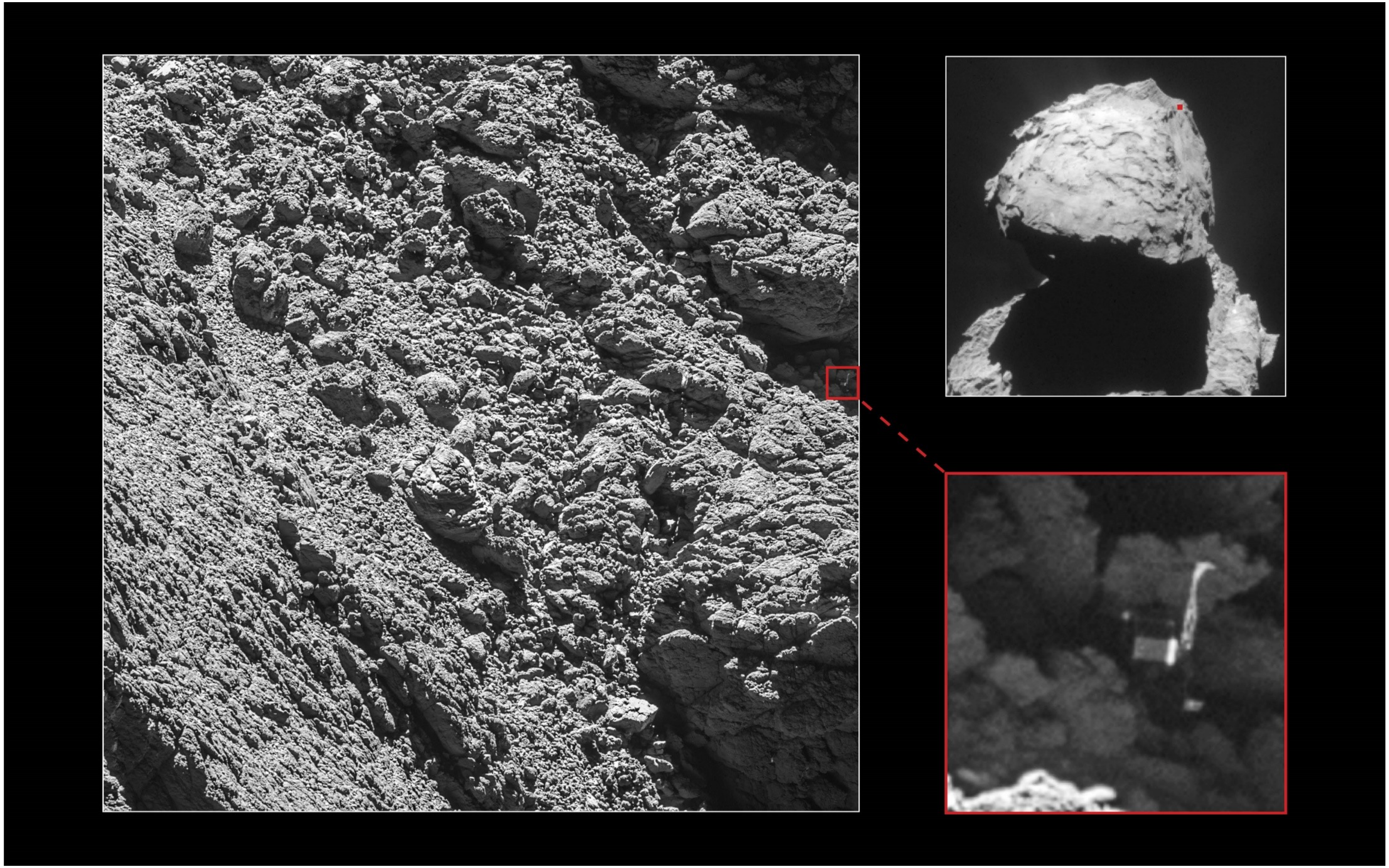

10:18:55


Rolis
3 km

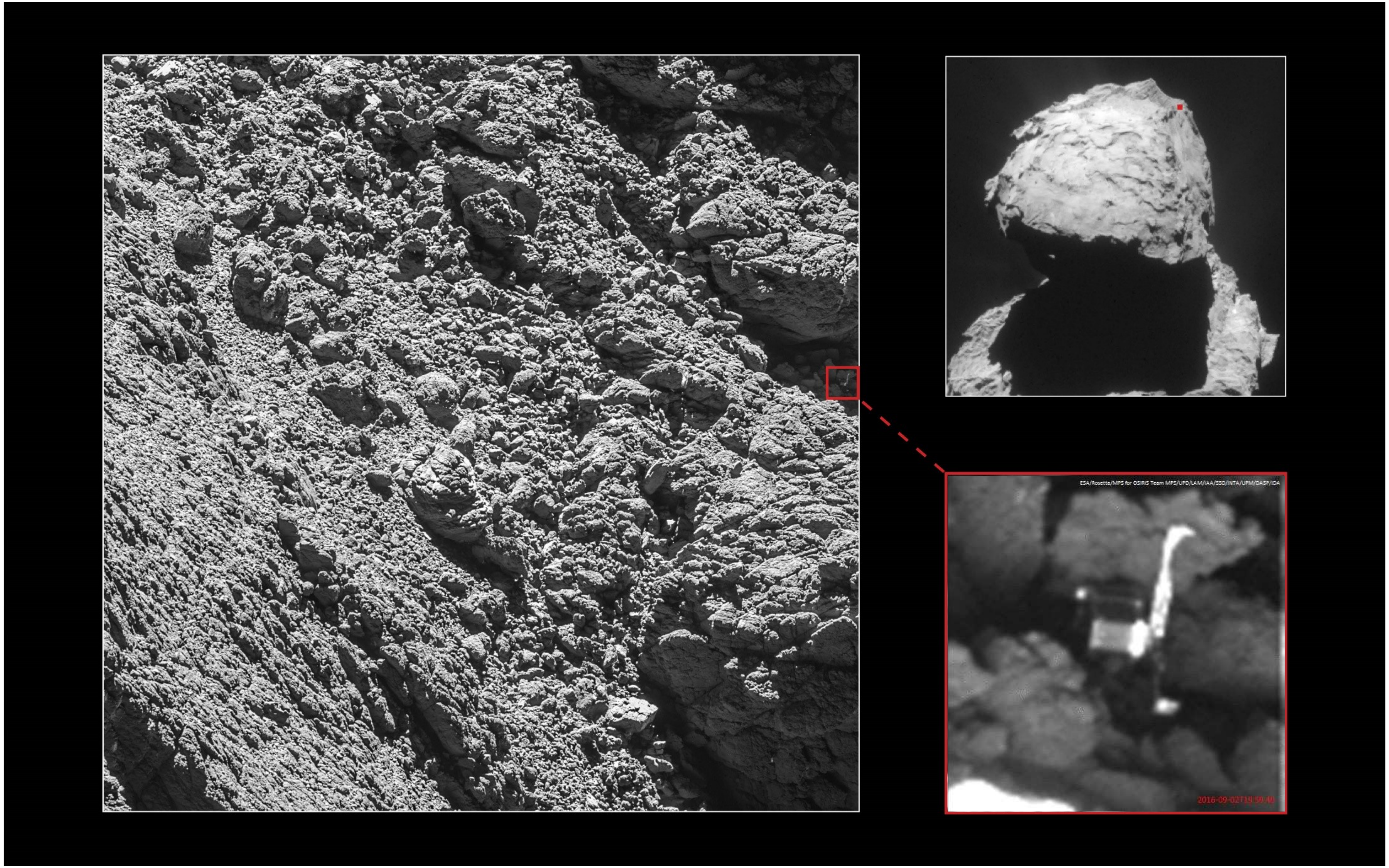

touchdown
point
taken at 15:43
before
taken at 15:18
15:43
15:23
15:19
15:14





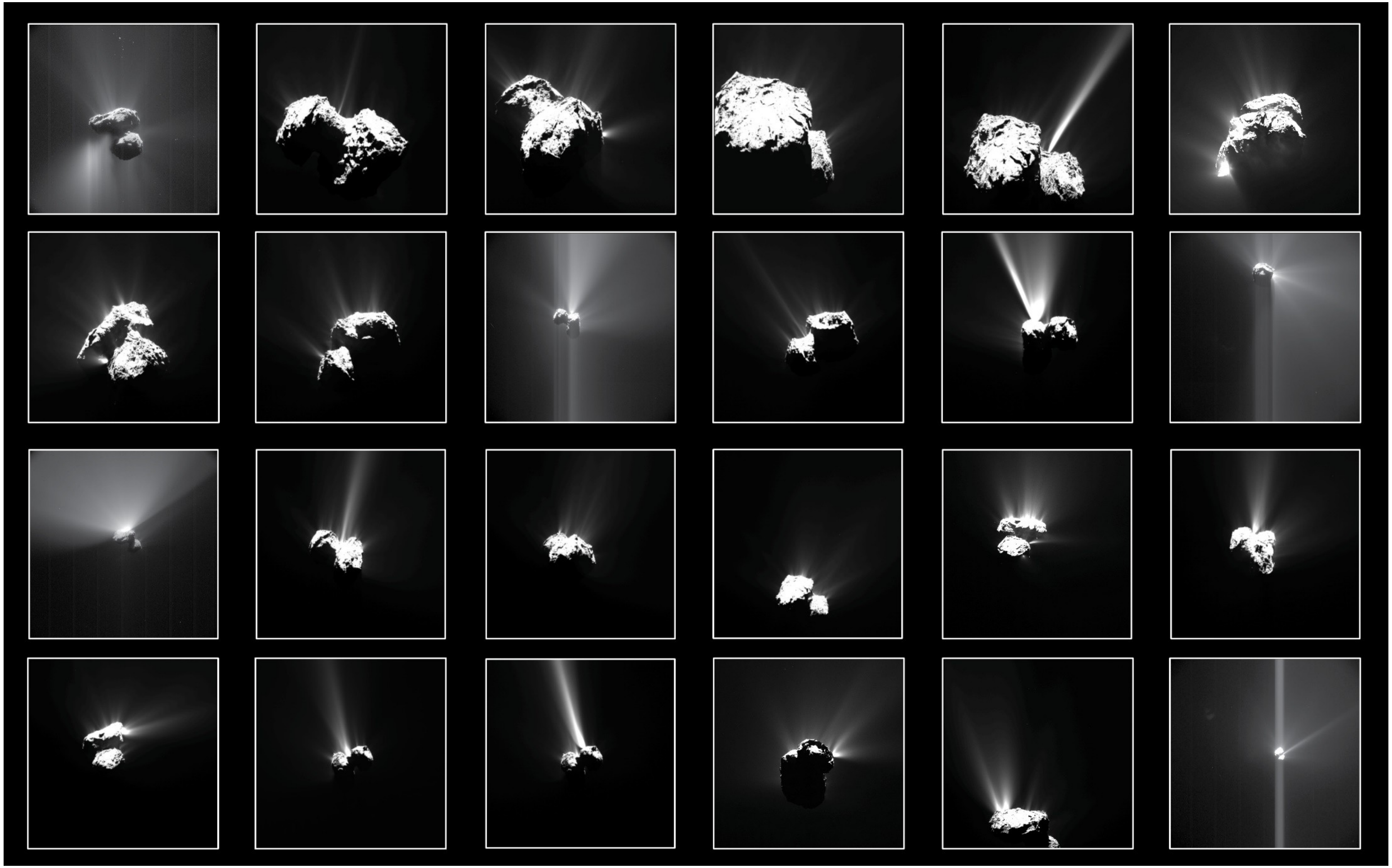


September 5th 2016



September 5th 2016

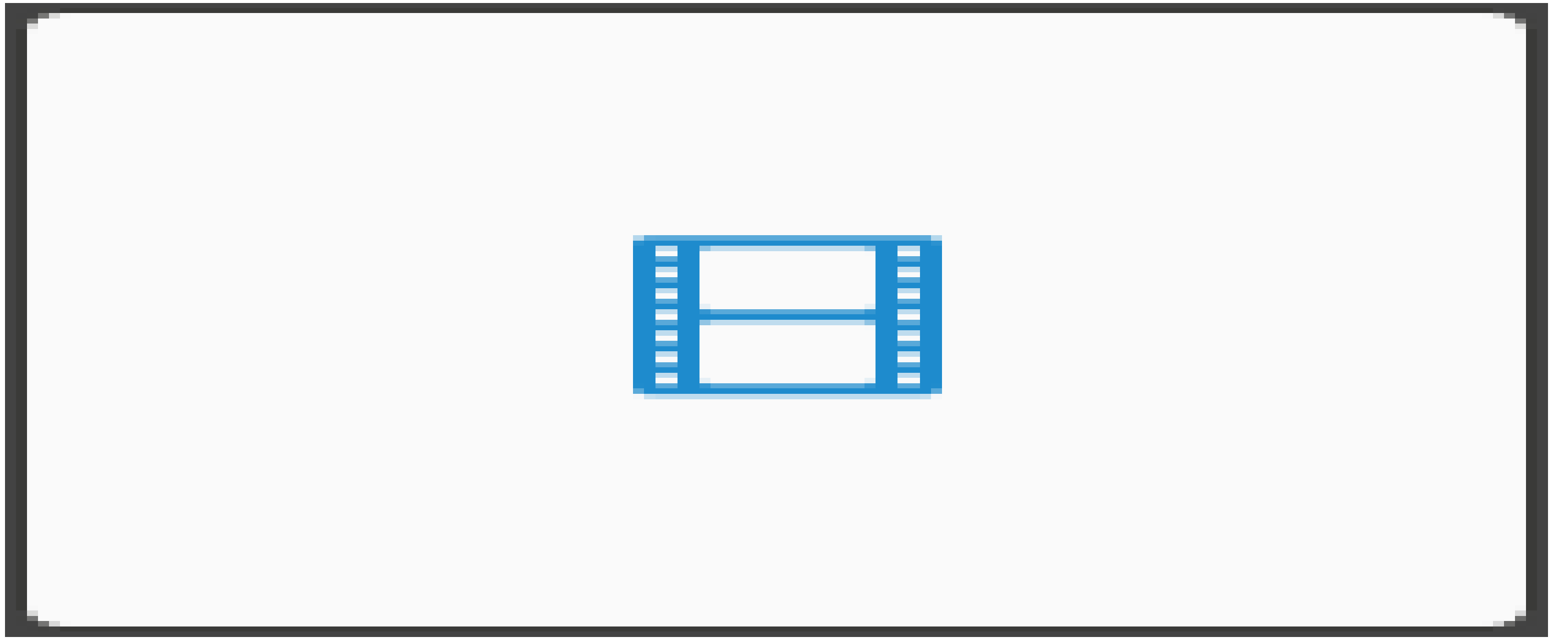
Summer 2015 Fireworks



Photos prises par la sonde Rosetta pendant sont passage au périhélie, été 2015
Credits: OSIRIS: ESA/Rosetta/MPS for OSIRIS Team MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA; NavCam: ESA/Rosetta/NavCam – CC BY-SA IGO 3.0

July 29th, 2015

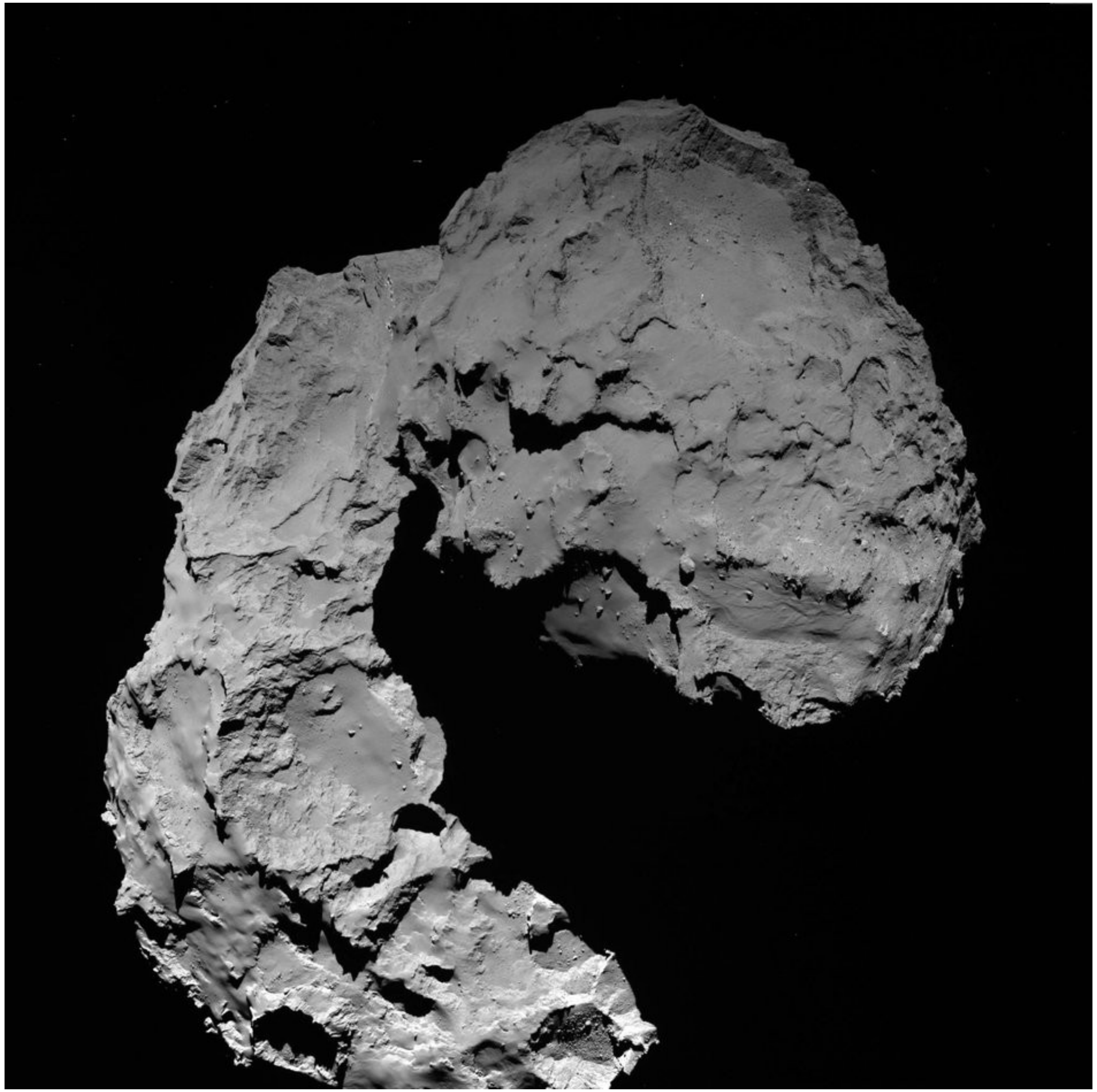
Credits: ESA/Rosetta/MPS for OSIRIS Team MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA



Deep Impact movie (1998)

End of Mission

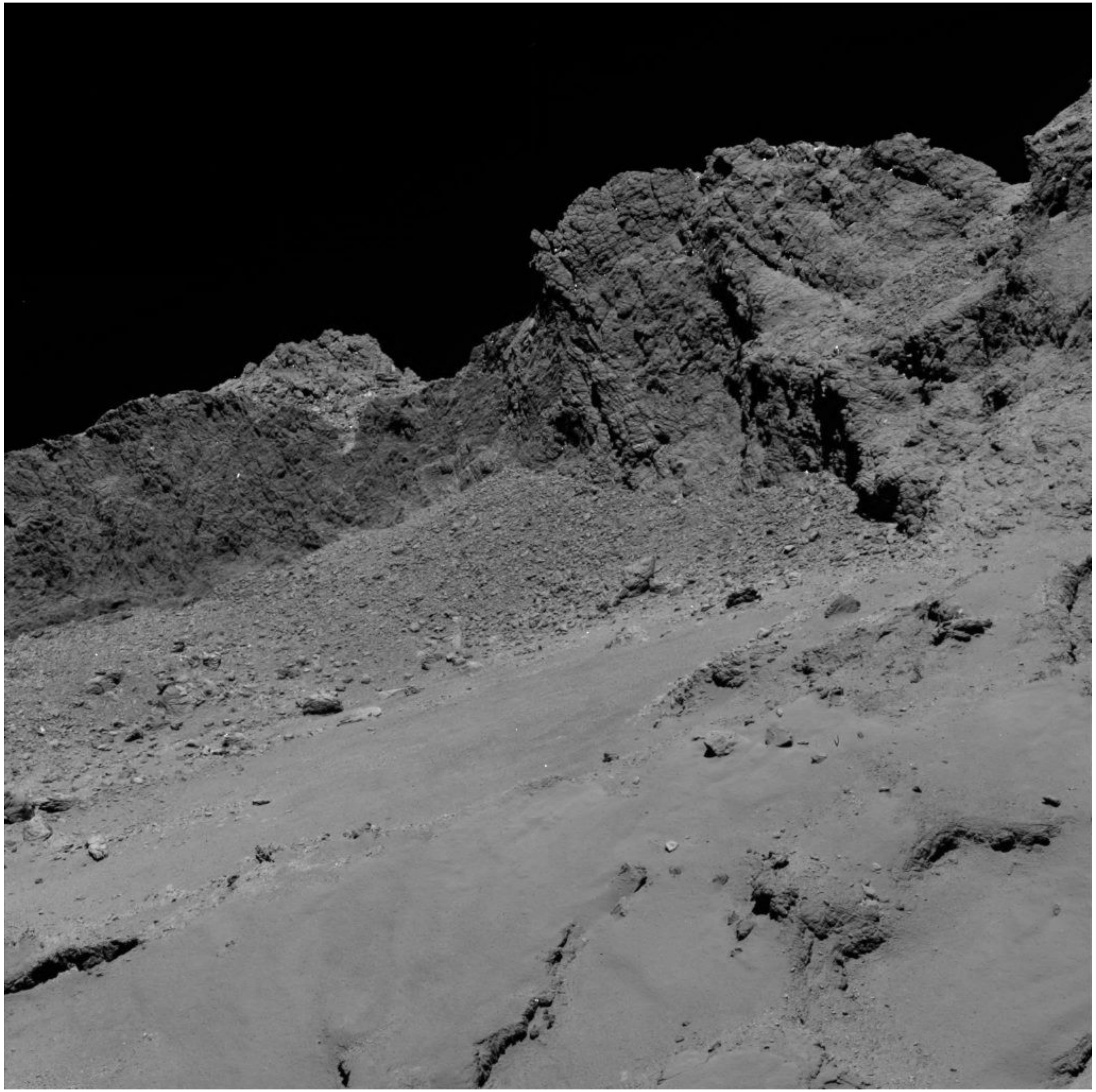
End of mission



September 29th, 2016
11h49
22.9 km from nucleus

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

End of mission

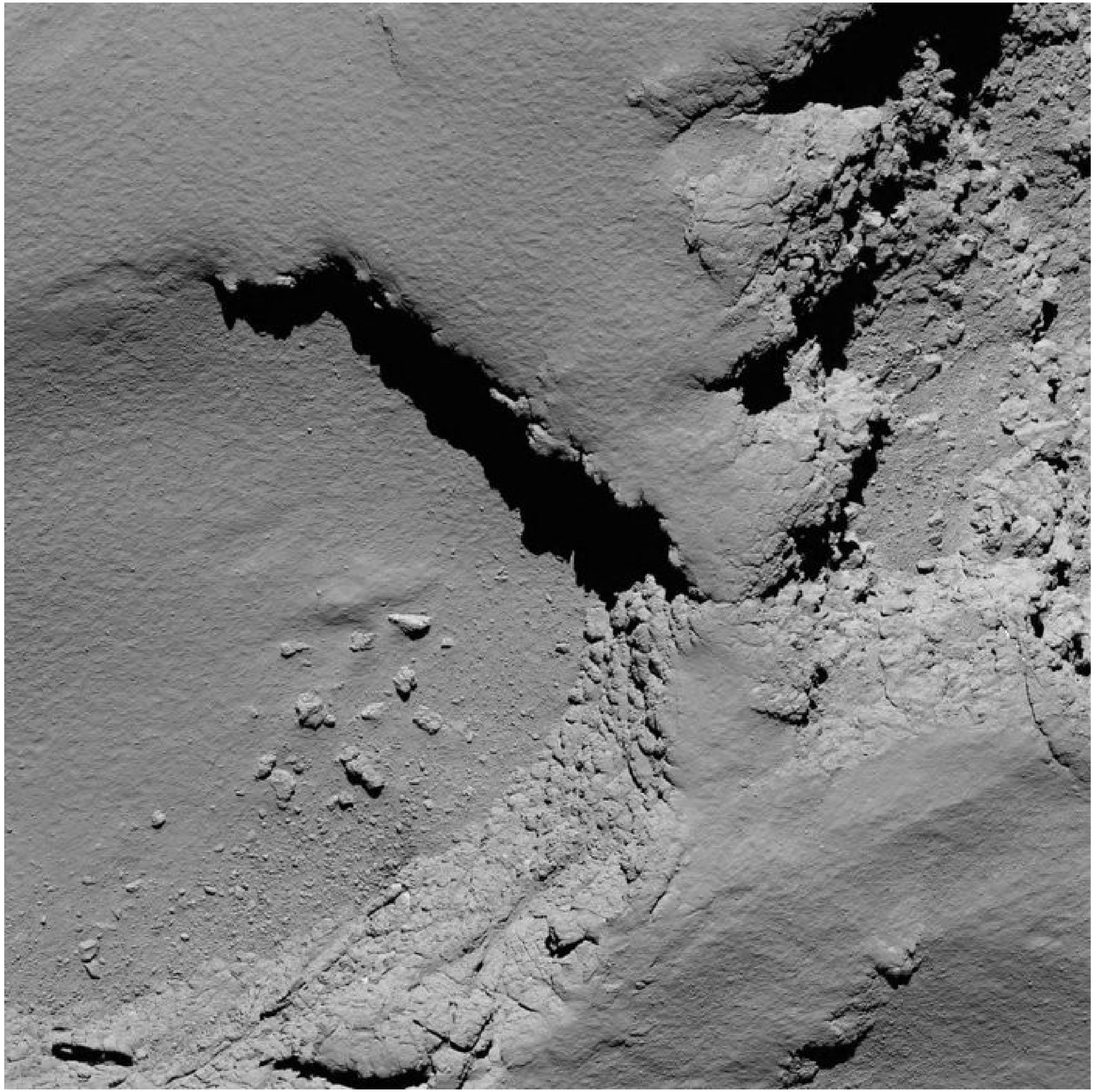


614 m

September 30th, 2016
3h20
16 km from nucleus

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

End of mission

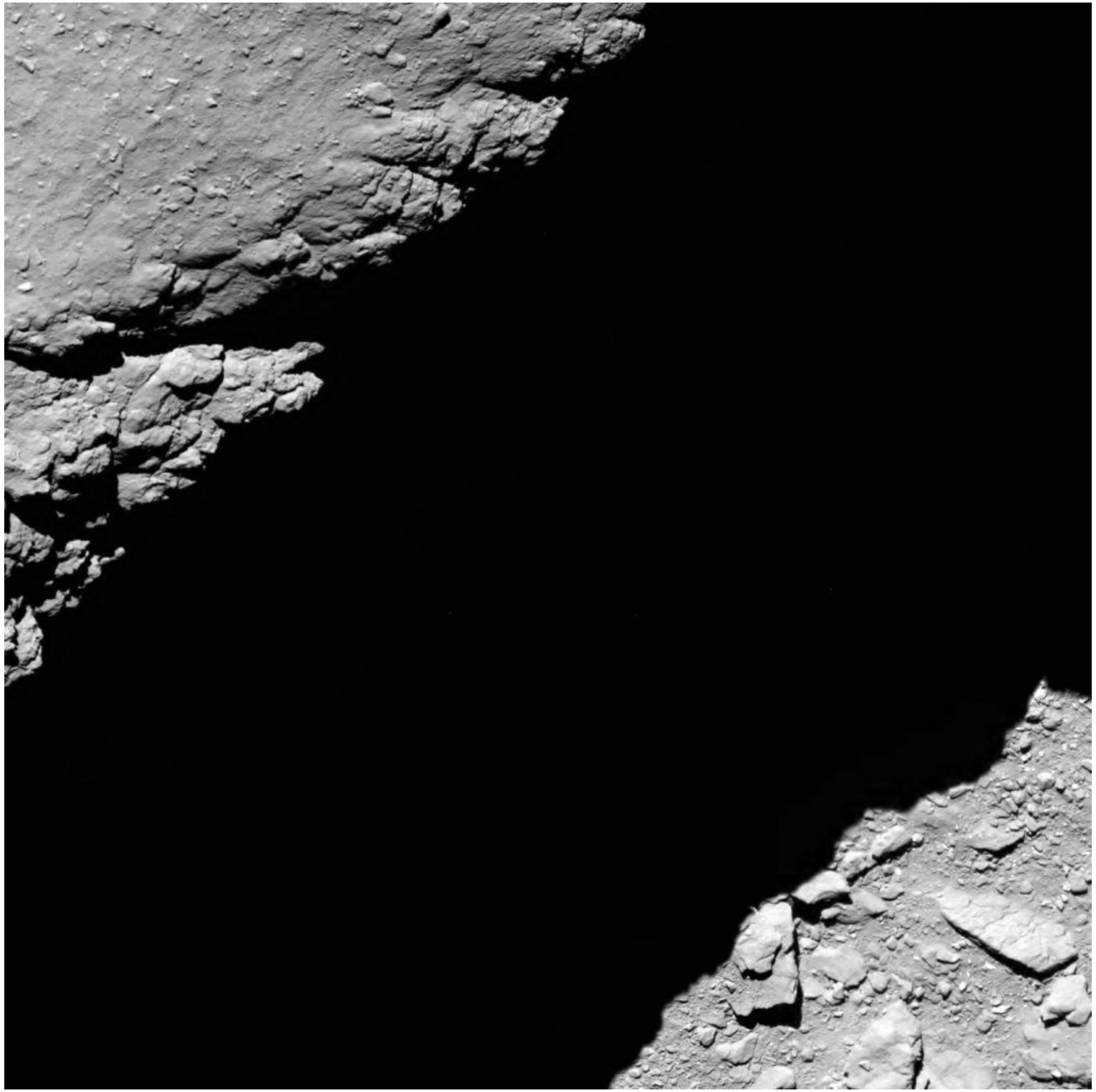


225 m

September 30th, 2016
10h18
5.8 km from nucleus

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

End of mission

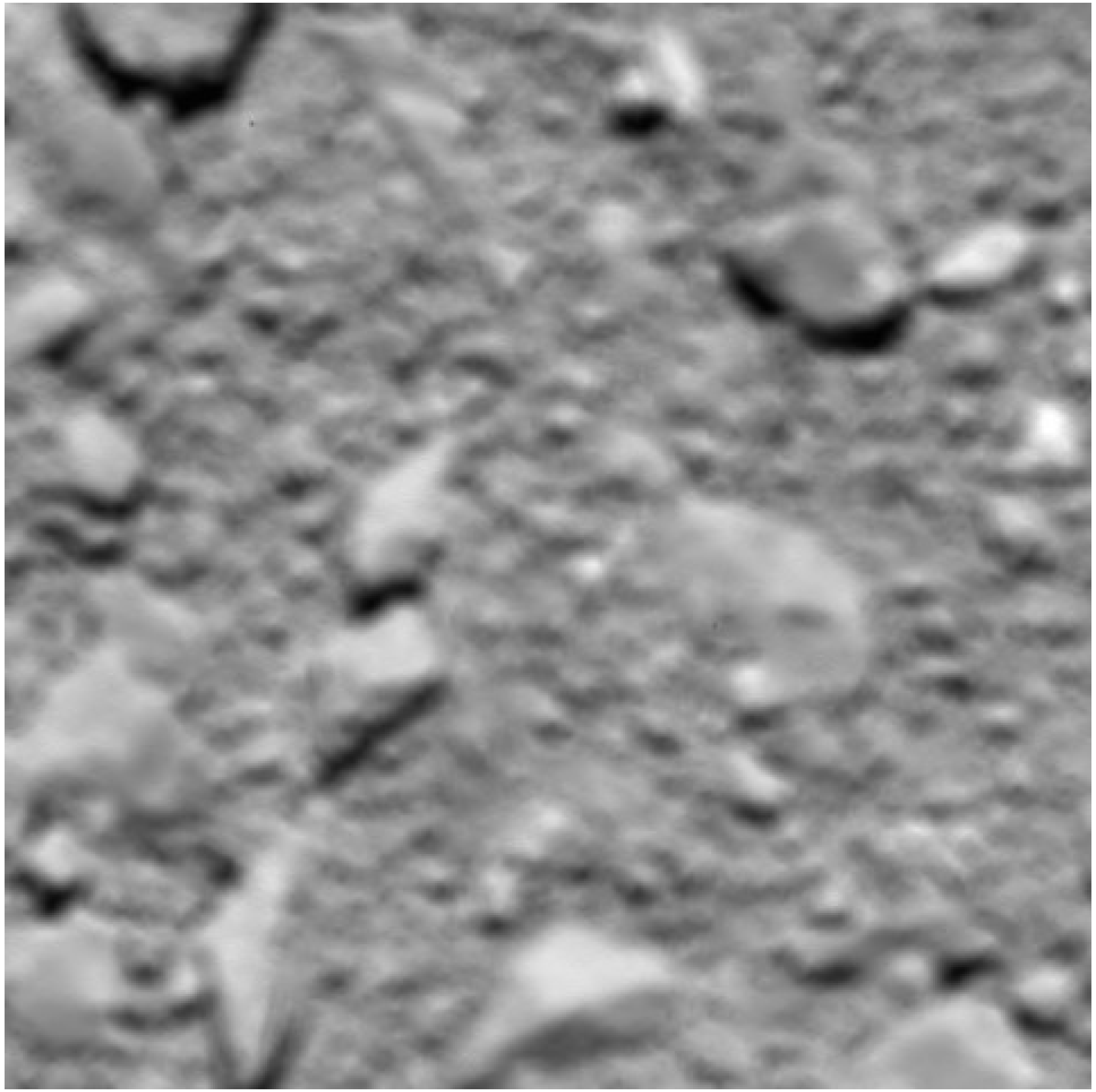


33 m

September 30th, 2016
12h14
1.2 km from nucleus

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

End of mission

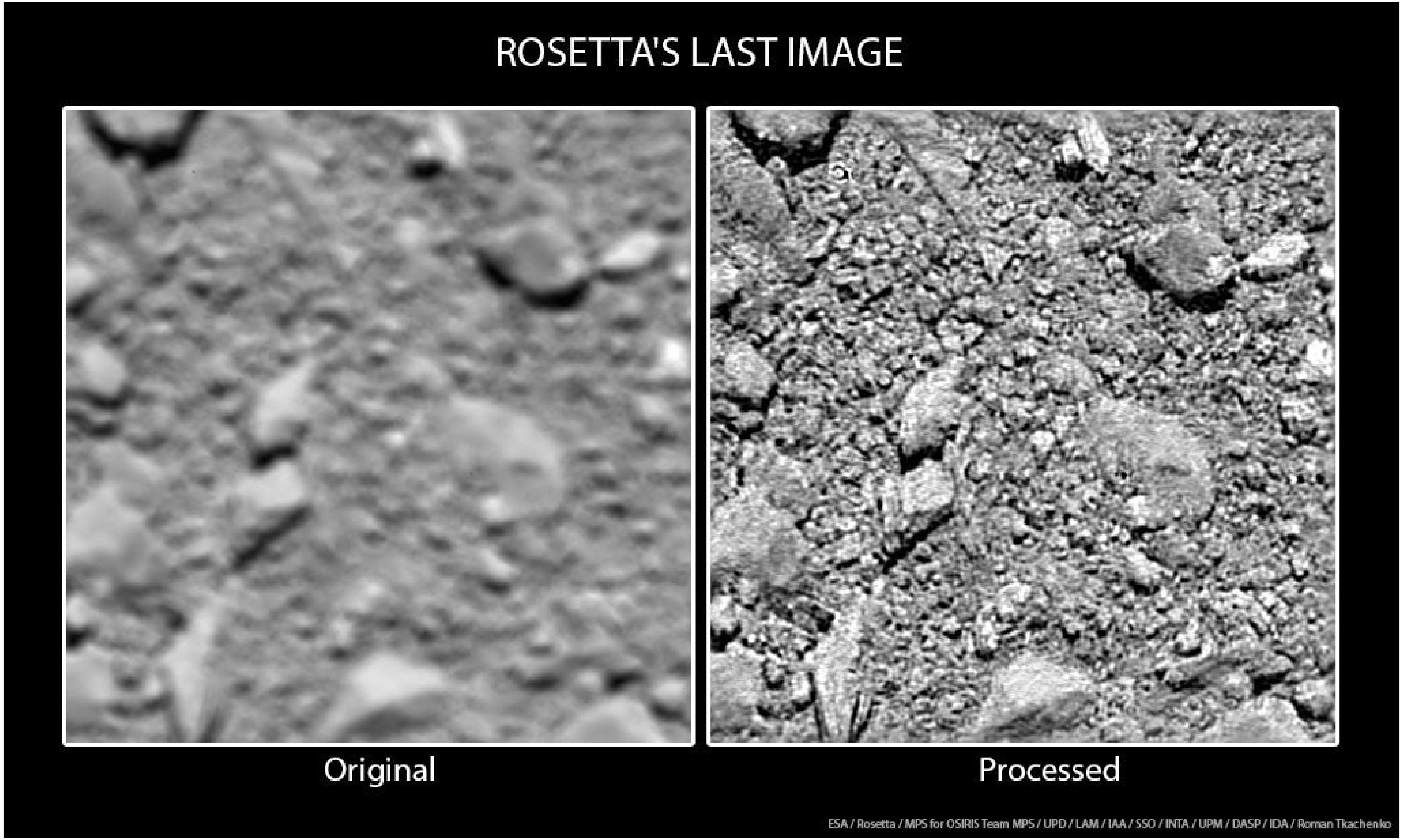


96 cm

September 30th, 2016
13h19
20 m from nucleus

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

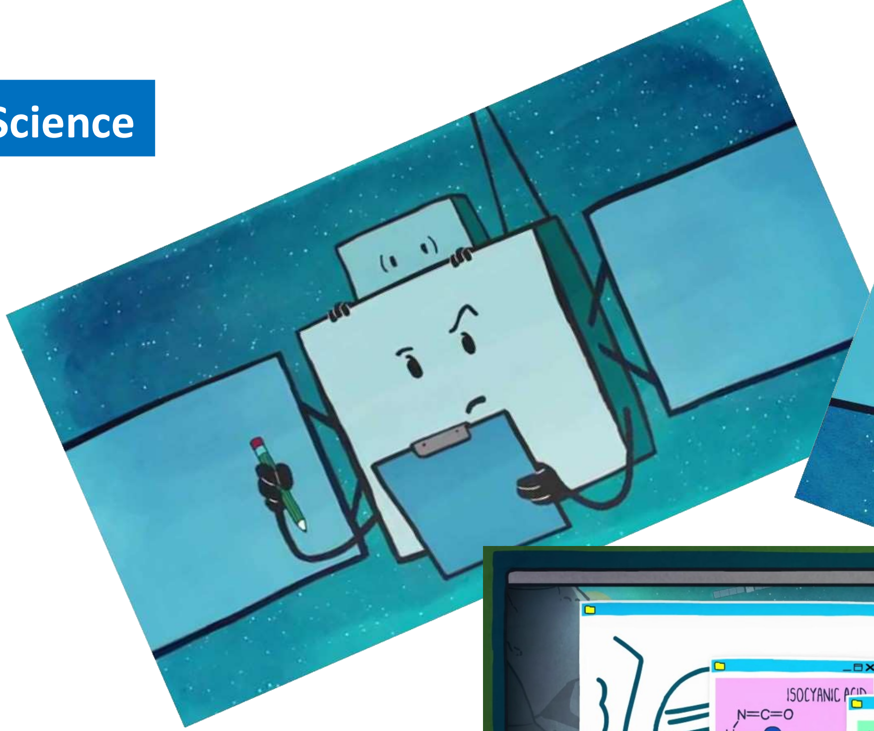
End of mission

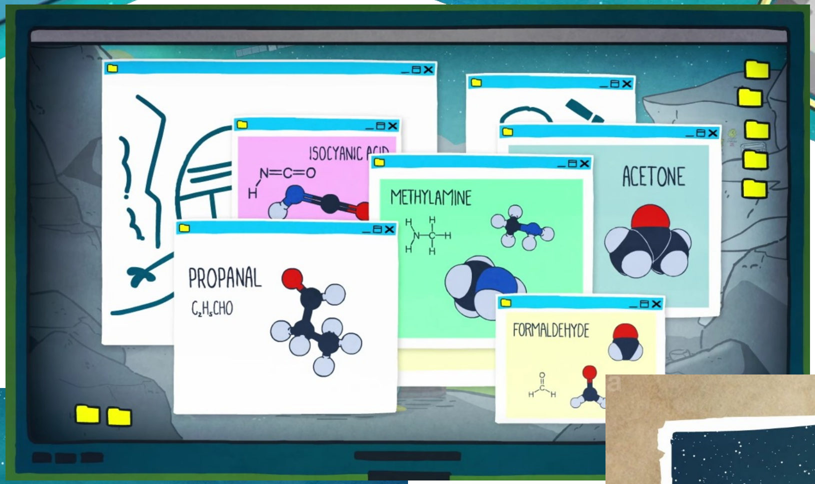


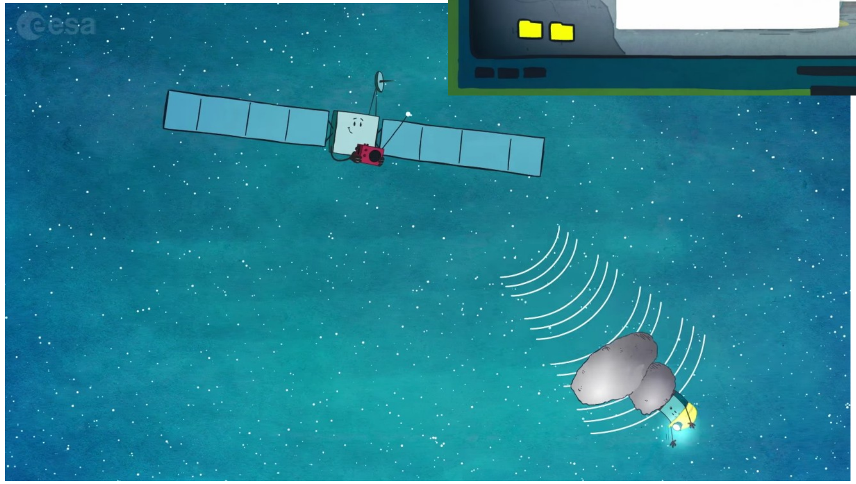
Fin de mission

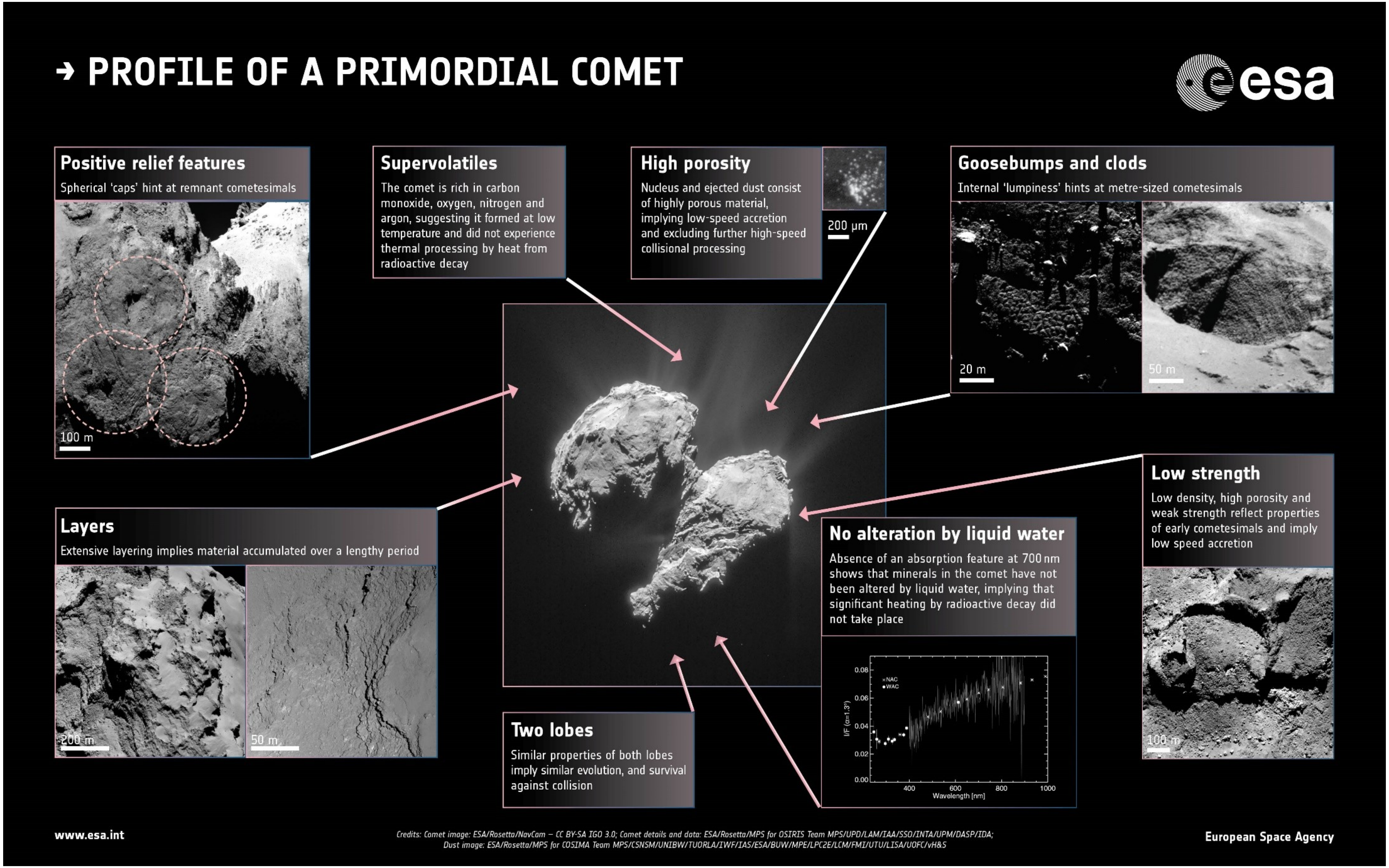
Septembre 30th – 13h19 20s

Rosetta Science









→ PROFILE OF A PRIMORDIAL COMET
esa
Positive relief features
Spherical 'caps' hint at remnant cometesimals
100 m
Supervolatiles
The comet is rich in carbon monoxide, oxygen, nitrogen and argon, suggesting it formed at low temperature and did not experience thermal processing by heat from radioactive decay
High porosity
Nucleus and ejected dust consist of highly porous material, implying low-speed accretion and excluding further high-speed collisional processing
200 μm
Goosebumps and clods
Internal 'lumpiness' hints at metre-sized cometesimals
20 m
50 m
Low strength
Low density, high porosity and weak strength reflect properties of early cometesimals and imply low speed accretion
100 m
Layers
Extensive layering implies material accumulated over a lengthy period
200 m
50 m
No alteration by liquid water
Absence of an absorption feature at 700 nm shows that minerals in the comet have not been altered by liquid water, implying that significant heating by radioactive decay did not take place
NAC
WAC
I/F (α=1.3°)
0.08
0.06
0.04
0.02
0.00
400
600
800
1000
Wavelength [nm]
Two lobes
Similar properties of both lobes imply similar evolution, and survival against collision
www.esa.int
Credits: Comet image: ESA/Rosetta/NavCam – CC BY-SA IGO 3.0; Comet details and data: ESA/Rosetta/MPS for OSIRIS Team MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA;
Dust image: ESA/Rosetta/MPS for COSIMA Team MPS/CSNSM/UNIBW/TUORLA/IWF/IAS/ESA/BUW/MPE/LPC2E/LCM/FMI/UTU/LISA/UOFC/vH&S
European Space Agency

Life of a cometary nucleus

Surface erosion, preserving the interior

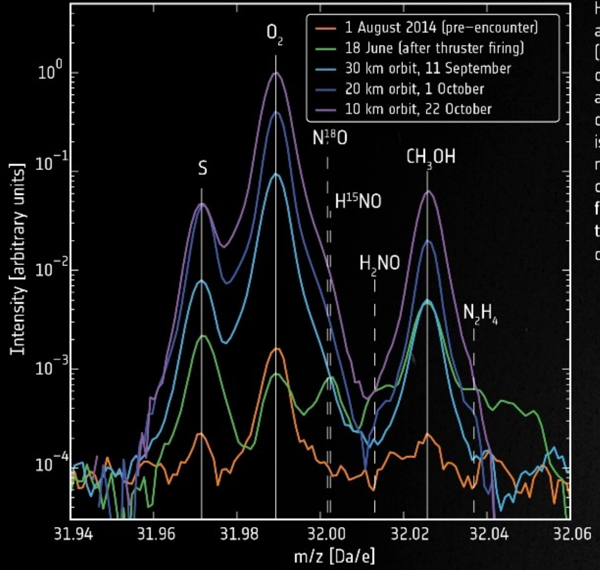
- Continuous degassing, throughout the mission, with a maximum of activity a few weeks after the perihelion.
- Diffuse & continuous ambient coma, sometimes accompanied by jets that may remain visible for a few minutes to a few hours.
- The jets mostly come from regions containing frost (CO_2 or H_2O) on the surface, or from cliffs.
    - erosion of the nucleus :
        - erosion of the cliffs
        - movements observed in the smooth zones,
        - displacement of blocks on the surface
        - opening of fractures
        - disappearance or deposition of fine materials.
- morphologies of wind origin (e.g. “dune”), change in color and composition (frost).
- erosion-related processes limited to the first few meters. The interior of the nucleus is thermally insulated from solar heating (low inertia), which preserves the materials located a few meters below the surface.

Composition:

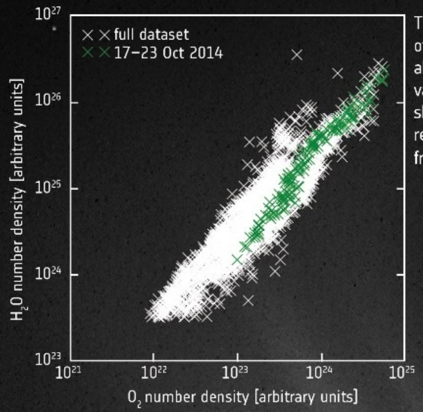
- Complex molecular composition and a high abundance of carbon
- Some surprises related to water, O_2…

→ ROSETTA HAS MADE THE FIRST DETECTION OF MOLECULAR OXYGEN AT A COMET

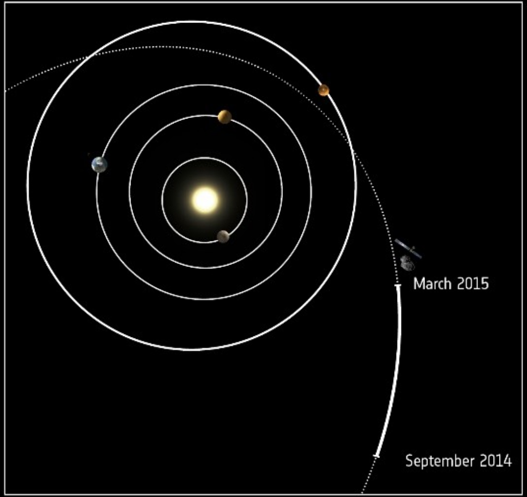
The measurements were made with the Rosetta Orbiter Spectrometer for Ion and Neutral Analysis Double-Focusing Mass Spectrometer (ROSINA-DFMS).



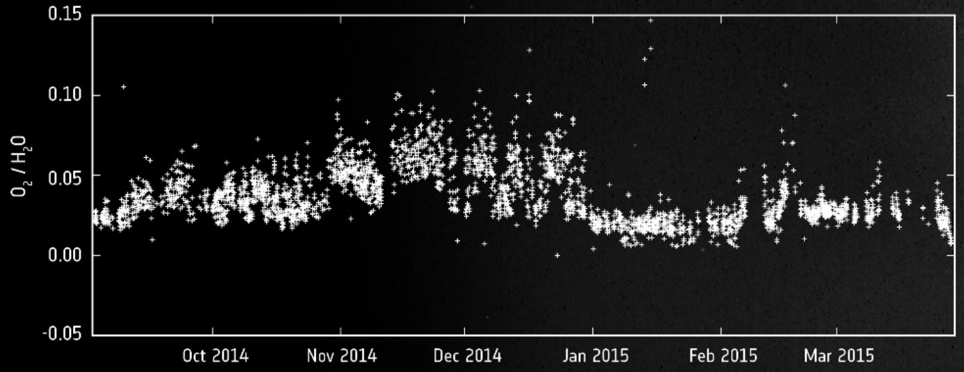
High-resolution measurements allowed molecular oxygen (O_2) to be distinguished from other species like sulphur (S) and methanol (CH_3OH). The detection of the coma gases is stronger closer to the comet nucleus, as expected. The contribution to the detection from contamination from the spacecraft thruster firings during manoeuvres is very low.



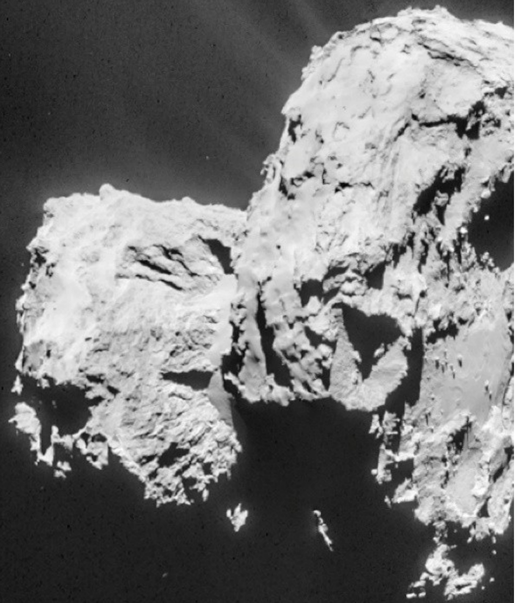
The strong correlation of molecular oxygen abundance with water vapour indicates a shared origin and release mechanism from the nucleus.



The results were collected between September 2014 and March 2015.



The O_2/H_2O ratio does not vary significantly over the study period. Short-lived strong variations are attributed to the decrease of the O_2 ratio for occasionally higher H_2O abundances linked to the daily water-ice cycle. The overall consistent level implies that O_2 is not produced today by solar wind or UV interaction with surface ices, otherwise it would rapidly decrease due to the comet´s increased activity. Instead, the O_2 must have been incorporated into the comet´s ices during its formation in the early Solar System, and is being released with the water vapour today.



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European Space Agency

How to detect O_2 in a comet

Very difficult by spectroscopy (O_2 is a symetrical molecule)

The detection was made by mass spectrometry: we “weigh the molecule” thanks to its electrostatic properties

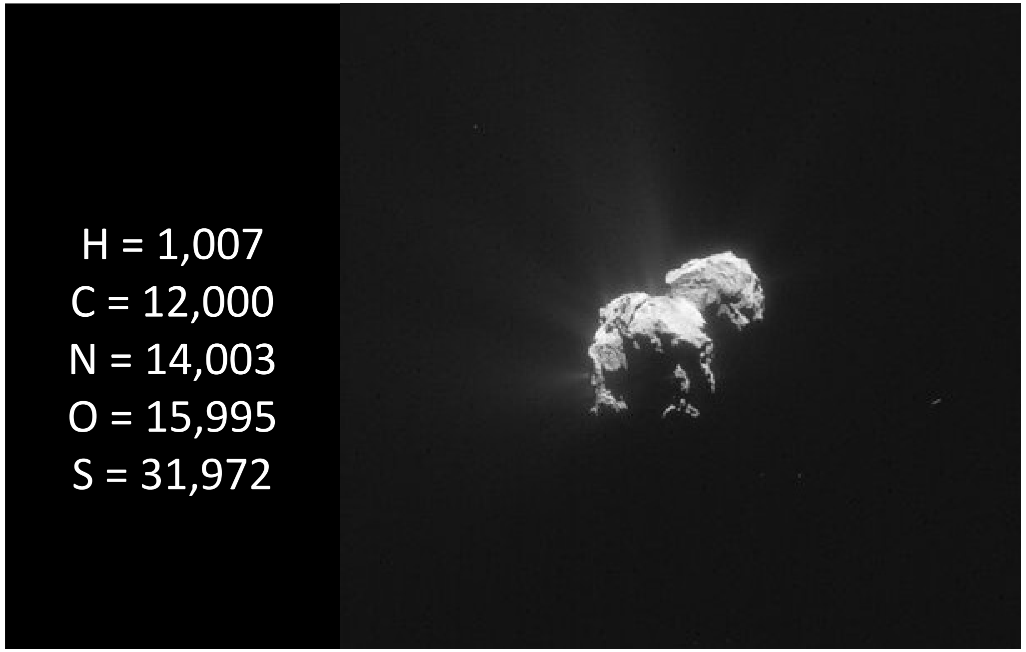
But some spectral confusions are possible

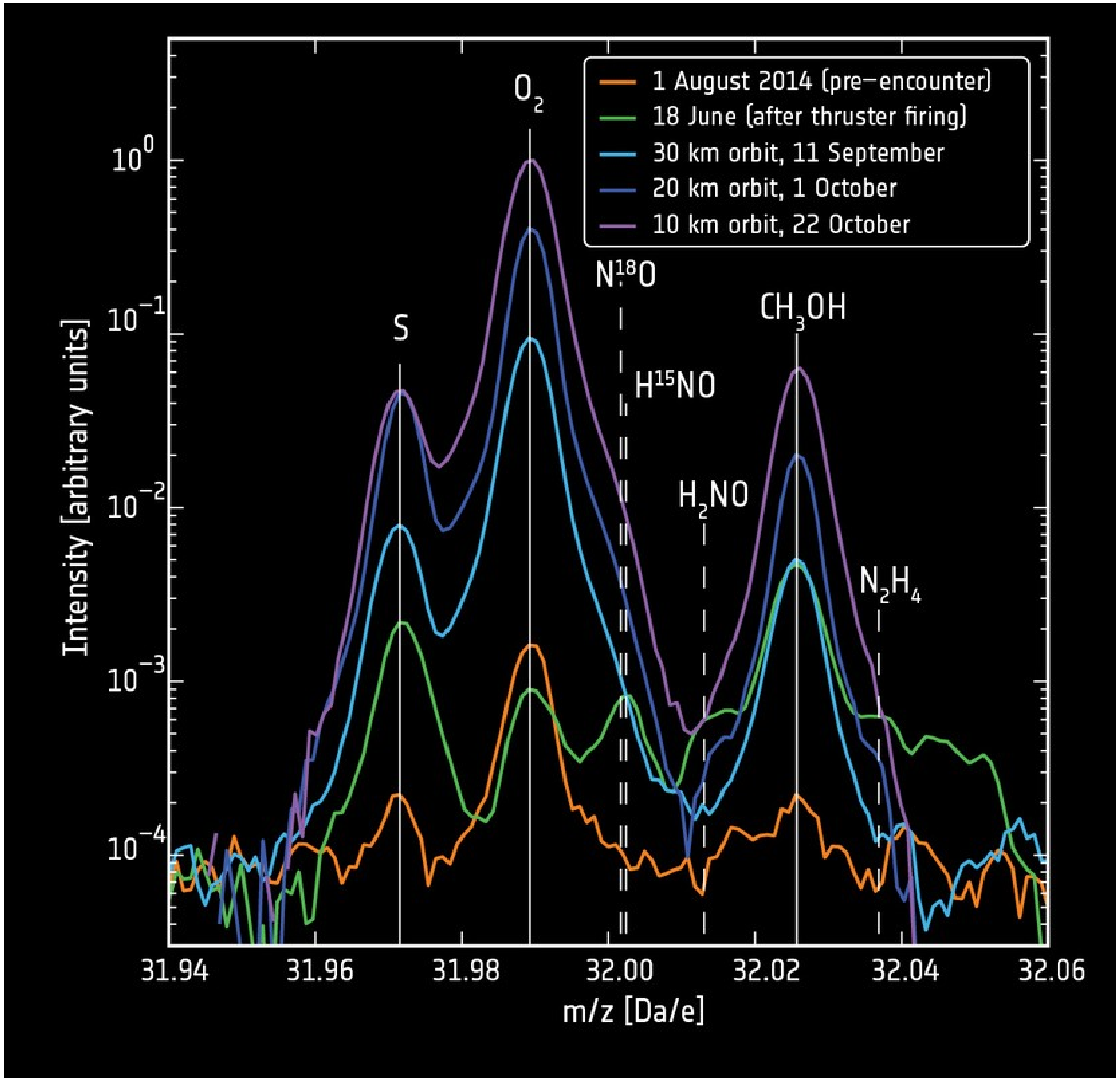
O = 16 => O_2 = 32

S = 32 !!

C = 12, H = 1,
CH_3OH = 32 !!

N = 14
N_2H_4 = 32 !!





1 August 2014 (pre−encounter)
18 June (after thruster firing)
30 km orbit, 11 September
20 km orbit, 1 October
10 km orbit, 22 October
O_2
S
$N^{18}O$
$H^{15}NO$
CH_3OH
H_2NO
N_2H_4
Intensity [arbitrary units]
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
31.94
31.96
31.98
32.00
32.02
32.04
32.06
m/z [Da/e]