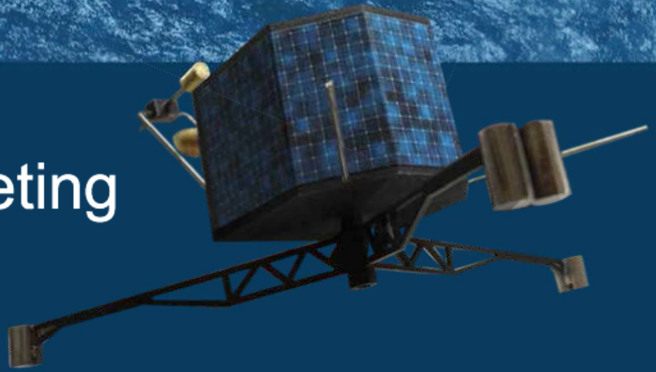
Rosetta Mission
AIAA and ASME Dinner Meeting
Oct. 15, 2015



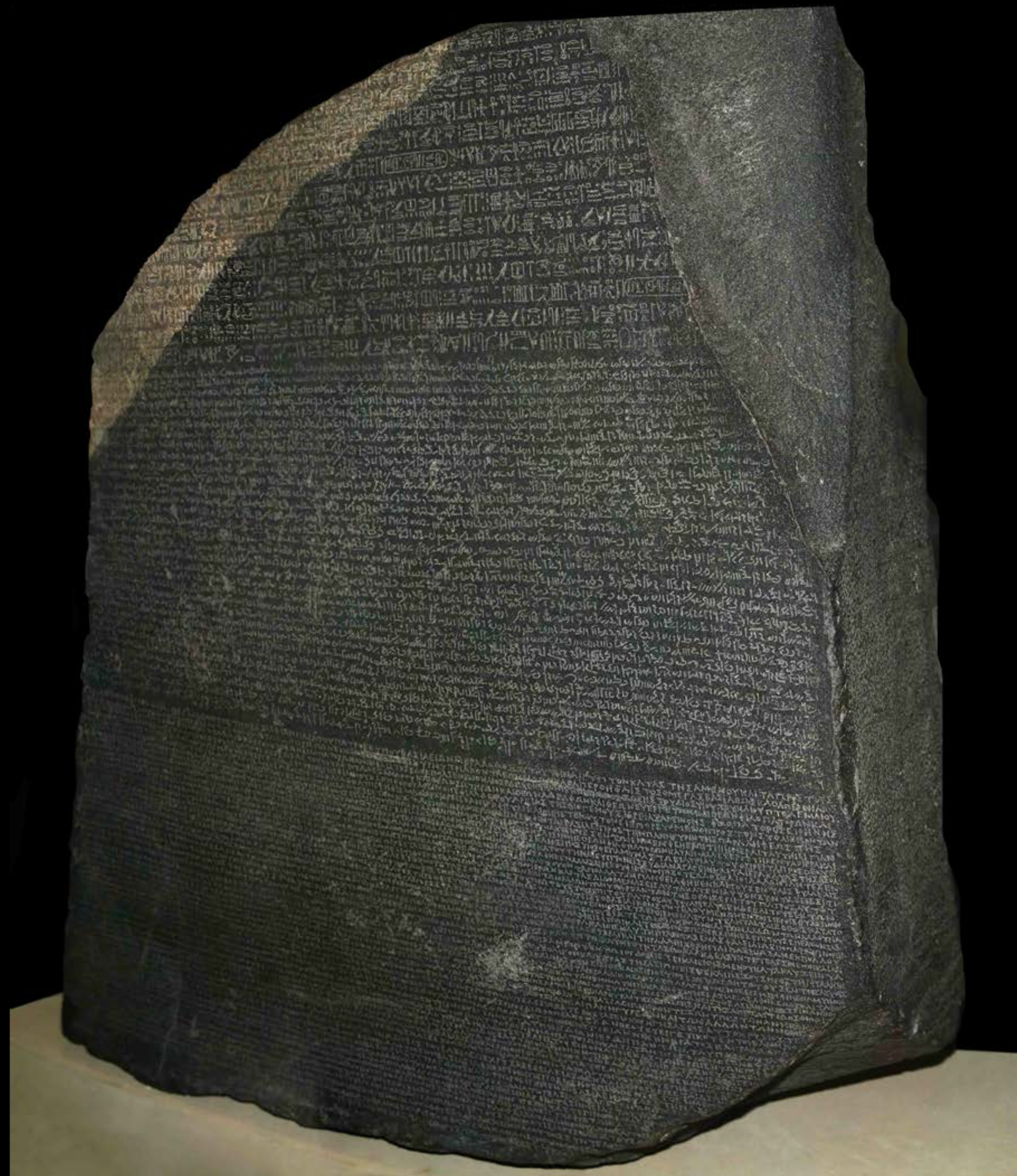
Adans Ko – Jet Propulsion Laboratory,
California Institute of Technology
US Rosetta Project Mission Assurance Manager
October 15, 2015

This research described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with National Aeronautics and Space Administration (NASA)

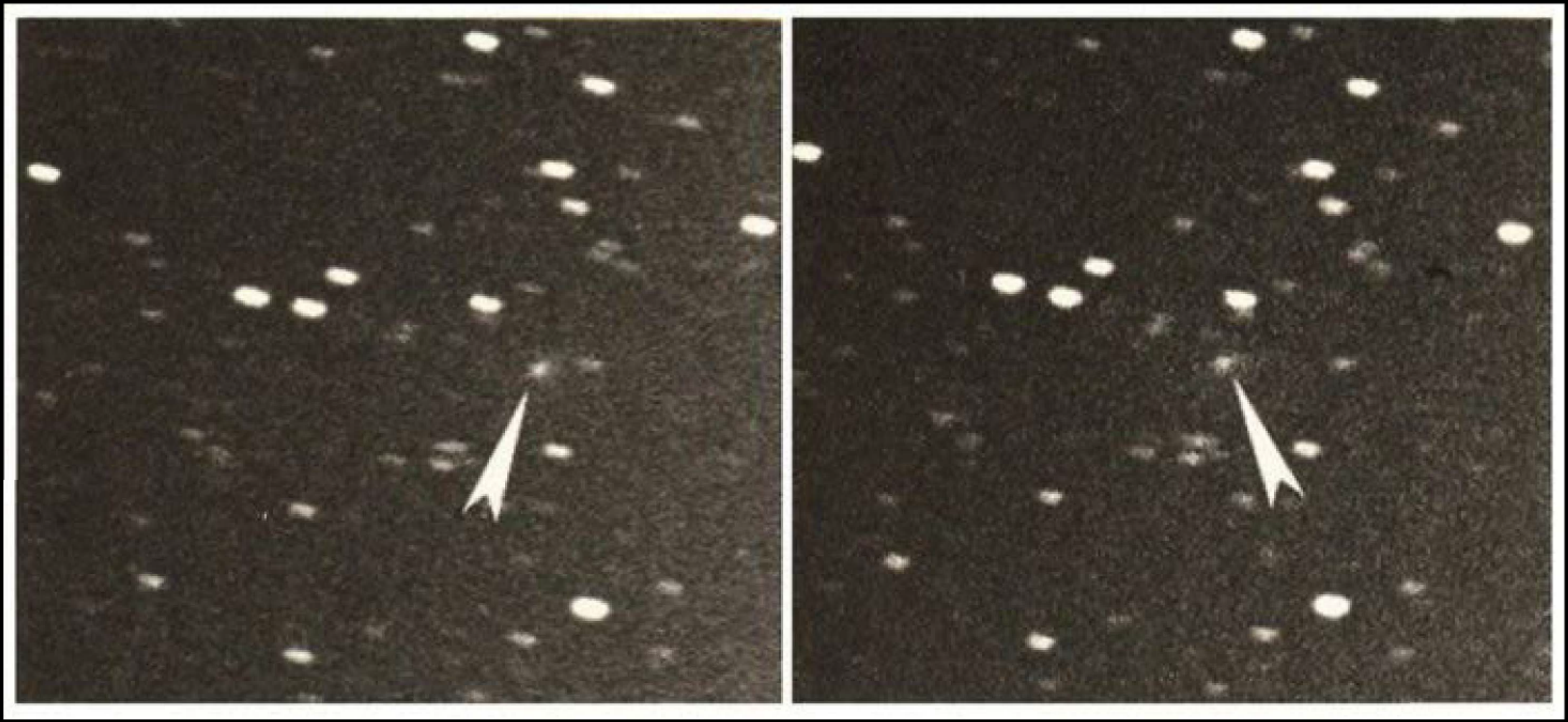
Formation

Credit: NASA/JPL Caltech

Why is this mission named "Rosetta"?



The original image of 67P by Churyumov-Gerasimenko



Klim Churyumov, 1969

Credit: ESA/Rosetta

Rosetta's Journey

Credit: NASA/JPL Caltech

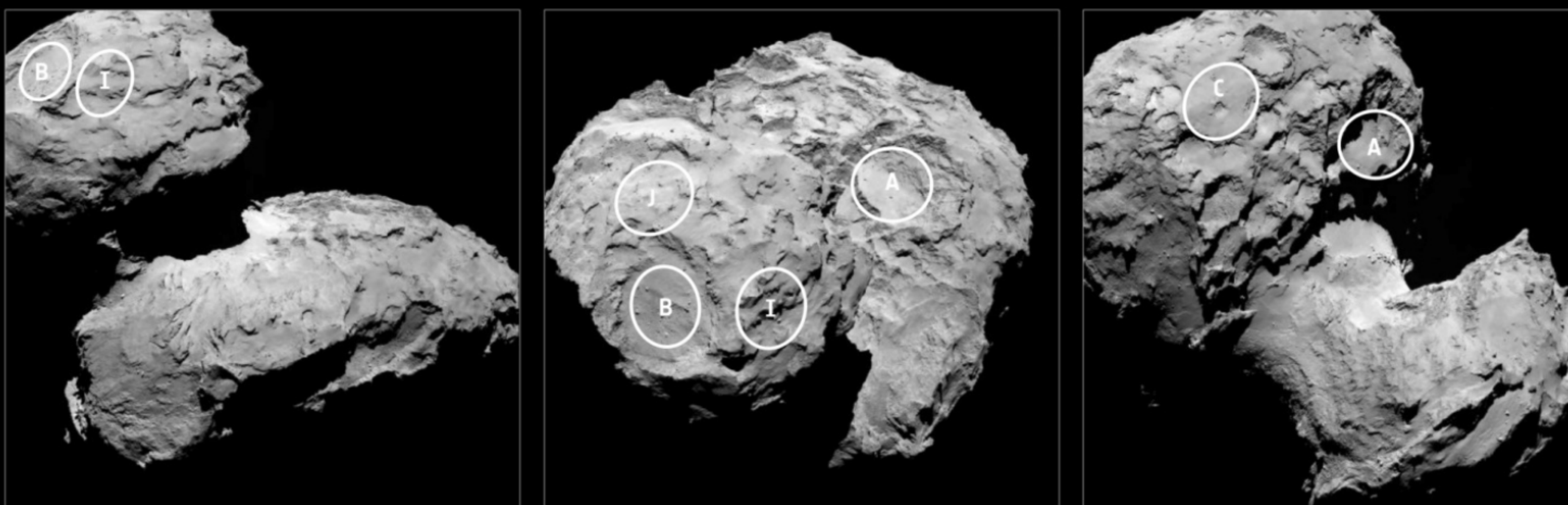
Best image of 67P 5 months before landing

Credit: ESA/Rosetta/NAVCAM

Credit:
ESA/Rosetta/Lander

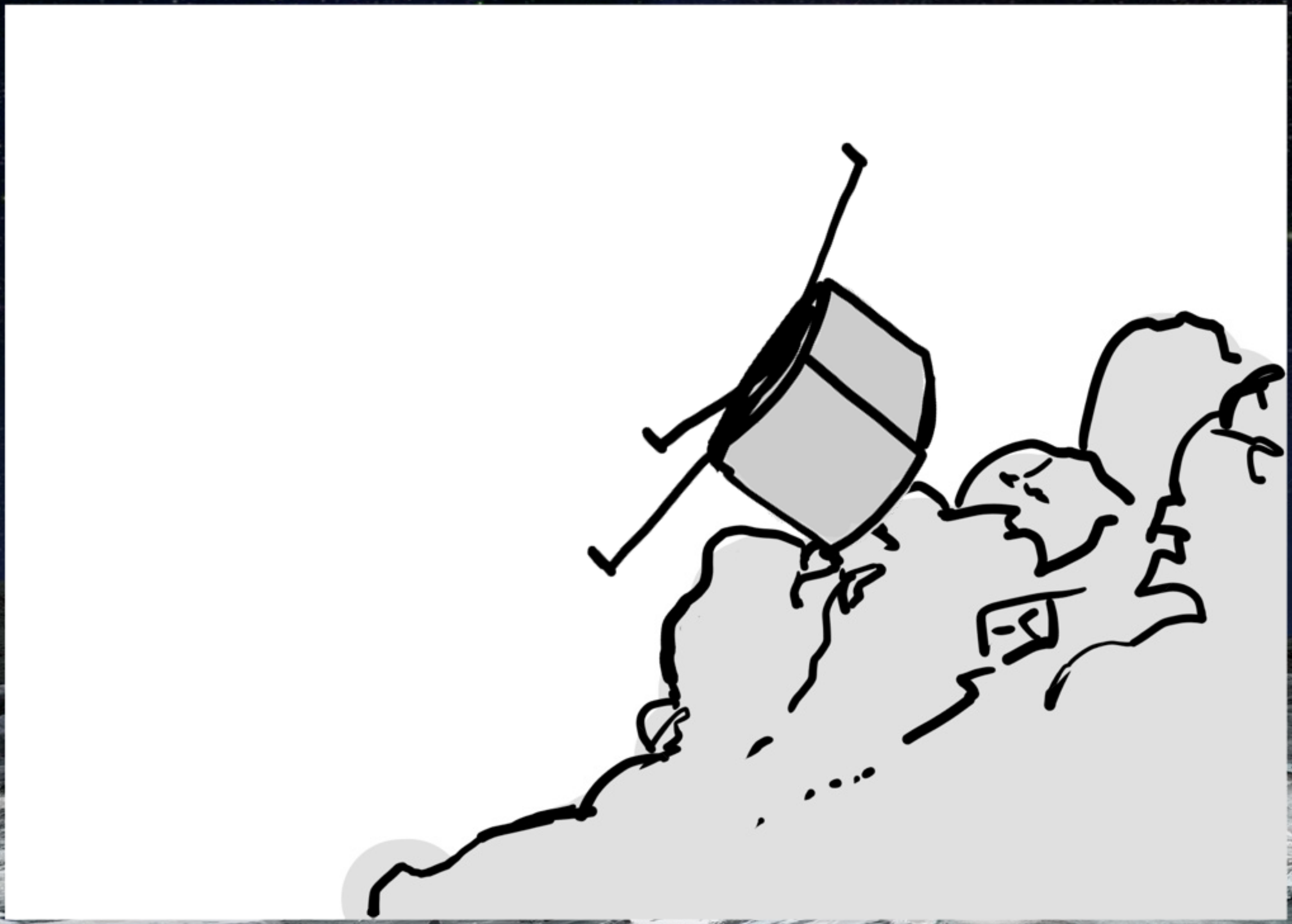
Lander Deployment

5 Landing Candidate Sites

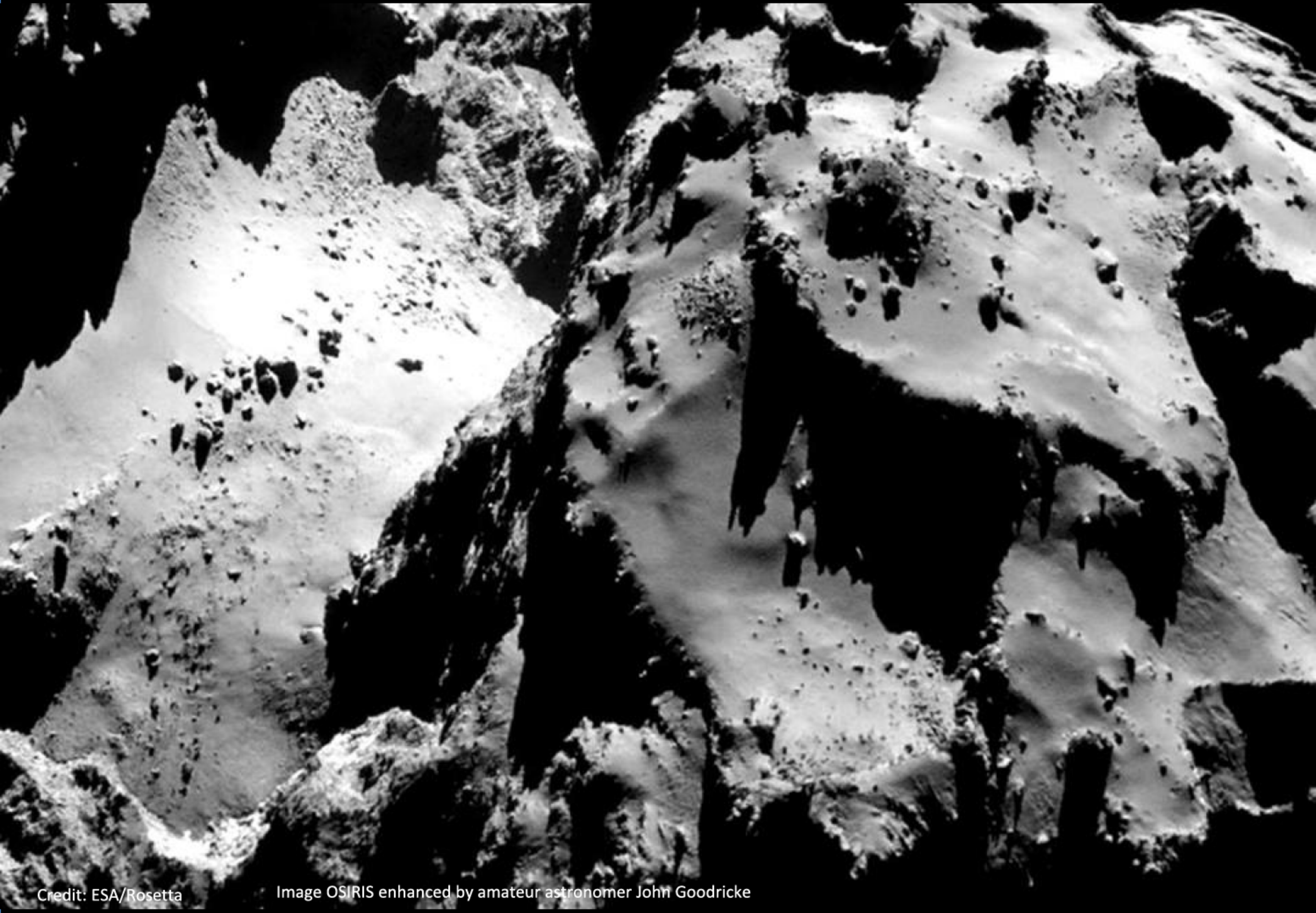


Credit: ESA/Rosetta/NAVCAM

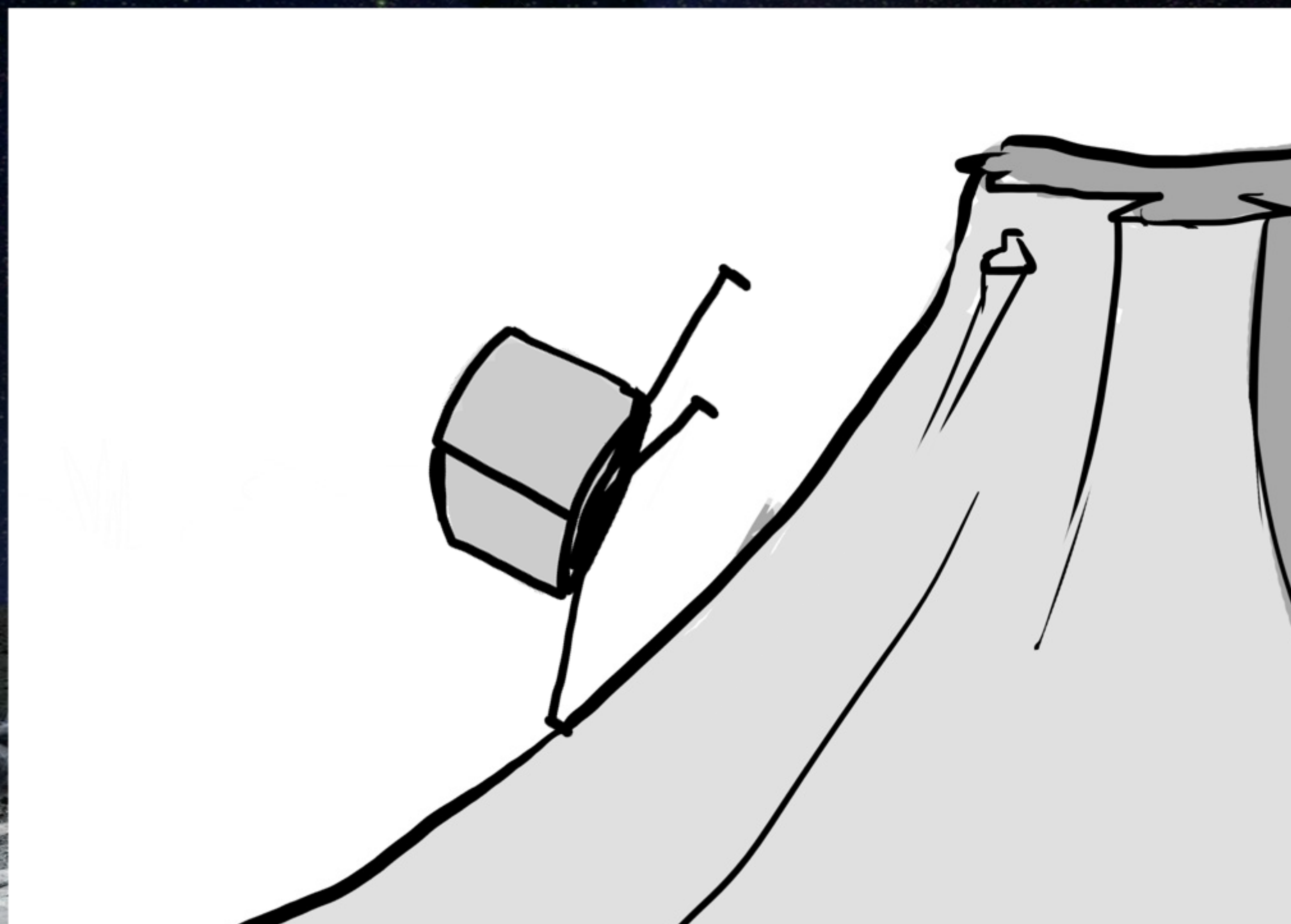
Avoid boulders and crevices



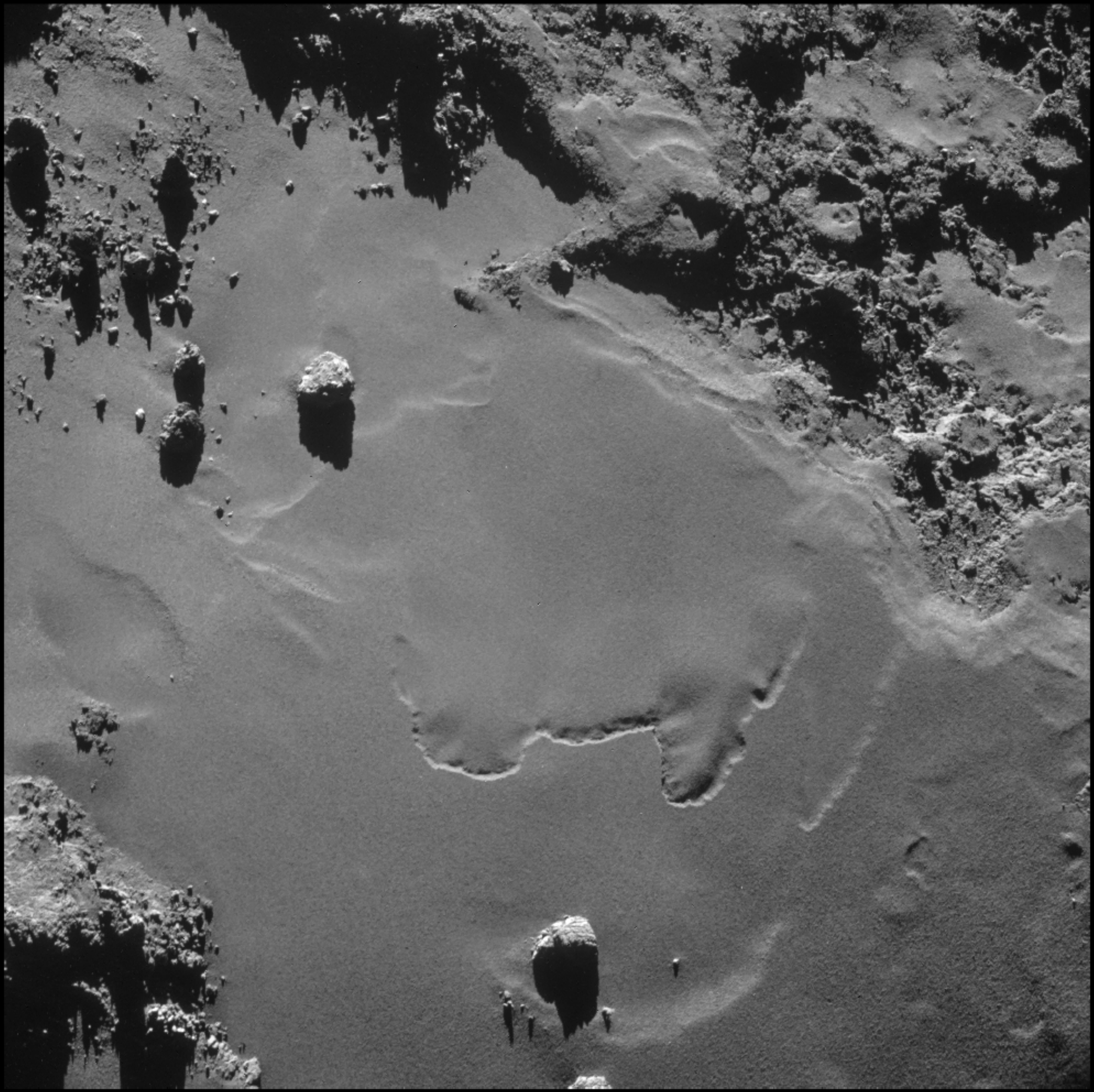
Credit: NASA/JPL Caltech


Credit: ESA/Rosetta
Image OSIRIS enhanced by amateur astronomer John Goodricke

Avoid slopes greater than 30 deg

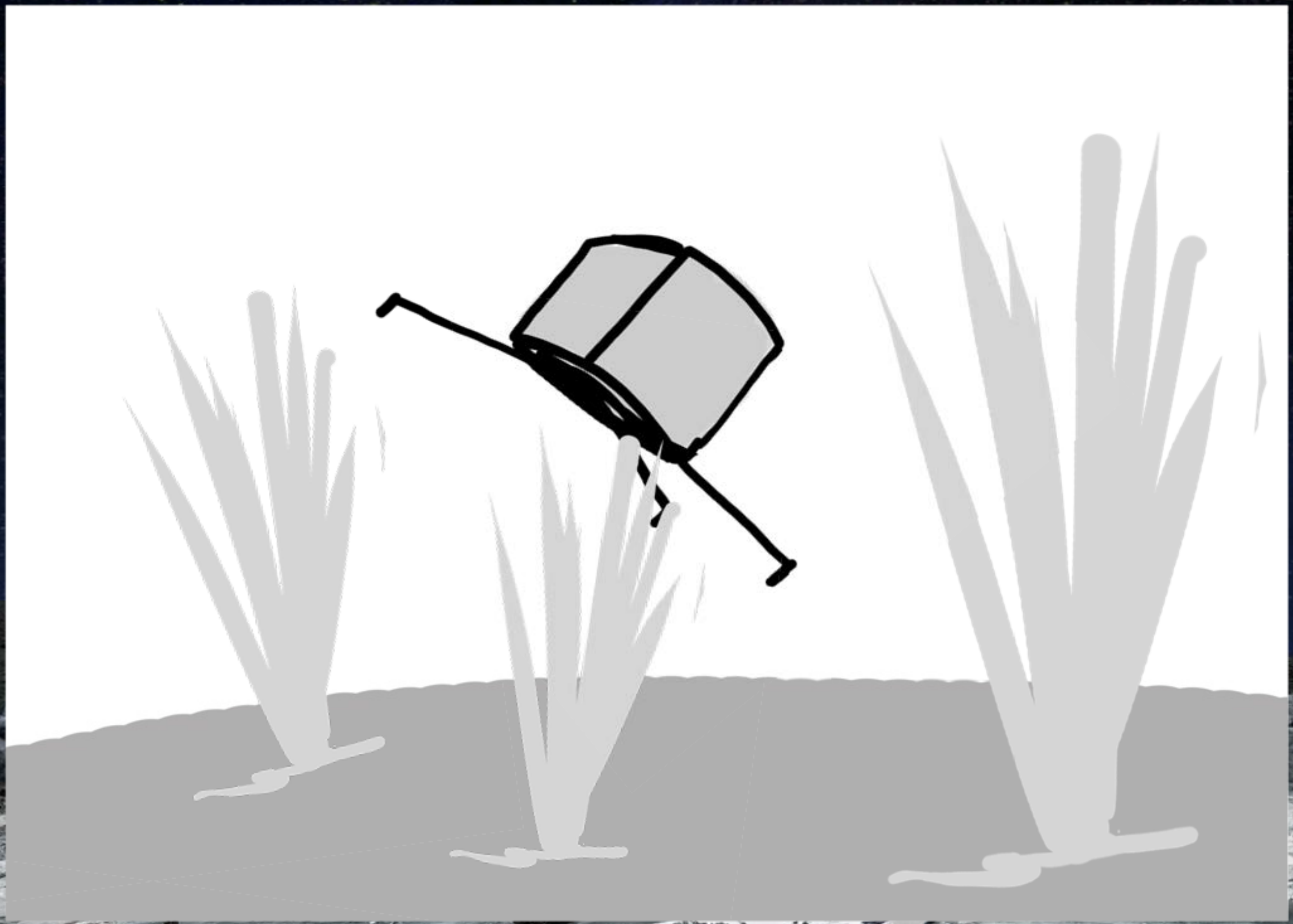


Credit: NASA/JPL Caltech

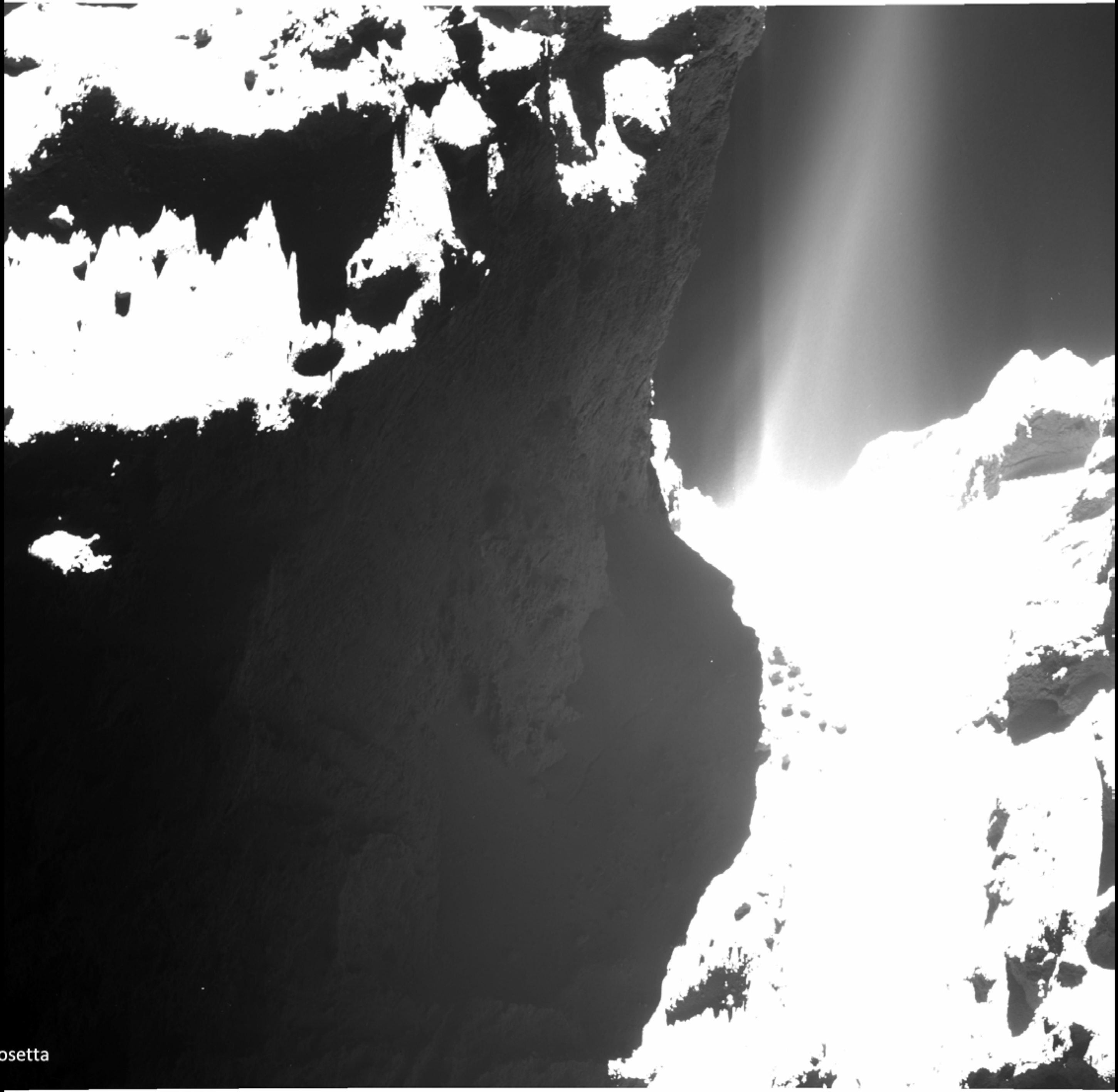


Credit: ESA/Rosetta

Don’t land on active areas

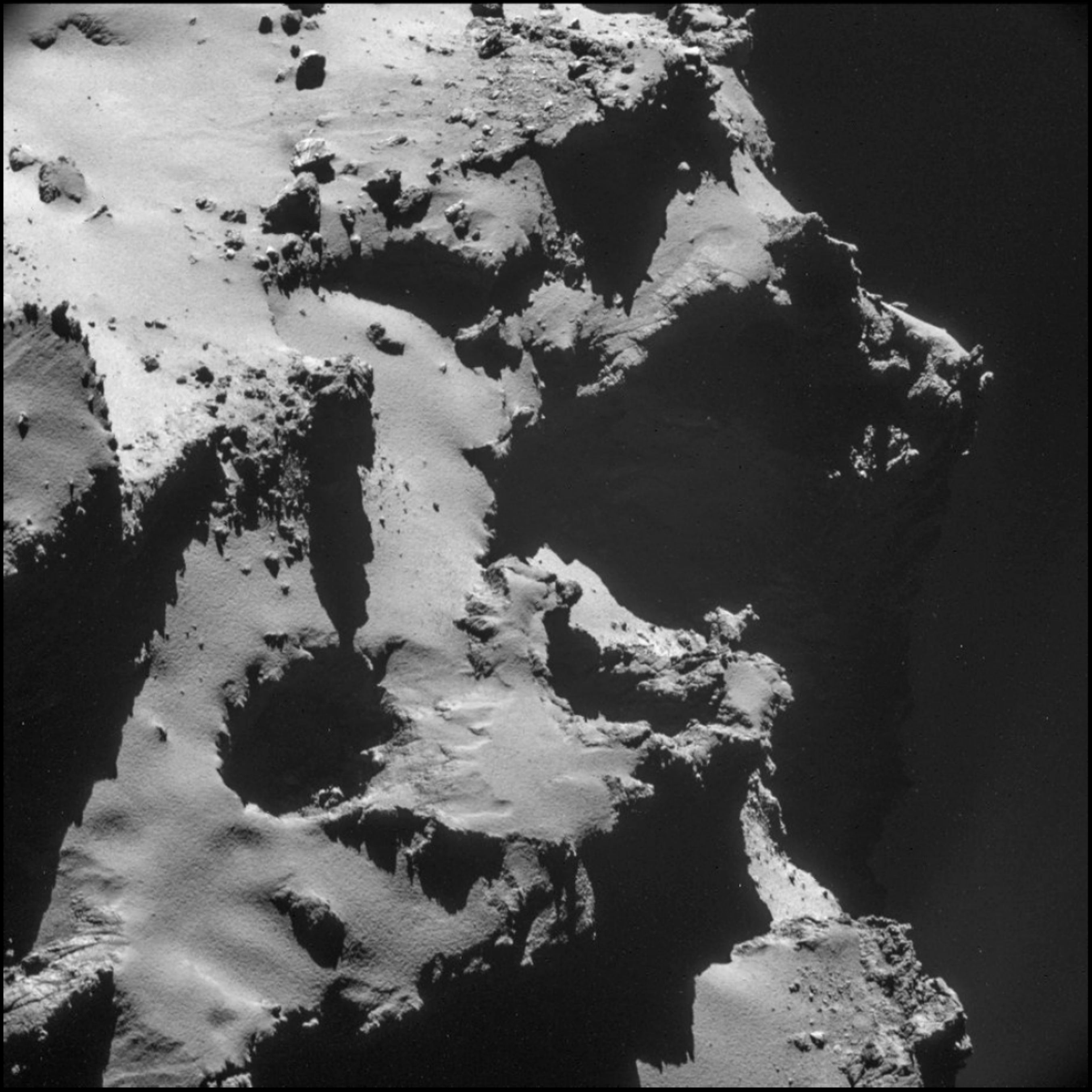


Credit: NASA/JPL Caltech



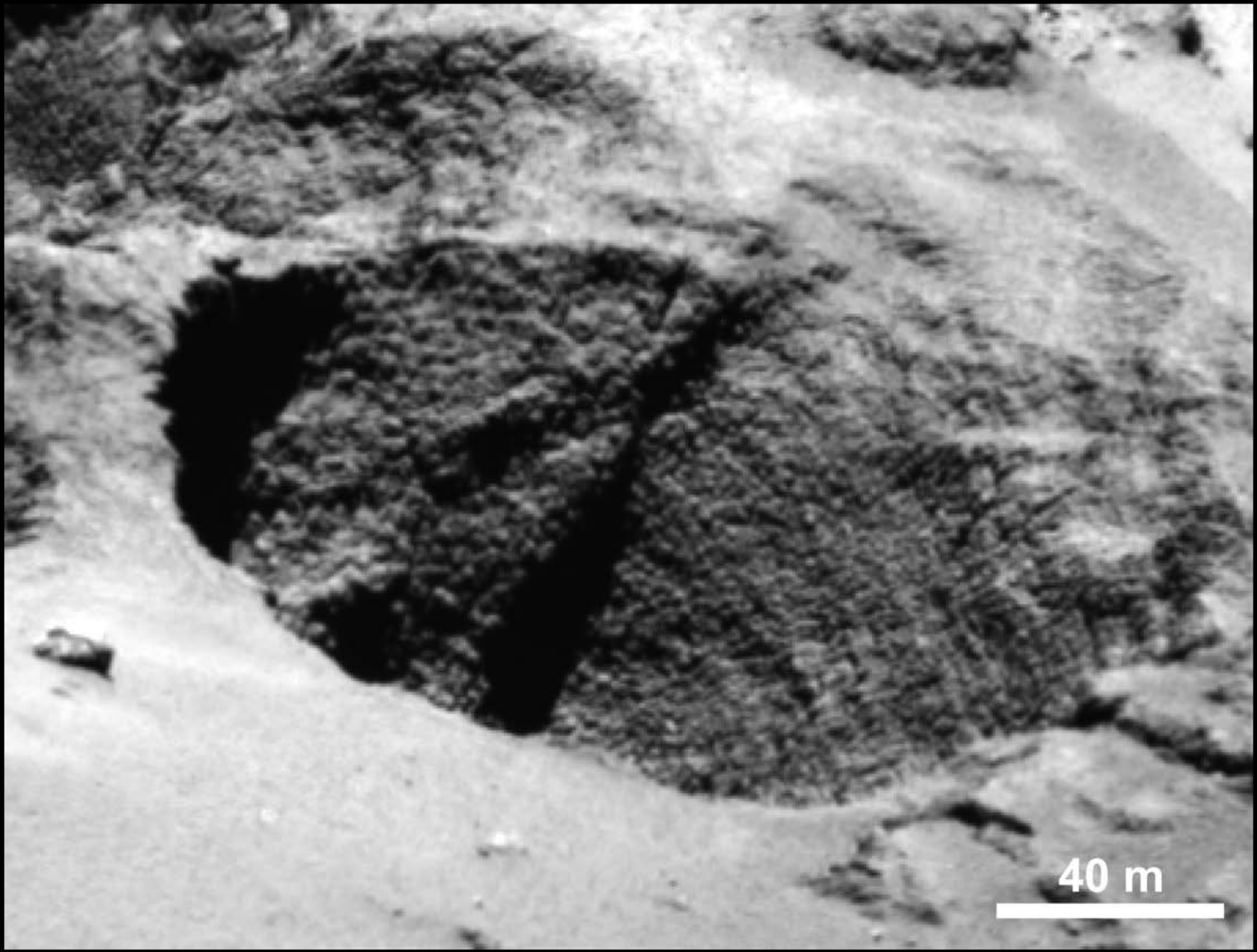
Credit: ESA/Rosetta

Credit: ESA/Rosetta



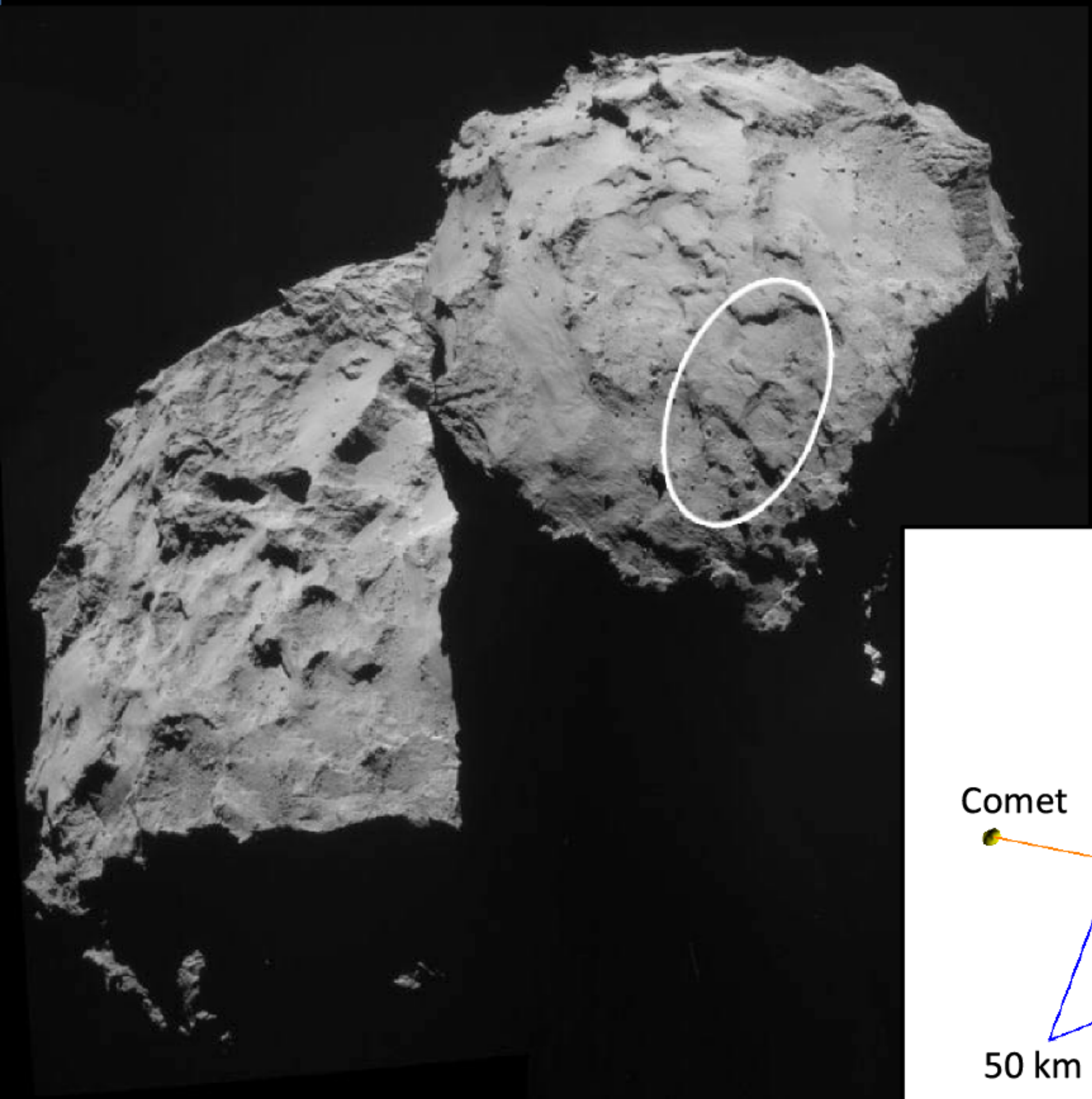
Credit: ESA/Rosetta

Dragon Eggs



The lander needed 6h of illumination per day

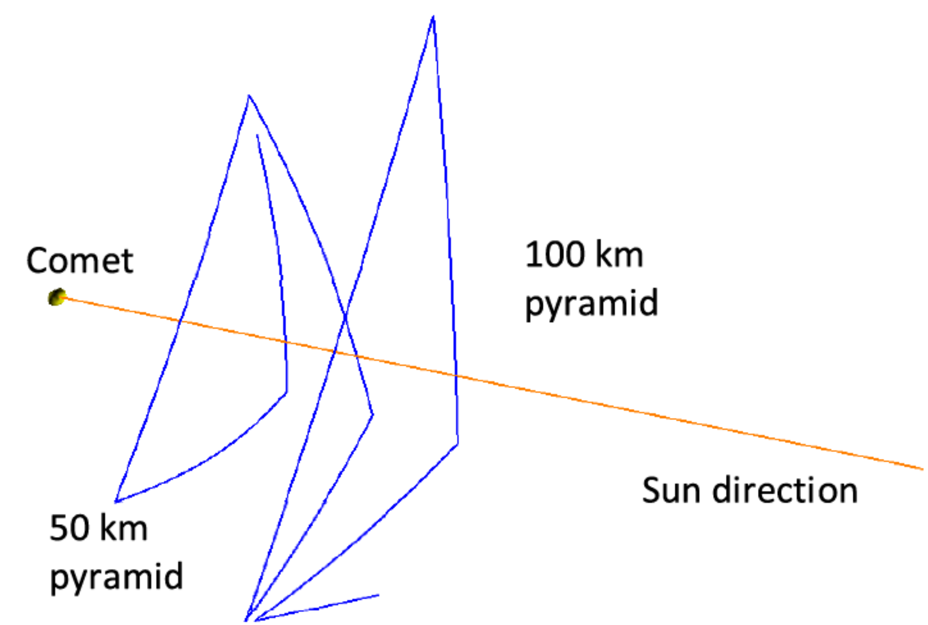
Selected landing site Aglikia



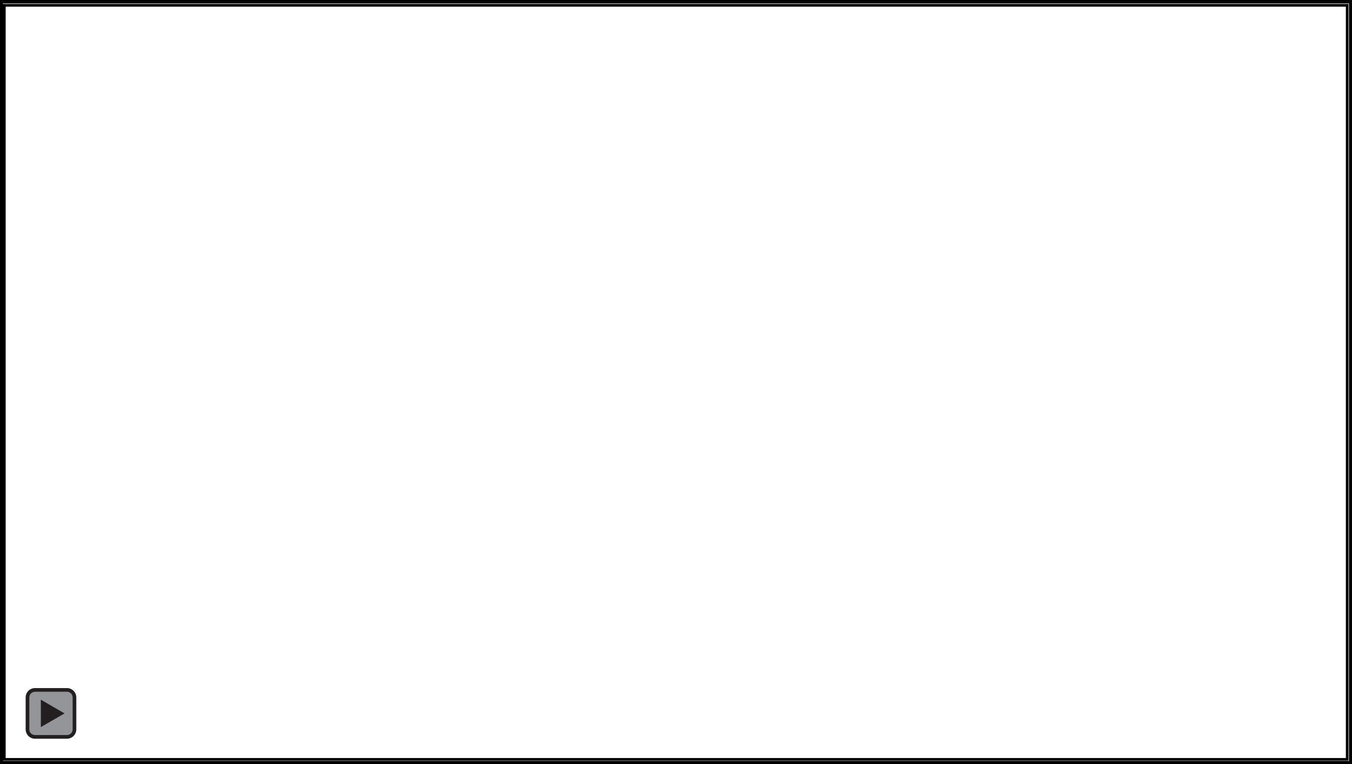
Credit: ESA/Rosetta/OSIRIS

Site considerations:

1. Trajectory
2. Illumination
3. Visibility
4. CONSERT
5. Slopes
6. Boulders
7. Jets
8. Dust

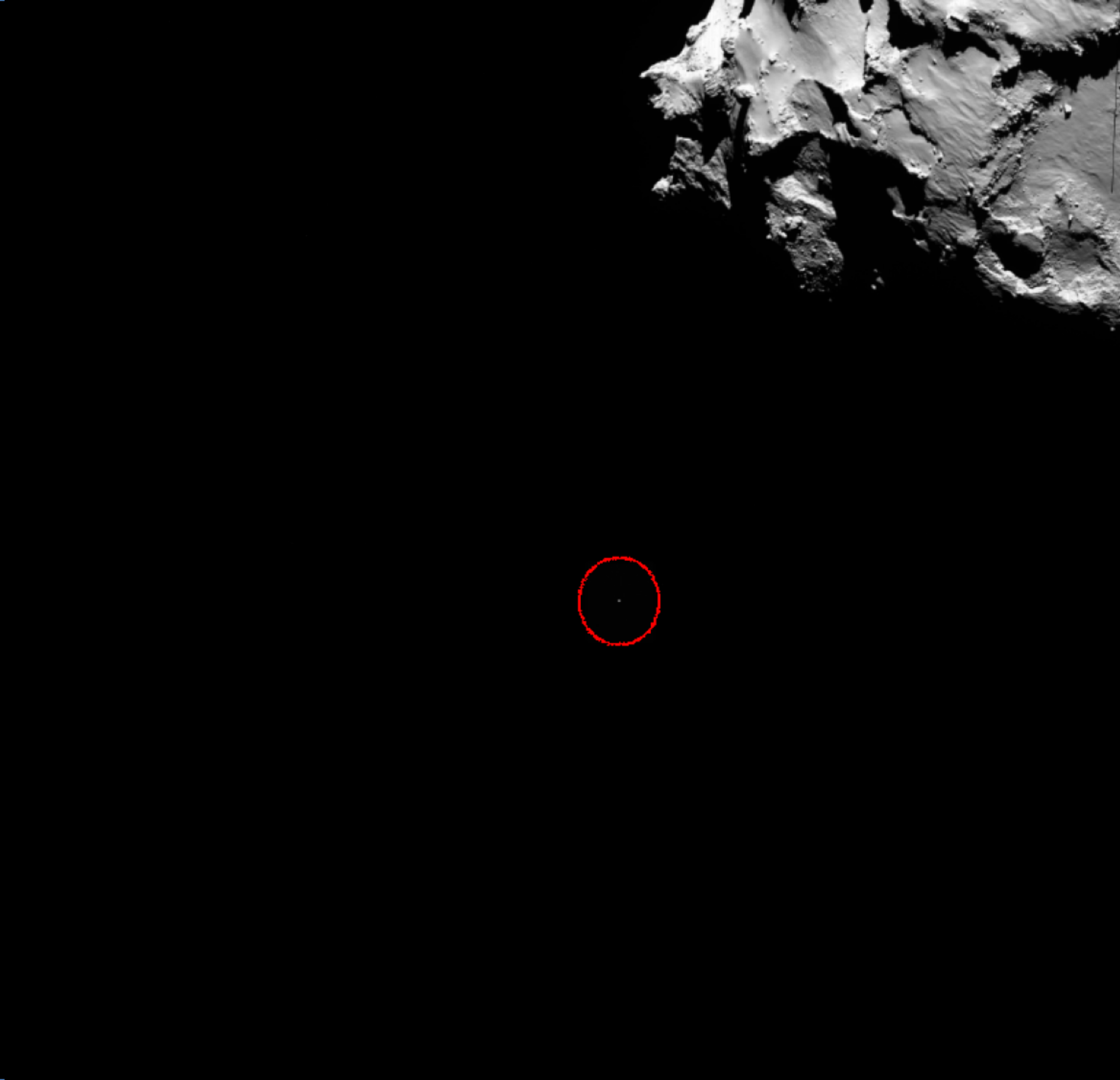


Philae Landing Site



Credit: S.F. Hviid/ESA/OSIRIS

Credit: ESA

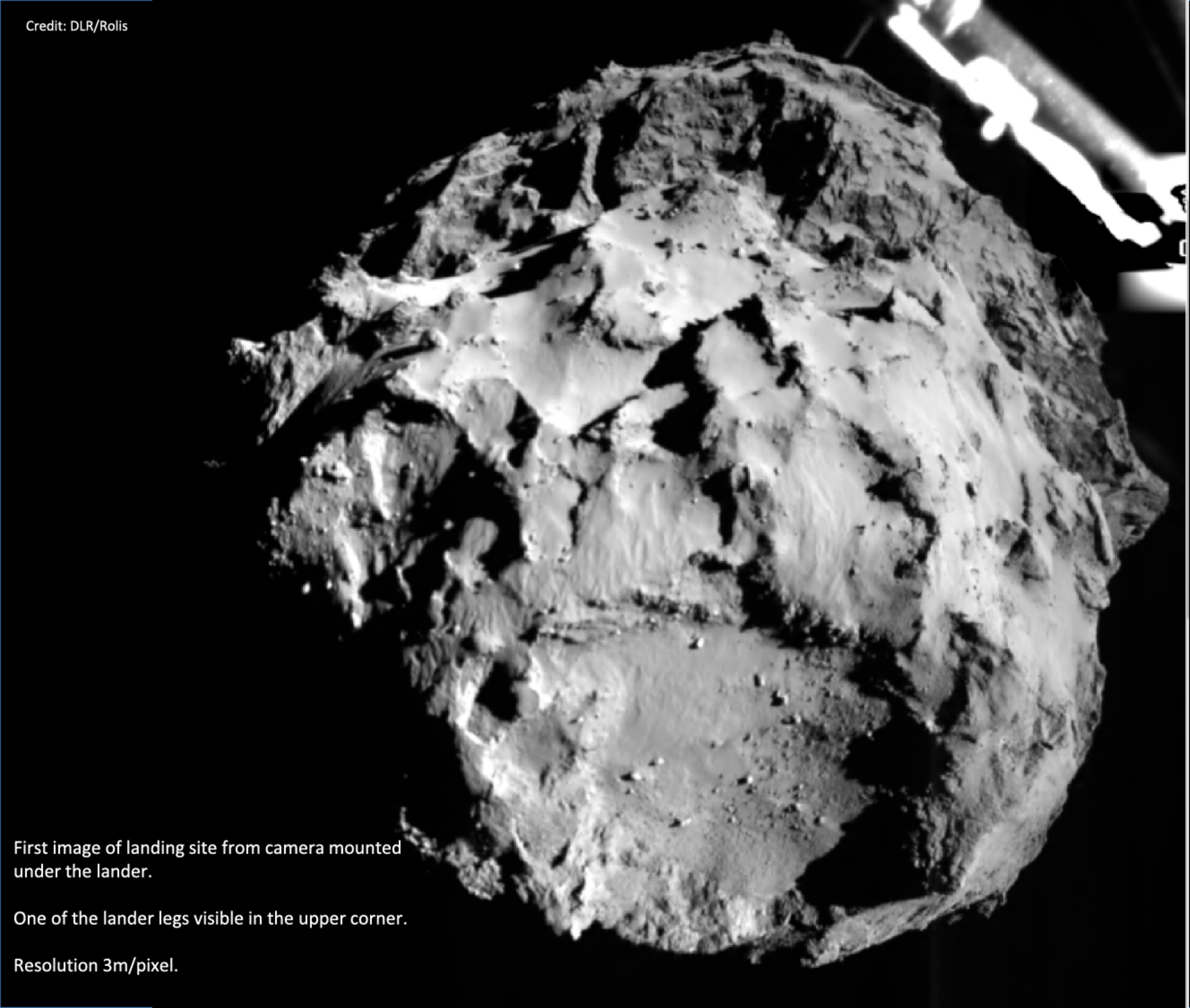


Philae in flight from Osiris on the Orbiter

Close up of Philae in flight from the science camera OSIRIS. Navigators took a sight of relief seeing this picture because it showed that the lander attitude is correct, the Rolis camera is pointed down, the legs are deployed.

Credit: ESA

Credit: DLR/Rolis

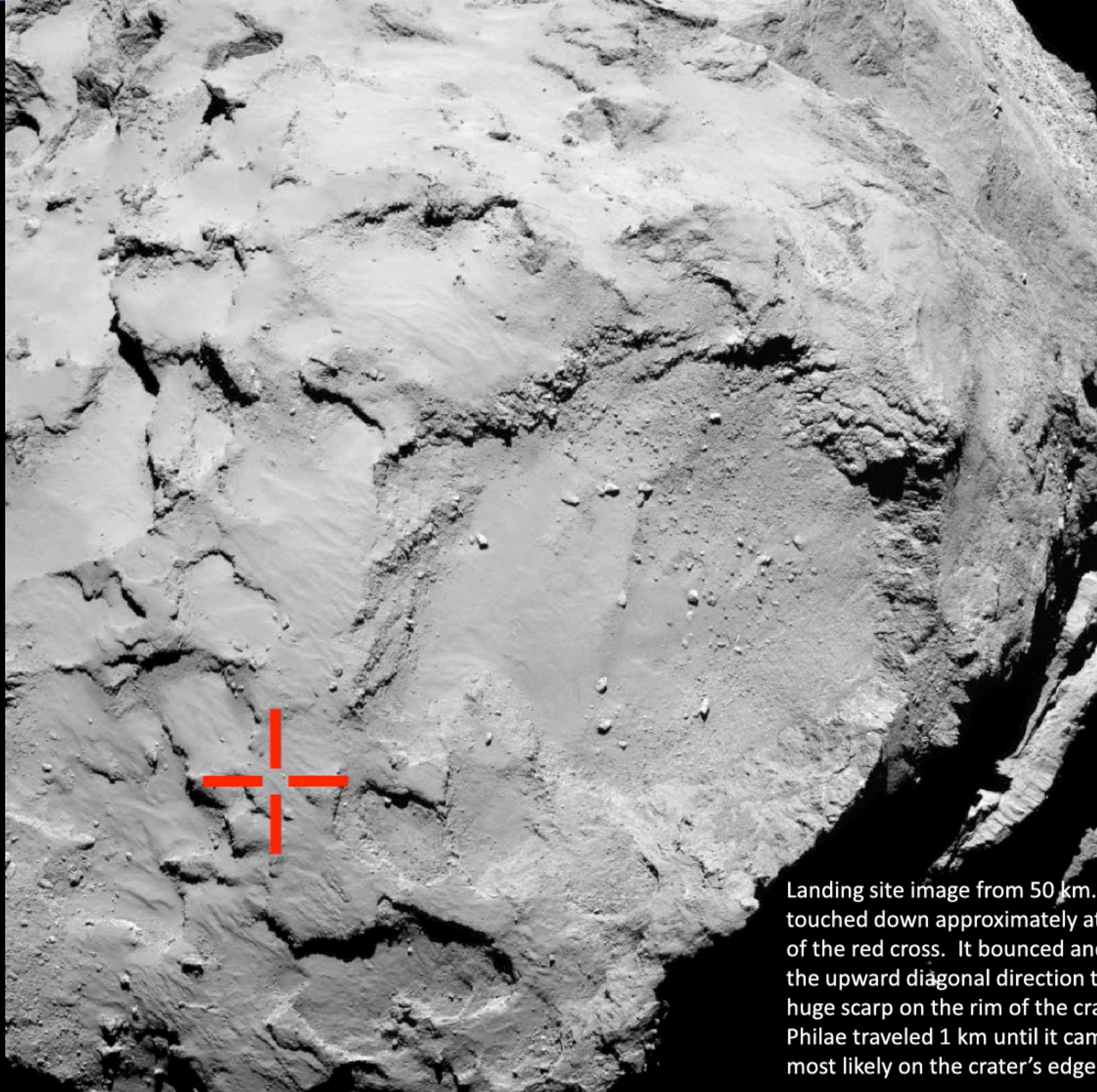


First image of landing site from camera mounted under the lander.

One of the lander legs visible in the upper corner.

Resolution 3m/pixel.

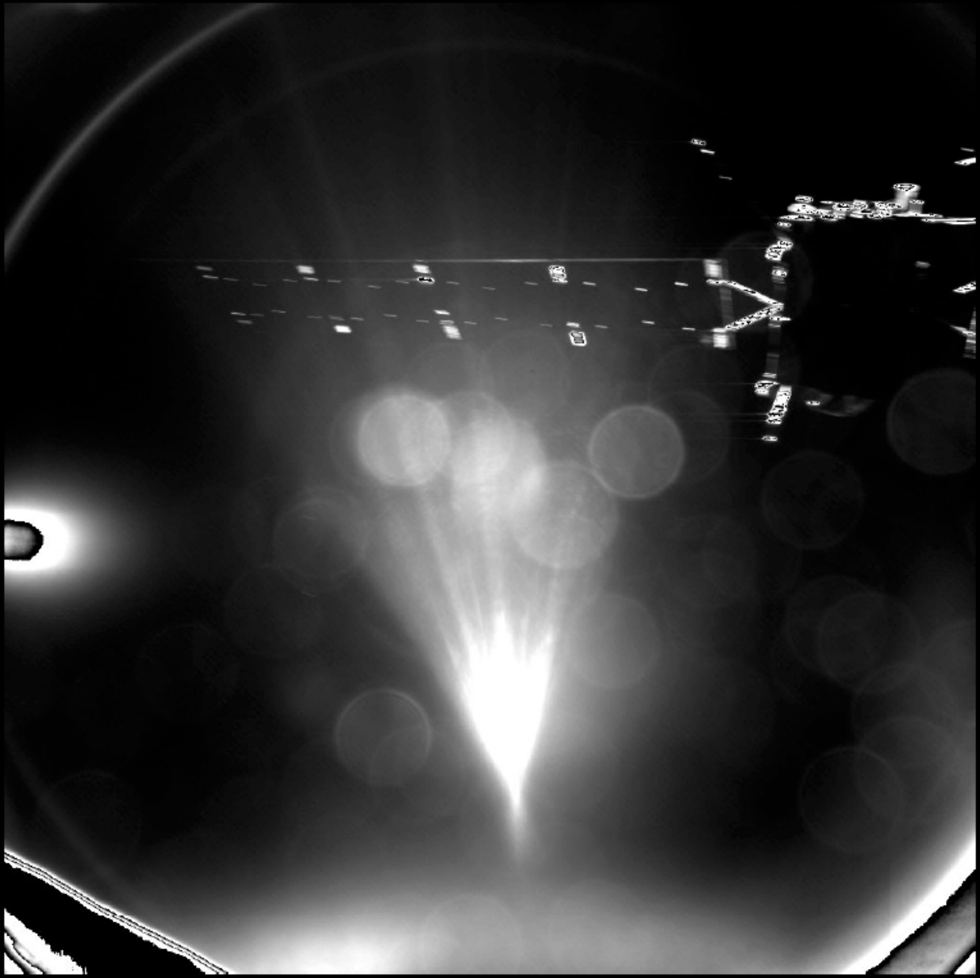
Credit: ESA



Landing site image from 50 km. The lander touched down approximately at the location of the red cross. It bounced and travelled in the upward diagonal direction toward the huge scarp on the rim of the crater (site B). Philae traveled 1 km until it came to rest most likely on the crater's edge.

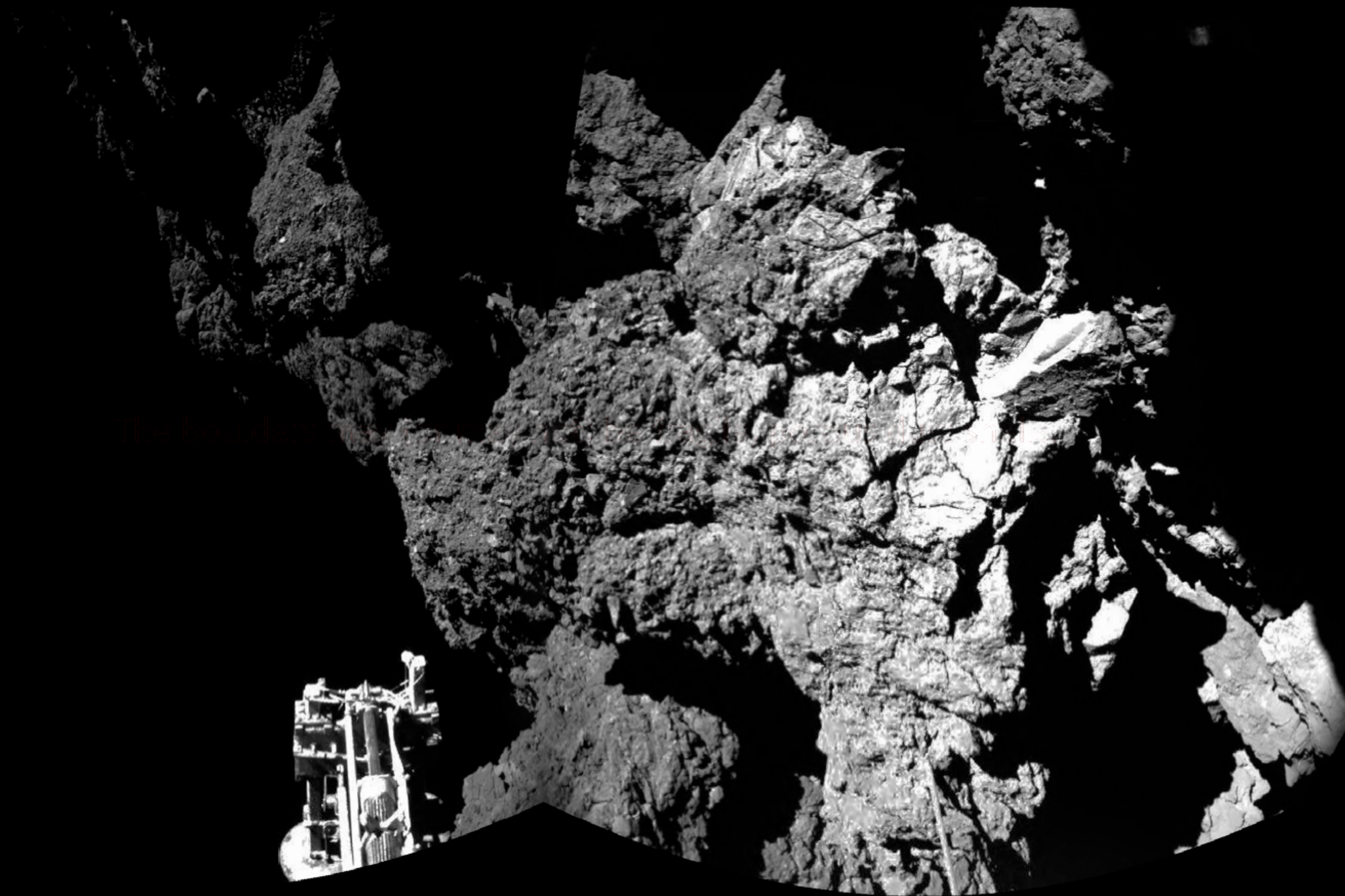
Credit: ESA/Rosetta

The last picture before touchdown. Boulder in the upper right corner is approximately 5 m in diameter. The boulder is partially covered with dust which seems to be floating over the surface. Scientists asked: are there clouds of levitated dust? How deep will Philae sink?

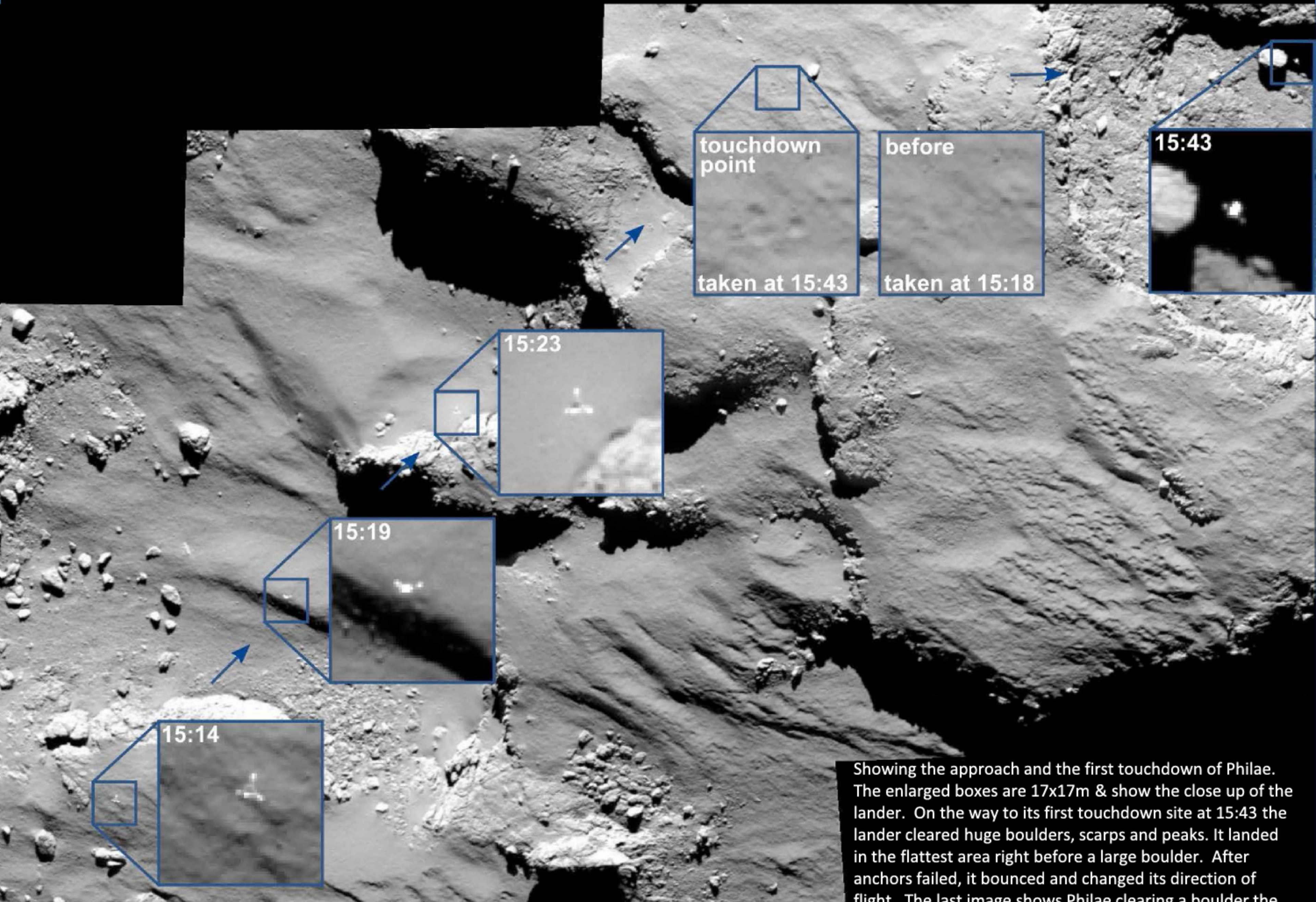


Credit: ESA/Rosetta/Philae/CIVA

Credit: ESA/CIVA



Credit: ESA

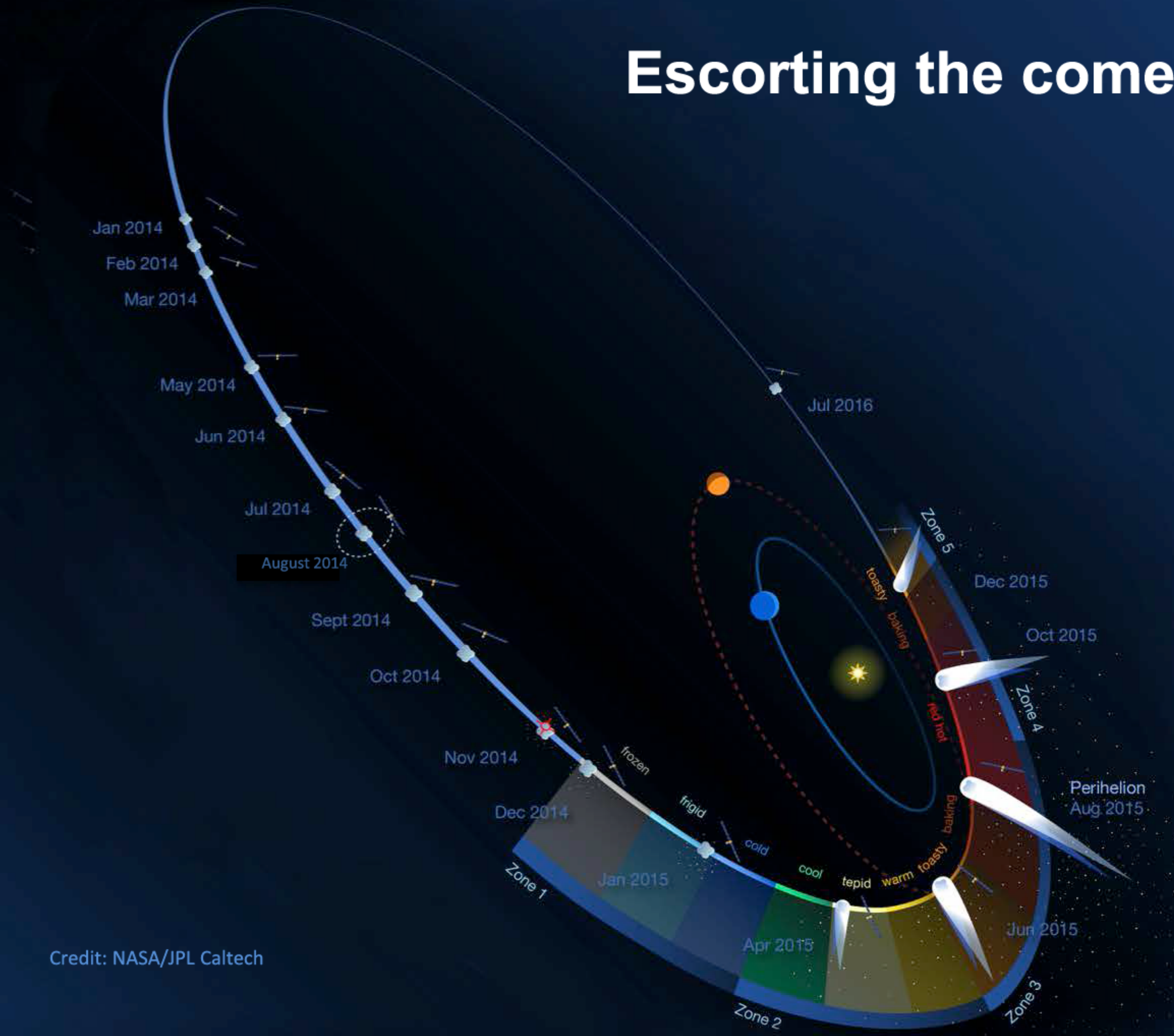


Showing the approach and the first touchdown of Philae. The enlarged boxes are 17x17m & show the close up of the lander. On the way to its first touchdown site at 15:43 the lander cleared huge boulders, scarps and peaks. It landed in the flattest area right before a large boulder. After anchors failed, it bounced and changed its direction of flight. The last image shows Philae clearing a boulder the size of a house.

The final landing place of Philae

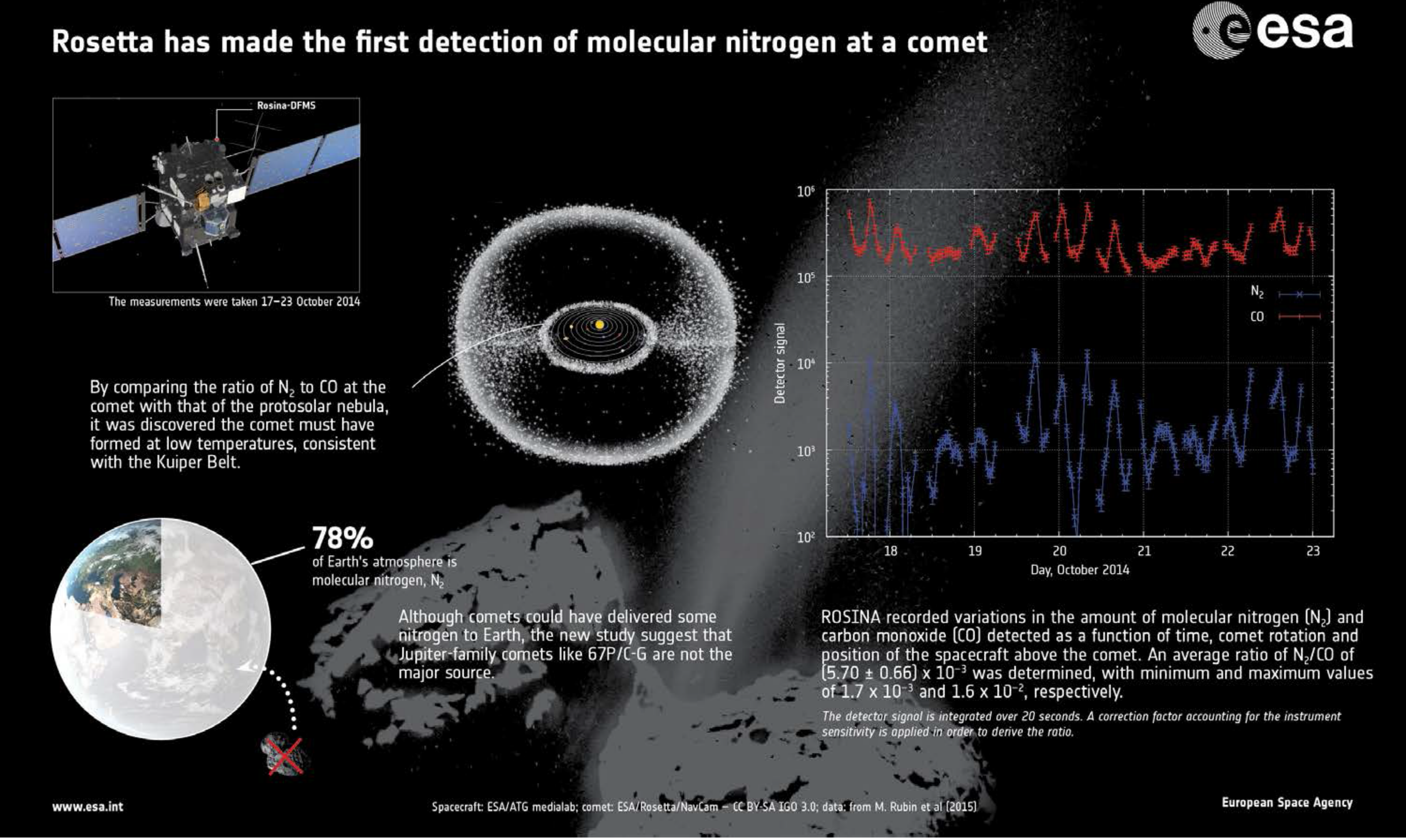
Credit: ESA/Rosetta/OSIRIS

Escorting the comet

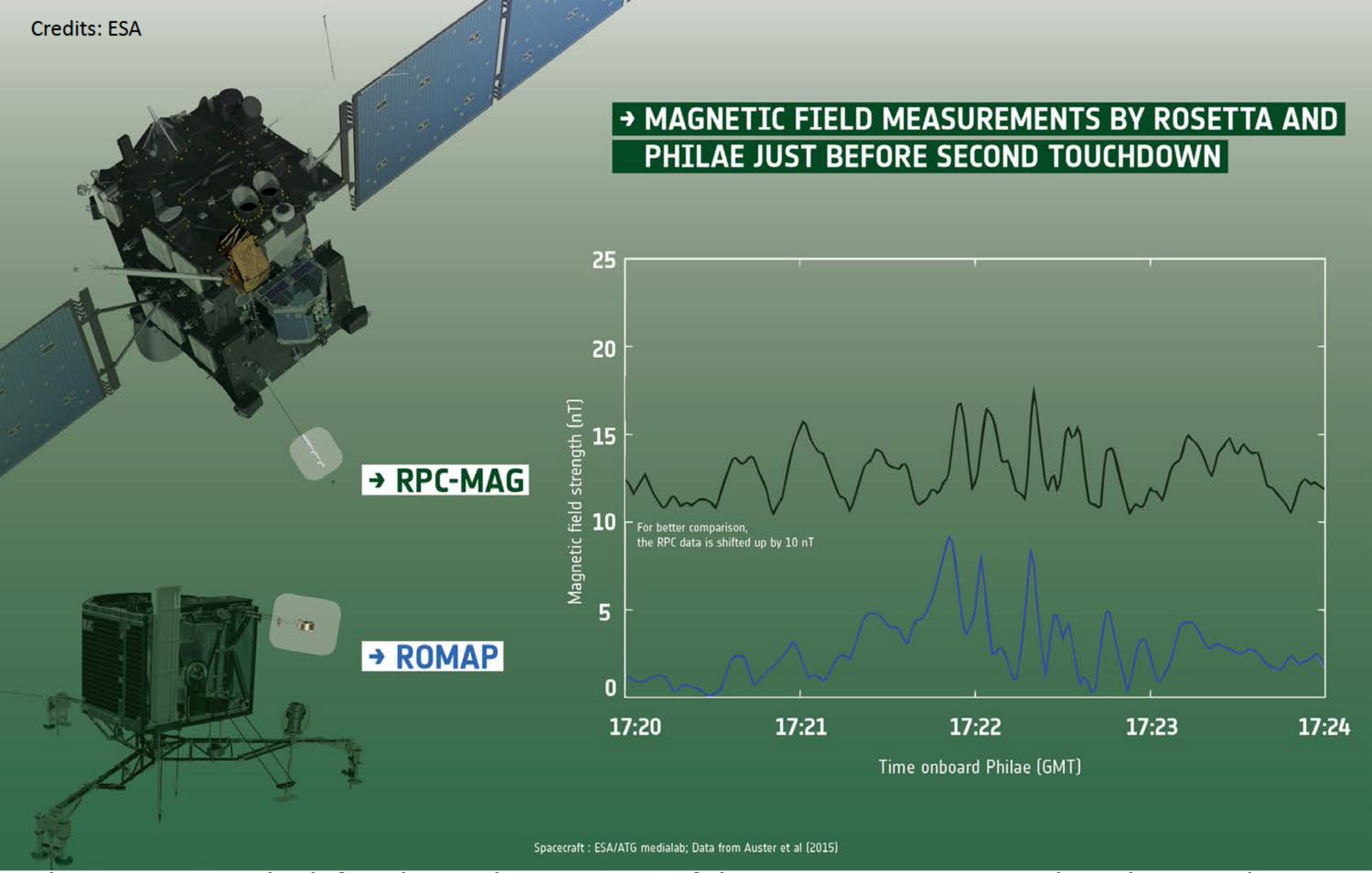


Credit: NASA/JPL Caltech

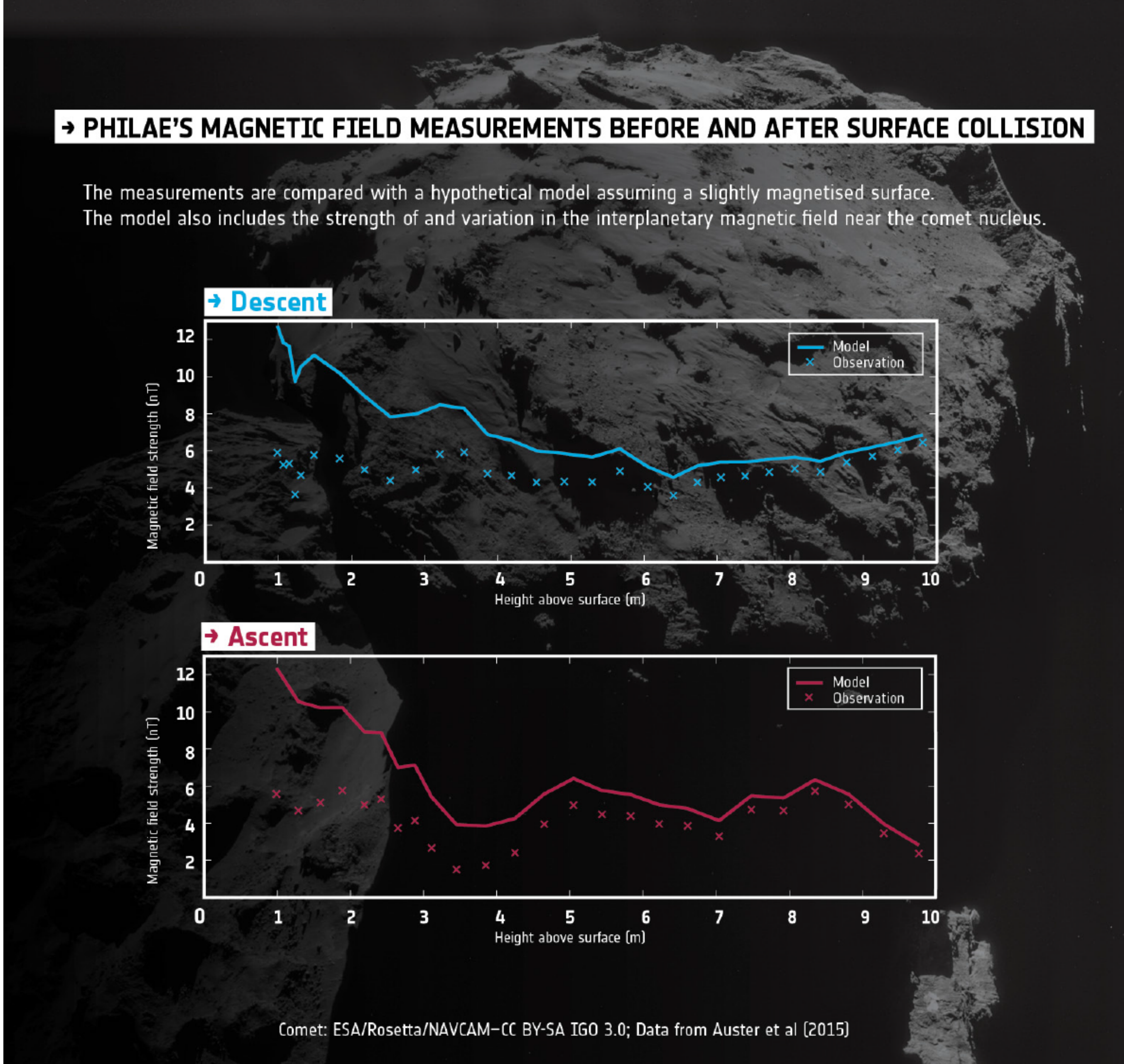
Credits: ESA/ATG



The results provide clues about the temperature environment in which Comet 67P/Churyumov–Gerasimenko formed.

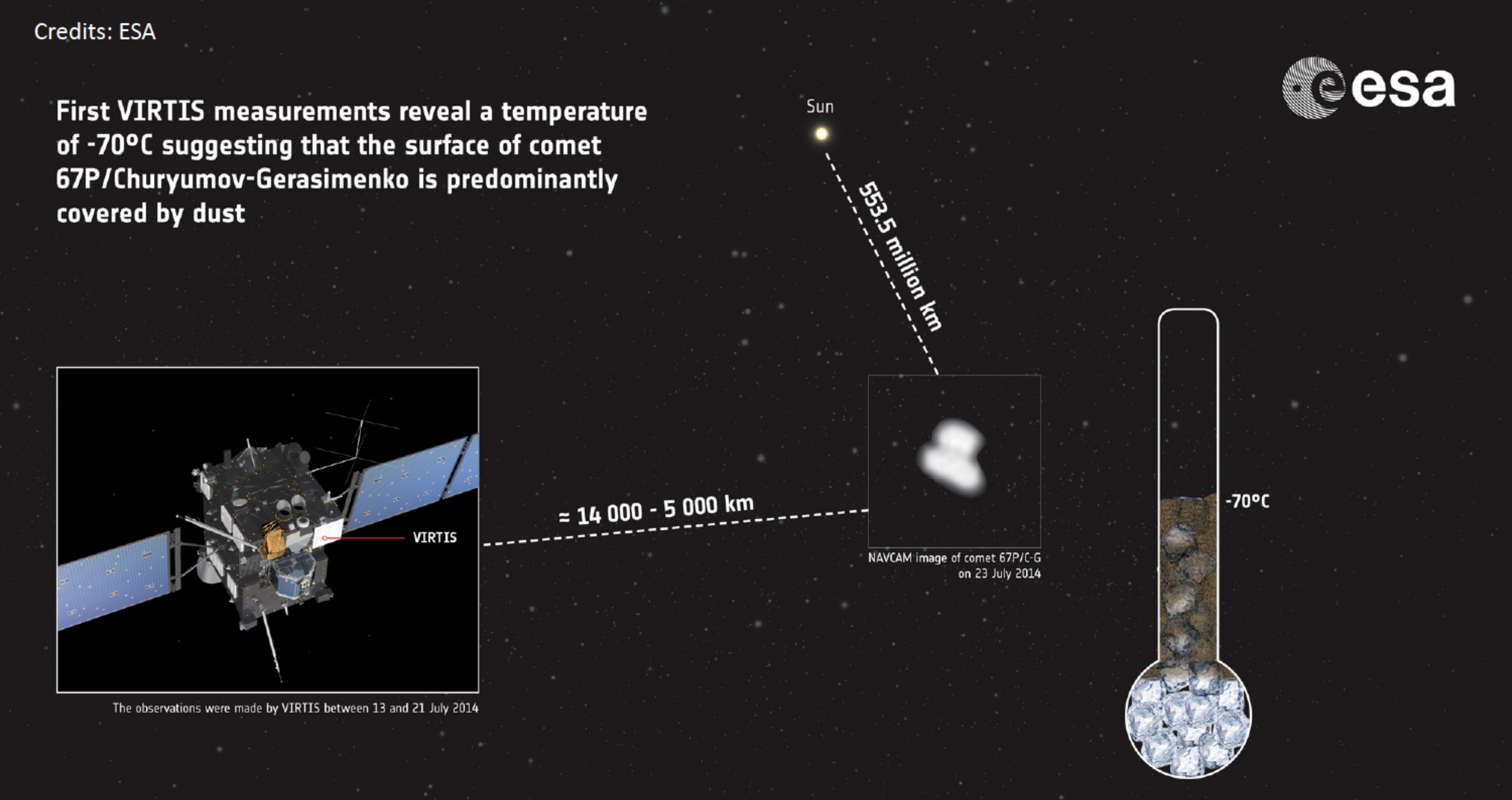


The pictures on the left indicate the positions of the two instruments on the orbiter and lander, respectively. The graph on the right shows the data collected by the instruments. Note that to better see the complementary nature of the two data sets, the RPC-MAG data have been shifted up by 10 nT.

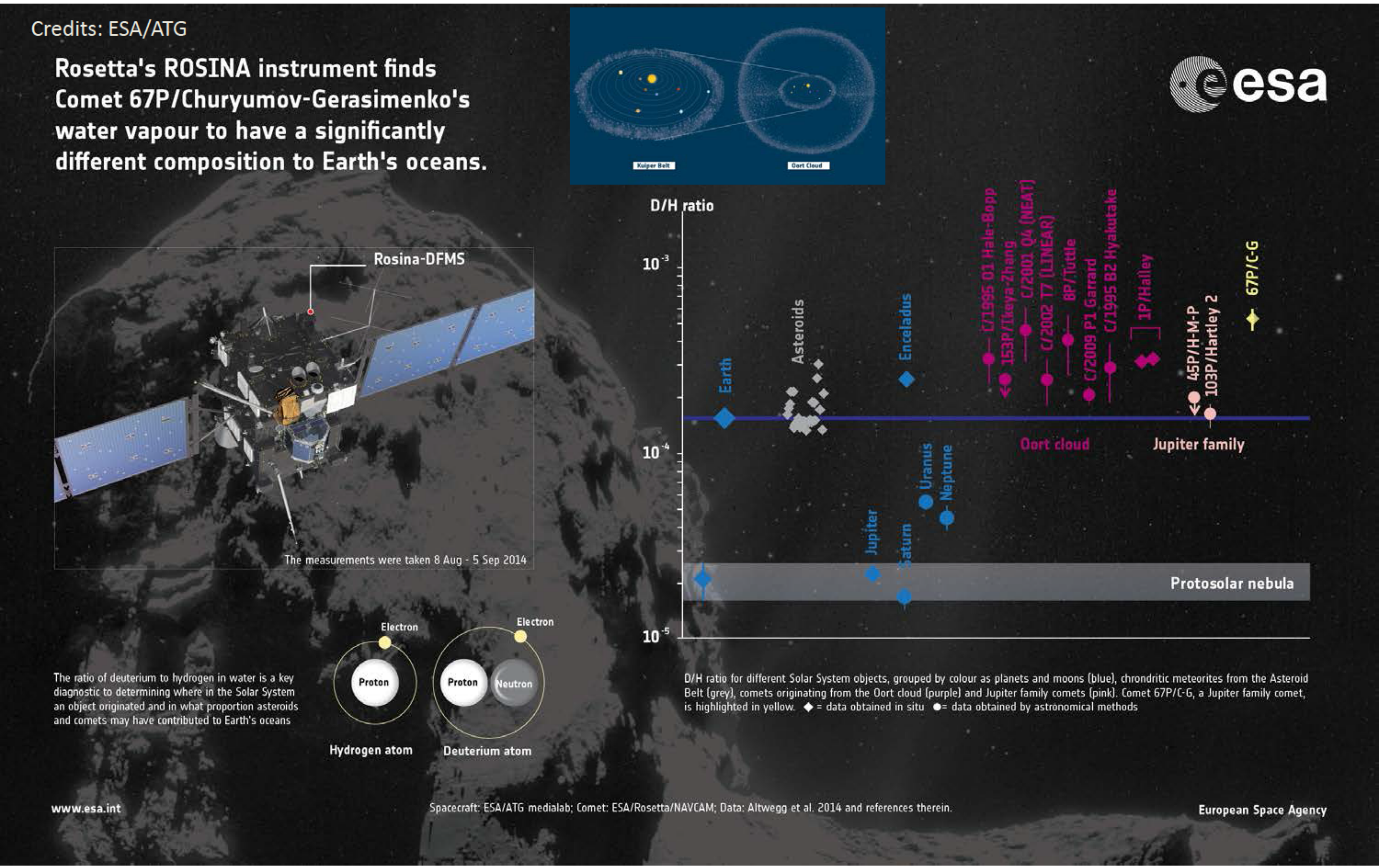


→ PHILAE'S MAGNETIC FIELD MEASUREMENTS BEFORE AND AFTER SURFACE COLLISION
The measurements are compared with a hypothetical model assuming a slightly magnetised surface.
The model also includes the strength of and variation in the interplanetary magnetic field near the comet nucleus.
→ Descent
Model
Observation
Magnetic field strength (nT)
Height above surface (m)
→ Ascent
Model
Observation
Magnetic field strength (nT)
Height above surface (m)
Comet: ESA/Rosetta/NAVCAM–CC BY-SA IGO 3.0; Data from Auster et al (2015)

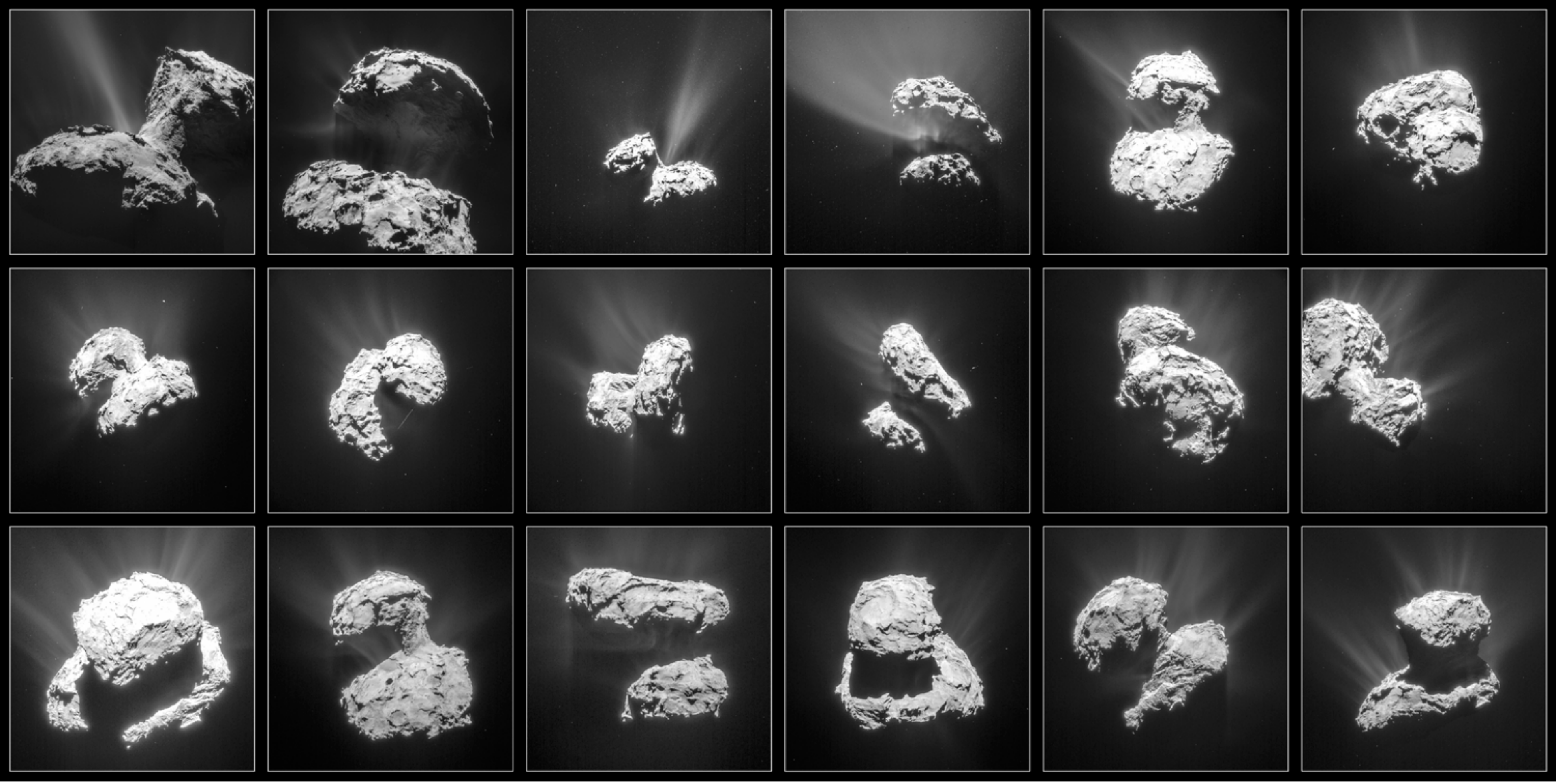
Credits: ESA



The first temperature measurements of comet 67P/Churyumov–Gerasimenko were made between 13 and 21 July, when Rosetta closed in from 14 000 km to the comet to just over 5000 km. The observations were made by the spacecraft's visible, infrared and thermal imaging spectrometer, VIRTIS, and revealed an average surface temperature of –70ºC. This implies the surface is predominantly covered in dust rather than ice, which would yield a lower temperature. The finding does not exclude localised patches of ice. The observations were made when the comet was roughly 555 million kilometres from the Sun.

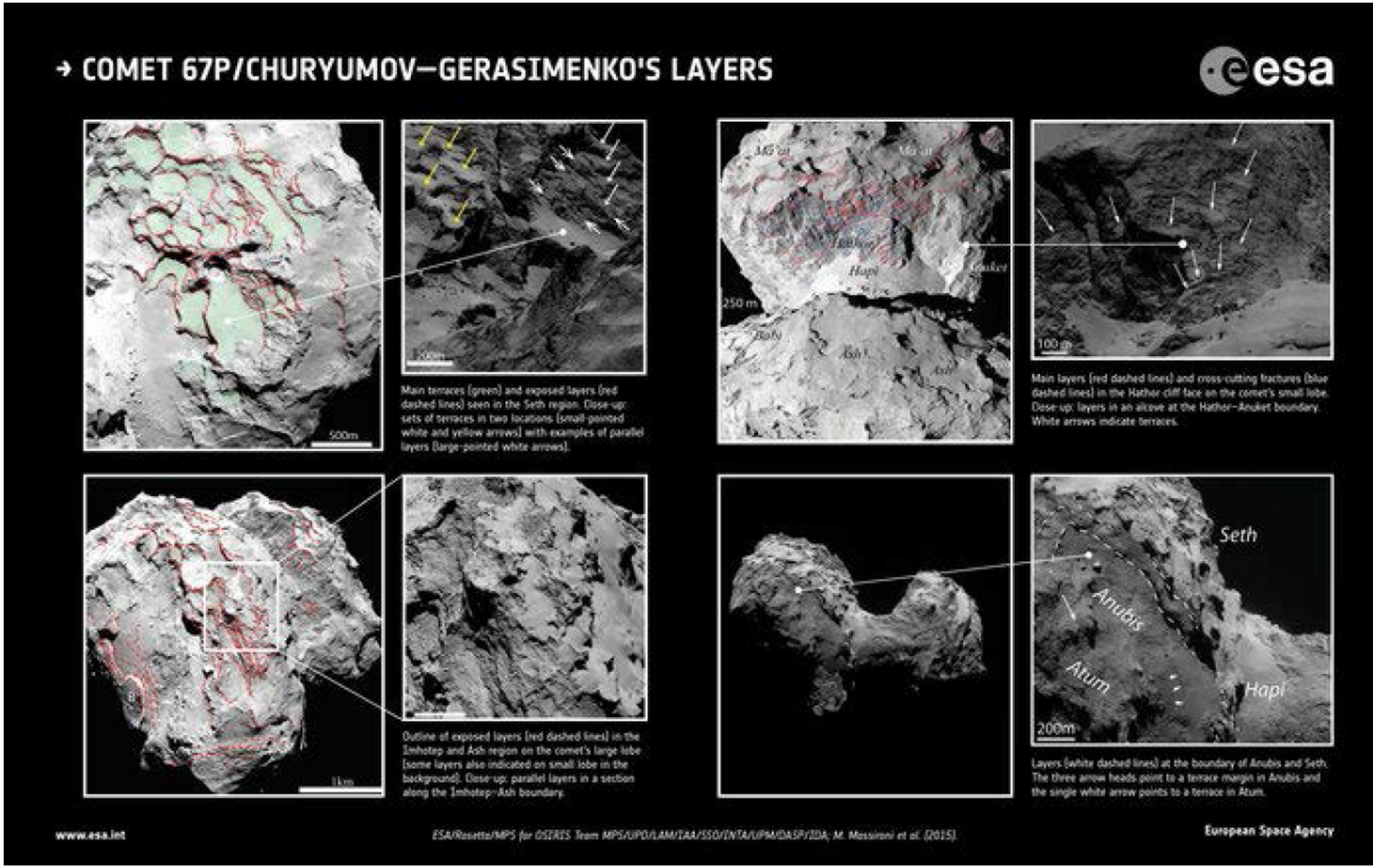


Upper middle: Illustration showing the two main reservoirs of comets in the Solar System: the Kuiper Belt, at a distance of 30–50 astronomical units (AU: the Earth–Sun distance) from the Sun, and the Oort Cloud, which may extend up to 50 000–100 000 AU from the Sun.



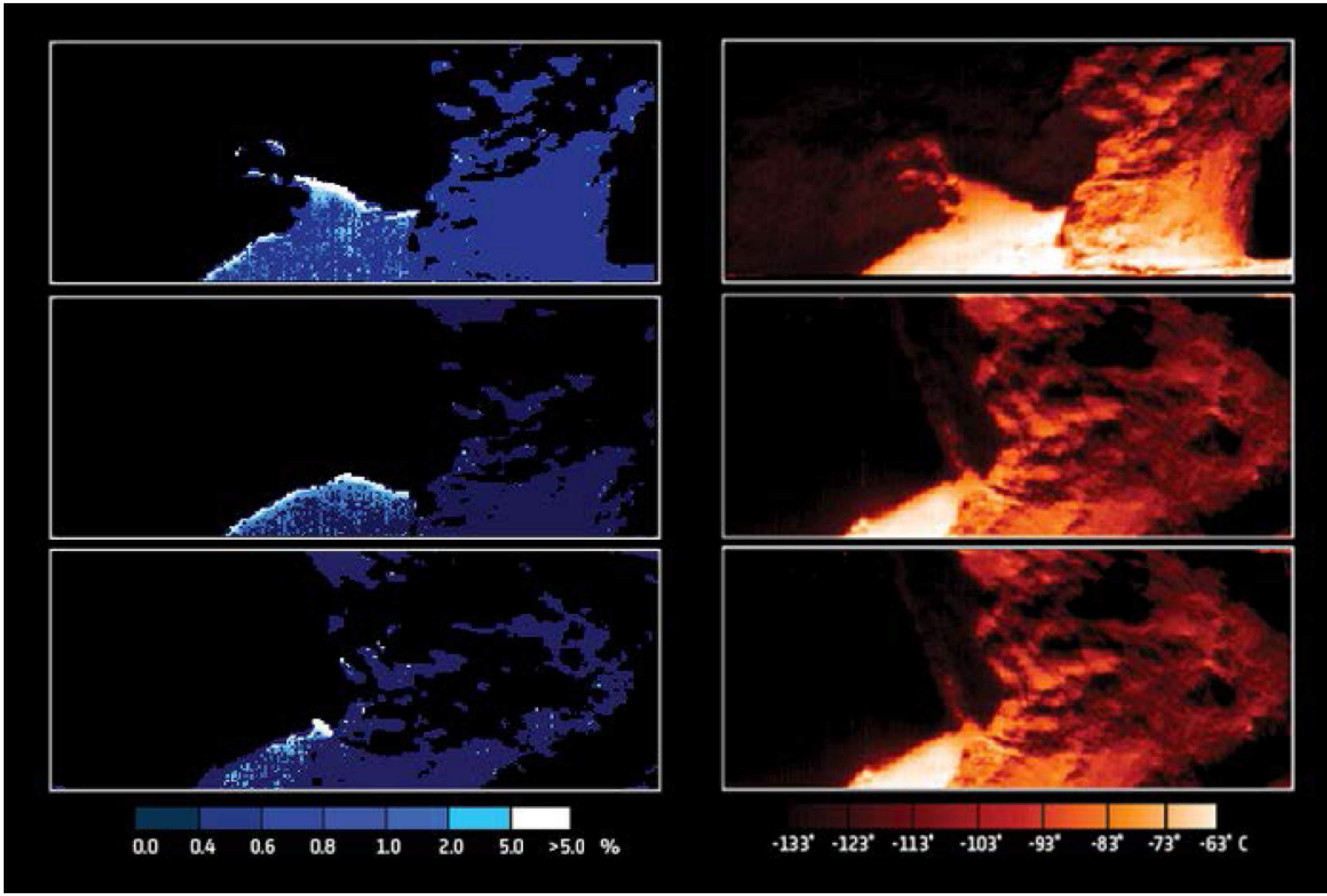
This spectacular montage of 18 images shows off the comet's activity from many different angles as seen between 31 January (top left) and 25 March (bottom right), when the spacecraft was at distances of about 30 to 100 km from the comet. At the same time, Comet 67P/Churyumov-Gerasimenko was at distances between 363 million and 300 million km from the Sun.

Credit: ESA/Rosetta/NAVCAM



A selection of high-resolution OSIRIS images used to identify patterns in Comet 67P/Churyumov–Gerasimenko's extensive layering..

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

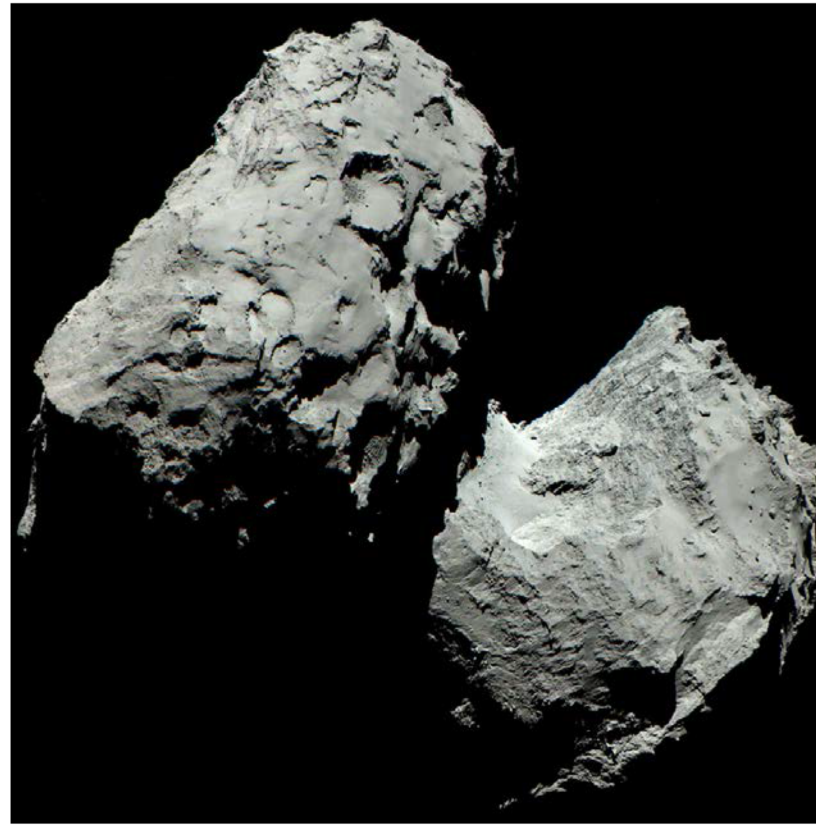


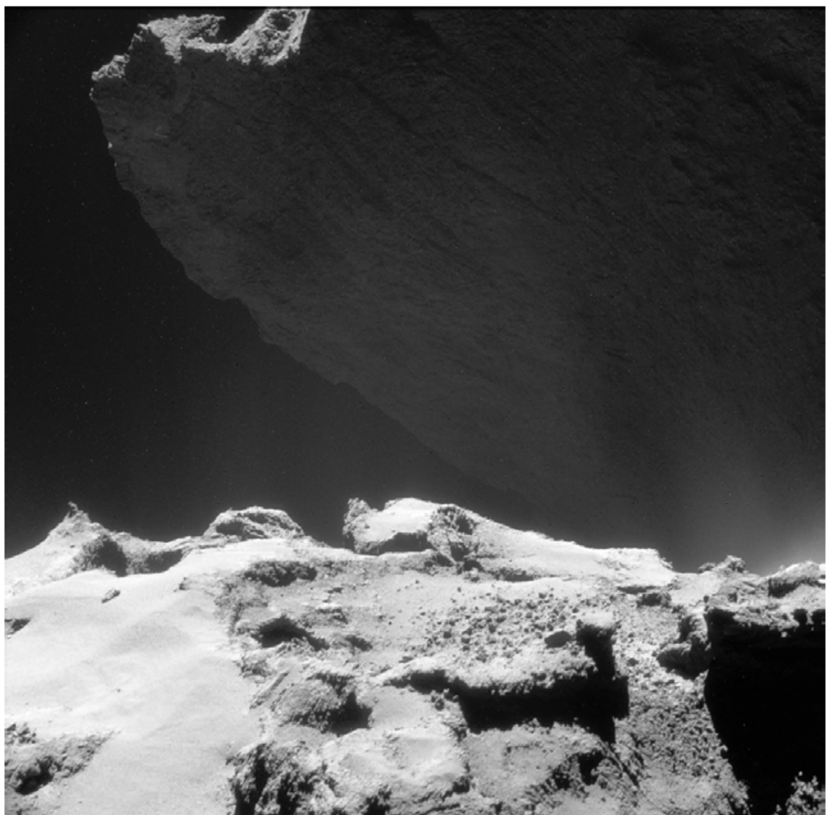
Maps of water ice abundance (left) and surface temperature (right) focusing on the Hapi 'neck' region of Comet 67P/Churyumov–Gerasimenko. These maps are based on images and spectra collected with Rosetta's Visible, InfraRed and Thermal Imaging Spectrometer, VIRTIS on 12 (top), 13 (middle) and 14 September (bottom) 2014.

Credit: ESA/Rosetta/VIRTIS/INAF-IAPS/OBS DE PARIS-LESIA/DLR; M.C. De Sanctis et al (2015)

Credit: ESA/Rosetta/NAVCAM ESA/Rosetta/MPS

The images were taken on 6 August 2014 from a distance of 120 kilometres from the comet.

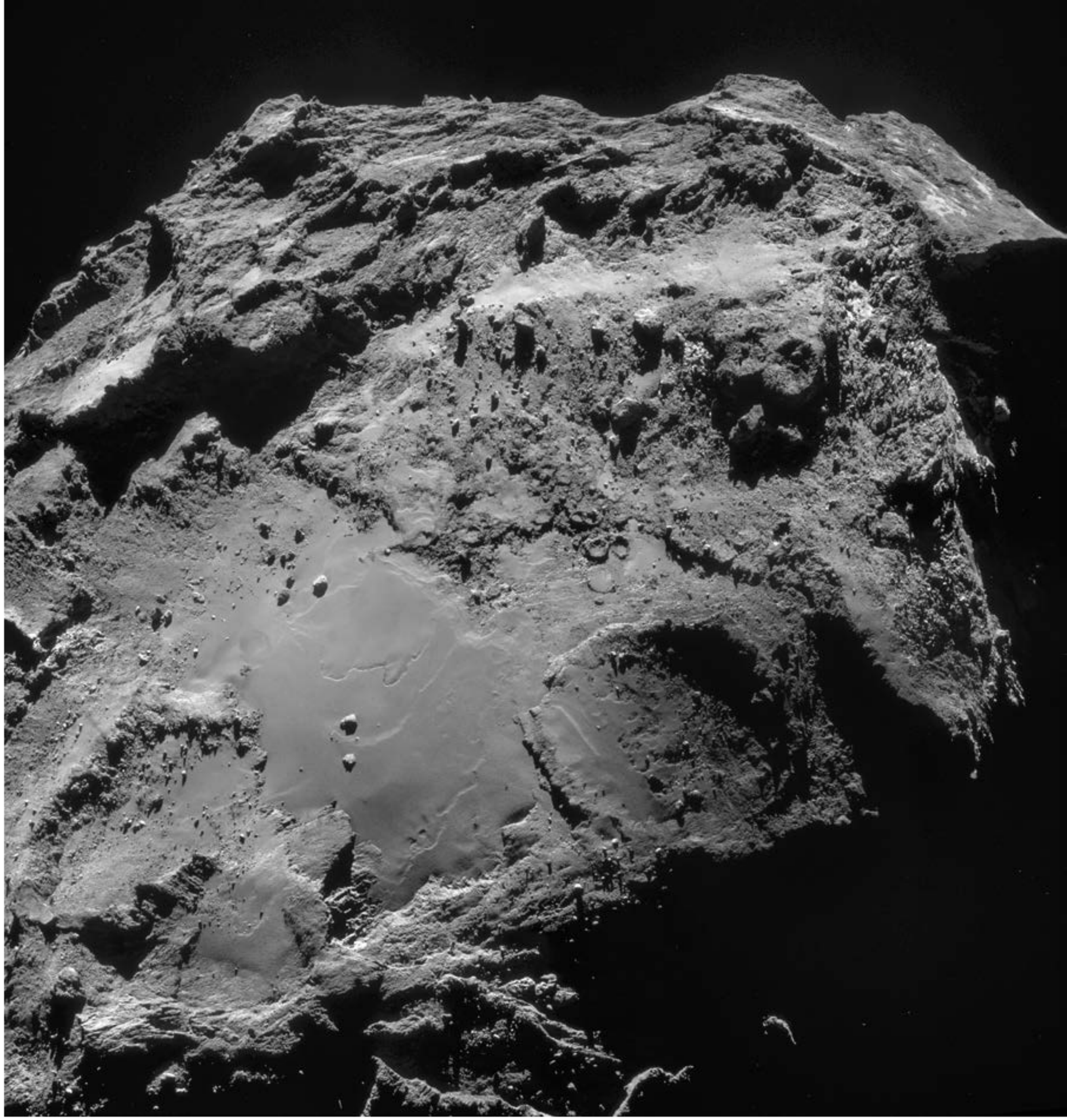




This single frame Rosetta navigation camera image of Comet 67P/Churyumov-Gerasimenko was taken on 23 October 2014 from a distance of 9.8 km from the comet centre.

Credit: ESA/Rosetta/NAVCAM

This four-image mosaic comprises images taken from a distance of 19.4 km from the centre of Comet 67P/Churyumov-Gerasimenko on 14 December.

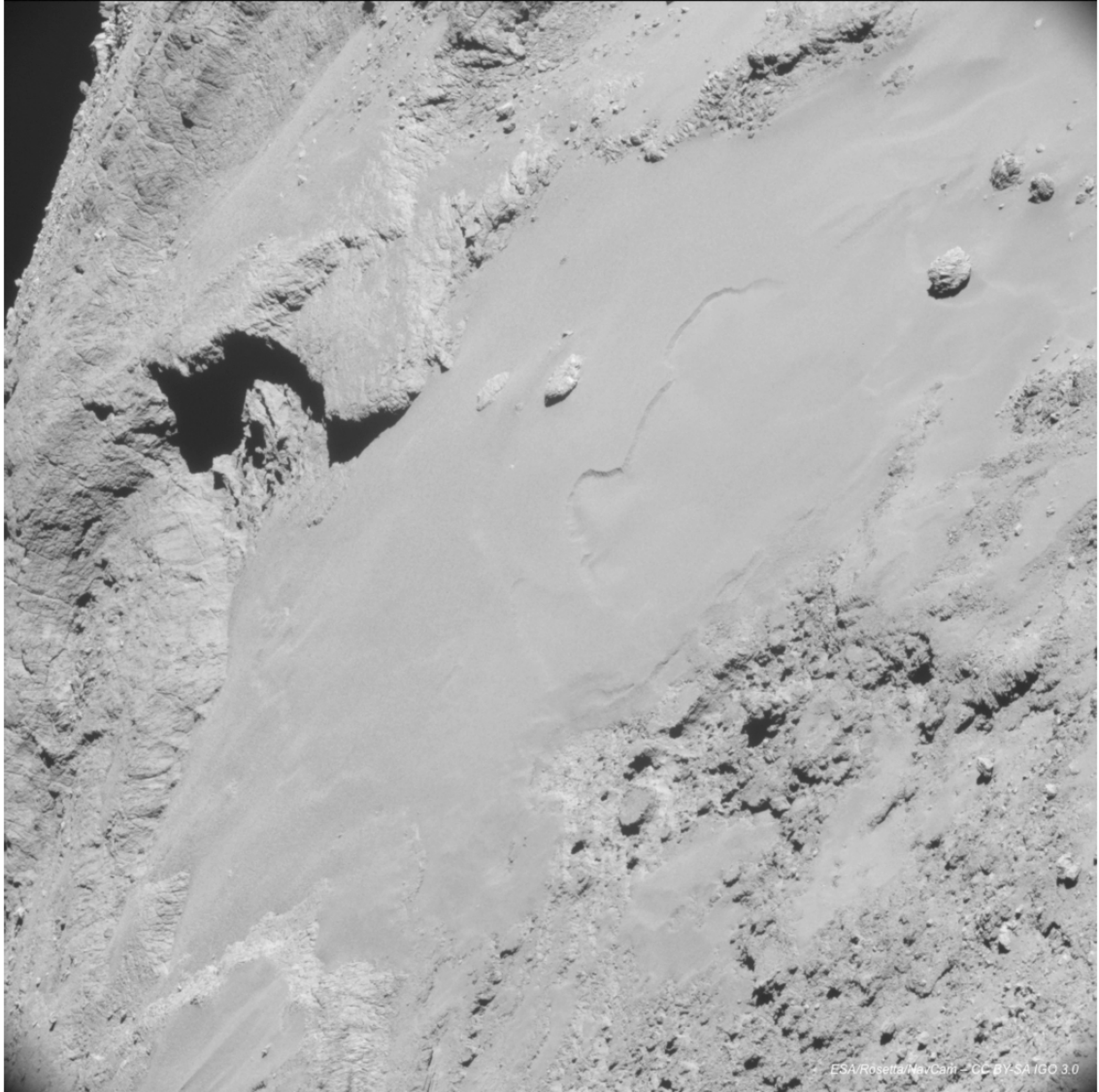


Credit: ESA/Rosetta/NAVCAM

This four-image mosaic comprises Rosetta navigation camera images taken from a distance of 27.9 km from the centre of Comet 67P/Churyumov-Gerasimenko on 21 January

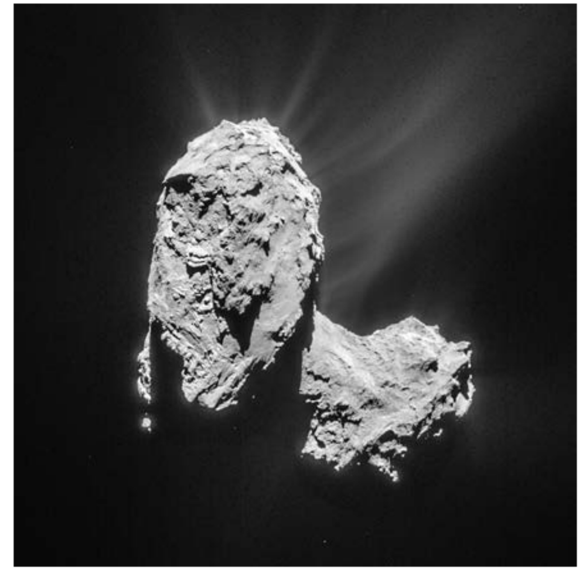
Credit: ESA/Rosetta/NAVCAM

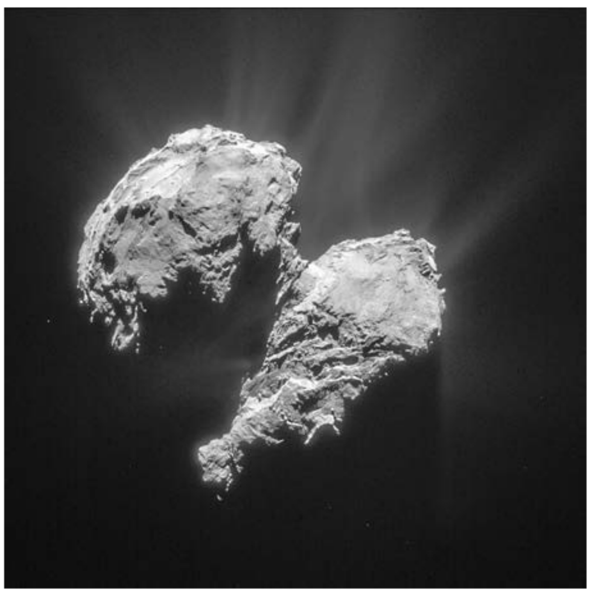
On 14 February 2015, Rosetta swooped over the surface of Comet 67P/Churyumov–Gerasimenko at a distance of just 6 km. The closest approach took place at 12:41 GMT over a region known as Imhotep, which is on the larger of the comet's two lobes.



Credit: ESA/Rosetta/NAVCAM

This single frame Rosetta navigation camera image was taken from a distance of 82.6 km from the centre of Comet 67P/Churyumov-Gerasimenko on 21 March 2015.

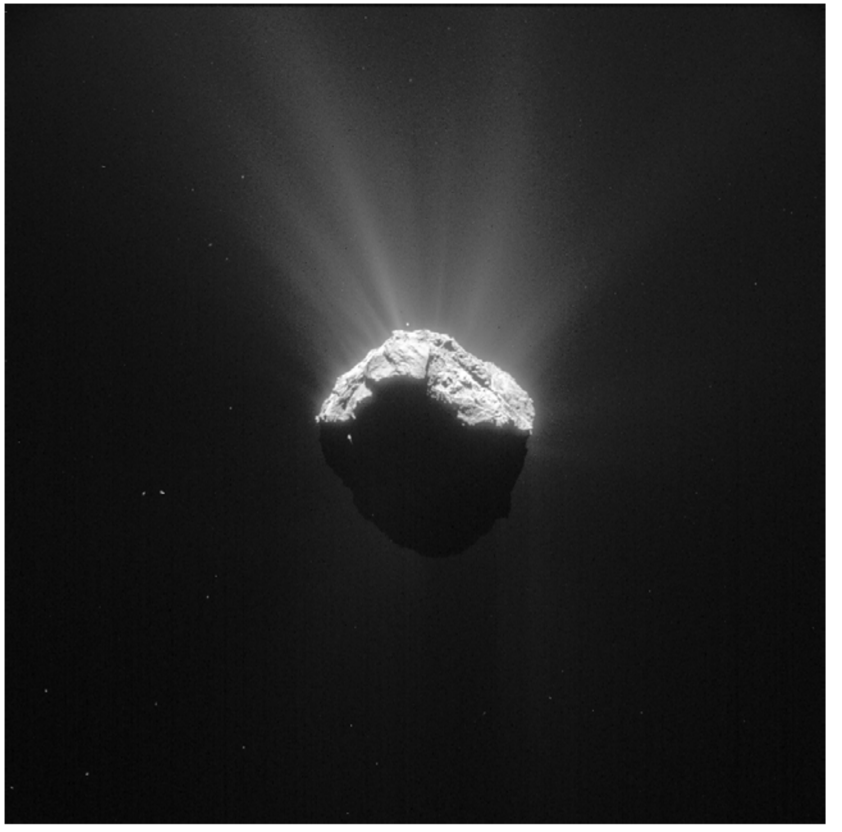


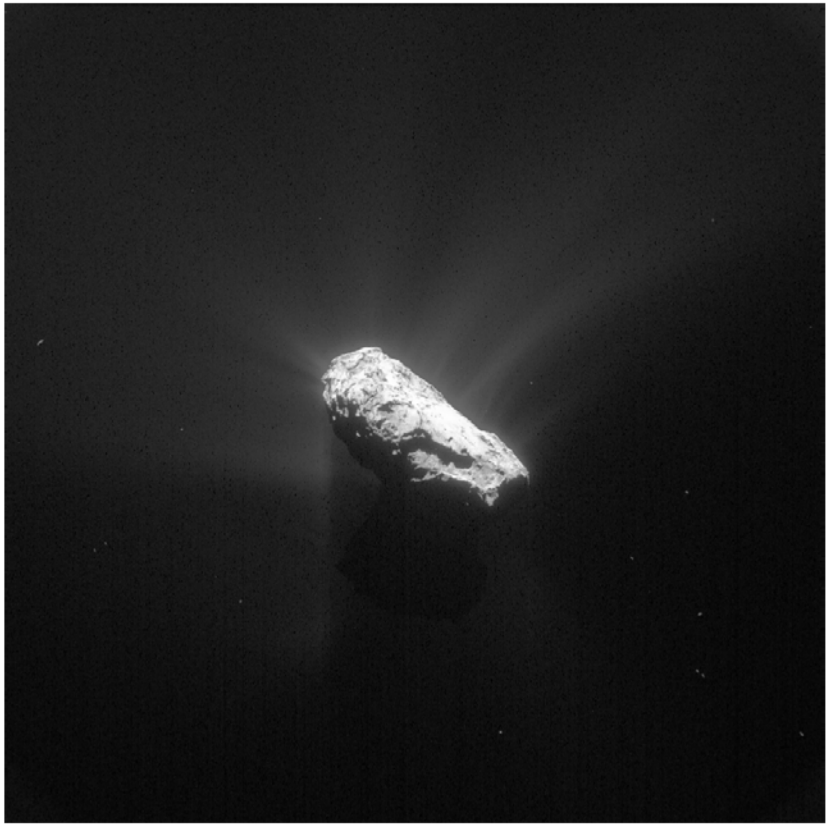


This single frame Rosetta navigation camera image was taken from a distance of 77.8 km from the centre of Comet 67P/Churyumov-Gerasimenko on 22 March 2015

Credit: ESA/Rosetta/NAVCAM

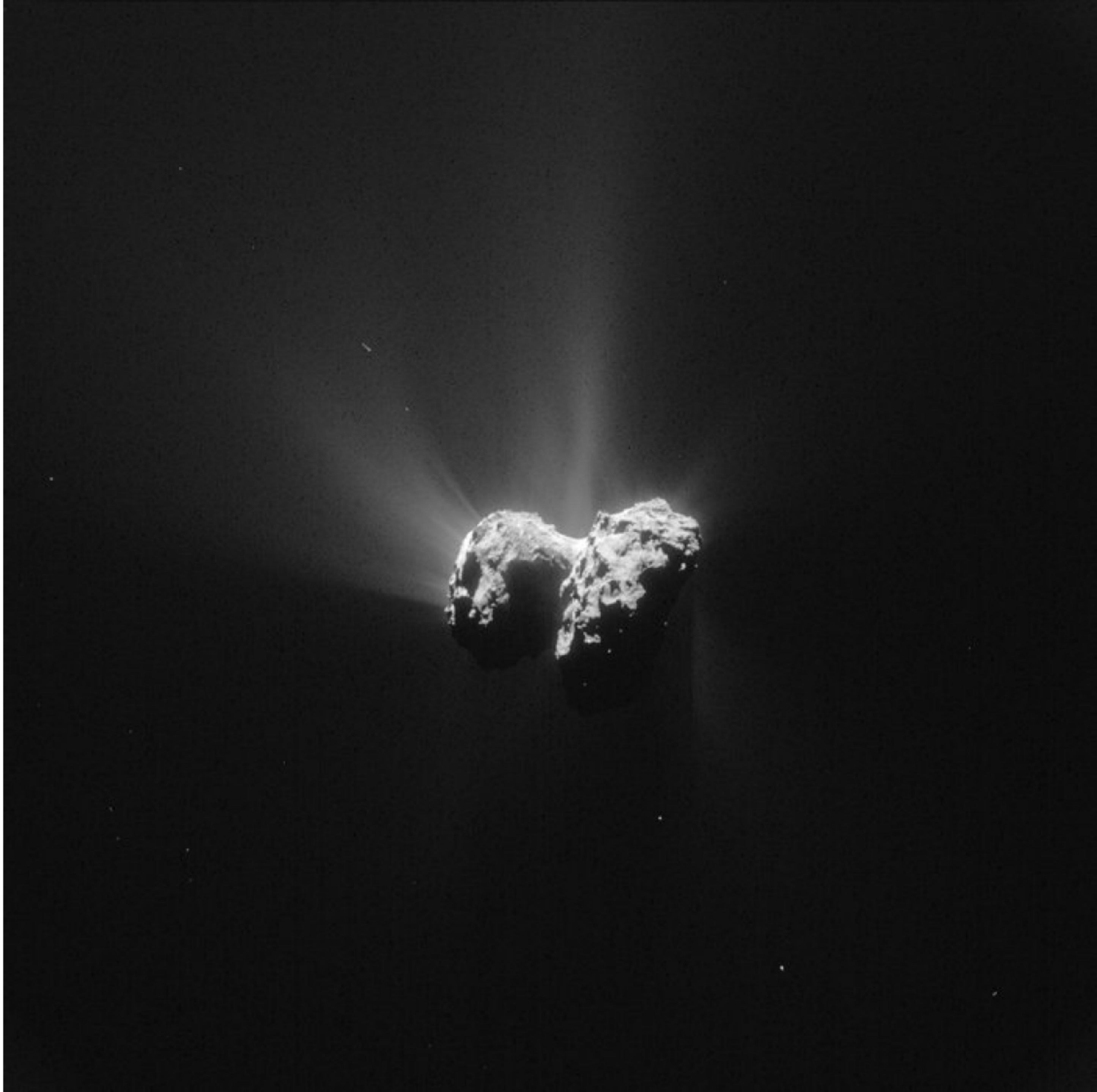
This single frame Rosetta navigation camera image of Comet 67P/Churyumov-Gerasimenko was taken on 15 April 2015 from a distance of 162 km from the comet centre.





This single frame Rosetta navigation camera image of Comet 67P/Churyumov-Gerasimenko was taken on 12 May 2015 from a distance of 166 km from the comet centre.

On 15 June 2015, at a distance of just 207 km. This single frame Rosetta navigation camera image of Comet 67P/Churyumov-Gerasimenko was taken on 15 June 2015 from a distance of 207 km from the comet centre. The image has a resolution of 17.7 m/pixel and measures 18.1 km across.



The images were captured on 30 July 2015, about 185 km from the comet. The object measures between one and 50 m across; however, the exact size cannot be determined as it depends on its distance to the spacecraft, which cannot be inferred from these images.

Credit: ESA/Rosetta/VIRTIS/INAF-IAPS/OBS DE PARIS-LESIA/DLR; M.C. De Sanctis et al (2015)

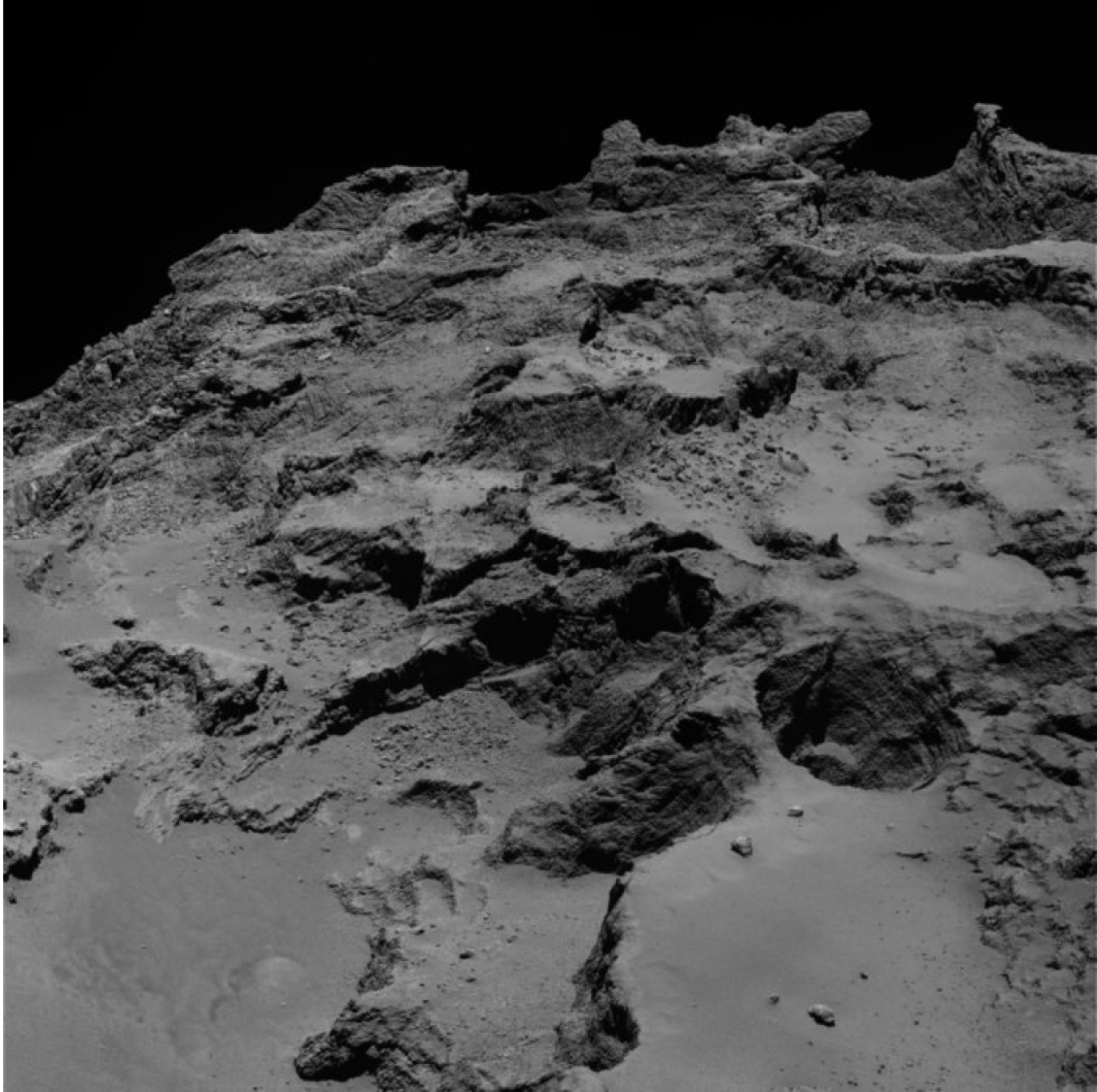
Credit: ESA/Rosetta/MPS for OSIRIS Team MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA

Approaching perihelion:

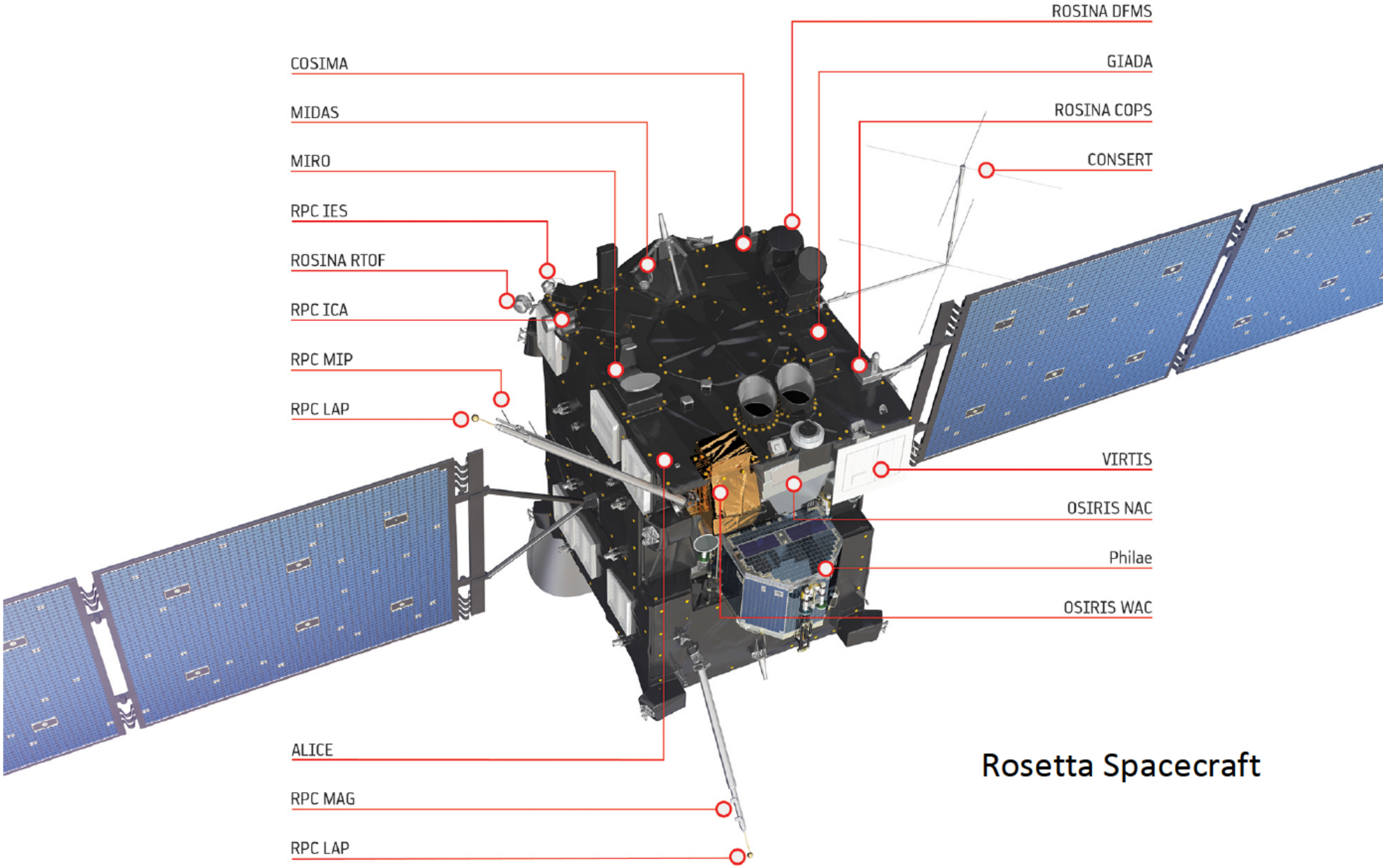
On 12 August 2015, at a distance of just 330 km. The comet’s activity, at its peak intensity around perihelion and in the weeks that follow, is clearly visible, including a significant outburst.

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

On 22 September 2015, at a distance of just 28 km. It focuses on the irregular, fractured and stratified morphology of the Seth region of the main body. A wide terrace is seen in the foreground with a deep pit revealing the inner layered skeleton of the comet nucleus.



Credits: ESA/ATG



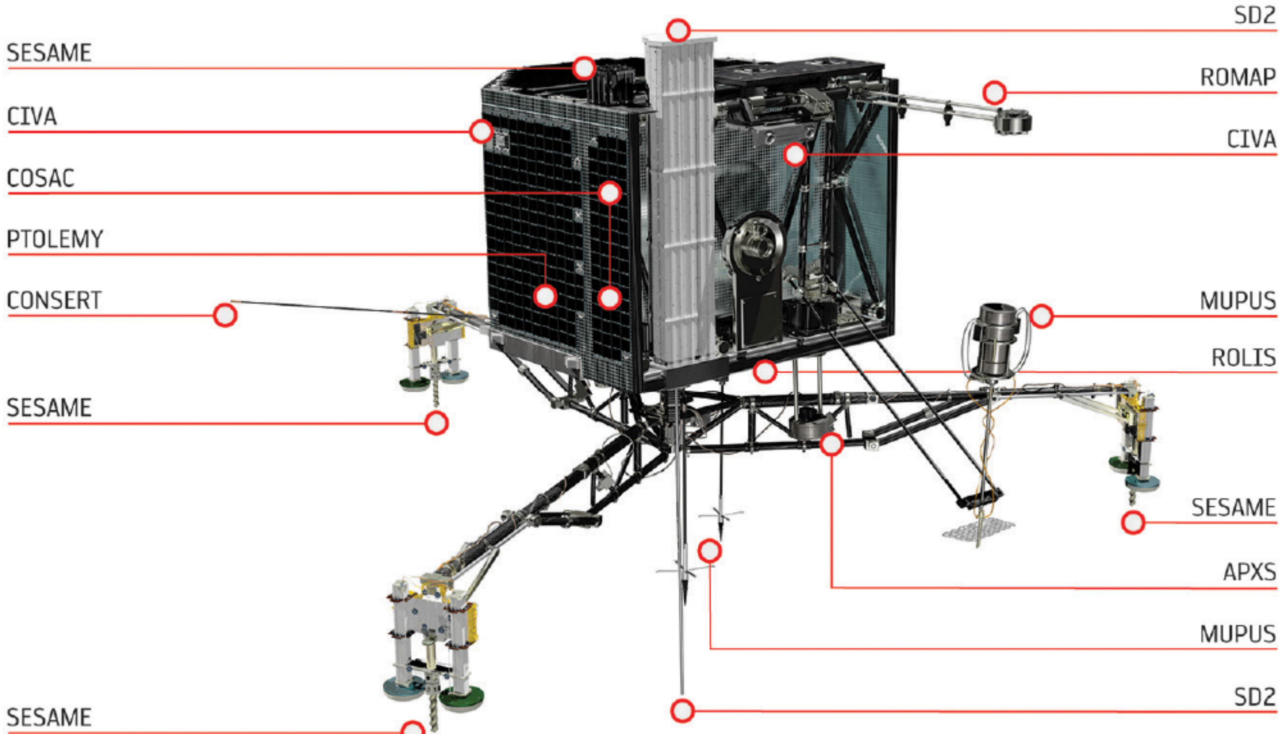
Rosetta Spacecraft

Credits: ESA/ATG

Rosetta Spacecraft’s 11 instruments

- ALICE: Ultraviolet Imaging Spectrometer – (characterising the composition of the comet nucleus and coma)
- CONSERT: Comet Nucleus Sounding Experiment by Radio wave Transmission (studying the internal structure of the comet with lander Philae)
- COSIMA: Cometary Secondary Ion Mass Analyser (studying the composition of the dust in the comet’s coma)
- GIADA: Grain Impact Analyser and Dust Accumulator (measuring the number, mass, momentum and velocity distribution of dust grains in the near-comet environment)
- MIDAS: Micro-Imaging Dust Analysis System (studying the dust environment of the comet)
- MIRO: Microwave Instrument for the Rosetta Orbiter (investigating the nature of the cometary nucleus, outgassing from the nucleus and development of the coma)
- OSIRIS: Optical, Spectroscopic, and Infrared Remote Imaging System Camera (a dual camera imaging system consisting of a narrow angle (NAC) and wide angle camera (WAC) and operating in the visible, near infrared and near ultraviolet wavelength range)
- ROSINA: Rosetta Orbiter Spectrometer for Ion and Neutral Analysis (determining the composition of the comet's atmosphere and ionosphere, and measuring the temperature, velocity and density of the gas flow, comprising: DFMS (Double-focusing mass spectrometer), RTOF (Reflectron Time-Of-Flight mass spectrometer) and COPS (Comet Pressure Sensor))
- RPC: Rosetta Plasma Consortium (studying the plasma environment of the comet, comprising: ICA (Ion Composition Analyser), IES (Ion and Electron Sensor), LAP (Langmuir Probe), MAG (Fluxgate Magnetometer), MIP (Mutual Impedance Probe), PIU (Plasma Interface Unit))
- RSI: Radio Science Investigation (tracking the motion of the spacecraft to infer details of the comet environment and nucleus)
- VIRTIS: Visible and Infrared Thermal Imaging Spectrometer (studying the nature of the comet nucleus and the gases in the coma)

Credits: ESA/ATG



Philae Lander

Credits: ESA/ATG

Philae's 10 Instruments

- APXS: Alpha Proton X-ray Spectrometer (studying the chemical composition of the landing site and its potential alteration during the comet's approach to the Sun)
- CIVA: Comet Nucleus Infrared and Visible Analyser (six cameras to take panoramic pictures of the comet surface)
- CONSERT: COmet Nucleus Sounding Experiment by Radiowave Transmission (studying the internal structure of the comet nucleus with Rosetta orbiter)
- COSAC: The COmetary SAmpling and Composition experiment (detecting and identifying complex organic molecules)
- PTOLEMY: Using MODULUS protocol (Methods Of Determining and Understanding Light elements from Unequivocal Stable isotope compositions) to understand the geochemistry of light elements, such as hydrogen, carbon, nitrogen and oxygen.
- MUPUS: MUlti-PUrpose Sensors for Surface and Sub-Surface Science (studying the properties of the comet surface and immediate sub-surface)
- ROLIS: Rosetta Lander Imaging System (providing the first close-up images of the landing site)
- ROMAP: Rosetta Lander Magnetometer and Plasma Monitor (studying the magnetic field and plasma environment of the comet)
- SD2: Sampling, drilling and distribution subsystem (drilling up to 23 cm depth and delivering material to onboard instruments for analysis)
- SESAME: Surface Electric Sounding and Acoustic Monitoring Experiment (probing the mechanical and electrical parameters of the comet)

Acknowledgements

I would like to thank Mr. Art Chmilewski, the U.S. Rosetta Project Manager, for providing much of the information in the presentation slides. I would also like to appreciate the European Space Agency Rosetta Project team for allowing us to use the Rosetta and Philae Lander images in this presentation.