Séminaire CEA 29-01-2019

The Rosetta Space mission at 67P/Churyumov-Gerasimenko

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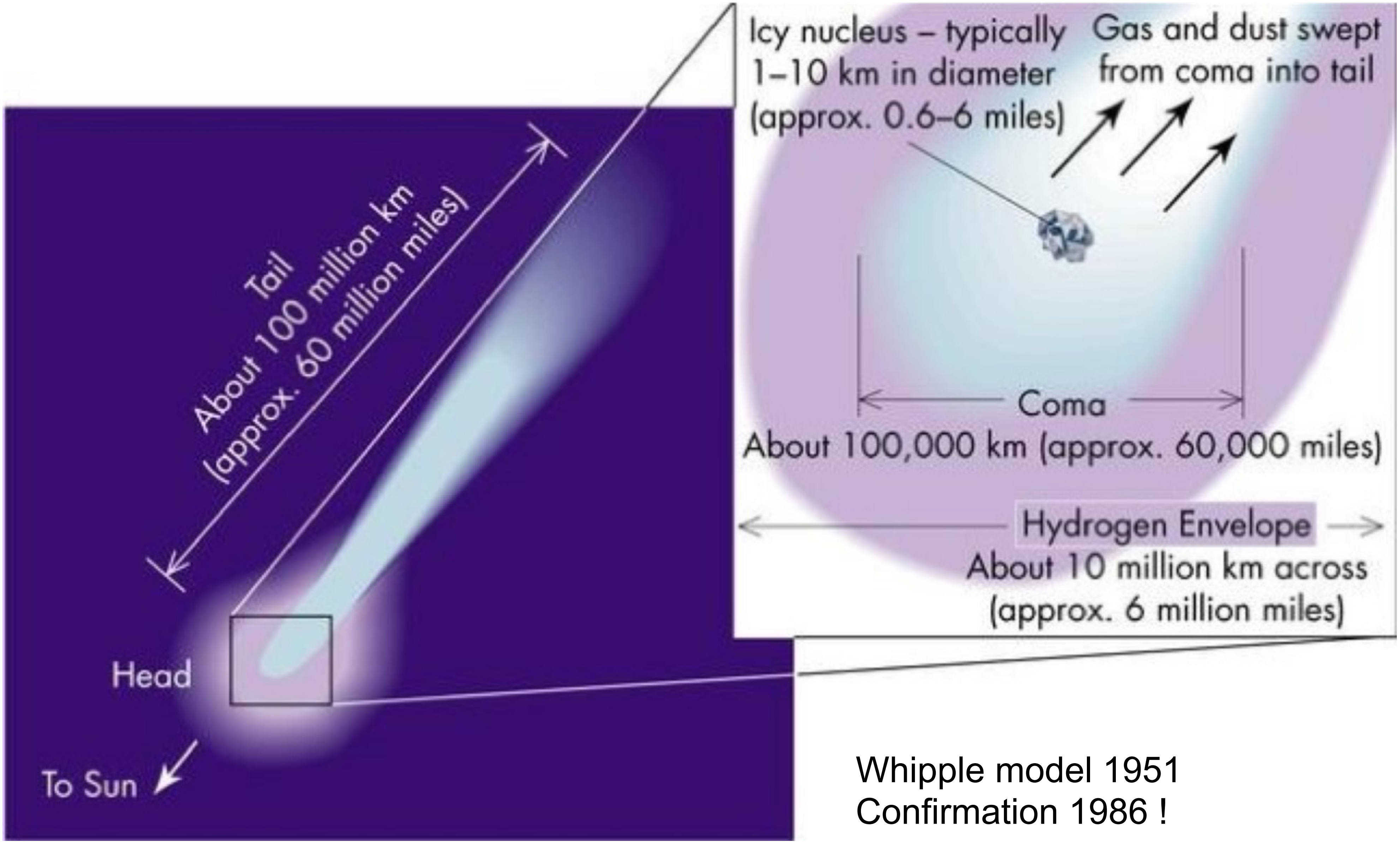
Highlights

1. Why do we study comets?
    1. Comet properties
    2. Solar system formation, LHB and Nice model
    3. Transitional link with asteroids ?
2. The Rosetta mission
    1. Description of the mission
    2. 2 years of 67P exploration
3. What’s next?
    1. The Kuiper Belt and beyond

Comet properties

Comet properties



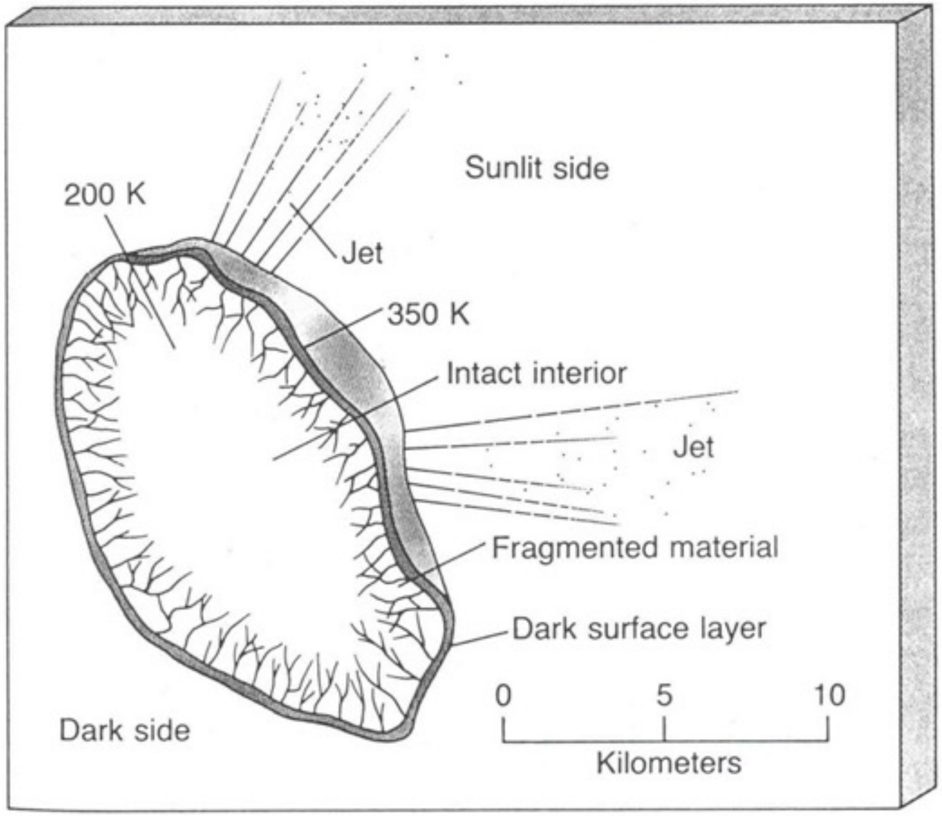
Whipple model 1951
Confirmation 1986 !

Comet properties

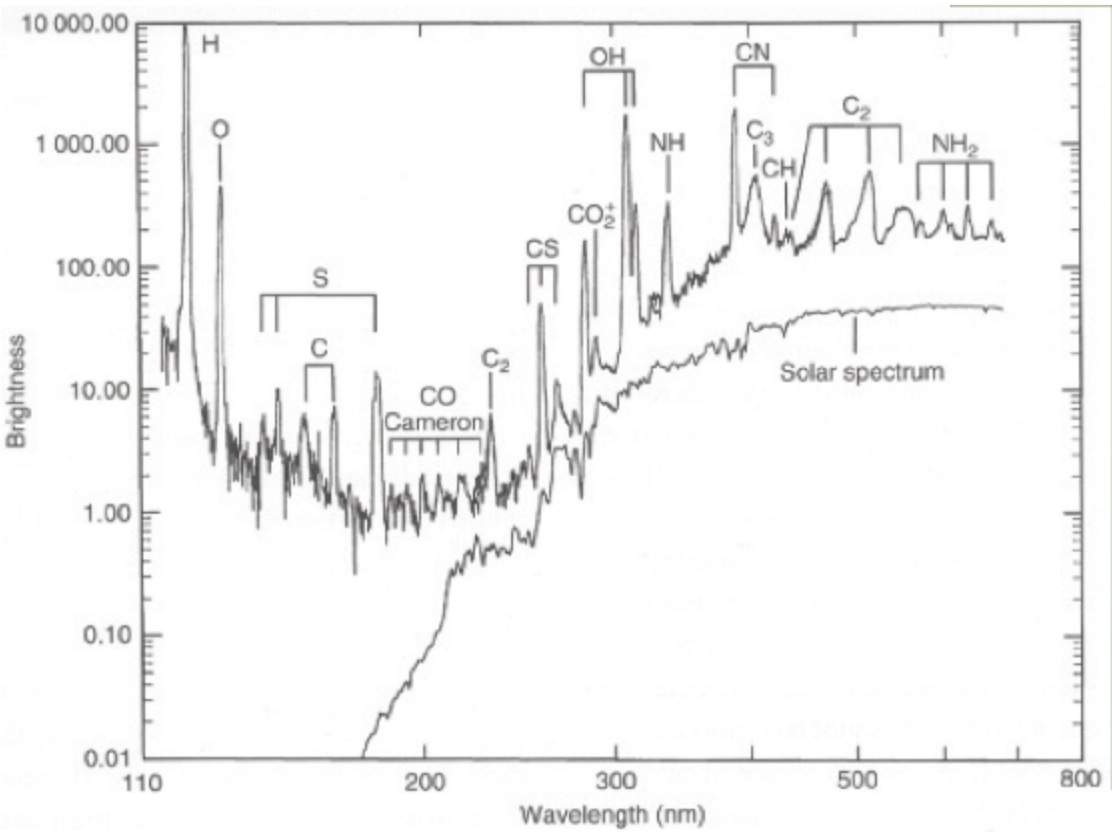
- Irregular object: 15 x 7 x 10 km. Dark color, neutral spectrum without features, reddish. Albedo ~4%.
- Similar to very dark asteroids, rich in volatiles and organic compounds from the external Main Belt (types P, D)
- Composition (number of molecules):

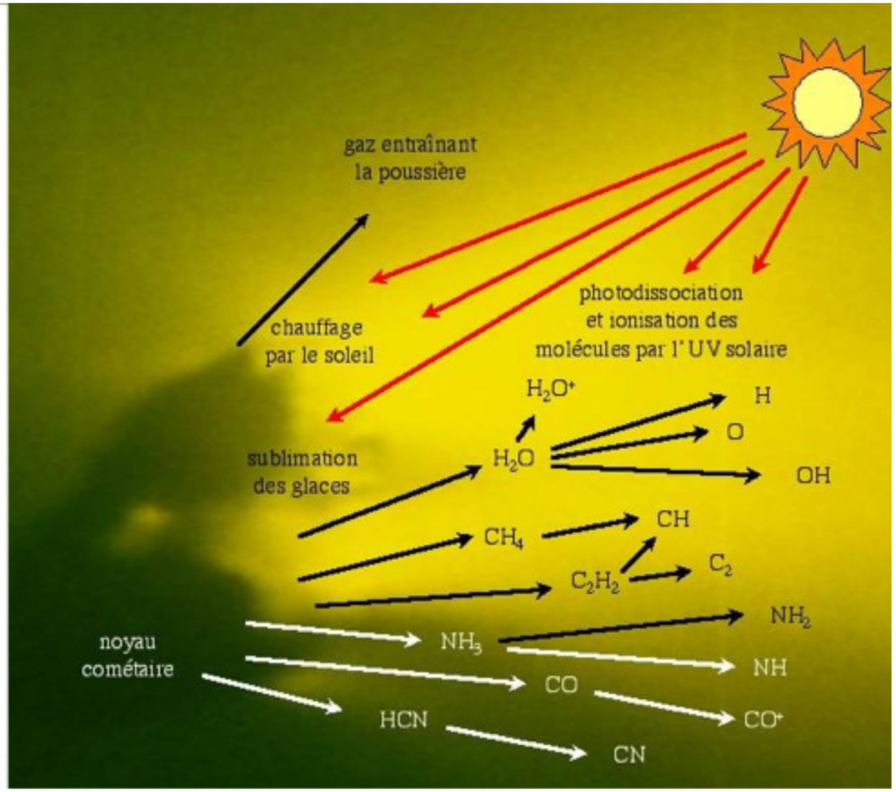
water ice	80%
Carbon monoxide	10%
Carbon dioxide	3.5%
Organic compounds (CHON)	1-2%

- slowly rotating, periods of many days, and usually present a nutation movement.



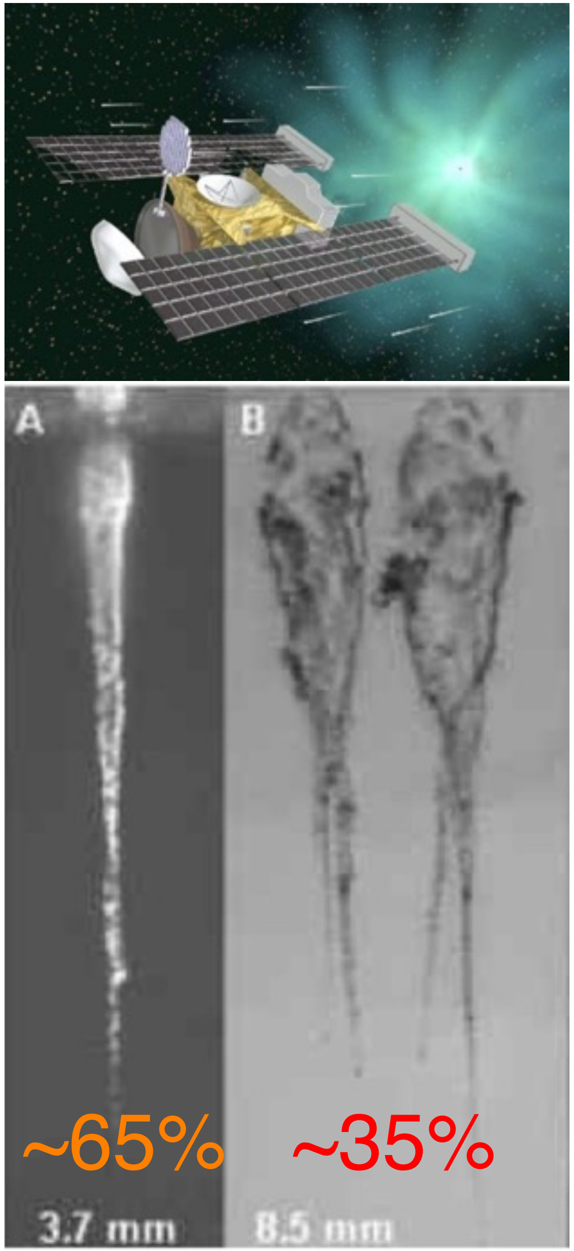
Comet properties





103P/Hartley 2 (EPOXI target;
Weaver et al. 1992)

Comet properties

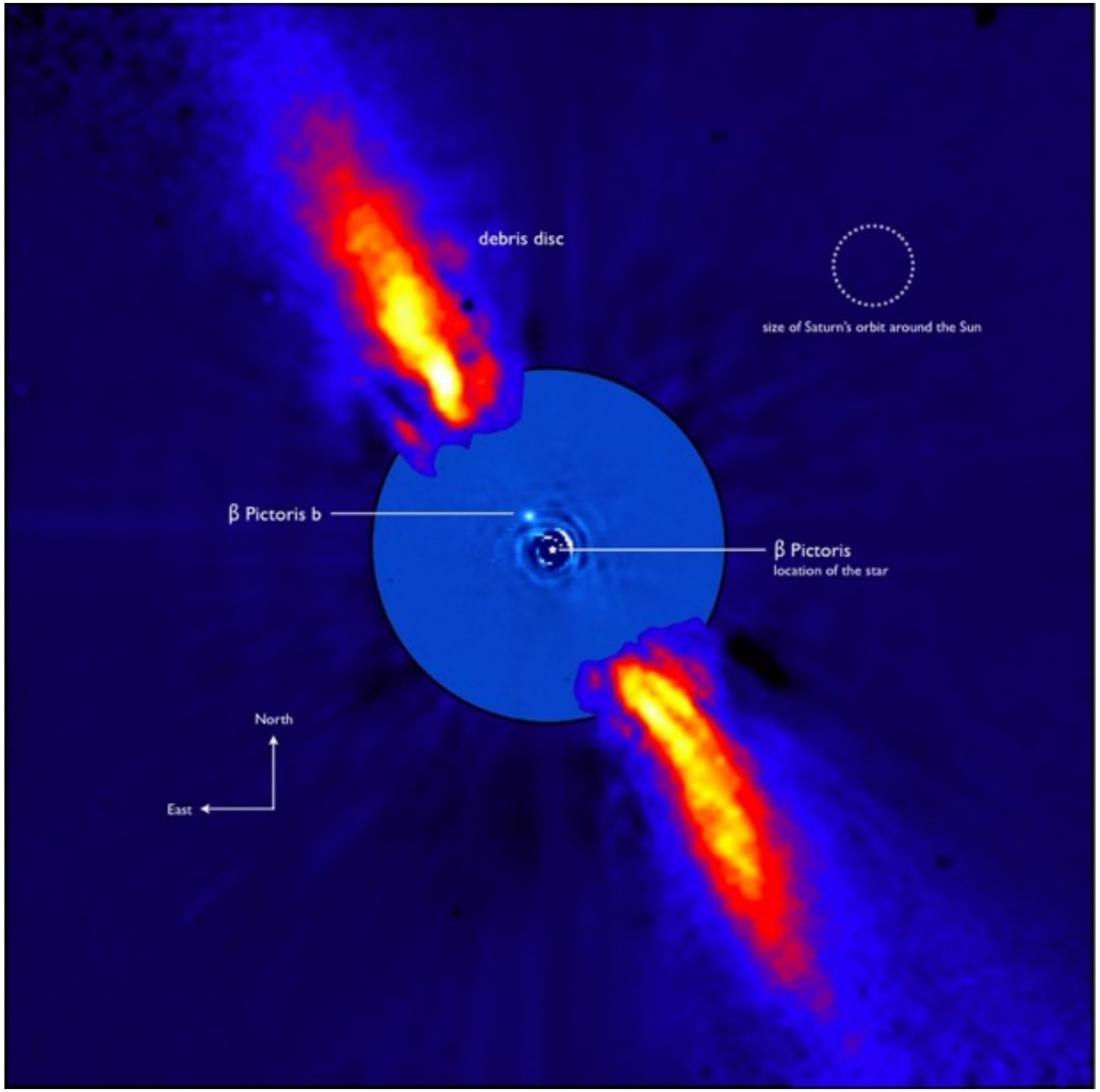


Cometary samples returned in 2006:

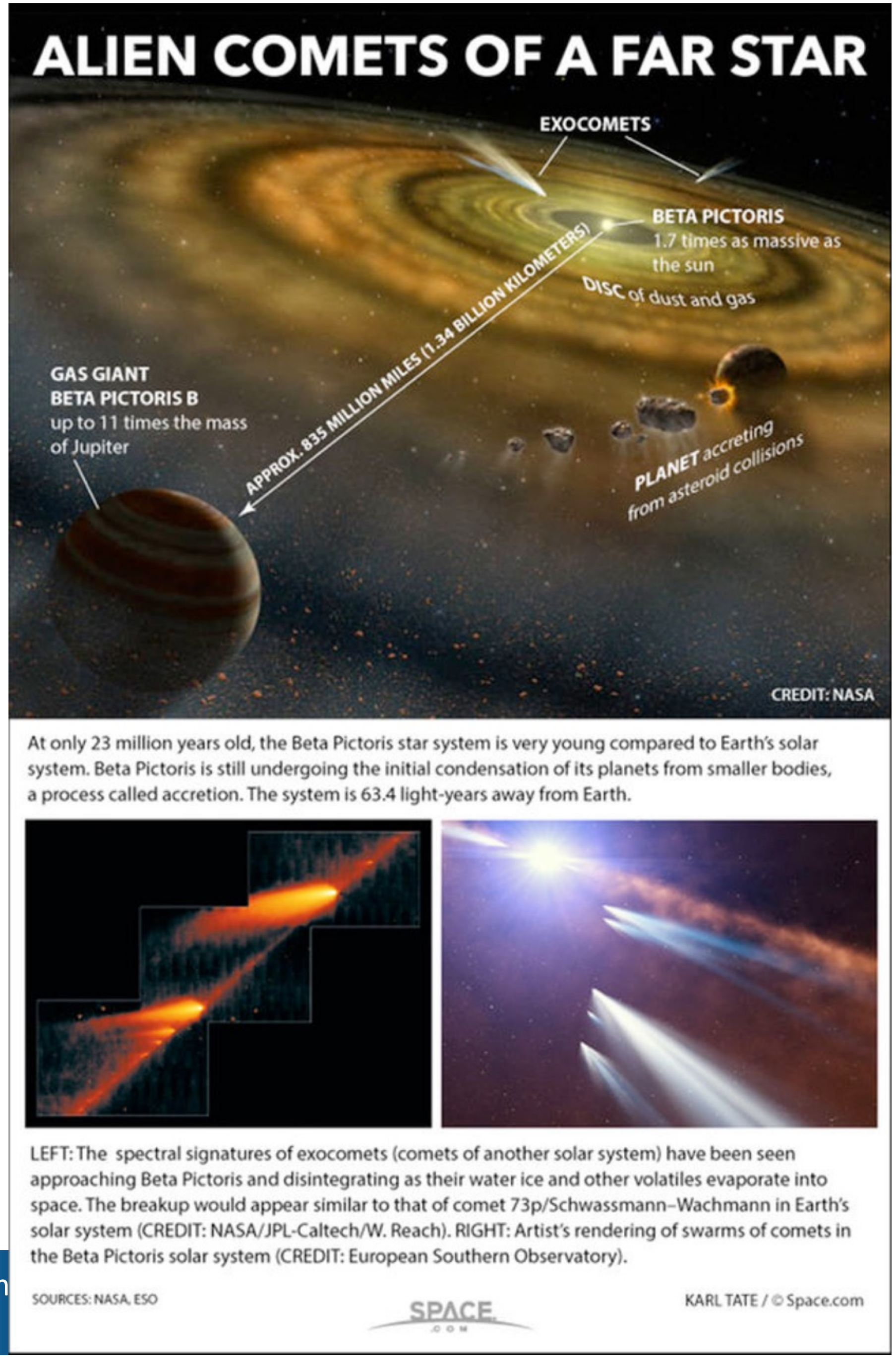
- Abundances similar to carbonaceous IDPs and CI chondrites (Flynn et al., 2006)
- Mineralogical variety with crystalline silicates (1500K) indicates large scale mixing in the primordial nebula (Zolensky et al., 2006; Keller et al., 2006)
- Some peculiar compositions : particles rich in Na, Cr, K (Joswiak et al., 2007; 2008)
- Glycine (amino-acid) discovered (Elsila et al., 2009)

Stardust (2004): 81P/Wild 2

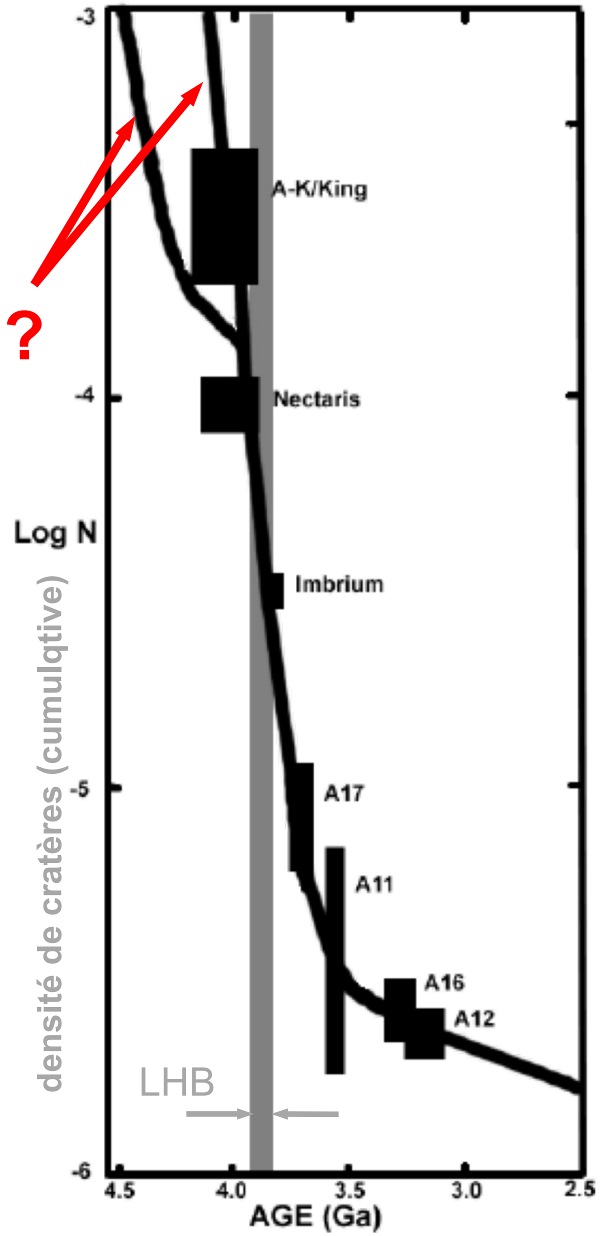
Solar system formation, LHB and Nice model

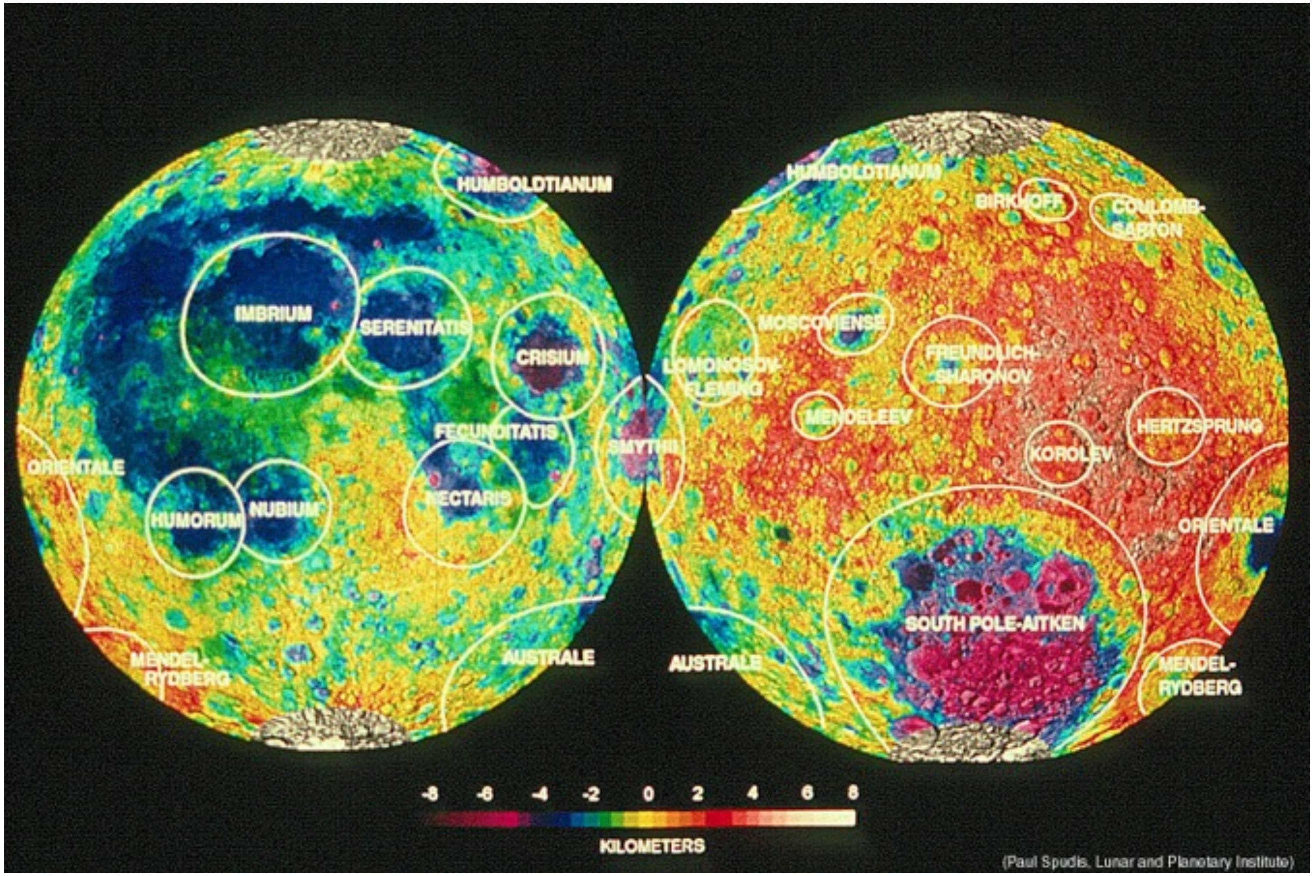


Lagrange et al. 2008 A&A Let.



Solar system formation, LHB and Nice model

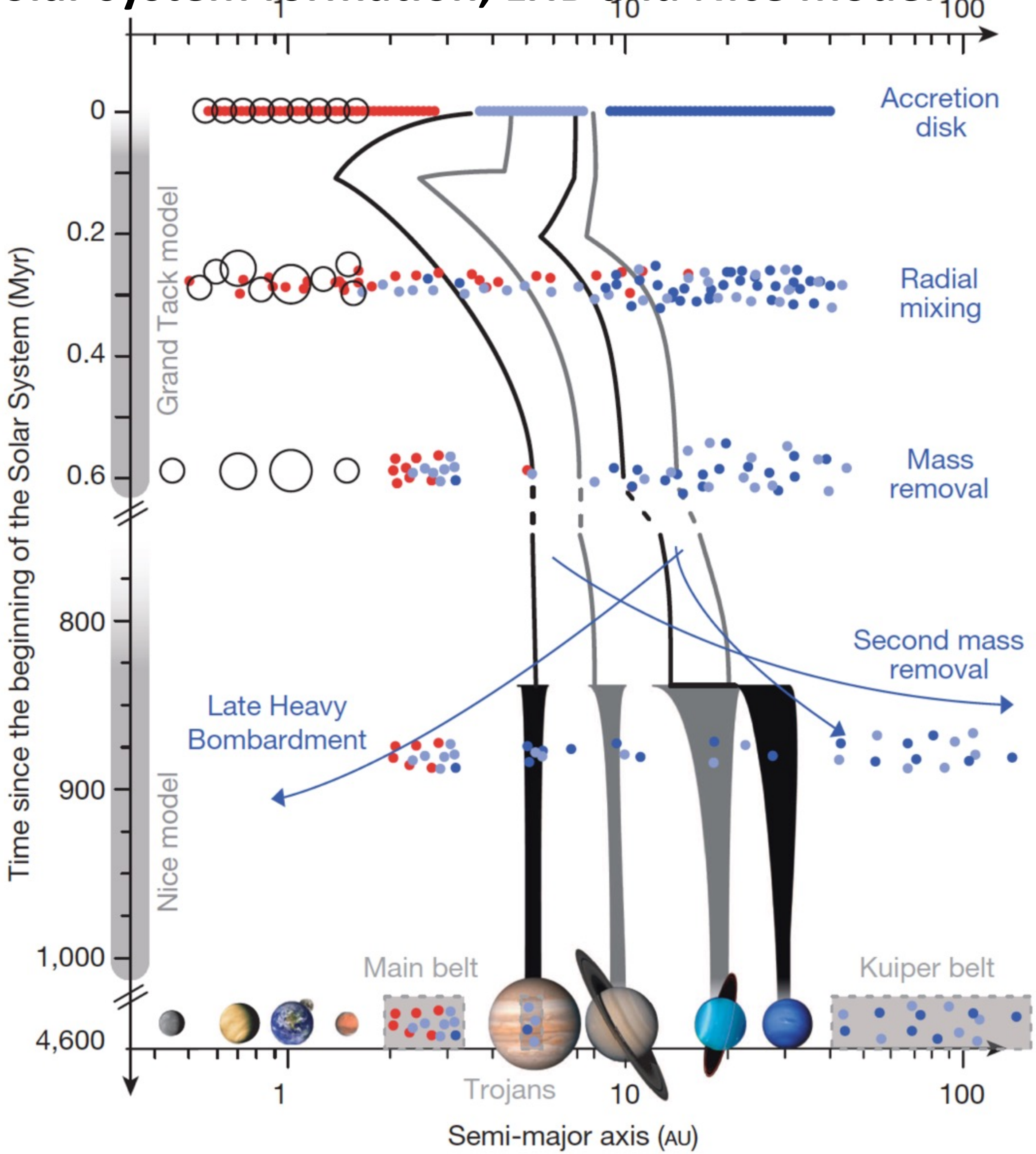




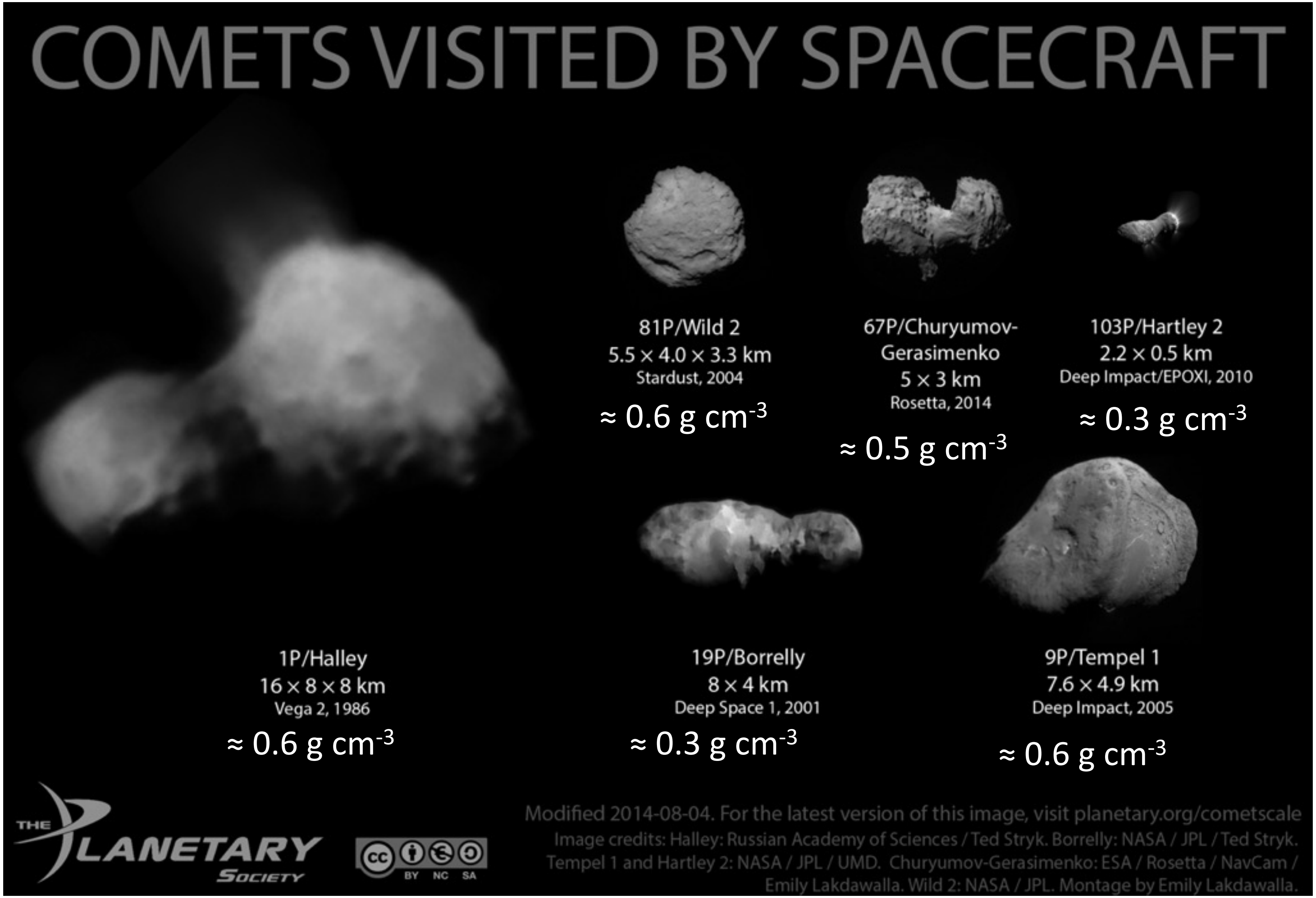
Implies: short cataclysmic bombardment (50-100 Ma) with formation of impact basins between 4 and 3.8 Ga: Late Heavy Bombardment (LHB)

Solar system formation, LHB and Nice model

De Meo & Carry Nat 2014

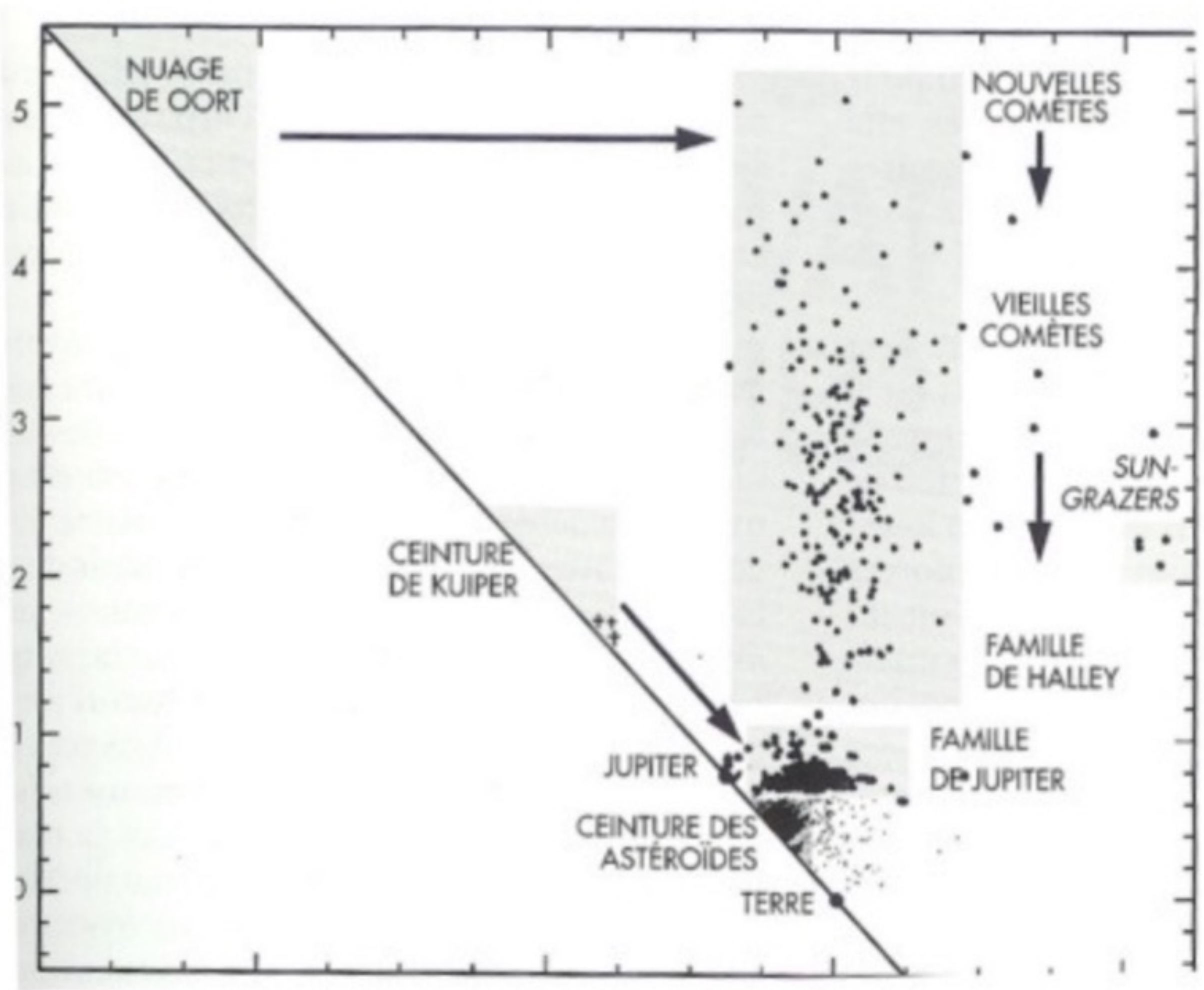


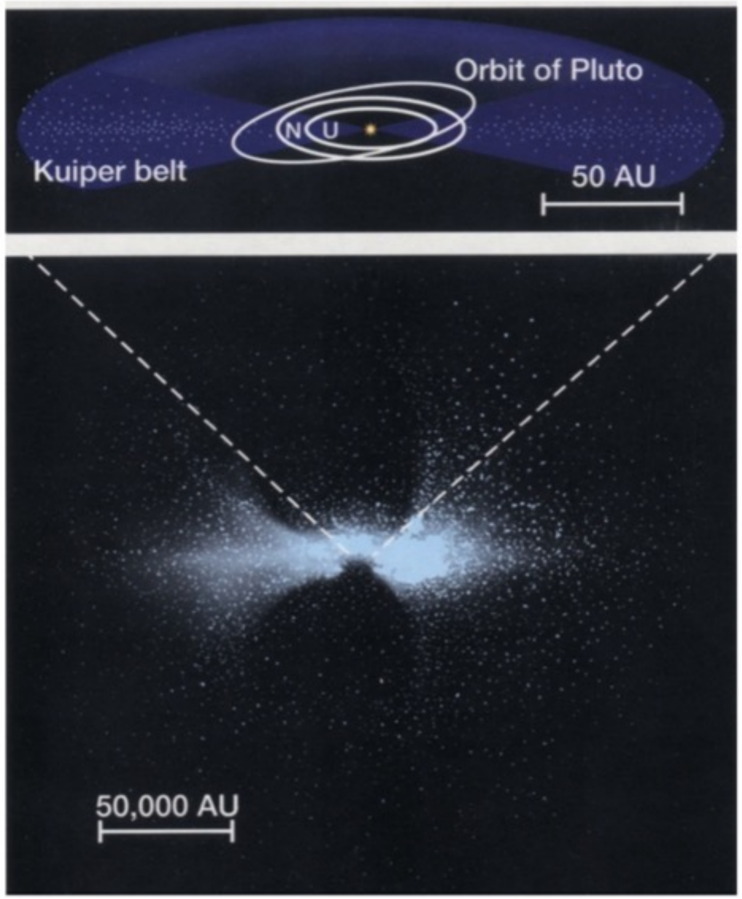
Transitional link with asteroids?



Transitional link with asteroids?

Comet reservoirs





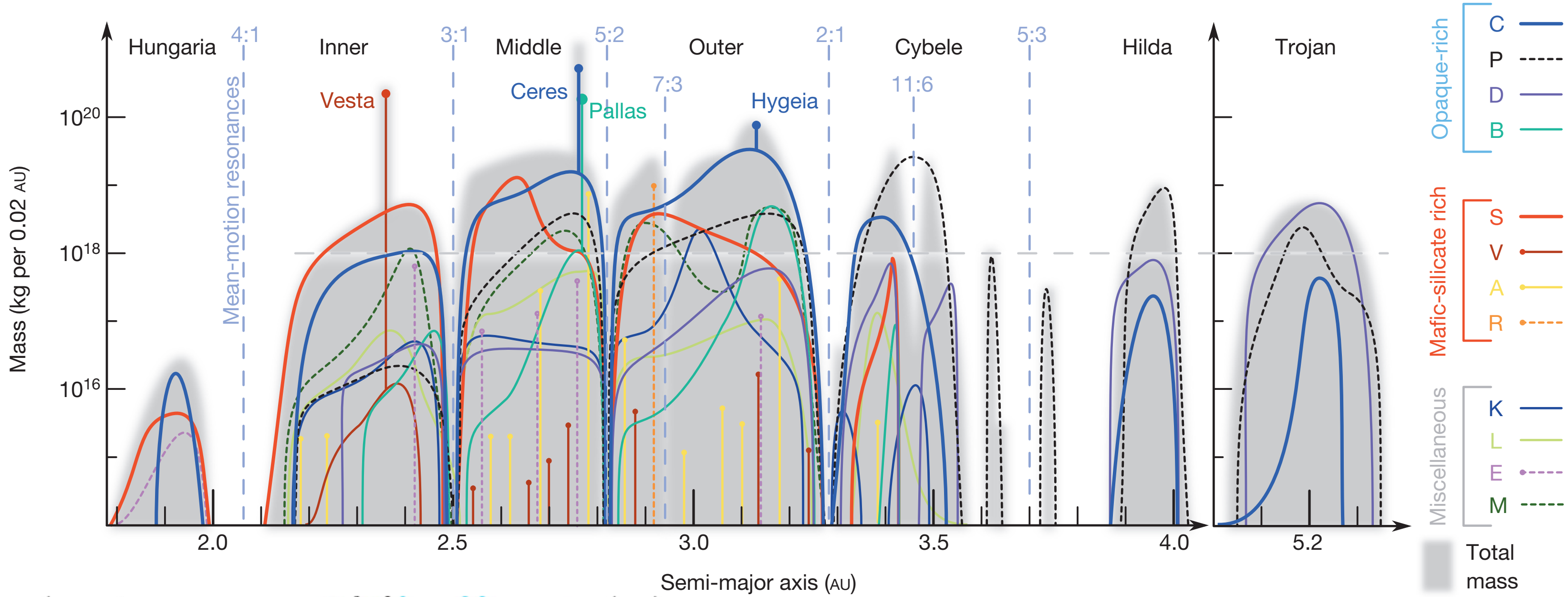
Log(a) vs Log(p)

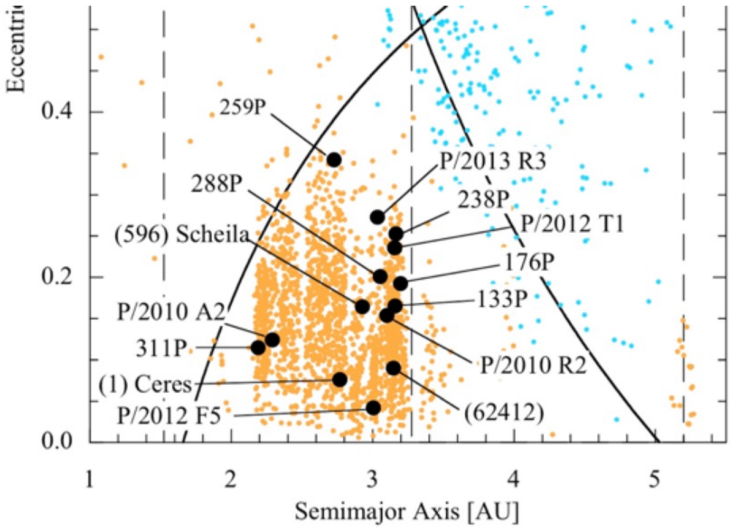
Crovisier and Encrenaz 1995

Transitional link with asteroids?

Distribution in the solar system

DeMeo and Carry, Nature 2014



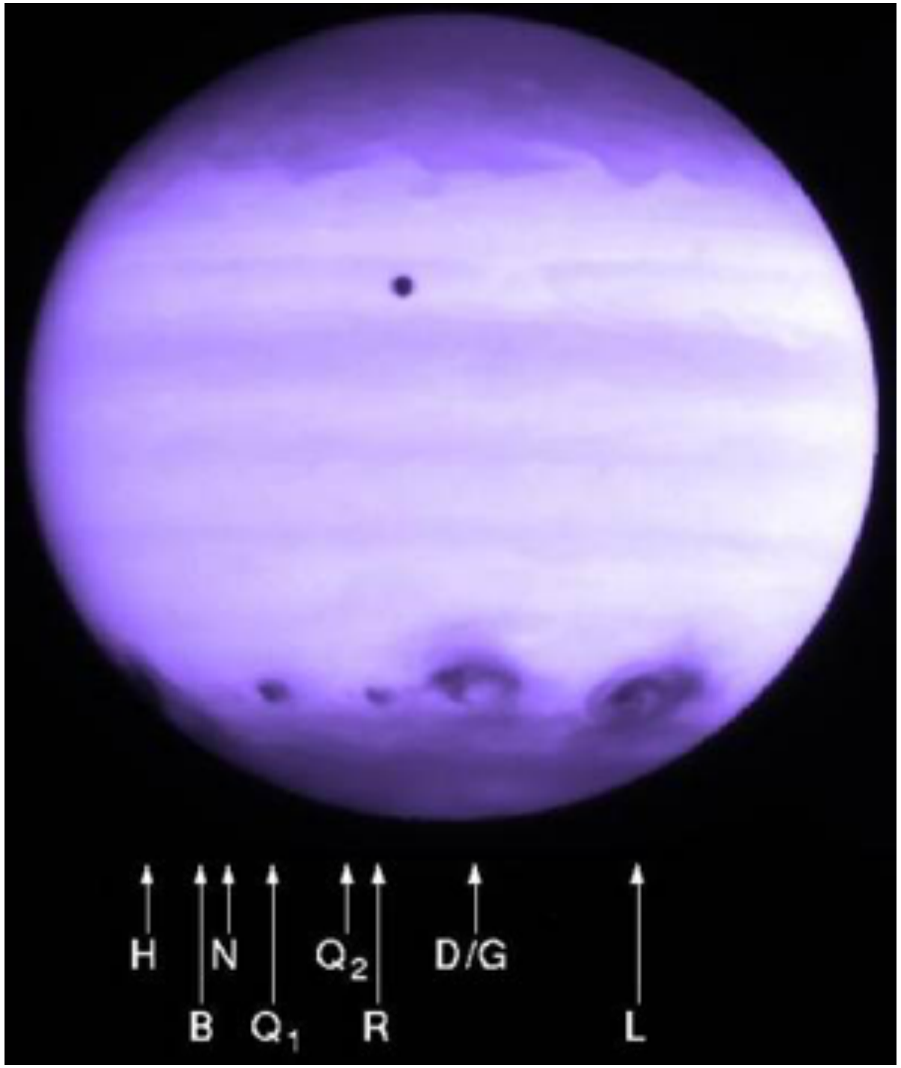


Main belt comets distribution, updated from Jewitt, AJ 2012

Possible activity mechanisms include: **sublimation**, impacts, electrostatics, rotational bursting, thermal effects, radiation pressure sweeping

- Danger ! -

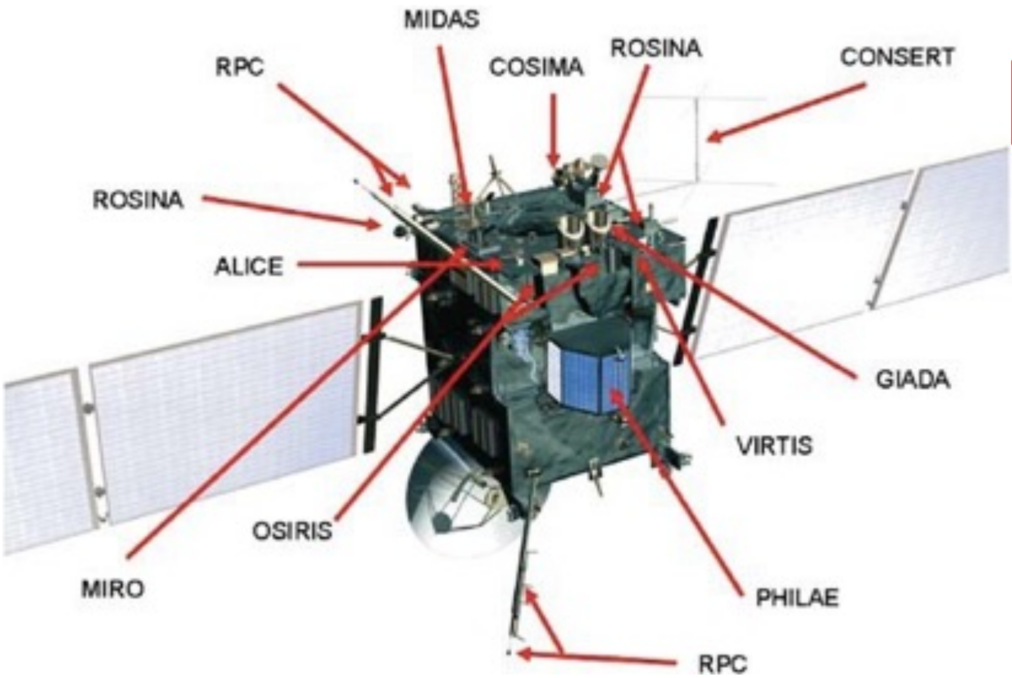

Comet P/Shoemaker-Levy 9 (1993e) • May 1994
A B C D E F G H K L N P Q R S U V W


H
N
Q2
D/G
B
Q1
R
L

The Rosetta mission

Rosetta Payload

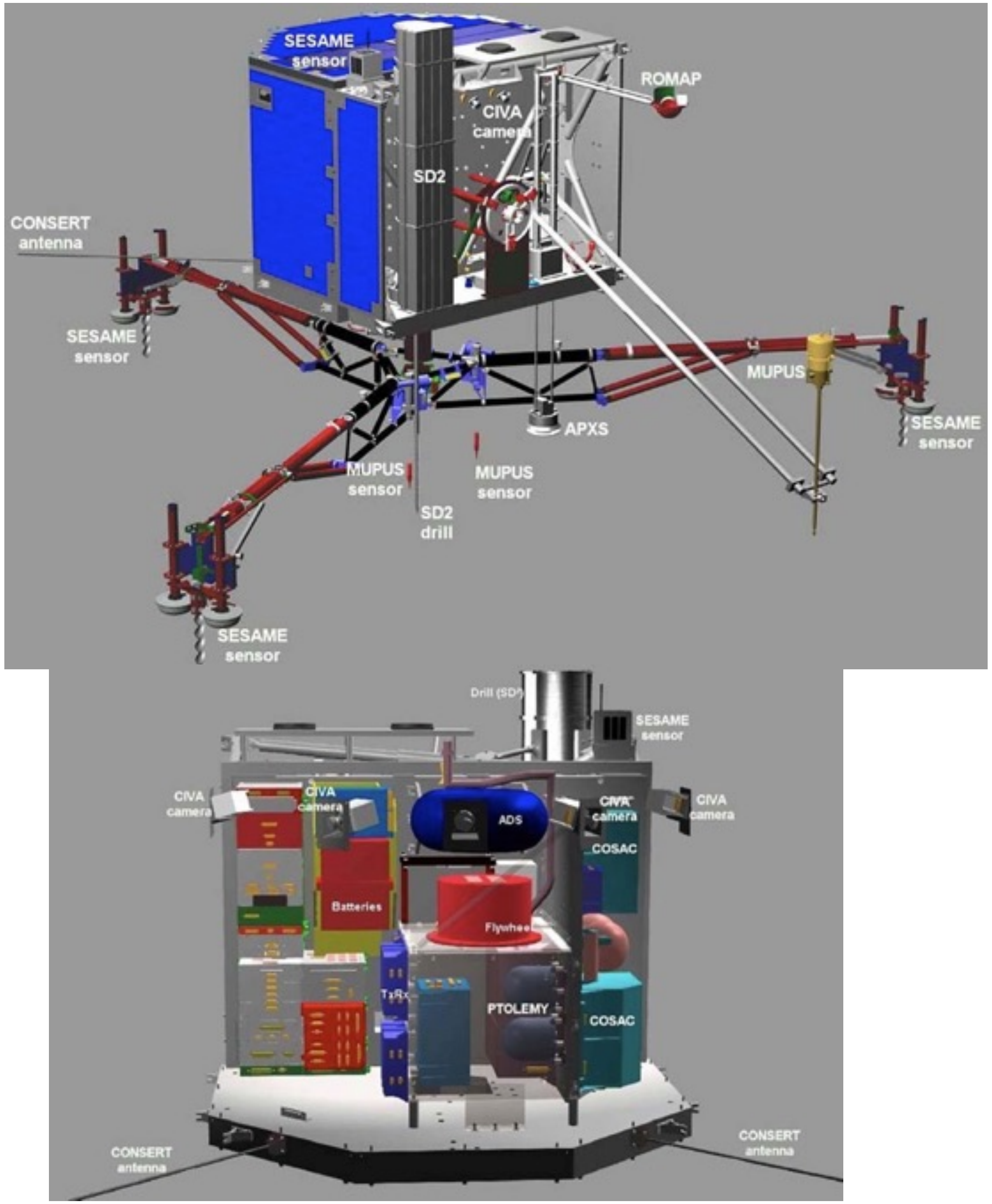
Rosetta main goals include : understand the formation of comets, determine their composition, analyze the surface and the interior, determine what role they played for Earth's evolution.



11 instruments :

ALICE **VIRTIS**	UV, vis & IR spectroscopy
OSIRIS	vis, near IR&UV camera
CONSERT	bistatic radar
COSIMA **ROSINA**	Mass spectrometry
MIRO	microwave detection
GIADA	dust dynamics detection
MIDAS	dust grains microscope
RPC	plasma measurements
RSI	Radio science

Rosetta Payload



Subsurface probes:

µwave MIRO (~ cm)
MUPUS (10 cm)
Drill S2D (few 10 cm)
SESAME/PP (~ 1 m)
Radar CONSERT (100 m)
RSI (whole nucleus)

9 instruments :

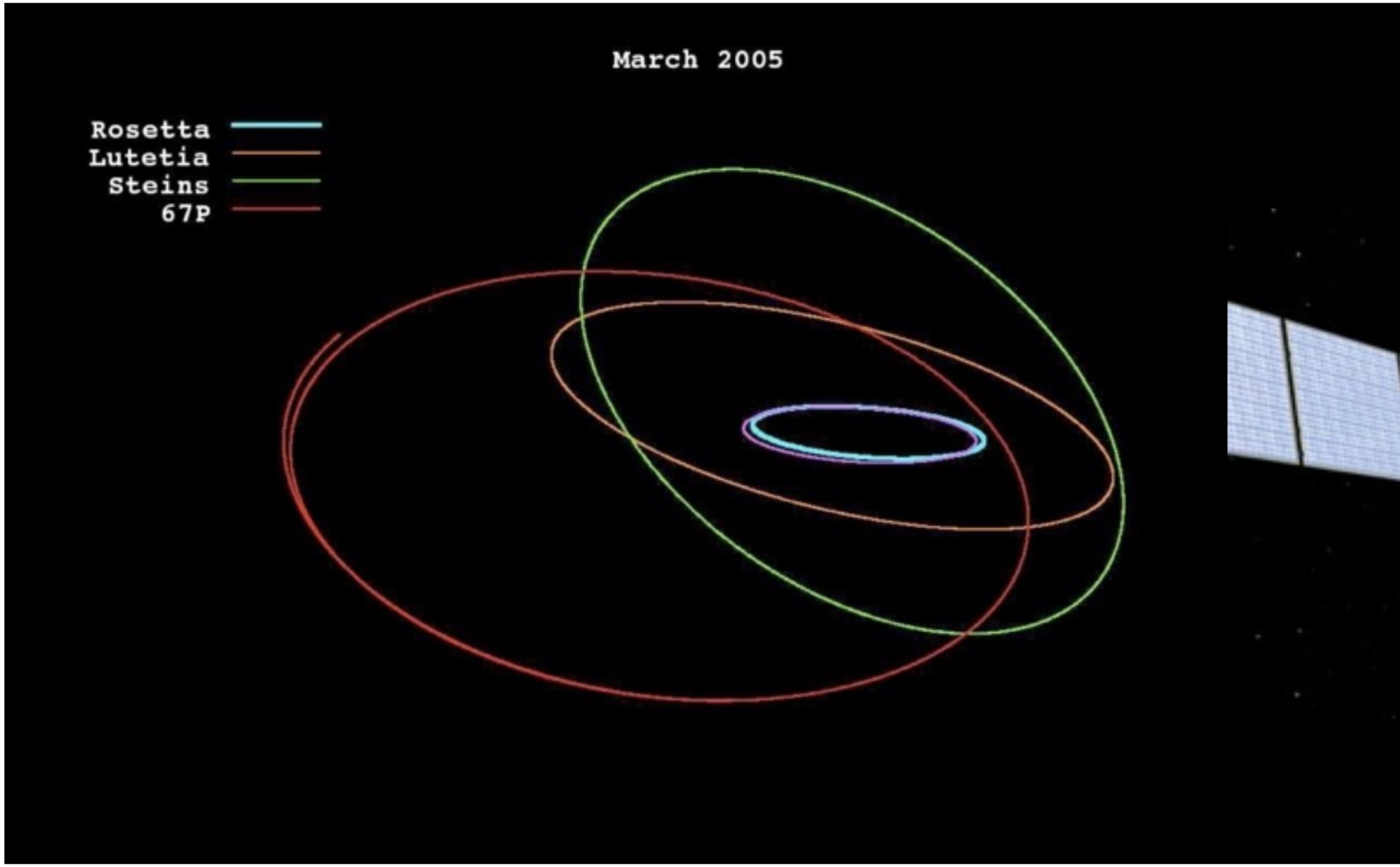
COSAC complex molecules analysis
MODULUS-Ptolemy isotopes
CONSERT bistatic radar
APXS composition
MUPUS penetrating sensors
ROMAP magnetometer and plasma
SESAME surface physical properties
CIVA VIS and IR camera
ROLIS CCD camera

Rosetta mission phases

Mission phases. March 2004: launch from Kourou
Initially scheduled for Jan 2003 for 46P/Wirtanen in 2011

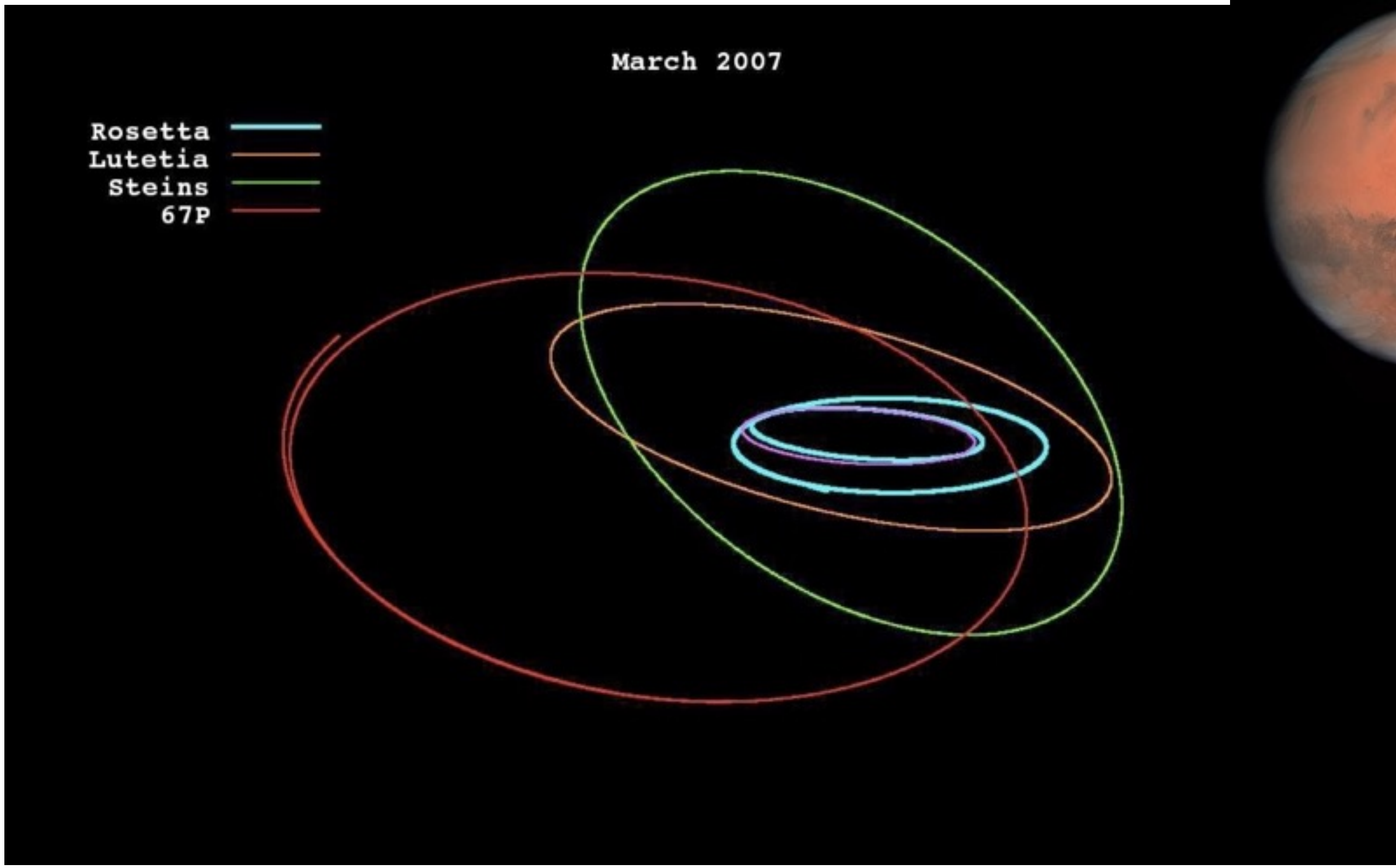
Rosetta mission phases

Mission phases. March 2005: gravity assist by Earth 1

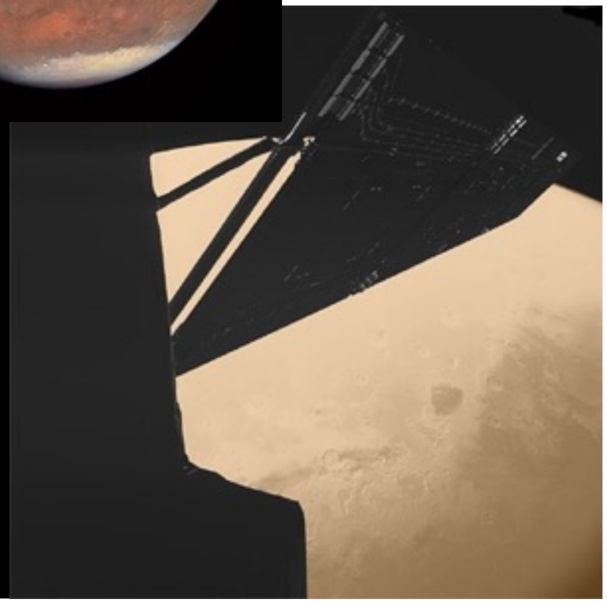


Rosetta mission phases

Mission phases. March 2007: gravity assist by Mars

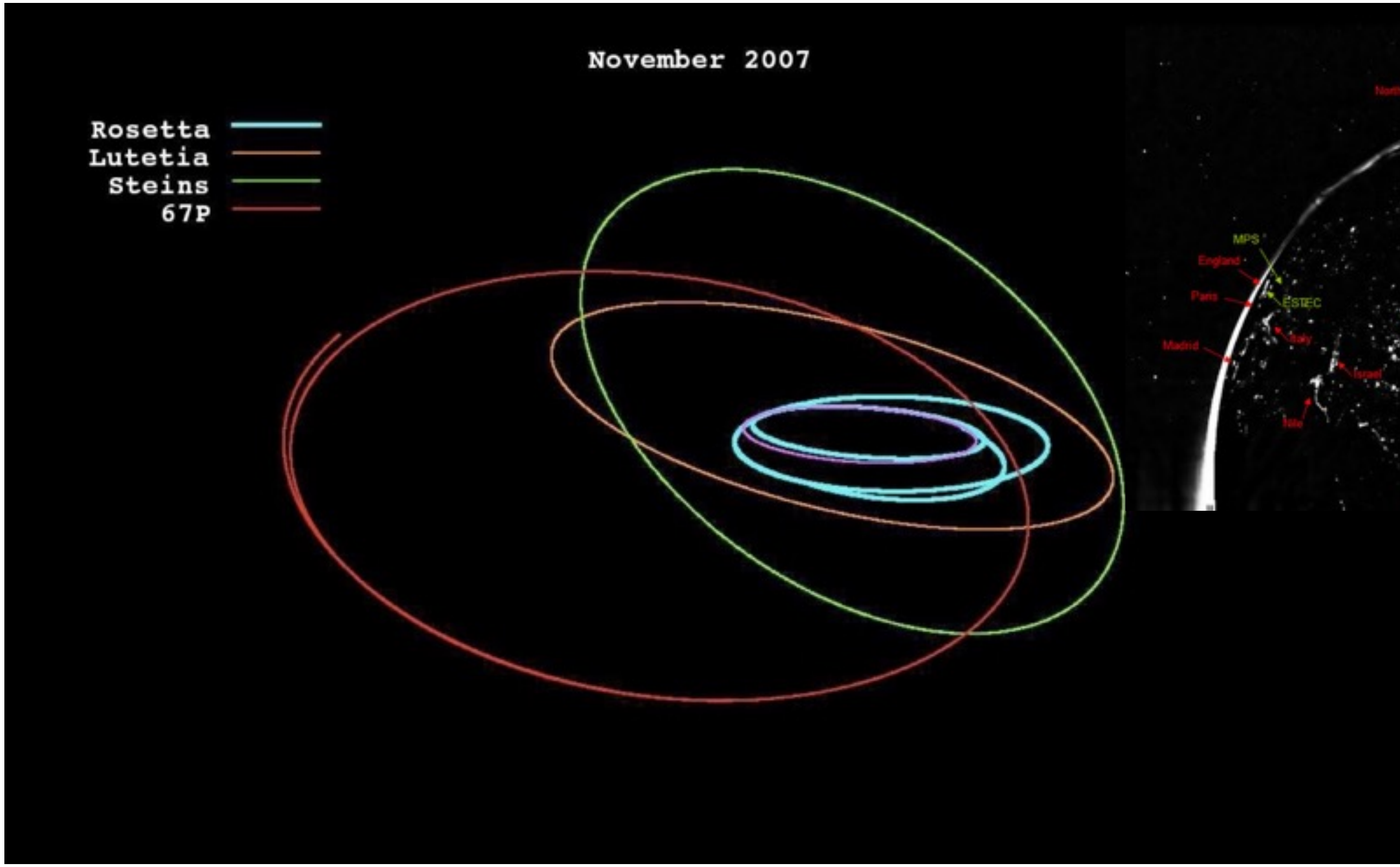


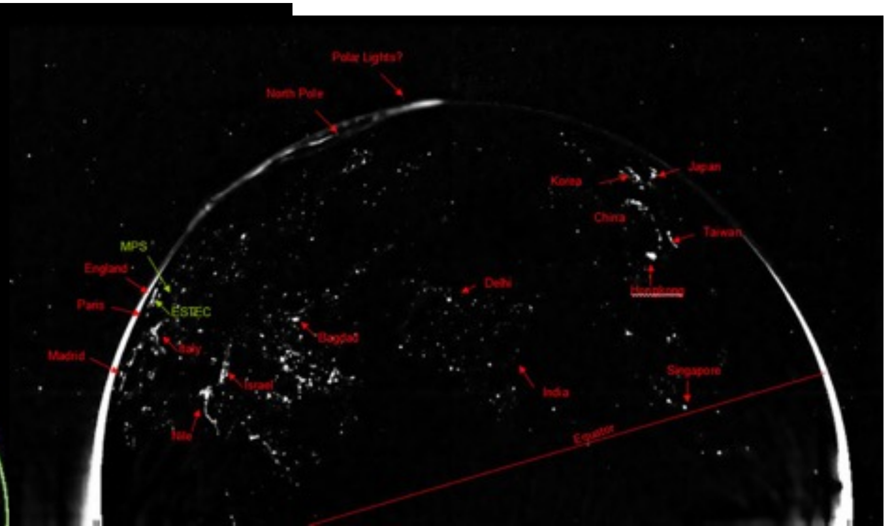
Osiris
Civa



Rosetta mission phases

Mission phases. Nov 2007: Gravity assist Earth 2

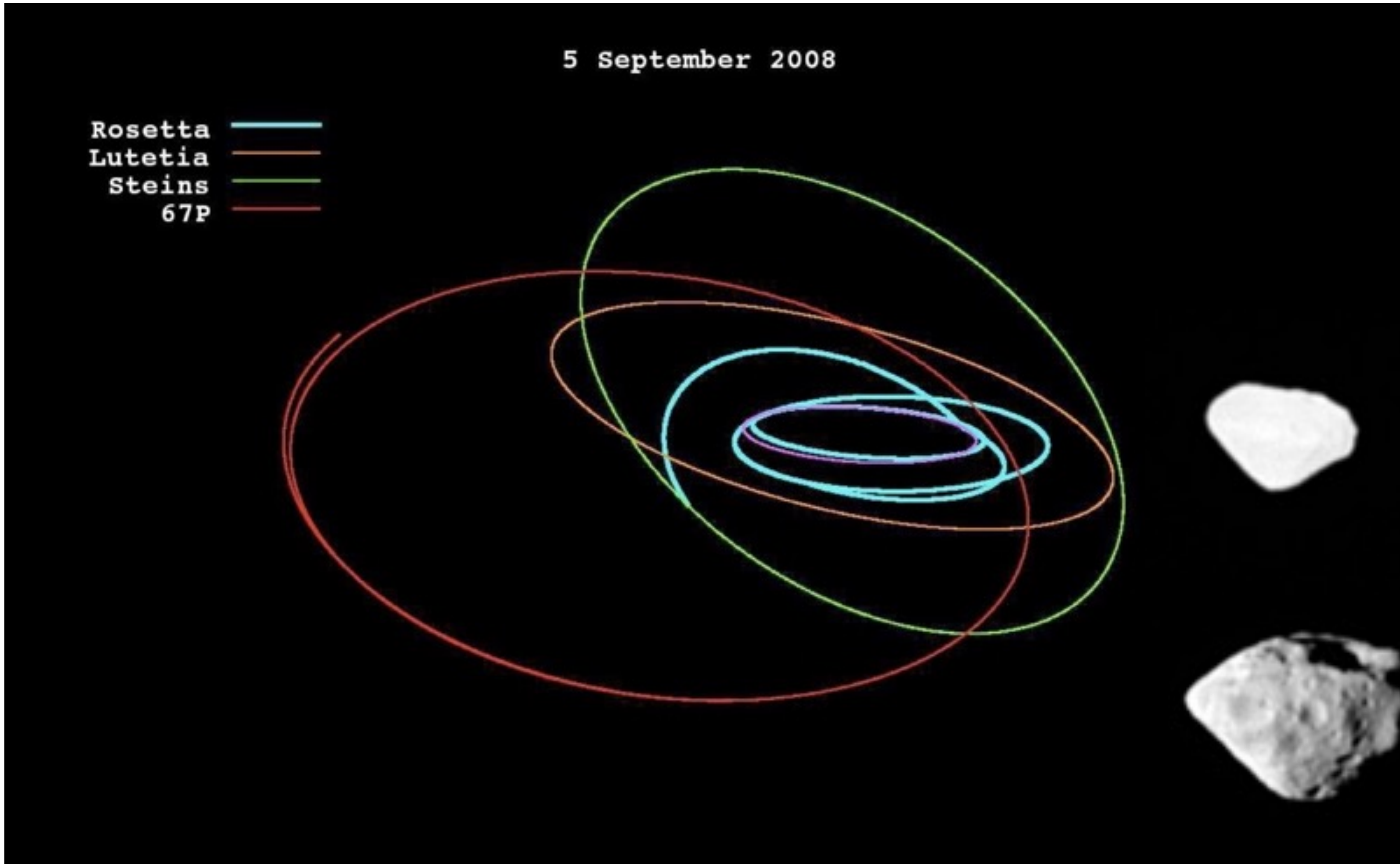




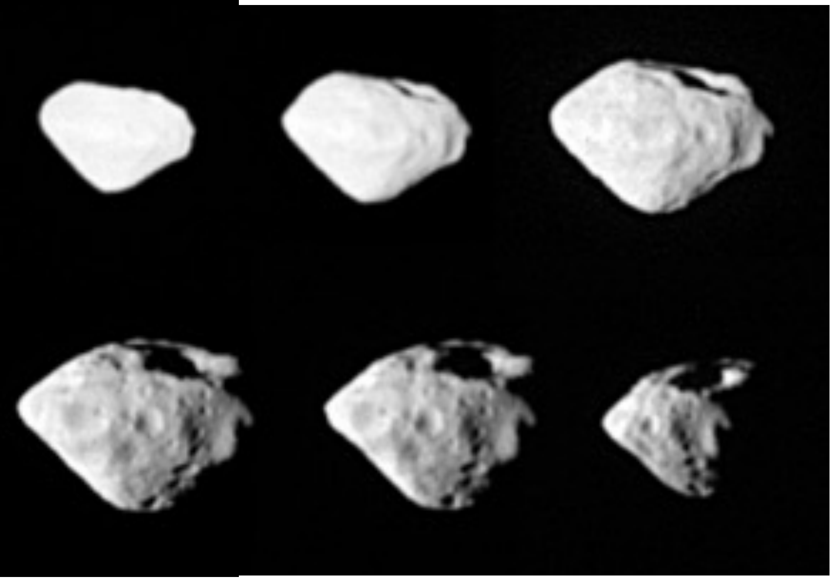
Osiris

Rosetta mission phases

Mission phases. Sept 2008: 2867 Steins fly-by at 800km

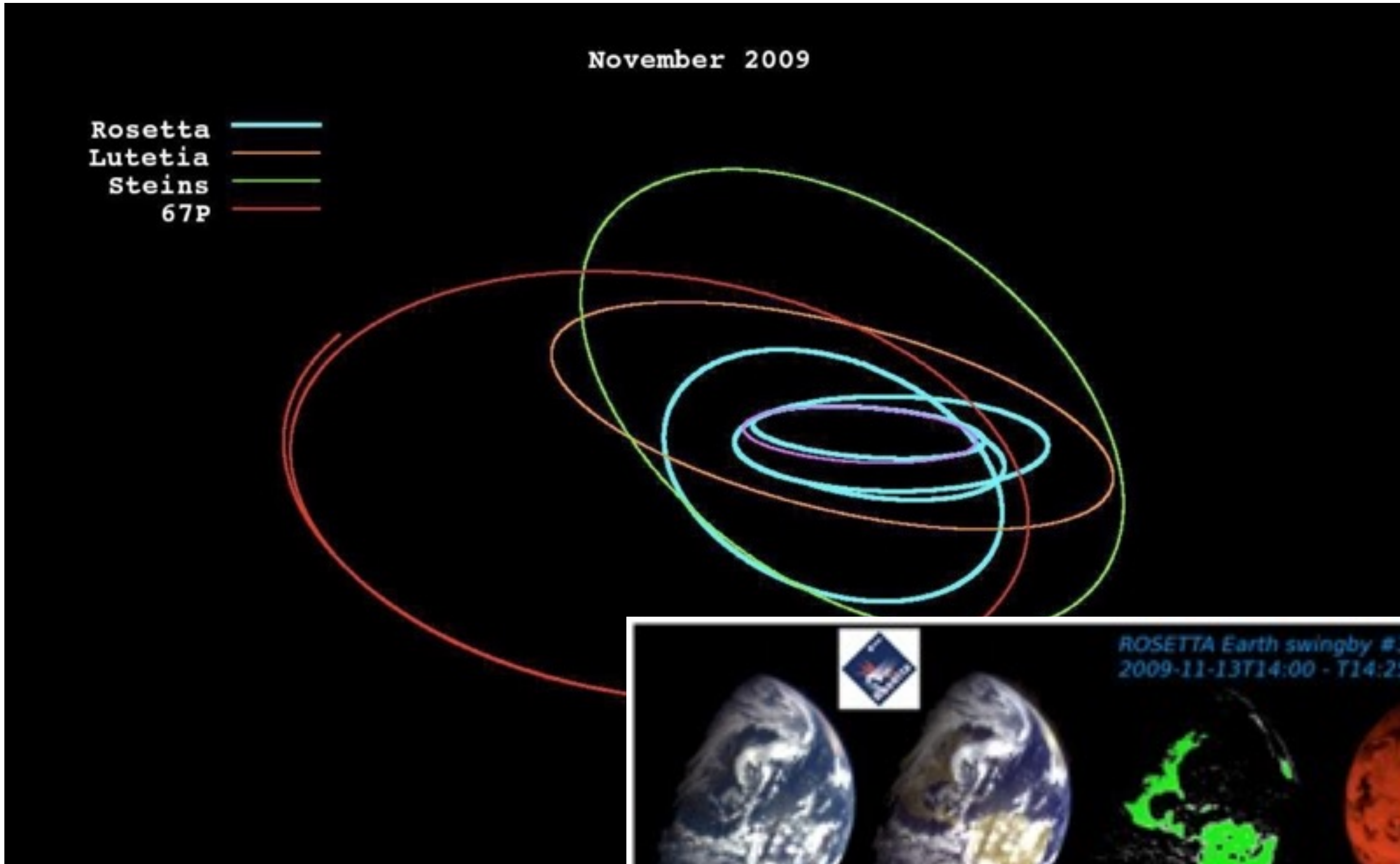


Probably an aggregate
Evidence for YORP effect

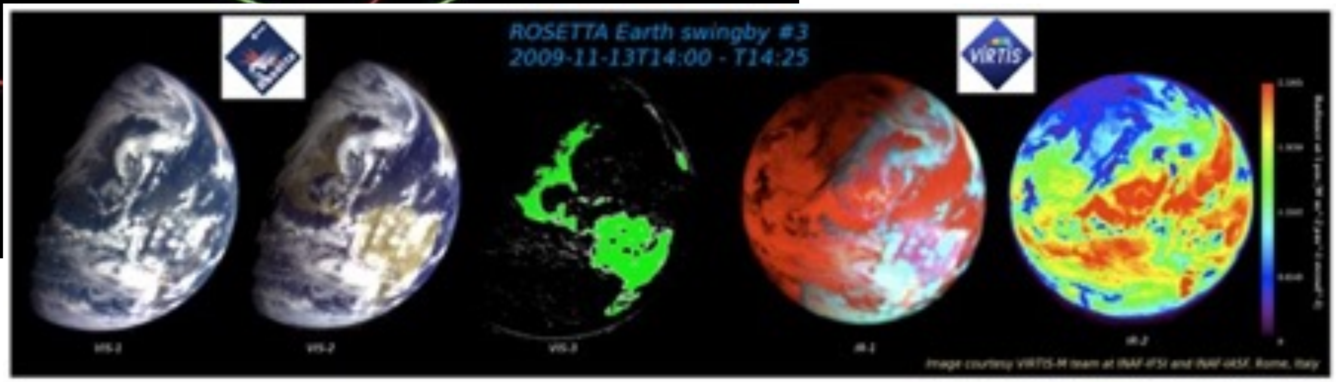


Rosetta mission phases

Mission phases. Nov 2009: Gravity assist Earth 3



Virtis

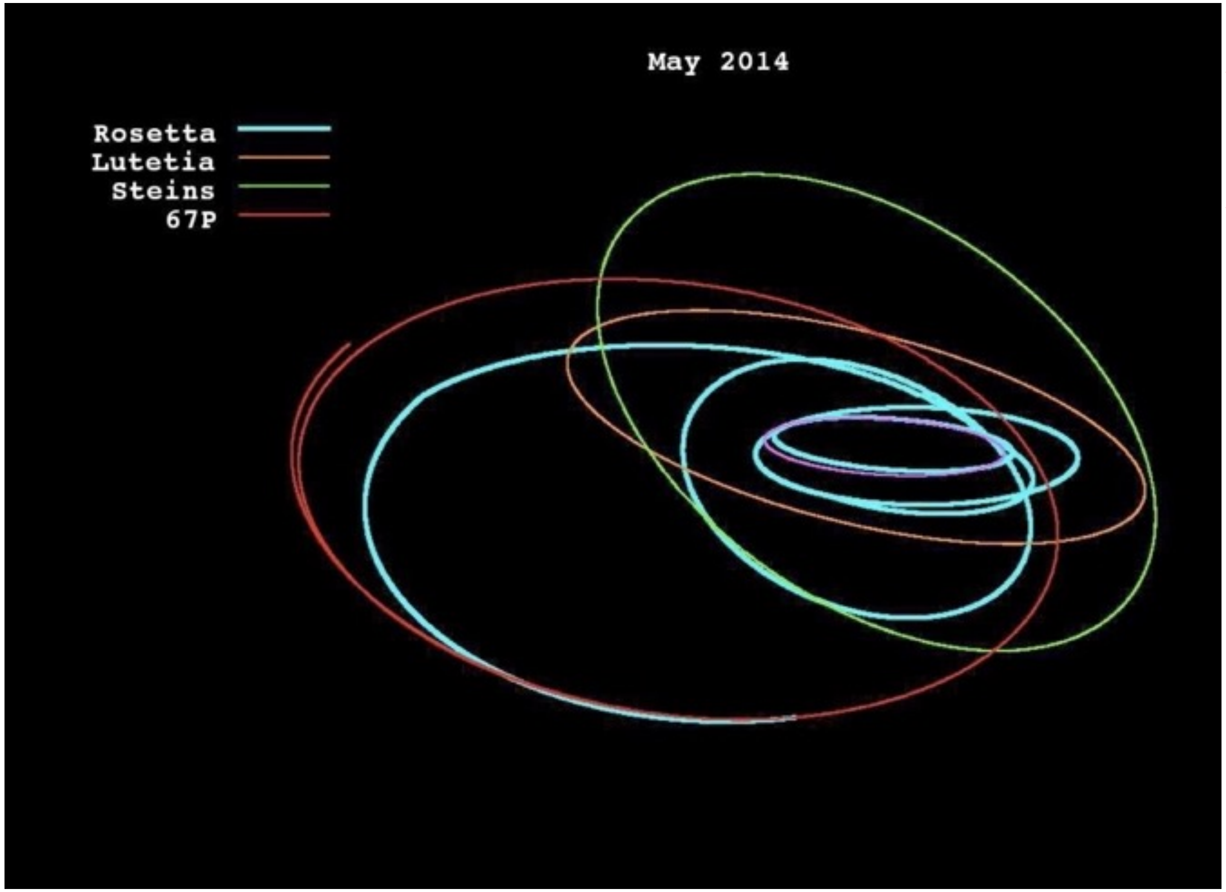


Rosetta mission phases

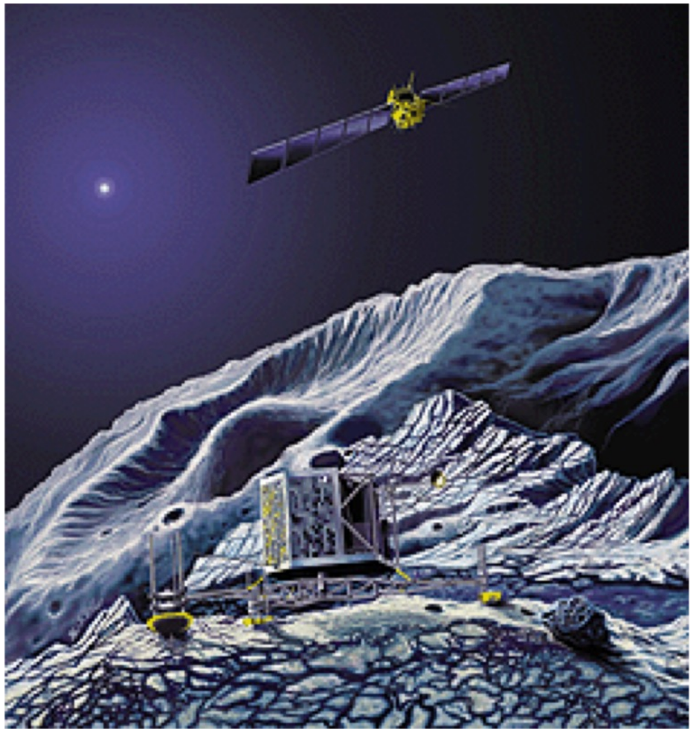
Mission phases. Jul 2010: 21 Lutetia fly-by at 3160 km

Rosetta mission phases

Mission phases. May 2014: rendez-vous maneuver

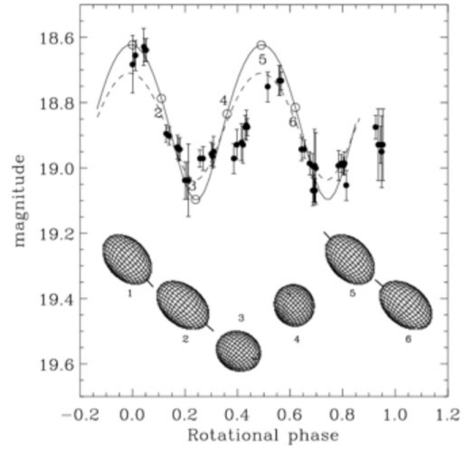


Aug 2014: nucleus close-in
Nov 2014: landing
Aug 2015: perihelion passage
Sept 2016: end of mission



Rosetta rendez-vous

Lamy et al., A&A 2006



Mission phases. 2014-15: rendez-vous and landing

Mission issues:

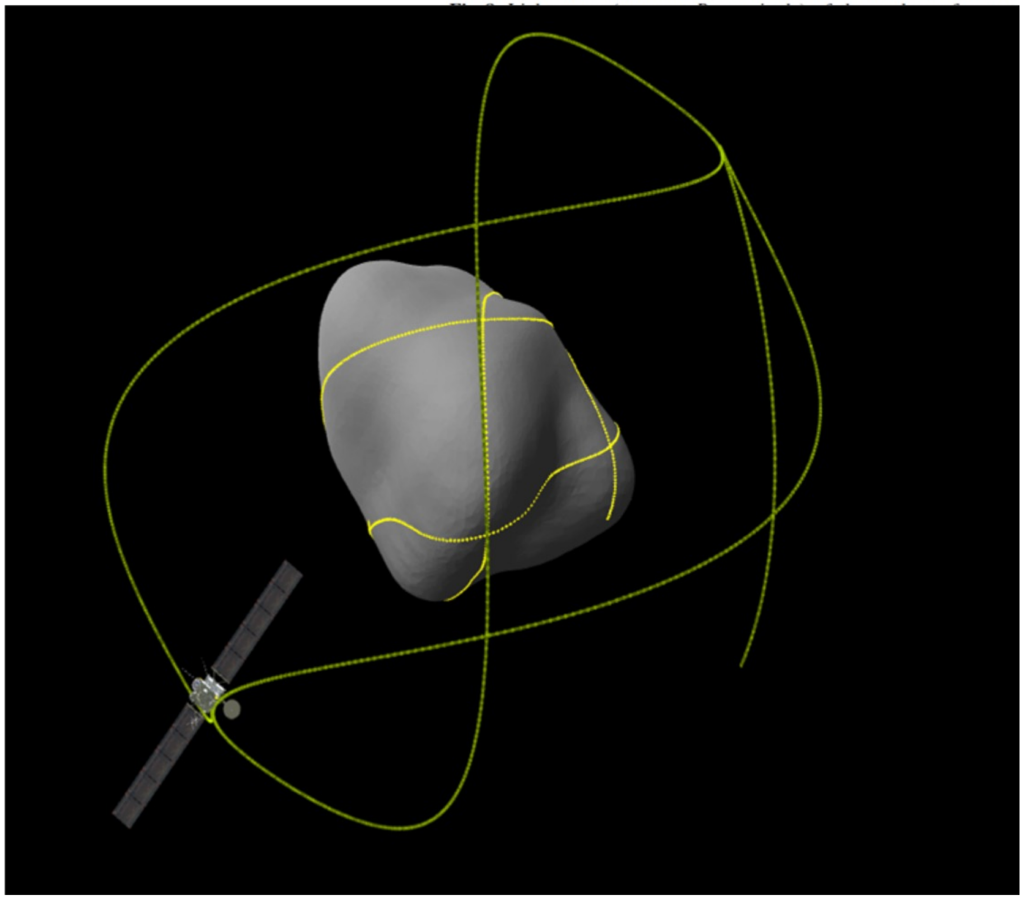
➢distance => communication ~50min

➢Low gravity =>
Gas drag force > g ($5\ 10^{-4}\ ms^{-2}$)

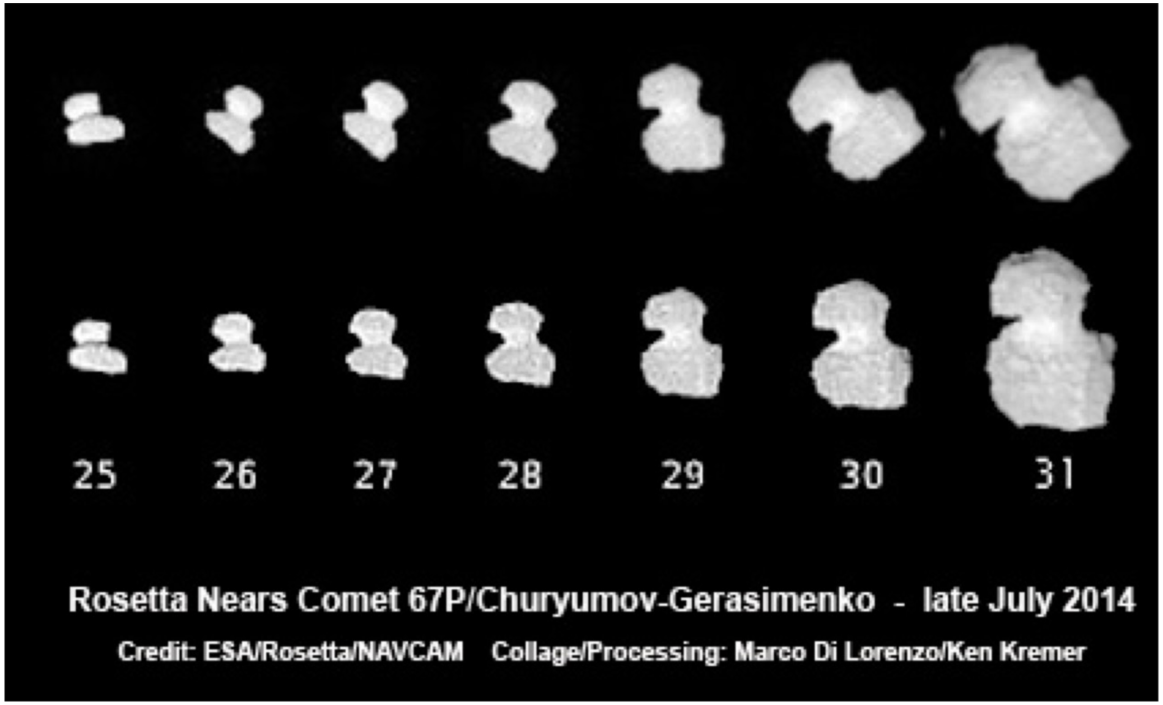
➢Rotation 12.55 h~ orbital period

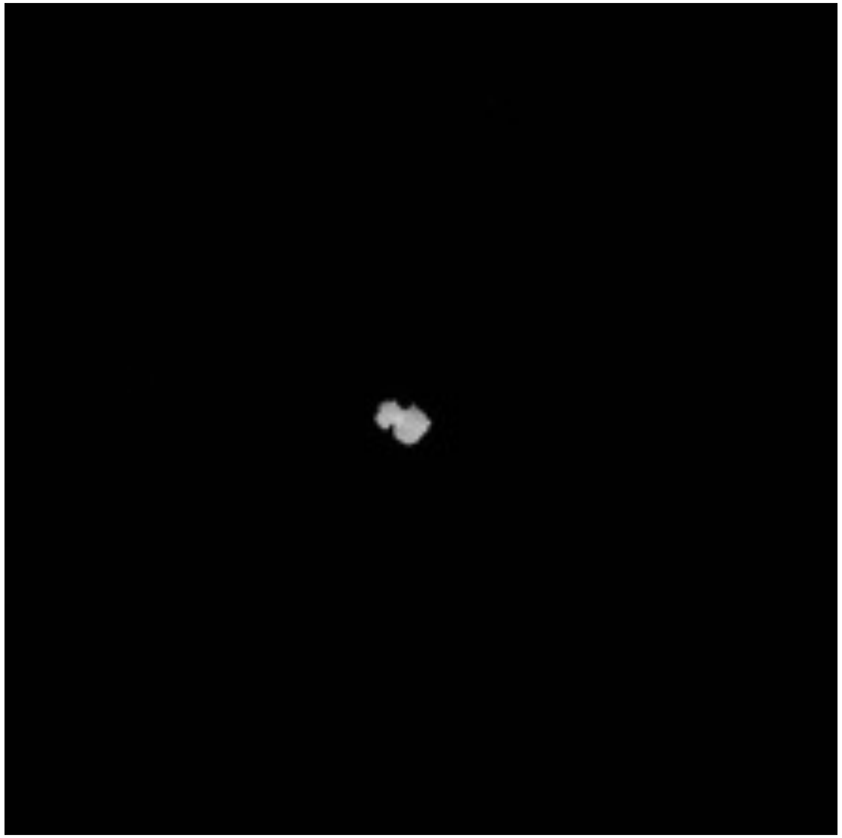
➢Unknown environment => dust

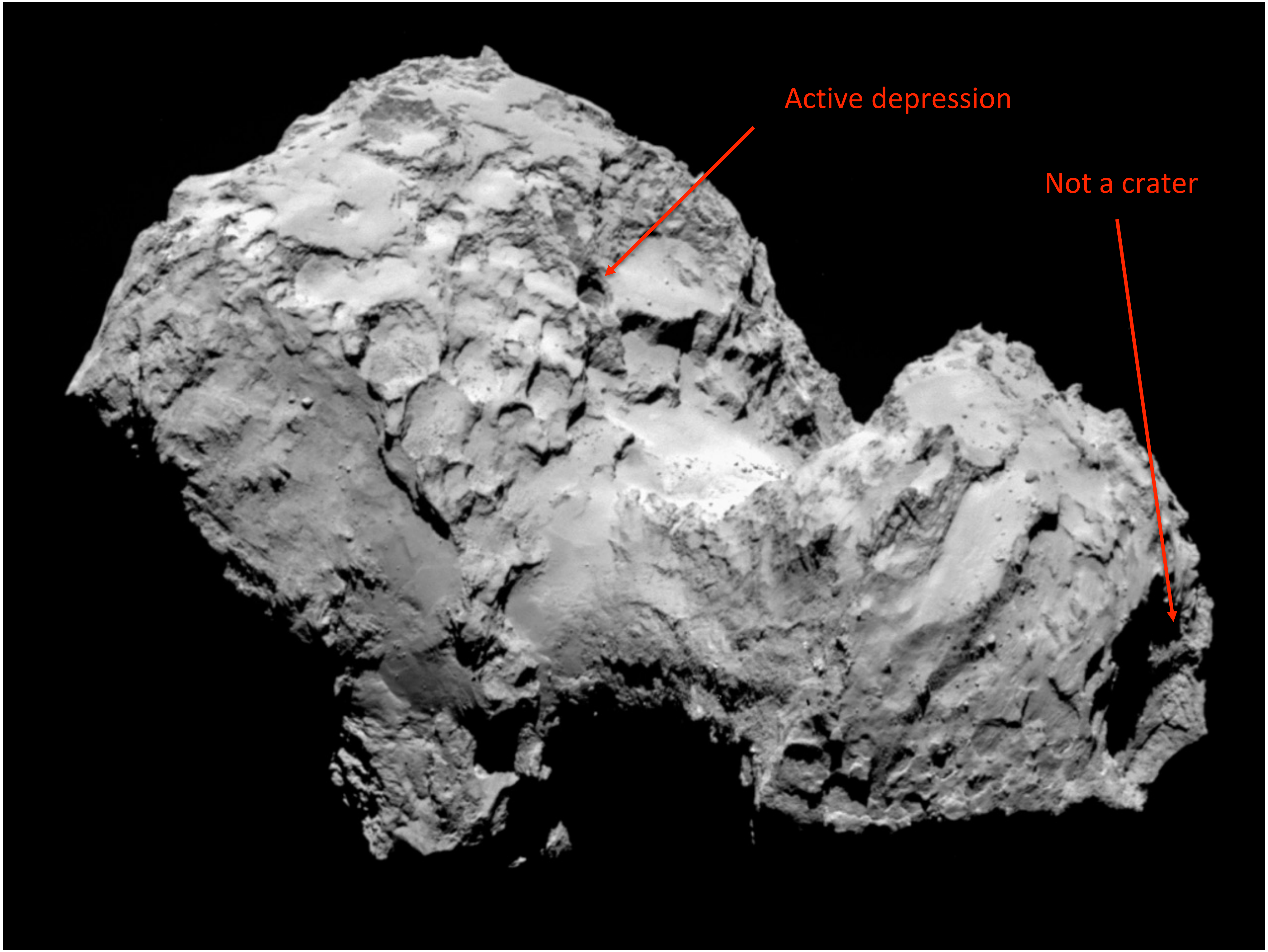
➢Extremely porous body



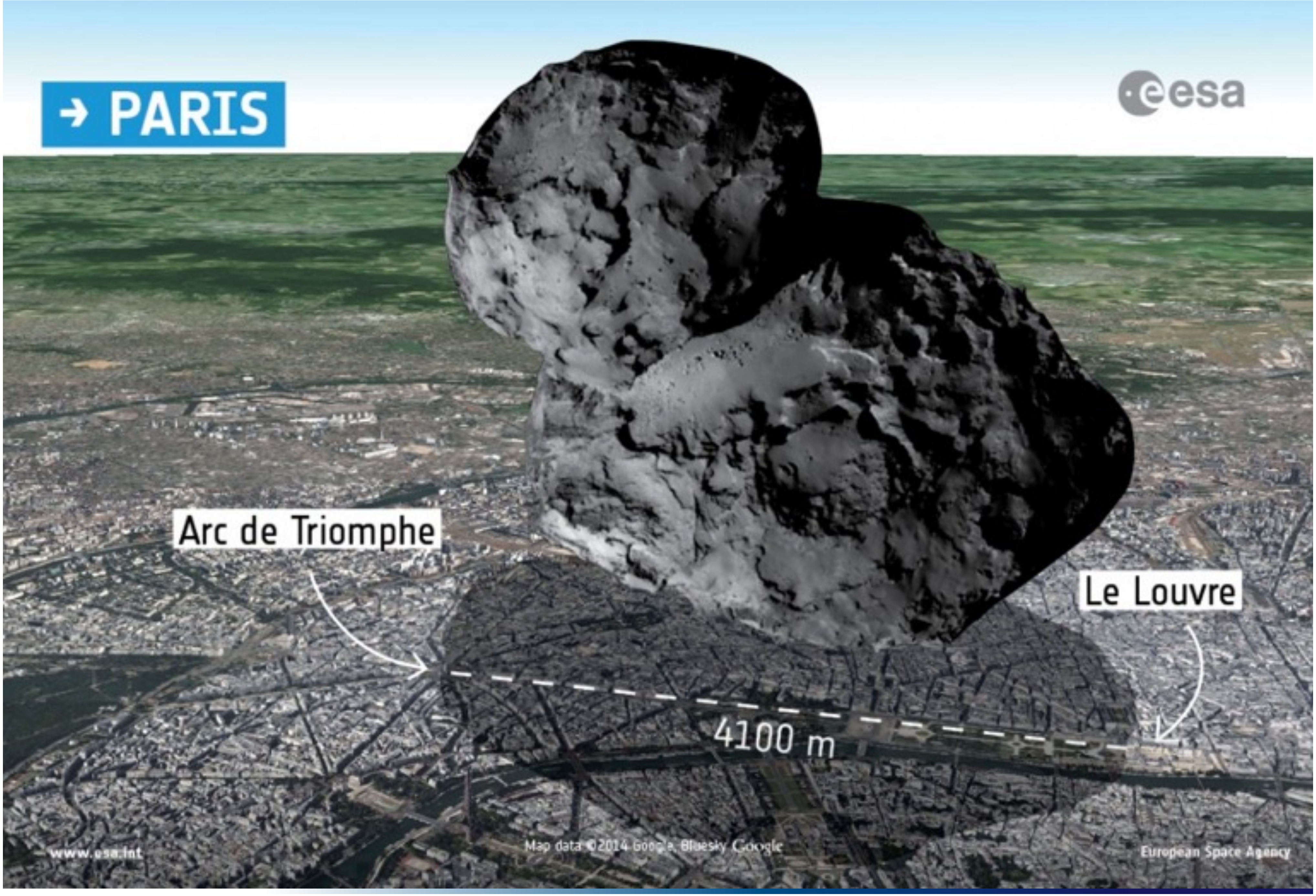
Rosetta rendez-vous






Active depression
Not a crater

Rosetta rendez-vous



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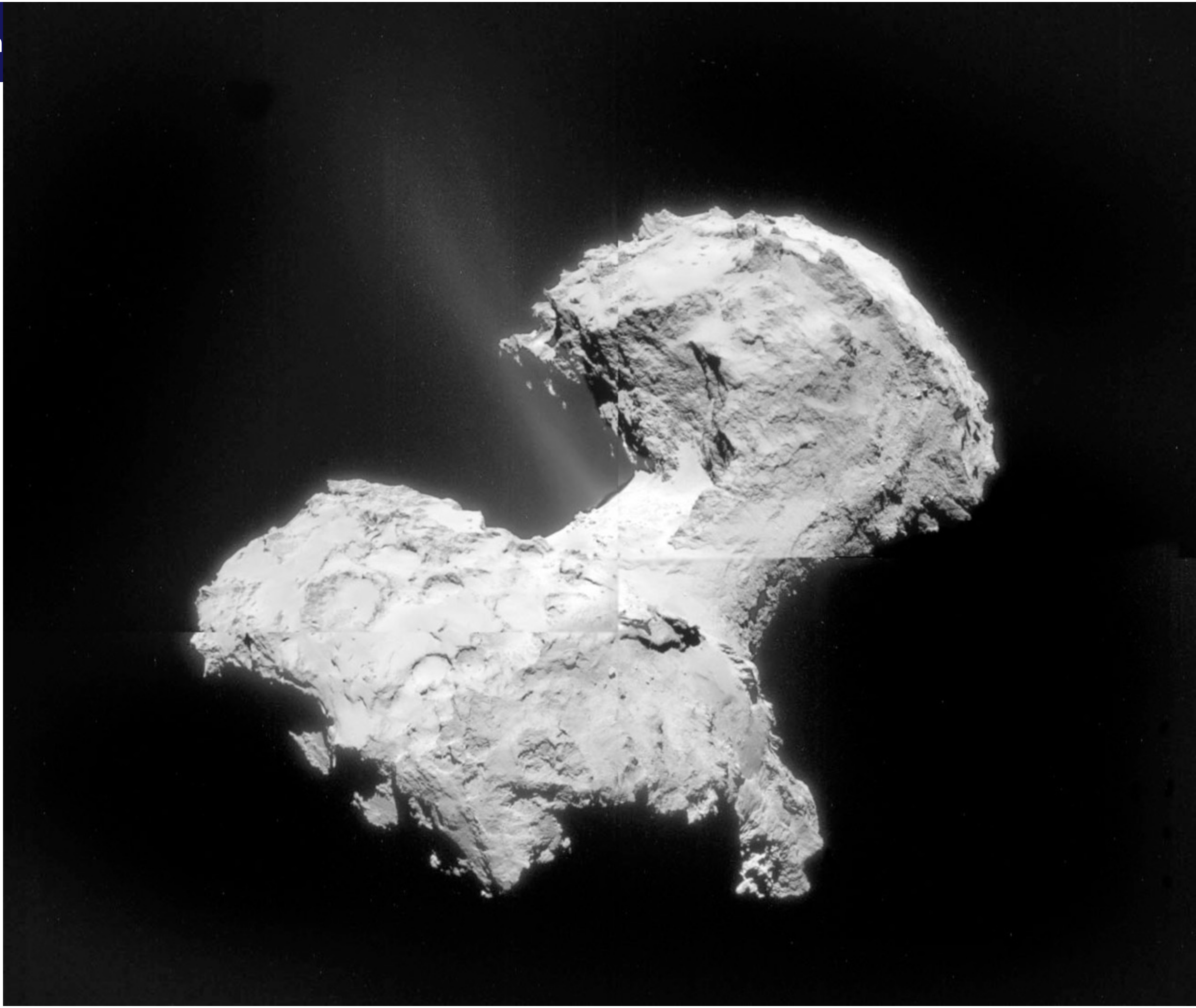


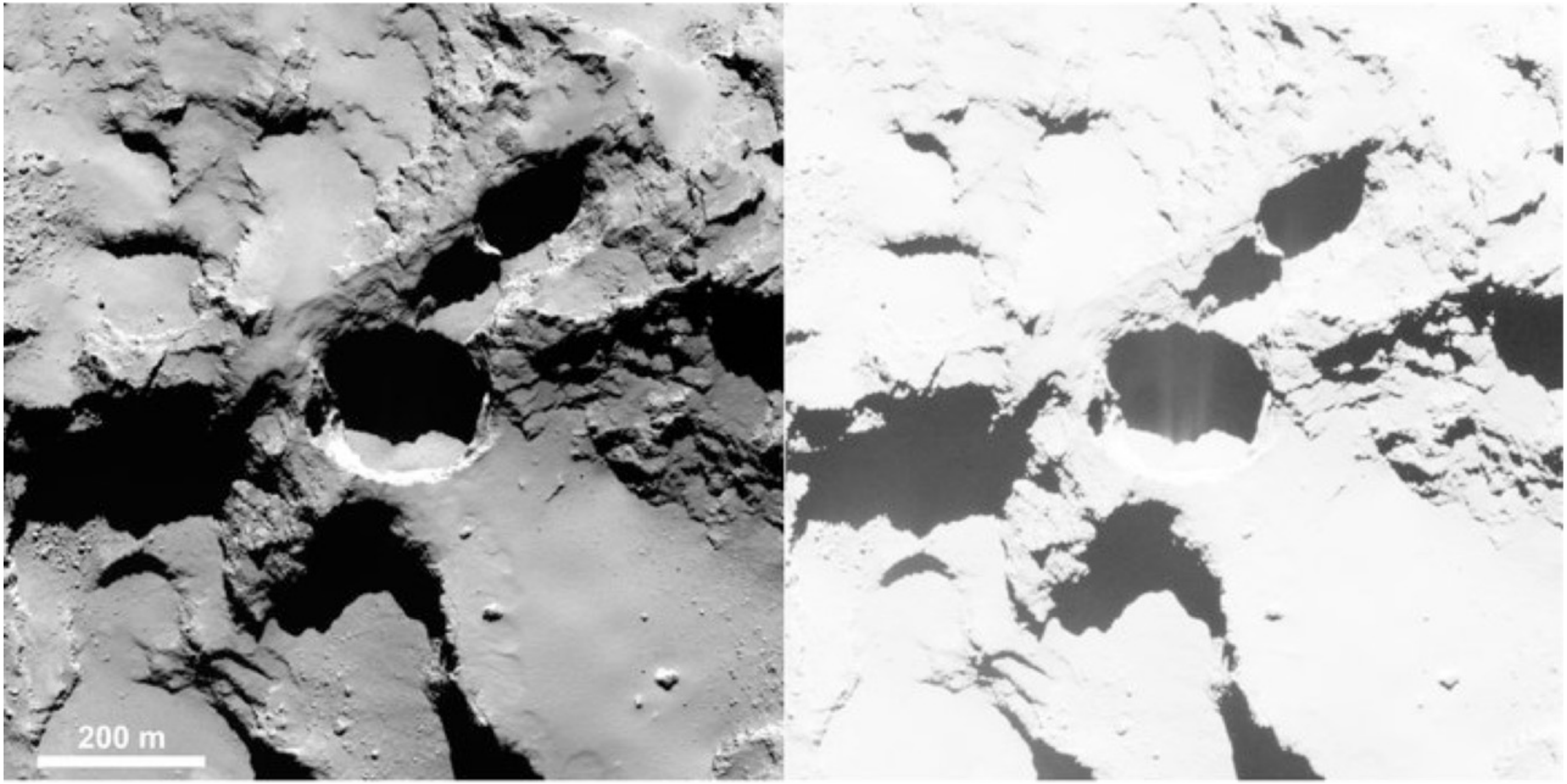
2 years of exploration

- A short-lived outburst from Comet 67P/Churyumov–Gerasimenko was captured by Rosetta's OSIRIS narrow-angle camera on 29 July 2015.
- The jet is estimated to have a minimum speed of 10 m/s and originates from a location on the comet's neck, in the rugged Anuket region.

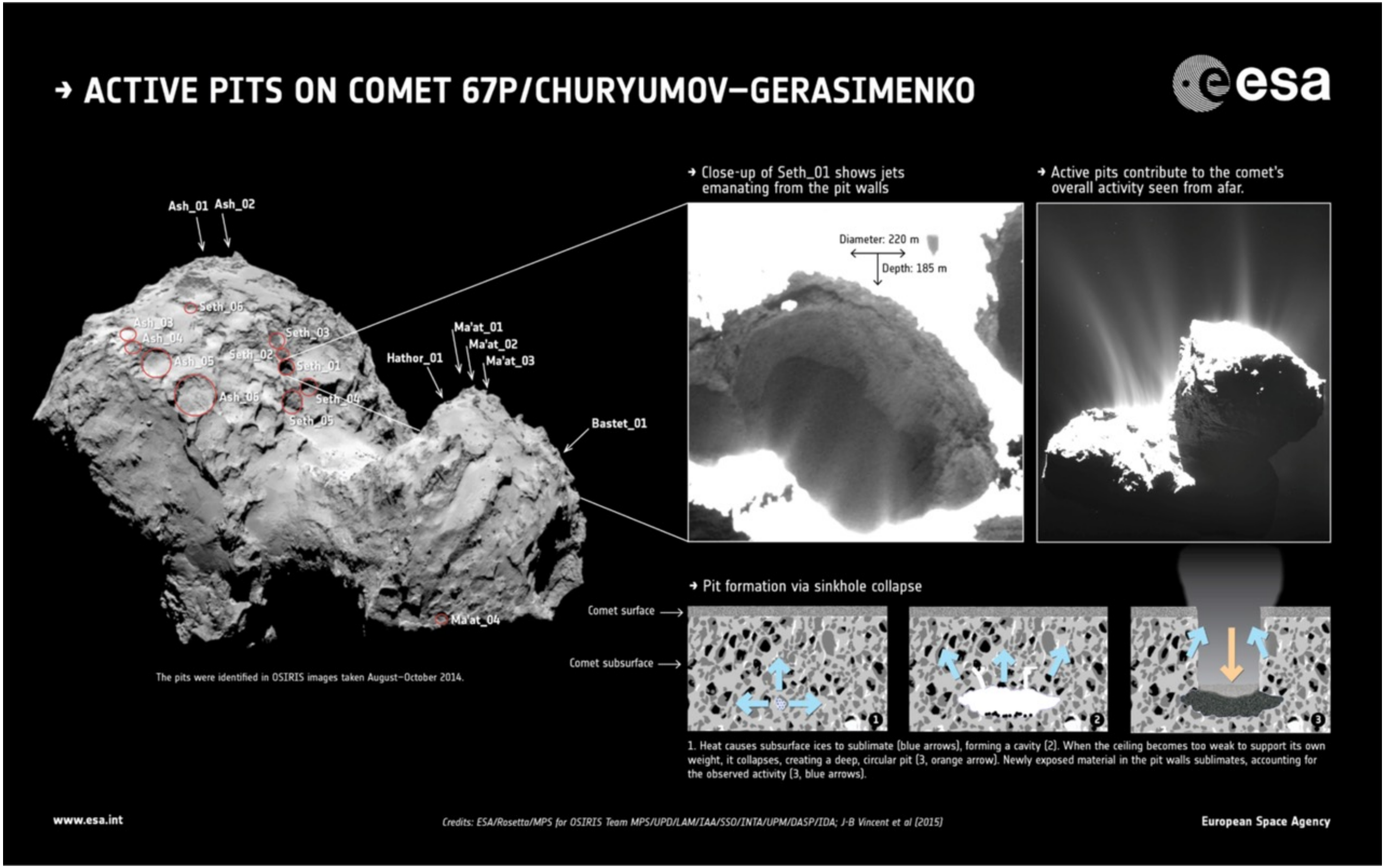
2 years of exploration

Credit: ESA/Rosetta/OSIRIS Team

Sierks et al., Science 2015



2 years of exploration

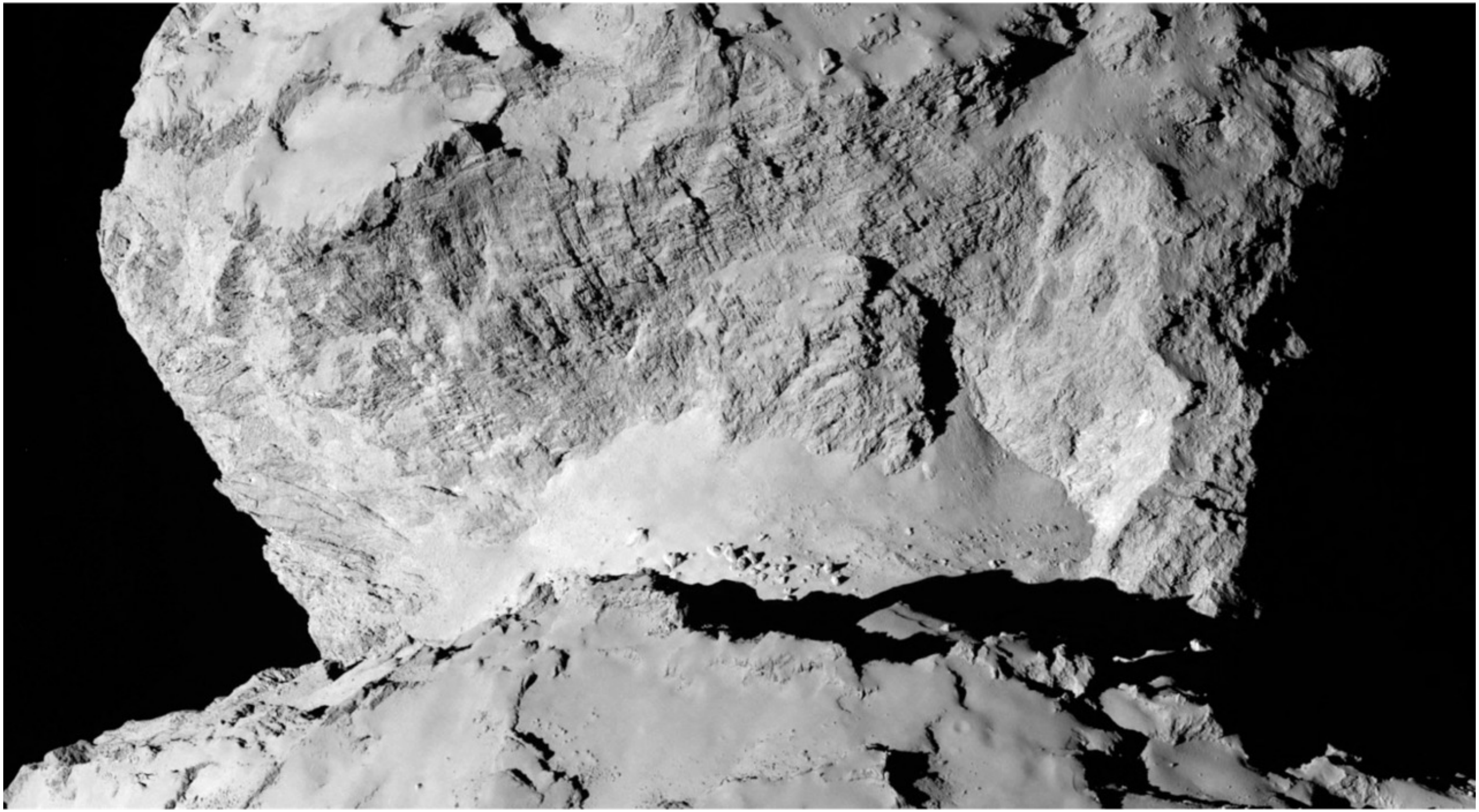


2 years of exploration

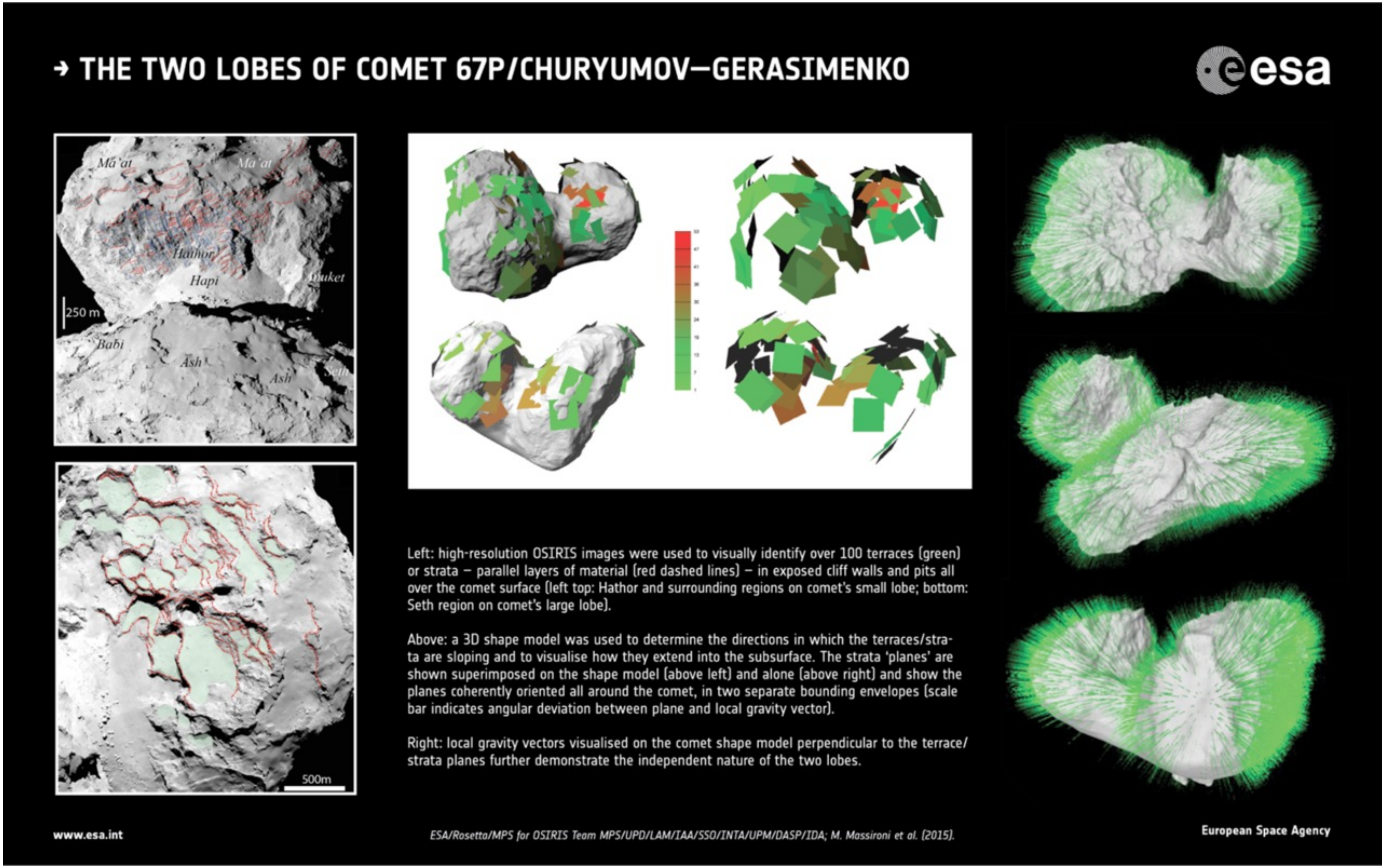
Fractures and debris in the Hathor region

Credit: ESA/Rosetta/OSIRIS Team

Thomas et al., Science 2015



2 years of exploration



2 years of exploration

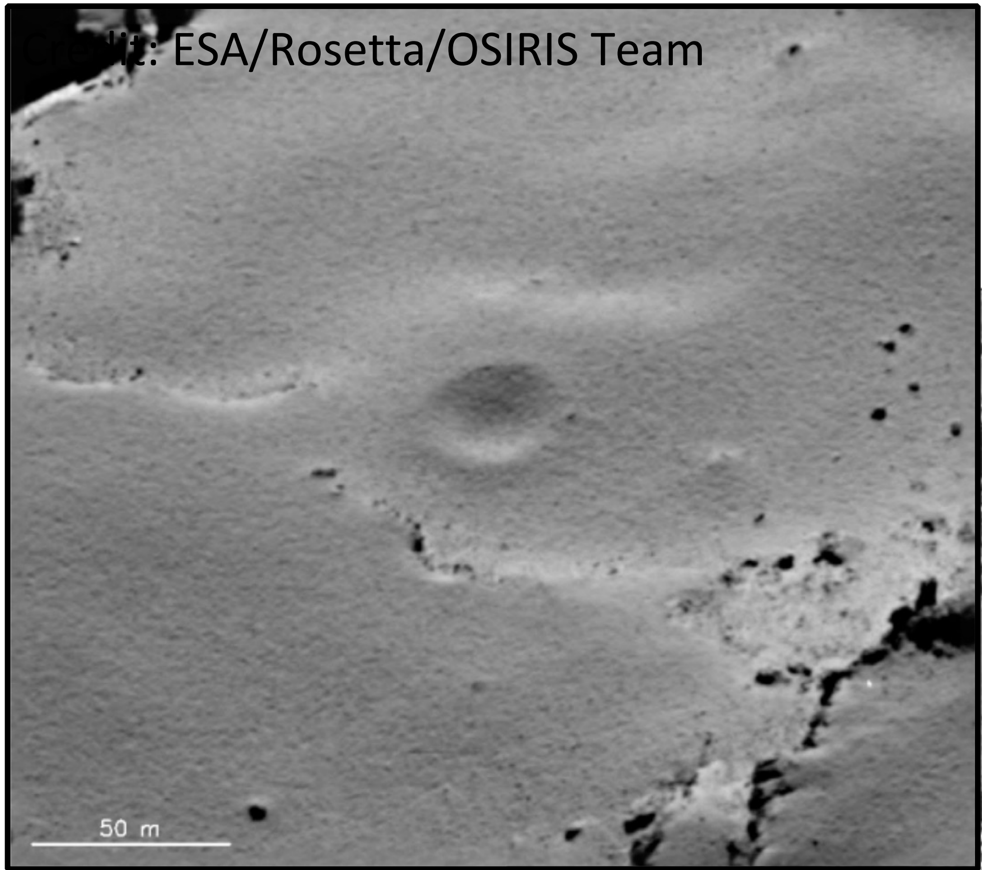
Wall meter scale structures in the Seth region.

Credit: ESA/Rosetta/OSIRIS Team

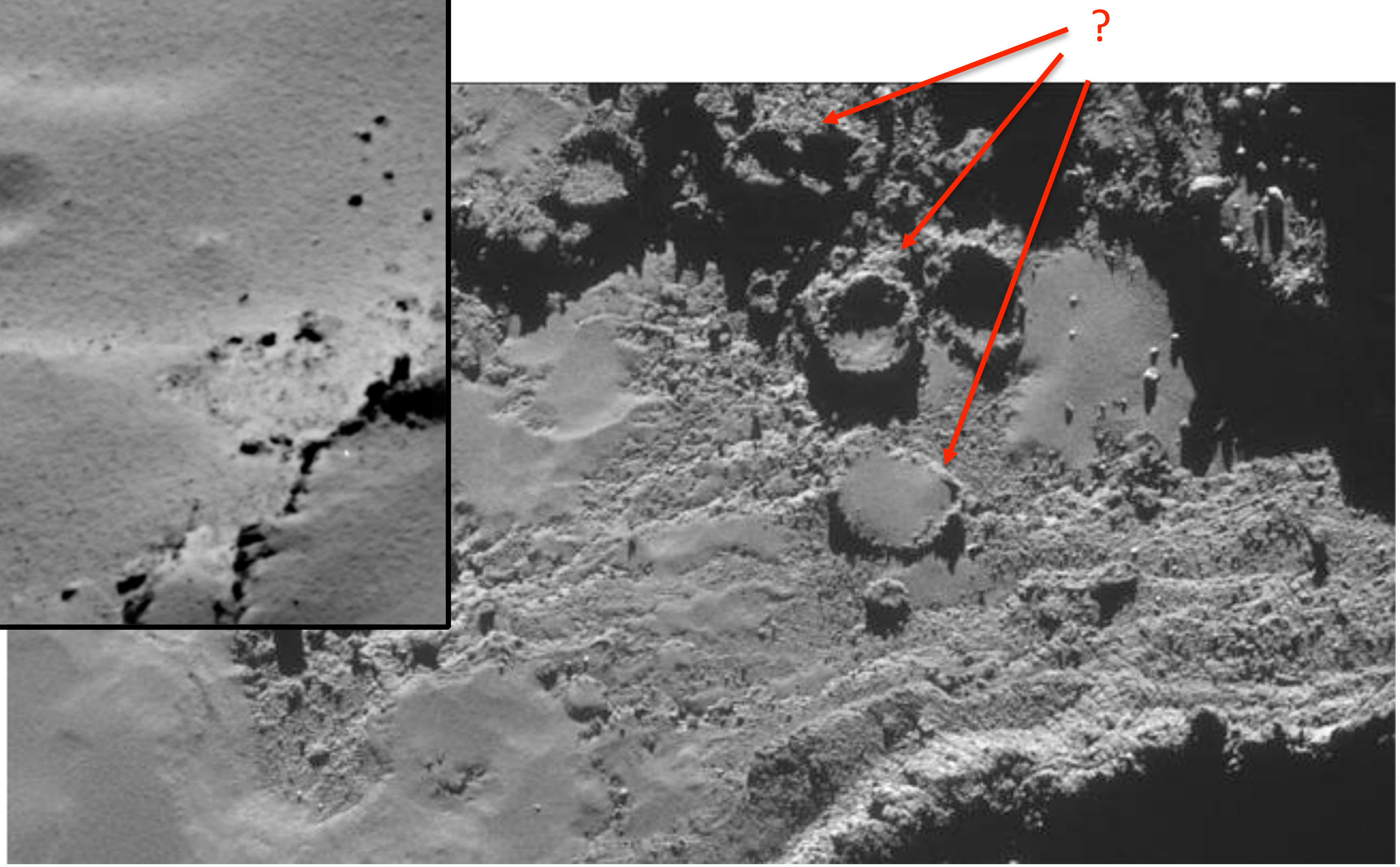
Sierks et al., Science 2015

2 years of exploration

Craters ?



Sierks et al., Science 2015



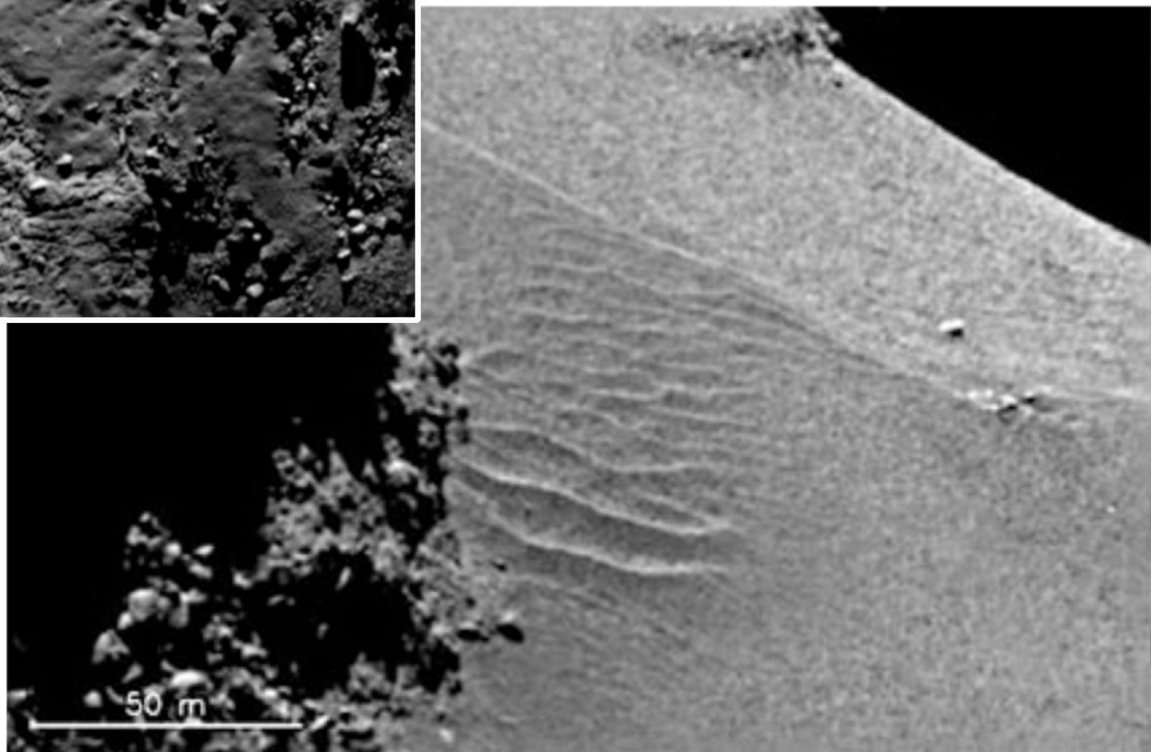
2 years of exploration

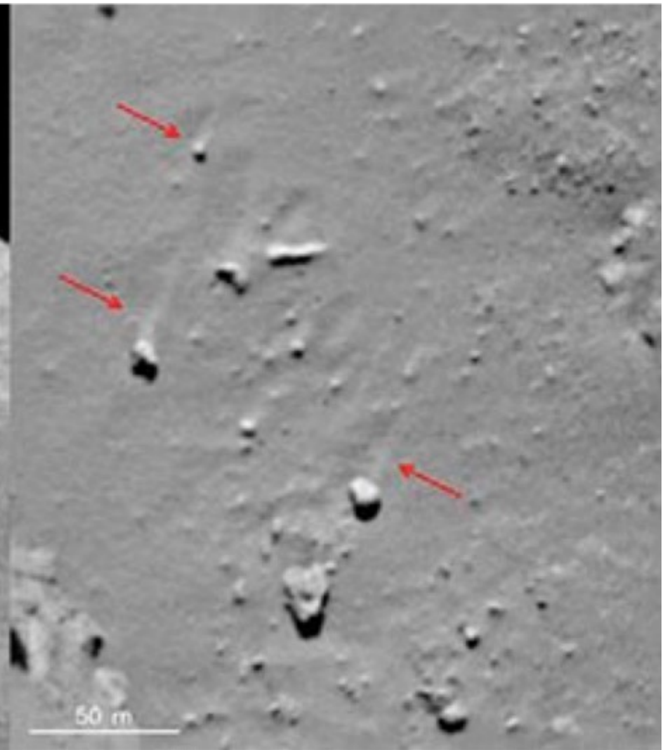
Sierks et al., Science 2015
Thomas et al., Science 2015

Cryovolcanism ?

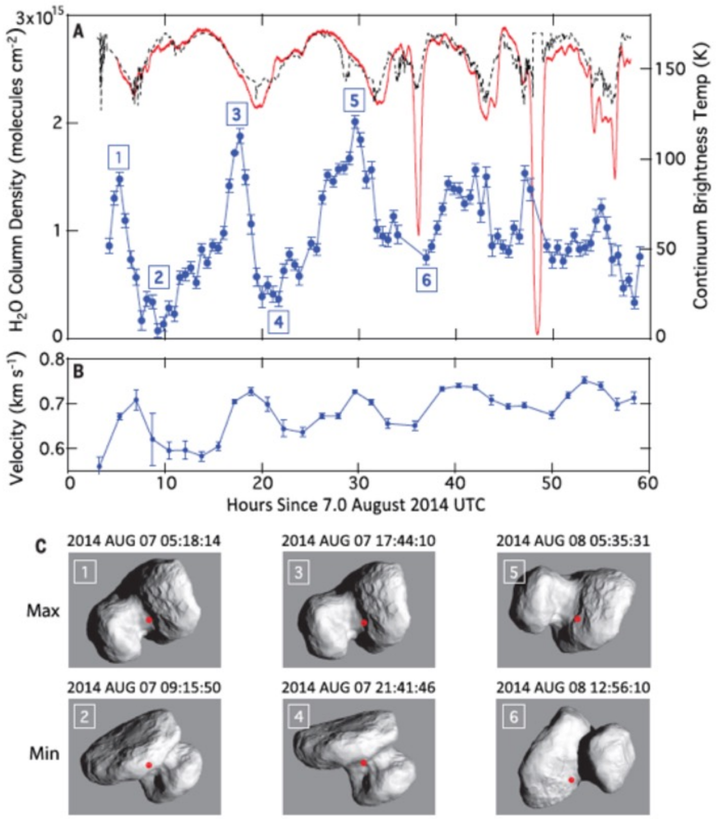
dunes ?

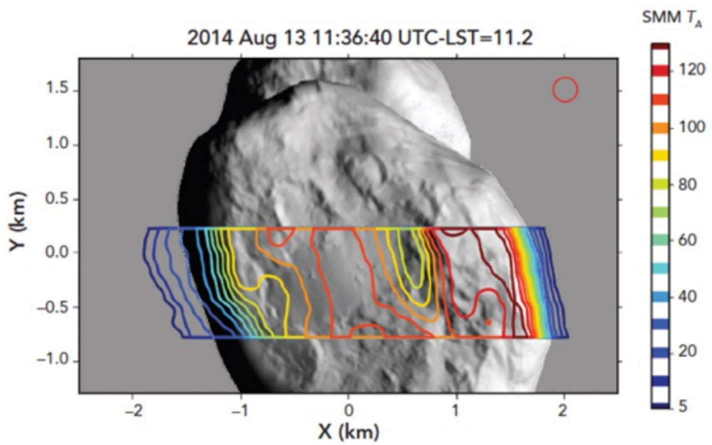
Credit: ESA/Rosetta/OSIRIS Team





2 years of exploration



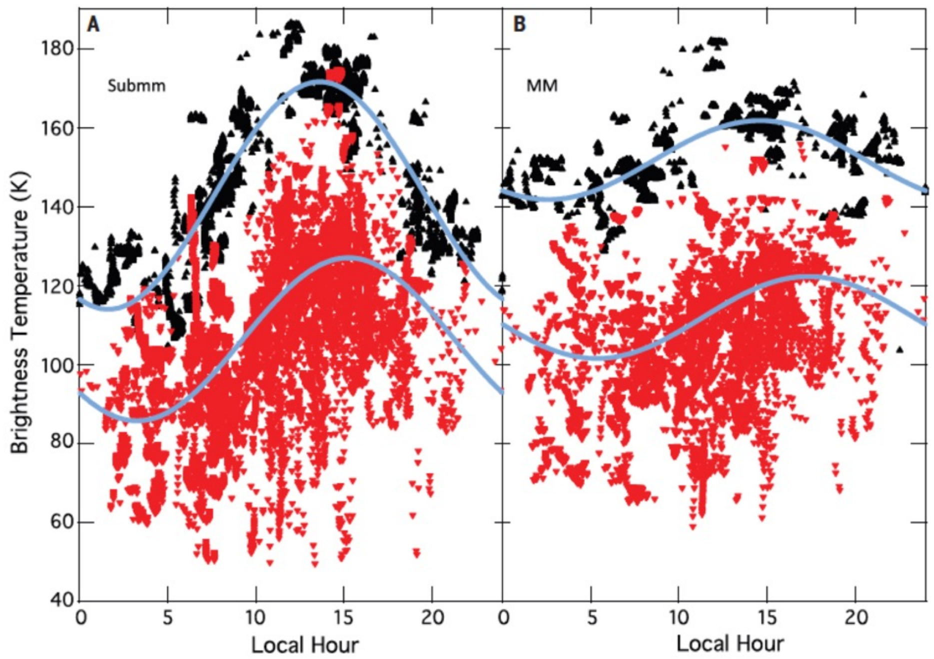


Subsurface temperature from MIRO

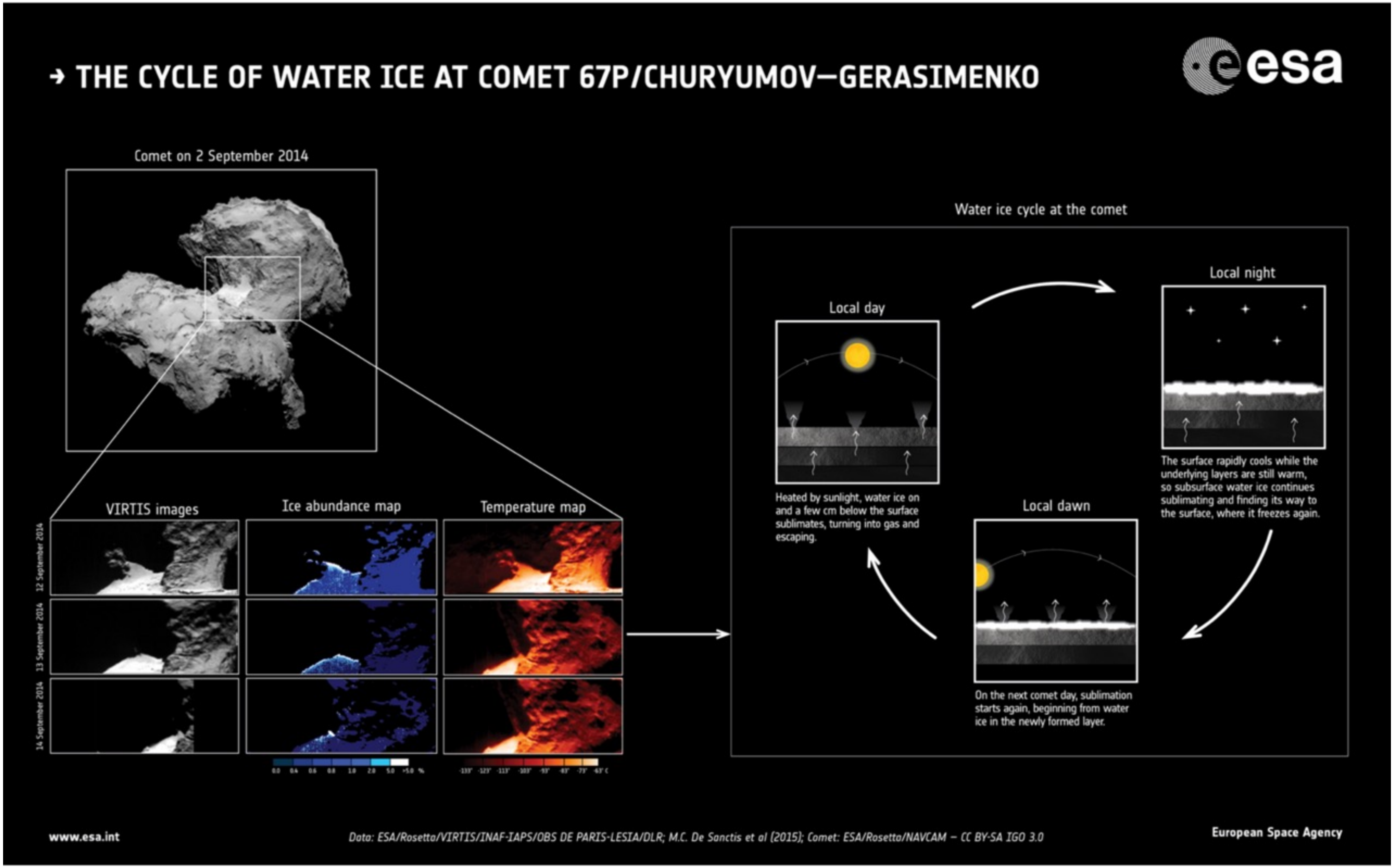
=> A very low thermal inertia (~10 to 50 J K^{-1} m^{-2} s$^{-0.5}$)

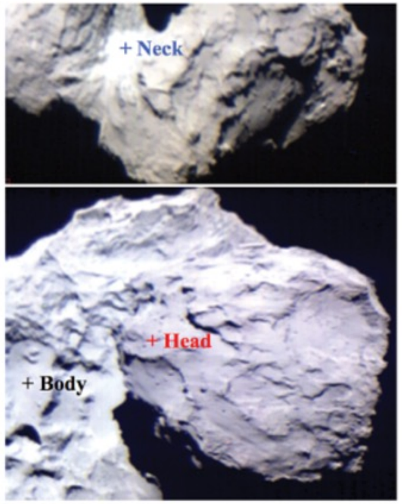
(Gulkis et al. 2015)

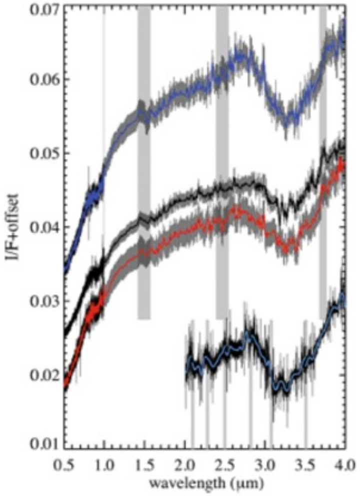
Fig. 5. Brightness temperatures as a function of local solar time, from MIRO continuum measurements of September 2014, are shown for effective latitude bins of 20° to 30° N (black data points) and 20° to 30° S (red data points). The solid curves are diurnal sinusoidal fits to the data. Both effective latitudes and the local solar time are computed from the shape model–derived surface orientation at the MIRO beam center. Only points for which the MIRO beams lie entirely within the nucleus are included. The data are restricted to the 100° to 200° longitude band in order to eliminate data in the neck region, where extreme shadowing conditions obscure the interpretation of the diurnal heating curve. (**A**) Submillimeter data. (**B**) Millimeter data.

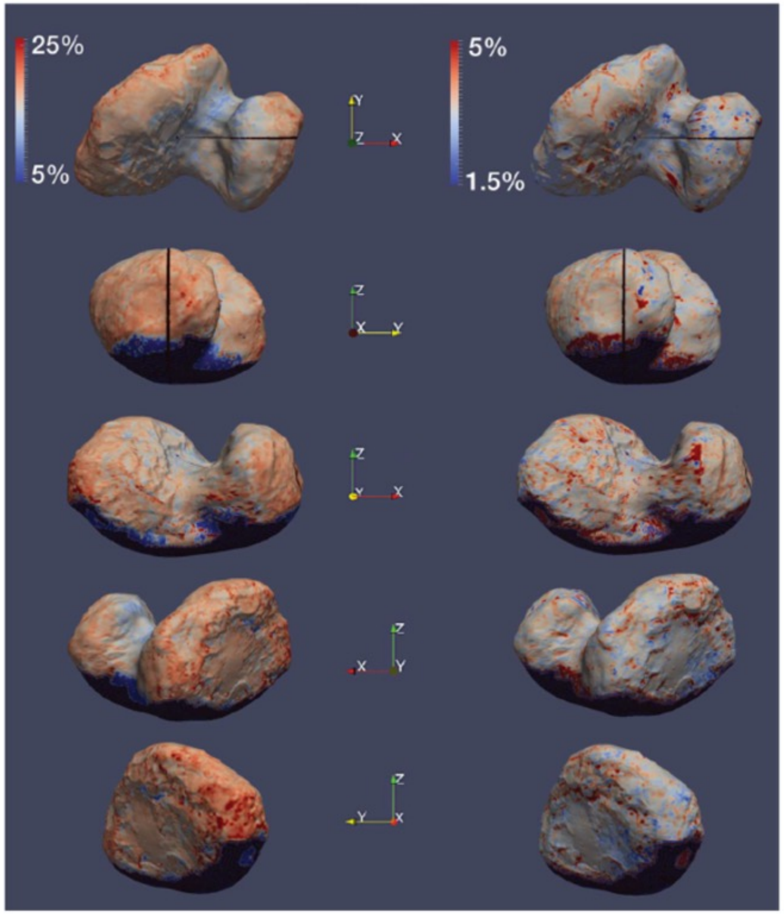


2 years of exploration









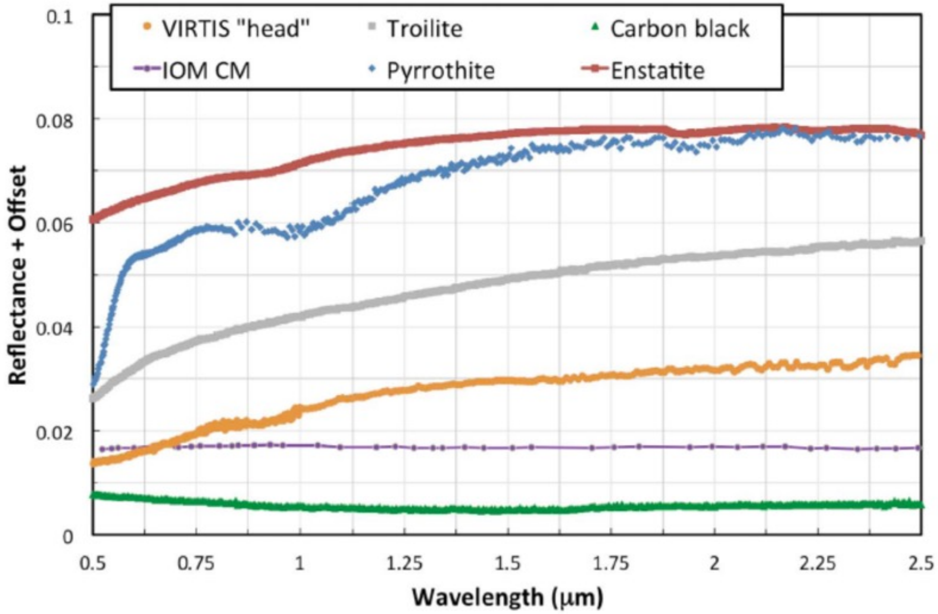


Fig. 3. The spectrum of the head shown in Fig. 1 is compared (in the spectral range 0.5 to 2.5 μm) to the spectra of several other compounds described in the text. Enstatite, pyrrothite, and troilite spectra are scaled down by 100, 75, and 50%, respectively. The Murchison IOM is from (*16*), enstatite spectrum from (*29*), troilite and carbon black spectra from (*30*), and pyrrothite spectrum from (*31*).

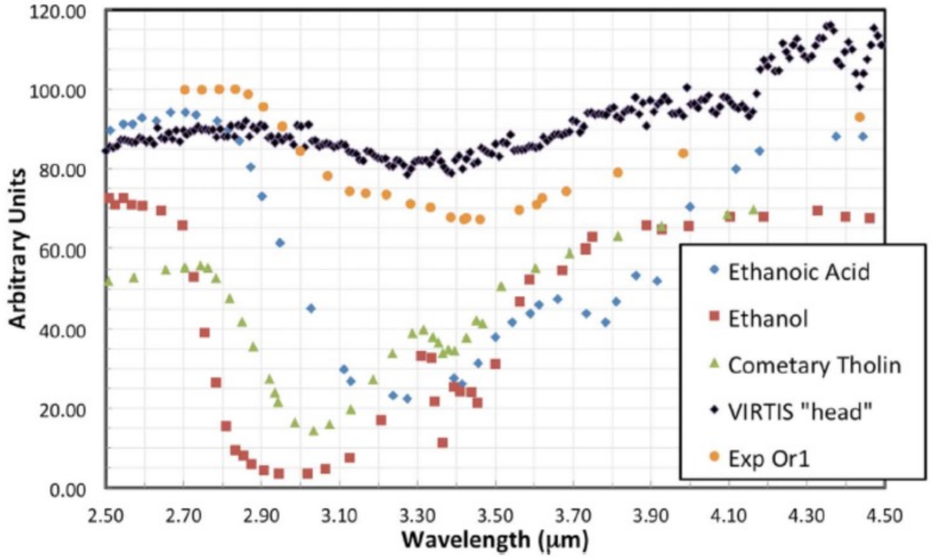
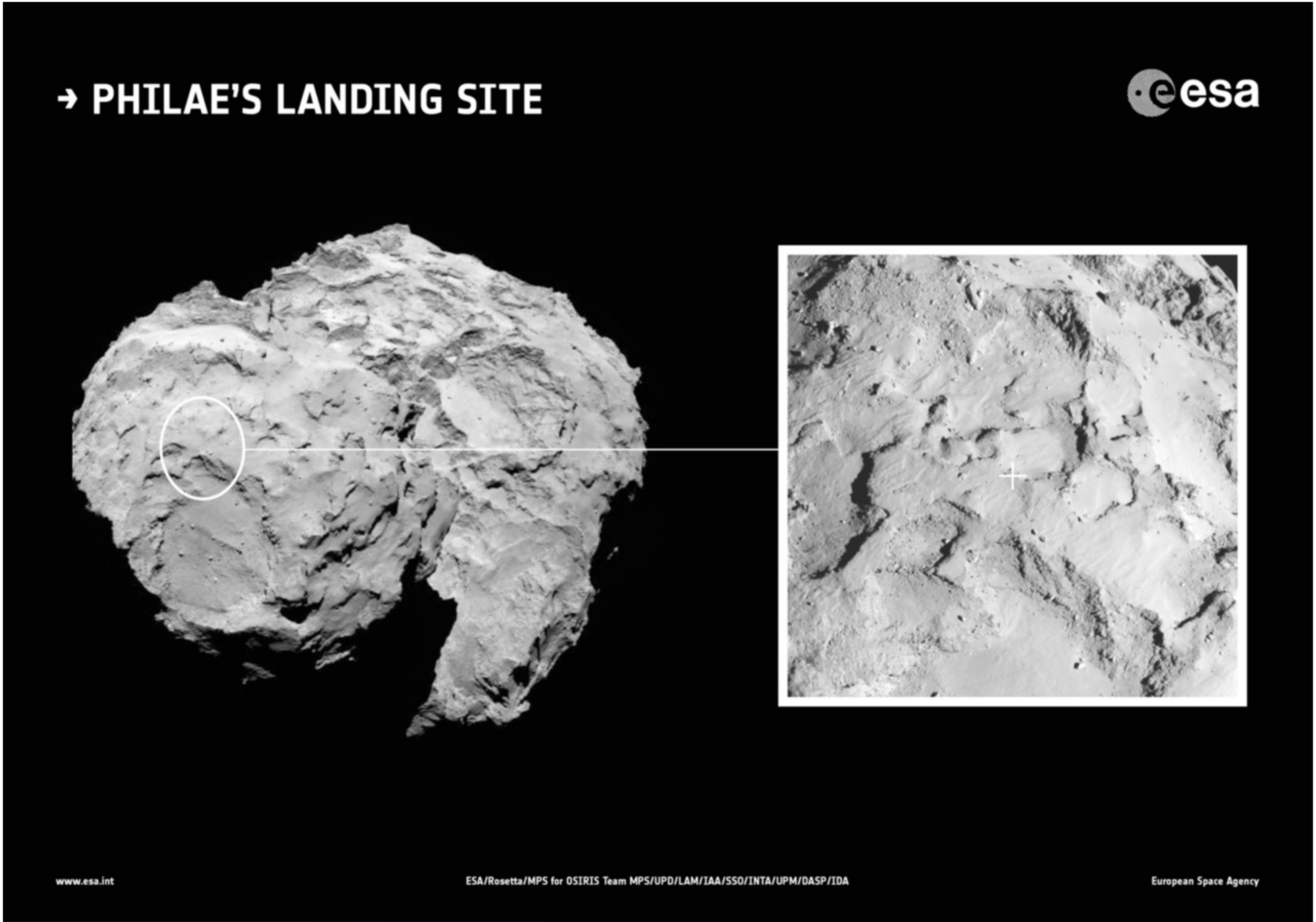
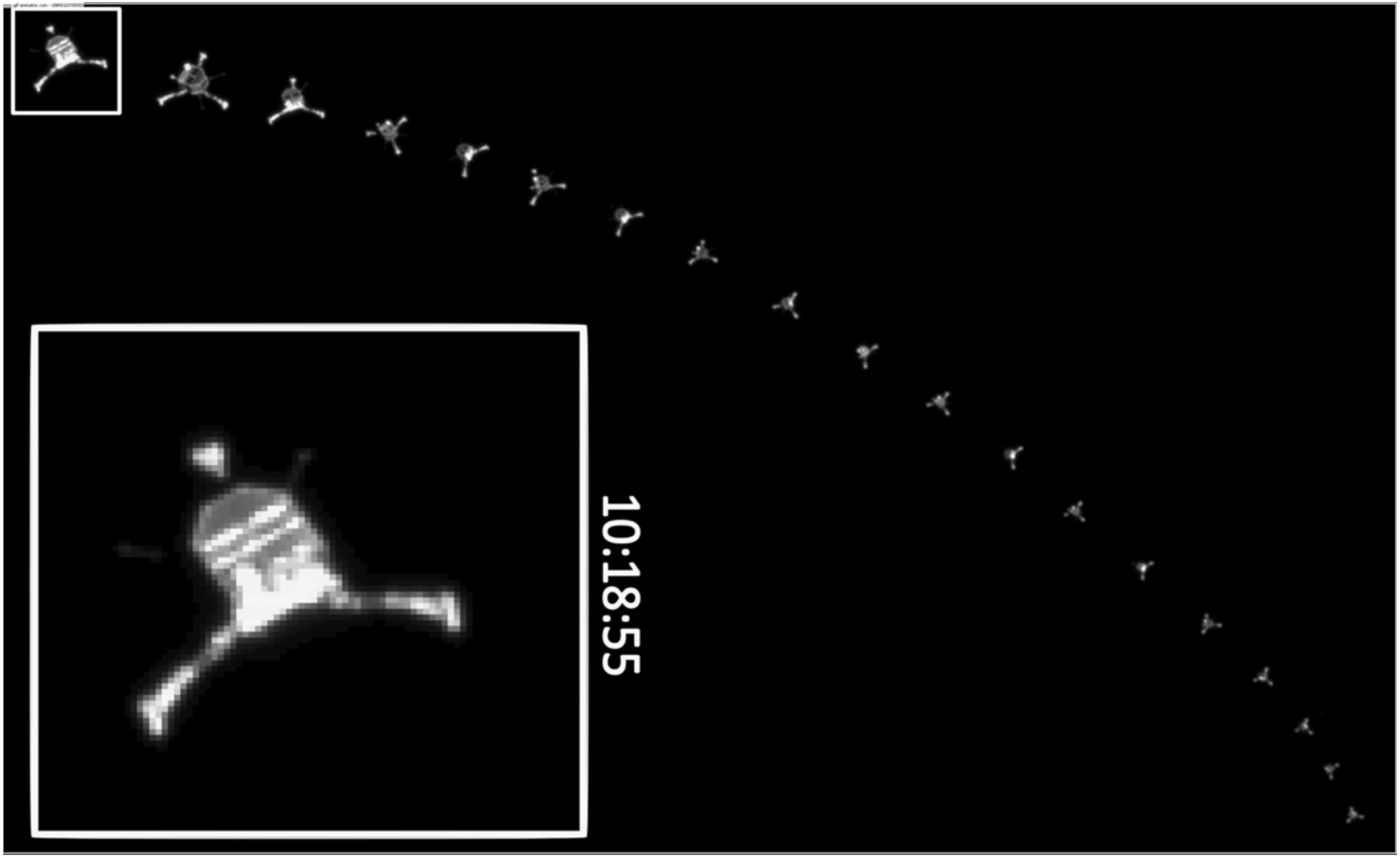


Fig. 4. The spectrum of the head in the spectral range 2.5 to 4.5 μm is compared to several other organic compounds described in the text. The VIRTIS spectrum is rescaled in arbitrary units to compare the X-H stretch region with ethanol and ethanoic (acetic) acid spectra (*32*), a cometary tholins (obtained after ion irradiation of a mixture of 80% H_2O, 16% CH_3OH, 3.2% CO_2, and 0.8% C_2H_6) (*33*), and a refractory residue (labeled "Exp Or1") obtained after UV irradiation of a mixture of H_2O:CH_3OH:NH_3:CO:CO_2 in the ratio 2:1:1:1:1 (*34*).


→ PHILAE'S LANDING SITE
esa
www.esa.int
ESA/Rosetta/MPS for OSIRIS Team MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA
European Space Agency

2 years of exploration - landing

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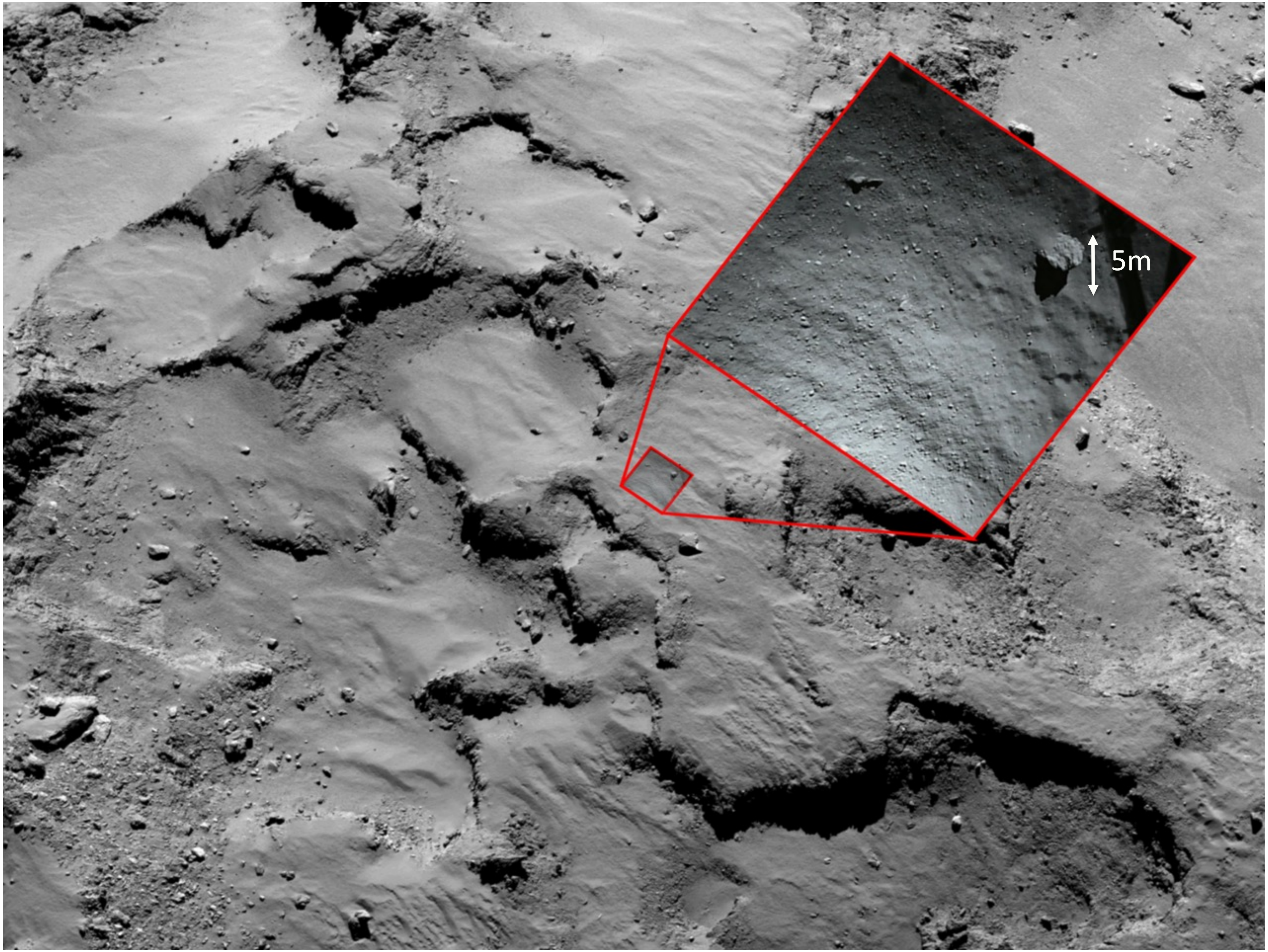
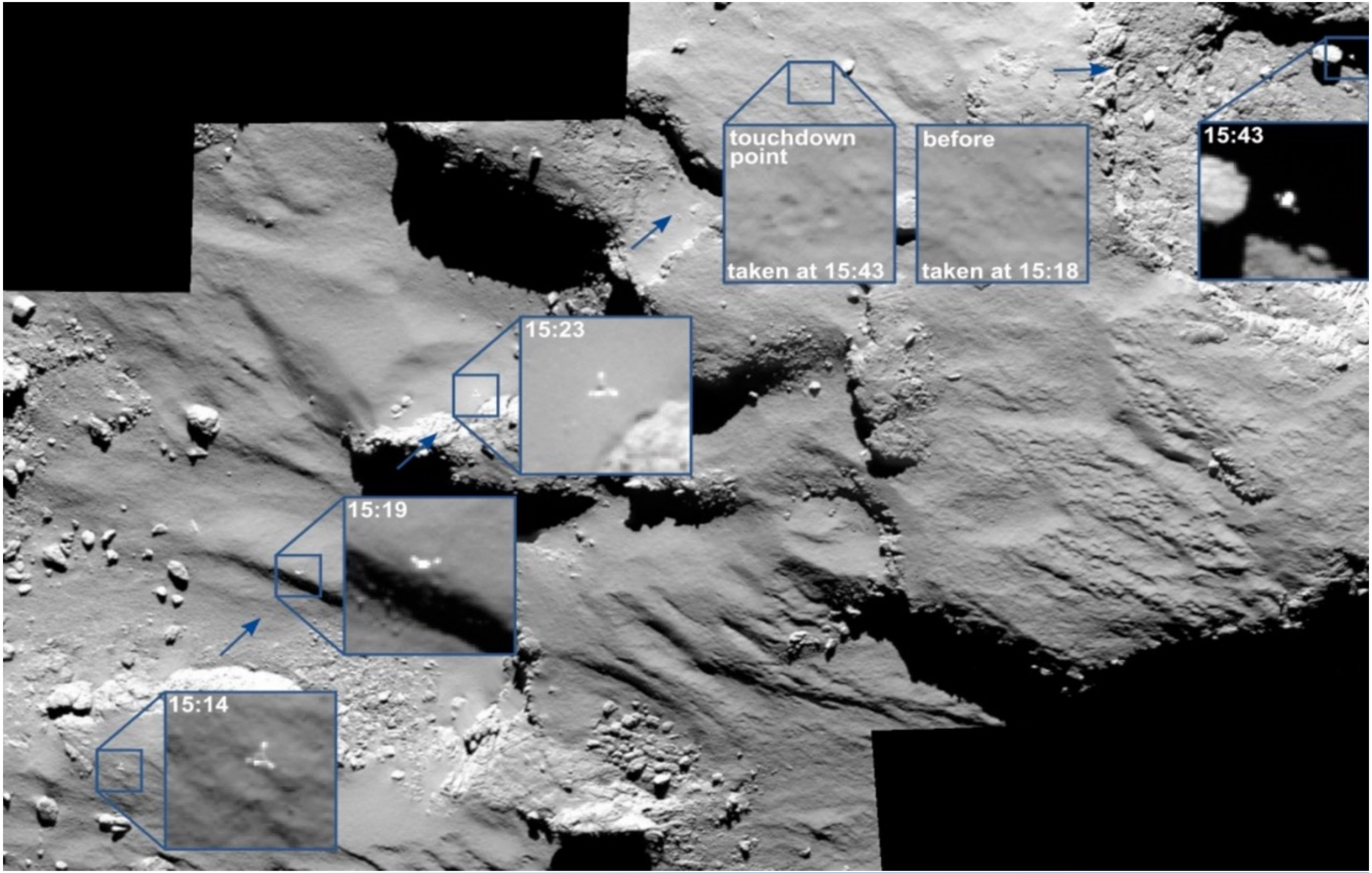
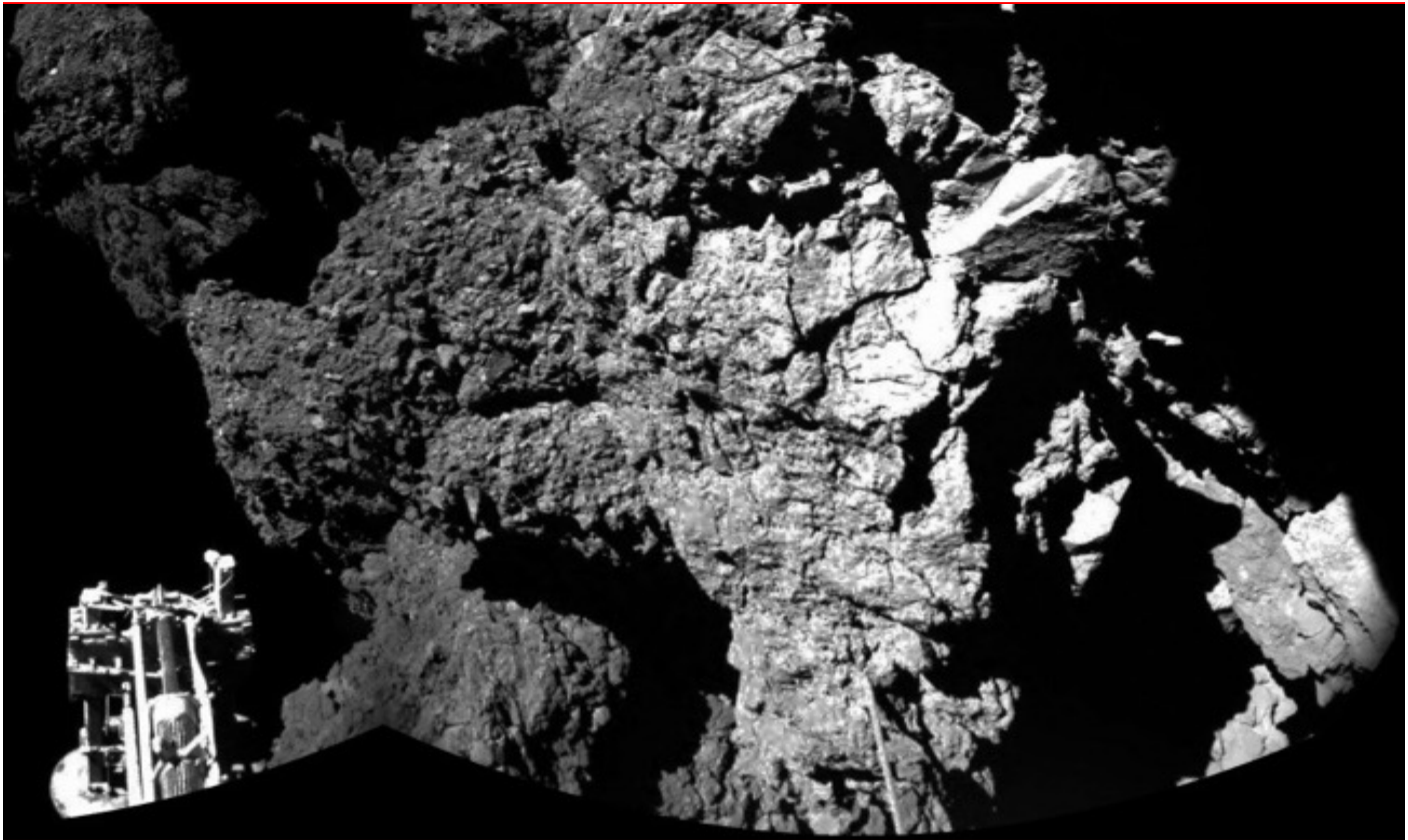

5m

2 years of exploration - landing

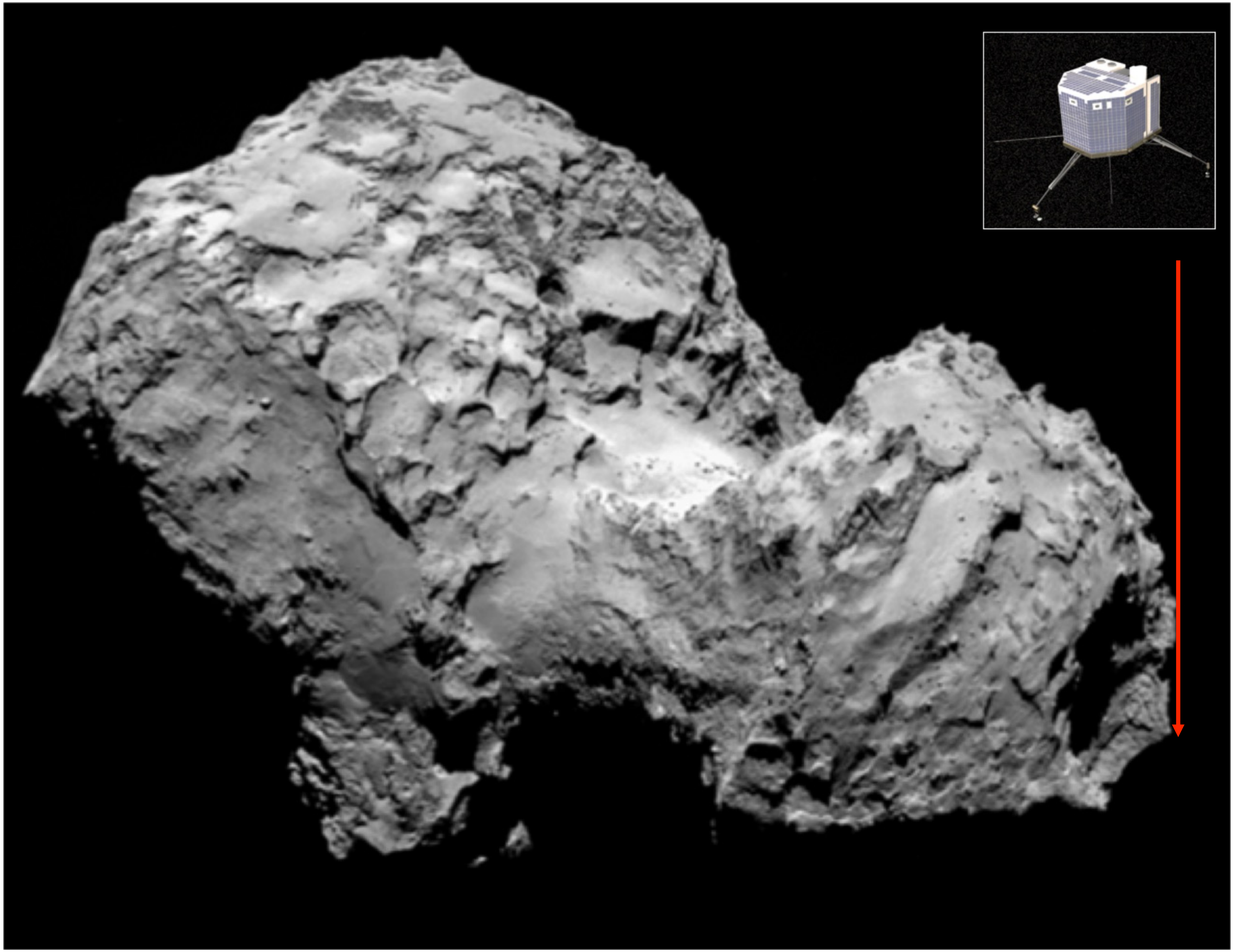


2 years of exploration - landing

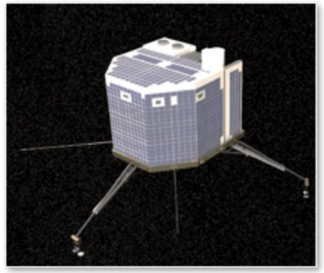
ESA / Rosetta / Philae / ÇIVA

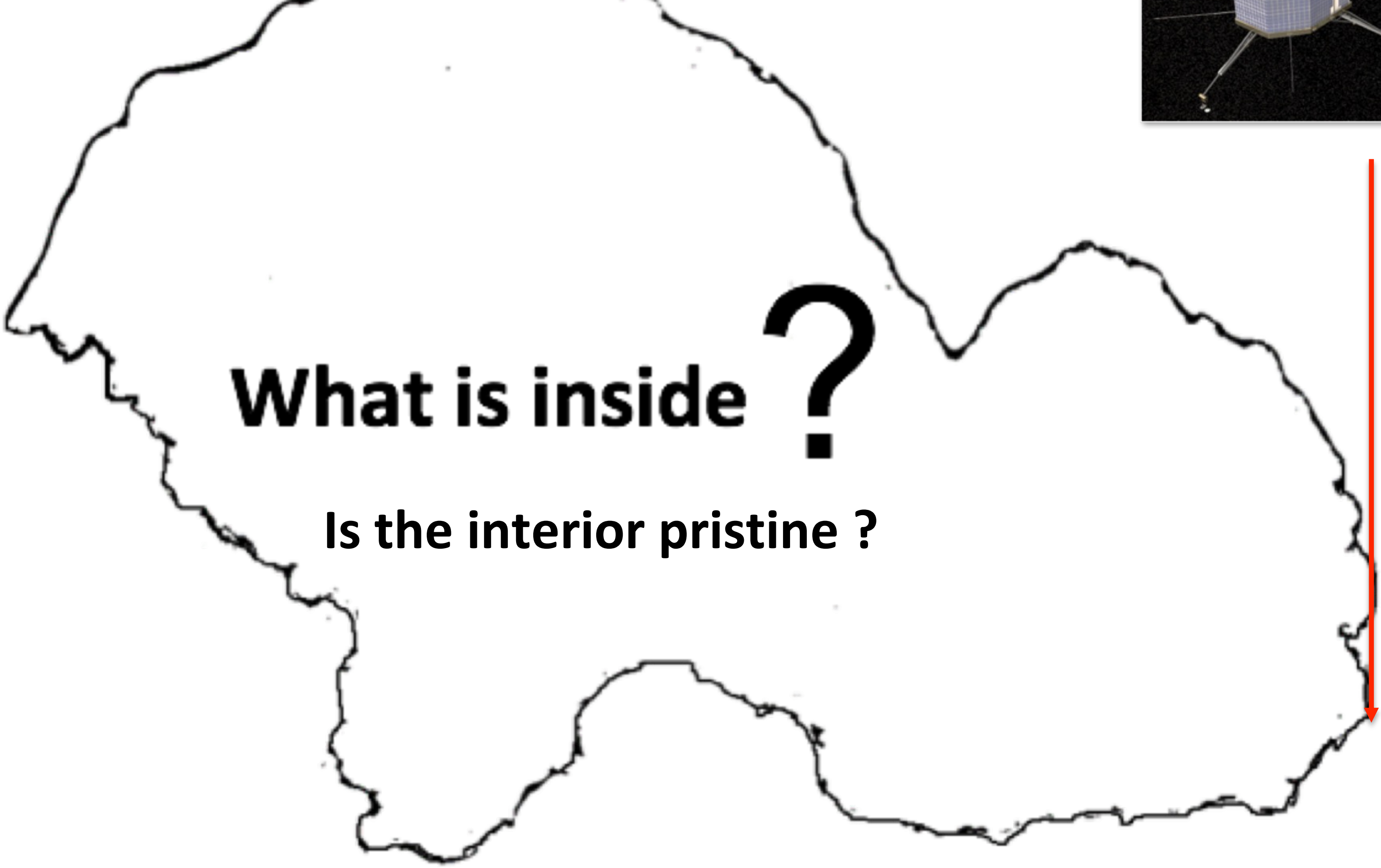


Philae landing site: vicinity of Abydos



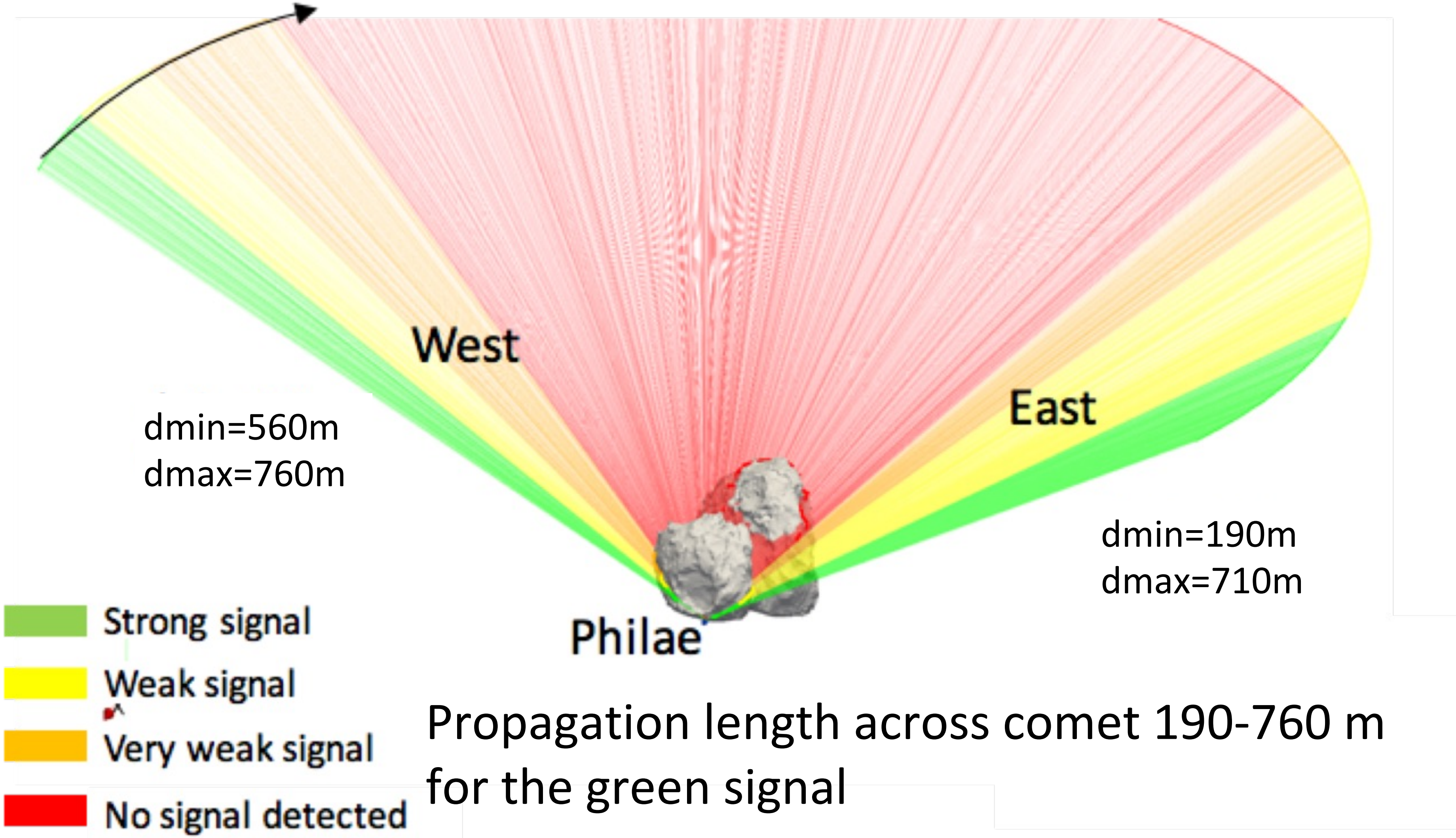
Philae landing site: vicinity of Abydos





Areas sounded during CONSERT FSS

CONSERT data



Propagation length across comet 190-760 m for the green signal

Kofman et al., Science, 2015

Interior results

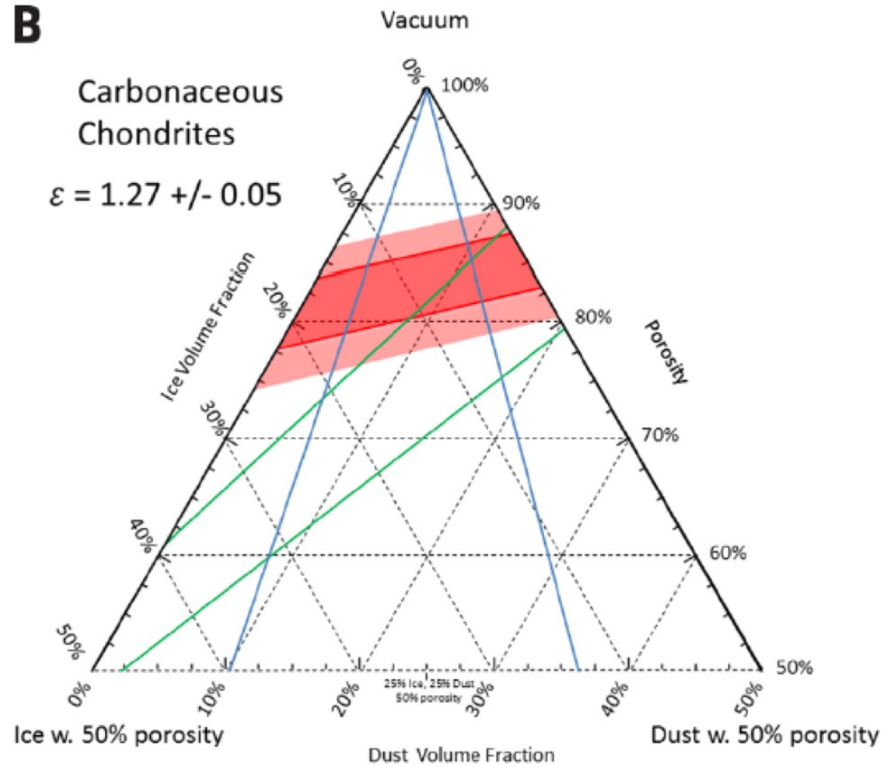
- From propagation delays measured by CONSERT
  Mean permittivity 1.27 ± 0.05 (H_2O ice:3.2, CO_2 ice:2.5)
  Porosity : 75-85%
  Dust/ice ratio ~ 0.4 – 2.6
  Density comet ~ 470 kg/m^3
  Dust : analogous to Carbonaceous chondrites CC

Kofman et al., Science 2015
Sierks et al., Science 2015
Pätzold et al., Nature, 2016
Sierks et al., Science , 2015

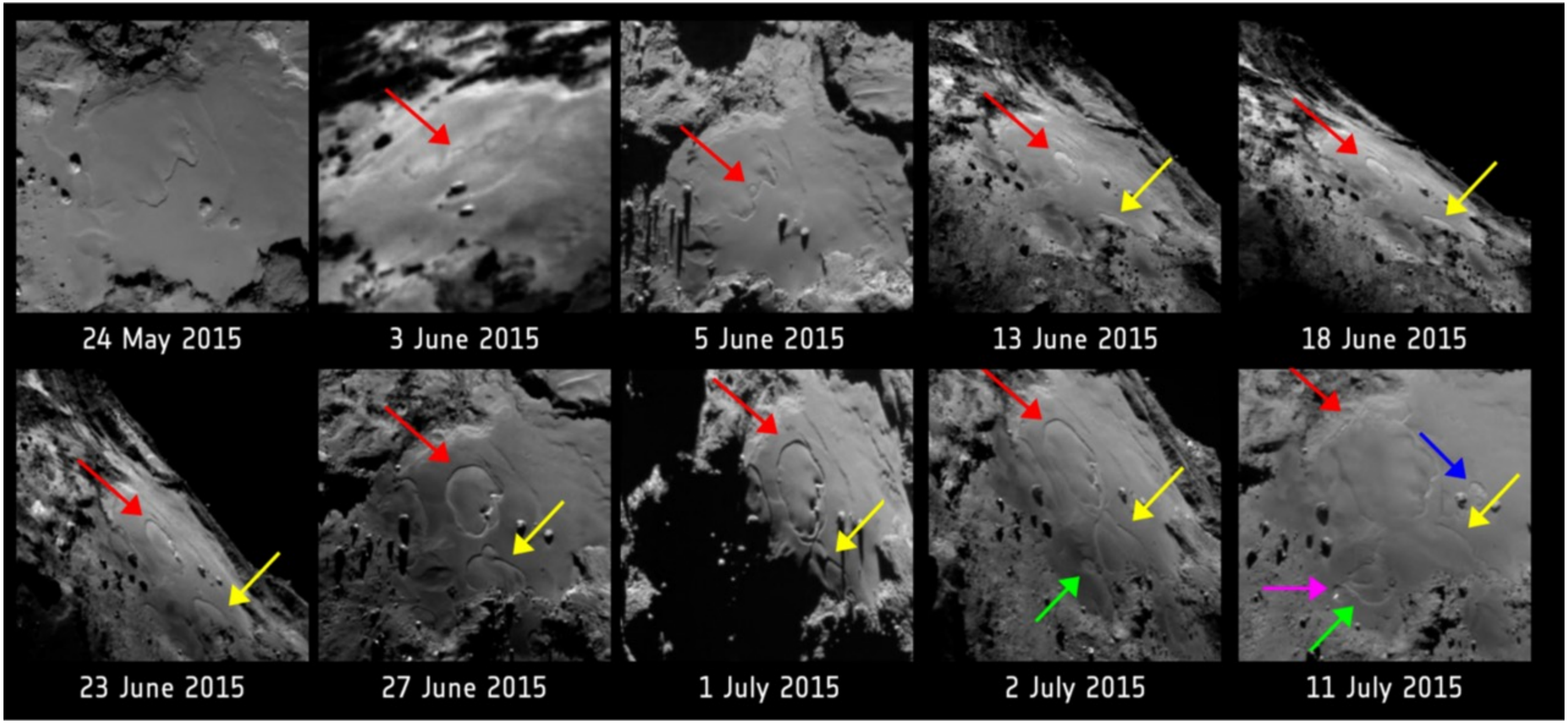
- From the density (volume and mass) :
  Average density 533 ± 6 kg/m^3
  Porosity > 70%

- A decrease of permittivity value with depth (2.4 -> 1.3) linked to higher porosity or more ice content. (*Ciarletti et al. A&A 2015*)

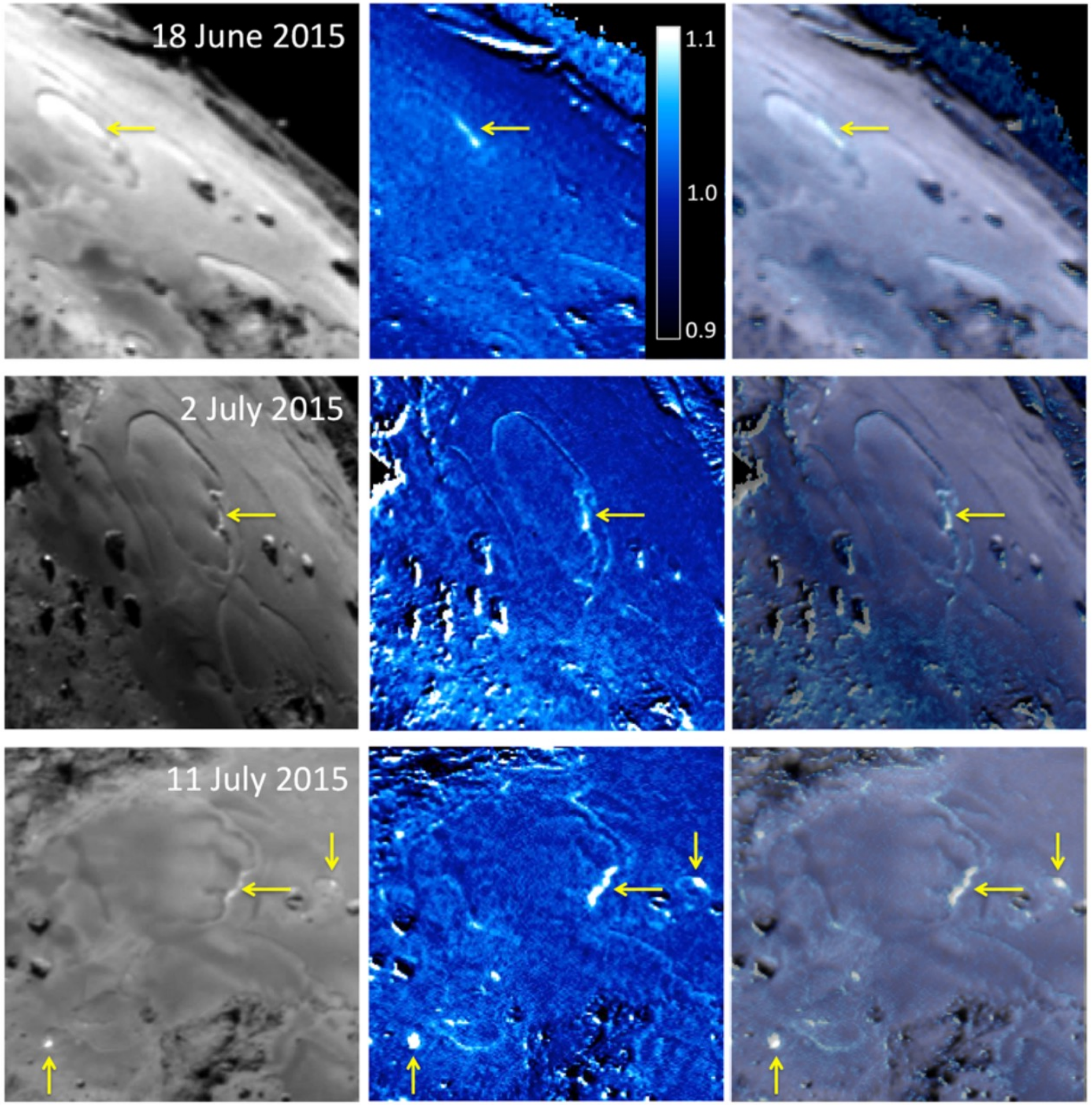
- No indications of internal structures at the scale of CONSERT's wavelength ~1m (*Ciarletti et al. MNRAS 2017*)



2 years of exploration



2 years of exploration

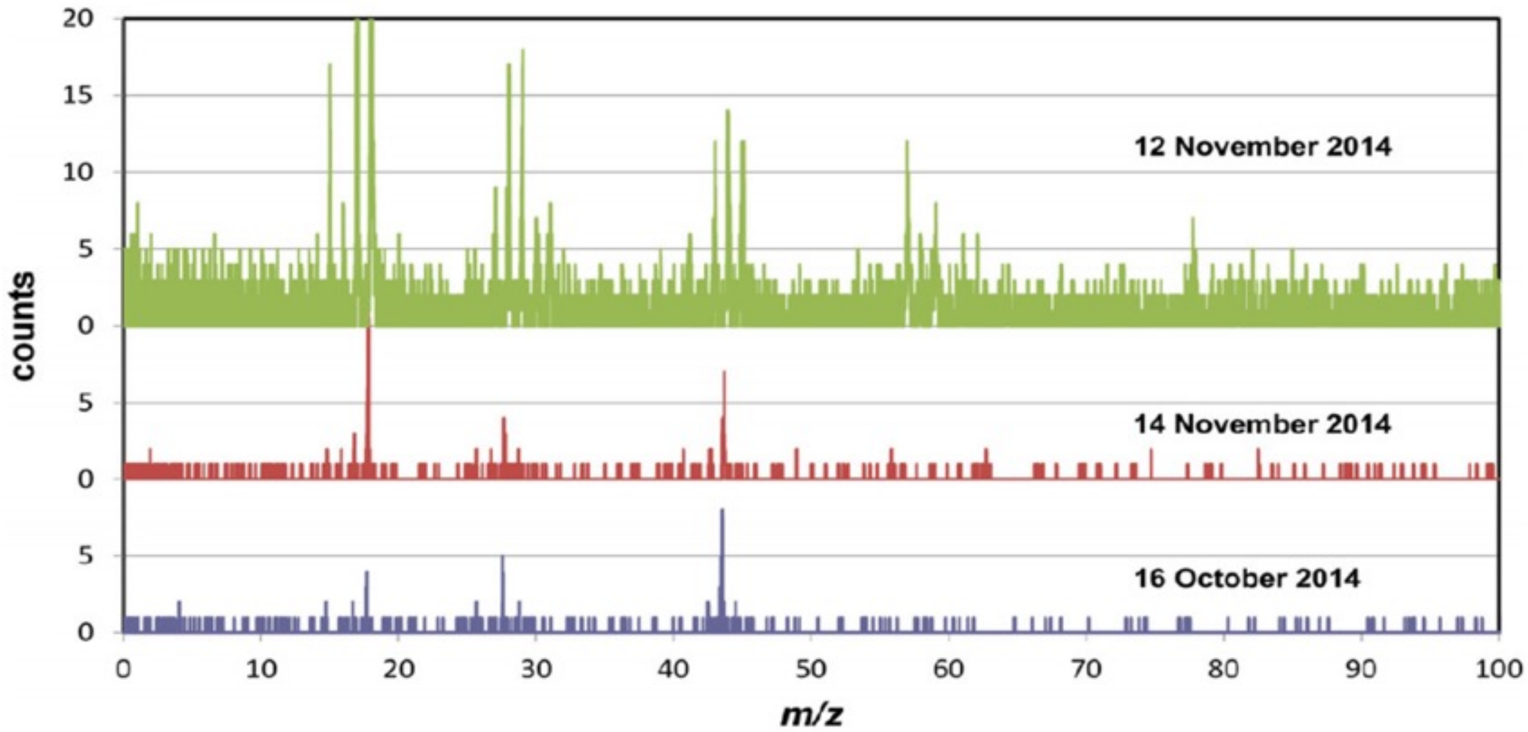


2 years of exploration

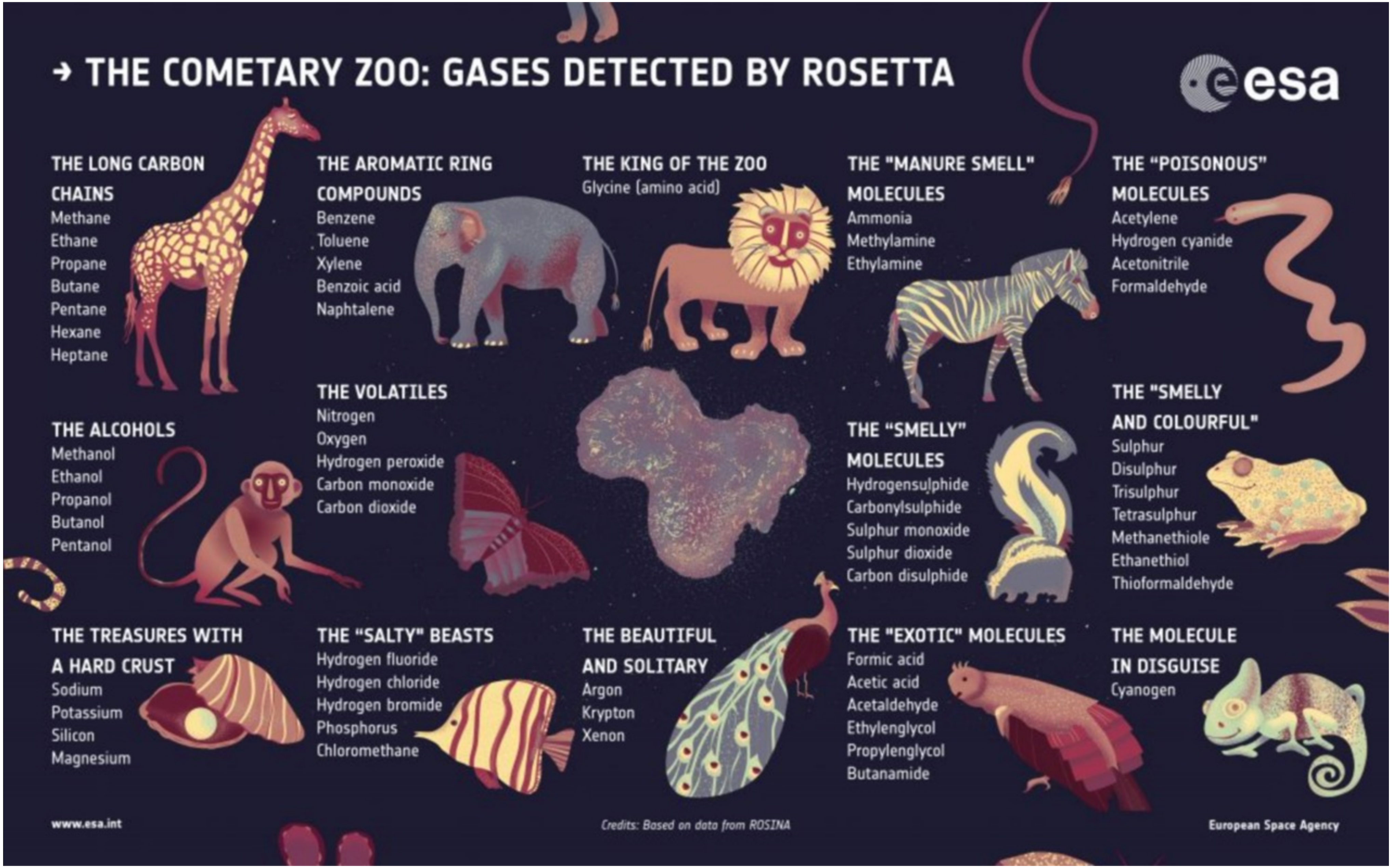
Comets have provided compounds required for the birth of life on Earth :

PTOLEMY : complex molecule chains as : polyoxymethylene (O-CH2), composition ratios of water (75%), CO2 (15%), CO (7%), Autres (3%) ?

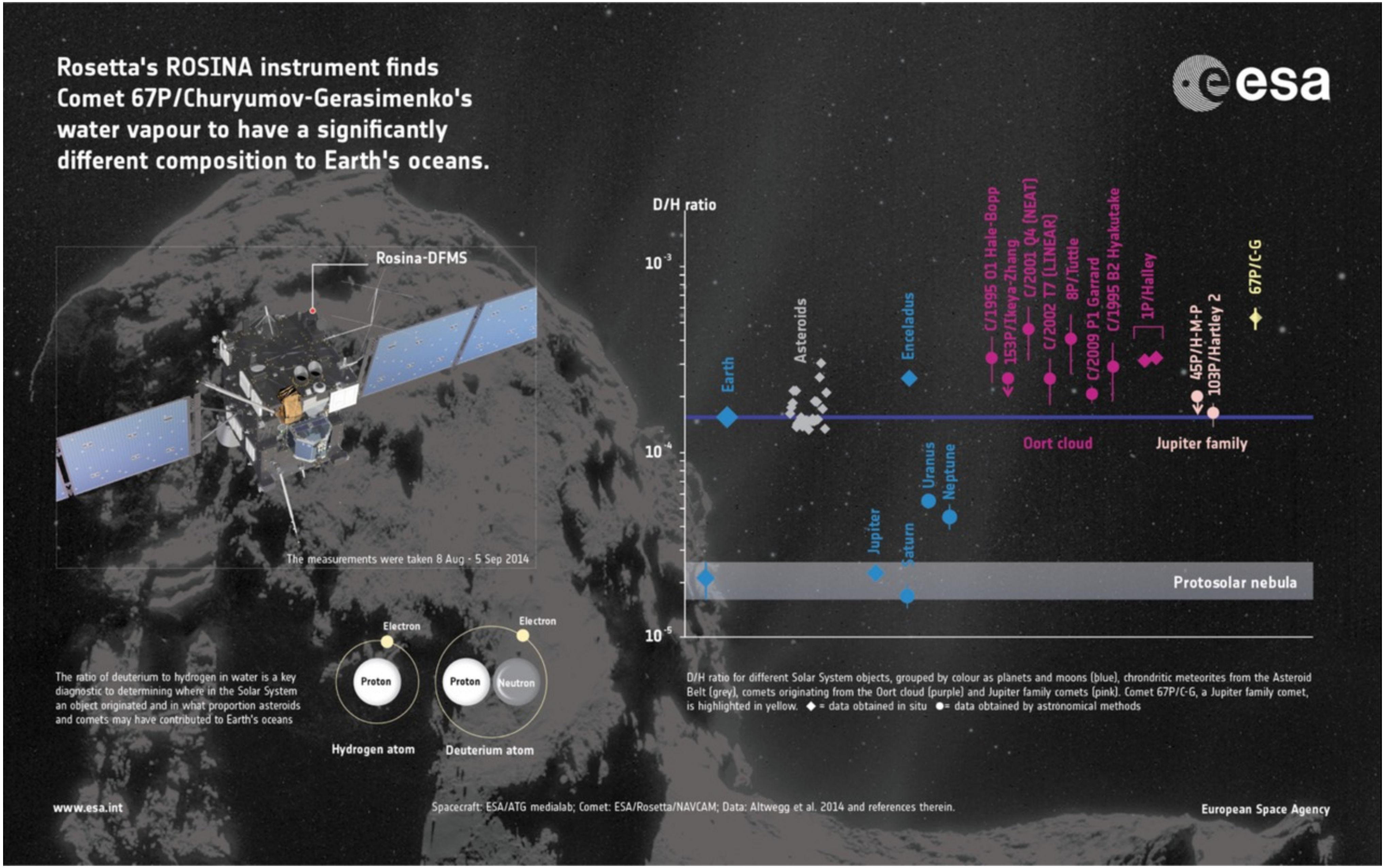
COSAC : 16 organic molecules identified, with 4 never detected in space (methyl-isocyanate, acétone, propionaldéhyde, and acétamide)



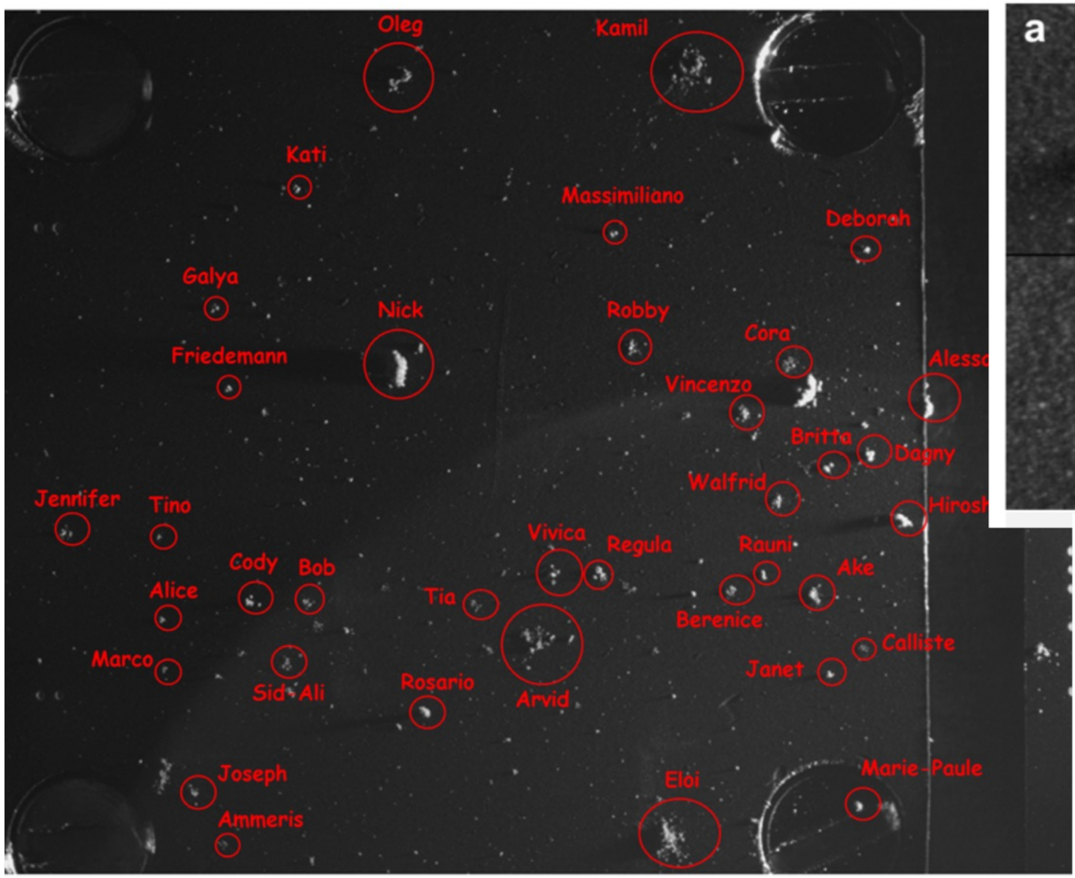
2 years of exploration

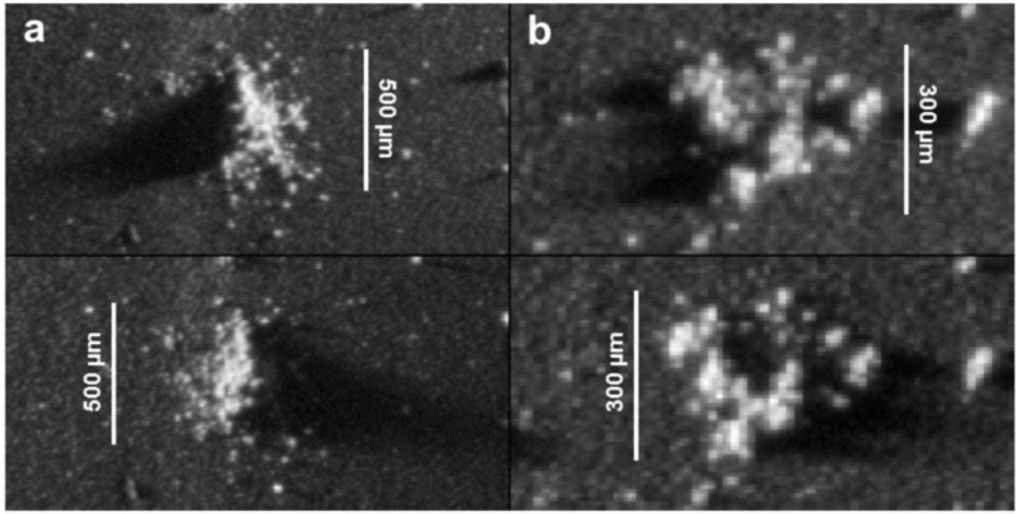


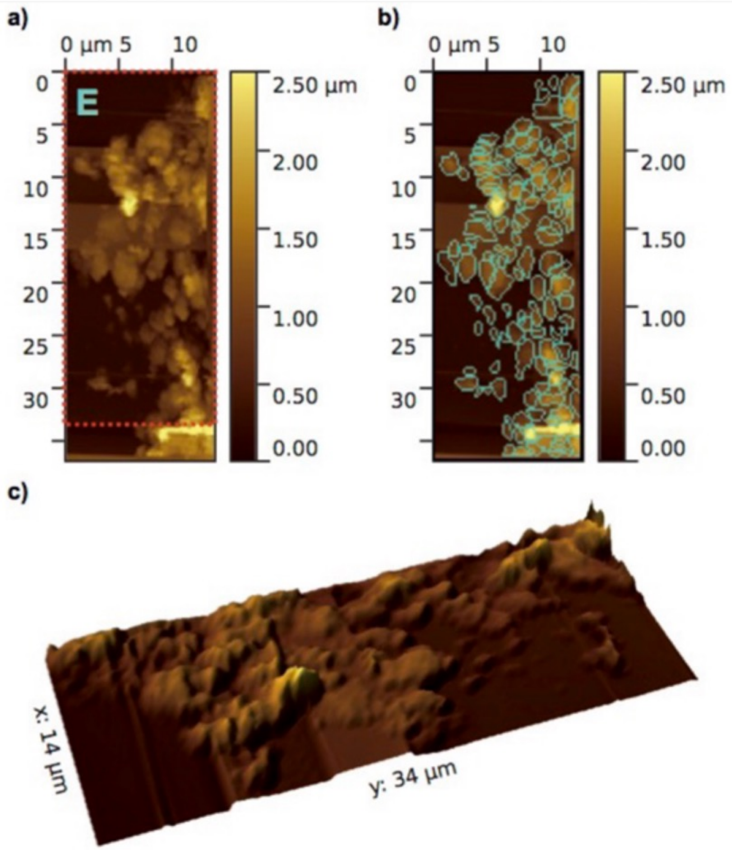
2 years of exploration



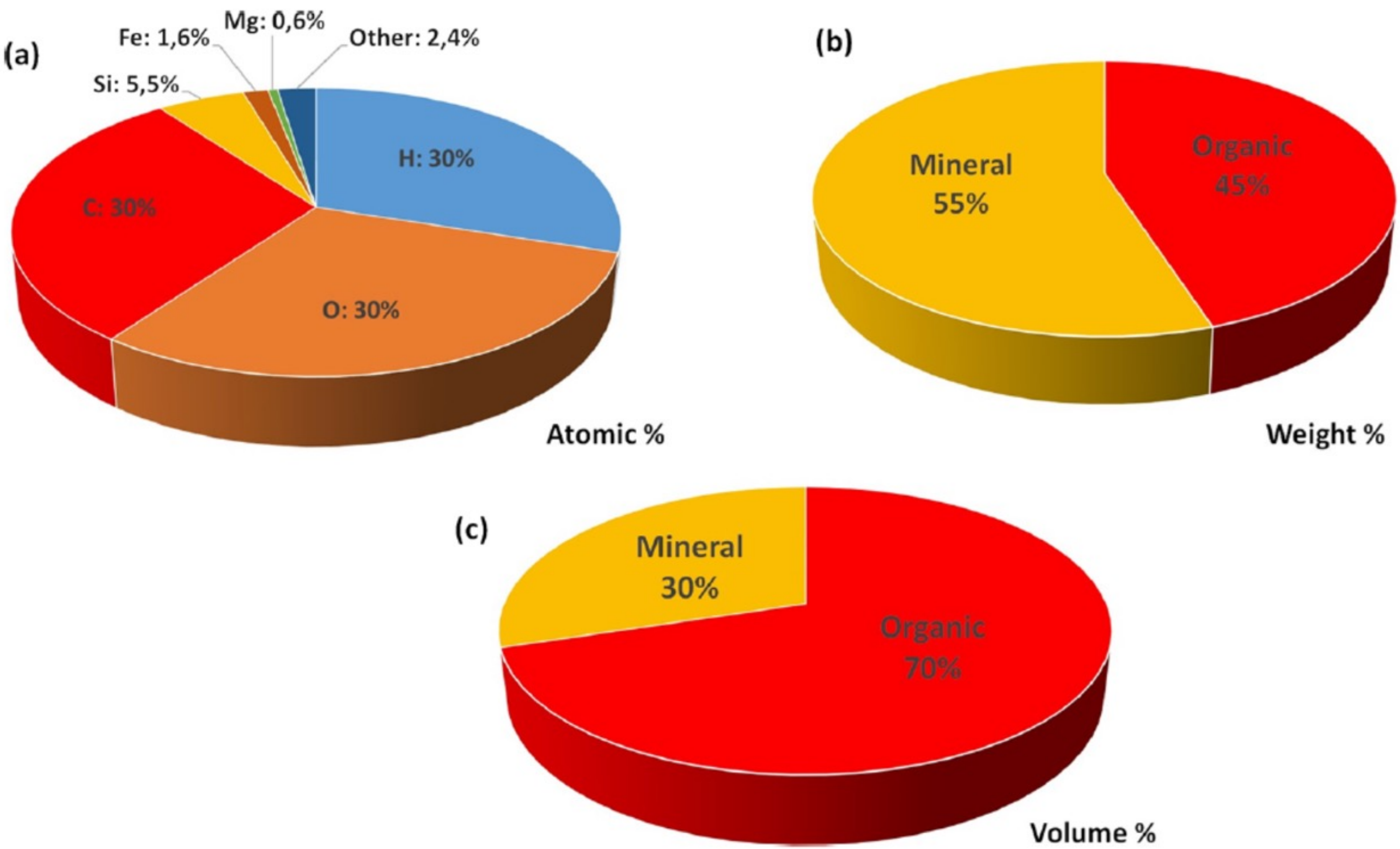
2 years of exploration





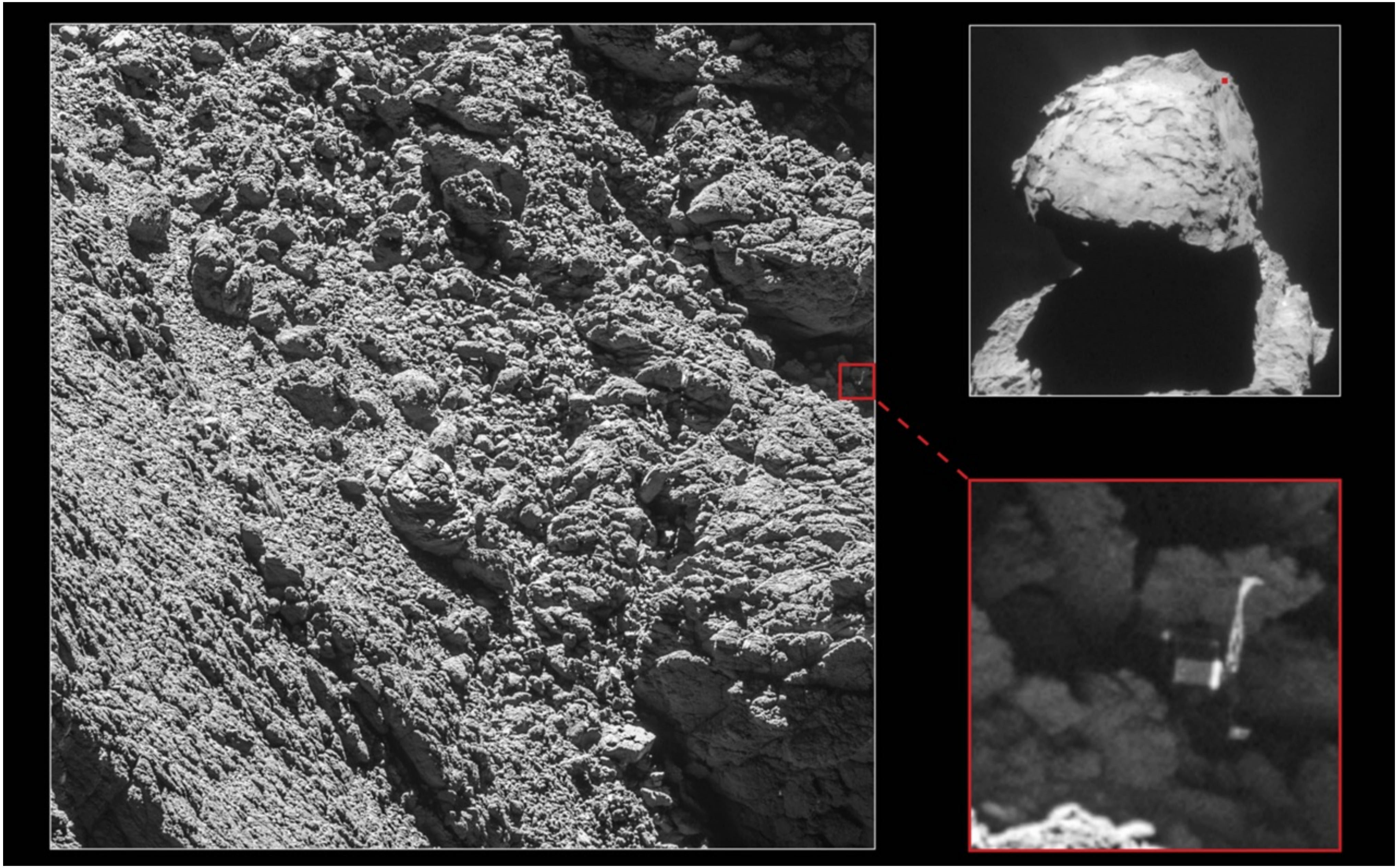


2 years of exploration

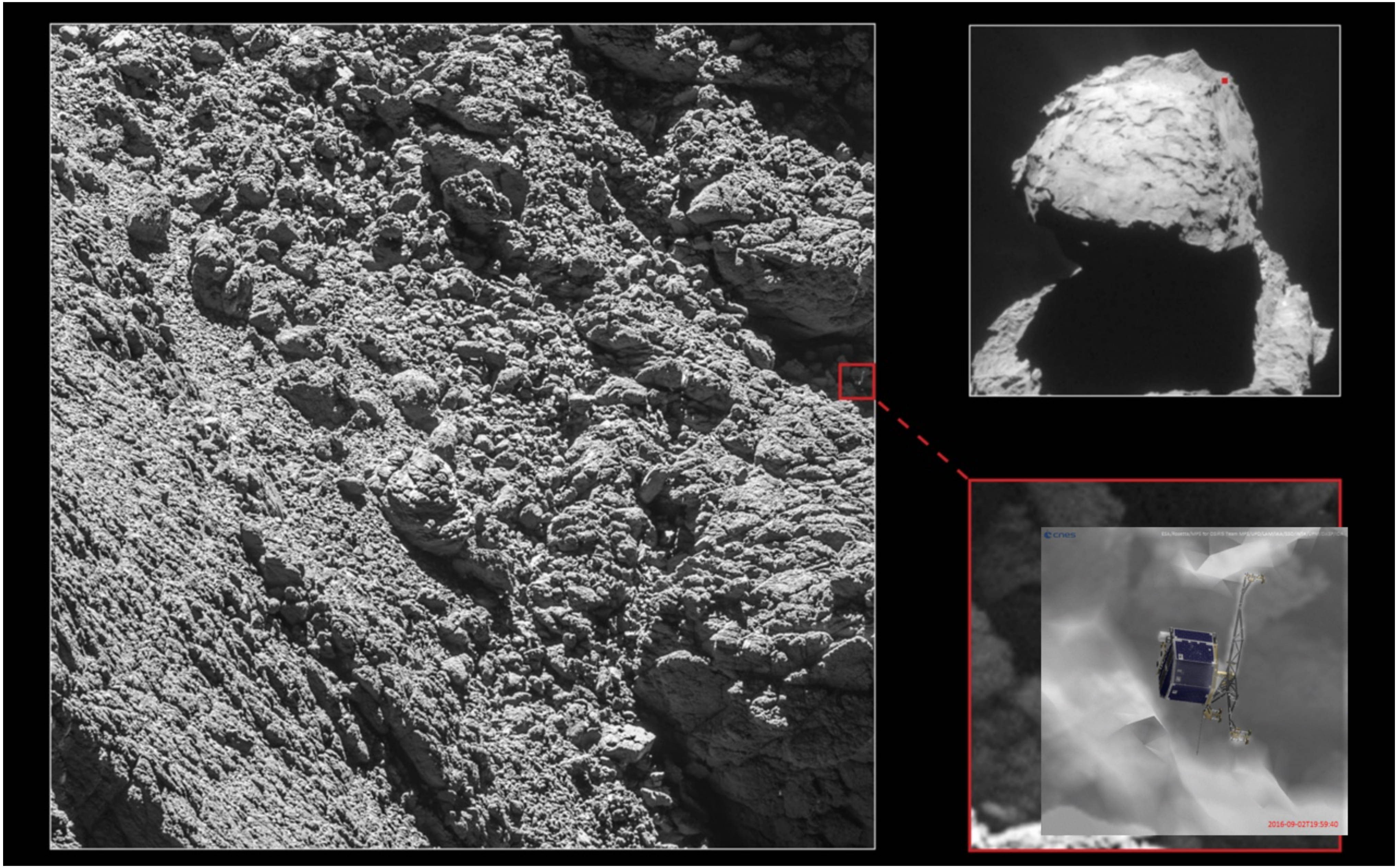


Levasseur-Regourd et al. SSR 2018

2 years of exploration



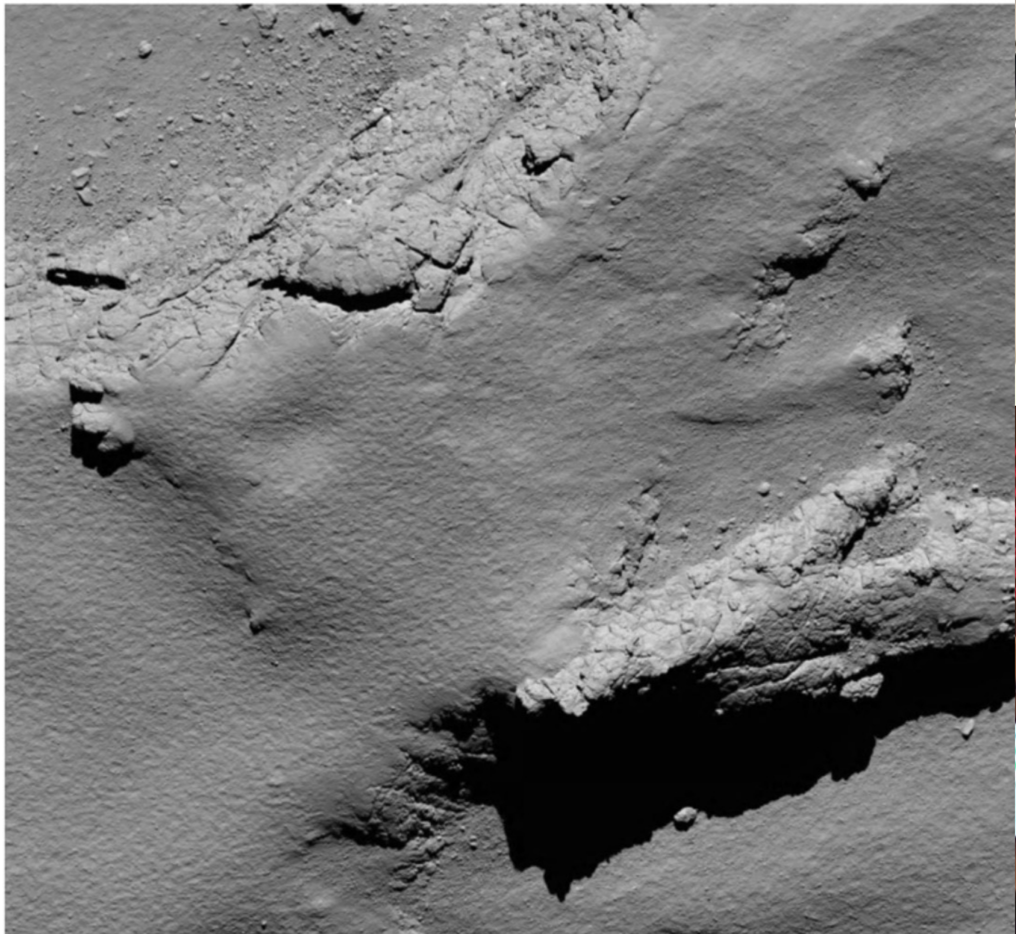
2 years of exploration



End of mission

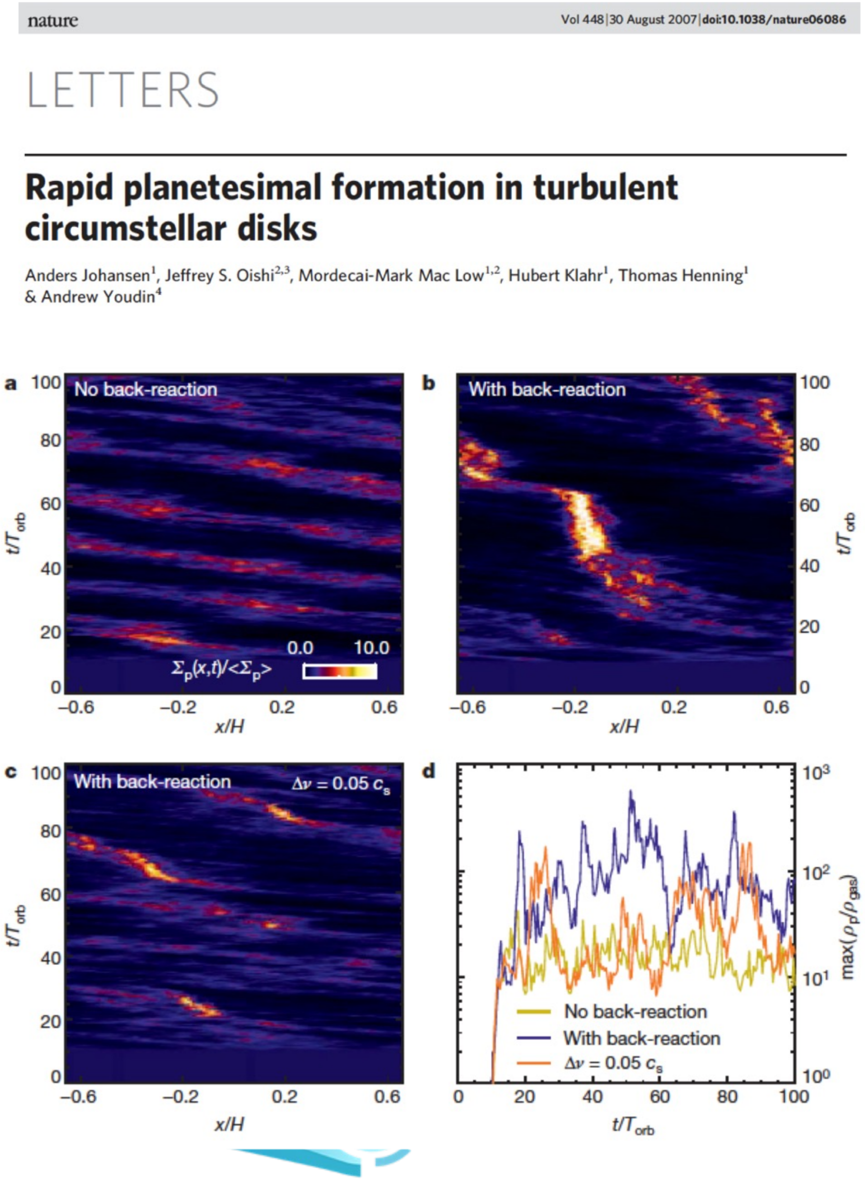
→ COMET LANDING DESCENT IMAGE – 5.7 KM

Another striking image of the Ma'at region of Comet 67P/Churyumov-Gerasimenko from Rosetta's descent onto the surface of the comet, taken with the OSIRIS narrow-angle camera at 08:21 GMT from an altitude of about 5.7 km.



images/Images/2016/09/Comet_from_5.7_km_narrow-angle_camera

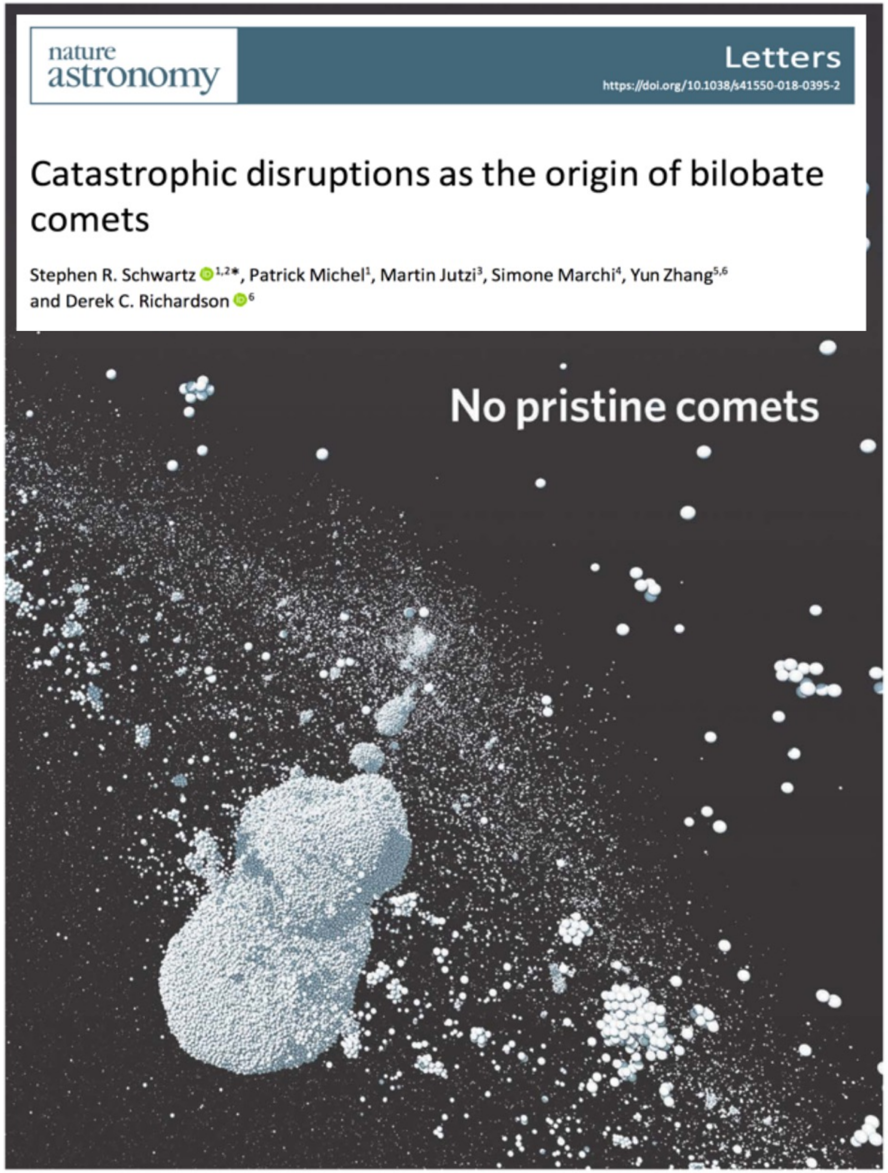
Pristine body ?


nature Vol 448|30 August 2007|doi:10.1038/nature06086

LETTERS

Rapid planetesimal formation in turbulent circumstellar disks

Anders Johansen[1], Jeffrey S. Oishi[2,3], Mordecai-Mark Mac Low[1,2], Hubert Klahr[1], Thomas Henning[1] & Andrew Youdin[4]


nature astronomy Letters https://doi.org/10.1038/s41550-018-0395-2

Catastrophic disruptions as the origin of bilobate comets

Stephen R. Schwartz[1,2]*, Patrick Michel[1], Martin Jutzi[3], Simone Marchi[4], Yun Zhang[5,6] and Derek C. Richardson[6]

Comet Astrobiology Exploration SAmple Return (2025-2038)

Kuiper Belt exploration – Ultima Thule