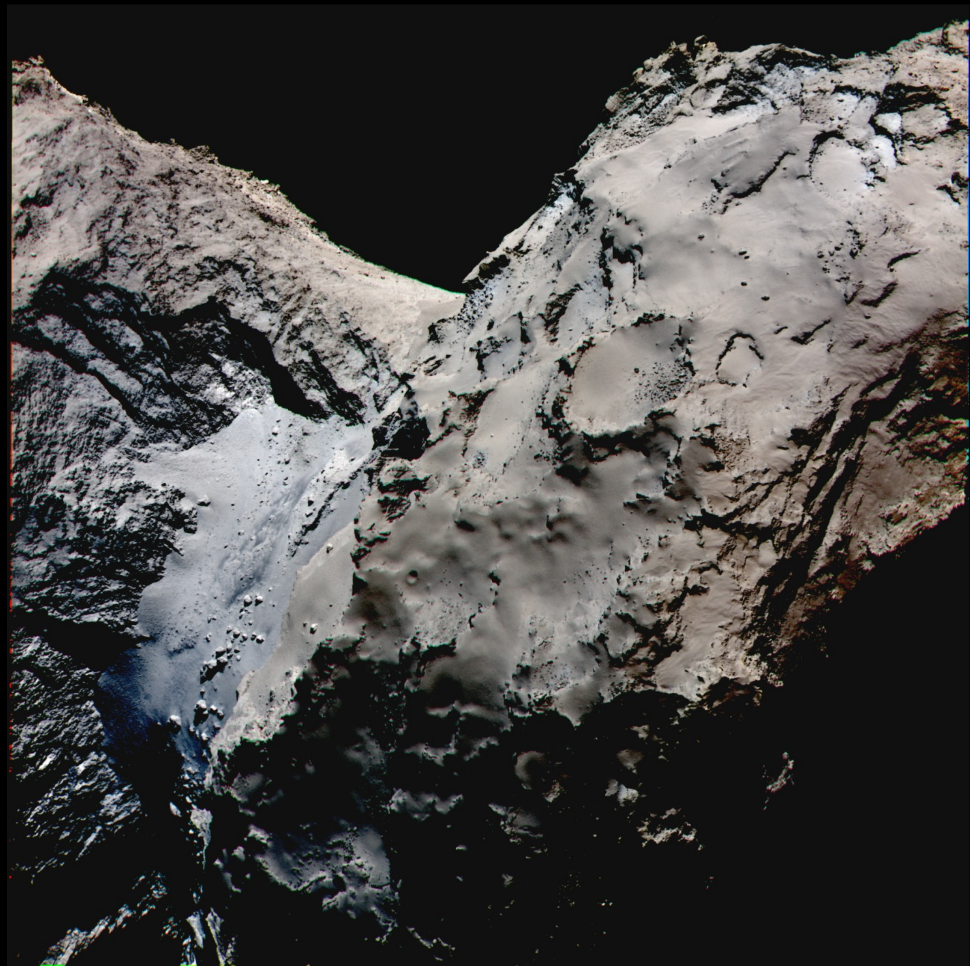
La comète 67P/Churyumov-Gerasimenko à l'heure de la mission Rosetta



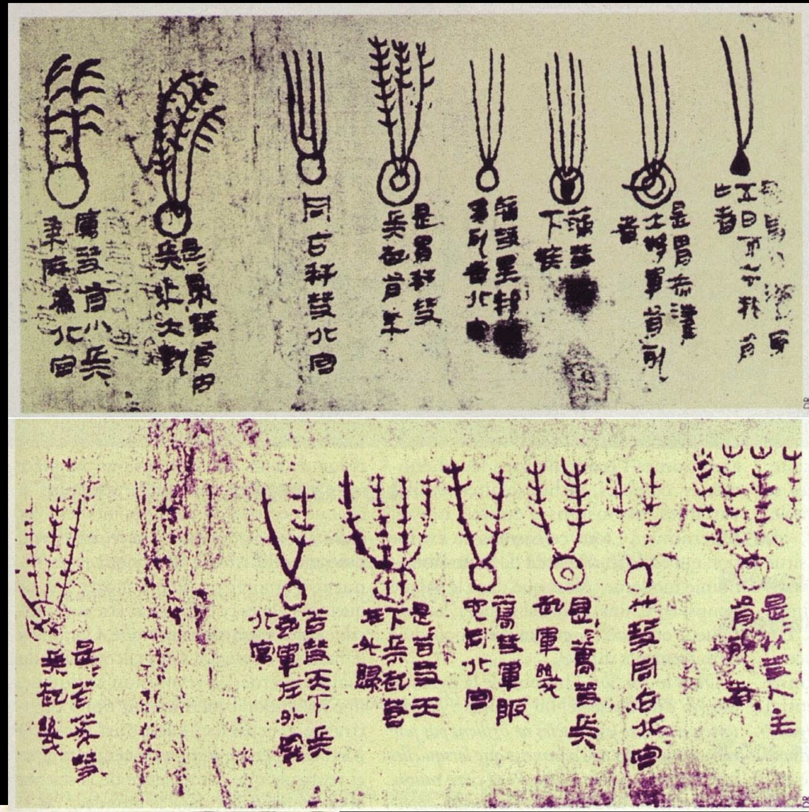
Eric Quirico

IPAG

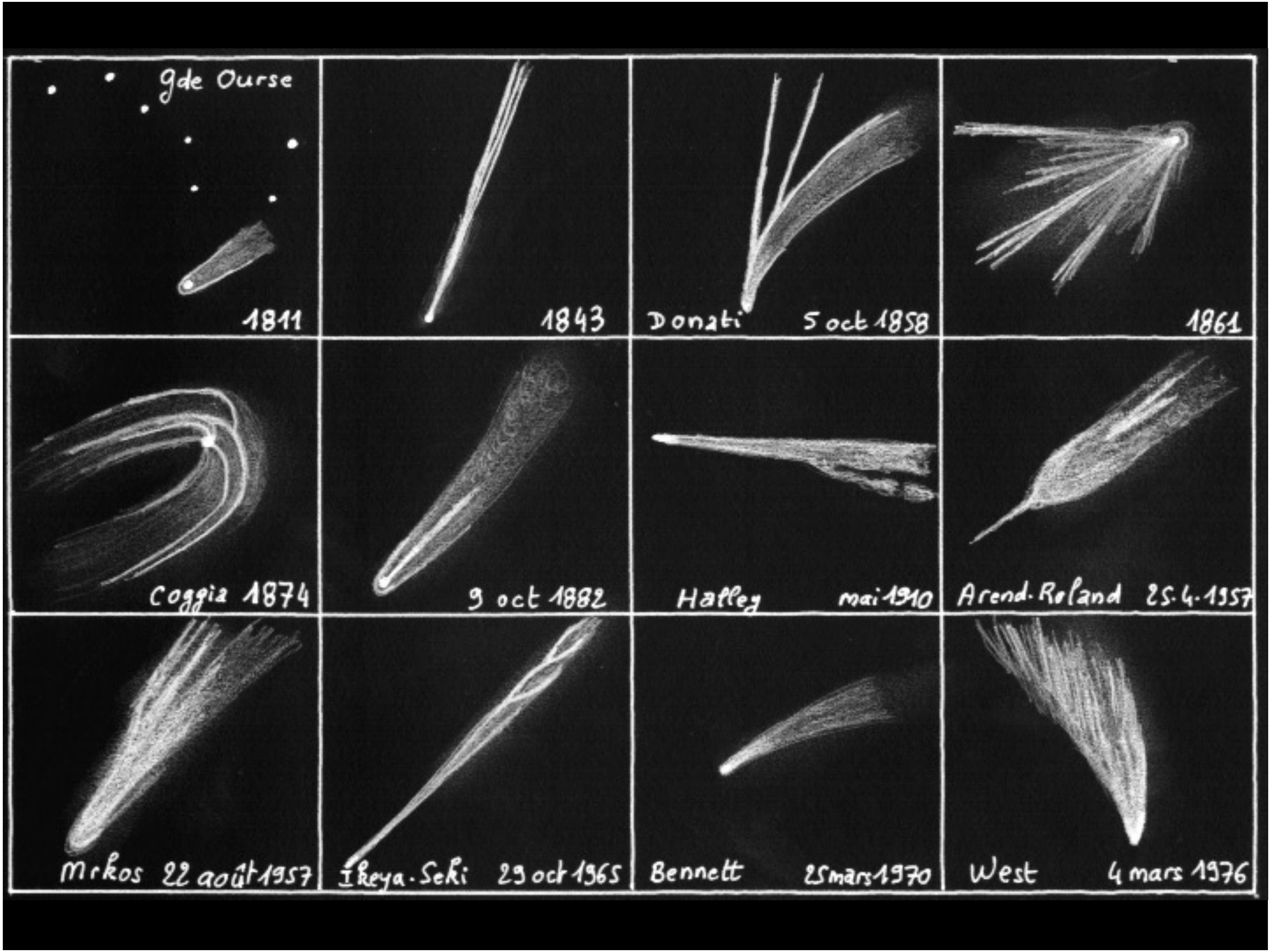
Université Grenoble Alpes

1301 – Padova

-300 av JC – Chine



1066 - Normandie

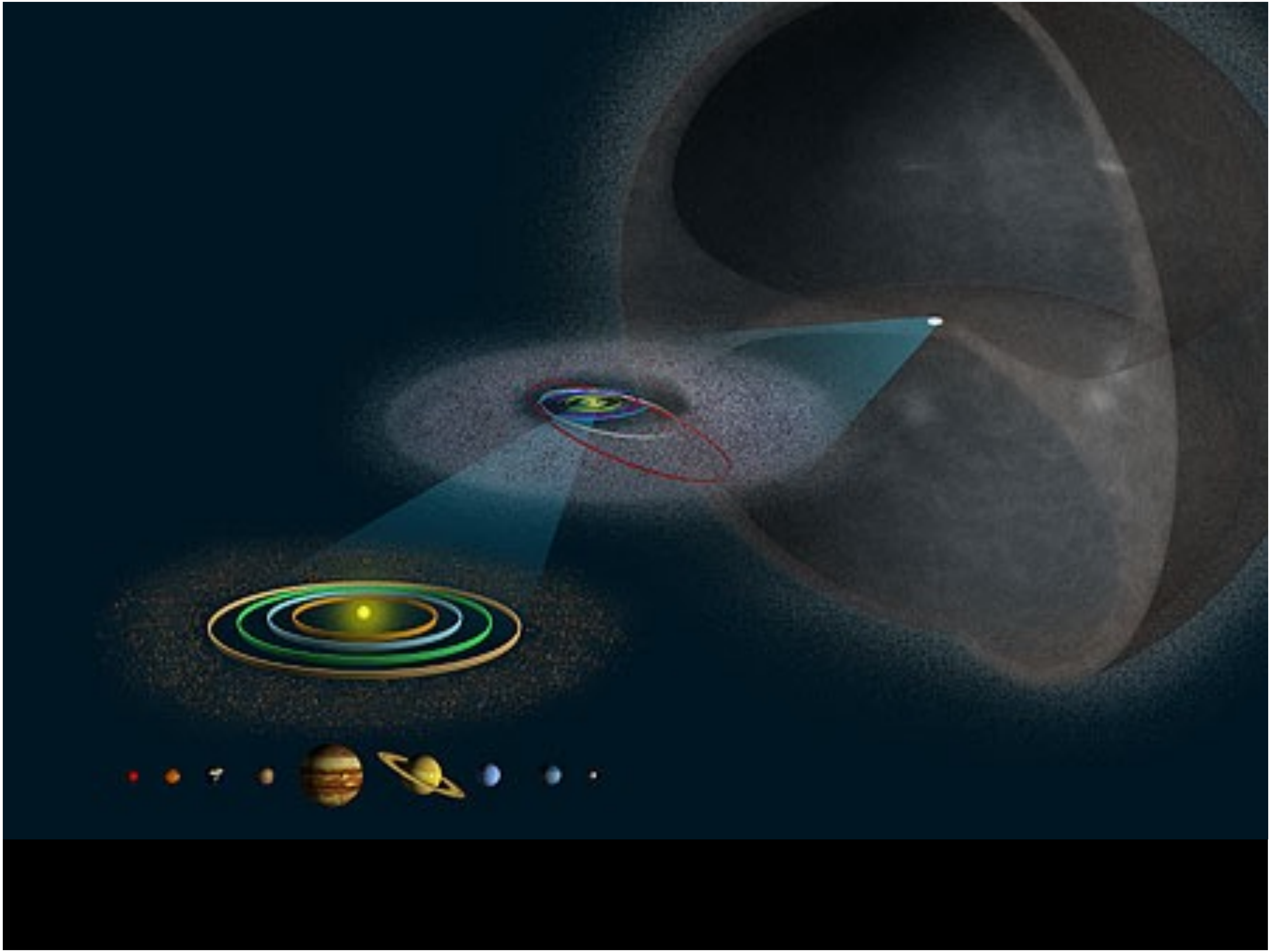

gde Ourse
1811
1843
Donati
5 oct 1858
1861
Coggia 1874
9 oct 1882
Halley
mai 1910
Arend-Roland 25-4-1957
Mrkos 22 août 1957
Ikeya-Seki 29 oct 1965
Bennett 25 mars 1970
West 4 mars 1976

" Les Grecs appellent "comète" et les Romains "étoiles chevelues" celles qui sont hérissées d'une touffe de poils couleur de sang, se dressant à leur sommet comme une chevelure.

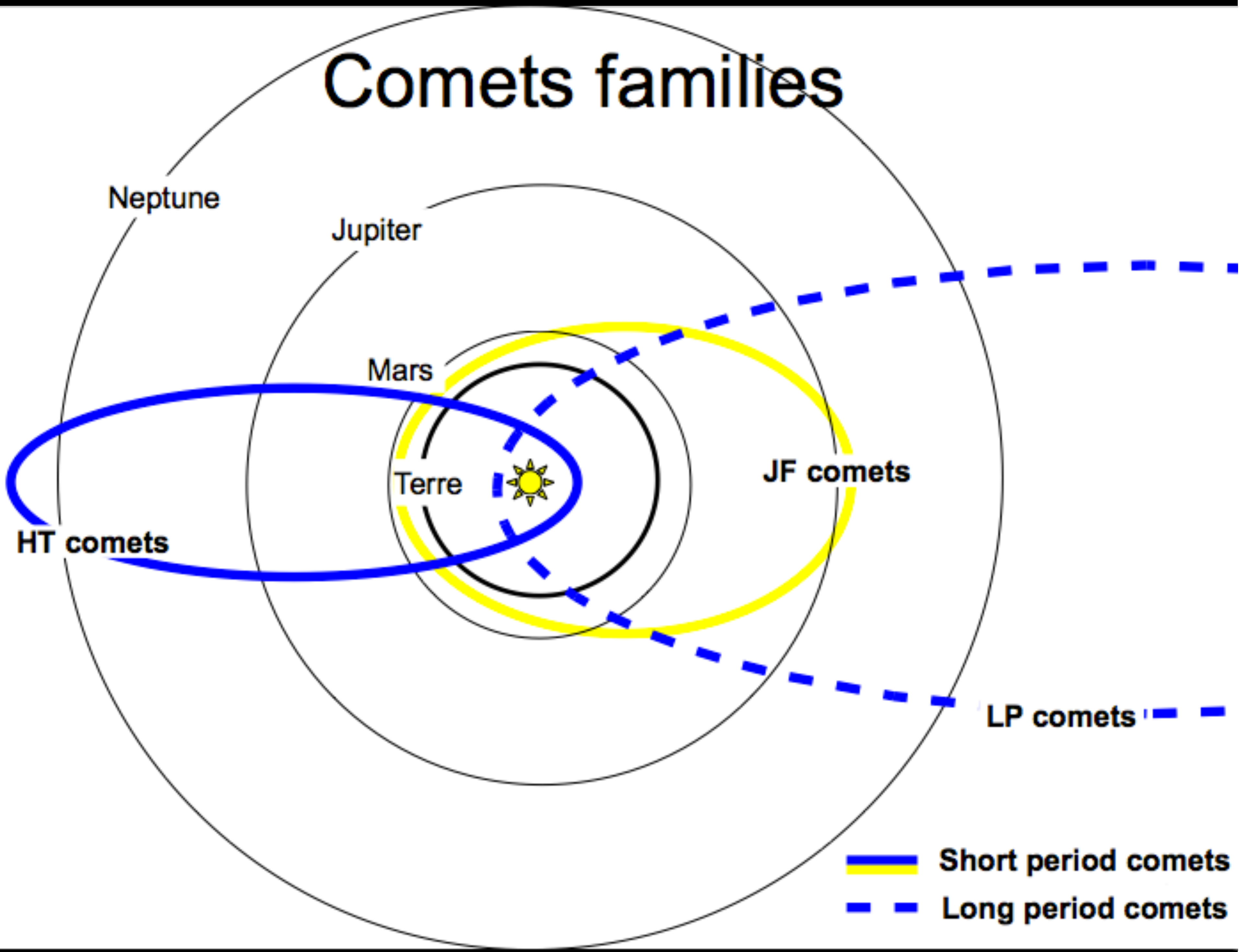
Les Grecs nomment "Pogonias" (barbues), celles qui traînent à leur partie inférieure une crinière en forme de longue barbe.
Les "Acontias", présages d'événements tout à fait imminents, filent comme des javelots.
Les "Certias" ont la forme d'une corne.
Les "Lampadias" imitent les torches ardentes. Les "Hippias", des crinières de chevaux animées d'un mouvement très rapide et tournoyant sur elles-mêmes.
On rencontre aussi les comètes "Boucs" d'aspect poilu, enveloppées d'une sorte de nuage.

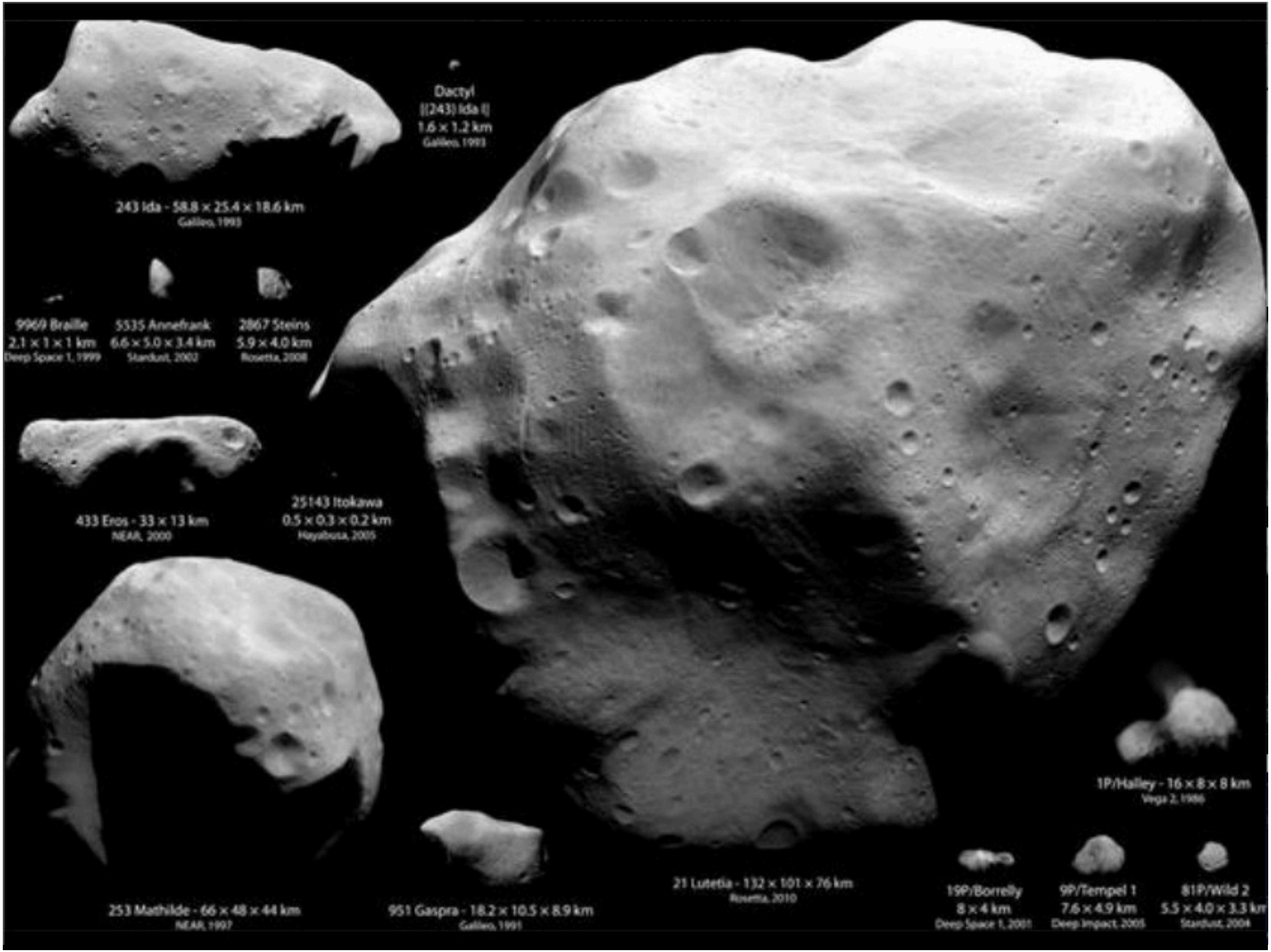
Il est arrivé une fois qu'une crinière s'est transformée en lance...".

Pline l'Ancien, 77 ap. JC

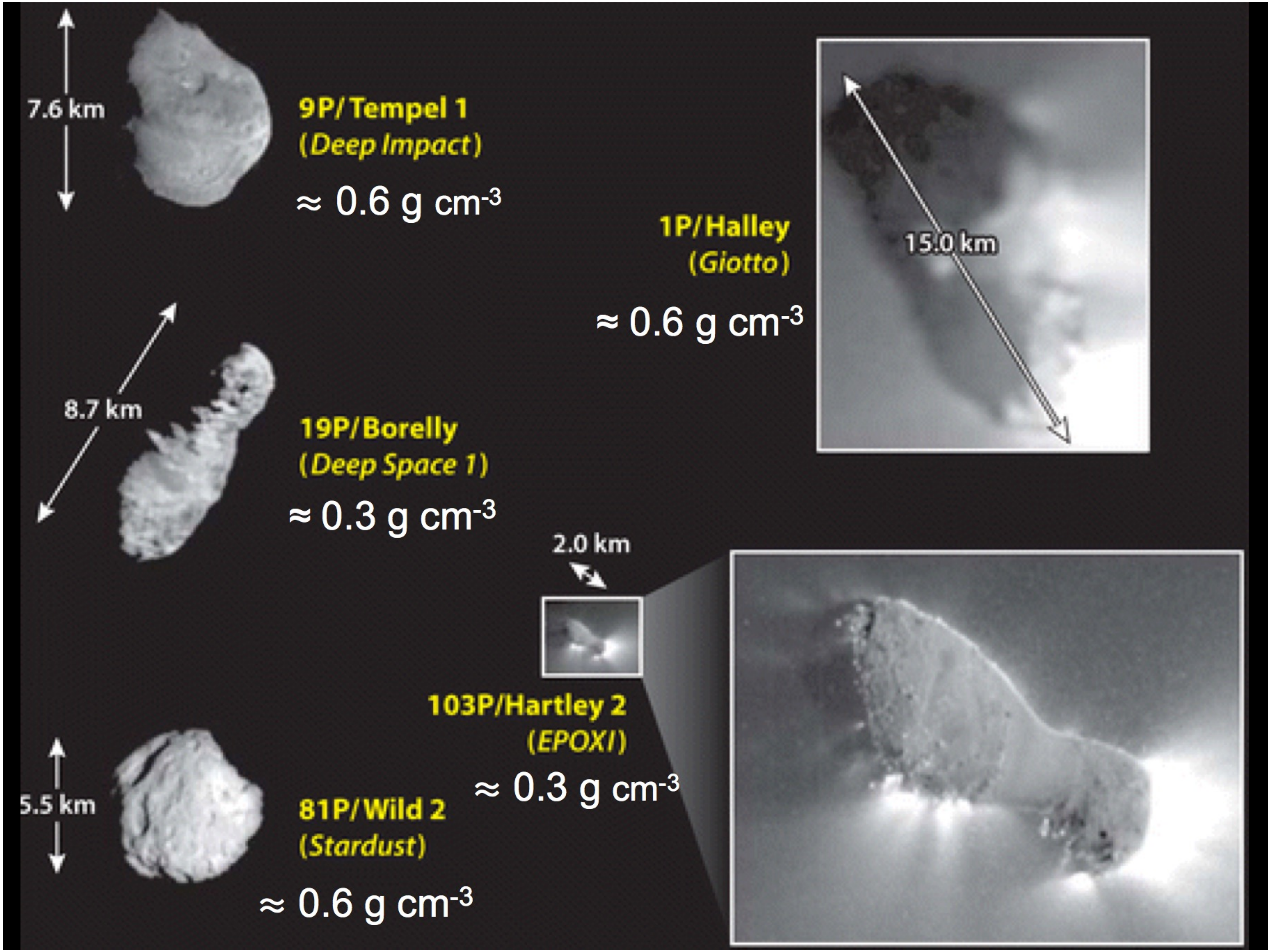


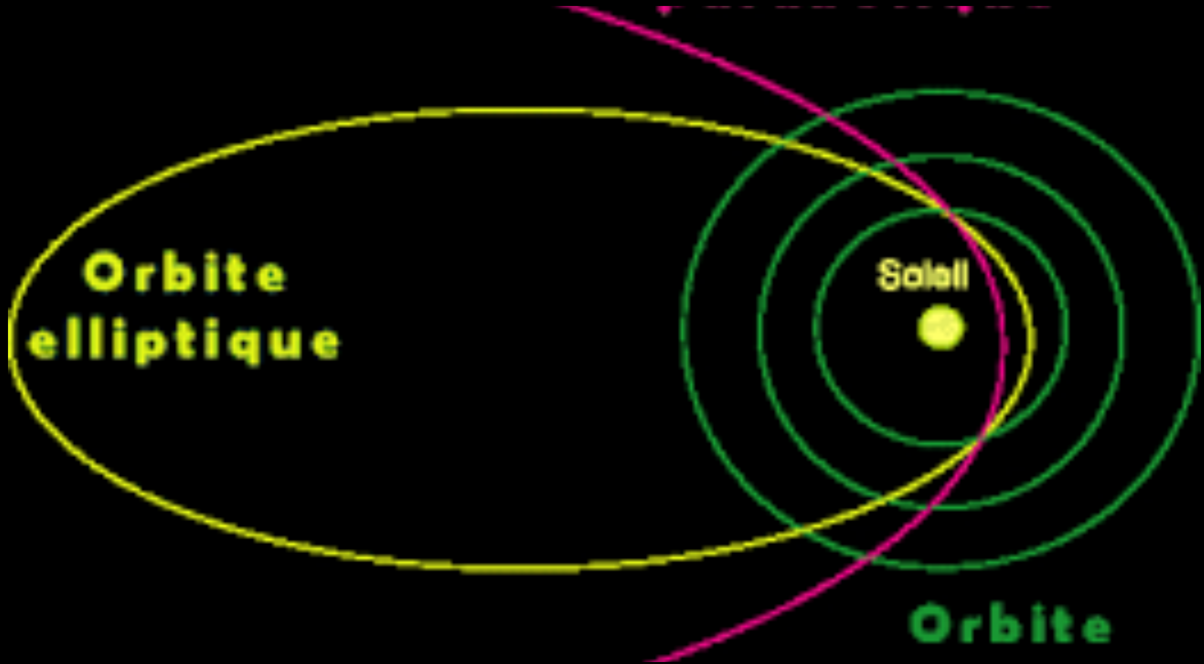
Comets families

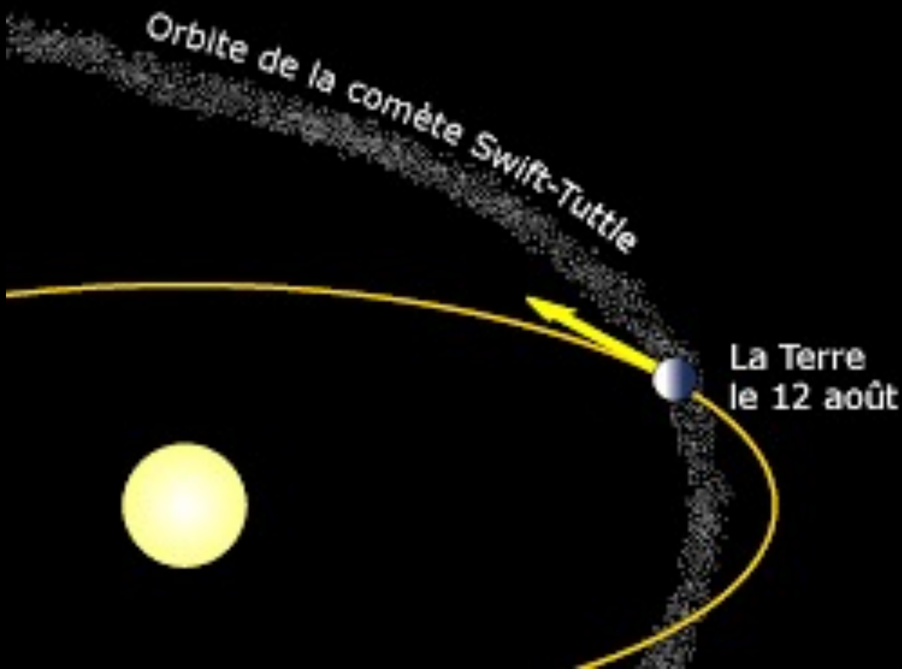


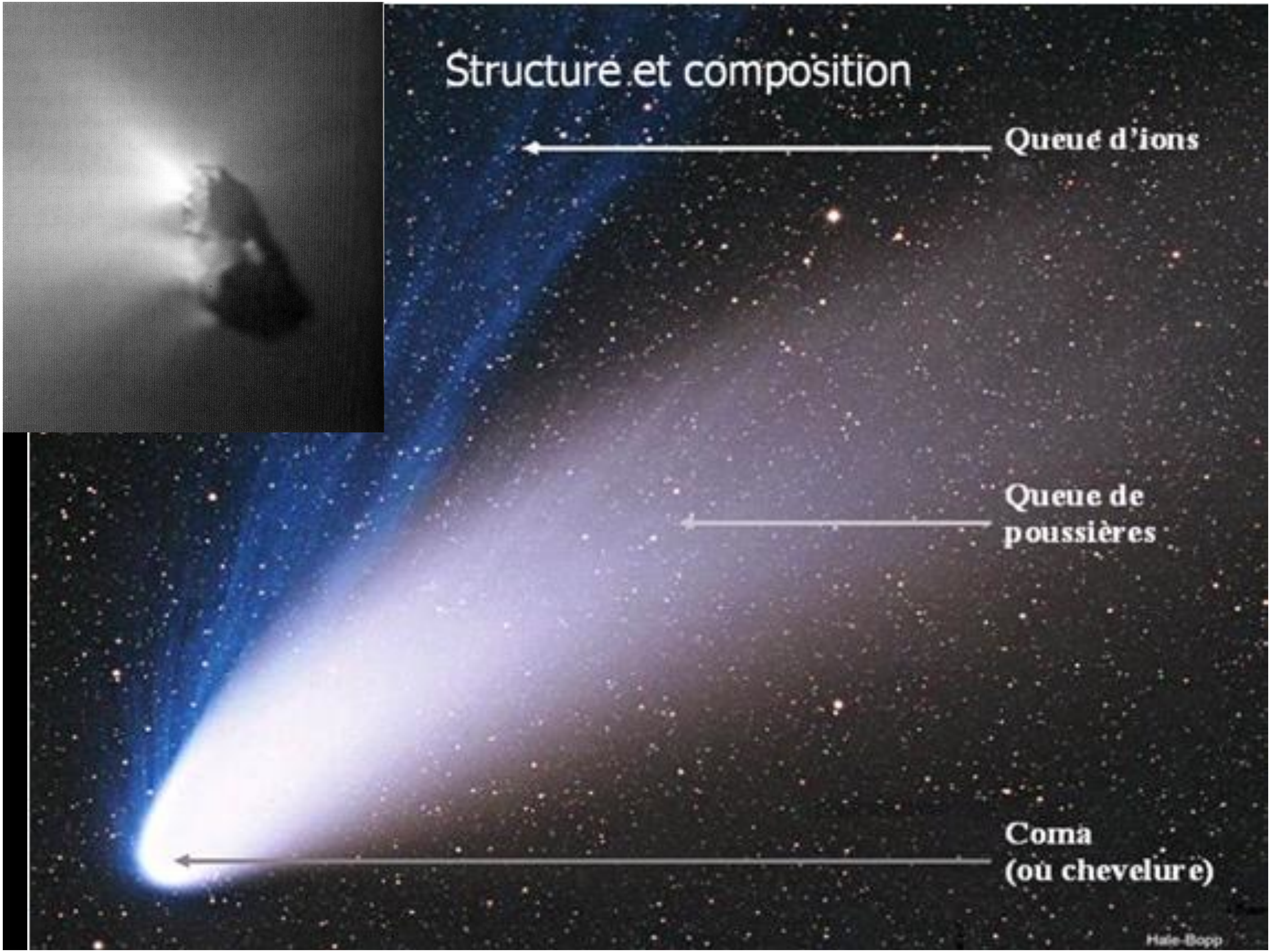


243 Ida - 58.8 × 25.4 × 18.6 km
Galileo, 1993
Dactyl
[(243) Ida I]
1.6 × 1.2 km
Galileo, 1993
9969 Braille
2.1 × 1 × 1 km
Deep Space 1, 1999
5535 Annefrank
6.6 × 5.0 × 3.4 km
Stardust, 2002
2867 Steins
5.9 × 4.0 km
Rosetta, 2008
433 Eros - 33 × 13 km
NEAR, 2000
25143 Itokawa
0.5 × 0.3 × 0.2 km
Hayabusa, 2005
253 Mathilde - 66 × 48 × 44 km
NEAR, 1997
951 Gaspra - 18.2 × 10.5 × 8.9 km
Galileo, 1991
21 Lutetia - 132 × 101 × 76 km
Rosetta, 2010
1P/Halley - 16 × 8 × 8 km
Vega 2, 1986
19P/Borrelly
8 × 4 km
Deep Space 1, 2001
9P/Tempel 1
7.6 × 4.9 km
Deep Impact, 2005
81P/Wild 2
5.5 × 4.0 × 3.3 km
Stardust, 2004

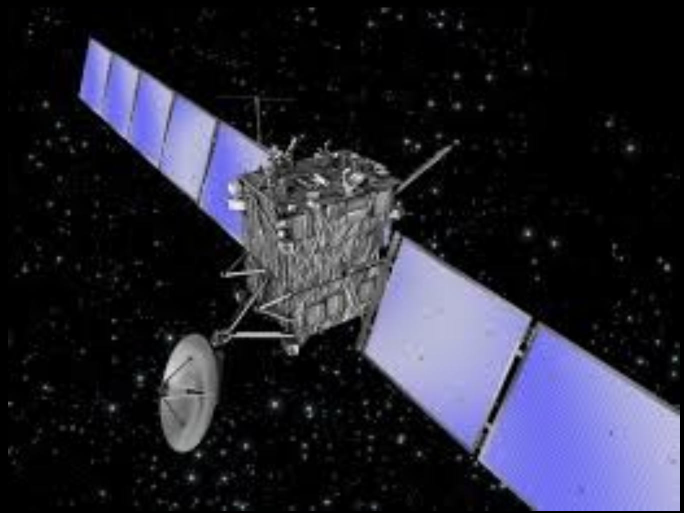

7.6 km
9P/Tempel 1
(Deep Impact)
≈ 0.6 g cm-3
1P/Halley
(Giotto)
≈ 0.6 g cm-3
15.0 km
8.7 km
19P/Borelly
(Deep Space 1)
≈ 0.3 g cm-3
2.0 km
103P/Hartley 2
(EPOXI)
≈ 0.3 g cm-3
5.5 km
81P/Wild 2
(Stardust)
≈ 0.6 g cm-3

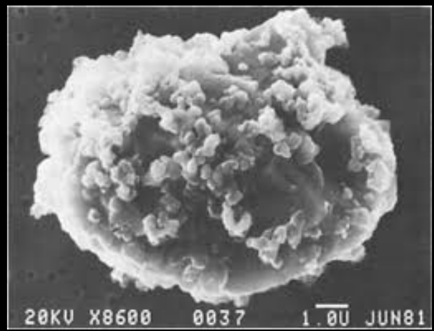

Orbite
elliptique
Soleil
Orbite

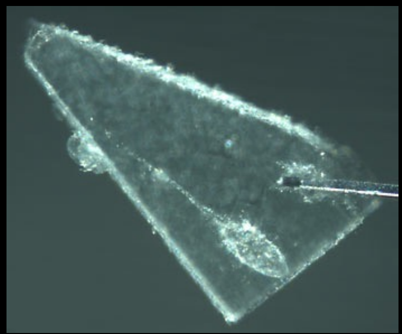

Orbite de la comète Swift-Tuttle
La Terre
le 12 août


Structure et composition
Queue d'ions
Queue de poussières
Coma (ou chevelure)
Hale-Bopp

Comment étudie-t-on les comètes ?

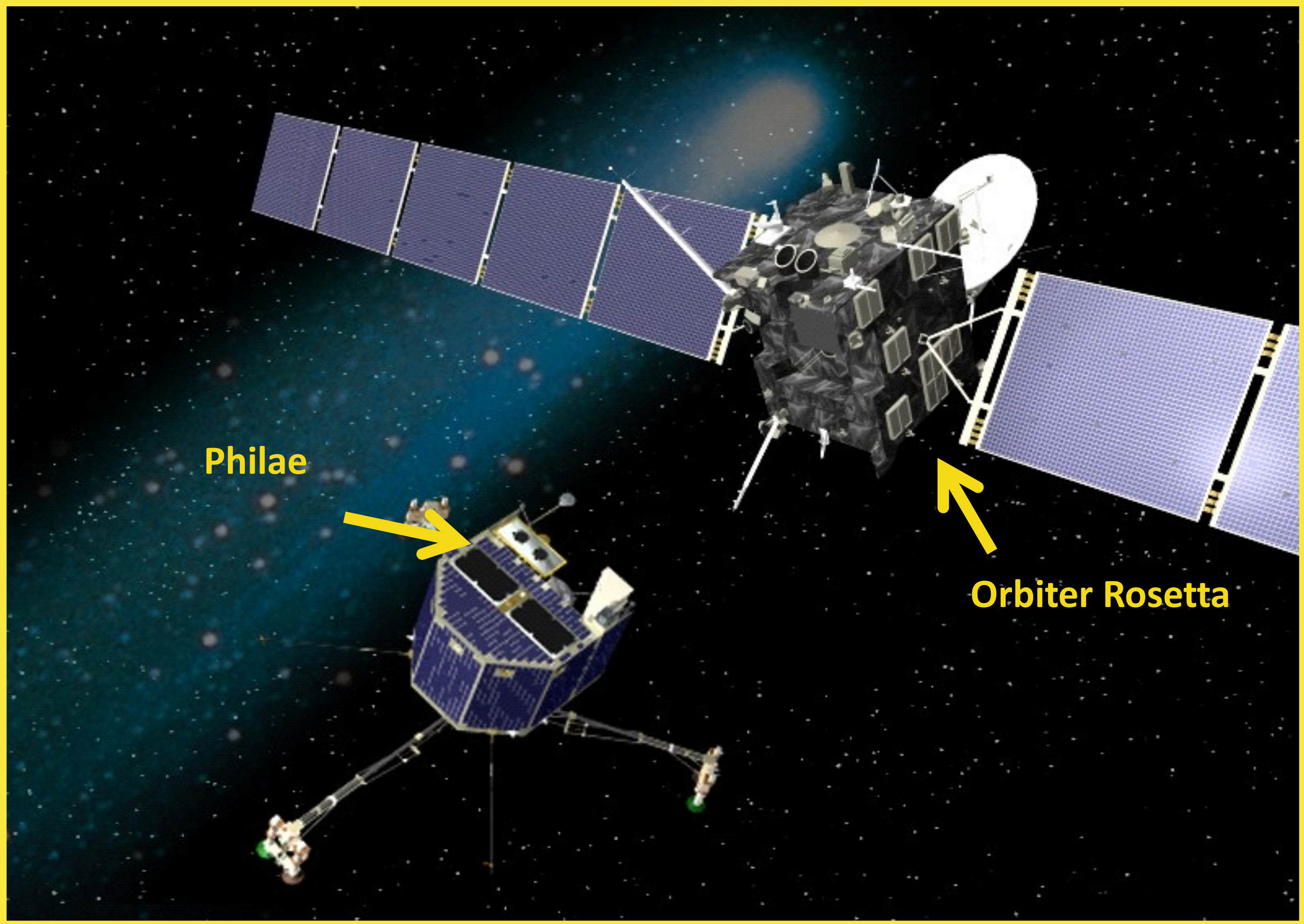


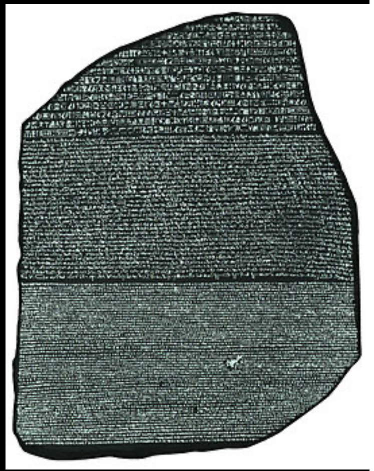




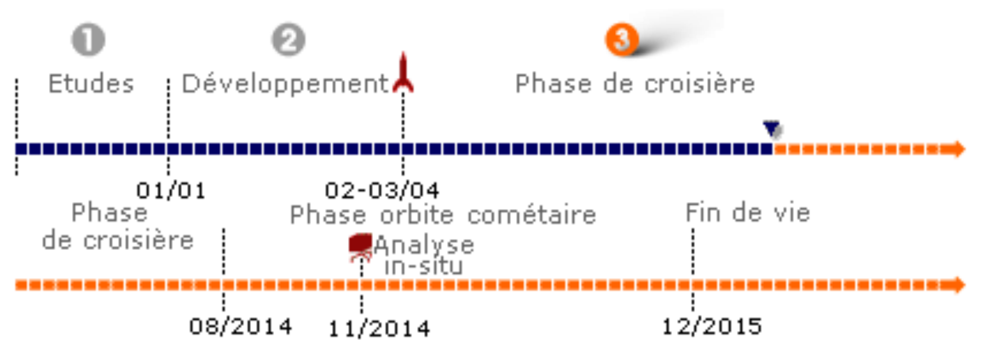
ROSETTA: A Comet rendezvous Mission + Philae lander for in situ studies

study the origin of comets, the relationship between cometary and interstellar material and its implications with regard to the origin of the solar system.

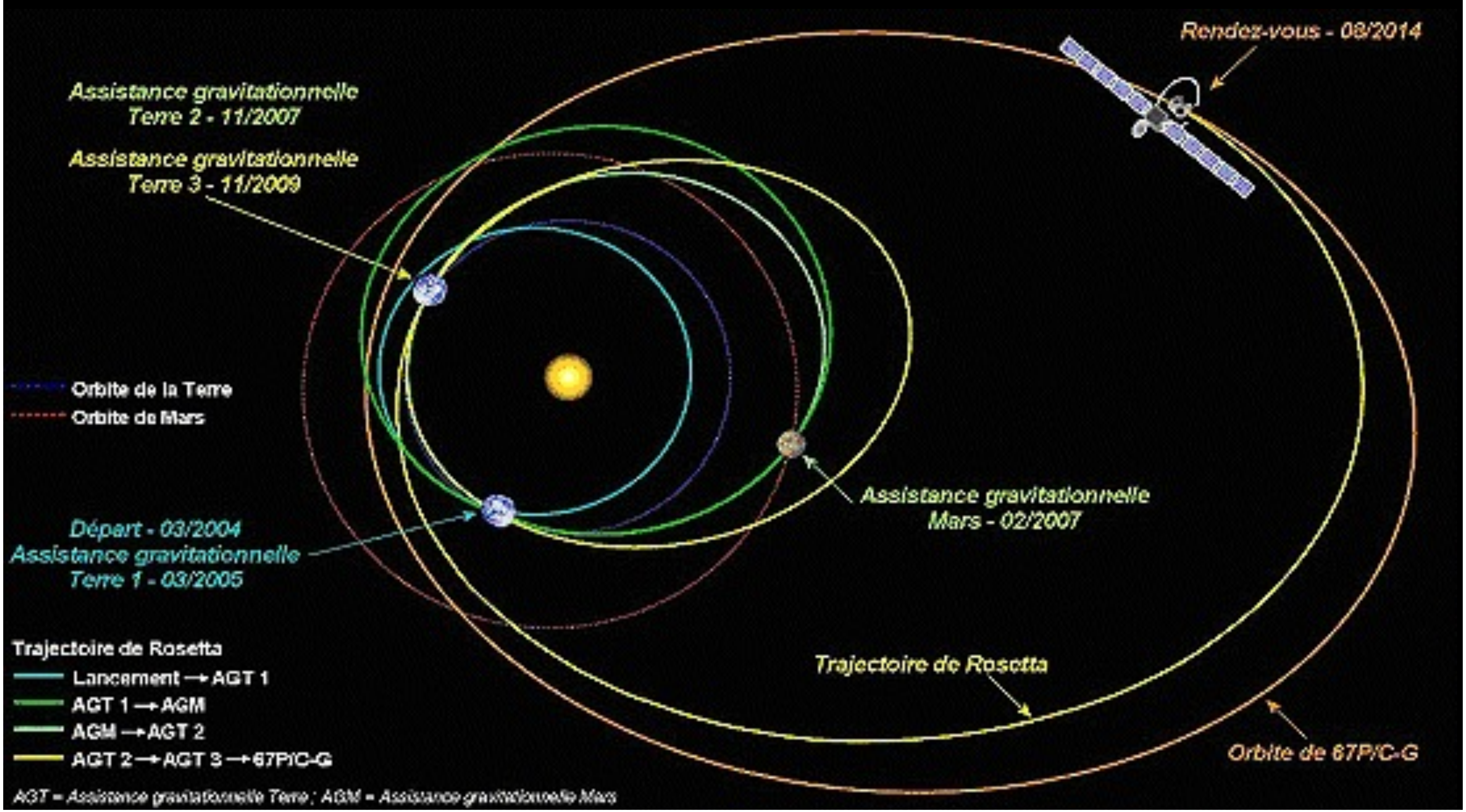




ESA-ROSETTA



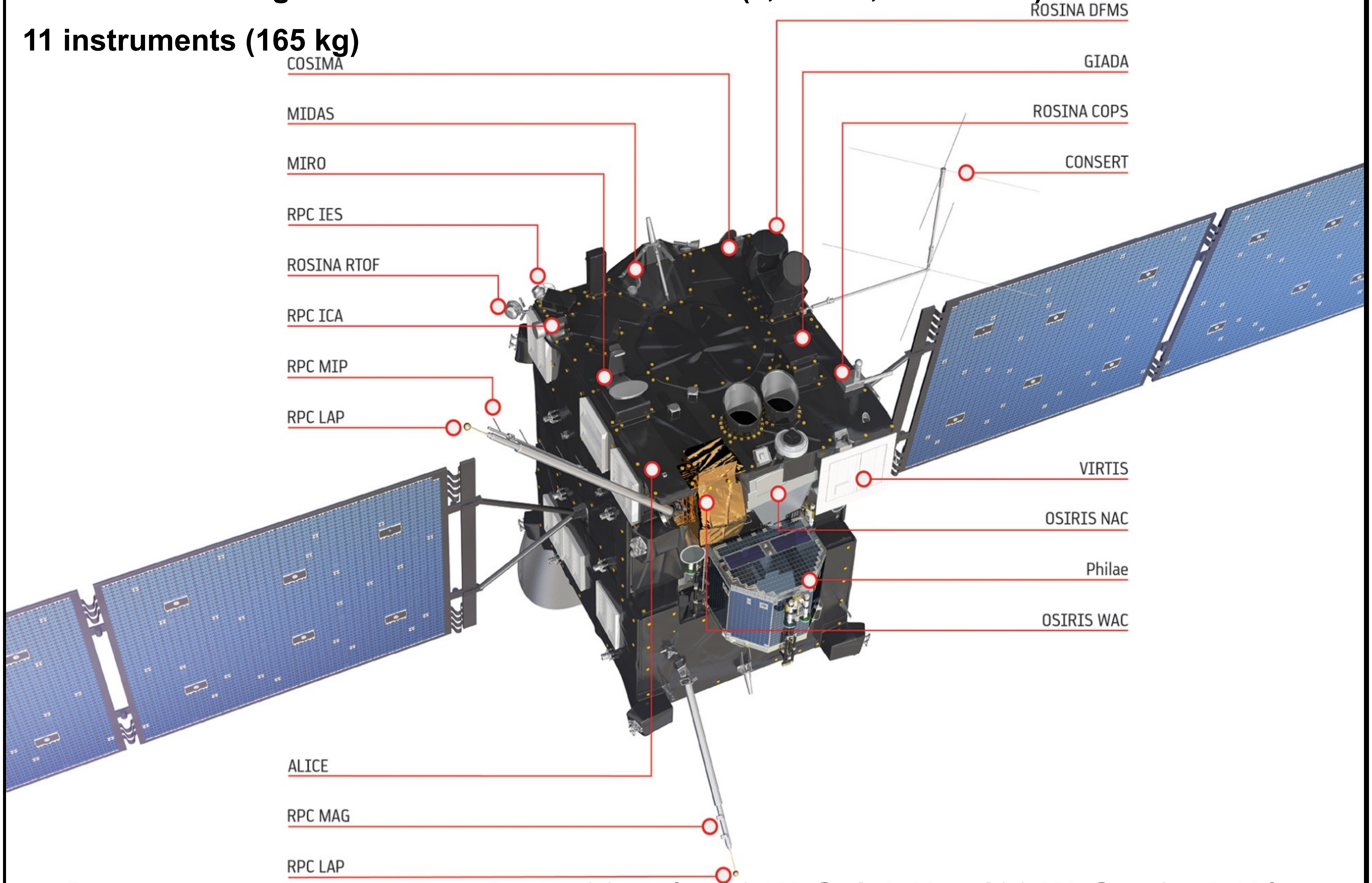
Etudes
Développement
Phase de croisière
01/01
02-03/04
Phase de croisière
Phase orbite cométaire
Analyse in-situ
Fin de vie
08/2014
11/2014
12/2015



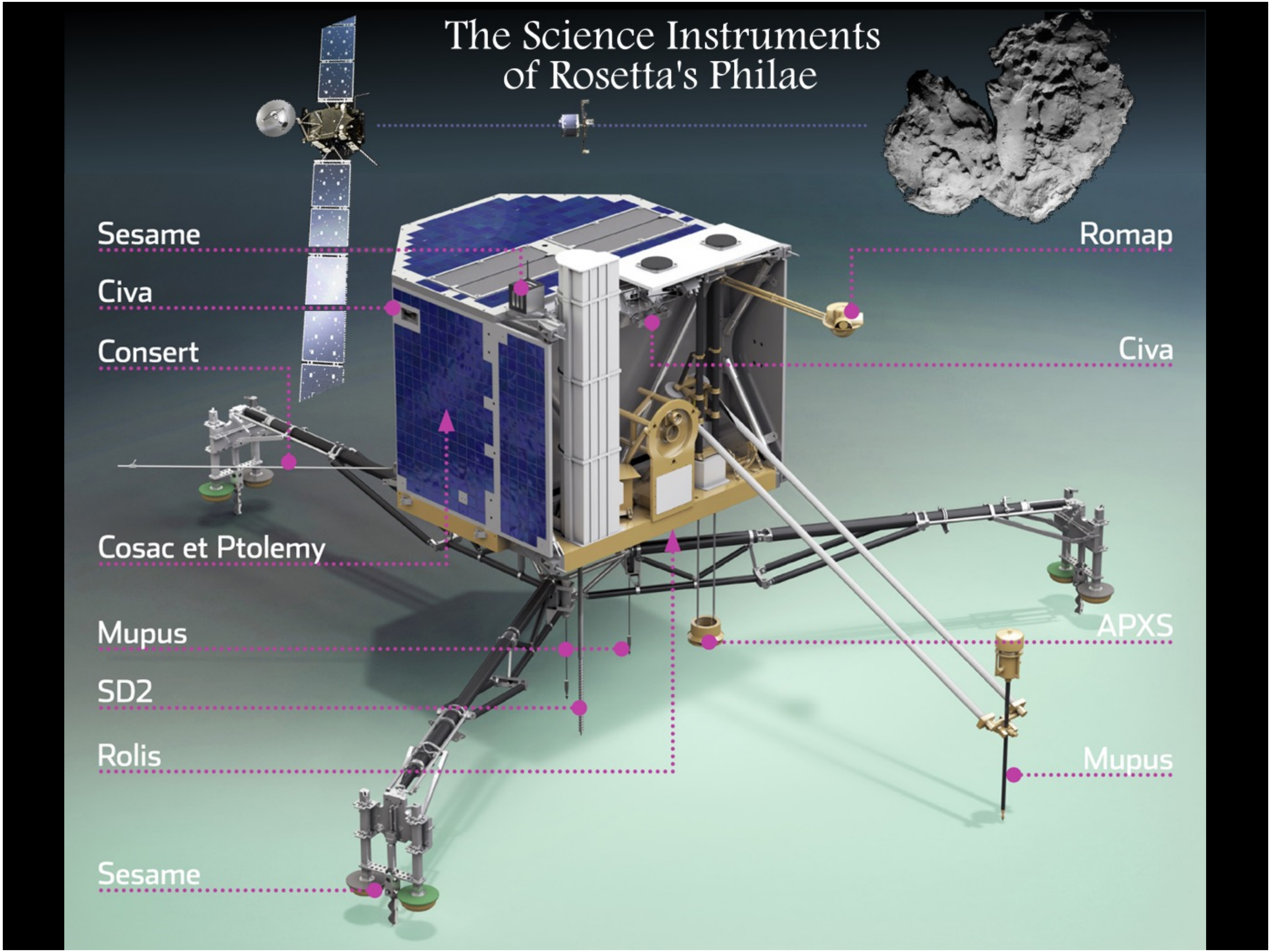
Rendez-vous - 08/2014
Assistance gravitationnelle Terre 2 - 11/2007
Assistance gravitationnelle Terre 3 - 11/2009
Orbite de la Terre
Orbite de Mars
Assistance gravitationnelle Mars - 02/2007
Départ - 03/2004
Assistance gravitationnelle Terre 1 - 03/2005
Trajectoire de Rosetta
Lancement → AGT 1
AGT 1 → AGM
AGM → AGT 2
AGT 2 → AGT 3 → 67P/C-G
Trajectoire de Rosetta
Orbite de 67P/C-G
AGT = Assistance gravitationnelle Terre ; AGM = Assistance gravitationnelle Mars

Masse au décollage : 3.0 t dont 1.7 t de carburant (2,8m x 2,1m x 2.0 m)

11 instruments (165 kg)



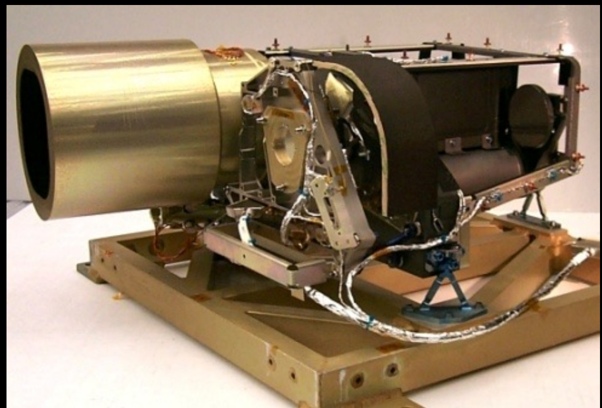
Panneaux solaires: envergure : 32 m (5700 W @ 1 A.U. - 400 W @ 5.25 A.U.)


The Science Instruments
of Rosetta's Philae
Sesame
Civa
Consert
Cosac et Ptolemy
Mupus
SD2
Rolis
Sesame
Romap
Civa
APXS
Mupus

OSIRIS

- H. Sierks (PI,Max Planck MPS, Gottingen),

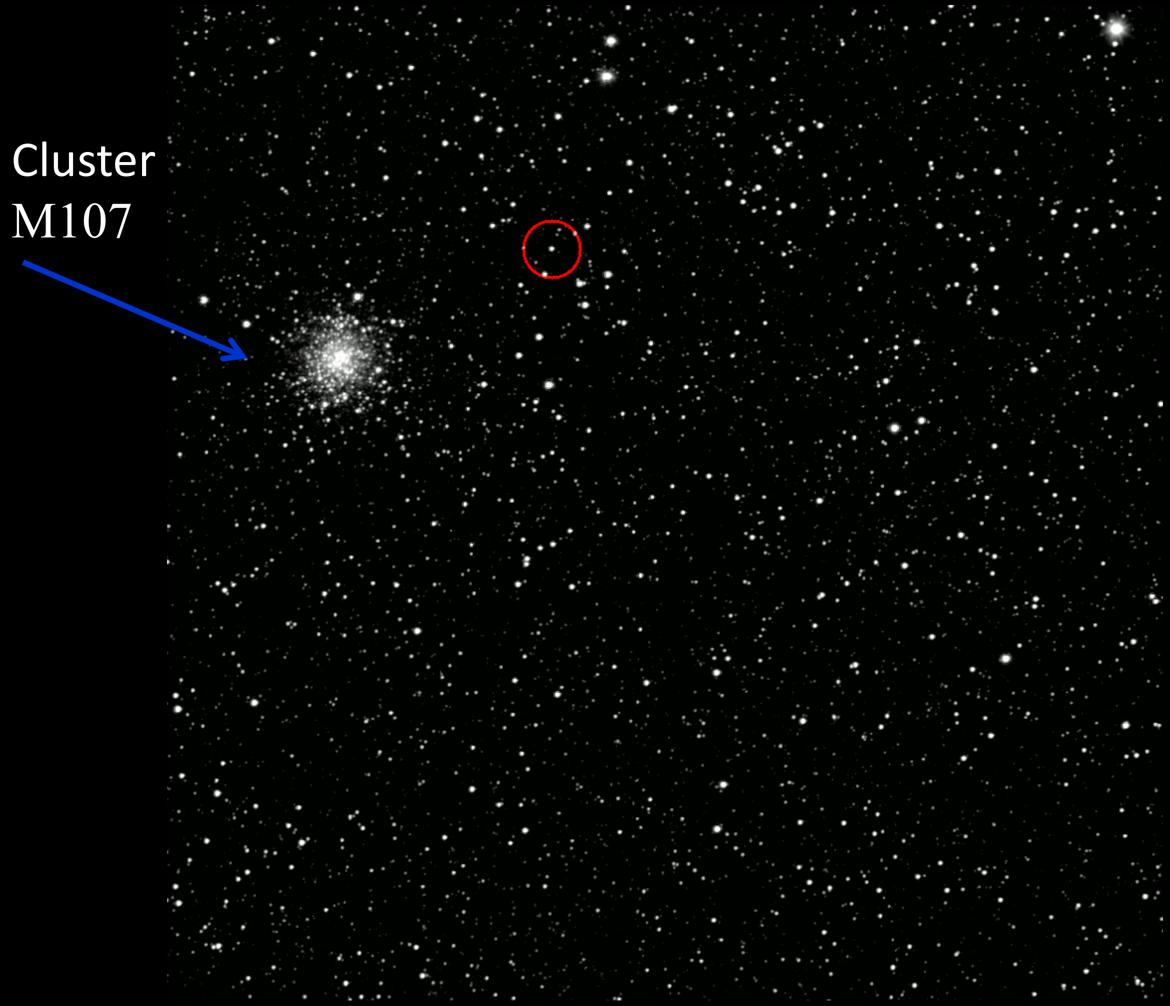
NAC
FOV 2.2x2.2 °, 3 mirrors
4”/px, f/8



WAC
FOV 12x12°, 2 mirrors
21 “/px f/5.6

NAC: 11 Filters [250-1000 nm] +2 Ire-focussing lens
WAC: 14 Filters [230-750 nm]
CCD: 2048 x 2048 pixel ; squared pixel =13.5 μm

Premières images



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

OSIRIS-Caméra NAC
24 Mars - 4 May

5 →2 millions km from 67P

Solar dist: 4 AU

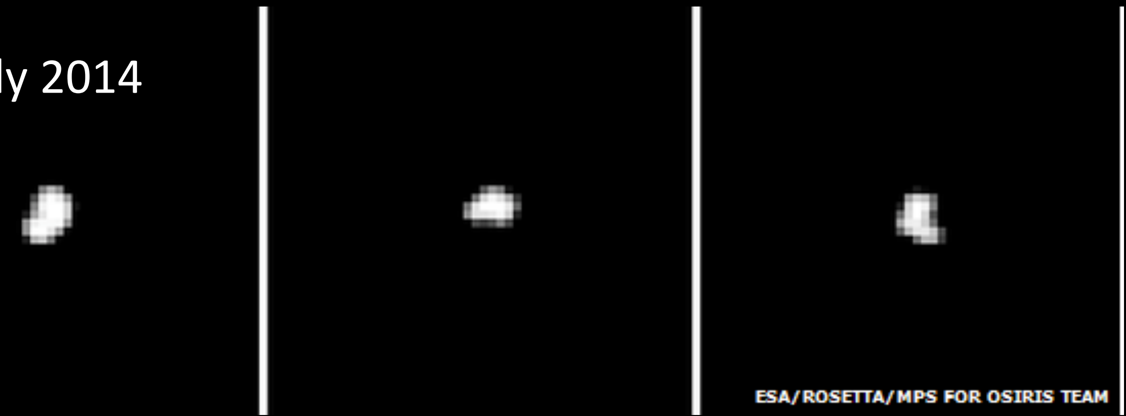
Outburst during 27 -- 30 April 2014

•Coma 1300 km wide, originated by volatils like CO and CO_2

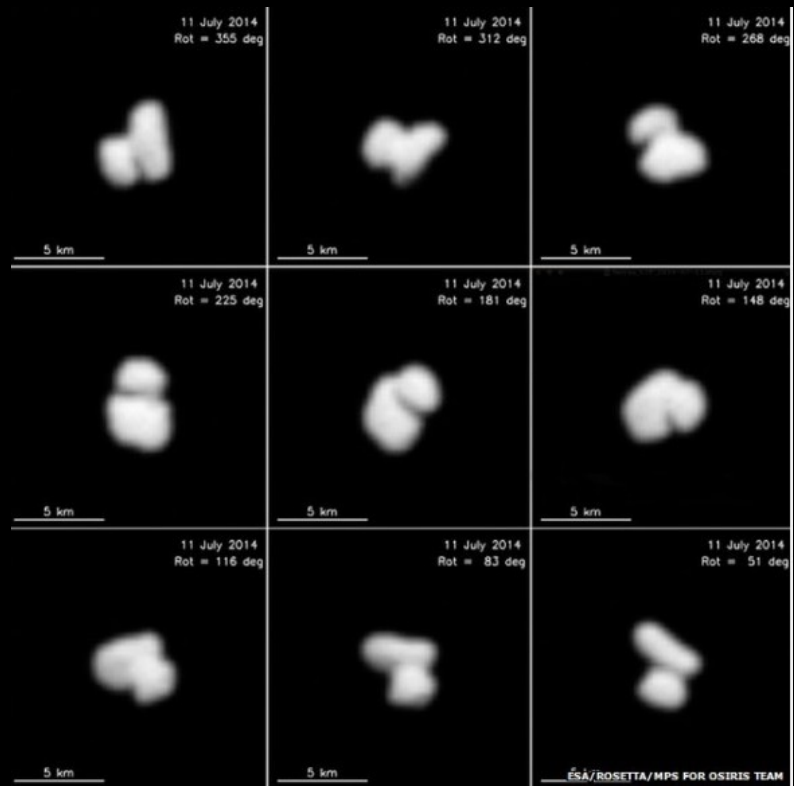
Juillet 2014 : première surprise…

Lamy et al. (2007)
HST observations

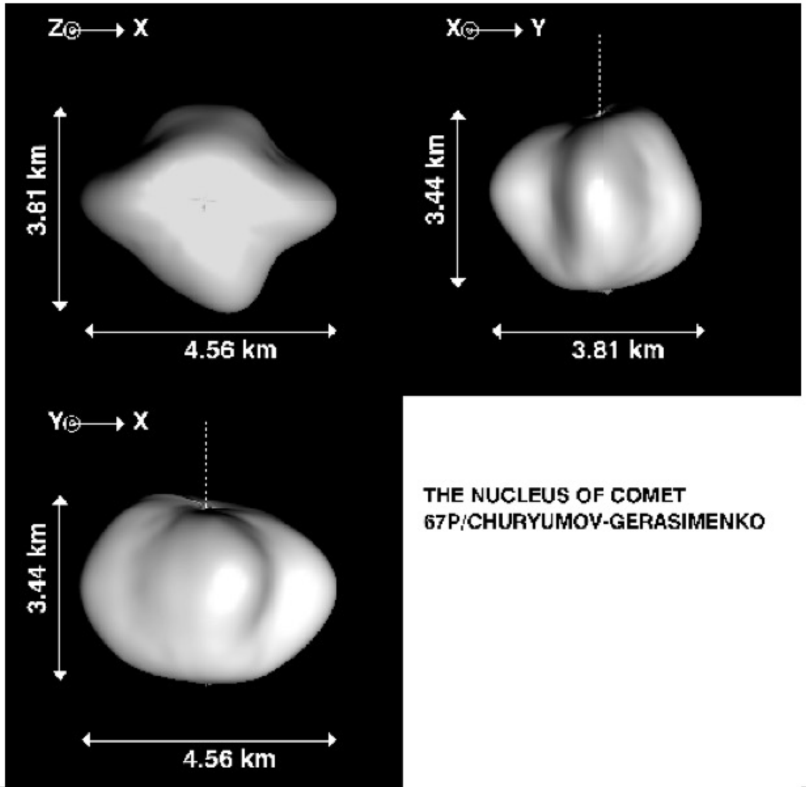
7 July 2014

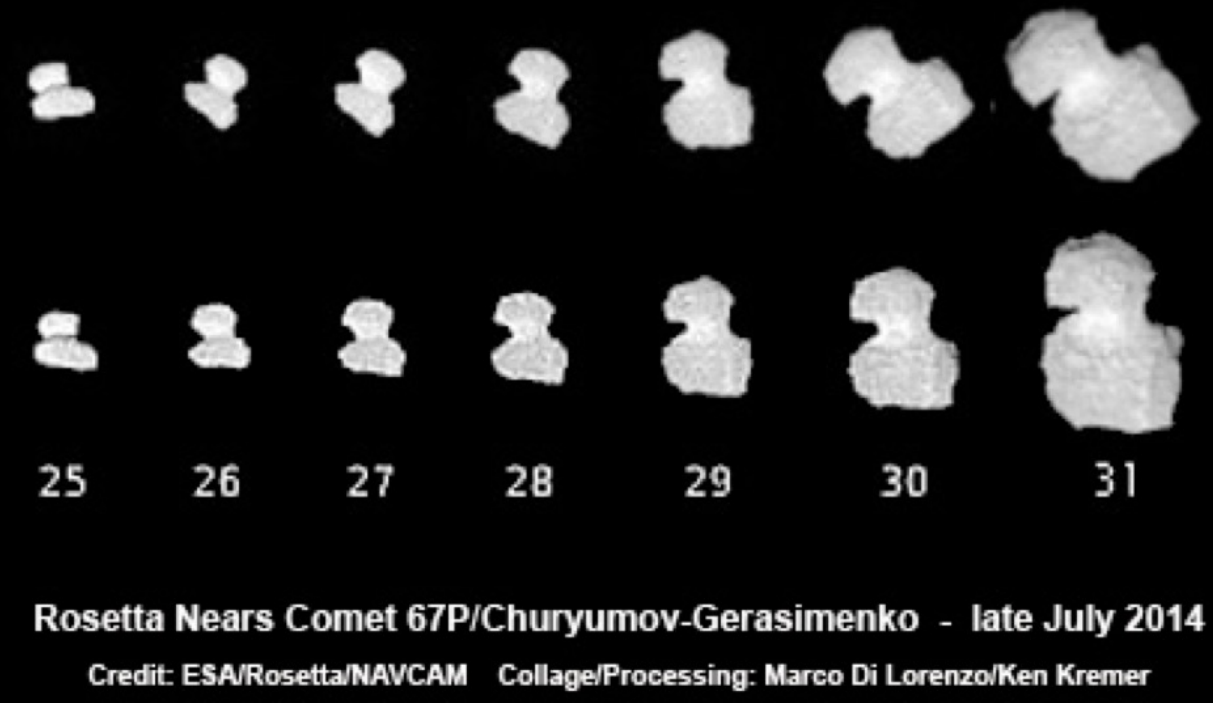


11 July2014

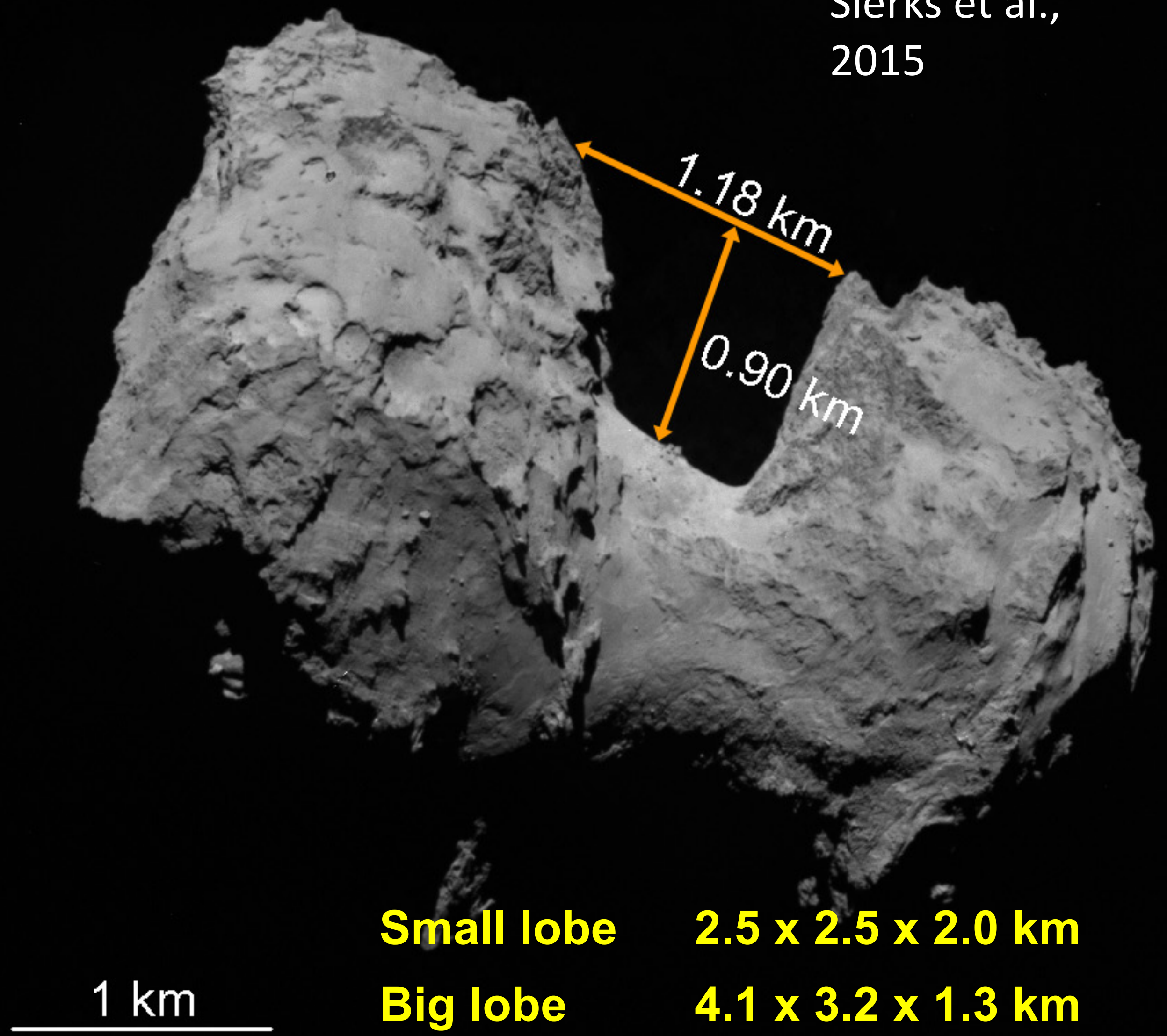


Binary shape with 2 lobes!


Z → X
3.81 km
4.56 km
X → Y
3.44 km
3.81 km
Y → X
3.44 km
4.56 km
THE NUCLEUS OF COMET
67P/CHURYUMOV-GERASIMENKO


25
26
27
28
29
30
31
Rosetta Nears Comet 67P/Churyumov-Gerasimenko - late July 2014
Credit: ESA/Rosetta/NAVCAM Collage/Processing: Marco Di Lorenzo/Ken Kremer

Nucleus physical properties



Small lobe 2.5 x 2.5 x 2.0 km

Big lobe 4.1 x 3.2 x 1.3 km

70% of the surface observed

$V=21.4\pm2.0$ km^3

Mass = 10^{13} kg

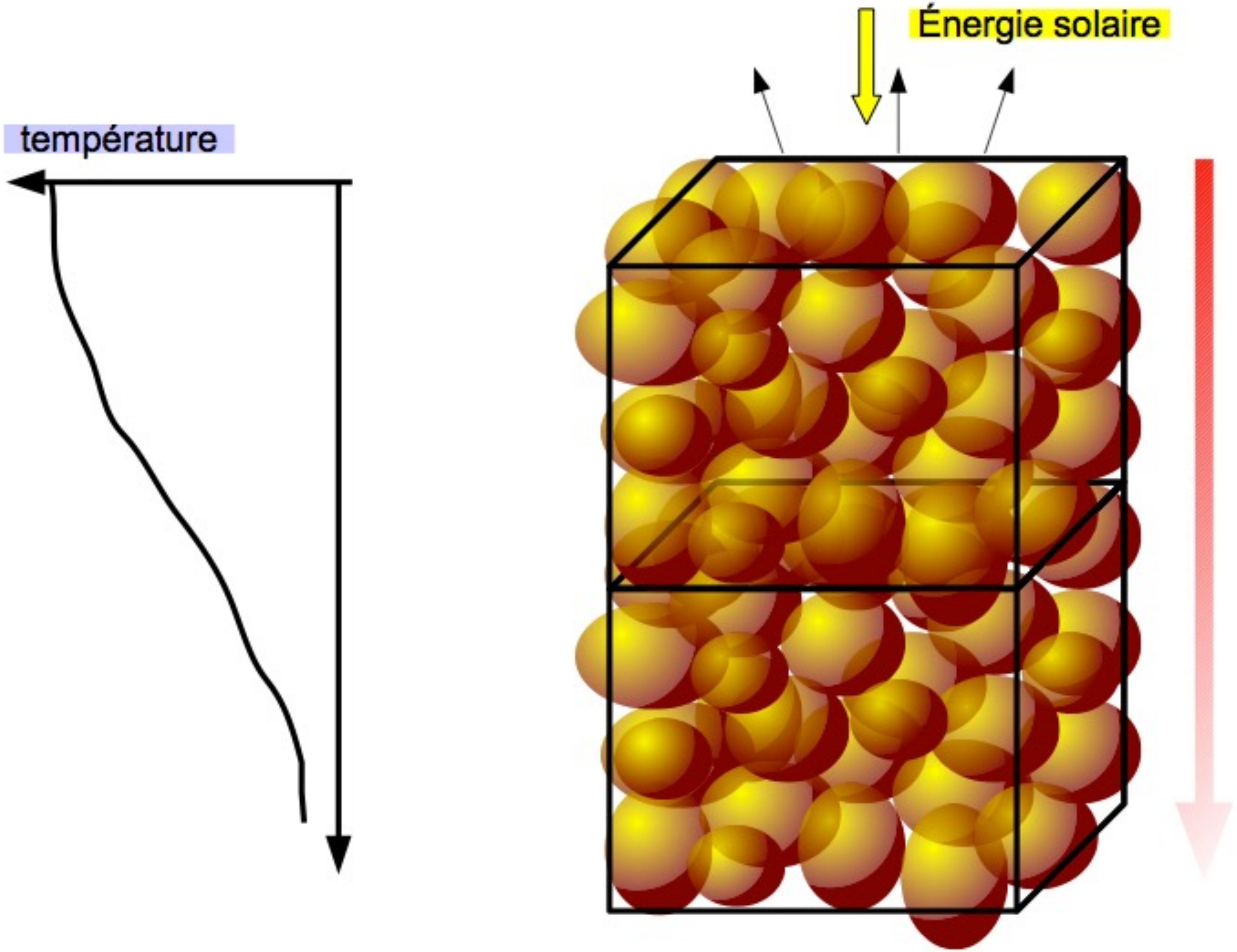
$\rho=470 \pm45$ kg/m^3

Porosity: 70-80%

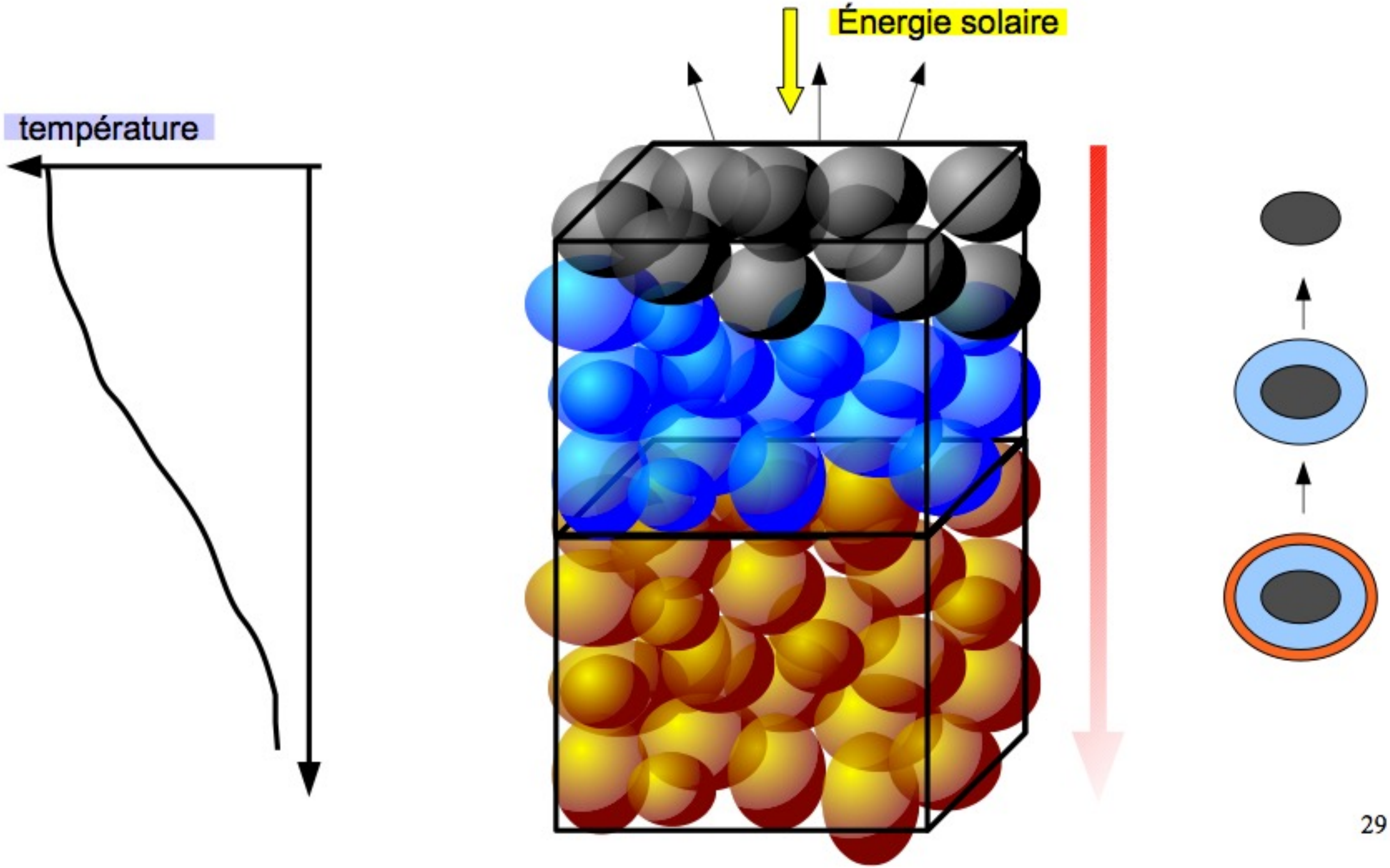
Nucleus structure

- **contact binary?**
- **monolith?**

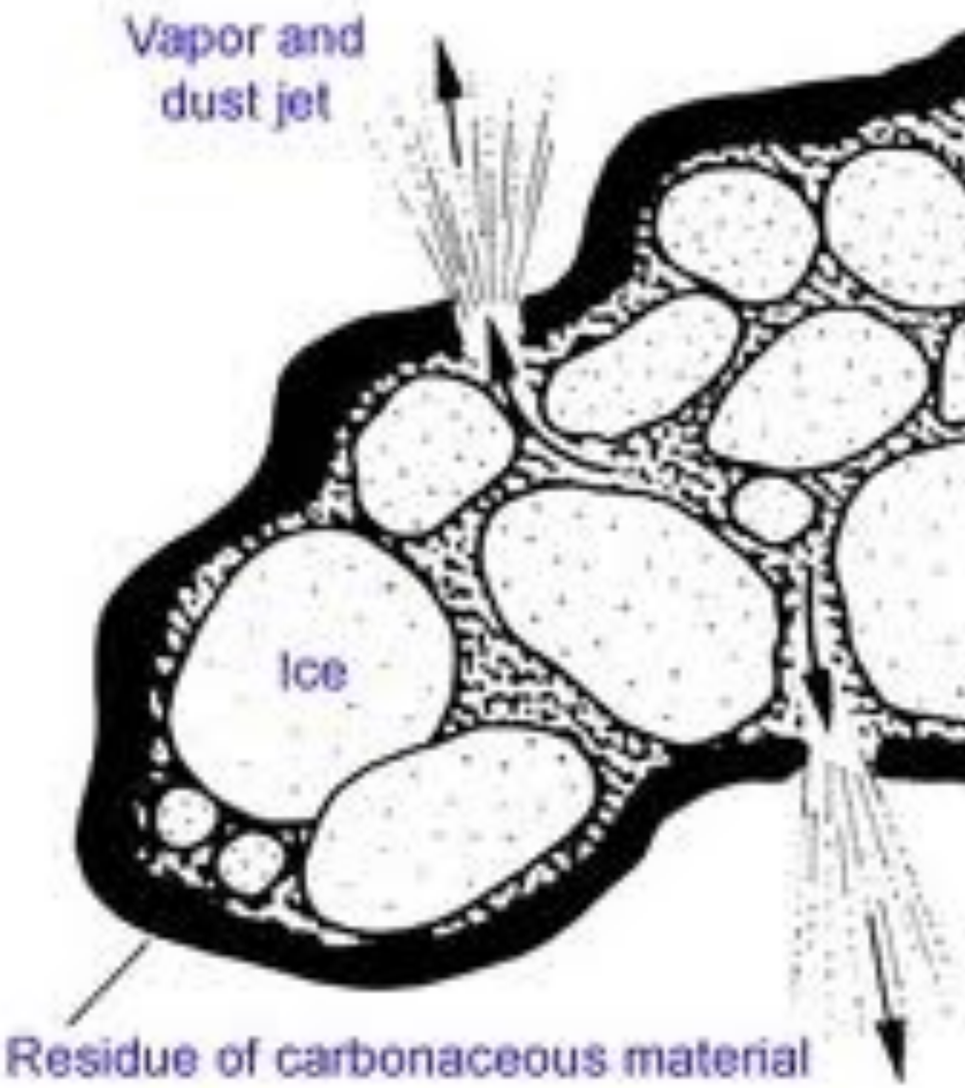
Différenciation d'un noyau cométaire



Différenciation d'un noyau cométaire



[redacted]

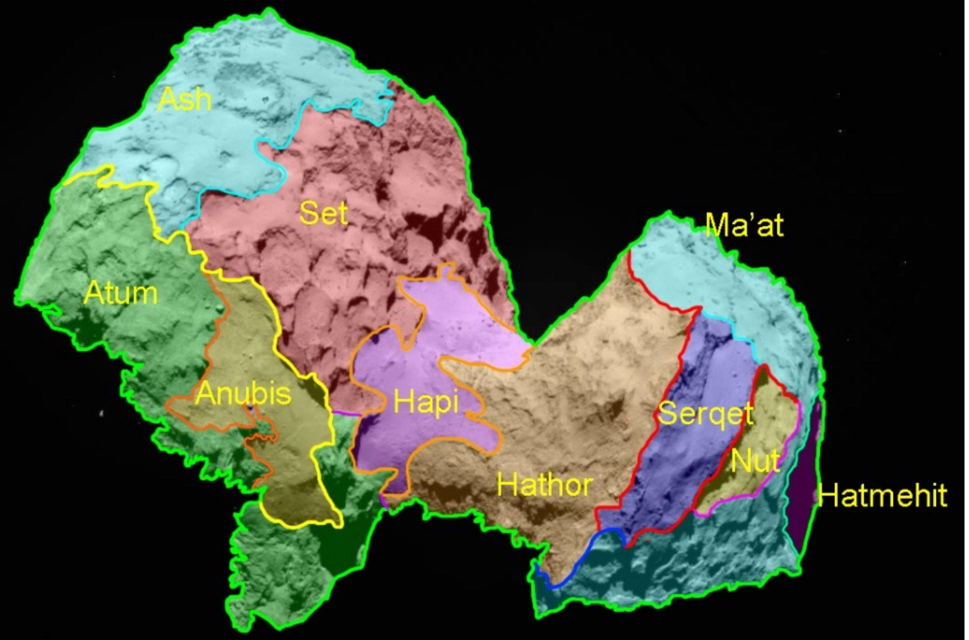


[redacted]

Different geological structures indicating erosion, re-deposition of materials

Fragile terrains with pits: Seth

Big depressions : Aten, Hatmehit, Nut

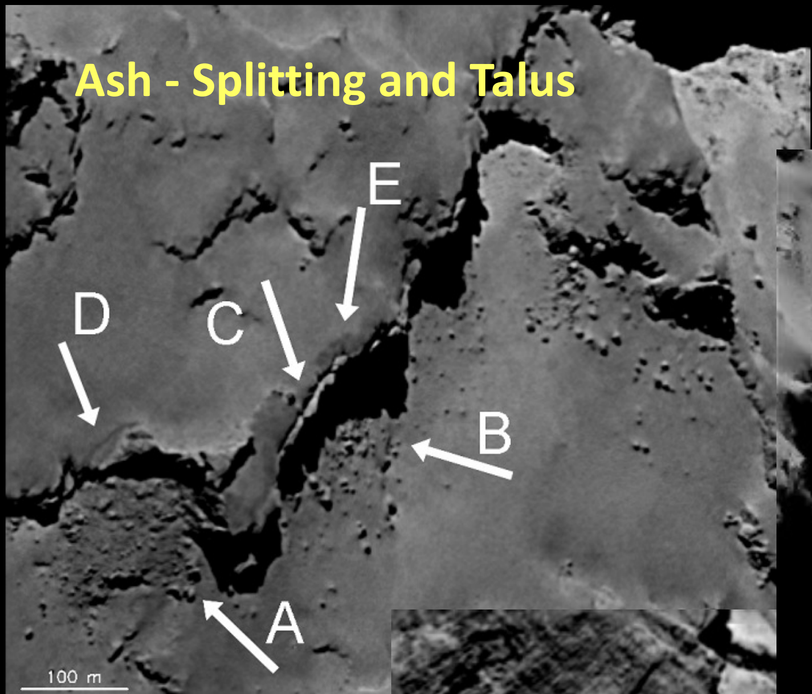


surfaces covered by regolith : Ash, Babi, Ma'at

Rocky consolidated materials surfaces: Aker, Anuket, Apis, Atum, Bastet, Hathor, Khepry, Maftet, Serqet.

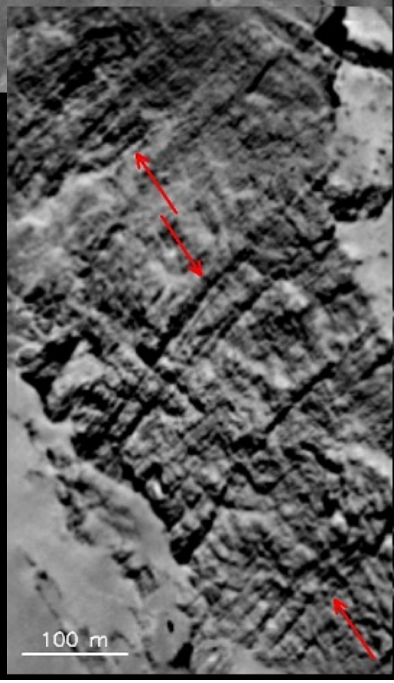
Smooth terrains : Anubis, Hapi, Imhotep

The nucleus is heavily fractured at several scales; fractures produced by the rapid heating–cooling cycles that are experienced cometary day and orbit

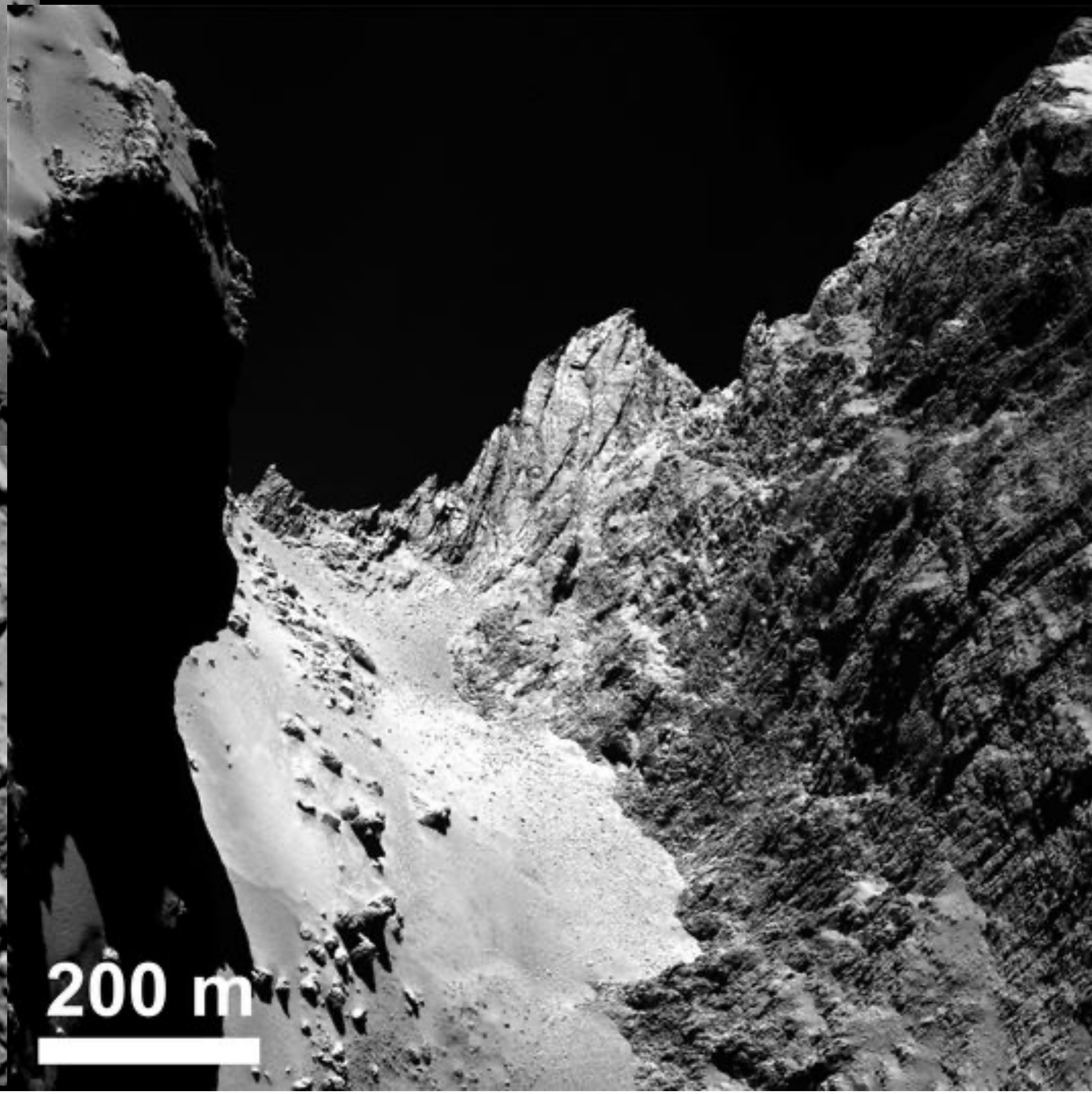


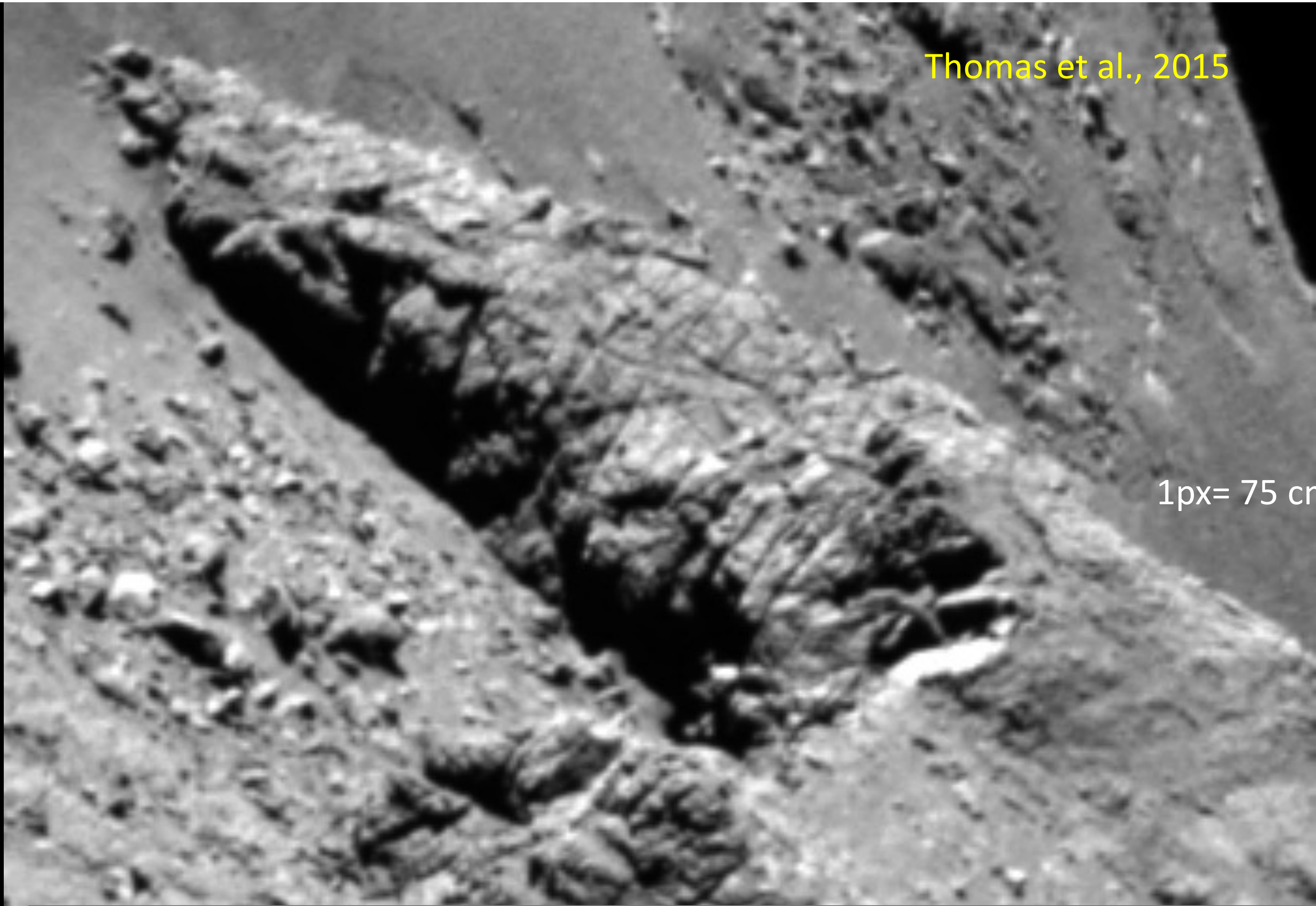
Low structural strength
(< 20 Pa)

Thomas et al., 2015



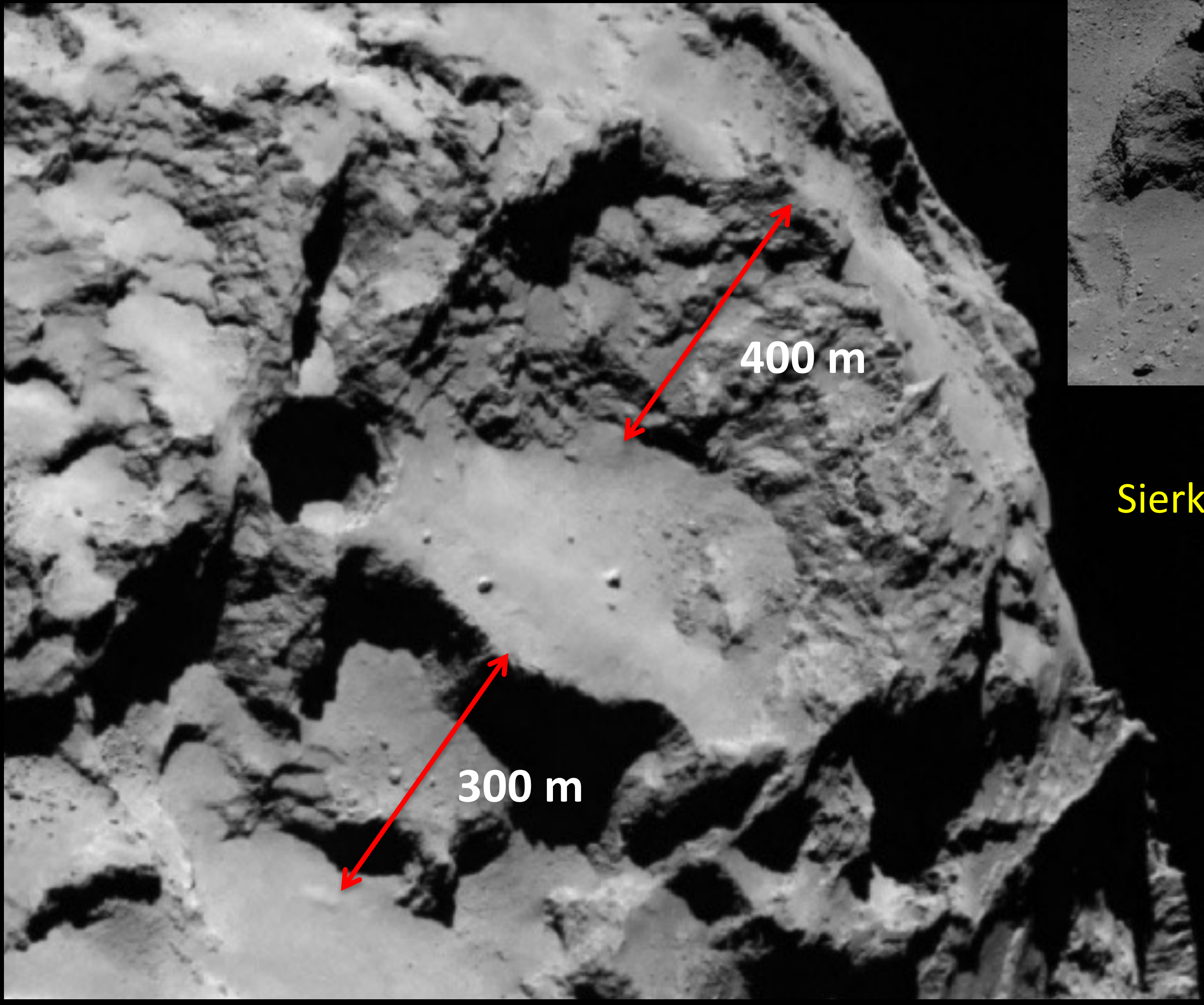
Aker Region: 200 m long fractures in a more consolidated material.

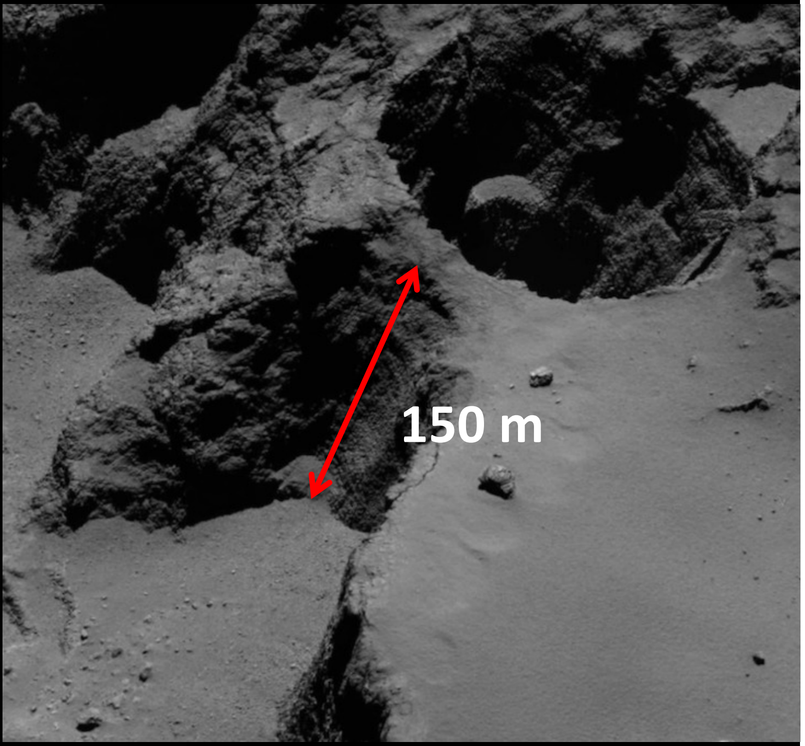




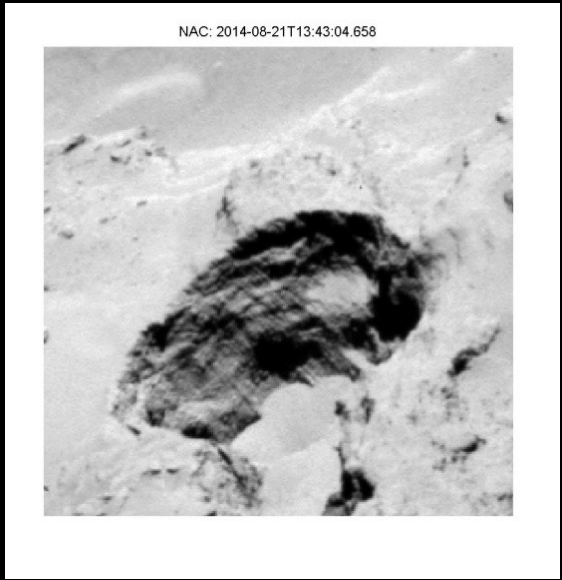
Small-scale cracking possibly resulting from insolation weathering

Seth region: pits





Sierks et al., 2015

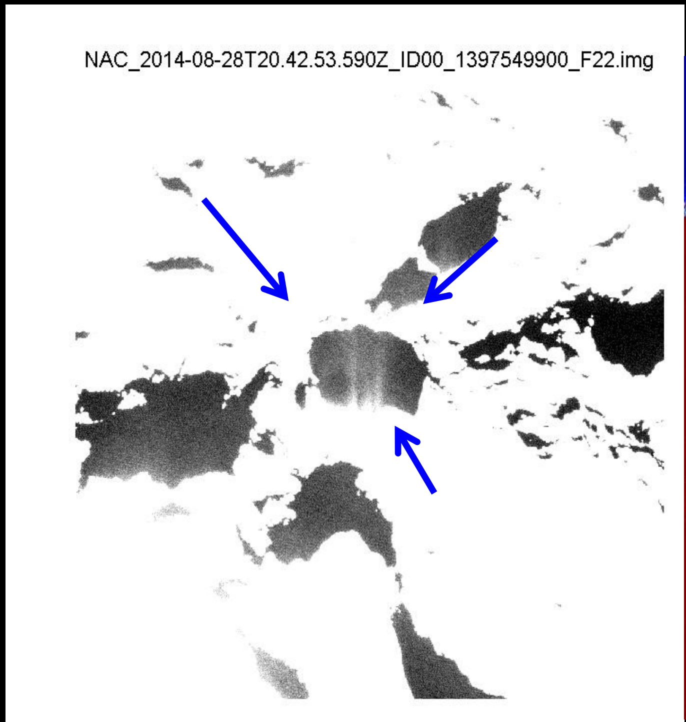


Puits actifs

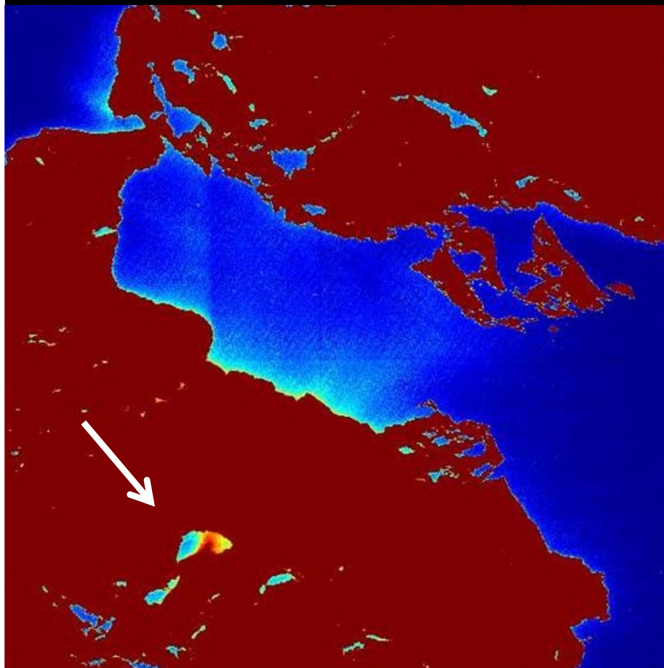
- The pit has a very peculiar morphology, with horizontal layers and vertical striations.
- Many jets can be linked to this hole, apparently starting from the bright walls on both sides.

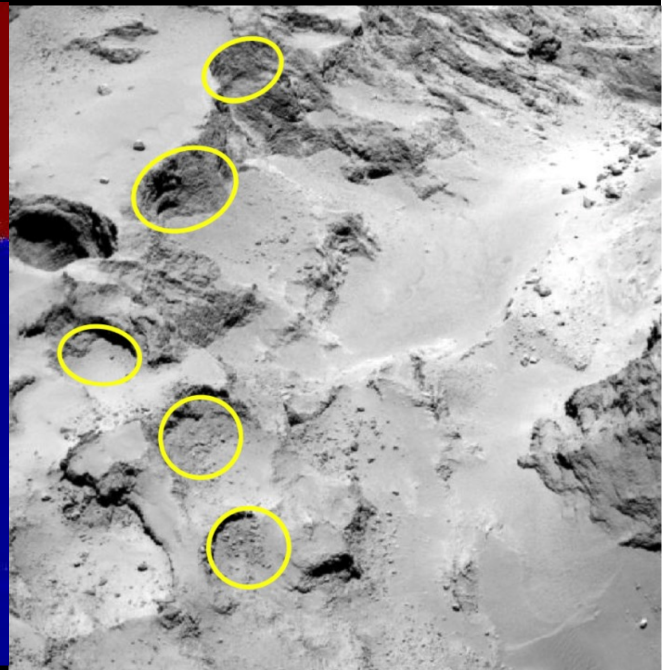
Diameter : 50-300 m, depth 10-200 m

→endogenic activity: explosive activity + collapse processes

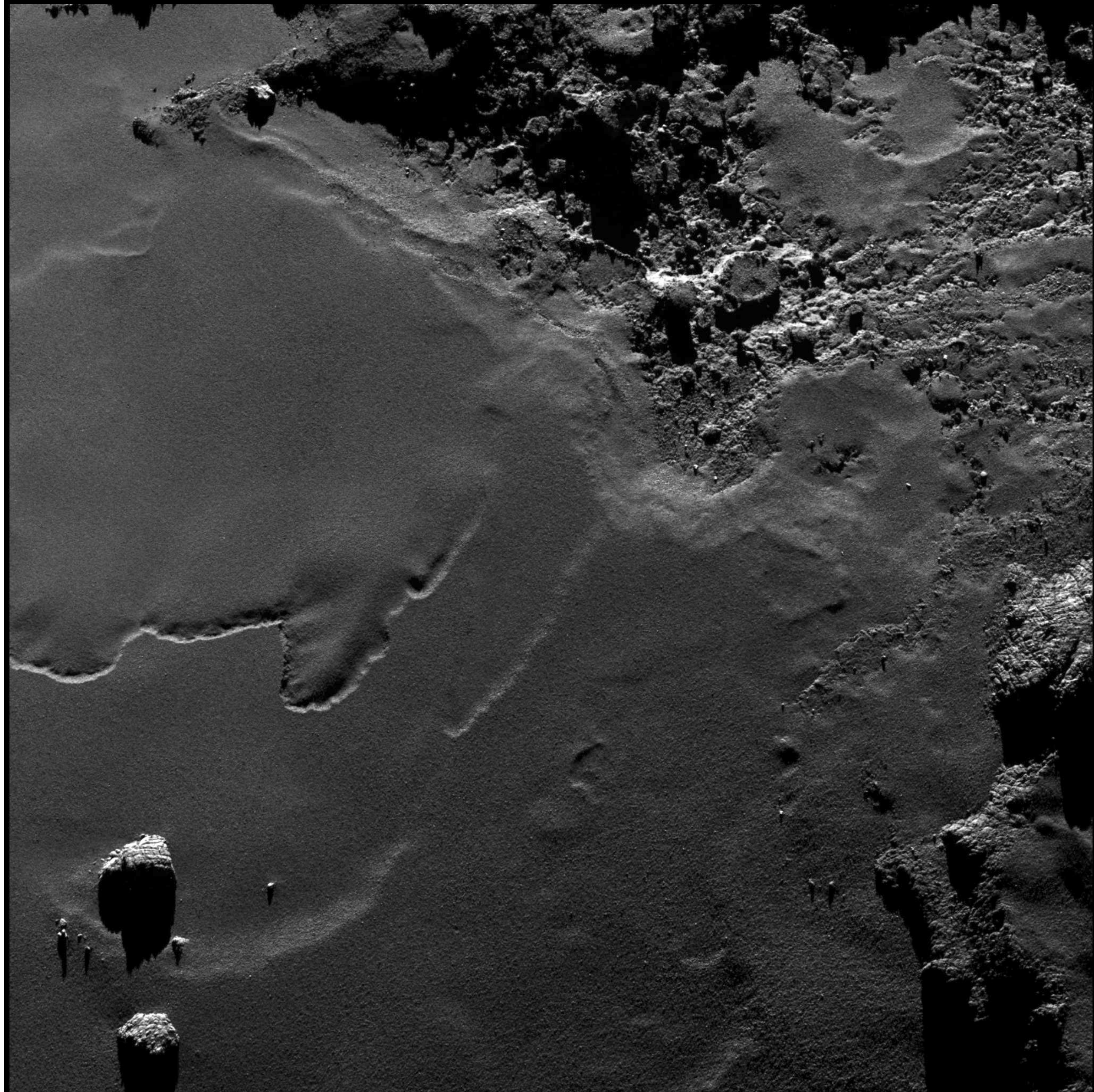


Vincent et al., 2015





Imothep: terrains lisses

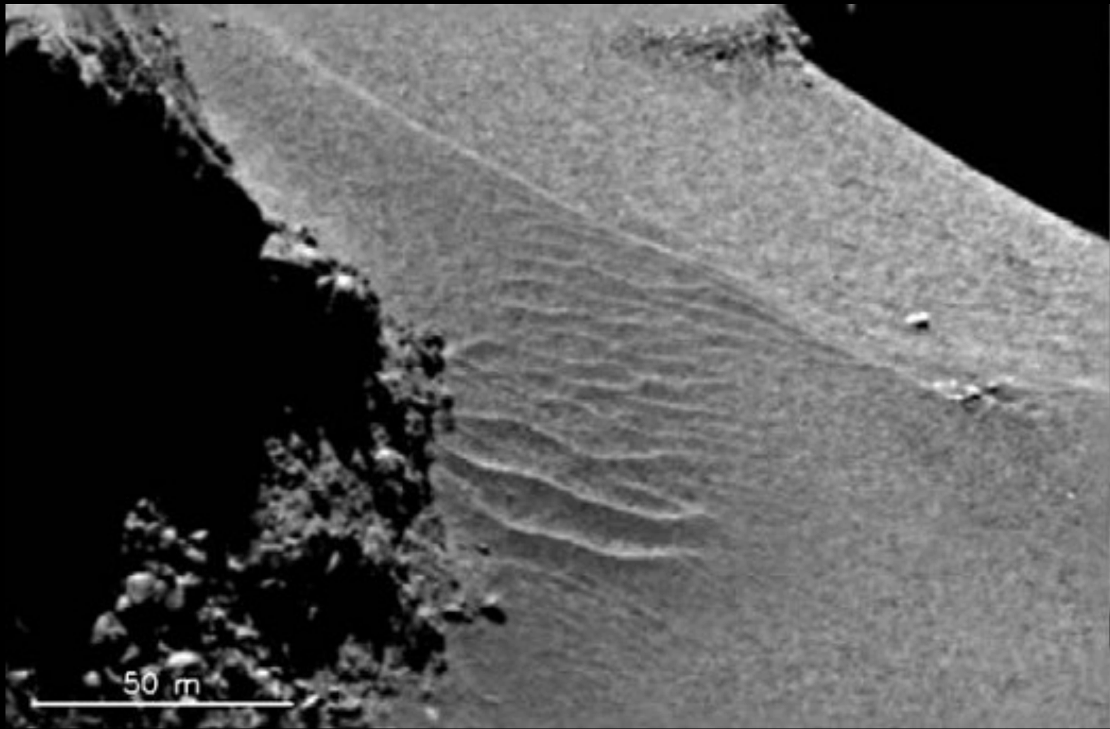


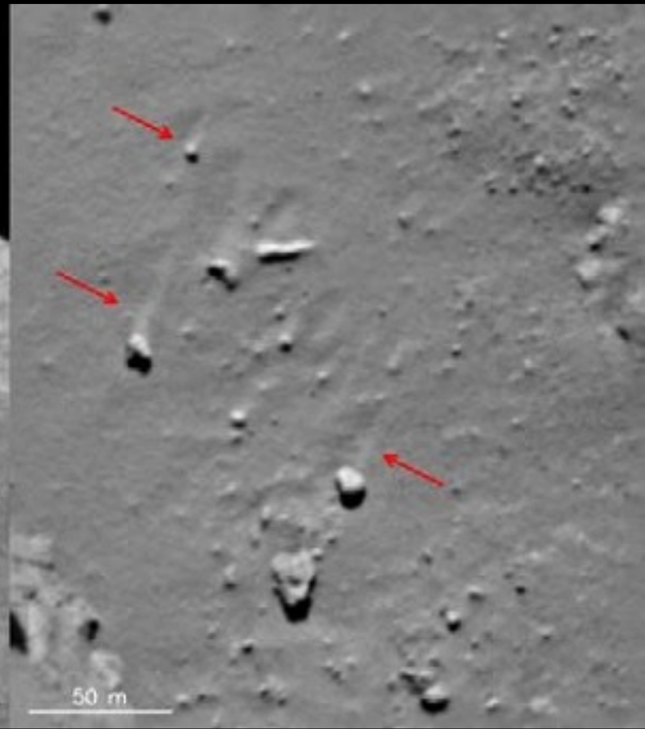
Cracks, Uniform Deposits, Material transport or Multiple Fluid Events?

Auger et al., 2015, A&A, in press

NAC_2014-10-05T16.09.11.549Z_ID30_1397549900_F22

Dunes & wind tails in HAPI





HAPI shows aeolian ripple field, and several boulders appear to have wind tails

aeolian dust transport may be of significance

Estimated gas velocity = 335 m/s, comparable to gas flow velocities seen in most fluid dynamics calculations

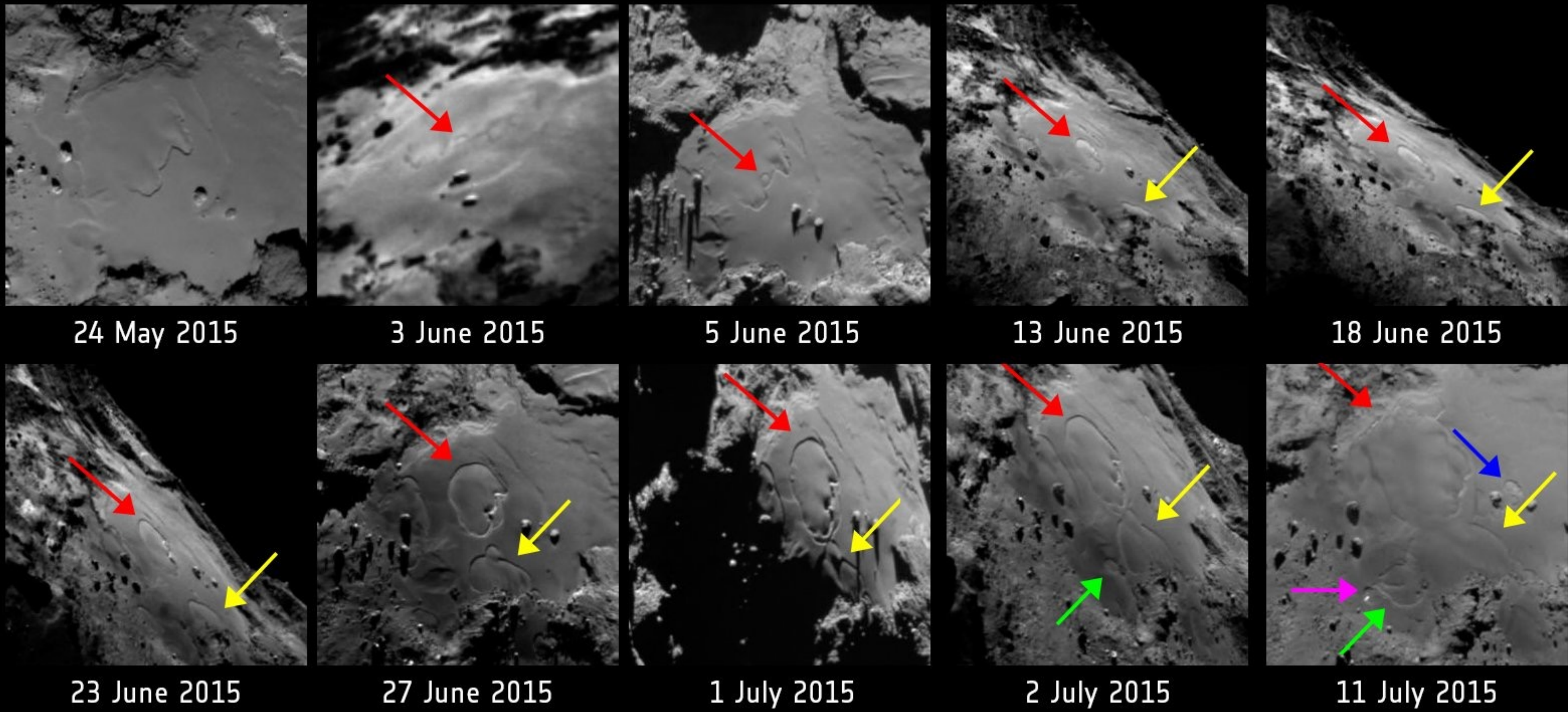
Thomas et al., 2015; Sierks et al., 2015

Activité de la comète

NAC images
25-26 July
12 m/px

WAC images, filer OI
9-10 September
3.5 m/px

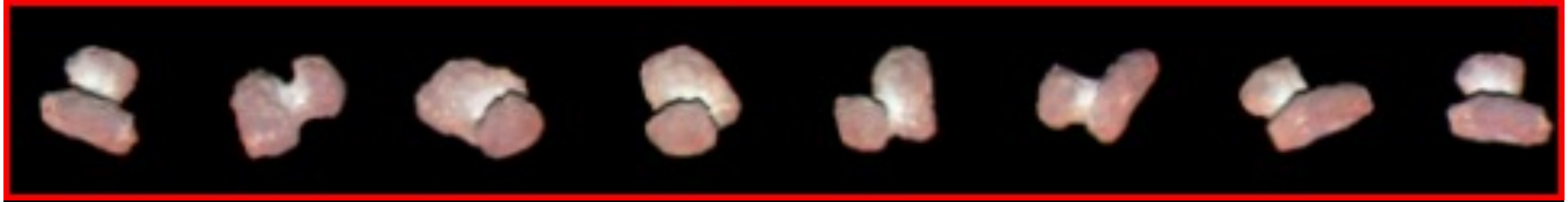
Rajeunissement de surface



Variations de couleur

The 67P surface is heterogeneous: the central region, which is also a clear source of activity looks brighter .

25 July data: res 56m/px, 360-535-743 color maps

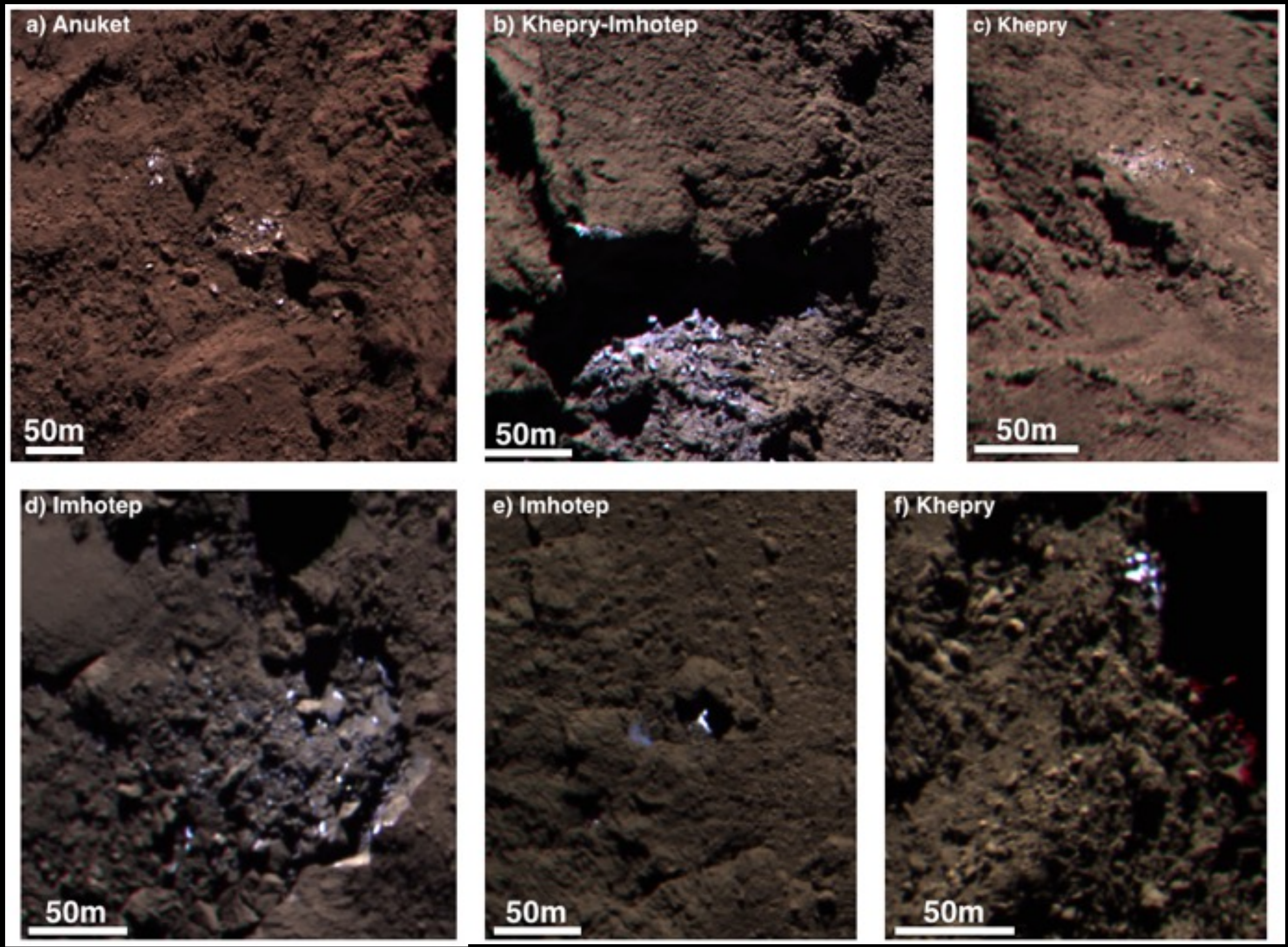


1 August data: res 18.5m/px, 480-535-649 color maps

5 Sept 08h, phase 70°

Rochers clairs ~ 1 m

- *Appear in all types of morphologic regions but some regions show a much higher concentration of these features: Imhotep, Khepri…*
- *Concentrated in the areas that receive the lowest insolation: often surrounded by shadows.*



Pommerol et al., 2015, A&A

Variable size and shape, but in the range of metres

Clustered (20) or isolated

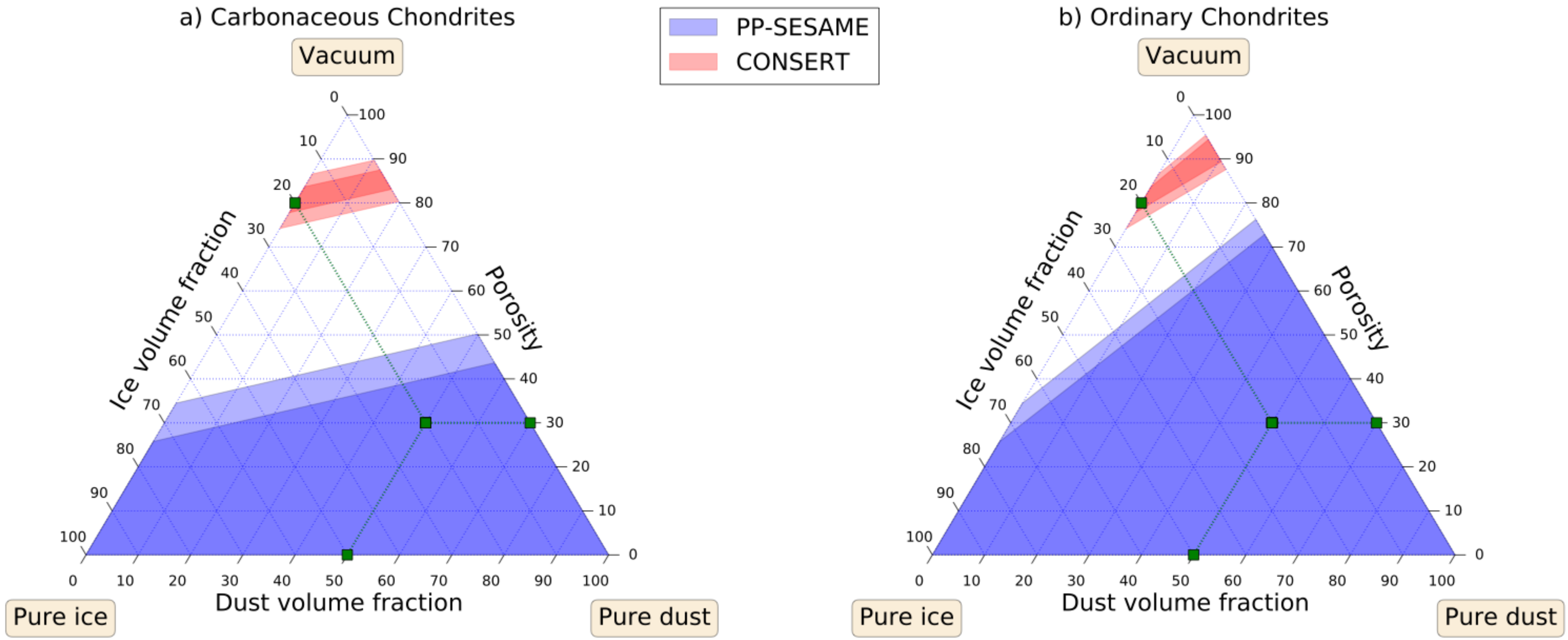
Ten times brigther than sourronding regions, and bluer

Exposed water ice!

CONSERT et SESAME-PP

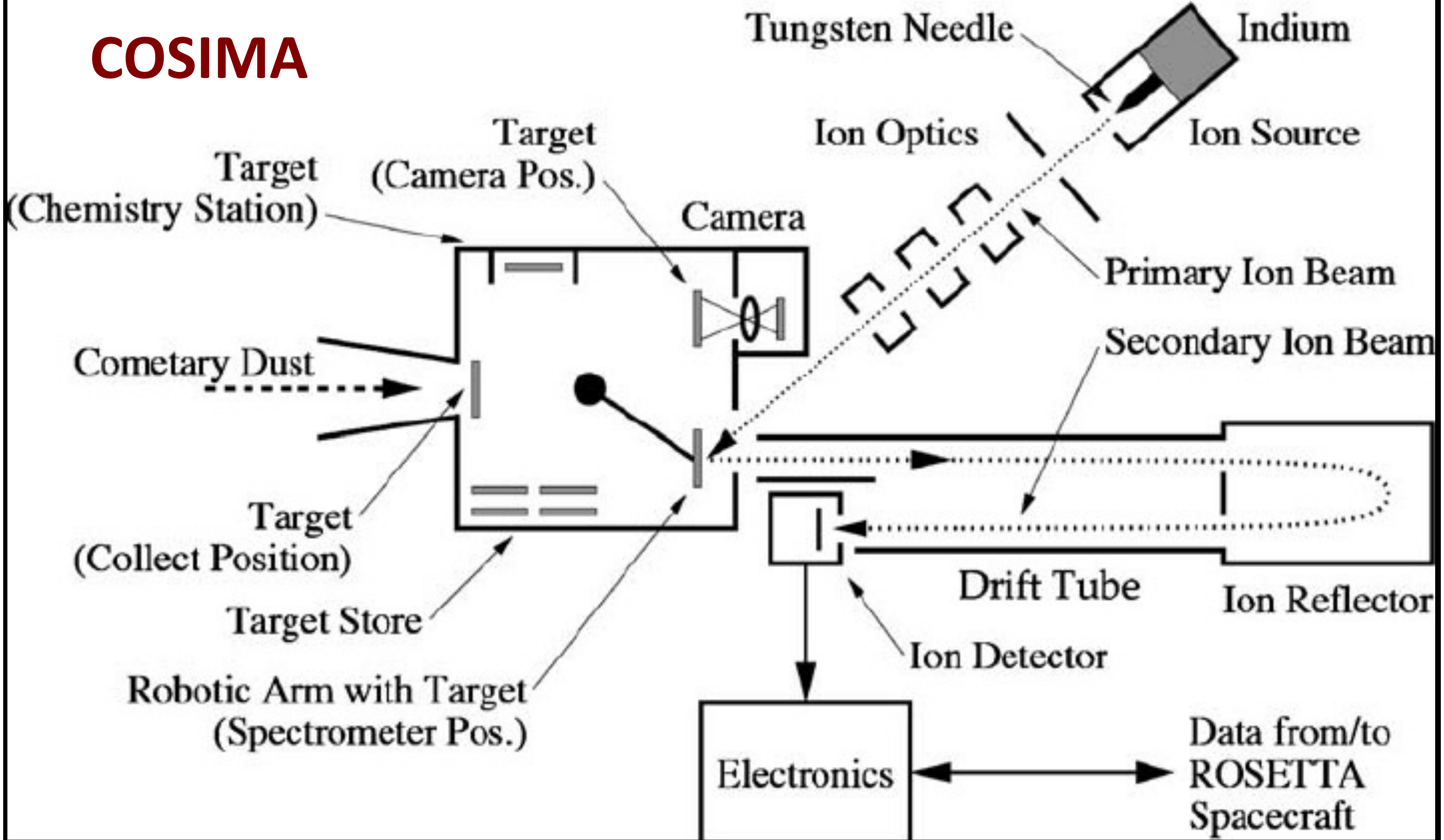
Kofman et al. (2015) Science
Ciarletti et al. (2015) A&A
Lethuillier et al. (2016) A&A

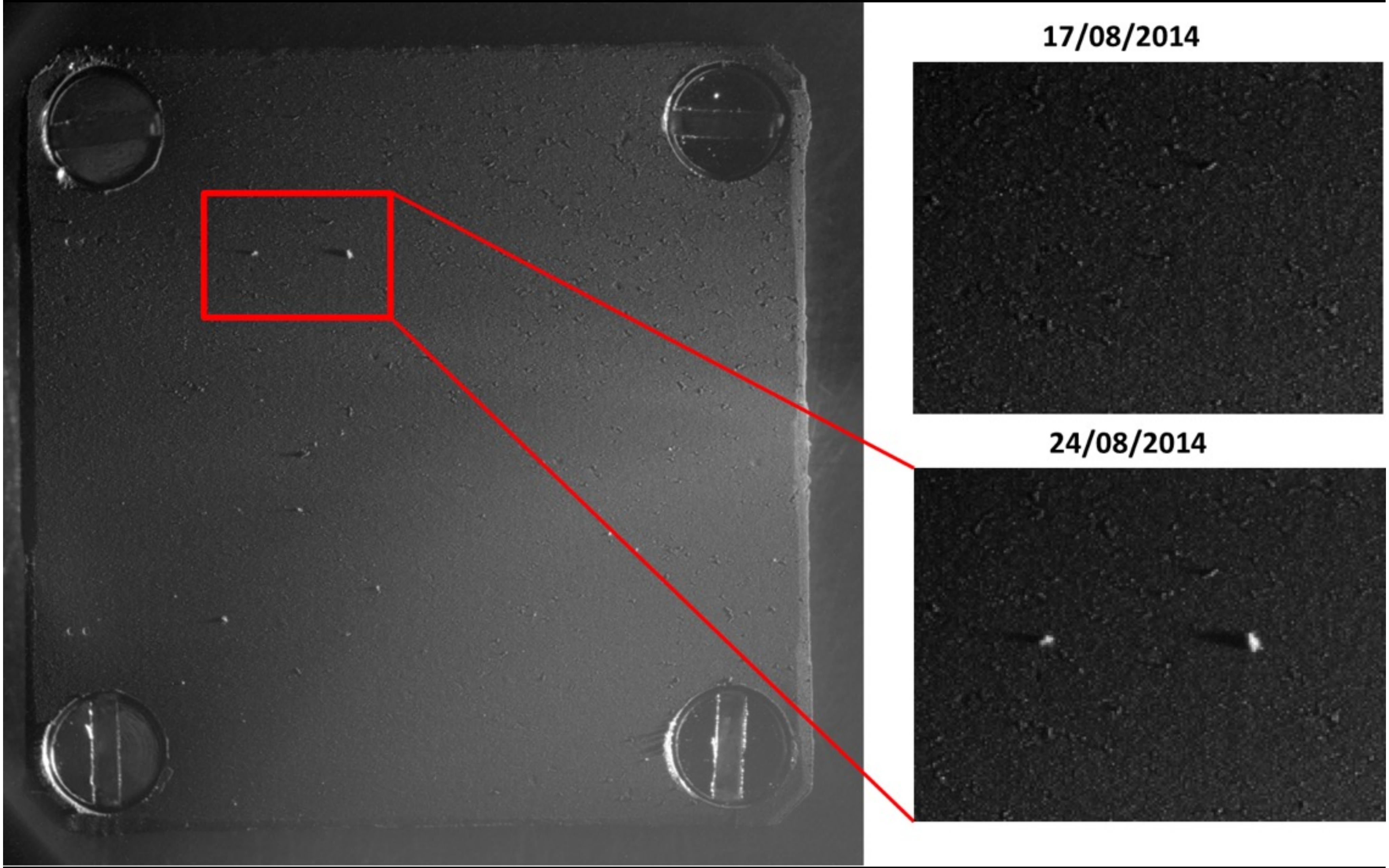
Basse porosité dans les premiers mètres

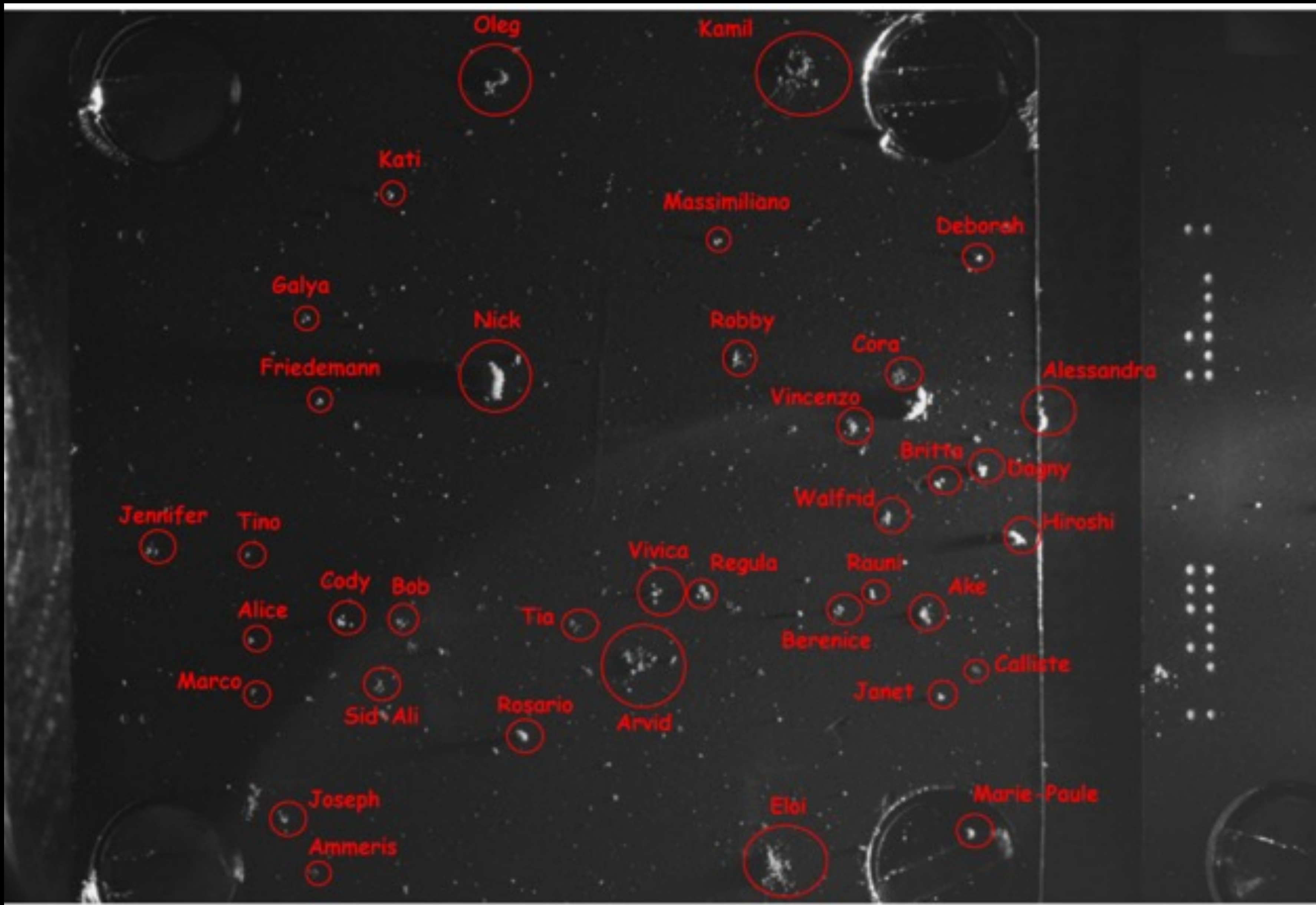


La poussière cométaire

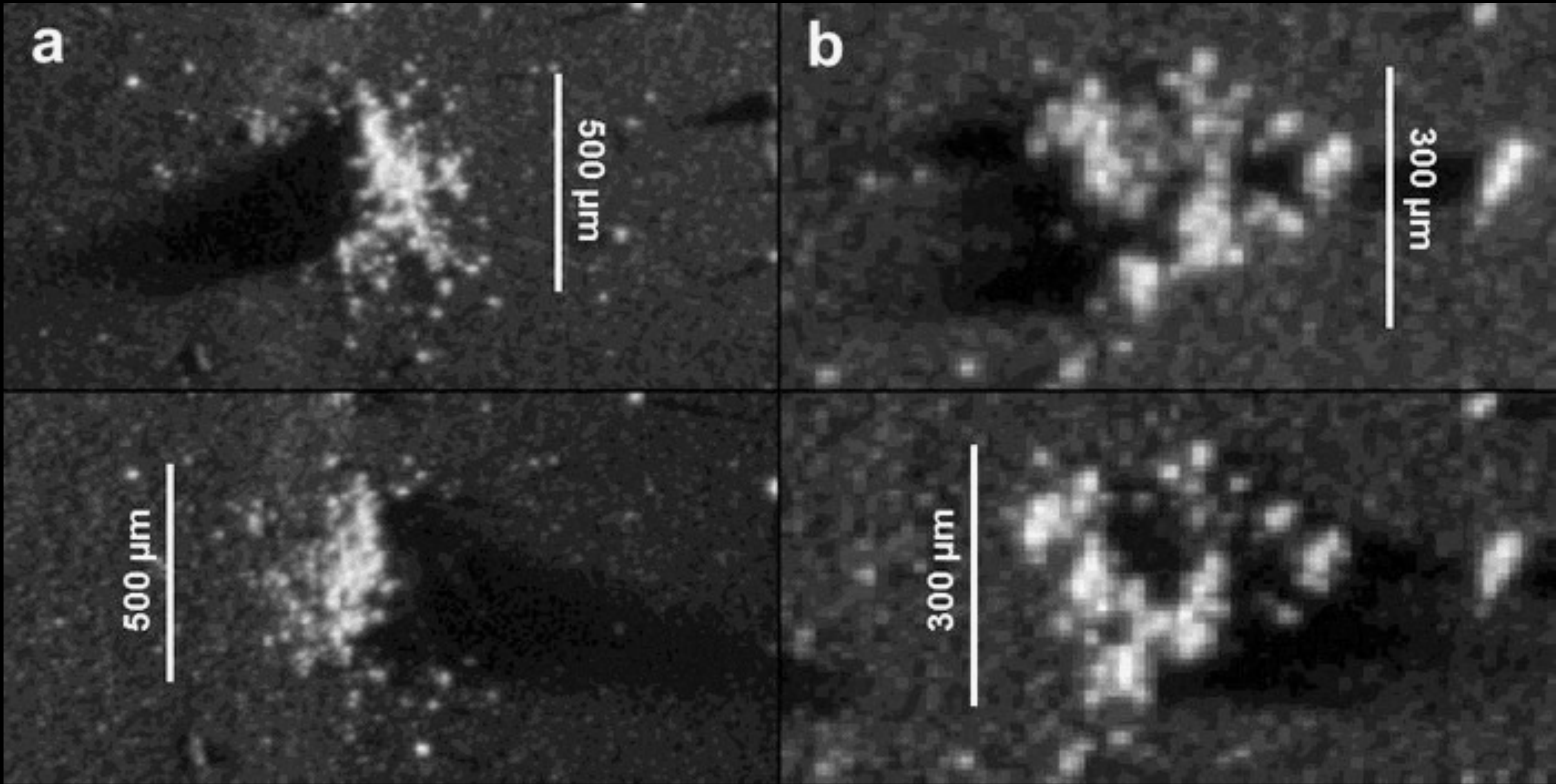
COSIMA

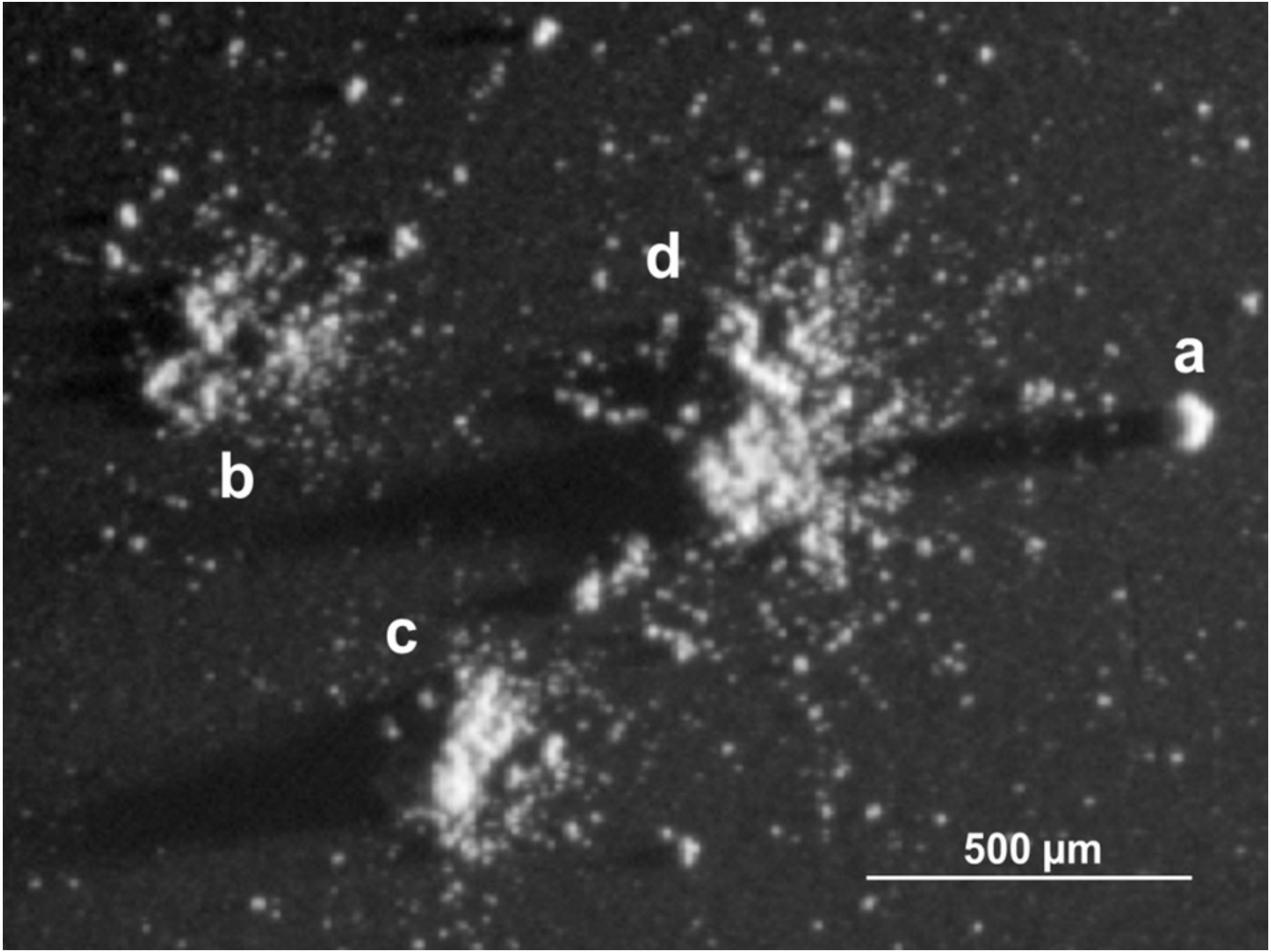



17/08/2014
24/08/2014

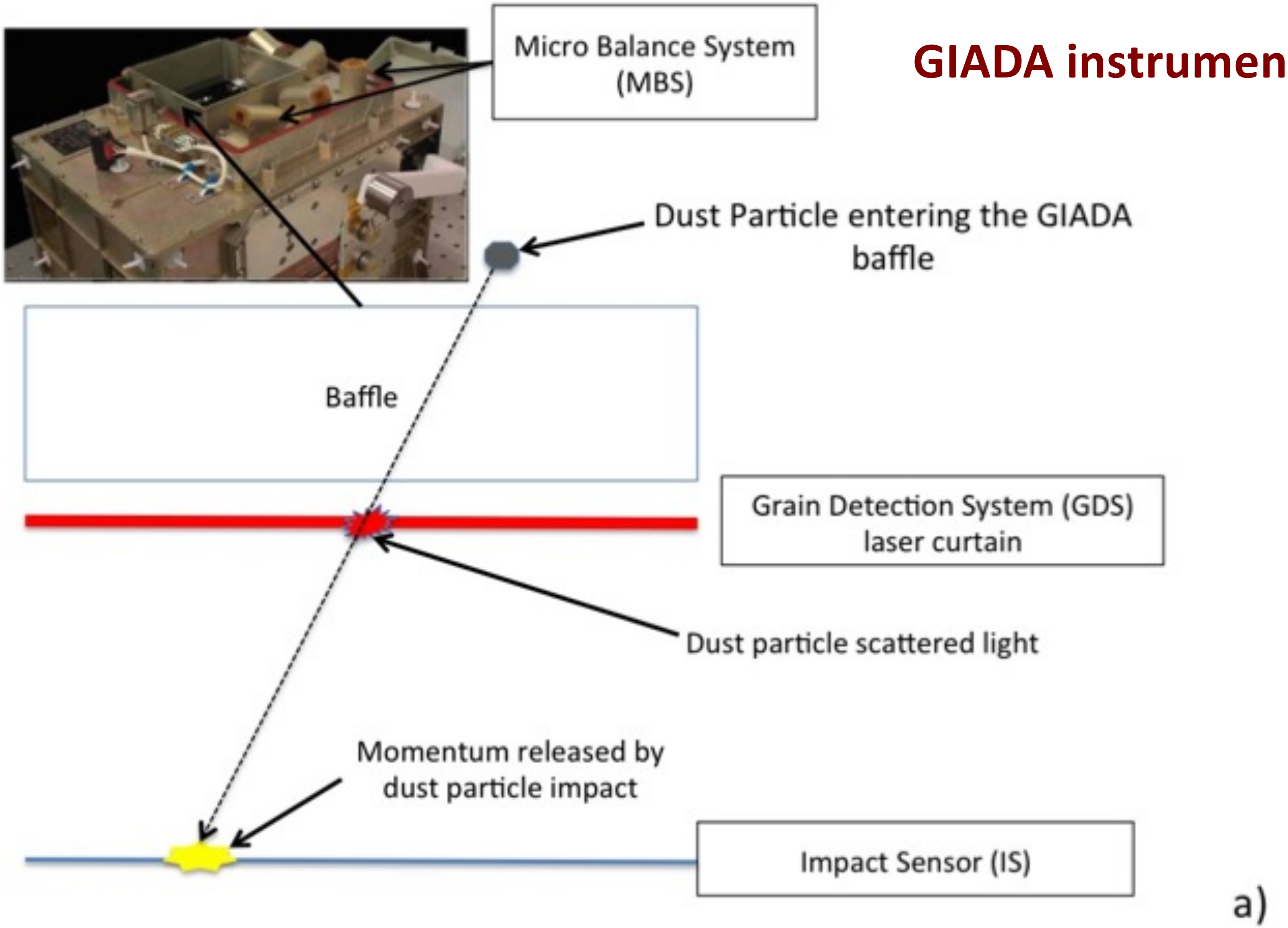

Oleg
Kamil
Kati
Massimiliano
Deborah
Galya
Nick
Robby
Cora
Friedemann
Alessandra
Vincenzo
Britta
Dagny
Walfrid
Jennifer
Tino
Hiroshi
Vivica
Regula
Rauni
Cody
Bob
Ake
Alice
Tia
Berenice
Calliste
Marco
Janet
Sid Ali
Rosario
Arvid
Joseph
Eloi
Marie-Paule
Ammeris

La poussière




d
a
b
c
500 µm

GIADA instrument



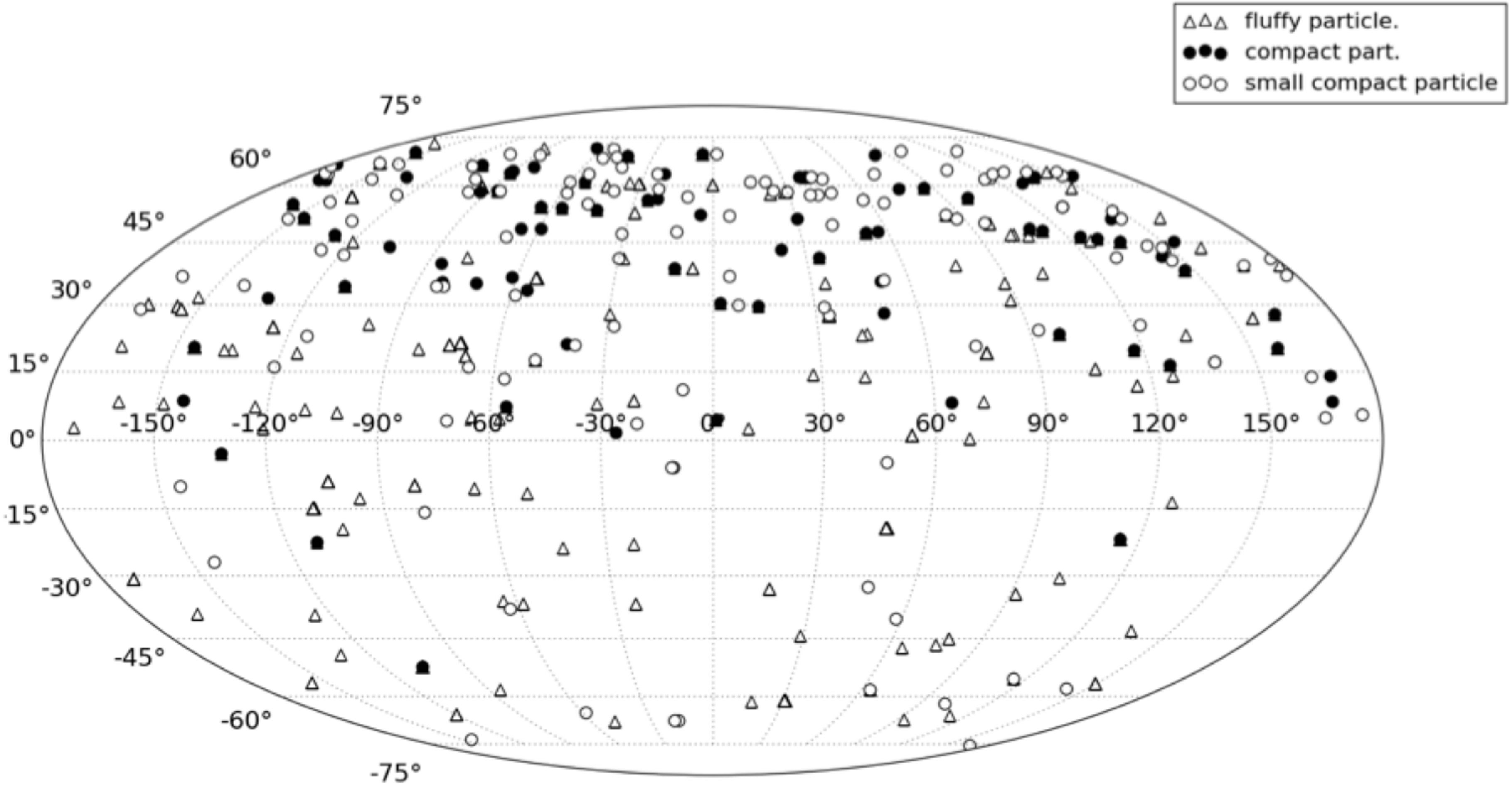


Fig. 3. Particle spatial distribution by type: fluffy, compact, and small compact detected during the bound-orbit phase. Fluffy particles, plotted as clusters, i.e., only the detection of each shower is reported, seem the more dispersed particles together with, although to a lesser extent, small compact particles.

MIDAS

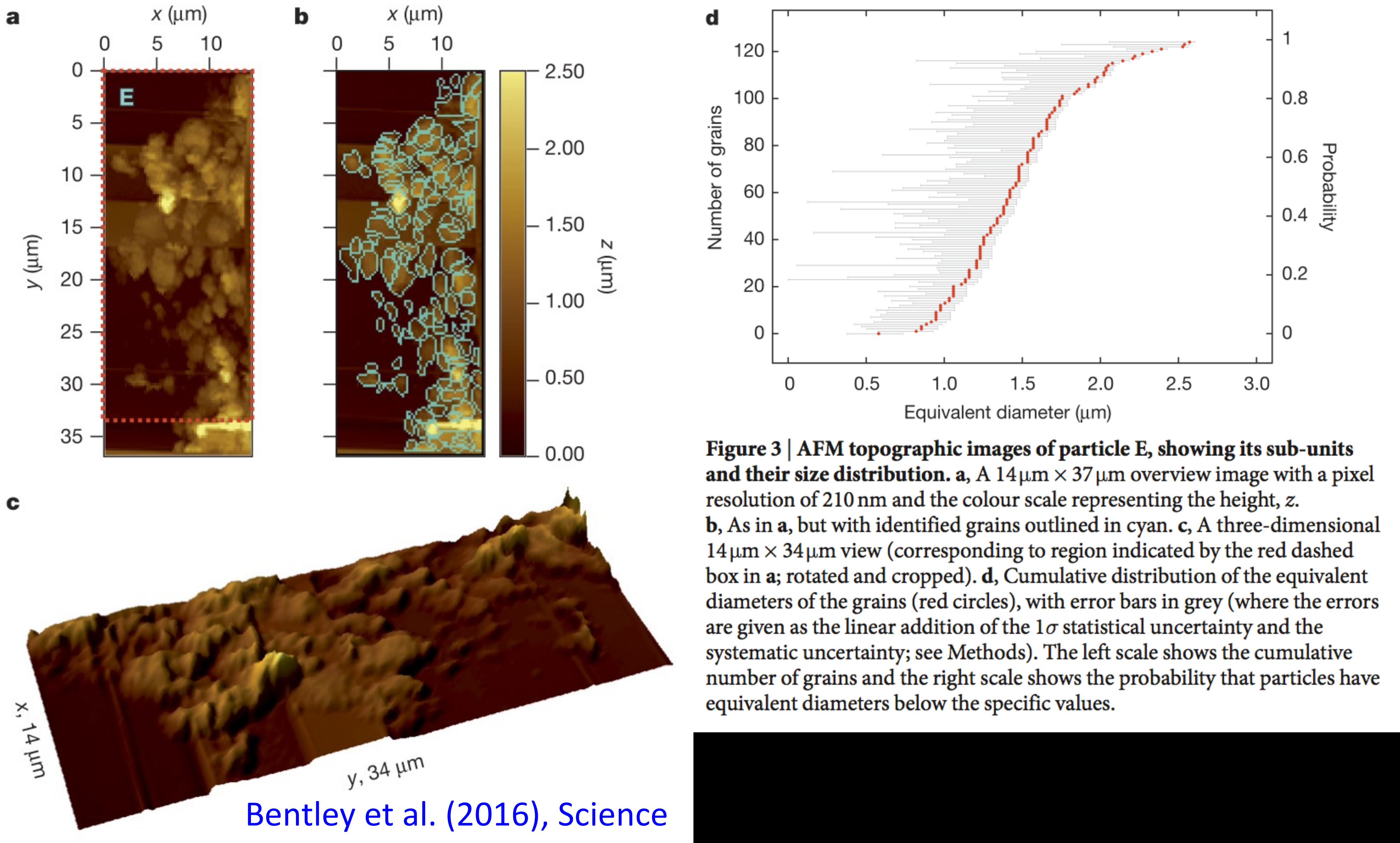


Figure 3 | AFM topographic images of particle E, showing its sub-units and their size distribution. a, A 14 μm × 37 μm overview image with a pixel resolution of 210 nm and the colour scale representing the height, *z*. **b,** As in **a**, but with identified grains outlined in cyan. **c,** A three-dimensional 14 μm × 34 μm view (corresponding to region indicated by the red dashed box in **a**; rotated and cropped). **d,** Cumulative distribution of the equivalent diameters of the grains (red circles), with error bars in grey (where the errors are given as the linear addition of the 1σ statistical uncertainty and the systematic uncertainty; see Methods). The left scale shows the cumulative number of grains and the right scale shows the probability that particles have equivalent diameters below the specific values.

Bentley et al. (2016), Science

doi:10.1038/nature19320

High-molecular-weight organic matter in the particles of comet 67P/Churyumov–Gerasimenko

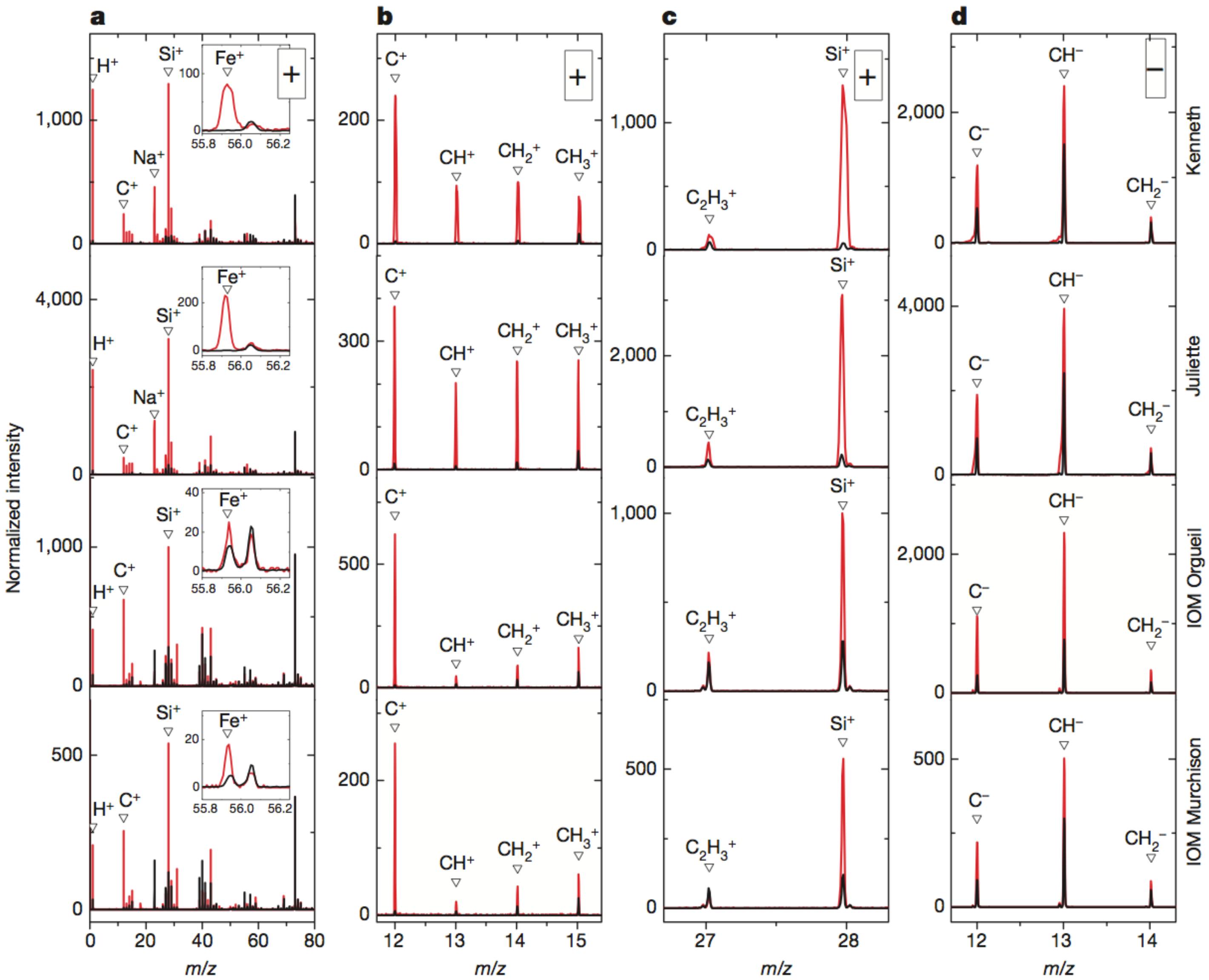
Nicolas Fray[1]*, Anaïs Bardyn[1,2]*, Hervé Cottin[1]*, Kathrin Altwegg[3], Donia Baklouti[4], Christelle Briois[2], Luigi Colangeli[5], Cécile Engrand[6], Henning Fischer[7], Albrecht Glasmachers[8], Eberhard Grün[9], Gerhard Haerendel[10], Hartmut Henkel[11], Herwig Höfner[10], Klaus Hornung[12], Elmar K. Jessberger[13], Andreas Koch[11], Harald Krüger[7], Yves Langevin[3], Harry Lehto[14], Kirsi Lehto[15], Léna Le Roy[3], Sihane Merouane[7], Paola Modica[1,2], François-Régis Orthous-Daunay[16], John Paquette[7], François Raulin[1], Jouni Rynö[17], Rita Schulz[18], Johan Silén[17], Sandra Siljeström[19], Wolfgang Steiger[20], Oliver Stenzel[7], Thomas Stephan[21], Laurent Thirkell[2], Roge
Jochen Kissel[7] & Martin Hilchenbach[7]

Kenneth

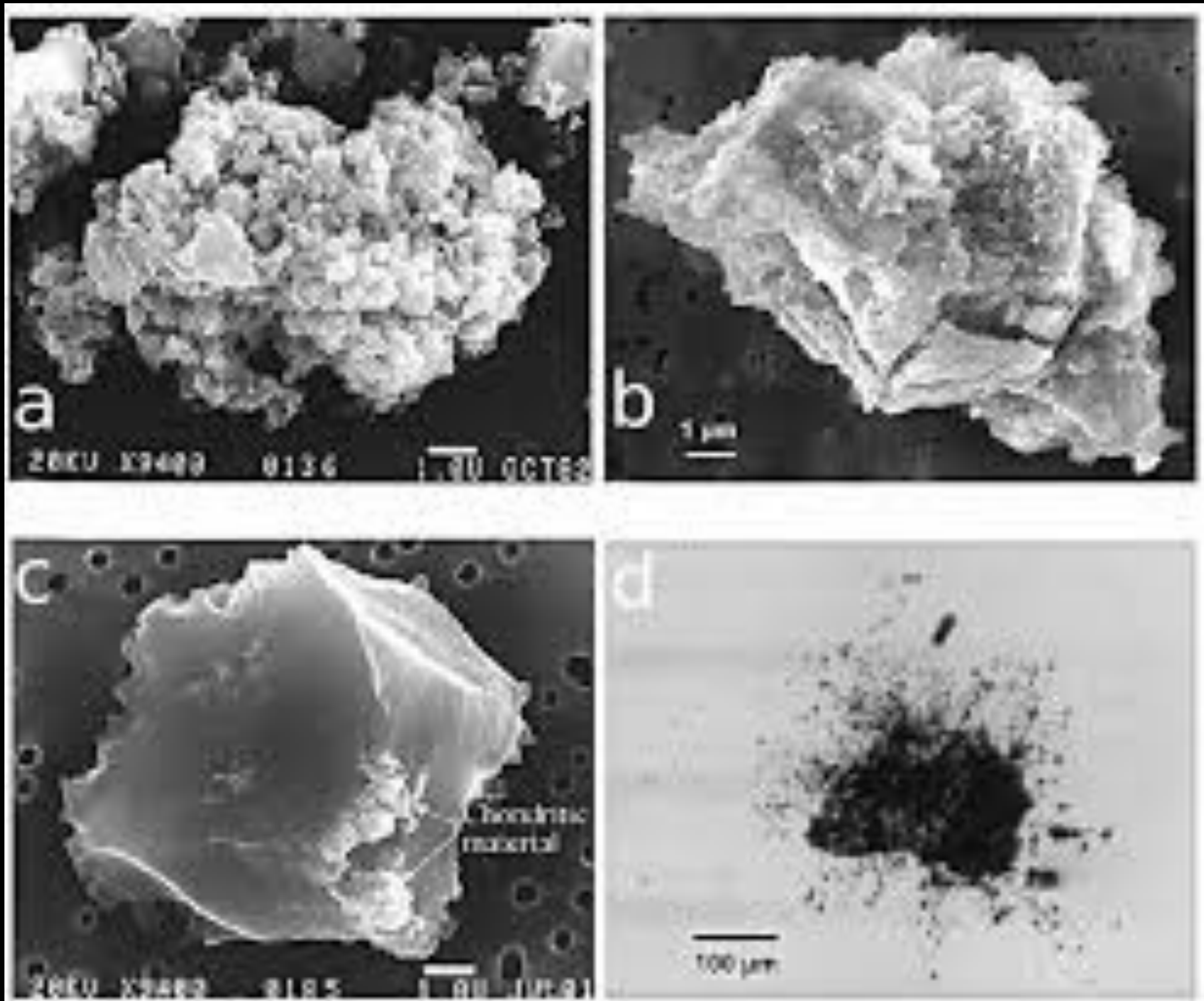
Juliette

Orgueil IOM

Murchison IOM



Poussières stratosphériques et Antarctiques

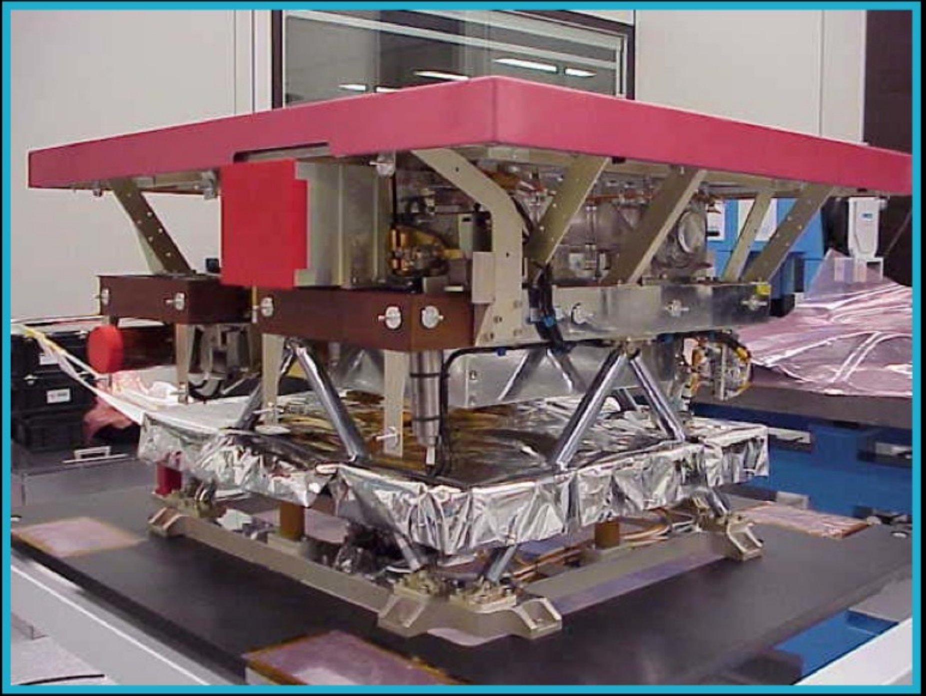


La composition de la surface

VIRTIS

Visible, InfraRed and Thermal Imaging Spectrometer

VIRTIS combines an imaging spectrometer (M) and a high resolution spectrometer (H).

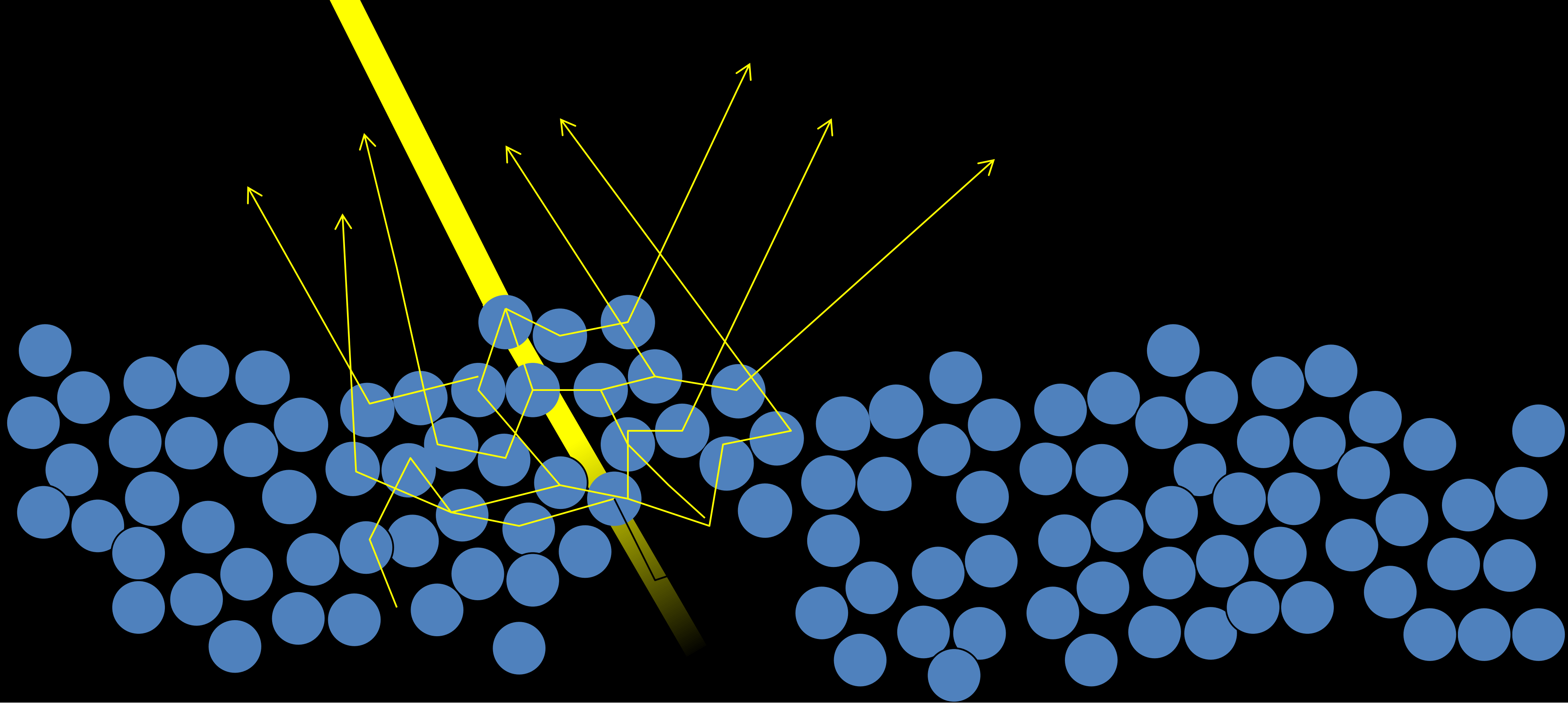


VIRTIS –M is a slit spectrometer; acquires hyperspectral images with a max spatial resolution of 250μrad, using an internal scan mirror, in the spectral range 0.25-5 μm.

VIRTIS –H is a high-resolution infrared spectrometer in the 2-5 μm range. It uses a prism and a grating to achieve a spectral resolution as high as 3000 on a matrix detector identical to the VIRTIS-M IR FPA.

agenzia spaziale italiana INAF l'Observatoire de Paris LESIA Laboratoire d'Études Spatiales et d'Instrumentation en Astrophysique cnes De l'espace pour la Terre DLR

Spectroscopie de réflectance



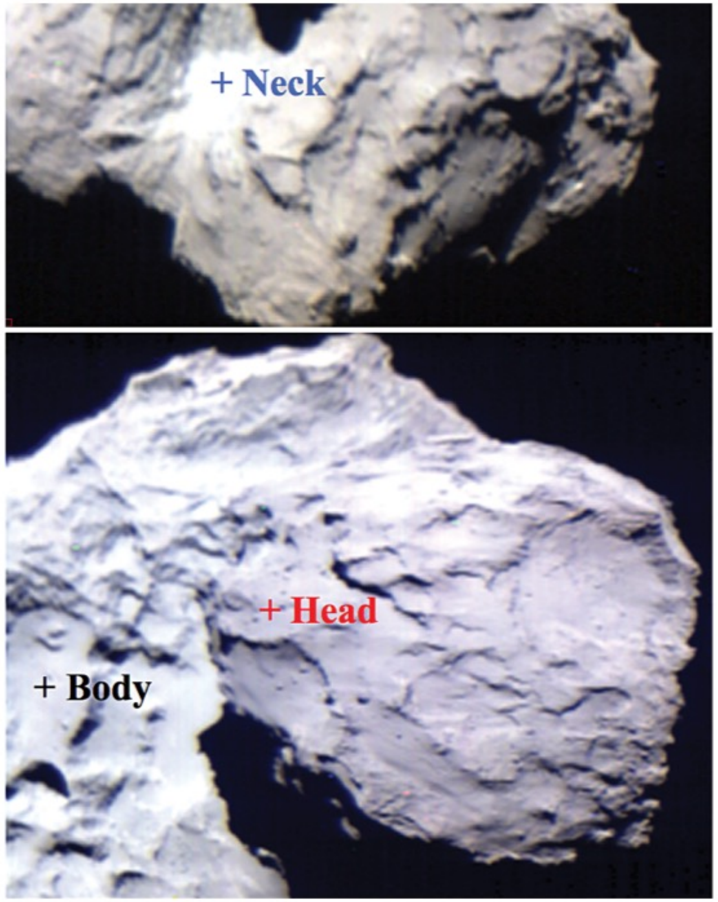
VIRTIS-M imaged 67P/CG surface within 0.4-5 μm

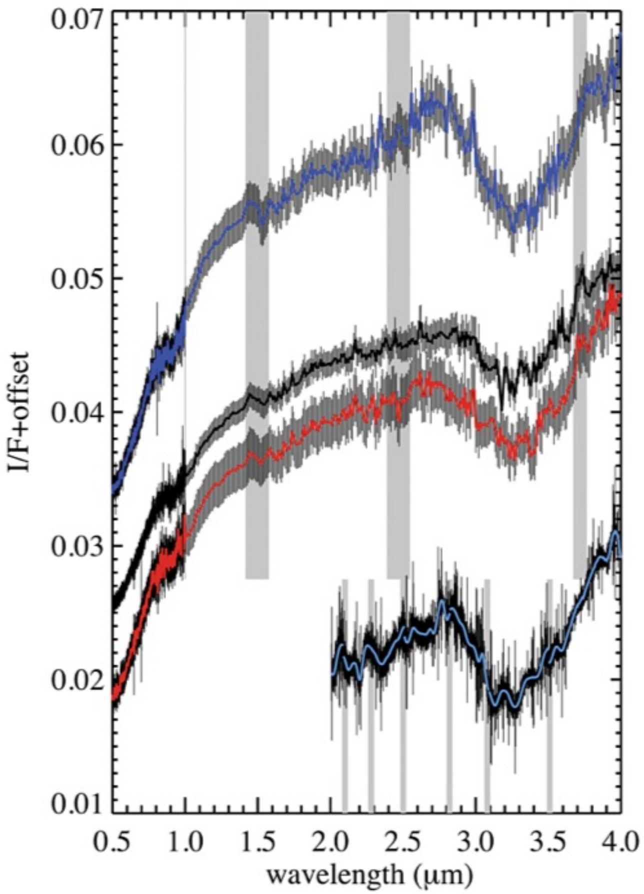
Here we focus on the chemical interpretation of the spectra of ice-free regions

COMETARY SCIENCE

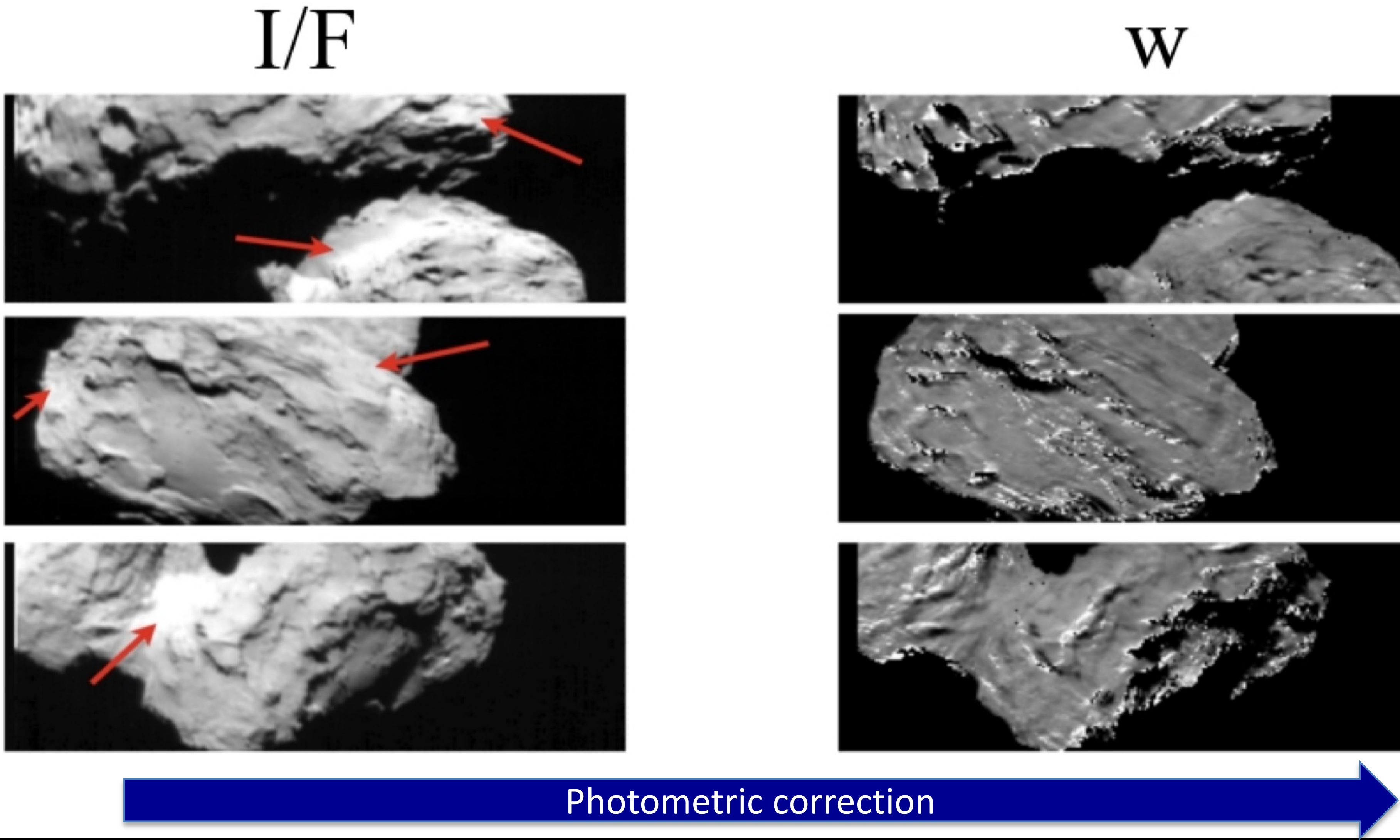
The organic-rich surface of comet 67P/Churyumov-Gerasimenko as seen by VIRTIS/Rosetta

F. Capaccioni,[1*] A. Coradini,[1†] G. Filac
M. C. De Sanctis,[1] D. Bockelee-Morvan
E. Quirico,[4] P. Cerroni,[1] V. Mennella,[5] A
E. Palomba,[1] E. Ammannito,[7] M. A. Bar
A. Blanco,[10] M. Blecka,[11] R. Carlson,[12]
M. Combi,[13] J. Crovisier,[2] T. Encrenaz
P. Irwin,[17] R. Jaumann,[3,18] E. Kuehrt,[3]
P. Palumbo,[19] G. Piccioni,[1] U. Schade,[20]
N. Biver,[2] L. Bonal,[4] J.-Ph. Combe,[6] D.
D. Grassi,[1] M. Gudipati,[12,23] A. Longoba
G. Rinaldi,[1] K. Stephan,[3] M. Cartacci,[1] A
S. Jacquinod,[2] R. Noschese,[1] G. Peter,[25]



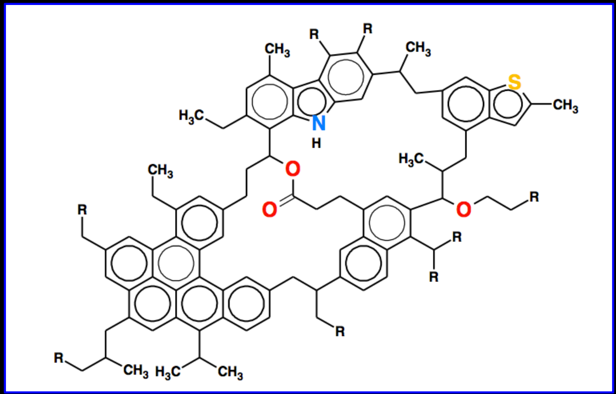


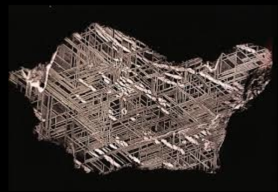
[redacted]

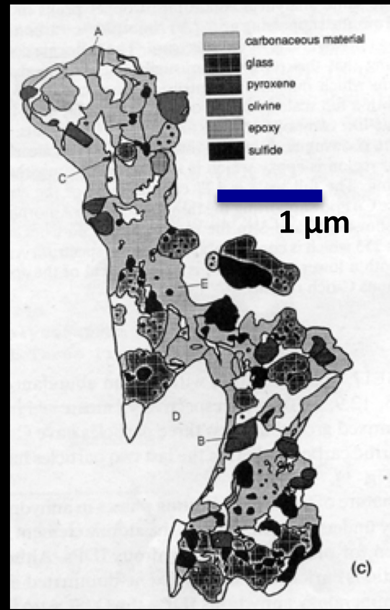


[redacted]

Comète sombre= Organiques + Minéraux opaques

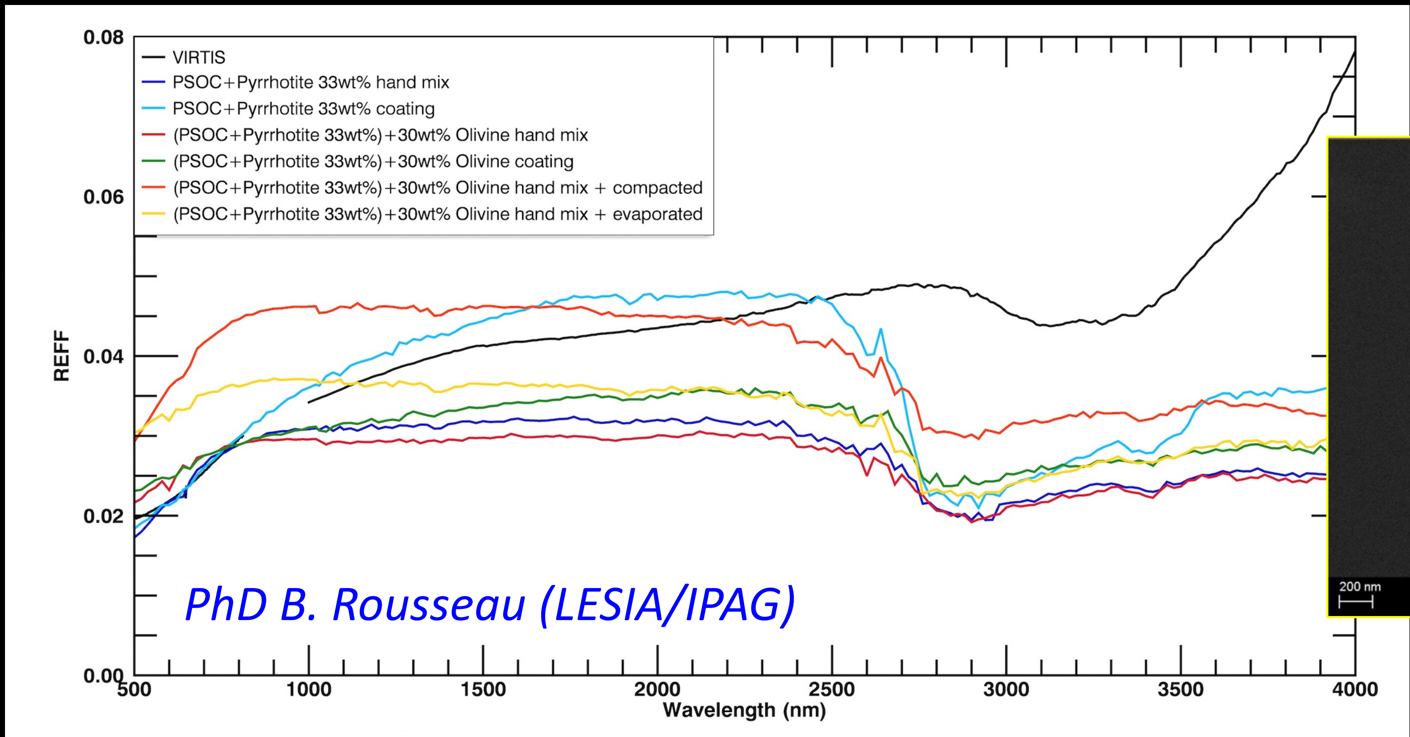


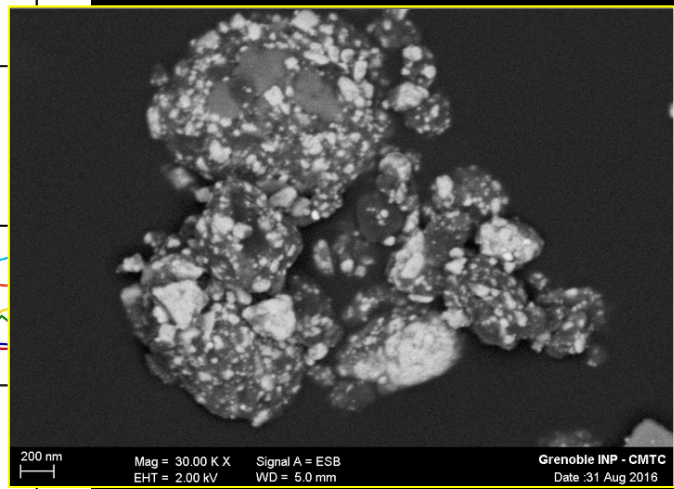




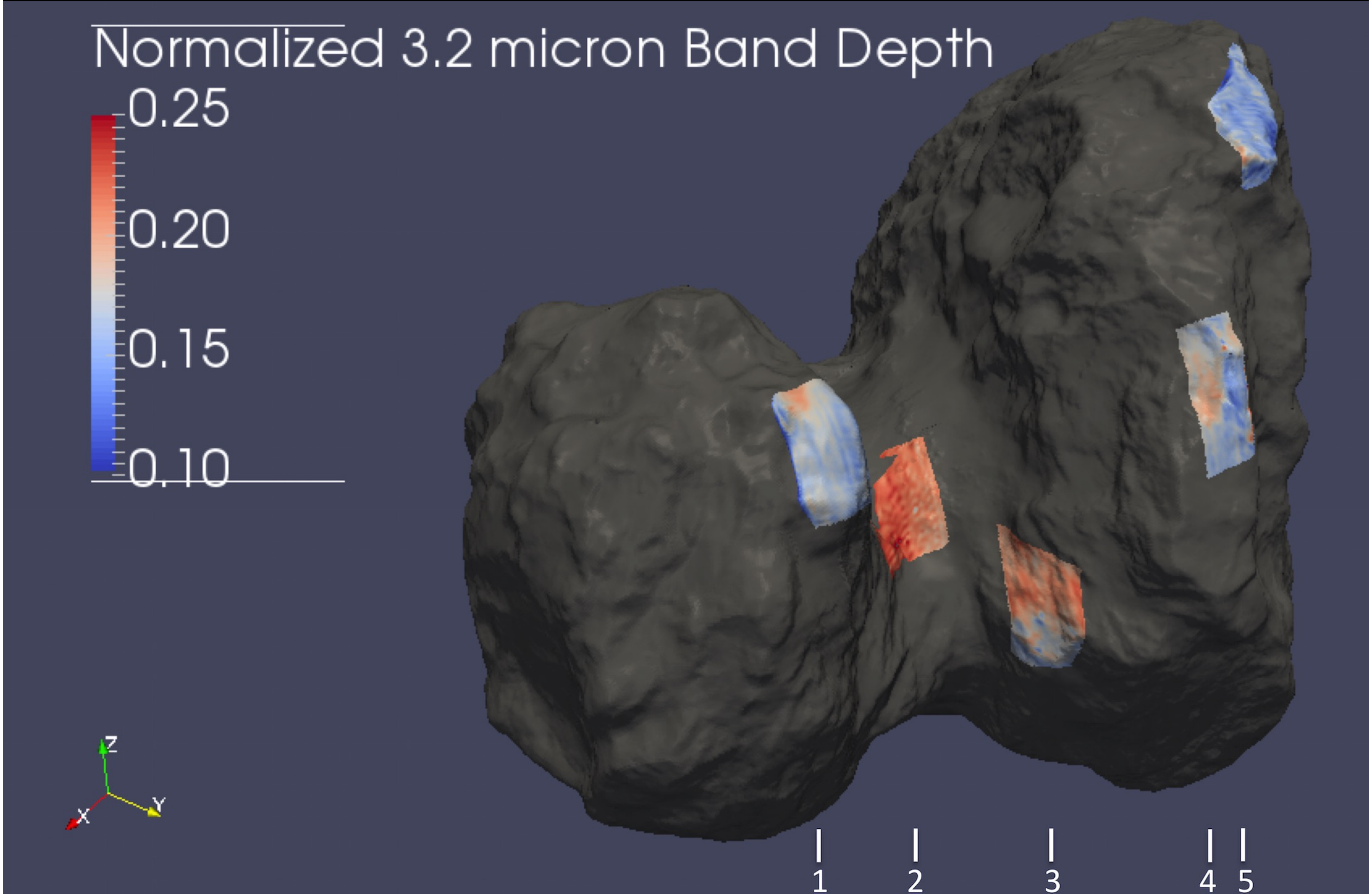
Thomas et al. (1993) GCA

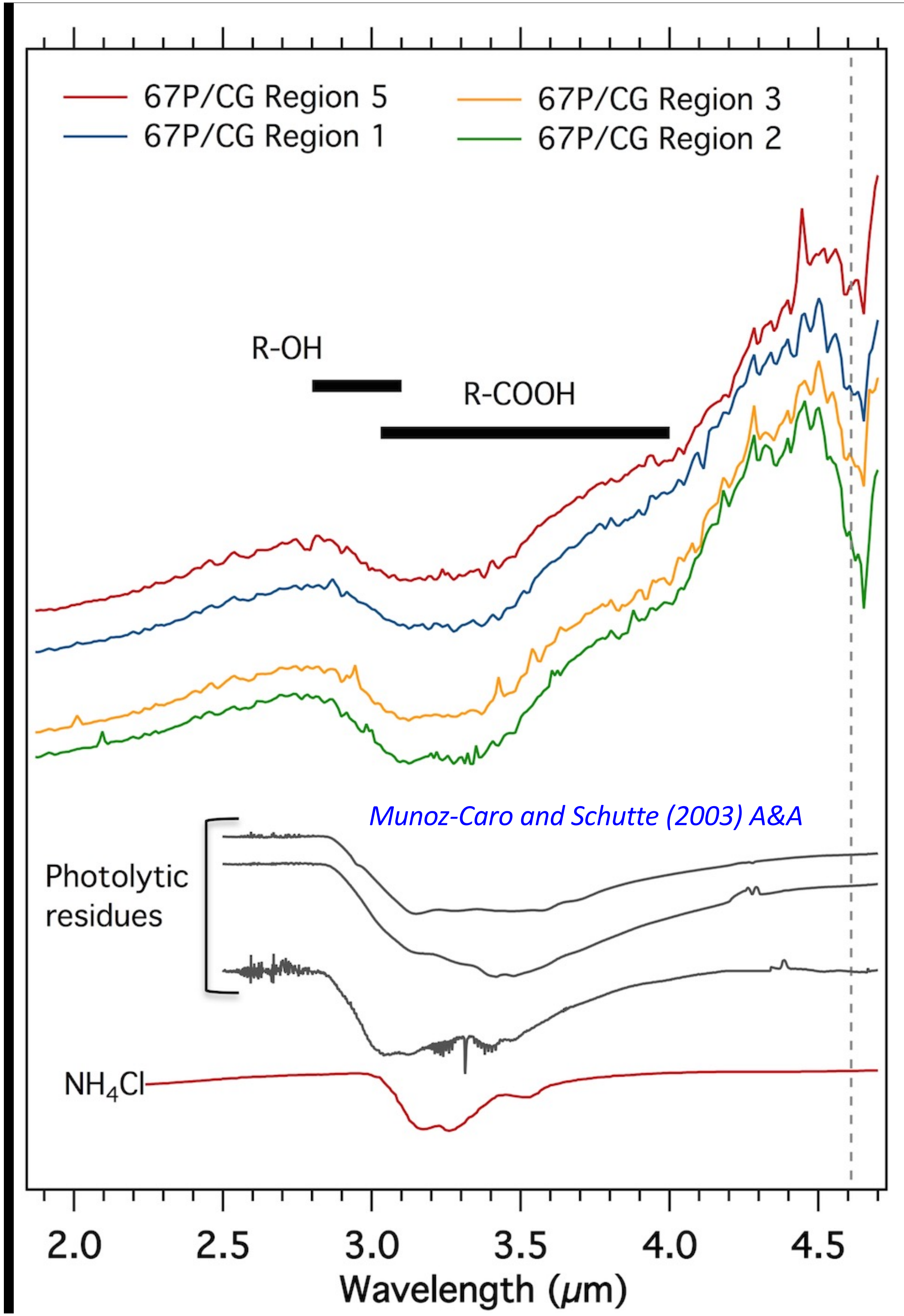
Chondritic comet (C/Si – S/Si – Fe/S – Mg/Si)





The 3.2 µm band





Other ROSETTA instruments

Ptolemy ***Wright et al., 2015***

- ***No detection of POM. May be present, but minor with respect to other species.***

Cosac ***Goessman et al., 2015***

- ***R-COOH major – no detection in Cosac***
- ***Amino groups minor – significant in Cosac (~50% of species)***

Cosima ***Fray et al., Tuesday Talk***

- ***Refractory N/C ~0.05 > Consistent***
- ***Fe,S co-detection => FeS likely***

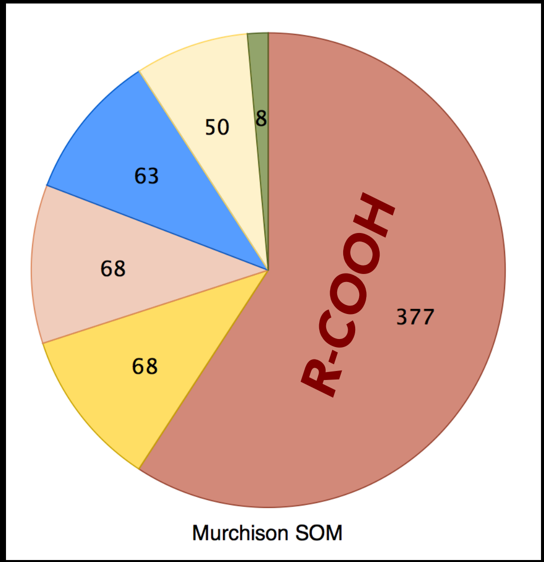
Photolytic residues ?

- ***Form complex organics from simples ices***
- ***Large variety of « 3 µm band »***

Un lien avec les météorites primitives ?

- *R-COOH highly plausible*
- *CH_2/CH_3, aro-H plausible*
- *NH_4^+ plausible, but $-NH_2$ weak*

Compounds	Abundances (%)	µg g^{-1} (ppm)	Ref.
Macromolecular material	1.45		26
Carbon dioxide		106	27
Carbon monoxide		0.06	27
Methane		0.14	27
Hydrocarbons: aliphatic		12–35	28
aromatic		15–28	29
Acids: monocarboxylic		332	27, 30
dicarboxylic		25.7	31
α-hydroxycarboxylic		14.6	32
Amino acids		60	4
Alcohols		11	33
Aldehydes		11	33
Ketones		16	33
Sugar-related compounds		~60	34
Ammonia		19	35
Amines		8	36
Urea		25	37
Basic N-heterocycles (pyridines, quinolines)		0.05–0.5	38
Pyridinecarboxylic acids		>7	39
Dicarboximides		>50	39
Pyrimidines (uracil and thymine)		0.06	40
Purines		1.2	41
Benzothiophenes		0.3	42
Sulfonic acids		67	43
Phosphonic acids		1.5	44



Sephton 2002 Nat. Prod. Rep.

Merci de votre attention !