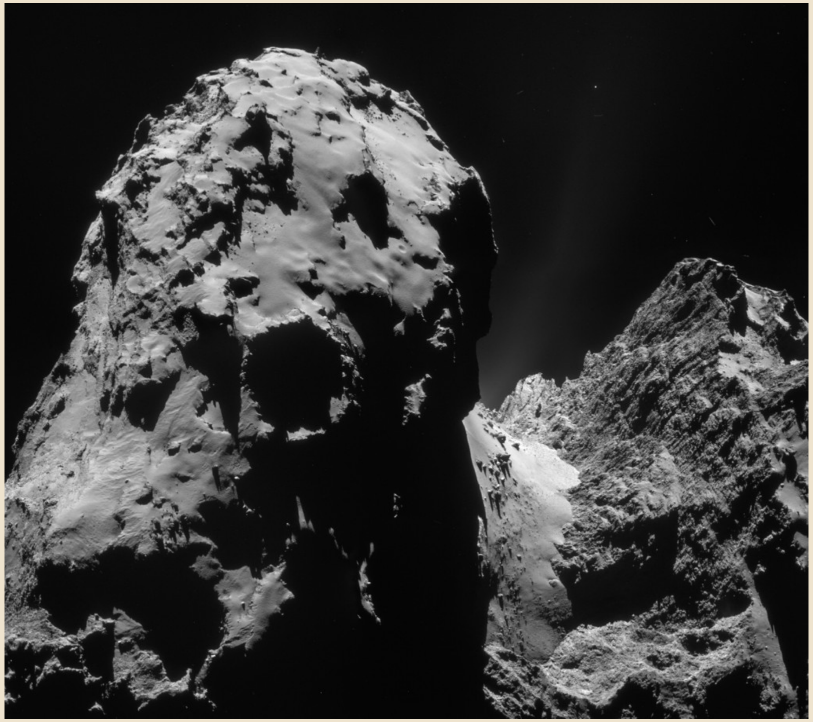
WATER IN COMETS :
NEW INSIGHTS FROM THE ROSETTA MISSION



Rosetta/ESA/NAVCAM

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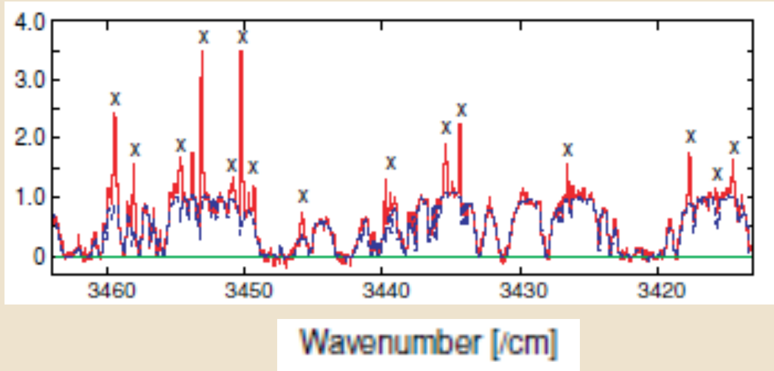
Observatory of Paris

l'Observatoire de Paris LESIA
Laboratoire d'Études Spatiales et d'Instrumentation en Astrophysique

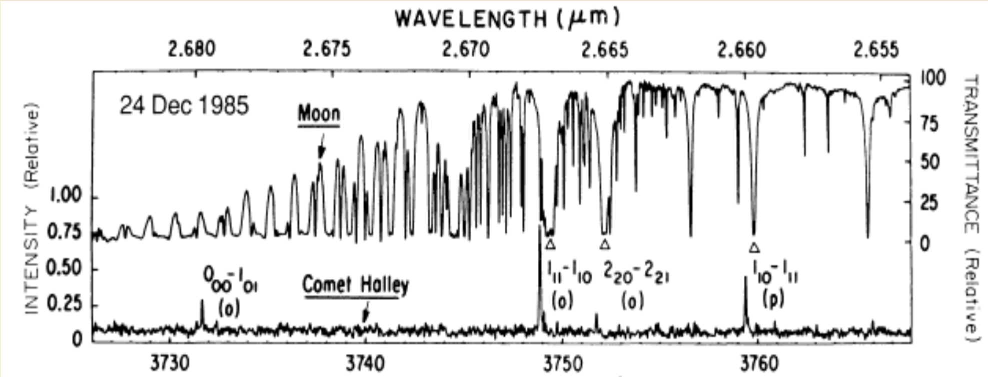
Observation of water vapor in comets

- **Infrared : fundamental and hot bands**

Kawakita et al. 2009, Keck II, C/2004 Q2



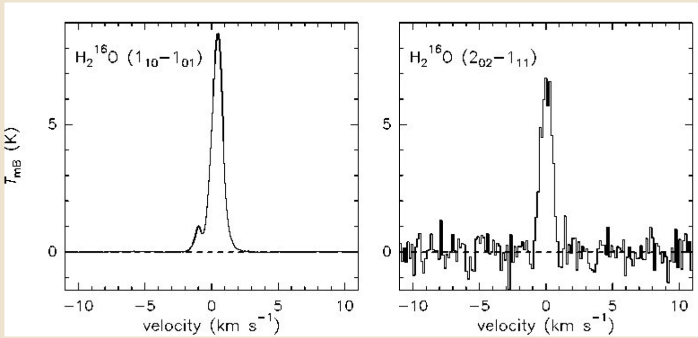
KAO: 1P/HALLEY – First detection of water

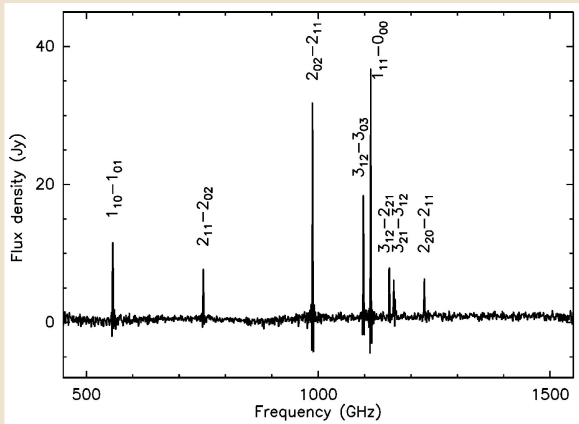


- **Submillimeter, far-IR** : SWAS, Odin, Herschel

Herschel/SPIRE *comet 103P*

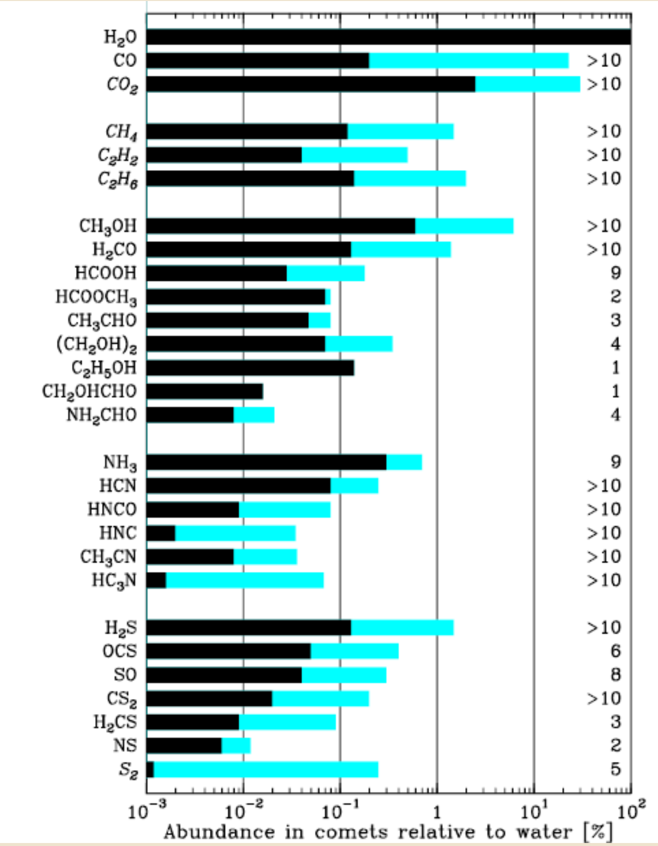
Herschel/HIFI
comet C/2009 P1
Bockelée et al. 2012

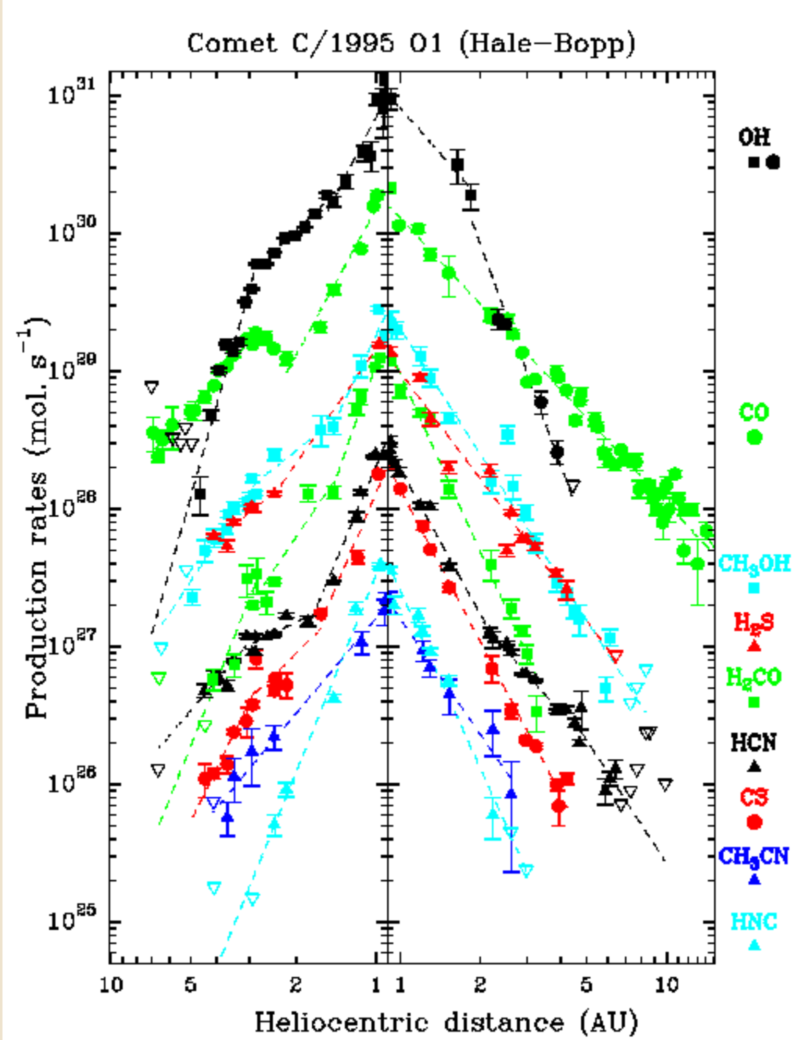




Water sublimation – comet activity

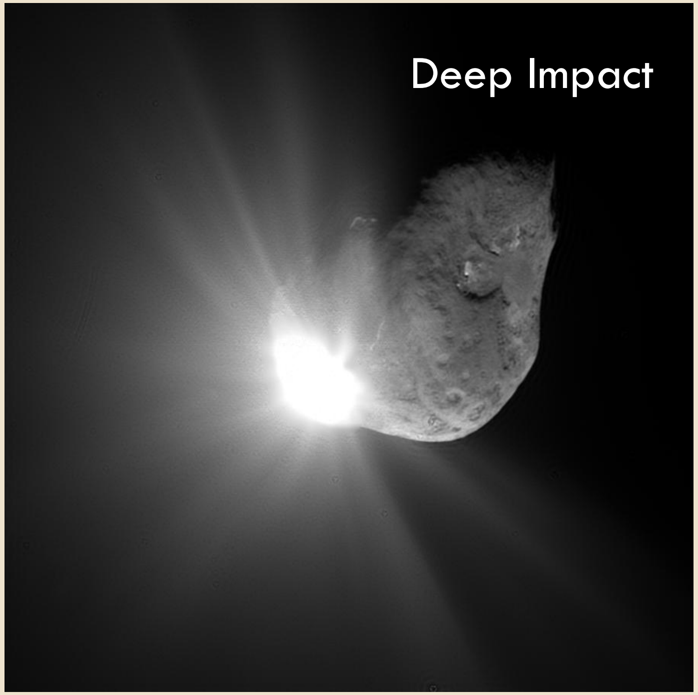
- Water constitutes 50-80 % of ice content
- Water is the **main driver** of cometary activity





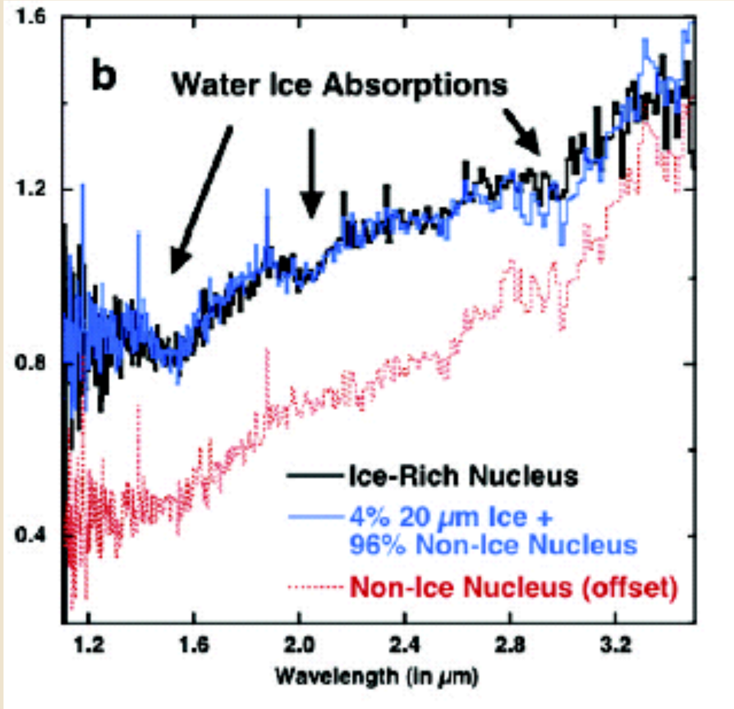
Biver et al. 2002

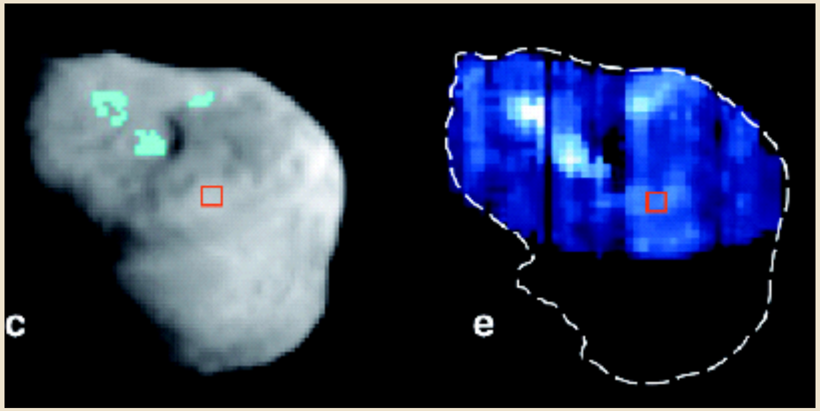
Little ice at the surface



A'Hearn et al. 2005

9P/Tempel 1, 4 July 4 2005

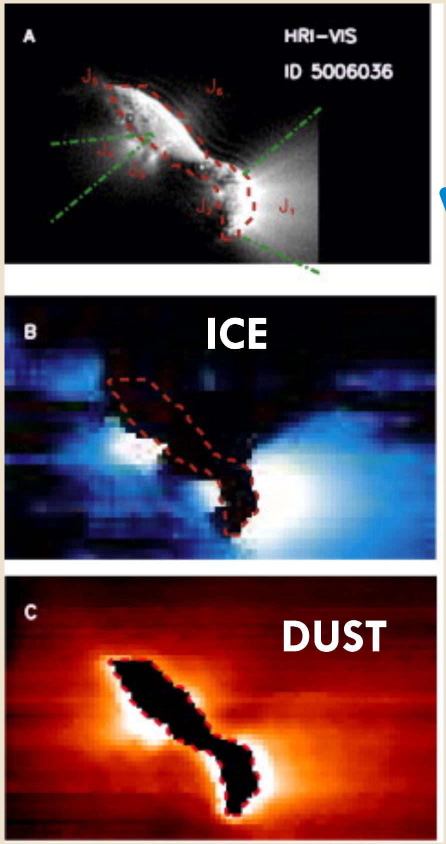


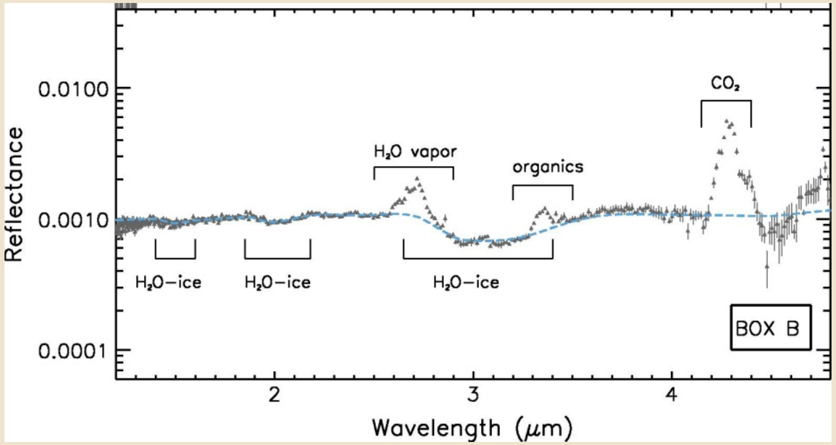


A'Hearn et al. 2005
Sunshine et al. 2006

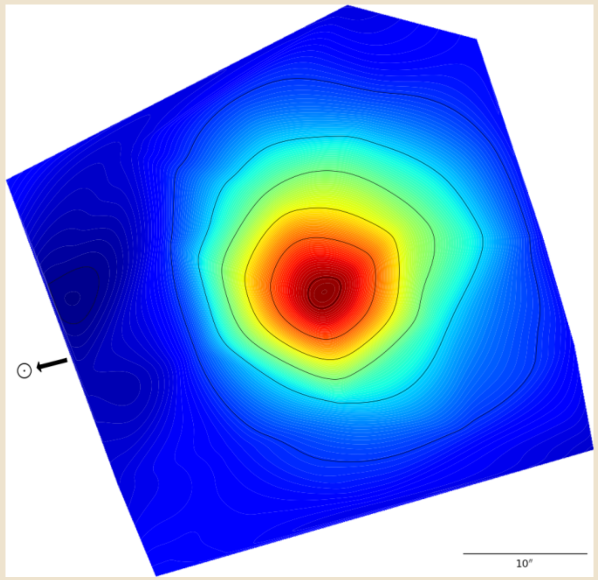
Icy grains contributing to water vapor

- **Comet 103P, EPOXI**





PACS
H_2O (2_{21}-2_{12}) 180.5 μm



Protopapa et al. 2014, Icarus

Water : New insights from the Rosetta mission

- Rosetta
  - A suite of instruments to monitor cometary activity and investigate surface properties along comet 67P orbit (4 AU to 1.3 AU)

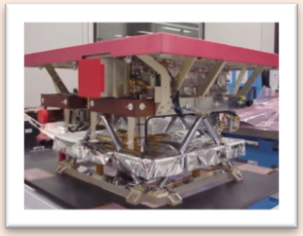
- Regional and seasonal variations

- Water properties :
  - crystalline versus amorphous state
  - isotopic ratio : D/H, $^{16}O/^{18}O$

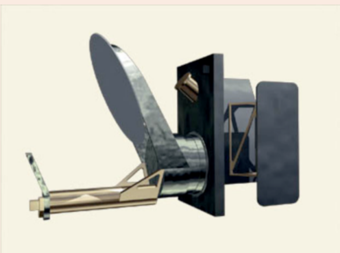
Rosetta Orbiter instruments

ALICE
(UV)

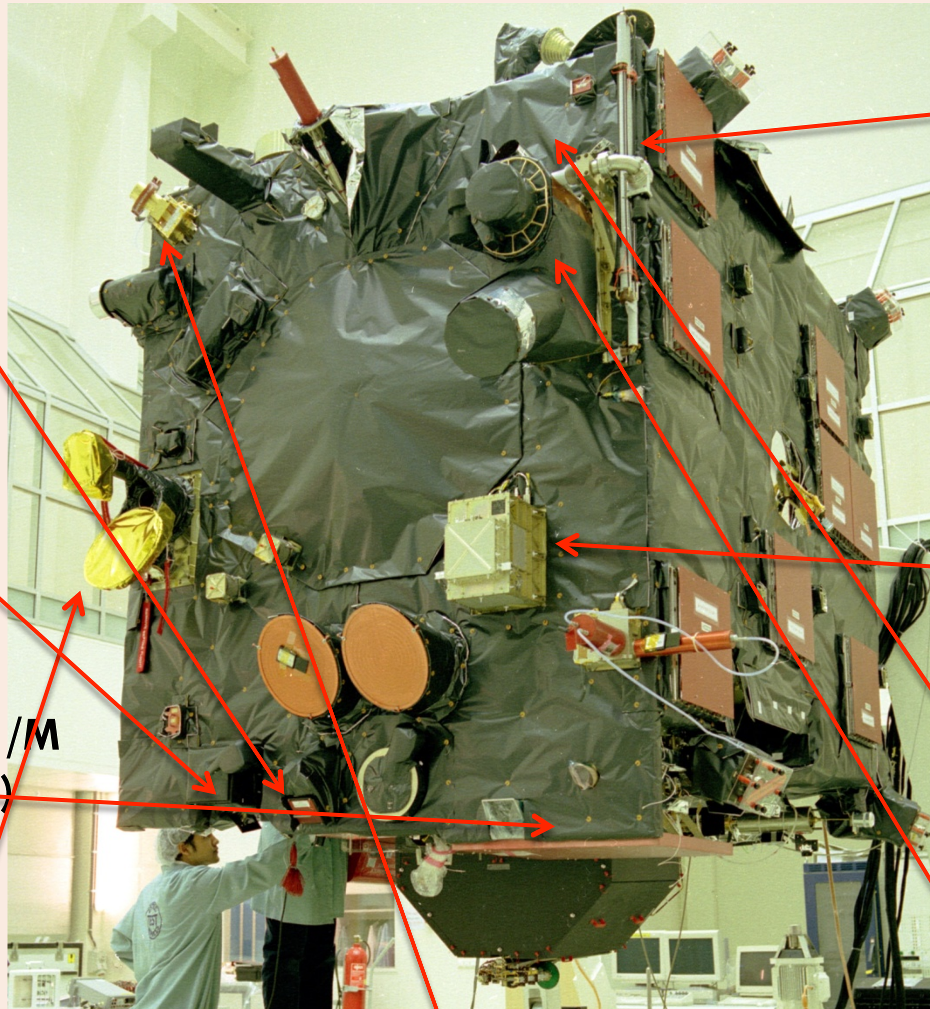
OSIRIS
(Vis.)



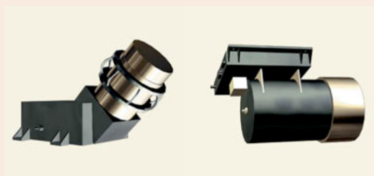
VIRTIS H /M
(VIS + IR)



MIRO (sub
mm & mm)

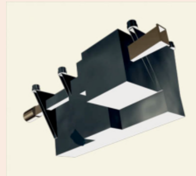


RPC



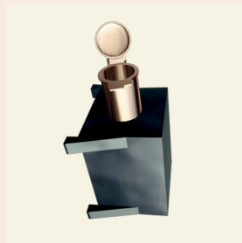
CONSERT

COSIMA

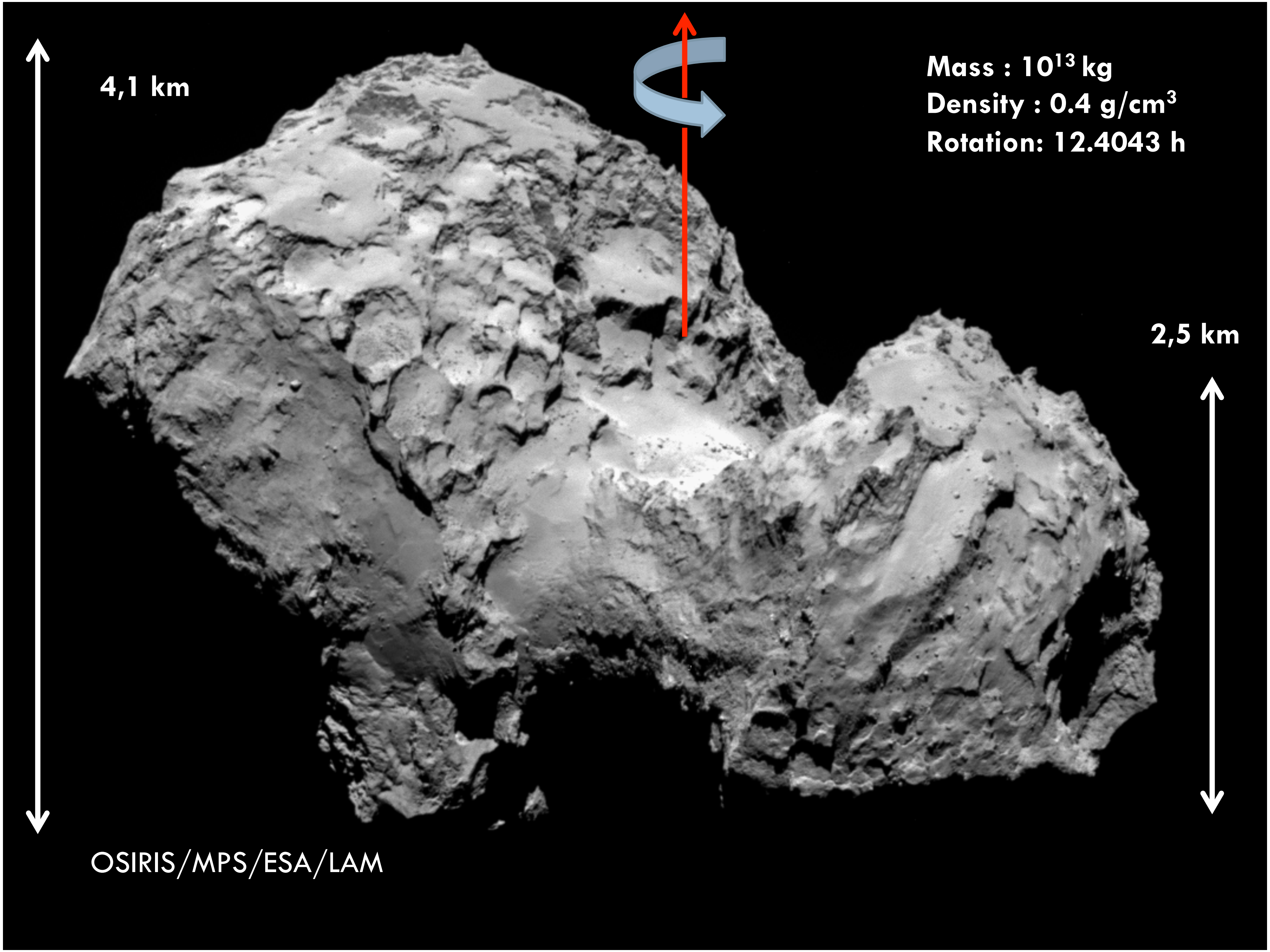


GIADA

MIDAS

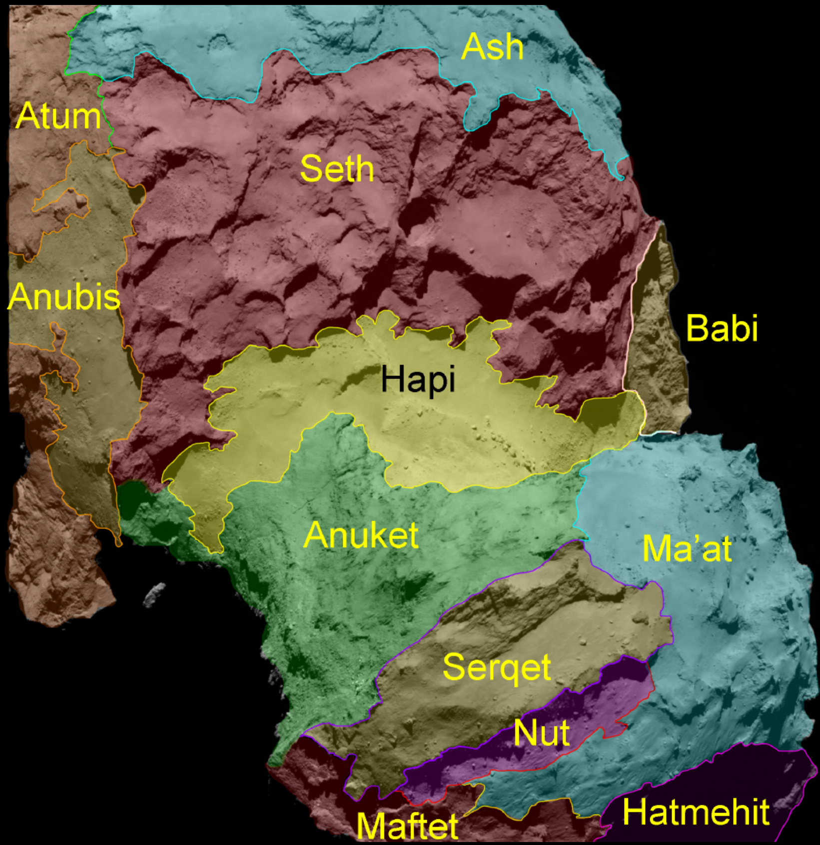


ROSINA



4,1 km
Mass : 10^{13} kg
Density : 0.4 g/cm^3
Rotation: 12.4043 h
2,5 km
OSIRIS/MPS/ESA/LAM

Geomorphologic regions

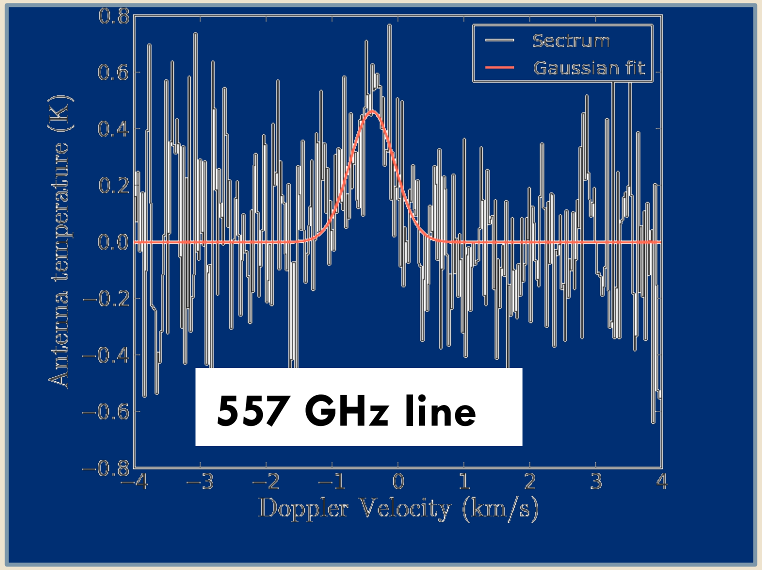


El-Maary et al. 2015

3 types
- consolidated terrains
• smooth terrains
• dépressions

Water production of comet 67P

- First detection at 3.9 AU inbound (MIRO)

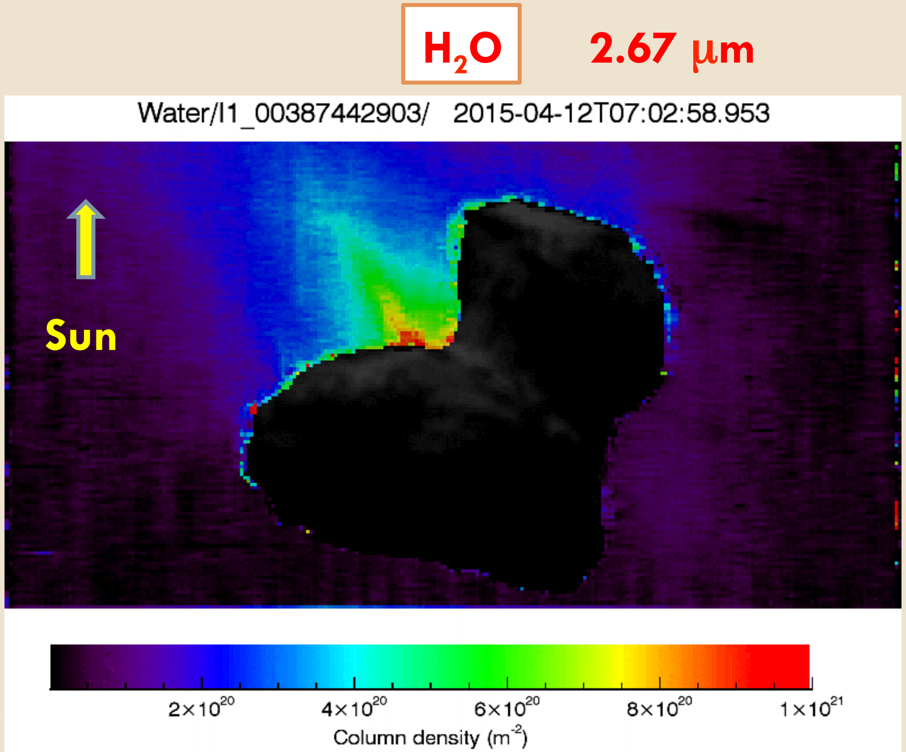


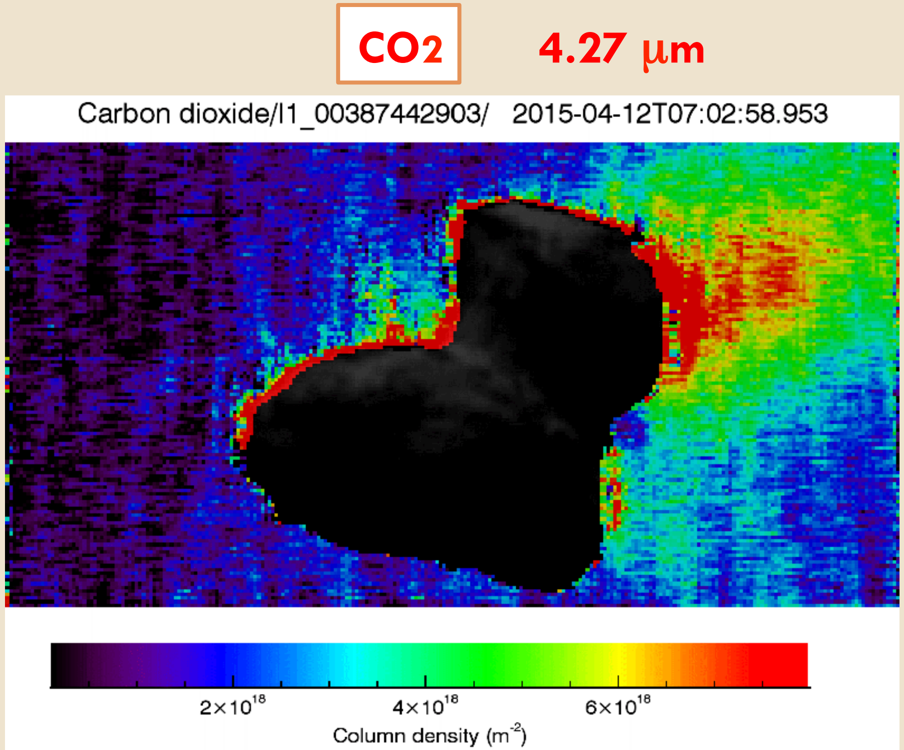
- Water production increased by a factor of 1000

from 4 to 1.3 AU

Source regions of water vapor

April 2015, 1.9 AU



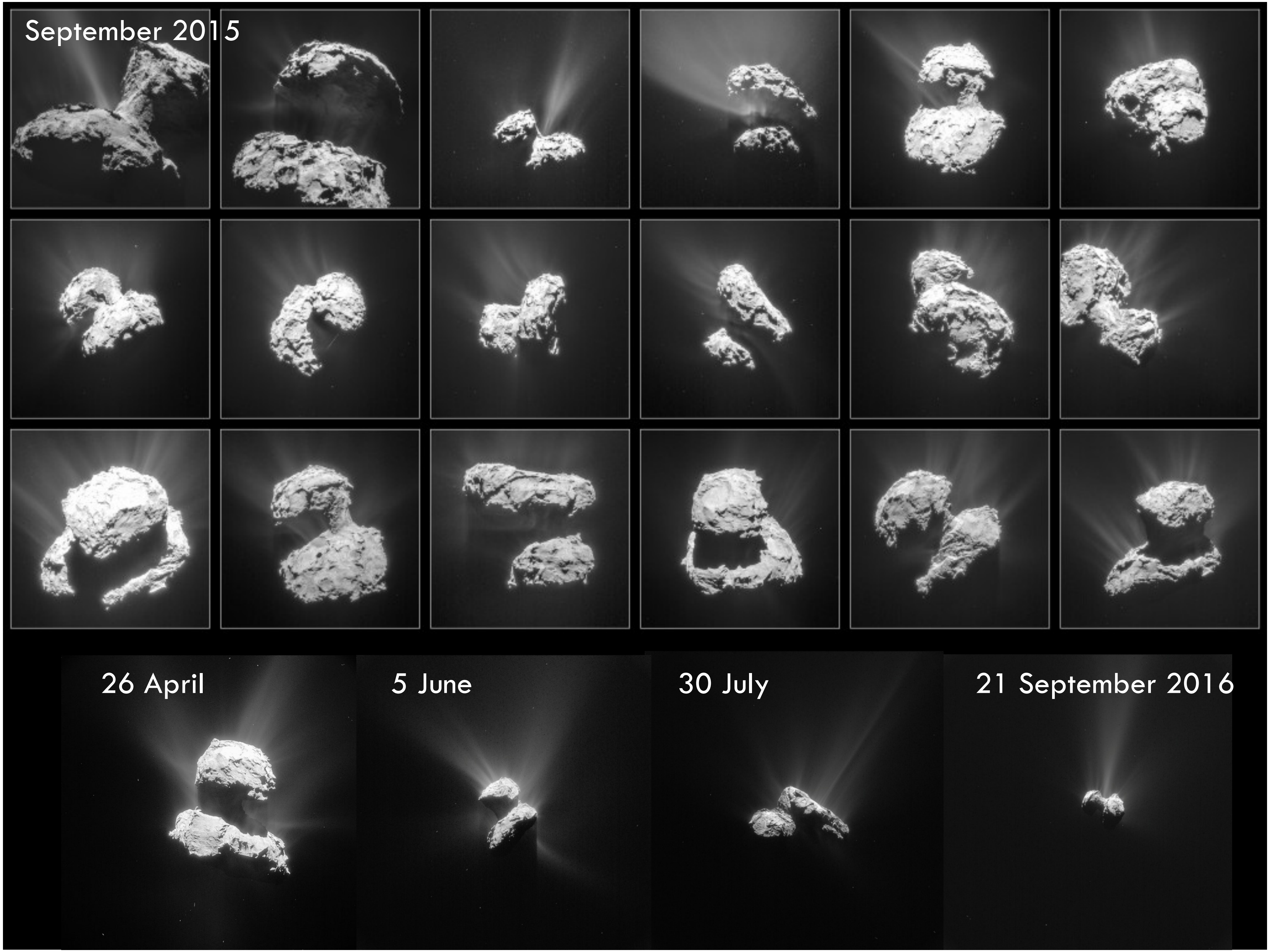


Migliorini et al. 2016

Dust Jets from neck region

OSIRIS/MPS/ESA/LAM

OSIRIS/MPS/ESA/LAM


September 2015
26 April
5 June
30 July
21 September 2016

Surface ice

- Broadband photometry (OSIRIS)
- Multi- Spectral imaging (VIRTIS)

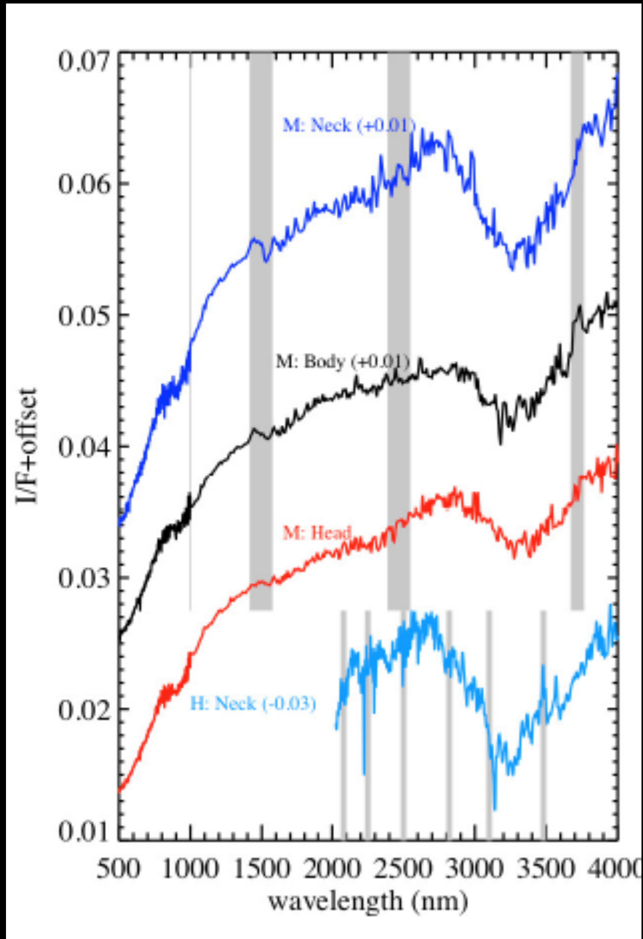
- Dark, red nucleus
- Poly-aromatics, opaque minerals
- Dehydrated : no philosilicates

- Regional variations of color, spectral slope associated to the presence of water ice

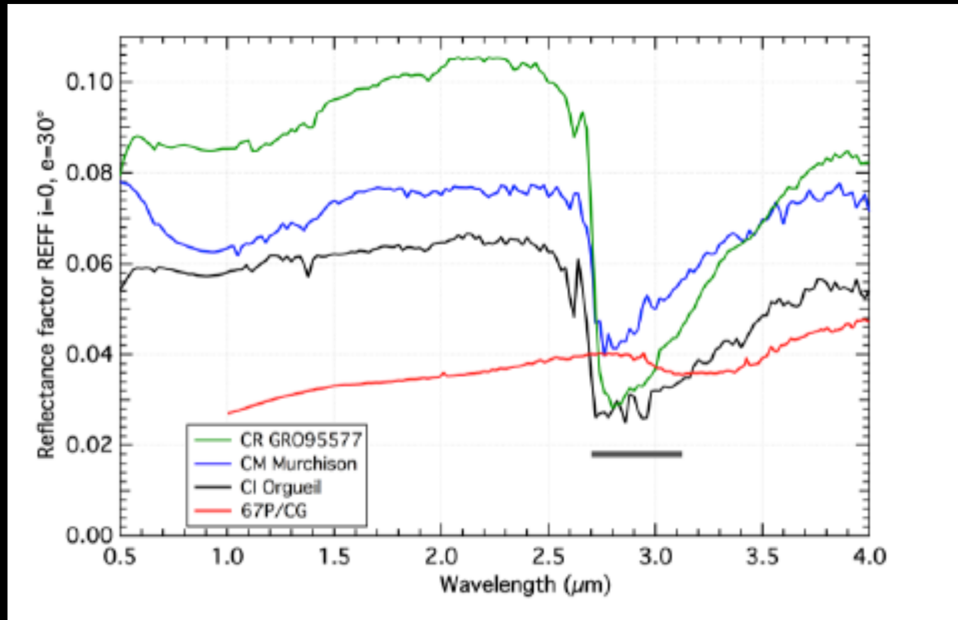
- Neck is bluer (neutral) explaining pronounced water activity pre-perihelion

Fornasier et al. (2015)

Surface composition from VIRTIS



Capaccioni et al. 2015, Quirico et al. 2016



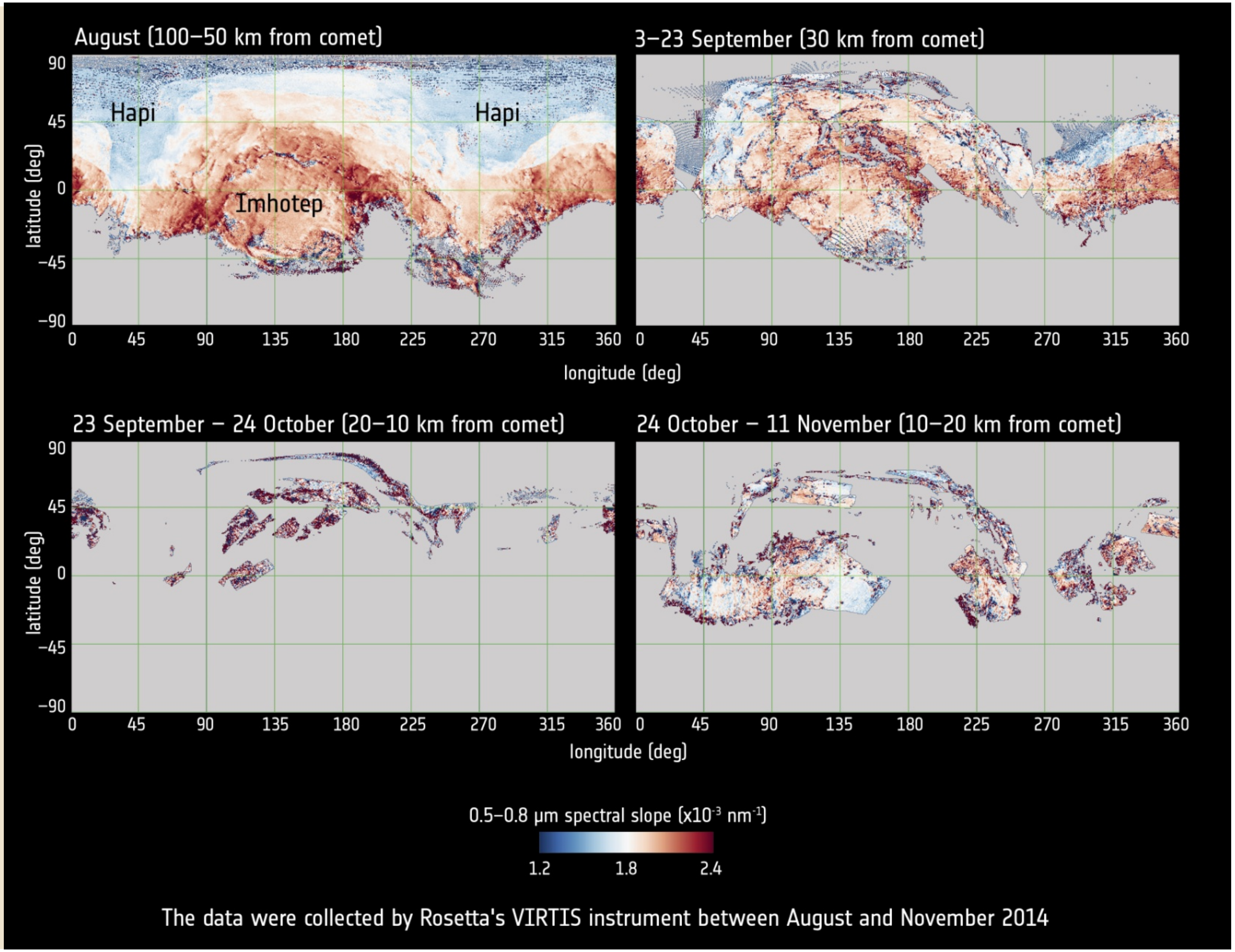
Quirico et al. 2016

- **low albedo & redenning:** poly-aromatics <u>& opaque minerals</u> (sulfides – FeS and Fe-Ni alloys)
- **3.2 μm band:** carboxyl groups RCCOH - NH4+ compounds
- **no hydrated minerals**

Colour-changing of the comet

- •Spectral slopes
- •Albedo

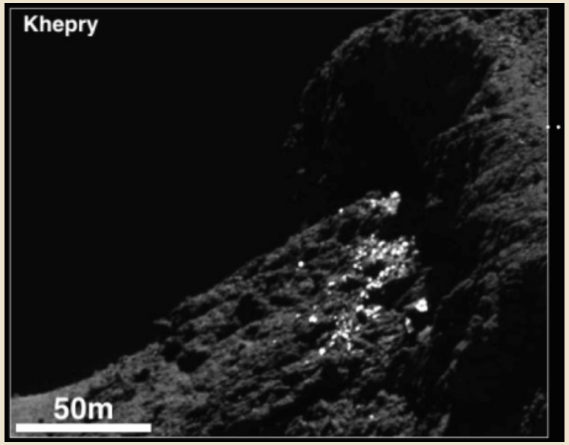
More water ice exposed as 67P approached Sun



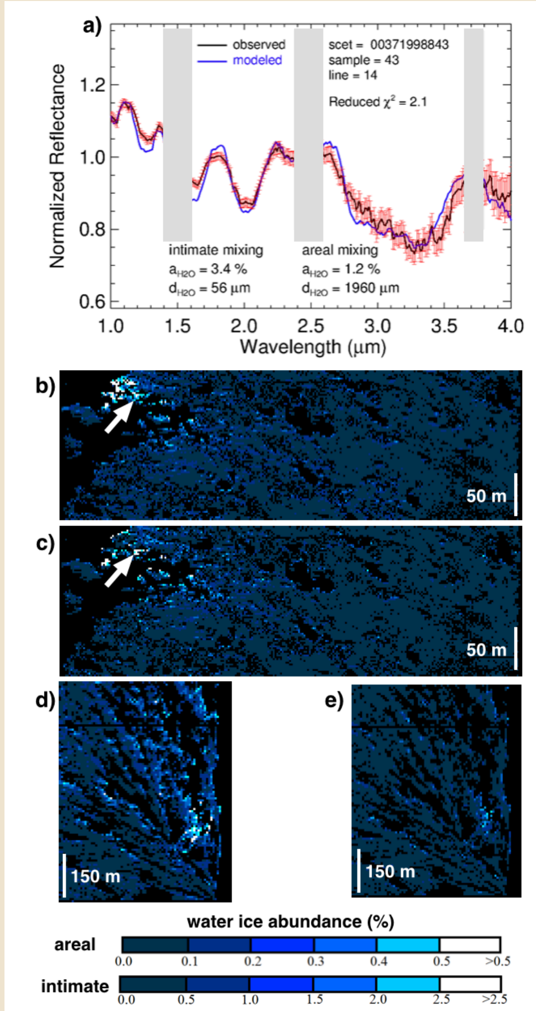
Filacchione et al. 2016

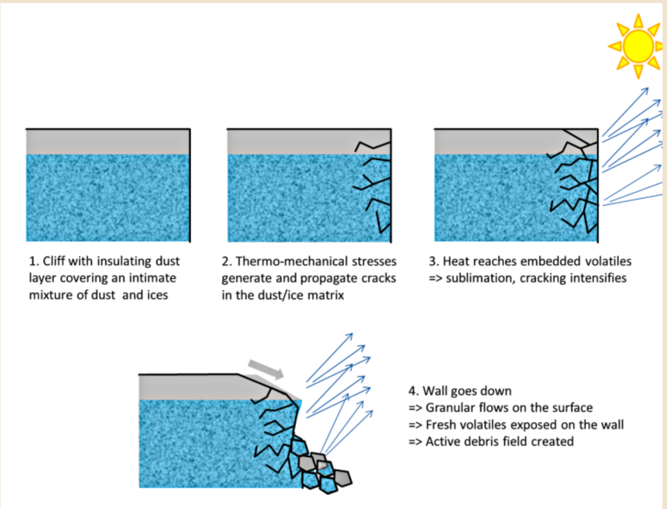
Water ice-rich spots

- Ice spots associated to debris falls related to erosion and mass Wasting – short or long-lived
- Correlation between color, ice signature, and temperature
- Dust jets associated to fractured walls and mass wasted debris

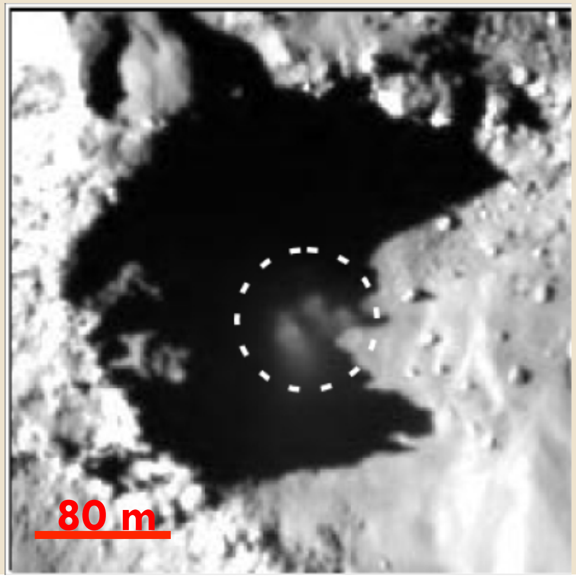


OSIRIS/Pommerol et al. (2016)

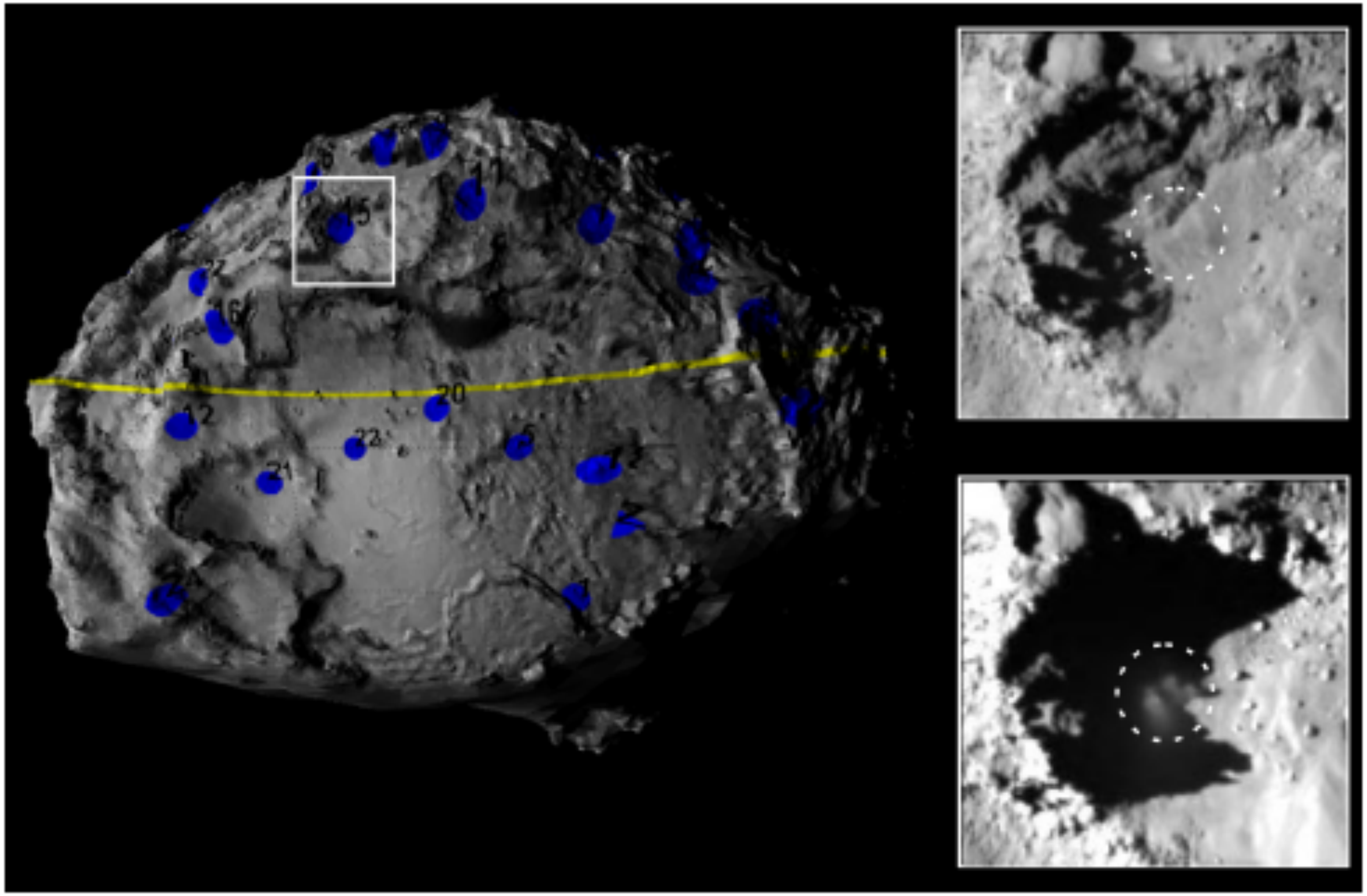




OSIRIS/Vincent et al. (2016)

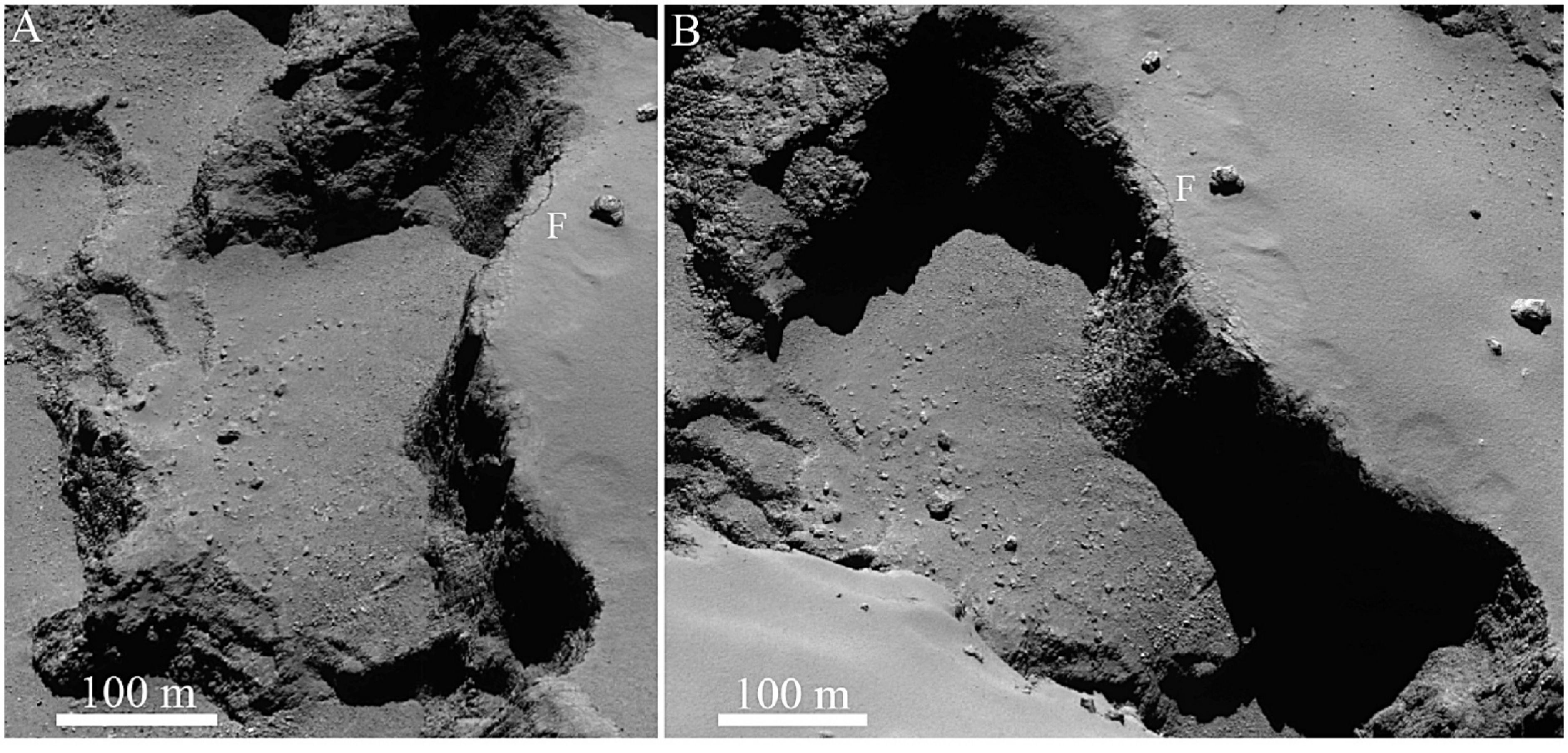


VIRTIS/Filacchione et al. 2016



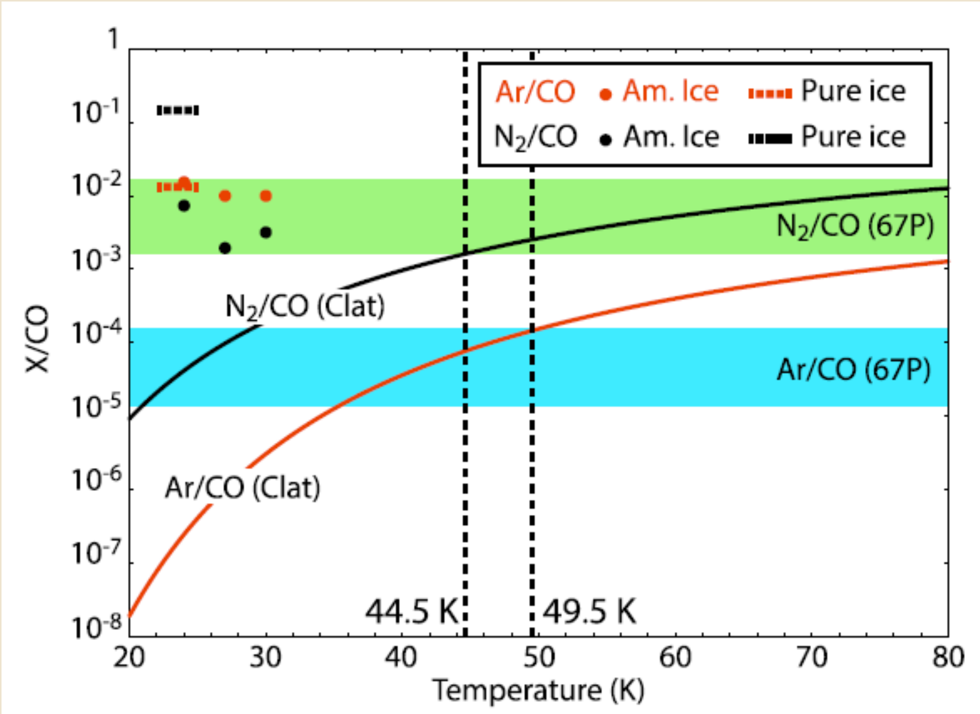
OSIRIS/Vincent et al. (2016)

Cliffs and fractures on comet 67 P



Water ice properties

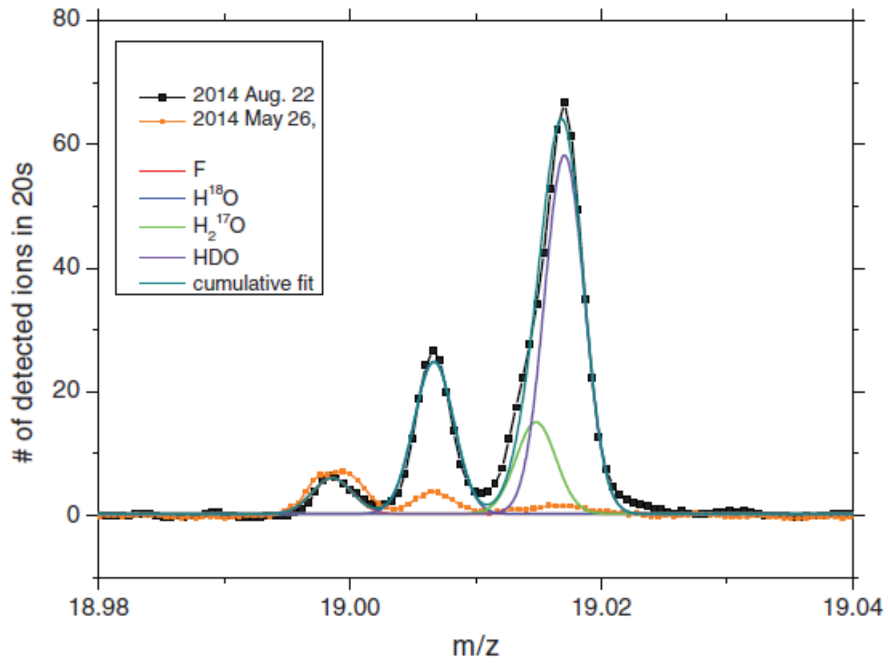
- **A long debate** : is deep water ice **crystalline or amorphous** ?
- How volatiles are trapped ? Some argue for the presence of clathrate hydrates trapping volatiles
- Minor species abundances/outgassing behavior may provide answers
- N_2 and Ar detected with ROSINA
  - $N_2/CO \sim (0.15 - 1.6) \times 10^{-2}$
  - $Ar/CO \sim (0.15 - 1.5) \times 10^{-4}$
- N_2/CO consistent with trapping in amorphous ice at T ~ 30 K
- N_2, Ar ratios consistent with **trapping in crystalline ice** at 45-50 K

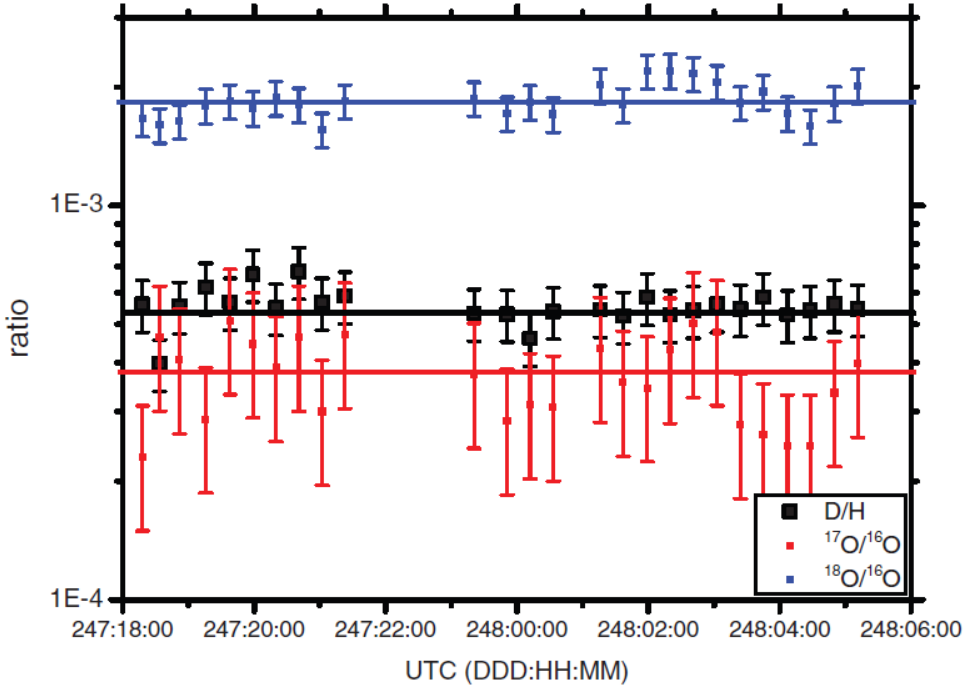


Mousis et al. 2016

Water isotopic ratios : D, ^{17}O, ^{18}O

Comet 67P, ROSINA DFMS mass spectrometer



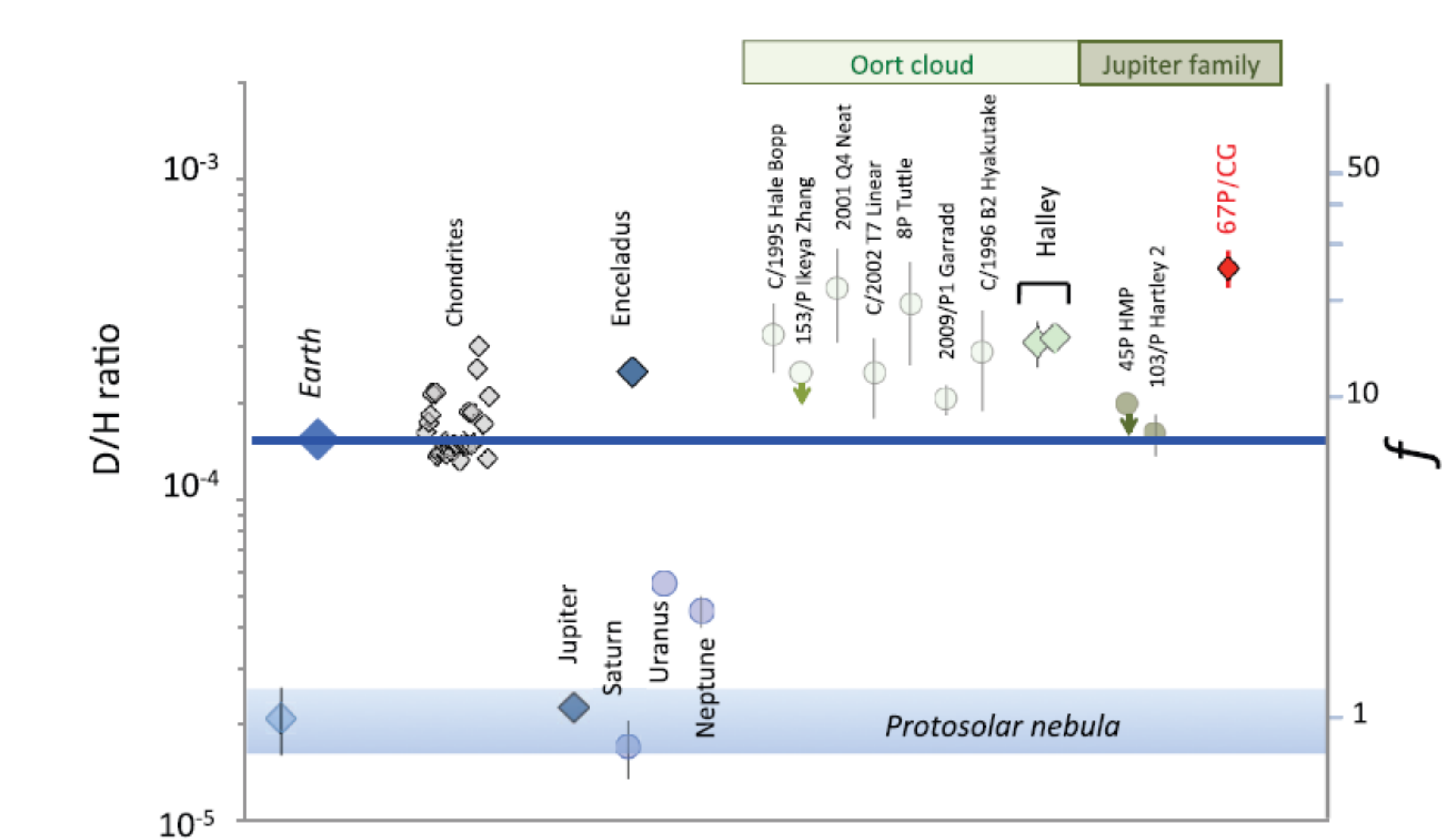


D/H = (5.3 ± 0.7) 10^{-4}
$^{16}O/^{18}O$ = 556 ± 62
$^{16}O/^{17}O$ = 2703 ± 657

Altwegg et al. Science, 2015

MIRO results on oxygen isotopic ratios yet unpublished

Diversity of D/H ratio in comets



Altwegg et al. Science, 2015

Summary

- Rosetta is providing clues of how cometary activity works
- More to come by combining surface and coma data sets
- Beyond water topic, many key results on ice composition and isotopic ratios