Large-scale Morphological Changes in the Hapi region on Comet 67P/C-G

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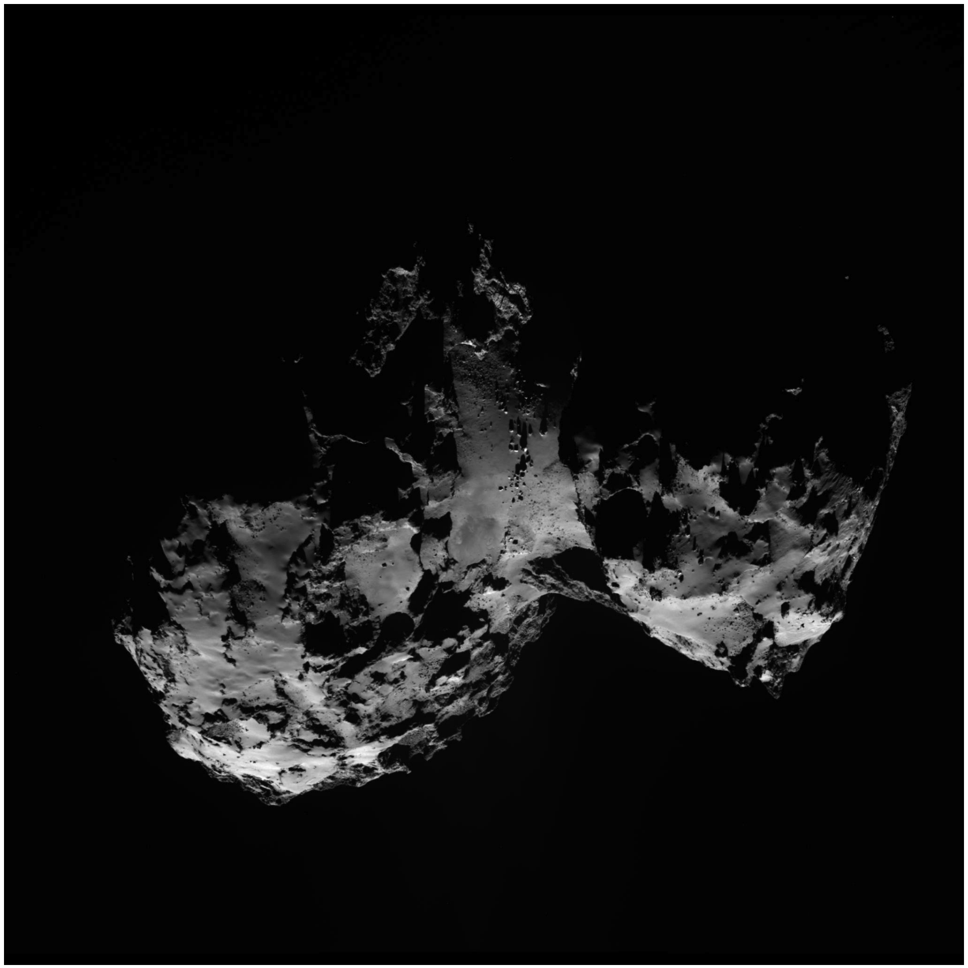
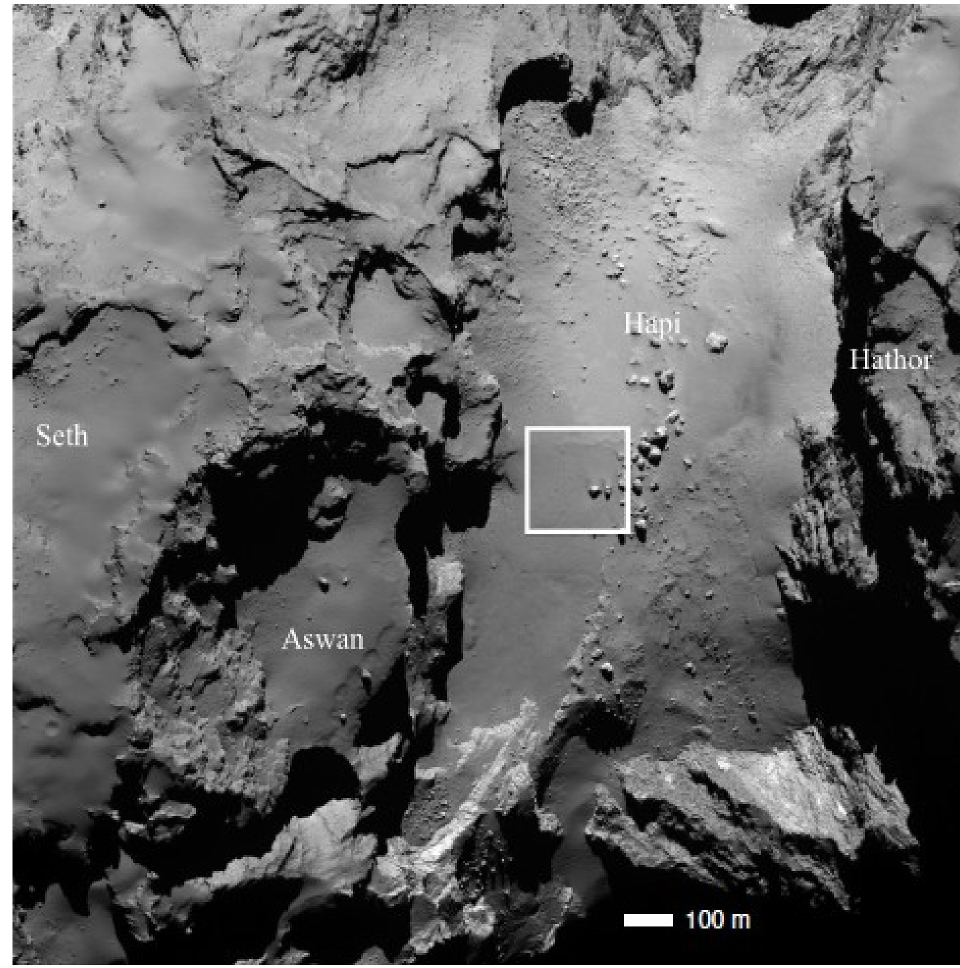
Summary

- OSIRIS has detected several episodes of large-scale changes in the Hapi region
  - Morphology versus time
  - Shape model: local gravity and illumination conditions
  - Spectrophotometry
- MIRO measures thermal emission from the nucleus at mm and sub-mm wavelengths
  - Temperature versus time and depth
  - Thermal inertia, ice abundance, extinction and scattering coefficients
  - Characterize conditions before, during, and after events
  - Compare with similar control regions where no changes were observed
- Work in progress – this is a status report!

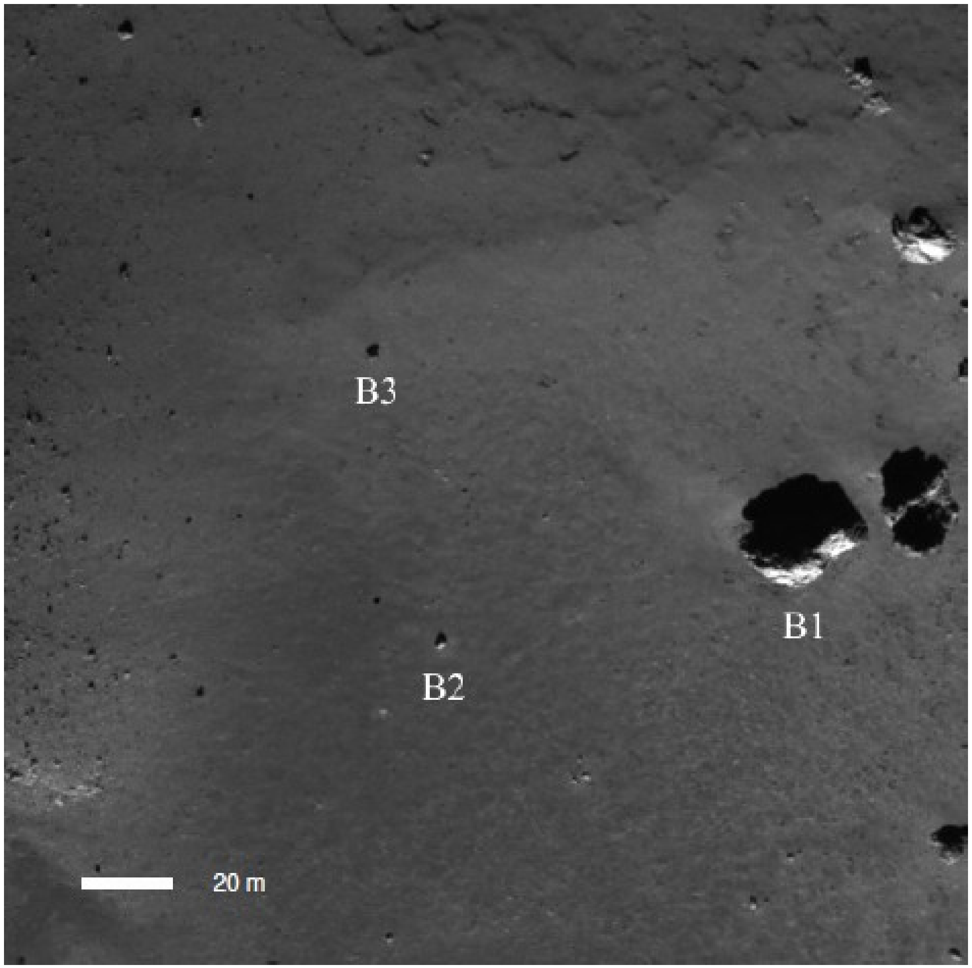
Context



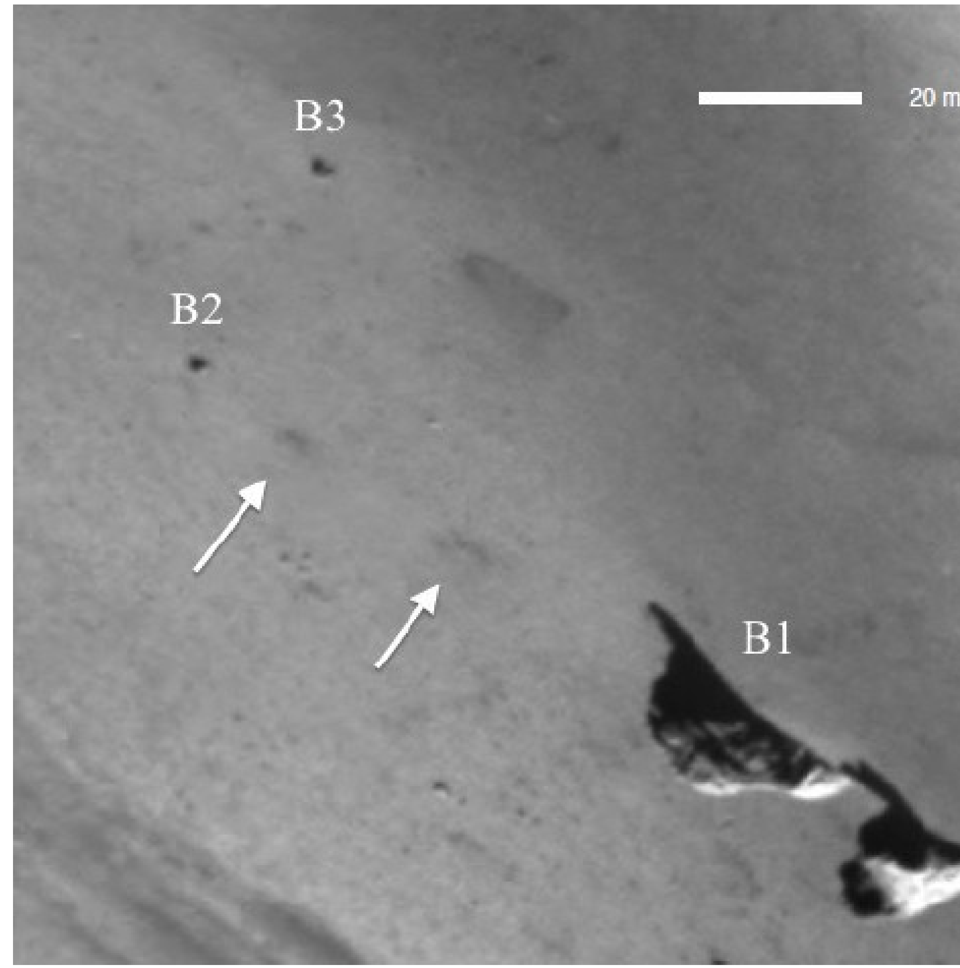


Credit: ESA/Rosetta/MPS for OSIRIS Team MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA and Davidsson *et al.* (2016, in preparation)

A large shallow depression emerges



Dec 10, 2014. NAC 20 km: 0.35 m px^{-1}.
No change since Aug 2014.



Dec 30, 2014. NAC 28 km: 0.49 m px^{-1}.
Two dark spots ~ 5-8m across.

Credit: ESA/Rosetta/MPS for OSIRIS Team MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA and Davidsson *et al.* (2016, in preparation)

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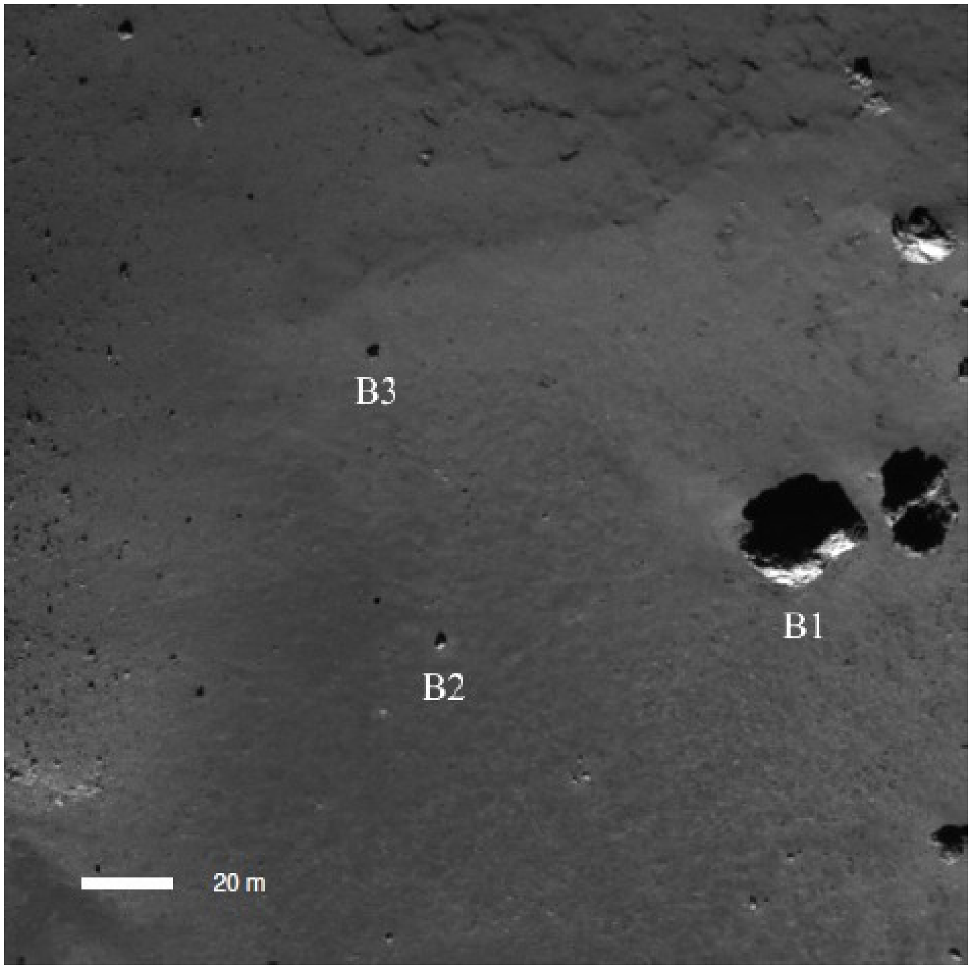

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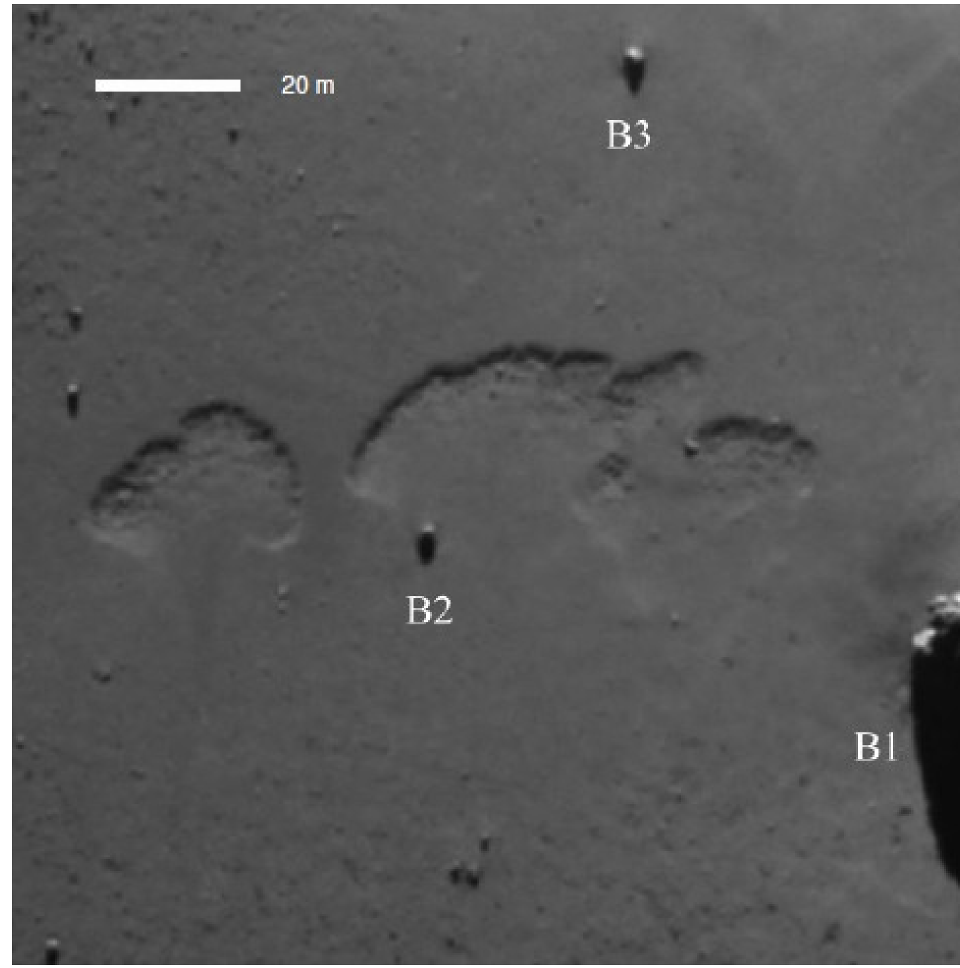
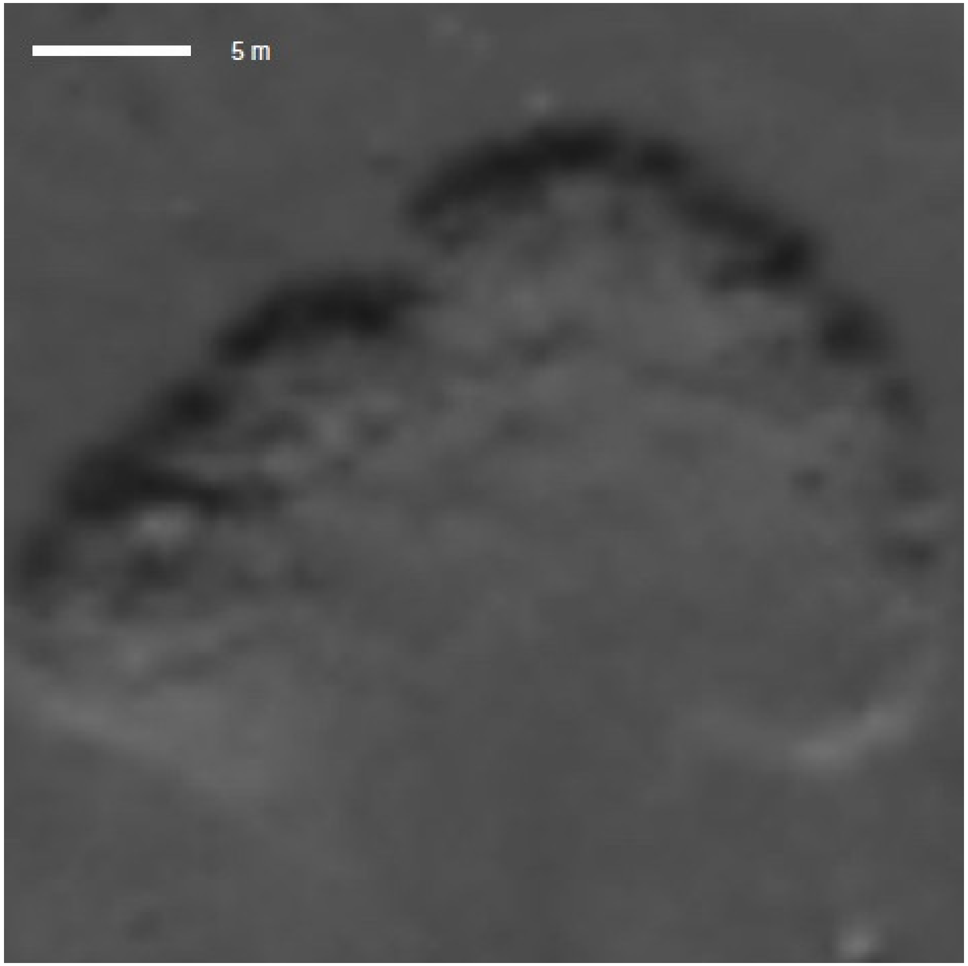
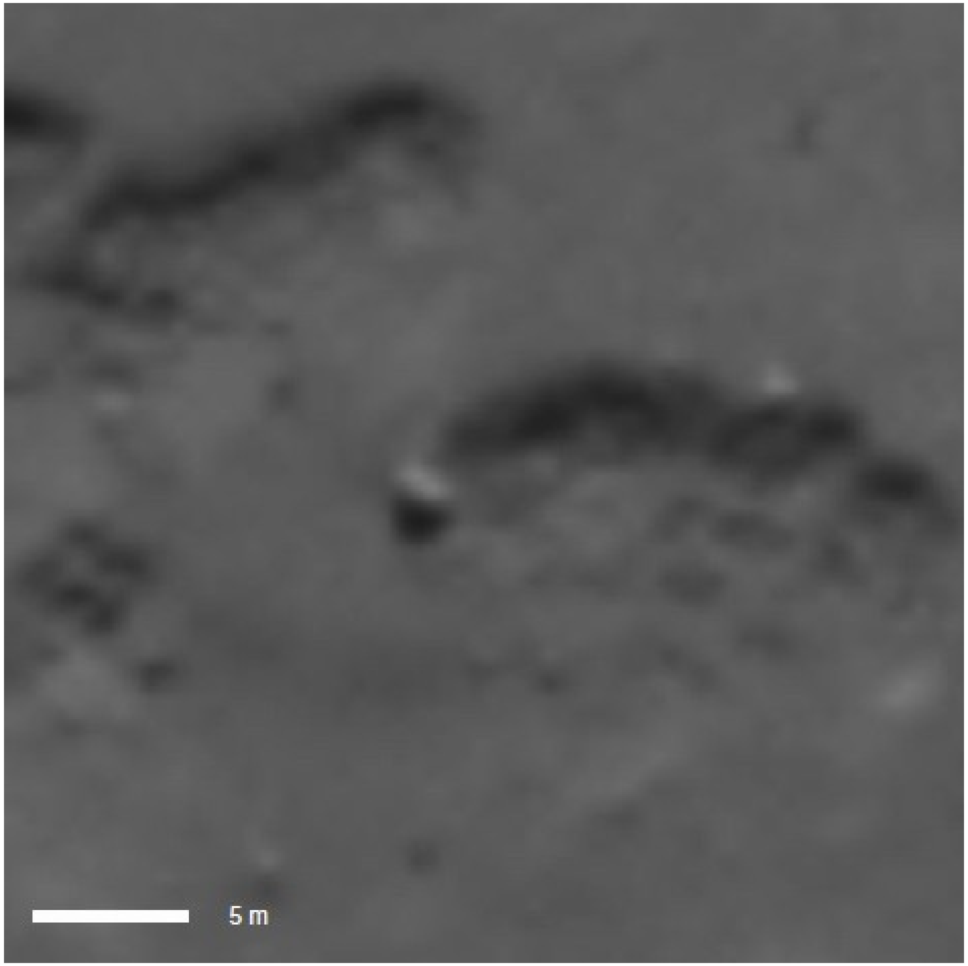


Jan 22, 2015. NAC 27km: 0.49 m px^{-1}.

Credit: ESA/Rosetta/MPS for OSIRIS Team MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA and Davidsson *et al.* (2016, in preparation)

Close-up





After 11 days: 29 x 20 x 0.5m
Expanded ~ 0.9 m day^{-1}

Right half of a 63 x 22 x 0.5m feature
Pit floor irregular and pitted compared to surroundings.

Credit: ESA/Rosetta/MPS for OSIRIS Team MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA and Davidsson *et al.* (2016, in preparation)

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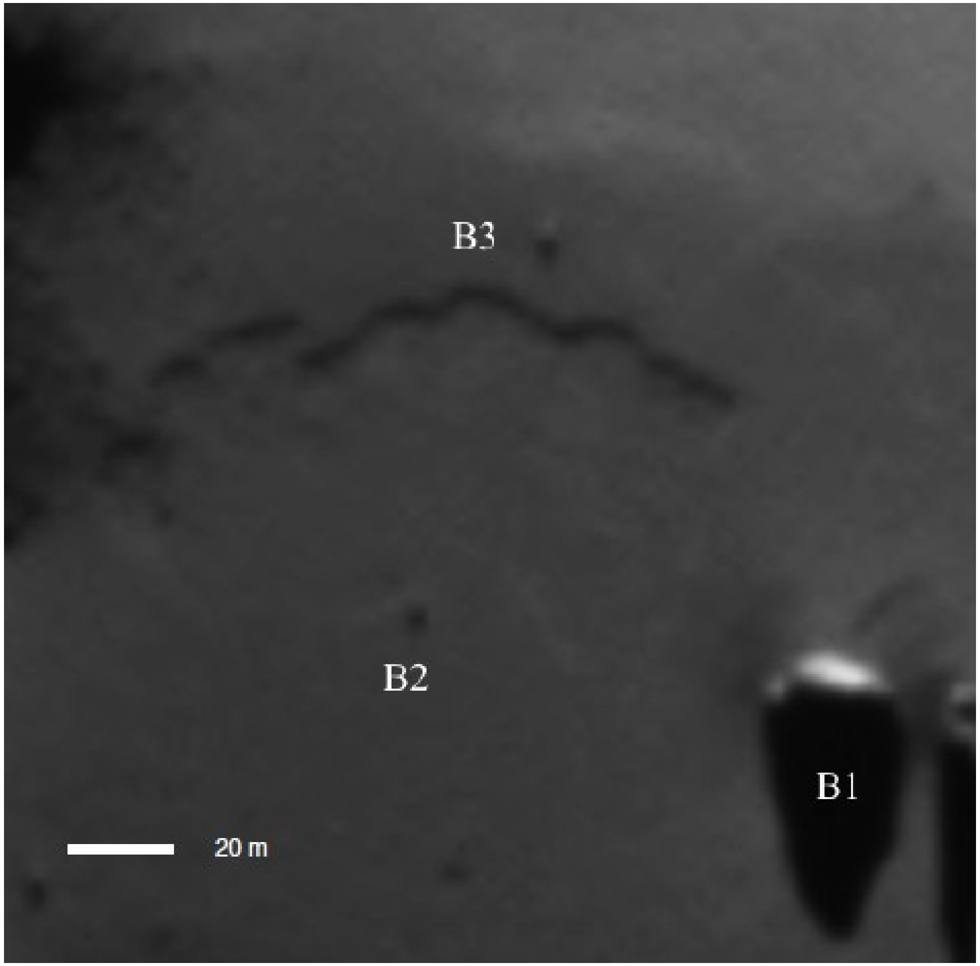
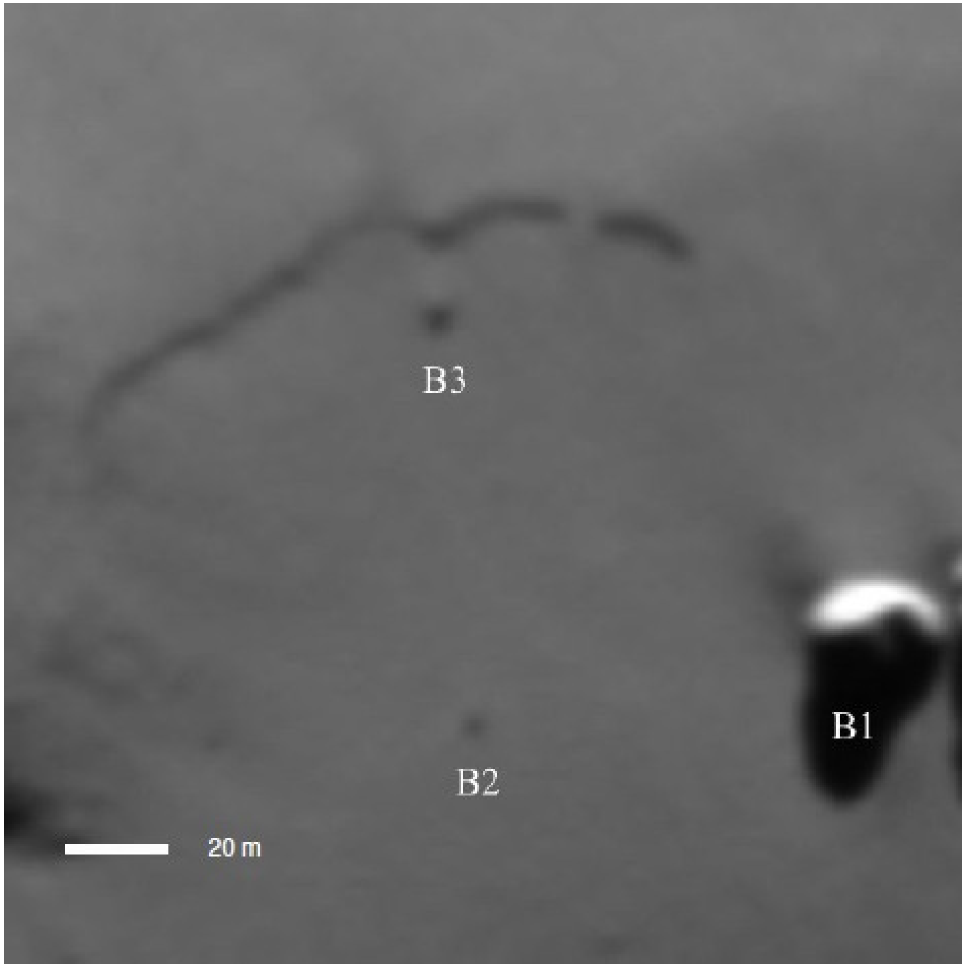


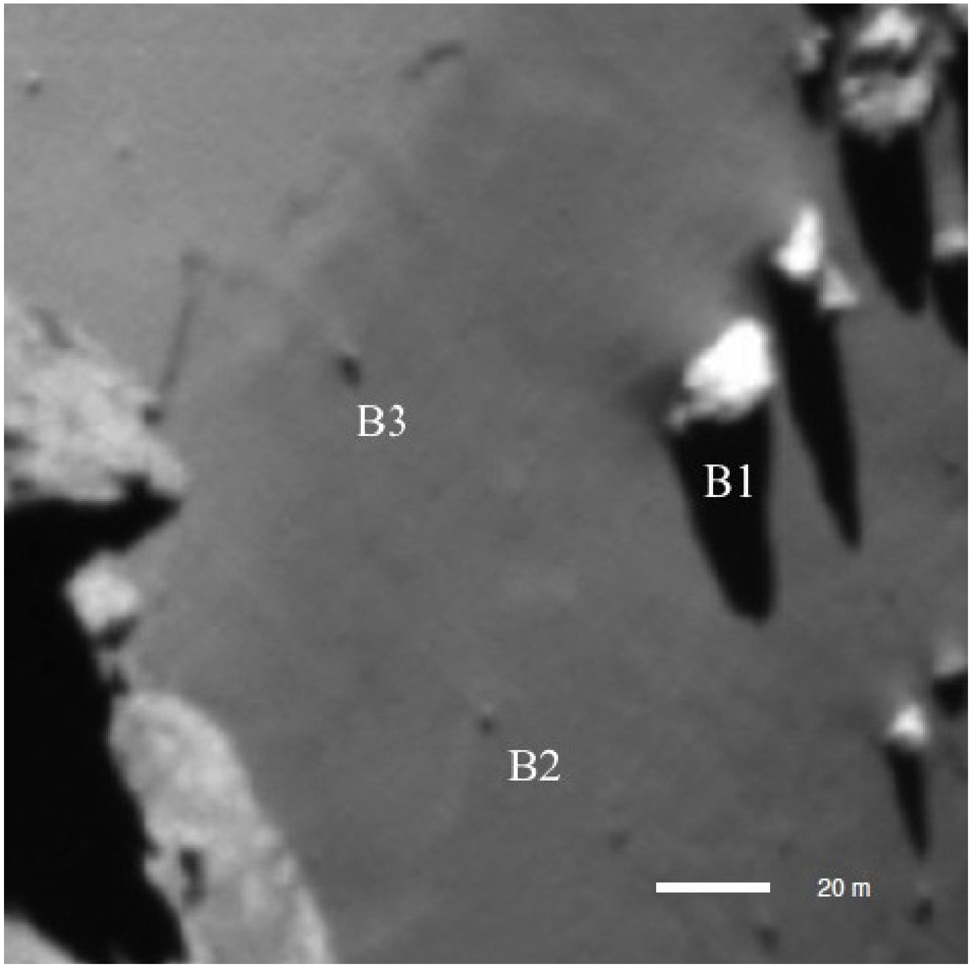
Feb 9, 2015. NAC 106 km: 1.89 m px^{-1}. Features have merged, moving at 1.7 m day^{-1}



Feb 28, 2015. NAC 108 km: 1.93 m px^{-1}. Escarpment has passed boulder B3.

Credit: ESA/Rosetta/MPS for OSIRIS Team MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA and Davidsson *et al.* (2016, in preparation)

A large shallow depression emerges



Mar 17, 2015. NAC 77 km: 1.37 m px^{-1}.
Escarpment stops beyond a low ridge.

Feature grew to 75 x 110 m in ~ 60 days.

Volume: ~4000 m^3.
Mass: ~2000 metric tons.

Propagation speed ~ 1 m day^{-1}.

r_h≈2.5 AU in mid Jan:
Sublimation: ~ 0.01 m day^{-1}.

Credit: ESA/Rosetta/MPS for OSIRIS Team MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA and Davidsson *et al.* (2016, in preparation)

Landslide?

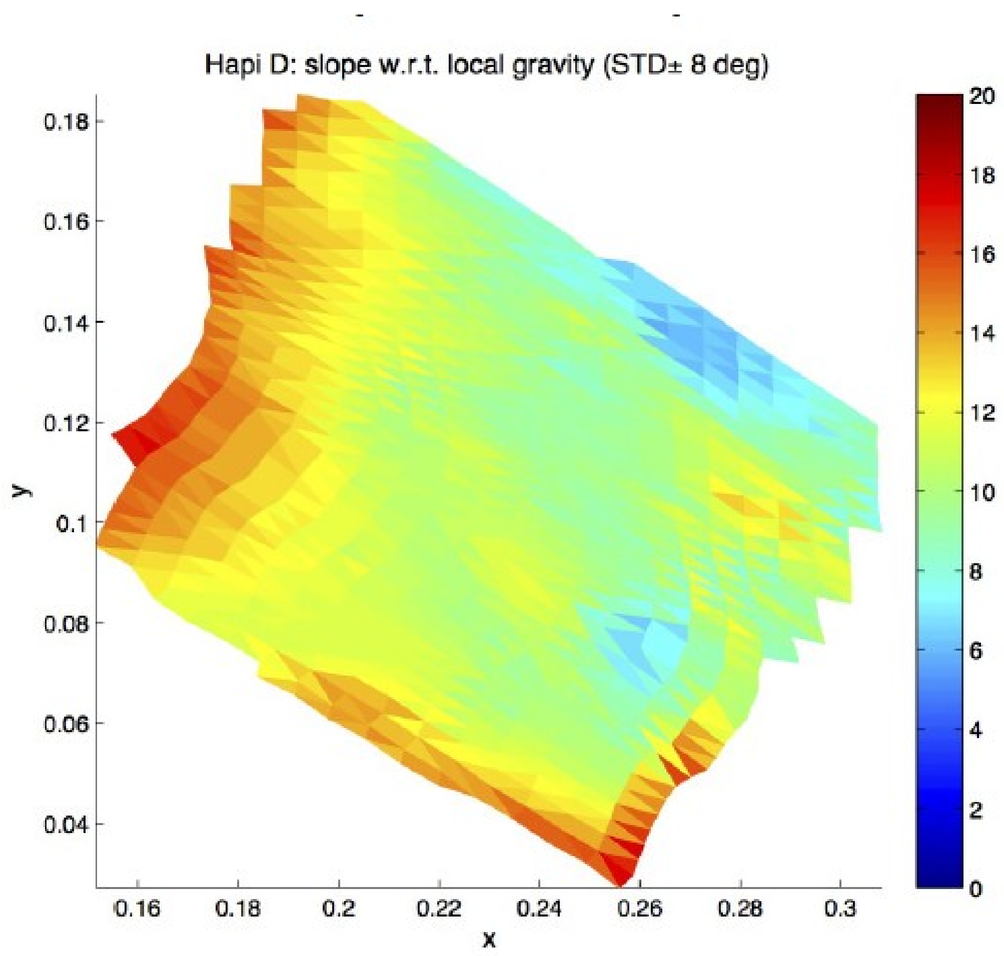
Death Valley sand dunes:

Land slide on steep slopes.

Upper edge propagates to the rim.

Credit: Davidsson

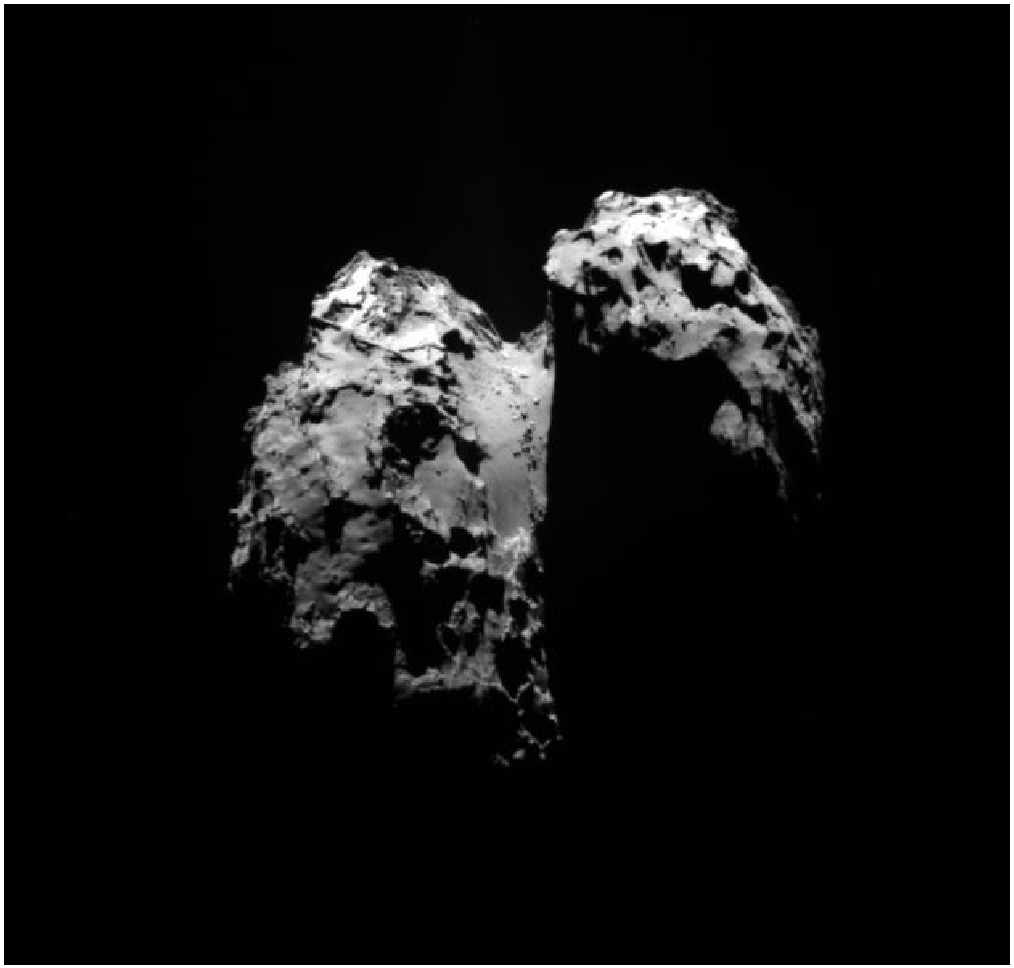
Probably not...



Tilt of the normal versus local gravity is only 5-18°.

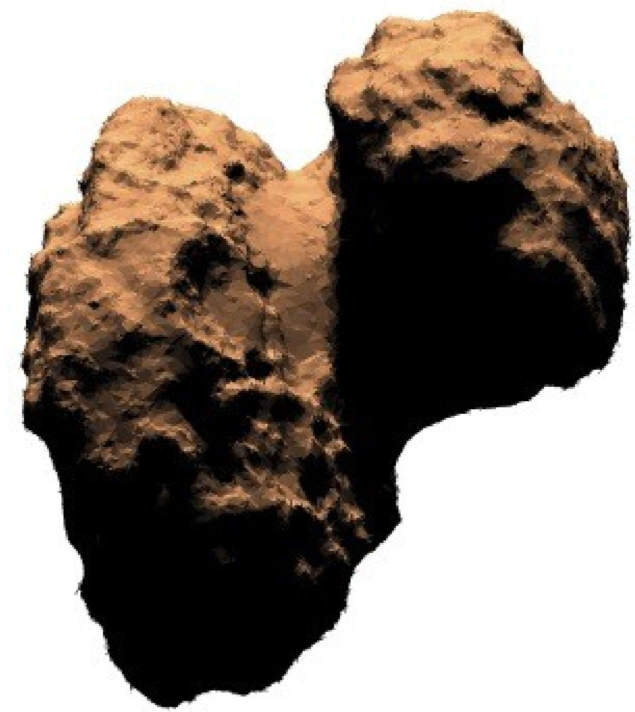
Credit: Davidsson

Accurate illumination conditions throughout orbit



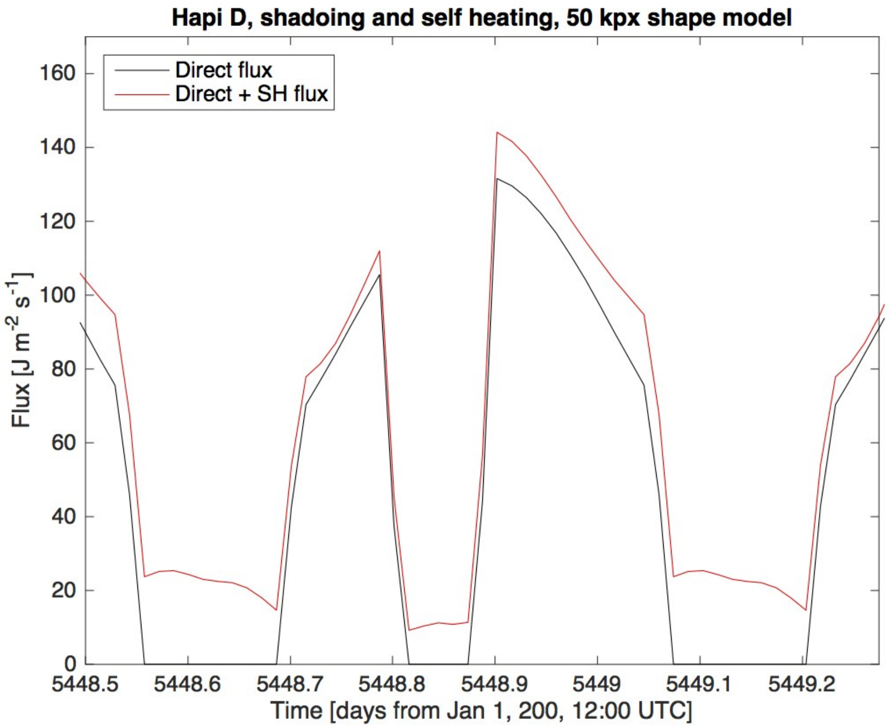
WAC image on Feb 9, 2015,
13:32:56.344 UTC

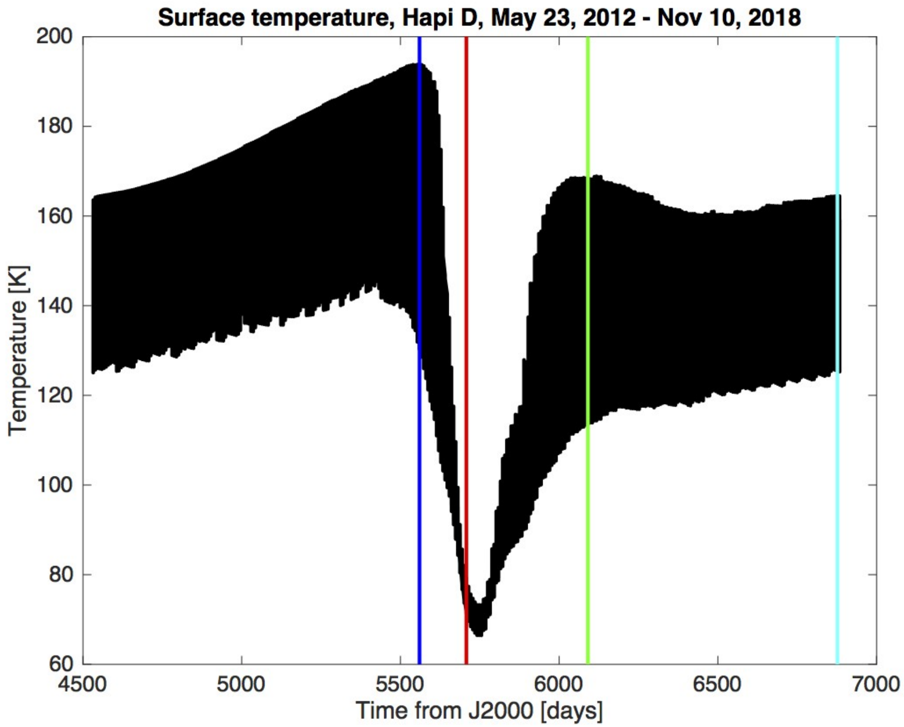
Credit: ESA/Rosetta/MPS for OSIRIS Team
MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA



Synthetic image generated with the model of
Davidsson & Rickman (2014, *Icarus* **243**, 58-77)
Shape model SHAP5 version 1.5 (degraded)
by Jorda *et al.* (2016, *Icarus*, **277**, 257-278)

Accurate illumination conditions throughout orbit





Credit: Davidsson

Shape model with 50,000 facets

Direct solar illumination and shadowing by topography

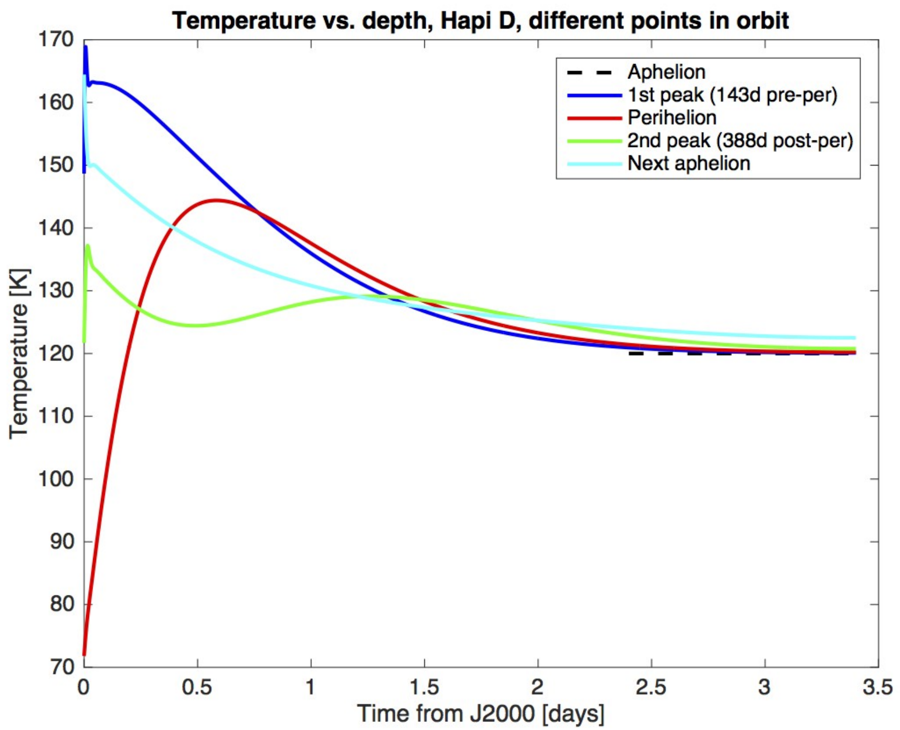
Vis+IR self-illumination from surrounding terrain.

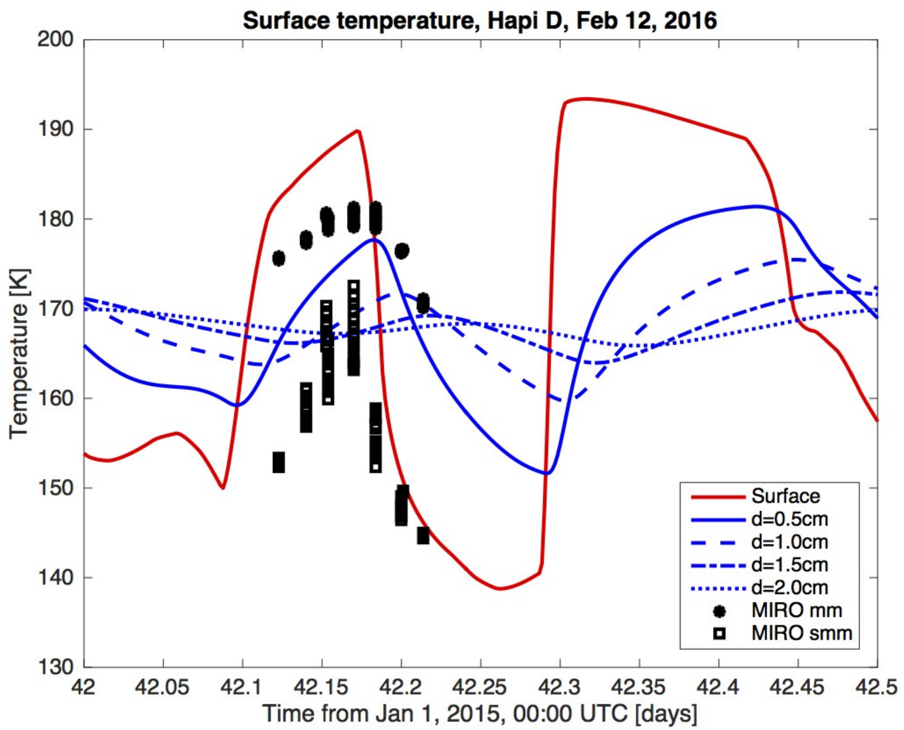
10° rotational steps throughout orbit.

1D heat conduction equation with upper boundary condition balancing illumination, thermal emission, heat conduction, ice sublimation.

Temperature T versus depth x and time t. Start with 90K during 1959 Jupiter encounter, integrate until present.

Temperature variations





Credit: Davidsson

Modeling the upper 3.4 meters. These T=T(x) at different t illustrate changes during orbit.

T=T(t) at different x illustrates changes during one nucleus rotation (red/blue)

The MIRO antenna temperatures (black) is a measure of *radiance* and should NOT be directly compared with T(x,t)

Radiative transfer solver

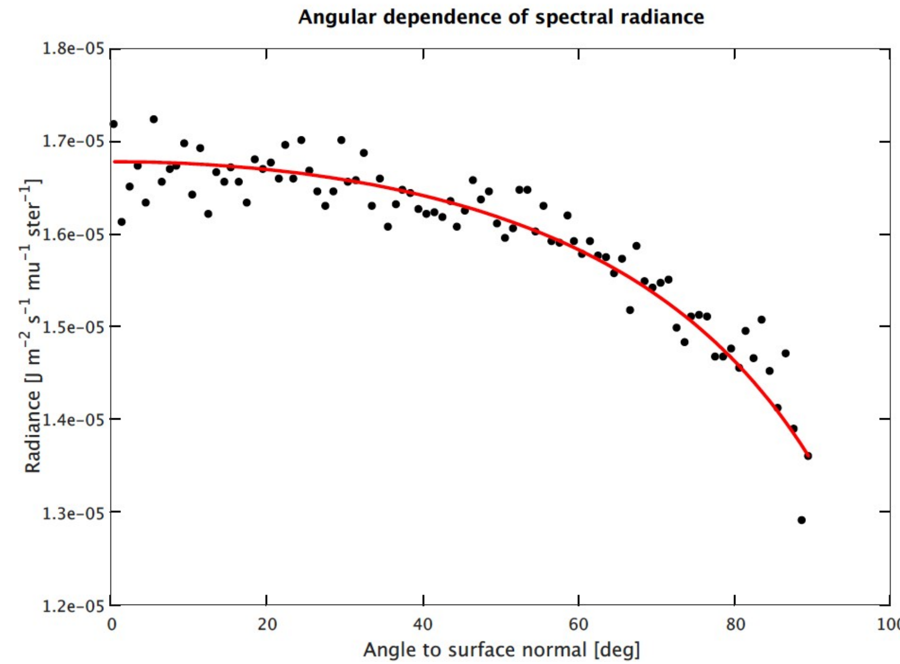
$$-\cos\vartheta \frac{\partial I(\tau,\Omega)}{\partial\tau} = -I(\tau,\Omega) + \frac{w}{4\pi}\int_{4\pi} I(\tau,\Omega')p(\tau,\Omega',\Omega)\,d\Omega' + J\frac{w}{4\pi}p(g)e^{-\tau/\mu_0} + \frac{\gamma^2}{\pi}U(T,\tau), \qquad (13.31)$$

$$U(T,\tau) \simeq U_0(T_0) + U_1(T_0)e^{-\tau/\mathscr{Y}}$$

$$I(i,e,g) = J\frac{w}{4\pi}\frac{\mu_0}{\mu_0+\mu}[p(g) + H(\mu_0)H(\mu) - 1] + \gamma H(\mu)\frac{U_0}{\pi} + \frac{\mathscr{Y}}{\mathscr{Y}+\mu}\gamma^2 H(\mathscr{Y})H(\mu)\frac{U_1}{\pi}, \qquad (13.36)$$

where $H(x)$ is given by the two-stream approximation for the H functions, $H(x) = (1+2x)/(1+2\gamma x)$. The details of the derivation of

Credit: Hapke (1993, *Theory of Reflectance and Emittance Spectroscopy*. Cambridge Univ. Press, Cambridge, UK.)

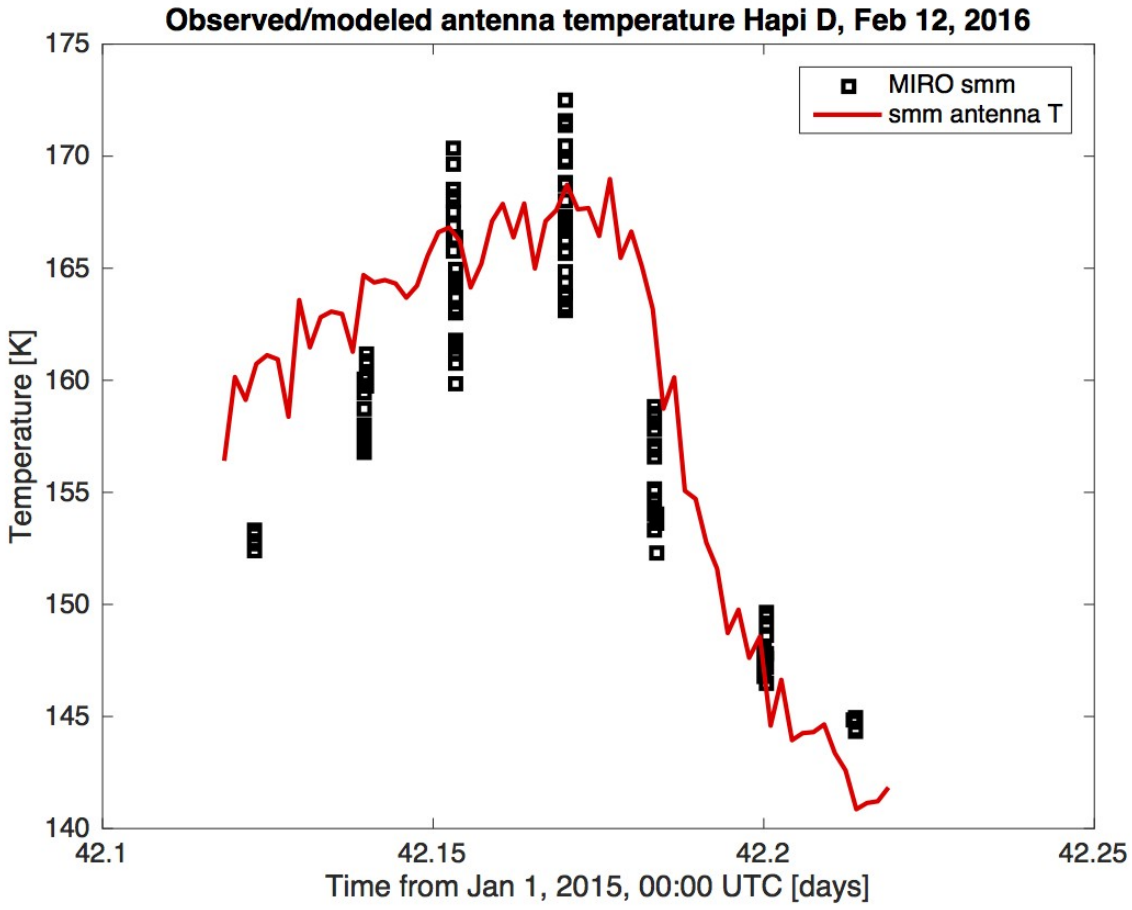


Credit: Davidsson

T drops linearly from 200K to 150K in top 15cm.

0.533mm radiance versus emergence angle for extinction coeff E=338 m^{-1} and single-scattering albedo w=0.5

(My) first model comparison with data



Thermal inertia 30 MKS
Dust/ice mass ratio 4
$E=169\ m^{-1}$
$w=0$

This is an example to illustrate the concept. No systematic attempt to minimize residuals (yet).

The goal is to look for changes in fitted parameters versus time in regions with and without resolved morphological evolution.

Credit: Davidsson, MIRO team (particularly Pete Schloerb & Seungwon Lee)

Questions?