Heat input, diffusion and retention

Latent heat exchange / phase transitions
- sublimation/condensation
- crystallization
- clathrate destabilization

Bertrand CHAZALLON - PhLAM (Lille, France)

Gas diffusion

Dust mantle formation/destruction,
dust entrainment

$\boldsymbol{\tau_{conduction} \sim 10^{4\text{-}6}}$ **yrs in KB**

$\boldsymbol{\tau_{CO subl.} \sim 10^{7}}$ **yrs in KB**

$\boldsymbol{\tau_{gas} \sim}$ **few** $\boldsymbol{10^{2\text{-}4}}$ **yrs in KB**

As summarized in Huebner et al. (2006) for 4015 Wilson-Harrington

Multistage injection

CO depletion
Crystallization

Eventually close to the Sun,
erosion and dust mantling

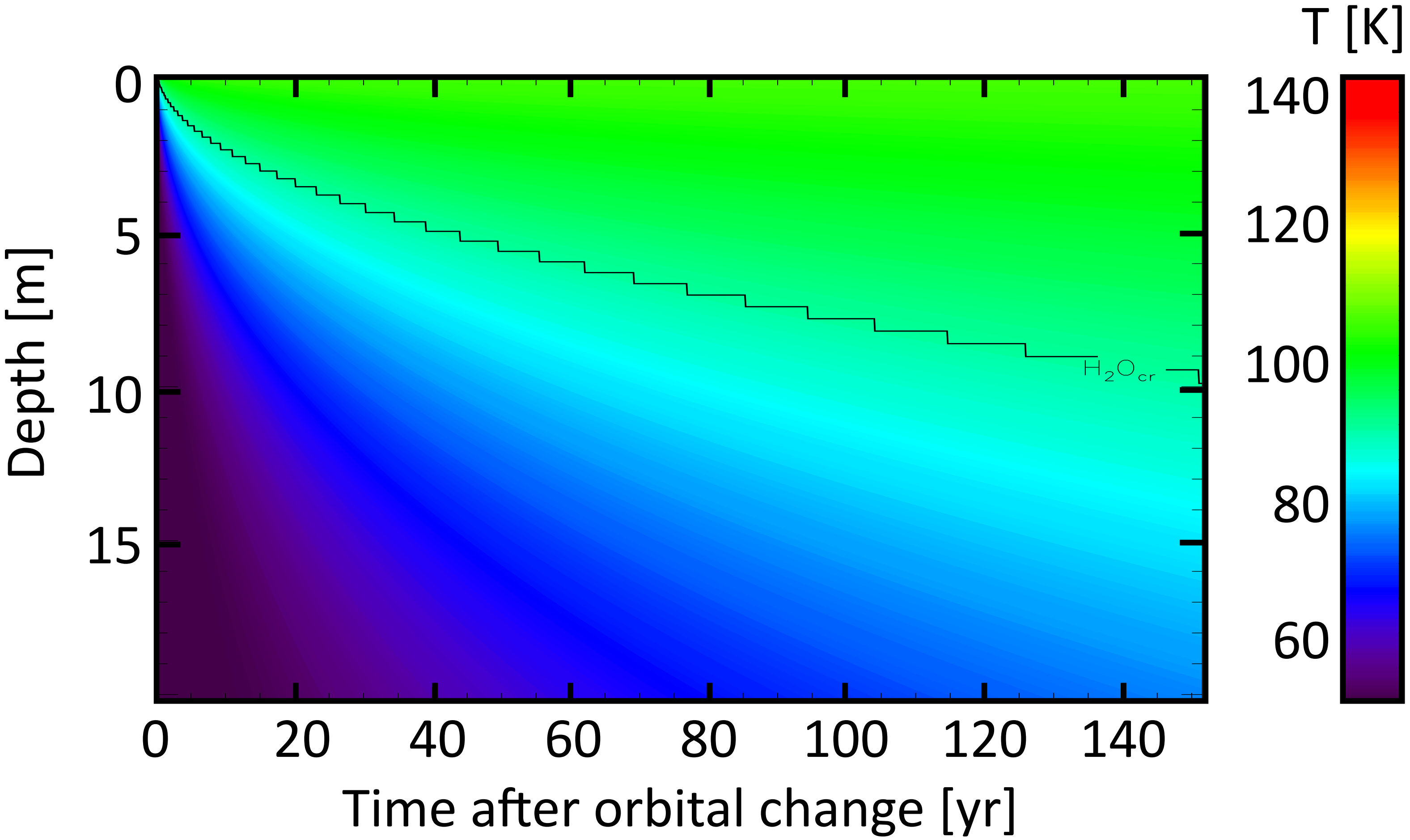
Direct injection

Similar surface temperature
(dominated by water and dust)
Simultaneous erosion
and heat wave propagation
(volatiles remain close to the surface)
Dust mantling

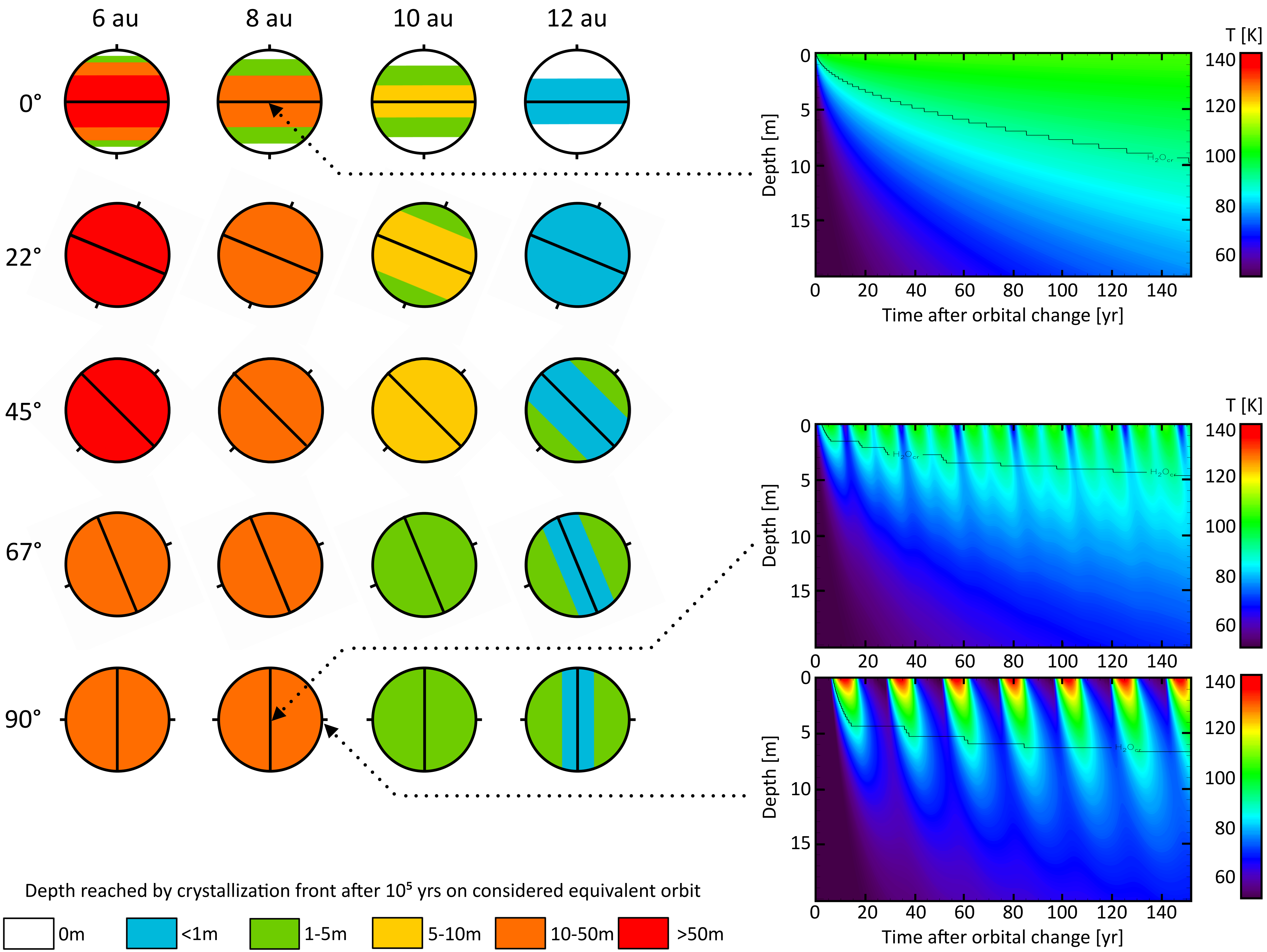
Major differences: final stratigraphy

CO depletion, front located up to hundreds of m depth
(some level of decoupling from water emission, with low ratio)
Water and other volatiles behave similarly
Crystallization front located at depth

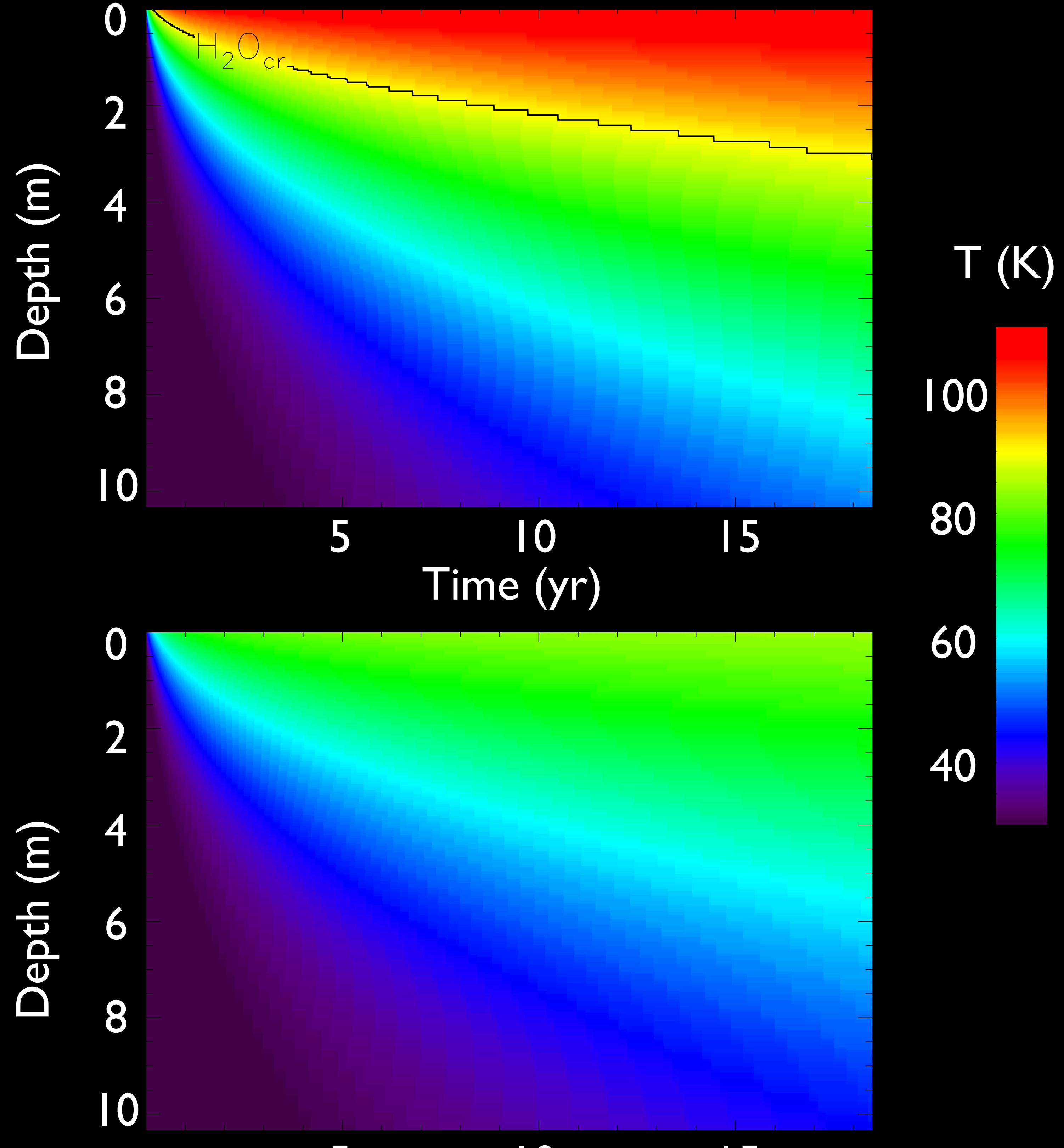
Centaur @8au



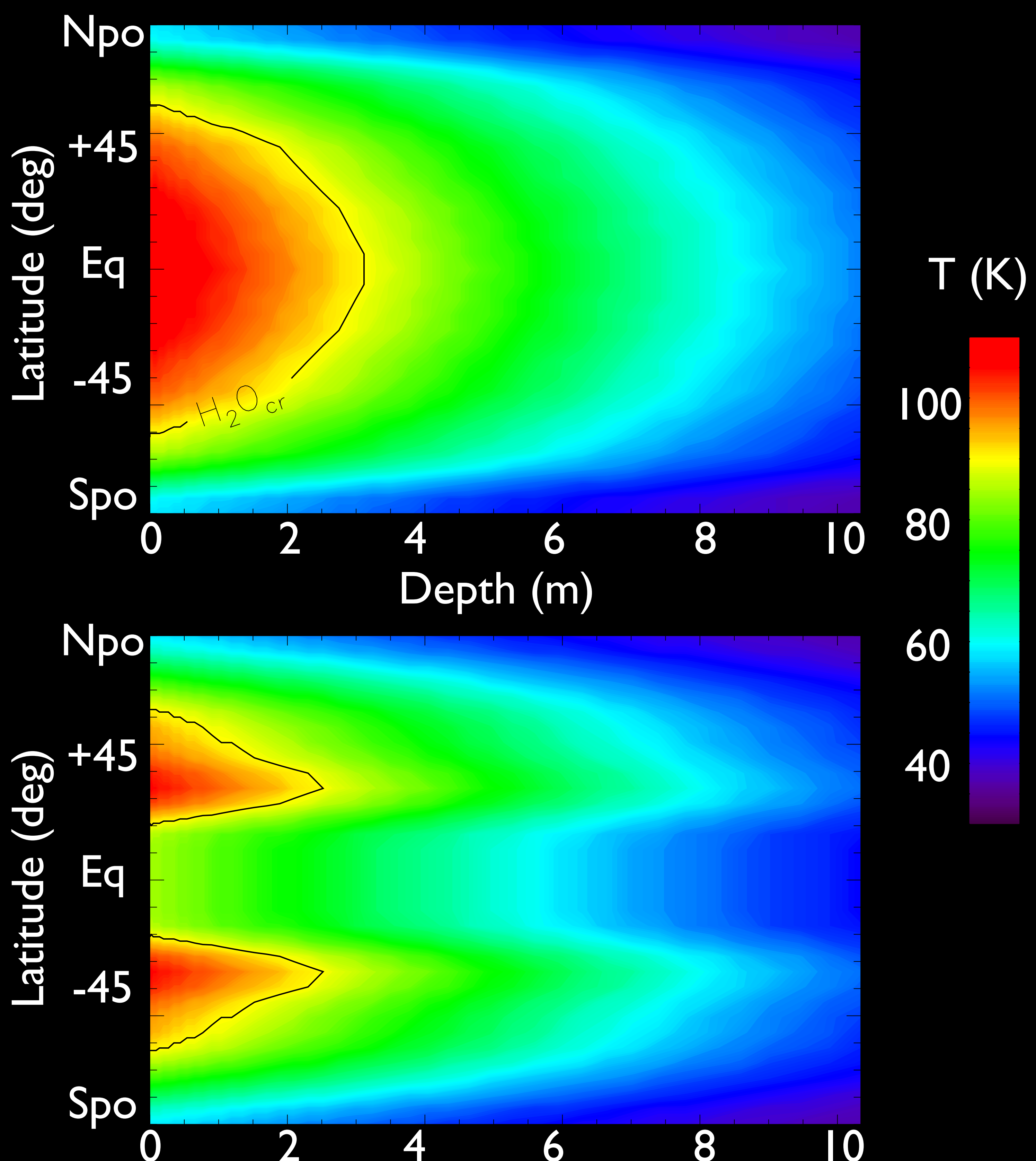
T [K]
140
120
100
80
60
0
5
10
15
Depth [m]
0
20
40
60
80
100
120
140
Time after orbital change [yr]
H_2O_{cr}



6 au
8 au
10 au
12 au
0°
22°
45°
67°
90°
Depth reached by crystallization front after 10^5 yrs on considered equivalent orbit
0m
<1m
1-5m
5-10m
10-50m
>50m
Depth [m]
Time after orbital change [yr]
T [K]



Guilbert-Lepoutre & Jewitt (2011)



Guilbert-Lepoutre & Jewitt (2011)

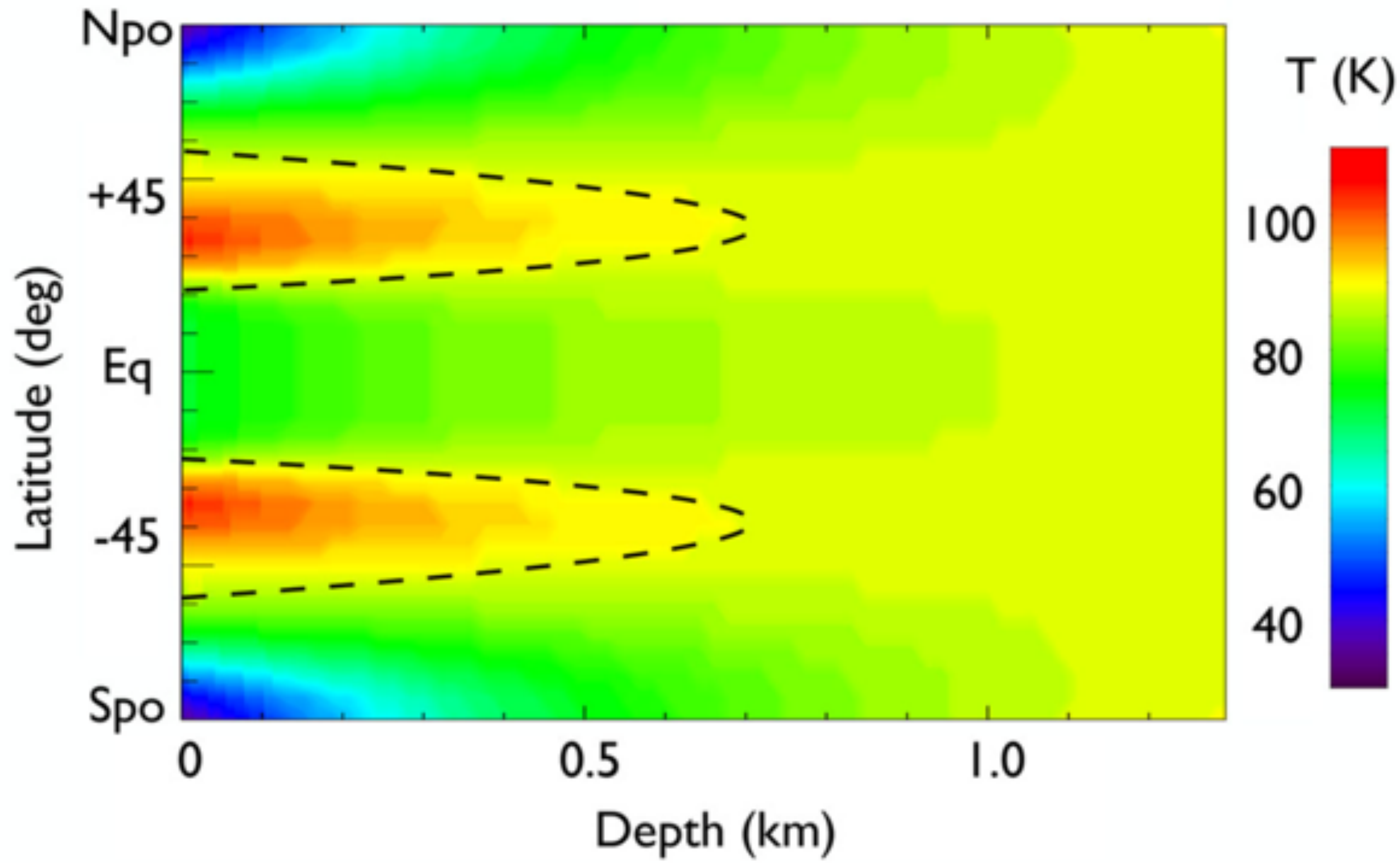


Figure 1. Temperature distributions along a meridian for a model with a surface albedo spot located between latitudes +22.°5 and −22.°5 (bottom panel), after 10 Myr on a Centaur orbit at 7 au as described in Guilbert-Lepoutre & Jewitt (2011). The boundary between amorphous and crystalline water ice is highlighted by a black dashed line.

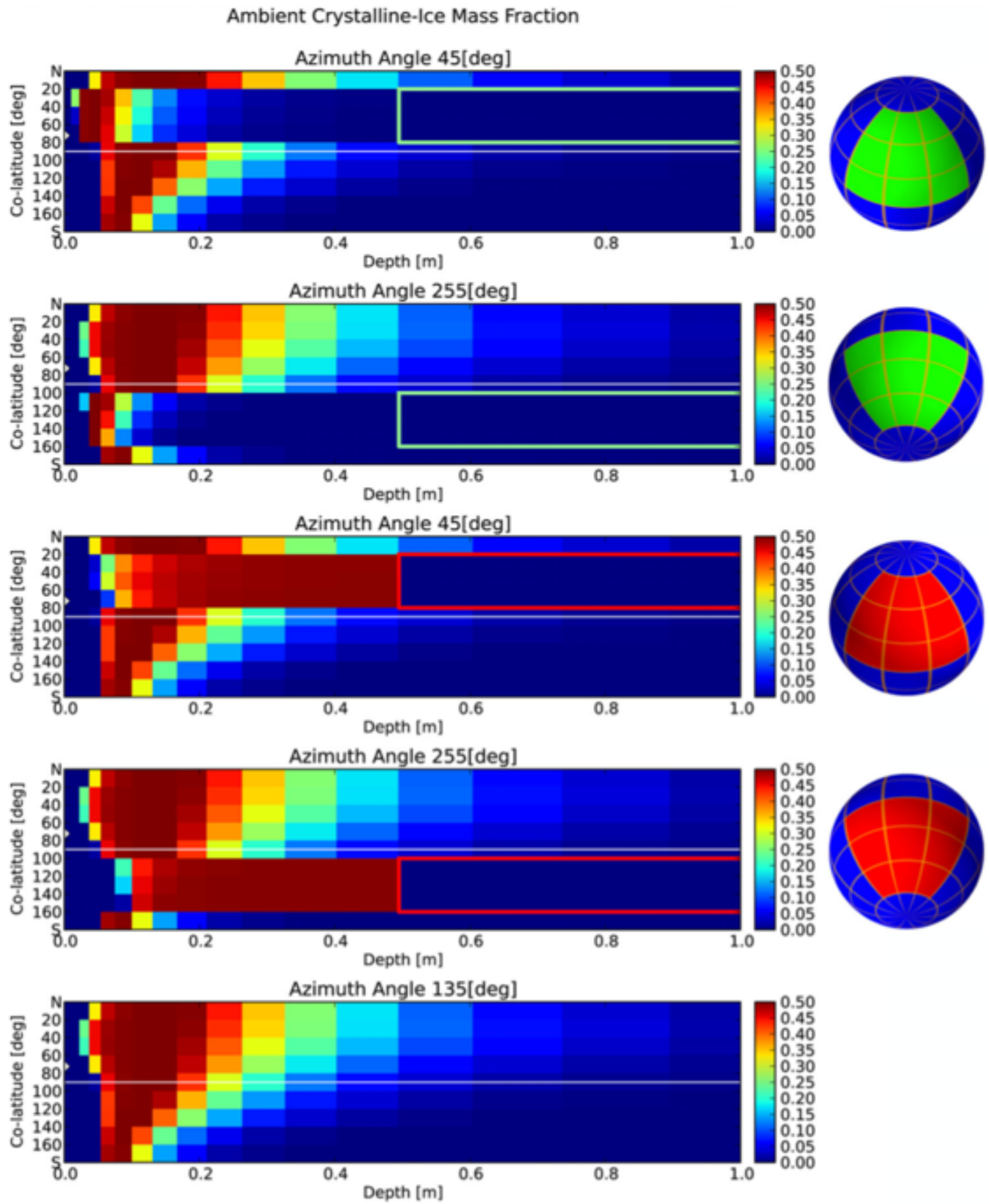
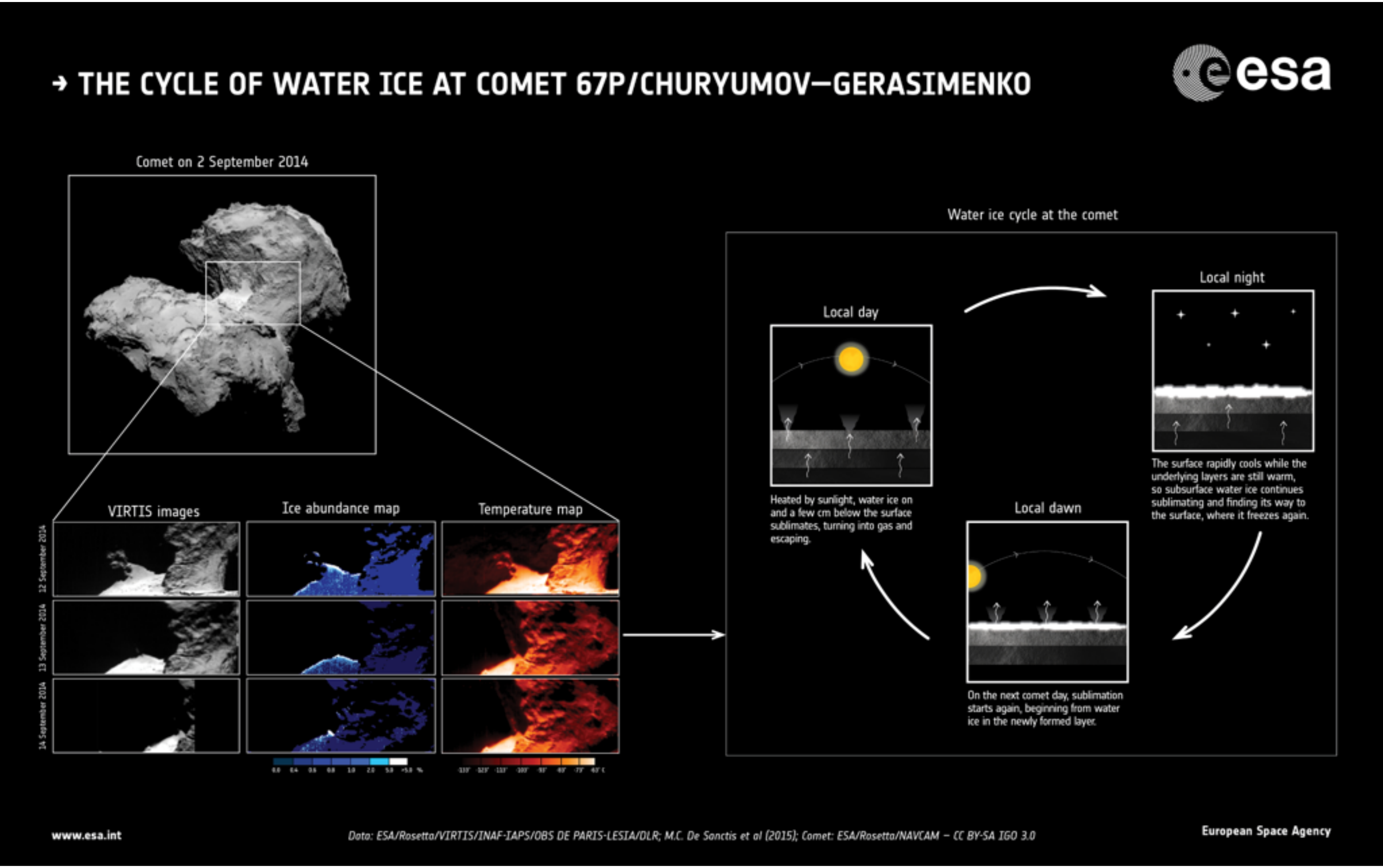


Figure 2. Mass fraction of crystalline ice as a function of depth down to 1 m (abscissa) and co-latitude (ordinate). Each panel – marked by its azimuth angle – represents a 'slice' of the nucleus. The bottom panel is used as the homogeneous reference case. The red and green frames mark the location of patches (red – porous ice, green – compact dust). The horizontal line represents the equator and the diamond marks the sub-solar co-latitude angle. The position of each patch is illustrated on the right-hand side of each panel.



→ THE CYCLE OF WATER ICE AT COMET 67P/CHURYUMOV–GERASIMENKO
esa
Comet on 2 September 2014
VIRTIS images
Ice abundance map
Temperature map
12 September 2014
13 September 2014
14 September 2014
Water ice cycle at the comet
Local day
Heated by sunlight, water ice on and a few cm below the surface sublimates, turning into gas and escaping.
Local night
The surface rapidly cools while the underlying layers are still warm, so subsurface water ice continues sublimating and finding its way to the surface, where it freezes again.
Local dawn
On the next comet day, sublimation starts again, beginning from water ice in the newly formed layer.
www.esa.int
Data: ESA/Rosetta/VIRTIS/INAF-IAPS/OBS DE PARIS-LESIA/DLR; M.C. De Sanctis et al (2015); Comet: ESA/Rosetta/NAVCAM – CC BY-SA IGO 3.0
European Space Agency

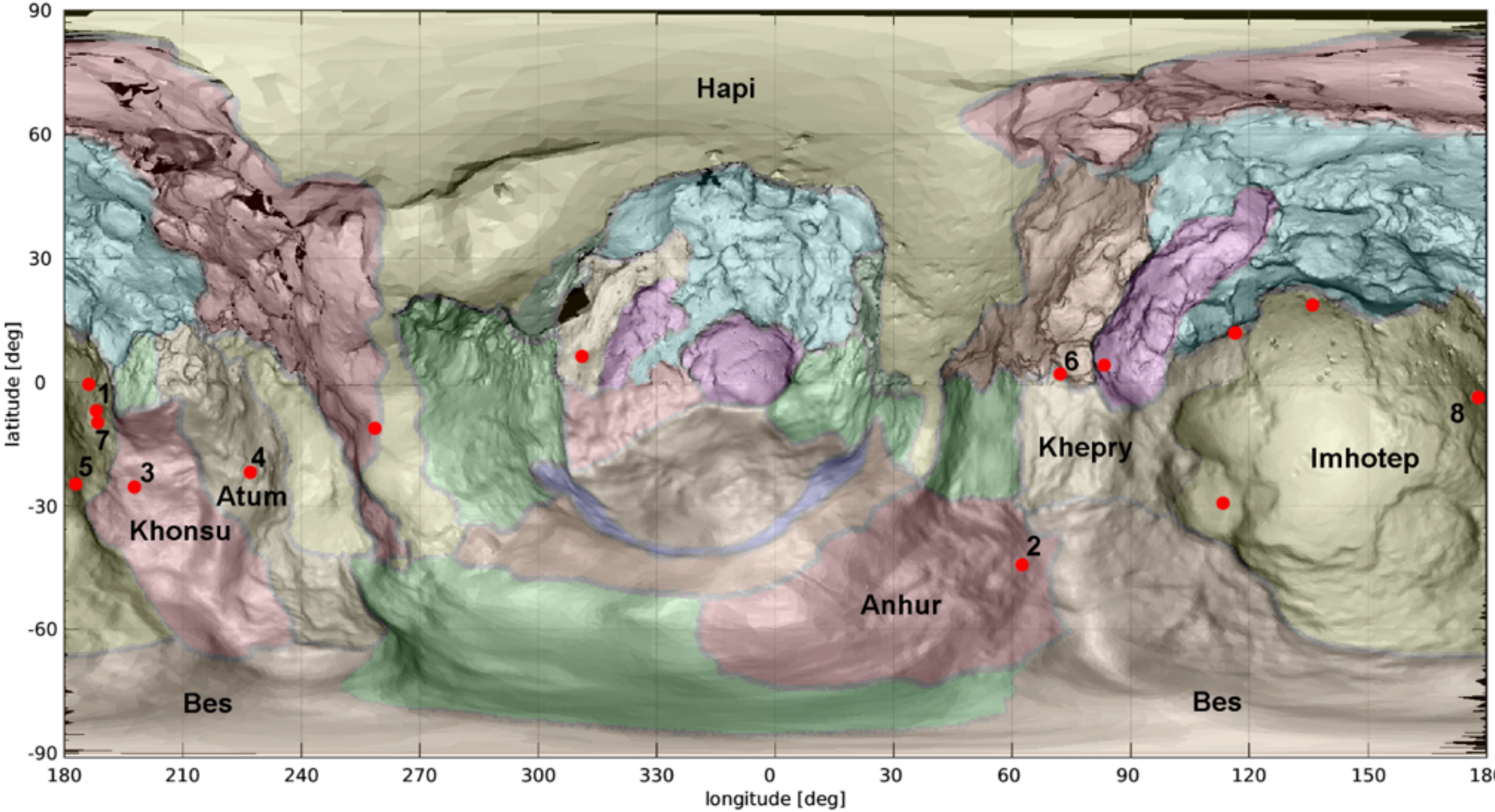
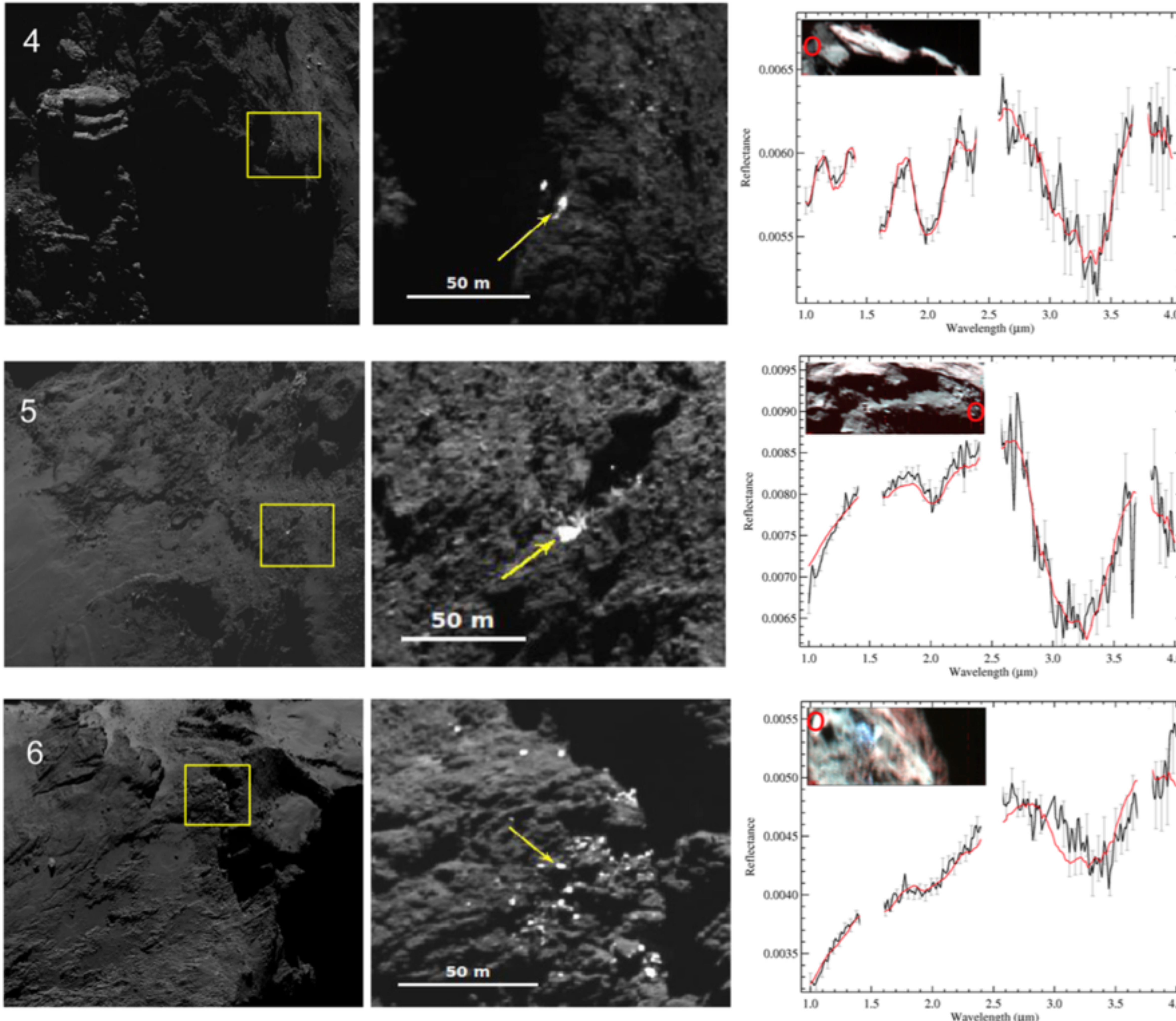


Fig. 1. Map of comet 67P/Churyumov-Gerasimenko, resulting from merging a more detailed shape model SHAP4S (Preusker et al. 2015) for the northern hemisphere and shape model SHAP5 (Jorda et al. 2016) for the southern hemisphere. In red the selected bright spots are reported, based on OSIRIS images and a spectro-photometric analysis, considered as good targets to be investigated by an analysis of VIRTIS data, plus the two bright spots analysed by Filacchione et al. (2016a). The numbers (1–8) represent the spots with positive detection of H_2O ice by VIRTIS analysis discussed in this paper.


4
50 m
Reflectance
Wavelength (μm)
5
50 m
Reflectance
Wavelength (μm)
6
50 m
Reflectance
Wavelength (μm)

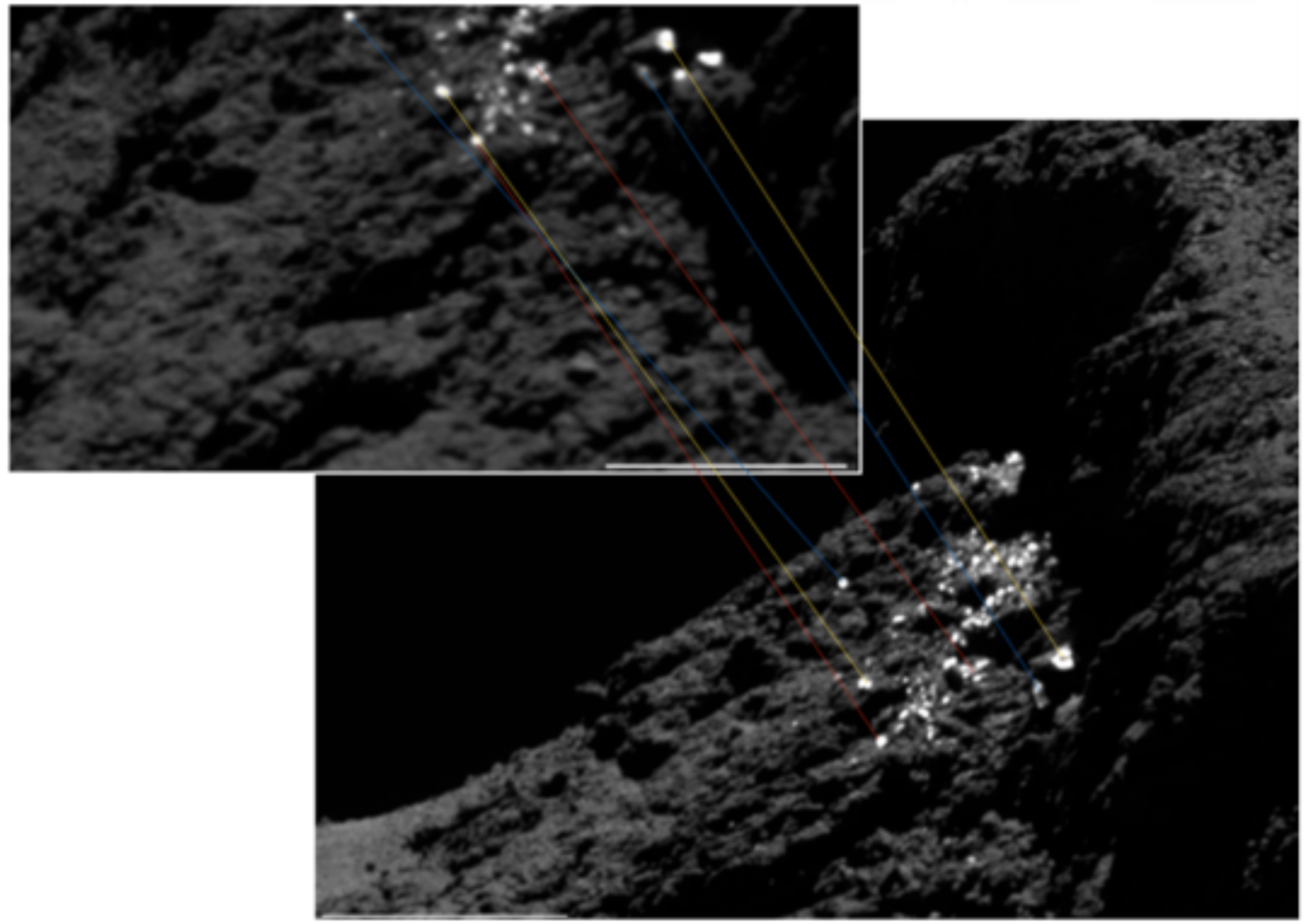


Fig. 6. Comparisons of OSIRIS NAC images of the cluster of bright spot 6, observed two months apart, which shows the stability of the bright features with time.

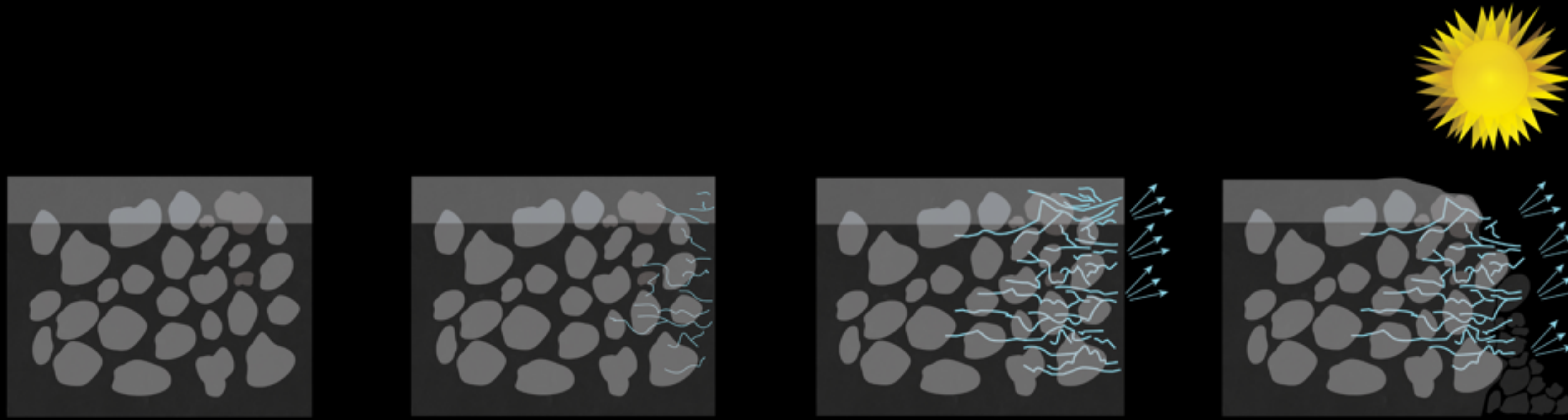
All the bright spots are on consolidated dust free materials, either on boulders or on freshly exposed outcropping regions that often display penetrative fractures. This suggests that H_2O ice can mainly be found on the consolidated substratum exposed along scarps or detached in the form of boulders. Some of the bright spots have been in place for weeks and months, while others seem related to diurnal variation.

Table 6. Mass release rate of H_2O from the surface of 67P at the location of H_2O ice-rich spots.

Spot	T [K]	Q_{H_2O} [kg m^{-2} s^{-1}]	OSIRIS observations
1	203	3.357×10^{-4}	Size receded from 57 m to 36 m in 3 weeks
2	197	1.336×10^{-4}	Observed for 5 weeks
3	218	2.485×10^{-3}	Size receded from 18 m to 8 m in 3 weeks, disappear in the following 3 weeks
4	168	0.662×10^{-6}	Cluster stable for 11 weeks
5	188	3.003×10^{-5}	Stable for 13 weeks
6	179	0.625×10^{-5}	Cluster stable for 13 weeks
7	163	2.156×10^{-7}	Cluster stable for 3 weeks
8	158	0.701×10^{-7}	Stable for 15 weeks

Notes. In the last column an indication of the observed lifetime of the spots is summarised.

→ COMET ACTIVITY AND CLIFF EROSION

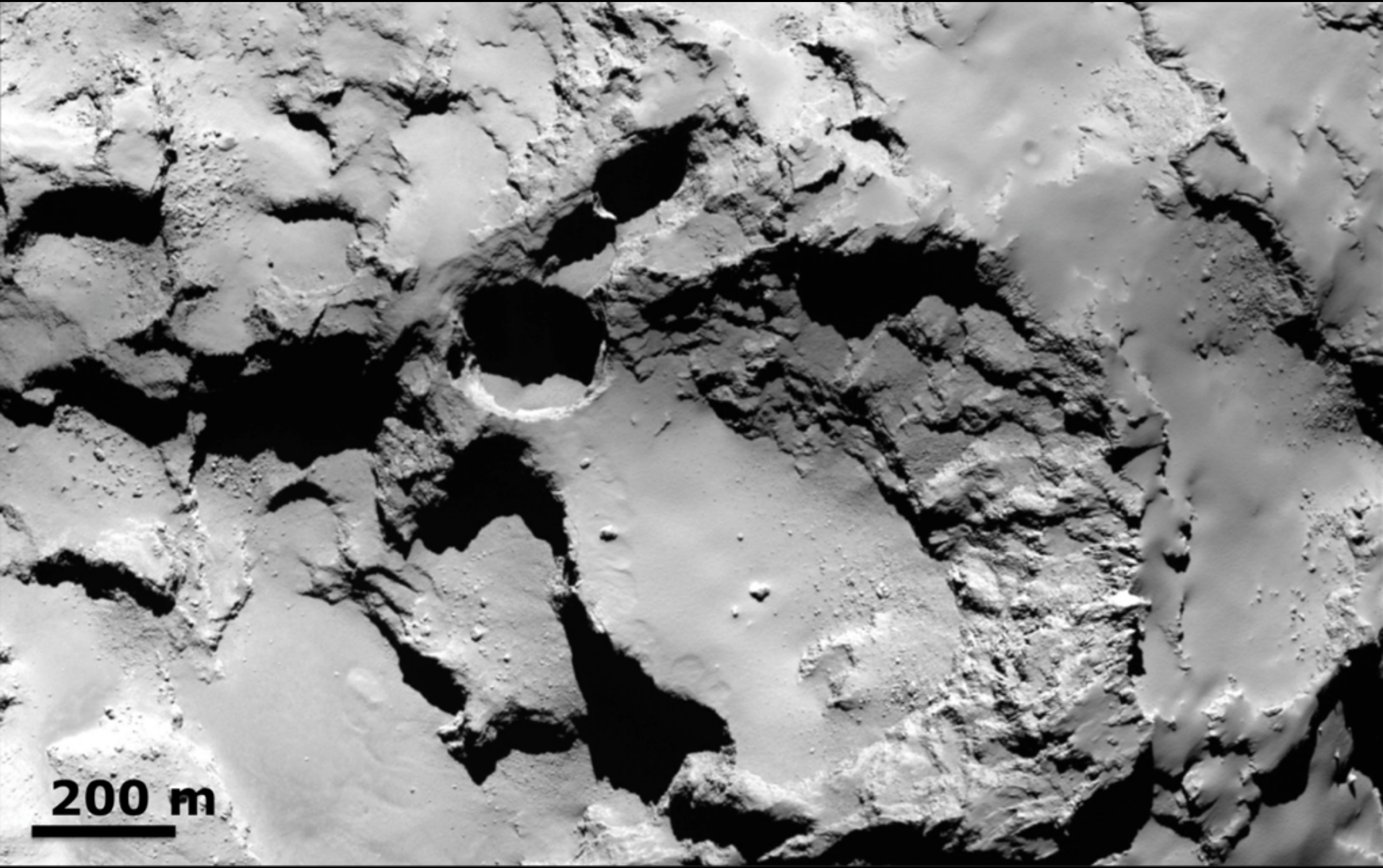


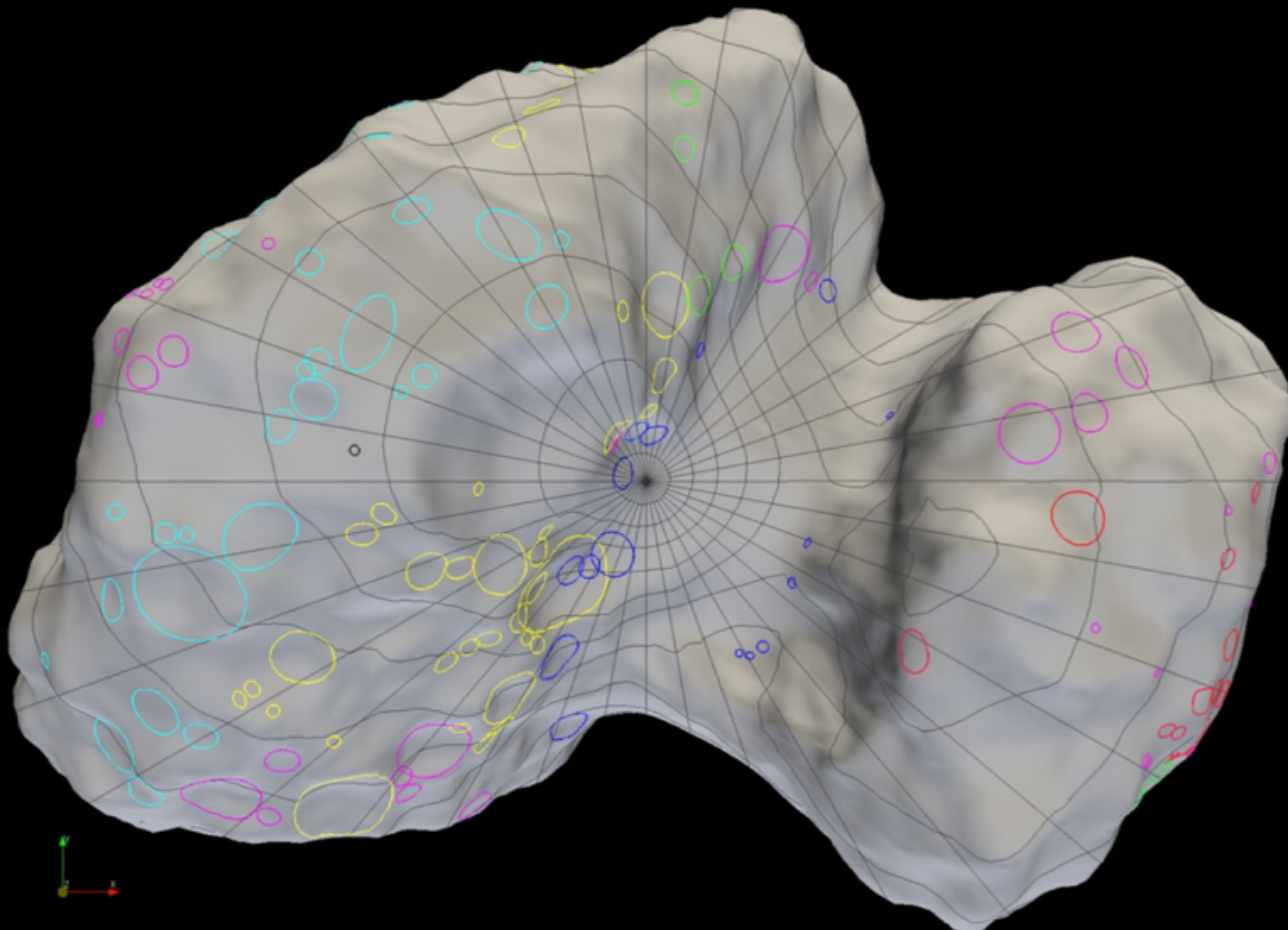
1. Cliff with insulating layer of dust covers mix of ice and dust

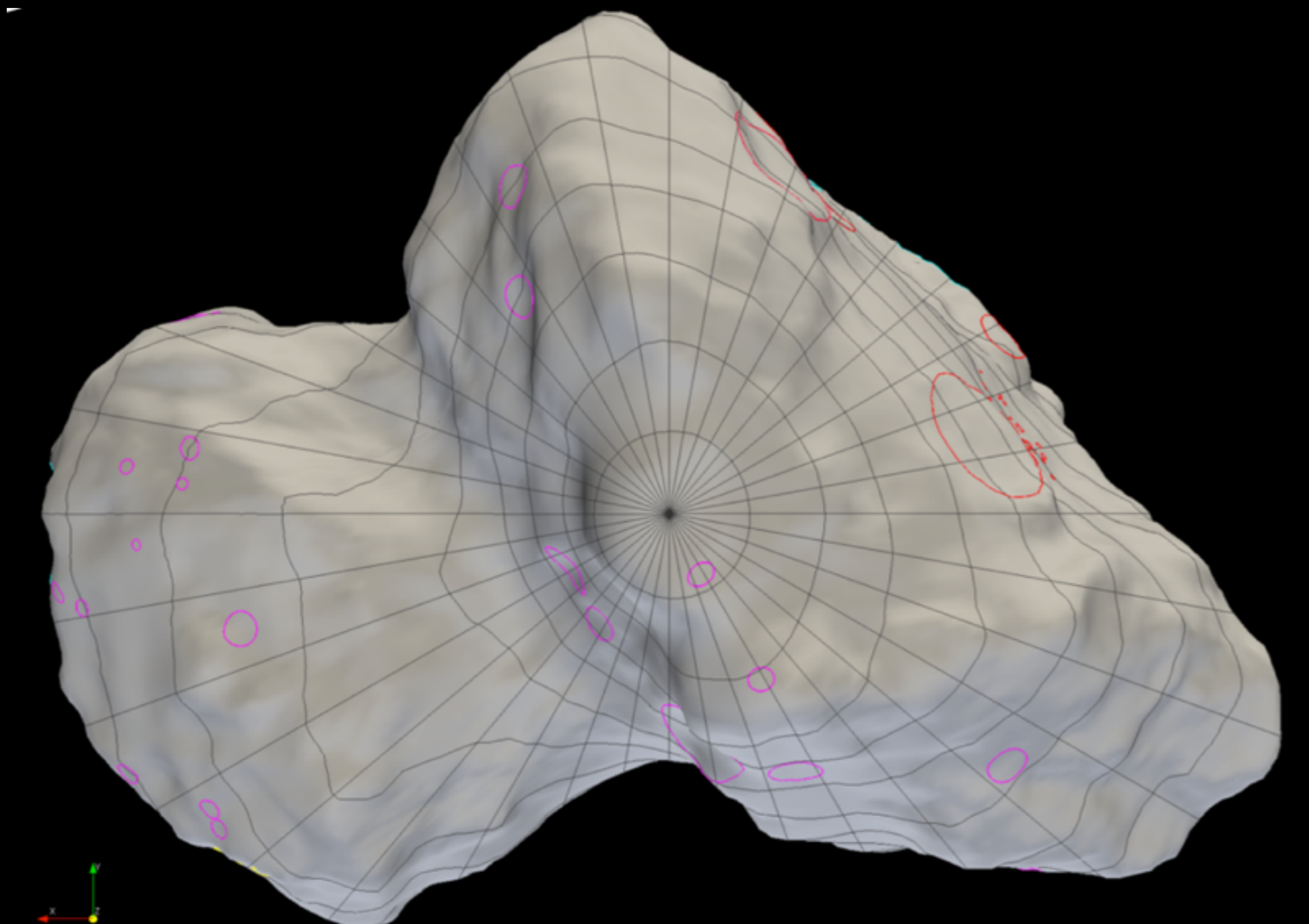
2. Cracks generate and propagate from cliff edge due to thermal and mechanical stresses

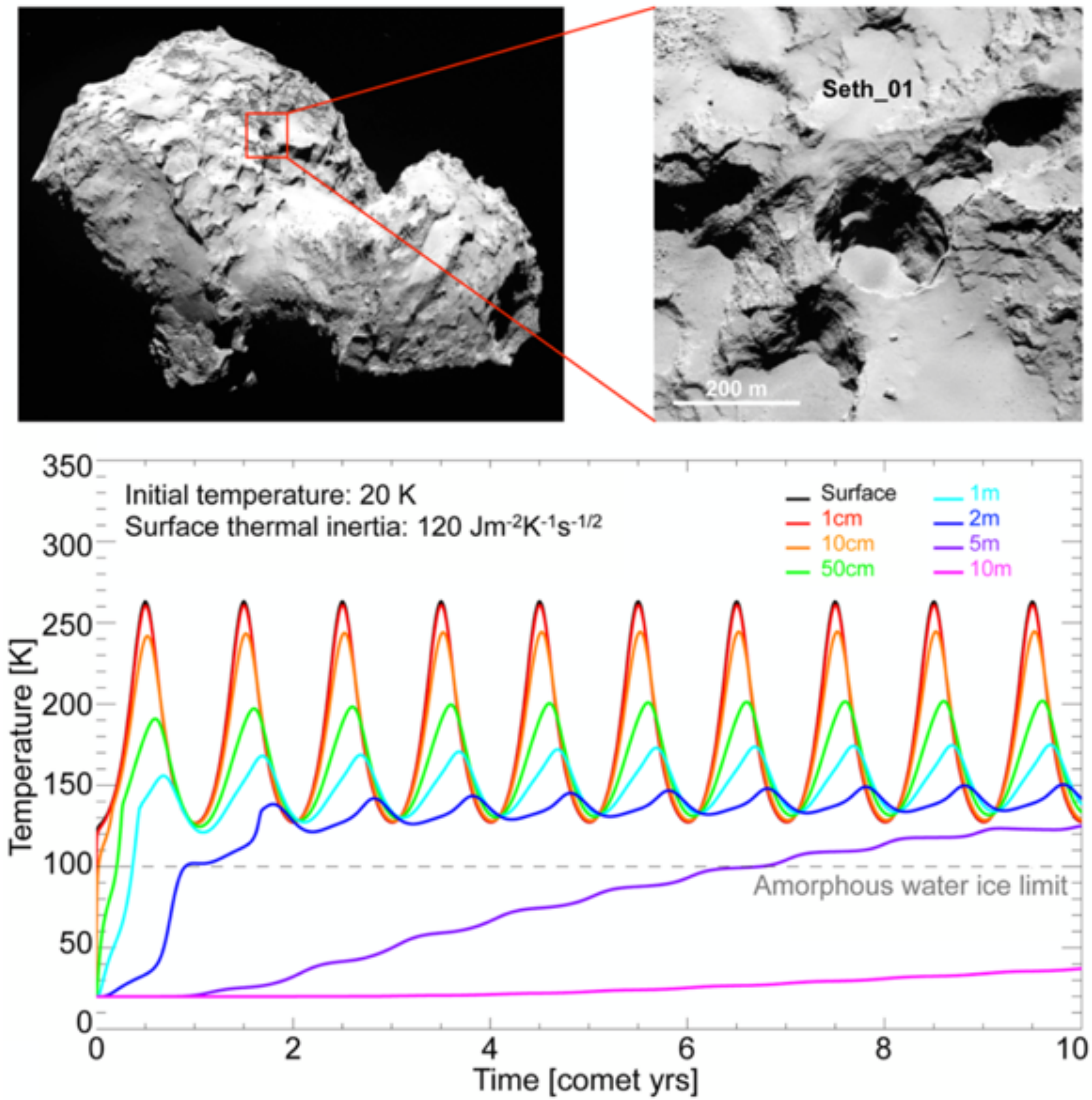
3. Heat reaches buried ices, sublimation intensifies cracking

4. Weakened wall collapses; freshly exposed ices and fallen boulders generate additional activity


200 m

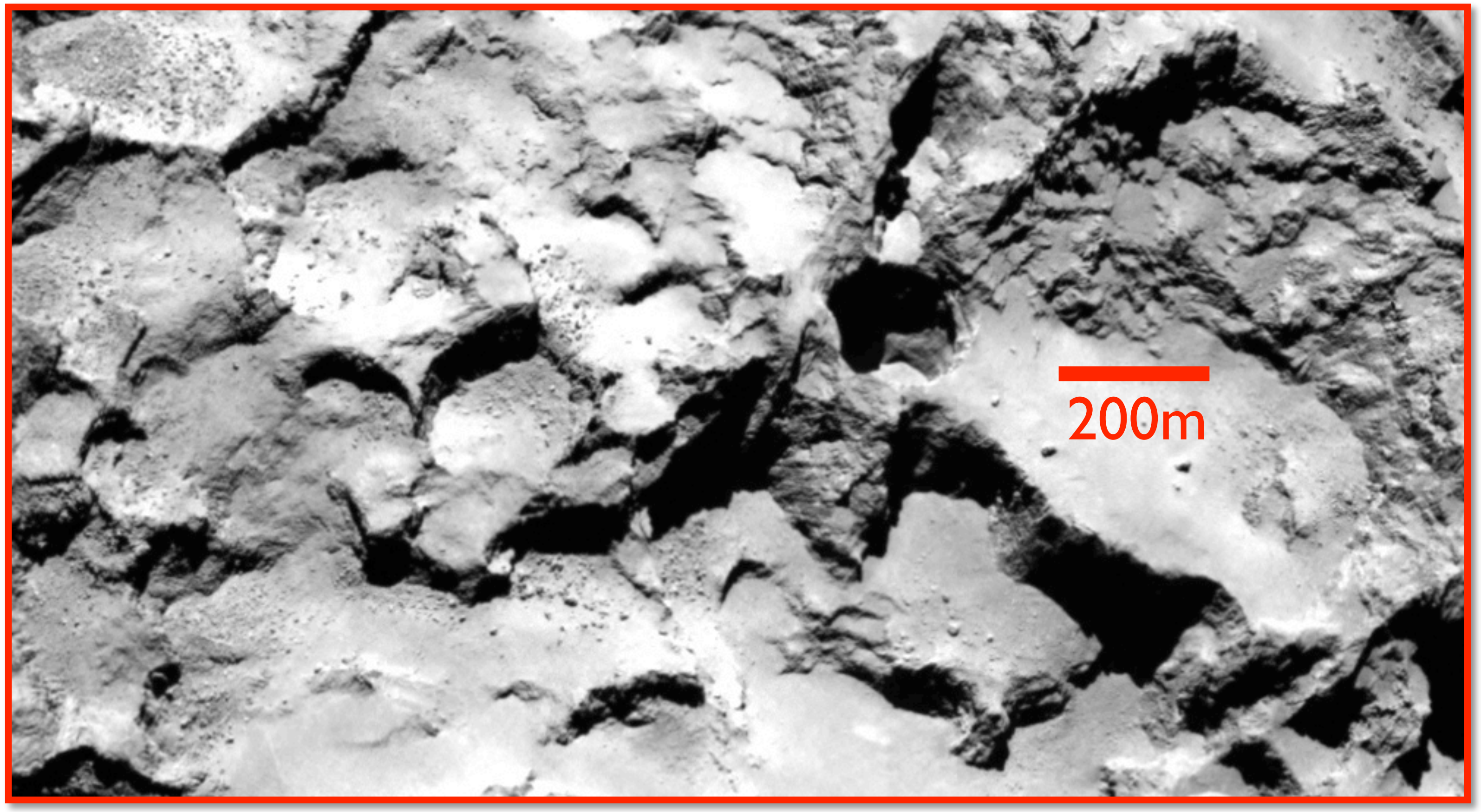






Guilbert-Lepoutre et al. (2016)

Seth region



Evolution via sublimation possible but limited

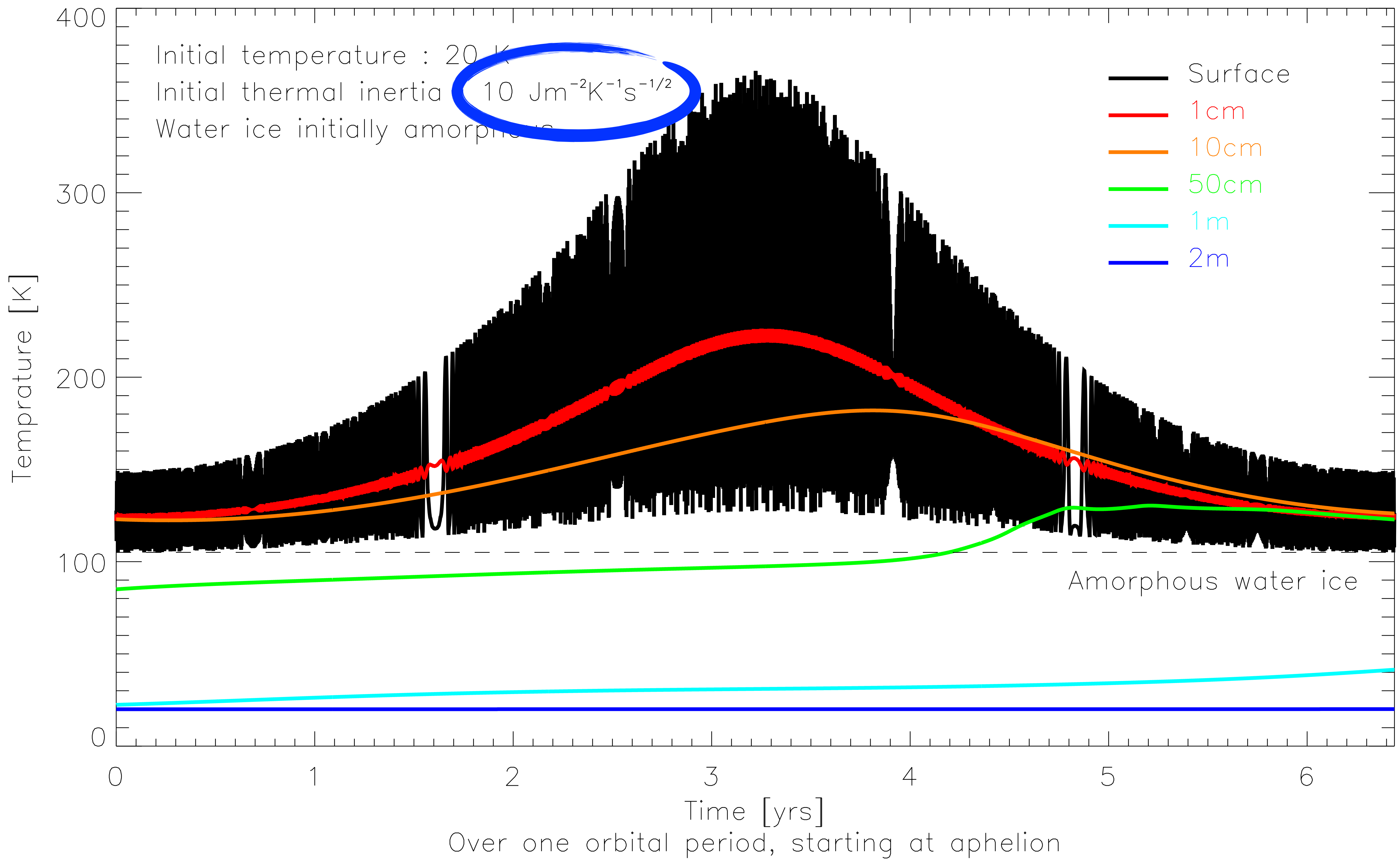
➔ Regressive erosion in preferential direction

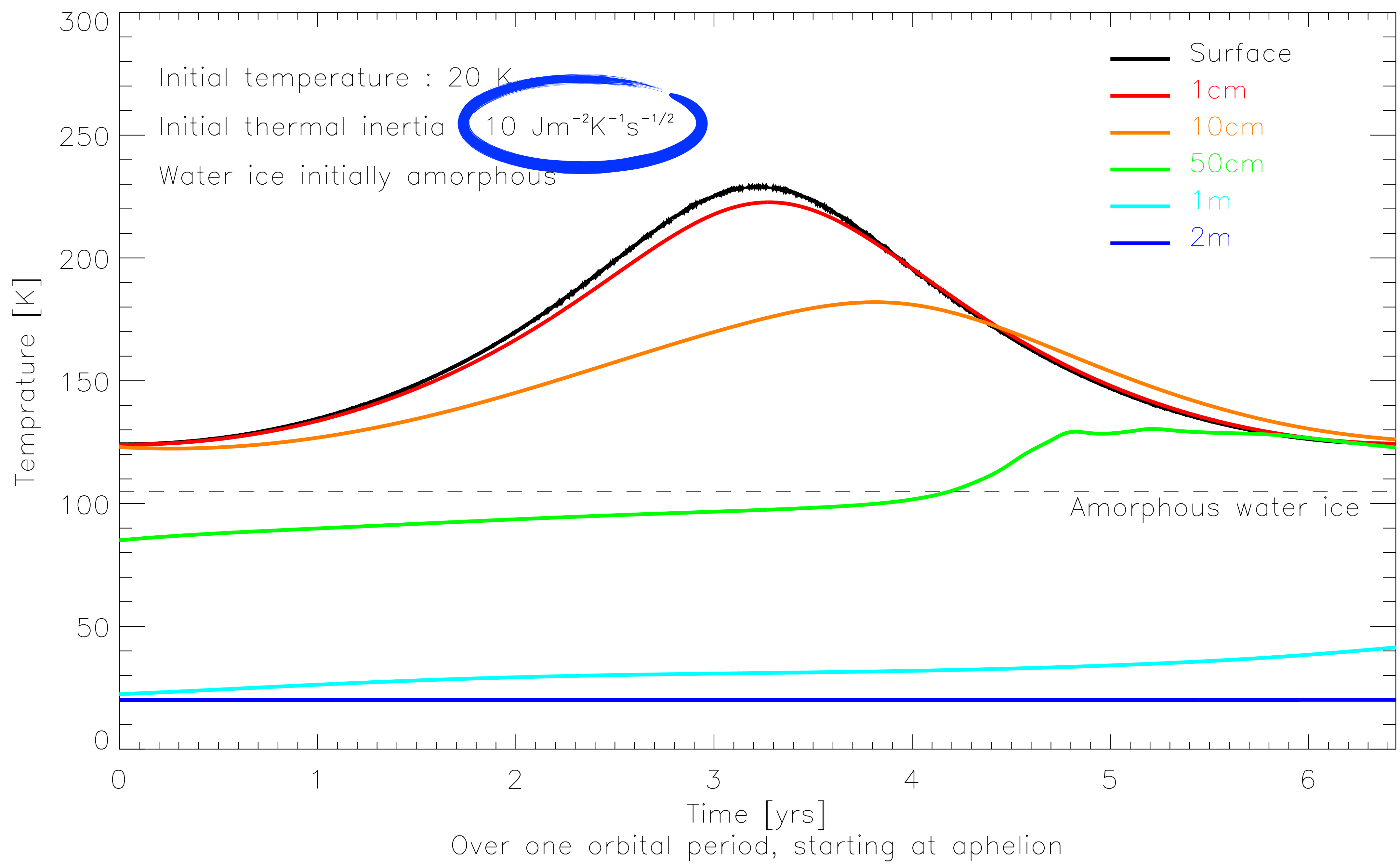
For 67P, from thermal inertia measured at the surface

diurnal skin depth — 1mm to 9cm
orbital skin depth — 80cm to 7m

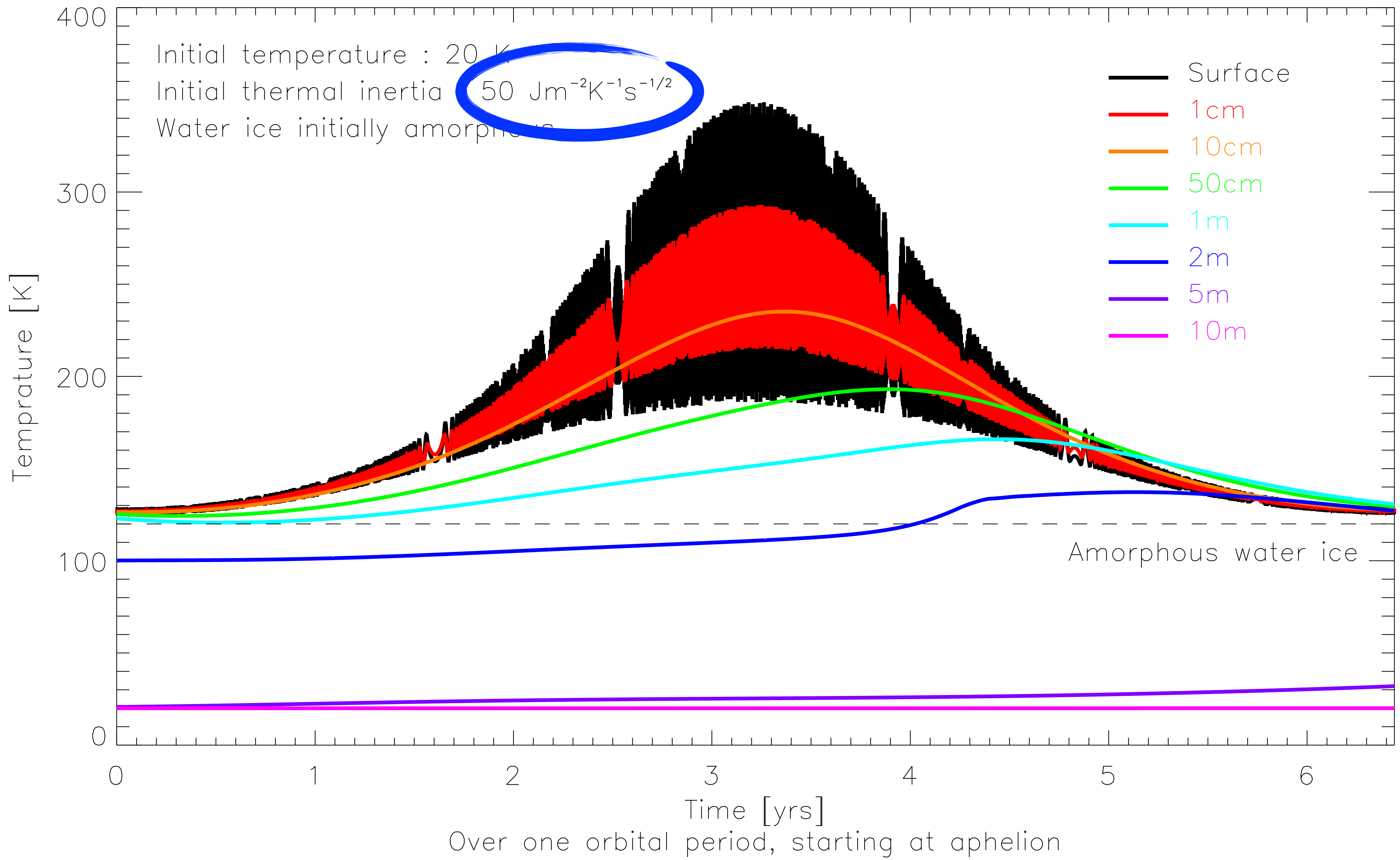
below: whatever happened in the past life of 67P, previous JFC orbits, Centaur orbit etc…

Pit formation on one of the current orbit: extent not achievable with any of the known mechanisms (crystallization, sublimation, clathrate destabilization)

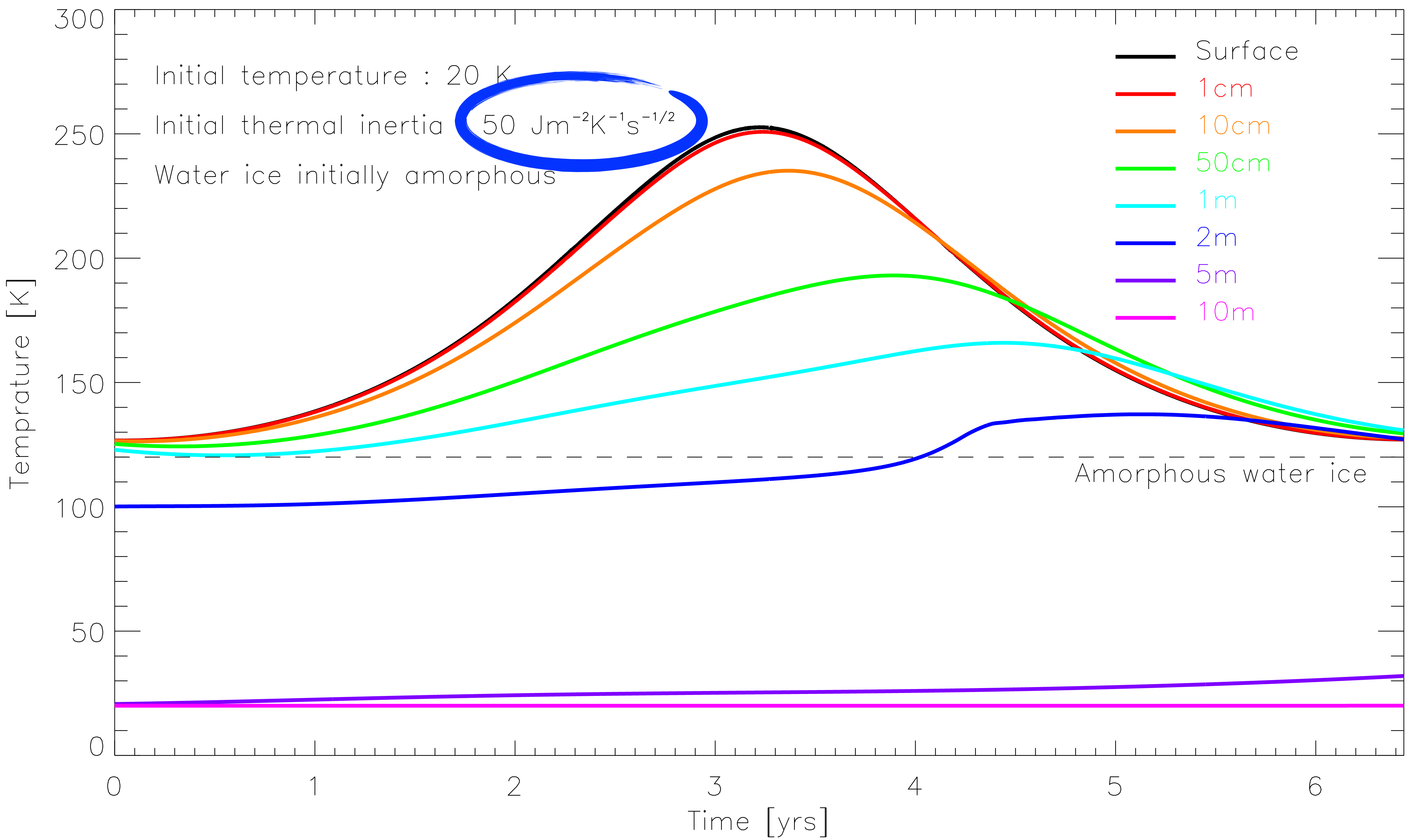




Initial temperature : 20 K
Initial thermal inertia 10 Jm⁻²K⁻¹s⁻¹/²
Water ice initially amorphous
Surface
1cm
10cm
50cm
1m
2m
Amorphous water ice
300
250
200
150
100
50
0
Temprature [K]
0
1
2
3
4
5
6
Time [yrs]
Over one orbital period, starting at aphelion



Initial temperature : 20 K
Initial thermal inertia 50 Jm^{-2}K^{-1}s$^{-1/2}$
Water ice initially amorphous
Surface
1cm
10cm
50cm
1m
2m
5m
10m
Amorphous water ice
Temprature [K]
400
300
200
100
0
0
1
2
3
4
5
6
Time [yrs]
Over one orbital period, starting at aphelion



Over one orbital period, starting at aphelion