Constraints on cometary surface evolution derived from a statistical analysis of 67P's topography

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European Planetary Science Congress

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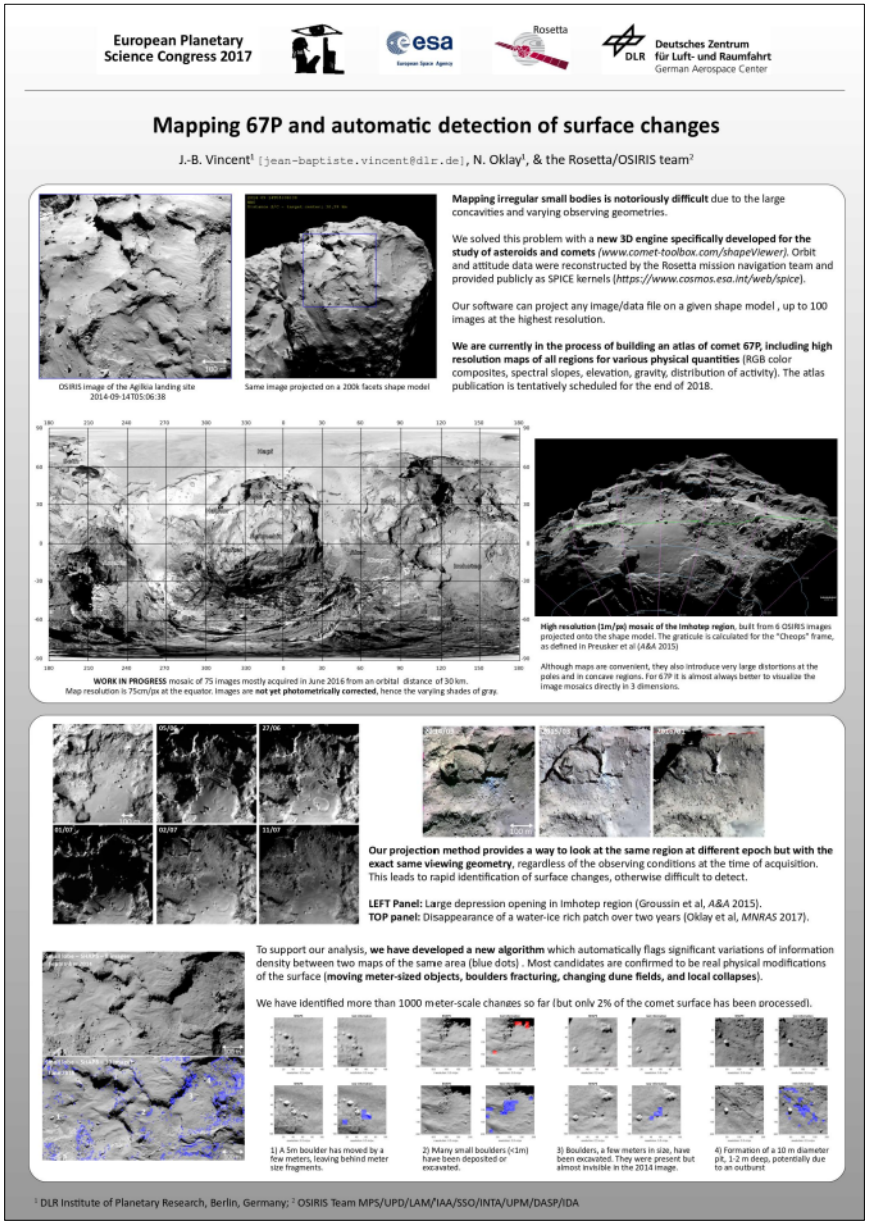
Interested in surface changes ?



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Mapping 67P and automatic detection of surface changes

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OSIRIS image of the Agilkia landing site 2014-09-14T05:06:38

Same image projected on a 200k facets shape model

Mapping irregular small bodies is notoriously difficult due to the large concavities and varying observing geometries.

We solved this problem with a **new 3D engine specifically developed for the study of asteroids and comets** *(www.comet-toolbox.com/shapeViewer)*. Orbit and attitude data were reconstructed by the Rosetta mission navigation team and provided publicly as SPICE kernels (*https://www.cosmos.esa.int/web/spice*).

Our software can project any image/data file on a given shape model , up to 100 images at the highest resolution.

We are currently in the process of building an atlas of comet 67P, including high resolution maps of all regions for various physical quantities (RGB color composites, spectral slopes, elevation, gravity, distribution of activity). The atlas publication is tentatively scheduled for the end of 2018.

WORK IN PROGRESS mosaic of 75 images mostly acquired in June 2016 from an orbital distance of 30 km. Map resolution is 75cm/px at the equator. Images are **not yet photometrically corrected**, hence the varying shades of gray.

High resolution (1m/px) mosaic of the Imhotep region, built from 6 OSIRIS images projected onto the shape model. The graticule is calculated for the "Cheops" frame, as defined in Preusker et al (*A&A* 2015)

Although maps are convenient, they also introduce very large distortions at the poles and in concave regions. For 67P it is almost always better to visualize the image mosaics directly in 3 dimensions.

Our projection method provides a way to look at the same region at different epoch but with the exact same viewing geometry, regardless of the observing conditions at the time of acquisition. This leads to rapid identification of surface changes, otherwise difficult to detect.

LEFT Panel: Large depression opening in Imhotep region (Groussin et al, *A&A* 2015).
TOP panel: Disappearance of a water-ice rich patch over two years (Oklay et al, *MNRAS* 2017).

To support our analysis, **we have developed a new algorithm** which automatically flags significant variations of information density between two maps of the same area (blue dots) . Most candidates are confirmed to be real physical modifications of the surface (**moving meter-sized objects, boulders fracturing, changing dune fields, and local collapses**).

We have identified more than 1000 meter-scale changes so far (but only 2% of the comet surface has been processed).

1) A 5m boulder has moved by a few meters, leaving behind meter size fragments.

2) Many small boulders (<1m) have been deposited or excavated.

3) Boulders, a few meters in size, have been excavated. They were present but almost invisible in the 2014 image.

4) Formation of a 10 m diameter pit, 1-2 m deep, potentially due to an outburst

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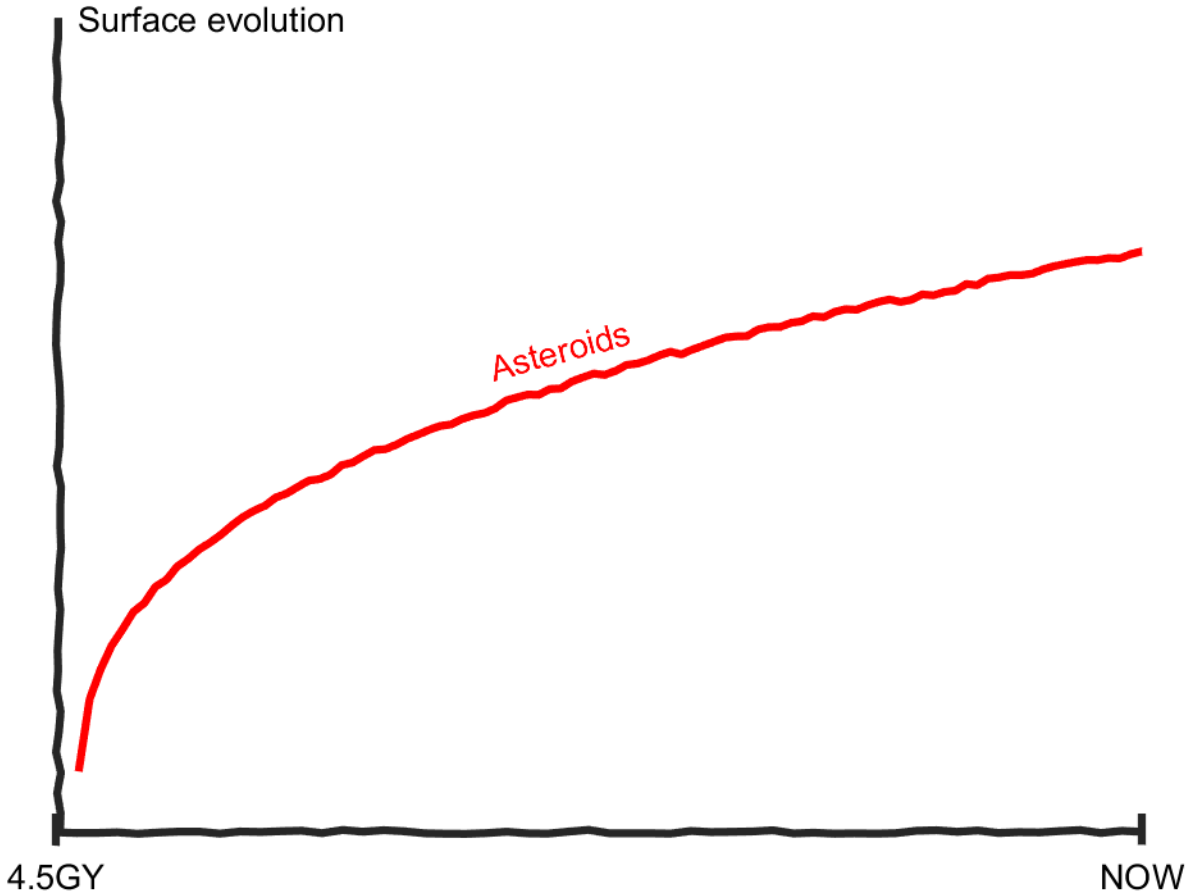
We have developed the capability to map 67P at the highest resolution and automatically detect 1-10 m surface changes.

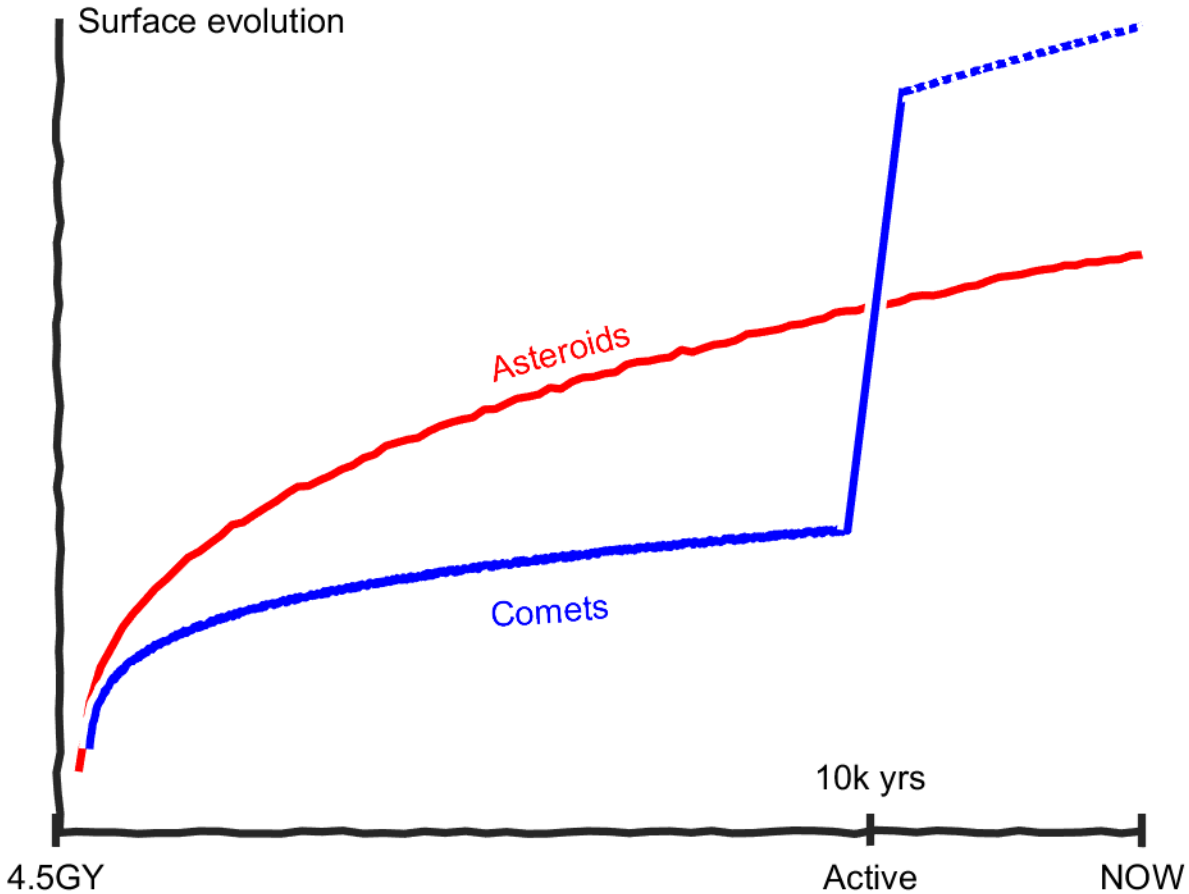
> 1000 features already found on < 2% of the surface !

See P142 after this session

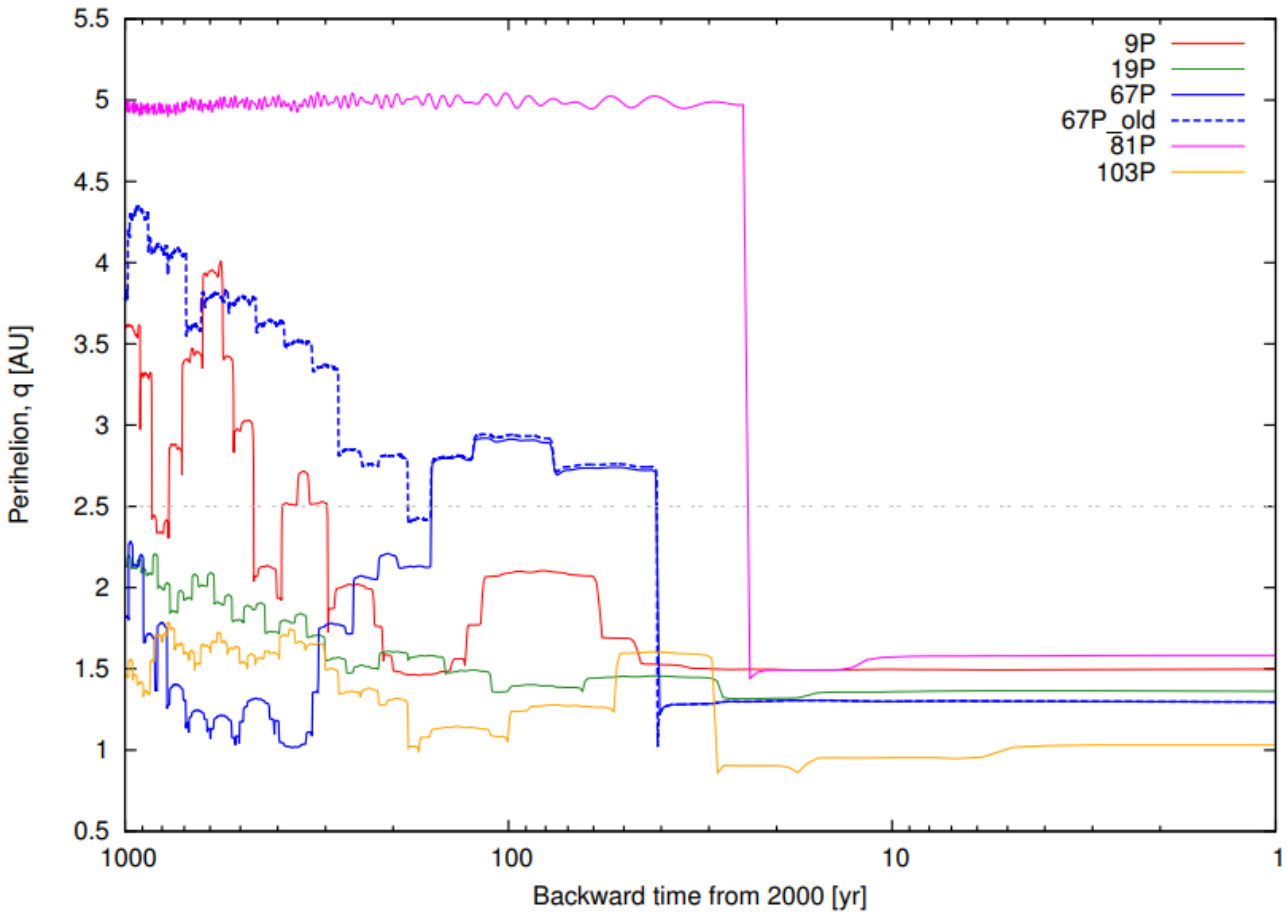
Small bodies surface evolution



Small bodies surface evolution



Small bodies surface evolution



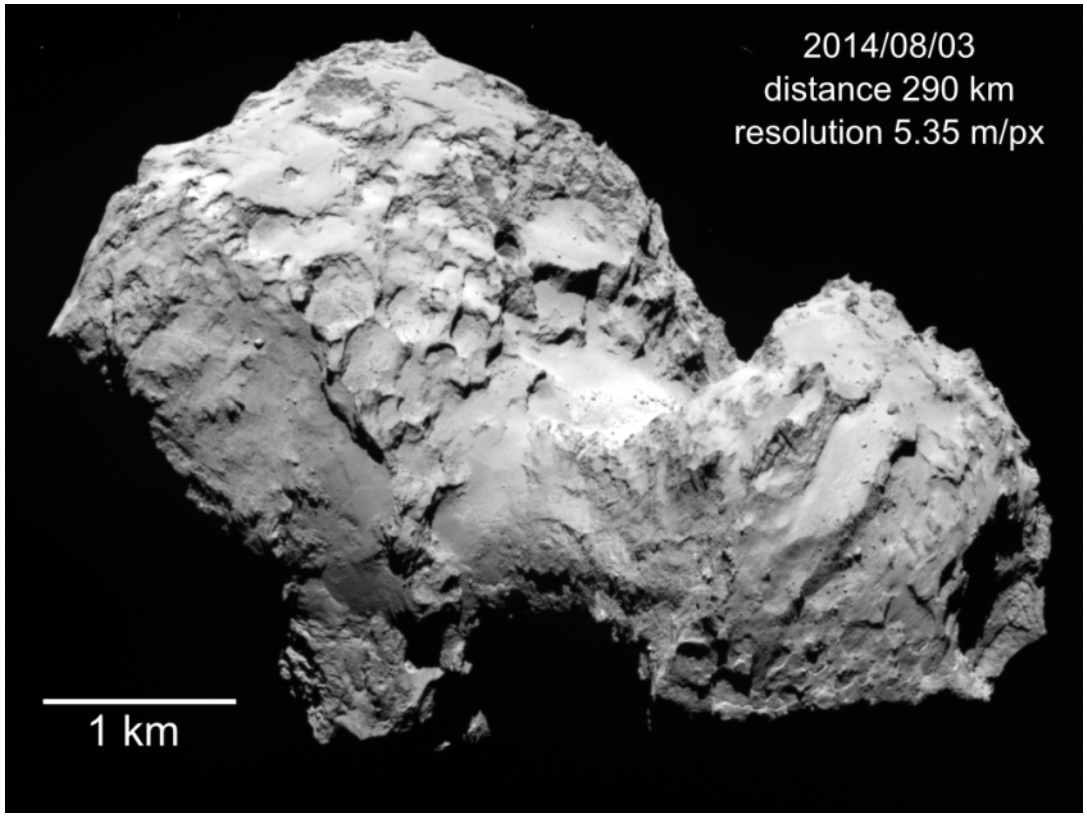
Comet orbits are difficult to reconstruct accurately beyond their last encounter with Jupiter

How to define the age of the surface ?

Improving orbital simulations requires an additional set of constraints, like topography or composition.

Ip et al, A&A (2016)

Comet 67P/Churyumov-Gerasimenko



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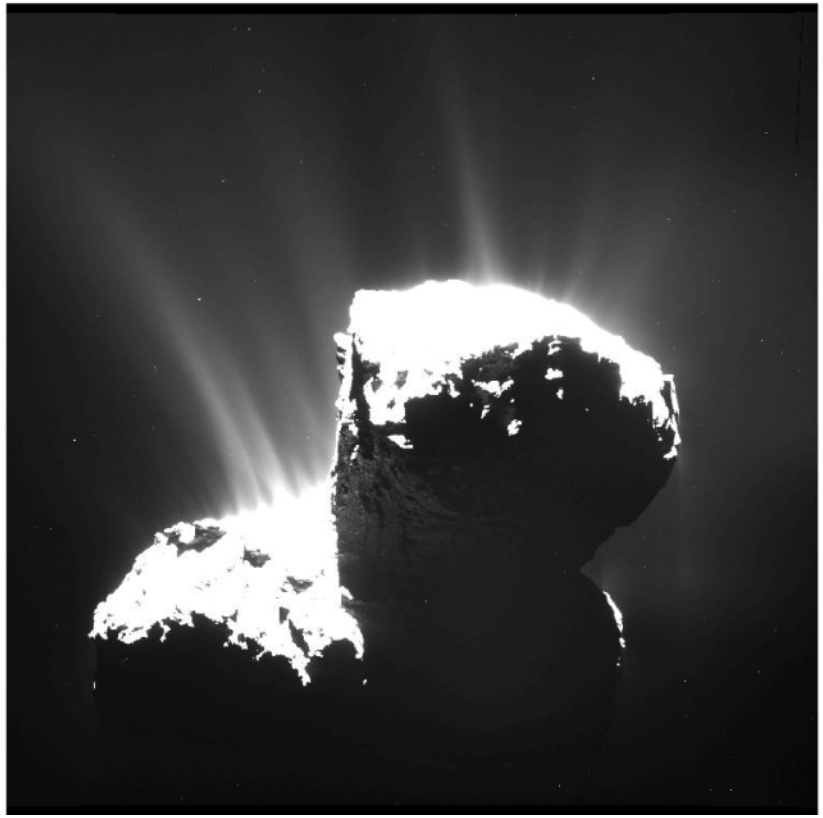
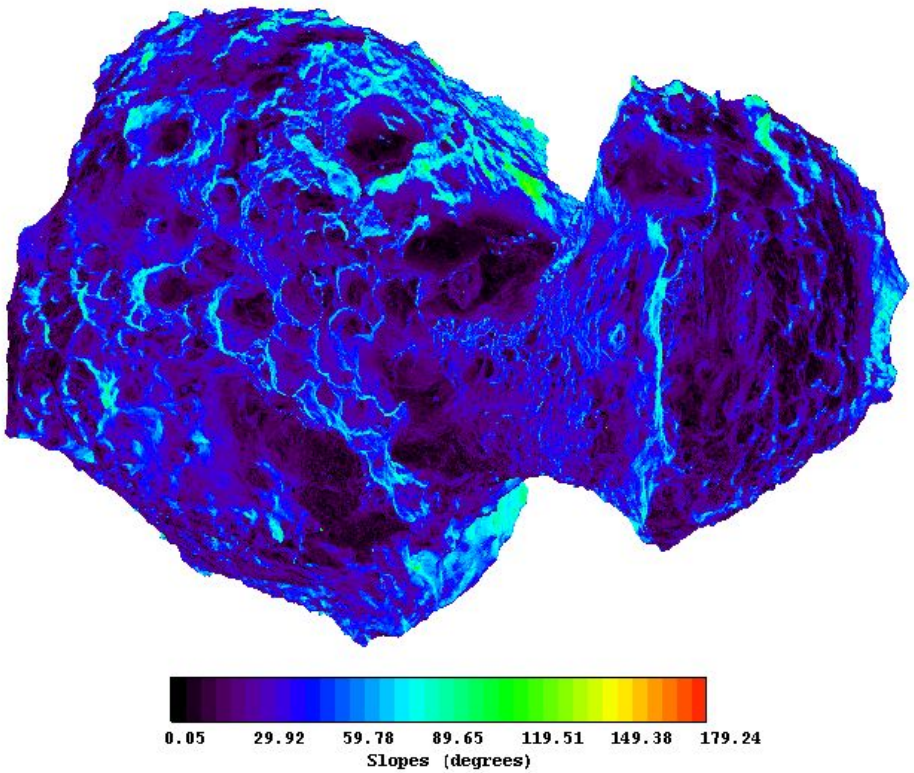
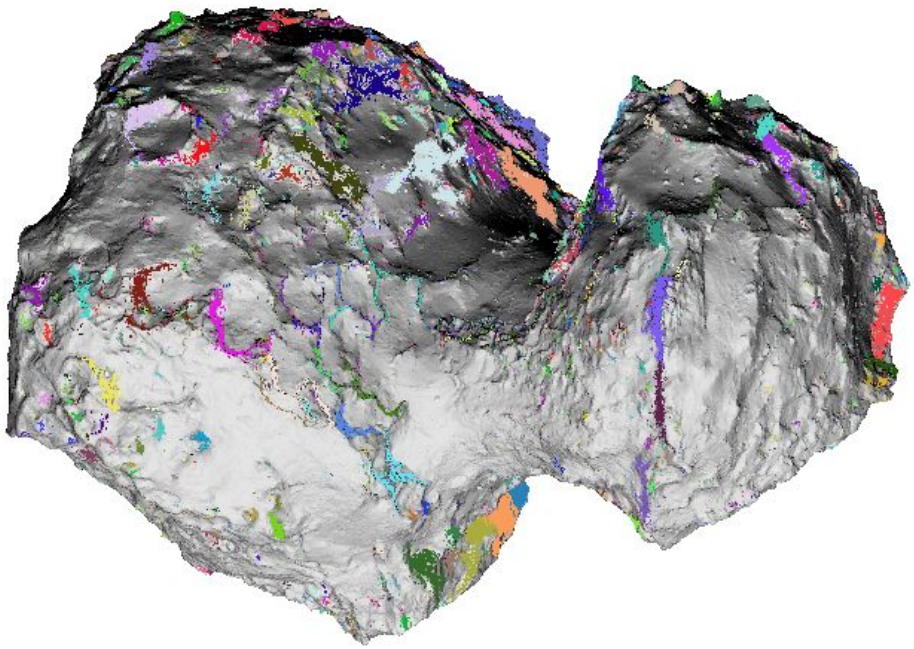


No obvious craters, but surface covered with large scale topographic features, such as pits and cliffs. These structures are intimately linked to the activity: they focus gas and dust jets and their collapse may explain outbursts. (Vincent 2015a, 2016a, 2016b; Gruen 2016, Pajola 2017).

How do they evolve ?

Automatic cliff detection



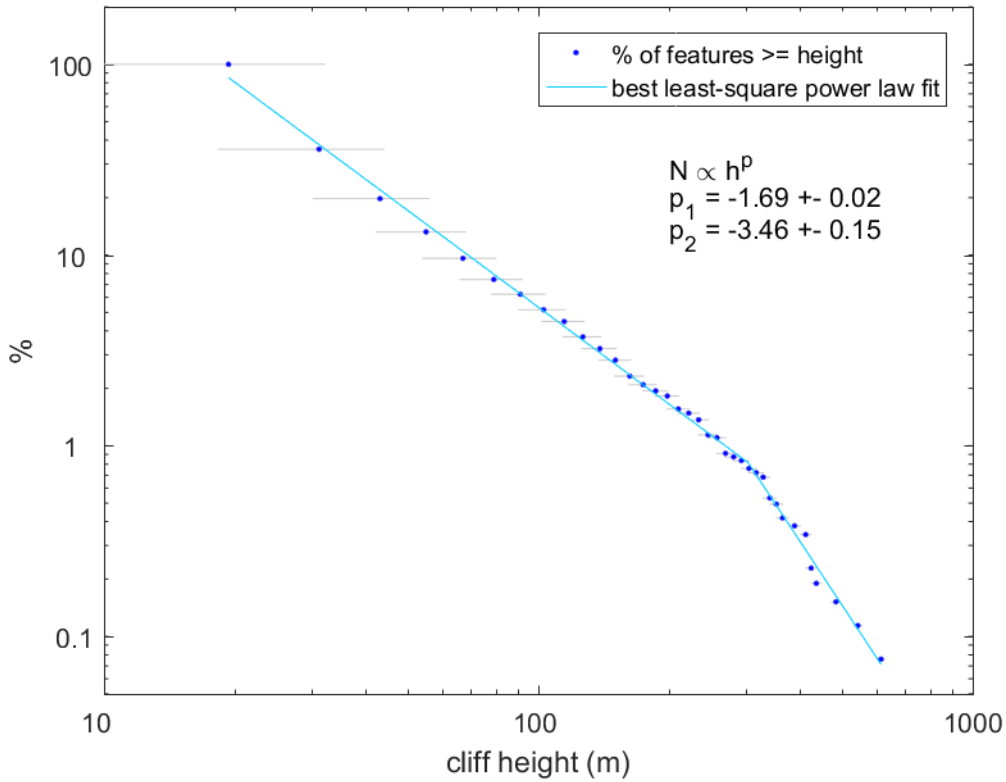


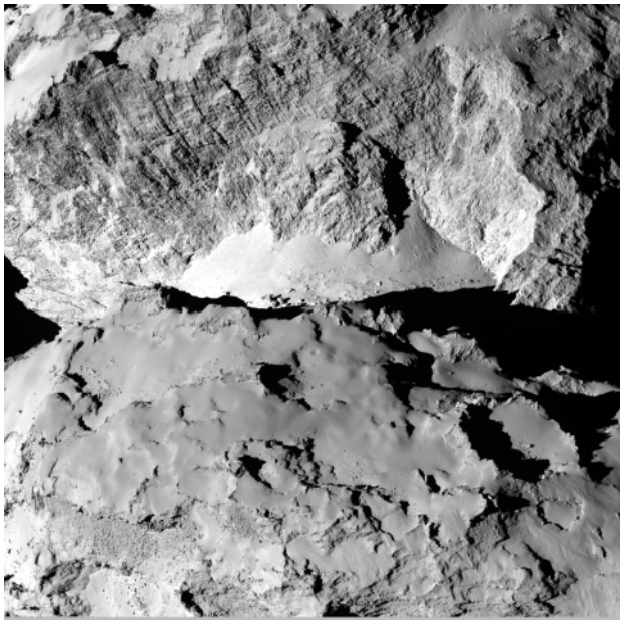
Gravity calculated for a constant density of 535 kg.m^{-3}, using Werner & Scheeres 1996 model.

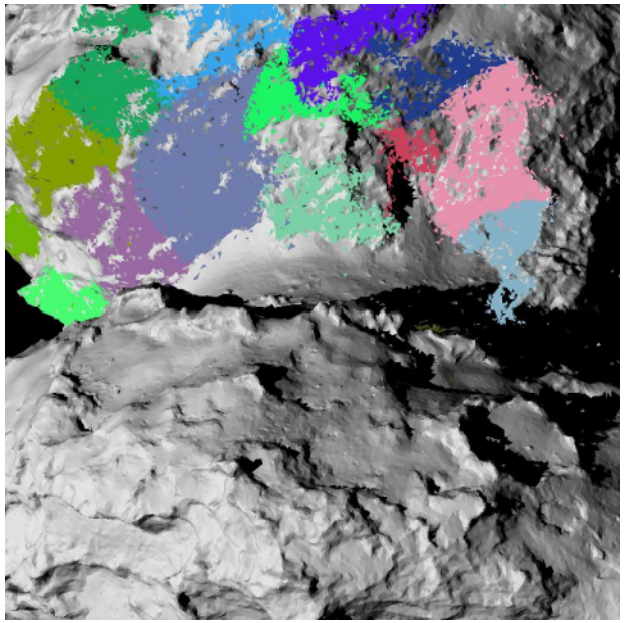
“Cliffs” are defined as sets of connected facets with an effective gravitational slope above the angle of repose.

The algorithm detects 2633 cliffs, with a height between 13m and 621m.

Global cumulative size distribution







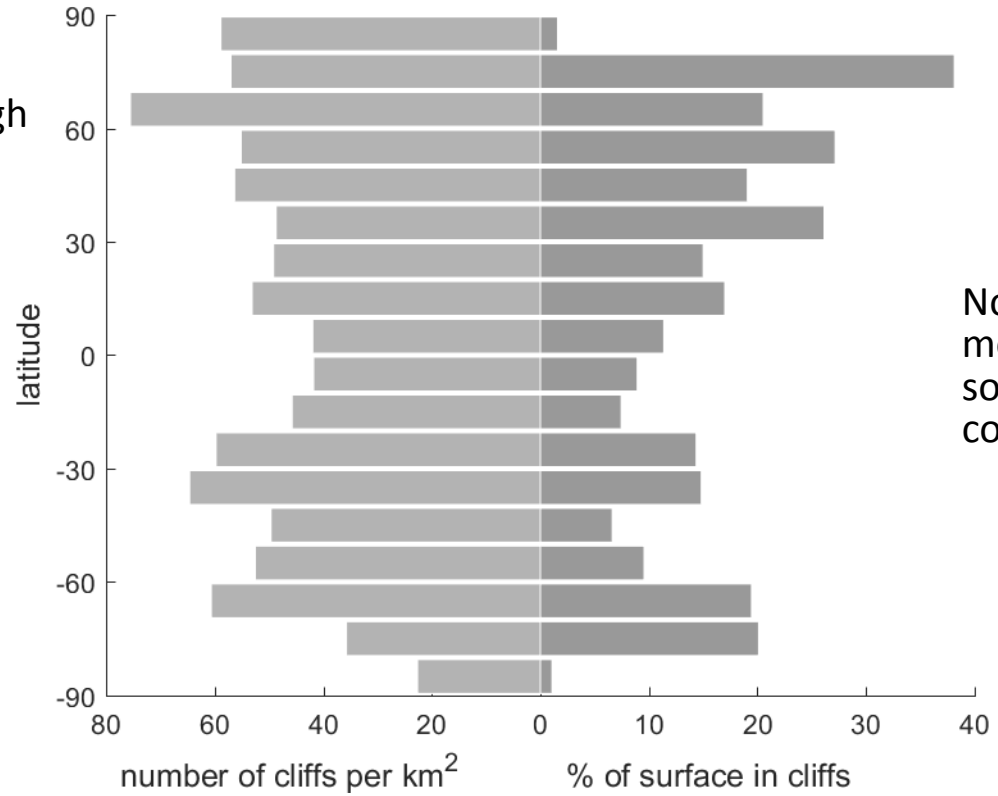
99.3 % of the cliffs have a height < 300m, and their distribution can be represented by a power law

The remaining features (0.7% = 18 cliffs) are located mostly in Hathor (not discussed here, see *Vincent et al MNRAS 2017*)

Size distribution per latitude

Northern cliffs most likely to be found at high latitudes (Seth/Hathor)

Southern cliffs mostly at mid-latitudes (also preferred location for outbursts)

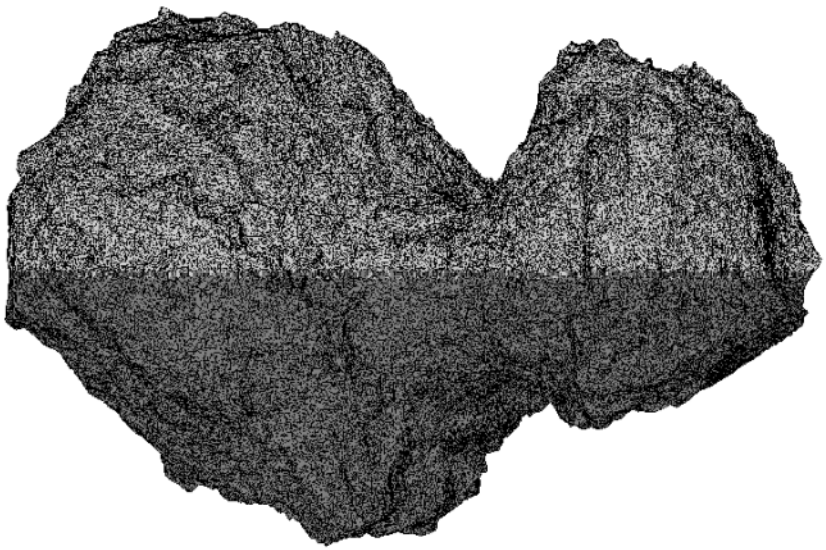


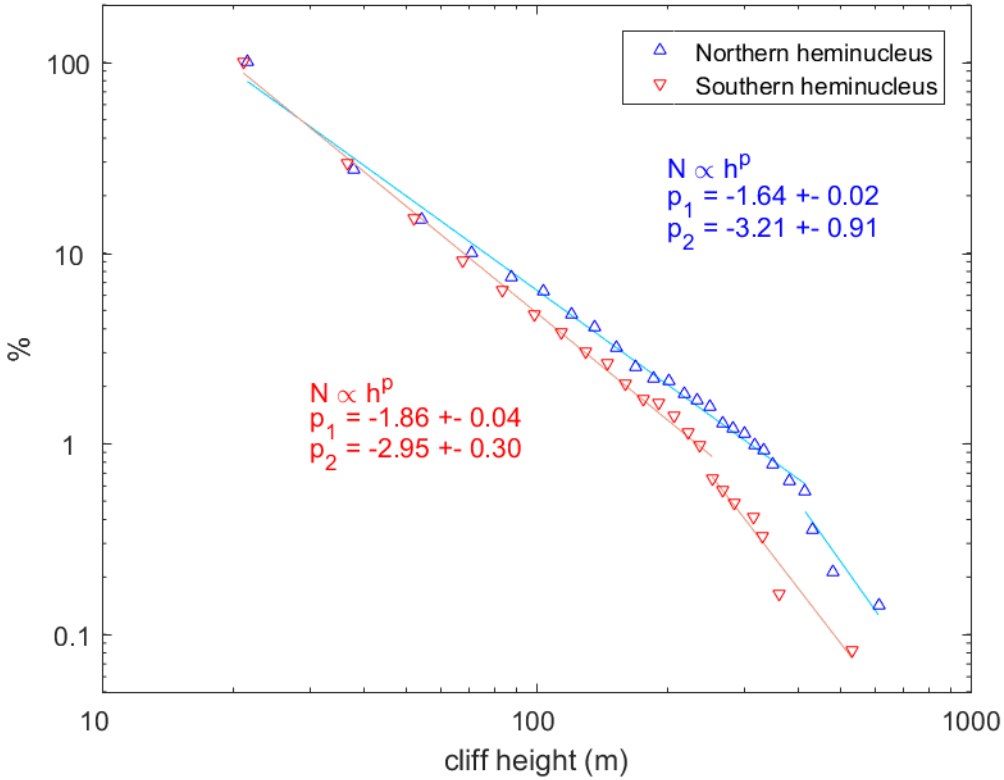
Northern cliffs tend to more extensive than southern ones, and cover a larger area

- Northern cliffs extend laterally for >100m
- Southern cliffs extend laterally for a few 10 m

} measure of macro-roughness

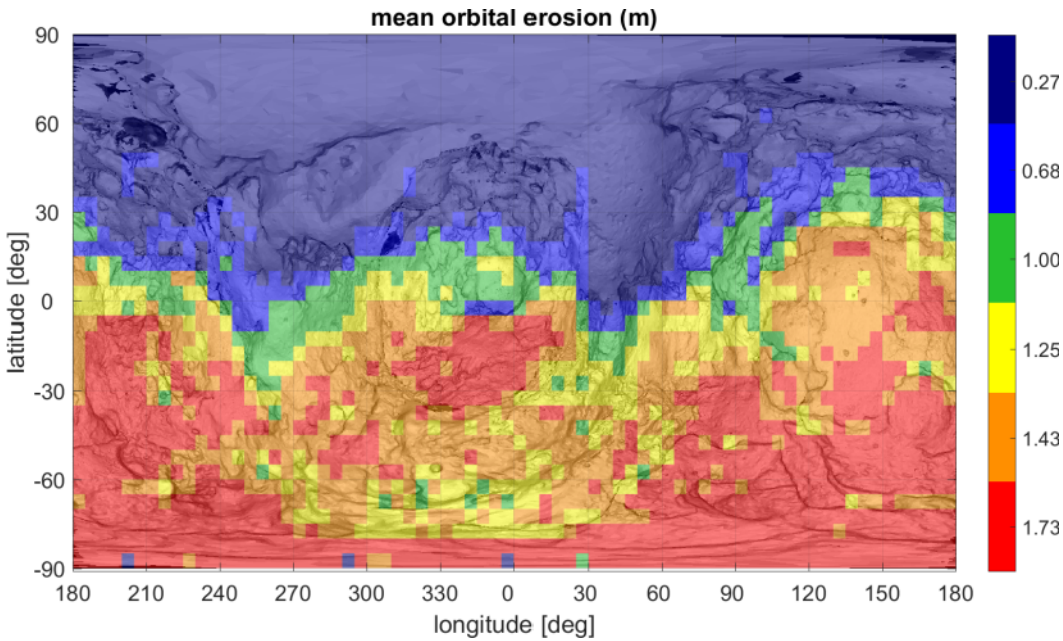
North vs South

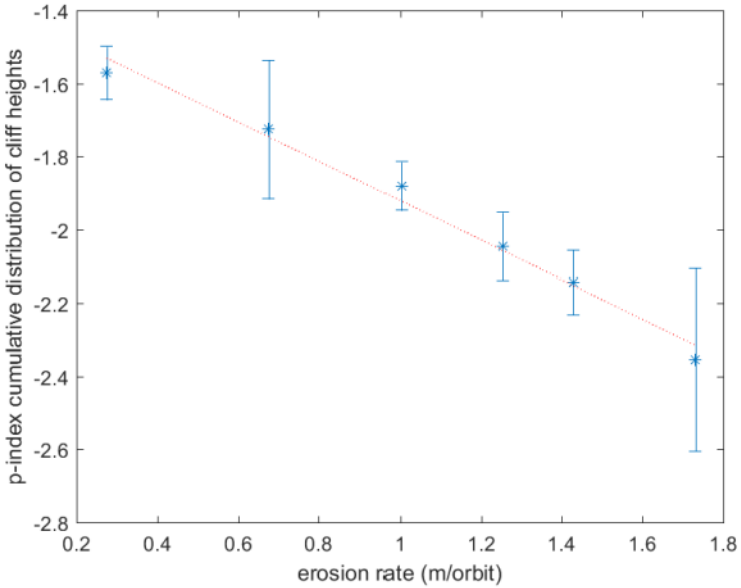




- The well known North/South dichotomy presented in many papers is also visible in this data set
- Power law 15% steeper in the South => more small cliffs, fewer large ones

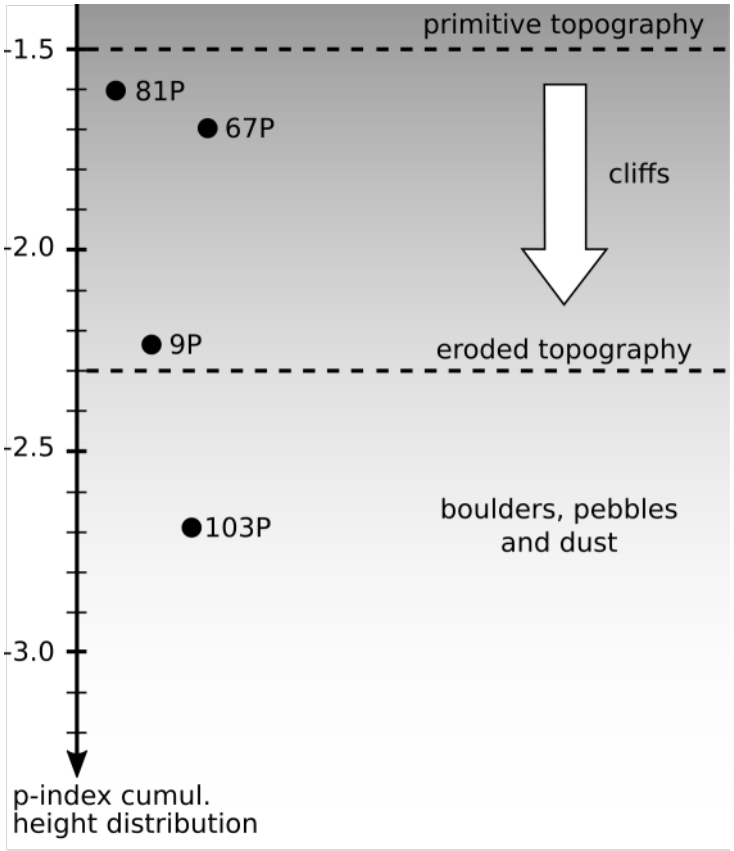
P-index vs erosion

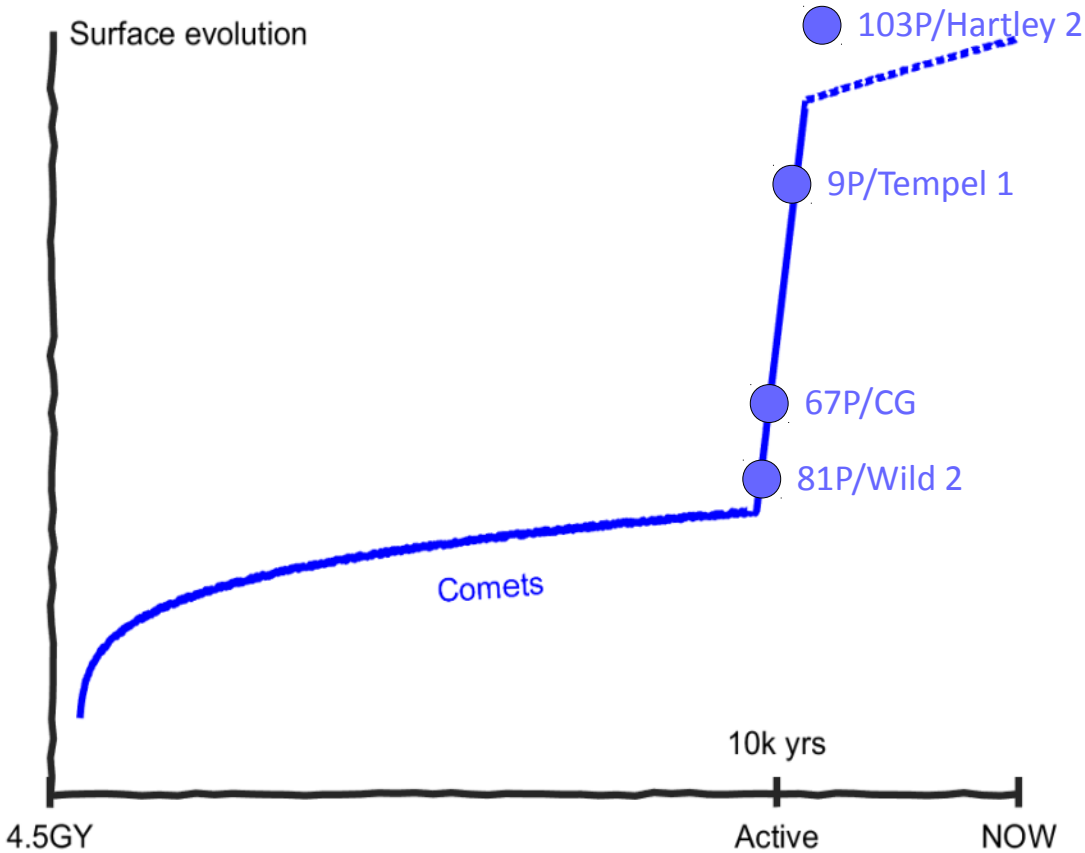




- We separated the surface in 6 regions of increasing orbital erosion rate, Keller et al (2015). Erosion rate is model dependent and a lower limit for the actual erosion. Well calibrated against multi instrument observations.
- **We find a perfect correlation between p-index and erosion.**
- **The most eroded regions are also the ones with the smallest cliffs**. If the two processes are related, it means that erosion is crumbling the existing topography, rather than carving out large features.
- **=> By extrapolation: low p-index is characteristic of a primitive topography.**

Comet surface evolution





- **Primitive comets (81P, 67P) are characterized by the presence of large pits and cliffs**, which likely result from early impacts and outbursts shortly after formation.
- **Evolved comets show very little topography (9P, 103P)**, with most features being erased by activity + gravitational collapse.

Summary and outlook

- On comet 67P, **cliffs size distribution follow a power law** with an average cumulative power index = −1.69 ± 0.02.
- This power varies from region to region, and correlates well with the orbital erosion rate of the surface **=> The more eroded the area, the steeper the power law.**
- This observation can be generalized to other comets. **The size distribution of large vertical features provides a direct measure of a comet's erosional history,** like crater counts are used to date rocky surfaces.

The cumulative power index of the topography size distribution measures how primitive a comet nucleus is.

Primitive comet: p = -1.5*

Evolved comet: p = -2.3*

Model published in *Vincent et al, MNRAS 2017*

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