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The need for a new understanding of cometary processes in the light of Rosetta's results

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Recent Reviews

Hans Rickman (2018): ***Origin and Evolution of comets – Ten years after the Nice el and one year after Rosetta***
World Scientific*Mod/Advances in Planetary Science, Vol. 2*

Marco Fulle et al. (2016): Unexpected and significant findings in comet 67P/Churyumov-Gerasimenko: a interdisciplinary view. MNRAS **462**, S2-S8

Tobias Kramer et al. (2018): Dust and gas emission from cometary nuclei: the case of comet 67P/Churyumov-Gerasimenko. Advances in Physics X(2018), Vol. 3/1

In the following we will largely refer to their summaries, aside of original research based on Rosetta measurement results!

Some open issues – what was not expected?

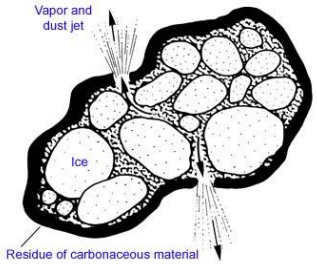
- The outgassing of the nucleus and the structure of the coma seems to be much more controlled by the shape and roughness of the nucleus rather than by the nature of the surface (active versus passive regions) - what is the real size of activity centres – **if they exist at all?**
- Strength of the cometary surface – why it was so hard at Philae's final landing site?
- D/H ratio different from the value found in terrestrial water/ice
- Density of emitted particles – compact versus fluffy/fractal?

Historical views - how does a comet „work“?

F. Whipple – *Dusty snowball model:* Active emission of volatiles and dust where ever the surface is irradiated by the Sun.

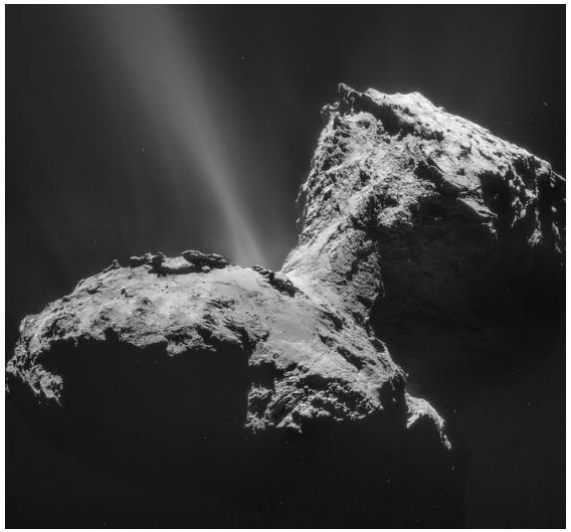
After the 1986 Halley encounters – H.U. Keller – *Icy dirtball model:* Most part of a comet‘s surface remain inactive, only a few percent of the surface turn into „active areas“ as the comet approaches the Sun!

Local activity creates jet-like emissions

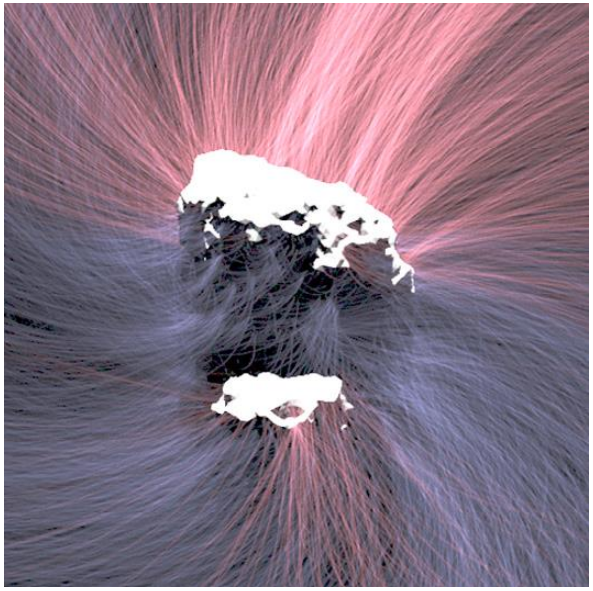


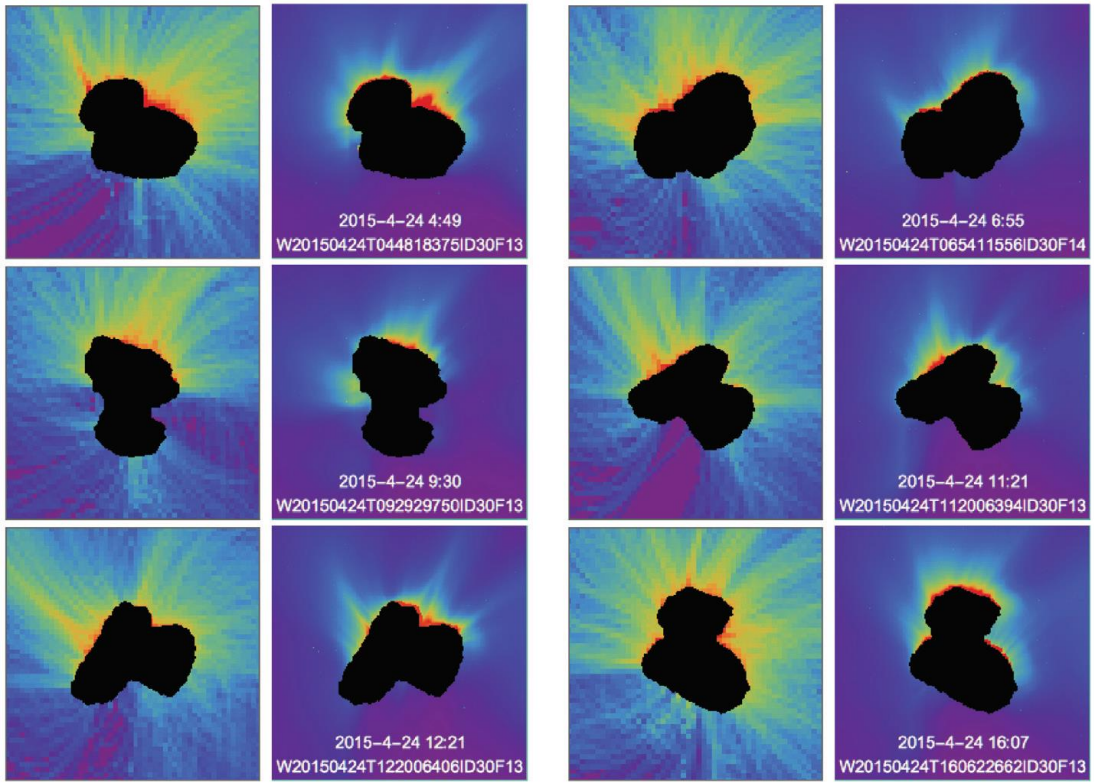
Later fly-by missions more or less seemed to confirm this view.

However, after several years of Rosetta observations this simple view is again highly questioned, because „Active regions are hard to find“ (Fulle 2016).



Where does the activity come from?

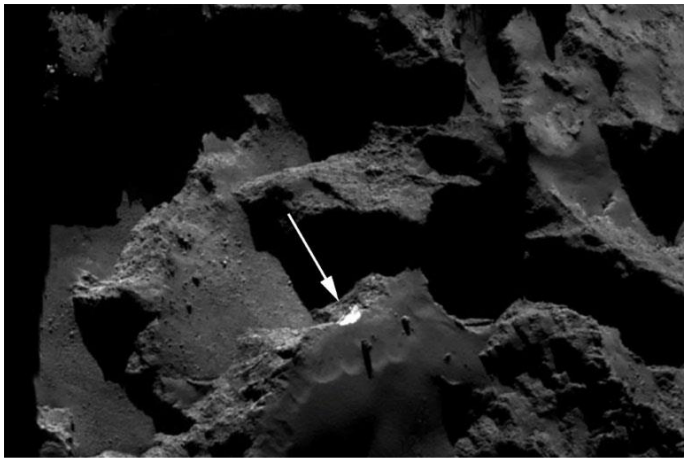


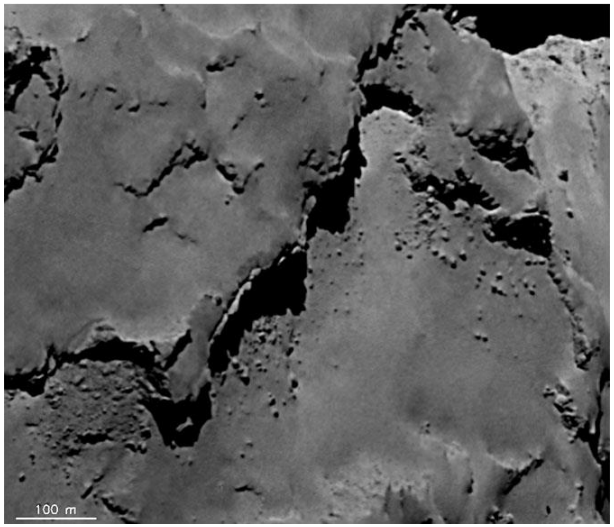


Dust/gas emission models versus dust jets observed by OSIRIS camera [credit: Kramer et al. 2018]

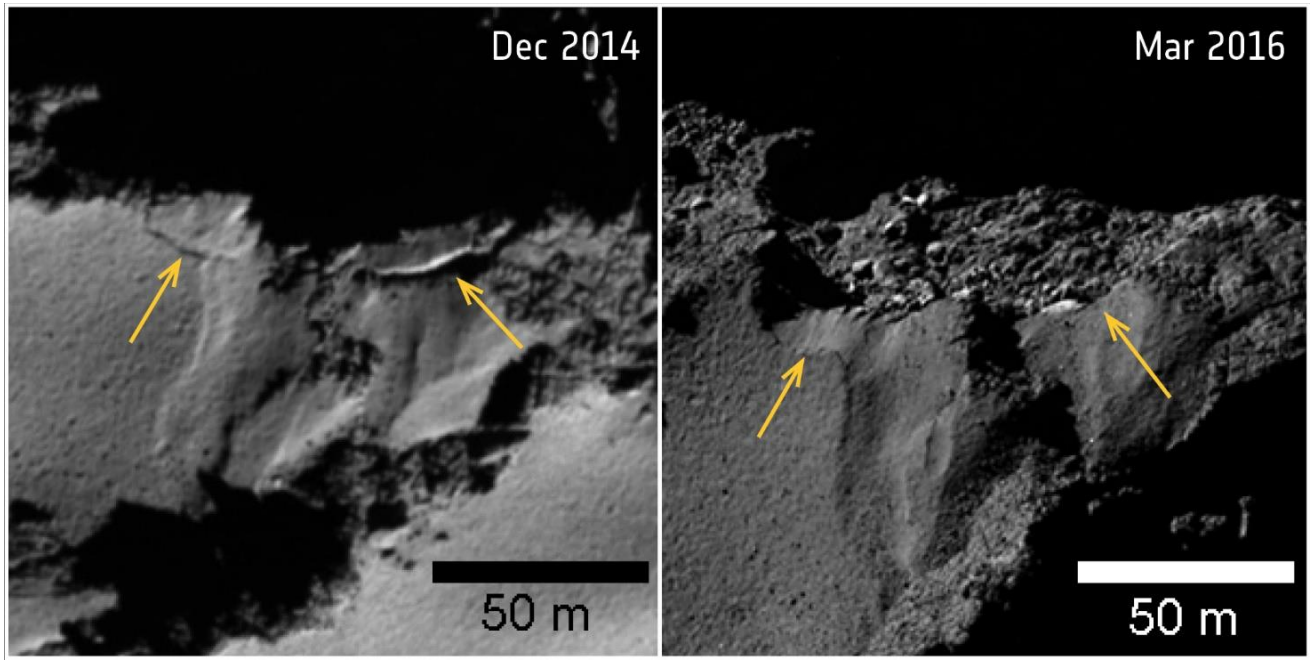
The best over-all coincidence of several modelling efforts to predict the coma structure (jets of dust/gas emitted from the surface) as observed by the OSIRIS camera is obtained under the assumption that the whole nucleus surface becomes active when irradiated by the Sun! [Fulle 2016]

Cliffs as sources of activity?





ESA / Rosetta / DLR / MPS for OSIRIS

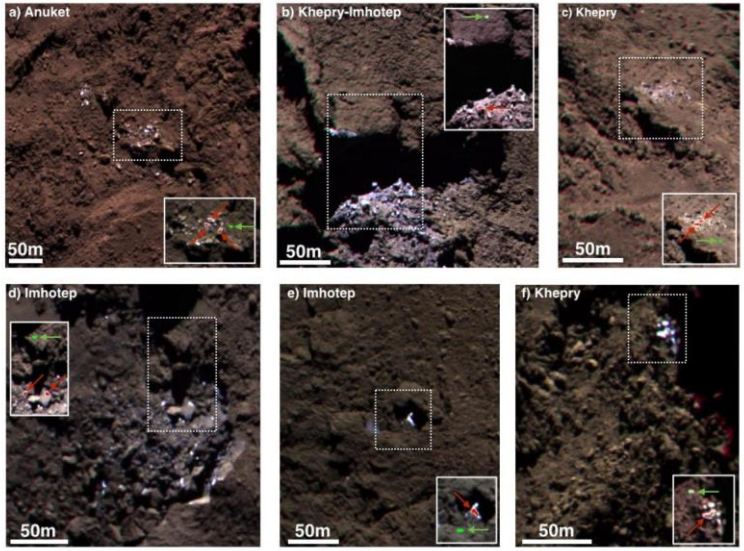


Several examples of cliff collapses observed by the OSIRIS camera.

After collapse of parts of a cliff a brighter surface (probably exposed water ice) is frequently seen.

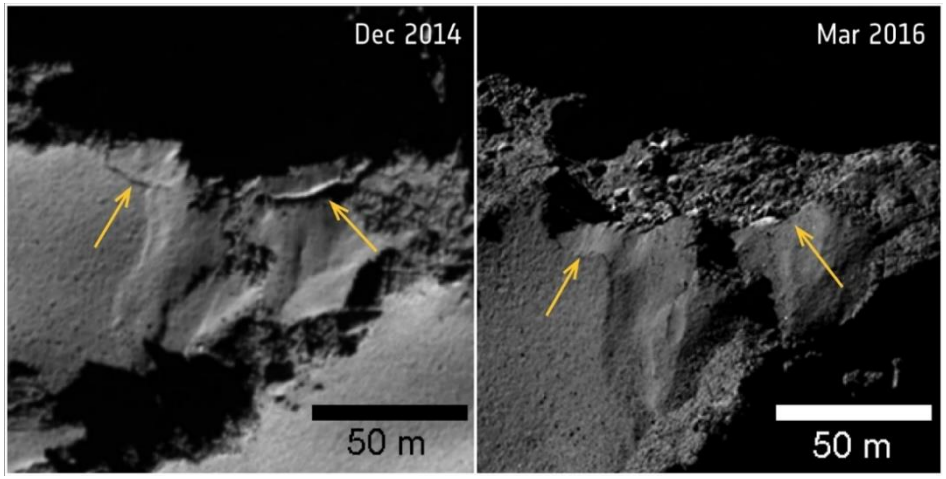
Such exposed regions are preferred sources of gas/dust emission!

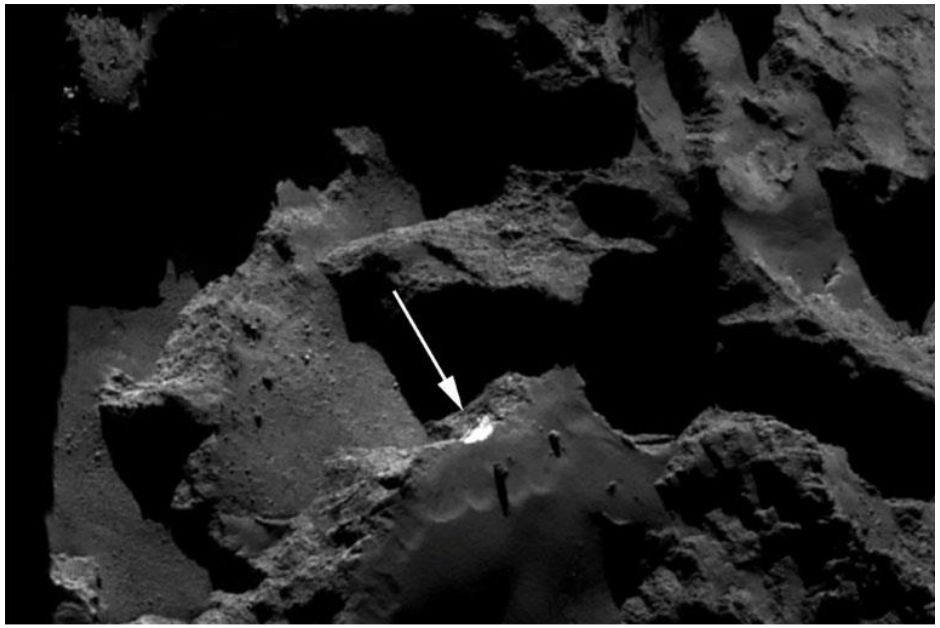
Ice exposure by cliff collapse – sources of „smooth“ activity?



Credit: Pommerol et al. (2015)

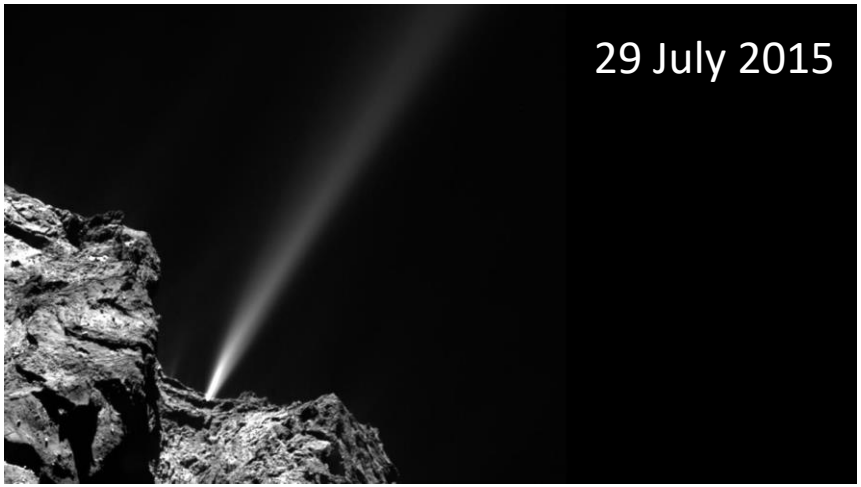
- Exposures of water ice (bright spots) are frequently observed at cliffs after „landslides“. Such areas are supposed to be a major source of gas and dust emission.
- Such „landslides“ may be caused by repeatitive cracking of the surface due to thermal cycles.



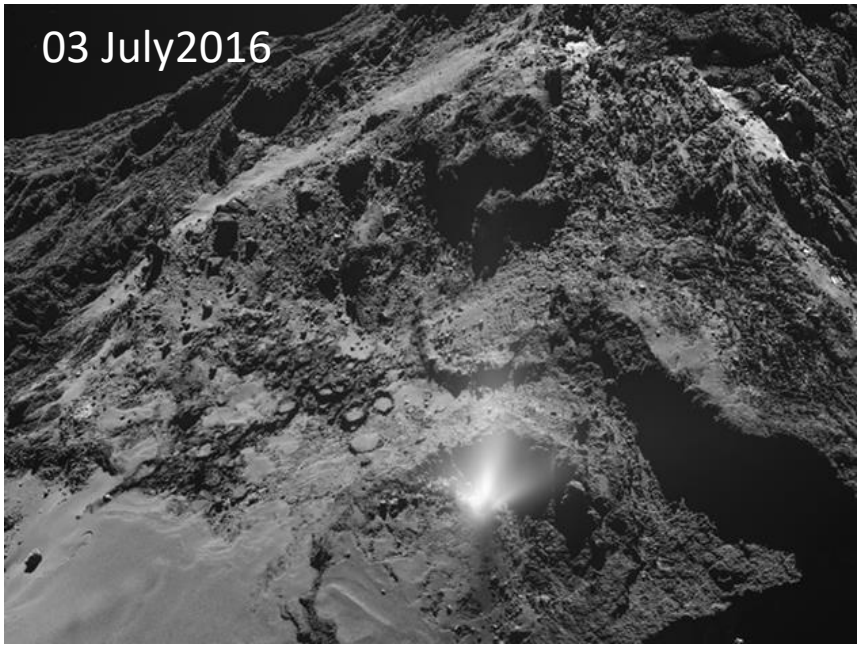


Credit: ESA / Rosetta / DLR / MPS for OSIRIS

Cometary outbursts – powered by what?



Credit: ESA / Rosetta / DLR / MPS for OSIRIS

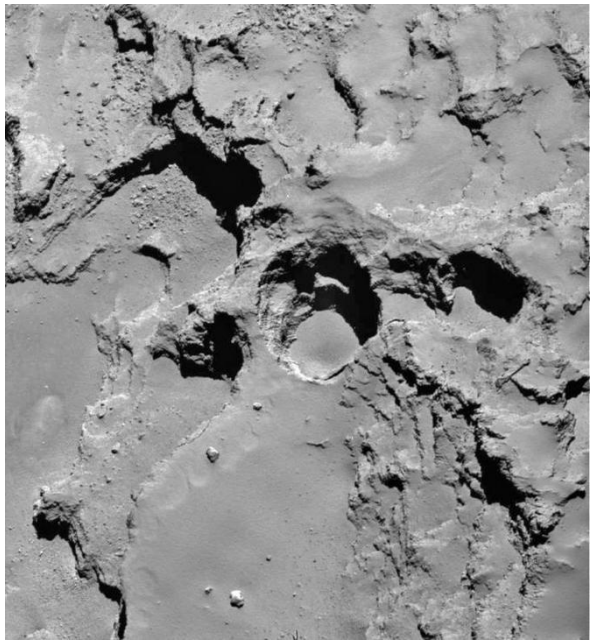


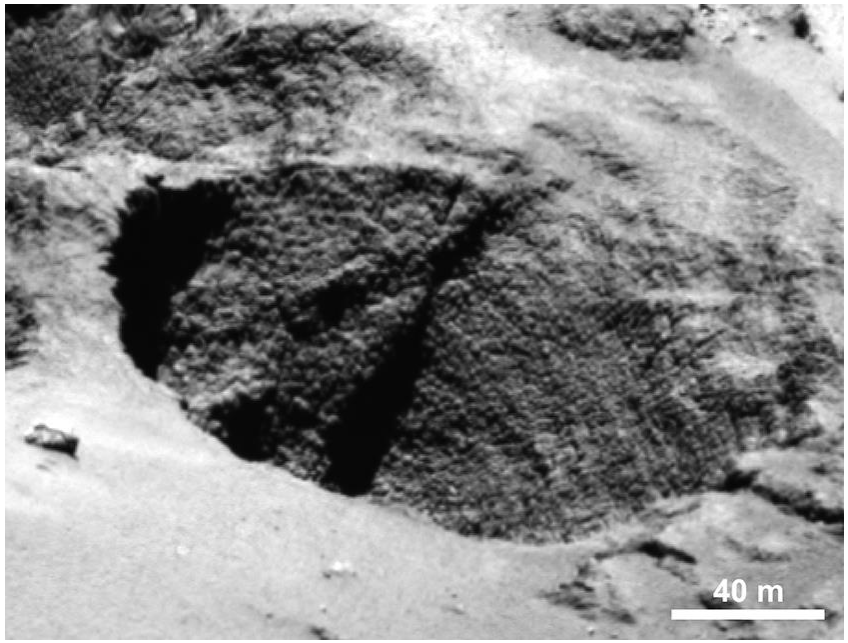
The short-term „outbursts“ are different from the „normal“ smooth activity observed all over the cometary surface.

They have an „explosive“ character and last a few days maximal. It seems still unclear which power source drives them!

Chemical reactions?
Amorphous ice metamorphosis?
Other?

Goosebumps inside pits – what are they?



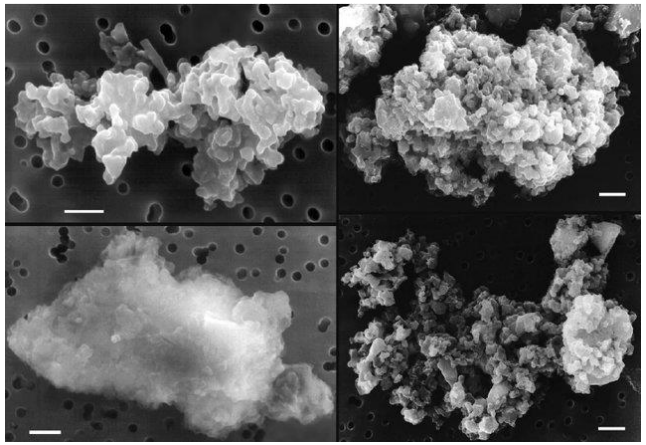


Credit: ESA / Rosetta / DLR / MPS for OSIRIS

Circular pits are requently observed on the surface – some of them show a „granular“ wall structure with a typical scale of a few metres!

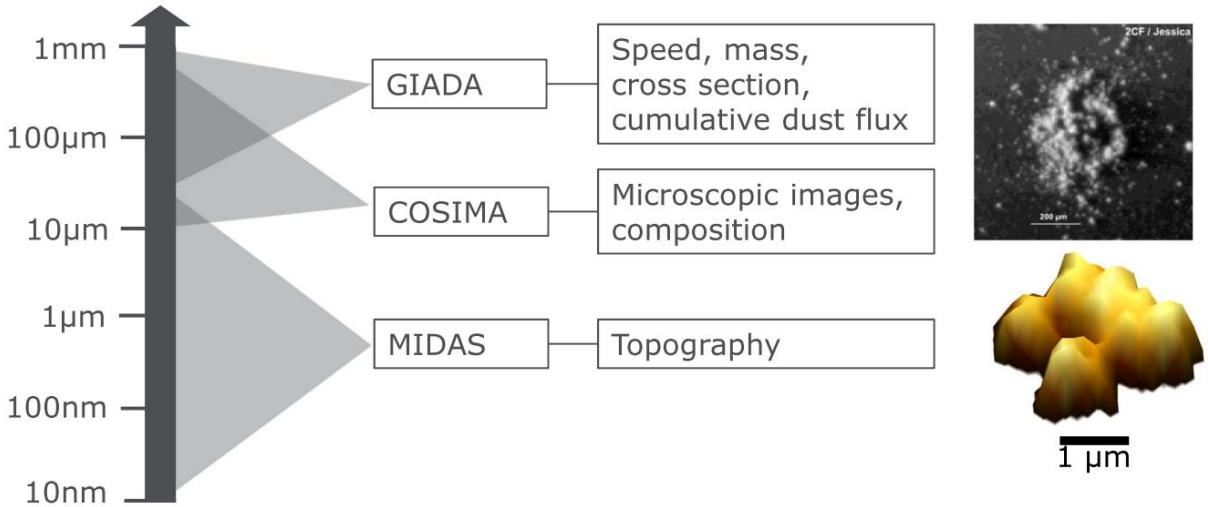
Are these features the basic building blocks of the comet? Are they the „planetesimals“ out of which the comet finally formed by slow collisions? Are they glued together by ices? Is the comet‘s interior also built up by blocks of this size?

Compact versus fluffy/fractal particles?



Interplanetary dust particles
[Credit: Zubko 2012]

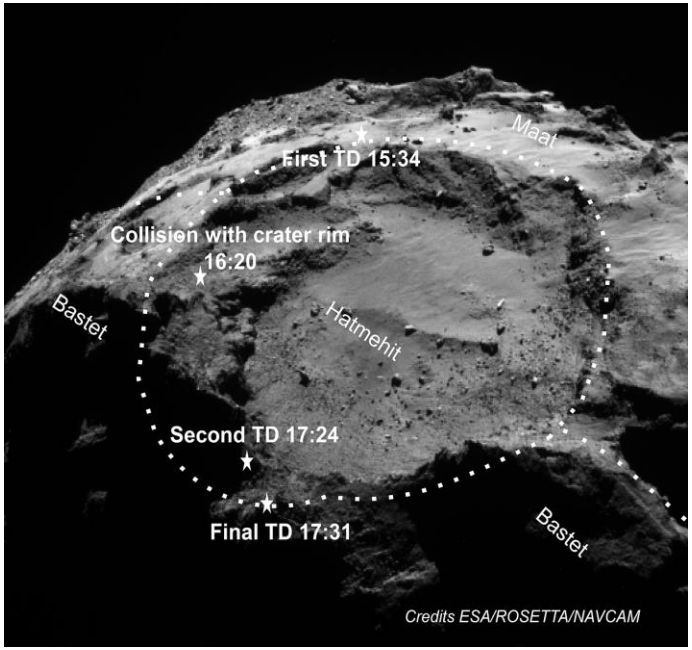
- Unlike previous expectations, a large percentage of the emitted cometary dust particles on comet 67P seems to consist of compact rather than of fluffy (low density) material [Fulle 2016].
- Only a minor percentage resembles the fractal/fluffy structures known from interplanetary particles collected in the terrestrial stratosphere.



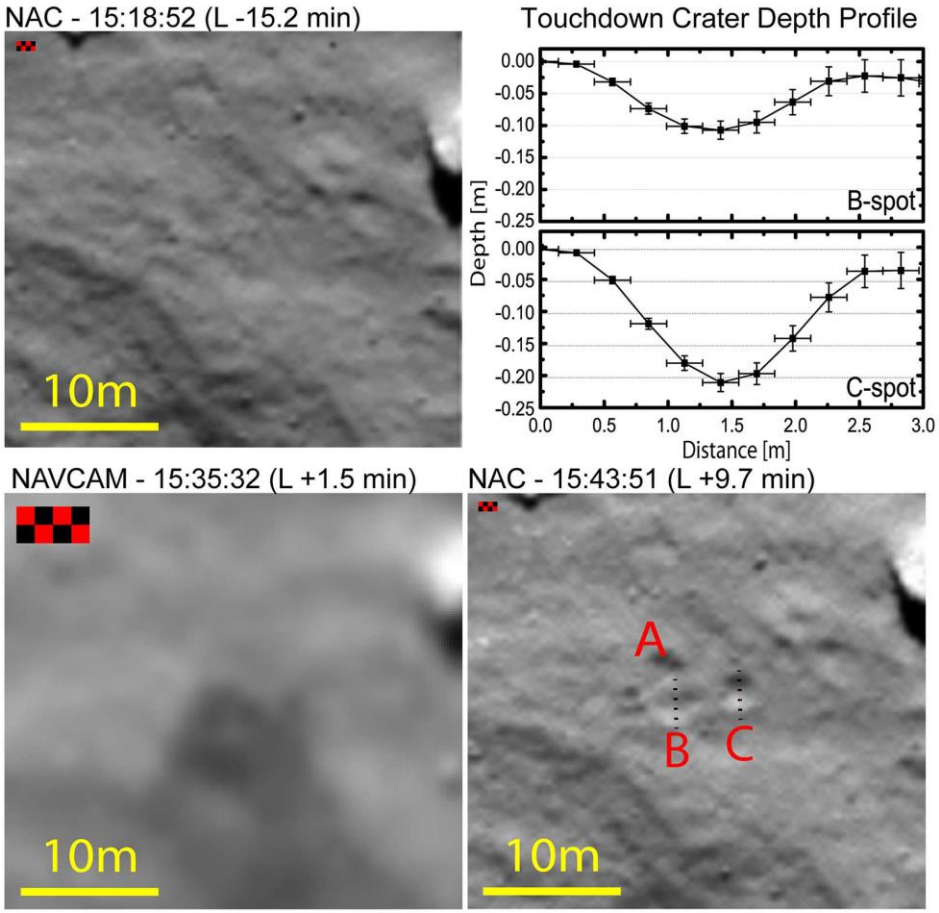
MIDAS finds hints for a „hierarchical“ structure of cometary particles down to nanometre scales!

Dust investigation instruments on Rosetta: [Credit: Mannel 2018]

Surface strength at Agilkia?

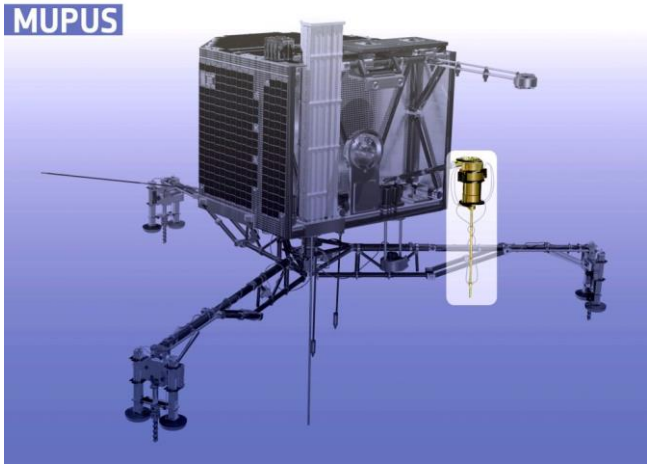


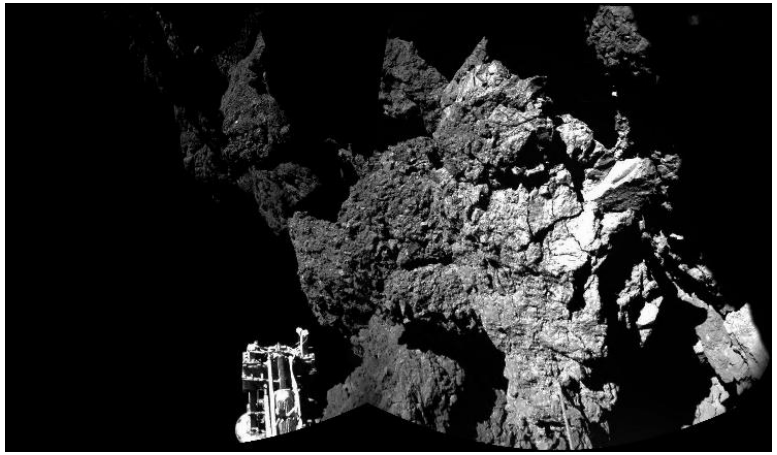
[credit: Biele et al. 2014]

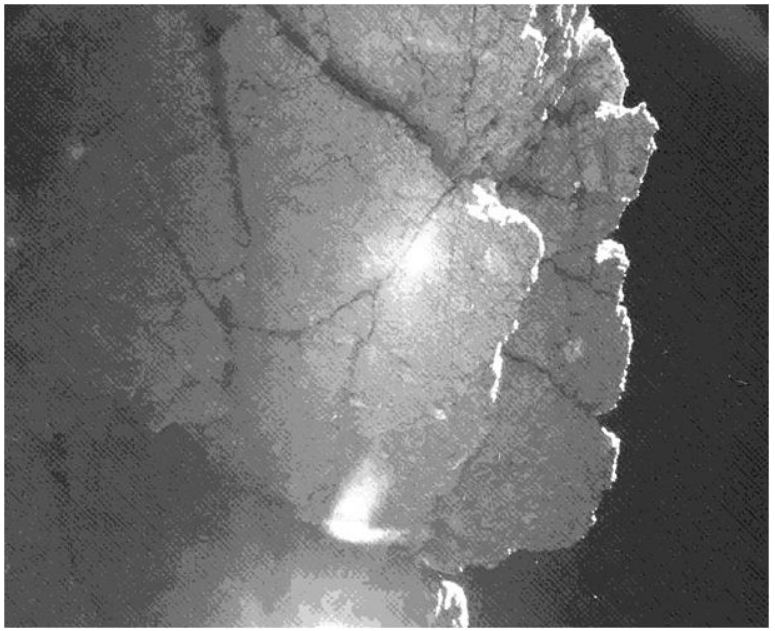


The surface condition at the first touch-down site Agilkia is consistent with the presence of a non-cohesive dust layer above cohesive material!

Surface strength at Abydos?







The local surface at the final (unintended) landing site Abydos is completely different from that at Agilkia:

- No loose dust!
- Hard surface (MUPUS probe unable to penetrate the surface despite hunderts of hammering strokes! [Spohn et al. 2015])
- Many cracks in the surface!
- No obvious activity (dust release) observed!

[credit: ESA2014; CIVA/Rolis Team 2014]

D/H ratio and high volatile species

- Observed D/H-ratio at 67P is rather different from that of the terrestrial oceans, but rather close to that of „molecular clouds! → 67P gas formed at very low temperatures !
- However, in other comets, e.g. comet 103P, has a value similar to Earth.
- The value measured at 67P is inconclusive w.r.t. the question if the Earth‘s ocean water stems from impacting comets.
- Presence of highly volatile species (O2, N2, Ar) indicate ice formation at very low temperatures!

Ideas for future work

New and innovative concepts for thermal and emission models are necessary to understand Rosetta observations!

- What is the role of thermal cracking for activating the surface?
- What is the real size of dust and gas emitting areas and why are the observed dust jets so focussed and filamentary?
- Which mechanisms drive the „smooth“ dust outflows what is the physical reason for the observed sudden outbursts?
- How can it be that almost no ice is present at the visible surface, but almost any part of the surface can emit dust and gas when illuminated by the Sun?

The role of the organic material covering most of the surface must be better understood. Can it act as a lid with low gas permeability but reasonable thermal conductivity and thus cause gas pressure buildup below the surface?