A new take on the formation and evolution of circular depressions at the surface of 67P/Churyumov-Gerasimenko

Selma Benseguane¹, Aurélie Guilbert-Lepoutre¹, Jérémie Lasue², Cédric Leyrat³, Sébastien Besse⁴, Arnaud Beth⁵, Marc Costa Sitjà⁶, Björn Grieger⁶, and Maria Teresa Capria⁷

¹Univ Lyon, UCBL, ENSL, UJM, CNRS, LGL-TPE, F-69622, Villeurbanne, France (selma.benseguane@univ-lyon1.fr)
²IRAP, Université de Toulouse, CNRS, CNES, UPS, 9 avenue Colonel Roche, FR-31400, Toulouse, France
³Laboratoire d’Etudes Spatiales et d'Instrumentation en Astrophysique, Observatoire de Paris, CNRS, Sorbonne Univ., Univ. Paris-Diderot, Meudon, France
⁴Aurora Technology B.V. for the European Space Agency, ESAC, Madrid, Spain
⁵Department of Physics, Umeå University, 901 87 Umeå, Sweden
⁶Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA, 91109-8099
⁷Istituto di Astrofisica e Planetologia Spaziali (IAPS), INAF, via del Fosso del Cavaliere, I-00133 Roma, Italy

Introduction

Some of the comets visited by spacecraft missions display some circular depressions at their surface: 81P/Wild 2 (Brownlee et al. 2004), 9P/Tempel 1 (Belton et al. 2013), 103P/Hartley 2 (Bruck Syal et al. 2013), 67P/C-G (Vincent et al. 2015). For 67P, they consist of circular holes, half holes or cliffs, with a size range of tens of meters to a few hundreds of meters (Ip et al. 2016). Owing to the high precision of the shape model obtained from the Rosetta/OSIRIS images (Preusker et al. 2015, Sierks et al. 2015), it is possible to investigate the thermal processing of 67P’s surface in relation to the formation and evolution of these features (Mousis et al. 2015, Vincent et al. 2015, Guilbert-Lepoutre et al. 2016).

Methods

We aim to investigate the formation and evolution of 67P’s circular depressions (or pits, thereafter) by thermally-induced processes (for instance sublimation and amorphous water ice crystallization) on its current orbit. In a departure from the aforementioned studies, we consider a high-resolution shape model of the nucleus, which allows to study several facets for each pit: at the bottom, and on the walls. For each facet, the complete thermal environment is considered, including self-heating and shadowing, either by neighboring facets or due to the complex global morphology of the comet. We compute the illumination, self-heating and shadowing conditions for 125k facets during a full orbit, with a time step of ~8 min, then use these conditions as an input of a 1D thermal evolution model for each facet. The model includes standard features: heat conduction, phase transitions, gas diffusion, erosion, dust mantling (De Sanctis et al. 2005, 2010, Lasue et al. 2008). Various initial setups have been considered, and many tests were conducted to assess the influence of each
parameter. The behaviour of 30 circular depressions (pits, half pits and cliffs) was studied in detail (see Figure 1).

**Results and discussion**

- We find that the following processes do not contribute significantly to the evolution of pits: sublimation of CO and CO2, crystallization of amorphous water ice, and dust mantling. When added to the model, they induce a relatively limited effect, altering the results by less than 10%. Sublimation of water, and therefore erosion, is the main acting process.
- We find that direct illumination is the main driver for gas production and erosion. Self-heating is not negligible, and in many cases, it allows to sustain some processing for longer periods of time and enhance local erosion. This is especially true for surface features located close to the neck, where facets additionally receive the VIS+IR flux from the small lobe. The total flux received per orbit is crucial, so is the flux received at perihelion. In this regard, we find strong differences between the Northern and Southern hemispheres of the nucleus, observed in other studies (Keller et al. 2015, Tosi et al. 2019). Finally, there is a tendency for facets in the North which are directed towards the equator to sustain more erosion than other facets at similar latitudes.
- At the scale of a given pit, there is a general tendency for cliffs and walls to receive more energy than the bottoms, and thus erode more. With time, the fate of a circular depression on 67P is thus to become wider and shallower. Nevertheless, in limited instances of small deep pits (such as Seth01), self-heating can be the driver for erosion of both the walls and bottom, since direct illumination is very limited. However, local erosion rates remain relatively low compared to erosion rates sustained by pits with direct illumination by the Sun.
- In general, we find that the erosion sustained after 10 orbits cannot reach the size extent of pits as they were observed by Rosetta. It is therefore very unlikely that current illumination conditions were able to produce those features. This results joins previous studies (Besse et al. 2015, 2017, Guilbert-Lepoutre et al. 2016).
- Because we have performed this study with a uniform set of thermo-physical parameters for all facets, we cannot exclude that local heterogeneities, such as the presence of ice patches in the bottom of some pits (Lamy et al. 2018) may help accelerate the erosion at depths in those pits.

![Fig 1: Erosion sustained after 10 orbits in the current illumination conditions (solar+shadowing+self-heating), for a selection of facets in the 125k resolution shape model.](image-url)
**Acknowledgements**

This study is part of a project that has received funding from the European Research Council (ERC) under the European Union’s Horizon 2020 research and innovation programme (Grant agreement No. 802699). We gratefully acknowledge support from the PSMN (Pôle Scientifique de Modélisation Numérique) of the ENS de Lyon for the computing resources.

**References**

Belton et al. (2013) Icarus, 222, 477-486
Besse et al. (2015) EPSC conference, id.EPSC2015-114
Besse et al. (2017) ACM conference
Brownlee et al. (2004) Science, 304, 1764-1769
Bruck Syal et al. (2013) Icarus, 222, 610-624
Guilbert et al. (2016) MNRAS, 462, 146-155
Sierks et al. (2015) Science, 347, aaa1044