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Testing the surface evolution hypothesis of JFCs with ground photometric observations

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Abstract

Rosetta has established that surfaces of comet nuclei are largely shaped by sublimation-driven erosion. The differences in morphology among the different parts of the nucleus of 67P, as well as between all comets visited by spacecraft have been linked to detectable differences in photometric properties.

Motivated by this, we identified a correlation of increasing albedo for increasing phase-function slope using ground-based and spacecraft observations of 14 Jupiter-family comets (JFCs). This can be interpreted as an evolutionary path of JFCs, according to which dynamically young JFCs start their evolution with relatively high albedos and steeper phase functions. During their lifetimes, sublimation-driven erosion gradually makes their surfaces smoother, and their phase-function slopes and albedos decrease.

If confirmed, this correlation will provide a compelling opportunity to study the surface characteristics and evolution of JFCs from the ground. We have therefore designed ground-based observing programs which aim to validate the correlation and to study its nature. We will present the results from our observing campaigns in 2018 and 2019. We will also discuss the results of our effort to compare the surface properties of JFCs to those of Centaurs and dormant comets in order to check the validity of our evolution hypothesis for the different evolutionary stages of JFCs.

1. Surface evolution hypothesis

Between 2014 and 2016, Rosetta monitored the effects of sublimation on the nucleus of 67P/C-G and established the connections between activity and changes in morphology. Comparisons of 67P with other comets visited by spacecraft also prove the connection between surface morphology and surface erosion [5]. Vincent et al. [5] compared the cumulative cliff-height distribution on different regions of 67P and of three other comets, 9P, 81P, and 103P and discovered that the regions on comet 67P which receive the highest insolation lack large cliffs. They hypothesised that the topography of comet nuclei is initially dominated by steep cliffs which gradually get eroded down to flatter surfaces composed of smaller fragments (pebbles and dust) due to sublimation.

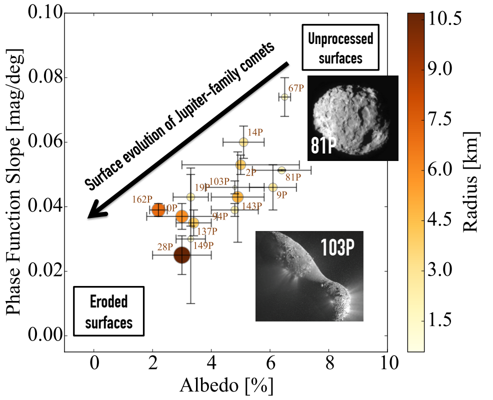

Figure 1: Trend of increasing phase function slope with increasing albedo. This is interpreted to reflect the evolution stage of JFCs from spacecraft and ground-based observations. According to the evolutionary hypothesis in [1], newly incoming JFCs start their evolution from the top right and gradually evolve to the bottom left side of the plot with time. The size of the points corresponds to the size of the comets.

The surfaces of comets can be characterised by photometric parameters such as surface albedo, colours (colour indices) and phase functions, which describe the decrease of brightness with phase angle (α, the Sun-Object-Earth angle). It has been demonstrated that different surface morphologies are related to different photometric behaviour [3]. Additionally, recent models of the macro-roughness on comet surfaces by [4] indicate that the self-shadowing of different types of surface topographies can produce measurable differences in the comets' phase functions.

These discoveries motivated us to look for ways to distinguish between the erosion level of JFCs using photometric properties accessible to ground observers. In [2], we found a correlation of increasing phase-function slope with increasing albedo for 14 JFCs (Fig. 1). In agreement with the findings from the in-situ observations, we interpret this correlation as an effect of the surface evolution of the comets [1]. In this scenario, dynamically young JFCs start their evolution with relatively high albedos and steeper phase functions. During JFCs' active lifetime, sublimation-driven erosion gradually makes their surfaces smoother, and their phase-function slopes decrease. As the dust-covered portions of the nuclei progressively increase, the comets become less active and the sublimation gradually decreases. Finally, the dust layers gradually lose their volatiles and the surfaces darken even further as the comets become dormant.

This hypothesis offers a fascinating opportunity to study the evolution of cometary surfaces with ground-based observations. This is particularly important since no space missions to further comet nuclei have been planned for the next 2 decades and the only currently available way to continue exploring comet nuclei in the next years is through telescope observations.

If the correlation in Fig. 1 is confirmed it would allow us to study the surface evolution of a large sample of JFCs. It would also allow us to distinguish between the oldest most evolved nuclei and the youngest least-altered comets. The correlation between albedo and phase function will also enable us to distinguish between asteroids on cometary orbits and dormant comets, as currently it is impossible to distinguish dark asteroids from comets [1, 3].

2. Objectives

The main objective of this work is to validate the correlation in Fig. 1 with further observations. To do this, we have collected observations that allow us to determine the albedos and phase-function slopes of additional comets and check whether they agree with the observed trend. Furthermore, we are working to understand to what extent additional effects could influence the albedo and phase-function measurements. In particular, we attempt to understand the effects of the non-linear increase of the phase function at small phase angles (opposition effect, OE) on the estimate of the linear phase-function slope.

Additionally, we aim to explore whether the phase-function–albedo correlation can be used to trace the evolutionary path of JFCs – from Centaurs to dormant comets. We, therefore compare the comets in Fig. 1 to additional JFCs, as well as to Centaurs and dormant comets. We also attempt to connect the proposed evolutionary hypothesis to evidence for colour differences between different JFCs.

3. Observing programmes

In order to address these questions, we designed two observing campaigns distributed over five 2-8m telescopes over the past two years. In 2018, we conducted an observing campaign to study the phase function of 162P down to $\alpha = 0.15°$ aiming to detect the opposition effect of a comet for the first time with ground observations. In 2019, we have followed a selection of currently inactive JFCs nuclei with known sizes (43P, 169P, P/2005Y2, 233P, 315P, 172P). We have adopted the techniques in [1] and [2] to derive their albedos and phase functions and to compare them to the other comets in Fig. 1.

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