Relationship between the phase-function slope and albedo of comets and asteroids

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In this work, we compare the relationship between the linear phase-function slope (\(\beta\)) and the geometric albedo of Jupiter-family comets (JFCs) to other minor planet populations: Trans-Neptunian objects, Centaurs, Jupiter Trojans, Hilda asteroids, Main-belt asteroids, Near-Earth objects (NEOs), and asteroids on cometary orbits (ACOs). With this analysis, we test whether these two parameters are a good indicator of the surface differences between the various populations and probe whether they can be used to study the surface changes experienced due to the evolution of the various populations.

The albedos and phase functions of small bodies have been used widely to study the surfaces of minor planets throughout the Solar system. However, obtaining both parameters for large samples was difficult in the past. In particular, studies of the surfaces of small bodies focused on the phase-functions’ opposition effect at small phase angles and on the phase integral both of which require well-constrained phase functions that cover a large range of phase angles and careful correction for rotational variability. It is possible, however, to derive the slopes of the linear part of the objects’ phase function with sufficient precision using relatively sparse photometric observations. Moreover, the geometric albedos of large samples of objects have been determined using targeted observations and large surveys in the mid-IR in recent years. Therefore, if the relationship between \(\beta\) and albedo is indicative of the differences in the surfaces of the different populations, it can be used to study a very large number of objects.

In earlier work, we identified a correlation of increasing albedo for increasing phase-function slope using ground-based and spacecraft observations of 14 Jupiter-family comets (JFCs) \(^{[1,2]}\). This was interpreted as an evolutionary path of JFCs. According to this hypothesis, dynamically young JFCs start their evolution with relatively large albedos and steeper phase functions. Then, during their lifetimes, sublimation-driven erosion gradually makes the comets’ surfaces smoother, and their phase-function slopes and albedos decrease.

Interestingly, the correlation identified for JFCs follows the opposite trend to that identified for Main-belt and Near-Earth asteroids (Fig. 1). According to the analysis of Belskaya and Shevchenko (2000) \(^{[3]}\) the phase coefficients of asteroids in the range \(\alpha=5-25^\circ\) increase linearly as albedo decreases. A similar correlation that also covers lower albedo- and size ranges typical for JFCs was found for NEOs \(^{[4]}\).

These findings raise two compelling questions. Firstly, if the possible phase-function-albedo
correlation for JFCs reflects their sublimation-driven erosion, then can a comparison of JFCs with related populations in the TNOs, Centaurs, and NEOs, and even in the Trojan and Hilda populations be used to reveal more details about the evolution of icy small bodies at different heliocentric distances? Secondly, does the difference in the \( \beta \)-albedo correlation for NEOs and Main-belt asteroids reflect a difference in the surfaces of the two populations, or is it caused by the different size ranges of the objects in the two samples?

We attempted to answer these questions using two lines of investigation. As a first step, we collected objects from all populations with phase-function slopes and albedos in V-band available in the literature. These objects were compared to the JFCs and asteroids in Fig. 1 to check whether they agree with the correlations identified. In the interpretation of this comparison, we took into account the current best understanding of the dynamical history of each population and considered focused studies of individual objects.

Secondly, in order to study the asteroid phase-function slope-albedo anti-correlation, we collected a larger dataset of Main-belt asteroids, NEOs, ACOs, Jupiter Trojans, and Hildas with albedos known from WISE/NEOWISE (Mainzer et al. 2019) and photometric observations available from the Minor Planet Center. We used this dataset to derive the linear phase-function slope of \(~10000\) objects from all four populations. Even though the individual phase-function slopes and albedos can have relatively large uncertainties, the large number of objects allow us to characterize the relationship between \( \beta \) and geometric albedo of the individual populations.

In addition to the findings on the surface properties of the different populations, this work provides useful insights that would serve as a foundation for future phase-function studies (e.g. with the Vera Rubin Observatory’s Legacy Survey of Space and Time; LSST). We will discuss the limitations of the currently available photometric data and will highlight the specific improvements that could be achieved with LSST.
Fig. 1. Relationship between the linear phase-function slope $\beta$ and the geometric albedo in V-band for the 14 JFCs in [1,2] (plotted as circles), Main-belt asteroids from [3] (triangles) and NEOs from [4] (squares). The lines correspond to the linear relationships found for each sample.