Characterization of comet dust based on near-infrared polarimetry

L. Kolokolova
University of Maryland, College Park, USA, ludmilla@astro.umd.edu

Abstract
The paper reviews the available polarimetric observations of comets in the near infrared (NIR). Through computer modeling of light scattering by aggregates it is shown how polarimetric data in the NIR can be used to determine porosity and other characteristics of comet dust particles. Applications to other types of cosmic dust are also discussed.

1. Introduction
Polarimetric observations in the NIR are crucial for understanding properties of comet dust. At these wavelengths micron-size particles become comparable with the wavelength which allows better evaluation of the size of comet dust particles. In the case of aggregates of submicron monomers, in the NIR the monomers become Rayleigh particles and should demonstrate a bell-shaped dependence on phase angle with 100% polarization at 90°. Deviations from the Rayleigh behavior tell us about interactions between the monomers in aggregates and depend on the aggregate porosity and composition.

2. Observations
Although comet polarimetric data in the NIR are still very sparse, they already allow us to notice specifics of comet polarization at these wavelengths. The most prominent fact is the change in the wavelength dependence of polarization. If in the visual the majority of comets show an increase of the absolute value of polarization with increasing wavelength, in the NIR the trend is opposite: polarization decreases with wavelength (Fig.1a). The negative spectral gradient of polarization (blue polarimetric color) observed for comets in the NIR is typical for asteroids and some comets (Fig. 1b) where it considers as “anomalous” [1]. At small phase angles some comets show similar negative polarization in the visual and NIR [4]; for some other comets negative polarization is smaller in the NIR (Fig. 1a, bottom curves), and comet Hale-Bopp showed no negative polarization at all [5].

Figure 1: Wavelength dependence of comet polarization. 1a: the typical behavior in the visual (positive trend) and in the NIR (negative trend); the data from [1, 2]. 1b: examples of the negative polarimetric color in some comets; adapted from [3]

3. Computer modelling
Kolokolova and Kimura [6] considered comet dust particles as aggregates of submicron monomers and showed that the difference between the polarimetric characteristics of comet dust in the visual and NIR can be due to the difference in the strength of electromagnetic interaction between the monomers. This strength depends on the number of monomers covered by a single wavelength. The electromagnetic interaction depolarizes the scattered light (similar to depolarization of light by multiple scattering); if more monomers are covered by a single wavelength the polarization of light decreases. The visual wavelengths can cover 1-3 submicron monomers and the effect of the depolarization is negligible. However, in the NIR a single wavelength may cover a significant number of the monomers and therefore depends on the porosity of the aggregate. The more compact the aggregate, the more monomers a single wavelength covers and the more depolarized the light becomes. Fig. 2 shows the results of the computer modeling that confirms this effect. For the computations, a new version of the T-matrix code adapted for parallel computing [7] was used. The computations were done for aggregates of 1024 monomers, porosities from 95% to 75%, and for the refractive indexes m=1.6+i0.01 (silicates) and m=1.88+i0.47 (comet-like material, see [8]). Fig. 2 demonstrates that depending on the aggregate
porosity the change from positive (red) to negative (blue) polarimetric color starts at different wavelengths; in the case of compact aggregates (75% porosity) the polarimetric color can be blue even in the visual. Notice that compact silicate aggregate does not show a smooth change of polarization with wavelength. This is caused by a stronger interaction between the monomers in the case of transparent materials [6] and that makes the aggregate behave as a solid particle of the size of wavelength whose light scattering is characterized by resonant oscillations [9]. An important result of the computations was that only large aggregates (> 1000 monomers) produced phase-angle dependence of polarization close to the observed one. For smaller aggregates, a single NIR wavelength covered the whole aggregate, and its phase curve was also characterized by numerous resonant features.

Figure 2: Modeled wavelength dependence of polarization at 90° phase angle for a variety of aggregate porosity for a silicate (left) and a comet-like material (right) described in the text.

The considered aggregates in the majority of cases showed absence of negative polarization. Only the silicate aggregate of the porosity of 75% showed a well-developed branch of negative polarization with the minimum around 9°. This may indicate that positive polarization is more affected by the electromagnetic interaction whereas negative polarization is more influenced by the individual monomers, and only in the case of a very strong interaction (compact transparent materials) at small phase angles deviations from the Rayleigh scattering become noticeable.

6. Summary and Conclusions

The paper presents first results of modelling comet polarization in the NIR. However, they already allow us to draw important conclusions for the remote sensing of comet dust: (a) the wavelength at which red polarimetric color changes to the blue one is defined by the aggregate porosity; it can be used for the porosity evaluation; (b) blue polarimetric color in the visual in some comets and in asteroid regolith indicates compact particles; (c) negative polarization at small phase angles in the NIR can be produced only by compact particles. These are preliminary results; for a further analysis, systematic polarimetric observations in the NIR are necessary. The results of this paper can be applied to interplanetary dust, dust in debris disks and aerosols in planetary atmospheres.

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References