Surface compositions of small solar system bodies and dwarf planets are characterized mostly through visible and near-infrared (NIR) wavelength measurements of albedo, photometric colors and diagnostic spectral features [1]. Such compositions include ices, hydro carbons and a refractory component of carbon-rich (e.g. amorphous carbon) and rock/mineral compounds [2].

Additional insight into surface composition comes from laboratory study of cometary grains, such as some interplanetary dust particles (IDP) collected in the Earth's stratosphere [3, 4], or those collected in-situ [5]. These studies show the presence of refractory carbonaceous units that are usually sub-micron in size. This indicates that the size of every sub-unit is much smaller than the wavelengths commonly covered in surface spectroscopy.

We use Maxwell-Garnett effective medium theory to approximate the effect of processing by solar and cosmic ions. It is motivated by laboratory measurements of collected cometary grains and IDPs [6].

Our assumption here is that the composition of cometary dust can be considered as a representative analog for at least some of the surface material of small bodies. As such, this is a good starting point to explore the visible-NIR spectral effects of the different mixtures (silicates vs. carbons, etc.).

Our icy surface spectral model is compatible with both volatile loss and surface processing by solar and cosmic ions. It is motivated by laboratory measurements of collected cometary grains and IDPs [6].

We map the 2 micron band depth onto the mass fraction space of water ice and carbon. Fractions cover the range from pure-refractory to pure-ice grains (0 to 1) and from carbon-depleted to completely carbonaceous refractory sub-inclusions (0 to 1). Results shown here are for low and high-sensitivity detection limits. Even small inclusions of carbon, in terms of mass fraction, are extremely efficient at masking the icy composition of a grain, at both the small and large size limits (7 and 50 micron).

The calculated V-band albedo values show that the sub-resolution mixing of water-ice and refractory components renders the albedo independent of composition and grain size, up to a water ice mass fraction of ~0.45. Beyond that only small grains, which are moderately-enriched in carbon, have albedos similar to those of icy objects in the outer Solar System [8].

The distribution of our calculated surface colors, in (B-V) vs. (V-R), follows our “reference dust” assumption and tracks the path in color space when changing the dust-to-ice ratio in the grain.

Conclusions

- Sub-wavelength scale inclusions play a critical role in biasing our interpretation of surface compositions and modification from reflectance spectra.
- A non-detection of the leading water ice band depth does not necessarily mean a lack of considerable fraction of water ice, if it is well-mixed in the sub-micron level.
- Over 50% (by mass) of water ice can be masked at 10% detection sensitivity, due to strong absorption of the carbon component.
- Sublimation-induced volatile loss and irradiation-induced volatile destruction may not be discernable by measuring spectral slopes.

References