The Carbon Did It – Masking Surface Ice Features On Small Distant Bodies

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Introduction

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, hydrocarbons 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.

Model

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 use Maxwell-Garnett effective medium theory to approximate the effect of sub-wavelength refractory inclusions (as suggested in [7]). This procedure takes the optical constants of several components and mixes them according to their respective mass fractions and densities. Inclusions are considered sub-resolution scale and spherical, with similar dielectric properties of the medium and inclusions. We compute an average wavelength-dependent dielectric function for the synthetic material, representing our desired component mix, and then calculate the disk-integrated albedo spectra for aggregate particles at different sizes.

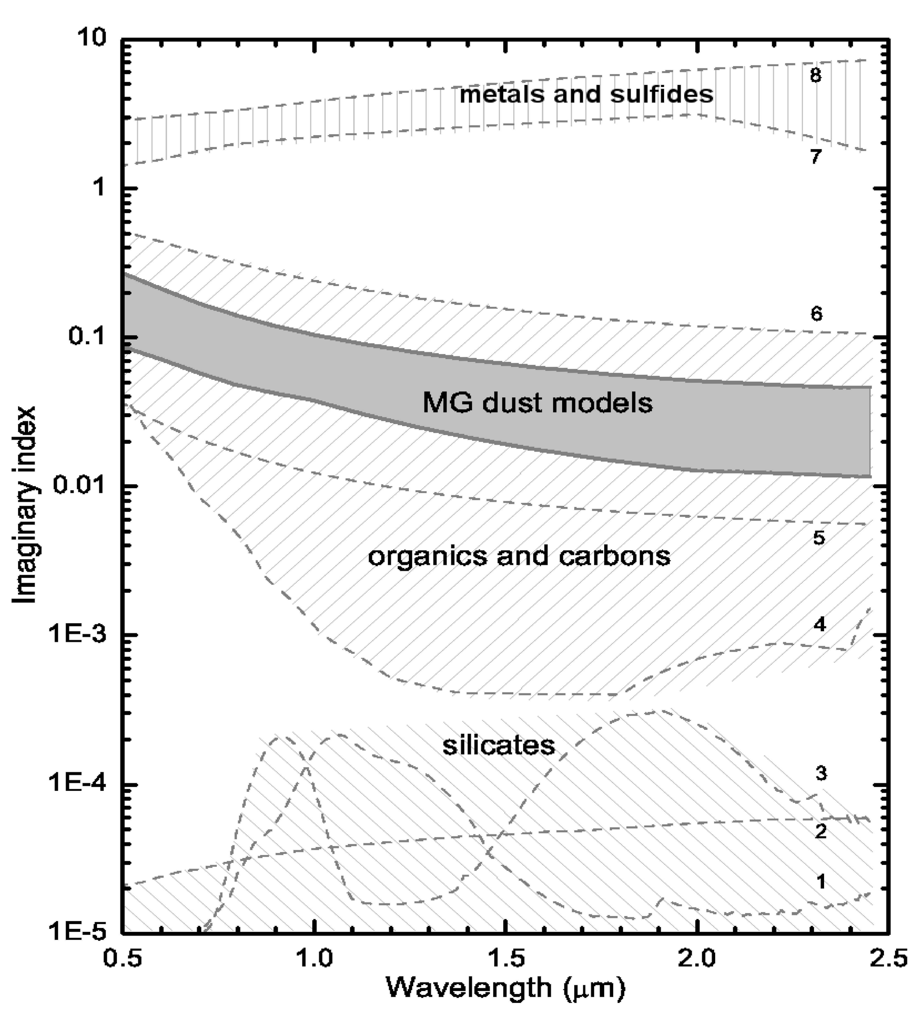

Fig. 1 - Imaginary refractive index for our model components: crystalline olivine (1), amorphous pyroxene-like silicate (2), crystalline pyroxene (3), tholins (4), irradiated methane (5), amorphous carbon (6), iron sulfide (7) and metallic iron (8). The gray shaded area ("MG dust models") is the range of sub-resolution mixtures considered in this work, from silicate-rich to carbon-rich dust.

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.).

We derive 3 key parameters from our synthetic spectra, which are commonly used to characterize small body surfaces [8, 9]: Depth of the <u>2 micron water ice band</u>, V-band (and R band) <u>albedo</u> and <u>color</u> indexes (broad spectral gradients in the Vis-NIR range).

Results - 1

Our results should be considered as a scheme for the effects of sub-micron inclusions on the reflectance spectra. Thus, we do not present here any rigorous fitting or analysis of the complete available data set of observations.

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).

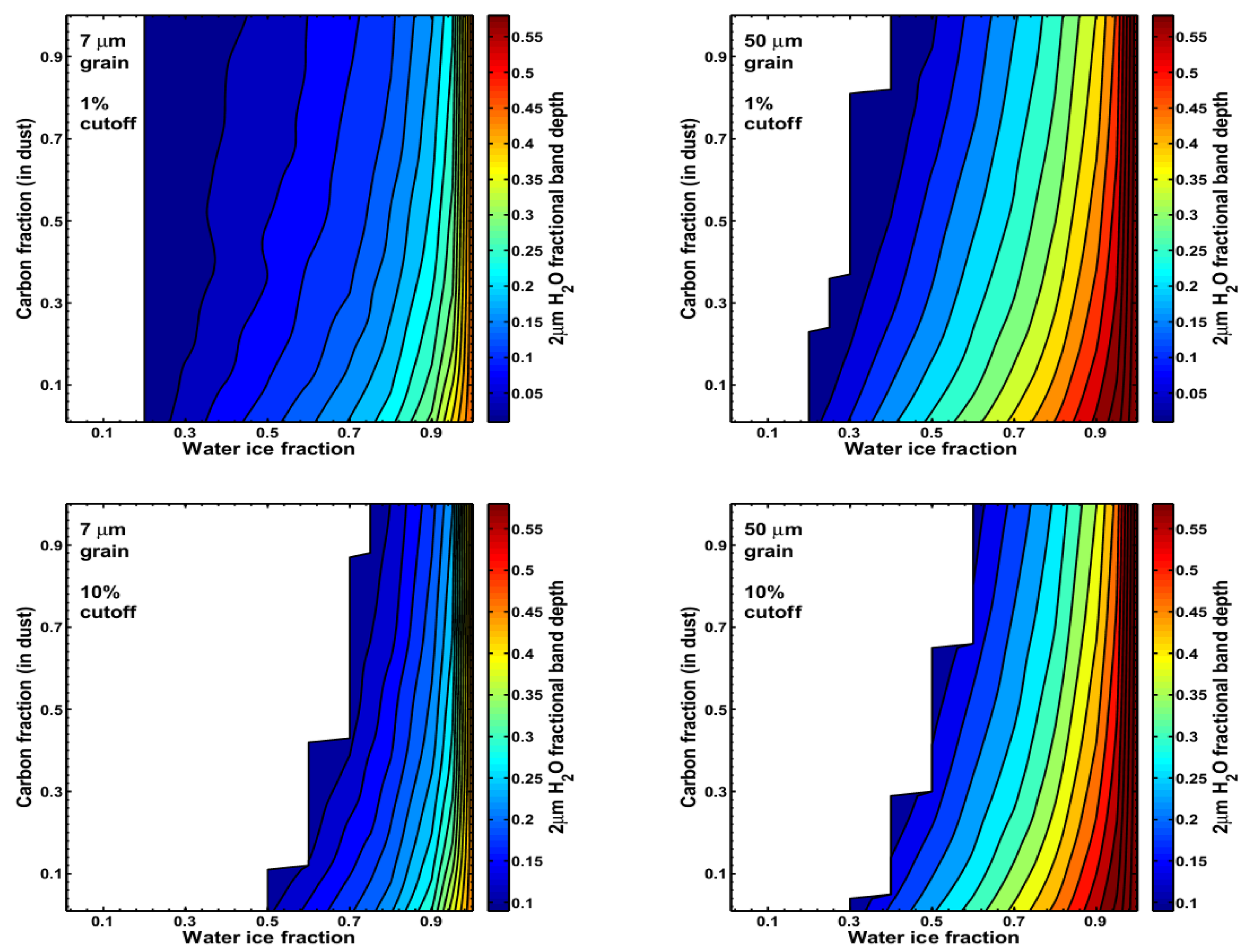

Fig. 2 - Fractional depth (relative to the continuum) of the 2 micron band for varied abundances of water ice in the grain and carbon fractions in the dust component. Results are shown for the large (50 micron) and small (7 micron) end members of grain sizes.
We present cases for low/high-sensitivity (10% and 1% cutoff), comparable with current observational capabilities. We can see that the higher the fraction of carbon the smaller the band depth, for a given amount of water ice.

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].

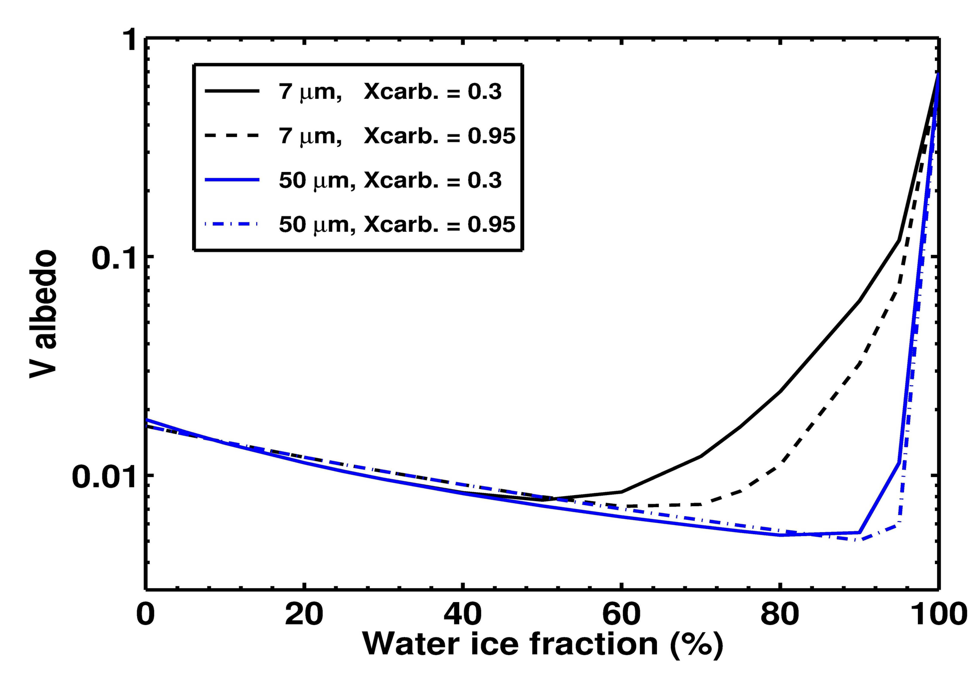

Fig. 3 – V-band albedo variation, as a function of water ice fraction in the grains. Results are shown for 7 (black) and 50 (blue) micron grain. These are either carbon "average" (0.3) or enriched (0.95), as mass fraction in the dust. We note that a composition of small grains and a moderate inclusion of carbon produces albedo values comparable to those measured for some outer Solar System objects, but only for very icy grains.

Results - 2

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.

This model is compatible with both volatile loss and space weathering destruction of volatiles. This is due to the fact that both processes reduce the global hydrogen-to-carbon atomic ratio of the surface material mixture, while still being intrinsically different. Comparing with previous ion irradiation experiments [10], we find that sublimation-induced volatile loss and radiation-induced volatile destruction follow similar trends in color-color diagram.

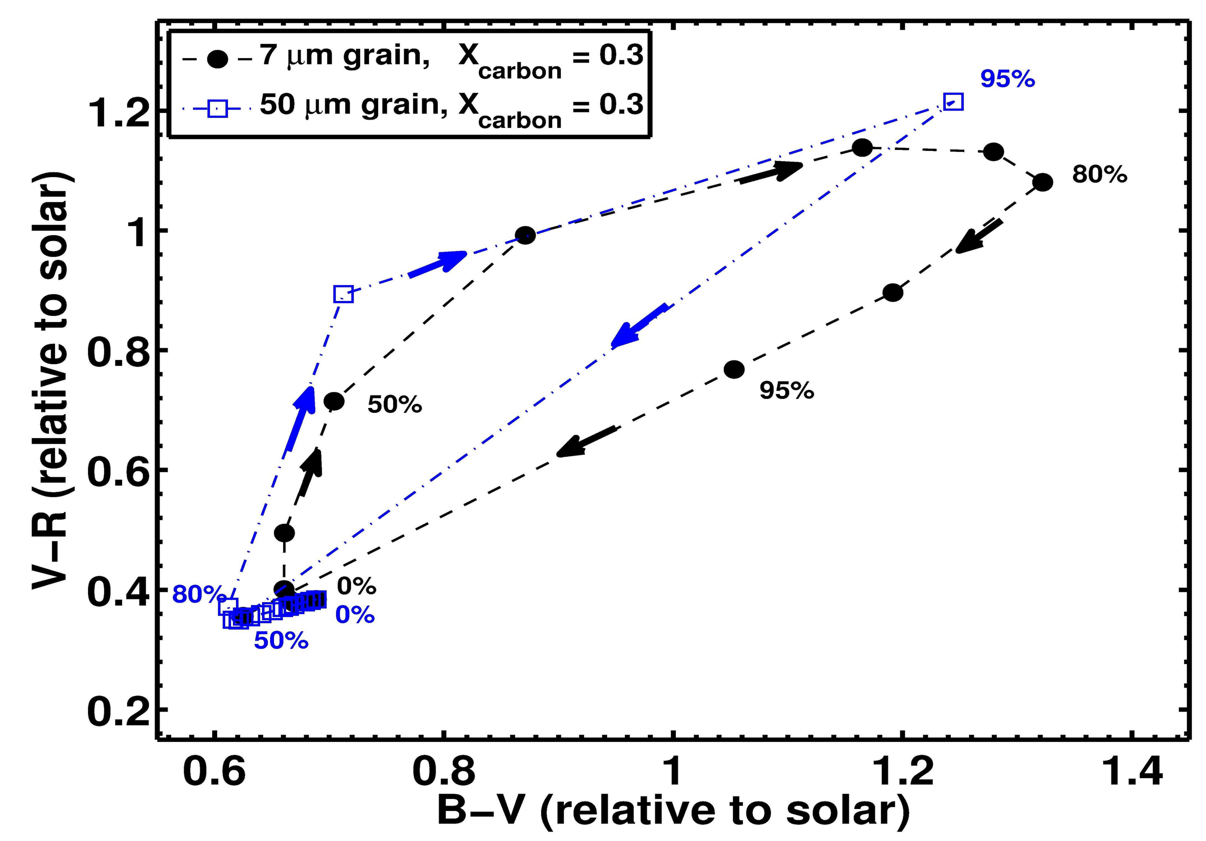

Fig. 4 – B-V vs. V-R colors, for varying water ice fractions and grain sizes (7 and 50 micron). Filled black circles (open blue squares) show the distribution of a few sample points from our spectral model, for an assumed "reference dust" composition. The associated lines and arrows depict the path in color-color space, as the water ice fraction is varied from 0 to 1. Note that the nearly closed loops in color spaces, indicate that the sub-resolution composition in our model may not be uniquely determined by a single spectral slope.

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

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