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Space weathering and the color indexes of minor bodies in the outer Solar System

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Abstract

We present a model based on laboratory results which contributes to the "nature" versus "nurture" debate on the colors of small bodies in the outer Solar System (OSS). According to our model, objects having suffered the same balance of irradiation and impacts follow specific curves in color-color diagrams. Appropriate combination of composition and weathering can reproduce the whole range of colors observed on OSS small bodies

1. Introduction

Visible and near-IR spectroscopic studies have revealed that the surfaces of small bodies in the outer Solar System (OSS) are rich in organic compounds and carbonaceous refractories mixed with ices and silicates [1]. Red colors of these bodies are likely caused by a combination of both primordial organic composition and space weathering of the surface. In a classical collisional resurfacing scenario, the space weathering processes alter the small bodies surface spectra but are in competition with resurfacing agents that restore the original colors. The result of these competing processes continuously modifying the surfaces is supposed to be responsible for the observed spectral variety of Centaurs and trans-Neptunian objects [5].

2. Experimental facts

We have measured the color indexes B-V, V-R and V-I of several samples irradiated with different ions in recent years at the Experimental Astrophysics Laboratory in Catania (Fig. 1, A1, A2, A3 asphaltite, O1 – olivine; OP1, OP2 olivine pellets with deposited layer of polystyrene; for details on experiments see [6] and [3]). We use simple equation that as an example for color V-R is:

$$V - R = 2.5 log \frac{Refl_R}{REfl_V} \quad (1),$$

where $Refl_R$ and $Refl_V$ are the values of the diffuse reflectance measured at R = 787.4 nm, V = 545.5 nm (B = 438.3 nm, I = 864.8 nm). Moreover, we have estimated the timescale necessary to induce the effect observed on laboratory samples by ions of the Solar wind at 10 AU. Further, colors of the laboratory samples were compared with the colors of objects in the OSS, compilated in The Minor Bodies in the Outer Solar System database ([2], http://www.eso.org/~ohainaut/MBOSS). Our laboratory data were corrected for solar colors, since the color indexes of asteroids correspond to the reflected light from the Sun. Laboratory samples cover a range of colors larger than that of virtually all of the minor bodies of OSS. Important fact is, that OP2 at highest irradiation doses reproduces the colors of asphaltite. This because transparent organic material, exemplified by polystyrene, is able upon ion irradiation to cover a very wide range of colors and, at the highest doses it is carbonized and has a flat spectrum and low albedo (see also [5]).

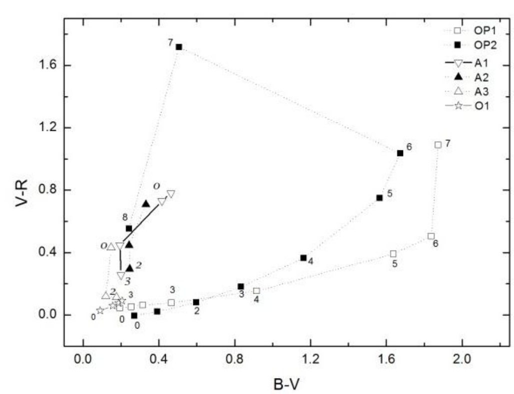

Figure 1: Color-color diagram for several laboratory samples. Numbers are relative to different irradiation fluences.

3. Model

We suggest that the observed colors of OSS objects are due to the linear combination of: a flat component (i.e. having solar colors) but with different albedo (from 1 i.e. pure methane ice, to about 0 i.e. more or less pure carbon); and a material similar to the sample OP2 – polystyrene layer deposited on olivine pellet and irradiated with 400 keV Ar^{++}. Polystyrene is here considered as a template for any kind of organic material, including frozen hydrocarbons that can be present on planetary objects. The amount of weathering and its timescale depend mainly on the distance from the Sun (i.e. from solar wind flux). The fraction of irradiated vs. "pristine" surface depends on the intensity of meteoritic bombardment and/or ice sublimation. We show the experimental points with different fractions of weathered organics. Values B-V, V-R, and V-I have been obtained by system of equations (example for B-V):

$$B - V = 2.5 log \frac{X.Refl_V 1 + Y.Refl_V 2}{X.Refl_B 1 + Y.Refl_B 2} \quad (2),$$

where B-V is the resulting color index; X = the fraction of pristine surface; Y = fraction of weathered surface. $Refl_B 1 = Refl_V 1$ are the reflectances of the pristine surface with a flat spectrum and X+Y=1. Fig. 2 shows the results for an albedo of pristine material 0.4 (values 1 and 0.01 were used as well).

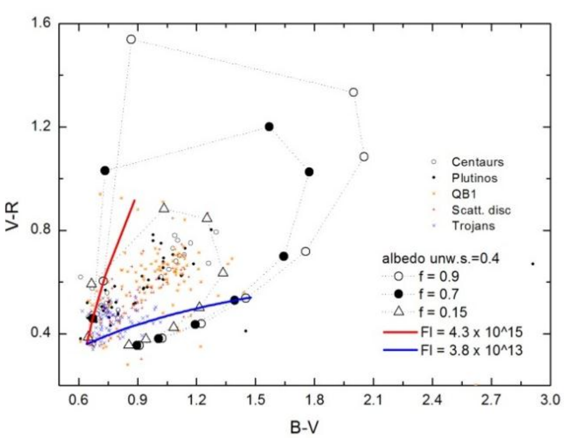

Figure 2: Comparison of the color-color diagram of the objects in the MBOSS catalogue with the model. Dotted lines represent loci of the points having different fraction (0.9(○), 0.7(●) and 0.15(△)) of weathered material but equally weathered. Full lines are relative to laboratory fluences corresponding to the exposure times (at 10 AU) of 100-1000 yrs and $2x10^4$-$2x10^5$ yrs.

4. Summary

In this work we present a model, based on laboratory results, that gives an original contribution to the "nature" versus "nurture" debate by addressing the case of surfaces showing different fractions of rejuvenated vs. space weathered surface, and calculating the corresponding color variations. The model predicts that surfaces receiving the same irradiation would tend to align on specific curves of the color-color plot. If the model is correct, this translates into the fact that in a color-color diagram, objects having suffered the same balance of irradiation and impacts would scatter, but they would tend to follow specific curves.

Acknowledgements

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