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Astronomical silicate nanoparticle analogues produced by pulsed laser ablation on olivine single crystals

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Silicate nanoparticles, otherwise referred to as very small grains (VSGs) [1], occur in various astrophysical environments. These grains experience substantial processing (e.g., amorphization) during their lifetime in the diffuse interstellar medium due to events such as grain-grain collisions and irradiation [2]. Moreover, several studies have pointed out that the main building blocks of these silicates are O, Si, Fe, Mg, Al and Ca, all elements that are among the principal constituents of the Earth's surface [3], thus leading to the name "astronomical silicates". However, the structure and chemical evolution together with the origin of these grains are still poorly understood and intensively debated [4,5].

The aim of this study is the simulation of space weathering processes on olivine single crystals by liquid phase pulsed laser ablation (LP-PLA). The study of the resulting structure of both the target and the ablated material together with their chemical evolution has been carried out by a multiple technique characterization. In particular, spectroscopy and dynamic light scattering measurements, analyses of the electrostatic properties and reactivity to acids and bases on the obtained colloidal solutions of the ablated nanoproducts have been performed and coupled with high-resolution transmission electron microscopy (HR-TEM).

Selected olivine target crystals (Fo_{87}) from the São Miguel island (Azores) were analyzed by Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray spectroscopy (EDX). LP-PLA experiments were performed with a Nd:YAG laser focused via a singlet lens onto the surface of the target, which was fixed at the bottom of a polystyrene box filled with 4 ml of deionized water (type 1) to immerge it completely. Laser pulses of 5 ns and 100 mJ simulate the timeframe and energy exchange occurring during grain-grain interstellar collisions [6] and they generate a plasma plume at the crystal/liquid interface. The rapid cooling induced by the confining liquid layer brings about the condensation of the chemical vapor it contains with production of a colloidal solution of nanoparticles. These solutions were analyzed by dynamic light scattering techniques and optical absorption spectroscopy in the range from 200 nm to 1100 nm (6.20 eV - 1.13 eV). Absorption measurements on the colloidal solutions have been compared against reference colloidal solutions dispersed in deionized water (i.e. mesoporous silica [SiO_2] nanoparticles, brucite [$Mg(OH)_2$] nanoparticles, aluminum hydroxide [$Al(OH)_3$] nanoparticles, chrysotile [$Mg_3Si_2O_5(OH)_4$] nanotubes, and synthetic forsterite [Mg_2SiO_4] nanoparticles). Moreover, additional absorption analyses have been carried out as a function of the addition of known aliquots of sulfuric acid and sodium hydroxide solutions. TEM/EDS analyses were then performed on the ablated nanoparticles deposited via electrophoresis on C-coated Cu grids and compositional variations of the ablated target were determined by X-ray photo-emission spectroscopy analyses.

The size distribution of LP-PLA synthesized nanoparticles is typically multimodal due to aggregation phenomena. Aggregation is consistent with the measured ζ-potential, which is negative with a relatively low absolute value, within the range 30-50 mV. Nonetheless, a recurrent mode is centered at about 2 nm (hydrodynamic diameter) and it is consistent with the measured size distribution obtained by transmission electron microscopy analysis (average nanoparticles diameter around 3-5 nm). Optical absorption measurements on the ejected material show a main band around 215 nm. This feature is very similar to the "B_2 band" reported in several studies on silica glass [7] and ascribed to oxygen vacancies, but its nature is still far to be fully understood. We also found that this feature at 215 nm is very common among both Si and Mg compounds (*e.g.*, Si-oxide, Mg-hydroxide, chrysotile). Moreover, additional absorption bands in the range 240-350nm are observed suggesting the formation of new space weathering products as result of the ablation process.

Therefore, these results suggest that substantial chemical processing might be expected during space weathering of "typical" interstellar grains into VSGs. Moreover, coupling these experimental results with remote sensing datasets will provide fundamental information about the origin and evolution of these silicate grains.

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