Update on automated classification of interplanetary dust particles

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Introduction: Every year, the Earth accretes about 40,000 tons of extraterrestrial material less than 1 mm in size on its surface [1]. These dust particles originate from active comets, from impacts between asteroids and may also be coming from interstellar space for the very small particles [2, 3].

Since 1981, NASA Jonhson Space Center (JSC) has been systematically collecting the dust from Earth'strastosphere by airborne collectors and gathered them into "Cosmic Dust Catalogs". In those catalogs, a preliminary analysis of the dust particles based on SEM images, some geological characteristics and X-ray energy-dispersive spectrometry (EDS) composition is compiled. Based on those properties, the IDPs are classified into four main groups: C (Cosmic), TCN (Natural Terrestrial Contaminant), TCA (Artificial Terrestrial Contaminant) and AOS (Aluminium Oxide Sphere). Nevertheless, 20% of those particles remain ambiguously classified.

Lasue et al. presented a methodology to help automatically classify the particles published in the catalog 15 based on their EDS spectra and nonlinear multivariate projections (as shown in Fig. 1) [4]. This work allowed to relabel 155 particles out of the 467 particles in catalog 15 and reclassify some contaminants as potential cosmic dusts. Further analyses of three such particles indicated their probable cosmic origin [5].

The current work aims to bring complementary information to the automatic classification of IDPs to improve identification criteria.

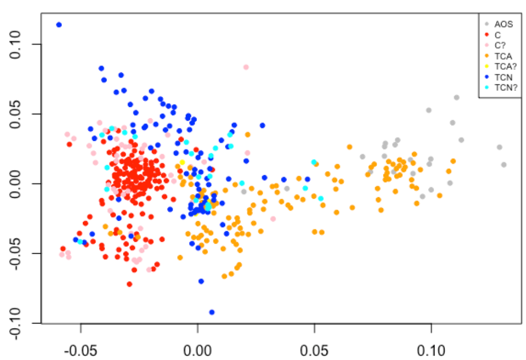

Figure 1:Nonlinear projection using the Sammon's algorithm for Cosmic dust catalog 15. Colors correspond to the JSC preliminary classification labels

Information from the images of IDPs: The first attempt to complete the classification of [4] is to use the IDPs surface structure visible in the images, knowing that unaltered cosmic IDPs often present a very irregular surface structure. In order to use a quantitative surface structure criterion, the fractal dimension and the lacunarity of the particles images are calculated with a Box-Counting algorithm. The fractal dimension value informs about the complexity of the pattern on the surface of the particle while the lacunarity gives information on the visual texture of the particle, as it characterizes the heterogeneity of its surface [6].

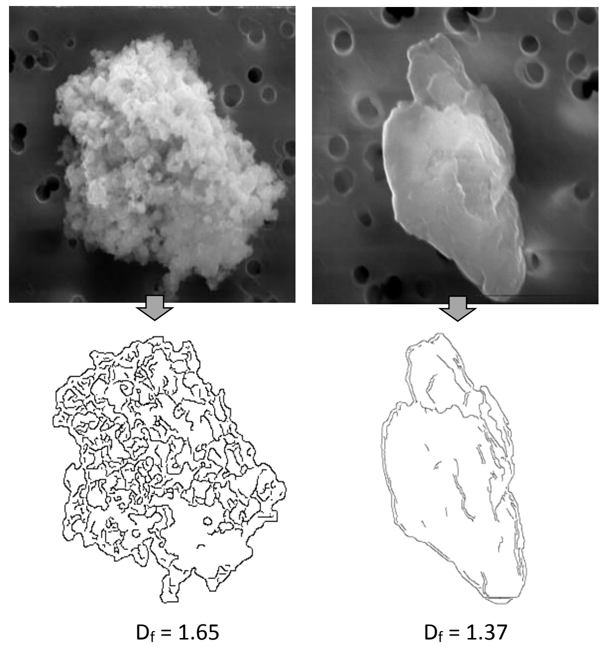

Figure 2: Automated image processing on a C particle L2021A1 (left) and a TCA particle L2021A2 (right) for fractal dimension and lacunarity calculation. Differences in surface structure affect the values.

After processing the IDPs' images using a canny edge detection, and binary transformation, the fractal dimension and lacunarity can be computed as shown in Fig. 2. C-type particles present a higher D_f value than the other types of particles, indicating a more irregular or complex surface structure for those particles as plotted in Fig. 3. The surface lacunarity appears generally lower.

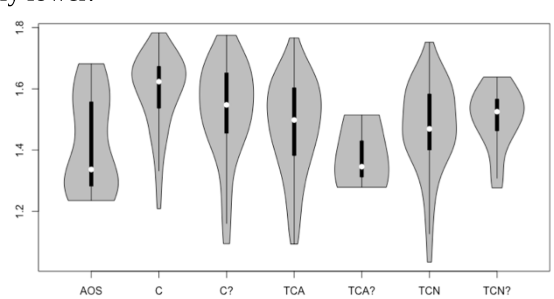

Figure 3: Violon plot and associated boxplots of fractal dimension for each group of IDPs in catalog 15.

The fractal dimension and the lacunarity are not the only information that can be combined with the composition information from the EDS spectra. Indeed, for each IDP in the catalog 15, the catalog informs on their size, their color and their luster, all characteristic that appear to differentiate the C-type particles from the others. We included those information in our data set and recomputed the Sammon's map represented in Fig. 1. Unfortunately, this additional information decreases the particles clusters separation and does not appear to provide a more precise classification scheme than just using the elemental composition of the particles. The second part of the study considers the EDS spectra alone.

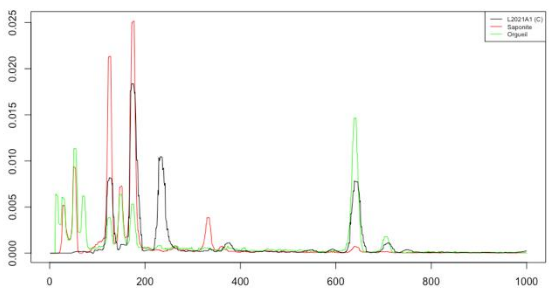

Figure 4: Superposition of 3 different types of EDS spectra: C-type IDP L2021A1 (black), saponite (red), and Orgueil meteorite fragment (green)

Comparison of IDPs with terrestrial materials and meteorites: In order to improve the nonlinear projection classification from Fig. 1, we complemented the database of EDS spectra from the cosmic dust catalog with those of 11 terrestrial minerals of interest (enstatite, troilite, fayalite, forsterite, saponite, etc.) and 132 meteorite analyses from carbonaceous and ordinary chondrites (e.g. Allende, Orgueil). The spectra were processed with denoising, baseline removal and scaling so that all spectra are comparable as illustrated in Fig. 4.

We recalculated a new nonlinear Sammon's projection based on this improved database. This map is shown in Fig. 5. Several observations can be made from this projection:

1- The meteorites appear to insert themselves as a consistent cluster located at the transition between the main C-type IDPs cluster and the TCN-TCA clusters.
2- The cosmic IDPs and meteoritic samples are well separated indicating a detectable difference in major elements composition between the two samples
3- The pure minerals spread along the side of the projection as endmembers of interest for some of the directions given by the map.

The distribution of meteorites samples and pure minerals in the projection appears linked around the position of the IDPs. This can allow us to identify endmembers amongst the IDPs and define more precisely their clusters.

Conclusion: Systematics of interplanetary dust particles are notoriously difficult to interpret. In this study, we point out that we can further the automated classification of IDPs presented in [1] with spectra from meteorites and minerals. The new projection indicates significant separation between IDPs and meteorites samples, confirming the fact that IDPs represent a different population of extra-terrestrial material than meteorites from asteroids. Further analysis of the respective clustering may allow us to link the IDPs classification and their origin.

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References: [1] Love, S. G., & Brownlee, D. E. Science, 262, 550-550 (1993) [2] Brownlee, D. E. AREPS, 13(1), 147-173 (1985) [3] Rietmeijer, F. J. M. in Planetary materials (ed: J. J. Papike), Chap 2, p. 2-01 - 2-96 (1998) [4] Lasue, J. et al. MAPS, 45(5), 783-797, (2010) [5] Krestina, N., Petaev, M.I. and Jacobsen, S.B., LPSC 2011, #2615. [6] de Melo, R. C. (2007). Using fractal characteristics such as fractal dimension, lacunarity and succolarity to characterize texture patterns on images. *PhD*.

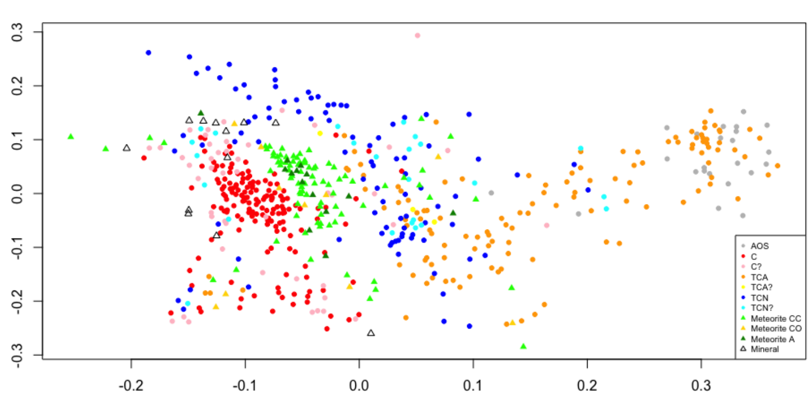

Figure 5: Nonlinear Sammon's projection of cosmic dust catalog 15 with added mineral and meteorite data. Colors correspond to the JSC preliminary classification labels and spectra of meteorites and minerals