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Geological modeling of the layered lobes of 67P/Churyumov-Gerasimenko: using bootstrap for model uncertainty assessment and hypothesis testing

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During the two-year Rosetta space mission a countless number of high-resolution images of comet 67P were produced by the imaging system OSIRIS, onboard the spacecraft. One of the most unexpected discoveries was that the two lobes of comet 67P are independently layered in an onion-like fashion (1). The layering can be observed on the surface thanks to presence of morphological terraces parallel to linear features, mostly visible on cliffs. At that stage of the mission only images of the Northern hemisphere were available and geological cross sections were produced to represent the inner layering of the two lobes. Since this first analysis many efforts have been made to provide a comprehensive three-dimensional geological model of the layers, unified for both the Northern and the Southern hemispheres of the body.

Thanks to an extremely detailed 3d mesh model of the surface (2) produced by stereophotogrammetry methods, it was possible to generate a large dataset of bedding attitude measurements, by estimating the average orientation of terraces. Due to the presence of dusty deposits and the faint nature of the linear features associated with the layering it was instead not possible to identify key horizons or to clearly discern different geological units, to explicitly constraint the stratigraphy. The attitude of the layers were then used to fit a 3D implicit model, representing each layer as a set of concentric ellipsoidal shells (3). We were able to derive a simplified model representing the onion-like structure of layers by using just 8 physical parameters (three for the center of the ellipsoidal layers, 2 for the axial ratios controlling the sphericity of the model and 3 to represent the orientation in space).

To provide accurate estimates of the error associated with the geological model, of fundamental importance for any derived parameters (e.g. the total volume of the layered body) we made use of a Monte-Carlo-based bootstrap approach (4), which rely on the randomized draw of observations, intended to mimic the effects of new hypothetical observation collection campaigns. At each iteration a new fit of the model was obtained, thus providing thousands of equally-valid geological models. From the distribution of the parameters defining the models, we then obtained accurate estimates of the most likely solution, together with standard errors for the parameters. We furthermore show how this same technique can be employed for testing alternative hypothesis: it was in fact speculated that terraces might not be representative of an inner layering but instead they could be aligned to the average surface. To test this hypothesis we repeated the same process by randomly picking points on the comet surface and then we used the local orientation as an hypothetical bedding plane observation. Thanks to the parameters distributions we were able to show that this second hypothesis is extremely unlikely, and should be indeed rejected.