Organic Matter in Space
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Solid organics in cometary comae

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Abstract. It is known since long ago that in comets a large quantity of organic matter exists in form of grains or is embedded in silicate grains. This was detected in situ by cometary space missions as well as inferred as a distributed source of some molecules observed in comets. Since organic matter is rather volatile, finding slow sublimating grains in comets can be good evidence of organics as a constituent of such grains. Here we describe a method to detect sublimating grains in comets. It consists of specific observations, specific data analysis, and some light-scattering modeling. We detect sublimating grains by measuring the quantity of grains as a function of the nucleocentric distance. Once detected, it is possible to get their photometric characteristics and compare them with the results of light-scattering modeling. The method has been applied to several comets. Sublimating grains were reliably identified for two of them.

Keywords. Astrobiology, comets: general, methods: data analysis

1. Introduction

Comets may have played an important role in depositing the organic matter that, between 4.6 to 3.6 billion years ago, allowed the formation of life on the primordial Earth. Radio and near-IR observations have detected many complex organic molecules in the gaseous component of comet atmospheres (for a review, see Bockelée-Morvan *et al.* 2005). However, a large quantity of organic matter may be preserved in cometary solids in the form of organic grains or organics embedded in silicate grains. The Giotto mission to Comet 1P/Halley provided the first evidence of the presence of organic grains in the coma. It was evaluated that they accounted for almost 50% of the mass of the solid component present in the coma of comet Halley (see, e.g., Fomenkova 1999). Remote detection of solid organics is very difficult since their spectroscopic signatures are hidden in more prominent spectroscopic features of other components of cometary dust and since they usually rapidly sublimate under solar radiation. However, the presence of organic matter in solid form has been inferred in several comets indirectly as a distributed source of gas in comae. It has been observed that in some comets the spatial profiles of some molecules cannot be fitted assuming that they are produced directly from the nucleus. Such a distributed source, which cannot be just a more complex parent molecule, is likely constituted by organic grains. For example, Cottin *et al.* (2004) suggested that the distributed source of Formaldehyde observed in comet C/1995 O1 (Hale-Bopp) could be a polymer: Polyexymethylene. Here we describe another method that not only provides a non-spectroscopic remote search for organic solids in coma, but also allows one to figure out their properties.

2. Method & Results

Our method assumes that organics in the grains contain some semivolatile matter, i.e., the grains sublimate under the solar radiation with lifetimes variable from a few hours to tens of hours. By measuring the total cross section of the grains, it is possible then to evaluate, from its change with time, the possible presence of sublimating grains. In the case of a cometary outburst, this can be made by measuring the cross section of the grains in the coma as a function of time. Usually this is difficult to perform because the time elapsed between the onset of the outburst and the first observation is too long and most of the organic grains have already sublimated. However, the method is perfectly applicable to *man-made* outbursts, such as that produced by the *Deep Impact* mission. In case of regular comets, the presence of sublimating grains can be checked by measuring their cross section as a function of the projected nucleocentric distance (ρ), since the grains move away from the nucleus with a constant velocity. Although we integrate along the line of sight, i.e., include different nucleocentric distances, the grains at the corresponding projected distance provide the most significant contribution to the integral because their density is changing as ρ^{-2}. Our method uses the so called ΣAf function, that is Albedo multiplied by the total area covered by the grains in an annulus of radius ρ and unitary depth. For a regular, "quiet" comet, i.e., with constant outflow velocity of the grains and no changes in the production rate, in the absence of fragmentation and/or sublimation this function is constant with ρ. Grain sublimation or the onset of an outburst will be seen as an increase of the function at small nucleocentric distances. To disentangle between the two phenomena it is necessary to repeat the observations about 24 hours later. In the case of an outburst, which is a time dependent phenomenon, the nucleocentric profile of ΣAf will change. In the case of sublimation, the profile will be independent of time. Once the sublimating component is detected, it is possible to figure out its characteristics by measuring ΣAf at ρ=0 and then study the scale length of its change. If the measurements are made with narrowband filters in the visible or/and the near-IR (i.e., in the spectral region where the emission mechanism is the scattering of solar radiation), it is possible to find the scattering efficiency of this sublimating component as a function of the wavelength. Comparison of these efficiencies with the ones computed with some light-scattering model (e.g., Kolokolova *et al.* 2007), allows one to obtain the optical constants of the sublimating component, and hence information on its composition. Several comets have already been observed and analyzed with this method. Some did not show any presence of sublimating components, while others were too active to permit this kind of analysis (C/1995 O1 (Hale-Bopp), C/2001 Q4 (NEAT), 73P/S-W3). However, two of the observed comets, C/1999 WM1 and 9P/Tempel 1, allowed a positive detection of sublimating grains (Tozzi *et al.* 2004, 2007). For the latter comet, the target of the *Deep Impact* mission, a sublimating component was detected pre-impact as well as in the impact cloud.

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