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Organic grains in Cometary Coma

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Abstract. It is known since long ago that a large quantity of organic matter in comets 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 a 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, a 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 the light-scattering modeling. The method has been applied to several comets. For two of them, sublimating grains were reliably identified.

Key words. Comets, Organic grains, sublimation

1. Introduction

Comets may have played an important role in depositing the organic matter that, between 4,6 to 3,6 billion of years ago, allowed the formation of life on the primordial Earth. Radio and near-IR observations allowed discovering many complex organic molecules in the gaseous component of comet atmospheres (see for a review Bockelée-Morvan et al, (2005)). However, a large quantity of organic matter may be preserved in cometary solids in 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 (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 the solar radiation. However, the presence of organic matter in the 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; they have to be produced by a distributed source in the coma. Such a source, which cannot be just a more complex parent molecule, is likely constituted by organic grains. It was

Send offprint requests to: G. P. Tozzi shown by Greenberg and Li (1998) that some simple molecules in comet comae like CO, C_2, C_3, CN, H_2CO appeared to be distributed in such a way that they could be neither directly emitted from the nucleus nor created as daughter molecules from more complex gas phase species. Thus, the only remaining possible source is the organic component in comet dust. Also, recently, Cottin et al, (2004) have suggested that the distributed source of Formaldehyde observed in comet C/1995 O_1 (Hale-Bopp) could be the Polyoxymethylene, a Formaldehyde polymer with the chemical formula -(-O-CH_2-)$_n$-. It exists only in solid form and, thus, can be present in comets only as grains or embedded in dust grains.

Here we describe a method that not only provides non-spectroscopic remote search for organic solids in coma, but also allows to figure out their properties.

2. Method

Our method assumes that the organics in the grains contains some semi-volatile matter, i.e. the grains sublimate under the solar radiation with lifetimes variable from few hours to dozens of hours. By measuring the total cross section of the grains in the coma, it is possible then to evaluate, from its change with time, the presence of sublimating grains. In a case of a cometary outburst, like that of comet 17P/Holmes (Buzzi et al, 2007), 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 the *man-made* outbursts, as that produced by the *Deep Impact* mission (A'Hearn et al, 2005)

In case of regular, low-active, 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 main, most significant, contribution to the integral because their density is changing as ρ^{-2}. Our method uses the so called ΣAf function (Tozzi et al, 2004), that is derived from the comet images and it is the geometrical albedo (A) multiplied by the total area covered by the grains in an annulus of radius ρ and unitary depth ($2\pi\rho f(\rho)$). For a regular, "quiet" comet, i.e. with constant outflow velocity of the grains and no changes in the production rate and 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. As shown in figure 1, in the case of an outburst, which is a time dependent phenomenon, the nucleocentric profile of ΣAf changes. In the case of sublimation, the profile will be independent of time. If the measurements are made with filters in the visible or/and in the near-IR (i.e. in the spectral regions where we observe the light produced by the scattering of solar radiation by the grains), it is possible to find out scattering efficiency of this sublimating component as a function of the wavelength. Since in the visible spectral region the emission of the gaseous component of the coma is not negligible, the images in this region have to be taken with narrow band filters, with the central wavelength centered in the regions where the gas emissions are absent.

The ΣAf profiles that show a presence of sublimating grains, as that in figure 1, right panel, can be fitted with two functions: one is constant and represents the refractory grains, and the other one is exponential, it is for the sublimating grains. From the last one we can get the projected scalelength and the values of ΣAf at ρ=0. These values, as a function of the central wavelength of the corresponding filter, give the scattering efficiency of the sublimating component. The comparison of these efficiencies with the ones computed with some light-scattering model (Kolokolova et al, 2007), allows to obtain the optical constants of the sub-

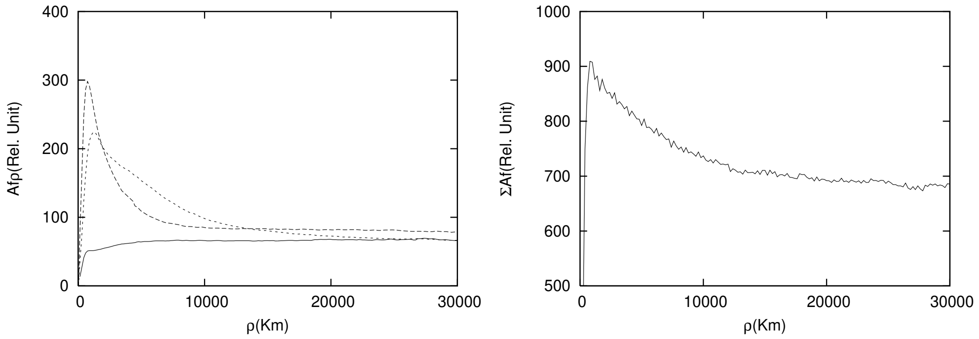

Fig. 1. Example of ΣAf profiles produced by an outburst (left panel) and by sublimating grains (right panel). The profiles corresponding to the outburst was measured in comet C/1999 S4 just before its complete disruption (Tozzi and Licandro, 2007) during three consecutive nights. The profile of the first night (full line) was almost constant, with a slight indication of a decrease of dust production. The profile of the second night (dashed line) show a sharp increase in the inner part, that is surely due to an outburst, because it is different from that of the previous night. The outburst nature is confirmed by the profile of the third night (dotted line), where it is possible to notice the expansion of the dust shell. On the other hand, the profile produced by the sublimating component is stable with time, as indicated in the right panel where the pre-impact observations of comet 9P/Tempel 1 (Tozzi at al, 2007) are presented. Here, for clarity, only one profile has been reported.

limating component, and, hence, information on its composition.

3. Results

Several comets have been already observed and analyzed with this method. Some of them did not show any presence of sublimating components, others (C/1999 S_4 (LINEAR), C/1995 O_1 (Hale-Bopp), C/2001 Q_4 (NEAT), 73P/Schwassmann-Wachmann 3) were too active to permit this kind of analysis. Positive detections of sublimating grains have been for two comets: C/1999 WM_1 (LINEAR) (Tozzi et al, 2004), where two sublimating components were found, and 9P/Tempel 1 (Tozzi at al, 2007). For the latter one, the target of the *Deep Impact* mission, a sublimating component was detected pre-impact as well as in the post-impact ejecta cloud. The sublimating grains detected pre-impact had characteristics different from that found in C/1999 WM_1: for Tempel 1 they were highly transparent in the visible, whereas for WM_1 both the components scattered in the visible as well as in the near-IR. Also, their lifetimes at 1AU, computed assuming a r_h^2 dependence (with r_h the heliocentric distance) and an outflow velocity of 0.2 km/s, where pretty different: about 5 hours in Tempel 1; 17 and 1.3 hours for the two components in the WM_1.

4. Conclusion

The method described here allows the detection of organic grains and gives hints on their composition. However it is necessary to refine that method. For example, the observations need to be done with more narrow band filters or with an integral-view spectrograph, in order to have a better wavelength sampling for a more firm identification of the sublimating components. Many other issues remain unresolved: why the sublimating components have been detected in two comets only (which, by the way, have different dynamical origin: WM_1 originated from the Oort cloud while Tempel 1 is a well known Jupiter family comet originated from the Edgewort-Kuiper belt)? What is the mechanism of sublimation of those grains? - Is it directly produced by photons (scalelength going as r_h^2) or through the heating (scalelength dependent on r_h and grains size)? And, of course, the main question: what is the nature of the sublimating grains and how much organic matter in comets is in the solid state?

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