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Organic Solids in Comets: the examples of C/2000 WM_1 (LINEAR) and C/2001 Q_4 (NEAT)

G. P. Tozzi[1] and M. Delbò[2]

[1]Istituto Nazionale di Astrofisica – Osservatorio Astrofisico di Arcetri,
Largo E. Fermi 5, I-50125 Firenze, Italy
e-mail: tozzi@arcetri.astro.it
[2]Istituto Nazionale di Astrofisica – Osservatorio Astronomico di Torino,
Strada Osservatorio 20, I-10025 Pino Torinese, Italy
e-mail: delbo@to.astro.it

Abstract. According to the latest models, the primordial Earth atmosphere was mainly composed by Carbon Dioxide, Nitrogen and Water Vapor, *i.e.* it was very poor in reducing components. With such a composition the spontaneous formation of the first organics elements necessary to the formation of life seems very unlikely. On the contrary, extraterrestrial contribution of carbon and organic material by comets and asteroids seems the most probable mechanism. Complex organic molecules are nowadays "routinely" detected in bright comets by remote observations in the near-IR (3.5 μm region) and in the radio (sub-mm region). However, according to the results of mass spectrometer onboard of fly-by missions to Halley's comet, a large amount (50% of the mass of the solid component) of organic material is under the form of solid or embedded in dust particles. This material is very difficult to be detected by remote observations because usually it shows only wide spectroscopic bands that are blended with dust emission. In this paper we will describe a method developed by our group with the aim of studying the solid components in the coma of comets with a special attention to the organic solids. We give here the results for two comets observed and analyzed with this method.

Key words. Comets: solid organics – dust – nucleus

1. Introduction

One of most important questions we may ask is how the life started. Earth formed about 4.6 billions of years ago and, as revealed by geological studies of rocks, just 1 billion years afterward it was already full of micro-organic life. How inanimate organic matter was transformed in life is still a mystery. We know that essential elements for life formation were liquid water and complex organic molecules based on carbon, like amino acids and sugars. The Urey-Miller is a famous experiment showing how amino acids could be spontaneously formed by electrical discharge in a strongly reducing atmosphere, composed by ammonia, methane, hydrogen and water vapor. However,

Send offprint requests to: G.P. Tozzi

the latest models have shown that the primordial Earth atmosphere was pretty inert, formed mainly by water vapor, carbon dioxide and nitrogen. With such an atmosphere the spontaneous formation of complex organic molecules was almost impossible.

Analysis of carbonaceous chondrite meteorites, originating from the most pristine asteroids, have shown that many amino acids and sugars should be present in the extraterrestrial environment. Famous is the Murchison meteorite, found just after its fall in Australia in 1969. Analyzes of this meteorite have shown that about 50 amino acids are present in its interiors. Terrestrial contaminations can be excluded, not only because of its sudden recovery, but also because some of the amino acids detected are not naturally present on the Earth and because some others show right hand chirality, while terrestrial amino acids have only left hand chirality.

On the present Earth the fall of extraterrestrial organic matters is still going on, being the meteors from comets the almost exclusive contributors. It is evaluated that every years a total of 330 tons of organic matter is deposited on Earth surface by the meteors (Gilmour & Sephton 2004). On the other hands on the Earth, just after its formation, there has been a tremendous comet bombardment that brought 10^{16}–10^{18} kg of organic matter in 100 million of years. This was due to the comets that were formed in the giant planet region and that, shortly afterward, were scattered everywhere in the solar system falling on all the planets. The surviving comets today are in a stable zone at 40000-50000 AU from the Sun, the Oort cloud, which is the reservoir of long period comets.

Complex organic molecules are nowadays "routinely" detected in comets by remote observations. New instrumentation's and the fortunate passage of a very bright comet, the Hale-Bopp, has allowed the detection of numerous new molecules (Bockelée-Morvan et al. 2005). Most of those molecules are released directly from the nucleus. They are usually detected by means of their resonant scattering of the solar radiation either in the near-IR region (3.5 μm), by their ro-vibrational transitions, and, in the sub-mm radio region (only for those with permanent dipole momentum), by their rotational transitions.

However there are indications that a large part of organic matter may be under the form of solid. The mass spectrometers onboard of fly-by missions to the Halley comet detected a large amount of organic grains in the inner coma, that has been evaluated to be as large as 50% of the mass of the whole solid component (Fomenkova 1999). The spatial profiles of some of the organic molecules indicate that they cannot come directly from the nucleus, but from a distributed source that may be organic grains or organic matter embedded in dust.

The detection of the organic solids by remote observation is very difficult because they rapidly sublimate, *i.e.* they are confined in a small region close to the nucleus, and because they do not show sharp spectroscopic lines, but only wide spectral features, difficult to identify. For example, the polyoxymethylene has been proposed as distributed source of the formaldehyde (Cottin et al. 2004). With laboratory experiment they showed that the lifetime of this solid organic is of the order of some hours. Unfortunately the polyoxymethylene shows spectroscopic features that are very similar to those of silicates, *i.e.* difficult to detect spectroscopically.

2. Our method

To study the solid components of cometary comae, with particular attention to short sublimating components, we developed a method that consists of a observative technique, data analysis and a model fitting procedures.

The observative method consists of multi-wavelength, quasi-simultaneous observations of comets that have close approach to the Earth (< 0.5 AU) to have the maximum spatial resolution. For example at 0.5 AU of geocentric distance, 1″ corresponds to about 360 km. The covered spectral regions should be in the visible, near-IR and, possibly, thermal IR. Spectra, narrow band images and, possibly, polarimetric maps should be recorded in each region. The narrow band images are required not only to avoid saturation for bright comets, but also to record just the scattering of the solid component, avoiding the gas contamination (important in the visible region). With all these observations we can have a large amount of information on the solid components allowing us to derive their nature. For example, by comparing narrow bands images recorded in the thermal infrared we can derive the temperature of the grains in the coma. And by comparing the emission map in the near-IR region with the temperature ones we can derive also an albedo map of the grains in the coma.

The data analysis of the images is made in order to enhance possible sublimating components in the inner coma. It uses the so called ΣAf (Tozzi et al. 2004), that is the albedo (A) multiplied by the total area covered by the solid component in a annulus of radius ρ and unitary depth. This function is proportional to the average column density of the solid component at the projected cometocentric distance ρ. At first approximation, in the case of outflow at constant velocity (as is the case of the solid components of the coma, out of the so-called collision zone), without sublimations and/or fragmentation, the function ΣAf is constant with ρ. Asymmetries, like jets, fans, do not change the function, as long as the production rate of the solid components does not change. Non constant functions may indicate variation of activity, easily detected if the observations are repeated several hours later, and/or grain sublimation and/or fragmentation.

Finally the scattering properties (mainly color and polarimetry) of the solid components are compared with those computed by a radiation scattering model (Kolokolova et al. 2001) using optical constants measured in laboratory for various possible material. Spherical particles with a power law size distribution are usually assumed. With a trial and error method the best agreement between measured and computed properties is searched.

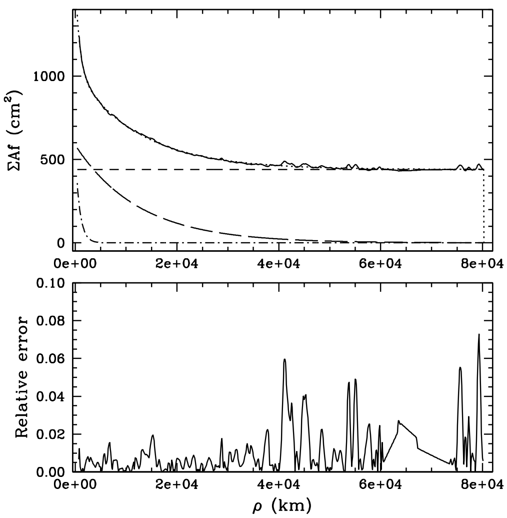

Fig. 1. Upper panel: ΣAf function of LINEAR WM_1 (I band) and fitted components. The continuous line represents the measured function; the dotted line, almost coincident with the continuous line, is computed by the fitting procedure. Dashed, dot-dashed and long-dashed lines are the refractory, the long and short scalelengths component, respectively. Lower panel gives the relative error. Usually it is less than 1-2%. Higher values are due to field stars.

3. Results

3.1. Comet C/2000 WM_1 (LINEAR)

Comet C/2000 WM_1 (LINEAR), hereafter LINEAR WM_1 was observed at ESO (La Silla) on December 2001, when it was at its closest approach with the Earth (0.32 AU). Details of observations and some results have been already published (Lara et al. 2002; Tozzi et al. 2002; Lara et al. 2004; Tozzi et al. 2004). The comet was observed with three telescopes: the 1.5Danish, equipped with EFOSC, was used for the visible spectral range, the NTT, equipped with SOFI, for the near-IR range, and the 3.6m, equipped with TIMMI2, for the thermal IR range. The observations were originally planned to cover three half nights, but bad weather conditions and technical problems allowed us to have some good data in the near-IR

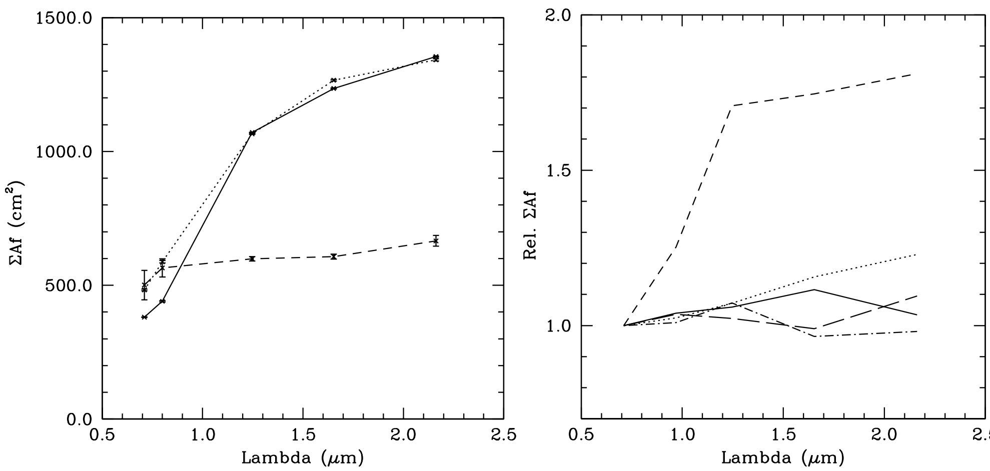

Fig. 2. Left: Measured ΣAf for the three solid components in R, I, J, H, K. Solid line is for the refractory component, dotted and dashed lines are respectively for the long and short lifetime sublimating components. Right: Spectral trend of various organic materials: full, dotted, dashed, long dashed, dot-dashed lines are for water ice, laboratory organics, EURECA organics, tholin and kerogen, respectively (see text)

and in the visible only for a little more than half night.

In spite of the "quietness" of this comet the presence of two sublimating components was detected in its inner coma, as it can be checked by the exponential behavior of the ΣAf function shown in Fig. 1. The lifetimes of the two sublimating components, assuming an outflow velocity equal to 0.2 km/s, is of the order of 1.3h and 17h for the short and long lifetimes, respectively. By comparing the ΣAf functions of the three components (two sublimating plus the refractory ones) measured with different filters it is possible to measure the color of the sublimating components and of the refractory one, as shown in Fig. 2 left panel. By using the optical constants of various materials, assuming a power law size distribution of the form $n(r) \propto r^{-a}$, we found that the best agreement was obtained with a = 2.75 and, for the short-lifetime component using laboratory organics (Jenniskens 1993), and, for the long-lifetime component, using the EURECA organics (Fig. 2, right panel). The difference between these two organic materials is that the laboratory organics by Jenniskens, the so-called "first generation" organics, are produced by irradiation of a mixture of gases (H_2O, CO, CH_4, NH_3) in the laboratory, whereas the EURECA organics, the "second generation" ones, result from exposing the laboratory-created residues to the solar ultraviolet irradiation on the EURECA satellite for 6 months (Li & Greenberg 1997). Thus, the EURECA organics represent more processed organics, already having experienced the solar irradiation that could make them less volatile. This may explain why the observed dust component that has a spectral trend similar to the EURECA organics has a longer lifetime than the organics that have a spectral trend more typical of less processed, laboratory organics.

3.2. Comet C/2001 Q_4 (NEAT)

Comet C/2001 Q_4 (NEAT), hereafter NEAT Q_4, was observed for three half nights at ESO La Silla on May 2004 at its closest approach to the Earth. Geocentric and heliocentric distances were 0.32 AU and 0.97 AU respectively. The observations were performed with 3.6m telescope equipped with TIMMI2, for the thermal IR region, and NTT, equipped alternatively with SOFI and EMMI, for the near-IR and vis-

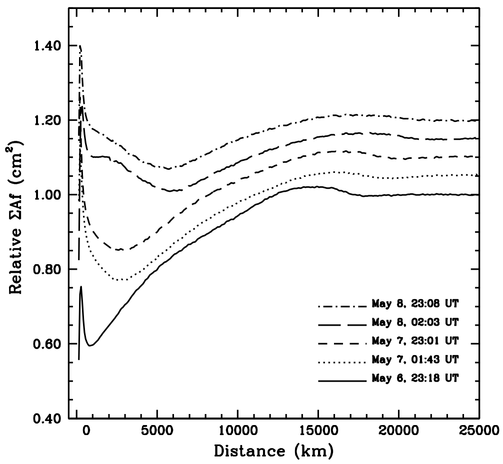

Fig. 3. ΣAf functions as measured with the narrow band filter at 1.08μm during the three nights of observations. Date of observations are indicated on the figure. The values are relative and shifted with respect to each other by 0.05 along Yaxis, for clarity. Comet showed a strong activity with variation of Q_{dust} by a factor 1.7 in few hours! Note the peak always present for $\rho < 200$ km.

ible regions, respectively. Unfortunately, the observations in the visible and in the near-IR could not be performed simultaneously, but in sequence because we had to switch from one focal plane instrument to the other. Since the comet was bright (V≈3) and gas emissions were present in the visible, we used narrow band filters with pass-bands centered in region of only dust emission.

The observations were very good for all the three half nights, with seeing of the order of 0.6-1″, good transparency and very low atmospheric thermal emission.

Data analysis of the observations have shown that the comet was pretty active, with recursive outbursts with period of the order of 21 hours. The activity can be clearly seen on the ΣAf profiles of Fig 3. Starting with the observations at 23:18 UT on May 6 (bottom), it is possible to note that the function at $\rho < 12000$ km is much lower with respect to that at larger nucleocentric distances. This is because the dust production rate at the observations time should have been lower than that of some hours before. Then the profiles of the observations taken 2:25 hours after show a strong increases in the inner part, indicating a rise of dust production rate Q_{dust} of about 70%. During the following nigths the profiles became more flat because of the increase of dust production. The images continued to show a lot of jets and fans. Preliminary analysis of these jets and shells indicate a periodicity of the activity with a period of about 21h. Unfortunately this large change in activity of the comet does not allow us to make a direct comparison of inner coma images in the visible and near-IR, to derive, for example, the color map. Indeed, due to the instrument switching, the elapsed time between the near-IR and the visible observations is always more than 1 hour. Since the measured expansion projected velocities are of the order of 0.12–0.35 km/s, in one hour the shell would move by 430-1260 km. For the same reason the presence of sublimating components analogous to those found in LINEAR WM_1 is also difficult to detect. However, as can be noticed in Fig. 3, a sharp increase of the ΣAf function for $\rho < 200$ km is always present in all the observations. To isolate these peaks, to the ΣAf function was subtracted its fitting, made with a polynomial function in the region between 200 and 6000 km. The resulting functions give just the peaks, that we tried to fit with a exponential function of ρ. The results were good and gave an average scalelength of 150 km, corresponding to 0.64″, that unfortunately it is just the value of the seeing. That means that the peak is seeing limited, or in other words, the dimensions of the "thing" that gives this peak are lower than the seeing of the observations. The average of integral of the ΣAf peaks, *i.e.*the covered area multiplied the albedo A is of the order of 4.4 km^2. What is the origin of this peak? A very short lifetime sublimating component? Possibly, but we do not have any way to check it. If it is that, its lifetime should be shorter than 12 minutes, assuming an outflow velocity of 0.2 km/s. A cloud of large dust grain surrounding the nucleus? Also possible. The nucleus itself? It would be the first time a nucleus is detected in an active comet. Assuming an albedo of 0.04 the projected surface of the nucleus would be 110 km^2, corresponding to a diameter of the order of 12 km. This is a little greater than the 5-10 km estimate from observations of the comet at large distance (Tozzi et al. 2003), but it is a value plausible. A more detailed analysis has to be done to check the nature of the peak.

4. Conclusion

Solid organic matter has been detected by remote observations in comet LINEAR WM1 while in comet NEAT Q4 has been found "something" with scalength < 150km. The nature of this last is still unclear, but if it is a sublimating component it should have a lifetime shorter than 12min, *i.e.* it should be very different from the sublimating components found in LINEAR WM_1. To understand if solid organics are present in most of the comets further observations of bright comets with close approach to the Earth have to be done.

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