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DUST AND GAS JETS. EVIDENCE FOR A DIFFUSE SOURCE IN HALLEY'S COMA

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ABSTRACT

The distribution of dust-scattered intensity in Halley's inner coma is measured with the Vega three-channel spectrometer at three selected wavelengths : 377, 482 and 607 nm. The variation along a cometo-centric radius may be described by a p^{-s} law where p is the distance between nucleus and optical axis and s is an exponent which is equal to 1 except in an intermediate 3000 $<p<$ 7000 km region where s = 1.5. The shape of the radial distribution may be explained with a model including solar radiation pressure effect and quantum scattering efficiencies calculated from Mie theory. Monochromatic images inside an angular sector having its apex at the nucleus show evidence of two dust jets which extend to 40000 Km. The pixel-to-pixel ratio of two images of dust intensity at 377 and 482 nm shows that the scattered intensity presents an excess of blue coloration in a zone located around the jets between 10000 and 25000 km. This coloration is interpreted as being due to a population of sub-micronic grains which results of the fragmentation of dust particles transported in the jets. It is suggested that the diffuse source where an additional quantity of CO was detected might be connected with the presence of a dust jet. In present scheme, grain particles with a size of several µm or 10 µm would be transported inside a dust jet to distances of several 10 000 km where they would suffer fragmentation and produce sub-micronic particles and a release of gas which would be at the origin of the diffuse source.

INTRODUCTION

The video cameras of Giotto (Keller et al., 1986) and Vega (Sagdeev et al., 1986) have clearly demonstrated the existence of jets originating from the nucleus. The field of view of these close-up images is of the order of 100 km. Images obtained at a greater scale, from the ground, show the presence of gas jets (A'Hearn et al., 1986), but do not give evidence of dust jets (Cosmovici et al., 1987). In order to know what is the source of the emissive molecules of the gas jets, it is of importance to evaluate at what distance the dust jets can extend.

A second type of measurement has introduced a new insight into the coma. It is the detection by the NMS instrument of Giotto (Eberhardt et al., 1987) of a diffuse source of CO located as far as 10 000 to 15 000 km from the nucleus. The detection of H_2CO in comets Austin and Levy (Crovisier, 1991; Schloerb and Weiguo 1991) has led to a confirmation of this concept of extended source.

RADIAL DISTRIBUTION

The data used here are the spectra transmitted by the Vega 2 three-channel spectrometer during the approach and encounter session on March 9, 1986.The scanning capability of the instrument allows to explore an angular sector of the inner coma having its apex at the nucleus and a radial extent of 40000 km. Monochromatic images in the major emissions, OH, NH, CN, C_3 and C_2 can be assembled and compared (Clairemidi et al., 1990,a,b). In the case of dust-scattered intensity, three spectral windows are selected in the blue-near-UV at 377 nm, the visible at 482 nm and the red at 607 nm, where the contribution of molecular emissions are minimum.

The radial distribution of dust intensity is plotted in Fig. 1. For each wavelength, two radial profiles are plotted, along a radius where no jet is present (labelled "valley") and along a radius which follows a jet pattern (labelled "jet"). Both profiles show the degree of anisotropy of the coma at distances of several 10000 km. The overall shape of the curves may be described by a p^{-s} law where p is the distance from the nucleus to the optical axis and s an exponent. The exponent value measured in Fig. 1 is $s \cong 1$ for $p<3000$ km and $p>7000$ km and $s \cong 1.5$ in the intermediate 3000 - 7000 km region.

In order to analyse the main features of the measured radial profile, a dust fountain model was elaborated. It includes the effects of gravitation and radiation pressure of solar origin. The treatment of particle trajectory is conducted as explained by Massonne (1985). The mass distributions of particles at cometocentric distances >8100 km are derived from Mazets et al., (1987). At distances <8100 km, the mass distribution is not known for the time of observation. The data of Mazets were extrapolated and a parameter was introduced to adjust the particle population in the small mass decades 10^{-16}-10^{-12} g. The Mie scattering quantum efficiency, Q_{sca} is calculated in using the method of Eaton (1984). The complex index is taken as n = 1.387 - 0.031 i which is the value recommended by Mukai et al. (1987)

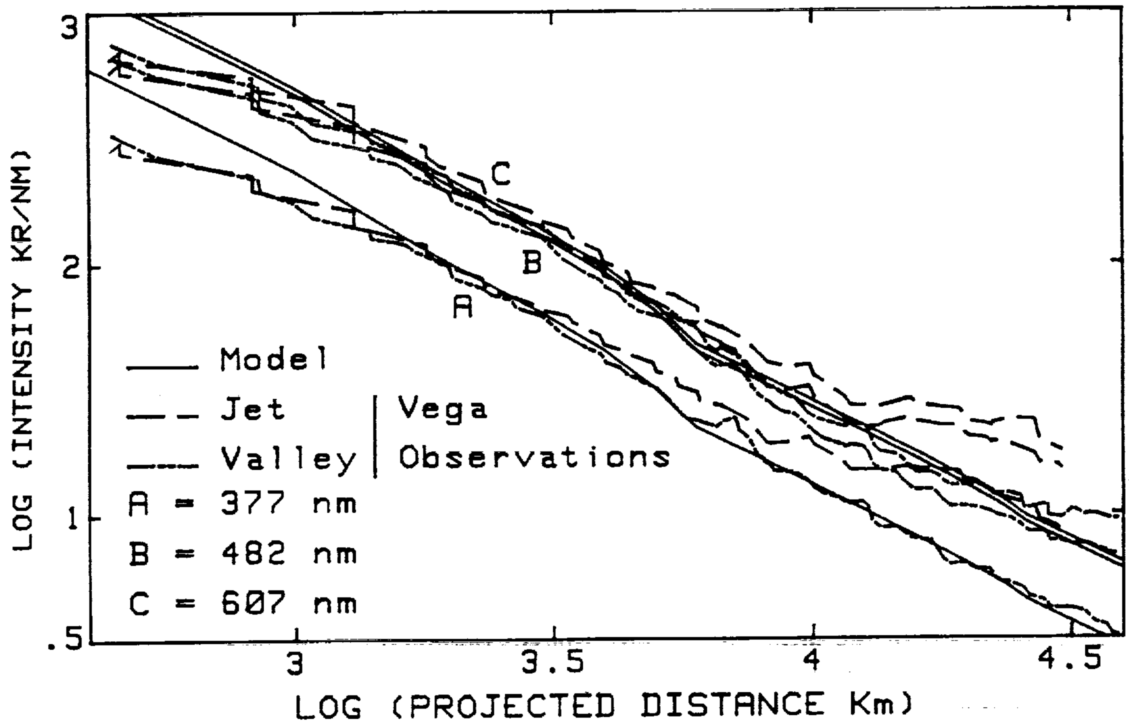

Fig. 1 Radial profiles of dust-scattered intensity measured during the Vega 2 encounter session and compared with the results of a simple model based on Mie theory for spheres and the mass distribution function of particles for r>8100 km given by Mazets et al., (1987). The intensity profiles are compared at three selected wavelengths: 377 nm (A), 482 nm (B) and 607 nm (C). For each wavelength, three profiles are drawn: as calculated with the model (full line), as measured in the main jet (dashed line) and as measured in the valley (dotted-dashed line).

The results, given in Fig 1, show a good quantitative agreement with the measured intensities. The change in the slope value between 4000 and 6000 km is due to the reflexion of small particles in the 10^{-14}-10^{-12} g range under the effect of radiation pressure. At distances p<1000 km, the calculated intensity is higher than the measured value because the model, in its present version, does not take into account the actual relative rotation motion of the optical axis around the nucleus during the close encounter period.

The computed intensity, expressed in photon units, is :

$$I(p,\lambda) = \int_{z1}^{\infty} \int_{m1}^{m2} n'_m(z).\Pi a^2.Q_{sca}(a,\lambda).\Phi(\phi).F_0(\lambda).dm.dz$$

where: z is a coordinate measured along the optical axis, m is the dust particle mass, $n'_m(z)$ is the dust particle density per mass unit, a is the particle radius, $\Phi(\phi)$ is the phase function; ϕ : phase angle for dust, $F_0(\lambda)$ is the solar flux of photons per surface unit and time unit.

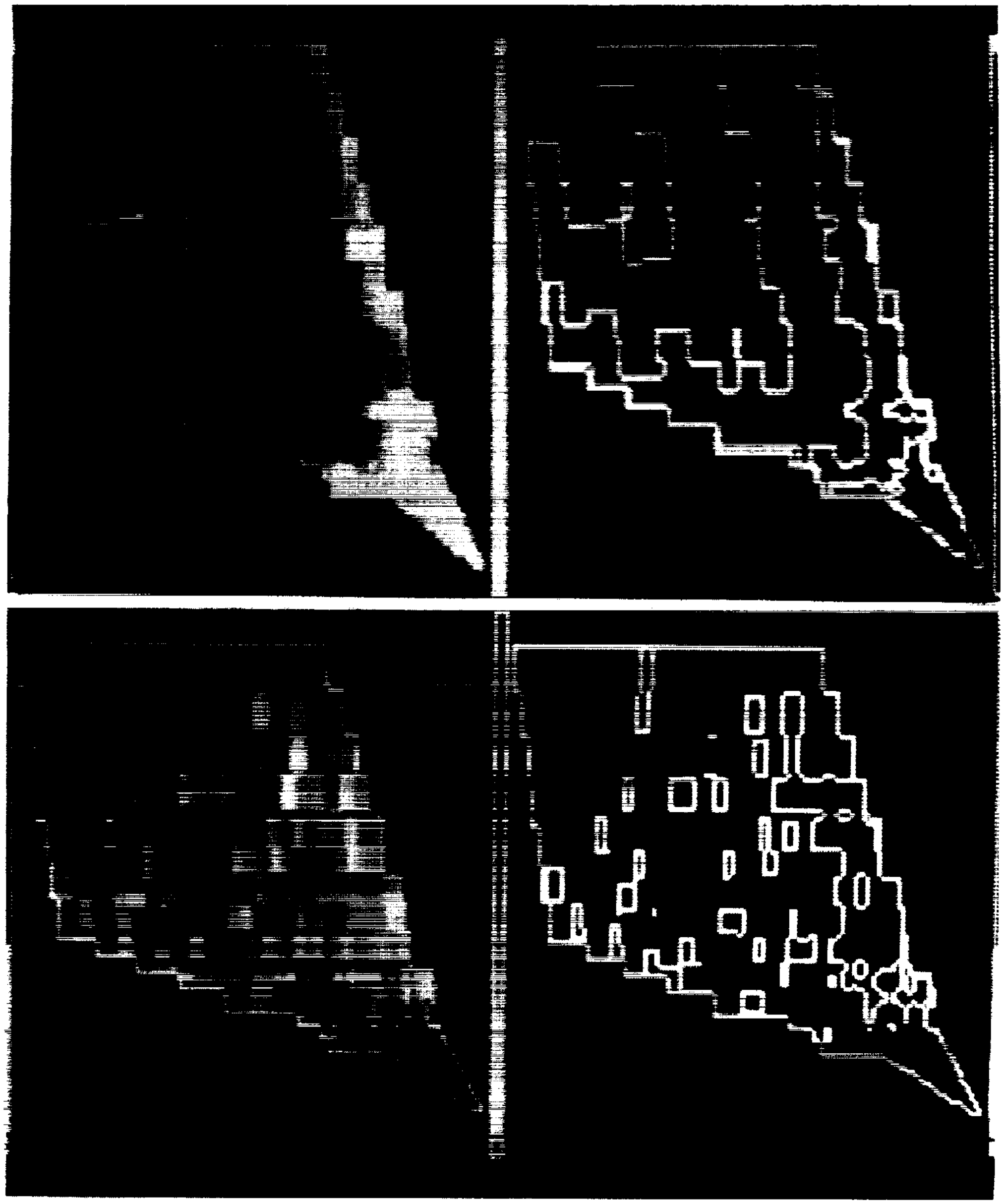

Fig 2a, upper left: intensity plot; Fig 2b, upper right: intensity contour plots
Composite monochromatic image of dust-scattered intensity at 482 nm. The nucleus is located at the apex, on the lower right. The radial extent of the field of view is 40000 km. The Sun is located on the left.

Fig 2c, lower left: radiation color plot; Fig 2d, lower right: color contour plots
Pixel-to-pixel ratio of two images of dust-scattered intensities at 377 nm and 482 nm. This composite image shows that the visible jets in Fig 2a,b present a slight blue coloration in the 10000-25000 km range.

The calculation is based upon the assumption that the cometary dust particles are spherical and homogeneous, which is far from reality when considering particles with a size of several μm or 10 μm. However, it shows that the high value of the exponent s measured in the 4000-7000 km region implies that, on the basis of the fountain model, a population of small sub-micronic grains exists in the inner coma.

SPATIAL EXTENT OF DUST IN THE INNER COMA

The radial profiles presented in Fig. 1 may be completed with a bi-dimensional representation of the scattered intensity inside the field of view scanned by the spectrometer. A composite image of this type, which depicts the intensity at 482 nm is given in Fig. 2a,b. Two jets appear in this monochromatic image: a weaker one, on the left, in the direction of the Sun and a stronger one, in a perpendicular direction. As a result, the distribution of dust at distances of 10000 to 40000 km from the nucleus appears as strongly anisotropic. As shown in Fig. 1, the intensity inside the jets is two times more intense than inside the valley (between the jets).

PRODUCTION OF AN EXTENDED SOURCE BY DUST JETS

The spatial distribution of dust particles may be visualized at different wavelengths, in the near-UV at 377 nm and the red at 607 nm. A pixel-to-pixel ratio of the images at $\lambda_1 = 377$ and $\lambda_2 = 482$ nm is presented in Fig. 2c,d. A slight excess of blue coloration, of the order of 25% in intensity, is apparent in the 10000-25000 km region, closely correlated with the presence of jets. This coloration is interpreted as being due to the existence of a population of sub-micronic grains located in the vicinity of the jets. The calculation of the ratio of the quantum efficiencies at two wavelengths, $Q_{sca}(\lambda_1) / Q_{sca}(\lambda_2)$ based upon Mie theory shows that a small excess of tiny grains with $a < 0.8$ μm can produce a slight coloration of the scattered radiation. In present case, we calculated that the observed coloration may be reproduced if one assumes that a fraction of 10^{-7}-10^{-6} of the dust particles present at 20000 km undergoes fragmentation and produces small grains of mass 10^{-15}-10^{-13} g. This results from the fact that the optical scattering efficiency of a given mass of dust particles is roughly inversely proportional to the average radius of the particles.

In an attempt to explain the dust-scattered radiation measurements in the inner coma, it is necessary to introduce a fragmentation mechanism which produces sub-micronic particles. The existence of dust jets and the slight coloration observed in the vicinity of the jets give serious arguments supporting the following process : dust jets originating from fissures at the nucleus surface and extending to several 10000 km. A small fraction of the dust particles would suffer fragmentation after having been heated for several hours starting from their ejection from the nucleus. During this process, they would release gas components such as the CO molecules which were found to form, during the Giotto encounter (Eberhardt et al., 1987), an extended source around 10000 km.

CONCLUSION

The spatial distribution of dust-scattered intensity in the inner coma shows the existence of two well-contrasted dust jets inside the field of view of the spectrometer. A model based on Mie theory and the particle measurements of Mazets et al., (1987) shows that the slight coloration observed in the jets between 10000 and 25000 km may be explained by a population of sub-micronic particles of mass 10^{-15}-10^{-13} g. It is proposed that this population of very small grains results from the fragmentation of the dust particles inside the jet and that the gas released during this process constitutes the diffuse source measured in CO in comet Halley and in H_2CO in comet Levy.

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