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INTERPRETATION OF THE MEASUREMENTS OF SECONDARY ELECTRON CURRENTS INDUCED BY IMPACTS DURING THE FLYBY OF COMET HALLEY

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ABSTRACT

The Giotto, Vega-1 and Vega-2 spacecraft flew through the environment of comet Halley at a relatively close range with velocities of the order of 70-80 km/s. The fore sections of their surface were bombarded by neutral molecules and dust grains which caused the emission of secondary electrons and sputtered ions. This paper makes use of the secondary electron current measurements performed on Vega-1 to infer some characteristic features of the cometary atmosphere. The total gas production rate is estimated to be of the order of 10^{30} molecules/s and is found to vary with time; the presence of a major jet is also detected at closest approach.

INTRODUCTION

The interaction between the surface of a spacecraft and its environment during a cometary flyby has been the subject of many workshops and publications prior to the encounters with comet Halley /1 to 7/. It had therefore been decided to monitor this phenomenon by measuring the electron emission induced by gas and dust impacts on identical reference electrodes integrated on the Giotto, Vega-1 and Vega-2 spacecraft /8/; complementary information about secondary emission has also been derived from other plasma analysers /9/.

The preliminary results obtained with the Vega-1 and Vega-2 detectors have already been presented elsewhere /10/; the Giotto instrument has returned no data for reasons which still remain unexplained. The topic of this paper is to give a more thorough interpretation of the measurements performed during the flyby of Vega-1. A particular emphasis is placed on secondary electron emission caused by the impact of neutral molecules with the aim to contribute to a better understanding of the cometary gas environment.

THE MEASUREMENTS

The sensor is planar and gold plated; the central target, a disk of area $A_o = 1$ cm^2, and its electric guard ring are biased at a constant negative potential of -17V with respect to the surrounding ground; the sensor is connected to the electronic circuitry by means of a coaxial cable (Fig. 1). The sampling interval and the integration time of the measurements are respectively 1s and 2s /8/.

The saturation current measured with this instrument is the sum of the contributions of the different charged species which are either emitted or collected:

$$i = i_g + i_d + i_{ph} + i_{ia} + i_{is}, \qquad (1)$$

where i_g is the current of secondary electrons extracted from the target by the continuous flow of incoming gas molecules; i_d is associated with the emission of discrete electron bursts which are caused by dust particle impacts; i_{ph} is the photoelectron current; i_{ia} and i_{is}, respectively, are the currents of ions which either have a cometary origin or have been sputtered from the spacecraft surface by the flow of gas and dust.

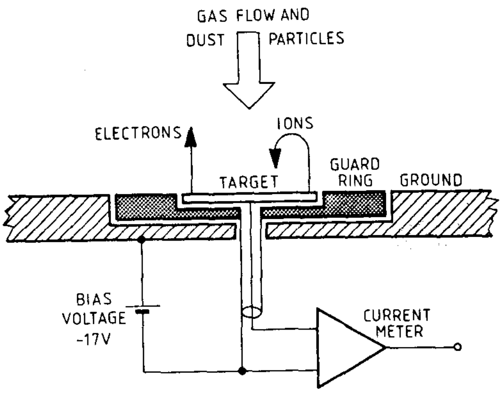

Fig. 1. A simplified diagram of the sensor and the electronics.

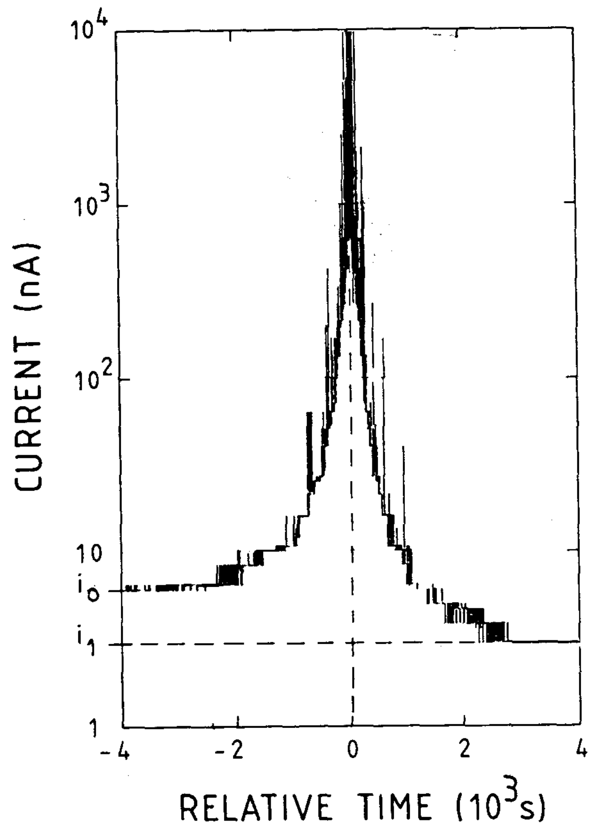

Fig. 2. The electron current emitted by the target during the Vega-1 flyby on 6 March 1986; the closest approach occurred at 07.20.06 UT, at a distance of 8889 km.

The cometary ion thermal velocity is of the order of 3-5 km/s /5/, much less than V, the relative velocity of the spacecraft (70-80 km/s), so that the ambient ion current collected by the probe can be written

$$i_{ia} = n_{ia}VAe, \tag{2}$$

where n_{ia} is the cometary ion density, A the target area and e the elementary charge. The gas impact current is given by

$$i_g = n_gVAYe, \tag{3}$$

where the electron yield, Y, lies in the range 0.1-0.4/11,12,13/ and n_g, the neutral gas density if about three orders of magnitude larger than n_{ia} /9,14/. It follows that

$$i_{ia} \ll i_g. \tag{4}$$

It is found experimentally, in addition, that the sputtered ion current collected by a Langmuir probe mounted at a distance of 1m from the solar panels is negligible with respect to the photoelectron current /15/. The impact plasma monitor is mounted closer to the spacecraft body, but it is fitted with an electric guard which prevents the collection of sputtered ions; we shall therefore tentatively assume that

$$i_{is} \ll i_{ph}. \tag{5}$$

Taking into account the relations (4) and (5), it is seen that equation (1) can be approximated by

$$i = i_g + i_d + i_{ph} \tag{6}$$

The current measured on Vega-1 is shown in Fig. 2.

THE EFFECTIVE AREA OF THE TARGET

The saturation current given by equation (6) reduces to i_{ph} at large distances from the nucleus where the dust and gas impact effects are negligible and it stays constant as long as the attitude of the spacecraft with respect to the sun is unchanged. It is observed on Fig. 2, however, that the photoelectron current after flyby, i_1, is substantially less than its level before flyby, i_0, this phenomenon is also observed on Vega-2.

If the photoelectron current density is considered to be constant, then this feature can be explained by a diminution of the effective target area, either by erosion or contamination, from A_0 to A_1 during the flyby, so that

$$i_{ph}/A = i_0/A_0 = i_1/A_1, \quad (7)$$

where A is the area at time t:

$$A = A_0 + \int_{-\infty}^{t}(dA/d\tau)d\tau\ , \quad (8)$$

and τ is an integration variable.

We make the hypothesis that the rate of reduction of the area is proportional to the flow of matter (gas and dust) which impacts the target:

$$dA/dt = KAf, \quad (9)$$

where f is the incoming flux of matter and K is a negative constant:

$$K = dA/(Afdt) = \int_{-\infty}^{\infty}(dA/d\tau)d\tau \Big/ \int_{-\infty}^{\infty}Afd\tau \quad (10)$$

Integrating the numerator of equation (10) and combining with equations (8) and (9) yields

$$A = A_0-(A_0-A_1)\int_{-\infty}^{t} Afd\tau \Big/ \int_{-\infty}^{\infty}Afd\tau \quad (11)$$

If we assume in addition that the flux of matter is in first approximation proportional to the sum of the gas and dust impact currents i_g+i_d, equation (11) combined with equations (6) and (7) becomes

$$A = A_0-(A_0-A_1)\int_{-\infty}^{t}(i-i_0A/A_0)d\tau \Big/ \int_{-\infty}^{\infty}(i-i_0A/A_0)d\tau\ . \quad (12)$$

This integral is solved numerically and the time variation of the target area from $A_0 = 1$ cm^2 to $A_1 \simeq 0.5$ cm^2 is shown in Fig. 3. It is seen that 90% of the area reduction occurs within an interval of 400 s centered around the time of closest approach.

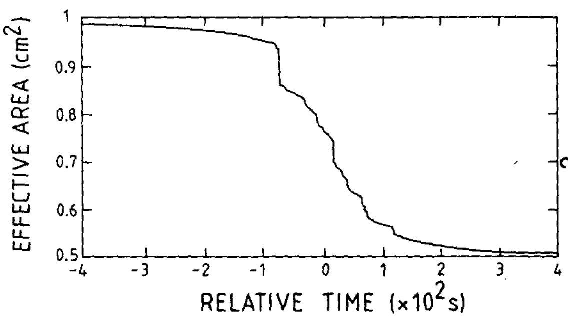

Fig. 3. Decrease of the target effective area indicating a progressive erosion and/or contamination of the surface by gas and dust impacts during the flyby.

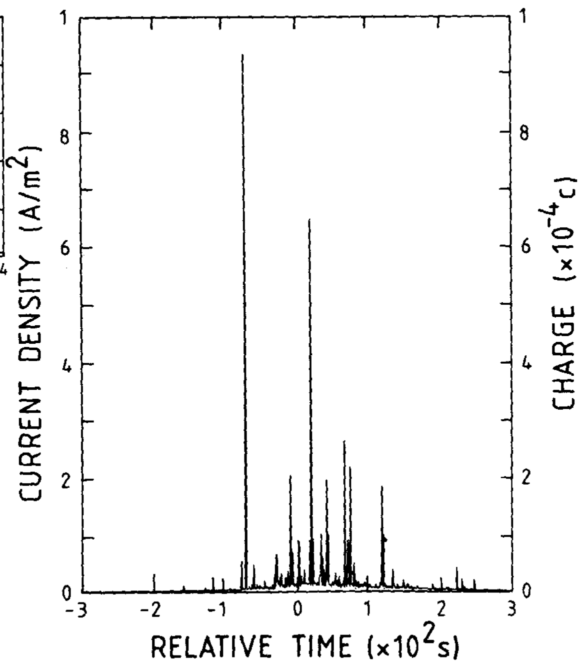

Fig. 4. Current density (left scale) or electric charge released during an interval of 1s from an area of 1 cm^2 (right scale) associated with gas and dust impacts.

DUST AND GAS IMPACT CURRENTS

The electron emission phenomena associated with gas and dust impacts are illustrated in Fig. 4. The left ordinate axis gives a linear scale for the current density,

$$j_e = (i_g+i_d)/A, \quad (13)$$

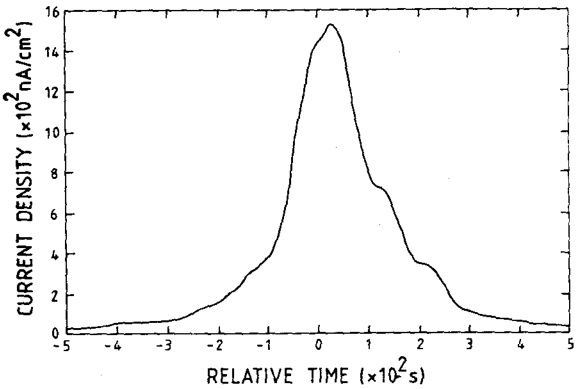

Fig. 5. Current density due to the emission of secondary electrons induced by incoming gas molecules after taking out the dust impact contribution.

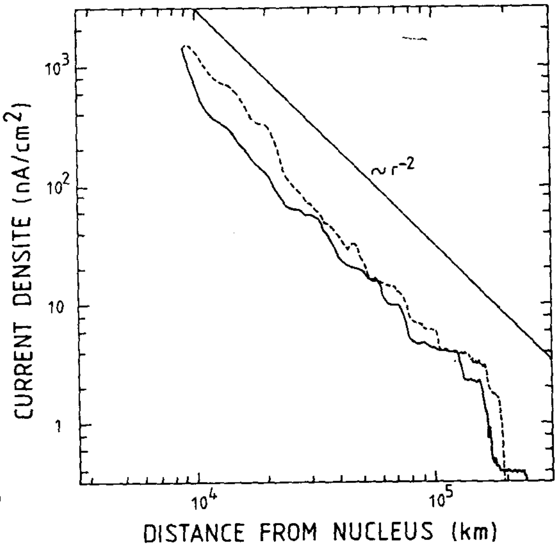

Fig. 6. The electron current density induced by molecule impacts against the distance from the nucleus during the approach (full line) and exit (dashed line) of Vega-1.

which may be used for the evaluation of the continuous background emission of secondary electrons due to gas molecules. The right ordinate axis is graduated in coulombs and gives the electric charge

$$q_e = j_e A_o t_o \tag{14}$$

emitted from a reference surface $A_o = 1\ cm^2$ during the sampling interval t_o 1s; this axis is more appropriate for reading the net negative charge extracted from the target at each dust impact. The contribution of the gas to the total electron current density

$$j_g = i_g/A \tag{15}$$

has been enlarged in Fig. 5 where the spikes caused by dust particles have been taken out. The same current density is plotted in Fig. 6 against the distance from the nucleus, r ; the current density profiles during approach and exit can be compared with the reference slope r^{-2}.

THE GAS PRODUCTION RATE

Assuming an isotropic model the gas production rate from the nucleus can be written

$$Q = 4\pi r^2 n_g v_g \tag{16}$$

where v_g, the velocity of the gas molecules, is about 900 m/s /9/. Combining equations (3), (15) and (16) yields

$$Q = (4\pi r^2 v_g j_g)/(VYe), \tag{17}$$

where V = 79.2 km/s for Vega-1 and Y is tentatively taken equal to 0.3. The gas production rate, which can be written

$$Q = 2.97 \times 10^{18} j_g r^2 \tag{18}$$

is plotted in Fig. 7. This parameter displays a peak near the point of closest approach which coincides with the time of occurrence of a dust jet detected by another experiment on board Vega-1 /9/. Otherwise, the average gas production rate appears to increase steadily during the flyby with relative time t measured in s according to the law

$$Q \simeq 1.5 \times 10^{30}(1 + 2 \times 10^{-4}t)\ \text{(molecules/s)}. \tag{19}$$

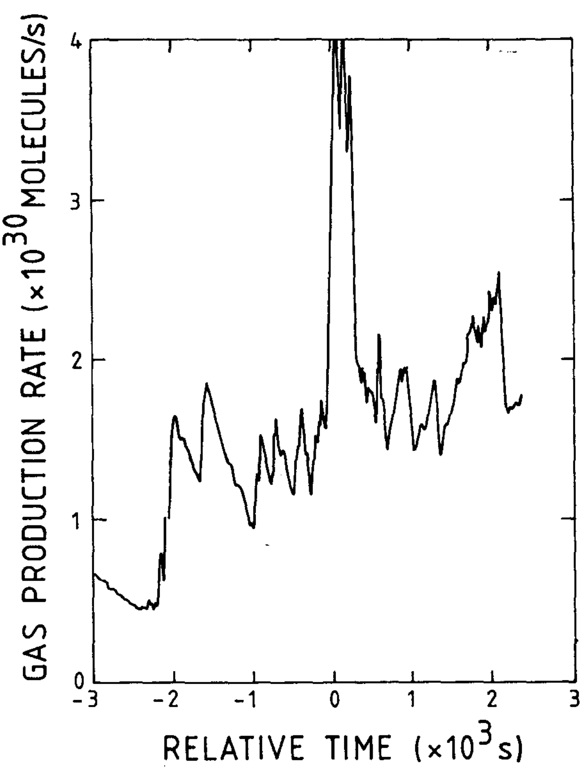

Fig. 7. The evolution of the gas production rate of the nucleus assuming an isotropic model.

CONCLUSION

A gold plated target exposed to the flow of gas and dust was probably damaged over 50% of its effective area during the flyby of Vega-1 through the environment of comet Halley. The measurement of the electron current emitted from this probe gives information about dust impact rates and neutral gas flow. A yield of 0.3 for secondary emission seems reasonable, it lies within the range of predictions based on laboratory measurements and leads to cometary neutral densities which are consistent with those independently derived by other experiments. The Vega-1 results show that the gas density encountered on the outbound leg of the trajectory is larger than that seen during the approach. This phenomenon may be caused by an increase of the nucleus gas production rate; it may also simply reflect the fact that the spacecraft passes the point of closest approach before crossing the cometary solar meridian plane.

A sharp increase of up to 100% is seen in the apparent gas production rate; this phenomenon begins near closest approach and lasts for about 300 s. This feature is most likely associated with a jet which is simultaneously observed by an instrument detecting dust particles in the range of masses larger than 1.5×10^{-13}g /9/.

The investigation of these results shall be continued in order to perform an analysis of the dust impacts and to compare the Vega-1 and Vega-2 measurements.

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