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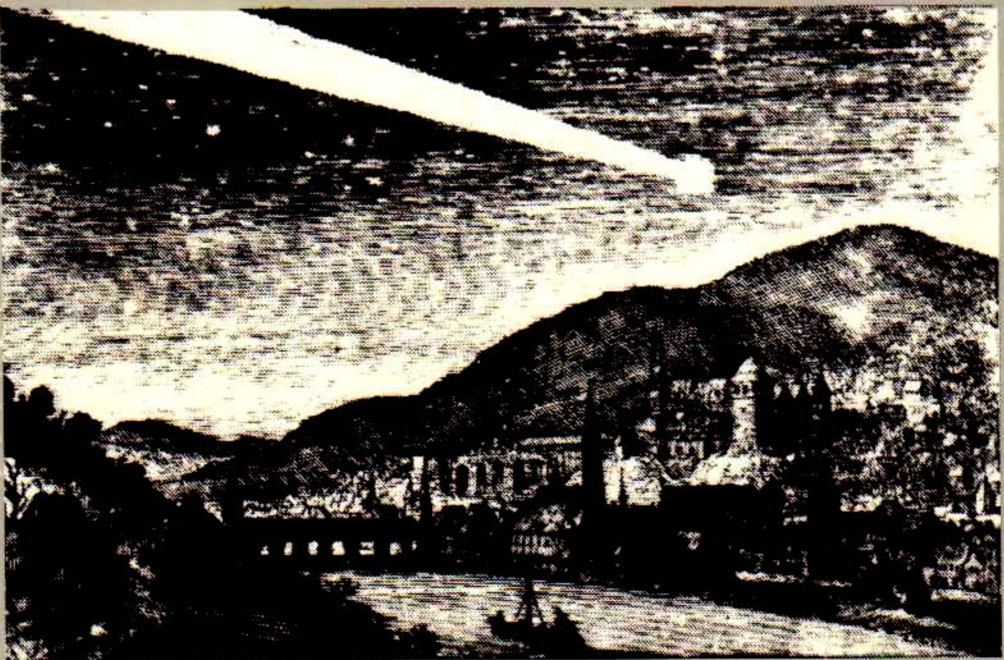
20th ESLAB SYMPOSIUM on the EXPLORATION OF HALLEY'S COMET



Comet over Heidelberg in 1618 A.D.; copper engraving by Matthäus Merian

Proceedings of the
International Symposium
Heidelberg, Germany
27—31 October 1986

esa
european space agency

Volume 1:
Plasma & Gas

esa SP-250
December 1986

20th ESLAB SYMPOSIUM on the EXPLORATION OF HALLEY'S COMET

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Organised jointly by

- Space Science Department of ESA, ESTEC, Noordwijk, The Netherlands
- Max-Planck-Institut für Kernphysik, Heidelberg, W. Germany

Sponsored by

- Inter-Agency Consultative Group (IACG)
- International Halley Watch (IHW)

Co-sponsored by

- Committee on Space Research (COSPAR)
- International Astronomical Union (IAU)

european space agency / agence spatiale européenne

8-10, rue Mario-Nikis, 75738 PARIS 15, France

Proceedings published and distributed by	ESA Publications Division ESTEC, Noordwijk, The Netherlands
Edited by	B. Battrick, E.J. Rolfe & R. Reinhard
Price	Dutch Fl. 175 (3 volumes)
ISSN	0379 6566

MEASUREMENTS OF NEUTRAL PARTICLE DENSITY IN THE VICINITY OF COMET HALLEY BY PLASMAG-1 ON BOARD VEGA-1 AND VEGA-2

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ABSTRACT

The PLASMAG-1 plasma instrument package included two Faraday cups. One was oriented along the spacecraft-comet relative velocity vector and detected secondary electrons and ions produced by neutrals striking a metallic emitter. The results of these measurements performed on VEGA-1 and -2 are discussed, and the density profiles of neutral particles in the coma of comet Halley out to cometocentric distances of 3×10^6 km are presented.

Keywords: VEGA, cometary neutral gas

1. INTRODUCTION

In the PLASMAG-1 instrument package on board both spacecraft VEGA-1 and VEGA-2 a Ram Faraday Cup was used to measure the neutral gas density in the vicinity of Comet Halley (Refs. 1-3). The results obtained by VEGA-1 on its inbound leg were published earlier (Refs. 4,5). This work presents a more detailed description of the observational method and additional data measured on board VEGA-2 and on the outbound leg of VEGA-1.

2. OBSERVATIONAL METHOD

Figure 1 shows the schematics of the Ram Faraday Cup (RFC), one sensor of the PLASMAG-1 instrument package to measure the density distribution of the cometary neutral gas along the trajectory of both spacecraft VEGA-1 and VEGA-2. This sensor is different from the Faraday cups traditionally used on space probes. In order to avoid the damage of the grid by cometary dust, the analyzing grid system was substituted by a flat disc electrode system G_1–G_6. There were 19 holes on each disc and the diameter of the holes were increasing towards the collector C.

When neutral particle fluxes were measured, the voltages -40 V and +3500 V were applied to the electrodes G_2 and G_4 (Figure 1), respectively. Photo- and secondary electrons of the surrounding plasma with energies $E_e \lesssim 40$ eV, and cometary and solar wind ions of energies $E_i \lesssim 3500$ eV were thereby diverted from the collector by these potentials.

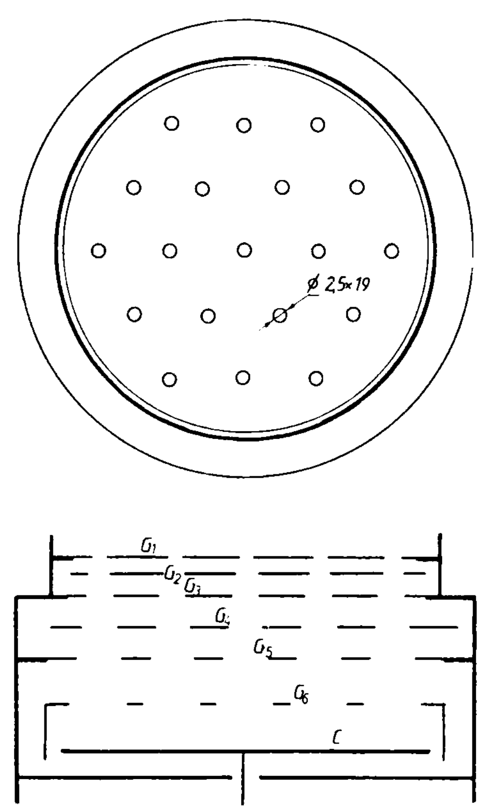

Figure 1. Schematics of the PLASMAG-1 Ram Faraday Cup (RFC) for measuring the neutral gas distribution in the vicinity of Halley's comet.

In this way the collector current I_c of the RFC is given by the following terms in the vicinity of the comet:

$$I_c \approx I_{se} - I_{si} + I_{ph} - I_e \qquad (1)$$

where I_{se} and I_{si} are the secondary electron and ion currents, which are proportional to the flow of neutral particles (the individual short bursts in I_c are associated with the registration of dust particles), I_{ph} is the photoelectron current, and I_e is the current of energetic electrons reaching the collector. In order to register I_{se} and I_{si} separately, a potential of +40 V and -60V was applied to the electrode G_6, respectively. In the first case, when the current of secondary electrons is measured, I_{si} is suppressed and I_c is determined by I_{se}, I_{ph} and I_e, i.e.

$$I_{ce} \approx I_{se} + I_{ph} - I_e \qquad (2)$$

In the second case, when the current of secondary ions is registered, I_{se} is suppressed, I_{ph} decreases significantly and changes its sign (now this current is not produced by photoelectrons originating from the collector, but by the photoelectrons originating from the electrode G_6), and the current I_e slightly decreases since in this case only the electrons with energy E_e >60 eV can reach the collector. Thus,

$$I_{ci} \approx - I_{si} - I_{ph} - I_e \qquad (3)$$

In this work the following equation was used to determine the neutral gas density on the basis of the measured $I_{ce,i}$ values

$$n_n = \frac{I_{ce,i} - I_o}{q\ V\ S\ Y_{e,i}} \qquad (4)$$

Here I_o is the sum of currents I_{ph} and I_e, q is the electron charge, V = 79.2 km/sec (76.8 km/sec) is the velocity of VEGA-1 (VEGA-2) relative to the comet, S = 0.93 cm^2 is the total surface of the holes of the sensor (see Fig. 1) and $Y_{e,i}$ is the yield of secondary electrons and ions provided by neutral particles impacting the collector. In general, I_o in equation 4 is not a constant, as it will depend on time and on the distance from the nucleus. However, for the estimation of n_n we assumed I_o = constant and used the value as measured by RFC at large distances from the comet where $I_{se,i} \approx 0$.

3. OBSERVATIONS

Figure 2 presents the current of secondary electrons measured by both VEGA-1 and VEGA-2 as a function of cometocentric distance. The increase in I_{ce} caused by the increase of n_n while approaching the comet began at a distance of about $3x10^6$ km from the nucleus. This distance significantly exceeds the distance at which all the other instruments performing direct neutral gas measurements in the vicinity of Halley's comet first detected cometary neutrals.

The plasma impact detector (PID), which was part of the PLASMAG-1 instrument package (built by SSD/ESA) and which in principle was similar to the RFC, began observing an increase in I_{ce} at cometocentric distances r $\lesssim 2x10^5$ km (Ref. 6).

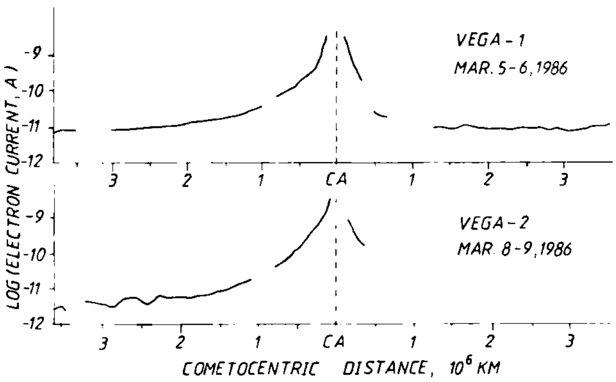

Figure 2. Results of measurements by the RFC on both VEGA-1 and VEGA-2 in the operation mode when secondary electrons are detected at distances smaller than ~ 3 x 10^6 km from the nucleus before and after closest approach (CA).

However, the sensitivity of PID is by two orders of magnitude smaller than the sensitivity of RFC since its background current level is $I_o \approx 6x10^{-9}$ A compared to $I_o \lesssim 10^{-11}$ A of the RFC. This higher level of background current in case of PID is due to the fact that its collector is exposed directly to solar wind ions and UV radiation, while the collector of RFC can be reached only by scattered UV radiation and by ions with energies E_i > 3500 eV. The neutral mass spectrometer (NMS) on board of GIOTTO, which is a significantly more complicated instrument than RFC and PID, began detecting neutral gas at distances $\approx 4 \times 10^4$ km from the nucleus (Ref. 7). The lower sensitivity of this instrument is determined by the relatively small efficiency of the ionization of neutrals by the electron source inside this device.

For cometocentric distances of r $\lesssim 1.5x10^5$ km the collector current I_{ce} of the RFC sensor is exceeding the upper limit of the range of the instrument for measuring secondary electron currents (see Fig. 2). But approximately at the same distance the current I_{ci} is increasing in the operation mode of measuring secondary ions on both VEGA-1 and VEGA-2 as presented in Fig. 3. For cometocentric distances of r $\lesssim 1.5x10^4$ km also this current is exceeding the upper limit of the range of the RFC sensor in this operation mode (see Fig. 3). On the basis of these two operation modes of the RFC sensor it is possible to determine the distribution of n_n along the trajectories of VEGA-1 and VEGA-2 for cometocentric distances 1.5 x 10^4 km < r $\lesssim 3x10^6$ km.

Figure 4 and 5 show the dependence of neutral gas density on cometocentric distance determined by equation 4 from the $I_{ce,i}$ currents presented in Figures 2 and 3. For comparison, in both Figures 4 and 5 the thick solid line represents the dependence

$$n_n (r) = n_o (r_o /r)^2 \exp (-r/\lambda) \qquad (5)$$

with $n_o \approx 10^4$ cm^{-3}, $r_o \approx 10^5$ km, and $\lambda \approx 2x10^6$ km. When calculating n_n from the results of the I_{ce} measurements for $r \gtrsim 10^5$ km, it was assumed that the yield of secondary electrons is $Y_e \approx 0.3$. For VEGA-1 $I_o \approx 8.5 \times 10^{-12}$ A and for VEGA-2 $I_o \approx 2.8x10^{-12}$ A was used (compare the values in Fig. 2).

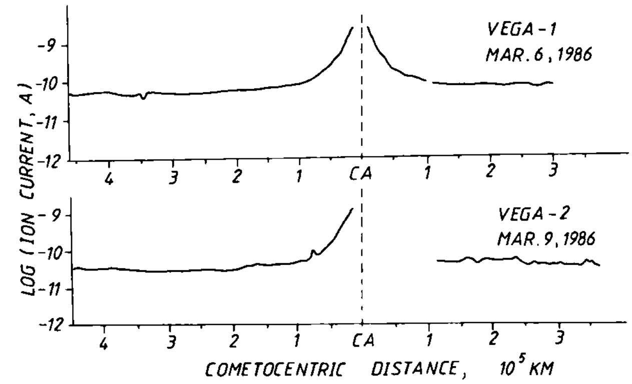

Figure 3. Results of measurements by the RFC on both VEGA-1 and VEGA-2 in the operation mode when secondary ions are detected at distances smaller than $\sim 4.5x10^5$ km from the nucleus before and after closest approach (CA).

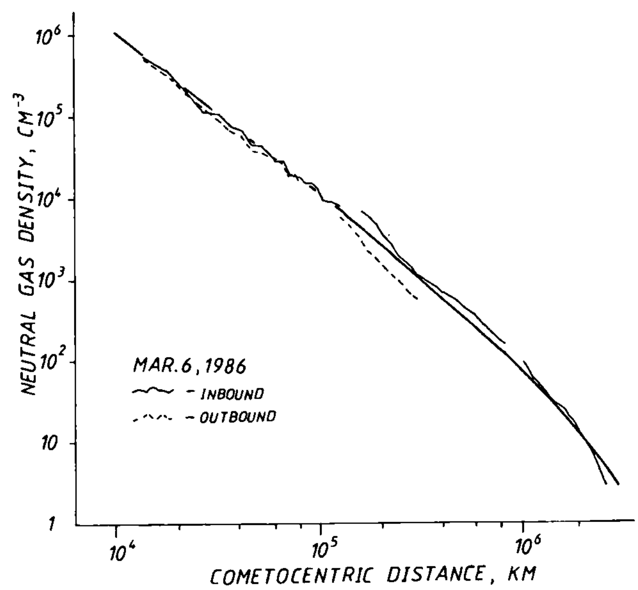

Figure 4 Cometocentric density profiles for neutral particles estimated from the data measured by the RFC on board VEGA-1. The thick solid line shows the approximated dependence of $n_n(r) \sim r^{-2} \exp(-r/\lambda)$

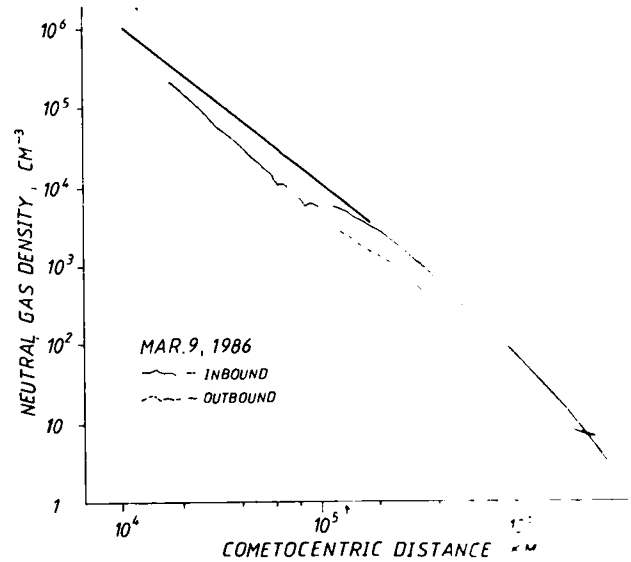

Figure 5 The same density profiles as in Fig. 4 from the data measured by the RFC on board VEGA-2

For the calculation of n_n from the measurements of I_{ci} ($r < 10^5$ km) the yield of secondary ions was taken as $Y_i = 0.005$ and the value of I_o was adjusted in such a way that the results for n_n determined from both operation modes could be fitted together, i.e. $I_o = 3.2x10^{-11}$ A for VEGA-1 and $I_o = 1.5x10^{-11}$ A for VEGA-2.

3. DISCUSSION

From the data presented in Figures 4 and 5, it readily follows that the values of n_n estimated from the measurements of the RFC on board both VEGA-1 and VEGA-2 are quite close (within an accuracy of a factor of 2) to the simplest theoretical model described by equation 5 (Ref. 8), assuming that there is a radial outflow of neutral molecules with a constant velocity V and with a limited life time of λ/V. With the help of this model it is possible to estimate the gas production rate of Halley's comet $Q = 4\pi V n_o r_o^2 \approx 1.3 \times 10^{30}$ sec^{-1} for $V \approx 1$ km/sec (Refs. 4,5).

In some regions, however, the measured value for n_n systematically deviates from this $r^{-2} \exp(-r/\lambda)$ dependence. For example, on the inbound leg of VEGA-2, the estimated n_n values were 2 times smaller than for VEGA-1 at distances 1.5×10^4 km $< r < 10^5$ km, although the n_n values estimated from the data of both spacecrafts are significantly closer to each other further away from the nucleus. Moreover, the values of n_n estimated from the I_{ce} measurements on the outbound leg of both VEGA-1 and VEGA-2 at distances $1.5x10^5$ km $< r < 3 \times 10^5$ km are about 2 times smaller than the corresponding n_n values on the inbound leg (see Figures 4 and 5).

These and other deviations might be caused by jets of neutral gas originating from the rotating nucleus. Besides the solar UV radiation scattered by the comet may have some influence on the instrument performance and also the solar radiation pressure can influence the asymmetry of the neutral gas distribution along the spacecraft trajectory. The possible influence of similar effects on these results will be studied in the future. It should be mentioned here that the deviation of n_n from the r^{-2} dependence at cometocentric distances $r < 3x10^4$ km was also observed by the instruments PID (Ref. 6) and NGE Ref. 9) on board VEGA-1.

Although equation (Ref. 5) does quite well describe the average distribution of n_n as determined from the RFC measurements presented in Figures 4 and 5, the accuracy of the parameters of this expression estimated on the basis of the RFC data is quite low. When determining the values of $n_o \, r_o^2$ the main error stems from the uncertainty of the yield coefficients $Y_{e,i}$ for electrons and ions produced by neutral gas impacting the nickel collector of the RFC at a velocity of about 80 km/sec. According to our estimation, the inaccuracy of the value for $n_o \, r_o^2$ and for the gas production rate for Halley's comet determined from the RFC data is about a factor of 2. Nevertheless, the gas production rate of Halley's comet estimated from the RFC observations on board VEGA-1 and VEGA-2 is in reasonable agreement with the estimations provided by other instruments on board VEGA-1, VEGA-2 and GIOTTO. The production rates for the H_2O and OH molecules were determined as $Q_{H_2O} \approx 4 \times 10^{29}$ sec^{-1} and $Q_{OH} \approx 1.7 \times 10^{30}$ sec^{-1} from the spectroscopic observations by the three-channel spectrometer (TKS) on board VEGA-2 in the visible and infrared spectral ranges (Ref. 10) and as $Q_{OH} \approx 9 \times 10^{29}$ sec^{-1} in the near ultraviolet range (Ref. 11). The value of Q estimated from the data measured by PID on board of VEGA-1 is varying between $10^{30} < Q < 4 \times 10^{30}$ sec^{-1} at cometocentric distances $r \lesssim 1.5 \times 10^5$ km. Finally, a preliminary estimation of the gas production rate of $Q \approx 6.9 \times 10^{29}$ sec^{-1} was provided by the instrument NMS on board GIOTTO (Ref. 7)

4. CONCLUSIONS

Comparing the results obtained independently by different experiments, we may conclude that, in general, a quite reliable description for the distribution of the neutral gas in the vicinity of Halley's comet is provided by the measurements of the RFC sensor of the PLASMAG-1 instrument package. Besides, at cometocentric distances $2x10^5$ km $< r < 3 \times 10^6$, the RFC was the only sensor on all spacecraft that was able to measure the distribution of neutral gas along the trajectory. Further correction of the neutral gas distribution in the vicinity of Halley's comet determined from the RFC measurements can be made by measuring the yield coefficients of secondary electrons and ions $Y_{e,i}$ more precisely and by taking into account all the factors that may influence the performance of the RFC in the vicinity of the comet.

The authors are indebted to Dr. R. Grard for useful discussion.

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