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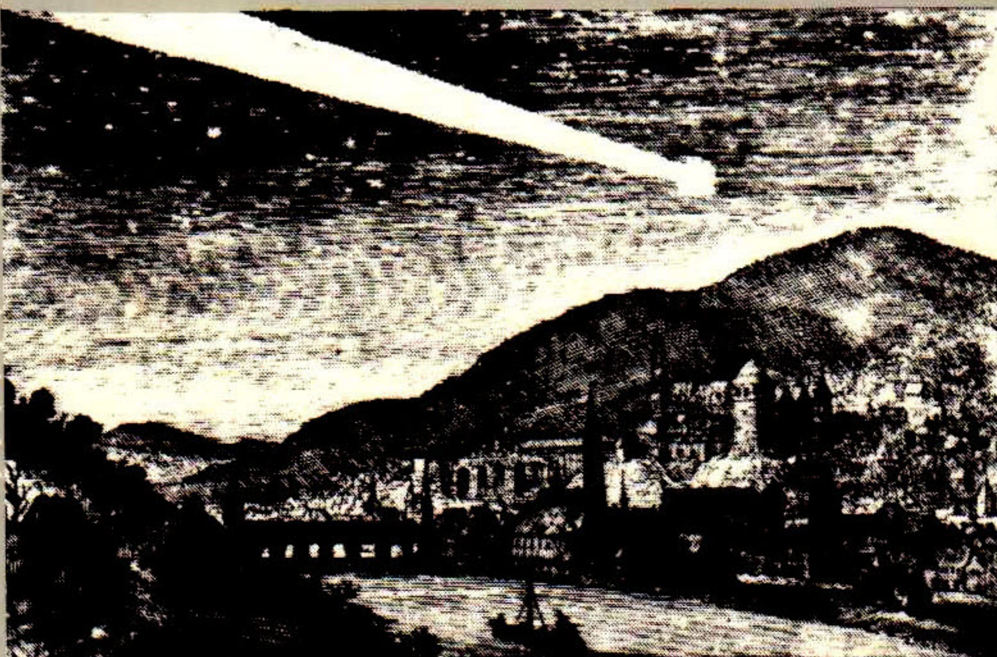

Comet over Heidelberg in 1618 A.D.; copper engraving by Matthäus Merian

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ELECTRON COMPONENT OF THE PLASMA AROUND HALLEY'S COMET MEASURED BY THE ELECTROSTATIC ELECTRON ANALYZER OF PLASMAG-1 ON BOARD VEGA-2

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ABSTRACT

Measurements of the electron spectra obtained by VEGA-2 in the vicinity of comet Halley are presented. It is shown that the temperature of thermal electrons decreases from about $4x10^5$ °K shortly behind the bow shock to about $2x10^5$ °K at the cometopause. Inside the cometopause a fast increase in the flux of energetic electrons of about 1 keV is observed. Various possibilities for the differences in the electron spectra measured by VEGA-2 and by Giotto are discussed.

Keywords: VEGA, electron spectra.

1. INTRODUCTION

The electrostatic electron analyzer (EA) of the plasma instrument package PLASMAG-1 on board VEGA-2 was designed to measure the energy spectra of electrons of the interplanetary and cometary plasma. This analyzer was oriented perpendicular to the ecliptic plane, and it observed the electron flux in 30 logarithmically spaced energy intervals in the energy range of 3-10000 eV. Some energy spectra of electrons measured by EA in the vicinity of Halley's comet and a more detailed description of the analyzer have been published recently (Refs. 1-4). In this paper further electron measurements in the vicinity of Halley's comet will be presented and they will be compared with the electron observations performed on board Giotto.

2. OBSERVATIONS

Figure 1 shows 2 minute averages of the energy spectra of electrons determined by the EA on board VEGA-2 at distances between $8x10^5$ and $1.5x10^4$ km from the nucleus when approaching Halley's comet. The data are presented on a logarithmic scale and the base line corresponds to a counting rate of 10^2 sec^{-1}. The first spectra in Figure 1 were measured in the cometosheath region downstream of the cometary bow shock which had been crossed at about 2.20-2.30 UT at a distance of about $1.3x10^6$ km from the nucleus (Ref. 5). Within the cometosheath the main feature of the energy spectra is a well defined maximum at a few times ten eV corresponding to the thermal electrons. The energy E_m of these electrons gradually decreases in the

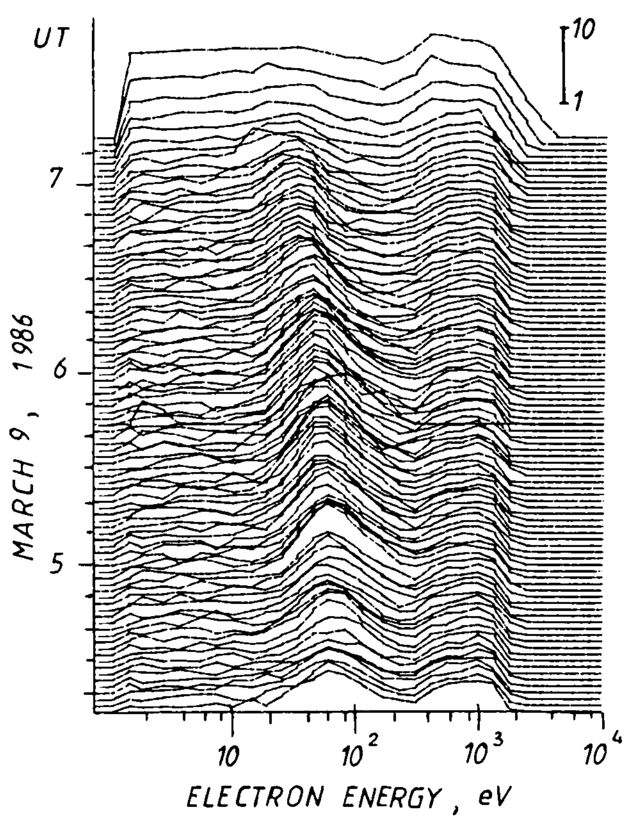

Figure 1. Counting rates measured by the electrostatic electron analyzer on board VEGA-2 at distances between $8x10^5$ km and $1.5x10^4$ km from the nucleus of Halley's comet.

cometosheath when approaching the cometopause, which is located at a distance of about $1.6x10^5$ km from the nucleus (~ 6.45 UT) (Ref. 6). This decrease in E_m indicates the gradual cooling of electrons. Assuming an isotropic Maxwellian distribution for electrons with the temperature T_e, the counting rate is proportional to $E^2 \exp(-E/kT_e)$ and $E_m = 2 kT_e$. Figure 2 shows the estimated T_e values for the

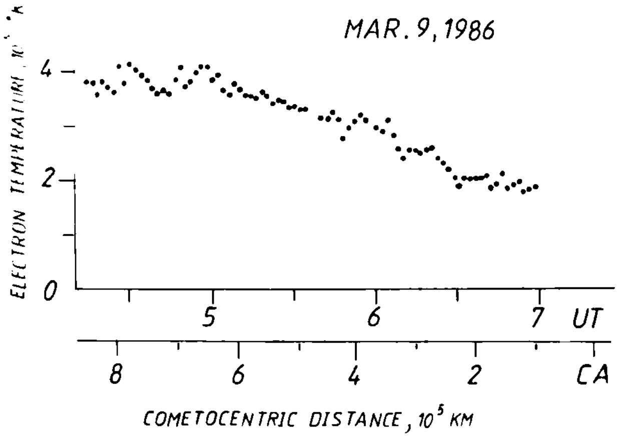

Figure 2. Distribution of the electron temperature in the cometosheath at cometocentric distances between $8x10^5$ km and $1.6x10^5$ km (cometopause).

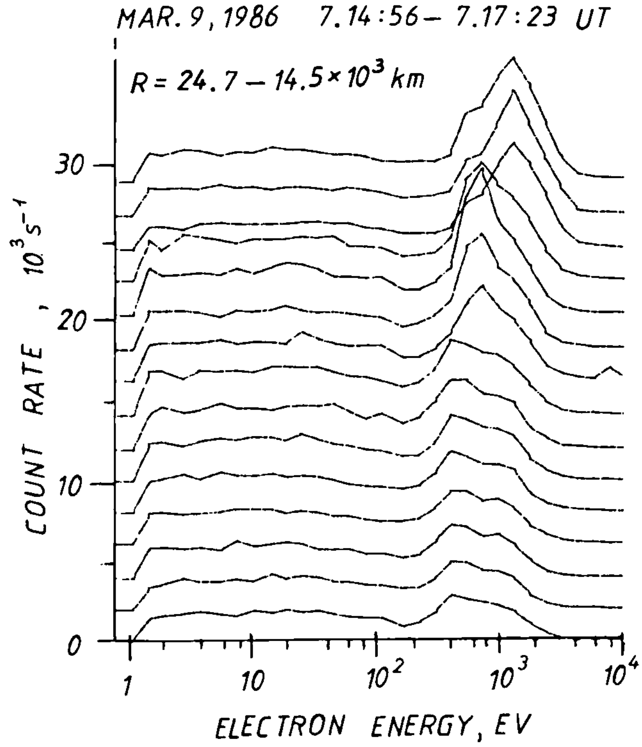

Figure 3. Counting rates measured by the electrostatic electron analyzer on board VEGA-2 at distances between $2.5x10^4$ km and $1.5x10^4$ km from the nucleus.

EA data presented in Figure 1. As shown in Figure 2, the electron temperature is decreasing by a factor of 2 in the cometosheath from $T_e \approx 4x10^5$ °K in the outer region to $T_e \approx 2x10^5$ °K at the cometopause. It has to be mentioned here that at a distance of about $5-6x10^6$ km from the nucleus the temperature of the undisturbed solar wind electrons was also about $2x10^5$ °K. However, approaching the bow shock, T_e was changing towards a final value of $T_e \approx 3.5-4x10^5$ °K in the foreshock region, i.e., at a distance of about $3x10^5$ km upstream of the bow shock.

Figure 3 represents 10 sec averages of the electron energy spectra near closest approach just before the PLASMAG-1 instrument package temporarily ceased working (presumably it was hit by a cometary dust particle). At distances $2.5-1.5x10^4$ km from the nucleus the counting rates are increasing in the energy interval of 0.3-3 keV, but at the same time also the energy distribution is changing: the maximum counting rates are observed at higher energies.

3. DISCUSSIONS

Beside the electron energy spectra measured on board VEGA-2, electrons were also observed in the vicinity of Halley's comet by the electrostatic electron analyzer EESA of the RPA-Copernic instrument on board Giotto (Ref. 7). It is interesting to compare the results of the two observations.

Before the encounter with Halley's comet, the temperature of the electrons measured by Giotto in the undisturbed solar wind was about $2.5x10^5$ °K, very similar to the value observed by the PLASMAG-1 EA. Also in the foreshock region, i.e., a few times hundred thousand km upstream of the bow shock, EESA measured an increase in the electron temperature up to $T_e = 3.5x10^5$ °K (Ref. 7), as did EA aboard VEGA-2.

According to the measurements by EESA, there were significant fluctuations in the electron temperature present at distances $1.15x10^6$–$5.5x10^5$ km from the nculeus in the cometosheath, but the average temperature practically stayed $T_e \approx 3.5x10^5$ °K in correspondance to the temperature observed by VEGA-2 at distances $8x10^5$–$6x10^5$ km from the nucleus, i.e., at the beginning of the high time resolution measurements (see Figure 2). Afterwards, both spacecraft observed a decrease in temperature down to $T_e \approx 2x10^5$ °K while approaching the cometopause or collisionopause (Ref. 7), respectively.

The cooling process of the electrons from $T_e \approx 4x10^5$ °K at the bow shock to $T_e \approx 2x10^5$ °K at the cometopause seems to be caused by inelastic collisions between electrons and cometary neutrals whereby the electrons loose energy. The neutral density is $n_n \approx 5x10^3$ cm^{-3} (Ref. 8) in the vicinity of the cometopause at a distance of about $R \approx 1.6x10^5$ km. The energy loss of electrons caused by inelastic collisions with water vapour of the density given above is $n_n \cdot L_e \approx 2x10^{-11}$ eV/cm, where $L_e \approx 4x10^{-15}$ cm^2 eV is the energy loss function for electrons with an energy of about 40 eV (Ref. 9). The velocity of the plasma flow is $V \approx$ 200 km/sec close to the cometopause (Ref. 6), and therefore the characteristic time for the plasma flow through the cometosheath is $\tau = R/V \approx 800$ sec. During this characteristic time the electrons with a velocity of about 4000 km/sec propagate a distance of about

$3x10^6$ km and their energy loss is about 6 eV. This value is comparable with the cooling of the electrons in this region. In this way the cooling process of the electron component observed by both VEGA-2 and Giotto can be explained by the energy loss through inelastic collisions with neutrals of the water group.

As presented earlier (see Refs. 1,2 and Figure 3 with discussion), the PLASMAG-1 EA observed a peak in the electron spectrum at an energy of about 1 keV that was not observed by Giotto at the same distance of R ≈ $1.5-2x10^4$ km from the nucleus. It is quite possible that energetic electrons were measured by VEGA-2 but not by Giotto, if these electrons were of sporadic nature. For example, they might have been produced by a "magnetospheric substorm" similar to the events occurring in the terrestrial magnetosphere. Ip and Mendis (Refs. 10,11) have already discussed the possibility of such events. Figure 4 presents the schematic model of a cometary substorm as suggested by Ip and Axford (Ref. 12) and Mendis et al. (Ref. 13). In a stationary

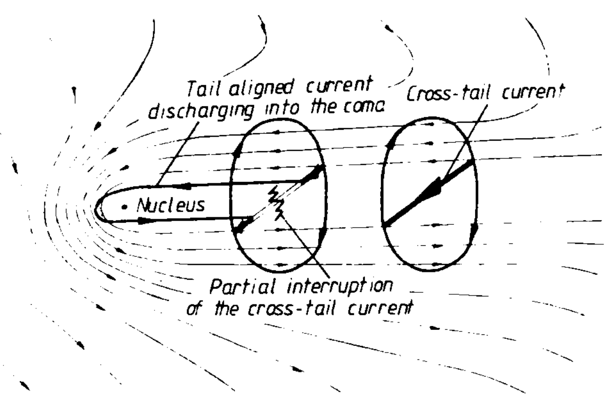

Figure 4. Schematic picture of the processes producing energetic electrons around the comet.

case, the simplified current flow system in the cometary tail has the usual θ-shape configuration. When the cross-tail current gets partially disrupted, the produced tail-aligned currents can discharge through the coma as shown in Figure 4. In these non-stationary processes, electrons may be accelerated to a few keV like auroral electrons are in the terrestrial upper atmosphere. Energetic electrons, generated during such a "cometary substorm", might have been observed by VEGA-2.

The UV spectra of Halley's comet measured by IUE on March 18-19, 1986 (Ref. 14) may provide an indirect support for this temporal occurrence of high energy electrons in the coma of P/Halley. In the paper by Feldman et al. (Ref. 14) two spectra were compared both taken on the tailward side of the nucleus within a distance of about 40 000 km. The comparison showed a decrease by more than a factor of four in a period of 37 minutes for the CO_2^+ emission while the OH brightness remained nearly constant. This difference between the two UV spectra could be explained by the existence of localized energetic electron currents close to the nucleus. The authors suggested that a similar event might have occurred when VEGA-2 detected the 1 keV electrons.

Finally, the problem of possible instrumental effects will be discussed here. The electron electrostatic analyzer EA on board VEGA-2 observed a significant increase of the instrumental background in the cometary plasma region after crossing the cometopause. The EA provided the possibility to measure electrons in the first 15 energy intervals (E < 150 eV) with a lower sensitivity (about 100 times below normal) for every forth spectrum. In this low sensitivity mode the maximum corresponding to thermal electrons in the cometosheath was not observed, indicating that it was not caused by instrumental background which could be determined in this way for EA. Deep inside in the cometary plasma region, the counting rates practically did not change for energies below 150 eV when switching to the lower sensitivity mode. Therefore the quick increase in the counting rates of EA for E < 150 eV when going deeper into the cometary plasma region (Figure 1) seems to be caused only by the increase of the instrumental background level and is not due to a real increase of electron fluxes. This does not influence our conclusion regarding the cooling of thermal electrons in the cometosheath with decreasing cometocentric distance, as this thermal electron component is disappearing in the low sensitivity mode.

Although the observation of the high energy peak in the electron energy spectra measured by VEGA-2 seems to be reliable and although its temporal occurrence may well be explained, we are still concerned about the possibility of an instrumental background which cannot be easily determined for energies E > 150 eV, as there was no decreased sensitivity mode for this energy range. The 1 keV peak increased faster compared to the lower energies around the distance of $2x10^4$ km from the nucleus, and it was shifted to higher energies afterwards (Figure 3). At this time the counting rates at the peak above 1 keV were 5-7 times higher than the background rates at 200-300 eV. The fact that a small peak remained at the same energy even 2 days after the encounter (as shown in Figure 5 in Ref. 1 and Figure 6 in Ref. 2) could possibly be regarded as an indication that this might be, at least partially, an instrumental effect. Several laboratory tests have been performed with an electrostatic electron analyzer similar to the flight model, but no similar instrumental effect has been found so far. However, investigations concerning this problem will be continued.

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