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Analysis of the electron measurements from the Plasmag-1 experiment on board Vega 2 in the vicinity of comet P/Halley

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Summary. Measurements of electron spectra, as obtained by the Plasmag-1 experiment on board Vega 2 in the vicinity of comet Halley, are presented. It is shown that the temperature for thermal electrons gradually decreases when the comet is approached from about $4\,10^5$ K behind the cometary bow shock to about $2\,10^5$ K at the cometopause. In the region inside the cometopause a fast increase in the flux of energetic electrons of about 1 keV energy is observed. Various possibilities are discussed regarding the differences in the electron spectra measured by Vega 2 and Giotto, respectively.

Key words: electron measurements – comet Halley

1. Introduction

The electron electrostatic analyzer EA was part of the plasma instrument Plasmag-1 on board the Vega 2 spaceprobe, which encountered comet Halley in March 1986. This sensor was designed to measure the energy spectra of electrons in the interplanetary and in the cometary plasma. It was oriented perpendicular to the ecliptic plane, and it observed the flux of electrons in the energy range of 3 eV to 10 keV in 30 logarithmically spaced energy intervals. A detailed description of this experiment can be found in Gringauz et al. (1986a) and Apàthy et al. (1986), and first measurements have been published by Gringauz et al. (1985 and 1986b). In the present paper we will present the Vega 2 electron measurements in the vicinity of Halley's comet, and we will compare these observations with those obtained on board the Giotto spaceprobe.

2. Observations

Figure 1 shows the sequence of the two minute averaged electron spectra as observed during the inbound leg of Vega 2 between app. $8\,10^5$ and $1.5\,10^4$ km from the cometary nucleus. The intensity is presented on a logarithmic scale (see insert in the upper right-hand corner) where the baseline corresponds to $10^2\,s^{-1}$. The first spectra in Fig. 1 were measured downstream of the cometary bow shock, which was crossed at about 2.20 UT at a cometocentric distance of about $1.3\,10^6$ km (Galeev et al., 1986), and the sequence includes the crossing of the cometopause (Gringauz et al., 1986c), which was located at a distance of about $1.6\,10^5$ km or at about 6.45 UT, respectively.

A first, well defined maximum in the electron intensity is identified at an energy E_m of a few times ten eV, corresponding to the thermal electrons. While passing through the cometosheath region towards the cometopause, we find a gradual decrease of the energy E_m. Assuming an isotropic Maxwellian distribution for these thermal electrons, the counting rate is proportional to $E^2 \exp(-E/kT_e)$, with T_e being the electron temperature and k

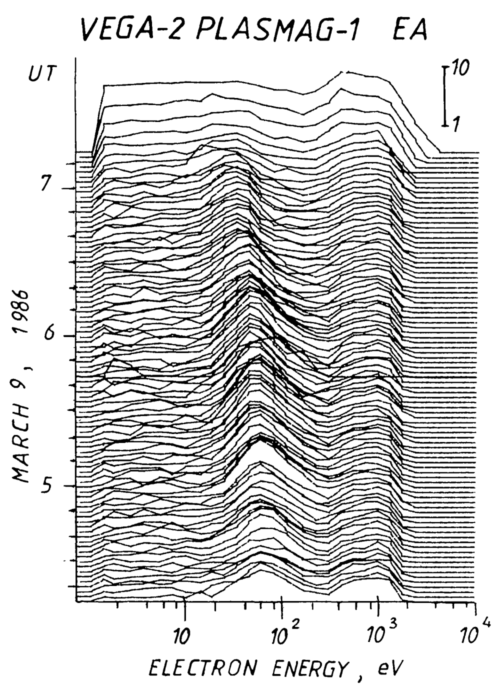

Fig. 1. Time sequence of 2 min averaged energy spectra, i.e. counting rate vs. energy, of electrons measured by the electron electrostatic analyzer EA on board Vega 2 between $8\,10^5$ and $1.5\,10^4$ km from the nucleus of comet Halley

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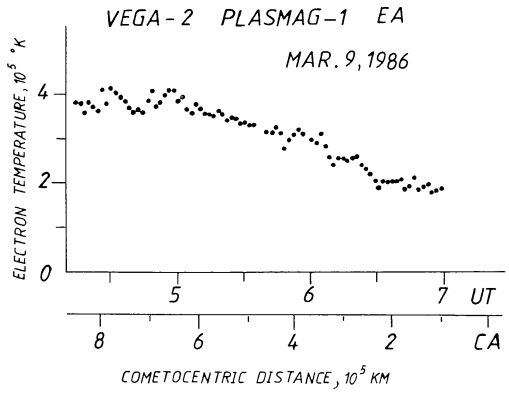

Fig. 2. Distribution of the electron temperature in the cometosheath of comet Halley between $8\,10^5$ and $1.6\,10^5$ km (cometopause). CA = closest approach

the Boltzmann constant. Thus, $T_e = 2E_m/k$. In Fig. 2 the radial dependence of T_e is shown in the distance range from about $8\,10^5$ to $1.6\,10^5$ km, respectively.

From this Figure it readily follows (1) that there is an overall decrease of T_e by a factor of two from about $4\,10^5$ K to about $2\,10^5$ K within this region, (2) that T_e decreases fastest within the region of about $5.5-6\,10^5$ km, but stays app. constant outside, and (3) that there are significant fluctuations in T_e present in the region outside of about $6\,10^5$ km. It should be mentioned that at a cometocentric distance of about $5-6\,10^6$ km, i.e. in the undisturbed solar wind, the electron temperature was also about $2\,10^5$ K, and that it increased to its maximum value of about $3.5-4\,10^5$ K already at a distance of about $3\,10^5$ km upstream of the cometary bow shock.

Reconsidering Fig. 1 we find that during the time of closest approach to the cometary nucleus, i.e., after about 7.10 UT, the counting rates are increasing for the keV electrons. This situation is depicted in Fig. 3, representing the sequence of 10 s

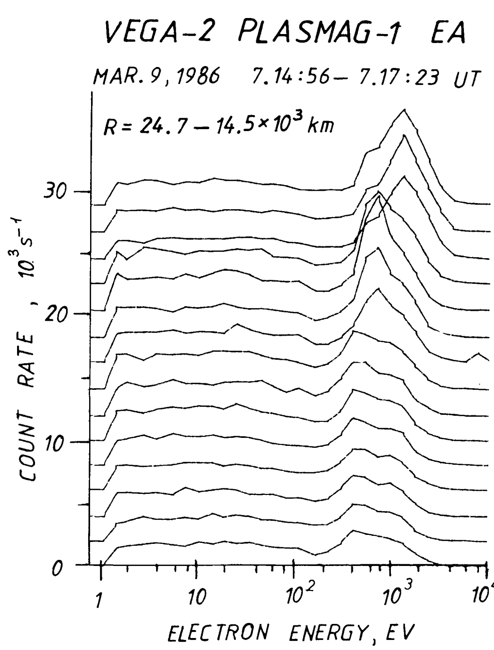

Fig. 3. Time sequence of 10 s averaged energy spectra of electrons measured by Vega 2 between $2.5\,10^4$ and $1.5\,10^4$ km from the nucleus of comet Halley

averaged electron energy spectra within the distance range of $2.5-1.5\,10^4$ km. The maximum counting rates are now observed in the energy interval of 0.3–3 keV with a fast increase of the maximum intensity and with a change in the distribution. At the end of this sequence the Plasmag 1 experiment temporarily ceased operating, presumably because it was hit by a cometary dust particle.

3. Comparison with the Giotto observations

During the encounter of the Giotto spacecraft with comet Halley, electrons were measured by the electron electrostatic analyser EESA of the RPA experiment (Rème et al., 1986). In the undisturbed solar wind the electron temperature was about $2.5\,10^5$ K, and it increased to about $3.5\,10^5$ K a few times 10^5 km upstream of the bow shock. Downstream, in the region from $1.15\,10^6$ km to $5.5\,10^5$ km T_e stayed practically constant ($3.5\,10^5$ K) but with large fluctuations being superimposed, while afterwards, in approaching the cometopause, T_e decreased to about $2\,10^5$ K. Inside the cometopause and during closest approach, however, the RPA experiment did not observe any electrons in the keV energy range.

Thus, outside the cometopause both the Vega 2 and Giotto electron measurements are in excellent agreement with each other, not only with respect to the actual values of T_e but also with respect to its overall radial dependence. The only, yet essential difference between both observations is the observation of keV electrons of Vega 2 during its closest approach to comet Halley.

4. Discussion

We propose that the decrease in the electron temperature from about $4\,10^5$ K near the bow shock to about $2\,10^5$ K at the cometopause, as observed by Vega 2 and Giotto independently, might be due at least to some extent to inelastic collisions between the thermal electrons and the cometary neutral gas. Near the cometopause at $R \approx 1.6\,10^5$ km the neutral density is about $N_n \approx 5\,10^3\,\mathrm{cm}^{-3}$ (Remizov et al., 1986). The energy loss of electrons caused by inelastic collisions with neutrals of the water group is $N_n L_e \approx 2\,10^{-11}\,\mathrm{eV\,cm}^{-1}$, where $L_e \approx 4\,10^{-15}\,\mathrm{cm}^2\,\mathrm{eV}$ is the energy loss function for electrons with an energy of about 40 eV (Olivero et al., 1972). The plasma velocity near the cometopause is $V \approx 200\,\mathrm{km\,s}^{-1}$ (Gringauz et al., 1986c). The characteristic time for the plasma flow through the cometopause is therefore $\tau = R/V \approx 800$ s. During this time the thermal electrons at an average velocity of about $4000\,\mathrm{km\,s}^{-1}$ have traversed a distance of about $3\,10^6$ km. Thus, according to the above equation their energy loss is about 6 eV.

The observation of electrons at an energy of about 1 keV by Vega 2 at a distance of $1.5-2\,10^4$ km from the nucleus could either be due to a purely instrumental effect of the EA analyser, or to the sporadic occurence of these particles in the sense that they were observed by Vega 2 on March 9 but not by Giotto on March 13/14, 1986. Let us first discuss the question of the instrumental effect: After crossing the cometopause, the EA sensor observed a significant increase in the overall background counting rate inside the cometary plasma region (see also Fig. 1). Besides in its normal mode of operation, the EA sensor also provided the possibility to measure electrons in the first 15 energy intervals

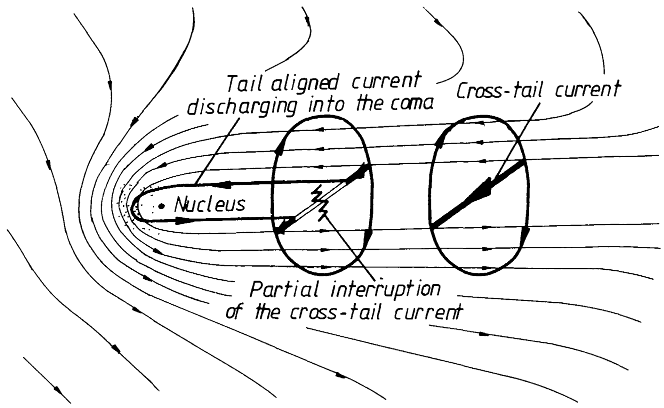

Fig. 4. Schematics of a cometary cross-tail disruptive event, which could have produced the keV energetic electrons observed by Vega 2 during closest approach (see Fig. 3)

($E_e < 150$ eV) at an about 100 times lower sensitivity for every forth spectrum. Inside the cometary plasma region the counting rates for electrons <150 eV did practically not change when switching from the normal mode to this lower sensitivity mode. Thus, the fast increase in the intensity of these thermal electrons at the crossing of the cometopause (Fig. 1) seems to be a result of an increase in the instrumental background rather than a real increase of the electron flux. This may also hold for the energy range $E_e > 150$ eV, although there was no decreased sensitivity mode for this energy range. Yet, according to Fig. 3 the maximum intensity at about 1 keV increased much faster as compared to the lower energies from a distance of about $2\,10^4$ km onwards, and it was even shifted to higher energies further inside the cometary plasma region. At this time the maximum counting rate at about 1 keV was 5 to 7 times higher than the background rates at about 200 eV. Moreover, several laboratory tests have been performed in the meantime with an electron analyzer similar to the flight sensor, but an effect like this observed one has not yet been identified. Thus, the observation of keV electrons by Vega 2 cannot be explained by an instrumental effect only. On the other hand, if the occurence of such energetic electrons is real, what sporadic acceleration mechanism could have caused their appearance? The onset of a magnetospheric substorm similar to the events occuring in the terrestrial magnetosphere could provide the explanation. The occurence of such events in the cometary magnetotail has been proposed by Ip and Mendis (1976) and by Ip (1986). A schematic representation of a cometary substorm, as suggested by Ip and Axford (1982) and by Mendis et al. (1985), is shown in Fig. 4. In the stationary case the flow system of the tail electric current adopts the usual θ shape configuration. If the cross-tail current gets partially disrupted, induced tail-aligned currents can discharge through the cometary coma. By such a process electrons can be accelerated to some few keV energies, as in case of auroral electrons in the terrestrial upper atmosphere. Vega 2 might have observed such substorm-generated energetic electrons, while Giotto did not.

Finally, we would like to summarize another observation pointing also towards the possibility that energetic electrons may occur sporadically in the coma of comet Halley. In the paper by Feldman et al. (1986) two UV spectra measured by IUE on March 18–19, 1986, on the tailward side of the nucleus at a distance of about 40,000 km and about 30 min apart were compared. It was found that the CO_2^+ emission had decreased by more than a factor of four, while the OH^+ brightness had remained nearly constant. The authors proposed that this difference could be explained by the existence of localized currents of energetic electrons close to the nucleus.

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