PERMANENT AND NONSTATIONARY PLASMA PHENOMENA IN COMET HALLEY'S HEAD

K.I. Gringauz and M.I. Verigin

Space Research Institute, Profsoyuznaya 84/32, 117810 Moscow GSP-7, USSR.

Abstract The characteristics of various plasma phenomena observed near comet Halley in 1986 are studied to determine whether or not they are permanent features of the comet. Taking as the criteria for permanence that they should be observed by all spacecraft or be physically explicable, the permanent features include the near-cometary bow shock, the cometosheath, with its unique energy distribution of ions, the systematic cooling of electrons in this region, the cometopause, and the tangential discontinuity near the cometary nucleus. Among nonstationary events observed there are the unusual burst of ions with energies 100 -1000 eV recorded in a direction from the Sun in the region of cometary ions at $r \sim (1 - 2) \times 10^4$ km, the magnetic field pile-up boundary (in the region of the cometopause), the mystery region, and the precipitation of energetic electrons with ~ 1 keV at $r \sim (1.5 - 2.5) \times 10^3$ km.

1. Introduction

The in situ plasma and magnetic measurements made near Halley's comet nucleus in March 1986 detected a considerable number of phenomena. Some of them had been anticipated before 1986. They are the near-cometary bow shock, the tangential discontinuity near the nucleus (not very adequately called the contact surface or ionopause), and auroral phenomena in the head of the comet due to the events in its tail. The other phenomena were not mentioned in the literature prior to 1986 and received the new names: "cometosheath", "cometopause", [Gringauz et al., 1986], "pile-up boundary" [Neubauer, 1987], and "mystery region" [Reme et al., 1987].

Some of these phenomena were observed from all three spacecraft which came close to the comet nucleus (VEGA-1, 2 and Giotto), while the other ones were detected by only one of these spacecraft. Among them is the tangential discontinuity near the comet nucleus. This phenomenon was observed by the Giotto spacecraft only, because the other spacecraft passed by too far from the nucleus.

Some phenomena always occur in a comet head at a distance of 1 a.u. from the Sun. Along with this it is obvious that the structure of the plasma (and of the magnetic field) near the comet nucleus should change with time since it is a result of the interaction of two opposite flows of particles highly unsteady with time - a solar wind flow (with unsteady interplanetary magnetic field), and a neutral gas flow evaporating from the nucleus and subjected to ionization. So, one would expect (and it was expected previously to 1986 [Mendis, Houpis and Marconi, 1985]) that the plasma and magnetic field near the comet nucleus will be unsteady. In particular, the changes in the characteristics of the solar wind plasma and interplanetary magnetic field should lead to variations in the characteristics and maybe in the structure, of the near-cometary plasma and magnetic field. For this reason it is clear that not all plasma phenomena near the comet nucleus are permanent.

The spacecraft passed by the nucleus under different interplanetary conditions. In spite of this some phenomena were observed during all three flybys, and so they can probably be considered as permanent. We can only consider phenomena observed from one spacecraft as permanent in the case where there is a clear understanding of its physical nature and of the reason why it could not be observed by other spacecraft.

If we only had the data from a single spacecraft, there would be a risk of believing that all the detected features of the near-cometary plasma are permanent. However, with the information from three spacecraft, obtained at different times and in different conditions we can make an attempt to identify the near-cometary plasma formations and peculiarities created by the changes in interplanetary space and in characteristics of gas flow evaporating from the nucleus. It is this attempt that is the objective of this paper.

In comparing results obtained from all spacecraft, due consideration should be given to the different characteristics of the instruments, particularly to their energy ranges and fields of view. Thus, for example, the lower velocity ions in the cometocentric system were well recorded by the instruments whose fields of view covered the direction of the relative velocity vector, but they could not be recorded by those instruments whose fields of view did not include the above-noted direction.

2. Permanent Phenomena.

2.1 Bow shock

Figure 1 gives the near-cometary trajectory portions of the VEGA-1, 2, Giotto and Suisei spacecraft. The crosses show the bow shock positions determined from plasma velocity changes, from plasma heating, and from magnetic field jumps at the bow shock; the plasma velocity vector projections to the plane of the figure are denoted by the arrows [Suisei data, Mukai et al., 1986]. Each crossing had its individual features (for example, sometimes plasma heating started earlier than

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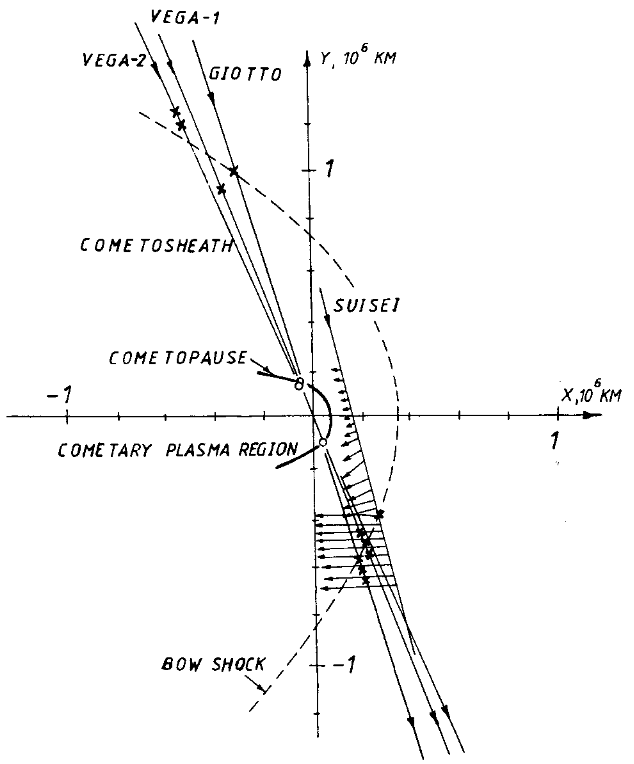

Fig 1. General overview on the in- and outbound locations of the bow shock and of the cometopause as well as of the cometosheath and of the cometary plasma region as identified from VEGA-1,2, Giotto and Suisei observations during their encounters with comet Halley.

the plasma velocity decreased and turned) nonetheless in all cases the observed bow shock positions fit each other well. The bow shock subsolar point was located about 3.5 x 10^5 km from the comet nucleus.

The observed bow shock positions were close to the smooth empirical shock surface (dashed line in Figure 1), despite the fact that the solar wind velocity during the flyby of Giotto was two times lower than during the flybys of VEGA-1 and VEGA-2. Apparently this was associated with the fact that the neutral gas production by the comet on March 13th, 1986 was lower than that on March 6th and 9th, 1986, perhaps due to the different orientation of the asymmetric nucleus relative to the Sun. The cometary bow shock formation is not caused by solar wind compression and heating due to interaction of the supersonic plasma flow with a sufficiently rigid obstacle (as in the case of solar wind flow around the near-Earth magnetic obstacle or around the non-magnetized ionospheric plasma confined by the strong gravitational field of Venus). The bow shock forms due to mass-loading of the solar wind by picked-up ions of cometary origin [Galeev, 1987]. It is beyond any doubt that the near-cometary bow shock is a permanent feature of Halley's comet at heliocentric distances of ~ 1 a.u.

2.2 Cometosheath

It was proposed that the plasma transition region downstream of the near-cometary bow shock be called "cometosheath" [Gringauz et al., 1986] since the energy distribution of ions in this region is unique compared with similar regions near the solar system planets, for example, the magnetosheath near Earth or the ionosheath near Venus. One of the differences is that three different branches of ions are present in the ion energy distribution; the ratio of intensities of these branches changes with the cometocentric distance. This feature of the cometosheath is associated with the above-noted principle difference in the bow shock formation process near planets and comets.

Figure 2 gives the results of measurements made with the JPA instrument (ion energy-mass analyzer) aboard the Giotto spacecraft in Halley's comet head [Johnstone et al., 1986]. The spectrogram of the ion fluxes shown in Figure 2 presents the energy spectra of ions recorded in the sector of the field of view containing the solar direction (the instrument had a fan-type field of view). Two upper branches (1, 2) in this panel correspond to the ion mass interval which included water group ions; the lowest branch (p) is an instrumental "ghost" of the energy distribution of the protons.

The upper branch of the distribution (1) is formed by water group ions picked-up by the solar wind upstream of the bow shock [Thompson et al., 1987] and coming to the spacecraft with the velocity twice that of the solar wind. Their energy should be greater than that of solar wind protons by a factor of about 4M times where M is the mass of the cometary ions. According to Figure 2, that corresponds to the results of the observations.

The branch (2) is formed by water group ions picked-up in the cometosheath where the velocity of the solar origin plasma is reduced compared with the velocity in interplanetary space. For this reason their energy is also lower. According to Thompson et al. [1987] energy splitting of water ions in the cometosheath in branches (1) and (2) can be explained by the stepwise decrease of plasma velocity on the bow shock. Along with this, the observation that the energy of the ions in branch (2) rapidly decreases and becomes close to that of the protons (also observed by VEGA-1 and VEGA-2 (Figure 3, Gringauz et al.,1986])still remains to be studied.

However, the fact that the cometosheath, with its unique energy ion distribution, is a permanent feature of comet Halley's head at ~ 1 a.u., is beyond doubt.

2.3. Cometopause

The VEGA-2 spacecraft recorded a sharp (~ 10^4 km along trajectory) change of the ion distribution function at a distance of ~ 1.6 x 10^5 km from the nucleus [Figure 4, Galeev et al, 1988]. This change corresponds to the boundary between two regions: in one, the solar wind protons are predominant, in the other heavy ions of cometary origin dominate. There was no simultaneous change of the distribution function of electrons, so the plasma number density and electron temperature had no discontinuity. This "chemical discontinuity" in plasma was called the "cometopause" [Gringauz et al., 1986; Gringauz et al., 1986a].

According to the VEGA-2 data the magnetic field absolute value actually did not change near the cometopause [Riedler et al., 1986], however the amplitude of electric field oscillations rapidly grew (during ~ 2 min) in the lower-hybrid frequency range (8 -14 Hz). Plasma flux oscillations were recorded in the whistler wave range, and the frequency at which the intensity of these waves was a maximum increased from ~

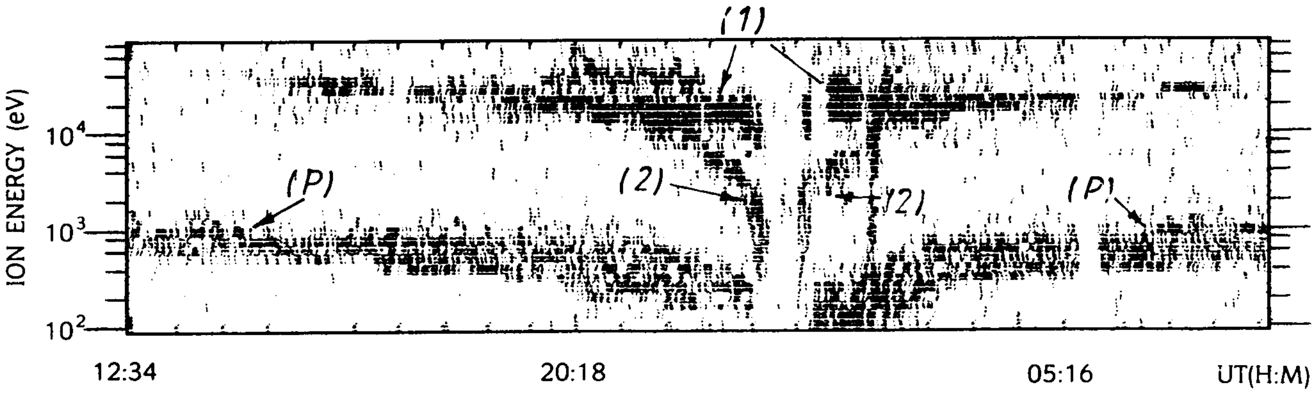

Fig. 2. Black-and-white version of colour coded spectrogram of IIS time-of-flight sensor of JPA instrument onboard Giotto spacecraft. Branch (P) corresponds to protons of solar wind origin, branches (1,2) - to cometary ions of mass 12-22 AMU.

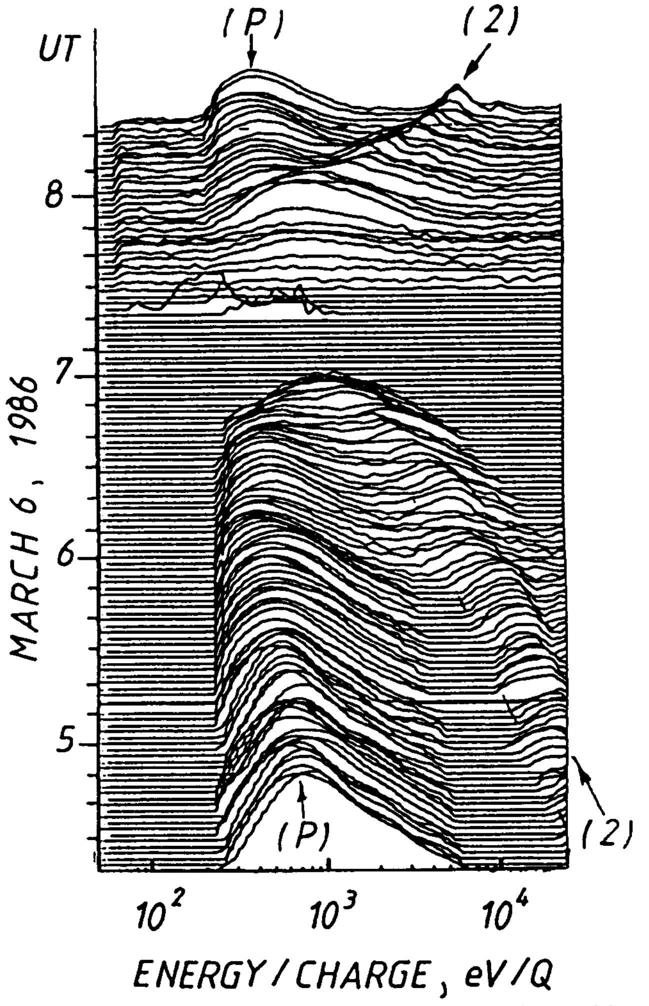

Fig. 3. Sequence of energy-per-charge spectra observed by the solar direction ion analyser onboard of VEGA-1. Branches (P) and (2) are similar to those in Figure 2. Near VEGA-1 closest approach (~ 7.20 UT) short non-stationary spike of accelerated ions was registered.

250 Hz to ~ 900 Hz while the s/c approached the cometopause [Galeev et al., 1988].

The cometopause thickness of (1 - 2) x 10^4 km was determined using the data from the Giotto/JPA instrument [Amata et al., 1986]. According to data from the HERS sensor of the IMS instruments aboard Giotto, the transfer from the light ion region to the heavy cometary ion region seems to more gradual [Balsiger et al., 1987].

The cometopause separated the cometosheath region where protons are dominant (and picked-up water group ions can be considered as minor components) from the region where cometary ions are dominant. There is no doubt now that the fast transition from one region to another is accompanied by the rapid growth of the charge exchange rate between protons and cometary neutrals. In other words, there is a growing number of collisions of protons with neutrals, although the study of the physical processes that can lead to the formation of a sharp cometopause boundary is not completed. The decrease of the proton fluxes recorded by the CRA analyzer onboard VEGA-2 can be partially due to their collisionless isotropization.

It has been noted by Galeev et al. [1988] that, in the vicinity of the cometopause, conditions are met for the firehose instability if one assumes that the involvement of cometary ions in the motion along the magnetic field is not effective.

The fast isotropization of protons in the vicinity of the cometopause promotes the acceleration of the process of charge exchange which decreases their concentration by several times. The characteristic time of proton charge exchange τ is related to their total velocity:

$$\tau \sim (\sigma v n)^{-1} \sim 5 \times 10^3 s,$$

where $\sigma \sim 2 \times 10^{-15}$ cm^2 is the charge exchange cross section; n is the neutral concentration equal to about 5 x 10^3 cm^{-3} [Remizov et al., 1986], v ~ 200 km/s is the velocity of the motion of protons in front of the cometopause which is of the order of magnitude of the velocity of their gyration on the cometopause (and downstream of it due to pitch-angle scattering by the ion - excited oscillations).

The time estimated above is comparable with the characteristic time of the plasma flow interaction with the

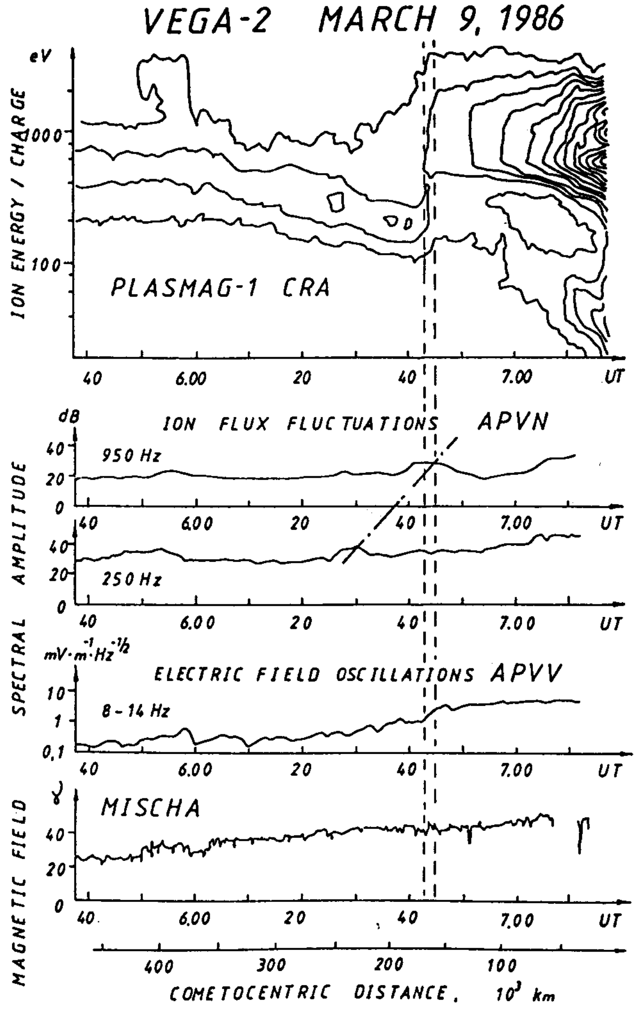

Fig. 4. Plasma and field data collected by four different instruments during last 100 min before VEGA-2 closest approach. From top to bottom: spectrogram of ion flux in ram direction, plasma wave activity in three different frequency ranges, total magnetic field. The cometopause indicated by dashed lines. The outermost isolines in top panel correspond to ram ion analyzer of PLASMAG-1 instrument count rate of $10^3 s^{-1}$, and the ratio between count rates represented by adjacent isolines is equal to 2.

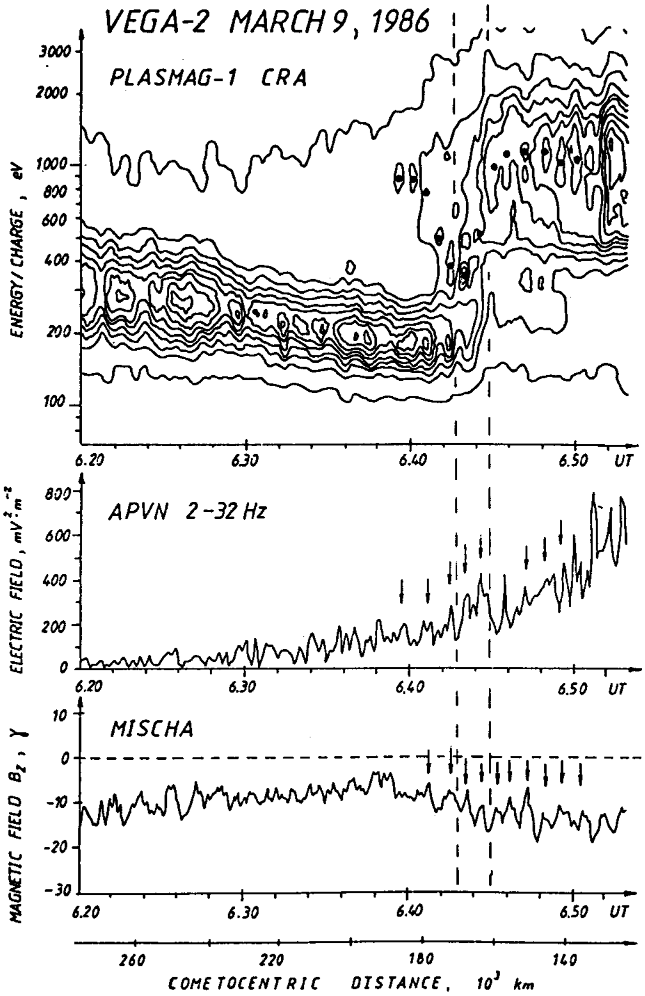

Fig. 5. Fluctuations of ion flux, electric field and B_z component (pointing towards the north pole of ecliptic) of the magnetic field around the cometopause (dashed lines). Maxima are shown by dots and arrows. Here the difference between count rates of PLASMAG-1/VEGA-2 ram ion analyzer (top panel) represented by adjacent isolines is $440 s^{-1}$, and the outermost isolines corresponds to a count rate of $10^3 s^{-1}$.

cometary neutrals at the cometopause which is equal to about $2r/v_\iota \sim 5 \times 10^3$ s where $v_\iota \sim 60$ km/s is the flow velocity downstream of the cometopause. This indicates that the charge exchange is effective in this region. However, the characteristic scale of this process exceeds much of the cometopause width.

Modelling of the cometopause within the frame of the two-fluid hydrodynamic model [Gombosi, 1987] cannot completely explain, in some respects, the "too sharp" boundary which was observed by VEGA-2. The effect of collective interactions in the plasma should be incorporated in a complete model. Figure 5 [Galeev et al., 1988] illustrates the existence of intense plasma wave processes near the cometopause; one can see synchronous oscillations of ion fluxes and electric and magnetic fields near this boundary.

Processes occurring on the cometopause depend on the properties of the plasma flow moving towards the nucleus and connected with the variable solar wind, as well as on parameters of the flow of the neutral gas, which is also varying in time. Therefore, we should expect that the position and, maybe, the width of the cometopause can and should vary in time. However, the existence of the cometopause as a permanent feature in the head of Halley's comet is in no doubt.

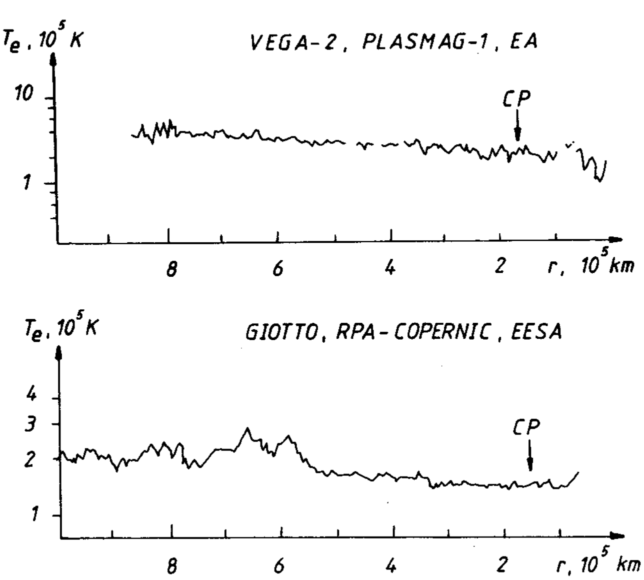

Fig. 6. Cometocentric profiles of electron temperature estimated by VEGA-2 electron electrostatic analyzer EA of PLASMAG-1 instrument data, and Giotto EESA sensor of RPA instrument data.

2.4. Cooling of electrons with the decrease of cometocentric distance

Using Figure 6 one can compare the results of measurements of the plasma's electron component from VEGA-2 [Gringauz et al., 1987], and Giotto [Reme et al., 1987] spacecraft. The top panel show the values of T_e calculated from the data of the EA electrostatic analyzer on board VEGA-2, while the bottom panel is from the data of the EESA instrument onboard Giotto. Within the cometocentric distance range from r ~ 8 x 10^5 km to the cometopause CP, the electron temperature decreases by (1 - 2) x 10^5 K. This cooling of electrons by 10 - 20 eV can be explained by losses of electron energy during their inelastic collisions with the cometary neutral gas.

Indeed, at r ~ 1.6 x 10^5 km, the density of neutral particles n is ~ 5 x 10^3 cm^{-3} [Remizov et al., 1986]. The electron energy loss due to inelastic collisions during electron motion through water vapour of such density is nL ~2 x 10^{-11} eV/cm, where L ~ 4 x 10^{-15} cm^2 eV is the electron energy loss function value at E ~ 40 eV. If the plasma flow velocity is v ~ 200 km/s the characteristic time of the flow-around is ~ 2r/v ~ 1.5 x 10^3 s (with due account of the fact that the spacecraft is approaching the nucleus at an angle of 110° with the direction to the sun). During this time, an electron moving with a velocity of 4 x 10^3 km/s can cover a distance of 6 x 10^6 km, and on this path it can lose an energy of ~ 12 eV. This value is comparable with the observed systematic cooling of the electron component.

Hence, with allowance for the fact that the results of the VEGA-2 observations coincide with Giotto measurements and that the physical process caused this effect is clearly understandable, it should be considered as a permanent feature of the cometosheath within the interval of cometocentric distances discussed above.

2.5. The tangential discontinuity (ionopause, the contact surface)

The existence of a sharp boundary of the cavity adjacent to the nucleus where there is no magnetic field but where there is plasma had been predicted prior to missions to Halley's comet.

This surface was only detected by Giotto at a distance of ~ 5000 km from the nucleus; the other spacecraft had flight trajectories too far from the nucleus. The main characteristics of this region are well known and we will not discuss them here.

The plasma turned out to be very cold so that the force balance at the cavity boundary was due to the friction between the neutrals and ion balanced by the magnetic field pressure [Cravens, 1986; Ip and Axford, 1987] rather than the equality of the cometary ionosphere plasma and external magnetic field pressures. The physical processes which create such a surface are now well understood. Therefore, this surface can also be considered as a permanent feature of the head of Halley's comet at ~ 1 a.u. regardless of the fact that it has been observed only once.

3. Non-Stationary Phenomena

3.1 Discontinuities of the magnetic field in the cometary plasma region.

It should be again noted that the VEGA-1, VEGA-2 and Giotto flybys in the head of Halley's comet were performed under essentially different conditions in the interplanetary plasma. Interplanetary magnetic field (IMF) conditions were also very different. At the time of the VEGA-1 flyby, one IMF sector boundary passed through the cometary plasma region.

Arrows on Figure 7a show the results of magnetic field measurements with the MISHA magnetometer along the VEGA-1 trajectory [Riedler et al., 1986]. It is seen from this figure that, as a whole, the magnetic field behaves as if it was draped around the cometary nucleus, and was directed sunward at the outbound leg of the trajectory. However, between 7.11 UT and 7.24 UT, the direction of the magnetic field was reversed. Several hours prior to this VEGA-1 detected a change of IMF direction also. Therefore, the magnetometer investigations supposed that part of the magnetic field which had been measured near the closest approach point was the remnant of the previous direction of the interplanetary magnetic field slowly moving towards the nucleus, frozen-in the decelerated plasma flow and hence, approaching the nucleus with a delay in time. Later, 3D MHD-modeling of the solar wind interaction with the comet confirmed this supposition [Schwingenschuh et al., 1987].

Figure 7b illustrates the results of the Giotto magnetic field measurements [Raeder et al., 1987]. It can be seen from this figure that the magnetic field direction changed many times during the Giotto flyby. According to our knowledge, a detailed analysis of the passage of these multiple discontinuities in the IMF through the cometary plasma region has not been made yet. However, we have no doubt that discontinuities in the IMF on the magnetic field influence the cometary plasma region as in the results of the VEGA-1 spacecraft.

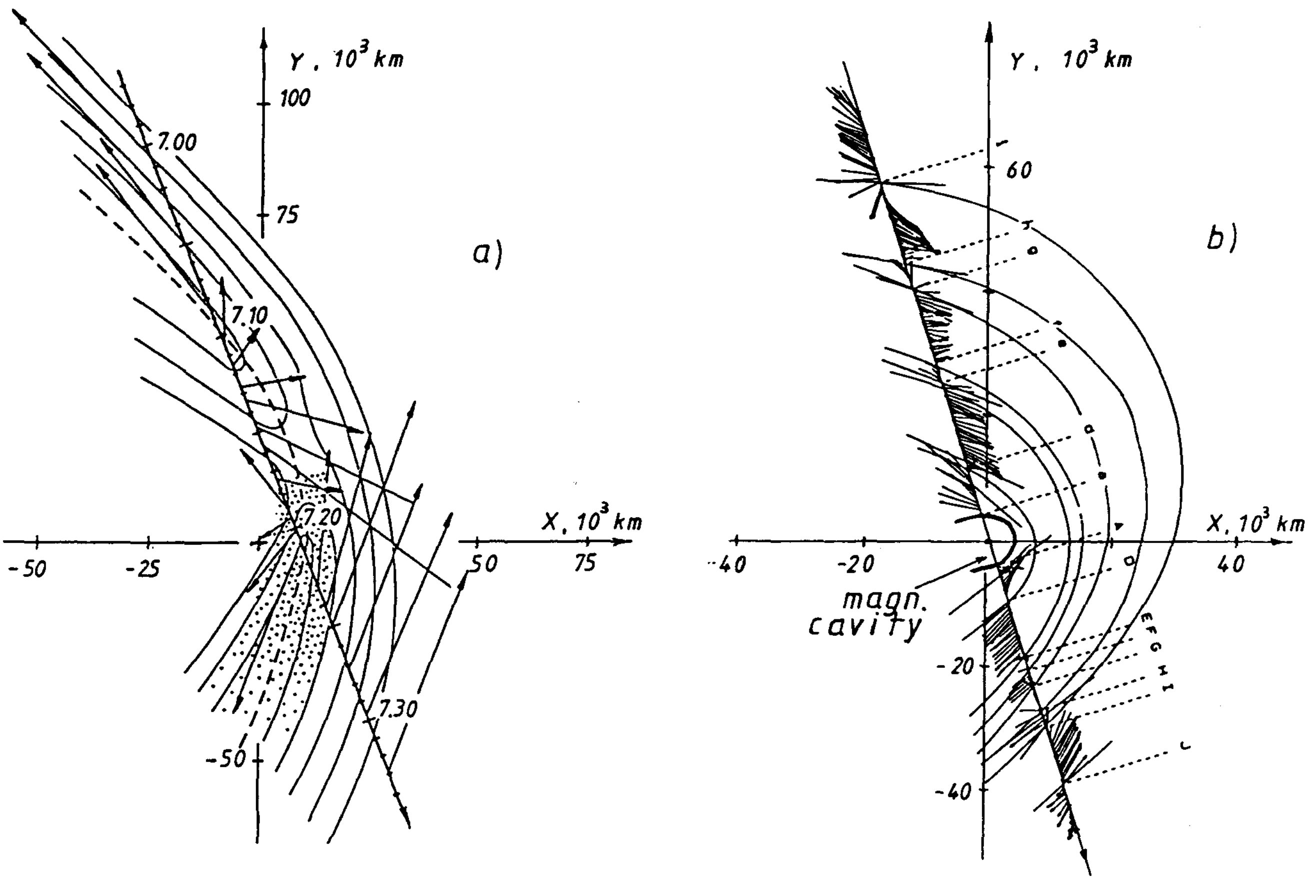

Fig. 7. Overall topology of magnetic field around the closest approaches of VEGA-1 (a) and Giotto (b). The dotted area represents the region in which the burst of accelerated ions (see Figure 3) was observed.

3.2 Unusual fluxes of ions with energies 100-1000 ev in the cometary plasma region.

In the region downstream of the cometopause (in the cometary plasma region), there were no observations of significant fluxes of ions in the direction from the sun except for the VEGA-1 measurements which observed rather intense ion fluxes (F ~ (5 - 8) x 10^9 cm^{-2} s^{-1} by the Sun-oriented electrostatic ion analyzer and Faraday cup) with energies 100 - 1000 eV for five minutes (from 7.19 UT to 7.24 UT, see Figure 3) soon after closest approach.

A group of scientists from the Space Research Institute, USSR Academy of Sciences, and the Max-Planck Institut fur Aeronomie have analyzed this event [Verigin et al., 1987]. Omitting their arguments we should only note that the analysis showed the following: at cometocentric distances of ~ 10^4 km the ion fluxes were observed in the vicinity of the surface which separates the regions with oppositely-directed magnetic fields (the dotted region in Figure 7a). They could have been accelerated in the process of reconnection of magnetic fields, and thus would leave the region of reconnection (around the x-point) with the velocity v directed along the separatrix surface. It was shown that in order to appear in the FOV of the ion sensors oriented towards the Sun (with due account of the relative velocity of the spacecraft and the cometary nucleus), it is necessary that v should be > 35 km/s. In this case, the energy of the detected water-group ions should be > 200 eV in the spacecraft-fixed system of coordinates; this is in agreement with measurement results. Then from ion flux measurements, the concentration of accelerated ions can be estimated as (1 - 2) x 10^3 cm^{-3}, which also corresponds to the estimates made from the data of the Faraday cup oriented to the ram direction.

Thus, from the independent but self-consistent results of measurements of the magnetometer, the electrostatic analyzer, and the Faraday cup, the conclusion was reached that the unusual five-minute burst of the cometary ion flux observed near the spacecraft closest approach to the cometary nucleus is caused by the directed motion of water group ions accelerated up to a velocity of several tens of km/s. The acceleration of these ions could be due to the reconnection of magnetic fields with opposite polarity retarded by the cometary plasma.

3.3. The "mystery region" in the electron component of plasma detected form the Giotto spacecraft.

Figures 8a and 8c refer to the VEGA-2 electron EA analyzer [Gringauz et al., 1986b] and Figure 8b and 8d - to the Giotto EESA instrument data [Reme et al., 1987]. Comparing the VEGA-2 and Giotto data, for the portions of the trajectories in

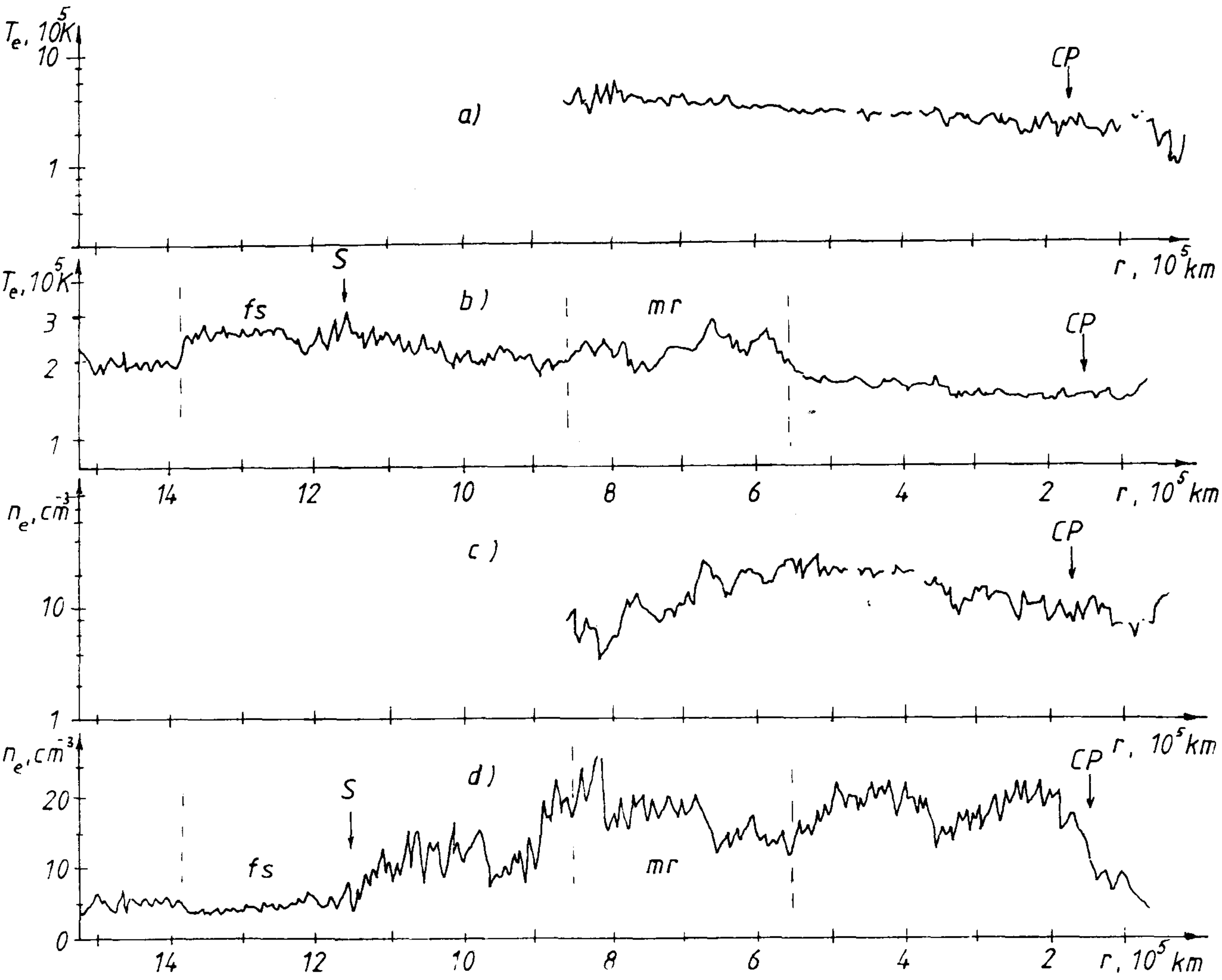

Fig. 8. Comparison of cometocentric profiles of elecron temperature (a, c) and density (b, d) estimated from VEGA-2 PLASMAG-1/EA data (a, b), and from Giotto EESA/RPA data (c, d).

the region called "mystery region" ("mr") by the authors of the Giotto experiment, one can see that in this region the electron temperature does not decrease with decreasing r and even increases (is varying) from time to time, according to the Giotto data, but is decreasing almost monotonically according to the VEGA-2 data. We can suggest that the different peculiarities of the electron temperature variations seen in these two cases are associated with the difference of conditions in interplanetary space. Any other explanations for the behavior of the plasma's electron component in the "mystery region" require an explanation for the absence of such behavior during the fly-by of VEGA-2. It seems to us that the "mystery region" peculiarities should be regarded as a result of nonstationary effects.

3.4 The magnetic field "pile-up boundary"

Figure 9 shows the results of measurements of the magnetic field absolute value made from VEGA-1 (a), VEGA-2 (b) [Riedler et al., 1986] and Giotto (c) [Neubauer et al., 1987]. At r ~ 1.35 x 10^5 km, at the inbound leg of the trajectory, there is a jump in the Giotto data called the "pile-up boundary" (PB) by the authors of the experiment. Approximately at the same distance the cometopause (CP) is observed in the VEGA-1, 2 data however, any dramatic feature like the "pile-up boundary" has not been detected in the VEGA magnetic data.

The curve (c) illustrates that the pile-up boundary was not observed for the case of Giotto on the outbound leg of the trajectory, so the arrow designated PB was drawn arbitrarily at this position of the trajectory.

The difference between the VEGA-1, 2 and Giotto magnetic data within the interval (1 - 2) x 10^5 km, and the absence of the pile-up boundary signature at the time when Giotto was receding from the nucleus, give grounds to the suggestion that this boundary should also be referred to as a non-stationary event.

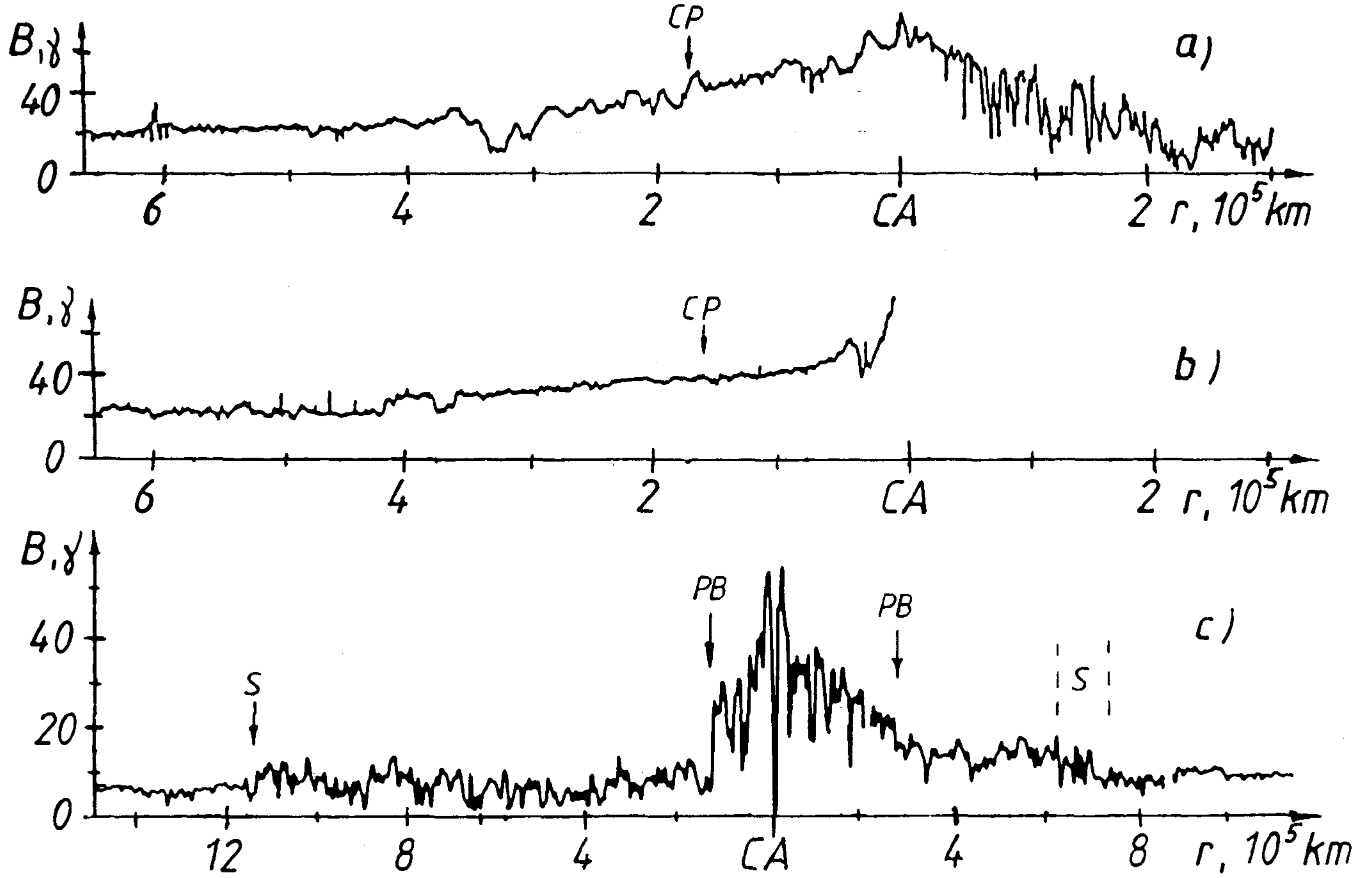

Fig. 9. Cometocentric profiles of magnetic field absolute values as measured by MISHA magnetometer onboard VEGA-1 (a) and VEGA-2 (b), and onboard Giotto (c).

3.5 Precipitation of electrons with energies ~ 1 kev near r ~ 10^4 km.

At a distance of (1.5 - 2.5) x 10^4 km from the nucleus, VEGA-2 recorded electron fluxes with energies of about 1 keV (note that the electron analyzer was oriented perpendicular to the ecliptic plane). Similar electron fluxes were not observed during the Giotto flyby near the cometary nucleus. Thus, it is also a nonstationary event.

Figure 10a illustrates the growth of the peak in the spectrum of electrons at E ~ 1 KeV (VEGA-2). Figure 11 (top spectrum) shows the energy spectrum of electrons detected on March 9th, 1986 from VEGA-2 at a distance of 1.5 x 10^4 km from the nucleus (the bottom spectrum was also recorded by the same instrument two days after the encounter with the comet on March 11th, 1986). The appearance of auroral electrons in the upper atmosphere of the Earth is also a typical non-stationary event. Substorms in cometary magnetospheres (Figure 10b) were predicted by Ip and Mendis [1976], and Ip and Axford [1982].

During the VEGA-2 flyby near the nucleus, the comet was not observed simultaneously in the optical and UV bands. However, the presence of sporadic precipitation of electrons in the atmosphere of Halley's comet is confirmed by non-simultaneous remote observations of this comet in the UV range. The IUE satellite observations made on March 18-19th, 1986 showed that for 37 minutes between measurements of two spectra, the CO^+ ion line intensity decreased by about 4 times whereas the OH line brightness remained practically the same [Feldman et al., 1986]. The authors explain this effect by additional ionization by sporadic fluxes of electrons similar to those observed from VEGA-2.

The 1536 Å line was observed in the UV spectrum recorded on February 26th, 1986 during the rocket experiment. This oxygen line cannot be excited by solar radiation but can be caused by impact of energetic electrons in the inner region of coma [Woods et al., 1986].

Using the data of electron measurements made from VEGA-2 and Giotto, the authors of rocket UV observations performed on February 26th, 1986 and March 13th, 1986 indicate that the presence of impact ionization by electrons can solve the so-called "carbon puzzle in the inner coma" (the excess of atomic carbon at $r < 10^5$ km which cannot be explained by photodissociation of carbon-bearing molecules). At $r > 3 \times 10^5$ km the amount of carbon is satisfactorily explained by photodissociation of carbon-bearing molecules [Woods et al., 1987].

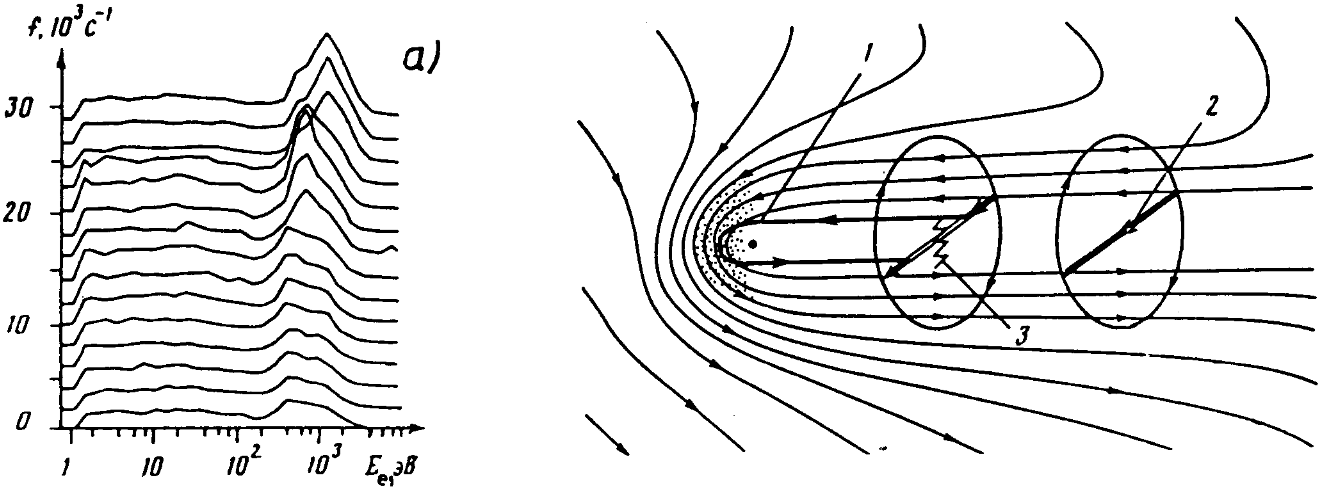

Fig. 10. Results of electron spectra measurements in cometary plasma region (r ~ (24.7 - 14.5) x 10^3 km by VEGA-2/EA analyzer (a), and schematics of "cometary substorm" processes (b). 1 - tail aligned current discharging into the coma, 2 - cross tail current, and 3 - partial interruption of the cross-tail current.

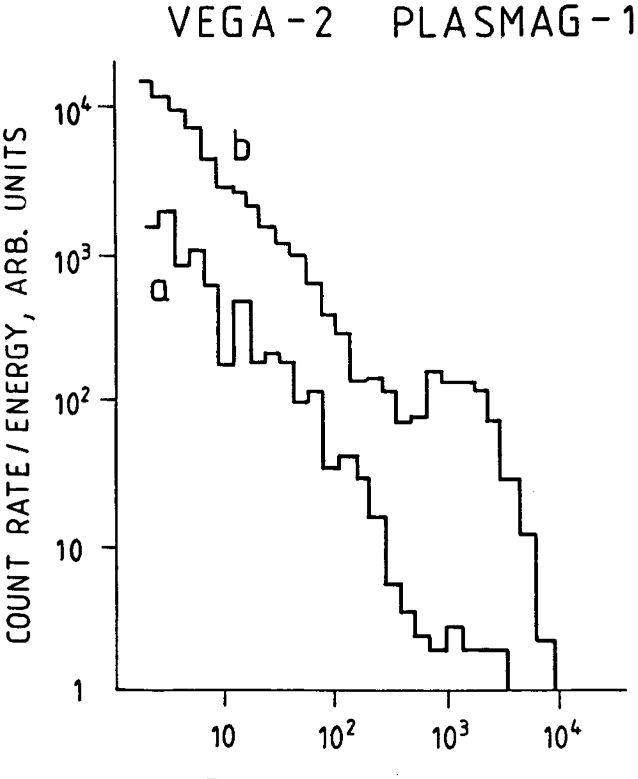

Fig 11. Two electron spectra as measured by the VEGA-2 electron analyzer in solar wind (a, 7.03 UT, March 11th) and near the closest approach (b, 7.16 UT, March 9th). Notice the occurrence of kev electrons close to the nucleus.

4. Conclusion

An attempt has been made above to separate the non-stationary events (not always occurring at ~ 1 a.u.) from the permanent events which had been observed in the head of Halley's comet on three spacecraft - VEGA-1, VEGA-2 and Giotto, which encountered the comet during March 1986. Permanent events should always take place when comet Halley passes at distance of 1 a.u. from the sun, regardless of conditions in the interplanetary medium or variations in gas production by the comet due to its nuclear rotation.

The above analysis employed two criteria: (i) the repetitive character of results obtained from all spacecraft flying near the cometary nucleus, and/or (ii) the existence of a clear physical understanding of the observational results.

The permanent events include the near-cometary bow shock, the cometosheath, with its unique energy distribution of ions, the systematic cooling of electrons in this region, the cometopause, and the tangential discontinuity near the cometary nucleus.

Among nonstationary events observed (boundaries, discontinuities, and so on) there are the unusual burst of ions with energies 100-1000 eV recorded in a direction from the Sun in the region of cometary ions at r ~ (1 - 2) x 10^4 km, the magnetic field pile-up boundary (in the region of the cometopause), the mystery region, and the precipitation of energetic electrons with ~ 1 keV at r ~ (1.5 - 2.5) x 10^3 km.

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