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COMETOPAUSE REVISITED

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ABSTRACT

The existence of the cometopause discovered by Vega-2 plasma observations in comet Halley's coma /1,2/ was recently questioned by Rème et al. /3/ based on their interpretation of Giotto data. This paper discusses the earlier presented Vega-2 observations with some new aspects supporting the existence of a boundary between the solar wind controlled cometosheath and the heavy cometary ion dominated plasma region.

INTRODUCTION

On the basis of ion energy spectra observed by the Plasmag-1 instrument aboard Vega-2, Gringauz et al. /1,2/ discovered the cometopause. It was described as a relatively sharp "chemical" boundary separating the solar wind controlled external and the heavy cometary ion dominated inner regions at $\sim 1.6\times 10^5$ km from comet Halley's nucleus. In agreement with the fact that the cometopause was not predicted by global MHD models, a comprehensive analysis of plasma and field data showed that neither of the flow parameters changed dramatically at this boundary /4/.

The discovery of the cometopause has raised extended discussions, especially when Gringauz and Verigin /5/ suggested that it must be a permanent boundary in the plasma environment of the comet. A broader compositional transition region was observed in the Giotto Ion Mass Spectrometer (IMS) data /6/ and in the Johnstone Plasma Analyser (JPA) data /7/ at cometocentric distances $2-1\times 10^5$ km where cometary ions became dominant over solar wind protons and alpha particles. In a recent review of Giotto plasma observations, Rème et al. /3/ declared that there is no evidence for a permanent and steady "cometopause" at comet Halley in spite of the fact that the term "cometopause" has been widely used.

VEGA AND GIOTTO PLASMA OBSERVATIONS

The Plasmag-1 instrument package had two spherical electrostatic analysers to measure the energy spectra of solar wind and cometary ions. The Cometary Ram Analyser (CRA) had an acceptance angle of 14°×32° centered on the ram direction while the Solar Direction Analyser (SDA) had an acceptance angle of 38°×30° centered on the solar direction /1/. The energy/charge range was 15 – 3600 eV/Q for CRA (devided into 120 logarithmically spaced intervals) and 60 – 27000 eV/Q for SDA (60 intervals). According to the color scaled energy spectra shown in Fig. 1. of Gringauz et al. /2/, a sudden decrease of proton fluxes and a simultaneous increase of heavy ion fluxes was observed at a cometocentric distance of $\sim 1.6\times 10^5$ km. This sudden change in the ion distribution occurring within about 10^4 kms was interpreted as a boundary separating the solar wind controlled external region (cometosheath) from the cometary plasma region where heavy cometary ions dominate the plasma flow /1,2/. Fluctuations having a characteristic period of about 1 min are also seen in the spectra around the transition. These were later explained as a result of large-scale MHD waves /4/ since oscillations of the same period were also observed in the electric field and in the perpendicular magnetic field component. While wave activity increased in the whistler and lower hybrid frequency range around the cometopause, neither of the flow parameters showed any abrupt change. Therefore this boundary observed by Vega-2 has never been described as a magnetohydrodynamic discontinuity.

The Giotto spacecraft carried three plasma analysers each having two independent detectors /8/. The RPA-EESA observed electrons, the others detected ions of solar wind and cometary origin.

Two ion spectrometers oriented into the ram direction performed mass analysis of heavy cometary ions in the inner coma of comet Halley. RPA-PICCA had a viewing angle from −6° to +6° while IMS-HIS covered the range from −3° to +22.5° with respect to the ram direction. The remaining three ion detectors which detected also particles of solar origin did not cover the ram direction. Their viewing angles were relative to the ram direction: IMS-HERS 15°−75° (continuous), JPA-IIS 15°−165° (with gaps), and JPA-FIS 35°−180° (continuous). Since Giotto was a spin-stabilized spacecraft and its ion spectrometers separated different species, this spacecraft provided a much more detailed description of the three-dimensional plasma distribution compared to the plasma observations performed aboard Vega-2. However, protons were not measured in the ram direction.

On the basis of ion energy spectra measured by JPA-FIS, Amata et al. /9/ identified the cometopause at $\sim 1.7 \times 10^5$ km where the relative importance of proton and water group ion peaks changed. Formisano et al. /10/ found a large decrease in the centre of mass speed (computed for protons and water group ions from JPA-FIS and IIS measurements) at $\sim 1.8 \times 10^5$ km interpreting it as the cometopause. Goldstein et al. /11/ and Neugebauer et al. /12/ questioned the above results since the angular coverage of the JPA sensors was limited towards the ram direction. On the basis of IMS data (HERS and HIS), they stated that the hydrodynamic parameters of the different plasma components show no sharp transition between the solar wind dominated and the cometary plasma regions.

Giotto observed an abrupt increase in the magnetic field at 1.35×10^5 km from the nucleus /13/. At this time JPA /7/ and IMS-HERS /14/ detected a sudden sharp decrease in the solar wind proton density. Also, there was a change in the electron parameters /15/, but no jump was observed in the heavy ions. This MHD discontinuity was called the pile-up boundary. No similar boundary was observed by the Vega spacecraft. The Vega-2 cometopause and the Giotto pile-up boundary were found to be totally different when their characteristic features were compared /16/. Recently, Rème et al. /3/ suggested that the pile-up boundary may be a transient effect (due to the passage of an interplanetary disturbance) and the cometopause does not exist.

DISCUSSION

One of the arguments against the exsistence of the cometopause has been that color scaling (like Fig. 1 of Gringauz et al. /2/ and Fig. 3. of Gringauz et al. /1/) may exaggerate relatively smooth changes. For comparison, rainbow colors with smooth transitions are used here in Fig. 1 to show 20 sec averages of the ion energy distributions measured by CRA and SDA (count rates are given in arbitrary units, background is subtracted). The time interval from 05:00 UT to 07:17 UT corresponds to cometocentric distances from 6.5×10^5 km to 1.5×10^4 km. While SDA spectra show no dramatic change around 6:45 UT ($\sim 1.6 \times 10^5$ km from the nucleus), the plasma composition suddenly changes in the section of velocity space observed by CRA. The higher energy part of the last 40 mins boxed in the CRA spectra corresponds to Fig. 1 of Korth et al. /17/ showing the distribution of cold cometary ions measured by RPA-PICCA aboard Giotto. Electron spectra are not presented here since they do not show any characteristic change around the cometopause.

The CRA and SDA aboard the three-axis stabilized Vega spacecraft had limited acceptance angles and there was a gap of ~44° between the field of view of the two analysers. It is impossible to determine the densities of the two populations around the cometopause since the main part of the plasma flow is probably not seen by either detector. In order to get an estimate of the relation of the light and heavy ion population, counts measured in the energy interval of light ions (protons and alphas) and heavy particles were added up separately. In Fig. 1 dashed lines show the energy limit between the light and heavy ions. Since the energy range of both analysers was logarithmically spaced (with different spacings for CRA and SDA) and the relative energy resolution was the same for all energy intervals, the summarized counts shown in Figs. 2a and 2b represent comparable ion flux intensities of the two populations as measured by CRA and SDA, respectively. Ion flux intensities shown in Fig. 2a are not comparable to those shown in Fig. 2b.

At about 1.6×10^5 km from the nucleus (6:45 UT), there is a sudden drop in the proton intensity of CRA which together with the steeper increase of the heavy ion intensity at the same cometocentric distance produces the sharp decrease in the ratio of the two populations (about an order of magnitude within $1 - 2 \times 10^4$ km). This narrow region was originally called the cometopause /2/ where heavy ions outnumber protons as seen by the CRA. (The JPA aboard Giotto observed the number density crossover of the two populations at about 2×10^5 km /7/.) On the basis of Figs.

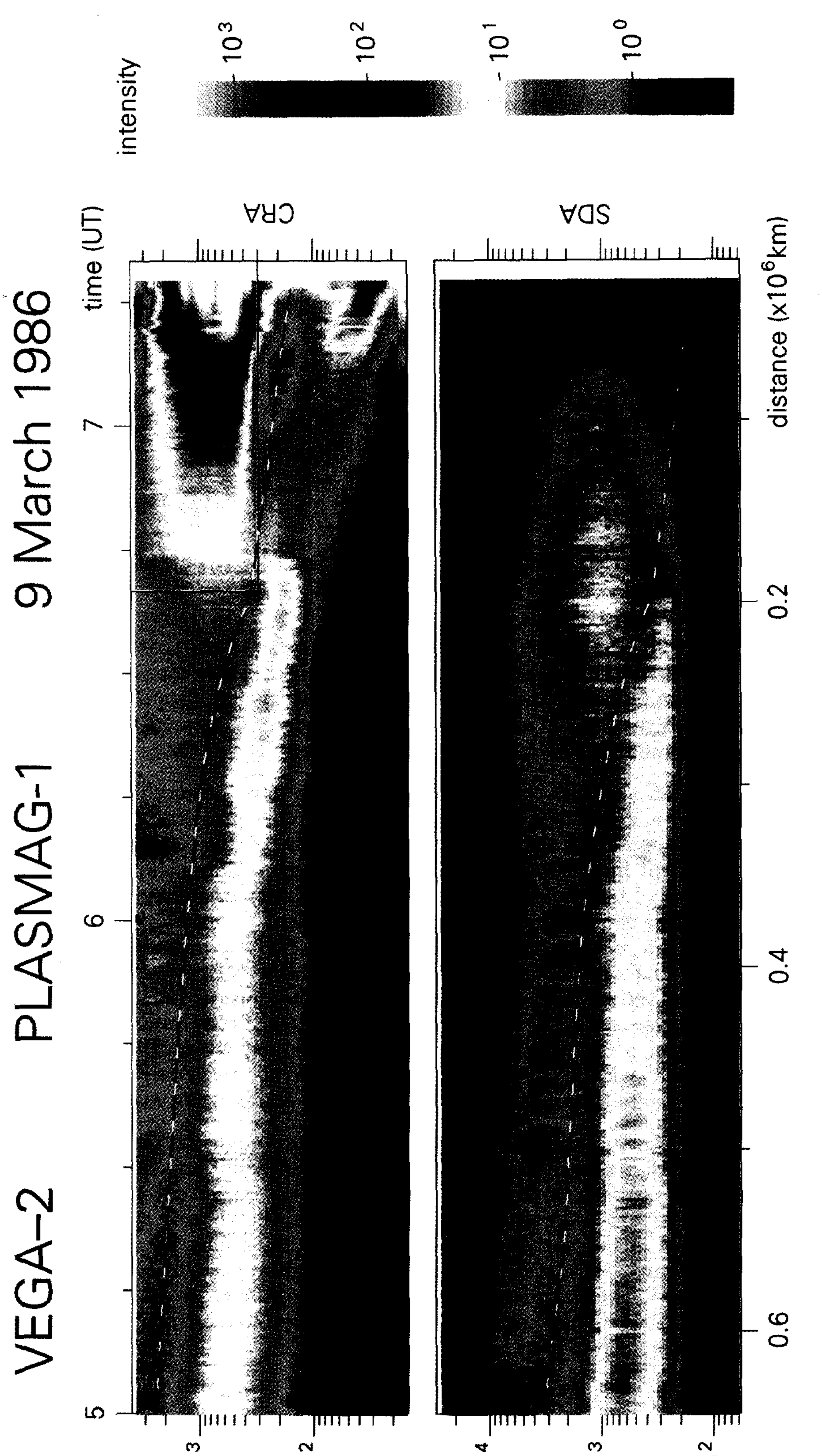

Fig. 1. Ion energy spectra measured in the ram (CRA) and solar (SDA) direction.

1 and 2a, it is difficult to prove what portion of the light ions is of solar origin upstream of the cometopause. The intensity of this population is surprisingly stable at cometocentric distances of 6 – 1.6×10^5 km and the deceleration is very slow. On the other hand, the intensity of heavy ions show a general increasing trend superposed by fluctuations which can be explained by possible changes in the density of the pickup shell. Also, the higher energy part of this population was outside of the range of the CRA farther upstream of the cometopause.

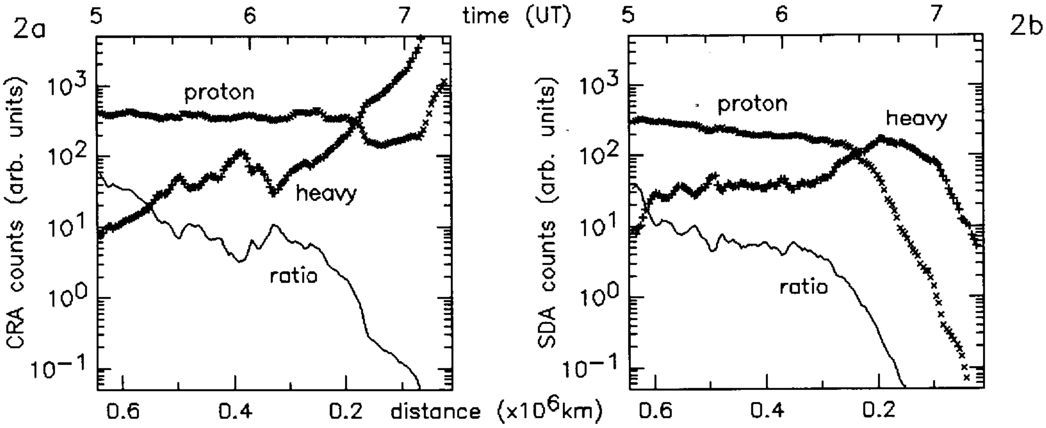

Figure 2. Intensity of protons and alphas (×), heavy ions (+), and the ratio of the two populations (continuous line) as observed by the CRA (2a) and SDA (2b).

According to Figs. 1 and 2b, the SDA observations do not indicate the existence of a sharp cometopause or any other discontinuity. The intensity of the shocked solar wind protons is slowly decreasing as the flow is getting out of the field of view of the detector. This trend gets steeper at $\sim2.5\times10^5$ km. The intensity of heavy ions is increasing at the same distance, but with further deceleration and cooling of the flow, the pickup ring is also getting out of the range of the SDA.

As estimated by Galeev et al. /4/, the bulk speed of the proton flow (presuming that the alpha population is a minor part) is about 200 km/s relative to the comet just upstream of the cometopause. On the downstream side of the cometopause, however, the velocity of the heavy ion population (if the majority of the ions belong to the water group) is only about 60 km/s in the cometary frame of reference. At the cometopause where the density of cometary gas is around 4×10^3 cm^{-3} /1/ and the solar wind is relatively fast, charge exchange is getting increasingly important for removing solar protons and producing cometary ions. The increasing ionization leads to an instability caused by the large velocity difference between the solar wind protons and the newly born cometary ions as the slowly moving heavy ion stream is getting dominant in the flow. This instability results in large-scale MDH fluctuations. At the time of the Giotto encounter, solar wind velocity was much lower ($\sim$ 250 km/s just upstream of the bow shock) than in the case of Vega-2. Downstream of the shock the velocity difference between the two components was small as observed by JPA /7/. At $\sim2\times10^5$ km, the bulk speed of both components was below 50 km/s.

On the basis of Plasmag-1 observations, we cannot tell how sharp might be the transition from the solar wind dominated outer region to the heavy ion dominated inner region in those sections of velocity space which were not seen by the instrument. A smooth transition was observed in the solar direction while both streams were gradually moving out of the viewing angle of the SDA. The sudden change observed in the ram direction suggests that there must be a basic change in the relation of the two streams. Pickup shell distributions will disappear for heavy ions around the cometopause since these ions form the main stream of the flow downstream as illustrated by Fig. 3 of Galeev et al. /4/. This change in the distribution function could explain why the proton flux suddenly decreases in the field of view of the CRA.

CONCLUSIONS

Between the bow shock and the contact surface both Vega and Giotto observed two plasma regions: a solar wind proton dominated sheath and a heavy ion dominated region close to the nucleus. There were, however, contradicting observations: a) Plasmag-1 detected a relatively sharp boundary in the ram direction, whereas the Giotto plasma analysers could not identify anything similar as neither of them observed protons in the ram direction; b) the difference between the proton and heavy ion velocity was significant around the ion flux intensity crossover region for Vega-2, while the flow velocities were close in the case of Giotto. Also, Giotto observed a magnetic pile-up boundary, but there is a broad concensus that it is different from the cometopause.

The conflict of opinions on the cometopause may be resolved if the sharpness of the transition layer between the two regions depends on the velocity relation of the proton and heavy ion component. The difference in flow velocities may result in an instability influencing the charge exchange process. There are neither enough theoretical understanding of cometary magnetospheres, nor enough experimental data to assess the effect of velocity differences between the two plasma streams in the density crossover region.

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