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TITLE: Giotto Observations of the Bow Shock at Comet Halley

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GIOTTO OBSERVATIONS OF THE BOW SHOCK AT COMET HALLEY

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ABSTRACT

Preliminary results from the JPA instrument on Giotto indicate that Comet Halley, even on the flanks, has a bow shock which moves backwards and forwards over the spacecraft. To understand the structure properly will require more detailed investigation of the relationships between three particle populations, cometary ions, solar wind ions and electrons.

INTRODUCTION

One of the most important tasks for the plasma instrumentation on Giotto was to determine whether a bow shock existed, as expected /1/ and, if so, to investigate its structure. Results from the International Comet Explorer (ICE) at Comet Giacobini Zinner, have been equivocal so far /2/ about whether the structure observed at a distance of 10^5 km from the nucleus was a bow shock or not. Some investigators have preferred to refer to it in a non-committal way as a bow wave /3/.

OBSERVATIONS

The JPA instrument /4/ on Giotto includes two three-dimensional positive-ion sensors; one of the sensors, the Implanted Ion Sensor, uses time of flight to discriminate between different masses. Its five individual sensors view at different angles over a wide angular range, but do not provide continuous angular coverage. In Figure 1 the total count rate, integrated over ion energy and angle, is shown for two of the mass groups. The upper curve is for cometary ions in the mass range 13-25 amu; the lower curve is for solar wind protons, mass range 0.8-1.5 amu. The dominant feature in each curve on the inbound leg is the increase, by a factor of 12.5 for cometary ions and 10 for solar wind protons, which takes place between 18 and 20 hrs GRT (Ground Received Time). The increase in the cometary ions occurs more rapidly than would be expected on the basis of photoionisation scale lengths /5/. Two other processes, one instrumental, the other cometary, probably also contribute. If the angular distribution changes, then more of the flux can move into the fields of view of the sensors. This process could account for all the increase, but we believe that there could also be a real increase in the cometary ion flux which should be attributed to another ionisation mechanism. The increase in the solar wind begins at 19:30, as indicated by the vertical dashed line, but the increase in the cometary ions begins approximately one hour before at 18:30. The period between 18:30 and 19:30 coincides with the foreshock region defined by Reme et.al. /6/ which is associated in their data with an increase in the electron temperature. It remains to be determined whether the change in electron temperature is responsible for the increase in ionisation by electron collisions, or whether it is a consequence of the increase in cometary ion flux.

Also at 18:30 GRT, simultaneously with the electron temperature increase, the amplitude of waves in the solar wind increases as shown in figure 2. The fluctuations occur in all the parameters plotted, but the most significant changes occur in the speed (dominated by the Vx component). During some of the disturbances the speed decreases by more than 50km/s. While there are changes in temperature correlated with the speed changes, there is no increase in the average temperature of the solar wind distribution, as would be expected from crossing a bow shock. In fact initially the temperature decreases when the speed decreases. This may

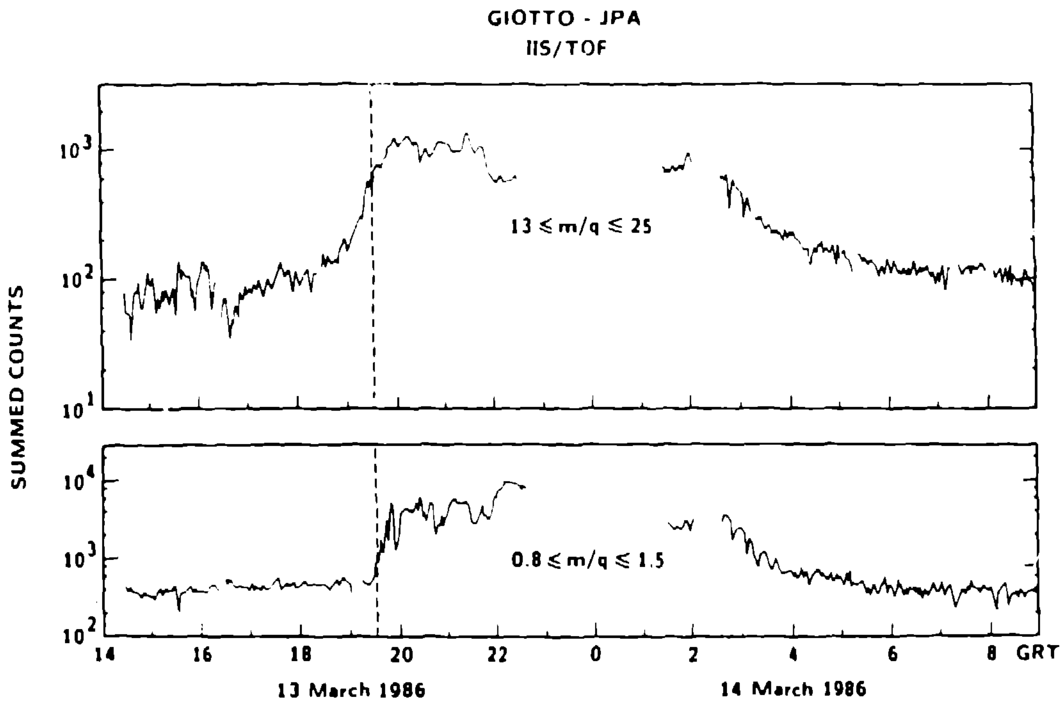

Figure 1

The total flux, integrated over energy and angle, for two mass groups. No allowance is made at this stage for fluxes in the angular sectors between the individual analysers in the Implanted Ion Sensor. The upper panel shows water-group cometary ions; the lower panel shows solar wind.

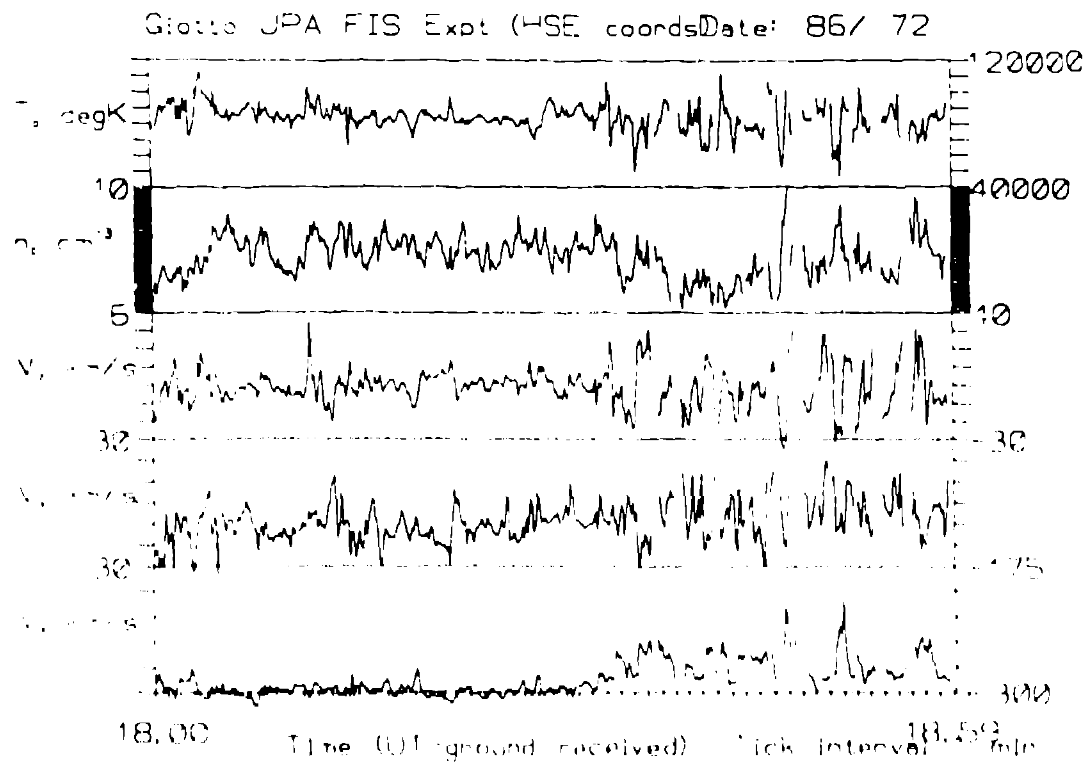

Figure 2

Solar wind proton bulk parameters obtained from the fast Ion Sensor. Flow velocity components are given in Halley Solar Ecliptic coordinates. At 18:30 GRT, the spacecraft crosses the foreshock and the level of waves in the solar wind increases subtantially.

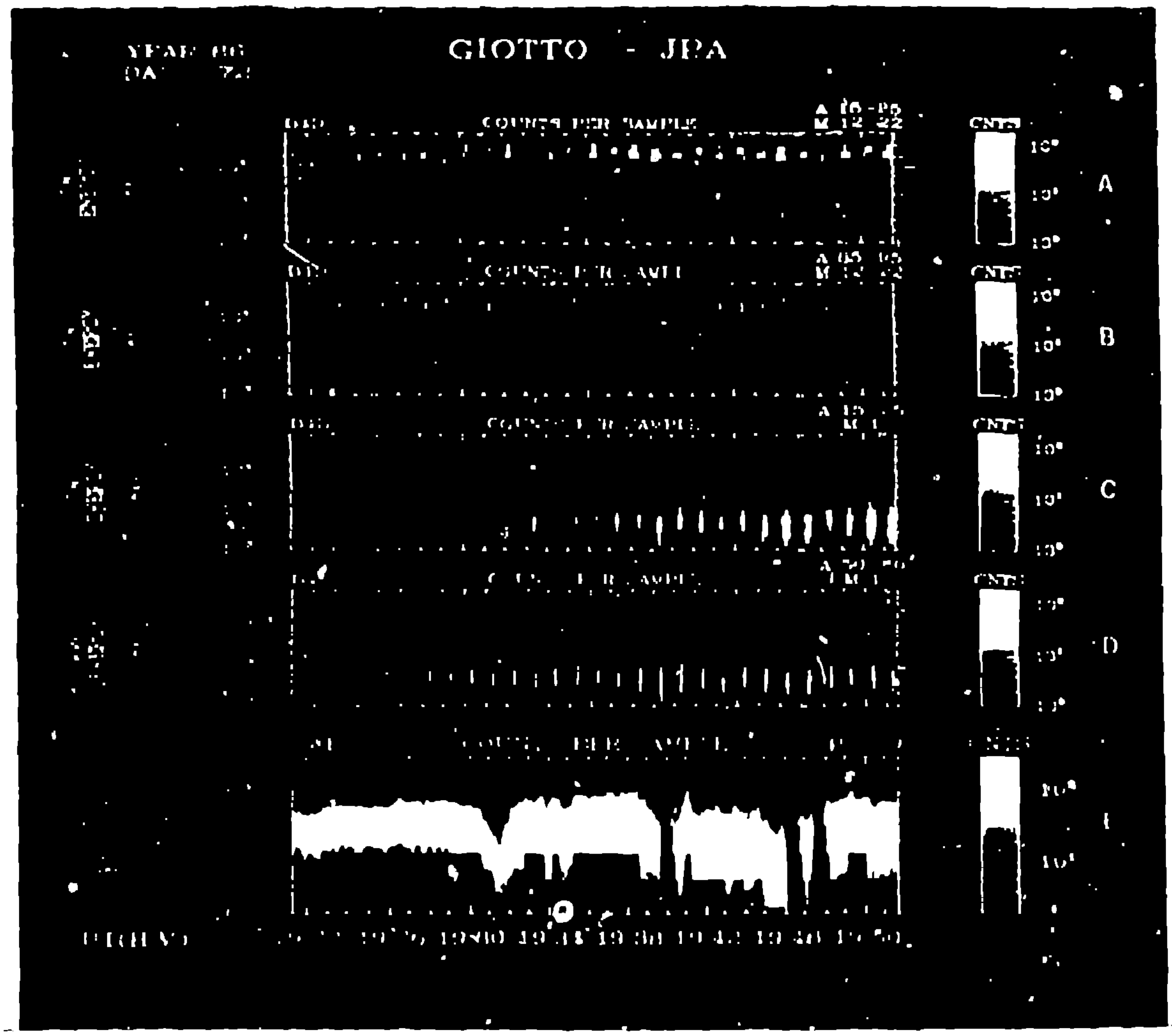

Figure 3

The top four panels A,B,C,D show high resolution data from the Implanted Ion Sensor for the period 19:21:30 to 19:51:30 GRT. Each feature is a minipanel of energy (vertical scale) by spin angle (horizontal scale) plotted within the time it was collected. Each distribution is essentially symmetrical about the solar direction. The bottom panel E shows high resolution solar wind data from the Fast Ion Sensor. The time scale is UT at the time the signal was received at the ground.

be related to the unshocklike anticorrelation between electron density and electron temperature found at comet Giacobini Zinner /7/.

This behaviour continues until 19:31 GRT when there is a very large decrease in the solar wind speed. This is shown in the bottom panel of the composite plot of figures 3 and 4. These data were obtained by the Fast Ion Sensor in the solar wind mode. The sensor has an energy autoranging facility which ensures that the narrow energy range of the solar wind mode is always centred on the solar wind distribution. If the maximum count rate in the spectrum drops below a preset value, the sensor begins to cycle through the complete energy range in case the sensor has "lost" the distribution. This would occur if the distribution is deflected out of the field of view, or is broadened as the result of an increase in temperature. The range cycling occurs as a result of both effects several times during the period of figures 3 and 4 and is seen in the panel as gaps in the spectrogram. Eventually at 20:03 GRT the cycling becomes continuous until a command disabling the autoranging and fixing the sweep in the lowest energy range is seen to be acted on at 20:20 GRT.

The top four panels A,B,C,D show data from the Implanted Ion Sensor for two different polar angles for each of two mass groups. Each plot is effectively divided into minipanels 64 secs long which show an energy (vertical)/spin phase angle (horizontal) plot in the time period in which it was collected. Panels C and D show protons of both solar wind and cometary origin. The two angular bins cover the solar wind direction (panel D) nearly the same as the Fast Ion Sensor plot and a direction closer to the spacecraft velocity vector

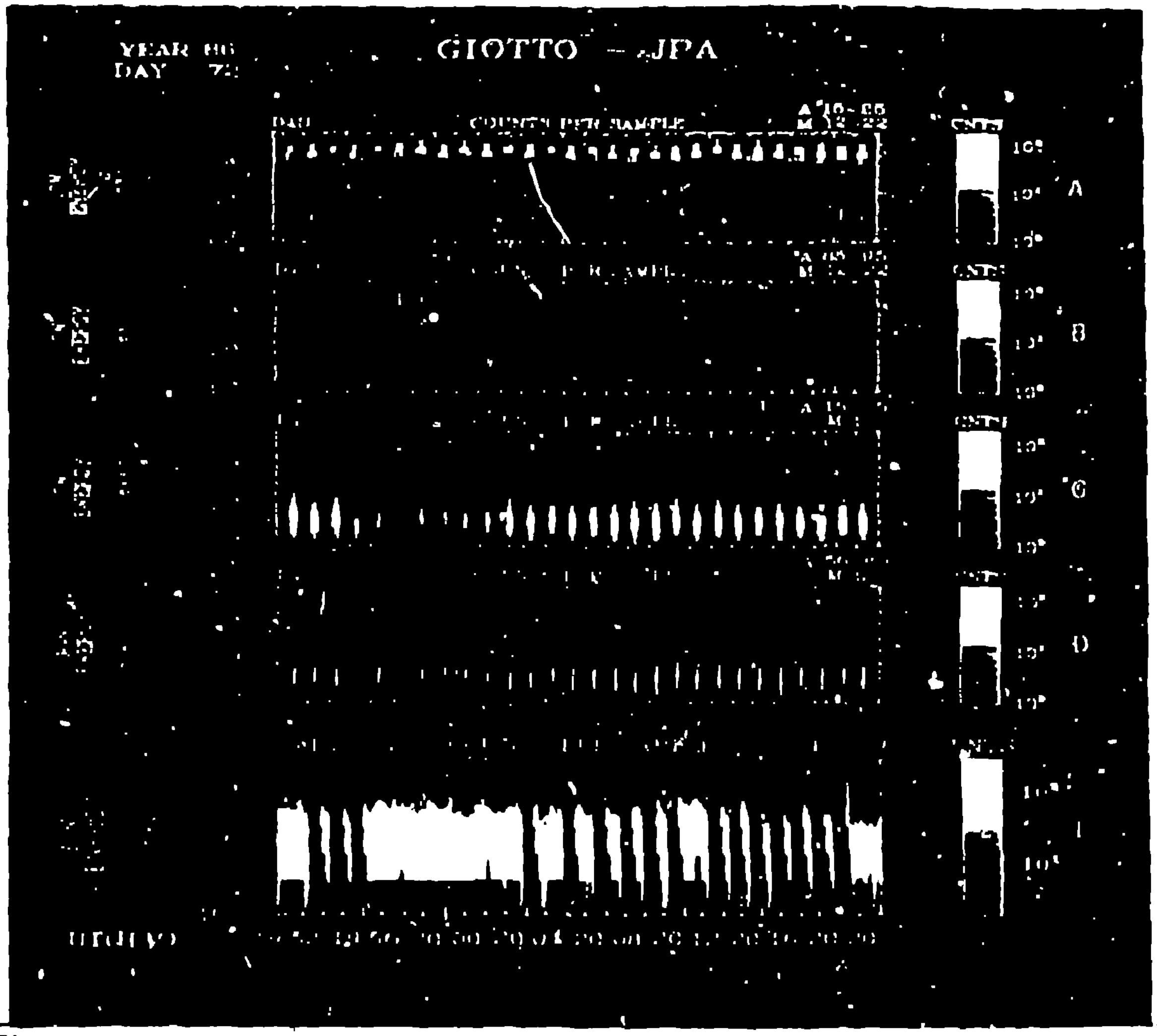

Figure 4

The same plot as for figure 3 for the period 19:51:30 to 20:22:00 GMT.

(panel C) into which the solar wind is deflected, as we shall see, by the shock wave. The two angles for the cometary ions (masses 13 to 25) are the direction approximately perpendicular to the magnetic field (panel B) and, the same as the proton plot, the direction into which the solar wind is deflected (panel A). These panels show the behaviour of three separate particle populations as the shock is crossed. The first is the population of heavy cometary ions. At the beginning of the plot the distribution shows some shell-like characteristics, but suddenly, at 19:30 GMT, just as the solar wind (panel E) begins its large decrease in speed, the distribution broadens, increases in flux, and the maximum energy increases. This trend continues throughout the plot, but is clearly initiated within the duration of one 64 sec minipanel, equivalent to a distance of 4300kms relative to the comet along the spacecraft trajectory. At this time the gyroradius of a water ion of 30keV is approximately 13,000km. The second population consists of protons of cometary origin, visible as a shell-like distribution at the beginning of panel C. Like the heavy ions described above, this population broadens in angle and energy within the 64 sec duration of a minipanel. However, the broadening occurs two minipanels, or 2 mins, later or 8500kms further on.

The behaviour of the solar wind is more complex. Whilst initially in panel D of the Implanted Ion Sensor, as the distribution broadens it moves to panel C where it appears at lower energies than the cometary protons. The first occasion it does so clearly is at 19:40 GMT, coincident with the observation of a second large decrease in solar wind speed by the

Fast Ion Sensor (panel E) and 10 mins after the broadening of the distribution of heavy cometary ions. For the following 40 mins, until 20:20 GRT it appears that this transition moves backwards and forwards over the spacecraft. In particular, between 19:57 GRT and 20:03 GRT, the spacecraft is in a relatively high speed flow (230km/s) below the speed observed at 19:28 (290km/s) but well above the speed at 20:20 GRT (180km/s), after which the spacecraft remains continuously in a thermalised solar wind distribution.

SUMMARY

Between 19:30 GRT and 20:20 GRT

(a) the solar wind flow speed is reduced from 290kms to 180km/s:

(b) the direction of flow changes by approximately 15°, in the sense at which it is deflected away from the comet-sunline:

(c) The temperature increases:

(d) the changes occur several times over distances of the order of a cometary ion gyroradius or less in such a way that it appears the boundary is moving backward and forward over the spacecraft /7/:

(e) The distribution of cometary ions, both protons and water group ions, becomes broadened before the solar wind does, with the more massive ions showing the effect first.

The shock identified as an increase in electron density by the electron detector in the RPA instrument /6/ coincides with the broadening of the distribution of cometary ions and the first major solar wind speed decrease at 19:30 GRT.

The feature observed by Giotto between 19:30 GRT and 20:20 GRT appears to be a bow shock since irreversible changes in velocity, density, and temperature occur over distances of the order of ion gyroradii along the spacecraft track. The structure of the shock is complex, involving three important particle populations with quite different behaviour, namely cometary ions, solar wind ions and electrons, in relationships which require more investigation to understand.

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