EXPLANATION AND MODELING OF THE PRONOUNCED DECLINE IN ENERGETIC PARTICLE FLUX INTENSITIES (OBSERVED RANGE – 100–300 KEV) RECORDED BY THE EPONA AND TUNDE-M INSTRUMENTS ON GIOTTO AND VEGA-1 ON APPROACHING THE COMETOPAUSE OF COMET P/HALLEY

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ABSTRACT

Energetic particle data were recorded on the Giotto and Vega-1 Missions in situ at comet P/Halley in the approximate energy range 100-300 keV (assuming that the ions recorded were of the water group) by the EPONA and Tunde-M instruments respectively. These data sets each show a pronounced decline in flux intensities as the cometopause was approached (1-2 X 10^5 km from the nucleus). Modeling of this decline on the assumption that the effect is primarily due to the charge exchange of high energy ions in collision with neutral cometary molecules, provides a satisfactory fit to the experimental data from both instruments.

INTRODUCTION

Data recorded by the energetic particle instruments EPONA and Tunde M, in the approximate energy range $E \approx 100$-300 keV, on the Giotto and Vega-1 spacecraft during the comet P/Halley apparition of 1986, individually show the occurrence of a pronounced decline in fluxes, as the cometopause was approached. Further, the Tunde M data indicates that the depth of the decline increased with energy. This latter effect, however, can be overestimated due to the high noise background present in the lowest energy record concerned. Accounts of EPONA and Tunde-M and of their similar method of measurement are contained, respectively, in /1/ and /2/.

The fluxes recorded by these instruments in the environment of comet P/Halley are interpreted in several papers (e.g. /3/, /4/) to have constituted water group ions. In the present paper an attempt is made to explain, and associatively model, the depletion effect.

POSSIBLE EXPLANATIONS

In attempting to explain the recorded depletion /3/ and /4/ have already suggested the presence of four influences. (1) Already ongoing deceleration of the plasma flow due to mass loading would contribute to the gradual disappearance of energetic ions from the higher energy channels of both instruments; (2) Escape of high energy ions would occur along the magnetic field lines which, close to the cometopause, are effectively open; (3) Gradient B drift, which causes a displacement dz of the guiding centre in the direction of $\vec{B}$ x grad B, should enhance effect 2; (4) There would be a contribution due to charge exchange when high energy ions collide with neutral cometary molecules. It is noted in /4/ that this latter influence should, however, be neglected since, firstly it is deemed to be too small by an order of magnitude to be significant and, secondly, this effect is expected to decrease rather than to increase with energy (in contradiction to what is observed).

Several comments on the various points mentioned above are pertinent here. (i) At the location concerned, 'fading' of pickup ions from the high energy channels would not be a large effect; (ii) Energetic particles moving along the magnetic field lines can both arrive at and escape from the locations successively occupied by the spacecraft; (iii) The displacement of the guiding centre in the grad B drift (calculated in /4/ to be < 35 X 10^3 km for 200 keV ions) is rather small compared with the distance over which the phenomenon is observed (~ 1.5 X 10^5 km). This displacement, additionally, takes place in a direction perpendicular to the spacecraft trajectory

($V_d \sim \vec{B}$ x grad B), where grad B is generally looking towards the comet, so that, again, ions are both coming in to, and exiting from the various locations successively occupied by the spacecraft; (iv) The contribution of energetic ion charge exchange to the depletion effect, considered to be too low by an order of magnitude in /4/ to explain the observations, is considered by the present authors to have been seriously underestimated, and it is necessary (see below) to multiply by a factor of $\sqrt{\left(\frac{2E}{M}\right)}/V_{flow} \sim$ 10-20, where M is the ion mass, in order to take into account fast rotation (1000-2000 km/s) of the energetic particles in the slow plasma flow considered.

Further, while it is true that the charge exchange cross section is decreasing with the increasing energy of the ions, this logarithmic decrease is very slow ($\sigma \sim (a - b \ In(E))^2$. Indeed it attains only 12% of the decrease in σ pertaining in the range 106-273 keV, and is accordingly well over compensated by the 60% increase due to multiplying by $\sqrt{(E)}$, thereby, again, allowing energetic ions to undergo charge exchange more effectively due to their longer path in the cometary neutral gas.

MODELING THE EFFECT

In considering energetic ion charge exchange, we take

$$dF \approx -F\, n_n\, \sigma(E)\, ds \approx -F\, n_n\, \sigma(E) \sqrt{(2E/M)}\, dt$$
$$\approx -F\, n_n\, \sigma(E) \sqrt{(2E/M)}\, dx/V, \qquad (1)$$

where F is the energetic ion flux; n_n is the neutral gas density; σ(E) is the charge exchange cross section; ds and dx are the distances along the particle trajectory and along the flow tube respectively.

Within the cometocentric distance range 5 X 10^4 – 5 X 10^5 km, the Giotto plasma flow velocity V (r) can be approximated by

$$V(r) \approx V_o \times (r/r_o) \qquad (2)$$

with $V_o \approx$ 30 km/s and $r_o \approx 10^{50}$ km (see Fig. 5, in /5/) In the case of Vega 1 however, the solar wind speed was approximately twice higher ($V_o \approx$ 60 km/s) and the neutral gas density about

$$n_n \approx n_o \times (r_o/r)^2 \qquad (3)$$

with $n_o = 10^4\ cm^{-3}$ in the case of Vega 1, /6/, and at a value about twice lower in the case of Giotto, /7/. Charge exchange cross sections can be calculated by extrapolating the Tables of Virin et al., 1979, /8/, using the expression

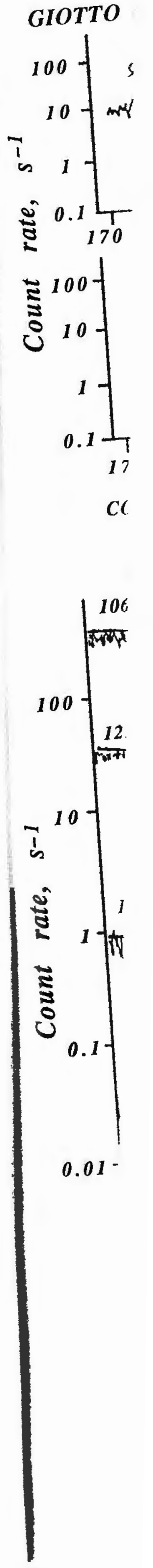
$$\sigma(E) \approx (a - b\ InE)^2 \qquad (4)$$

with a ≈ 3.07; 5.6 and b ≈ 0.24; 0.48 for the resonant process $0^+ + 0 \rightarrow 0 + 0^+$ and for the non resonant process $0^+ + H_2 0 \rightarrow 0 + H_2 0^+$ respectively. In the following estimations, we use an average of the two cross sections giving for (1)

$$F \approx F_o \exp\left(-\sigma(E) \sqrt{(2E/M} \int n\, dx/V\right)$$
$$\approx F_o \exp\left(-\sigma(E) \sqrt{(2E/M}\, n\, 2r/V\right) \qquad (5)$$

with a specific integration distance of about 2 r. Substituting (2,3) in (5) we obtain

$$F \approx F_o \exp\left(-\frac{2 n_o r_o^3}{V_o r^2} \sigma(E) \sqrt{\frac{2E}{M}}\right) \qquad (6)$$



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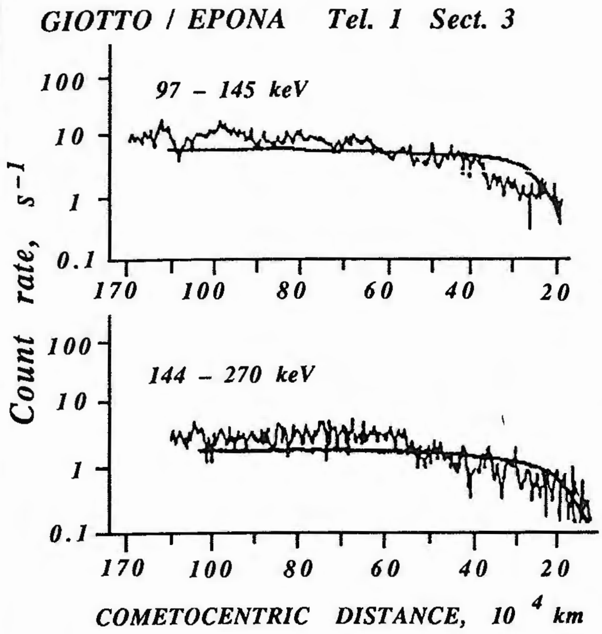

The results obtained by calculating the energetic flux profiles for Giotto and Vega 1 using (6) are shown by solid lines in Figs. 1 and 2 superimposed, respectively, on the experimental data recoorded in complementary directions by EPONA (Tel.1, Sector 3) and by Tunde-M. These comparisons show that the model provides a satisfactory fit to the data from both instruments.

Fig. 1; Superposition of the model (heavy curve) derived using (6) on ion profiles recorded by EPONA in Tel.1, Sector 3, in the energy ranges 97-145 keV (upper) and 144-270 keV (lower) in the vicinity of the cometopause of comet P/Halley on 13 March 1986.

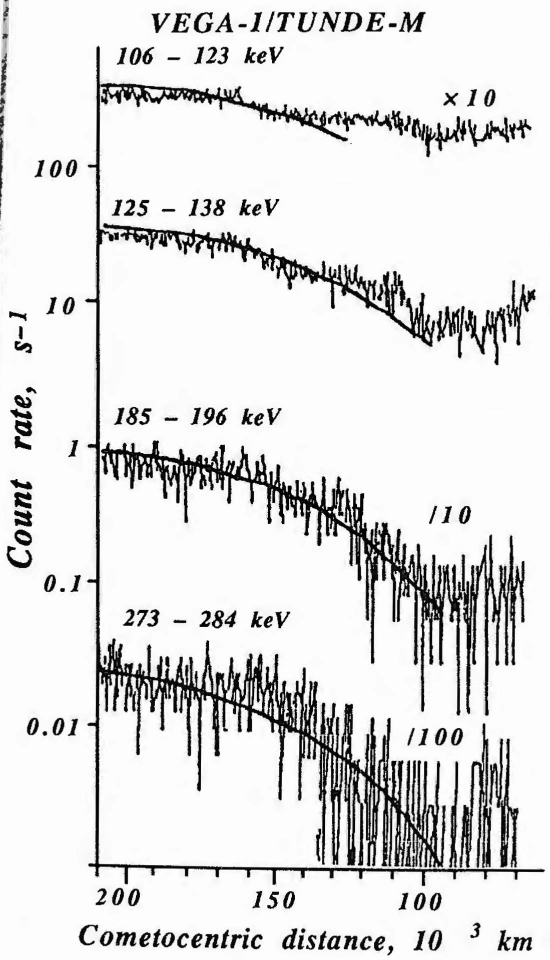

Fig.2; Superposition of the model (heavy curve) derived using (6) on ion profiles recorded by Tunde -M in the energy ranges 106-125 keV (upper); 125-138 keV; 185-196 keV and 273-284 keV (lower) in the vicinity of the cometopause of comet P/ Halley on 6 March 1986.

CONCLUSIONS

The statement in /4/ that the contribution due to the charge exchange of high energy ions i collision with neutral cometary molecules would be too low by an order of magnitude to explai the observed depletion in ion intensities between 330-160 X 10^3 km from the nucleus, ha been critically examined. It is shown that satisfactory fits to the experimental measurement made by the EPONA and Tunde instruments in the regime concerned can be obtained throug modeling the influence of charge exchange on the high energy ions.

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