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CONDENSATION PRODUCTION IN COMET TAIL PLASMA

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RESUMEN

Los solitones producen condensaciones en la cola del cometa, como resultado de su interacción con el viento solar. Se obtienen las condiciones de excitación de las ondas ion acústicas y polvo-acústicas. La teoría presentada, trata sobre los solitones ion-acústicos polvosos en este plasma magnetizado. Se demuestra que la longitud de Debye y el radio de cyclotrón de las partículas de polvo cargadas, definen la dimensión transversal de los solitones polvo-acústicos. Para valores típicos de los parámetros, las dimensiones estimadas de los solitones son de varios Km, lo cual concuerda con los datos obtenidos de las observaciones.

ABSTRACT

Condensations are produced by solitons in a comet's tail plasma by its interaction with the solar wind. The conditions of excitation of ion acoustic and dust-acoustic waves are found. The theory presented here focuses on the ion dust-acoustic solitons in this magnetized dusty plasma. The density distribution function and potential in these solitons have been obtained. It is shown that the Debye length and the cyclotron radius of charged dust particles define the transverse sizes of dust-acoustic solitons. For typical values of the parameters, the estimated sizes of the solitons are several thousand Km, which are in agreement with the observational data.

Key Words: **COMETS: GENERAL — COMETS: INDIVIDUAL (P/HALLEY) — PLASMAS — WAVES**

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1. CONDENSATION OBSERVATIONS

In this paper, the analysis of earth-based observations of P/Halley and data from spacecraft is presented. In 1986, five spacecraft from USSR (Vega international project), Japan and the European Community (*Giotto*) visited Comet P/Halley, and obtained a lot of information about it. The first part of this paper deals with the observation of condensations. During earth-based observations of P/Halley, in accordance with the IHW and SORPROCH programs, in the Comet Halley's tail plasma some ring structures (condensations) were detected, which are not halos (Churyumov & Rspayev 1986). These structures were detected on the plates of K. I. Churyumov and F. K. Rspayev received in December 12, 16 and 17, 1985 and in May 11, 1986. They used the 1-m Zeiss reflector at the highland station of the Astrophysical Institute of the Kazakh Academy of Science (H=2700 m) in Assy (on hypersensibilized plates). Highly distinctive structures appeared on the plate received in December 17, 1985, 63362 UT (see Fig. 1). The comet has a distinct borderline, from the opposite side to the sun, there was a doublet structure with a width=$30''$; on the sun's side nearer to the nucleus of comet, the front was more diffuse and had width=$1'$; the diameter of the ring D=$3'$; the distance from the nucleus was $\approx 8'$ or 130,000 km; the angle position was 51^o, that made 15^o with the tail axis (a.p.=66^o, see Fig. 1).

2. CONDENSATIONS AS DUST-ACOUSTIC SOLITONS

It is assumed that the condensations are stable and dense structures. The theory of three-dimensional, spatially limited ion acoustic solitons is as follows. Magnetized dusty plasma is considered, which consists of

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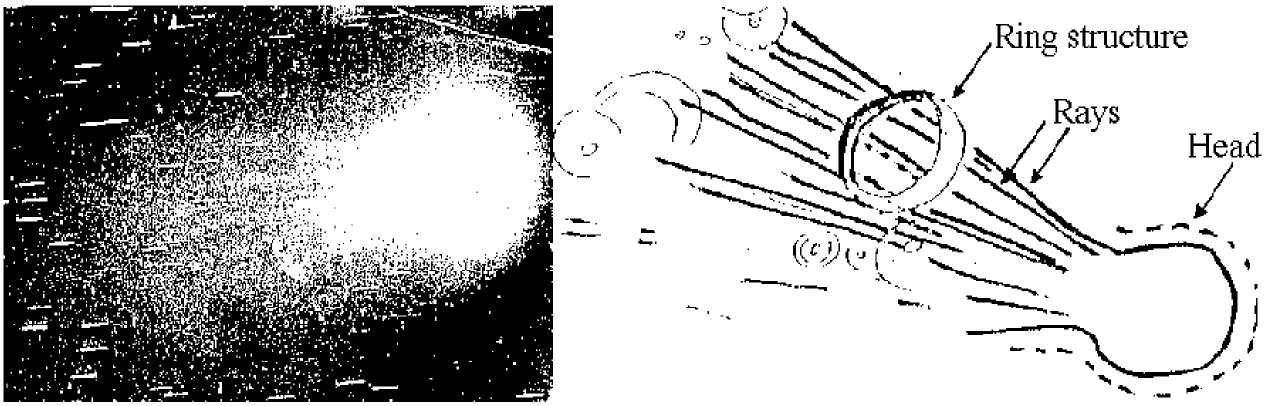

Fig. 1. (*Left*) Photograph and (*right*) structural drawing of P/Halley, Dec. 17, 1995.

electrons, ions and negatively charged dust grains. The basic equations are shown in Table 1, where n_0 is the dust grain equilibrium density, Z is the charge number of a dust grain. All grains are assumed to be identical particles, with mass m and charge Z_e.

TABLE 1

BASIC EQUATIONS

The electrons and ions distributions (temperatures in eV)	$n_e = n_{e0} e^{e\phi/T_e}, \quad n_i = n_{i0} e^{e\phi/T_i}$	(I)
Relationship between equilibrium densities	$n_{i0} = n_{e0} + Zn_0$	(II)
Poisson equation	$\Delta\phi = 4\pi e \left(n_e + Zn - n_i\right)$	(III)
Continuity equation (with grain density, $n = n_0 + n_1$)	$\frac{\partial}{\partial t} n_1 + \nabla \cdot \left(\left(n_0 + n_1\right) \vec{V}\right)$	(IV)
Grain velocity (obtained from momentum equation)	$\frac{\partial \vec{V}}{\partial t} + \left(\vec{V} \cdot \nabla\right) \vec{V} = \frac{Z_e}{m} \nabla\phi - \vec{V} \times \vec{\omega}_H$	(V)

The dust grain cyclotron frequency is

$$\omega_H = Z_e B_0 / (mc) \quad , \tag{1}$$

and the magnetic field $\vec{B}_0$ is oriented along the Z-axis. In the linear approximation, the waves propagate at an angle θ to the magnetic field (with all quantities varying as $exp\left(i\left(\omega t - k_{bot} x - k_z z\right)\right)$ with $k_{bot} = k \sin\theta$, $k_z = k\cos\theta$). From the equation system (I)–(V) the dispersion relation is

$$1 + k^2 a_D^2 = \frac{k_z^2 C_D^2}{\omega^2} + \frac{k_\perp^2 C_D^2}{\omega^2 - \omega_H^2} \quad , \tag{2}$$

where $a_D = \sqrt{T_e T_i / 4\pi e^2 \left(n_{e0} T_i + n_{io} T_e\right)}$ is the electron-ion Debye radius, $C_D = \omega_p a_D$, the speed of the dust-acoustic wave, and $\omega_p = \sqrt{4\pi Z^2 e^2 n_0 / m}$ is the Langmuir frequency of charged grains. Assuming $k a_D << 1$, $k r_H << 1$, $\omega << \omega_H$, where

$$r_H = c_D / \omega_H \tag{3}$$

is the dust cyclotron radius, from equation (2) there are two solutions

$$\omega_1 \approx k_z C_D \left(1 - \frac{k^2 a_D^2}{2} - \frac{k_\perp^2 r_H^2}{2}\right), \quad \omega_2 \approx \omega_H \left(1 + \frac{k^2 r_H^2}{2}\right) \quad . \tag{4}$$

The first part of equation (4) describes a dust-acoustic wave (Rao, Shukla, & Yu 1990), and the second part, a dust-cyclotron wave, (D'Angelo 1990). Expanding equation (2) to second order and using equation (III), the

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electrostatic potential and dust density can be related through

$$\Psi \approx -N - a_e^2 \Delta N + pN^2 \quad , \tag{5}$$

where $p = Z(\delta - 1)\left(\eta^2\delta - 2\right)/2\left(1 + \eta\delta\right)^2$, $\Psi = e\phi/mC_D^2$, $\delta = 1 + Zn_0/n_{e0}$, $\eta = T - E/T_i$, $N = n_1/n_0$ and $a_e = \sqrt{T_e/4\pi n_{0e}e^2}$ is the electron Debye radius. Using the method of Zakharov & Kuznetsov (1974), which they used for the investigation of solitons in electron-ion plasma, from equations (5), (IV) and (V), the equation for N is given by equation (6). The one-dimensional soliton solution is given by Equation (7).

$$\frac{\partial N}{\partial t} + C_D \frac{\partial N}{\partial z} + \frac{C_D}{2}\frac{\partial}{\partial z}\left(\frac{N^2}{\beta^{-1}} + a_e^2 \frac{\partial^2 N}{\partial z^2} + \left(a_e^2 + r_H^2\right)\Delta_\perp N\right) = 0 \quad , \tag{6}$$

$$N(z,t) = \frac{N_{max}}{ch^2\left(\frac{z-Ut}{a_e}\sqrt{A}\right)} \quad , \tag{7}$$

where $\beta = 3Z/2 - p$, $U = C_D\left(1 + \beta N_{max}/3\right)$ and $A = 2\beta N_{max}/3$. The general solution of equation (6) for N(x,y,z,t), found by Zakharov & Kuznetsov (1974), describes the ellipsoidal form of solitons with characteristic transversal sizes proportional to the cyclotron radius of charged grains:

$$\ell_\perp \propto r_H \sqrt{\frac{4n_0}{n_{1max}}} \quad . \tag{8}$$

3. AVERAGES AND RESULTS

Plasma parameters in Halley's tail were measured by the Vega and Giotto probes. The following averages are feasible. Grain density: $n_0 \approx 10^{-7}$ cm^{-3}; grain radius: $R \approx 10^{-4}$ cm; grain mass: $m \approx 10^{-12}$; $B_0 \approx 10^{-4}$; $n_{e0} \approx 100$ cm^{-3}; T_e, $T_i \approx 1$ eV and $Z \approx 10^5$. Using these values in equations (1) and (3) and taking a reasonable value of $4n_o/n_{1max} \approx 3$ we obtain $\ell_\perp \approx 10^3$ km, close to the observed sizes.

4. CONCLUSIONS

Condensations in the comet tail plasma may be explained as electrostatic spatially limited dust-acoustic solitons. Estimated transverse sizes of these solitons, using parameters of the dust component of Comet P/Halley, measured by the Vega and Giotto spacecraft, show a good agreement with theory and observations.

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