THE STABILITY OF INNER COMETO-SHEATH WITH LARGE LARMOR RADIUS EFFECTS

KRISHNA M. SRIVASTAVA and V. KUMAR
Department of Mathematics, University of Roorkee, Roorkee, India

and

V. SHARMA
Institute for Systems Studies and Analyses,
Department of Defence Research Development, Delhi, India

(Received 23 July, 1993)

Abstract. An investigation of the linear stability of the cometary inner sheath, the boundary layer surrounding the ionopause which separates the outflowing unmagnetized plasma from an inflowing magnetized plasma, has been carried out by taking into account the large Larmor radius effects. The structure of the boundary layer is determined by the balance between an outward ion-neutral collisional drag force and an inward magnetic stress. The eigenvalues and the eigenfunctions are obtained numerically by treating the cometary ionosphere as a layer of finite thickness, bounded by the contact surface, i.e., the diamagnetic cavity boundary. Certain limiting cases of the wave equations are also discussed. In general, the cometary ionosphere is structurally linearly unstable and the effects of recombination, photoionization, plasma pressure, though stabilizing are unable to quench the instability completely. The large Larmor radius also has a destabilizing effect on the system. The instability of the cometosheath is further proved by the $\alpha c/\tau_i$ assuming a value greater than 30 that is sufficient for the convection of perturbations down into the cavity surface and this is in agreement with the observations of ripples in the ionopause.

1. Introduction

A magnetic field free diamagnetic cavity extending approximately up to 4500 km s$^{-1}$ from the nucleus of the comet Halley was encountered by the Giotto mission (Neubauer, 1986). The boundary of this cavity called as ionopause or cavity surface separates the inflowing solar wind plasma loaded by the cometary ions from the outflowing purely cometary plasma. The equilibrium structure of this cavity surface is determined by the balance between the inward Lorentz body force on the plasma element and an outward ion-neutral collisional drag force. The magnetic field in the ionosphere of the comet drops from $\sim 20$ nT to nearly zero within a thin layer of about 25 km thickness, whereas it increases smoothly as a function of distance from the nucleus outside the boundary and exhibits a maximum of $\sim 60$ nT.

The stability of the cometary atmosphere surrounding the ionopause, having a field structure determined by the balance between collisional drag and Lorentz body forces, is worth investigation. This is intrinsically different from a tangential discontinuity, usually formed by the interaction of solar wind with planetary bodies. It is, therefore, expected that the magnetic field structure resulting from the precarious balance may not exhibit Kelvin–Helmholtz and Rayleigh–Taylor insta-
bilities associated with tangential discontinuity surfaces. In their stability analysis of the cometary ionopause ionosphere Ershkovich et al. (1989) and McKenzie et al. (1990) have shown by using JWKB approximation, that an overturning instability similar to unstable atmospheres (Brunt, 1941) can occur. But the inclusion of the effects of photoionization and dissociative recombination results in the stabilization of the whole configuration except the Halley ionopause and an adjacent ionospheric layer of about 100 km thickness. Further, they found that the effect of plasma pressure was also stabilizing.

Srivastava et al. (1993) obtained the numerical solution of the MHD stability wave equations derived in Ershkovich et al. (1989) and McKenzie et al. (1990), for the cometary ionosphere determined by the balance between the inward and outward forces by using a two-point boundary value method. The eigenvalues and the eigenfunctions were obtained numerically by treating the cometary ionosphere as a layer of finite thickness, bounded by the diamagnetic cavity boundary. The magnetic field structure discovered in the ionosphere of comet Halley was found to be linearly unstable. Though the effects of finite plasma pressure, dissociative recombination, and mass loading were found to be stabilizing, they were unable to quench the instability completely. It was also found that the higher the neutral production rate the lesser was the growth rate for the instability.

In a further work, Srivastava et al. (1993) included the effects of plasma motion and resistivity in the stability analysis of the cometo-sheath and obtained numerical solutions for certain parameters for comet Halley by using a two-point boundary value method. The magnetic field structure was still found unstable although the growth rates were reduced drastically. Also, the slow plasma motion resulted in the stabilization of the cometo-sheath since perturbations are convected downstream with the plasma bulk velocity before growing substantially. Thus, the effects of plasma pressure, dissociative recombination, mass loading due to photoionization, resistivity, and plasma motion altogether resulted in a stabilized configuration. However, the diamagnetic cavity boundary and the adjacent layer of about 100 km thickness of comet Halley was found to have ripples in agreement with the observations.

Another interesting aspect is to study the effect of the large ion Larmor radius on the stability of the cometary atmosphere surrounding the ionopause. In general, most plasmas of interest are characterized by a scale length, \( L \), much larger than the electron and ion gyro-radii, \( \rho_e, \rho_i \), and the frequency, \( \omega \), much smaller than the electron and ion gyro-frequencies, \( \omega_{ce} \) and \( \omega_{ci} \). There are, however, a number of interesting situations where these orderings do not hold. A few examples are: barium releases in magnetosphere (Bernhardt et al., 1987), plasma flow near small planetary bodies such as comets (Ip and Axford, 1982; Sagdeev et al., 1986; Reidler and Schwingenschuh, 1986). Here, \( L \) is intermediate between the electron and ion gyro-radii, i.e. \( \rho_e \ll L \ll \rho_i \), and \( \omega \) is intermediate between electron and ion gyro-frequencies, i.e. \( \omega_{ci} \ll \omega \ll \omega_{ce} \). In this paper, we analyse the stability of the cometary atmosphere surrounding the ionopause.