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HYDRODYNAMIC MODELS OF THE COMETARY ATMOSPHERE

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As a cometary nucleus, regarded as an admixture of ices and dust (Whipple, 1950), approaches the sun, the ices sublimate and the resulting gases freely expand dragging along some of the dust.

For a typical medium bright comet (e.g., P/Halley) at 1 AU, the cometary atmosphere is collision dominated within a radius R_c, within which the collision mean free path is equal to the radial distance itself. Within this radius, the cometary atmosphere may be considered as a continuum, and described by hydrodynamic equations. Admittedly, this definition of the regime of hydrodynamic flow is rather crude, and what one has is a gradual transition from pure hydrodynamic flow when $r << R_c$ to slip and transitional flow when $r \approx R_c$, to free molecular flow when $r > R_c$. Depending on whether one considers neutral-neutral collisions or neutral-ion collisions $R_c \sim 5 \times 10^3 - 10^4$ km for a medium bright comet at a heliocentric distance of 1 AU.

Considerable effort has gone into modeling this collision dominated cometary atmosphere. One approach has concentrated on the chemistry while making simplifying assumptions about the dynamics and thermodynamics. These essentially solve the continuity equations for the "parent" and "daughter" species while assuming, for instance, uniform expansion (u = const) and isothermal conditions (T = constant). Much work along these lines has been done by Heubner and co-workers, and by Huntress and co-workers (e.g., Huebner and Giguere, 1980; Mitchell et al, 1981; Mitchell et al, 1982).

The opposite approach is to restrict oneself to the probable dominant parent molecules, while concentrating on the dynamics and the thermodynamics. This approach leads to the temperature and velocity profile in the cometary atmosphere, and is expected to provide a reasonable approximation to the total electron density profile. Both the dynamics and the thermodynamics are affected by the dust. In particular the dust drag on the gas partially chokes it and makes the flow transonic, as first shown by Probstein (1968).

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The earlier hydrodynamic models were single-fluid in which all the chemical species attained the same temperature and velocity within the collision-dominated region (see Mendis and Houpis, 1982, for a recent review). The dominant parent molecule generally appears to be H_2O (e.g., Delsemme, 1973), and the dominant input of energy into the inner coma is associated with the photodissociation of H_2O. The lighter hydrogen atom carries off most of the excess energy during this photodissociation process, and due to the mass disparity it is very inefficient in transferring its excess energy to the heavier species even within the collision-dominated region (Ip, 1982). Therefore, a proper description of the inner coma requires a multi-fluid approach, which treats the atomic hydrogen separately from the heavier species. Furthermore, while the photoelectrons rapidly thermalize by self collisions within the entire cometary atmosphere, they do not exchange energy efficiently with the ions and the neutrals and cool mainly by in-elastic collisions with H_2O and by expansion.

Recently we (Marconi and Mendis 1982a,b) have obtained self consistent transonic multi-fluid solutions of the dynamical and thermal structure of a two-phase dusty-gas cometary atmosphere of a dirty H_2O-clathrate ice nucleus. This was done by solving the simultaneous set of differential equations representing conservation of number density, momentum, and energy, together with the transfer of solar radiation in streams responsible for the major photolytic processes and heating of the nucleus. The problem is a two-point boundary value one and has to be solved by a two-step iteration technique which obtains a self-consistency between the flow profile and the radiation fields.

Some of the results of the calculation for a 2.5 km radius cometary nucleus (with 85% H_2O, 10% CO_2 and 5% N_2 by a number and dust/gas ratio of 1 by mass) at a heliocentric distance of 1 AU are shown in the following figures. The velocity and Mach number profiles of the heavy species (R) and the velocity of the dust within the subsonic region are shown in Figure 1. It is interesting to note that the subsonic region is very thin (∿ 40 m) even though the dust-gas coupling persists to about 50 km from the nucleus. Also, the initial Mach number of the gas . 0.76.

The profiles of the Mach number and the velocities of the gas and dust in the supersonic region are shown in Fig. 2. The Mach number of the heavy species increases from 1 to a maximum of about 9.4 around 400 km (which is close to the temperature minimum; see Fig. 3) before decreasing to about 2.5 at r = 2.5x10 km, due to the photo-heating in the outer coma. An interesting feature in this figure is the velocity profile of the pre-thermalized photo-produced hydrogen (H*). It reaches a value of about 12.5 km s^{-1} at r = 2.5x10 due to the rapid decrease in the collision frequency between H* and R. Farther outside the collision zone u * can be shown to asymptotically approach ∿ 18 km s^{-1}. Indeed, the interpretation of the Lya isophotes and line profiles of several comets seems to indicate rapid outflow of hydrogen in the outer coma with one component having an outflow velocity ≈ 20 km s^{-1}

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(e.g., Meier et al, 1976).

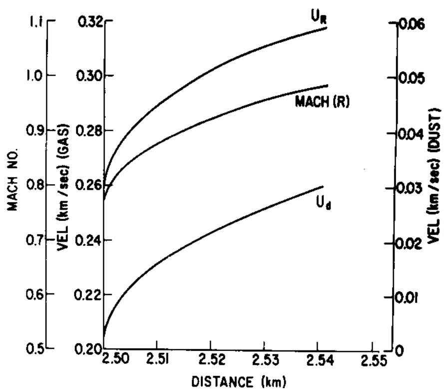

Fig. 1. Radial profiles of the Mach number of heavy species (R) velocities of R and dust (D). Lines terminate at the sonic point.

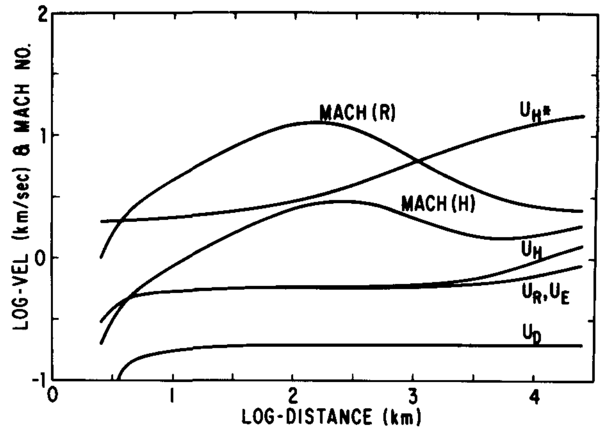

Fig. 2. Radial profiles of the Mach number of heavy species (R), thermal hydrogen (H), velocities of R, H, prethermal hydrogen (H*), dust (D) and electron gas (E).

The temperature profiles of the dust and gas in the supersonic region are shown in Fig. 3. While the dust temperature remains more or less constant, the temperatures of both the heavy species and hydrogen fall to very small values (4-5^{o}K) around 300 km from the nucleus before increasing in the outer coma. This strong temperature inversion is due to the effects of IR cooling and rapid expansion in the inner coma. The temperature increase in the outer coma of the heavy species is due to UV photolytic heating. But the heating is not as efficient as supposed previously, since the photo-produced H and electrons do not exchange energy effectively with the heavy species. Consequently the temperature of the heavy species at $r = 2.5 \times 10^4$ km is only about 250^{o}K rather than 800^{o}K as in the earlier model (Marconi and Mendis, 1982c).

Another interesting feature is the temperature of the electron gas. While the ambi-polar electric field constrains the electrons to move with the same speed as the ions and the neutrals, the electron temperature remains very much higher than the temperature of the ions (and the neutrals) for the reasons discussed earlier.

The high electron temperature decreases the efficiency of removing electrons by dissociative recombination, and consequently the electron density throughout the ionosphere remains higher than the predictions of the earlier models. Fig. 4 shows the radial profiles of the electron density of the dominant ions. The combination of these two effects increase the electron thermal pressure by several orders of

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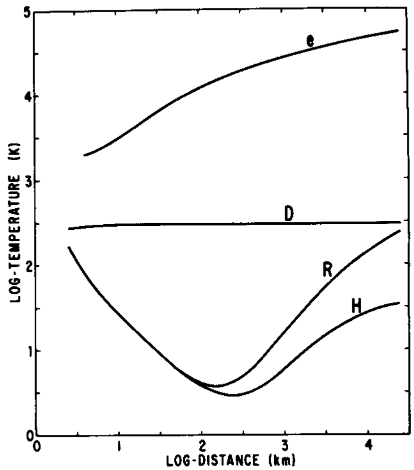

Fig. 3. Radial profiles of the temperatures of dust (D), heavy species (R), thermal hydrogen (H) and thermal electrons (e).

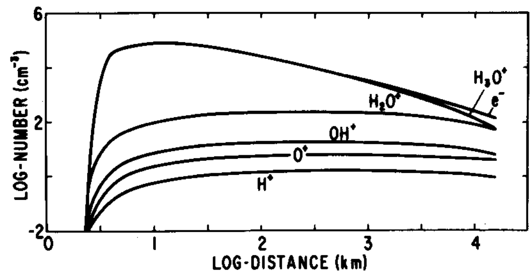

Fig. 4. Radial profiles of densities of electrons and ions, in collision dominated region.

magnitude, and is, in fact, sufficient to balance the ram pressure of the inflowing solar wind at about 2×10^3 km from the nucleus. Consequently, even if collision with neutrals is inefficient in slowing the solar wind (e.g., Houpis and Mendis, 1981), the solar wind cannot penetrate too deep into the cometary atmosphere, as was suggessted by Wallis and Ong (1976).

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REFERENCES

Delsemme, A. H., 1973, Space Sci. Rev. 15, pp. 89-101. 15 89.
Houpis, H.L.F., & Mendis, D.A., 1981, Astrophys. J. 243, pp. 1088-1102.
Huebner, W. F., and Giguere, P. T., 1980, Astrophys. J. 238, pp. 753-762.
Ip, W-H., 1982, Astrophys. J., (in press).
Marconi, M. L., & Mendis, D. A., 1982a, The Moon and the Planets, in press.
Marconi, M. L., and Mendis, D. A., 1982b, Astrophys. J., (submitted).
Marconi, M. L., and Mendis, D. A., 1982c, Astrophys. J., (in press).
Meier, R. R., Opal, C. B., Keller, H. U., Page, T. L., Carruthers, G. R., 1976, Astron. Astrophys. 52, pp. 283-198.
Mitchell, G. F., Prasad, S. S., and Huntress, W. T., 1981, Astrophys. J., 244, pp. 1087-1093.
Probstein, R. F., 1968, Problems of Hydrodynamics and Continuum Mechanics, (Ed. M. Lavrent'ev). Philadelphia, Pa.: SIAM, pp. 568-583.
Wallis, M. K., and Ong., R. S. B., 1976, Study of Comets, (Eds., B. Donn et al.). Washington, D. C.: NASA SP-393, pp. 856-876.