NAG 8-795

Technical Report on the Physics of Heavy Ions (1989-1990)

During the last year we made significant progress on understanding the enhancement of O^+ outflow in the polar wind. We completed studies on polar wind ion heating due to kinetic ion beam instabilities and the effects of such ion heating on the outflow of O^+ in the polar wind.

DE 1 observations of O^+ and H^+ ion beams ($\sim 10 - 100$ eV) in the polar cap at altitudes of $\sim 2.5 - 3.5\ R_E$ found in a previous joint study with NASA Marshall Space Flight Center and Lockheed Palo Alto [*Chen et al.*, 1990] motivated the kinetic study of ion beam instabilities. The upflowing field-aligned O^+ and H^+ beams which may have been formed as upflowing-energetic ions from the dayside cusp $\vec{E} \times \vec{B}$ convect into the polar cap provide free energy to the polar cap plasma (see figure 1). We first examined the linear instabilities associated with an O^+ and H^+ polar wind plasma in the presence of O^+ and H^+ beams for a range of O^+ /H^+ beam densities, T_e/T_i, and ion beam speeds. Then, we studied the nonlinear heating of the polar wind ions using numerical simulations. We modelled the O^+ and H^+ polar wind ions by isotropic Maxwellian distributions and the electrons, O^+ beams and H^+ beam ions by drifting Maxwellian distributions. The electron distribution drifted so that there was no zeroth-order current in the plasma.

It was found that in the presence of O^+ and H^+ beams, the slow ion acoustic and slow ion cyclotron modes can couple to the normal modes of the plasma (for example, the O^+ and H^+ cyclotron modes for perpendicular propagation) and be driven unstable. When the O^+ beam density is dominant over the H^+ beam density, which is sometimes observed [*Chen et al.*, 1990], the slow O^+ acoustic and/or slow O^+

(NASA-CR-188013) PHYSICS OF HEAVY IONS (1989-1990) Final Report (California Univ.) 10 p CSCL 04A

N91-22627

Unclas
G3/46 0001574

cyclotron modes are triggered unstable while the H^+ beam modes are damped. Figure 2 shows the dispersion relation, frequency normalized by the O^+ gyrofrequency versus wavenumber normalized by the plasma frequency over the speed of light, of both the real part of the frequency and the growth rate for such a case. Note that the slow O^+ beam modes are unstable for a large range of wavenumbers due to their coupling with several O^+ and H^+ cyclotron harmonics associated with the polar wind. As T_e approaches T_i, the maximum growth rate of the slow ion acoustic mode decreases due to damping of the waves by the ions. At low beam speeds, the growth rate due to the coupling of the slow O^+ beam modes with the O^+ cyclotron harmonics are dominant while at larger ion beam speeds, the growth rates of the coupling with the H^+ cyclotron harmonics are dominant.

Particle simulations showed that when the O^+ beam density is dominant over the H^+ beam density, the slow O^+ acoustic mode predicted by linear theory to be unstable is excited and can resonantly heat both the O^+ and H^+ polar wind ions in the perpendicular direction. In fact, the O^+ polar wind ions are preferentially heated over the H^+ polar wind ions when the O^+ beam density is dominant over the H^+ beam density. Figure 3 shows the time histories of the normalized perpendicular H^+ and O^+ temperatures and electrostatic energy. The polar wind ions are significantly heated at the expense of the electrostatic wave energy.

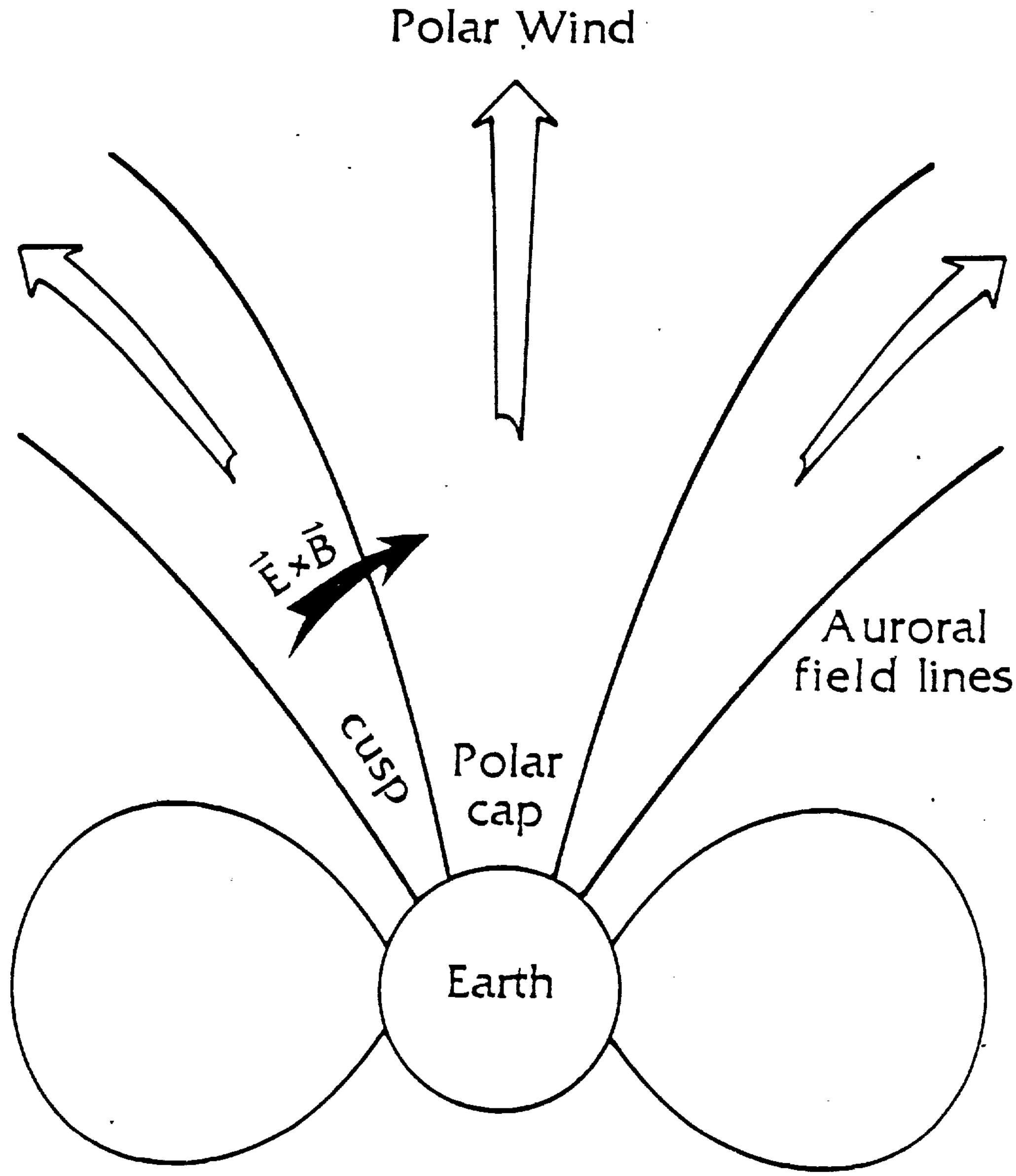
This ion heating could have very important implications on the polar wind outflow if it can alter the polar wind ions' scale heights. We examined the effects of the kinetic ion heating on the outflow of the polar wind ions from the ionosphere using a time-dependent hydrodynamic model. We developed a numerical code to solve the O^+ and H^+ continuity and momentum equations in a flux tube from ionospheric (200 km) to magnetospheric altitudes ($\sim 6-7R_E$). We included the effect of ion heating by allowing for the altitudinal variation of the ion temperatures in the momentum equation. The ion temperature profiles were specified based on the ion heating characteristics found from our previous kinetic simulations. We assumed that the heating occurred above 1500 km and increased to a saturated value of temperature that we obtained directly from the kinetic simulation study (see Figure 3). Since electrons were not significantly heated due to the ion beam instabilities, the electron temperature was kept constant.

First, we studied the characteristics of the dynamical polar wind without ion heating. We simulated a flux tube on closed field lines ($u_i = 0$) that suddenly became open at $t = 0$. Figure 4 shows the density and velocity profiles of the H^+ and O^+ polar wind ions at various times in the absence of ion heating. In comparison to the H^+ ions, there is not much outflow of O^+ in the polar magnetosphere. Although there may be temporal enhancements of the O^+ fluxes, they last for only about 15 min. and are due mainly to the initially large upward gravitational force when the flux tube suddenly becomes open. Clearly, there is not much sustained escape of O^+ ions from the polar ionosphere without ion heating.

We then included the effects of ion heating. To gain some physical insight, two limiting cases were considered: preferential H^+ heating ($T_H > T_O$) and preferential O^+ heating ($T_O > T_H$). These two cases corresponded to when the O^+ beam density is comparable to and dominant over the H^+ beam density in the kinetic study, respectively. Figure 5 shows the steady state results for these cases superimposed on the no heating case ($T_O = T_H$). When the H^+ ions are heated, the H^+ velocity increases. This is because the heating increases the upward pressure gradient force and accelerates the H^+ ions at higher altitudes. However, the H^+ density does not alter much because the amount of H^+ which can escape the polar ionosphere is limited by charge exchange of neutral H with O^+ in the collisional ionosphere. Since ion heating occurs where the plasma is collisionless, H^+ heating does not affect the outflow that much For the O^+ ions, there is not only an increase of O^+ velocity but a dramatic increase of O^+ scale height above the heating region. This is because the O^+ ions were essentially gravitationally bound and the O^+ heating which increases the upward pressure gradient can help enhance the O^+ outflow. It does not matter whether the O^+ or H^+ ions are preferentially heated. As long as there is significant O^+ heating, the O^+ escape from the polar ionosphere is enhanced. Thus, we showed how O^+ heating can lead to enhanced polar wind O^+ fluxes in the polar magnetosphere.

References

Chen, M.W., W.K. Peterson, M. Ashour-Abdalla, T.E. Moore and A. Persoon, The plasma characteristics of upflowing ion beams in the polar cap region, J. Geophys. Res., 95, 3907, 1990.



Schematic of Polar Magnetosphere

Fig. 1. A shematic of the polar magnetosphere which shows the polar wind flowing out of the polar ionosphere and the direction of the $\vec{E} \times \vec{B}$ convection of upflowing energetic ions from the dayside polar cusp region into the polar cap region.

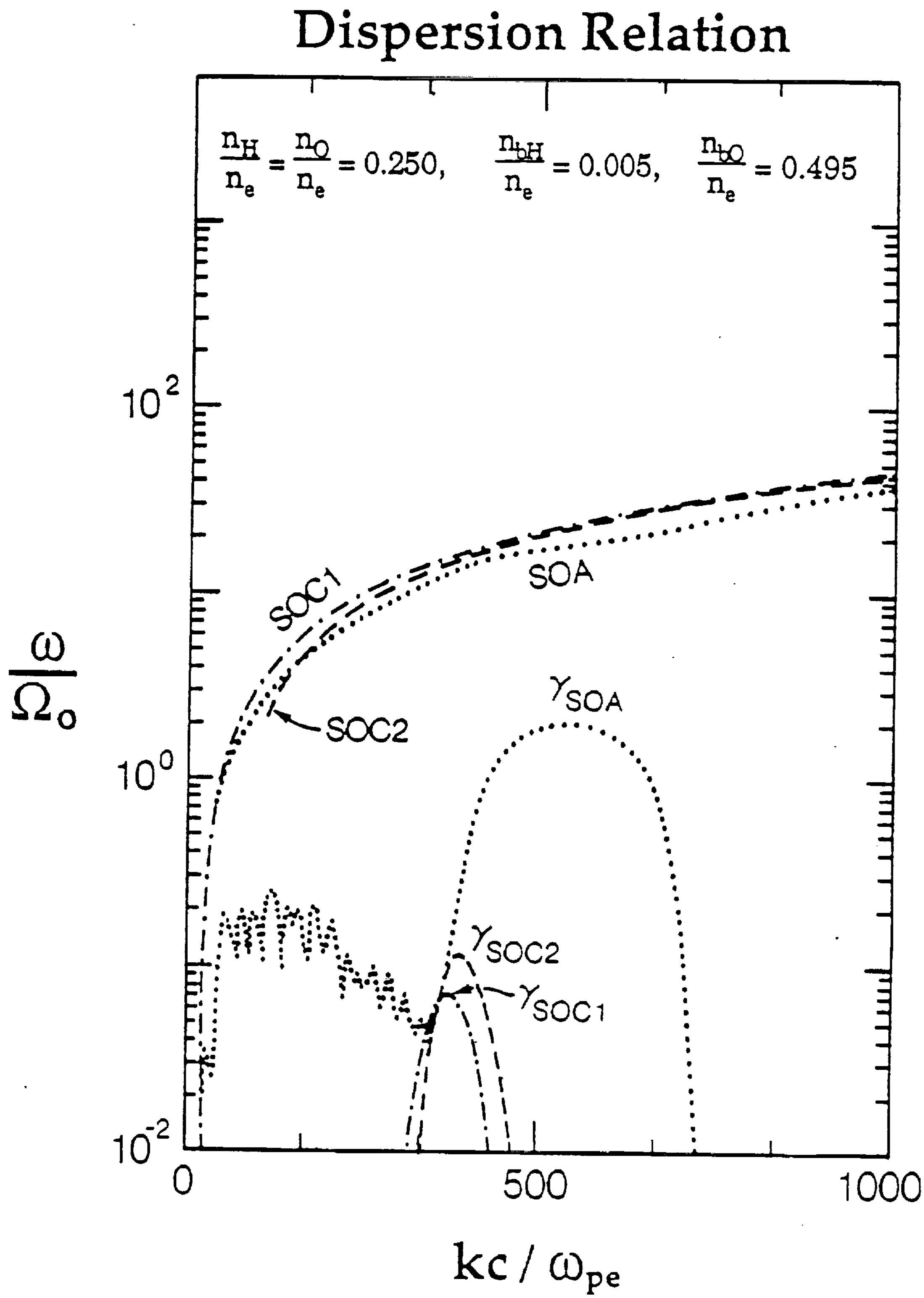


Fig. 2. The dispersion relation when the O^+ beam is dominant over the H^+ beam. The modes and their growth rates are distinguished by different legends. (SOA = slow O^+ acoustic, SOC(n) = nth slow O^+ cyclotron harmonic).

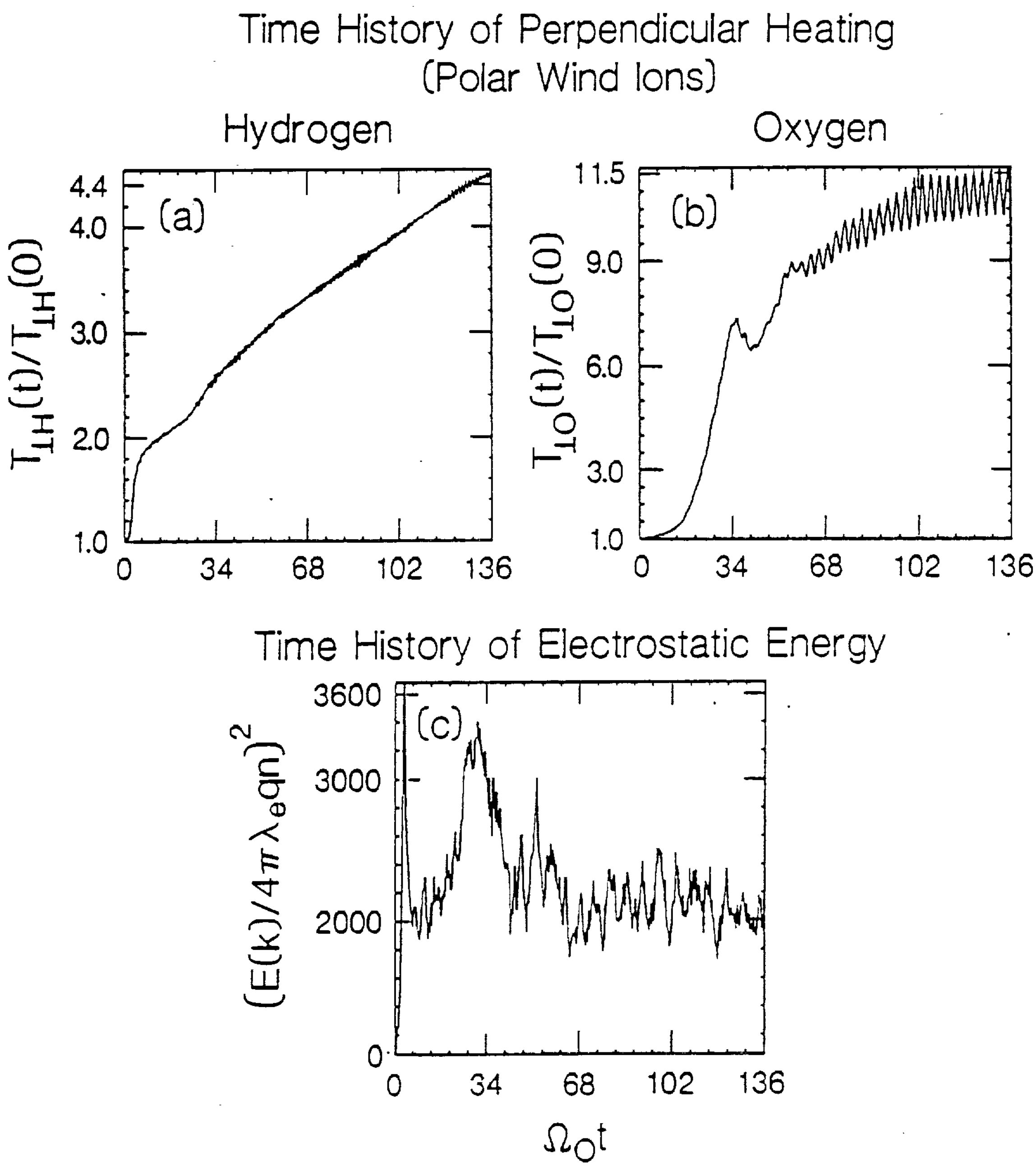


Fig. 3. The time history of the perpendicular (a) H^+ and (b) O^+ temperatures normalized by their initial perpendicular temperatures. The time history of the electrostatic energy is shown in (c).

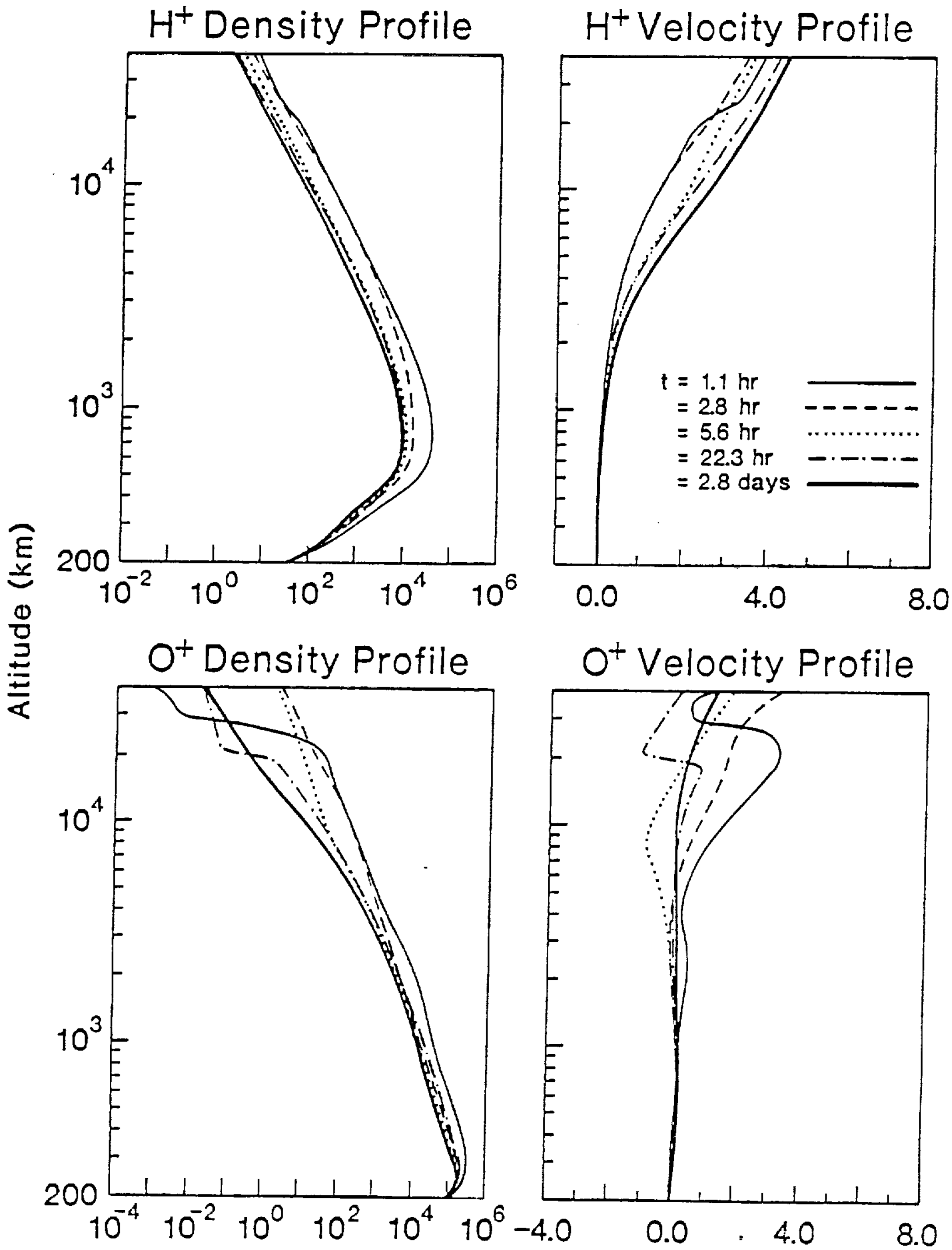


Fig. 4. The altitude (km) versus (*a*) H^+ density, (*b*) H^+ Mach number, (*c*) O^+ density, (*d*) O^+ Mach number for later times in the simulation when both H^+ and O^+ ions are included in the plasma.

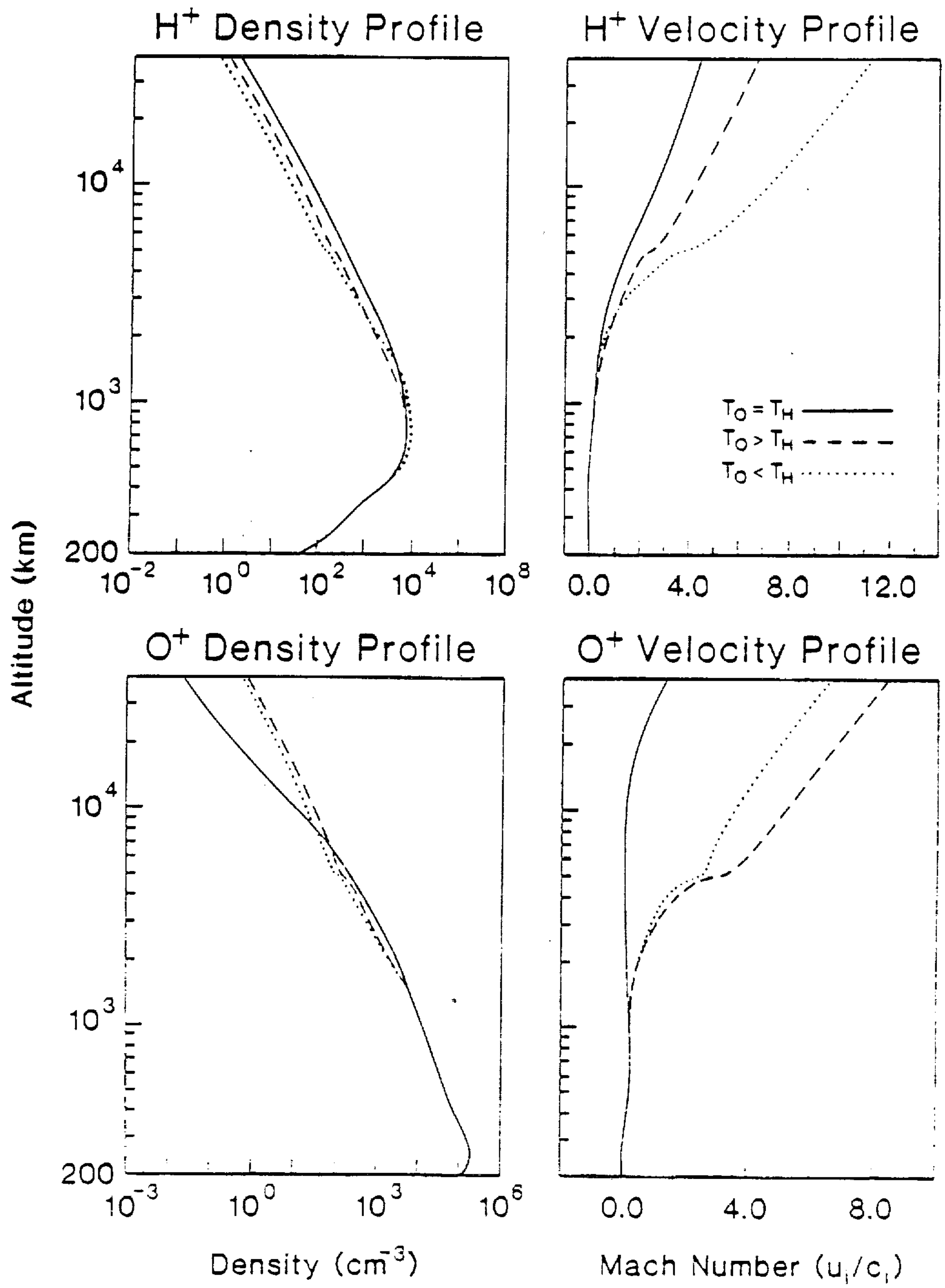


Fig. 5. The (*a*) H^+ density, (*b*) H^+ Mach number, (*c*) O^+ density, (*d*) O^+ Mach number profiles for 3 cases: no ion heating, preferential O^+ heating, and preferential H^+ heating.

Publications Credited to Grant NASA NAG 8-074 in 1989-1990

Chen, Margaret, The polar wind and ionospheric outflow, Ph. D. dissertation, University of California, Los Angeles, 1990.

Chen, Margaret, and Maha Ashour-Abdalla, Heating of the polar wind due to ion beam instabilities, J. Geophys. Res., 95, 18949, 1990.

Contributed Presentations Credited to Grant NASA NAG 8-074 in 1989-1990

Chen, M.W. and M. Ashour–Abdalla, Study of the dynamic polar wind, AGU, Baltimore, May 1989 (EOS, 70, 431).

Chen, Margaret W., and Maha Ashour-Abdalla, The effect of ion heating on the dynamic polar wind, AGU, Baltimore, May 1990 (EOS, 71, 605).

Chen, Margaret W., Maha Ashour-Abdalla, and T.E. Holzer, The effects of ion heating on the polar wind outflow, Dec. 1990 (EOS, 71, 1493).