N91-14162

RADIATIVE THERMAL CONDUCTION FRONTS

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I INTRODUCTION

The discovery of the O VI interstellar absorption lines in our Galaxy by the *Copernicus* observatory was a turning point in our understanding of the ISM. It implied the presence of widespread hot ($\sim 10^6$ K) gas in disk galaxies. The detection of highly ionized species in QSOs absorption spectra may be the first indirect observation of this hot phase in external disk galaxies.

Previous efforts to understand extensive O VI absorption line data from our Galaxy were not very successful in locating the regions where this absorption originates. The location at interfaces between evaporating ISM clouds and hot gas was favored, but recent studies of steady-state conduction fronts in spherical clouds by Ballet, Arnaud, and Rothenflug (1986) and Böhringer and Hartquist (1987) rejected evaporative fronts as the absorption sites. We report here on time-dependent nonequilibrium calculations of planar conductive fronts whose properties match well with observations, and suggest reasons for the difference between our results and the above. We included magnetic fields in additional models, not reported here, and our conclusions are not affected by their presence.

II THE CONDUCTION FRONT

We consider the structure and evolution of a conduction front propagating between the hot ISM and a cold planar cloud. Gas at constant temperature and pressure is distributed uniformly in each phase. The hot phase cools through the emission of the optically thin radiation. As a result, the hot gas temperature T_h decreases with time from its initial value T_{h0}. The cold gas at temperature 10^4 K is assumed to be in a stable thermal equilibrium, with radiative losses balanced by energy sources. Initially, the temperature changes discontinuously from T_{h0} to 10^4 K at the transition between the two phases.

The early stage of the front evolution is dominated by conductive heating of the cold gas. Radiative losses can be neglected, and a self-similar solution (Balbus 1986) accurately describes the front evolution. Temperature profile in this stage in our representative model with $T_{h0} = 7.5 \times 10^5$ K and pressure of $3750\,\mathrm{K\,cm^{-3}}$, somewhat modified by radiative losses, is shown in Figure 1 as a function of the hydrogen column density at 2.8×10^5 years. Note the front steepness at low temperatures. The conduction front broadens continuously, resulting in reduced conductive heating of the cold medium. Radiative losses eventually become important, first at temperatures $\sim 10^5$ K (where line cooling is particularly effective), and later throughout the whole front. Finally, the front becomes sufficiently broad for radiative losses to balance the rate at which energy is conducted from the hot gas. The front comes to a halt at this time, which we denote t_{rad}. We find that $t_{rad} \sim 2 \times 10^6$ *years is an order of magnitude less than the cooling time* $\sim 2 \times 10^7$ *years of the hot gas.* The temperature profile for the quasi-static front is shown in Figure 1 at 2.2×10^6 years.

At still later times $t \geq t_{rad}$, radiative cooling dominates the evolution. *The gas is now flowing from the hot phase towards the cold phase, rather than evaporating from the cold cloud.* This late-time evolution can be described as a cooling wave propagating into the hot gas (Doroshkevich

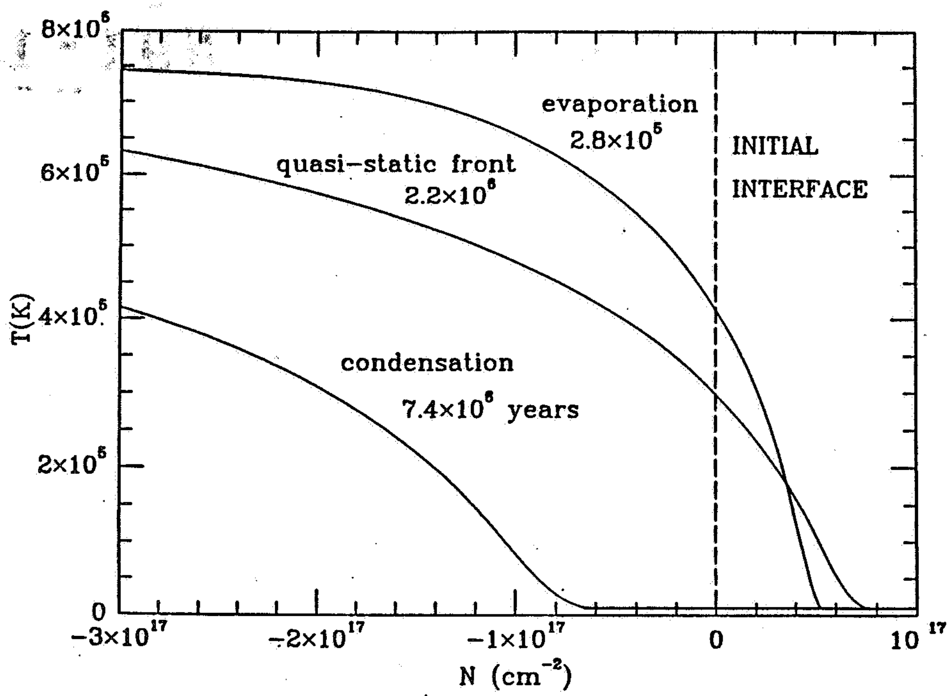

Figure 1: Temperature T vs. hydrogen column density N in a model with the initial hot medium temperature 7.5×10^5 K and pressure of 3750 K cm^{-3}.

and Zel'dovich 1981). The late-time temperature distribution is shown in Figure 1 at 7.4×10^6 years.

III COLUMN DENSITIES

In Figure 2, we present a plot of ionic column densities for selected species as a function of time t. Initially, the gas is underionized, and the front is deficient in highly ionized species. Their column densities increase with time, however, as the evaporated hydrogen column density increases and the collisional ionization becomes effective. The column density of each ion species i attains maximum at time $t_{i,coll} \sim (n_e C_i)^{-1} \approx T_{h0}/C_i(T_{h0}/2)P$, where C_i is the collisional rate coefficient (cm^{3}s^{-1}) from state i.

At later times, the front has grown sufficiently broad that a quasi-steady state develops, and the column densities remain nearly constant, or gradually decrease as the gas flows from the cold to the hot phase. Finally, the structure of the front changes from an evaporative to a cooling front when the conductive heating is balanced by radiative losses. The column densities decrease (see dips in Figure 2 at $\sim 2 \times 10^6$ years), but as the cooling front continues to broaden the values again increase. However, the column number density of each ion species i is fairly constant after the time $t_{i,coll}$, and does not depend on pressure P.

Column number densities of important ions present in conduction interfaces are insensitive to the detailed structure of these interfaces, provided that the hot medium temperature T_{h0} exceeds 7.5×10^5 K. A detection of highly ionized species with the column densities such as in Figures 2 should be considered as a strong evidence for the presence of conduction interfaces in the ISM. Such quantities of O VI were detected by the *Copernicus* satellite (Jenkins 1978). Two-thirds of the O VI bearing gas originates in the discrete components with 10^{13} ions per cm^{-2}. This agrees very well with our results (Figure 2).

The observations of other highly ionized atoms are consistent with both evaporative and condensing interfaces, with the notable exception of Si IV. The N V/O VI column density ratio is equal to ~ 0.1 (York 1977), in agreement with our results shown in Figure 2. A recent survey

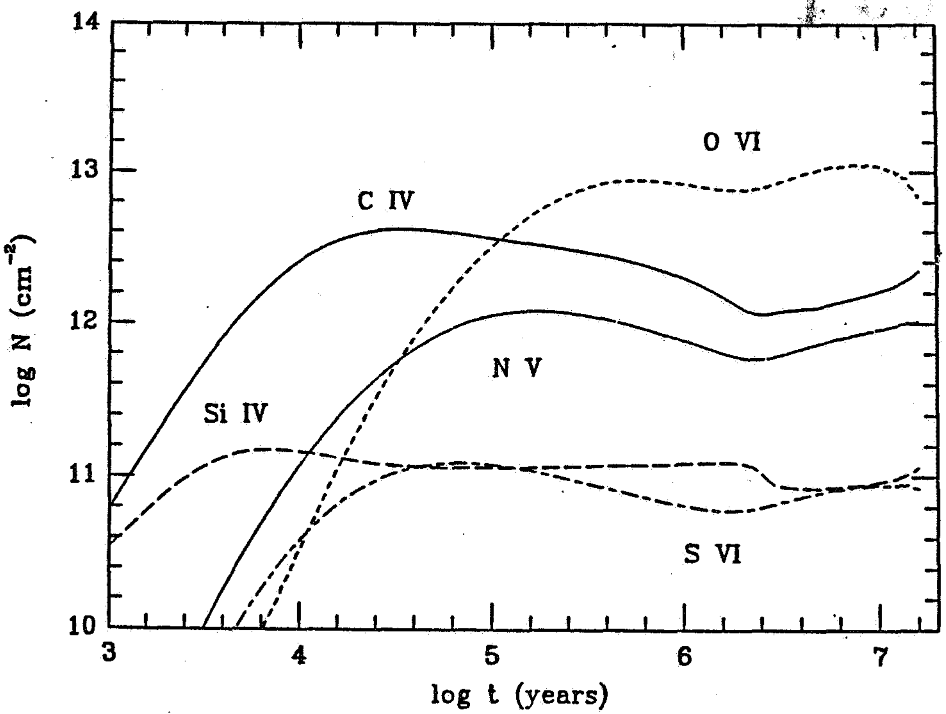

Figure 2: The ion column densities along the front normal vs. time *t*.

of N V, C IV, and Si IV interstellar absorption lines (Savage and Massa 1987) give an average number density ratio, relative to O VI, of 0.11, 0.25, and 0.07, respectively. The C IV/O VI ratio again agrees with our results, but Si IV absorption lines are an order of magnitude stronger than expected, indicating that Si IV is probably produced by photoionization.

IV DISCUSSION

Böhringer and Hartquist (1987) rejected evaporative fronts as the sites where the O VI absorption originates because the calculated line widths were larger than the observed widths. While this argument applies also to planar conductive fronts in the evaporative stage of their evolution, the temperature of the line formation region is lower in condensing fronts which results in better agreement with the observed line widths. The identification of condensing conductive fronts as the sites where highly ionized atoms, such as O VI, N V, and possibly C IV, are present, leads to interesting conclusions. Haloes of disk galaxies are thought to contain hot gas whose cooling onto embedded clouds could produce highly ionized ions seen in absorption in QSOs absorption systems. Condensing conductive fronts could also be present in clusters of galaxies (Doroshkevich and Zel'dovich 1981) and in elliptical galaxies which exhibit signs of cooling flows.

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