

NON-EQUILIBRIUM IONIZATION AROUND CLOUDS  
 EVAPORATING IN THE INTERSTELLAR MEDIUM

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It is of prime importance for global models of the interstellar medium to know whether dense clouds do or do not evaporate in the hot coronal gas. The rate of mass exchanges between phases depends very much on that. McKee and Ostriker's model (1977), for instance, assumes that evaporation is important enough to control the expansion of supernova remnants, and that mass loss obeys the law derived by Cowie and McKee (1977). In fact, the geometry of the magnetic field is nearly unknown, and it might totally inhibit evaporation, if the clouds are not regularly connected to the hot gas. Up to now, the only test of the theory is the U.V. observation (by the Copernicus and IUE satellites) of absorption lines of ions such as OVI or NV, that exist at temperatures of a few  $10^5\text{K}$ , typical of transition layers around evaporating clouds.

As a first step Ballet et al. (1986) studied the effect of late ionization in evaporating flows, in the framework of Cowie and McKee's model (1977). A simple analysis predicts that, for a given ion, the delay depends only on the outer temperature  $T$  and the product  $N_e R$ , in which  $N_e$  is the outer electronic density and  $R$  is the cloud radius. For a given  $T$ , the delay is increasing as  $N_e R$  decreases, and for a given  $N_e R$ , it is maximum at the temperature corresponding to the onset of "saturation" of the electronic conduction (happening if the mean free path of electrons is of the same order as the cloud radius). Numerical calculations have confirmed that dependance. In typical interstellar conditions, the delay in the ionization of CIV, NV, OVI (to CV, NVI, OVII) is important. As a result, these ions survive much longer than inferred from equilibrium estimates, and reach layers further from the cloud surface. Their average density in the interstellar medium would be one or two orders of magnitude above the equilibrium predictions.

The numbers derived from U.V. observations (Jenkins, 1984) are way below predictions for all reasonable interstellar conditions. That suggests that evaporation is severely quenched. It is true if all OVI, NV and CIV present is observed. McKee and Ostriker (1977) had remarked that slightly subsonic turbulence would broaden the U.V. lines beyond detectability. If such turbulence takes place, only ions located close to cloud surfaces may appear in U.V. absorption lines surveys. Concerning OVI, NV and CIV, that would happen only in the case of a small delay in ionization. On the other hand, if the interstellar conditions imply a large delay, the flow could become turbulent before OVI and NV are reached. Such interstellar conditions would

allow a large amount of those ions to go unobserved in turbulent conditions. If  $N_e$  and  $T$  are typical of the hot gas, that would require  $N_e RT < 10^{3.8} \text{ cm}^{-3} \text{ pc K}$ . U.V. lines of CIV would set somewhat tighter constraints if the abundance of gaseous interstellar carbon is more than  $\frac{(C)}{(H)} = 1.5 \cdot 10^{-4}$ ,

corresponding to less than 2/3 of carbon in grains.

More recently, following a private suggestion by B. Lazareff, I investigated the effect on ionization of non-thermal electrons. The "saturation" effect occurs because the basic assumption of the analysis (that the electronic distribution is Maxwellian at each point with only a slight anisotropy leading to the heat flux) breaks down. The distribution function cannot be represented by a Maxwellian curve. Since the e-e collision rate goes down with energy, the existence of a hot tail in the cold layers is expected even before the onset of saturation. The ionization cross sections are zero below the ionization potential, 98 eV for NV and 138 eV for OVI, so that the ionization coefficients are sensitive only to electrons above that energy, corresponding to the bulk of the outer thermal electrons at  $10^6 \text{ K}$ . It is obvious therefore that a better treatment of those hot electrons in the inner layers was necessary. Luciani et al. (1985) have suggested using an integral delocalization formula for computing the heat flux. They obtained a similar approximate formula for computing the isotropic part of the distribution function itself, and adapted it to the spherical case for my purpose. Because finding a self consistent solution would be too time consuming, I applied this delocalization formula directly to McKee and Cowie's model. It is also justified by the fact that the effect on ionization is expected to be more drastic than on the heat flux. After the distribution function is estimated at one point, the ionization coefficient is obtained by integrating the ionization cross section (from Arnaud and Rothenflug, 1985) over energy.

That effect increases the coefficients for ionization, and therefore speeds it up, reducing the previous delay in ionization and therefore the discrepancy between predictions and observations. However, as long as the flow is not altered, the ion quantity cannot be reduced below a lower limit proportional to  $\dot{m}$  and the minimum time spent in the form of OVI or NV, that is usually  $t_{\min} = 1/N_e C_i(T)$  where the ionization coefficient is calculated at the outer temperature. That is still true if delocalization is taken into account, because at high energies the distribution function is always less than the outer Maxwellian.

#### References

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