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DECOMPRESSIVE QUASI SHOCKS IN RADIATIVE PLASMAS

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RESUMEN

Se encuentra un frente de rarefacción supersónico y estable en plasmas radiativos. La propagación del frente corresponde a la transición entre dos estados de equilibrio cuando la función de pérdidas radiativas tiene dos máximos. Esto es posible debido a que las pérdidas radiativas cambian la velocidad del sonido. La velocidad efectiva del plasma caliente delante del choque puede ser menor que la del plasma frio detrás del frente. De esta manera el frente satisface el criterio de estabilidad de Landau. Los plasmas radiativos son sistemas abiertos y la producción de entropía puede ser tanto positiva como negativa.

ABSTRACT

A stable rarefaction front in radiative plasmas is found. The front propagation corresponds to the transition between two stable equilibria when the radiative loss function has two separated peaks. This is possible because radiative losses significantly change the sound speed. The effective sound speed in the hot plasma ahead of the front may be smaller than the sound speed in the cool plasma behind the front. Thus, the front satisfies the Landau stability criterion. Radiative plasmas are open systems, and the entropy production may be positive as well as negative.

Key Words: **PLASMAS — SHOCK WAVES**

Decompressive shock waves, i.e., shocks, where the pressure behind the front P1 is smaller than the pressure P2 ahead of it, are forbidden in classic gas dynamics (Landau & Lifschitz 1987). First, entropy production is positive only if P2 > P1. Second, a decompressive shock does not satisfy the Landau stability criterion; the front velocity must be larger than the sound speed in the unperturbed medium. It is shown in this paper that some stable shock-like decompression fronts may exist in radiative plasmas. First, radiative plasmas are open systems, and it is not necessary for the entropy production to be positive. Second, radiative losses may change the sound speed significantly. The dispersion relation in radiative plasma was obtained in Helander et al. (1995). For long wavelength modes, i.e., under the condition $v_{Rn},\ v_{RT} >> 1$ it has three roots. The first one corresponds to the radiative aperiodic mode, $v_{ph} >> 1$. If $v_{RT} > 0$, this mode is strongly damped. The other two roots correspond to the modified sound:

$$v_{ph} = \pm \left(1 - \frac{v_{Rn}}{v_{RT} + v_\kappa}\right)^{1/2} + \frac{i}{2(v_{RT} + v_\kappa)} \left(1 - \gamma - \frac{v_{Rn}}{v_{RT} + v_\kappa}\right), \tag{1}$$

where $v_{ph} = \omega / k v_T$, Q and S are radiative losses and energy source respectively, ω is the frequency, k is the wave number, $v_T = \sqrt{2T/m}$, $v_{Rn} = \frac{\gamma-1}{2Tkv_T}\frac{\partial(Q-S)}{\partial n}$, $v_{RT} = \frac{\gamma-1}{2nkv_T}\frac{\partial(Q-S)}{\partial T}$, γ is the adiabatic index, and $v_\kappa = \frac{\gamma-1}{2}\frac{\kappa k}{n v_T}$. If the difference $v_{RT} - \nu_\kappa - v_{Rn}$ is small, the phase velocity may be significantly smaller than v_T. For intermediate k the first root corresponds to the slow radiative condensation mode. Two other solutions correspond to slightly modified sound waves. For the high temperature these modes are damped by heat conductivity. With increasing k the sound branch is transformed into "isothermal sound" which may be damped by the viscosity. The shock wave corresponds to the transition between two stable states (Fig. 1, arrows show the temperature evolution.).

Let the temperature in a cool medium behind the front be small enough to neglect the heat conductivity. The sound can propagate without significant damping. Its speed may be larger than the modified sound speed in the medium ahead of the front. All fast perturbations ahead of the front may be also damped. Thus,

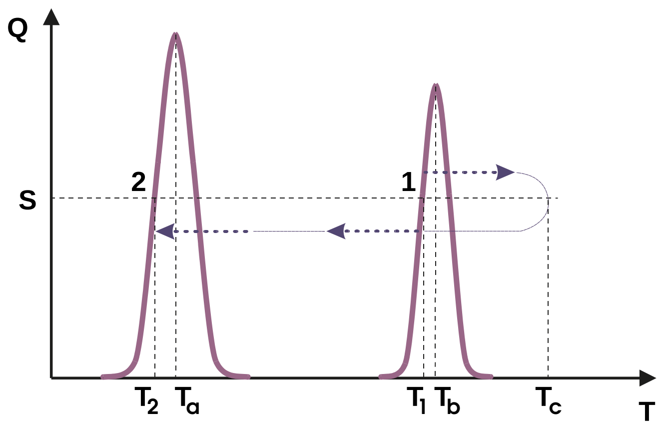

Fig. 1. Radiative losses model.

the shock speed is larger than the effective sound speed in the unperturbed medium and smaller than the sound speed behind the front. Thus, the front is stable. The front structure may be found analytically for the simplified radiation model with two radiating impurities, $Q = Q_1$ if $T_1 < T < T_1^1$; $Q = Q_2$ if $T_2 < T < T_2^1$; and $Q = 0$ for any other temperature. The values Q_1 and Q_2 are functions of the impurity densities. These values are eigenvalues and the front profile is an eigenfunction (Fig. 2). The shock runs from the right to the left and $y = (T/T_{-\infty})^{7/2}$. The plasma is accelerated by the shock.

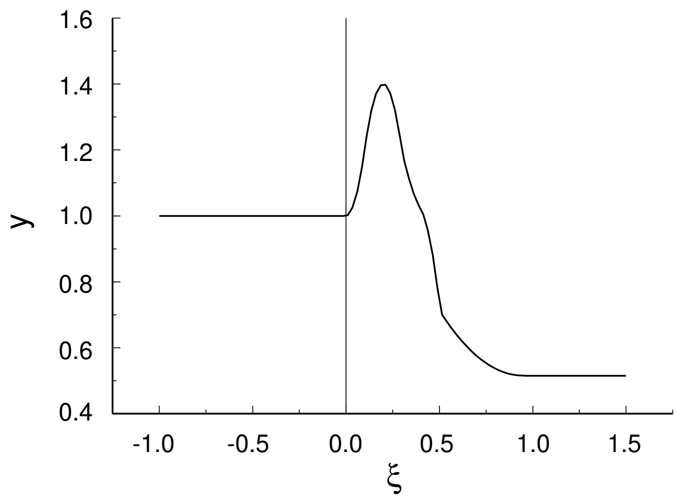

Fig. 2. Front structure.

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