INSTABILITIES DRIVEN IN YOUNG SUPERNOVA REMNANTS BY ELECTRON HEAT CONDUCTION

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1. INTRODUCTION

Adiabatic models of supernova remnants (SNRs) show very large temperature gradients. The effect of thermal conduction on the Sedov solution was studied by a number of authors (Solinger et al., 1979; Cox and Edgar, 1983; Cowie, 1977).

The observations show, however, that young SNRs such as SN 1006 (Hesser and van den Bergh, 1981) and SN 1572 (Strom, Goss and Shaver, 1982) are in an intermediate state between free expansion and the Sedov phase. In these cases stellar matter cannot be neglected. Following Chevalier (1982), the freely expanding ejecta of a Type I SNR can be modeled in such a way that the inner 4/7 of the mass have constant density and the outer 3/7 have a $\rho \propto r^{-7}$ profile (the "ramp"). The interaction of the ejecta with the uniform circumstellar medium (CSM) gives rise to a pair of shocks. As long as the reverse shock is within the r^{-7} part of the density profile, the interaction region is described by a self-similar solution (Chevalier, 1982). Such a solution holds for an adiabatic single fluid; the temperature gradient, however, is so large that it may give rise to a quite high heat flux.

2. ASSUMPTIONS AND RESULTS

In order to investigate the effect of such a flux on the Chevalier solution, we performed numerical computations based on a number of assumptions:

i) We adopted an expression for the electron heat conduction which takes into account saturation effects (cf. Cowie and McKee, 1977), the plasma being collisionless.
ii) For the same reason, the electron (T_e) and ion (T_i) temperatures are expected to be different inside the remnant, and we calculated the ion and electron fluids separately.
iii) Observational data from young SNRs such as Cas A and Tycho (Pravdo and Smith, 1979) suggest that non-Coulomb electron-ion coupling occurs on the collisionless shock fronts; we therefore assumed that T_e and T_i are equal on the shocks.
iv) We suppressed heat conduction through the shocks, as suggested by X-ray observations of SNRs.

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Our numerical results show that the solution remains self-similar until the inner shock is reached by the top of the ramp. The remnant expansion follows the same temporal power law as in the adiabatic case.

Fig. 1 shows the density distribution of our solution at different times, as long as the inner shock propagates into the ramp. The most striking feature is represented by two reverse shocks in the ejecta. Much of the thermal energy generated at the external shock is transported inward, raising the temperature of the inner shock. The stellar material, once having entered this latter shock, at first slows down but then quickly starts to expand almost freely because of the high temperature; the flow eventually becomes supersonic, and a second reverse shock is thus formed as the shocked ejecta impinge on the contact surface.

The non-adiabatic solution presented here is clearly not consistent with our initial assumption that thermal conduction is suppressed through shock fronts. If the thermal flux is quenched at the intermediate shock, the latter is pushed by the heat and accelerates. On the contrary, the inner shock is no longer sustained by this flux and slows down (in a reference frame co-moving with the contact surface). It is eventually overtaken by the other reverse shock while new intermediate shocks develop. Fig. 2 shows the density distribution after six years. After ten years several shocks have developed, interacting and giving rise to additional sub-shocks. The motion ceases to be tractable; we may however conclude that the flow becomes chaotic in a very short time.

3. DISCUSSION

It is quite difficult to assess the influence of heat flux on the flow of young SNRs, since plasma turbulences are still an open field. On one hand we may assume that heat flux suppression and electron-ion coupling happen only in well developed shock fronts; on the other hand it is possible that these effects happen as soon as the plasma perturbations grow out of the linear regime.

In this latter case thermal conduction is regulated by a very efficient feed-back mechanism. The heat flux is reduced just when its dynamical effect starts to become effective, while T_e and T_i tend to be equal because of the energy equipartition. The remnant, therefore, can be described by the adiabatic, one-fluid Chevalier model; heat conduction produces plasma turbulence on small scales only.

Radio observations effectively show a great deal of small scale turbulence (Dickel, 1983). The feed-back mechanism set up by thermal conduction could explain such turbulence.

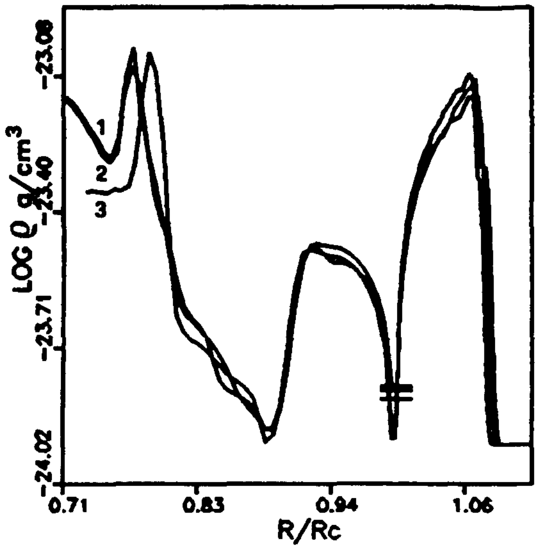

Fig. 1. Density distribution at three different times. 1) t=4.3 yr; 2) t=73.2 yr; 3) t=309.6 yr. This latter curve refers to the time when the inner shock is reached by the top of the ramp. Distances are normalized to the value of the radius of the contact surface.

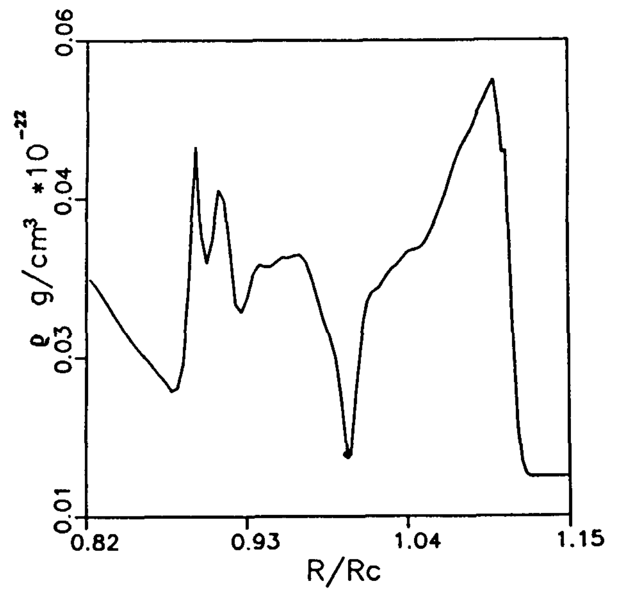

Fig. 2. Density distribution at t=6 yr when the heat flux is suppressed through the intermediate shocks.

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Consider now the possibility that the heat flux is inhibited only in well developed shock fronts. Then the fluid motion must be chaotic. The remnant is likely to assume a clumpy appearance, losing the well defined two-shell structure. Such a structure is however confirmed for Tycho's remnant by X-ray observations (Seward, Gorenstein and Tucker, 1983). Clumps are definitely present, but they are distributed in the inner shell and their presence may easily be explained in terms of Rayleigh-Taylor instability.

In contrast to Tycho, Cas A shows a quite different aspect. Tuffs (1983) reported predominantly chaotic proper motions of some 342 radio features. They present a poorly defined mean expansion age of 949 yr. Several structures have components of proper motion directed towards the optical expansion centre. This slow, chaotic expansion remains puzzling; heat-flux driven instabilities provide a likely explanation. As a possibility, we may assume that plasma turbulences are such that the feed-back mechanism does not work. In this case heat conduction in Tycho is impeded by some other process which could not be active in Cas A; in this latter remnant additional shocks would be free to form, driving chaotic motions.

Alternatively, we may assume that the CSM surrounding Cas A is cloudy, as testified by the quasi-stationary flocculi (Peimbert and van den Bergh, 1971). The ambient clouds may be able to penetrate into the inner shell and partially convert the kinetic energy of ejecta into thermal energy. In this case the heat flux would be greater than that allowed by the feed-back mechanism, giving rise to a chaotic motion.

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