SHOCK STRUCTURE INCLUDING COSMIC RAY ACCELERATION

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The backreaction of shock accelerated cosmic rays (CR) on the hydrodynamic flow is studied in a simple macroscopic model introduced by Axford et al. (1977): the fluid is isentropic except at discontinuities and the energy of the scattering wave field is neglected. With gas density ρ, velocity u, pressure p_G and a constant specific heat ratio γ_G we have in the one dimensional steady state:

$$\rho u = A; \; A\,u + p_G + p_C = B \qquad (1)$$

$$u\frac{\partial p_C}{\partial x} + \gamma_C \cdot p_C \cdot \frac{\partial u}{\partial x} = \frac{\partial}{\partial x}\int dp \cdot \kappa' \cdot p^3 \cdot v \cdot \frac{\partial f}{\partial x} \qquad (2)$$

where the CR pressure $p_C = 4\pi\int p^2 dp.p.v.f(x,p)$ and γ_C equals 4/3 (5/3) in the (non-)relativistic case but is assumed constant; with an effective diffusion coefficient (assumed positive) determining the spatial structure $\kappa(x) = \int p^3 v dp \cdot \kappa' \cdot (\partial f/\partial x) / \int p^3 v dp \partial f/\partial x$, given in terms of the CR momentum distribution f(x,p) and the diffusion coefficient κ', (2) integrates to

$$\frac{1}{2}A\,u^2 + \frac{\gamma_G}{\gamma_G - 1}\,u p_G + \frac{\gamma_C}{\gamma_C - 1}\,u\,p_C = C + \frac{\kappa}{\gamma_C - 1}\,\frac{\partial p_C}{\partial x} \qquad (3)$$

with A,B,C constant. The figure is a(u,p_G) diagram for studying (1) and (3); it shows the physically allowed triangular region, wherein the upstream and downstream states lie on the hyperbola $\partial p_C/\partial x = 0$. Those adiabats that do not cross the line $Au = \gamma_G p_G$ between these states correspond to smooth transitions. Adiabats having intersection points with the sheared reflection of the hyperbola in that line may continue from one of them as shock transitions along p_C = const., with $\gamma_C u p_C - \kappa(\partial p_C/\partial x)/(\gamma_C - 1)$ continuous. In general there exist 3 or 1 solutions, the extension of the test particle solution (Axford et al., 1977; Bell 1978a,b; Blandford and Ostriker, 1978) corresponds to that with smallest downstream p_C. The two other possible solutions have finite p_C downstream and finite or zero p_C upstream. In the latter case they should be interpreted as CR confinement and acceleration by a CR-

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free supersonic wind. They have no correspondent test particle solution of CR accelerated at a stellar wind terminal shock.

The relation between upstream and downstream pressures and the magnitude of discontinuities can be (at least time-asymptotically) determined within the model which also shows that a shock can put almost all its flow energy into cosmic rays.

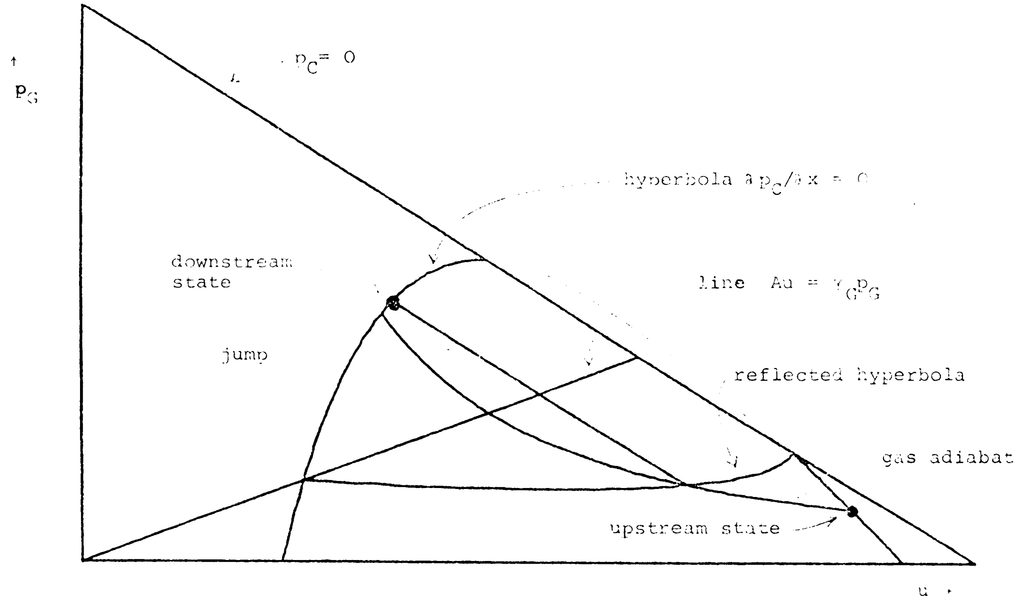

Fig The shock construction for the case $M=2.0$, $N=0.3$, $\gamma_G=5/3$, $\gamma_C=4/3$.

References

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