SUPERNOVA EXPLOSIONS IN STELLAR WIND BUBBLES

S. JANE ARTHUR
Department of Applied Mathematics
The University
Leeds LS2 9JT
UK

ABSTRACT. Type II supernovae play a major role in the dynamics of the interstellar medium. The interstellar medium in which such supernovae evolve is often considerably modified by the strong stellar winds both from the progenitor and other nearby stars. The result is that the appearance and energetics of the remnants can be very different from that of remnants in a uniform medium. In this paper we will consider the evolution of supernova remnants in stellar wind bubbles including the effect of departures from spherical symmetry. The aim is to understand both the appearance of such remnants and their effect on the overall energetics of the interstellar medium.

1. Introduction

In this paper we are going to consider a supernova explosion at the edge of a ~300 pc diameter cavity evacuated by the combined strong stellar winds of an OB association. Such bubbles and cavities are common in both the LMC and SMC (see e.g. Meaburn, 1978). Since an O star can travel up to 100 pc from its birthplace by the end of its $\sim 3\times10^{6}$ yr life, it is not unreasonable to assume it will have reached the edge of the cavity by the time it goes supernova. The radius of curvature of such a cavity is so large that we can simplify the problem to that of an explosion at a plane density interface. The density contrast at the cavity rim can be as high as 10,000 depending on whether the external medium is diffuse intercloud medium or dense molecular cloud.

2. Explosion at a plane density interface

Assume that the explosion remains adiabatic and that the time elapsed since the explosion is long enough for the initial details (apart from the energy of the explosion) to have been forgotten.

If α is the ratio of densities either side of the cavity rim, E_0 is the explosion energy, and ρ_c is the (uniform) density in the cavity, then this problem has one dimensionless parameter, α, and no independent length or time scales. It is therefore self-similar. The limiting cases are $\alpha = 1$, the classical Sedov explosion, (Sedov, 1959) and $\alpha = \infty$, the

R. Haynes and D. Milne (eds.), The Magellanic Clouds, 331–333.

hemispherical explosion where all of the explosion energy goes into the diffuse material (Anti-Safecracker Theorem).

For intermediate values of α the picture is not so simple. We cannot work out the flow analytically since we do not know the shape of the bounding shock. We could, of course, integrate the full time dependent axisymmetric Euler equations numerically but this would involve rezoning to allow for expansion of the flow zone, and constant checking to see if the solution has become self-similar. A more interesting and efficient method is to exploit the self-similarity of the problem and transform the time dependent equations to a time independent set in the similarity plane.

For the explosion parameters above we can construct a variable with dimensions of length, $L = (E_0/\rho_c)^{2/5} t^{1/5}$, and with this define two similarity variables $\xi = r/L$, and $\eta = z/L$. Further, we define dimensionless analogues of ρ, u_r, u_z, p by G, U, V, P where

$$\rho = \rho_c G(\xi,\eta,\alpha),\quad u_r = \frac{L}{t} U(\xi,\eta,\alpha),\quad u_z = \frac{L}{t} V(\xi,\eta,\alpha),\quad p = \rho_c \frac{L^2}{t^2} P(\xi,\eta,\alpha)$$

The transformed set of equations is time independent and we seek the steady solution in the similarity plane using a flux vector splitting scheme (Steger and Warming, 1981) which ensures good shock resolution. The use of multigrids (see e.g. Brandt, 1977) can improve the rate of convergence to the steady state and produce higher resolution solutions for small extra computing cost. See (Arthur, 1990) for a full description of the numerical method.

3. Results

In figures 1 and 2 we present results of calculations for values of α of 5 and 1000. These choices show the effect of a slight departure from the uniform density case, and that of a slight departure from the hemispherical case. In figure 3 we have plotted the ratio of energies in the flow zones either side of the interface against $\log(\alpha)$, the ratio of densities.

4. Conclusions

Even for relatively small values of α, e.g. 100, the majority of the energy of the explosion goes into the cavity. Gas swept up by the blast wave in the cavity will take a long time to cool as the shock will be very strong and the medium is not very dense. On the other hand, gas swept up by the blast wave moving out of the cavity will cool fairly rapidly as it is much more dense and the shock is moving much slower. From an observational point of view what will be seen is a bright arc bulging from the cavity rim where the dense gas is cooling radiatively. The part of the remnant in the cavity will be visible only in the X-ray part of the spectrum.

The energy going back into the cavity will contribute to further expansion and heating of the cavity gas.

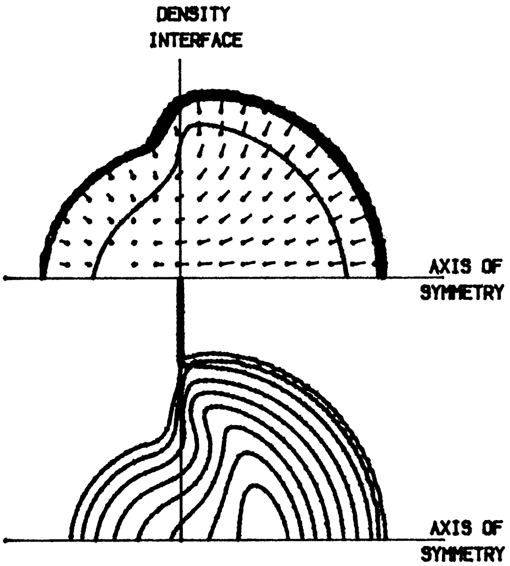

Figure 1. 10% contours of log(density) (bottom) and 10% contours of log(pressure) together with velocity vectors (top), for a density ratio of 5.0.

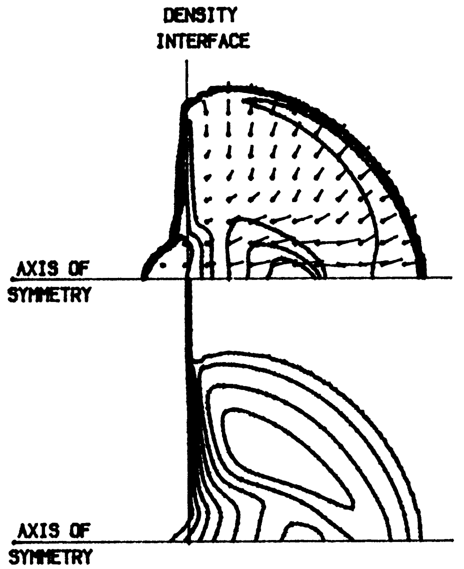

Figure 2. Same as Fig. 1 for a density ratio of 1000.0.

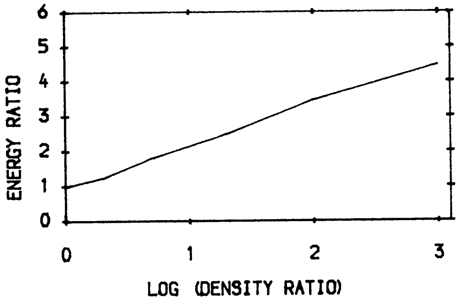

Figure 3. Graph of relative energies in flow zones either side of the density interface against log(α).

5. References

Arthur, S.J.: 1990, *Multigrid Methods Applied to a Point Explosion at a Plane Density Interface*, in preparation.

Brandt, A.: 1977, *Multi-level adaptive techniques (MLAT) for partial differential equations: Ideas and Software* in *Mathematical Software III* (J.R.Rice ed.), Academic Press, New York.

Meaburn, J.: 1978, *Astrophys. Space Sci.*, **59**, 193.

Sedov, L.I.: 1959, *Similarity and Dimensional Methods in Mechanics*, Academic Press, New York.

Steger, J.L. and Warming, R.F.: 1981, *J. Comp. Phys.*, **40**, 263.

https://doi.org/10.1017/S0074180900200715 Published online by Cambridge University Press