NUMERICAL MODELS OF SUPERSHELL DYNAMICS

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80309-0440

Abstract: Superbubbles play an important role in determining the state of the ISM in both spiral and irregular galaxies. We are modeling supershell dynamics in both homogeneous and stratified atmospheres using ZEUS, a 2-D hydrocode. We find that when a superbubble blows out of a Gaussian atmosphere, the cold, dense shell is not greatly accelerated. In addition, we believe that we observe the Vishniac overstability in radiative, decelerating shells.

Introduction: It is becoming increasingly apparent that the location of most Type II SNe in or near their parent OB associations has important consequences for the state of the ISM. The repeated SNe occurring in a typical OB association, along with the stellar winds from the hotter members of the association, will form a large, hot cavity surrounded by a thin, dense shell of swept up ISM.

In a disk galaxy, with an H I layer only a few hundred parsecs thick, such a superbubble can blow a hole completely through the disk, producing structures similar to the "worms" observed by Heiles (1979, 1984) in the Milky Way H I layer. In an irregular galaxy superbubbles can grow to great sizes. An example of this is the X-ray superbubble recently discovered in the LMC with radius 500-700 pc, identified with Shapley III (Singh et al. 1987). Superbubble dynamics are of theoretical importance as well. In disk galaxies, they provide a means to vent SN energy to the halo (Ikeuchi 1987), and to accelerate mass out of the disk, while in irregulars, supershells are probably significant sites of star formation when they go gravitationally unstable (McCray and Kafatos 1987). In addition, we hope to learn more about the instabilities that a radiative, decelerating shock is subject to (Vishniac 1983, Bertschinger 1986).

Technique: We are using ZEUS, a general purpose two-dimensional hydrodynamics code described by Norman and Winkler (1986), to model superbubbles in homogeneous and stratified atmospheres. This code has a fluid interface tracker that makes it well suited to modeling the dynamics of a thin shell.

We approximate the SNe from an OB association as a continuous energy source (Mac Low and McCray 1987). We model this source by placing mass with a temperature 10^3 that of the background medium in the center of the superbubble. This results in the right order of magnitude of mass being

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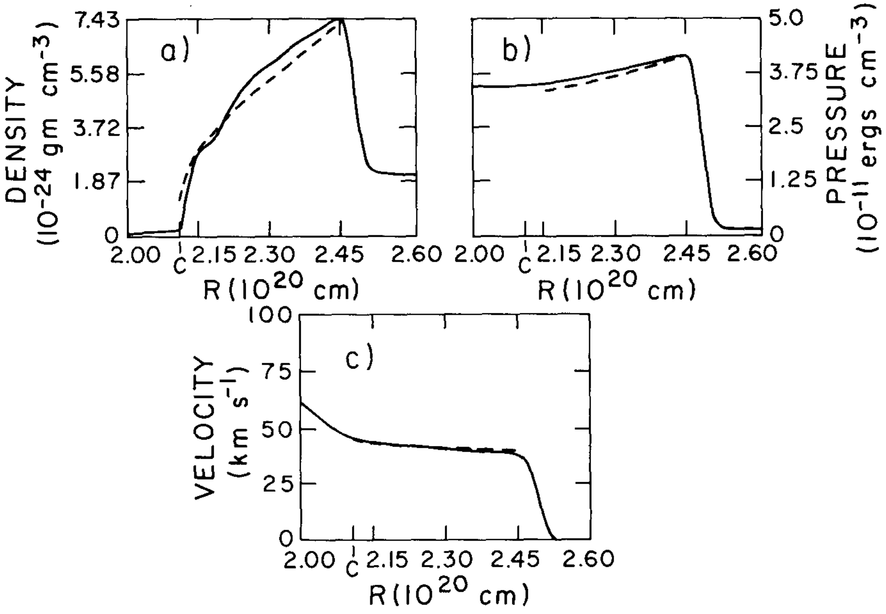

Fig. 1. Comparison of (a) density, (b) pressure, and (c) velocity profiles of Weaver et al.'s (1977) similarity solution with profiles through an adiabatic supershell modeled with ZEUS. The theoretical position of the contact discontinuity is marked by a C in each plot.

inside the superbubble despite our neglect of the effect of evaporation of mass off the cold shell. We use the cooling function given by MacDonald and Bailey (1981), which is essentially that of Raymond et al. (1976) between 10^5 and 10^7 K. In addition, we include a heating function linearly proportional to density just large enough to hold the background ISM at a steady temperature of 10^4 K.

Weaver et al. (1977) found a similarity solution for the structure of an adiabatic stellar wind bubble which is applicable to the case of an adiabatic supershell. In Fig. 1, we show the close agreement between that solution and profiles through an adiabatic supershell modeled with ZEUS. The theoretically calculated position of the contact discontinuity also agrees very well with the ZEUS result.

Results: In Fig. 2, we compare the density distribution in radiatively cooled and adiabatic supershells. We believe the clumpiness evident in the radiatively cooled model is a manifestation of the Vishniac (1983) overstability of a thin shell. If we are indeed observing this overstability, then we find that it damps fairly quickly once it becomes nonlinear. Clumps with a factor of 2 density contrast form very quickly in the shell, but they do not condense much further than this.

In Fig. 3 we show the time evolution of a superbubble evolving in a Gaussian atmosphere with a scale height of 100 pc, an atomic number density of 1 cm^{-3} in the plane (we assume 10% He by number)and a temperature

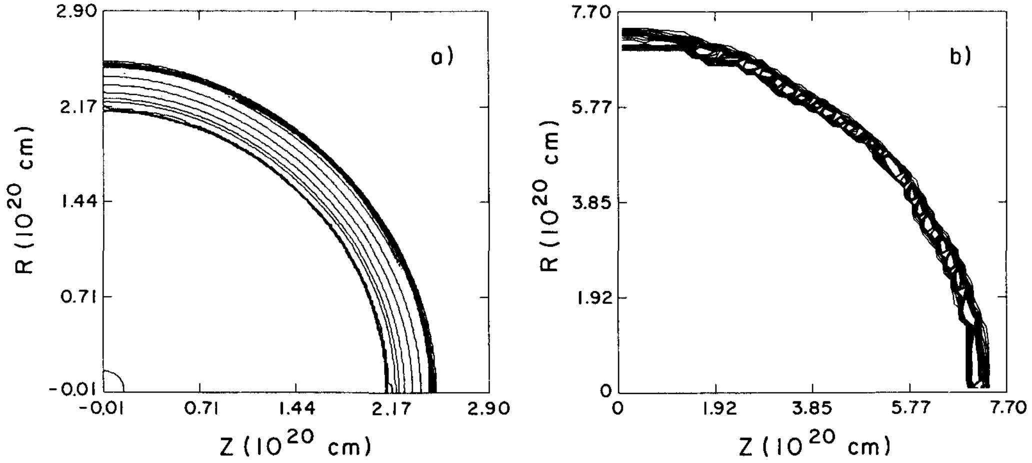

Fig. 2. Density distribution in (a) an adiabatic supershell and (b) a radiatively cooled supershell (at a later time). The contours are linearly spaced from zero to (a) 8.4×10^{-24} cm^{-3} and (b) 2.11×10^{-23} cm^{-3}.

of 10^4 K. The luminosity of this model is equivalent to one SN every 3×10^5 yr, which implies an OB association with ≈150 potential SNe. As soon as the supershell begins to accelerate upward Rayleigh-Taylor instabilities set in, disrupting it and allowing the hot interior gas to escape into the low density halo.

The large central spike is a result of our assumption of cylindrical symmetry. In a three-dimensional model, non-axisymmetric modes of the Rayleigh-Taylor instability would be excited, and the central portion of the shell would fragment into several pieces. The key result that the shell fragments are not accelerated by the expanding hot gas would not change, however.

We thank Dr. Mike Van Steenburg, Steve Voels, and CASA for assistance in producing Figure 3. This work was partially supported by NASA grant NAGW-766 under the NASA Astrophysical Theory Program. Computations were performed on the NASA Cray X-MP.

References

Bertschinger, E. 1986, Ap. J., **304**, 154.
Heiles, C. 1979, Ap. J., **229**, 533.
_____. 1984, Ap. J. Suppl., **55**, 585.
Ikeuchi, S. 1987, preprint.
MacDonald, J. and Bailey, M. E. 1981, M.N.R.A.S., **197**, 995.
Mac Low, M.-M., and McCray, R. A. 1987, Ap. J., submitted.
Mac Low, M.-M., Norman, M. L., and McCray, R. A. 1987, in preparation.
McCray, R. A. and Kafatos, M. C. 1987, Ap. J., **317**, 190.
Norman, M. L., and Winkler, K.-H. A. 1986, in Astrophysical Radiation Hydrodynamics, eds. K-H. A. Winkler and M. L. Norman (Dordrecht: Reidel).

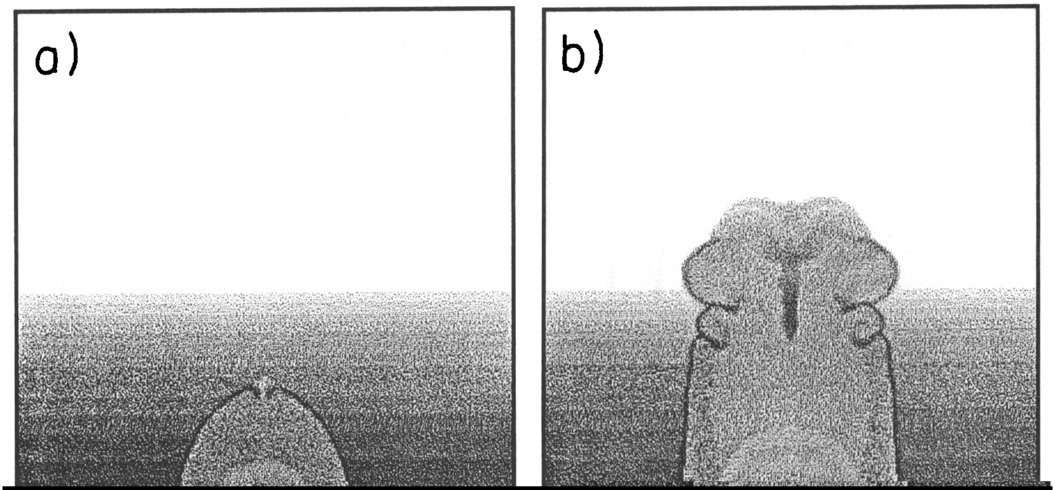

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Fig. 3. Time evolution of a superbubble in a Gaussian atmosphere with parameters given in the text. Density (on a log scale ranging from 10^{-6} to 10 cm^{-3}) is shown at times of (a) 3.5 Myr, (b) 4.8 Myr, (c) 5.4 Myr, (d) 6.1 Myr.

Raymond, J. C., Cox, D. P., and Smith, B. W. 1976, Ap. J., **204**, 290.
Singh, K. P., Nousek, J. A., Burrows, D. N., and Garmire, G. P. 1987, Ap. J., **313**, 185.
Vishnaic, E. T. 1983, Ap. J., **274**, 152.
Weaver, R., McCray, R. A., Castor, J., Shapiro, P., and Moore, R. 1977, Ap. J., **218**, 377; erratum, **220**, 742.