A MODEL FOR THE INTERACTION BETWEEN STARS AND GAS IN THE INTERSTELLAR MEDIUM

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Abstract: A global model for the ISM is described in which separate fluids of stars and gas interact through star formation, mass loss, stellar heating, and gaseous cooling processes. In all simulations, a steady state develops in which rarefied ionized regions separate ridges of neutral gas.

Global models for the interstellar medium have been discussed by Cox and Smith (1974), McKee and Ostriker (1977), and Cox (1981) under the assumption that the primary source of heating is from supernovae. We have extended these models by studying the fluid dynamics of gas that is heated by young stars. In our model, which is based on the work of Chiang and Prendergast (1985), gas can form into stars while stars can lose mass and heat the gas through stellar winds and supernovae. In addition, gas can cool radiatively. Because the stars as well as the gas are approximated as fluids, only one kind of star is considered, and this is an average Pop I star. The two fluids are coupled by a star formation rate proportional to the gas density, and a mass loss and heating rate proportional to the stellar density. In addition, the gas cools radiatively.

When only wind heating is considered, the heating process is continuous in time and the stability of the system can be examined. For conditions appropriate to interstellar gas, the equilibrium state, in which heating balances cooling, star formation balances mass loss, and both fluids have the same mean velocity, is subject to a star formation instability (Chiang and Prendergast 1985; Chiang and Bregman 1987). The nonlinear behavior of the system was studied with one and two dimensional numerical hydrodynamic models. After a characteristic time (the star formation and stellar mass loss time, taken to be 10^8 yr), the gaseous component forms dense connected ridges of neutral gas separated by large volumes of rarefied ionized gas (Fig. 1a). Most of the mass (70%) is in the neutral ridges, which have a typical length

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of 100-200 pc, yet occupy about 20% of the volume. The ridges have a lifetime of about the star formation time and move with a velocity of a few km/sec. Enhancements in the stellar density lie adjacent to the ridges (rather than at the bubble centers) and drive the motion of the gas. The ionized gas is never hotter than 20,000 K, which is a consequence of the smoothness of the heating process and the steepness of the cooling curve above 10^4 K. If the calculation had been performed in three spatial dimensions, the ridges would become shells or sheets of HI. The most prominent HI features would occur at the interface of two shells (HI sheets), of three shells (HI filaments), or at the vertex of four shells (dense HI clouds).

The two dimensional models were extended to include the effects of supernovae, which lead to the creation of million degree gas that cools slowly. Three models were calculated in which wind 1.4×10^{49} erg/pc, and the supernova rates were taken to be 0.142, 0.0472, and 0.0157 SN/kpc^2/10^8 yr for models s1, s2, and s3 respectively (Fig. 1 b,c,d). The local supernova rate is assumed to be proportional to the Pop I star density, although the actual occurrence of an event at a particular time is random. For model s1, the amount of heating provided by the supernovae is equivalent to that provided in the above wind model.

The porosity of the gas changes dramatically as a function of the supernova heating rate. In model s1, the overwhelming volume of gas is occupied by dilute ionized gas, with neutral HI appearing as islands. In model s3, the dilute ionized gas appears as isolated bubbles, and little of this gas is hotter than 10E6 K. The intermediate case, s2 has several well defined bubbles, some of which have merged to form larger structures. The typical size of a bubble, 200-300 pc is reminiscent of holes in the HI distribution seen in M31 (Brinks and Bajaja 1986)) and of the superbubbles seen in our Galaxy (Heiles 1979, 1984).

We have calculated line profiles through the grid for both the wind and supernova models (Fig. 2) and find that the line width increases with the supernova heating rate, as expected. It is not straightforward to interpret peaks in the line profile as distinct HI ridges since velocity crowding sometimes leads to such features in the profile. In the wind model, and models s2 and s3, HI would appear to be pervasive to an observer for a line of sight exceeding 200 pc, as suggested by the data (Liszt 1983, Lockman et al. 1986). The resemblance between the calculated and observed line profiles and structure of the ISM lend encouragement that this sort of model may ultimately reproduce a variety of features in the ISM and provide a suitable model for understanding the ISM.

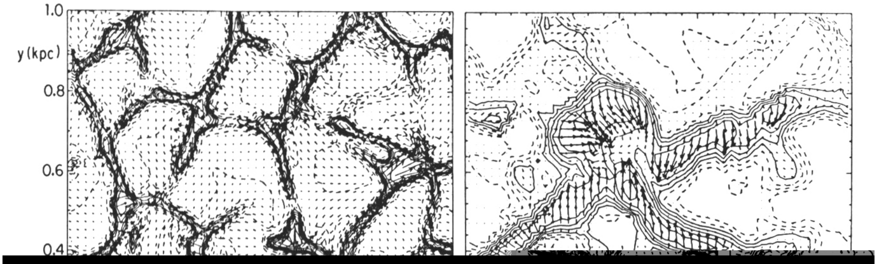

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Fig. 1. The gas density contours and momentum vectors of the gas in a 1 kpc square grid are presented for the wind model and supernova models s1, s2, and s3 (a-d respectively). The wind model has twice the computational resolution of supernova models. The porosity of the gas decreases rapidly as the supernova rate is reduced by a factor of 9 from models s1 to s3.

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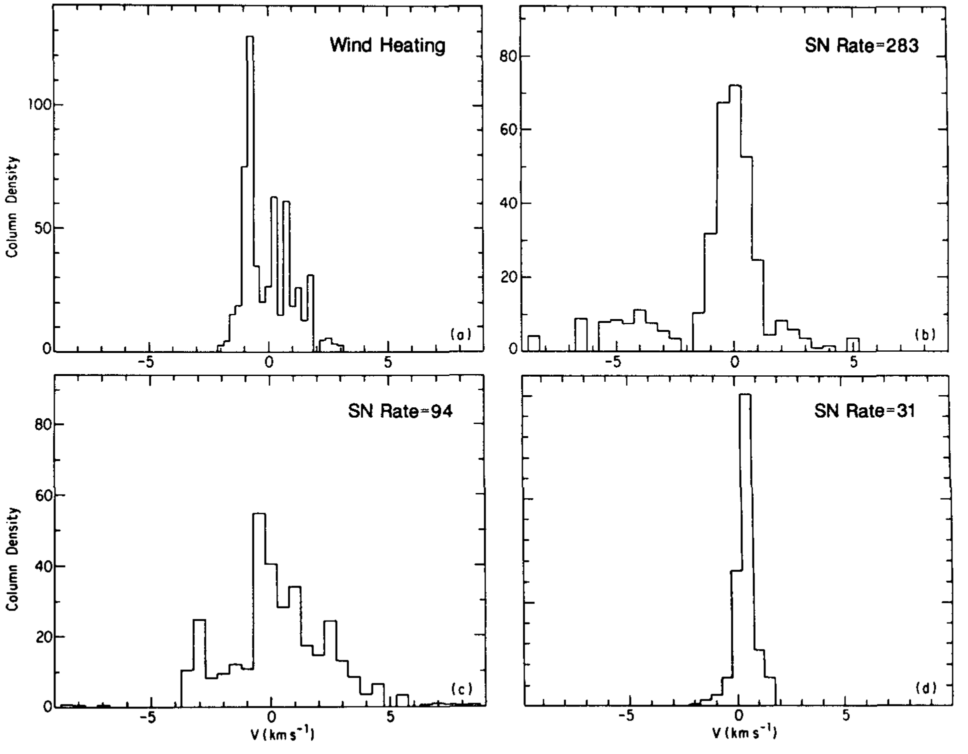

Fig. 2. The line profiles in arbitrary units are given for the wind model and supernova models s1, s2, and s3 (a-d respectively). The line width for the wind model and model s3 is about 2-4 km/sec while it is about 5 km/sec for model s2 and 5-10 km/s for model s1. Greater supernova rates lead to wider line profiles.

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