STELLAR WINDS AND THE INTERSTELLAR MEDIUM

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ABSTRACT

Theoretical models for the interaction of stellar winds and the interstellar medium are described. Stellar wind energy sources are listed, and observations of expanding shells around stars and star clusters are reviewed. Giant expanding shells, or "superbubbles," with radius > 100 pc, are formed by the combined action of stellar winds and supernovae from clusters of OB stars. Smaller expanding shells around Wolf-Rayet stars are probably formed by the interaction of the WR stellar wind with matter ejected in a previous red supergiant phase of stellar evolution. Stellar wind activity is evident in regions of star formation in dense molecular clouds.

INTRODUCTION

Observations in the past few years have provided a great deal of detailed information on stellar winds and evidence for their dynamical effects on the interstellar medium (e.g., Conti and McCray 1980). This evidence, which ranges from the radio to the X-ray bands, has been seen in the following contexts: (1) large (radius > 10 pc) wind-driven cavities surrounded by expanding shells, or "bubbles," around isolated OB stars; (2) very large (radius > 100 pc) expanding shells, or "superbubbles," around OB associations; (3) planetary nebulae; (4) ring nebulae around Wolf-Rayet (WR) stars; and (5) high velocity gas in the vicinity of regions of star formation in dense molecular clouds.

What structure results from the action of a stellar wind on interstellar gas? How can this interaction be observed? Are the current theories adequate to explain and interpret the presently available observations? What can be learned about the properties of

Richard M. West (ed.), Highlights of Astronomy, Vol. 6, 565–579.

stellar winds and the interstellar medium? How important are stellar winds for the global structure and dynamics of the interstellar medium (ISM)? In this brief review I shall attempt to address these questions in the light of current observations. I shall stress in particular the observations of bubbles and superbubbles around OB stars and clusters and the observations of ring nebulae around WR stars, mentioning only briefly the effects of stellar mass loss in dense molecular clouds.

For another discussion of these and related topics, see Dyson (1981).

STELLAR WIND PARAMETERS

Table 1 lists typical parameters for the stellar winds of various types. Column 1 lists the star or system involved, column 2 gives the mass loss rate, $\dot{M}_w$, column 3 gives the terminal velocity, V_w, of the wind, column 4 gives the mechanical power of the wind, $L_w = \dot{M}_w V_w^2/2$, column 5 gives an estimate of the likely or inferred age of the sytem, column 6 gives an estimate of the net mechanical energy that might be provided by such a wind, and column 7 gives typical values of the radii of the ISM structures that have been observed or might be expected. These numbers and estimates are rough, and in some instances may be off by as much as an order of magnitude. They will be discussed further, but it is worth noting here the considerable range in energies and sizes involved.

IDEALIZED INTERSTELLAR BUBBLE THEORY

In order to provide a framework for discussing the observations, I briefly summarize here the theory of Castor et al. (1975) and Weaver et al. (1977) for the structure and evolution of an idealized interstellar bubble. The need for modification and further development of the theory will be discussed in subsequent sections, where observations are reviewed.

The assumptions of the idealized model are: (1) that the ambient ISM has uniform, constant density, $\rho_0 = \mu m_H n_0$, where μ is the mean molecular weight; (2) that the star is at rest with respect to the ISM; (3) that the stellar wind is isotropic; and (4) that the wind power, L_w, is constant. These assumptions can be, and, of course, must be relaxed in order to describe actual systems.

Table 1: Stellar Wind Parameters.

Source	$\dot{M}_w$ ($M_\odot$ yr^{-1})	V_w km s^{-1}	L_w ergs s^{-1}	t yr	E ergs	R pc	Ref
04I star	10^{-4}	3000	2×10^{38}	3×10^{5}	3×10^{51}	30–100	1
09V star	10^{-8}	1000	2×10^{34}	10^{7}	10^{48}	30–100	1
OB cluster	10^{-4}	3000	10^{39}	10^{7}	10^{52} -10^{53}	200 -1000	2
WR star	3×10^{-5}	2500	5×10^{37}	10^{5}	2×10^{50}	0.3–10	3
Red giant star	10^{-6}	10	10^{32}	$\sim10^{6}$	10^{46}	~10	4
Planetary nebula	10^{-7}	2500	2×10^{35}	10^{4}	5×10^{46}	0.1–1	5
Orion cloud	10^{-3}	100	3×10^{36}	3000	3×10^{47}	0.3	6
L1551	10^{-6}	200	10^{34}	3×10^{4}	10^{46}	0.5	7
T-Tauri star	10^{-7}	200	10^{33}	10^{6}	3×10^{46}	?	8

1. Garmany et al. 1981
2. Abbott et al. 1981
3. Willis 1982
4. Castor 1981
5. Castor et al. 1981
6. Genzel and Downes 1983
7. Snell et al. 1980
8. Edwards 1982

The stellar wind will create a cavity, of radius $R_s(t)$, compressing the ambient ISM into a thin expanding shell having mass $M_s(t) = 4\pi R_s(t)^3/3$ and velocity $V_s = \dot{R}_s$. After a relatively short time compared to the duration of the wind, this mass substantially exceeds the mass expelled by the wind, so that the dynamics of the shell can be described simply by Newton's second law:

$$\frac{d}{dt}\left[M_s(t)V_s(t)\right] = 4\pi R_s^{2}P_{int} \quad , \qquad (1)$$

where P_{int} is the pressure of the interior of the cavity. If P_{int} is specified, the dynamics of the shell is known.

At this stage a critical bifurcation in the theoretical models occurs with two different idealized assumptions about P_{int}: (a) the

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thermal energy of the shocked stellar wind is conserved; (b) the interior thermal energy is lost to radiation, so that the stellar wind impacts directly on the inner surface of the shell. According to the respective assumptions, the interior pressure is given by

$$P_{int} = \alpha L_w t/(4\pi R^3/3) \quad , \tag{2a}$$

or

$$P_{int} = \dot{M}_w V_w/(4\pi R^2) \quad . \tag{2b}$$

(In 2a the numerical factor α = 10/33 rather than 2/3 because 5/11 of the wind energy remains in the interior, and the rest does work on the expanding shell.) The resulting solutions of equation (1) are given, respectively, by

$$R(t) = 27 \text{ pc } (L_{36}/n_0)^{1/5} t_6^{3/5} \quad , \tag{3a}$$

or

$$R(t) = 16 \text{ pc } (L_{36}/n_0 v_{1000})^{1/4} t_6^{1/2} \quad , \tag{3b}$$

where $L_{36} = L_w/(10^{36}$ ergs $s^{-1})$ and $V_{1000} = V_w/(1000$ km $s^{-1})$. In either case the age of the system can be inferred from the observed velocity and radius of the shell, viz.:

$$t = 0.6\ R_s/V_s \tag{4a}$$

or

$$t = 0.5\ R_s/V_s \quad . \tag{4b}$$

For interpreting observations, the difference between (4a) and (4b) is not significant.

However the difference between models (a) (energy conservation) and (b) (momentum conservation) becomes very significant when one attempts to infer the power of the wind from observations of the expanding shell. The difference in the dynamics of the models is clearly characterized by defining the parameters in Table 2. The parameter ε is the ratio of kinetic energy in the shell to total wind energy provided, and the parameter π is the ratio of momentum (per unit solid angle) in the shell to that imparted by the wind. The parameter t_{rad} is discussed below. In general, systems described by model (b) have smaller radius, less velocity, and much less energy than systems described by model (a).

Table 2. Parameters for Momentum and Energy Conservation

		Theoretical Value	
Parameter	Definition	Model (a)	Model (b)
ε	$M_s V_s{}^2/(2L_w t)$	0.2	$\sim 0.2(t/t_{rad})^{-1/2}$
π	$M_s V_s/(\dot{M}_w V_w t)$	>1	1

The choice between model (a) and model (b) is determined by the radiative losses in the hot interior of the bubble. Figure 1 illustrates the structure of the energy conserving (model a) case. The stellar wind (region W) encounters a shock at a radius R_1, which is substantially less than R_s, causing its temperature to rise from a few times 10^4 K to coronal temperatures $>10^6$ K. Most of the interior volume (region C) of the bubble is filled with this coronal gas, which

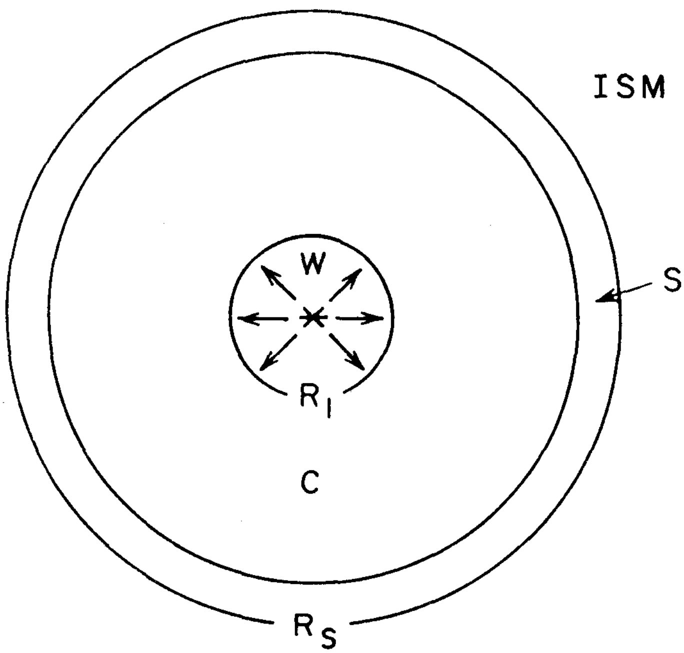

Fig. 1. Schematic diagram of an interstellar bubble indicating the regions and boundaries of the flow.

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provides the pressure to push the thin shell (region S) of swept-up interstellar gas. A second shock occurs at R_s, where the outer boundary of the shell encounters the undisturbed ISM (region I). In the absence of diffusive processes, the coronal gas would be separated from the shell by a contact discontinuity at the interior surface of the shell. However, diffusion and thermal conduction cannot be ignored at this interface, because the temperature changes dramatically, from $>10^6$ K in the coronal gas to $\sim 10^4$ K in the dense shell, and the density varies inversely with the temperature in order to maintain approximate pressure equilibrium. Consequently, electrons conduct heat from the coronal gas into the shell, causing gas to evaporate from the shell into the interior. The result of these processes is to lower the temperature of the interior, to increase its mass, and to increase its radiative losses.

When the radiative losses of the coronal gas become comparable to L_w, region (C) will begin to collapse, allowing R_1 to move outward toward the shell. Call this time t_{rad}, and the corresponding shell radius R_{rad}. For $t > t_{rad}$ the dynamics of the shell is described approximately by the momentum conserving model (b), so that at t_{rad} (R_{rad}) the radius of the shell changes from the $t^{3/5}$ law of model (a) to the $t^{1/2}$ law of model (b). For an idealized bubble expanding into a low density ISM, t_{rad} and R_{rad} are given by:

$$t_{rad} = 3\times10^6 \text{ yr } L_{36}^{0.3} n_0^{-0.7} \quad , \tag{5}$$

and

$$R_{rad} = 50 \text{ pc } L_{36}^{0.4} n_0^{-0.6} \quad . \tag{6}$$

Interstellar bubbles can, in principle, be observed in many ways. The most obvious signature of a bubble would be a ring-shaped emission nebula around the star seen in H_α and O III λ5007. In the idealized (spherically symmetric) model the center of the nebula should be brighter than the surrounding HII region by a factor $\sim(V_s/10 \text{ km s}^{-1})^2$, and the ring should be limb-brightened by a factor ~3 to 10. The expanding shell can also be observed by UV absorption spectroscopy against the central star. Observations of density sensitive lines such as NIIλ1085 are particularly valuable, because they give a measure of the interior pressure of the bubble.

If the star is near relatively dense interstellar gas, the ionization front may be trapped in the expanding shell itself, so that one may observe a dense HI shell expanding with the same velocity as the H II shell. If the star is near an interstellar cloud, the

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expanding shell may also contain an outer layer of H_2, which would show anomalously high rotational excitation due to ultraviolet pumping by the nearby star (Hollenbach et al., 1976). Such excitation has been seen in the UV absorption spectra of a few OB stars (Jura 1975).

The hot interior of the bubble is observed best by UV studies of absorption lines from highly ionized species such as O VI λ1035. (Observations of absorption lines such as C IV λ1549 and N V λ1240 are less useful in this respect, because these ions can be produced by photons with energy less than the He II edge, so that their column densities are more likely to include a contribution due to photoionization by the central star.) The O VI λ1035 absorption line is produced mainly in the conduction front between the hot interior and the expanding shell. The theory of Weaver et al. (1977) predicts a column density $N(OVI) \approx 5\times10^{13}$ cm^{-2}, almost independent of the parameters of the model, such as ISM density, system age, or wind luminosity. Copernicus observations of O VI λ1035 in the absorption spectra of OB stars have found such column densities to be typical (Jenkins 1978). However, one cannot conclude that the observed column densities actually come from the bubble interior, because any conduction front between coronal gas and cooler gas along the line of sight to the star will have roughly the same column density. The best way to see whether the observed O VI lines are formed in the bubble would be to study the correlations of velocities of the O VI lines with those of other UV absorption lines from less ionized species in the expanding shell, but such observations must await the launch of new far UV spectrometers with higher resolving power than the Copernicus spectrometer.

The interior of the bubble is hot enough to emit soft X-rays. According to the calculations of Weaver et al., the ratio of soft X-ray luminosity to wind luminosity should be $L_x/L_w \sim 10^{-3}(n_0t_6)^{1/2}$. For a typical nominal bubble ($L_w \sim 10^{36}$, $n_0t_6 \sim 1$, $R_s \sim 30$ pc), the resulting X-ray surface brightness will be well below the galactic soft X-ray background, and hence impossible to observe. However, as I shall discuss below, X-ray emission may be observable from the interior of a "superbubble," formed by the combined action of the winds of many stars.

INTERSTELLAR SHELLS AND SUPERSHELLS

Nominal O-star bubbles may be hard to find. O stars are mostly found in clusters, in which case a superbubble is formed. O stars not in clusters tend to be high velocity runaways, in which case the resulting bubble is highly distorted. The structure of a nominal O-star

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bubble is hard to distinguish from that of a defunct supernova remant (faint circular H II region of radius ~30 pc, no X-rays, no nonthermal emission); the most obvious difference is that the bubble should have a star somewhere near its center. The best candidate for a nominal O-star bubble may be the faint nebulosity (radius ~15 pc) around the Of star HD 148937 (Bruhweiler et al., 1981). This interpretation implies that the star is very young, $<10^6$ yr.

In the past decade, considerable evidence has accumulated for coherent shells of much larger dimensions, ranging from ~50 pc to 1 kpc or more. A prototype is the Gum Nebula, which has a radius ~125 pc (Reynolds 1976). This subject was discussed in some detail here in the session on "The Violent Interstellar Medium," in recent reviews of observations of optical supershells around OB associations (Meaburn 1983) and of X-ray supershells (Cash 1983). Heiles (1979) has summarized the evidence for supershells seen in the HI 21 cm emission line, and Cowie et al. (1981) have discussed evidence from UV absorption line studies for expanding supershells around the Orion and Carina OB associations. In some cases the observed kinetic or thermal energy of the shell is several times 10^{52} ergs. In other cases, the shells have stalled and have present kinetic energy $<10^{51}$ ergs, but their very size suggests that they were formed by a now defunct energy source that has imparted $>10^{52}$ ergs. To summarize, it seems that the combined action of stellar winds and supernova explosions of stars in OB associations can create these supershells by imparting some 10^{52} - 10^{53} ergs of mechanical energy to the surrounding ISM over a period $\sim 10^7$ - 10^8 years (McCray and Snow 1979; Bruhweiler et al., 1980; Tomisaka et al., 1981).

In the energy conserving phase, the radius of a supershell is given by an equation identical in form to the Sedov solution:

$$R_s = 130 \text{ pc } [E_{51}(t) t_7^{\,2}/n_0]^{1/5} \quad , \tag{7}$$

where $E_{51}(t)$ is the accumulated net energy of stellar winds and supernovae in units of 10^{51} ergs and $t_7 = t/(10^7$ yr). (The numerical coefficient of equation [7] varies from 130 pc for the case of steady energy input to 200 pc for the case of a single impulsive injection of energy.)

Abbott (1982) has investigated the properties of a complete sample of early-type giant stars and WR stars within 3 kpc of the sun; he estimates that approximately 20% of the mechanical energy input to the ISM is provided by stellar winds, and 80% by supernova explosions. Most of the stellar wind power, and about half of the supernova power,

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comes from a few massive OB associations. It seems that the stellar winds alone from the Cyg OB2 association can provide the energy ($\sim 3\times10^{52}$ ergs) needed to form the Cygnus X-ray superbubble (Abbott et al., 1981), although it is certainly possible that a few supernovae have also occurred in Cyg OB2 and contribute to the total energy of the superbubble.

David Abbott and I have estimated the energy input function for a cluster such as Cyg OB2, using an idealized model in which all the stars were born at once. We find that $E_{51}(t)$ is dominated by the stellar winds for about 10^7 years, at which time stars with about 20 $M_\odot$ are departing the main sequence. Thereafter, supernova explosions dominate. According to our model, Cyg OB2, with an age $\sim 3\times10^6$ years, has imparted only ~10% of the ultimate energy, $\sim 3\times10^{53}$ ergs, that it will ultimately provide to the superbubble. The soft X-ray luminosity of the interior is comparable to the observed value (Cash et al., 1980). By 2×10^7 years, stars of initial mass 8 $M_\odot$ (the assumed minimum mass for a type II supernova progenitor) have evolved, and the cluster ceases to impart significant energy to the ISM. However, the cluster remains as a source of radiation that can cause the supershell to fluoresce as an H II region long after it has lost its kinetic and thermal energy. Clearly, OB associations can make the observed supershells; indeed, the formation of such supershells may dominate the structure and dynamics of the ISM, at least the coronal phase.

The interpretation of the observations of supershells is uncertain, owing mainly to our uncertainty about the structure of the ISM. It is easy enough to fit an ideal bubble model to the observations and derive energies, ages, etc., but the shells are so large that the basic assumption of a homogeneous ambient ISM must be suspect. In particular, if most of the volume of the ISM is filled with coronal gas, with temperature $>10^6$ K and density $n_0 \sim 10^{-2}$ cm^{-3}, as suggested by Cox and Smith (1974) and McKee and Ostriker (1977), even a single supernova explosion or the wind of a single massive O-star can create a cavity with radius >100 pc, and an OB cluster can create a cavity of radius >1 kpc, which will discharge most of its energy into the galactic halo. Such a superbubble will certainly entrain a considerable number of interstellar clouds of higher density as it propagates through the coronal gas, and the effects of thermal conduction into these clouds will enhance the radiative losses of the interior. However, I estimate that these enhanced radiative losses do not significantly affect the dynamics of the superbubble during the 2×10^7 year dynamically active lifetime of the cluster.

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RING NEBULAE

A very exciting development in the past few years has been the observations of expanding rings around WR stars (e.g. Chu 1981, 1982; Heckathorn et al., 1982; Johnson 1982; Lozinskaya 1980; Schneps et al., 1981; Treffers and Chu 1982). Along with some planetary nebulae, such as the famous Ring Nebula NGC 6720, the bubble nebulae around WR stars provide the best examples of expanding shells around early-type stars. Roughly 10% of WR stars have clearly discernible ring nebulae, and most of these stars are of the WN type. Some of the more spectacular examples are NGC 7365, NGC 6888, and NGC 2359. Indeed, the planetary ring nebulae and the bubble nebulae around WR stars may be closely related phenomena.

Ring nebulae around WR stars have typical properties as follows: radius 3 - 10 pc, expansion velocity 20 - 80 km s^{-1}, age (from eq. 2) 2×10^4 - 2×10^5 yr, shell mass 5 - 20 $M_\odot$. However, substantially greater masses, 147 $M_\odot$ and 400 $M_\odot$, have been inferred from observations of the ring nebulae RCW 104 and NGC 3199, respectively (Chu 1982).

The dynamics of the WR ring nebulae do not obey the energy conserving theory of Weaver et al. (1977). Chu (1982) has tabulated the parameters ε and π for five expanding ring nebulae; she finds in four out of the five cases that $\varepsilon \sim 10^{-2}$ and $\pi \sim 0.5$ (in the fifth case both ε and π have lower values). The observations are consistent with $\pi = 1$, indicating that these ring nebulae are in the momentum conserving phase.

Why are ring nebulae associated particularly with WR stars, and not with other OB stars that also have strong stellar winds? I believe that the answer is that most of these ring nebulae are bubbles formed by the interaction of the WR stellar wind with gas ejected by the star in a previous stage of evolution. The argument that drives me to this conclusion stems from the observations by Garmany et al. (1982), showing that the locations of WR stars are highly correlated with those of the most massive (>30 $M_\odot$) OB supergiants. The conclusion that the WR stars are the descendents of these stars is supported by calculations by Maeder (1982), which indicate that the WR stage follows a red supergiant stage in the evolution of a massive star. But such massive O stars are known to have great stellar winds, which must certainly have made their own interstellar bubbles, driving the ambient interstellar gas to a radial distance $\sim R_{rad}$ > 30 pc (eq. 6). Since the bubbles around WR stars are small and relatively young, the gas from which they are formed must have been provided by the star itself. This conclusion is supported by the observation of enhanced abundances of nitrogen and helium in NGC 6888 (Kwitter 1981).

Therefore, it seems that the ring nebulae around WR stars are the massive star analogues of planetary nebulae.

It has long been suspected that stellar winds were responsible for the ring-like morphology of some planetary nebulae (e.g., Pikel'ner 1973; Arkhipova and Lozinskaya 1978), and it is now clear that the central stars of planetaries do have strong stellar winds (e.g., Castor et al., 1981). Recently, Kwok et al. (1978) have presented a model for expanding planetary nebulae in which the wind of the central star is colliding with the wind from a previous red giant phase. The same model may apply to the bubble nebulae around WR stars. According to the model, both winds have constant terminal velocity and density distribution $\rho(r) \sim r^{-2}$. The resulting expansion law for the shell follows from equation (1); for the relevant momentum conserving case (b), the shell has constant velocity given approximately by

$$V_s \cong \left[(\dot{M}_{WR}/\dot{M}_{RG})V_{WR}V_{RG}\right]^{1/2} \quad , \tag{8}$$

where $\dot{M}_{WR}$, $\dot{M}_{RG}$, V_{WR}, and V_{RG} are mass loss rates and terminal velocities of the stellar winds of the WR star and of its red giant predecessor, respectively, and we have made the approximation $V_{WR} \gg V_{RG}$.

The bubble nebulae around WR stars raise many interesting problems for further theoretical and observational study. For example, we need to understand why the bubbles are in the momentum conserving phase rather than the energy conserving phase. I estimate that the bubble interior must contain several solar masses of gas in order to radiate away the thermal energy of the shocked wind. Since neither the WR wind nor evaporation from the inner surface of the expanding shell can provide this much mass, it seems that some fraction of the red giant wind mass must be entrained in the interior as the shell expands. This entrainment could result from Rayleigh-Taylor instability of the shell. The shell is unstable if its velocity increases with radius or time. Generally, one can show that for wind power $L_W \sim t^m$ and ambient gas density $\rho \sim r^{-n}$, the shell velocity increases with time if $m + n > 2$. Therefore, the colliding wind model of Kwok et al., for which $m + n = 2$, is the marginally stable case, and the shell will become unstable if the wind power of the WR star increases with time or if density of the red giant envelope decreases faster than r^{-2}.

This issue is related to the duration of the red giant phase. If the red giant wind has a typical terminal velocity $V_{RG} \sim 10$ km s^{-1}, it

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reaches a distance ~10 pc in 10^6 years. When the shell reaches the terminus of the wind, it will become unstable and the bubble will "burst." The shell will no longer be a nice ring, but will probably break up into radially oriented striations. Some nebulae do appear to have such structure. The wind power may propagate between the striations, causing a new (possibly much fainter) bubble to form in the interstellar medium beyond. Perhaps, then, the typical radii of the observed WR bubbles are determined by the radii of the wind envelopes of the red giant predecessors. Counts of red supergiants, WR stars with and without bubbles, and massive OB supergiants in clusters will provide important constraints on the lifetimes of these systems and will test the proposed evolutionary scenario.

We certainly need better theoretical models for the structure and evolution of the WR bubble nebulae in order to take full advantage of UV spectroscopic observations, particularly those that will be provided by ST.

Finally, the inferred masses of 147 $M_\odot$ and 400 $M_\odot$ for two bubble nebulae are a threat to this entire picture, because they would require OB supergiant predecessors of even greater mass. Hugh Johnson tells me that the estimates of nebula masses are very uncertain, so perhaps the problem is not real. Alternatively, these two nebulae may be examples of bubbles formed in interstellar gas rather than in the stellar ejecta. But we should not rule out the exciting possibility that such supermassive stars really do exist.

STELLAR WINDS IN MOLECULAR CLOUDS

Perhaps the most significant aspects of the interaction of stellar winds with the ISM is the activity associated with regions of star formation in dense ($n_0 > 10^4$ cm^{-3}) molecular clouds. It is beyond the scope of this article to review this rapidly developing and complex subject, but I feel obliged at least to mention a few key points and references. The reader can find more comprehensive discussions in the proceedings of the IAU Symposia, Interstellar Molecules (Andrew 1980), and Regions of Recent Star Formation (Roger and Dewdney 1982).

Evidence for high velocity (20-250 km s^{-1}) flows in these regions is seen in broad emission lines of CO (Scoville 1980), infrared emission lines of H_2 (Beckwith 1980), and in OH, H_2O, and SiO maser lines (Genzel and Downes 1983). These flows have typical scale sizes ~0.1 pc and dynamical timescales 10^3-10^4 yr. Inferred mass loss rates range from ~10^{-7} $M_\odot$ yr^{-1} for T-Tauri stars (Edwards 1982) and Herbig-

Haro objects (Snell et al. 1980) to $\gtrsim 10^{-3}$ $M_\odot$ yr^{-1} for the active regions in Orion and W51. The momentum in these flows exceeds (by factors $\sim 10^2$) the momentum of any associated source of radiation, so the winds driving the flow must have a very different physical mechanism from the winds of hot stars. In some cases the flows have bipolar geometry, possibly indicating collimation by magnetic fields or an accretion disk.

In a dense ($n_0 \sim 10^5$ cm^{-3}) molecular cloud a supernova or a wind-driven bubble will radiate its energy and stall in a short time, $\sim 10^4$ yr, at a radius ~ 0.2 pc (Shull 1982). Silk and Norman (1980) have pointed out that T-Tauri stars may be sufficiently numerous in molecular clouds that their winds can account for the apparent supersonic turbulence and perhaps stimulate the formation of low mass stars. On the other hand, the cumulative effects of stellar winds and supernovae from an embedded OB cluster may disperse a molecular cloud (Norman and Silk 1980). Although we hardly understand the sources of high velocity flows in molecular clouds, it is clear that they play an important role in the star formation process.

This research was supported by a grant from the National Science Foundation.

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