THE EFFECT OF MASS-LOSS ON THE EVOLUTION OF HII REGIONS IN THE L.M.C.

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ABSTRACT

Empirical calibrations based on prior studies of Galactic OB Stars are used to determine the integrated stellar wind mechanical luminosity (L_W) and the integrated Lyman continuum photon luminosity (S_*) for 10 OB clusters in the L.M.C. These values of L_W and S_*, together with narrow band H-α surface photometry of an overlapping sample of 15 L.M.C. HII regions, are used to show that the large shell-like HII regions, in the L.M.C. are stellar wind bubbles 3 to 5 million years old. In order to reproduce the general properties of these HII shells, a thick cushion of shocked stellar wind gas must have been present on the inside of the shell for most of the life time of the nebula, and the shell itself must be ram pressure confined by the HI/molecular cloud out of which it formed.

THE TWO STELLAR-WIND MODELS

The stellar-winds of young OB associations sweep up a shell in the surrounding I.S.M., the properties of which are dependent on the mode of interaction of the wind with the shell. The two extreme possibilities are:

1) that there is a reverse-shock set up in the stellar-wind creating a pad of hot shocked gas between the free-flowing stellar-wind and the shell (Hot cushion model, HC; Weaver et. al. 1977).

2) that the wind impinges directly onto the shell due to a collapse of the hot pad of shocked gas early in the lifetime of the nebula (Direct-impingement model, DI; Steigman et. al. 1975).

The three major characteristics which can be used to distinguish the two models are:

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1) the dependence of the nebula radius (R_{SH}) upon the stellar-wind parameters, stellar age and I.S.M. density ie:

$$R_{SH}(\text{p.c.}) = 427.9\, L_{29}^{1/5}\, n_{II}^{-1/5}\, t_6^{3/5} \qquad \text{HC Model (1a)}$$

$$R_{SH}(\text{p.c.}) = 402.5\, M_{23}^{1/4}\, n_{II}^{-1/4}\, t_6^{1/2} \qquad \text{DI Model (1b)}$$

where L_{29} (10^{29} Joules), M_{23} (10^{23} Newtons), n_{II} (m^{-3}) and t_6 (10^6 years) are the mechanical luminosity of the stellar wind, the wind momentum, the density of the surrounding media and the nebula age, respectively.

2) whether or not the shell nebula is ionization-bounded. It is possible for the forming shell to become sufficiently massive to absorb all of the ionizing photons from the central cluster. The conditions for this to occur prior to the shell stalling is given by:

$$n_{II}\, L_{29}^{3}\, S_{48}^{-2} \geq 9.05 \times 10^4 \qquad \text{HC Model (2a)}$$

$$n_{II}\, M_{23}\, S_{48} \geq 1.07 \times 10^{10} \qquad \text{DI Model (2b)}$$

where S_{48} (10^{48} photons/sec) is the number of ionizing photons emitted by the OB cluster.

Taking typical values of L_{29} (13.0), S_{48} (40.0) and M_{23} (5.0) (Wilson 1983), we can see that the photons are cut off prior to stalling if, $n_{II} \geq 1.2\text{x}10^6$ for the HC model, and $n_{II} \geq 1.4\text{x}10^{11}$ for the DI model. This means that the HC will produce an ionization-limited shell-like HII region, in all except low density media, while the DI model will only produce this type of nebula if the surrounding media is exceptionally dense. In almost all cases the DI model will produce a HII shell stalled within a larger HII region.

3) different densities in the shells due to different pressures being applied to the inner surface of the shell ie.

$$n_{HC} = 2.80 \times 10^{10}\, L_{29} t_6 R_{SH}^{-3} \qquad \text{HC Model (3a)}$$

$$n_{DI} = 6.03 \times 10^{7}\, M_{23} R_{SH}^{-2} \qquad \text{DI Model (3b)}$$

OBSERVATIONS

The M.K. spectral types of 25 OB stars in 10 clusters associated with the L.M.C. HII regions were determined (Wilson 1983). These classifications were used to derive Teff, L_*, R_* and M_* for each of the stars, which in turn were used to determine the stellar mass-loss rates ($\dot{M}$) via an empirical calibration relating $\dot{M}$ to the stellar parameters (Wilson and Dopita 1983). These rates were then integrated to obtain L_{29} and M_{23} for each of the clusters, assuming V_∞ = 3Vesc (Abbott 1978). The integrated S_{48} for each cluster was also obtained from an empirical expression relating S_{48} to the spectral type of the star (Morton 1969, Georgelin et. al. 1975).

15 narrow band H-α images of L.M.C. HII regions, taken with an S.E.C. Vidicon T.V. photometer, were used to determine S_{48} for each nebula. The nebula surface brightnesses were also used to determine the r.m.s. densities of the HII regions through the adoption of simple geometric models.

DISCUSSION AND CONCLUSIONS

Figure 1a shows that the observed integrated H-α flux emitted by the HII regions (and hence the Lyman photon emission rate S_{48}) is equal to or larger than the integrated H-α flux (S_{48}) expected to be produced by the ionizing flux of the exciting stars. This is confirmed by a larger sample of data plotted in figure 1b, which shows that there is a general relationship between an HII region's integrated H-α flux and its diameter. Figure 1c shows a similar plot for the integrated H-α flux expected to be produced by the ionizing cluster. Comparing figures 1b and 1c we see that almost all of the HII regions appear to absorb a greater number of ionizing photons (0.2-0.4 in log(S_{48})) than that expected from the ionizing cluster. This difference can be explained by the decreased line blanketing in the L.M.C. due to reduced metalicity, which makes a star of a given spectral type appear bluer and more luminous, and hence increases S_{48}. In order to produce agreement between the expected and observed S_{48} (ie for the HII region to be marginally ionization bounded) the Lyman continuum spectral distribution of L.M.C. OB stars would have to mimic that of a star with a T_{eff} 2-4,000 K hotter than that of a corresponding star in the Galaxy. This is the largest increase in U.V. colour temperature we could reasonably expect, thus figures 1a-1c show conclusively that the L.M.C. HII regions observed are in general ionization bounded. This conclusion, coupled with the fact that all the larger nebulae show a distinct shell morphology, strongly favours the HC model.

Table 1 shows the observed r.m.s. densities for the HII shells (column 6) which can be compared with mean shell densities predicted the HC and DI models (columns 4 and 5 respectively). The observed densities also strongly support the HC model.

The HC model can successfully reproduce the observed shell morphologies, the fact that the nebulae are ionization bounded and the shell densities. Taking this model as being applicable to the nebulae, we can substitute t_6, R_{SH} and L_{29} into equation 1a to determine the I.S.M. densities. The densities obtained (column 7) are much higher than what is typically expected in the I.S.M., though they compare favourably with the densities expected in the outerlying parts of massive gas clouds ($\sim 10^5\ M_\odot$) which are in the latter stages of isothermal collapse (column 8; Wilson 1983).

TABLE 1

NEBULA	R(pc)	t_6	n_{HC}	n_{DI}	n_{OB}	n_{II}	n_C
301	53.0	3.6	8.7	0.10	5.8	13.4	20.6
25	43.5	3.3	6.0	0.08	4.6	13.2	17.8
137	88.5	-		0.06	2.4	4.7	5.7
229	66.1	3.4	9.5	0.72	6.2	10.1	12.9
196	47.5	3.2	7.8	0.12	6.0	14.8	18.1
106	53.0	5.6	9.6	0.12	-	15.6	54.9
11	24.4	2.8	28.9	0.20	-	58.9	194.8
226	31.0	3.0	21.9	0.22	-	40.4	105.0
235	39.0	3.8	7.3	0.08	-	18.5	35.5
31	71.5	2.4	4.8	0.12	-	4.2	2.7

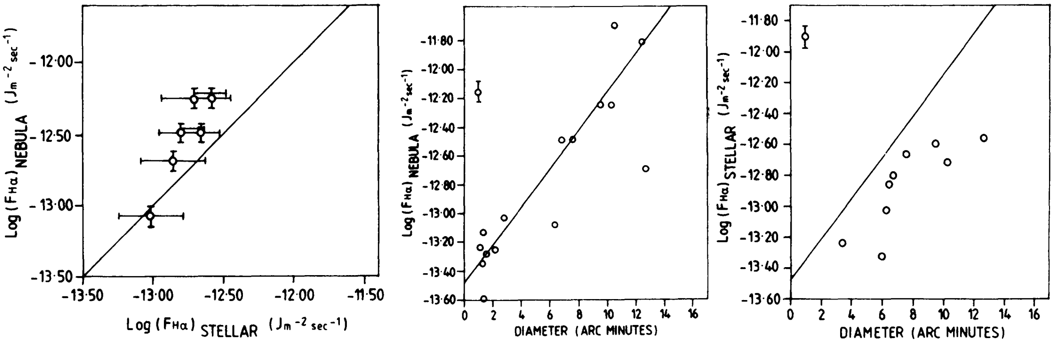

Figure 1a: The integrated dereddened H-α flux ($F_{H\alpha}$)for 6 nebulae compared to the $F_{H\alpha}$ produced by the exciting cluster.
Figures 1b and 1c: $F_{H\alpha}$ plotted against the nebula diameter.

Thus large shell-like HII regions in the L.M.C. are stellar-wind bubbles, 3-5 million years old, which have been formed by a thick pad of shocked stellar wind gas and are ram-pressure confined by the infalling gas of the massive cloud out of which they formed.

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