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LMC HII Region Luminosities versus Observed Ionising Stars

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Abstract: We use the stellar census of OB associations in the Large Magellanic Cloud (LMC) to predict the Hα luminosities of the host HII regions, based on results from stellar atmosphere models. These values are compared to the observed HII region luminosities, yielding an estimate for the mean fraction of H-ionising photons that escape the local nebulae in this sample. We formally estimate that, overall, 0–51% of the ionising radiation escapes the local HII regions and is available to ionise the warm, ionised medium in the LMC. We find both nebulae that appear to be density-bounded and ones that appear to be radiation-bounded.

Keywords: stars: early-type—ISM: general—HII regions—Magellanic Clouds

1 Introduction

Are O stars the principal source of ionisation for the diffuse, warm, ionised medium (WIM) in galaxies? Most recent evidence has suggested that this is probably the case. O stars are one of the only sources capable of meeting the power requirement (e.g. Reynolds 1984) and spatial distribution (Miller & Cox 1993; Dove & Shull 1994) of this pervasive component of the interstellar medium (ISM). The localisation of diffuse, ionised gas near HII regions is also highly suggestive of ionisation by O stars (Walterbos & Braun 1994; Ferguson et al. 1996).

But HII regions have traditionally been considered as essentially radiation-bounded objects, and aggregate samples appear to be broadly consistent with this interpretation (e.g. Kennicutt 1988; Banfi et al. 1993). In that case, there would be essentially no significant ionising flux escaping the nebulae, therefore requiring one of the alternative mechanisms for ionising the WIM. We can investigate this question by examining individual HII regions: how do the ionising fluxes from the observed O stars actually compare with the observed nebular luminosities? Here we summarise this simple study, which is reported in greater detail by Oey & Kennicutt (1997).

2 Methods

The Large Magellanic Cloud (LMC) offers a broad range of HII regions of varying luminosities and morphologies, and for over a dozen of these, a complete, classified census is available for the hottest, most massive stars (e.g. Massey et al. 1995; Oey 1996). Likewise, a catalog of uniform nebular photometry is available for the Hα luminosities of the HII regions (Kennicutt & Hodge 1986). With the aid of stellar atmosphere models, it is possible to estimate the Lyman continuum (Lyc) photon emission rate for the individual stars, and obtain a predicted total nebular Hα luminosity to compare directly with the observed values.

Table 1 shows the results of this comparison for 12 objects. Column 1 identifies the nebula by its designation in the Davies, Elliott & Meaburn (1976; DEM) Hα catalog, and column 2 identifies the corresponding OB association from the Lucke & Hodge (1970; LH) catalog. In the third column, we list the number of O stars ($n_\star$) identified spectroscopically from the reference shown in the last column. We have considered the ionising contributions of only O stars, but we identify those associations containing WR stars with an asterisk on $n_\star$. Column 4 shows the ratio of the observed Hα luminosity ($L_{\rm obs}$) to that predicted ($L_{\rm SdK}$) from the observed O stars, using the stellar Lyc emission rates of Schaerer & deKoter (1997). $L_{\rm SdK}$ is adjusted for the observed extinction, derived from the reddenings found in the stellar observations. Further details regarding the measurement of $L_{\rm obs}$ and computation of $L_{\rm SdK}$ may be found in Oey & Kennicutt (1997). In column 5, we classify the nebular morphology as diffuse HII region (D), superbubble (S), or composite (C).

The median $L_{\rm obs}/L_{\rm SdK}$ is $0{\cdot}74$, suggesting that many HII regions are significantly density-bounded. However, there are many sources of substantial uncertainty, which are discussed in detail by Oey & Kennicutt (1997). These include uncounted O and WR stars; the effect of B stars, whose ionising fluxes

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Table 1. Ratio of observed and predicted HII region luminosities

DEM	LH	$n_\star$	L_{obs}/L_{SdK}	Morph	Reference
10B	2	7	0·81	D	J. W. Parker, unpublished
31	6	6	0·40	S	Oey (1996)
34	9, 10	44*	0·66	C	Parker et al. (1992)
106	38	8	0·61	S	Oey (1996)
152, 156[a]	47, 48	35*	0·66	C	Oey & Massey (1995)
192	51, 54	25*	0·83	S	Oey & Smedley (1998)
199	58	22*	1·22	C	Garmany et al. (1994)
226	73	4	0·93	S	Oey (1996)
243	83	11	0·54	D	Oey (1996)
293	110	1	1·09	D	Conti et al. (1986)
301	114	7	0·20	S	Oey (1996)
323, 326	117, 118	20	1·13	D	Massey et al. (1989)

*WR star excluded; DEM 199 contains three WR stars.
[a]Not including DEM 152A.

are poorly known; accounting for LMC metallicity; observational errors in extinction; and error in the LMC distance. However, the modelled ionising fluxes of O stars are by far the dominant source of uncertainty, contributing about $\pm 50\%$ to the overall median L_{obs}/L_{SdK}. We therefore estimate that $0{\cdot}49 < L_{obs}/L_{SdK} < 1{\cdot}1$, or equivalently, that a median fraction of ionising radiation that escapes the local nebulae is in the range 0–51%.

3 Results

The WIM has been found to comprise 20–53% of the total Hα luminosity in nearby star-forming galaxies (see Ferguson et al. 1996). In the LMC, Kennicutt et al. (1995) found this fraction to be $35 \pm 5\%$. Our estimate of 0–51% for the proportion of escaping ionising radiation is therefore fully consistent with the possibility that these photons are the ionising source for the WIM. If the nebulae in our LMC sample are typical in their properties and relationship to the ISM, then these results may also be applicable to other galaxies. We note that our median value of 0·74 in the ratio of observed to predicted Hα luminosities is in close agreement with the results of Hunter & Massey (1990). The data in that study show a median value of 0·7, using the stellar Lyc estimates of Panagia (1973).

We believe that our sample is representative of the range of nebular properties in the LMC. As seen in Table 1, we include objects with a variety of morphologies, including classical, diffuse HII regions, superbubbles, and composite objects with both shell and diffuse components. The sample also spans a range in Hα luminosity, including some of the brightest nebulae in the LMC (with the exception of 30 Doradus); and also objects an order of magnitude, or more, fainter. We do not find any compelling trends in L_{obs}/L_{SdK} with either morphology or luminosity. We find that the mean ratio is 0·59 for the superbubbles, 0·89 for the diffuse nebulae, and 0·85 for composite objects. Although the superbubbles appear on average to have a somewhat smaller ratio of observed to predicted luminosity, it is apparent from Table 1 that there is a large scatter in the individual values. Given the small numbers of objects available, we therefore refrain from attributing significance to this possible difference.

Although formally the uncertainties yield a range in escaping ionising radiation of 0–51%, we emphasise the existence of several HII regions which appear to be convincingly density-bounded. The lower limit to the fraction of escaping photons is therefore somewhat larger than 0, although it is difficult to constrain this more specifically. We also note the existence of objects that appear to be convincingly radiation-bounded.

Thus a direct comparison of Hα luminosities with observed stellar ionising rates shows that the fraction of escaping Lyc radiation is consistent with O star ionisation of the WIM. However, at present, the large uncertainties, dominated by uncertainties in stellar ionising fluxes, do not permit us to rule out alternative mechanisms. But we do find a number of HII regions that appear to be significantly density-bounded, while others appear to be radiation-bounded.

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