WOLF-RAYET STARS IN OPEN CLUSTERS AND ASSOCIATIONS

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1. INTRODUCTION

We have made a search for line-of-sight coincidences between WR stars and open clusters using the new catalogue of galactic WR stars (van der Hucht *et al.*, 1981, called the HCLS catalogue) and the catalogue of open cluster data (Lyngå and Lundström, 1980). As a measure of the separation we used the angular distance between the WR star and the cluster centre expressed with the cluster angular radius, r', as unit.

By comparing the results found from the real angular distributions of WR stars and open clusters with those found if the WR stars were redistributed by changing signs in their latitudes, we concluded that the majority of WR stars with separations less than 3 r' are true cluster members. For larger separations only a few stars can be expected to be members. We have therefore limited our investigation to those WR stars that were found within 5 r' from an open cluster.

2. THE FREQUENCY OF CLUSTER AND ASSOCIATION MEMBERS

From earlier investigations we selected the best determinations of distance moduli for the clusters and mean colour excesses close to the WR stars. From these data we then tried to decide whether the WR stars were true cluster members or not.

For WR stars within 3 r' we found 15 definite or probable cluster members and 7 definite or probable non-members. For 6 stars no firm conclusions could be made, mainly since the available observations of the clusters were limited or very discordant. In the interval 3 to 5 r' only 3 WR stars were found to be probable cluster members.

We have also studied WR stars suspected to be members of OB associations. In this case we found 15 probable WR type members, but this number will probably be considerably increased when more associations have been investigated more thoroughly.

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There are 32 WR stars in the HCLS catalogue brighter than v = 10. We find 18 of these (56 %) to be probable members of open clusters or OB associations. There is of course the possibility that a few of these in fact are non-members, but it is equally possible that more of the bright WR stars will be found to be association members in the future. We thus conclude that at least 50 % of the galactic WR stars are members of young open clusters or OB associations.

If we only consider the cluster members, we believe that our sample is almost complete for stars brighter than v = 12. There are 76 WR stars in the HCLS catalogue brighter than this limit, and we find 15 of these (20 %) to be probable cluster members. It is then interesting to note that large differences between subgroups exist. For example, 13 of the 45 WN stars are cluster members, but only 2 of the 30 WC stars. However, there are 6 WN7 type cluster members, but only 3 non-members. Clearly, the concentration of WN7 stars to open clusters is significantly more pronounced than for WR stars in general. If we exclude the WN7 stars, the differences between WN and WC stars are no longer significant. On the other hand, WR+OB binaries then show a tendency of being more often found in open clusters than the rest of the WR stars. This is however only marginally significant at the 5 % level, and this result should not be overinterpreted.

WN7 and WN8 stars have often been grouped together as "transition WR stars". The motivations have been their high luminosities and their high H/He ratios. However none of the seven WN8 stars with $v \leq 12$ is found to be a member of an open cluster (or OB association). We therefore conclude that the distributions of WN7 and WN8 stars with regard to open clusters and associations are highly different.

3. THE ABSOLUTE MAGNITUDES OF WR STARS

Using the distance moduli and mean colour excesses derived for the clusters and associations, it is often possible to calculate the absolute magnitudes and intrinsic colours of the WR type members. Unfortunately, many of these are binaries, and the effects of the non-WR components on the combined magnitudes and colours have to be removed. Even if it is possible to estimate the magnitude differences rather accurately, the fact that the OB components often are more luminous, make the derived absolute magnitudes, and in particular the intrinsic colours, very uncertain.

In Figure 1 we present the individual determinations of absolute magnitudes for the WR type cluster and association members. The corresponding mean values are shown in Table 1, column (2). A strong correlation between absolute magnitude and spectral type is evident for the WN4 to WN7 stars. No such correlation is obvious for the WC stars, but a slow increase in luminosity from WC6 to WC9 might be present.

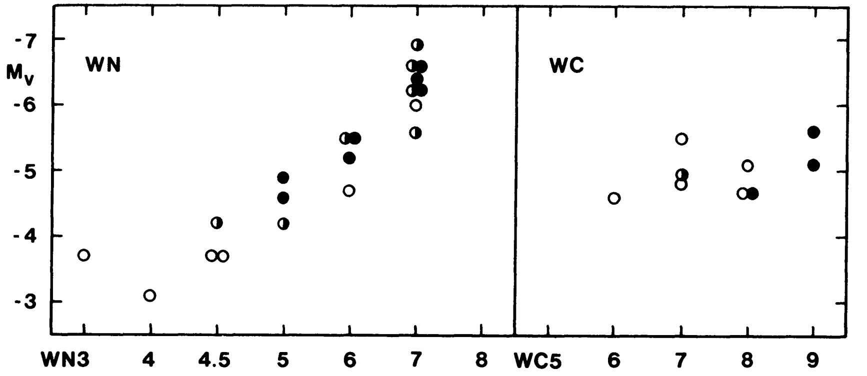

Figure 1. Absolute magnitudes for WR stars versus spectral type. Filled circles represent determinations given full weight. Half-filled and open circles indicate that the determinations are uncertain and very uncertain respectively.

Smith (1968) derived absolute magnitudes and intrinsic colours for WR stars in the Large Magellanic Cloud. However, the spectral types used by Smith are in some cases obviously incorrect (Breysacher, 1980), and we have therefore made a reanalysis of the stars observed by Smith.

Using the same observations and reddening corrections as Smith, but with the spectral types from Breysacher and a slightly different distance modulus, $18^{\rm m}.5$ (Westerlund, 1964), we derived the absolute magnitudes shown in column (3) of Table 1. Combining these two sets of data we have adopted what we believe are the best estimates of absolute magnitudes for WR stars that can be made at present. These are shown in column (4) of Table 1.

Table 1. Absolute magnitudes and intrinsic colours for WR stars. Numbers within parentheses indicate number of stars observed.

Sp. type	M_v Galaxy	M_v LMC	M_v Adopted	$(b-v)_0$ Galaxy	$(b-v)_0$ LMC	$(b-v)_0$ Adopted
WN2	-	-	-3.8::	-	-	
WN3	-3.7: (1)	-3.9 (5)	-3.8	-.30:: (1)	-.17 (5)	
WN4	-3.1: (1)	-3.9 (4)	-3.8	-	-.14 (4)	-.20
WN4.5	-4.0 (3)	-	-4.0	-.29:: (1)	-	
WN5	-4.7 (3)	-	-4.7	-.20 (2)	-	
WN6	-5.3 (5)	-	-5.3	-.25 (2)	-	
WN7	-6.4 (8)	-6.6 (4)	-6.4	-.27 (6)	-.20 (2)	-.25
WN8	-	-5.8 (2)	-5.8	-	-.24 (4)	
WN9-10	-	>-6.5 (1)	-6.0::	-	-	
WC4-5	-	-4.2 (6)	-4.2	-	-.21 (5)	
WC6	-4.6: (1)	-	-4.6:	-	-	-.25
WC7	-5.0 (3)	-	-5.0	-.30: (1)	-	
WC8	-4.8 (3)	-	-4.8	-.41: (1)	-	
WC8.5	-	-	-5.1::	-	-	-.45
WC9	-5.4 (2)	-	-5.4	-.48: (2)	-	

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The data for the intrinsic colours are more limited, mainly because the colours of the WR components in WR binaries often are impossible to calculate with reasonable accuracy. However, in Table 1, columns (5) and (6) we have gathered the information available for galactic WR stars and WR stars in LMC respectively. Column (7) of Table 1 shows the very coarse estimates of intrinsic colours that can be made from the present material. We would like to emphasize that the colours for individual stars might deviate from these mean values with as much as $0^m.05$-$0^m.10$.

4. FINAL REMARKS

The most straightforward interpretation of the differences in concentration towards open clusters is to regard them as effects of evolutionary status and age. Lyngå (in preparation) has shown that many of the O-type clusters are very loosely bound and that they might dissipate very rapidly. Individual stars might migrate away from the clusters even faster. If a large fraction of the progenitors to WR stars are born in such clusters, the differences between WN7 stars and other WR stars indicate that the WN7 stars are significantly younger than the rest of the WR star population.

There is probably no unique mechanism responsible for the formation of WR stars. A detailed analysis of the space distribution of WR stars must then take several different evolutionary scenarios into account. In any such investigation the relations between WR stars and young open clusters and OB associations are of great interest.

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DISCUSSION FOLLOWING LUNDSTRÖM AND STENHOLM

Moffat: If one adopts T_{eff}'s for WR stars (e.g. from Underhill, 1980) and derives M_{bol}'s is there still the trend that the hot-envelope stars are less luminous for WN or WC single stars? If so, it would appear that the L's and M's go together.

Lundström: Maybe, but I don't believe that we know the effective temperatures well enough.

Turner: Did you make any corrections to the luminosities of the WR stars in clusters of the Magellanic Clouds to correct these for the effects of companions?

Lundström: The LMC stars are all single stars as far as we know. For the galactic WR stars corrections for companions were made. These stars are usually indicated with crosses in Fig.2. Since the absolute magnitudes for the WR components will be more uncertain.

Abbott: If you did not find an association with a cluster of OB stars, does that mean one cannot exist?

Lundström: For WR stars brighter than 12^m we believe that our sample of cluster members is almost complete. For association members the sample is not at all complete. There could still exist undetected associations with very bright WR members.

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