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RESONANCE LINE-PROFILES IN GALACTIC DISK UV-BRIGHT STARS

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RESUMEN. Se ha efectuado un análisis comparativo de los perfiles de las líneas resonantes en los espectros ultravioletas de estrellas O miembros de cúmulos jóvenes o de asociaciones OB, con los de estrellas espectroscópicamente indistinguibles de éstas, pero muy alejadas de los sitios de formación estelar reciente (incluyendo a las estrellas "fugadas"). En general, se encuentra que los perfiles de las líneas resonantes de las estrellas calientes están dominados por los vientos estelares que, a su vez, parecen depender principalmente de la gravedad y temperatura superficiales y no de la masa de la estrella. Se peresentan los perfiles de las líneas resonantes de C IV, Si IV y N V en once estrellas, que no se habían publicado en los dos artículos precedentes. Además, se cuestiona el empleo de sólo la velocidad máxima del viento estelar observable en líneas resonantes para distinguir entre poblaciones estelares.

ABSTRACT. We have made a comparative analysis of UV resonance line-profiles in O-type stars members of young clusters and OB associations, with those of hot stars located away from sites of recent star formation (including "runaway" stars). The resonance line-profiles are found to be generally dominated by stellar winds that appear to depend mainly on the surface gravity and temperature of the star, and not on its mass. We also present the C IV, Si IV and N V resonance line-profiles for eleven stars not published in the previous two papers. The use of only the largest stellar wind velocity detectable in the resonance lines as a stellar population indicator, is disputed.

Key words: LINE PROFILE — STARS-EARLY TYPE

I. INTRODUCTION

Carrasco et al. (1976, 1979, 1980) and Costero et al. (1978) proposed that an important fraction of the apparently normal O-type stars are UV-bright stars, the field counterpart of those objects described by Zinn (1974), Norris (1974) and Harris et al. (1976).

The nature of early-type stars which are not members of young clusters or associations but have optical spectral indistiguishable from those of extreme Population I objects has been suggested to be:

1) True runaway stars of extreme Population I; i.e. stars which have been ejected from the cluster or association they were born in, because of (a) binary systems disruptions due to the supernova explosion of one component (Zwicky 1957, Blaauw 1961) or (b) dynamical relaxation processes of multiple systems (Poveda et al. 1967).

2) Old or intermediate Disk Population stars (Carrasco et al. 1980); i.e. low mass stars, field counterpart of the UV-bright stars in globular clusters, which are in similar evolutionary stages as Newell's (1973) HL subgroup of blue halo stars.

3) Young, massive stars formed in the collisions of high velocity clouds well above the galactic plane (Dyson and Hartquist 1983).

In Papers I (Costero and Stalio 1981) and II (Costero and Stalio 1984) the ultraviolet resonance line-profiles (C IV, Si IV and N V) for a sample of 40 O-type stars have been discussed. In Paper II a division of the stars in study into four groups was proposed: O subdwarfs, high luminosity Population II stars (HL), O-type stars not recognized members of clusters or associations, and members of clusters or associations.

In this paper (III) we present the resonance line-profiles not shown in the previous two papers, and rediscuss the problem of membership because it is relevant for the understanding of stellar evolution and kinematics. Specifically, we are searching for possible population indicators from stellar wind characteristics as inferred from UV resonance line-profiles, such as the one proposed by Carrasco (1980).

II. THE LINE PROFILES AND WIND VELOCITIES

Figures 1 through 3 show the N V, Si IV and C IV line-profiles for eleven of the stars studied in Paper II; the profiles for the rest of the stars were published in the previous two papers. Each spectrum was normalized to the same height of the pseudo-continuum near the corresponding line and shifted to the star's rest velocity (see Paper II). The profiles are in increasing order of C IV edge velolocity. Ten out of the eleven stars whose profiles are shown here were considered in Paper II as not recognized members of clusters and associations; the exception is HD 152408, which is a Population I star.

We would like to find out if stars that are probably far away from recent stellar formation sites, such as OB associations and young clusters, have resonance line-profiles with statistically diffrent edge velocities (the maximum shortward wavelength displacement in each line, measured as described in Section 3.2 of Paper II). The comparison should be made with the extreme Population I stars they mimic. In this discusion we will not consider the subdwarf and HL stars because they clearly are evolved objects, and usually show very little or no stellar wind.

Table 1 lists the edge velocities, in km s^{-1}, for the C IV, Si IV and N V resonance lines of stars considered in Paper II to be away from young associations. We have excluded here the stars HD 13268 and HD 193322; the former might be associated with Per OB1, as mentioned in that paper; the latter is a multiple system with early-type components and, hence, even if it might not be associated with Cyg OB9, as considered in Paper II, is probably a Population I object whose apparently isolated position remains to be explained. The stars in Table 1 are listed in increasing order of C IV edge velocity; the symbol ph is given whenever only the photospheric component of the line is detectable.

Table 2 contains the edge velocities of those stars in Paper II considered to be likely members of young clusters and associations. They are also listed in increasing order of C IV edge velocity. The stars earlier than O6 (ζ Pup and 9 Sgr) have been omitted here because their visual spectral characteristics might not be correlated to their effective temperature and luminosity (Underhill 1982); besides, there are no stars earlier than O6 in our sample of objects away from OB associations. Also eliminated from this Population I group was ξ Per, whose membership to Per OB2 is questionable.

Excluding HD 105056 from Table 1, the sample of stars away from associations shows a clear division into three luminosity class groups: the class V stars lie all at the top of the table (low edge velocities), while those of intermediate luminosity (II and III) are at the bottom (high edge velocities); the luminosity class I stars lie all between these two groups. In lesser degree, the star's temperature (spectral type) and position within each luminosity class group are also correlated, the cooler stars generally showing smaller edge velocities. Such luminosity class and spectral type correlations with edge velocity are, if at all present, very weak among the Population I stars in Table 2. Two extreme anticorrelation exampes are:

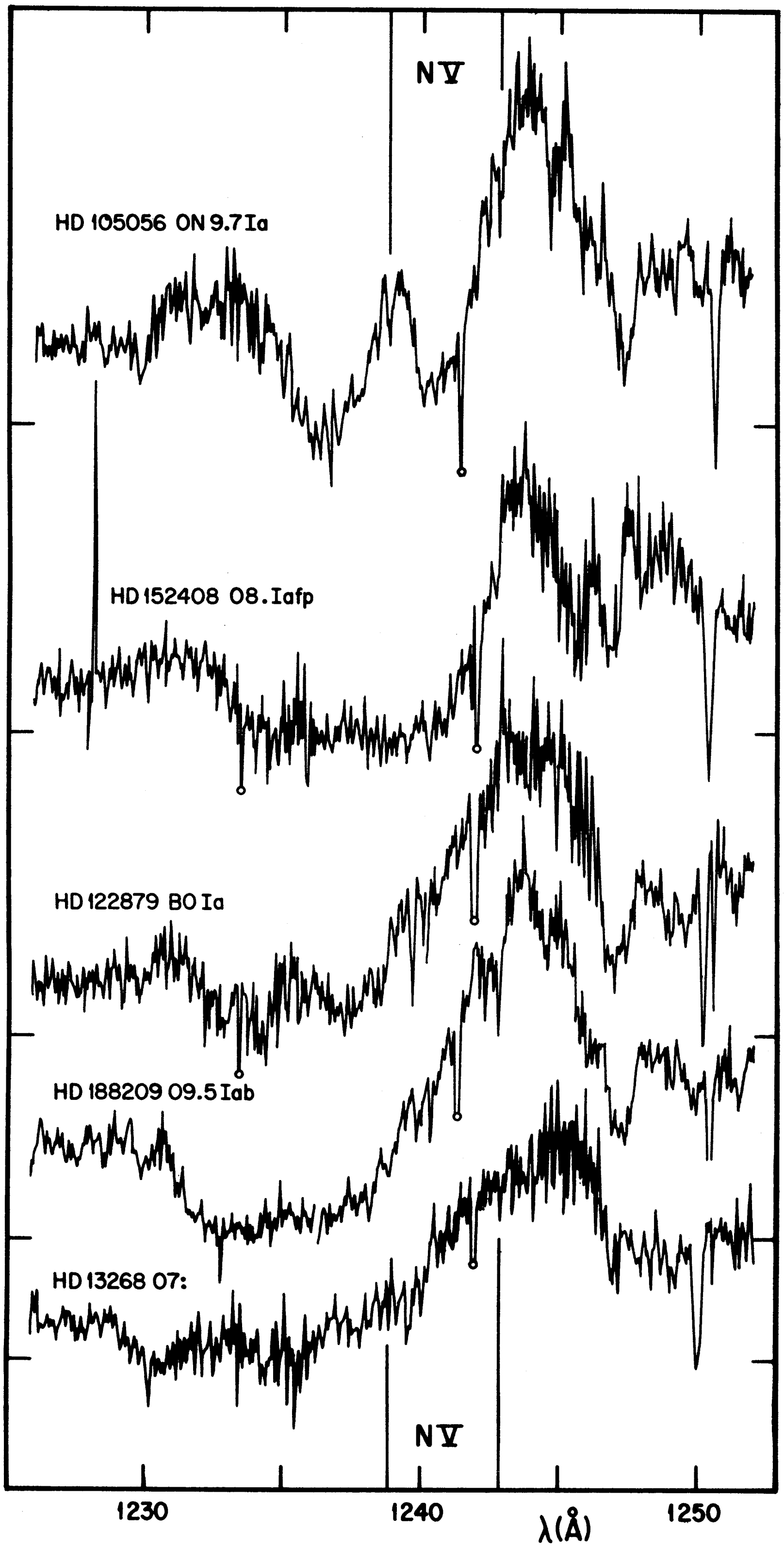

Fig. 1a. Sequence of N V λλ1237-1243 profiles for some of the stars studied in this and the previous papers. The vertical scale is "intensity" and the tick marks are zero-level intensity. The narrow vertical bars on the horizontal axes indicate the rest wavelengths of the doublet.

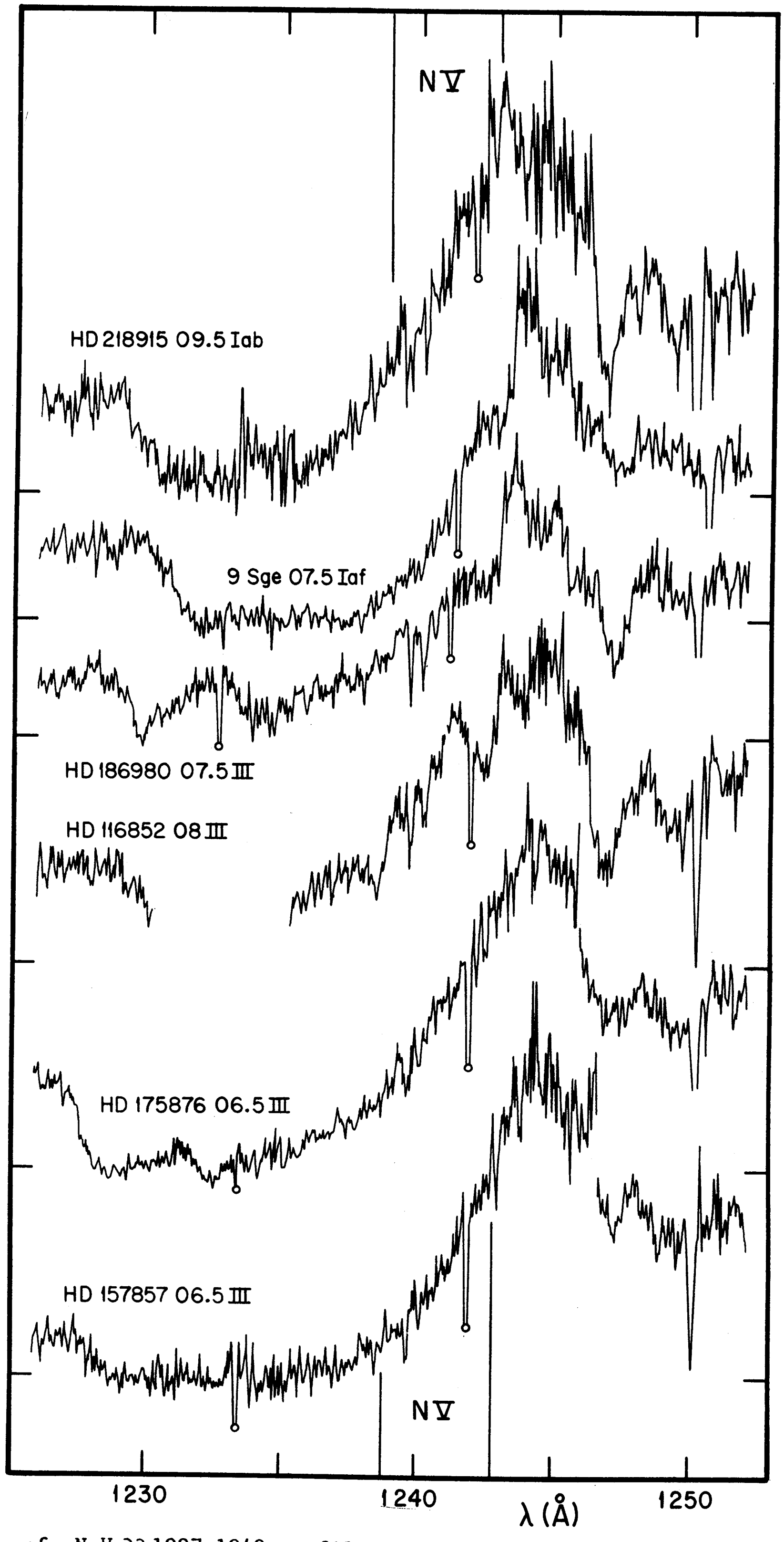

Fig. 1b. Sequence of N V λλ1237-1243 profiles for some of the stars studied in this and the previous papers. The vertical scale is "intensity" and the tick marks are zero-level intensity. The narrow vertical bars on the horizontal axes indicate the rest wavelengths of the doublet.

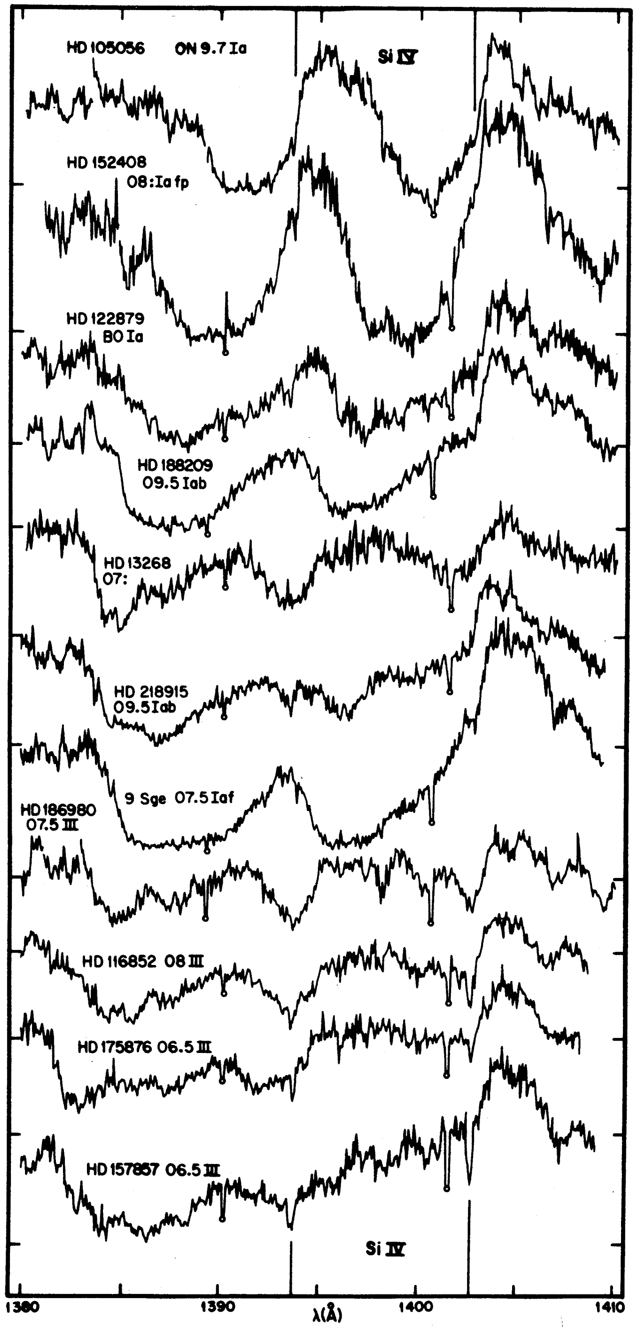

Fig. 2. Sequence of Si IV λλ1394-1403 profiles for the same stars in Figs. 1. The tick marks and the narrow vertical bars have the same meaning as in Fig. 1a.

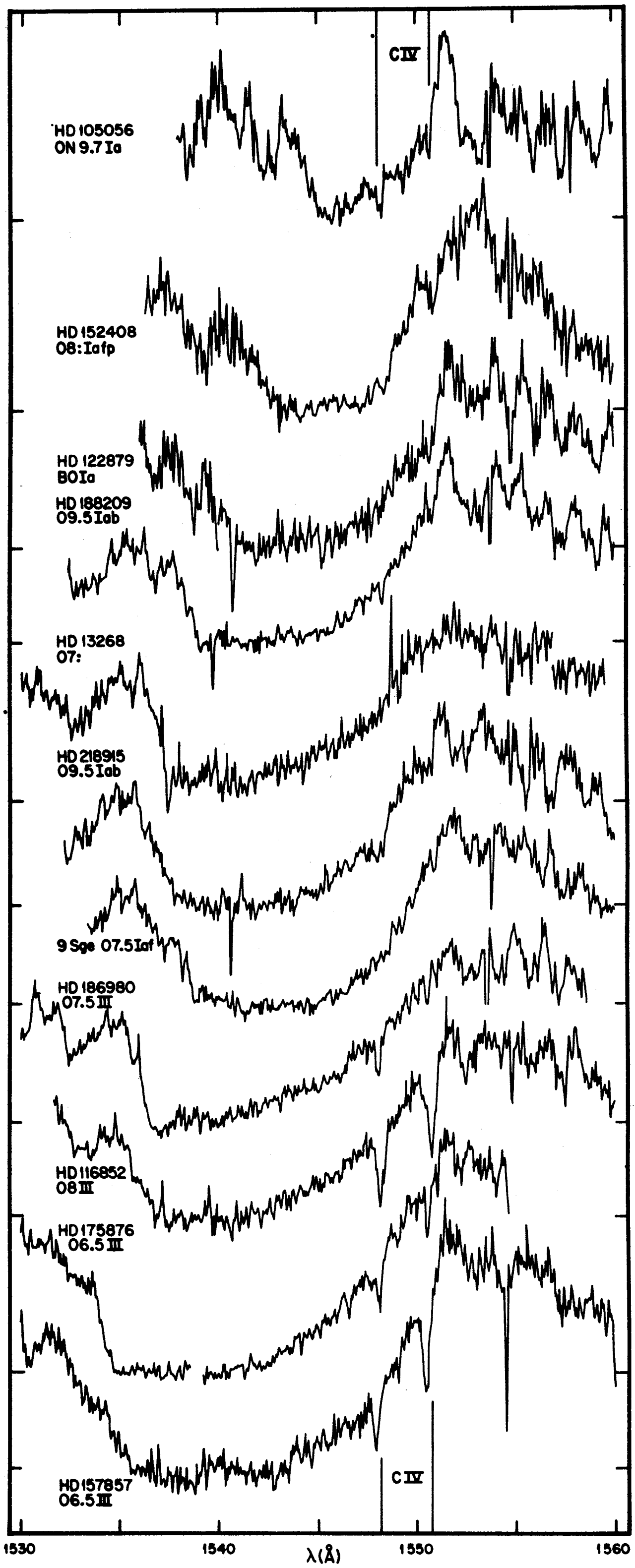

Fig. 3. Sequence of C IV λλ1548-1551 profiles for the same stars in Figs. 1. The tick marks and the narrow vertical bars have the same meaning as in Fig. 1a.

TABLE 1. Edge Velocities for Stars Away from Associations

STAR	SPECTRUM	C IV	Si IV	N V
HD 201345	ON9.5 V	560	ph	1470
HD 105056	ON9.7 Ia	900	1040	1130
AE Aur	O9.5 V	1100	ph	880
μ Col	O9.5 V	1140	ph	1070
HD 122879	B0 Ia	1980	2020	1700
α Cam	O9.5 Ia	2050	1930	1820
HD 188209	O9.5 Iab	2120	1980	1920
HD 112244	O7.5 Iaf	2160	2130	1770
HD 218915	O9.5 Iab	2300	2100	2210
9 Sge	O7.5 Iaf	2330	2120	2080
HD 186980	O7.5 III	2490	ph	2350
HD 175754	O8 II	2500	2330	2470
Hd 116852	O9 III	2540	2550	2200
HD 175876	O6.5 III	2830	2640	2710
HD 157857	O6 III	2970	2500	2760

TABLE 2. Edge Velocities for Stars of Population I

STAR	SPECTRUM	C IV	Si IV	N V
θ^2 Ori A	O9 V	1140	ph	--
HD 164816	O9.5 IV	1140	ph	--
10 Lac	O9 V	1410	ph	1120
HD 152408	O8:Iafp	1460	1460	1400
ϵ Ori	B0 Ia	2270	2070	--
τ CMa A	O9 II	2500	2180	2280
ζ Ori A	O9.7 Ib	2540	2180	1960
δ Ori A	O9.5 II	2560	2229	2400
λ Ori A	O8 III	2560	ph	2230
HD 162978	O7.5 II	2570	2290	--
λ Cep	O6 If	2570	2290	2520
HD 149404	O9 Ia	3100	2750	2960
HD 48099	O7 V	3340	ph	2860

a) HD 152408, whose edge velocities are much smaller than those of stars with similar luminosity class and temperature, maybe because its extreme Of character (see Paper II) is also responsible of a very opaque atmosphere which, in turn, precludes the radiation pressure to accelerate the wind at large distances, as in the case of the WR stars; and b) HD 48099, a main sequence star with almost the largest edge velocity in the whole sample of Paper II.

These two stars and those discussed in section 4.3 of Paper II are good examples of stellar individuality -the non predictability of the spectrum when one tries to reproduce the spectral features formed in the exo-photospheric stellar regions (Costero et al. 1981)-.

III. DISCUSSION

The edge velocities of the stars away from associations, listed in Table 1, are generally smaller than those for the Population I stars in Table 2. In order to compare average edge velocities, we subdivided the samples in groups of stars with similar luminosity class (namely V-IV, III-II or I) and spectral type (B0-O8 or O7.5-O6); then, for each group and ion we computed the average edge velocity. The results for C IV and N V are shown in Table 3, where the velocities are given in km s^{-1} and the number of stars used to obtain each average edge velocity is shown in parenthesis. The mean values for the Si IV line are very similar to those for the other two ions, except for the fact that all luminosity class V and IV (and two luminosity class III) stars show only the photospheric components of the line, and are useless for this analysis.

TABLE 3. Average Edge Velocities by Luminosity Class and Spectral Type

LUMINOSITY CLASS	SPECTRAL TYPE	C IV		N V	
		OUT OF ASSOC.	POP. I STARS	OUT OF ASSOC.	POP. I STARS
V - IV	B0 - O8	933 (3)	1230 (3,	1140 (3)	1140 (3)
	O7.5 - O6	-- (0)	3350 (1)	-- (0)	2860 (1)
	ALL	933 (3)	1960 (4)	1140 (3)	1990 (2)
III - II	B0 - O8	2520 (2)	2540 (3)	2335 (2)	2303 (3)
	O7.5 - O6	2763 (3)	2570 (1)	2607 (3)	-- (0)
	ALL	2666 (5)	2548 (4)	2498 (5)	2303 (3)
I	B0 - O8	1870 (5)	2340 (4)	1756 (5)	2107 (3)
	O7.5 - O6	2245 (2)	2570 (1)	1975 (2)	2520 (1)
	ALL	1977 (7)	2386 (5)	1804 (7)	2210 (4)

As shown in Table 3, almost all the the luminosity class and spectral type groups of stars away from associations have smaller mean edge velocities than the corresponding ones for the Population I sample. The clearest exception is the intermediate luminosity (classes III and II) group: those away from young associations have average wind velocities about 1.06 larger than their Population I counterparts. In fact, all the largest detectable wind velocities in our sample of isolated stars (Table 1) pertain to that intermediate luminosity class group, specially to the hottest stars, whereas the Population I giants and supergiants show very large dispersion in their wind velocities (see Table II). One might even speculate if "individuality" is a phenomenon characteristic of Population I stars only. Nevertheless, the intermediate luminosity stars of Population I also have larger average edge velocities than the other luminosity class groups; if this result is significant, its interpretation might be fundamental for the understanding of the stellar wind phenomenon.

The supergiant group -the largest in our sample- and that of luminosity classes V and IV -the smallest- behave more as expected for it if the stars away from stellar formation sites were, as suggested by Carrasco et al. (1980), evolved low mass objects: the masses and radii of these hot, disk UV-bright stars should be, respectively, about 30 and 10 times smaller than those of the Population I stars they mimic; hence, their average escape velocity and consequent mean terminal wind velocity should be about 0.6 that of the Population I O-type stars, assuming similar photospheric physical conditions (see Carrasco, 1980) and radiation pressure driven winds. The ratio of the average edge velocity of the isolated stars in our sample to that of the stars inside young clusters and associations is 0.55 for the low luminosity class objects and 0.83 for the supergiant stars in the sample.

We are aware that, in the case of the luminosity class V and IV stars, the above result is badly influenced by the extremely large wind velocity observed on HD 48099, an O7 V Population I star; the elimination of this star from the above analysis indeed decreases the average edge velocity of all the associated dwarf stars but, since it is the only "hot" dwarf in the whole sample, do not affect the "cool" dwarfs in Table 3, whose ratio of mean edge velocities is 0.76 for the C IV lines and 1.02 for the N V lines (because of the nitrogen enhanced stars, as noted in Paper II). Even if we eliminated all the anomalous objects -namely HD 48099 and HD 152408, the stars in Table 2 with "extreme individuality", as well as HD 105056 and HD 201345, the ON nitrogen enhanced stars in Table 1- the remainder that do not belong to young clusters or associations will still show lower average edge velocities than their corresponding Population I groups, being about 0.9 and 0.8 smaller for the luminosity class V and the supergiant stars, respectively. The intermediate luminosity group is unaffected by this elimination exercise. One must realize, however, that we are dealing with small number statistics of quantities that, we must emphasize, are sensitive to factors like differences in chemical and ionic abundances, variability and individuality. Indeed, samples larger than ours are needed in order to arrive to stronger conclusions.

The HL and subdwarf stars considered in Paper II and excluded from the discussion in this one, have very small or undetectable wind velocities; yet HD 49798 -a very hot, rather low surface gravity O subdwarf (47 000 K and log g = 4.25, respectively; see Kudritzki and Simon, 1978)-, other subdwarfs (see, for example, Rossi et al. 1980 and references therein) and some planetary nebulae nuclei (e.g. NGC 6543; see Pwa et al. 1984) have large wind velocities that are some times detectable only in one of their resonance lines. Hence, there are no grounds for the use of the maximum detectable wind velocity in a particular star to deduce its mass or the stellar population it belongs to; perhaps only the statistical analysis of the observable stellar winds in suitable groups is, nevertheless, significant.

A further concern is the problem of non membership to the Population I of the stars in Table 1. In this paper we have already excluded two objects from the original sample of stars (those considered in Paper II not to be recognized members of clusters or associations) because they might be young, massive stars. In addition, it is very suspicious that a group of stars in Table 1 have (if they were of Population I) about the same spectroscopic parallax, color excess and radial velocity, though they are generally located at large angular distances from each other and away from young associations. This group includes HD 175754, 175876, 186980, 188209, 9 Sge and HD 188209. A more careful study of O-type, "normal" stars suspected to be away from recent stellar formation sites, including those on Table 1, is under way.

IV. CONCLUSIONS

We have found some evidence in favor of the interpretation for the apparently normal O-type stars located away from young clusters and associations as evolved, low mass objects. Namely, the average maximum shortward wavelength displacement observed in the resonance UV line-profiles (edge velocities) of those stars, is smaller than that of the Population I massive stars they spectroscopically resemble by at least factors of 0.8, 1.0 and 0.9 for the supergiants, the giants and the luminosity class V objects in our sample, respectively. This values should be about 0.6 if the above interpretation is correct. The evidence is very weak because the measured stellar wind velocities show very large scatter among similar stars, and our sample is not large enough to compensate for it.

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