AGE OF LUMINOUS BLUE VARIABLE CANDIDATES FROM THEIR STELLAR AND NEBULAR ENVIRONMENT.

M.-C. LORTET
Département d'Astronomie extragalactique et de Cosmologie
Observatoire de Paris
F-92195 Meudon Principal Cedex, France

ABSTRACT. The study of the context of LBV stars, that is close neighbourhood (companions) and spatial relationship to young objects such as cepheids, stellar associations, red supergiants, enriched OB supergiants, HII regions, WR stars can provide useful clues on their true luminosity, their age thus eventually initial mass and evolutionary status.

The stars considered here are LBV candidates in a broad sense. The starting list is a compilation of the following families (mostly defined from the Atlas of high-resolution spectra of Stahl et al., 1985) : S Dor-like stars (four in the LMC, none in the SMC), P Cyg type stars (prototype R 81), Of or Of/WN9 or WN9/Of (late-type O), as defined by Walborn (1982) and now extended by Conti and Bohannan (see Walborn in these Proceedings), B[e] stars (Zickgraf et al., 1986 and Zickgraf, these Proceedings), dust shells ; I added Peculiar, B pec and B extr from recent spectroscopic surveys (Conti et al., 1986 ; Garmany et al., 1987) and stars with composite spectra (Cowley and Hutchings, 1978). The sample consists of 52 and 31 stars in the LMC and the SMC respectively, and is detailed in a catalogue (Lortet, 1988) which also gives indications on their environment.

The surveys for recognizing these families are all biased and incomplete, so that no statisticial approach is possible. We will mostly be concerned with the LMC.

1. RELATIONSHIP TO OB STELLAR ASSOCIATIONS, HII REGIONS AND RED SUPERGIANTS

A few general ideas have already emerged from the detailed study of regions of recent, but not active, star formation like Shapley II which is especially rich in LBV candidates (about 1° in diameter, see van den Bergh, 1981). Lortet and Testor (1987, 1988) found the LBV candidates of this region and a few additional areas to be associated with a rather old environment, filamentary, faint, extended nebulae, if any, and with either WN8 or later type WR stars or faint WNE, as well as red supergiants.

They also commented upon the case of R 84 (=HD 269227 = Sk-69 79 =

K. Davidson et al. (eds.), Physics of Luminous Blue Variables, 45–49.

Brey 18), which is a member of an aged association (Schild, 1987) and composite with a brighter M supergiant.

The examination of a large sample of LBV confirms these results. Many other examples of shells or filamentary nebulae related to LBV candidates are found, for instance : N9 (=DEM 31) around Sk-67 17 (=HD 32034, P Cyg type) and near the WR Brey 5 ; the southernmost part of N 30, related to Sk-67 64 (B[e], not far from Brey 17) ; [OIII] and Hα filaments, part of N 74 around Sk-67 266 (Of/WN9)).

LBV candidates as a rule are inside or less than 120pc from stellar associations (see Table 2 in Lortet, 1988). Outstanding exceptions are : a few B extr (may be an older population), two B[e] type stars, Sk-67 23 (=S12, distance 585pc) and Sk-69 46 (=R 66, distance 225pc), and the S Dor-type star R 71 which is discussed below.

From the point view of stellar evolution, the relationship of LBV candidates to red supergiants is crucial. As projected on the sky more than half of the LMC LBV candidates are definitely associated to red supergiants. The proportion increases to about 70% when excluding the B extr stars and those stars the only peculiarity of which is to be suspected of variability, Appendix in Stahl et al., 1984). Spatial association to WN early and WN8 and later is also conspicuous. Examples of such clusterings are :
Sk-69 171 (P Cyg type) and Sk-69 175 (=HD 269687) (Peculiar, newly classified as Of/WN9) near Brey 44a (WN8-9) and at least 7 red supergiants of known radial velocities close to = 275 km s^{-1}, of which two recently measured (Lindgren, private communication). This group had already been noticed by Lortet and Testor (1988).
Sk-67 266 (Of/WN9), three WN4 stars and red supergiants in or near LH 116.
Brey 64 (=BE 381) with four WNE stars and red supergiants in LH 85 + 89.

2. CLOSE NEIGHBOURHOOD

The existence of close companions seems rather frequent for the S Dor-like stars (types S, Of/WN9, P, B[e]). A systematic search and study is important for several reasons :
a) The existence of close companions if ignored lead to an overestimation of the luminosity of the star. Many similar instances exist for hot stars (overestimation by 0.5 to 3 magnitudes).
b) Search for variability requires that the close neighbourhood be first imaged. It may be dangerous to compare measurements made by different authors or with different positions and diameters of the aperture.

Table 1 describes the close neighbourhood of a few LMC LBV candidates. Two identifications and the HD number are given. The last column refers to a remark or a map. SL objects are possible compact clusters, RM1- and RM2- red supergiants and probable red supergiants respectively from Rébeirot et al. (1983). Otherwise the nomenclature is explained in Lortet (1986). Apart from the composite spectra (R 84 is one of those), close association with a red star is found in two cases. It would be important to check the consistency of the radial velocities and also to obtain even a crude photometry of the cluster stars.

https://doi.org/10.1017/S0252921100004279 Published online by Cambridge University Press

Table 1. Multiplicity or pecularities of LBV candidates in the LMC (classified by subtypes).

Sk	Other	HD	Type	Close neighbourhood	Ref.
Sk-69 94	S Dor	35343	S	In a cluster (diam. ~ 30")	A
Sk-69 142a	HV 5495	269582	S, OF/W	W10-35, 36, 39, inside 6"	B
Sk-69 220	R 127	269858f	S, OF/W	R 127B within 3"W, R 128 wihtin 18"	C
Sk-69 79	R 84	269227	W/OF + M	Composite with RM2-54, unresolved	-
Sk-69 249C	Brey 91	269927C	W/OF	Sk-69 249A and B, OB supergiants	D
Sk-69 92	R 85	269321	P, V	In a group of three stars inside 20", one is RM2-60	E
Sk-69 171	R 110	269662	P	SL 530: few stars, inside 20"	-
(Sk-69 147a)	S 111	(HD 269599)	B[e]	Cluster 10" in diameter	F
-	R 108	-	COMP	Composite with RM2-88	-
Sk-70 29	R 67	32763	COMP	RM2-29 at 5"	-
Sk-68 162	-	-	B extr	RM1-811 13" SE	-
Sk-71 29	HV 5827	-	B extr	N 202 (53"x59")	-
Sk-67 181	-	269736	V	Cluster SL 564, diameter 20"	-

A, Leitherer et al., 1985 ; B, in NGC 1983, Westerlund, 1961, Fig. 15 and Table 10 ; C, Stahl, 1985 ; D, Lortet and Testor, 1988, Fig.1 ; E, Brunet et al., 1975, p.136. F, the HD and Sk numbers refer to part of a cluster which also contains a normal OB star, R 105 ; *Appenzeller et al.*, 1984.

3. THE ENVIRONMENT OF R 71 (= HD 269006 = Sk-71 3)

R 71, one of the genuine S Dor-type stars in the LMC though subluminous, is known to be pretty isolated. Close examination confirms that no young object is physically related to it. A rather old cepheid (HV 12433, P = 7.5 day) is located at about 33pc. Red supergiants and other old cepheids are scattered farther than 10' away. The youngest objects are at about 16-20' in the south of the stellar association LH 28 studied by Lucke (1972) : an anonymous Hα knot, an O9 II star (Conti et al., 1986), a cepheid HV 2343, of period 42.172d. We notice that the B extr star Sk-71 12 is at 11-15' from these objects.

4. THE SMALL MAGELLANIC CLOUD

About the SMC, little can be said at present. Projection effects are severe. Excluding the 21 B extr stars, few interesting LBV candidates are known : no genuine S Dor-type star, only two P Cyg stars, three B[e], four Pec and one star suspected of variability (the candle AZVI 415 = R 40). Those stars are poorly related to HII regions and stellar associations (Hodge, 1985) except for the three B[e] stars and AZVI 6 (B pec) which is in association 8 and in the nebula DEM 14. No connection whatever between the 10 S Dor-like and the 8 known WR stars is found. This may be largely a question of incompletion of different kinds of surveys.

5. CONCLUSIONS

The close examination of the context of LBV candidates appears as both a guide

https://doi.org/10.1017/S0252921100004279 Published online by Cambridge University Press

and an independent complement to finer studies. The prediction of rather low mass from the moderately old age of the parent association (R 84, Schild, 1987) or environment has been confirmed in a few cases (e.g., R 81, Stahl et al., 1987). It is also in beautiful agreement with the enhanced atmospheric abundances described first for P Cyg (Lamers, 1986) and since then for several stars which thus appear as post-red supergiants.

Indeed, all the LBV candidates and WR stars in Shapley II (especially those quoted in Sect. 1) are potential post-red supergiants. The general questions are now : which are the distinctive observational and physical characteristics of those LBV's and WR stars which are post-red supergiants ? And more generally, into which WR subtypes do LBV's evolve ?

REFERENCES

Appenzeller, I., Klare, G., Stahl, O., Wolf, B., Zickgraf, F.-J. : 1984, The ESO Messenger 38, 28.

Brunet, J.P., Imbert, M., Martin, N., Mianes, P., Prévot, L., Rébeirot, E., Rousseau, J. : 1975, Astron. Astrophys. Suppl. 21, 109.

Conti, P.S., Garmany, C.D., Massey, P. : 1986, A.J. 92, 48.

Cowley, A.P., Hutchings, J.B. : 1978, P.A.S.P. 90, 636.

Garmany, C.D., Conti, P.S., Massey, P. : 1987, A.J. 93, 1070.

Hodge, P. : 1985, P.A.S.P. 97, 530.

Lamers, H.J.G.L.M. : 1986, IAU Symp. 116, 157.

Leitherer, C., Appenzeller, I., Klare, G., Lamers, H.J.G.L.M. : 1985, Astron. Astrophys. 153, 168.

Lortet, M.-C. 1986, Astron. Astrophys. Suppl. 64, 303.

Lortet, M.-C. : 1988, Bull. Inf. CDS 35, in press.

Lortet, M.-C., Spite, F. : 1986, Astron. Astrophys Suppl. 64, 329.

Lortet, M.-C., Testor, G. : 1984, Astron. Astrophys. 139, 330.

Lortet, M.-C., Testor, G. : 1987, Proc. Workshop "Starbursts and Galaxy Evolution", eds. T.X. Thuan, T. Montmerle and J. Tran Thanh Van, Ed. Frontières, Paris, 79.

Lortet, M.-C., Testor, G. : 1988, Astron. Astrophys. 194, 11.

Lucke, P.B. : 1972, Ph.D. Thesis, University of Washington.

Rébeirot, E., Martin, N., Mianes, P., Prévot, L., Robin, A., Rousseau, J., Peyrin, Y. : 1983, Astron. Astrophys. Suppl. 51, 277.

Schild, H. : 1987, Astron. Astrophys. 173, 405.

Shore, S.N., Sanduleak, N. : 1984, Ap.J. Suppl. 55, 1.

Stahl, O. 1985, The ESO Messenger 39, 13.

Stahl, O., Wolf, B., Leitherer, C., Zickgraf, F-.J., Krautter, J., de Groot, M. : 1984, Astron. Astrophys. 140, 459.

Stahl, O., Wolf, B., de Groot, M., Leitherer, C. : 1985, Astron. Astrophys. Suppl. 61, 237.

Stahl, O., Wolf, B., Zickgraf, F.-J. : 1987, Astron.Astrophys. 184, 193.

van den Bergh, S. : 1981, Astron. Astrophys. Suppl. 46, 79.

Walborn, N. : 1982, Ap.J. 256, 452.

Westerlund, B. : 1961, Uppsala Astron. Obs. Ann. 5, No. 1.

Zickgraf, F.-J., Wolf, B., Stahl, O., Leitherer, C., Appenzeller, I. : 1986, Astron. Astrophys. 163, 119.

https://doi.org/10.1017/S0252921100004279 Published online by Cambridge University Press

DISCUSSION

Sreenivasan: (1) Are you suggesting that S Dor variables are in fact only 15--20 $M_\odot$ objects? (2) How old do you mean when you say they are older than previously believed?

Lortet: (1) I did not quote figures but indeed **some** may have masses as low as that. (2) "Old" means that some are found near red supergiants and/or in associations containing only B stars, *e.g.* R 84 (=Brey 18) in LH 39, studied by Schild. My guess is that they may be as old as 10 million years.

De Jager: In the discussion following Maeder's talk this morning, I suggested that some LBV's have smaller masses than supergiants at the same location in the H-R diagram, and that they are on the blueward evolutionary track. This seems to fit with your result that LBV's are older than has been assumed so far.

Leitherer: Your result that S Dor variables have lower masses than generally assumed agrees nicely with the mass that we and the Munich group have independently derived from NLTE analyses of R 71, $M \approx 10$--$15\,M_\odot$. S Doradus itself may also have a mass less than about $40\,M_\odot$.

Lortet: These fine results show that the study of the environment may be very effective.

Appenzeller: A mass of 15--20 $M_\odot$ appears reasonable for R 71, which is one of the least luminous LBV's. However, the most luminous LBV's, such as R 127, must be quite massive ($\geq 40\,M_\odot$). Otherwise they would be significantly above their Eddington luminosities.

Lortet: I agree that some LBV's may be more massive than $40\,M_\odot$; R 127 is the hottest of them anyway.

Walborn: Do you find any clear associations between LBV's (including possible quiescent LBV's) and WR stars? If the former turn into the latter on a short time-scale, then such associations are to be expected.

Lortet: This is indeed a very important point. Also, which WR subtypes do LBV's become, if any? The best place for suggesting an answer is in the LMC and especially in Shapley II. There are clear associations between LBV's and red supergiants on one hand, and LBV's and WR stars on the other. My guess is that LBV's may be related to WN 8,9,10 or Of/WN9 stars, or to early-WN's, but not to WN 6 or WN 7.

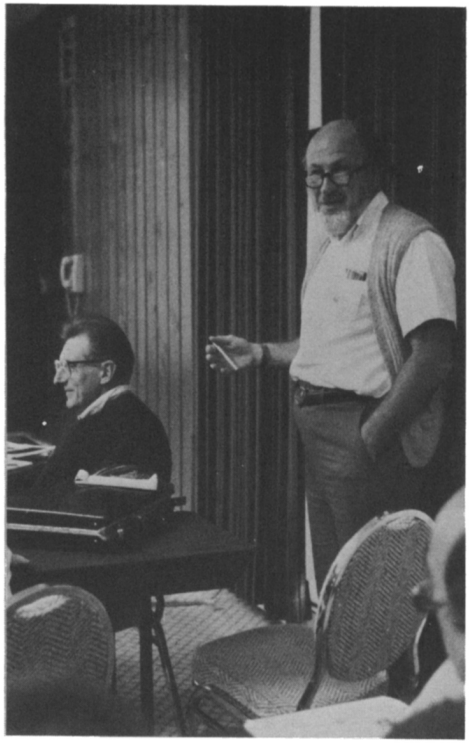
Gallagher: If some S Dor stars originate from binaries, then delayed evolution may occur. Mass-exchange time scales for a high-mass binary can be longer than the nuclear evolution time-scale of a single star with the same total mass.

Lortet: I agree.

https://doi.org/10.1017/S0252921100004279 Published online by Cambridge University Press

Sally Heap

Peter Conti
and
Francesco Paresce



https://doi.org/10.1017/S0252921100004279 Published online by Cambridge University Press