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Light variations of massive stars (α Cygni variables)

XIII. The B-type hypergiants R81 (LBV), HD 80077 (LBV?), HD 168607 = V 4029 Sagittarii (LBV) and HD 168625 = V 4030 Sagittarii*

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Abstract. We present and discuss *VBLUW* and *uvby* photometry of four α Cyg variables: the B-type hypergiants R 81, HD 80077, HD 168607 = V 4029 Sgr and HD 168625 = V 4030 Sgr. Quasi-periods of the light variations amount to 24, 41 or 55, 58 and 35 days, respectively. The maximum light amplitude (MLA) of R 81 and HD 168607 clearly reflects their LBV character. That for HD 80077 suggests that it could be an LBV also.

Normal α Cyg variables and those which suffer from episodic mass loss eruptions, the LBVs, appear to listen to the same P = constant lines in the HR diagram, but the light curves of both types show morphological differences.

Key words: photometry – stars: variable – stars: supergiants – stars: early-type – stars: oscillations

1. Introduction

In the course of our investigation on the intrinsic light variation of massive stars (α Cyg variables), in particular the hot ones, it became clear that a difference exists between the size of the light amplitude of normal ones and those suffering from episodic mass loss eruptions: the hot S Dor-type or LBVs. Careful inspection of long runs of photometry appears to support the point of view that the LBVs are presumably seldom or never in a real quiescent state and that part of the too high light amplitudes are due to the small S Dor eruptions of mass loss, or shell ejections, on a time scale of months to a year.

It became also clear that LBVs listen to the same P = constant lines in the HR diagram as normal α Cyg variables, as far as the uncertainties involved allow the comparison.

The results of the present paper add further proof to these statements.

Recent reviews on the intrinsic micro variations of α Cyg variables (mainly OBA-type stars and LBVs near minimum state) are given by Sterken (1989) and van Genderen (1991b) and on the micro and macro variations of LBVs by Lamers (1987).

2. Observations and reductions

2.1. The *VBLUW* photometry

The *VBLUW* photometry of the program stars, with the exception of R 81, were made with the 90 cm Dutch telescope equipped with the simultaneous *VBLUW* photometer of Walraven, at the ESO, La Silla, Chile, from 1987 up to 1991. A description and the aim of the photometric program, a description of the observational technique and of the desired accuracy with mean errors (m.e. $= \sigma/\sqrt{n}$) amounting to $\pm 0\overset{m}{.}002$ for each nightly average (NA) relative to the comparison star, can be found in van Genderen et al. (1985; hereafter Paper I).

The standard deviations (σ) per NA of the present material are of the order of $\pm 0\overset{m}{.}004$ in V and $B-L$, in the colour $V-B$ somewhat smaller, in $B-U$ and $U-W$ somewhat larger up to $\pm 0\overset{m}{.}010$ for the latter. Since the NAs of the present paper are mainly based on 4 observations rather than on 6 or 8 like mentioned in Paper I, we prefer to indicate in the figures the 2σ error bar (in log intensity scale) instead of the m.e. bar.

The transformation of the *VBLUW* parameters V and $V-B$ in the equivalent *UBV* parameters V_J and $(B-V)_J$ if given, were made with the aid of the formulae of Pel (1987) mentioned in van Genderen et al. (1989; hereafter Paper IX).

For HD 80077 we used the comparison star HD 80859 of spectral type B5V (Houk 1978). This comparison star appeared to be a "slowly pulsating B-type star" ($P = 2\overset{d}{.}862$) with an amplitude of $0\overset{m}{.}02$ in V (van Genderen et al. 1992a). The NAs for brightness and colours of HD 80077 relative to the comparison star, but corrected for the variability of the latter, are listed in Table 1.

The comparison star for HD 168607 and HD 168625, both members of the Sgr OB1 association was HD 168663, according to our photometry of spectral type ~F 4 and a main sequence star. Table 2 lists the average photometric parameters of the three program stars and the two comparison stars. The average σ's of the two comparison stars vary between ± 0.0030 and ± 0.0040 and ± 0.0020 and ± 0.0030 (log intensity scale), respectively.

It is of importance to compare the averages of HD 80077 listed in Table 2 with those obtained with the same photometer more than ten years ago: see Table 4 in Steemers & van Genderen (1986). Due to slight photometric changes it was necessary to apply the transformation formulae provided by Pel (1987). The transformed parameters of the earlier data set (1977–1978)

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* Observations collected at the ESO, La Silla, Chile.

1992A&A...264...88V

Table 1. The journal of observations of HD 80077 relative to the comparison star and corrected for the variability of the latter

JD – 2440000	ΔV	$\Delta(V-B)$	$\Delta(B-U)$	$\Delta(U-W)$	$\Delta(B-L)$
7612.70	0.0509				
7615.75	0.0490	0.6300	0.1656	0.2833	0.1627
7619.68	0.0431	0.6312	0.1662	0.2884	0.1623
7626.69	0.0408	0.6305	0.1680	0.2862	0.1642
7630.58	0.0489	0.6308	0.1627	0.2871	0.1618
7633.67	0.0642	0.6307	0.1655	0.2870	0.1634
7636.68	0.0778	0.6305	0.1553		0.1606
7639.70	0.0644	0.6298	0.1621	0.2839	0.1639
7643.69	0.0431	0.6322	0.1666	0.2842	0.1635
7662.59	0.0496	0.6284	0.1632	0.2831	0.1603
7666.58	0.0551	0.6284	0.1632	0.2833	0.1604
7669.51	0.0703	0.6288	0.1585	0.2837	0.1579
7672.54	0.0612	0.6300	0.1606	0.2870	0.1589
7677.50	0.0552	0.6304	0.1601	0.2870	0.1595
7680.62	0.0617				
7685.51	0.0568	0.6306	0.1609	0.2872	0.1604
7688.51	0.0571	0.6296	0.1626	0.2851	0.1610
7692.50	0.0714	0.6301	0.1594	0.2844	0.1588
7695.51	0.0641	0.6299	0.1603	0.2787	0.1605
7875.83	0.0668	0.6310	0.1612		0.1630
7881.78	0.0703	0.6272	0.1640	0.2861	0.1639
7898.82	0.0510	0.6288	0.1693	0.2858	0.1634
7916.77	0.0270	0.6289	0.1708	0.2859	0.1658
7924.87	0.0568	0.6289	0.1669		0.1656
7928.81	0.0894	0.6300	0.1672	0.2862	0.1656
7930.86	0.0934	0.6287	0.1615	0.2899	0.1641
7943.80	0.0887	0.6286	0.1649	0.2845	0.1658
7947.67	0.0824	0.6292	0.1624	0.2880	0.1630
7950.71	0.0790	0.6297	0.1641		0.1641
7956.76	0.0787	0.6284	0.1657	0.2869	0.1651
7963.76	0.0816	0.6311	0.1748	0.2907	0.1668
7964.74	0.0825	0.6298	0.1680	0.2865	0.1668
7965.70	0.0869	0.6302	0.1640	0.2854	0.1621
7966.71	0.0833	0.6302	0.1653	0.2885	0.1659
7967.69	0.0955	0.6284	0.1616	0.2862	0.1626
7968.69	0.0941	0.6307	0.1607	0.2856	0.1642
7969.69	0.0974	0.6295	0.1617	0.2849	0.1644
7970.68	0.0913	0.6298	0.1616	0.2824	0.1646
7974.62	0.0895	0.6322	0.1639	0.2870	0.1657
7976.54	0.0997	0.6313	0.1620	0.2886	0.1627
7978.56	0.1059	0.6317	0.1628	0.2866	0.1633
7982.59	0.0922	0.6331	0.1681	0.2860	0.1653
7983.59	0.0996	0.6316	0.1626	0.2914	0.1663
7985.63	0.0925	0.6306	0.1639	0.2866	0.1643
7987.66	0.1035	0.6287	0.1655		0.1630
7988.64	0.0895	0.6312	0.1670	0.2860	0.1675
7989.62	0.0929	0.6295	0.1648	0.2864	0.1641
7990.59	0.0956	0.6280	0.1650	0.2793	0.1624
7991.64	0.0909	0.6290	0.1640	0.2798	0.1644
7992.66	0.0831	0.6294	0.1659	0.2907	0.1676
8021.66	0.0686	0.6304			0.1677
8026.49	0.0625	0.6307	0.1652	0.2892	0.1641
8030.66	0.0797	0.6263	0.1655		0.1672
8033.61	0.0826				
8050.49	0.0868	0.6279	0.1618	0.2843	0.1645
8051.51	0.0798	0.6285	0.1662	0.2856	0.1632

Table 1 (continued)

JD − 2440000	ΔV	$\Delta(V-B)$	$\Delta(B-U)$	$\Delta(U-W)$	$\Delta(B-L)$
8061.49	0.0820	0.6282	0.1631	0.2773	0.1647
8066.49	0.0632	0.6268	0.1647	0.2801	0.1649
8068.49	0.0616	0.6278	0.1695	0.2825	0.1659
8072.52	0.0714	0.6289	0.1699	0.2816	0.1694
8075.49	0.0775	0.6280	0.1598	0.2831	0.1639
8077.49	0.0850	0.6287	0.1687	0.2735	0.1670
8079.51	0.0995				
8172.86	0.0524	0.6284	0.1693		0.1651
8173.86	0.0588	0.6259	0.1671	0.2906	0.1672
8176.83	0.0682	0.6281	0.1700	0.2812	0.1674
8179.85	0.0901	0.6274	0.1660	0.2812	0.1658
8182.84	0.0946	0.6305	0.1650	0.2806	0.1659
8184.84	0.1039	0.6281	0.1673	0.2817	0.1670
8187.84	0.1026	0.6279	0.1617	0.2795	0.1646
8189.80	0.1029	0.6275	0.1655	0.2869	0.1683
8191.84	0.0991	0.6283	0.1690	0.2887	0.1690
8193.84	0.0942	0.6292	0.1689	0.2835	0.1685
8196.82	0.0809	0.6289	0.1576	0.2842	0.1649
8200.75	0.0765	0.6279	0.1677	0.2866	0.1676
8201.83	0.0735	0.6295	0.1695	0.2779	0.1673
8202.84	0.0770	0.6298	0.1660	0.2834	0.1650
8203.85	0.0814	0.6296	0.1657	0.2900	0.1680
8207.79	0.0867	0.6311	0.1674	0.2895	0.1675
8269.72	0.0859	0.6324	0.1639	0.2859	0.1639
8272.71	0.0922	0.6321	0.1602	0.2878	0.1614
8274.72	0.0904	0.6334	0.1638	0.2867	0.1629
8277.75	0.0854	0.6350	0.1629	0.2898	0.1633
8279.75	0.0764	0.6342	0.1672	0.2916	0.1627
8282.73	0.0539	0.6350	0.1688	0.2918	0.1649
8284.79	0.0434	0.6365	0.1699	0.2966	0.1650
8286.74	0.0380	0.6352	0.1741	0.2962	0.1662
8290.71	0.0596	0.6338	0.1697	0.2919	0.1629
8292.84	0.0633	0.6319	0.1679	0.2908	0.1652
8294.65	0.0714	0.6329	0.1674	0.2873	0.1638
8296.78	0.0701	0.6300	0.1660	0.2895	0.1632
8298.74	0.0800	0.6314	0.1630	0.2855	0.1615
8300.68	0.0680	0.6333	0.1665	0.2884	0.1625
8302.72	0.0624	0.6313	0.1657	0.2876	0.1627

amount to as follows: $V=-0.298$, $V-B=0.596$, $B-U=0.298$ and $B-L=0.180$ (no $U-W$ could be measured then). The corresponding values for V_{J} and $(B-V)_{\mathrm{J}}$ were 7.58 and 1.27, respectively. All these values compare very well with those of Table 2, thus no large variations occurred since then.

Tables 3 and 4 list the NAs of HD 168607 and HD 168625, respectively.

2.2. The uvby photometry

The *uvby* photometry of Strömgren of the program stars R 81, HD 168607 and HD 168625 is taken from Manfroid et al. (1991). These data have been acquired in the framework of the long-term photometry of variables (LTPV) of Sterken. They comprise the observations obtained in the years 1982–1986. We only analyzed the *y* observations. Since the *y* values were made identical to the Johnson *V* of the *UBV* system, it is written here as V_{J}. (The analysis is only performed on the visual magnitude data, because these are the least affected by small extinction variations).

For R 81 two comparison stars A and B have been used and alternately measured a few times with the program star each night. Star A = HD 34144 (A4 III/IV) and star B = HD 34651 (F0V), spectral types and luminosity classes are from Houk & Cowley (1975). Usually the observations were made during a few consecutive weeks up to two months and if possible each night.

First we derived the average value (A − B) for the whole data set and transformed all B values in A values. The V_{J} for A and B amount to 9.377 and 8.396, respectively. The standard deviation (σ) for the NA of A and B amounts to $\pm 0\overset{\mathrm{m}}{.}010$. Then with the NAs (R 81-A), the light curve was constructed by plotting them versus

Table 2. The average photometric parameters (*VBLUW* and *UBV* systems) of three program stars and their comparison stars

Star	Sp. type	V	$V-B$	$B-U$	$U-W$	$B-L$	V_J	$(B-V)_J$
HD 80077	B2/3Ia$^+$	−0.270	0.594	0.314	0.303	0.217	7.51	1.26
HD 80859	B5V[a]	−0.346	−0.037	0.149	0.017	0.053	7.75	−0.11
HD 168607	B9Ia$^+$	−0.532	0.691	0.384	0.380	0.251	8.16	1.44
HD 168625	B8Ia$^+$	−0.622	0.628	0.396	0.333	0.228	8.39	1.33
HD 168663	F4V	−0.847	0.190	0.350	0.178	0.205	8.99	0.44

[a] Variable, see Sect. 2.1.

Table 3. The journal of observations of HD 168607 = V 4029 Sgr relative to the comparison star

JD − 2440000	ΔV	$\Delta(V-B)$	$\Delta(B-U)$	$\Delta(U-W)$	$\Delta(B-L)$
6961.69	0.2876	0.4990	0.0268	0.2047	0.0405
6973.77	0.2855	0.4998	0.0380	0.2065	0.0439
7085.54	0.2717	0.4984	0.0363	0.2020	0.0439
7086.53	0.2796	0.4992	0.0380	0.2013	0.0443
7087.56	0.2823	0.4984	0.0366	0.2006	0.0440
7088.59	0.2900	0.4984	0.0393	0.1949	0.0478
7089.52	0.2889	0.5000	0.0331	0.2009	0.0436
7090.52	0.2927	0.4988	0.0342	0.1954	0.0439
7092.52	0.3010	0.4982	0.0356	0.1940	0.0441
7095.53	0.3076	0.4969	0.0282	0.1884	0.0442
7096.52	0.3027	0.5011	0.0322	0.1958	0.0434
7097.52	0.2996	0.5002	0.0323	0.1918	0.0430
7098.50	0.2998	0.5002	0.0278	0.1967	0.0430
7101.52	0.2940				
7103.51	0.2934				
7305.75	0.3598	0.5036	0.0272	0.1990	0.0452
7308.80	0.3517	0.5041	0.0256	0.1978	0.0441
7313.88	0.3276	0.5051	0.0169	0.1981	0.0398
7315.80	0.3208	0.5050	0.0191	0.1973	0.0428
7317.77	0.3219	0.4985	0.0200		0.0429
7320.88	0.3308	0.4979	0.0252	0.1942	0.0430
7322.74	0.3410	0.5006	0.0263	0.1960	0.0442
7325.78	0.3332				
7330.72	0.3290	0.5023	0.0216	0.1970	0.0420
7333.68	0.3263	0.5001	0.0232	0.1944	0.0430
7336.86	0.3258	0.4999	0.0277	0.1982	0.0450
7339.72	0.3254	0.5016	0.0266	0.1987	0.0428
7376.65	0.2934	0.5107	0.0364	0.2272	0.0478
7378.75	0.2853	0.5084	0.0364	0.2203	0.0479
7382.57	0.2805	0.5027	0.0332	0.2189	0.0451
7384.72	0.2893	0.4998	0.0342	0.2060	0.0460
7388.68	0.3049	0.4973	0.0447	0.2048	0.0467
7390.68	0.3106	0.4981	0.0458	0.2060	0.0470
7393.54	0.3142	0.4981	0.0424	0.2095	0.0486
7397.55	0.3181	0.5050	0.0482	0.2122	0.0453
7398.56	0.3220	0.5013	0.0457	0.2171	0.0494
7438.56	0.3557	0.5012	0.0291	0.1895	0.0458
7441.59	0.3668	0.4999	0.0310	0.1896	0.0495
7443.58	0.3630	0.4970	0.0265	0.1770	0.0452
7446.53	0.3543	0.5019	0.0264	0.1927	0.0469
7450.57	0.3413	0.5026	0.0277	0.1969	0.0490
7461.56	0.3175	0.5001			0.0515
7464.56	0.3221	0.4982			0.0480

Table 3 (continued)

JD – 2440000	ΔV	$\Delta(V-B)$	$\Delta(B-U)$	$\Delta(U-W)$	$\Delta(B-L)$
7613.85	0.2876	0.5003	0.0370	0.1948	0.0451
7615.87	0.2885	0.5042	0.0328	0.2048	0.0417
7617.86	0.2908	0.4990	0.0331	0.2032	0.0415
7618.87	0.2958	0.4977	0.0342	0.1997	0.0437
7619.87	0.2981	0.4985	0.0352	0.2043	0.0427
7620.87	0.3030	0.4987	0.0388	0.2037	0.0458
7623.88	0.3156	0.5027	0.0365	0.2066	0.0460
7626.87	0.3165	0.5051	0.0283	0.2034	0.0445
7633.88	0.3050	0.5056	0.0107	0.1971	0.0402
7634.82	0.3051	0.5015	0.0129	0.1912	0.0403
7637.85	0.3049	0.4974	0.0108	0.1893	0.0401
7638.72	0.3056	0.4943	0.0154	0.1869	0.0412
7638.88	0.3072	0.4977	0.0116	0.1874	0.0375
7639.81	0.3076	0.4955	0.0154	0.1892	0.0386
7640.85	0.3121	0.4948	0.0185	0.1903	0.0394
7643.87	0.3187	0.4947	0.0239	0.1882	0.0400
7654.92	0.2897	0.5037	0.0307	0.1965	0.0440
7661.85	0.2752	0.4981	0.0317	0.2044	0.0410
7663.82	0.2745	0.5000	0.0335	0.2074	0.0404
7686.70	0.2686	0.4964	0.0327	0.1981	0.0413
7688.81	0.2688	0.4947	0.0317	0.2004	0.0390
7691.82	0.2767	0.4942	0.0351	0.1983	0.0417
7692.79	0.2810	0.4943	0.0341	0.1961	0.0410
7694.82	0.2781	0.4940	0.0352	0.1950	0.0411
7695.84	0.2763	0.4981	0.0338	0.1966	0.0416
7732.60	0.2837	0.5003	0.0332	0.1982	0.0404
7750.62	0.3035	0.5020	0.0346	0.2105	0.0422
7765.66	0.2566	0.5031	0.0381	0.2138	0.0458
7766.60	0.2535	0.5030	0.0396	0.2183	0.0445
7964.85	0.3261	0.5018	0.0353		0.0493
7966.88	0.3222	0.5020	0.0327	0.2054	0.0504
7969.88	0.3197	0.5052	0.0346	0.2091	0.0497
7981.88	0.3370	0.5038	0.0397		
7984.92	0.3447	0.5029			0.0498
7986.91	0.3513	0.5018	0.0348	0.2027	0.0488
7987.85	0.3532	0.5015	0.0377	0.2042	0.0503
7988.86	0.3556	0.5025	0.0372	0.2024	0.0488
7989.84	0.3574	0.5033	0.0373	0.2011	0.0505
7990.83	0.3571	0.5041	0.0314	0.2111	0.0479
7992.86	0.3522	0.5033	0.0345	0.2061	0.0515
8026.78	0.3374	0.5068	0.0332	0.2131	0.0476
8028.84	0.3424	0.5052	0.0316	0.2175	0.0457
8030.80	0.3539	0.5035	0.0328	0.2105	0.0516
8032.70	0.3616	0.5039	0.0350		0.0514
8050.67	0.3772	0.5054	0.0202		0.0465
8061.85	0.3670	0.4976	0.0221	0.1821	0.0479
8063.79	0.3616	0.4977	0.0273	0.1927	0.0494
8066.75	0.3456	0.4996	0.0339	0.1997	0.0490
8068.65	0.3357	0.5007	0.0382	0.1992	0.0513
8070.80	0.3230	0.5042	0.0365	0.2051	0.0502
8075.65	0.3045	0.5016	0.0335	0.2079	0.0467
8077.67	0.3011	0.5002	0.0358	0.2025	0.0452
8078.66	0.2937	0.5049	0.0364	0.2101	0.0432
8081.83	0.3073	0.4963	0.0420		0.0474
8082.62	0.3085	0.4958	0.0427	0.2160	0.0482
8084.70	0.3119	0.4980	0.0491	0.2151	0.0502
8097.72	0.3036	0.5005	0.0450	0.2123	0.0516

Table 3 (continued)

JD − 2440000	ΔV	$\Delta(V-B)$	$\Delta(B-U)$	$\Delta(U-W)$	$\Delta(B-L)$
8099.72	0.3093	0.5012	0.0413	0.2141	0.0473
8101.70	0.3207	0.4996	0.0430	0.2087	0.0495
8104.74	0.3341	0.4980	0.0438	0.1972	0.0494
8112.72	0.3382	0.4982	0.0316	0.1841	0.0512
8118.73	0.3278	0.5002	0.0333	0.2062	0.0524
8121.59	0.3296	0.5026	0.0357	0.2200	0.0507
8123.58	0.3326	0.5034	0.0378	0.2135	0.0518
8144.63	0.2704	0.4998	0.0404	0.2178	0.0463
8145.67	0.2710	0.4997	0.0429		0.0513
8147.58	0.2666	0.5020	0.0434	0.2291	0.0485
8148.67	0.2623	0.4986	0.0476	0.2324	0.0491
8156.55	0.2851	0.4987	0.0494	0.2097	0.0476
8157.55	0.2880	0.4980	0.0479	0.2100	0.0477
8159.54	0.2918	0.4968	0.0446	0.2026	0.0463
8160.51	0.2960	0.4989	0.0438	0.2135	0.0486
8163.57	0.2959	0.4975	0.0433		0.0500
8165.54	0.2996	0.4974	0.0426	0.1912	0.0490
8166.54	0.3007	0.4973	0.0430	0.2032	0.0476

Table 4. The journal of observations of HD 168625 = V 4030 Sgr relative to the comparison star

JD − 2440000	ΔV	$\Delta(V-B)$	$\Delta(B-U)$	$\Delta(U-W)$	$\Delta(B-L)$
6961.69	0.2338	0.4411	0.0450	0.1591	0.0202
6973.77	0.2221	0.4392	0.0481	0.1568	0.0232
7085.54	0.2467	0.4390	0.0426	0.1554	0.0232
7086.53	0.2417	0.4393	0.0423	0.1519	0.0220
7087.56	0.2328	0.4388	0.0402	0.1573	0.0213
7088.59	0.2264	0.4372	0.0391	0.1562	0.0212
7089.52	0.2330	0.4390	0.0461	0.1550	0.0238
7090.52	0.2422	0.4387	0.0433	0.1550	0.0246
7092.52	0.2418	0.4394	0.0440	0.1513	0.0230
7095.53	0.2279	0.4355	0.0428	0.1513	0.0205
7096.52	0.2272	0.4382	0.0470	0.1512	0.0218
7097.52	0.2190				
7098.50	0.2326	0.4379	0.0431	0.1553	0.0237
7101.52	0.2340	0.4370	0.0409		0.0221
7103.51	0.2374				
7305.75	0.2083	0.4373	0.0481	0.1603	0.0223
7308.80	0.2150	0.4397	0.0473	0.1570	0.0228
7313.88	0.2256	0.4410	0.0446	0.1578	0.0193
7315.80	0.2299	0.4388	0.0484	0.1613	0.0235
7317.77	0.2309	0.4358	0.0461		0.0232
7320.88	0.2262	0.4379	0.0461	0.1573	0.0220
7322.74	0.2402	0.4377	0.0452	0.1548	0.0222
7325.78	0.2398				
7330.72	0.2319	0.4382	0.0452	0.1514	0.0203
7333.68	0.2343	0.4384	0.0472	0.1500	0.0218
7336.86	0.2112	0.4410	0.0491		0.0234
7339.72	0.1980	0.4394	0.0532	0.1590	0.0246
7376.65	0.2353	0.4398	0.0420	0.1504	0.0219
7378.75	0.2416	0.4393	0.0408	0.1543	0.0227
7382.57	0.2387	0.4386	0.0410	0.1529	0.0237

Table 4 (continued)

JD − 2440000	ΔV	$\Delta(V-B)$	$\Delta(B-U)$	$\Delta(U-W)$	$\Delta(B-L)$
7384.72	0.2302	0.4376	0.0450	0.1538	0.0223
7388.68	0.2283	0.4388	0.0450	0.1571	0.0233
7390.68	0.2268	0.4382	0.0511	0.1554	0.0239
7393.54	0.2154	0.4368	0.0476	0.1604	0.0221
7397.55	0.2225	0.4416	0.0528	0.1580	0.0175
7398.56	0.2290	0.4396	0.0460	0.1618	0.0236
7438.56	0.2198	0.4370	0.0546	0.1528	0.0244
7441.59	0.2156	0.4388			0.0263
7443.58	0.2287	0.4338	0.0532	0.1423	0.0236
7446.53	0.2291	0.4373	0.0547	0.1564	0.0235
7450.57	0.2425	0.4389	0.0480	0.1464	0.0258
7461.56	0.2311	0.4428	0.0516		0.0259
7464.56	0.2266	0.4365			0.0241
7613.85	0.2183	0.4415	0.0488	0.1590	0.0222
7615.87	0.2148	0.4427	0.0494	0.1598	0.0194
7617.86	0.2342	0.4373	0.0456	0.1583	0.0210
7618.87	0.2330	0.4358	0.0467	0.1513	0.0197
7619.87	0.2342	0.4357	0.0464	0.1576	0.0211
7620.87	0.2366	0.4366	0.0480	0.1577	0.0203
7623.88	0.2249	0.4380	0.0467	0.1596	0.0225
7626.87	0.2427	0.4378	0.0486	0.1550	0.0220
7633.88	0.2326	0.4390	0.0442	0.1536	0.0204
7634.82	0.2318	0.4377	0.0434	0.1584	0.0215
7637.85	0.2415	0.4370	0.0430	0.1543	0.0198
7638.72	0.2358	0.4350	0.0446	0.1550	0.0209
7638.88	0.2361	0.4380	9.0436	0.1530	0.0186
7639.81	0.2301	0.4370	0.0449	0.1500	0.0184
7640.85	0.2342	0.4381	0.0455	0.1534	0.0197
7643.87	0.2376	0.4391	0.0400	0.1594	0.0189
7654.92	0.2224	0.4407	0.0441	0.1560	0.0210
7661.85	0.2250	0.4392	0.0412	0.1559	0.0206
7663.82	0.2130	0.4396	0.0411	0.1570	0.0188
7686.70	0.2047	0.4372	0.0507	0.1594	0.0202
7688.81	0.2120	0.4372	0.0527	0.1617	0.0216
7691.82	0.2290	0.4370	0.0490	0.1572	0.0213
7692.79	0.2350	0.4378	0.0461	0.1562	0.0219
7694.82	0.2358	0.4377	0.0457	0.1579	0.0190
7695.84	0.2327	0.4405	0.0447	0.1579	0.0205
7732.60	0.2380	0.4399	0.0414	0.1474	0.0187
7750.62	0.2235	0.4381	0.0401	0.1556	0.0203
7765.66	0.2189	0.4376	0.0441	0.1534	0.0215
7766.60	0.2163	0.4378	0.0457	0.1586	0.0198
7964.85	0.2251	0.4363	0.0502	0.1468	0.0245
7966.88	0.2114	0.4363	0.0481	0.1485	0.0262
7969.88	0.2109	0.4374	0.0567	0.1604	0.0257
7981.88	0.2428	0.4408	0.0433		
7984.92	0.2407	0.4394			0.0237
7986.91	0.2545	0.4377	0.0384	0.1548	0.0230
7987.85	0.2538	0.4385	0.0365		0.0218
7988.86	0.2502	0.4379	0.0418	0.1583	0.0224
7989.84	0.2508	0.4370	0.0433	0.1469	0.0245
7990.83	0.2525	0.4369	0.0419	0.1541	0.0233
7992.86	0.2557	0.4373	0.0396	0.1590	0.0248
8026.78	0.2173	0.4368	0.0507	0.1504	0.0250
8028.84	0.2265	0.4367	0.0529	0.1627	0.0231
8030.80	0.2284	0.4372	0.0470	0.1566	0.0240
8032.70	0.2159	0.4376	0.0499	0.1656	0.0240

Table 4 (continued)

JD – 2440000	ΔV	$\Delta(V-B)$	$\Delta(B-U)$	$\Delta(U-W)$	$\Delta(B-L)$
8050.67	0.2211	0.4400	0.0518	0.1569	0.0227
8061.85	0.2158	0.4368	0.0474	0.1505	0.0246
8063.79	0.2233	0.4354	0.0499	0.1536	0.0245
8066.75	0.2136	0.4375	0.0491	0.1530	0.0249
8068.65	0.2087	0.4358	0.0457	0.1520	0.0229
8070.80	0.2208	0.4355	0.0497	0.1587	0.0262
8075.65	0.2141	0.4383	0.0456	0.1601	0.0249
8077.67	0.2186	0.4371	0.0470	0.1497	0.0228
8078.66	0.2144	0.4411	0.0443	0.1552	0.0217
8081.83	0.2220	0.4375			0.0224
8082.62	0.2205	0.4367	0.0454	0.1585	0.0224
8084.70	0.2215	0.4361	0.0464	0.1591	0.0240
8097.72	0.2280	0.4355	0.0492	0.1582	0.0215
8099.72	0.2247	0.4353	0.0432	0.1596	0.0224
8101.70	0.2220	0.4352	0.0479	0.1547	0.0257
8104.74	0.2193	0.4352	0.0457	0.1493	0.0219
8112.72	0.2419	0.4334	0.0429	0.1492	0.0262
8118.73	0.2215	0.4369	0.0470	0.1524	0.0260
8121.59	0.2209	0.4370	0.0467	0.1577	0.0245
8123.58	0.2307	0.4361	0.0514	0.1605	0.0247
8144.63	0.2298	0.4386	0.0456	0.1486	0.0243
8145.67	0.2370	0.4371	0.0448	0.1487	0.0248
8147.58	0.2349	0.4353	0.0414	0.1517	0.0241
8148.67	0.2322	0.4347	0.0495	0.1496	0.0243
8156.55	0.2346	0.4383	0.0446	0.1560	0.0216
8157.55	0.2361	0.4380	0.0423	0.1639	0.0236
8159.54	0.2346	0.4390	0.0456	0.1459	0.0251
8160.51	0.2382	0.4405	0.0431	0.1577	0.0232
8163.57	0.2345	0.4378	0.0432	0.1560	0.0223
8165.54	0.2304	0.4347	0.0443	0.1435	0.0260
8166.54	0.2308	0.4336	0.0459	0.1351	0.0250

Julian Date. The standard deviation of such an NA amounts to $\pm 0\overset{\text{m}}{.}015$.

For HD 168607 and HD 168625 also two comparison stars A and B were used and a few times alternately measured with these two program stars. Star A = HD 168552 (B3Ib) and star B = HD 168896 (A2). The spectral types are taken from the list of Manfroid et al. (1991) and are based on various sources. The reductions to (program star-A) were performed in the same way as for R 81. The $V_{\rm J}$ for A and B amount to 8.088 and 8.481, respectively, with a $\sigma = \pm 0\overset{\text{m}}{.}010$. For the values (program star-A) $\sigma = \pm 0\overset{\text{m}}{.}015$.

3. The light and colour curves and the quasi-periods ($\bar{P}$)

3.1. R 81 = HDE 269128 (B2.5eq)

The LMC hypergiant R 81 = HD 269128 has a spectral type B2.5 eq according to Feast et al. (1960) and $V_{\rm J} \sim 10.4$. Stahl et al. (1987), who made an extensive photometric and spectroscopic study of this object, discovered the eclipsing binary nature with a period of $74\overset{\text{d}}{.}59$. The light curve is very unusual with a primary minimum of $0\overset{\text{m}}{.}4$ deep and a dip of about $0\overset{\text{m}}{.}15$ at phase 0.8. Further the maximum brightness between phases 0.15 and 0.80 is characterized by a linear trend sloping down, but with an intrinsic scatter of $\pm 0\overset{\text{m}}{.}08$. This intrinsic scatter shows by eye inspection evidently a characteristic timescale of 15–30 days.

In order to exclude any effect of the eclipsed part (primary minimum) and the dip at phase 0.8, the analysis was confined to the phase interval 0.2–0.7. In this interval the mean light curve shows a linear trend, which slopes down from (R 81-A) = $0\overset{\text{m}}{.}977$ to $1\overset{\text{m}}{.}077$. For each NA (R 81-A), the deviation with respect to this line was read off as follows: mean line minus (R 81-A) = $\Delta V_{\rm J}$. Consequently positive and negative values for $\Delta V_{\rm J}$ mean that the variable was brighter and fainter, respectively, than the mean line and that the sum of all residuals is zero.

The period search program of Sterken (1977) was performed on these residuals in a period interval between $10^{\rm d}$ and $30^{\rm d}$ with steps of $0\overset{\text{d}}{.}05$. The best result is for $\bar{P} = 24\overset{\text{d}}{.}1$ with a correlation coefficient of $r = 0.527$. The second best is for $20\overset{\text{d}}{.}0$ with $r = 0.395$ and obviously of no significance.

Stellingwerf's (1978) period search program applied in the same period interval with steps of $0\overset{\text{d}}{.}08$ and a bin-structure (5, 2), gave practically the same result: $\bar{P} = 24\overset{\text{d}}{.}2$ with the statistic $\theta = 0.787$ and a significance = 0.108. A search for a multi-periodicity after prewhitening was not successful.

1992A&A...264...88V

Figure 1 shows the phase diagram for $\bar{P}=24^{\rm d}.1$. The smooth curve drawn through the data points has an amplitude of $\approx 0^{\rm m}.06$, while the maximum range of the observations, or the maximum light amplitude (MLA) amounts to $0^{\rm m}.17$ (in log intensity scale 0.068). This value of the MLA is more than twice as high as extracted from Stahl's et al. (1987) paper (van Genderen 1989). The reason is that the individual observations were then not yet available.

3.2. HD 80077 (B2Ia$^+$)

HD 80077 is an extremely bright hypergiant and presumably a member of Pimis 11. Various sources claim that $M_{\rm bol} \approx -11$ (e.g. Carpay et al. 1991), yet its mass loss rate is relatively low: $\dot{M}=5\,10^{-6}\,M\,{\rm yr}^{-1}$ (Carpay et al. 1989). Also its intrinsic variations appeared to be relatively small during two photometric sessions performed more than a decade ago, Knoechel & Moffat (1982) and Steemers & van Genderen (1986): $\approx 0^{\rm m}03$ and $\approx 0^{\rm m}08$, respectively. In the present paper we shall show that the light amplitude in the much longer series of observations in the time interval 1989–1991 appeared to be larger and more in accordance with its luminosity.

Carpay et al. (1989) discussed the possibility that the star could be an LBV, since the gravity is very low and the luminosity very high. It should then be in a minimum or quiescent state. In this context Houk (1978) made an important remark on the spectrum, she wrote: "The lines are very shallow, but sharp. Hβ seems completely filled in or slightly in emission. Possibly it is a shell star rather than a supergiant". Thus some decades ago the mass loss rate may have been much higher indeed than at present.

The star appeared to hover around $V_{\rm J}=7.5\pm0.1$ the last 15 years. Figure 2 shows a typical example of the light and colour curves with the largest light range so far observed: $0^{\rm m}.2$. A year before our monitoring program started, Carpay et al. (1989) observed the star with the same photometer on May 15, 1988 (JD 2447296). Their results indicate that HD 80077 was then close to the same minimum brightness as observed by us 1.5 yr later, see the minimum in Fig. 2.

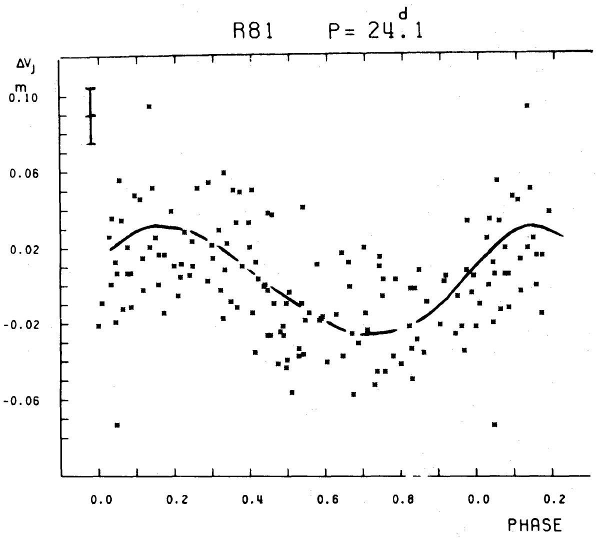

Fig. 1. The phase diagram for the intrinsic light variations of R 81 between the binary phases 0.2–0.7. The 2σ error bar at the left top

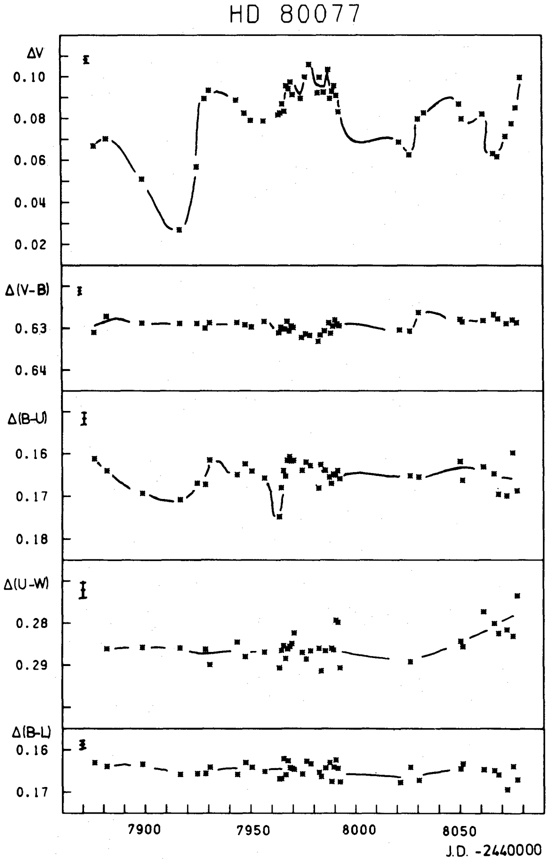

Fig. 2. The light and colour curves of HD 80077 in the *VBLUW* system (in log intensity scale) and relative to the comparison star, for the interval December 1989–July 1990. The 2σ error bars at the left top

The search for a quasi-period met with some difficulty. With Sterken's (1977) program applied on separate parts of our data set and on the complete set (V observations only), with steps of $0^{\rm d}.5$ in the period interval $20^{\rm d}$–$80^{\rm d}$, resulted in two possibilities: $41^{\rm d}.5$ and $55^{\rm d}.5$. Both periods have only slightly different and relatively low correlation coefficients r. Whether one period was more significant than the other depended on the selected part of the data set.

Figure 3 shows the phase diagram for the complete data set V relative to the comparison star and for $\bar{P}=41^{\rm d}.5$ ($r=0.36$). We took the first Julian date of Table 1 as the zero point. Although with $\bar{P}=55^{\rm d}.5$, $r=0.45$, we prefer to show the phase diagram for the shorter period, since in the other case two low brightness observations lie just at the phase of the maximum. The scatter of the other data points is slightly smaller with $\bar{P}=55^{\rm d}.5$ than with $\bar{P}=41^{\rm d}.5$, in accordance with the larger r value. Carpay et al.'s observation in 1988 coincides perfectly with the minimum of Fig. 3, while the fit in the phase diagram for $55^{\rm d}.5$ is less good, but acceptable. At the other side, if HD 80077 is an LBV indeed, then we should not mistrust the $55^{\rm d}.5$ period only because of two badly fitting observations. The reason is that none of the photometrically (and spectroscopically) well studied LBVs near minimum are really in quiescence. They show larger excursions of the median magnitude than normal supergiants, which are interpreted as small S Dor eruptions or shell ejections (van Genderen 1991a; Lamers 1987; Section 7 of the present paper).

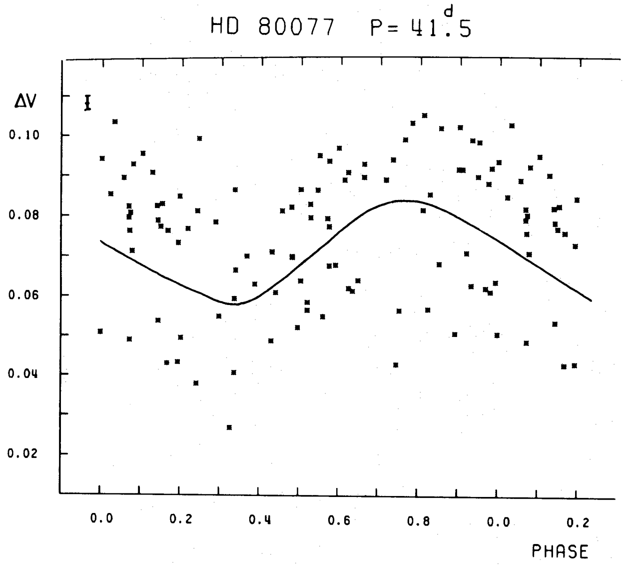

Fig. 3. The phase diagram of HD 80077, for the interval 1989–1991. V is relative to the comparison star and in log intensity scale. The 2σ error bar at the left top

Due to these ambiguities no definite conclusion can be made which of the two quasi-periods is the real one.

Since the phase diagrams for the colours do not show phase dependent variations of any significance (like most of the hot α Cyg variables), they are not shown. The reason for that absence is partly the crowding effect by the intrinsic variations. That they are present can be seen in detail with the aid of Fig. 2. They often run in phase with the light curve, but the precise trend differs from cycle to cycle. The largest variations occur in $B-U$ ($\leq 0^{\mathrm{m}}.02$), which is a measure for the Balmer jump.

Noteworthy are the three peaks in the light curve near JD 2447980 with a time scale of $\sim 10^{\mathrm{d}}$ and ranges of $\sim 0^{\mathrm{m}}.03$. During these three peaks the $V-B$ shows a relatively strong reddening as if small S Dor eruptions took place.

In IX and in van Genderen et al. (1990; hereafter Paper XI) the intrinsic colour variations were made quantitative by determining the σ of the average colour (neglecting the errors in the NAs since they are much smaller). Relationships appear to exist between $\sigma(V-B)$, T_{eff} and MLA and between $\sigma(V-B)$ and the ratios $\sigma(B-U)/\sigma(V-B)$ and $\sigma(B-L)/\sigma(V-B)$ (see Figs. 14 and 15 in Paper IX and Fig. 6 in Paper XI).

The σ's for HD 80077 amount to 0.0020, 0.0035, 0.0040 and 0.0024 (log intensity scale) in $V-B$, $B-U$, $U-W$ and $B-L$, respectively. They are larger by a factor 1.5–2 than those for normal α Cyg variables and LBVs of the same temperature, corrected for the small S Dor effects. This suggests that HD 80077 could well be an LBV in minimum. Also a support for this suspicion is the size of the MLA (Fig. 13 and Sect. 5). This takes away the reluctance of de Jager et al. (1991) to classify HD 80077 as an extremely bright object, possibly even as an LBV, because of the apparent lack of a significant brightness variation.

The photometric data set of Knoechel & Moffat (1982) covers 15 days only, much shorter than the quasi-period and is therefore not representative for the cyclic behaviour. Interestingly they found wavelength independent polarization variations and radial velocity variations modulated with the small light variations ($\sim 0^{\mathrm{m}}.03$). They tentatively suggested that these facts could be interpreted as caused by a binary modulation with $P=21^{\mathrm{d}}$, the companion should then be a small compact object. If this proposition is spurious, the polarimetric variations must be caused by light scattering in a circumstellar shell with density variations (e.g. Serkowski et al. 1975). Since the small light variations appeared to be modulated with the polarization variations, the atmospheric and wind characteristics are presumably connected in some way or another with the photospheric variations. Also of interest is the fact that the radial velocity variations, appeared to be more or less in phase with the light variations. Although the data are not numerous and the amplitude of the order of $\pm 5\,\mathrm{km\,s^{-1}}$ only, it is of interest to mention that for two other α Cyg variables such a phase relationship was found also, but then during a full cycle (van Genderen 1992; hereafter Paper XII).

3.3. HD 168607 = V 4029 Sgr (B9Ia$^+$)

HD 168607 = V 4029 Sgr is according to Chentsov & Luud (1990) an LBV, a statement based on their spectroscopic study. Our photometry proves that this is correct. The object is presumably a member of the M 17 complex in the Sgr OB1 association. Chentsov and Luud classified the star as B 9.4 ± 0.6 and Hiltner (1956) as B 9.

The very first light curve has been obtained by Sterken (1977) in 1973–1974 (Strömgren system). He derived a quasi-period of $63^{\mathrm{d}}.9$. Together with those obtained in the framework of the LTPV group in the interval 1982–1986 (Sect. 2.2) and the present one (1987–1990), we have a time base of 18 yr.

The average brightness per season hovered around $V_{\mathrm{J}}=8.2 \pm 0.1$. (If we consider the individual NAs, the total range amounts to $\pm 0^{\mathrm{m}}.16$). In the early fifties (Hiltner 1956) the brightness was close to this value: $V_{\mathrm{J}}=8.29$. Thus during 40 yr there were no dramatic light variations.

Figures 4 and 5 show typical examples of the light variability of HD 168607: the 1990 light and colour curves in the *VBLUW* system and the 1985–1986 light curve of the LTPV group. What we noticed as typical LBV characteristics in previous papers is confirmed by this one: (1) The total light range (MLA, viz. $0^{\mathrm{m}}.3$, see Sect. 5, Fig. 13) is higher than for normal α Cyg variables of the same temperature. (2) Small range oscillations (timescale $\sim 60^{\mathrm{d}}$) occur on different brightness levels. According to our interpretation HD 168607 is just like AG Car, HR Car, P Cyg and other LBVs seldom or never in real quiescence. They are always slightly unstable and show envelope processes by small S Dor eruptions on a time scale of months to a year, which can be seen spectroscopically as shell ejections (Lamers 1987) and by special photometric features (Paper XI, van Genderen 1991a and Sect. 7 of the present paper). (3) The light curves are relatively smooth compared to normal α Cyg variables (see for example the light curves of HD 168625 = V 4030 Sgr in Sect. 3.4).

Due to the 60^{d} oscillation on various brightness levels, the search for a quasi-period was as expected unsuccessful. Therefore, we collected the epochs of significant maxima (sometimes by interpolation between a rising and a descending branch). The estimated uncertainty in these epochs is of the order of $\pm 15^{\mathrm{d}}$, especially when there are two peaks close together of which one should be the real maximum and the other a secondary feature only.

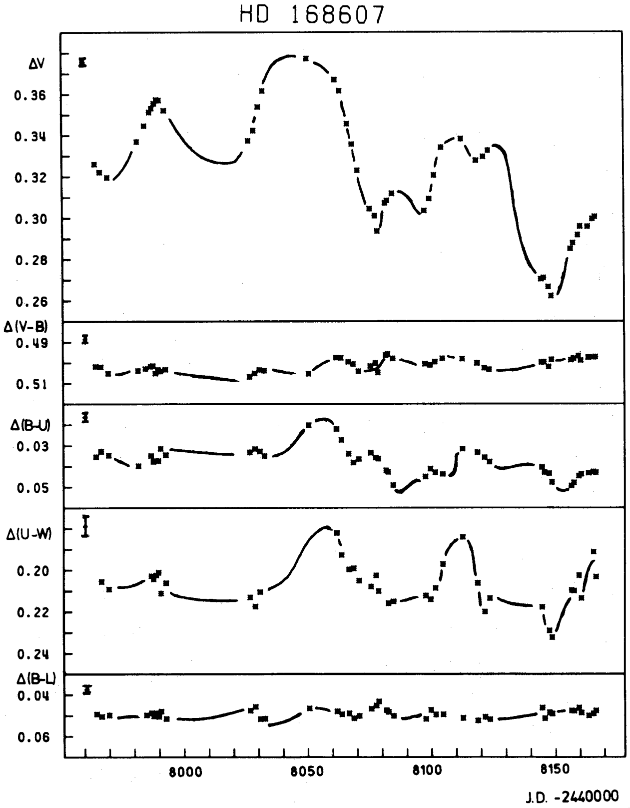

Fig. 4. The light and colour curves of HD 168607 = V 4029 Sgr in the *VBLUW* system (in log intensity scale) and relative to the comparison star, for 1990. The 2σ error bars at the left top

A least squares solution on 17 maxima resulted in the following linear ephemeris (mean errors added):

$$\mathrm{JD}_{\max} = 2447105.3 + 58\overset{\mathrm{d}}{.}48E$$

$$\pm 2.0 \pm 0.08 \text{ m.e.}$$

The quasi-period is not so much different from that of Sterken (1977). Table 5 lists the epochs of the maxima, the number of cycles and the (O – C) values. Figure 6 shows the (O – C)/*E* diagram. The (O – C) values are in most cases smaller than 10^{d} (15% of the period). This suggests a relative linearity caused by an imposed periodic force, rather than a pseudo-periodic one. However, prudence is called for. First, the time gap between the very first maximum in 1973 ($E = -90$) and the other ones is too large to be certain of the correct counting of epochs (although then one can still speak of a relative linearity in the interval 1982–1990). Second, the selection of the maxima is not objective. Incidentally, this is not the first α Cyg variable of which the ephemeris could be relatively linear. The other one is the LYV V 766 Cen = HR 5171A (Paper XII); of which the time base amounts to 18 yr and perhaps we can add also the LYV ρ Cas (Zsoldos & Percy 1991), see also the note added in proof in Paper XII). Most time bases for the other objects of this research program are not as long as for this one, therefore nothing can be said about their possible linearity.

The colour variations of HD 168607 have larger amplitudes than those for HD 80077 (Sect. 3.1) due to its lower temperature. Usually the colour variations are in phase with the light curve (blue in the maxima, red in the minima). The σ's of the intrinsic colour variations (see Sect. 3.2) amount to 0.0032, 0.0085, 0.0101 and 0.0037 in $V-B$, $B-U$, $U-W$ and $B-L$, respectively. They are much larger as well as the ratios $\sigma(B-L)/\sigma(V-B)$ and $\sigma(B-U)/\sigma(V-B)$, than for normal α Cyg variables, see Fig. 6 in Paper XI and Fig. 14 in Paper IX, respectively, facts which add further support to the LBV character of HD 168607.

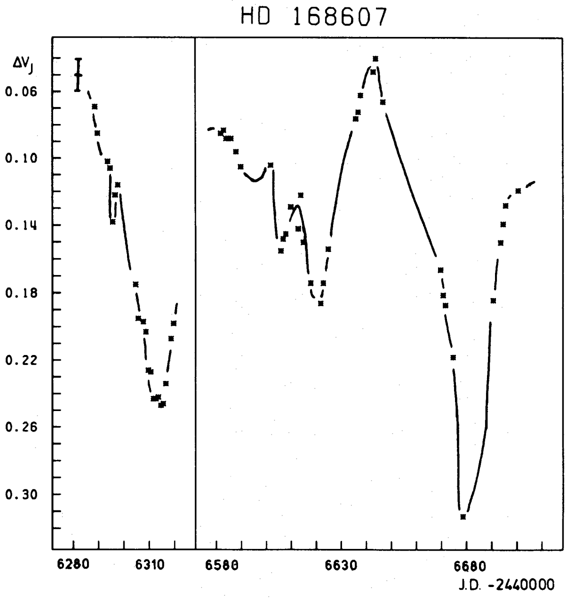

Fig. 5. The V_J light curve of HD 168607 = V 4029 Sgr relative to the comparison star for the interval 1985–1986. The 2σ error bar at the left top

Table 5. The epochs of the light maxima of HD 168607 = V 4029 Sgr, the number of cycles *E* and the O – C values according to the linear ephemeris of Sect. 3.2

No.	$\mathrm{JD}_{\max} - 2440000$	*E*	(O – C) (d)
1	1845	−90	3.0
71	5945	−20	9.3
72	5982	−19	−12.2
76	6230	−15	1.9
77	6280	−14	−6.6
82	6583	−9	4.0
83	6644	−8	6.6
91	7094	0	−11.3
94	7273	3	−7.7
96	7405	5	7.3
97	7441	6	−15.2
100	7634	9	2.4
101	7692	10	1.9
102	7744	11	−4.6
106	7989	15	6.5
107	8046	16	5.0
108	8109	17	9.5

1992A&A...264...88V

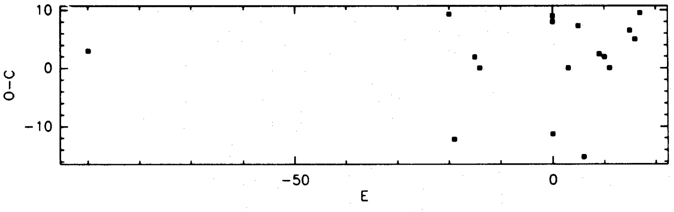

Fig. 6. The O − C values (in days) versus the number of cycles of HD 168607 = V 4029 Sgr according to the linear ephemeris of Sect. 3.3

In an attempt to eliminate the colour variations due to the small S Dor eruptions, the σ's were redetermined by making averages of the colours at high and low brightness levels separately, but the σ's became only slightly smaller (0.0030, 0.0084, 0.0101 and 0.0031, respectively). Consequently the position of HD 168607 stays abnormal in the two diagrams quoted above. Also the absence of any significant phase dependent colour variation in the phase diagrams, due to the large differences in behaviour from cycle to cycle, is striking.

3.4. HD 168625 = V 4030 Sgr ($B5/8Ia^{+}$)

HD 168625 = V 4030 Sgr is a late or mid B-type hypergiant and is separated by $\sim 1'$ from the object discussed in Sect. 3.3 and thus presumably member of the same cluster. Chentsov & Luud (1990) classified the spectrum as B 5.6 ± 0.3 and Hiltner (1956) as B 8. The first two authors mentioned above, tentatively identified the object with the IRAS source 18184–1623, although it is no LBV.

The very first light curve has been obtained by Sterken (1977) in 1973–1974 (Strömgren system). He derived a quasi-period of $64^{\mathrm{d}}.8$. Together with those obtained by the LTPV group in the interval 1982–1986 (Sect. 2.2) and the present ones (1987–1990), we have a time base of 18 yr. However, due to the complicated light curves, this long time base cannot be exploited to derive an accurate quasi-period as we shall demonstrate.

The average magnitude in the various seasons hovered around $V_J = 8.4 \pm 0.1$. In the early fifties (Hiltner 1956) the brightness was close to this value: $V_J = 8.41$. Thus, there were no dramatic light variations the last 40 yr.

Figures 7 and 8 show as typical examples the light and colour curves in the *VBLUW* system for the intervals 1988–June 1989 and 1990, respectively. Figure 9 shows the light curve obtained in the interval 1985–1986 by the LTPV group. These light curves are typical for normal α Cyg variables: a quasi-regular wave (in this case with a time scale of $\sim 35^{\mathrm{d}}$) with many secondary features. This object also shows relative smooth parts. Sometimes there are a number of fast oscillations with a timescale of a week or so.

The search was made between 20^{d} and 75^{d} with steps of $0^{\mathrm{d}}.2$ for Sterken's program and a bin-structure of (5, 2) for Stellingwerf's method. The search was firstly applied on the *VBLUW* data set 1988–10 April 1990 (JD 2447305–2447992). Then on the complete *VBLUW* and LTPV-group data sets separately. Various possibilities were the result, which had in the various data sets or parts of data sets and for the two search programs different, but often non-significant, correlation coefficients (r, Sterken's program), or statistics (Θ) and significances (Stellingwerf's method). Sometimes they were not consistent with each other. We shall not give too much details, but only a short review.

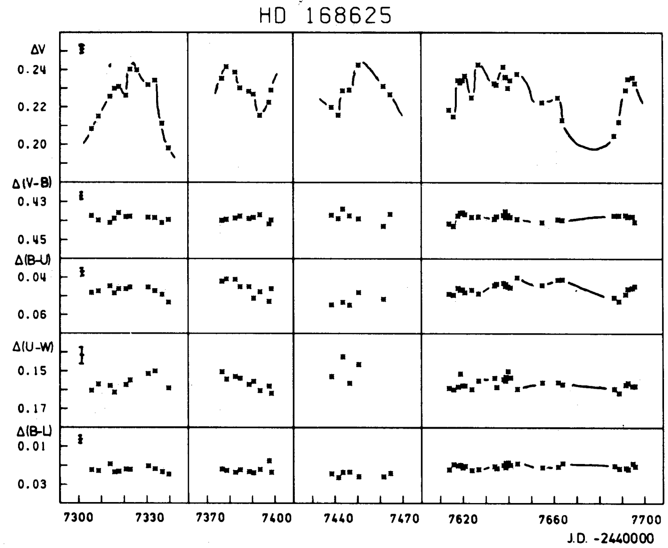

Fig. 7. The light and colour curves of HD 168625 = V 4030 Sgr in the *VBLUW* system (in log intensity scale) and relative to the comparison star for the interval 1988–June 1989. The 2σ error bars at the left top

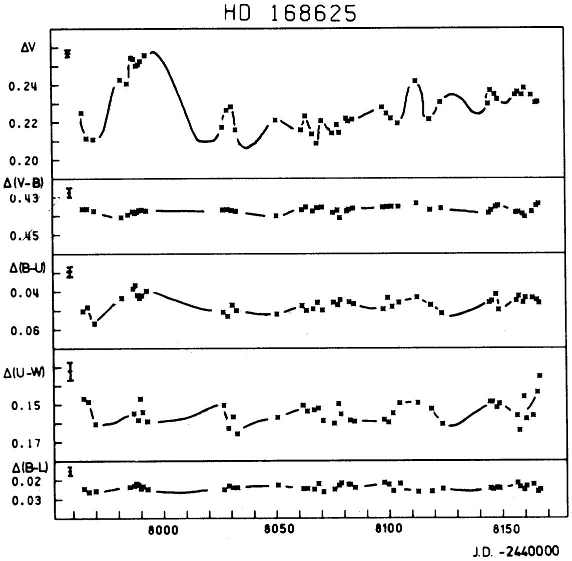

Fig. 8. The V_J light curve of HD 168625 = V 4030 Sgr relative to the comparison star, for 1990. The 2σ error bar at the left top

The rounded off values for the most significant quasi-periods are as follows: 35^{d}, 41^{d}, 44^{d}, 51^{d} and 60^{d}. Then by scrutiny of the various phase diagrams, of the grade of consistency between the various results, we made the following conclusions. The best phase diagram for the 1987–1990 data set is reached with $P = 34^{\mathrm{d}}.8$ ($\nu = 0.0287\ \mathrm{cd}^{-1}$), the second best is $51^{\mathrm{d}}.2$ ($\nu = 0.0195\ \mathrm{cd}^{-1}$). Since both differ by a factor 1.5 the latter could be an alias of the first one. For the 1982–1986 data set the best one is $\bar{P} = 36^{\mathrm{d}}.6$ ($\nu = 0.0277\ \mathrm{cd}^{-1}$) with $52^{\mathrm{d}}.0$ as a possible alias. Figures 10 and 11 show the phase diagrams for both first choices. Figure 10

1992A&A...264...88V

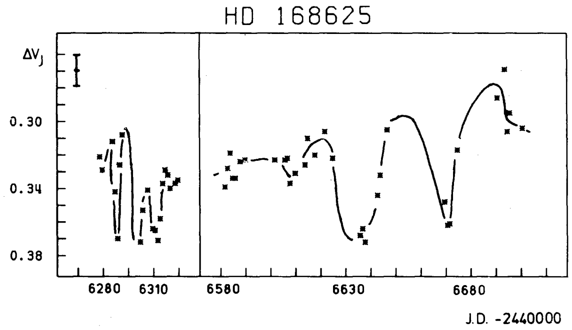

Fig. 9. The V_J light curve of HD 168625 = V 4030 Sgr relative to the comparison star for the interval 1985–1986. The 2σ error bar at the left top

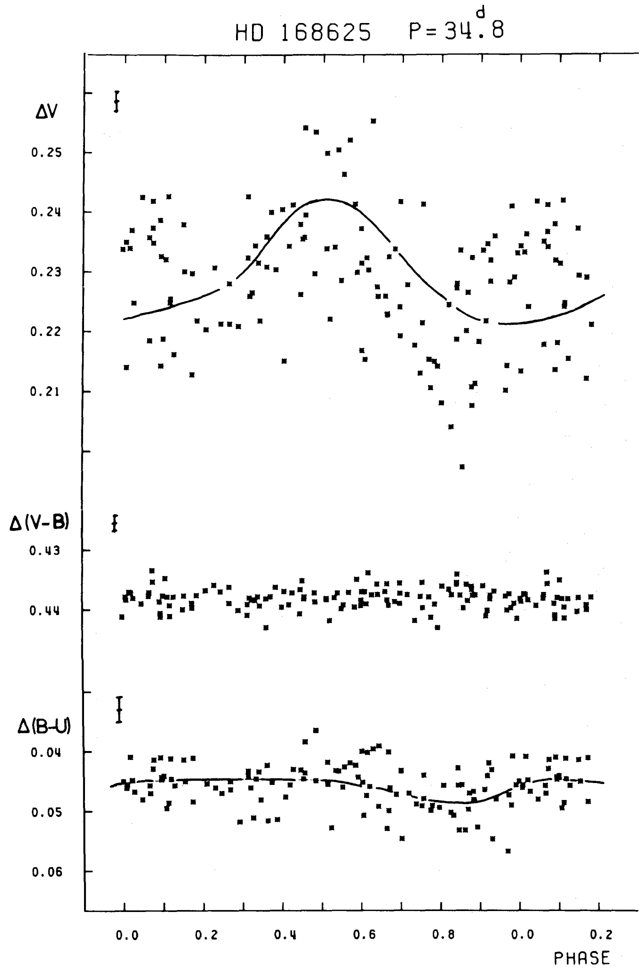

Fig. 10. Three phase diagrams of HD 168625 = V 4030 Sgr in the *VBLUW* system (in log intensity scale) and relative to the comparison star, for the interval 1987–1990. The 2σ error bars at the left top

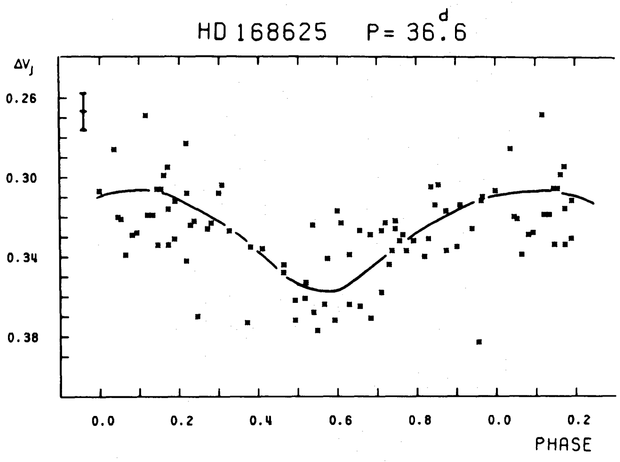

Fig. 11. The V_J phase diagram of HD 168625 = V 4030 Sgr relative to the comparison star, for the interval 1982–1986

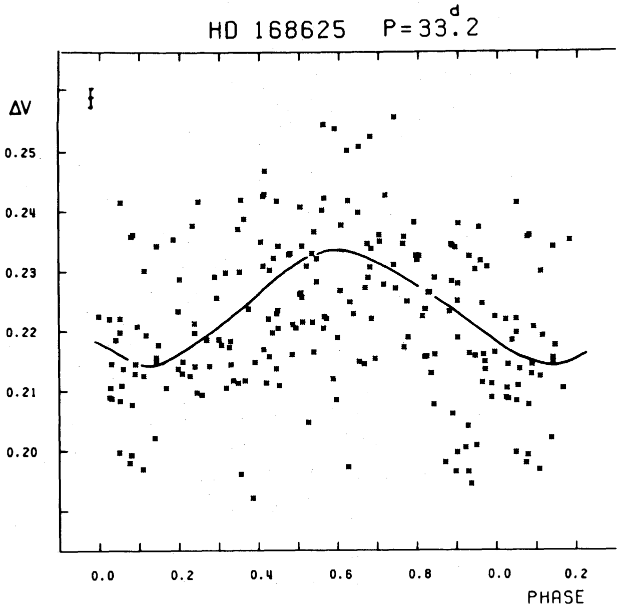

Fig. 12. The phase diagram of HD 168625 = V 4030 Sgr for the interval 1982–1990. *V* in log intensity scale and relative to the comparison star. The 2σ error bar for the observations obtained in the *VBLUW* system is shown at the left top, that for the observations from the LTPV group is 2.5 times larger

also shows the $V-B$ and $B-U$ curves with a phase relationship for the latter (a measure for the Balmer jump).

Thus an average of $\sim 35\overset{\mathrm{d}}{.}5$ would be an acceptable choice. However, the search in the complete data set 1982–1990 (the magnitude scale of the 1982–1986 data set was transformed to the log intensity scale of the 1987–1990 data set) did not confirm this. Three nearly equally high peaks appeared in the trend of r (~ 0.39) viz. for $33\overset{\mathrm{d}}{.}2$, $51\overset{\mathrm{d}}{.}8$ and $61\overset{\mathrm{d}}{.}0$. A fourth, but a larger peak appeared at $59\overset{\mathrm{d}}{.}8$ ($r = 0.481$). However, the phase diagram for the latter looked odd and is most likely an artifact of the regularity ($\sim 60^{\mathrm{d}}$) between the observing intervals in a number of seasons. The $61\overset{\mathrm{d}}{.}0$ period is presumably of the same origin, while $51\overset{\mathrm{d}}{.}8$ may be again the 1.5 times alias of $33\overset{\mathrm{d}}{.}2$. Figure 12 shows the phase diagram for the complete 1982–1990 data set with $33\overset{\mathrm{d}}{.}2$. Since the eye inspection of the light curve also indicated a primary wave of this order, our final conclusion is that the quasi-period must be of the order of 35^{d} indeed.

The quantitative measures for the intrinsic colour variations σ (see Sect. 3.2) amount to 0.0019, 0.0038, 0.0048 and 0.0020 for $V-B$, $B-U$, $U-W$ and $B-L$, respectively and are normal for the normal α Cyg variables of the same temperature.

4. Some physical parameters

4.1. *R81 = HDE 269128 (B2.5eq)*

Since we did not make the photometry ourselves, we refer the reader to the paper of Stahl et al. (1987).

4.2. *HD 80077 (B2Ia$^+$)*

Carpay et al. (1989) obtained a satisfactory fit to the spectral energy distribution of a Kurucz model $T_{\rm eff} = 17\,000$ K, $\log g = 2$ and $E(B-V)_{\rm J} = 1.54$. The average reddening based on previous studies amounts to 1.50 ± 0.05. The reddening in the *VBLUW* system based on the present photometry amounts to $E(V-B) = 0.634 \pm 0.050$ and is determined from the theoretical two-colour diagrams, computed by Lub & Pel (1987) and based on Kurucz (1979) models, adopting $\log g = 2$ (Carpay et al. 1989). The error in $E(V-B)$ is based on an uncertainty of ± 1 in $\log g$.

Due to the fact that the reddening line in the *UBV* system for large reddenings (as in this case) is much more curved than in the *VBLUW* system, the transformation to $E(B-V)_{\rm J}$ is done as follows as to prevent too large transformation errors. Via $(V-B)_0$ ($= V-B$ corrected for $E(V-B)$), $(B-V)_{\rm J0}$ is computed with the aid of the formula referred to in Sect. 2, giving $(B-V)_{\rm J0} = -0.12$. This agrees reasonably with Schmidt-Kaler's (1982) calibration for B 2 supergiants: ~ -0.16, especially if we take into account that the hypergiants should be a few hundredths of a mag redder than the supergiants. Then $E(V-B)$ is transformed in $E(B-V)_{\rm J}$ with the aid of the formula of Pel (1987):

$$E(B-V)_{\rm J}/E(V-B) = 2.39 - 0.17E(V-B),$$

resulting in $E(B-V)_{\rm J} = 1.45$. A transformation error should not be larger than ± 0.05. Consequently the agreement with the average reddening mentioned above is satisfactory. Table 6 lists the reddening and some other physical parameters with the references.

4.3. *HD 168607 = V 4029 Sgr (B9Ia$^+$)*

Chentsov & Luud (1990) determined various possible temperatures between 8500 and 10 500 K depending on the method. We shall adopt $T_{\rm eff} = 9300 \pm 200$ K (listed in Table 6) which is based on the Sp/$T_{\rm eff}$ table of de Jager & Nieuwenhuijzen (1987) adopting the spectral type of Chentsov & Luud (1990): B 9.4 ± 0.6.

The reddening, which is very high, is determined in the same way as described in Sect. 4.2, adopting $\log g = 1.0 \pm 0.5$ and amounts to $E(V-B) = 0.68 \pm 0.05$ in the *VBLUW* system. The value for the gravity is in agreement with those generally accepted for LBVs (Lamers 1986). (A $\log g$ value of 2 or higher results in a much too blue intrinsic colour $(B-V)_{\rm J}$. Then we find $(B-V)_{\rm J} = 0.01$, which agrees with Schmidt-Kaler's (1982) calibration: 0.00, thus $E(B-V)_{\rm J} = 1.55 \pm 0.12$. This compares reasonably well with Hiltner's (1956) corrected value 1.61. (He gave 1.66, but this was based on a Sp/$(B-V)_{\rm J}$ calibration given in his Table 6, which is $0\overset{\rm m}{.}05$ too blue compared to Schmidt-Kaler's calibration for B 9 supergiants.) As mentioned in Sect. 4.2 hypergiants should be slightly redder than supergiants, thus the difference between our reddening and Hiltner's corrected one will be even smaller.

Hiltner's (1956) observed colour $(B-V)_{\rm J} = 1.60$. We find $(B-V)_{\rm J} = E(B-V)_{\rm J} + (B-V)_{\rm J0} = 1.56$, which is also close to Hiltner's value and a confirmation that the transformation did not introduce too large errors ($\leq 0\overset{\rm m}{.}05$) by the large reddening.

For the determination of the luminosity (listed in Table 6), we used our reddening value and a distance of 2.2 ± 0.2 kpc (Humphreys 1978; Chini et al. 1980) adopting that it is a member of the M 17 complex in the Sgr OB1 association. The BC listed in Table 6 is taken from Schmidt-Kaler (1982). Further we applied the normal extinction law $R = 3.1$.

4.4. *HD 168625 = V 4030 Sgr (B5/8Ia$^+$)*

Chentsov & Luud (1990) derived a temperature of $\sim 13\,000$ K. We shall adopt $T_{\rm eff} = 12\,000 \pm 300$ K (listed in Table 6) based on the Sp/$T_{\rm eff}$ table of de Jager & Nieuwenhuijzen (1987) adopting the spectral type of Chentsov & Luud (B 5.6 ± 0.3).

The reddening, which is also high, is determined in the same way as described in Sect. 4.2 adopting $\log g = 1.5 \pm 0.5$ and amounts to $E(V-B) = 0.64 \pm 0.05$ in the *VBLUW* system. Log g

Table 6. Some physical parameters for three program stars.

Star	Sp. type	$E(V-B)$	Adopted $\log g$	$E(B-V)_{\rm J}$	$\log T_{\rm eff}$	BC	$M_{\rm bol}$	$\log L/L_\odot$
HD 80077	B2Ia+	0.634	2.0[a]	1.45[b] 1.50[c]	4.230[a]	−1.56[a]	−11.0 ± 1.2[d]	6.3 ± 0.5[d]
HD 168607	B9.4Ia+[f] B9Ia+[g]	0.68	1.0	1.55[b] 1.61[h]	3.970	−0.3	−8.7 ± 0.4	5.38 ± 0.2
HD 168625	B5.6Ia+[f] B8Ia+[g]	0.64	1.5	1.46[b] 1.47[h]	4.080	−0.75	−8.6 ± 0.4	5.34 ± 0.2

[a] Carpay et al. (1989); [b] Present photometry; [c] Average of various studies; [d] Carpay et al. (1991); [f] Chentsov & Luud (1990); [g] Hiltner (1956); [h] Hiltner's (1956) value corrected, see Sect. 4.3 and 4.4.

cannot be much larger, otherwise the intrinsic colour $(B-V)_{\rm J0}$ becomes too blue.

We find $(B-V)_{\rm J0}=-0.04$, which agrees with Schmidt-Kaler's (1982) calibration for a B 5.6 supergiant: -0.07, especially taking into account that hypergiants should be a few hundredths of a mag redder than supergiants (see Sects. 4.2 and 4.3).

The reddening turns out to be $E(B-V)_{\rm J}=1.46\pm0.12$, which agrees with Hiltner's (1956) corrected value 1.47. (He gave 1.55, but is based on a calibration which is $0^{\rm m}.08$ too blue compared with the Schmidt-Kaler calibration for mid-B-type supergiants, see Sect. 4.3.)

Hiltner's (1956) observed colour index $(B-V)_{\rm J}=1.46$. We find $(B-V)_{\rm J}=E(B-V)_{\rm J}+(B-V)_{\rm J0}=1.42$, which is just as in the case of HD 168607 (Sect. 4.3) only $0^{\rm m}.04$ bluer than Hiltner's value.

The procedure to find the luminosity is similar to that for the previous object, since both belong to the same cluster.

5. The MLA/log $T_{\rm eff}$ diagram

Figure 13 shows the maximum light amplitude MLA (in log intensity scale) versus log $T_{\rm eff}$ based on the results of van Genderen (1989), but supplemented with new results of various papers and of the present one (e.g. WRA 751: van Genderen et al. 1992b; HD 160529: Sterken et al. 1991).

Normal α Cyg variables are concentrated between the two broken curves. Those with high mass loss rates, like the LBVs, lie generally above the upper broken curve. The four objects discussed in the present paper confirm this trend. The MLAs amount to 0.068, 0.08, 0.125 and 0.06 for R 81, HD 80077, HD 168607 and HD 168625, respectively. As explained in the previous sections we suspect that HD 80077 is an LBV in minimum (see also Carpay et al. 1989, 1991). Its position above the upper limit confirms it. The same is true for R 81 (Sect. 3.1) and HD 168607 (upper symbol). The position of HD 168625 is below the upper limit as it should.

For four LBVs in or near minimum: AG Car, HR Car, P Cyg and HD 168607 the MLAs are corrected for the small S Dor eruptions. Thus the lowest symbol of the two connected by a vertical line, represents the MLA of the intrinsic oscillation only (e.g. Paper XI; van Genderen 1991a). They are now comparable with the MLAs of the normal variables.

A few remarks should still be made: (1) The MLA of P Cyg amounts to ~0.08 log intensity scale or $\sim0^{\rm m}.2$, including the small S Dor eruptions. (We presume that they originate at the same time as the spectroscopically detected shell ejections with a time scale of months to a year (Markova 1986; van Gent & Lamers 1986; Lamers 1987)). The MLA is based on the photometry discussed by Percy et al. (1988) and de Groot (1989) for the years 1985–1986 and 1988, respectively. Percy et al.'s $(B-V)_{\rm J}$ curve shows sometimes a reddening of a few hundredths of a mag during the light maxima belonging to the long time scale waves, supporting the suspicion that they reflect the small S Dor eruptions indeed. The MLA of the supposed intrinsic oscillations ($\bar{P}\sim18^{\rm d}$) superimposed on the long waves amount to $\sim0^{\rm m}.1$ or ~0.04 log intensity scale. (2) The MLA of HD 160529 is taken from Fig. 4 of Sterken et al. (1991) and amounts to ~0.12 log intensity scale or $\sim0^{\rm m}.3$. It is based on the individual waves when the star was still declining after a major outburs, but close to the minimum, see their Fig. 2. The size of the MLA confirms its LBV character. Our previous estimation of the MLA amounted to

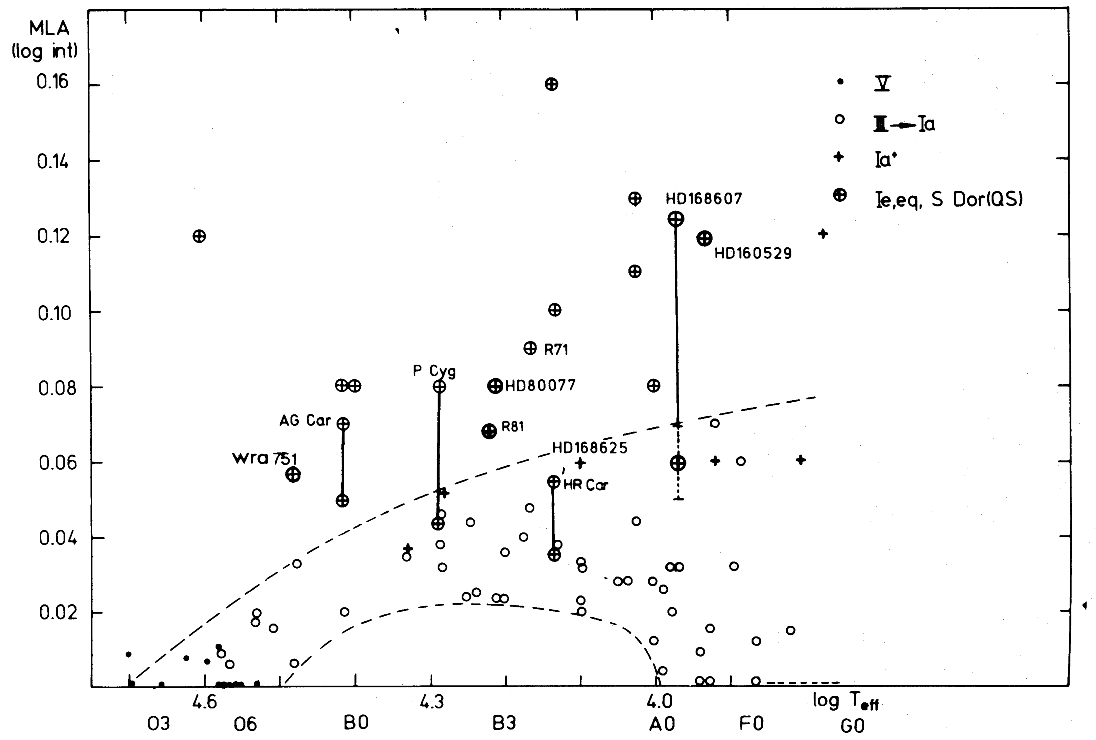

Fig. 13. The MLA/log $T_{\rm eff}$ diagram showing the normal α Cyg variables generally below the upper broken curve and the high mass loss rate objects, like the LBVs (in quiescent state, also called S Dor (QS)) generally above it

0.068 and was based on Sterken's (1977) first observations and clearly too low for an LBV (one needs many more observations to get a statistically significant MLA).

6. The HR diagram

Figure 14 shows the position of 12 α Cyg variables among which 11 LBVs and the P = constant lines for variable supergiants of Maeder (1980). For 9 LBVs $\bar{P}$ is known and bracketed in Fig. 14. See for R 71 Paper VI, for AG Car and HR Car Paper XI, for HD 160529 Sterken et al. (1991). For P Cyg we derived $\bar{P} \sim 18^d$ and is extracted from de Groot's (1989) light curve from 1988, since it is very well covered by uniformly obtained observations. The light curves discussed by Percy et al. (1988), comprising the years 1985–1986, are based on the photometry of various quality and made at different observatories. These curves also show oscillations with the time scales of 10^d–20^d, superimposed on the long-time scale waves of months. Since various researchers did not differentiate between the two types of light variations, it is not surprising that their search for a quasi-period failed.

The position of the 9 objects with known $\bar{P}$'s agrees satisfacotorily with the P = constant lines apart from HD 168625 = V 4030 Sgr, which is slightly too far out. However, considering the uncertainties in distances and temperatures it is surprising that most of the objects fit so reasonably well.

7. Discussion and conclusions

The present study is a new piece which fit the jigsaw puzzle of the α Cyg variables. The discernments listed below, mainly for the hot members of this group, can be considered as a repletion to those listed earlier (van Genderen 1991b). Other reviews, particularly on the hot S Dor type stars or LBVs, are given by Lamers (1987) and Sterken (1989).

1. There is a morphological difference between the light curves of normal α Cyg variables and those suffering of episodic mass loss eruptions, the LBVs. The latter, if in or near minimum, show intrinsic oscillations similar to normal massive stars, but superimposed on a longer time scale variation of months to a year, which are presumably the result of small S Dor eruptions or shell ejections. The intrinsic oscillations of LBVs tend to be smoother by showing less secondary features.

2. These non-periodic secondary features, visible as peaks and shoulders on the light curves of supergiants, were called "δ variations" (van Genderen 1986) and must be connected to various characteristics of the supergiant variability such like photospheric turbulence (see the review of Burki 1987).

3. LBVs in minimum are apparently seldom or never in real quiescence (see also Lamers & Fitzpatrick 1988). They are thus more unstable than their normal α Cyg counterparts. In this context it is of interest to mention that even η Car shows presumably small scale eruptions on a timescale of 1–3 yr (van Genderen & Thé 1984, 1987).

4. Quasi-periods ($\bar{P}$) can always be found provided that a substantial amount of accurate photometry is available. However for LBVs the effects of the small S Dor eruptions should be removed first.

5. If phase diagrams become very crowded because too many observations and cycles are involved, it does not rule out the existence of a linear ephemeris. For a few well observed cases the linear ephemeris are valid during a few tens of cycles and perhaps even much longer.

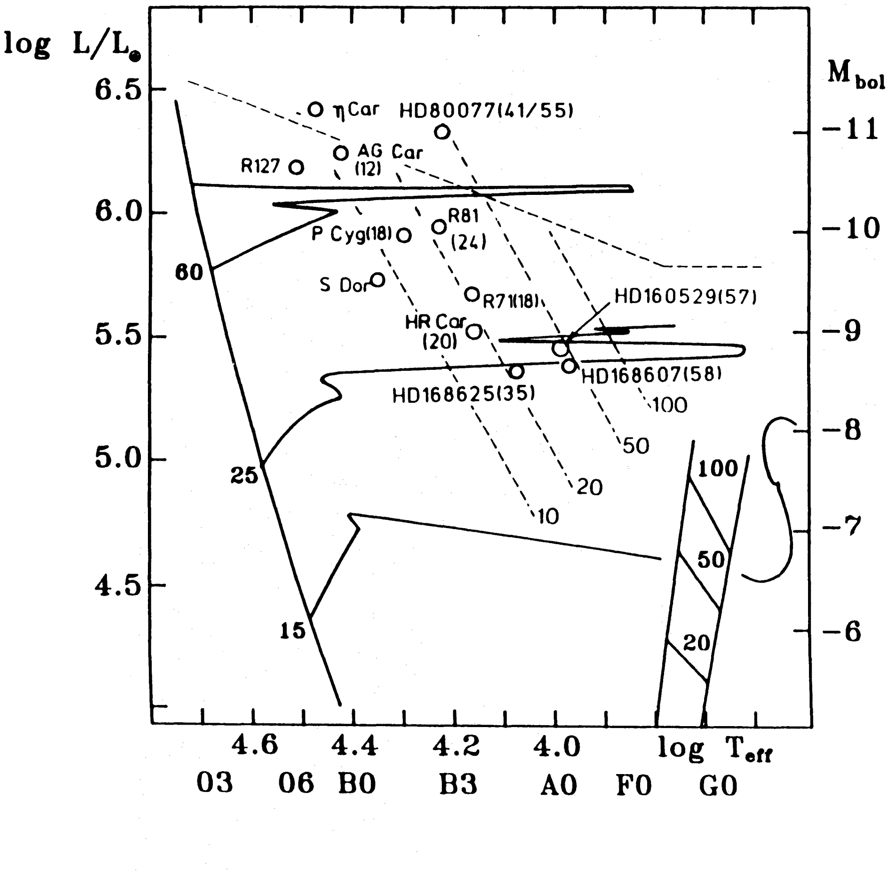

Fig. 14. The HR diagram for 12 α Cyg variables among which 11 LBVs. The P = constant lines for 10, 20, 50 and 100^d are shown as oblique dotted lines, the Humphreys–Davidson limit is represented by the upper broken line. The Cepheid strip is sketched in the right bottom corner

6. Both types of α Cyg variables fit the same P = constant lines, as far as the various uncertainties allow the comparison (see also Burki 1977).

7. LBVs are situated not necessarily close to the Humphreys-Davidson limit, as already noticed by various investigators: ~ 0.3 in log $T_{\rm eff}$ to the left (Lamers & Fitzgerald 1988) or up to $\sim 1\overset{\rm m}{.}5$ below it (see also Fig. 1 of Wolf 1989). Nice examples are HD 168607 and HD 160529.

In a recent study on the motion fields de Jager et al. (1991) concluded that large scale motion fields in OBAF-type supergiants consists of high mode internal gravity waves. What the precise effects are on the photosphere and subsequently on the irradiance of the continuum light is as yet unknown.

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