ASTRONOMY & ASTROPHYSICS
SUPPLEMENT SERIES

OCTOBER **1988**, PAGE 117

Astron. Astrophys. Suppl. Ser. **75**, 117-137 (1988)

The velocity field of the outer Galaxy in the southern hemisphere. III. Determination of distances to O, B, and A type stars in the Walraven photometric system (*)

J. Brand ([1,2]) and J. G. A. Wouterloot ([2])

([1]) Sterrewacht, P.O. Box 9513, 2300 RA Leiden, The Netherlands
([2]) Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, Bonn, F.R.G.

Received February 18, 1987, accepted March 23, 1988

Summary. — We have used the Walraven photometric system (*VBLUW*) to derive distances to stars of spectral type earlier than A7 ($T_{eff} > 8000$ K). We discuss the method and its accuracy, using it on member stars of (open) clusters with spectral types between O6 and A7. To obtain the weighted average distance modulus of a cluster, a weighting scheme is derived, based on the propagation of measurement errors in the distance modulus of a star as a function of its magnitude, T_{eff}, and colour. The average uncertainty in a cluster distance modulus is $0\overset{m}{.}13$ (6 % in distance). For a single, normal star (i.e. one without spectral peculiarities), the average deviation from the mean-cluster distance modulus is about $0\overset{m}{.}5$ (25 % in distance). A comparison with the literature shows that previous distance determinations, using different techniques, of the clusters studied here agree within $0\overset{m}{.}36$ (18 % in distance) with ours. For three clusters, Upper-Scorpius, NGC 3293, and IC 2944, a star-by-star comparison is made with published data. Although the average cluster distance moduli are equal within the uncertainties, the moduli of the individual stars can differ up to about 2^m. These differences are the consequence of the adopted absolute magnitude calibrations, and/or a slightly different spectral classification for the cluster stars between the *VBLUW* results and the literature. The latter are comparable to the variations in classification found in the literature, and are therefore within the resolution of the methods used to derive distances. A semi-empirical ZAMS relation for the Walraven system for spectral types from O to K is given.

Key words : photometry : Walraven (*VBLUW*) — Galaxy : structure — stars : distances — star clusters : NGC 2547, NGC 4103, NGC 6246, NGC 6281, NGC 3293, Upper-Scorpius, IC 2944, OCL 775.

1. Introduction.

This paper is part III of a series in which we determine the velocity field of the outer Galaxy in the southern hemisphere. We describe here how the Walraven photometric system is used for the specific purpose of getting distance moduli of early type stars.

In order to derive the velocity field we make independent determinations of the distance and the velocity of 223 HII regions and reflection nebulae with galactic longitudes between 230° and 305°. The catalogue of objects used is presented by Brand *et al.* (1986 ; Paper I), while CO observations of the majority of these regions are discussed in Brand *et al.* (1987 ; Paper II). Distances to selected stars in the nebulous regions in our catalogue are derived in Paper IV (Brand and Wouterloot, in preparation). The analysis of the velocity field is presented in Paper V (Brand and Blitz, in preparation ; see also Brand, 1986). The results of the present article will serve as a basic reference for Paper IV.

Although Pel (1976) and Lub (1977) used the Walraven system to study later type stars (A-G), it was originally designed to provide a two-dimensional classification of early type stars (O and B) (Walraven and Walraven, 1960). The most recent study making extensive use of the Walraven system for early type stars is that of Gathier *et al.* (1986). The present work is a more systematic approach, while special attention is paid to the very hot ($T_{eff} > 25000$ K) stars.

In section 2 the details of the observing procedure are given ; in section 3 we describe how the data are analysed and we discuss their accuracy. We also comment on the differences between our work and that of Gathier *et al.* (1986). In section 4 the results of observations of stars in eight well-studied star clusters are presented, compared with the literature, and discussed. Finally, in section 5, the conclusions are summarized. In Appen-

(*) Based on observations collected at the European Southern Observatory, La Silla, Chile.

Send offprint requests to : J. Brand, MPIfR, Auf dem Hügel 69, D 5300 Bonn 1, F.R.G.

dix A we give the ZAMS relation that has, in part, been derived from all photometric data collected in the course of this project.

2. Observations.

All data, except for those on Upper-Scorpius (data from de Geus, 1984), were taken during three observing sessions : April 1983, January-February 1984, and March-April 1984. We used the Walraven photometer, attached to the Dutch 91-cm telescope at the European Southern Observatory (ESO), La Silla (Chile) (Lub, 1979). The Walraven photometer measures the light of a star in five spectral bands simultaneously : *V, B, L, U,* and *W*.

Lub and Pel (1977) have presented a detailed analysis of the system calibration. The basic principles laid out in their paper are still valid, but the system specifications have changed somewhat since then (notably the location of the passbands (de Ruiter and Lub, 1986) and therefore the slopes of the reddening lines) ; the new values are given here (Tab. I and Sect. 3.3).

TABLE I. — *Data on VBLUW photometric system.*

	V	B	L	U	W
λ_{eff}(Å)	5441	4298	3837	3623	3235
Bandwidth (Å)	708	423	221	232	157

Integration times (see Tab. II) were chosen such that a 1 % ($0\overset{m}{.}01$) accuracy in the (*V-B*) colour would be obtained, irrespective of the magnitude of the stars (for $10^m \leqslant m_V \leqslant 15^m$). A 16.5 arcsec diaphragm was used for all measurements described in this paper.

TABLE II. — *Integration times.*

m_V	t (sec)
<10	32
10-12.5	64
12.5-13	128
13-14	256
14-15	384

The magnitudes of the stars were estimated from the diameters of the stellar images on the ESO/SRC J-prints. This procedure was calibrated with NGC 2477 (Hartwick *et al.*, 1972). The uncertainty in these estimates turned out to be $0\overset{m}{.}5$ to $1\overset{m}{.}0$ (comparable to what King and Raff (1977) found for Palomar Sky Survey prints), and usually the estimates were too bright (because many of our program stars are embedded in nebulosity). Consequently, integration times were too short to reach uniform accuracy over the whole magnitude range (up to $m_V \simeq 15$). This point will be discussed further in section 3.3.

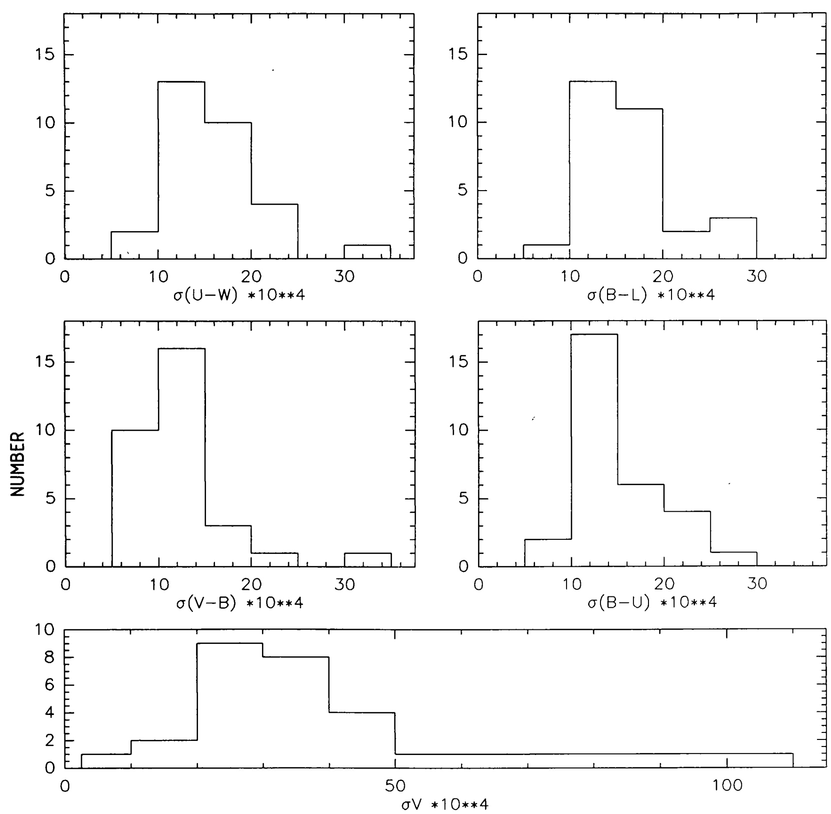

FIGURE 1. — Deviation of one standard star measurement with respect to the night's extinction and zero point solution (log *I*-units).

For stars without intense accompanying nebulosity, a sky measurement adjacent to the stars was subtracted. Blank skies were measured locally at regular time intervals ; the frequency of these measurements depended on the photometric quality of the night and the amount and rate of change of moonlight. For stars embedded in intense nebulosity, a measurement in the nebula away from, but close to the star was subtracted instead of a blank sky. Integration time on a nebula or blank sky was the same as that used on the faintest star in the preceding stellar measurements. We took care to select (from finding charts) that part of the nebula that would best represent the nebula at the star's position. After each nebular measurement a blank sky measurement was also made to check the nebula's influence. For HII regions the influence is negligible because of the choice of the passbands ; for bright reflection nebulae it is potentially important. Usually no significant difference was found in detected signal between nebula and sky, however.

During each observing night, standard stars were observed regularly, i.e. about six stars every two hours. These standards were used to determine the atmospheric extinction coefficients and the instrumental zero points for each night individually. Figure 1 shows the deviation of one standard star measurement with respect to the night's extinction and zero point solution, for 30 nights in 1984. Note that in the Walraven system all results are given in log-intensity units. Leaving out four nights with bad seeing or cirrus clouds, the average deviations are (in log I-units of 10^{-4}) 32 ± 12 (V), 12 ± 3 (V-B), 14 ± 4 (B-U), 15 ± 4 (U-W), and 16 ± 5 (B-L) respectively.

3. Data analysis.

3.1 General principles of the method. — In figure 2 (adapted from Gathier *et al.*, 1986) we summarize the steps that lead from stellar photometry to stellar distances. Schematically, this involves translating the observed colours into physically meaningful quantities such as effective temperature ($T_{\rm eff}$) and surface gravity (log g), by comparing the Walraven colour indices with stellar atmosphere models. This calibration gives the intrinsic colours of a star. Subtracting these from the observed colours, one obtains the reddening (Sect. 3.3). The absolute visual magnitude ($M_{\rm V}$) is derived from a two-dimensional calibration of $M_{\rm V}$ in terms of $T_{\rm eff}$ and gravity ; this calibration is based in part on stellar evolutionary models and in part on observations (Sect. 3.4).

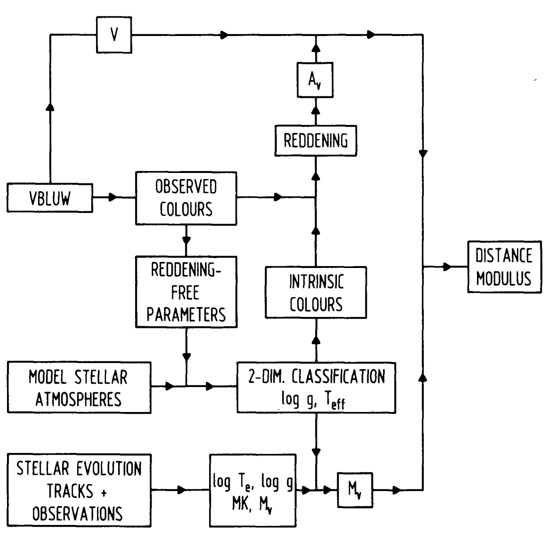

Figure 2. — Schematic representation of the steps to be taken in order to derive a star's distance modulus from its observed colours (adapted from Gathier *et al.*, 1986).

The distance modulus of a cluster of stars is a weighted average of the distance moduli of the individual stars. The weights depend on the magnitude, colour and $T_{\rm eff}$ of each star (Sect. 3.5).

3.2 $T_{\rm eff}$ and log g from Walraven colours. — From the five photometric bands, four independent colour indices can be constructed. For early type stars, they have the following use :

— (V-B) determines the reddening ;
— (B-U) measures the Balmer jump and for O and B stars it is mainly a temperature indicator ;
— (B-L) mainly depends on gravity (through the Balmer lines in the L-band) ;
— (U-W) measures the slope of the Balmer continuum, and is both gravity and temperature dependent.

The photometric parameters of a star depend on the conditions in the stellar atmosphere. The stellar spectral energy distribution that is emitted by a « normal » star, is determined by three parameters : $T_{\rm eff}$, log g, and the chemical composition.

Kurucz (1979) gives the spectral energy distribution of stars for a range of temperatures (5500 K $\leqslant T_{\rm eff} \leqslant$ 50000 K), gravities (from zero-age main sequence (ZAMS) to the radiation pressure limit), and abundances (1/100, 1/10 and 1 times solar) based on LTE model-atmosphere calculations. By folding the Walraven passbands with these models, Lub and Pel (pers. commun.) derived the relative intensities in all passbands and therefore the theoretical colours in the *VBLUW*-system for a large number of combinations of these basic atmospheric parameters. Because the photometric passbands are not known on an absolute flux scale, these theoretical colours contain a zero point that needs to be determined empirically. This *absolute* calibration is done by comparing the colours of stars with known energy distribution, $T_{\rm eff}$ and log g with the theoretical colours (Lub and Pel, pers. commun.). Because most of the calibration stars are on the main sequence, the theoretical colours are used with respect to the empirical main sequence.

The influence of chemical abundance on the grids of colour as a function of (log $T_{\rm eff}$, log g) is negligible for stars with $T_{\rm eff} > 8000$ K. Nearly all stars in our program are close to the galactic plane, and of Population I, and we will assume solar abundance throughout. Table III gives the intrinsic colours as a function of $T_{\rm eff}$ and log g.

TABLE III. — *Intrinsic Walraven-colours as a function of* T_{eff} *and* $\log g$ *for solar abundance.*

Teff (K)	log g	V-B	B-U	U-W	B-L
5500	0.0	0.3182	0.5607	0.4353	0.3269
	0.5	0.3070	0.5275	0.3841	0.3152
	1.0	0.2971	0.4933	0.3349	0.3027
	1.5	0.2892	0.4609	0.2899	0.2928
	2.0	0.2833	0.4319	0.2502	0.2866
	2.5	0.2792	0.4072	0.2156	0.2843
	3.0	0.2775	0.3883	0.1854	0.2876
	3.5	0.2779	0.3772	0.1577	0.2975
	4.0	0.2801	0.3737	0.1313	0.3127
	4.5	0.2836	0.3777	0.1056	0.3324
6000	0.5	0.2198	0.5374	0.3794	0.2388
	1.0	0.2195	0.5071	0.3356	0.2359
	1.5	0.2188	0.4738	0.2949	0.2325
	2.0	0.2186	0.4395	0.2583	0.2298
	2.5	0.2189	0.4065	0.2259	0.2287
	3.0	0.2199	0.3762	0.1979	0.2299
	3.5	0.2217	0.3504	0.1733	0.2342
	4.0	0.2242	0.3300	0.1517	0.2416
	4.5	0.2275	0.3169	0.1318	0.2524
6500	1.0	0.1448	0.5456	0.3350	0.1892
	1.5	0.1541	0.5132	0.2942	0.1937
	2.0	0.1598	0.4782	0.2576	0.1963
	2.5	0.1648	0.4407	0.2252	0.1983
	3.0	0.1696	0.4022	0.1973	0.2002
	3.5	0.1744	0.3648	0.1733	0.2024
	4.0	0.1791	0.3305	0.1533	0.2055
	4.5	0.1836	0.3013	0.1365	0.2099
7000	1.0	0.0774	0.5767	0.3370	0.1469
	1.5	0.0869	0.5609	0.2941	0.1647
	2.0	0.1033	0.5262	0.2558	0.1755
	2.5	0.1160	0.4864	0.2223	0.1816
	3.0	0.1251	0.4454	0.1932	0.1866
	3.5	0.1331	0.4025	0.1684	0.1900
	4.0	0.1404	0.3593	0.1479	0.1922
	4.5	0.1470	0.3181	0.1313	0.1933
7500	1.0	0.0416	0.5534	0.3291	0.1045
	1.5	0.0440	0.5658	0.2888	0.1293
	2.0	0.0517	0.5572	0.2505	0.1533
	2.5	0.0637	0.5308	0.2169	0.1719
7500	3.0	0.0817	0.4895	0.1877	0.1818
	3.5	0.0959	0.4440	0.1623	0.1875
	4.0	0.1066	0.3976	0.1410	0.1913
	4.5	0.1157	0.3503	0.1237	0.1922
8000	1.0	0.0333	0.4689	0.3006	0.0665
	1.5	0.0191	0.5223	0.2756	0.0904
	2.0	0.0214	0.5395	0.2400	0.1195
	2.5	0.0295	0.5354	0.2069	0.1484
	3.0	0.0403	0.5153	0.1786	0.1732
	3.5	0.0560	0.4792	0.1544	0.1896
	4.0	0.0740	0.4337	0.1334	0.1961
	4.5	0.0875	0.3844	0.1159	0.1984
8500	1.0	0.0398	0.3478	0.2381	0.0397
	1.5	0.0113	0.4492	0.2502	0.0599
	2.0	0.0040	0.4879	0.2252	0.0854
	2.5	0.0068	0.5039	0.1947	0.1165
	3.0	0.0149	0.5011	0.1677	0.1476
	3.5	0.0258	0.4842	0.1449	0.1762
	4.0	0.0397	0.4544	0.1257	0.1981
	4.5	0.0581	0.4111	0.1089	0.2060
9000	1.5	0.0088	0.3708	0.2134	0.0397
	2.0	-0.0043	0.4299	0.2041	0.0616
	2.5	-0.0063	0.4573	0.1812	0.0887
	3.0	-0.0015	0.4677	0.1552	0.1210
	3.5	0.0069	0.4621	0.1343	0.1524
	4.0	0.0184	0.4454	0.1163	0.1826
	4.5	0.0321	0.4178	0.1017	0.2052
9500	1.5	0.0063	0.3023	0.1729	0.0274
	2.0	-0.0089	0.3707	0.1768	0.0453
	2.5	-0.0144	0.4074	0.1634	0.0684
	3.0	-0.0131	0.4269	0.1432	0.0973
	3.5	-0.0071	0.4317	0.1234	0.1291
	4.0	0.0023	0.4237	0.1067	0.1616
	4.5	0.0148	0.4051	0.0931	0.1911
10000	1.5	0.0032	0.2445	0.1393	0.0184
	2.0	-0.0128	0.3187	0.1493	0.0342
	2.5	-0.0194	0.3597	0.1423	0.0544
	3.0	-0.0204	0.3831	0.1286	0.0790
	3.5	-0.0166	0.3947	0.1119	0.1084
10000	4.0	-0.0099	0.3946	0.0973	0.1401
	4.5	0.0007	0.3839	0.0847	0.1726
11000	2.0	-0.0197	0.2332	0.1046	0.0182
	2.5	-0.0273	0.2774	0.1032	0.0357
	3.0	-0.0299	0.3051	0.0963	0.0561
	3.5	-0.0290	0.3226	0.0866	0.0800
	4.0	-0.0251	0.3307	0.0765	0.1066
	4.5	-0.0187	0.3298	0.0676	0.1355
12000	2.0	-0.0262	0.1702	0.0738	0.0059
	2.5	-0.0342	0.2141	0.0741	0.0219
	3.0	0.0370	0.2414	0.0694	0.0404
	3.5	-0.0367	0.2594	0.0627	0.0613
	4.0	-0.0339	0.2697	0.0557	0.0843
	4.5	-0.0293	0.2728	0.0500	0.1085
13000	2.0	-0.0321	0.1213	0.0513	-0.0043
	2.5	-0.0406	0.1660	0.0530	0.0107
	3.0	-0.0435	0.1923	0.0496	0.0278
	3.5	-0.0434	0.2095	0.0442	0.0470
	4.0	-0.0410	0.2197	0.0386	0.0678
	4.5	-0.0370	0.2238	0.0342	0.0895
14000	2.0	-0.0369	0.0790	0.0340	-0.0133
	2.5	-0.0466	0.1274	0.0369	0.0011
	3.0	-0.0496	0.1535	0.0345	0.0173
	3.5	-0.0496	0.1698	0.0303	0.0352
	4.0	-0.0474	0.1796	0.0255	0.0545
	4.5	-0.0436	0.1837	0.0215	0.0744
15000	2.0	-0.0402	0.0384	0.0198	-0.0216
	2.5	-0.0519	0.0939	0.0243	-0.0075
	3.0	-0.0552	0.1212	0.0227	0.0081
	3.5	-0.0553	0.1373	0.0193	0.0251
	4.0	-0.0532	0.1463	0.0153	0.0430
	4.5	-0.0496	0.1503	0.0116	0.0616
16000	2.0	-0.0414	-0.0030	0.0068	-0.0292
	2.5	-0.0565	0.0634	0.0142	-0.0155
	3.0	-0.0604	0.0930	0.0134	-0.0002
	3.5	-0.0606	0.1096	0.0104	0.0161
	4.0	-0.0585	0.1184	0.0070	0.0330
	4.5	-0.0551	0.1223	0.0037	0.0505
17000	2.0	-0.0401	-0.0487	-0.0058	-0.0361
17000	2.5	-0.0602	0.0345	0.0053	-0.0229
	3.0	-0.0651	0.0673	0.0057	-0.0079
	3.5	-0.0654	0.0850	0.0032	0.0078
	4.0	-0.0633	0.0938	0.0000	0.0238
	4.5	-0.0602	0.0983	-0.0031	0.0406
18000	2.5	-0.0628	0.0062	-0.0033	-0.0300
	3.0	-0.0692	0.0436	-0.0010	-0.0152
	3.5	-0.0700	0.0626	-0.0026	0.0001
	4.0	-0.0681	0.0726	0.0056	0.0158
	4.5	-0.0650	0.0771	-0.0087	0.0317
20000	2.5	-0.0652	-0.0475	-0.0182	-0.0426
	3.0	-0.0753	0.0001	-0.0138	-0.0284
	3.5	-0.0775	0.0226	-0.0129	-0.0139
	4.0	-0.0764	0.0341	-0.0141	0.0006
	4.5	-0.0736	0.0397	-0.0165	0.0153
22500	3.0	-0.0802	-0.0472	-0.0269	-0.0428
	3.5	-0.0841	-0.0206	-0.0256	0.0293
	4.0	-0.0842	-0.0067	-0.0249	-0.0159
	4.5	-0.0823	0.0001	-0.0250	0.0027
25000	3.0	-0.0849	-0.0825	-0.0360	-0.0539
	3.5	-0.0895	-0.0553	-0.0349	-0.0422
	4.0	-0.0901	-0.0406	-0.0343	-0.0301
	4.5	-0.0890	-0.0334	-0.0340	-0.0188
	5.0	-0.0869	-0.0289	-0.0341	-0.0072
30000	3.5	-0.0986	-0.1038	-0.0473	-0.0607
	4.0	-0.1016	-0.0869	-0.0474	-0.0506
	4.5	-0.1008	-0.0801	-0.0470	0.0419
	5.0	-0.0990	-0.0768	-0.0469	-0.0339
35000	3.5	-0.0983	-0.1324	-0.0496	-0.0722
	4.0	-0.1058	-0.1203	-0.0533	-0.0663
	4.5	-0.1089	-0.1125	-0.0551	-0.0592
	5.0	-0.1088	-0.1086	-0.0557	-0.0528
40000	4.0	-0.1084	-0.1338	-0.0555	-0.0739
	4.5	-0.1113	-0.1300	-0.0571	-0.0703
	5.0	-0.1121	-0.1283	-0.0580	-0.0666
45000	4.5	-0.1139	-0.1375	-0.0591	-0.0752
	5.0	-0.1148	-0.1365	-0.0598	-0.0728
50000	4.5	-0.1158	-0.1428	-0.0605	-0.0786
	5.0	-0.1171	-0.1416	-0.0614	-0.0765

There are two temperature regimes for which the grids are less reliable :

— for $T_{eff} < 8000$ K, there is a transition in the stellar envelopes from mainly radiative to mainly convective energy transport, and line blanketing effects become important. Kurucz's (1979) models do not take these effects sufficiently into account. As a consequence, the colours of many stars are outside the grids at these temperatures. For our purposes this temperature regime is of no importance, however, because we are only interested in the earlier type stars ;

— for O stars ($T_{eff} > 30000$ K) non-LTE effects have a significant influence, but these effects are nòt included in the Kurucz (1979) models. As a result one tends to overestimate the T_{eff} derived in this way (Mihalas, 1978). Consequently, most stars measured by us in that temperature regime have colours that lie outside the calibration grids. Because these stars are important for our program, special precautions had to be taken to be able to use those stars. This will be considered below (Sect. 3.4).

3.3 REDDENING-FREE PARAMETERS ; EXTINCTION. — As mentioned in section 3.2, temperature, gravity, and abundance determine the spectral energy distribution of a star. The measured colours, from which $T_{\rm eff}$ and $\log g$ have to be determined, differ from the intrinsic colours because of extinction, be it circumstellar or interstellar. To avoid solving explicitly for extinction when determining temperature and gravity, we use *reddening-free* parameters (Lub and Pel, 1977 ; Lub, pers. commun.) :

$$[B\text{-}U] = (B\text{-}U) - 0.61 \times (V\text{-}B)$$
$$[U\text{-}W] = (U\text{-}W) - 0.45 \times (V\text{-}B)$$
$$[B\text{-}L] = (B\text{-}L) - 0.39 \times (V\text{-}B)\,.$$

The coefficients in these equations are the slopes of the reddening lines in the corresponding colour-colour diagrams, and depend on the reddening law (the standard law has been assumed, i.e. $R = A_V/E(B\text{-}V)_J = 3.2$ [Schmidt-Kaler, 1982]) and the properties of the passbands. As explained by Lub and Pel (1977) the reddening lines are very straight, and non-linear (i.e. colour-dependent) terms in the reddening corrections are negligible for $E(B\text{-}V) \leqslant 0.5$ (log-intensity units), corresponding to $A_V \leqslant 4$ magnitudes (we always find $A_V < 4^{\rm m}$ [Paper IV]). From the numbers in table III we can obtain the theoretical reddening-free parameters by applying the above relations, and construct two independent reddening-free two-colour diagrams (hereafter RFDs). These are shown in figure 3.

The derivation of $\log T_{\rm eff}$ and $\log g$ from the observed reddening-free parameters is done through linear interpolation in the RFDs.

For the highest temperatures relatively small uncertainties in measured colours lead to rather large uncertainties in $T_{\rm eff}$ and $\log g$ (see Fig. 3), and thus to large uncertainties in $M_{\rm V}$. Therefore the distance moduli derived for the stars of very early type (earlier than B1-

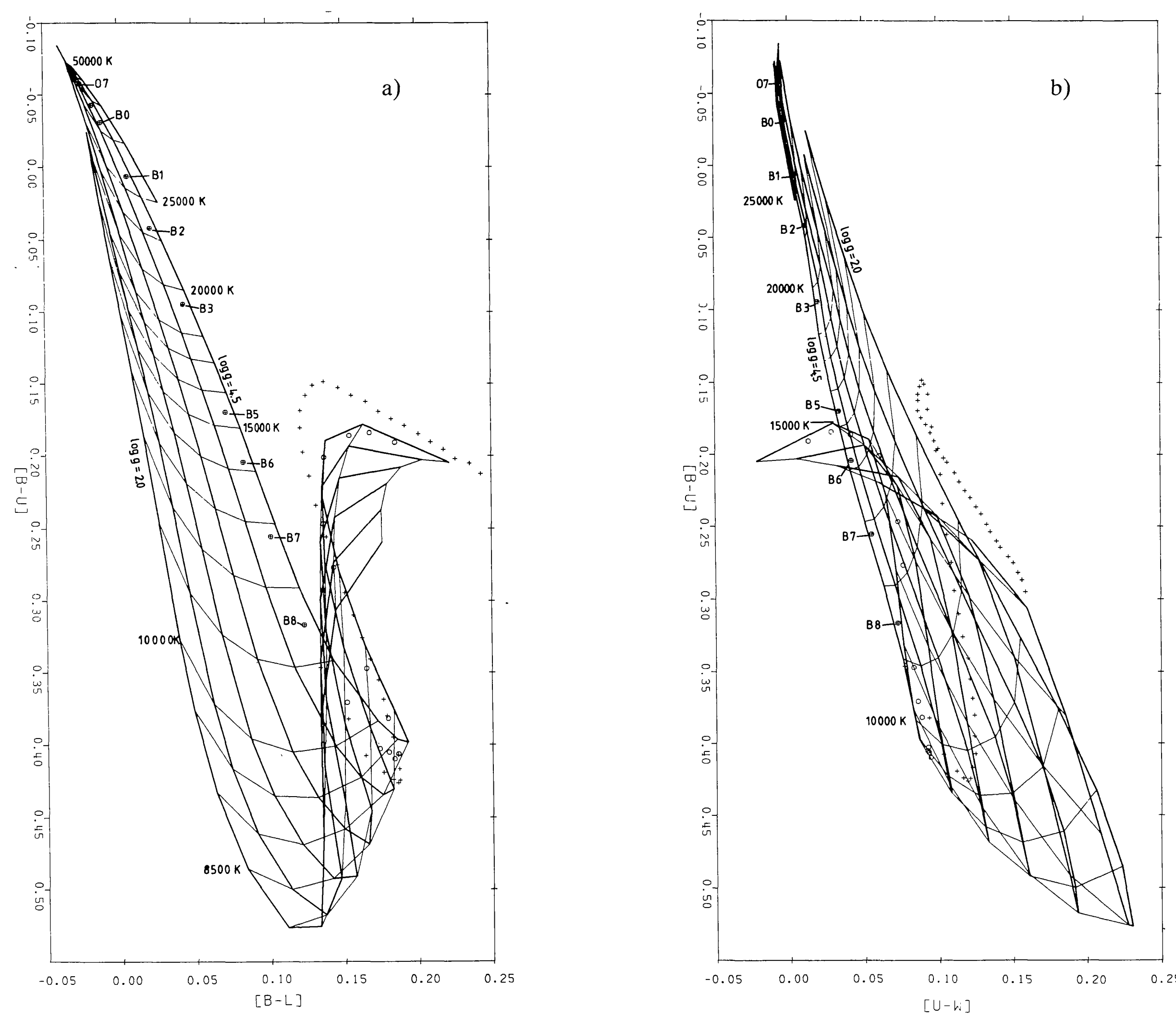

FIGURE 3. — a) The $[B\text{-}U]$ *versus* $[B\text{-}L]$-diagram, used to transform stellar colours into $T_{\rm eff}$ and $\log g$. Lines of constant $T_{\rm eff}$ and $\log g$ have been marked for the most interesting part of the grid. The $\log g$ values change in steps of 0.5. Also shown are the points corresponding to the ZAMS from Straizys and Kuriliene (1981 ; O) and from our data (+). For stars earlier than spectral type B8 they overlap ; deviations set in where the theoretical grid cannot be trusted anymore (see Appendix A) ; b) as a), for the $[B\text{-}U]$ *versus* $[U\text{-}W]$-diagram.

B2) have a larger uncertainty than those of later type stars.

Once log T_{eff} and log g are derived, linear interpolation in table III gives the intrinsic colours of the star, e.g. $(V\text{-}B)_0$. The colour excess $E(V\text{-}B)$ is the difference between the latter and the observed colour, while the extinction in the Walraven V-band (in log-intensity units) is calculated from

$$A_V/E(V\text{-}B) = 3.16 - 0.12 \times E(V\text{-}B)$$

(Lub and Pel, pers. commun.) .

For consistency, all steps in the analysis are carried out in the units of the Walraven system and only at the last step (the determination of the distance modulus) the switch to Johnson-magnitudes is made through

$$V_J = 6\overset{m}{.}884 - 2.5 \times (V_{Wal} + 0.039 \times (V\text{-}B))$$

(Pel, pers. commun.) .

For the derivation of temperature and gravity, one of the RFDs would suffice. It is however convenient (and in some cases necessary) to have some redundancy which enables one to recognize abnormalities that could either be inherent to the star (multiplicity, rotation, emission lines, chemical peculiarities) or due to measurement errors. Moreover, both diagrams are needed to resolve the ambiguity for stars with $T_{eff} \leqslant 10000$ K (see Fig. 3). The two RFDs are, however, not of equal weight. Of the four Walraven colour indices used, the U-W index is in general expected to have the lowest photometric accuracy because it is defined by the two bands of the system that lie most to the ultraviolet side of the spectrum (see Tab. I), and it suffers most from extinction. Only for very hot stars, with little reddening, the intensities in the U and W bands are comparable to those in V, B, and L.

From our sample of program stars (Paper IV), about 300 have been measured more than once, and for each of those stars we determine the average colours and their standard deviation. From this subset we calculate the average standard deviation (σ) per colour index as a function of the intensity in one of the passbands defining that colour. It is found that for stars brighter than 13th magnitude the standard deviations are the same for all colours. For fainter stars, $\sigma(U\text{-}W)$ rapidly becomes larger than the others, because the magnitudes of most stars were underestimated (see Sect. 2) and as a consequence integration times were too short. This implies that differences between log T_{eff} and log g, obtained from the two RFDs, can be large even for « normal » stars and it is not possible to reject stars offhand on the basis of these differences. Therefore, the relevance of the [B-U] *versus* [U-W]-grid is much reduced for the bulk of our data. Apart from this, there might be an intrinsic problem with the [U-W]-RFD : the photometric data for the Upper-Scorpius stars (de Geus, 1984) have small enough uncertainties in all colours ; while most stars lie inside the [B-L]-RFD, at their expected posi-

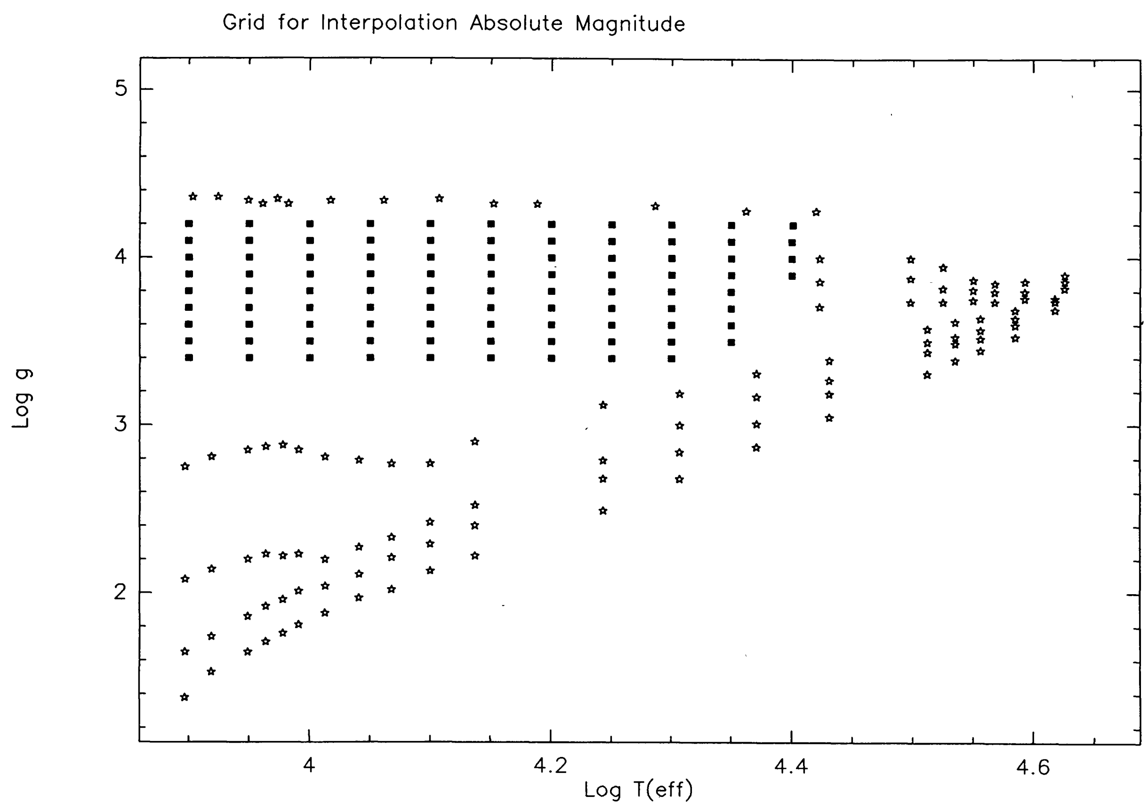

FIGURE 4. — Combinations of log T_{eff} and log g for which an absolute magnitude is available (stars : from Straizys and Kuriliene, 1981 ; squares : Gathier, pers. commun.).

tions, the majority of them lie outside the [*U*-*W*]-RFD. The same effect is seen when all our program stars (about 1400) are plotted. This suggests a faulty calibration of the Kurucz stellar atmosphere models in terms of Walraven colours at the short wavelengths (U, W), or shortcomings in the models themselves. *We have therefore used only the* [*B*-*U*] *versus* [*B*-*L*]*-diagram* (see also de Geus *et al.*, 1988).

3.4 ABSOLUTE MAGNITUDE FROM $T_{\rm eff}$ AND log g. — We have made use of tables published by Straizys and Kuriliene (1981) to find the absolute magnitude, M_V, for a set of ($T_{\rm eff}$, log g), as derived from the RFDs. We prefer to use their work because of the very convenient format of their data, which gives log $T_{\rm eff}$, log g, and M_V as a function of spectral type and luminosity class. The calibrations of Straizys and Kuriliene (1981) are based on a mixture of observations and model calculations ; for details we refer to their paper. Gathier *et al.* (1986) also give a calibration of absolute magnitude in terms of log $T_{\rm eff}$ and log g, for a more limited range of parameters (log $T_{\rm eff}$ between 3.85 and 4.40 in steps of 0.05 ; log g between 3.4 and 4.2, in steps of 0.1 ; in addition they give M_V for log g (ZAMS) in this temperature range), based entirely on stellar evolutionary models by Hejlesen (1980). Where they overlap, their data are consistent with those of Straizys and Kuriliene. Because of its denser and more regular spacing, we use the calibration of Gathier *et al.* in the region of overlap. For the relevant $T_{\rm eff}$-range, figure 4 shows the combinations of log $T_{\rm eff}$ and log g for which an M_V is available. The numerical values are given in table IV. The M_V's are determined through linear interpolation between these numbers.

As mentioned in section 3.2, the RFDs do not accurately represent the real stellar measurements for stars with $T_{\rm eff} > 30000$ K. As a consequence, no solution in terms of $T_{\rm eff}$, log g (and M_V) will be found from the colours for most of these stars. If we want to be able to use these stars at all, we have to use the *empirical* main sequence rather than the theoretical grids. Stars of lower temperature may also be just outside the RFDs of figures 3a, b, in this case due only to measurement uncertainties. Therefore, we have extrapolated the lines of constant $T_{\rm eff}$ in the [*B*-*L*]-RFD by about 0.01. Stars with $T_{\rm eff} < 25000$ K that lie in that extended section of

TABLE IV. — *Absolute magnitude* (M_V) *as a function of* log $T_{\rm eff}$ *and* log g *(from Straizys and Kuriliene, 1981 ; Gathier, pers. commun.).*

LOG T(eff)	LOG g	M(V)
4.626	3.90	-5.60
	3.86	-5.80
	3.82	-6.00
4.618	3.76	-6.30
	3.74	-6.60
	3.69	-6.90
4.593	3.86	-5.40
	3.80	-5.70
	3.76	-5.90
4.585	3.69	-6.30
	3.64	-6.60
	3.60	-6.90
	3.53	-7.20
4.568	3.85	-5.20
	3.80	-5.50
	3.74	-5.80
4.556	3.64	-6.20
	3.57	-6.50
	3.52	-6.80
	3.45	-7.20
4.550	3.87	-4.90
	3.81	-5.20
	3.75	-5.60
4.535	3.62	-6.10
	3.53	-6.40
	3.49	-6.70
	3.39	-7.20
4.525	3.95	-4.50
	3.82	-4.90
	3.74	-5.30
4.512	3.58	-5.90
	3.50	-6.30
	3.44	-6.60
	3.31	-7.20
4.498	4.00	-4.00
	3.88	-4.40
	3.74	-4.90
4.431	3.39	-5.60
	3.27	-6.10
	3.19	-6.50
	3.05	-7.20
4.423	4.00	-3.30
	3.86	-3.90
	3.71	-4.50
4.420	4.28	-2.30
4.401	4.20	-2.21
4.400	4.10	-2.50
	4.00	-2.83
	3.90	-3.16
4.371	3.31	-5.20
	3.17	-5.90
	3.01	-6.40
	2.87	-7.20
4.362	4.28	-1.60

LOG T(eff)	LOG g	M(V)
4.350	4.20	-1.73
	4.10	-2.04
	4.00	-2.37
	3.90	-2.69
	3.80	-3.01
	3.70	-3.31
	3.60	-3.61
	3.50	-3.90
4.307	3.19	-5.00
	3.00	-5.90
	2.84	-6.40
	2.68	-7.20
4.300	4.20	-1.30
	4.10	-1.62
	4.00	-1.93
	3.90	-2.25
	3.80	-2.56
	3.70	-2.84
	3.60	-3.15
	3.50	-3.48
	3.40	-3.86
4.286	4.31	-1.00
4.250	4.20	-0.88
	4.10	-1.20
	4.00	-1.50
	3.90	-1.82
	3.80	-2.12
	3.70	-2.40
	3.60	-2.72
	3.50	-3.07
	3.40	-3.43
4.243	3.12	-4.80
	2.79	-5.90
	2.68	-6.40
	2.49	-7.20
4.200	4.20	-0.49
	4.10	-0.80
	4.00	-1.11
	3.90	-1.43
	3.80	-1.71
	3.70	-2.00
	3.60	-2.32
	3.50	-2.67
	3.40	-3.04
4.188	4.32	-0.10
4.152	4.32	0.30
4.150	4.20	-0.10
	4.10	-0.40
	4.00	-0.72
	3.90	-1.04
	3.80	-1.29
	3.70	-1.60
	3.60	-1.92
	3.50	-2.28

LOG T(eff)	LOG g	M(V)
4.150	3.40	-2.61
4.137	2.90	-4.60
	2.52	-5.90
	2.40	-6.40
	2.22	-7.20
4.107	4.35	0.60
4.100	4.20	0.30
	4.10	-0.01
	4.00	-0.32
	3.90	-0.64
	3.80	-0.89
	3.70	-1.20
	3.60	-1.54
	3.50	-1.89
	3.40	-2.22
	2.77	-4.40
	2.42	-5.80
	2.29	-6.40
	2.13	-7.20
4.068	2.77	-4.20
	2.33	-5.80
	2.21	-6.40
	2.02	-7.20
4.061	4.34	1.00
4.050	4.20	0.72
	4.10	0.40
	4.00	0.09
	3.90	-0.20
	3.80	-0.46
	3.70	-0.79
	3.60	-1.13
	3.50	-1.49
	3.40	-1.80
4.041	2.79	-3.90
	2.27	-5.80
	2.11	-6.40
	1.97	-7.20
4.017	4.34	1.40
4.013	2.81	-3.60
	2.20	-5.70
	2.04	-6.40
	1.88	-7.20
4.000	4.20	1.14
	4.10	0.83
	4.00	0.50
	3.90	0.25
	3.80	-0.03
	3.70	-0.36
	3.60	-0.71
	3.50	-1.07
	3.40	-1.38
3.991	2.85	-3.40
	2.23	-5.50
	2.01	-6.40

LOG T(eff)	LOG g	M(V)
3.991	1.81	-7.20
3.982	4.32	1.60
3.978	2.88	-3.20
	2.22	-5.30
	1.96	-6.40
	1.76	-7.20
3.973	4.35	1.70
3.964	2.87	-3.10
	2.23	-5.20
	1.92	-6.40
	1.71	-7.30
3.961	4.32	1.80
3.950	4.20	1.63
	4.10	1.29
	4.00	0.99
	3.90	0.73
	3.80	0.44
	3.70	0.09
	3.60	-0.25
	3.50	-0.59
	3.40	-0.94
3.949	4.34	1.90
	2.85	-3.00
	2.20	-5.10
	1.86	-6.40
	1.65	-7.30
3.924	4.36	2.30
3.919	2.81	-2.90
	2.14	-5.00
	1.74	-6.50
	1.53	-7.50
3.903	4.36	2.60
3.900	4.20	2.21
	4.10	1.89
	4.00	1.58
	3.90	1.33
	3.80	1.01
	3.70	0.67
	3.60	0.33
	3.50	-0.03
	3.40	-0.39
3.897	2.75	-2.80
	2.08	-5.00
	1.65	-6.70
	1.38	-7.70
3.850	4.20	2.90
	4.10	2.59
	4.00	2.31
	3.90	2.03
	3.80	1.71
	3.70	1.37
	3.60	1.03
	3.50	0.65
	3.40	0.35

the grid were assigned the absolute magnitude for a ZAMS star at the temperature of the star under consideration. For stars with $T_{eff} \geqslant 25000$ K (i.e. more massive stars) evolution is faster and by the time they are optically visible they have moved away from the ZAMS. Therefore, such a star, lying in the extended section of the RFD, will be assigned the absolute magnitude for a *main sequence star* at that temperature.

3.5 Error sources; relative accuracy of distance moduli; derivation of a weighting scheme.

Stellar rotation, mass loss and duplicity can have important effects on the photometric parameters of stars. A quantitative analysis of the influences of these phenomena on the Walraven colours has only recently started (de Geus and van der Grift, pers. commun.). Therefore, the following discussion is simplified in the sense that no attention is paid to these effects.

Differences in distance modulus of a star between two observers will in general arise from any of the following factors :

1) Photometric uncertainty, leading to :

a) differences in derived T_{eff} (in the Walraven system mostly determined by the $[B\text{-}U]$ colour), resulting in differences in intrinsic colour (and thus extinction correction) and M_V ;

b) differences in derived $\log g$ (mostly determined by the $[B\text{-}L]$ and $[U\text{-}W]$ colour in the *VBLUW* system), leading to the same differences as mentioned under a) ;

c) differences in $(B\text{-}V)_J$ (derived from $V\text{-}B$ Walraven), leading to differences in visual extinction, and also affecting T_{eff} and $\log g$ through the reddening-free parameters (see a) and b)).

2) Differences in adopted absolute magnitude calibration.

3) Differences in adopted reddening law.

3.5.1 *Photometric uncertainties.* — For the early type stars, small errors in T_{eff} do not significantly alter the extinction correction. The largest influences come from the fact that small changes in T_{eff} and/or $\log g$ translate into changes in M_V ranging from a few tenths of a magnitude to sometimes a full magnitude or more. From the shape of the RFDs (Fig. 3) and the change of M_V with the position of a star in these grids (Tab. IV), it is seen that the accuracy in the final distance modulus depends very much on the T_{eff} of a star. This also implies that in calculating the mean distance modulus of a cluster, the distance moduli of the individual stars have to be weighted depending on their T_{eff}.

Deriving an analytical expression for the propagation of errors into the distance modulus would be a tedious task due to the non-uniformity of the absolute magnitude as a function of T_{eff} and $\log g$ (i.e. $[B\text{-}U]$ and $[B\text{-}L]$). We will therefore derive an empirical estimate of the uncertainties and base the weighting scheme on that.

Four temperature ranges will be considered, based on the shape of the RFDs. It is assumed that *within* each range the influence of photometric errors on the distance modulus does not change. The ranges are (1) $T_{eff} > 25000$ K, (2) $25000\ \text{K} \geqslant T_{eff} > 18000$ K, (3) $18000\ \text{K} \geqslant T_{eff} > 13000$ K, and (4) $13000\ \text{K} \geqslant T_{eff} > 8000$ K. We then simulate photometric measurements for a star in each temperature interval.

For each star an error is introduced in each of the simulated colours separately, after which the data are reduced as usual. The errors range between 0.0010 and 0.0125 (in log-intensity units), and are assumed to be uncorrelated. This gives $\langle \sigma(m_0\text{-}M) \rangle$, i.e. the average deviation from the true (i.e. extinction-corrected) value of the distance modulus for a particular assumed photometric uncertainty. For example, for an uncertainty of 0.0025 ($\log I$), $\langle \sigma(m_0\text{-}M) \rangle$ is $0^m.75$, $0^m.40$, $0^m.16$ and $0^m.16$ for T_{eff}-ranges 1 to 4 respectively.

A realistic value of the scatter in the distance moduli is obtained when the true photometric errors can be estimated. From stars observed at least twice we find that the photometric errors depend on colour and magnitude and it was decided to consider three intervals in colour and magnitude respectively. For each of these intervals a representative photometric uncertainty was determined by averaging the scatter in the $(B\text{-}U)$ and $(B\text{-}L)$ colours (we use only the $[B\text{-}U]$ *versus* $[B\text{-}L]$ RFD). This scatter is more or less constant in each interval. These data are presented in table V.

TABLE V. — *Representative uncertainties in photometry* $\langle (\sigma(B\text{-}U) + \sigma(B\text{-}L))/2 \rangle$ *in* $\log I$*-units.*

	V>-1	-1≧V>-2	V≦-2
V-B<0.1	0.0014	0.0013	0.0071
0.1≦V-B<0.4	0.0015	0.0045	0.0130
V-B≧0.4	0.0030	0.0130	0.0280

The values of $\langle \sigma(m_0\text{-}M) \rangle$ found from the simulated colours were scaled with these true photometric uncertainties. This scaling procedure assumes that the uncertainty in the distance modulus is directly proportional to the uncertainty in one of the colours, which was found not to be the case. Rather, the resulting errors are *upper limits* [when the true photometric errors are larger than 0.0025 ($\log I$)].

By assigning unity weight to that cell in the colour-magnitude plane that has the *highest* uncertainty, the relative weights of all other cells can be evaluated (here, weight 1 corresponds to an $\langle \sigma(m_0\text{-}M) \rangle$ of $8^m.4$). The resulting weights are shown in table VI.

3.5.2 *Absolute magnitude calibrations.* — When comparing results with the published literature, one has to bear in mind that differences in distance modulus can occur because of the particular M_V-calibrations used. For spectral types between O6 and A7 ($39000\ \text{K} \geqslant T_{eff} \geqslant 8000$ K) we have compared four M_V-calibrations that are frequently used in the literature (Johnson and Hiltner, 1956 ; Blaauw, 1963 ; Schmidt-Kaler, 1965 and 1982) with that of Straizys and Kuriliene (1981), as used in the present work.

TABLE VI. — *Assigned weights.*

Region 1	V>-1	-1≥V>-2	V≤-2
V-B<0.1	20	9	4
0.1≤V-B<0.4	19	6	2
V-B≥0.4	9	2	1

Region 2	V>-1	-1≥V>-2	V≤-2
V-B<0.1	38	17	7
0.1≤V-B<0.4	35	12	4
V-B≥0.4	18	4	2

Region 3,4	V>-1	-1≥V>-2	V≤-2
V-B<0.1	93	42	19
0.1≤V-B<0.4	84	29	10
V-B≥0.4	44	10	5

The differences in M_V depend on spectral type as well as on luminosity class. Compared to Schmidt-Kaler (1982), the M_V's we use are in general fainter for stars between the ZAMS and the giant branch (luminosity class III), and thus, all other factors being equal, lead to the derivation of smaller distance moduli. The differences are largest between spectral types B2/B3 and A0, and can be as large as $0^{m}.5$. For luminosity classes I and II the situation is reversed, and the differences are larger (up to $1^{m}.2$). Compared to Blaauw (1963) the situation is similar : in general his M_V's are brighter, except for luminosity classes I and II. On average the difference is a few tenths of magnitudes, but it can get as large as 1^{m} for luminosity class Ia stars. Finally, Johnson and Hiltners (1956) M_V's for main sequence stars are fainter than those of Straizys and Kuriliene (1981). To illustrate these differences, we show in figure 5 the comparison between the four M_V-calibrations for main sequence stars. For these stars, the maximum differences are about $0^{m}.5$ for the mid- to late B-type stars.

3.5.3 *Reddening laws.* — The visual extinction, A_V, is derived from the colour excess, $E(B\text{-}V)$, through $A_V = R \times E(B\text{-}V)$ (or its equivalent in the Walraven system — see Sect. 3.3). It is standard to take $R = 3.2 \pm 0.2$ (Mihalas and Binney (1981), p. 191). Using $R = 3.2$, all stars in our sample have $A_V \leqslant 4^{m}$. The quoted uncertainty in R then implies a maximum ± 10 % uncertainty in the derived distances. Throughout the literature people have claimed R-values considerably different from the standard value (e.g. $R = 4.8$ in M16, $R = 4.9$ in M17, and $R = 3.7$ in NGC 6334/6357 : Chini and Krügel, 1983). In that case of course, deviations in derived distance modulus will be much larger. For example, finding $A_V = 4^{m}$ using $R = 3.2$ in a region where $R = 4$, results in an overestimate of the distance modulus of 1^{m}. This overestimate will be (partially) offset by the fact that a higher value for R implies a steeper slope of the reddening lines in the two-colour diagrams ; using the standard slope would result in a derived T_{eff} corresponding to a later spectral type and

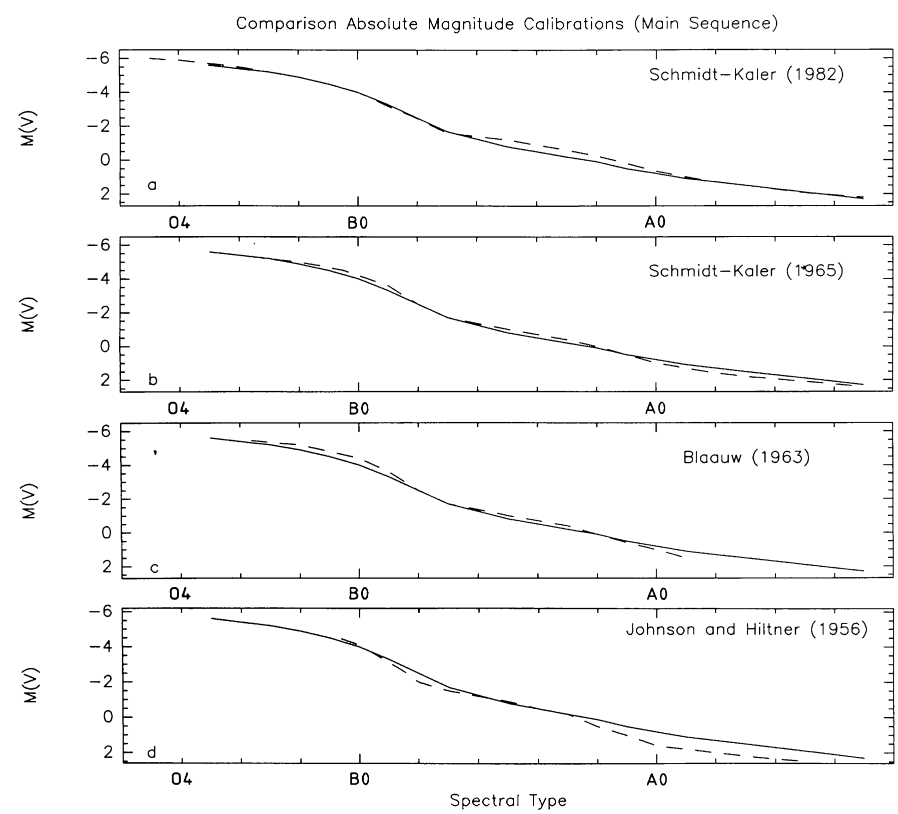

FIGURE 5. — Comparison of absolute magnitude calibrations for main sequence stars. The drawn line is the calibration of Straizys and Kuriliene (1981), used in the present work ; a) comparison with Schmidt-Kaler (1982) ; b) comparison with Schmidt-Kaler (1965) ; c) comparison with Blaauw (1963) ; d) comparison with Johnson and Hiltner (1956).

thus to a fainter M_V, leading to an underestimate of the distance modulus. Values of R, deviating from the standard value of 3.2 are only found in some regions of the Galaxy and the results are sometimes controversial (e.g. Turner, 1976). It is therefore best to adopt the standard value for all stars in the sample.

Gathier *et al.* (1986) basically use the same method to analyze Walraven photometric data. However, there are some aspects in their approach that differ from ours, and which render it less usable in general :

Firstly, Gathier *et al.* assign respectively $\log g = 3.4$ and $T_{eff} = 25000$ K to the few stars in their sample with $\log g < 3.4$ or $T_{eff} > 25000$ K. Instead, we have used the *full* T_{eff}- and $\log g$-extent of the RFDs (Fig. 3, Tab. III). This is important, because the stars with high temperatures (spectral types earlier than about B1) are the ones that are intrinsically the brightest and therefore the ones most likely to be visible over large distances (and thus important for the determination of the rotation curve at large distances from the galactic center).

Secondly, Gathier *et al.* apply a weighting system which is based on the difference in $\log g$, derived from the two RFDs, as well as the stellar intensity in the W-band. However, the weights are arbitrary and the lowest weight of the two is taken, rather than a combination of the two. Here, we base the weighting system on the variations in the distance modulus resulting from the true photometric errors and depending on the magnitude and colour of the stars and the T_{eff}-range in which they lie. The weights can therefore be traced back to measurement uncertainties, combined with properties of the RFD and the M_V-calibration. (Because we think the $[U\text{-}W]$-RFD gives unreliable results (Sect. 3.3), we could not have used their weighting system anyhow.)

Thirdly, Gathier *et al.* use a functional representation $M_V(\log T_{eff}, \log g)$ to derive the absolute magnitudes ; yet for $\log g \leqslant 3.6$ these functions do not fit the data points from which they are derived. In contrast to this, we use direct linear interpolation in a discrete grid of $M_V(\log T_{eff}, \log g)$ (see Fig. 4).

With the above considerations, we feel the present approach is to be preferred over that of Gathier *et al.* (1986).

4. Comparison with previously determined distances : accuracy.

To check our procedures, we observed eight star clusters. For each of these, the average (weighted) cluster distance modulus and its mean error were calculated. The results are collected in table VII. Finding charts and photometric data are given in Appendix B (Figs. A2-4, and Tab. AII-IV).

TABLE VII. — *Results of clusters-photometric study.*

NGC or other	OCL	n° stars used	VBLUW ⟨d.mod.⟩ ± m.e.	(1σ)	literature ⟨d.mod.⟩ ± m.e.	method	ref	Δd.mod.	earliest Sp.T (from VBLUW)
2547	753	27	7ᵐ.94 ± 0ᵐ.07	(0ᵐ.37)	7ᵐ.90 ± 0ᵐ.20	UBV, prop. motions	1	0ᵐ.04	B2.5
R76	775	8	11ᵐ.40 ± 0ᵐ.16	(0ᵐ.45)	10ᵐ.62	UBV	2	0ᵐ.78	B7.5
4103	871	11	11ᵐ.47 ± 0ᵐ.16	(0ᵐ.53)	11ᵐ.39 ± 0ᵐ.20	UBV, RGU	3	0ᵐ.27	B2
					11ᵐ.0	UBV	4		
6246	1001	17	10ᵐ.11 ± 0ᵐ.09	(0ᵐ.36)	10ᵐ.42	UBV	5	-0ᵐ.19	B3
					10ᵐ.42 ± 0ᵐ.20	UBV, RGU	3		
					10ᵐ.06	UBV	6		
6281	1003	7	8ᵐ.63 ± 0ᵐ.13	(0ᵐ.34)	7ᵐ.91	spec. par. H lines	7	0ᵐ.72	B7.5
Upper-Sco.		25	5ᵐ.57 ± 0ᵐ.12	(0ᵐ.58)	6ᵐ.17*± 0ᵐ.10	prop. motions	8	-0ᵐ.48	B0
					5ᵐ.93*± 0ᵐ.18	prop. motions	9		
3293		21	11ᵐ.81 ± 0ᵐ.13	(0ᵐ.59)	12ᵐ.08 ± 0ᵐ.10	UBV, MK-types	10	-0ᵐ.27	O7.5
					12ᵐ.08 ± 0ᵐ.08	uvby, Hß	11		
IC2944		13	11ᵐ.61 ± 0ᵐ.17	(0ᵐ.60)	11ᵐ.5 ± 0ᵐ.2	UBV	12	-0ᵐ.14	O6
					12ᵐ.0 ± 0ᵐ.2	UBV, MK-types	13		

* Both Bertiau (1958) and Jones (1971) studied the whole Sco-Cen association; the Upper-Scorpius distances quoted here were derived by us, selecting only those stars in their sample that are members of this subgroup.

References to Table 7

1) Fernie, 1959, 1960
2) Vogt and Moffat, 1973
3) Becker and Fenkart, 1971
4) Wesselink, 1969
5) Seggewiss, 1968
6) Moffat and Vogt, 1973
7) Rieke, 1935
8) Bertiau, 1958
9) Jones, 1971
10) Feast, 1958
11) Shobbrook, 1983
12) Turner et al., 1980
13) Ardeberg and Maurice, 1977

In table VII, columns 1 and 2 identify the star cluster, while column 3 lists the number of stars observed in each of them. Column 4 gives the distance modulus and its uncertainty, as derived from the Walraven data. The number in brackets is the 1 σ uncertainty. In column 5 we list the distance moduli found in the literature, with the method used to derive it in column 6 and the reference in column 7. Column 8 gives the difference between our result and that from the literature. In column 9 we give the earliest spectral type of the stars observed, as derived from our data.

The average error in the weighted cluster distance modulus is $0^m.13 \pm 0^m.04$, or 6 % in distance. From the 1 σ uncertainties in column 4 we find that the average deviation from the cluster mean-distance modulus one can expect from a single cluster-star is $0^m.48 \pm 0^m.11$, implying a 25 % uncertainty in distance. In this context we refer to Feast and Shuttleworth (1965) who find, from the scatter of individual distance moduli of the stars in NGC 3293 and NGC 4755, the average error in the distance modulus of a single star to be $0^m.48$, in agreement with our result. There may be a certain amount of « cosmic scatter » present in the M_V's, which results in a minimum uncertainty with which distance moduli can be determined. This « cosmic scatter » is due partly to unresolved binary or multiple systems in the star sample that is studied, and partly to a real spread in the T_{eff}-log g-M_V-relation.

A glance at the catalogue of Ruprecht *et al.* (1981) shows that distance moduli in the literature sometimes differ by $2^m.4$ to $4^m.2$ for the clusters listed in table VII (in one case even by $6^m.0$!). Cluster distances have been derived by various authors in different ways. We think that the values for the distance moduli, quoted in column 5, are the most trustworthy, based on the method used to obtain them. We preferentially selected results of proper motion studies, but photometric observations and subsequent ZAMS-fitting of member stars should give satisfactory results too. The cluster-diameter method is too inaccurate compared to these two. In the case of photometric studies and ZAMS-fitting, usually no errors are quoted for individual clusters. However, Becker and Fenkart (1971) quote an uncertainty of about 10 % in a distance (i.e. $0^m.2$ in distance modulus) derived in this way. For five of the clusters in table VII (the OCLs), no distances of individual stars are given in the literature, and we can only compare the average cluster distances. For the moment we disregard OCL 1003 and OCL 753 : for the former, the literature reference is rather old, no error is given, and an M_V-calibration is used that leads to an underestimate of the distance modulus ; for the latter, the difference is negligible. OCL 1001 and OCL 871 have a smaller literature-distance modulus, although within the uncertainties they are equal to those derived here. No uncertainty is known for the literature value of OCL 775, but assuming it is on the order of $0^m.20$, it differs significantly from our value. This is very likely due to the fact that the literature values are derived by assuming all stars are on the ZAMS, which results in a lower limit to the distance modulus. If the stars are actually on the main sequence, a potential error of 1^m in the distance modulus is introduced (i.e. the difference in M_V between the ZAMS and the main sequence).

The average difference in distance modulus between the literature value and our results (see column 8) is $0^m.09 \pm 0^m.46$ (s.d.) ; the average *absolute* difference is $0^m.36 \pm 0^m.27$ (s.d.). This is in agreement with the average standard deviation of $0^m.48$ found from our own results alone, and expected for the literature data (re. the « cosmic scatter »). There are no indications from these data that there are systematic differences between our results and those that are quoted in the literature.

In the previous section we already mentioned various causes for differences in distance moduli derived by different observers. In the following we make a detailed star-by-star comparison for Upper-Scorpius, NGC 3293, and IC 2944, thereby distinguishing between stars of spectral type earlier, respectively later, than B2.

4.1 Stars of spectral type later than B2.

Upper-Scorpius. — A check of the accuracy *per star* of the conversion from photometric parameters into absolute magnitude can be made with the stars from Upper-Scorpius (one of the subgroups of the Sco-Cen association), because distance moduli, spectral types and luminosity classes are available in the literature for many of the stars in this region. Relevant data are collected in table VIII.

In this table, column 1 gives the HD numbers ; columns 2, 3, 4, and 5 respectively the log T_{eff}, log g, M_V, and distance modulus that result from the Walraven photometry (data from de Geus, 1984). Column 6 lists the spectral type and luminosity class that is indicated by the log T_{eff} and log g, based on interpolation in the tables from Straizys and Kuriliene (1981) (for a ZAMS-luminosity class star we use the notation V_0). Interpolation in these tables is accurate to within 1/2 spectral class and 1/2 luminosity class as used by Straizys and Kuriliene (i.e. distinction is made between, for instance, type B0 and B0.5, type B3, B4 and B5 and class V, V-IV, and IV). The spectral types and luminosity classes in column 7 are taken from Buscombe (1977, 1980) and in column 8 we give the M_V for these spectral classifications according to Straizys and Kuriliene. In column 9 an « m » indicates the star is a *definite* member, based on proper motion data (Bertiau, 1958) and an « f » is used to denote the faint (but with $V_J < 8^m$) B-type stars in the region that are *probable* members, according to Bertiau (1958).

The average distance modulus from 54 certain and probable member stars (Tab. VIII) is $5^m.92 \pm 0^m.09$ (m.e.) (153 pc). Three probable member stars (HD 146332, 147889, and 147890) and one certain member (HD 142983) have been excluded because their distance moduli are systematically higher than the average (by $1^m.9$ to $3^m.3$). For the probable members this may indicate they are not belonging to the association. Alternatively, the problem may lie with the stars themselves : in two cases the spectrum is denoted « peculiar » by Buscombe

TABLE VIII. — *Relevant data on the Upper-Scorpius subgroup.*

	VBLUW-data. [B-U] vs. [B-L] only					Buscombe		
HD nr.	$\log T_e$	log g	M_V	d.mod.	Sp.T.,L.C.	Sp.T.,L.C.	M_V	Member
139094	4.122	4.25	+0.26	6.54	B6.5 V_o-V	B8 IV	-0.3	f
139365	4.259	4.25	-0.86	4.49	B4 V_o-V	B2.5 V	-2.1	m
139486	4.019	4.35	+1.38	6.04	B9 V_o	B9.5 V	+0.65	f
140008	4.180	4.35	-0.02	4.76	B6.5 V_o	B5 IV	-1.2	m
140817	4.031	4.45	+1.27	5.37	B8.5	A0 V	+0.8	
141180	4.074	4.15	+0.36	7.72	B7.5 V_o-V	B8 V	+0.1	
141404	3.989	3.55	-0.79	7.99	A0 II-III	B9 V	+0.5	f
141556	4.023	4.05	+0.47	3.50	B9 V	B9 IVp	+0.1?	[illegible]
141637	4.335	4.25	-1.49	5.65	B2.5 V_o	B2 V	-2.5	m
141774	4.039	4.15	+0.65	6.60	B8.5 V_o-V	B9 V	+0.5	f
142114	4.275	4.25	-1.01	5.24	B3 V_o-V	B2.5 Vn	-2.1	m
142165	4.151	4.25	+0.07	4.95	B6 V_o-V	B6 IVn	-0.9	m
142184	4.268	4.35	-0.84	5.74	B3	B2.5 Vn	-2.1	m
142250	4.148	4.35	+0.33	5.65	B6	B6 V	-0.5	f
142315	4.070	4.25	+0.68	5.81	B8 V_o-V	B9 V	+0.5	f
142378	4.216	4.35	-0.36	5.85	B4	B5 V	-0.8	m
142669	4.325	4.05	-1.99	5.80	B2.5 V	B2 IV-V	-2.8	m
142805	3.993	3.65	-0.48	7.01	B9.5 III	B9 V	+0.5	f
142883	4.211	4.45	-0.31	5.58	B4	B5 V	-0.8	f
142884	4.189	4.25	-0.28	6.54	B5 V_o-V	B9p	?	
142983	4.066	2.75	-4.26	9.18	B7 II	B5 IIIp	-1.7?	m
142990	4.259	4.25	-0.86	6.02	B3.5 V_o-V	B4 IVp	-1.75?	f
143018	4.404	4.05	-2.75	5.42	B1.5 V	B1 V	-3.3	m
143118	4.347	3.95	-2.51	5.92	B2 IV-V	B2.5 IV	-2.7	m
143275	4.445	3.95	-3.71	5.55	B0.5 IV-V	B0.5 IV	-4.15	m
143567	4.047	4.35	+1.12	5.58	B8.5 V_o	B9 V	+0.5	f
143600	4.031	4.25	+1.02	5.87	B9.5 V_o-V	B9 Vn	+0.5	f
143699	4.208	4.25	-0.44	5.30	B4 V_o-V	B6 IV	-0.9	m
144217	4.481	4.65	-3.84	6.42	B0	B0.5 V	-3.65	m
144218	4.357	4.50	-1.56	7.14	B2	B2 IV-V	-2.8	m
144294	4.266	4.15	-1.17	5.36	B3 V_o-V	B2.5 Vn	-2.1	m
144334	4.208	4.25	-0.44	6.12	B4 V_o-V	B8p	?	f
144470	4.421	4.15	-2.75	6.01	B1 V_o-V	B1 V	-3.3	m
144661	4.195	4.15	-0.60	6.61	B5 V_o-V	B7 IIIp	-1.0?	f
144844	4.116	4.50	+0.54	4.96	B7	B9 V	+0.5	f
145102	4.063	3.95	-0.16	6.29	B8 V-IV	B9 Vp	+0.5?	f
145353	4.039	4.05	+0.33	6.00	B8.5 V	B9 V	+0.5	f
145482	4.300	4.25	-1.21	5.65	B3 V_o-V	B2 V	-2.5	m
145483	4.051	4.35	+1.09	4.39	B8 V_o	B9 V	+0.5	f
145501	4.172	4.35	+0.08	5.40	B5.5	B9 III	-0.4	
145502	4.333	4.35	-1.37	4.57	B2.5	B2 IVp	-3.1?	m
145519	4.047	4.25	+0.88	6.13	B8.5 V_o-V	B9 Vn	+0.5	
145554	4.051	4.35	+1.09	5.89	B8	B9 V	+0.5	f
145631	4.035	4.25	+0.98	5.99	B8.5 V_o-V	B9.5 V	+0.65	f
145792	4.189	4.35	-0.11	5.93	B5	B7 IV	-0.6	f
146001	4.145	4.25	+0.11	5.45	B6 V_o-V	B7 IV	-0.6	f
146029	4.023	4.15	+0.79	6.20	B9 V_o-V	B9 V	+0.5	f
146284	4.074	3.85	-0.54	6.46	B7.5 IV-III	B8 V	+0.1	f
146285	4.081	4.35	+0.83	6.12	B7.5 V_o	B8 V	+0.1	f
146332	4.180	3.55	-2.34	8.83	B6.5 II-III	B5 III	-1.7	f
146416	4.047	4.25	+0.88	5.48	B8.5 V_o-V	B9.5: V	+0.65	f
146606	4.006	4.35	+1.46	5.60	B9.5 V_o	A0 V	+0.8	
146706	4.043	4.15	+0.62	6.34	B8.5 V_o-V	B9 V	+0.5	
147009	3.985	4.25	+1.41	5.74	A0 V_o-V	B9.5 V	+0.65	f
147012	4.035	4.25	+0.98	7.08	B8.5 V_o-V	B9 V	+0.5	
147013	3.985	4.35	+1.59	6.22	A0	A0 V	+0.8	
147084	3.906	2.45	-3.88	5.90	A6 II-Ib	A5 II	-2.9	m
147165	4.432	3.75	-4.30	5.97	B1 III-IV	B1 III	-4.5	m
147196	4.077	3.95	-0.29	6.53	B7.5 IV	B5 V	-0.8	f
147384	3.998	4.25	+1.30	6.02	B9.5 V_o-V	B9.5 V	+0.65	
147592	3.961	4.35	+1.80	6.34	A2	A1 V	+1.1	
147648	4.106	3.95	-0.52	7.23	B7 IV	B8 V	+0.1	
147701	4.189	4.35	-0.11	6.23	B5	B5 V	-0.8	
147703	4.023	4.15	+0.79	6.02	B9 V_o-V	B9 Vn	+0.5	
147809	3.971	4.35	+1.72	5.72	A1 V_o	A1 V	+1.1	
147888	4.247	4.25	-0.76	5.99	B4 V_o-V	B5 V	-0.8	m
147889	4.385	3.35	-5.18	9.64	B1.5 II-III	B1.5 V	-2.9	f
147890	4.070	3.65	-1.12	7.82	B8 III	B8p	?	f
147932	4.256	4.25	-0.84	6.60	B4 V_o-V	B5 V	-0.8	
147955	4.043	4.45	+1.16	5.99	B8.5	B9.5 V	+0.65	
148184	no solution					B2 IIIpe	-3.7??	m
148199	4.081	4.05	-0.01	6.45	B7.5 V	B8 V	+0.1	
148334	4.066	4.25	+0.71	8.38	B8 V_o-V	B9 V	+0.5	
148563	3.961	4.35	+1.80	6.27	A2	A2 V	+1.3	
148579	4.059	4.25	+0.78	5.50	B8 V_o-V	B9 V	+0.5	f
148594	4.106	3.95	-0.52	6.77	B7 IV	B8 Vnn	+0.1	f
148605	4.289	4.25	-1.12	5.69	B3 V_o-V	B2 V	-2.5	m
148703	4.343	4.15	-1.83	5.86	B2.5 V_o-V	B2 III	-3.7	m
148860	4.039	4.15	+0.65	6.74	B8.5 V_o-V	B9.5 V	+0.65	
149069	3.985	4.05	+0.81	9.02	A0 V	A1 V	+1.1	
149168	4.135	4.35	+0.41	8.93	B6.5 V_o	B7 V	-0.2	
149228	4.151	3.95	-0.89	9.46	B6 IV	A0p	?	
149367	4.066	4.05	+0.11	7.67	B8 V	B9 V	+0.5	
149438	4.481	3.95	-4.02	6.72	B0 IV-V	B0 V	-4.0	m
149464	4.039	4.15	+0.65	7.23	B8.5 V_o-V	B9 Vn	+0.5	
149883	4.031	4.05	+0.40	7.45	B8.5 V	B9 V	+0.5	
150347	4.043	3.95	+0.00	8.49	B8.5 IV	B9 V	+0.5	
150514	4.085	3.75	-0.92	8.86	B7.5 III	B8 III	-0.7	
151310	4.275	3.95	-1.88	10.53	B3 IV-V	B3 Vn	-1.7	
151346	4.169	3.75	-1.60	7.75	B5.5 III	B7 V	-0.2	
151865	4.095	4.25	+0.46	7.58	B7.5 V_o-V	B8 V	+0.1	
157056	4.351	3.95	-2.54	5.73	B2 IV-V	B2 IV	-3.1	m

(HD 142983 and 147890) ; HD 147889 has a very high extinction ($A_V = 3\overset{\mathrm{m}}{.}5$), which may require a non-linear reddening correction. One member star (HD 148184) has no solution in the *VBLUW*-system owing to its « pe » spectrum.

From the 25 certain members alone (HD 142983 and HD 148184 are again excluded), we find a distance modulus of $5\overset{\mathrm{m}}{.}57 \pm 0\overset{\mathrm{m}}{.}12$ (m.e.) (130 pc). The average absolute deviation of the distance modulus per (member-) star from this cluster-mean is $0\overset{\mathrm{m}}{.}46 \pm 0\overset{\mathrm{m}}{.}40$ (s.d.), in agreement with what is found from the clusters in table VII. The distance modulus quoted in the literature is $5\overset{\mathrm{m}}{.}93 \pm 0\overset{\mathrm{m}}{.}18$ (153 pc ; Jones, 1971 ; see note in Tab. VII), which differs by about 18 % from our distance (taking member stars only) ; Bertiau (1958) finds a distance modulus of $6\overset{\mathrm{m}}{.}17 \pm 0\overset{\mathrm{m}}{.}10$ (171 pc ; see note in Tab. VII), which differs by 32 % from our distance (member stars only). In what follows we try to trace the source of these differences.

For each star we define Δ(d.mod.) as the difference between its distance modulus derived from the *VBLUW* data, and that, derived by Bertiau. For 25 « certain member » stars, again leaving out HD 142983 and HD 148184, we find $\langle \Delta(\text{d.mod.}) \rangle = -0\overset{\mathrm{m}}{.}50 \pm 0\overset{\mathrm{m}}{.}57$ (s.d.). The individual Δ(d.mod.) show no dependence on $\log T_{\mathrm{eff}}$. This negative average difference points to a *systematic* underestimation of our distance moduli, because Bertiaus results are independent of an M_V-calibration. However, there are also indications that Bertiaus distance moduli may be too high : the average difference between the distance moduli of Jones (1971) and Bertiau, for the 42 stars they have in common, is $-0\overset{\mathrm{m}}{.}40 \pm 0\overset{\mathrm{m}}{.}26$ (s.d.). Our study of Upper-Scorpius has 17 stars in common with that of Jones (1971) ; the average difference between our distance moduli and his is $-0\overset{\mathrm{m}}{.}26 \pm 0\overset{\mathrm{m}}{.}50$ (s.d.), again excluding HD 142983 and HD 148184. This difference is smaller than that between our results and Bertiaus, but still suggests that our distance moduli are systematically somewhat too small. This may be due to our M_V-calibration : had we used that of Schmidt-Kaler (1982) our distance moduli, at least for stars of type B4 to A0, would increase by up to $0\overset{\mathrm{m}}{.}4$ (see Sect. 3.5, Fig. 5). In addition, there may of course be systematic errors in the stellar parallaxes of Bertiau (1958) and Jones (1971), for instance from the proper motions or the location of the convergence point.

There is another way in which we can analyse our results : we compare the M_V's that follow from the Walraven colours with those that are implied by Buscombe's spectral classification. This is identical to a comparison between the distance moduli of two observers who have used the same photometric data and the same M_V-calibration, but who have different ways to derive $\log T_{\mathrm{eff}}$ and $\log g$. If (random) photometric errors are the dominant source of uncertainty in deriving the distance modulus, we expect that on average the difference ΔM_V between the two M_V's (columns 5 and 8) should be distributed around zero. Some additional scatter will be introduced because of the limited accuracy with which M_V in column 8 can be derived from the spectral classifications in column 7. We find $\langle \Delta M_V \rangle = 0\overset{\mathrm{m}}{.}31 \pm 0\overset{\mathrm{m}}{.}67$ (s.d.) for 81 stars. The distribution of the ΔM_V's is shown in figure 6a. This result indicates that the M_V's, found from the ($\log T_{\mathrm{eff}}$, $\log g$)-values are in

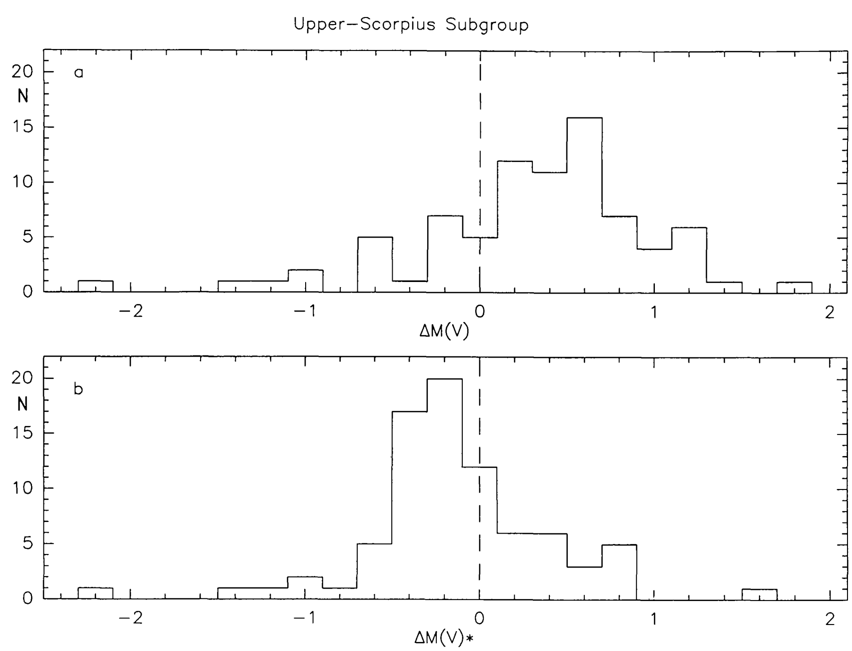

FIGURE 6. — a) Distribution of ΔM_V for stars from the Upper-Scorpius subgroup. ΔM_V is defined as the difference between the absolute magnitudes assigned on basis of the *VBLUW*-based classification and that of Buscombe (1977, 1980 ; Tab. VIII) ; b) as in a), but now assigning main sequence absolute magnitude to all stars that have luminosity class between ZAMS and main sequence according to the photometric classification. The absolute magnitude difference is now defined as ΔM_V^*.

general fainter than those, that are implied by Buscombe's spectral classification. Comparing columns 6 and 7 in table VIII it is seen that we find many stars lying between ZAMS and main sequence, while Buscombe assigns them to the main sequence. If we give the main sequence- M_V-value to all stars that are between ZAMS and main sequence, the differences in M_V, now denoted ΔM_V^*, have a narrower distribution and are closer to zero (Fig. 6b). We find $\langle \Delta M_V^* \rangle = -0\overset{m}{.}12 \pm 0\overset{m}{.}54$ (s.d.).

The main sequence takes up a broad section in the Hertzsprung-Russell diagram and distinction between ZAMS and main sequence is not made in Buscombe's catalogue. This effect explains the apparent difference between the two distance determinations.

4.2 STARS OF SPECTRAL TYPE EARLIER THAN B2. — As discussed in section 4.1, the distance determination works satisfactorily for stars of spectral type later than B2-3, or $T_{eff} < 20000$ K. Some additional problems arise for early type stars. First, the RFDs are based on Kurucz's (1979) stellar atmosphere models that do not take into account non-LTE effects for such early type stars (see Sect. 3.2) ; second, photometric uncertainties have a very large influence : a small error in $(B-L)$, for instance, leading to an error in log g immediately results in large differences in M_V (for a main sequence B0 star ($T_{eff} \simeq 30000$ K) a difference in $[B-L]$ of 0.006 (log I-units) corresponds to a difference in log g of 0.25 which results in a difference in M_V of $0\overset{m}{.}9$, i.e. the difference between a main sequence star and a giant). In order to analyse distance determination from Walraven colours for O- and early B-type stars, we studied two clusters : NGC 3293 and IC 2944. The photometric data are presented in Appendix B (Tab. AIII, AIV).

No proper motion-based distance moduli are available for the stars in these clusters. Where distances to individual stars are given in the literature, they are derived from photometric data in conjunction with either a spectral classification and an adopted M_V-calibration, or a Hβ-measurement and a β / M_V-calibration.

1) *NGC 3293.*

This young cluster ($\tau \simeq 5 \times 10^6$ y, Turner *et al.*, 1980) in Carina has been extensively studied by Feast (1958 ; MK-types, *UBV*), Turner *et al.* (1980 ; MK-types, *UBVRI*) and Shobbrook (1983 ; *uvby*, Hβ) among others. Shobbrook and Feast give distance moduli of individual stars. We observed 21 stars in common with Feast (of which 20 are also measured by Shobbrook). A finding chart for the cluster has been published by Turner *et al.* In table IX we collect data relevant to the comparison of results.

Column 1 gives the (Feast) star number. The log T_{eff} and log g that follow from the *VBLUW* data are listed in columns 2 and 3. Column 4 gives the spectral type and luminosity class indicated by these log T_{eff} and log g values, from an interpolation in the tables of Straizys and Kuriliene (1981). Column 5 lists our absolute magnitude, and column 6 the distance modulus. In column 7 we quote the spectral types of Feast, with his absolute magnitudes and distance moduli in columns 8 and 9 respectively. Column 10 gives the distance modulus (d.mod.*), derived from Feasts data, but using the M_V-calibration of Straizys and Kuriliene. Columns 11 and 12 give Shobbrooks results, and column 13 the spectral classification of Turner *et al.* Column 14 is reserved for remarks. Comparing columns 7 and 13 shows that spectral classifications in the literature agree,

TABLE IX. — *Relevant data on NGC 3293.*

1	2	3	4	5	6	7	8	9	10	11	12	13	14
	VBLUW-data; [B-U] vs. [B-L] only					Feast				Shobbrook		Turner e.a.	
F	$\log T_e$	log g	SpT,LC	M_V	d.mod.	SpT,LC	M_V	d.mod.	d.mod*	M_V	d.mod.	SpT,LC	Remarks
1	4.558	4.55	O7.5	-5.04	12.43	O7	-5.1	12.4	12.5	-4.82	12.3	O7 V(f)[1]	
2	4.390	3.45	B1.5 II-III	-4.76	12.62	B1 III	-4.4	12.3	12.4	-4.31	12.1	B1 IIn[2]	
3	4.459	3.55	B0.5 II-III	-5.30	10.99	B0.5 Ib	-5.8	11.5	11.7	-6.15:	11.8:	B0.5 Ia-Ib[3,4]	
4	4.495	3.55	B0 II-III	-5.81	11.47	B0 I(b?)	-6.2	11.8	11.7	-6.88:	12.5:	B0 Iab	
5	4.419	4.15	B1 V_o-V	-2.72	11.12	B1 III	-4.4	12.8	12.9	-3.63	12.0	B1 IV	ßCep var.
6	4.432	3.55	B1 II-III	-4.92	12.14	B0.5 III	-4.9	12.5	12.3	-5.83	13.0	B0.5 II	
7	4.390	3.65	B1.5 III	-4.07	11.78	B1 III	-4.4	12.1	12.2	-3.94	11.6	B1 III[5]	
8	4.412	3.45	B1 II-III	-5.07	12.05	B0.5 III	-4.7	11.7	11.7	-4.89	11.8	B0.5 II[5]	
10	4.406	4.15	B1 V_o-V	-2.47	11.13	B1 V	-3.1	11.8	12.0	-3.39	12.1	B0.5 V	ßCep var.
11	4.402	4.05	B1.5 V	-2.71	11.70	B1 V	-3.1	12.4	12.6	-3.19	12.2	B1 V	ßCep var.
14	4.412	3.85	B1 IV	-3.61	12.26	B1 V	-3.1	11.7	11.9	-3.70	12.4	B1 IV	ßCep var.
15	4.531	5.00	O9	-4.59	13.16	B1 V	-3.1	12.3	12.5	----	----	B2: IVn	
16	4.399	3.75	B1.5 III-IV	-3.86	11.91	B1 III	-4.4	12.4	12.5	-3.93	12.0	B0.5 III-V[3,6]	ßCep car.
18	4.402	4.25	B1.5 V_o	-2.15	10.72	B1 V	-3.1	11.8	12.0	-3.30	11.9	B1 IV	ßCep var.
19	4.427	3.55	B1 II-III	-4.86	12.60	B1 III	-4.4	12.1	12.2	-4.89	12.6	B0.5 IIn	
20	4.427	3.55	B1 II-III	-4.86	12.01	B1 III	-4.4	11.6	11.7	-5.05	12.2	B1 II	
22	4.411	3.55	B0.5 II-III	-4.62	11.16	B1 II	-4.9	11.5	11.8	-5.08	11.6	B1 Ib	
23	4.412	3.85	B1 IV	-3.61	11.99	B1 III	-4.4	12.7	12.8	-3.45	11.8	B1 III[6]	ßCep var.
24	4.414	3.85	B1 IV	-3.65	12.01	B1 III	-4.5	12.8	12.9	-3.77	12.1	B1 III[6]	ßCep var.
25	4.426	3.65	B1 III	-4.60	11.70	B1 III	-4.4	11.6	11.7	-4.81	11.9	B1 II	
27	4.383	3.85	B1.5 IV	-3.19	11.22	B0.5 III	-4.7	12.7	12.7	-3.50	11.5	B0.5 III[6]	ßCep var.

1. Walborn: 1973, Astroph. J. **78**, 1067
2. Garrison et al.: 1977, Astroph. J. Suppl. **35**, 111
3. Morgan et al.: 1955, Astroph. J. Suppl. **2**, 4
4. Walborn: 1976, Astron. J. **205**, 419
5. Hoffleit: 1956, Astroph. J. **124**, 61
6. Feast: 1958, Mon. Not. R.A.S. **118**, 618

on average, to within 1/2 spectral class and 1/2 luminosity class ; this is also the interpolation accuracy for the data in column 4 (see Sect. 4.1).

The average distance moduli from the stars in common are the same within the uncertainties (m.e.) :

$$\langle \text{d.mod.} \rangle_{VBLUW} = 11^{\text{m}}.81 \pm 0^{\text{m}}.13 \text{ (21 stars)}$$

$$\langle \text{d.mod.} \rangle_{\text{Feast}} = 12^{\text{m}}.12 \pm 0^{\text{m}}.10 \text{ (21 stars)}$$

$$\langle \text{d.mod.} \rangle_{\text{Shob.}} = 12^{\text{m}}.07 \pm 0^{\text{m}}.08 \text{ (20 stars)} .$$

The published distance moduli (using all stars measured) are $12^{\text{m}}.08 \pm 0^{\text{m}}.10$ (Feast) and $12^{\text{m}}.08 \pm 0^{\text{m}}.08$ (Shobbrook) respectively. [N.B. : we have used Shobbrooks results for the $\beta/[u\text{-}b]/M_V$-calibration from Eggen (1977) as this calibration appears to be more accurate than that of Crawford (1978) (Shobbrook, 1983, p. 1227)].

As before, we define for each star Δ(d.mod.) as the difference between its distance modulus derived from the *VBLUW* data, and that, taken from a literature source ; ΔM_V is the corresponding difference in M_V.

In figure 7, we compare Δ(d.mod.) with ΔM_V, the literature data taken from Feast and Shobbrook respectively. The good correlation indicates that the difference in distance modulus is completely accounted for by the difference in assigned absolute magnitude. In the comparison with Feast, four stars (Feast numbers 6, 11, 15, and 18) deviate very strongly. It can be shown that these deviations are due to errors in the photometric data used by Feast. On average, our distance moduli are smaller than those found by Feast: $\langle \Delta(\text{d.mod.}) \rangle = -0^{\text{m}}.30 \pm 0^{\text{m}}.67$ (s.d.). The average absolute difference, $\langle |\Delta(\text{d.mod.})| \rangle$, between the present work and Feasts, is $0^{\text{m}}.60 \pm 0^{\text{m}}.41$ (s.d.). (The deviations are generally smaller when comparing the *VBLUW* results with those of Shobbrook : $\langle |\Delta(\text{d.mod.})| \rangle = 0^{\text{m}}.45 \pm 0^{\text{m}}.38$ (s.d.)). This difference is not due to the fact that we do not use the same M_V-calibration (Feast uses that of Johnson and Hiltner (1956), see Fig. 5). The distance moduli (d.mod.*) in column 10 of table IX are corrected for this effect, by using Feasts spectral classification and the tables of Straizys and Kuriliene (1981) to assign an absolute magnitude. Subtracting these distance moduli from ours, we find $\langle \Delta(\text{d.mod.*}) \rangle = -0^{\text{m}}.41 \pm 0^{\text{m}}.67$ (s.d.), and $\langle |\Delta(\text{d.mod.*})| \rangle = 0^{\text{m}}.63 \pm 0^{\text{m}}.46$ (s.d.). In addition, Feast uses a ratio of total to selective extinction, R, of 3.0. With extinction ranging from $0^{\text{m}}.6$ to $1^{\text{m}}.4$, this systematically increases his distance moduli with respect to ours by at most $0^{\text{m}}.1$. For individual stars, Δ(d.mod.*) can be much larger (up to $-1^{\text{m}}.8$). Photometric errors are random, and therefore cannot be the cause of these (systematic) differences. Rather, the discrepancies in the distance moduli are due to the fact that the spectral classifications of Feast are usually close, but not identical to what is indicated by our $\log T_{\text{eff}}$ and $\log g$ (cf.

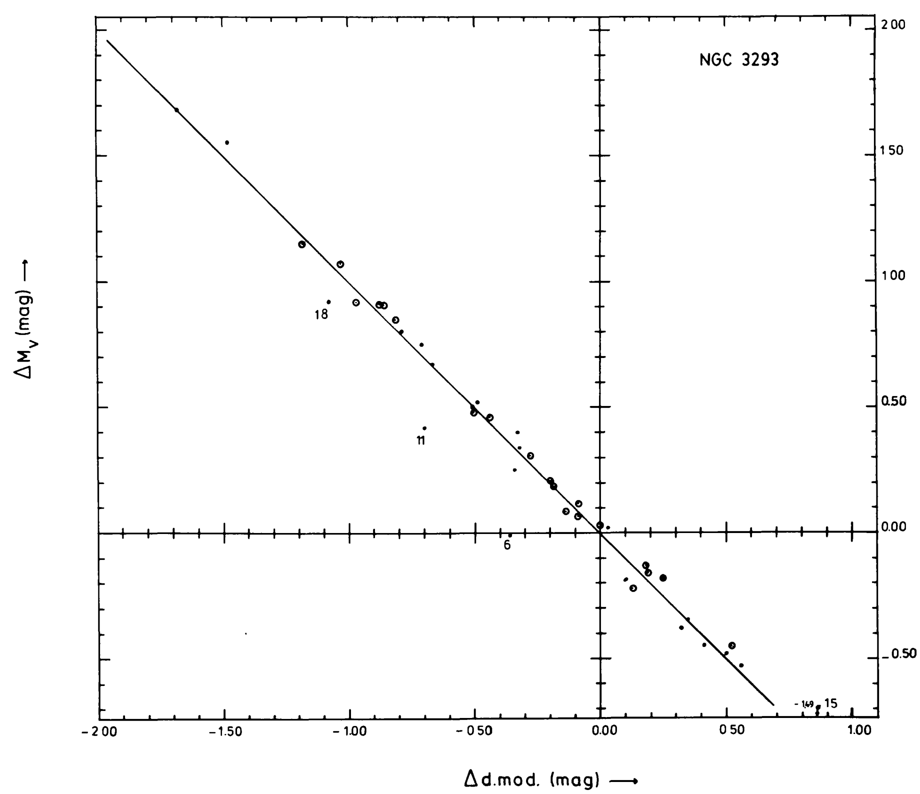

FIGURE 7. — Comparison of distance moduli and absolute magnitudes for 21 stars in NGC 3293. Per star the difference in both quantities from our data and respectively those by Feast (1958 ; •) and Shobbrook (1983 ; ⊙) is plotted. The drawn line is the locus of stars for which the difference in distance modulus is equal to the difference in assigned absolute magnitude. All stars lie on or very close to this line, except for stars (when compared to Feast) that deviate because of errors in the photometry used by Feast.

columns 4 and 7 in table IX). The differences on average amount to 1/2 spectral class and 1/2-1 luminosity class, and result in different M_V-values (i.e. d.mod.). These differences in spectral classification are not uncommon (cf. columns 7 and 13 ; see also the discussion on IC 2944), and are within the ranges of resolution of the method.

There is no influence on the results from the fact that nine of the stars are βCep variables ; these are short period variables, with amplitudes less than $0^m.1$, and often only a few hundredths of magnitudes (Voigt, 1974).

2) *IC 2944*

This is a very rich cluster near λCen, associated with the HII region RCW 62. It contains a fair number of O stars, making it an ideal test case for the uppermost part of the RFD. An extensive study of this cluster, giving distance moduli to individual stars, is that by Thackeray and Wesselink (1965 ; hereafter TW). Ardeberg and Maurice (1977a ; hereafter AM) determined spectral type and luminosity class for a large number of stars in the region. The same was done by Schild (1970) for a smaller number of stars. The relevant data of 21 stars that we have observed in common with these authors are given in table X. A finding chart is published by AM.

Column 1 identifies the star ; columns 2 through 6 summarize the *VBLUW* results, with column 4 giving the spectral classification indicated by the $\log T_{\rm eff}$ and $\log g$ values in columns 2 and 3. Column 6 gives the distance modulus. The data from TW are quoted in columns 7, 8, and 9. In column 10 is listed d.mod.* : the distance modulus derived from TW's data, but using the M_V-calibration of Straizys and Kuriliene (1981). Columns 11 and 12 give the spectral classification by AM and Schild, respectively.

Thirteen of the stars we observed are considered members of the cluster (see TW). The average cluster distance moduli are the same within the uncertainties (m.e.) :

$$\langle \text{d.mod.} \rangle_{VBLUW} = 11^m.61 \pm 0^m.17 \text{ (13 stars)}$$
$$\langle \text{d.mod.} \rangle_{TW} = 11^m.7 \pm 0^m.32 \text{ (13 stars)} .$$

From all 24 stars they studied TW find an average distance modulus of $11^m.5 \pm 0^m.2$ (m.e.) ; from *UBV*-photometry and ZAMS fitting, AM arrive at a distance modulus of $12^m.0 \pm 0^m.2$. As in the case of NGC 3293, even though the average cluster distance moduli agree very well, there are differences per star of up to $2^m.2$. In the following discussion, Δ(d.mod.), ΔM_V, and Δ(d.mod.*) are defined as before.

The differences in distance moduli are nearly totally due to differences in absolute magnitude, although the scatter around a one-to-one correlation is somewhat larger than for NGC 3293. A comparison with TW for the 19 stars observed in common, shows that there is no systematic difference in the distance moduli : $\langle \Delta(\text{d.mod.}) \rangle = -0^m.05 \pm 0^m.95$ (s.d.). However, the absolute difference is similar to what was found for NGC 3293, because $\langle |\Delta(\text{d.mod.})| \rangle = 0^m.61 \pm 0^m.72$ (s.d.). By calculating d.mod.*, we correct for the fact that TW use Blaauw's (1963) M_V-calibration. For the same 19 stars we then find $\langle \Delta(\text{d.mod.*}) \rangle = 0^m.07 \pm 0^m.92$ (s.d.), and $\langle |\Delta(\text{d.mod.*})| \rangle = 0^m.55 \pm 0^m.74$ (s.d.). These (non-systematic) differences between the distance moduli can be explained by photometric uncertainties (Tab. VI, Sect. 3.5). As for NGC 3293, for individual stars the potential photometric uncertainty cannot completely account for the actual Δ(d.mod.), because of differences in spectral classification, that lead to the differences in M_V (and distance modulus). As

TABLE X. — *Relevant data on IC 2944.*

1	2	3	4	5	6	7	8	9	10	11	12
HD, HDE	VBLUW-data;		[B-U] vs.	[B-L] only		Thackeray and Wesselink				AM	Schild
or CPD	$\log T_e$	logg	SpT,LC	M_V	d.mod.	SpT,LC	M_V	d.mod.	d.mod*	SpT,LC	SpT,LC
101008	4.519	4.05	O9 V	-4.39	12.70	B0.5 III:	-5.0	13.3	13.0	B0 III	---
101070	4.484	4.45	B0	-3.87	11.92	B2 III:	-3.6	11.8	11.9	B0.5 IV	---
101084	4.424	4.45	B1	-3.31	11.52	B1.5 V	-3.0	11.2	11.1	B1.5 V	B1 Ve
101131	4.571	5.00	O7	-5.23	11.33	O7n	-5.3	11.4	11.3	O6.5n	O6.5n
101190	4.587	5.00	O6	-5.35	11.58	O6n	-5.5	11.7	11.6	O5	---
101191	4.541	4.55	O8.5	-4.76	12.19	O9 V	-4.8	12.1	11.8	O9 III	O8 V
101205	4.562	4.85	O7.5	-5.09	10.53	O7n	-5.4	10.7	10.5	O6.5	O6
101223	4.519	4.55	O9	-4.39	11.70	O8	-5.2	12.4	12.1	O8	---
101298	4.585	5.00	O6.5	-5.34	12.22	O7.5	-5.3	12.2	12.0	O5.5	O6
101333	4.507	4.35	O9.5	-4.17	11.97	B0 Iab	-6.2	14.2	14.5	B0 III	---
101413	4.517	4.55	O9.5	-4.34	11.55	O9.5 III	-5.7	12.9	12.3	O9.5 IV	---
101436	4.562	4.55	O7.5	-5.09	11.53	O7	-5.4	11.6	11.4	O7.5	
308815	4.440	4.15	B1	-3.46	12.06	B2 V	-2.5	11.1	11.1	B0.5 V	---
-62° 2156	4.514	4.55	O9.5	-4.29	12.97	B0 V-III	-4.8	13.4	13.1	B0 V	B0 V
-62° 2157	4.368	4.50	B2	-1.68	11.40	B3: V	-1.7	11.4	11.4	B0.5 V	B1.5 V
-62° 2158	4.517	4.35	O9.5	-4.34	12.65	B1: III	-4.4	12.7	12.8	B0 V	O9.5 V
-62° 2160	4.116	3.55	B7 III	-1.84	11.08	B9 V	+0.6	8.9	9.0	B9 IV	B9p(e)
-62° 2184	4.154	4.05	B6 V	-0.59	10.10	B5: V	-1.0	10.6	10.4	B6 Ve	---
-62° 2185	4.439	4.25	B1 V_o	-3.45	12.38	B3 Vn	-1.7	10.8	10.8	B2 Vn	---
-62° 2188	4.434	4.45	B1	-3.40	11.94	---	---	---	---	B1 V	B0.5 V
-62° 2216	4.386	4.35	B1.5	-1.90	11.87	---	---	---	---	B1 V	---

illustration we have included spectral classifications from three different sources in table X (columns 7, 11, and 12). Ardeberg and Maurice (1977a, b) have compared the spectral types and luminosity classes for stars they observed in common with TW and others, and found that they sometimes classify stars systematically earlier or later, by as much as 1.2 subclasses. The dispersion around that systematic shift ranges from 0.6 to 1.3 subclasses. Our « classification » in column 4 does not differ more from the ones quoted from the literature in table X, then they do amongst each other. The resulting differences in distance moduli should therefore be considered inherent to the various methods used to derive them.

5. Conclusions.

Walraven photometry provides a useful tool for the derivation of distances to individual stars of spectral type between O6 and A7. The method, described in detail in this paper, was tested on eight star clusters. The mean error in the (weighted) average distance modulus of a cluster is found to be about $0^{m}_{.}13$, which corresponds to a 6 % uncertainty in distance. The average deviation from the cluster mean-distance modulus expected for a single star is $0^{m}_{.}48$, i.e. 25 % in distance. The average absolute difference in cluster-distance modulus between our results and those from the literature is $0^{m}_{.}36$ (i.e. 18 % in distance).

Using literature data, a star-by-star comparison was carried out in three clusters. Barring a few exceptions, the difference in distance modulus derived from Walraven photometry and that from the literature is always equal to that in the corresponding M_V-value. There is a slight tendency for our distance moduli to be somewhat lower, which is due to the fact that we make a distinction in M_V between the ZAMS and the main sequence. Although the average distance moduli of the clusters, derived here and in the literature, are equal within the uncertainties, for individual stars the differences in distance modulus may be quite large (up to about 2^{m}). The deviations are caused by differences in the spectral classification as implied by our log T_{eff} and log g values, and that which is found in the literature. These differences are in general within 1/2-1 spectral- or luminosity class, comparable to the variation in classification in the literature.

Acknowledgements.

This work was partially supported by The Netherlands Foundation for Astronomical Research (ASTRON). ASTRON is funded by The Netherlands Organization for Pure Scientific Research (Z.W.O.). Additional support was provided by the Leiden Kerkhoven-Bosscha Fonds, grant no. AST 83-15276 of the U.S. National Science Foundation and the Alfred P. Sloan Foundation.

We thank Drs. Lub and Pel for the calculation of the theoretical colours, and for providing other, still unpublished data on the Walraven photometric system. We are grateful to Eugène de Geus (Leiden) for making his photometric data on Upper-Scorpius available to us. We also acknowledge Drs. Lub, Habing, de Zeeuw and Blitz for a critical reading of an early version of the manuscript and discussions. The referee, Dr. Pel, is thanked for his critical comments, which have greatly improved the presentation of the work described here.

Appendix A.

Using all our photometric data (Paper IV), we are able to derive the colours of the ZAMS in the Walraven system. It is shown in figure A1 in the (*B-U*) *versus* (*V-B*) diagram ; ZAMS colours as a function of spectral type are given in table AI ; the value of M_V(ZAMS) is taken from Straizys and Kuriliene (1981). We will make use of this relation between spectral type, absolute magnitude, and colours in Paper IV.

We drew the envelope to all the data points in the colour-colour diagrams. Where the ZAMS changes direction (around A0 and F) its position in the diagrams was determined by careful consideration of the dereddened positions of the stars ; because there are three colour-colour diagrams, this was done by iteration. For compari-

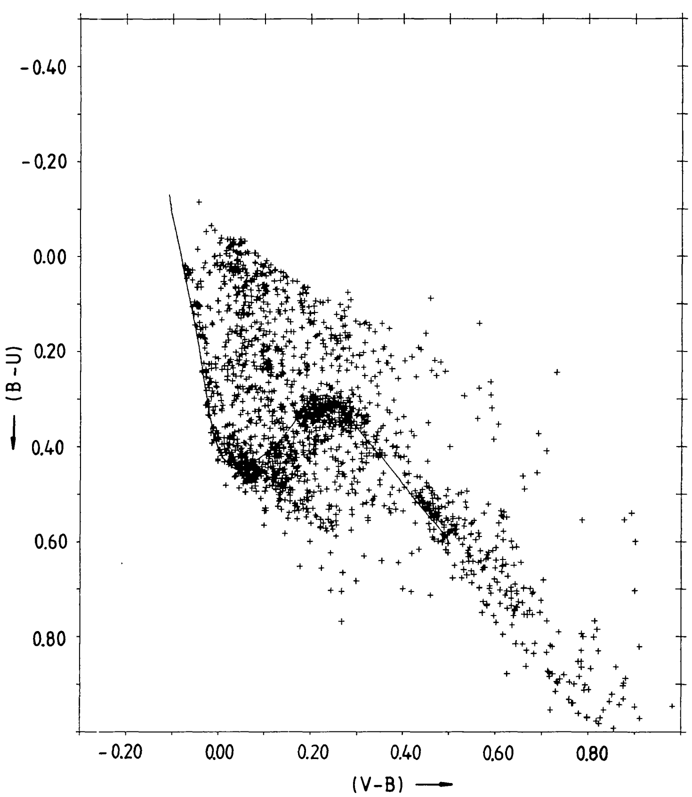

FIGURE A1. — The (*B-U*) *versus* (*V-B*) colour-colour diagram for all stars observed (Paper IV) with V_J brighter than $13^{m}9$. Units along the axis are in log *I*. The solid line is the (semi) empirical ZAMS (see also Tab. AI). The slope of the demarcation at the top of the diagram is that of the reddening line.

TABLE AI. — *Semi-empirical ZAMS relation for the Walraven photometric system.*

Sp. T.	$(V-B)_o$	$(B-U)_o$	$(U-W)_o$	$(B-L)_o$	M_V(ZAMS)	
O4	-0.1216	-0.1963	-0.0713	-0.0965	-5.2	(extrapolation)
O6	-0.1089	-0.1301	-0.0557	-0.0713	-4.0	
O7	-0.1079	-0.1234	-0.0548	-0.0673	-3.9	
O8	-0.1071	-0.1191	-0.0541	-0.0647	-3.7	
O9	-0.1054	-0.1071	-0.0520	-0.0584	-3.5	
B0	-0.1030	-0.0937	-0.0493	-0.0516	-3.1	
B1	-0.0930	-0.0504	-0.0380	-0.0303	-2.3	
B2	-0.0844	-0.0098	-0.0268	-0.0117	-1.6	
B3	-0.0718	0.0504	-0.0128	0.0151	-1.0	
B5	-0.0532	0.1372	0.0096	0.0504	-0.1	
B6	-0.0461	0.1759	0.0210	0.0649	0.3	
B7	-0.0367	0.2327	0.0389	0.0868	0.6	
B8	-0.0258	0.3005	0.0610	0.1133	1.0	
B9	-0.0099	0.3763	0.0891	0.1487	1.4	
A0.5	0.0062	0.4184	0.1112	0.1740	1.65	
A2	0.0256	0.4406	0.1295	0.1944	1.8	
A4	0.0449	0.4477	0.1420	0.2045	2.1	
A5	0.0643	0.4409	0.1533	0.2096	2.3	
A7	0.0837	0.4268	0.1611	0.2104	2.6	
A8	0.1030	0.4134	0.1670	0.2117	2.7	
F0	0.1228	0.3961	0.1707	0.2084	3.0	
F2	0.1465	0.3709	0.1752	0.2047	3.2	
F4	0.1702	0.3372	0.1796	0.1979	3.55	
F8	0.2177	0.2931	0.1915	0.2093	4.2	
G0	0.2651	0.3219	0.2061	0.2643	4.5	
G6	0.3125	0.3768	0.2361	0.3249	5.3	
K0	0.3600	0.4320	0.2731	0.3834	6.0	
K2	0.4074	0.4883	0.3114	0.4436	6.5	
K3-5	0.4548	0.5448	0.3492	0.5027	6.85	

son with the blue envelopes we transformed (log T_{eff}, log g) from the Straizys and Kuriliene tables to Walraven intrinsic colours by interpolating in the theoretical grids. For spectral types earlier than B8, the ZAMS given by Straizys and Kuriliene (1981) follows the blue envelope of data points in the colour-colour diagrams very closely, except for the top part (i.e. the very early spectral types) where we do not find any unreddened stars.

Therefore, for spectral types earlier than B8 we directly adopt the relation between type and colours that follows from the tables of Straizys and Kuriliene and the theoretical grids.

To obtain the Walraven colour $(V\text{-}B)$ (and the corresponding other colours of the blue envelope) as a function of spectral type for stars of type later than B8 we used the relation between spectral type and $(B\text{-}V)_J$ for the ZAMS (taken from Schmidt-Kaler, 1982) and transformed $(B\text{-}V)_J$ to $(V\text{-}B)$ *via* :

$$(V\text{-}B) = 0.0062 + 0.3873\ (B\text{-}V)_J \text{ for } (V\text{-}B) < 0.15$$

(Lub and Pel, pers. commun.), and

$$(V\text{-}B) = -0.0195 + 0.4744\ (B\text{-}V)_J \text{ for } (V\text{-}B) > 0.10$$

(derived using Pel's data on Hyades stars (Pel, pers. commun.)).

For stars of spectral type later than about F0 abundance effects are very important ; the outer envelope we have drawn around the data points is not necessarily the right one for all stars. Therefore, the ZAMS presented in table AI should be treated with the appropriate caution for stars of these spectral types.

Appendix B.

In tables AIIa-e the photometric data for the open clusters (Sect. 4.1, Tab. VII) are collected. Finding charts (Figs. A2-4) are given for OCL 753, OCL 775, and OCL 1003. In these figures, the length of the bar is 2 arcmin. For OCL 871, see Wesselink (1969) ; OCL 1001, see Vogt and Moffat (1973).

Photometric data for NGC 3293 and IC 2944 (Sect. 4.2) are given in tables AIII and AIV respectively.

TABLE AII (a-e). — *VBLUW data for open clusters. The last column in each table gives the number of observations for each star. a) OCL 753 (NGC 2547) ; b) OCL 775 (R 76) ; c) OCL 871 (NGC 4103) ; d) OCL 1001 (NGC 6242) ; e) OCL 1003 (NGC 6281).*

a)

Star	V	V-B	B-U	U-W	B-L	N
1	-0.1666	-0.0470	0.1014	0.0054	0.0341	45
2	-0.9723	0.0333	0.3854	0.0960	0.1597	1
3	-0.8072	-0.0095	0.3307	0.0759	0.1152	1
4	-0.4026	-0.0300	0.1738	0.0270	0.0610	1
7	0.1793	-0.0480	0.0977	0.0040	0.0302	1
8	-0.3933	-0.0354	0.1488	0.0229	0.0515	1
9	-1.6455	0.1442	0.3759	0.1575	0.2004	1
10	-0.5969	-0.0175	0.2256	0.0431	0.0841	1
11	-0.6897	0.0059	0.3242	0.0790	0.1202	1
15	-1.5603	0.1216	0.4148	0.1560	0.2102	1
16	-1.4074	0.1357	0.3859	0.1642	0.2123	1
17	-1.4752	0.1088	0.4162	0.1627	0.2154	1
18	-1.3358	0.0749	0.4464	0.1407	0.2105	1
19	-0.8576	-0.0050	0.3661	0.0726	0.1421	1
21	-0.7812	0.0230	0.4142	0.1015	0.1756	1
23	-0.5387	-0.0354	0.1636	0.0230	0.0574	1
24	-0.7333	0.0132	0.3579	0.0832	0.1275	1
25	-0.9846	0.0007	0.3842	0.0867	0.1553	1
26	-1.1477	0.0200	0.4031	0.0972	0.1746	1
29	-1.2634	0.0706	0.4401	0.1348	0.2142	1
30	-1.3364	0.1184	0.4465	0.1760	0.2198	1
32	0.2273	-0.0672	0.0264	-0.0195	0.0035	1
33	-1.0923	0.0177	0.2592	0.0662	0.1018	1
36	-0.5275	-0.0220	0.2250	0.0382	0.0814	1
37	-0.6030	0.0318	0.2474	0.0626	0.0969	1
38	-0.4669	-0.0144	0.2819	0.0533	0.1011	1
41	-0.5699	-0.0070	0.3721	0.0779	0.1424	1

b)

Star	V	V-B	B-U	U-W	B-L	N
2	-2.4095	0.1843	0.4577	0.1743	0.1847	1
3	-2.2774	0.1559	0.4905	0.1593	0.1768	1
4	-2.6295	0.1680	0.4464	0.1399	0.2012	1
5	-2.3771	0.1630	0.4276	0.1497	0.1776	1
6	-2.2709	0.1200	0.3517	0.1249	0.1342	1
11	-2.0854	0.1304	0.4211	0.1694	0.1532	1
12	-2.2684	0.1224	0.3951	0.1737	0.1566	1
14	-2.7334	0.1594	0.4575	0.1616	0.1999	1

c)

Star	V	V-B	B-U	U-W	B-L	N
1	-1.1552	0.0355	0.0662	0.0270	0.0304	1
2	-1.1674	0.0476	0.1294	0.0470	0.0470	1
4	-1.2431	0.0498	0.1117	0.0393	0.0451	1
6	-1.1752	0.0477	0.1225	0.0436	0.0544	1
7	-1.3344	0.0367	0.0931	0.0428	0.0402	1
9	-1.6481	0.0708	0.1770	0.0696	0.0818	1
10	-0.8749	0.0619	0.1228	0.0538	0.0472	1
13	-1.4407	0.0599	0.1203	0.0463	0.0521	1
80	-1.6377	0.0643	0.1203	0.0478	0.0566	1
192	-1.9886	0.0746	0.2221	0.0705	0.0877	1
333	-1.3677	0.0436	0.1171	0.0445	0.0465	1

d)

Star	V	V-B	B-U	U-W	B-L	N
1	-0.6539	0.1033	0.2357	0.0987	0.0878	2
2	-0.8914	0.1090	0.2281	0.0958	0.0889	2
3	-1.2253	0.1040	0.2259	0.0846	0.0977	2
4	-1.1557	0.1258	0.1930	0.1049	0.0922	3
5	-1.2625	0.1127	0.2313	0.1002	0.0930	2
7	-2.1239	0.1316	0.3554	0.1323	0.1595	2
8	-2.1190	0.1401	0.3608	0.1484	0.1773	2
9	-1.8937	0.1173	0.2830	0.0956	0.1245	3
10	-2.1361	0.1377	0.3964	0.1468	0.1648	2
11	-1.9949	0.1054	0.3046	0.1005	0.1302	2
12	-1.1324	0.0999	0.1596	0.0923	0.0757	2
13	-1.3944	0.0913	0.2337	0.0845	0.1041	2
14	-1.4440	0.0927	0.1992	0.0808	0.0914	2
15	-1.5793	0.1071	0.2257	0.0897	0.1037	2
20	-1.6693	0.1055	0.2302	0.0903	0.1079	2
21	-1.6764	0.1123	0.2396	0.0930	0.1098	2
23	-1.8630	0.1329	0.3144	0.1064	0.1378	2

e)

Star	V	V-B	B-U	U-W	B-L	N
1	-1.1213	0.0454	0.4160	0.1106	0.1597	1
3	-0.8663	0.0326	0.3767	0.1065	0.1265	1
4	-1.2334	0.0766	0.4307	0.1290	0.1809	1
5	-1.4787	0.1402	0.4544	0.1513	0.2318	1
9	-0.9754	0.0585	0.4379	0.1274	0.1546	1
18	-1.0555	0.0656	0.4457	0.1478	0.1671	1
19	-1.1431	0.0740	0.4624	0.1524	0.1808	1

TABLE AIII. — *VBLUW data for NGC 3293. The last column gives the number of observations for each star.*

Feast Number	V	V-B	B-U	U-W	B-L	N
1	-0.5147	-0.0097	-0.0556	-0.0072	-0.0227	1
2	-0.8931	0.0723	0.0458	0.0379	0.0214	1
3	0.0533	0.0390	-0.0089	0.0234	-0.0031	2
4	0.1257	0.0181	-0.0369	0.0056	-0.0163	1
5	-0.8580	-0.0106	-0.0006	-0.0033	-0.0007	1
6	-0.5416	0.0383	0.0070	0.0240	0.0031	2
7	-0.6930	0.0275	0.0252	0.0217	0.0085	2
8	-0.5620	0.0791	0.0344	0.0470	0.0185	1
10	-1.0660	0.0233	0.0272	0.0128	0.0161	1
11	-1.1503	0.0091	0.0187	0.0086	0.0087	1
14	-0.9617	-0.0094	-0.0015	-0.0032	-0.0040	1
15	-1.1504	0.0465	-0.0069	0.0382	0.0209	1
16	-0.7702	0.0074	0.0117	0.0078	0.0023	1
18	-0.9395	-0.0054	0.0122	0.0004	0.0068	1
19	-0.8895	0.0823	0.0365	0.0343	0.0211	1
20	-0.4672	0.0220	-0.0021	0.0138	-0.0036	1
21	-0.1702	1.0059	1.0903	0.8401	0.8591	2
22	-0.3046	0.0515	0.0260	0.0332	0.0122	2
23	-0.9416	0.0189	0.0150	0.0061	0.0065	1
24	-0.9500	0.0236	0.0158	0.0167	0.0069	1
25	-0.5048	0.0413	0.0155	0.0271	0.0078	1
27	-0.8329	0.0315	0.0387	0.0178	0.0170	1

TABLE AIV. — *VBLUW data for IC 2944. The last column gives the number of observations for each star.*

HD, HDE or CPD	V	V-B	B-U	U-W	B-L	N
101008	-0.9115	0.0050	-0.0394	-0.0098	-0.0161	1
101070	-0.8325	0.0158	-0.0130	0.0054	0.0006	1
101084	-0.9221	0.0330	0.0275	0.0184	0.0212	2
101131	-0.1061	0.0235	-0.0360	0.0049	-0.0066	2
101190	-0.1816	0.0314	-0.0357	0.0066	-0.0060	1
101191	-0.6542	0.0307	-0.0256	0.0102	-0.0030	2
101205	0.1459	0.0299	-0.0306	0.0083	-0.0046	2
101223	-0.7412	0.0772	0.0120	0.0369	0.0195	1
101298	-0.4848	0.0445	-0.0273	0.0173	-0.0015	1
101333	-0.8398	0.0482	-0.0033	0.0208	0.0076	1
101413	-0.5948	0.0445	-0.0069	0.0183	0.0072	1
101436	-0.2937	0.0422	-0.0249	0.0133	-0.0029	1
308815	-1.1138	0.0416	0.0217	0.0180	0.0163	1
-62 2156	-1.1095	0.0213	-0.0199	0.0031	-0.0009	2
-62 2157	-1.5200	0.0386	0.0645	0.0290	0.0433	2
-62 2158	-0.9726	0.0248	-0.0217	0.0022	-0.0036	2
-62 2160	-1.2951	0.0681	0.2774	0.1090	0.0909	2
-62 2184	-1.5358	0.1067	0.2651	0.0675	0.1134	1
-62 2185	-1.3032	0.0598	0.0343	0.0211	0.0249	1
-62 2188	-1.0789	0.0400	0.0283	0.0269	0.0236	1
-62 2216	-1.6936	0.0596	0.0624	0.0347	0.0387	1

FIGURE A2. — Finding chart for OCL 753.

FIGURE A4. — Finding chart for OCL 1003.

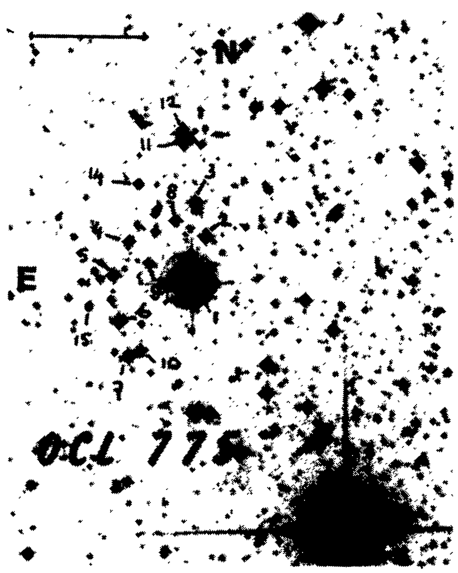

FIGURE A3. — Finding chart for OCL 775.

The stars listed in table AV are not shown in the finding chart for OCL 753 (column 1 identifies the star, columns 2 and 3 give the RA and DEC respectively; column 4 lists the Johnson apparent magnitude).

TABLE AV. — *Coordinates and Johnson apparent visual magnitudes for stars in OCL 753, not shown in the finding chart (Fig. A2).*

	(1950)		
Star nr.	RA	DEC	V_J
24	$8^h07^m07^s.2$	-49°31'55"	8.72
25	8 08 14 .0	-49 27 52	9.35
26	8 09 06.0	-49 23 40	9.75
29	8 03 57.4	-48 37 01	10.04
30	8 04 59.1	-48 38 45	10.21
32	8 05 12.0	-48 21 08	6.32
33	8 10 24.0	-48 35 44	9.61
36	8 12 39.6	-49 04 54	8.20
37	8 14 00.4	-48 53 45	8.39
38	8 13 46.2	-49 01 34	8.05
41	8 14 31.9	-49 01 49	8.31

References

ARDEBERG, A., MAURICE, E. : 1977a, *Astron. Astrophys. Suppl. Ser.* **28,** 153.
ARDEBERG, A., MAURICE, E. : 1977b, *Astron. Astrophys.* **54,** 233.
BECKER, W., FENKART, R. : 1971, *Astron. Astrophys. Suppl. Ser.* **4,** 241.
BERTIAU, F. C. : 1958, *Astrophys. J.* **128,** 533.
BLAAUW, A. : 1963, Basic Astronomical Data, Ed. K. Aa. Strand (Univ. of Chicago Press), p. 383.
BRAND, J. : 1986, Ph.D. Thesis, University Leiden.
BRAND, J., BLITZ, L., WOUTERLOOT, J. G. A. : 1986, *Astron. Astrophys. Suppl. Ser.* **65,** 537 (Paper I).
BRAND, J., BLITZ, L., WOUTERLOOT, J. G. A., KERR, F. J. : *Astron. Astrophys. Suppl. Ser.* **68,** 1 (Paper II) (Erratum in *ibid.*, **69,** 343).
BUSCOMBE, W. : 1977, MK Spectral Classification (Evanston).
BUSCOMBE, W. : 1980, *ibid.* Suppl.
CHINI, R., KRÜGEL, E. : 1983, *Astron. Astrophys.* **117,** 289.
DE GEUS, E. J. : 1984, Age Determination of OB-Associations (internal report Sterrewacht Leiden).
DE GEUS, E. J., DE ZEEUW, P. T., LUB, J. : 1988, *Astron. Astrophys. Suppl. Ser.* (in press).
DE RUITER, H. R., LUB, J. : 1986, *Astron. Astrophys. Suppl. Ser.* **63,** 95.
FEAST, M. W. : 1958, *Mon. Not. R. Astron. Soc.* **118,** 618.
FEAST, M. W., SHUTTLEWORTH, M. : 1965, *Mon. Not. R. Astron. Soc.* **130,** 245.
FERNIE, J. D. : 1959, *Mon. Not. Astron. Soc. South Africa* **18,** 57.
FERNIE, J. D. : 1960, *Mon. Not. Astron. Soc. South Africa* **19,** 120.
GATHIER, R., POTTASCH, S. R., PEL, J. W. : *Astron. Astrophys.* **157,** 171.
HARTWICK, F. D. A., HESSER, J. E., MCCLURE, R. D. : 1972, *Astrophys. J.* **174,** 557.
HEJLESEN, P. M. : 1980, *Astron. Astroph. Suppl. Ser.* **39,** 347.
JOHNSON, H. L., HILTNER, W. A. : 1956, *Astrophys. J.* **123,** 267.
JONES, D. H. P. : 1971, *Mon. Not. R. Astron. Soc.* **152,** 231.
KING, I. R., RAFF, M. I. : 1977, *Proc. Astron. Soc. Pac.* **89,** 120.
KURUCZ, R. L. : 1979, *Astrophys. J. Suppl. Ser.* **40,** 1.
LUB, J. : 1977, Ph.D. Thesis, University Leiden.
LUB, J. : 1979, *ESO Messenger* **19,** 1.
LUB, J., PEL, J. W. : 1977, *Astron. Astrophys.* **54,** 137.
MIHALAS, D. : 1978, Stellar Atmospheres (2nd éd. ; Freeman and Co.).
MIHALAS, D., BINNEY, J. : 1981, Galactic Astronomy, 2nd éd. (Freeman and Co.).
MOFFAT, A. F. J., VOGT, N. : 1973, *Astron. Astrophys. Suppl. Ser.* **10,** 135.
PEL, J. W. : 1976, Ph. D. Thesis, University Leiden.
RIEKE, C. A. : 1935, Harvard College Observatory Circular No 397.
RUPRECHT, J., BALÁZS, B., WHITE, R. E. : 1981, Catalogue of Star Clusters and Associations (Akadémiai Kaidó Budapest).
SCHILD, R. E. : 1970, *Astrophys. J.* **161,** 855.
SCHMIDT-KALER, Th. : 1965, Landolt-Börnstein, Vol. **VI/1** (Springer).
SCHMIDT-KALER, Th. : 1982, *ibid.* Vol. **VI/2b**.
SEGGEWISS, W. : 1968, *Z. Astrophys.* **68,** 142.
SHOBBROOK, R. S. : 1983, *Mon. Not. R. Astron. Soc.* **205,** 1215.
STRAIZYS, V., KURILIENE, G. : 1981, *Astrophys. Space Sci.* **80,** 353.
THACKERAY, A. D., WESSELINK, A. J. : 1965, *Mon. Not. R. Astron. Soc.* **131,** 121.
TURNER, D. G. : 1976, *Astron. J.* **81,** 97.
TURNER, D. G., GRIEVE, G. R., HERBST, W., HARRIS, W. E. : 1980, *Astron. J.* **85,** 1193.
VOGT, N., MOFFAT, A. F. J. : 1973, *Astron. Astroph. Suppl. Ser.* **9,** 97.
VOIGT, H.-H. : 1974, Outline of Astronomy (Noordhoff, Leiden) Vol. II, p. 326.
WALRAVEN, Th., WALRAVEN, J. H. : 1960, *Bull. Astron. Inst. Neth.* **15,** 67.
WESSELINK, A. J. : 1969, *Mon. Not. R. Astron. Soc.* **146,** 329.