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INVESTIGATION OF ULTRAVIOLET FLUXES OF NORMAL AND PECULIAR STARS

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Final Report

Principal Investigators

Dr. William A. Deutschman
Dr. Rudolph E. Schild

Prepared for

National Aeronautics and Space Administration
Washington, D.C. 20546

April 1974

Smithsonian Institution
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ABSTRACT

We have analyzed data from Project Celescope, a program that photographed the ultraviolet sky, in order to study several problems in current astrophysics. Data for two star clusters, the Pleiades and the Hyades, reveal differences between the two that we are unable to explain simply from their differences in chemical abundance, rotation, or reddening. Data for Orion show large scatter, which appears to be in the sense that the Orion stars are too faint for their ground-based photometry. Similarly, many supergiants in the association Sco OB1 are too faint in the ultraviolet, but the ultraviolet brightness appears to be only poorly correlated with spectral type.

Ultraviolet Celescope data for several groups of peculiar stars have also been analyzed. The strong He I stars are too faint in the ultraviolet, possibly owing to enhancement of O II continuous opacity due to oxygen overabundance. The Be stars appear to have ultraviolet colors normal for their MK spectral types. The P Cygni stars are considerably fainter than main-sequence stars of comparable spectral type, probably owing, at least in part, to line blocking by resonance lines of multiply ionized light metals. The Wolf-Rayet stars have ultraviolet color temperatures of O stars.

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1. CLUSTERS AND ASSOCIATIONS

1.1 Introduction

In dealing with poorly understood problems in astrophysics, it is customary to investigate star clusters because at least two parameters – mass and initial chemical composition – are common to all stars in a particular cluster. The principal remaining parameter for all the cluster stars is the stellar mass, although the principal observed quantity is the color, which must then be related to mass. We have concentrated our study on clusters to see how well color measured in the visible (B - V) compares with ultraviolet colors (U_2 - V and U_3 - V).

Because only a few clusters permitted Celescope observations (Davis, Deutschman, and Haramundanis, 1973) of individual stars, owing to crowding, we have considered, in addition, two large aggregates that appear to be coeval, called associations. These are the Orion Belt association and the association Sco OB1.

1.2 Pleiades, Hyades, and IC 2602

We list in Tables 1, 2, and 3 the relevant ground-based and Celescope photometry for the Pleiades, Hyades, and IC 2602 (θ Carinae cluster), respectively. The tables give the HD number identifying each star, the ground-based B - V and U - B colors, the spectral type, the color excess E(B - V), the magnitude V, and the ultraviolet colors corrected for interstellar extinction $(U_2 - V)_0$ and $(U_3 - V)_0$. Ratios $X_2 = 3.6 = E(U_2 - V)/E(B - V)$ and $X_3 = 5.0 = E(U_3 - V)/E(B - V)$ from Peytremann and Davis (1974) were used to derive corrected colors for all stars in Tables 1 to 5.

Table 1. Ground-based and Celescope data for Pleiades stars.

HD	B - V	U - B	Spectral type	E(B - V)	V	$(U_2 - V)_0$	$(U_3 - V)_0$
23155	0.15	0.10	A4	0.04	7.51	3.97	–
23156	0.25	0.14	A7V	0.05	8.23	3.72	–
23194	0.20	0.15	A5V	0.05	8.06	4.04	–
23287	0.39	0.01	F3V	0.00	8.95	4.88	–
23288	-0.04	-0.33	B7IV	0.08	5.46	2.27	3.02
23302	-0.11	-0.41	B6III	0.03	3.71	2.54	2.81
23324	-0.07	-0.36	B8V	0.00	5.65	2.65	3.48
23338	-0.11	-0.46	B6V	0.03	4.31	2.48	3.03
23361	0.21	0.18	A3V	0.12	8.04	3.65	–
23402	0.19	0.15	A5	0.04	7.81	3.58	–
23408	-0.07	-0.40	B7III	0.05	3.88	2.70	2.99
23410	0.04	0.01	A0	0.04	6.85	3.07	4.15
23430	0.22	0.12	A7	0.04	8.02	4.31	–
23432	-0.04	-0.23	B8V	0.05	5.76	2.24	–
23479	0.32	0.07	A7V	0.04	7.96	3.88	–
23480	-0.06	-0.43	B6IVnn	0.08	4.18	2.35	2.64
23489	0.10	0.12	A2V	0.04	7.35	3.25	–
23567	0.36	0.12	A9V	0.09	8.28	4.42	–
23568	0.02	-0.07	B9.5V	0.05	6.80	2.84	–
23610	0.25	0.13	A7	0.04	8.13	4.21	–
23628	0.21	0.12	A4V	0.09	7.66	3.68	–
23630	-0.09	-0.34	B7III	0.03	2.87	3.02	3.33
23631	0.05	0.04	A2V	0.00	7.26	3.74	4.72
23632	0.03	0.05	A1V	0.00	6.99	–	4.48
23642	0.06	0.02	A0V	0.04	6.81	3.10	–
23643	0.15	0.12	A3V	0.06	7.77	3.19	–
23664	0.26	0.14	A7	0.04	8.30	4.76	–
23733	0.36	0.11	A9V	0.09	8.27	4.07	–
23753	-0.07	-0.32	B8V	0.02	5.45	2.85	3.41
23763	0.12	0.09	A1V	0.09	6.95	2.97	–
23791	0.29	0.13	A8V	0.06	8.37	4.28	–

Table 1 (Cont.)

HD	B - V	U - B	Spectral type	E(B - V)	V	$(U_2 - V)_0$	$(U_3 - V)_0$
23850	-0.08	-0.36	B8III	0.01	3.64	2.93	3.26
23852	0.18	0.12	A4	0.04	7.72	3.59	–
23862	-0.08	-0.28	B8p	0.01	5.09	2.47	3.38
23863	0.22	0.10	A7V	0.02	8.12	3.89	–
23873	-0.03	-0.12	B9.5V	0.00	6.60	2.75	4.02
23886	0.18	0.13	A3V	0.09	7.97	3.21	–
23913	0.03	-0.02	B9.5	0.04	7.00	3.15	3.96
23923	-0.05	-0.19	B9V	0.01	6.17	2.97	3.97
23924	0.22	0.13	A7V	0.02	8.10	4.13	–
23948	0.08	0.08	A1	0.04	7.54	3.18	–
23949	0.17	0.14	A5	0.04	9.17	3.49	–
23950	-0.01	-0.32	B8III	0.08	3.6v	5.59	5.28
23964	0.06	-0.06	A0V	0.04	6.74	2.82	4.16
23985	0.24	0.08	A7	0.04	5.24	4.44	6.16
24013	0.13	0.12	A3	0.04	7.42	3.71	–
24076	0.09	0.03	A2V	0.03	6.93	3.11	–

In Figure 1, we compare the ultraviolet color-color diagrams for the Pleiades and the Hyades, where we see a clear separation between them in their $U_2 - V$ colors. Because the Hyades are unreddened and reddening in the Pleiades is very small ($E(B-V) = 0.04$), this difference is not likely to be due to reddening effects and is insensitive to the choice of X_2 and X_3. The Pleiades and Hyades are close in the sky, and the Pleiades measurements were made between several sets of Hyades measurements; therefore, it is very unlikely that small orientation or time-variable calibration effects cause the observed difference. The Pleiades data may be affected by completeness, especially for $B - V \geq 0.15$; however, the mean Pleiades relation in Figure 1 can be seen to be a smooth continuation of the $U_2 - V$ relation for hotter stars in both the Pleiades and the θ Carinae cluster. The agreement of the Hyades with the mean color-color calibration of Peytremann and Davis (1974) may not be

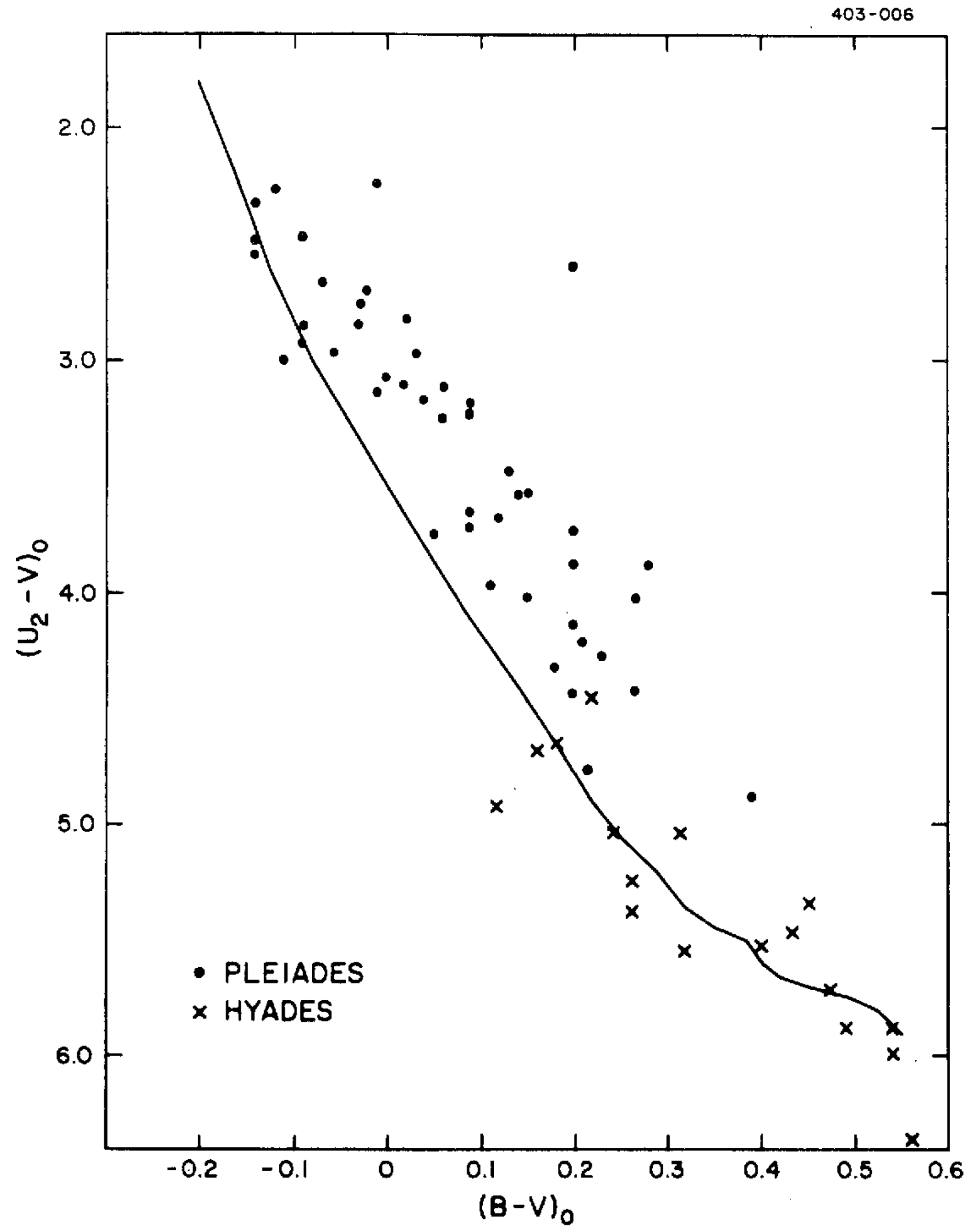

Figure 1. Ultraviolet color-color diagram for the Pleiades (dots) and Hyades (crosses). All colors have been corrected for interstellar reddening. Data for Pleiades stars may be affected by completeness, since observations were made to a magnitude limit in U_2.

significant because their calibration is based largely on Hyades stars, especially for the coolest stars. In principle, the earlier intrinsic color relation of Haramundanis and Payne-Gaposchkin (1973) can also be applied in the comparison, but it does not significantly differ from that of Peytremann and Davis. We have used the latter because it contains the calibration of giant stars.

Table 2. Ground-based and Celescope data for Hyades stars.

HD	B - V	U - B	Spectral type	V	$(U_2 - V)_0$	$(U_3 - V)_0$
27459	0.22	0.10	A9V	5.26	4.42	–
27561	0.40	0.00	F4V	6.61	5.51	–
27628	0.32	0.10	Am	5.72	5.51	–
27691	0.56	0.09	G0V	6.99	6.35	–
27991	0.49	0.02	F5V	6.46	5.87	–
28034	0.54	0.08	F8V	7.49	5.88	–
28205	0.54	0.06	F8V	7.42	5.97	–
28307	0.96	0.74	G9III	3.85	7.98	–
28319	0.18	0.13	A7IVn	3.41	4.63	–
28406	0.45	0.00	F6V	6.92	5.33	–
28546	0.26	0.10	Am	5.48	5.39	7.88
28556	0.26	0.09	F0Vn	5.40	5.24	7.84
28910	0.24	0.09	A8Vn	4.66	5.02	8.03
28911	0.43	0.00	F5V	6.62	5.49	–
29225	0.43	0.01	F5V	6.65	5.71	–
29338	0.12	0.11	A6Vn	4.27	4.91	–
29375	0.31	0.06	F0V	5.79	5.03	–
29488	0.16	0.12	A5Vn	4.68	4.68	–

Some differences between the Pleiades and the Hyades stars have previously been cited in the literature. Chaffee, Carbon, and Strom (1971) noted that Hyades stars have 50% higher metals abundances than do Pleiades stars and the sun. The Hyades are known to have many metallic-line stars, and Struve (1945) showed the Pleiades to have significantly higher mean projected rotational velocities.

Table 3. Ground-based and Celescope data for θ Carinae (IC 2602) stars.

HD	B - V	U - B	Spectral type	E(B - V)	V	$(U_2 - V)_0$	$(U_3 - V)_0$
92536	-0.08	-0.31	B8IV	0.01	6.34	2.83	3.72
92783	-0.05	-0.22	B8V	0.01	6.74	–	3.53
92938	-0.15	-0.58	B3V	0.01	4.81	2.07	0.48
93030	-0.23	-1.03	B0Vp	0.05	2.78	1.49	0.35
93163	-0.02	-0.55	B3V	0.15	5.79	2.15	2.28
93194	-0.14	-0.62	B5V	0.03	4.84	2.15	2.11
93540	-0.10	-0.48	B6V	0.04	5.36	2.21	–
93549	-0.09	-0.48	B7IV	0.05	5.26	2.26	–
93607	-0.15	-0.65	B4V	0.03	4.87	1.92	–
93714	0.00	-0.60	B2IV	0.24	6.57	1.93	1.29
93738	0.00	-0.16	A0V	0.05	6.48	3.02	3.56

Before considering the effects of abundance and rotation on ultraviolet fluxes, we might ask how field stars compare to the mean Pleiades and Hyades relations. In Figure 2, we have plotted $U_2 - V$ against spectral type, because UBV photometry is not available for a significant number of A stars having Celescope photometry. We see from the figure that the A stars in the field have far-ultraviolet fluxes similar to the Hyades stars, whereas the F stars are, if anything, fainter in the ultraviolet.

We consider now the effects of abundances on the far-ultraviolet and visible fluxes. We have reviewed the models of Chaffee et al. (1971) to determine the effects of metals overabundance on the U_2 and V fluxes. In Figure 3, we have plotted the far-ultraviolet fluxes for 25 and 50% metals overabundances, where 50% is the value adopted by Chaffee et al. For a 50% overabundance, these models predict that the ultraviolet fluxes in U_2 will be depressed by 0.21 mag, while the V magnitude will be increased by 0.025 mag. If we extrapolate these results to account for the Hyades (and field star!) ultraviolet deficiencies, we would need a factor of 2.5 overabundance of metals in Hyades and field stars relative to the sun and Pleiades stars. This large metals overabundance seems precluded by direct abundance determinations. Note that even such a large amount of ultraviolet line blocking, interpreted as an overabundance

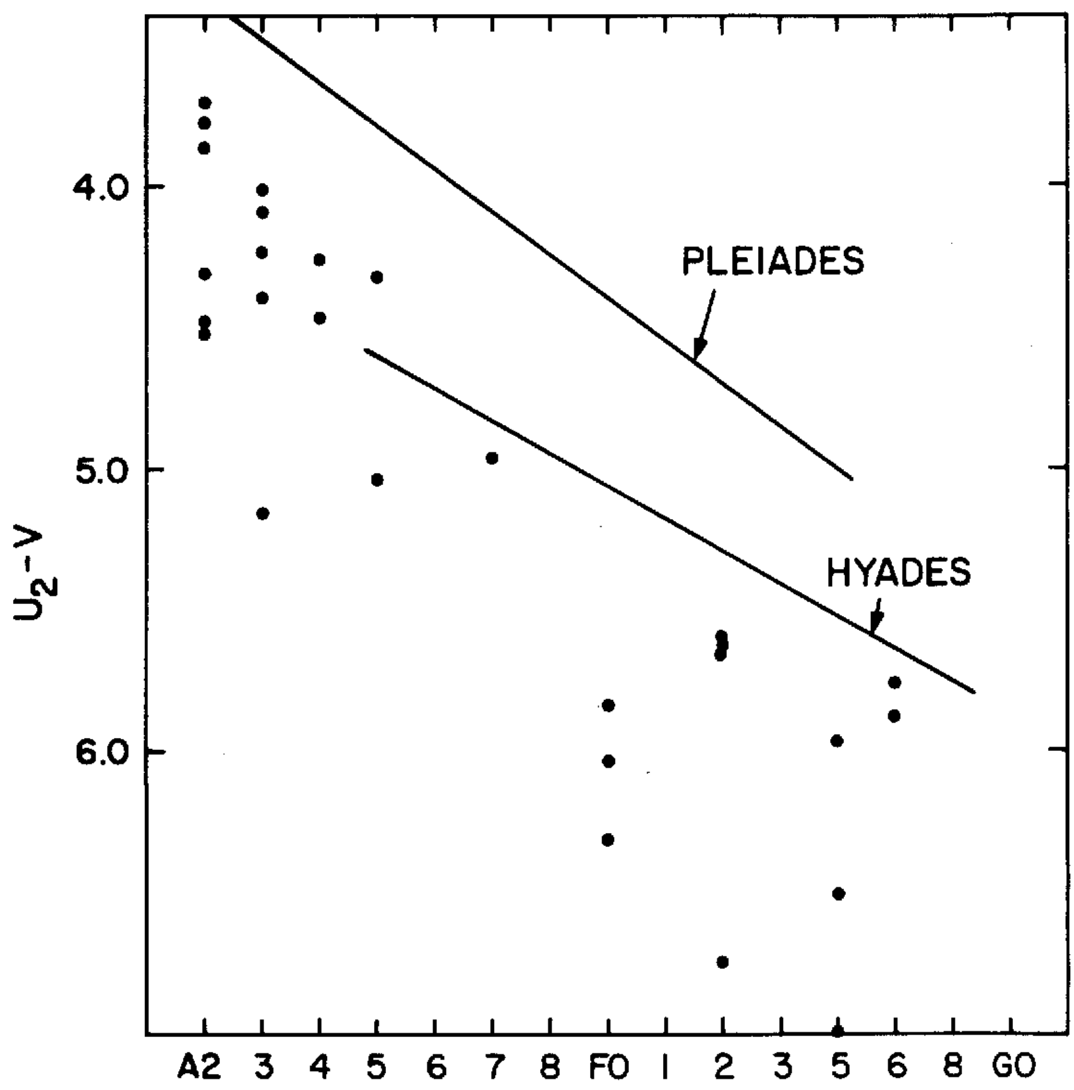

Figure 2. A comparison of the $U_2 - V$ fluxes of field stars, as a function of spectral type, with the mean Pleiades and Hyades relations. Not only are the field stars fainter at U_2, but the scatter is much greater than for stars in coeval groups.

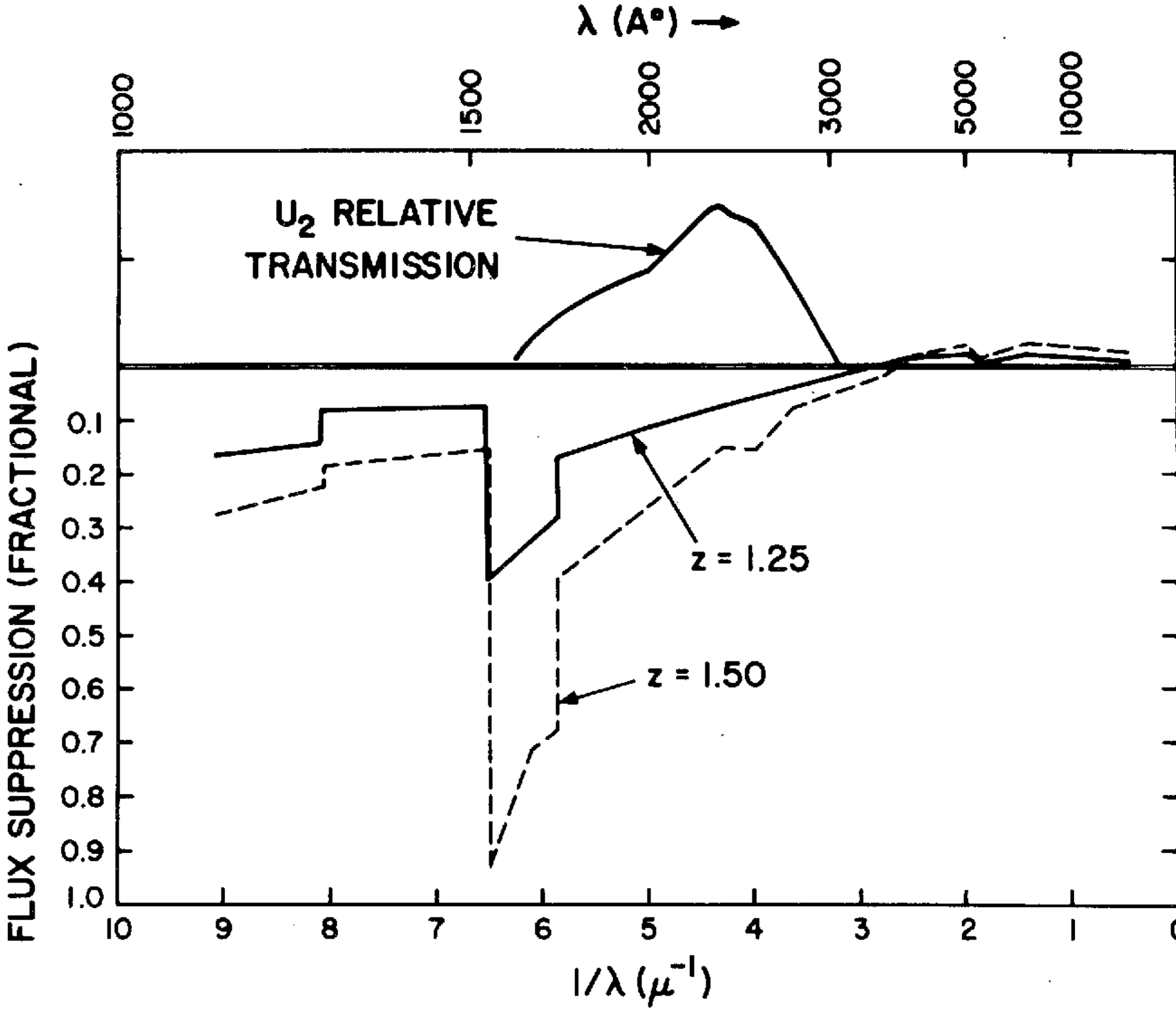

Figure 3. Ultraviolet flux suppression as a result of metals overabundance in a $T_{eff} = 7500$ K main-sequence star. The two curves show the suppression computed for 25 and 50% metals overabundances relative to the sun. Note that the curves change sign in the visible and near infrared, showing that the flux escapes the star in these spectral regions.

effect, appears to cause no more than a 0.1-mag increase in the V magnitude at constant T_{eff}. This is because the V magnitude is also strongly affected by blocking, and much of the radiation escapes in the infrared.

We conclude that if the Hyades ultraviolet deficiency is an effect of line blocking due to metals overabundance, the visual magnitudes are not likely to be affected by more than 0.1 mag; however, a metals overabundance sufficient to depress the ultraviolet as observed should have been easily detected in direct abundance determinations from coudé spectra.

We next consider the possibility that differences in rotation cause the observed differences in ultraviolet flux. Hardorp and Strittmatter (1968) have computed energy distributions of nonrotating and critically rotating stars. For a T_{eff} = 8600 K star, they find that, compared to a nonrotating star, a pole-on star rotating at 99% of breakup velocity is only 0.06 mag bluer in $U_2 - V$. Of course, the pole-on star and the rapid rotator both have sharp spectral lines. Relative to the sharp-lined stars, the critically rotating stars seen equator-on are 0.6 mag <u>fainter</u> in $U_2 - V$. Thus, whereas rotation can produce large changes in the ultraviolet fluxes, the sense is wrong to account for the fact that the apparently more rapidly rotating Pleiades stars are brighter in the ultraviolet than the Hyades and field stars.

It is well known that the Hyades have a relatively greater number of Am and Ap stars than do the Pleiades. Since the Am stars are binaries, could the presence of binary components cause the Pleiades-Hyades difference? For example, if secondary components contribute to the V magnitude, then the binaries will be fainter in $U_2 - V$. However, we feel that binary secondaries are not the cause of the observed differences in ultraviolet flux, because of the following:

A. From the amount of the effect, essentially all the binary systems would have to have equally luminous components.

B. The known spectroscopic binaries and Am stars are not displaced from the nonbinaries in Figure 1.

C. The nonbinary Hyades are redder in $U_2 - V$ than the Pleiades spectroscopic binaries.

We conclude that the ultraviolet faintness of the Hyades relative to that of the Pleiades stars measured by the Celescope experiment does not have a simple explanation in abundance, rotation, or spectrum peculiarity. As we have seen, for the observed ultraviolet faintness of the Hyades to be an abundance effect, the metals abundance would have to be so high as to have been detected on coudé spectra. Supression of the ultraviolet by rotation effects is in the wrong sense for the known difference in projected rotational velocities between the Pleiades and the Hyades. And the identification of the stars in Figure 1 known to be spectroscopically peculiar shows them not to be responsible for the effect. Until the origin of this ultraviolet difference is understood, the method of cluster fitting based on the Hyades must be applied with caution.

An ultraviolet color-color diagram for U_2 is shown in Figure 4, where data for θ Carinae are compared with the Pleiades and the mean relation of Peytremann and Davis (1974). This figure suggests that data for θ Carinae agree with the mean color curve of Peytremann and Davis and that the Pleiades stars are too bright in U_2.

The two bluest stars depart significantly from the mean curve. The strongest of these is θ Carinae, a B0p star known to have enhanced strength of absorption lines of light metals. It is tempting to speculate that enhanced absorption is significantly depressing the continuum at U_2. The second blue star departing from the mean cluster line is HD 93714, a star that from its spectroscopic parallax is a probable nonmember background star. Its B - V color excess exceeds the cluster mean by 0.21, consistent with its being a background star.

1.3 Orion

Because irregularities in the reddening or intrinsic properties of stars in the Orion Sword region are well known, we have limited our investigation to the Orion Belt region. This region has been studied by Sharpless (1952, 1954), and spectral types and UBV photometry are available for many stars. In Table 4, we list stars in the area (1900) $5^h15^m \leq \alpha \leq 5^h45^m$, $-4° \leq \delta \leq +2°$ having ground-based and Celescope data.

Schild and Chaffee (1971) have studied the peculiar ultraviolet colors of stars in the Orion Belt and found that the HD spectral types are in large systematic error with

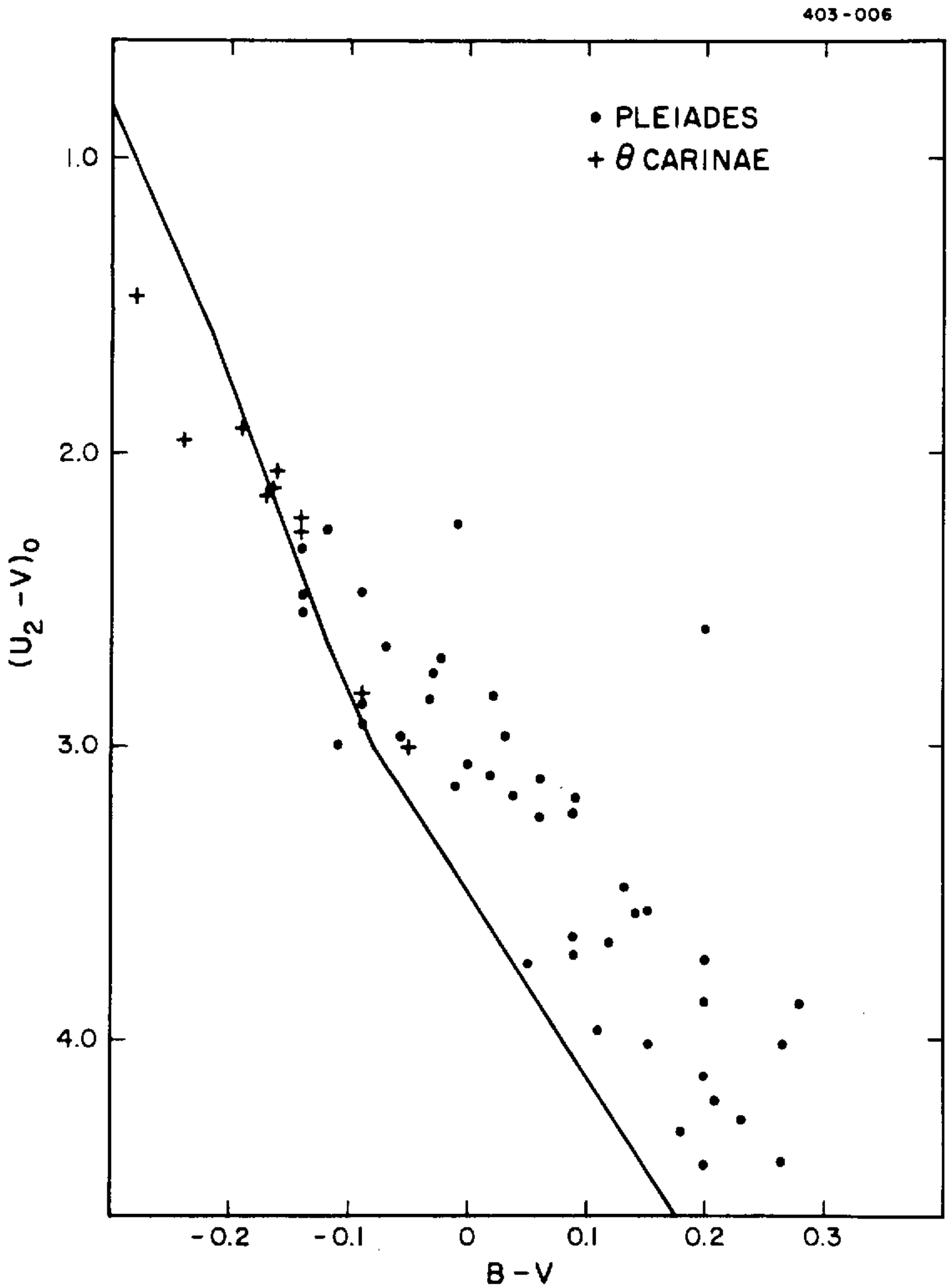

Figure 4. Reddening-corrected ultraviolet color-color diagram comparing θ Carinae with the Pleiades. The mean relation of Peytremann and Davis (1974) is shown for comparison (solid line).

Table 4. Ground-based and Celescope data for the Orion Belt stars.

HD	B - V	U - B	Sp (Q)	E(B - V)	V	$(U_2 - V)_0$	$(U_3 - V)_0$
35203	-0.09	-0.50	B5	0.06	7.97	3.35	3.02
35298	-0.14	-0.59	B5	0.04	7.88	2.57	2.63
35407	-0.16	-0.62	B3	0.00	6.31	2.34	1.64
35439	-0.21	-0.91	B1	0.05	4.94	2.04	0.94
35501	-0.06	-0.40	B6	0.06	7.42	2.63	3.54
35502	-0.03	-0.54	B3	0.13	7.35	2.28	–
35588	-0.18	-0.77	B3	0.02	6.14	2.25	1.30
35640	-0.07	-0.21	B9	0.00	6.23	3.06	–
35673	0.00	-0.23	B8	0.10	6.50	3.01	3.25
35715	-0.22	-0.92	B1	0.02	4.60	2.30	0.70
35730	-0.15	-0.69	B3	0.05	7.20	1.80	1.14
35762	-0.18	-0.73	B3	0.06	6.74	1.79	0.80
35834	-0.05	-0.37	B7	0.06	7.67	–	2.54
35881	-0.09	-0.50	B5	0.07	7.77	3.53	2.11
35910	-0.10	-0.55	B5	0.07	7.58	1.87	1.79
35912	-0.18	-0.74	B3	0.06	6.36	1.97	0.83
35971	-0.06	-0.24	B8	0.02	6.67	3.59	–
36012	-0.10	-0.65	B3	0.06	7.24	2.46	2.42
36013	-0.14	-0.65	B3	0.10	6.89	1.51	1.04
36058	-0.02	-0.08	B9.5	0.04	6.38	2.53	–
36120	-0.03	-0.36	B7	0.09	7.96	2.58	–
36133	-0.09	-0.60	B3	0.11	6.94	–	1.01
36151	-0.13	-0.57	B5	0.03	6.71	1.85	–
36166	-0.20	-0.84	B2	0.04	5.77	1.99	0.57
36267	-0.14	-0.54	B5	0.02	4.20	3.23	1.69
36285	-0.19	-0.86	B2	0.05	6.32	0.80	–
36351	-0.19	-0.83	B2	0.05	5.44	1.33	–
36392	-0.14	-0.67	B3	0.06	7.56	2.45	1.79
36429	-0.13	-0.64	B3	0.03	7.56	–	1.39
36430	-0.17	-0.77	B2.5	0.05	6.22	0.98	1.82
36486	-0.21	-1.06	O9	0.10	2.20	1.59	0.89
36487	-0.11	-0.54	B5	0.05	7.81	2.14	–

Table 4 (Cont.)

HD	B - V	U - B	Sp (Q)	E(B - V)	V	$(U_2 - V)_0$	$(U_3 - V)_0$
36512	-0.26	-1.07	B0	0.04	4.60	1.07	0.87
36591	-0.20	-0.95	B1	0.05	5.35	0.97	0.52
36627	-0.11	-0.54	B5	0.05	7.56	2.58	2.18
36646	-0.10	-0.64	B3	0.10	6.52	1.36	2.31
36668	-0.11	-0.45	B6	0.02	8.06	–	2.82
36695	-0.18	-1.09	B1	0.08	5.34	0.98	1.28
36741	-0.20	-0.77	B3	0.04	6.58	2.08	1.50
36760	-0.10	-0.43	B7	0.02	7.63	2.16	–
36779	-0.18	-0.81	B2	0.06	6.23	0.96	1.82
36824	-0.15	-0.72	B3	0.05	6.69	1.28	–
36826	0.00	-0.51	B5	0.16	8.22	2.88	–
36827	-0.17	-0.74	B3	0.03	6.69	1.13	1.67
36842	-0.11	-0.51	B5	0.05	8.09	2.18	–
36865	-0.07	-0.43	B7	0.06	7.40	2.34	2.50
36883	-0.08	-0.47	B5	0.08	7.22	1.96	2.33
36894	-0.16	-0.68	B3	0.04	7.70	1.91	2.52
36895	-0.20	-0.71	B3	0.04	6.74	2.42	2.11
36898	-0.07	-0.43	B6	0.09	7.04	2.70	–
36916	-0.10	-0.58	B4	0.08	6.73	2.45	2.45
245203	-0.17	-0.63	B4	0.01	8.30	1.17	2.11
36935	-0.13	-0.55	B5	0.03	7.51	2.39	–
36936	-0.11	-0.58	B5	0.05	7.52	2.21	2.09
36954	-0.10	-0.65	B3	0.10	6.94	1.23	1.75
36960	-0.25	-1.00	B0	0.05	4.78	0.53	0.19
36981	-0.11	-0.59	B5	0.05	7.81	1.75	–
37000	-0.13	-0.67	B3	0.03	7.49	0.43	–
37015	-0.05	-0.22	B8	0.03	8.33	–	3.34
37016	-0.15	-0.68	B3	0.05	6.23	2.01	1.55
37018	-0.20	-0.93	B1	0.04	4.59	1.02	0.16
37025	-0.12	-0.63	B3	0.08	7.17	0.84	–
37040	-0.15	-0.71	B3	0.09	6.30	1.39	–
37043	-0.25	-1.08	O9	0.06	2.76	1.62	1.13
37055	-0.13	-0.64	B3	0.07	6.40	1.17	1.92

Table 4 (Cont.)

HD	B - V	U - B	Sp (Q)	E(B - V)	V	$(U_2 - V)_0$	$(U_3 - V)_0$
37076	-0.08	-0.41	B7	0.04	8.10	2.27	–
37112	-0.08	-0.50	B5	0.08	8.02	1.91	–
37128	-0.19	-1.04	B0	0.05	1.70	2.22	1.41
37149	-0.10	-0.50	B5	0.05	8.03	1.87	–
37150	-0.18	-0.81	B2	0.03	6.55	1.11	1.80
37173	-0.06	-0.55	B5	0.10	7.86	2.17	–
37209	-0.24	-0.91	B1	0.02	5.70	1.49	1.57
37272	-0.11	-0.56	B5	0.05	7.91	1.95	1.78
37303	-0.20	-0.96	B1	0.06	6.03	1.35	1.47
37320	-0.07	-0.38	B7	0.05	5.87	3.10	2.03
37321	-0.08	-0.55	B5	0.08	7.10	1.77	2.26
37332	-0.13	-0.60	B5	0.03	7.60	2.13	1.83
37334	-0.17	-0.77	B2	0.05	7.19	1.44	1.98
37370	0.01	-0.34	B5	0.13	6.93	2.65	2.41
37468	-0.24	-1.04	O9	0.07	3.65	1.33	0.06
37481	-0.23	-0.91	B1	0.03	5.95	–	1.20
37490	-0.10	-0.76	B2	0.14	4.50	2.69	0.94
37525	-0.09	-0.60	B4	0.11	8.08	1.16	–
37526	-0.12	-0.56	B5	0.08	7.61	1.46	–
37606	-0.07	-0.34	B8	0.04	6.90	2.49	–
37641	-0.06	-0.38	B7	0.06	7.55	2.14	1.84
37642	-0.13	-0.62	B4	0.07	8.06	1.72	–
37674	-0.08	-0.58	B3	0.12	7.67	1.53	1.16
37687	0.03	-0.44	B5	0.19	7.05	2.38	1.54
37699	-0.13	-0.69	B2.5	0.09	7.62	1.94	1.87
37700	-0.09	-0.48	B5	0.07	7.96	2.74	–
37742	-0.21	-1.06	O9	0.10	1.75	1.84	1.13
37744	-0.22	-0.90	B1	0.05	6.21	1.31	0.73
37756	-0.22	-0.85	B2	0.00	4.93	1.81	1.36
37776	-0.14	-0.86	B1	0.10	6.98	0.88	1.59

respect to the MK system. Furthermore, we noted systematic differences between spectral types inferred from MK criteria and those from UBV photometry. The discrepancy was in the sense that $(B-V)_0$ inferred from the latter was always the same as or bluer than $(B-V)_0$ inferred from absorption-line ratios. This effect is very important for stars with MK type B5 and later. A similar effect had been noted by Garrison (1967) for stars in the Sco OB2 association, which has approximately the same age as does the Orion Belt.

To compute color excesses and ultraviolet corrections for reddening, we had to choose between $(B-V)_0$ derived from the UBV photometry and that from the MK criteria. We selected the former, on the assumption that Balmer discontinuity is the more sensitive indicator of the radiative gradient in the B-star atmosphere. We shall return to this point later.

In Table 4, we list the spectral types inferred from the UBV photometry, denoted Sp (Q), and the corresponding B - V color excess, together with the corrected Celescope colors $(U_2-V)_0$ and $(U_3-V)_0$. The data are graphed in Figures 5 and 6. It is immediately evident that a very great amount of scatter exists in the Celescope magnitudes. The scatter of 2 mag for spectral types B2 to B5 may be comparable to that for the cooler stars, for which data are incomplete because the Celescope Catalog (Davis et al., 1973) was compiled of stars to a limiting ultraviolet magnitude. The scatter for the Orion Belt stars far exceeds the errors in the magnitude determinations. In particular, the color-color diagrams for the Pleiades, Hyades, and IC 2602 show very much less scatter. Because the reddening corrections are small and not likely to be seriously in error, we conclude that the scatter must be in the stars themselves.

Particularly interesting is a comparison of the Celescope colors with the intrinsic ultraviolet color relations of Peytremann and Davis. The Orion Belt stars have about the expected scatter above the mean relation, but many stars seem to be much too faint in the ultraviolet. It is tempting to conclude that the Orion Belt stars have some extra source of opacity in the ultraviolet, or that some strong interstellar absorbing material exists that does not cause reddening in B - V.

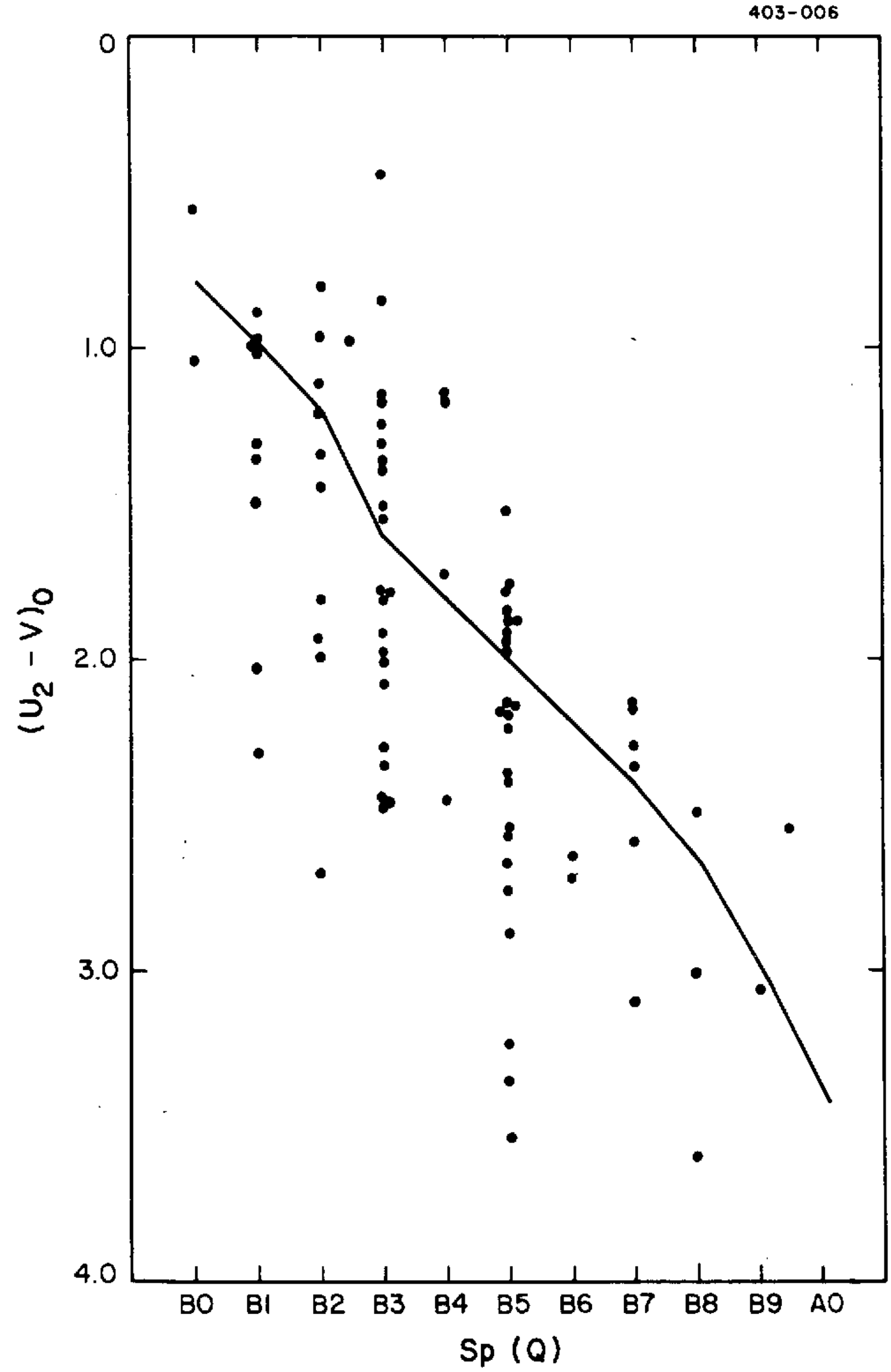

Figure 5. Ultraviolet color $(U_2 - V)_0$ as a function of color, expressed as spectral type Sp (Q), for stars in the Orion Belt association.

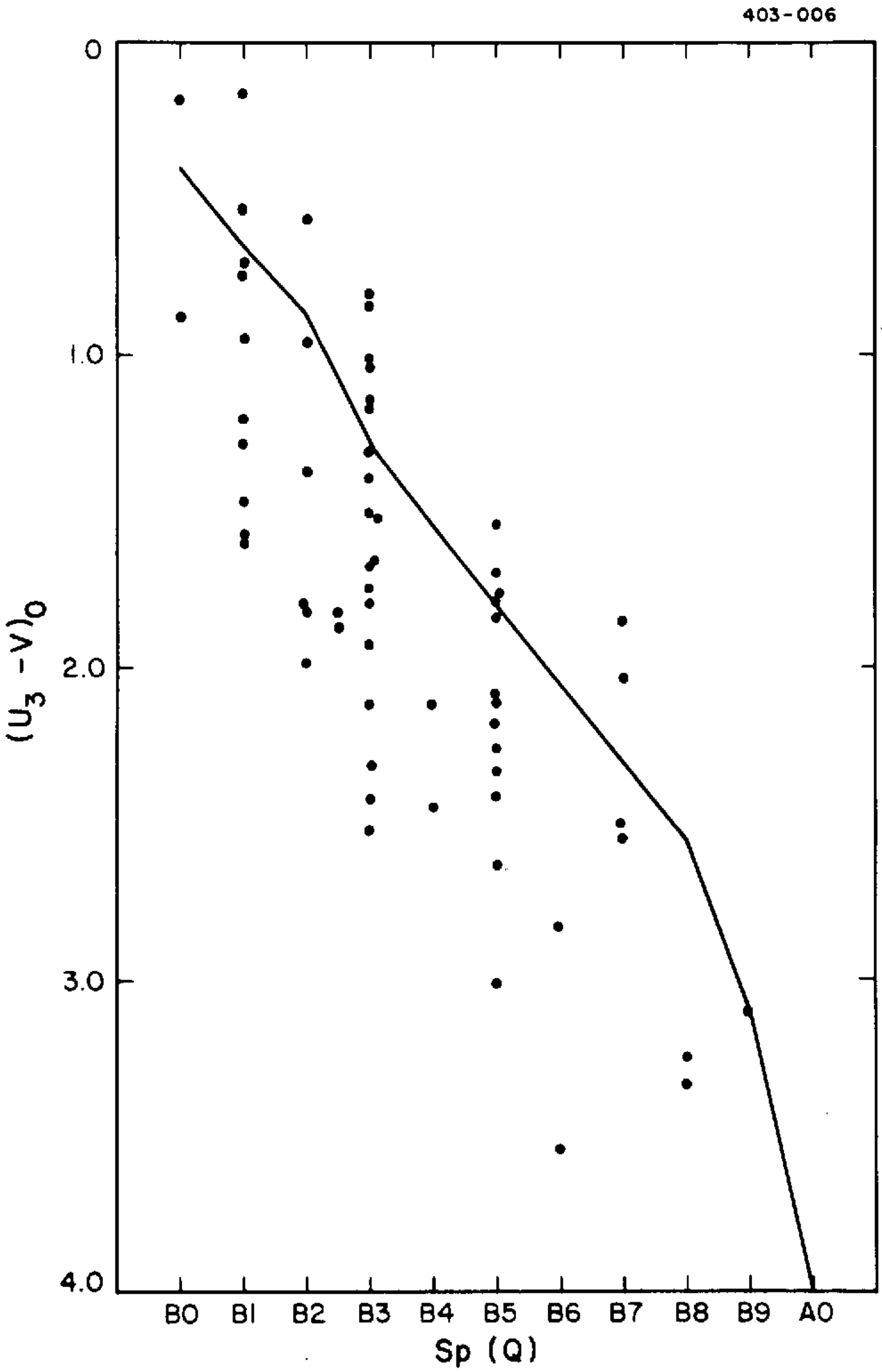

Figure 6. Ultraviolet color $(U_3 - V)_0$ as a function of color, expressed as spectral type Sp (Q), for stars in the Orion Belt association.

Because some doubt may remain about the effect our use of UBV photometry in preference to MK spectral types may have on our results, we plot in Figure 7 the reddening-corrected $U_2 - V$ photometry as a function of MK spectral type. There is no evidence that the scatter is significantly reduced by this treatment of the data. We emphasize that no difference would be expected for the hottest stars (B3 and earlier), for which the photometry and spectral types are in agreement.

1.4 Sco OB1

The association Sco OB1 appears to be especially favorable for study because it contains so many astrophysically interesting objects, including two Wolf-Rayet stars, two P Cygni stars, and some of the most luminous supergiants in the sky. Data for many stars may be lost, however, because of crowding, especially in the vicinity of the very young cluster NGC 6231. Good ground-based data, including MK spectral types, are available for these stars. An analysis of the reddening to Sco OB1 indicates that it originates predominantly in the local spiral arm, whereas the association lies in the next area toward the galactic center (Schild, Neugebauer, and Westphal, 1971).

Celescope photometry is available for 20 stars in Sco OB1, as listed in Table 5. Figure 8 is an ultraviolet color-spectrum diagram for the association. The stars generally scatter below the intrinsic $U_2 - V$ relations for main-sequence and giant stars, as given by Peytremann and Davis (1974). While there is a loose correlation between U_2 faintness and intrinsic luminosity – in the sense that the more luminous stars are fainter in the ultraviolet – the correlation is not firmly established for the small sample of stars available here. It is likely that the suppression of the ultraviolet energy distributions of supergiants is due to blocking by many lines of multiply ionized light metals.

The Wolf-Rayet star HD 151932 is shown in the location implied from its UBV photometry corrected for this emission (Schild, Hiltner, and Sanduleak, 1969). Its location is essentially that expected from its intrinsic luminosity and the correlation of luminosity minus $U_2 - V$ noted above. The two P Cygni stars HD 151804 and HD 152408 have very similar $U_2 - V$ colors, but this is probably a coincidence; they

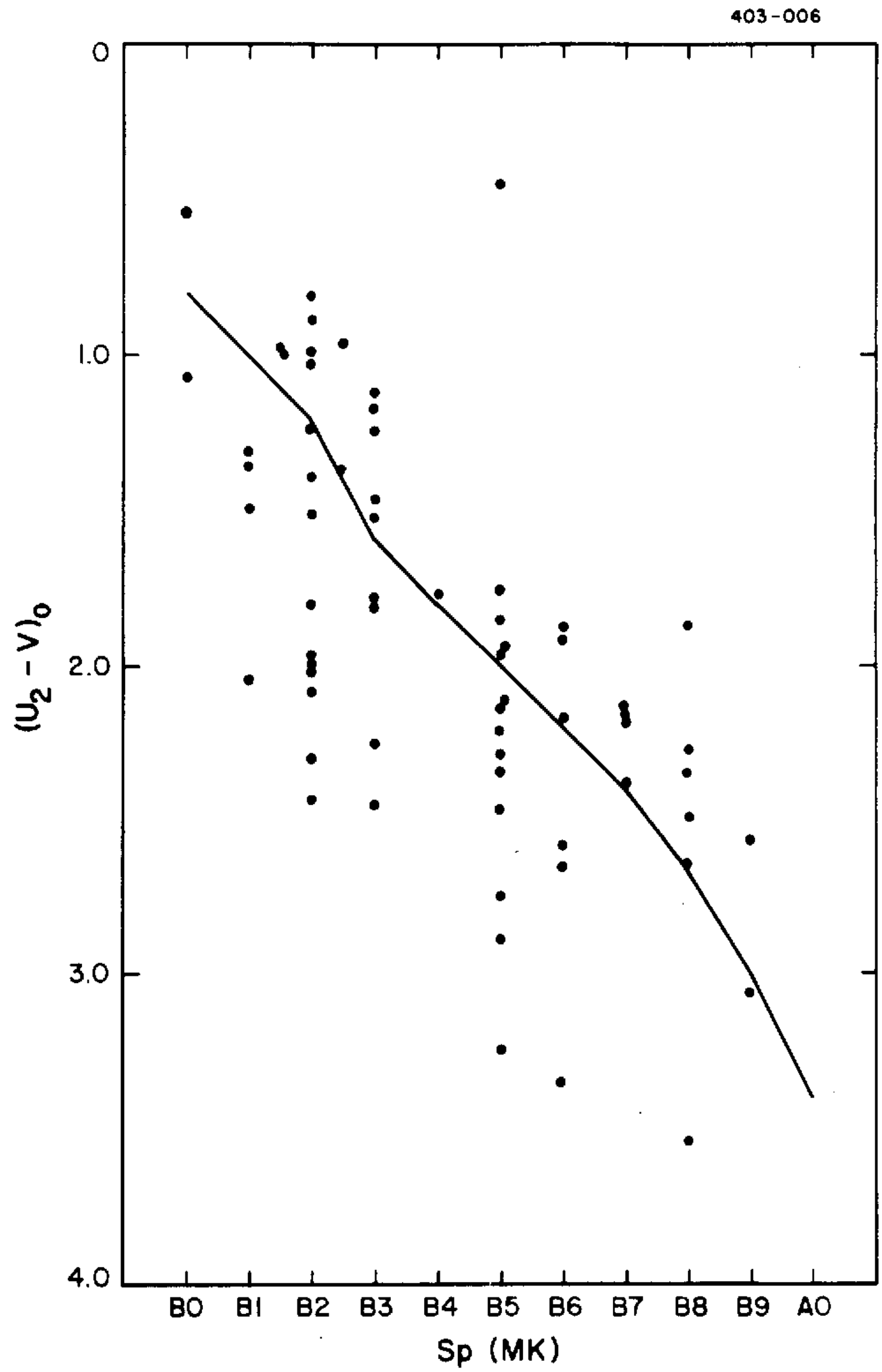

Figure 7. Ultraviolet color $(U_2 - V)_0$ as a function of MK spectral type for stars in the Orion Belt association.

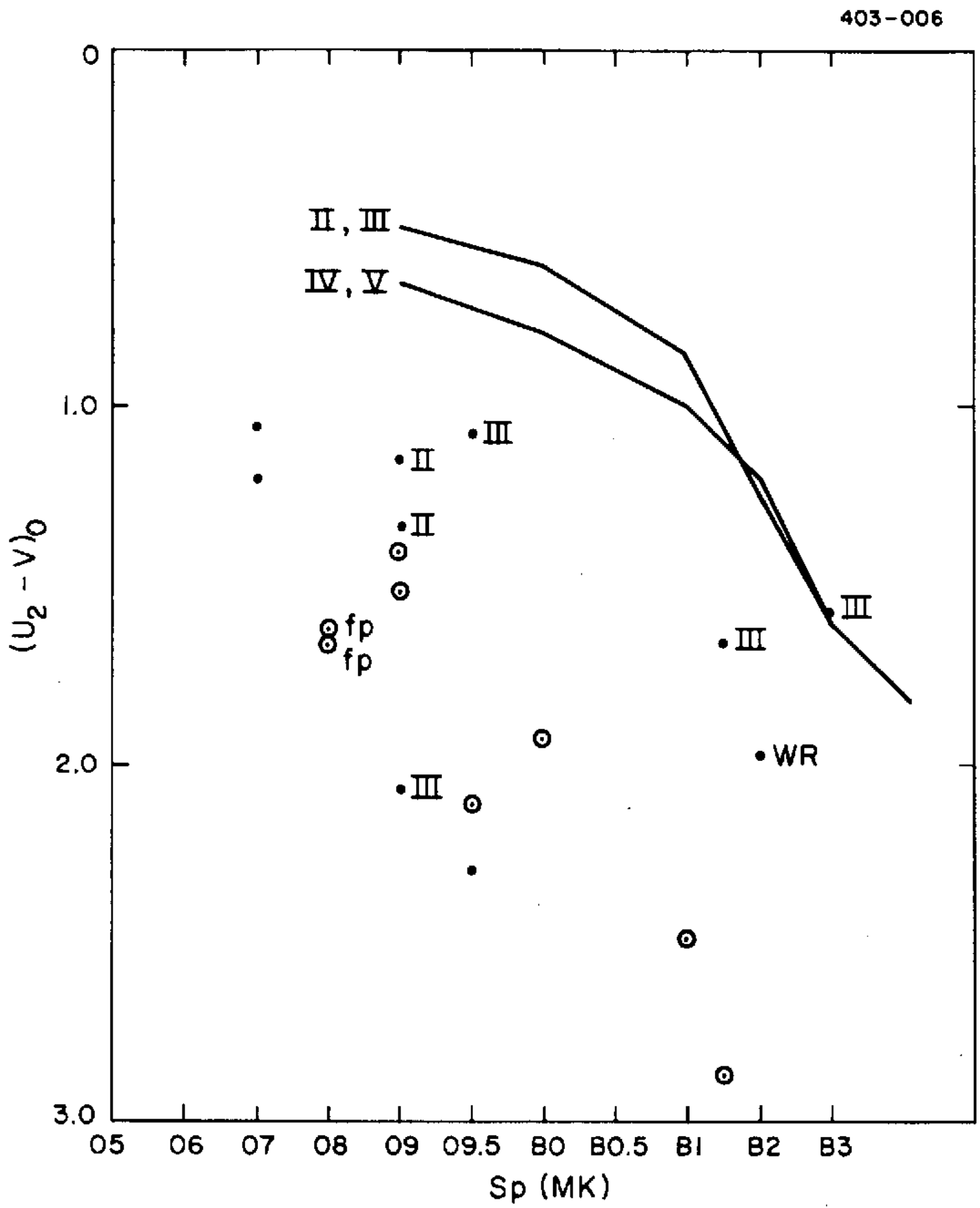

Figure 8. Ultraviolet color $(U_2 - V)_0$ as a function of spectral type for stars in the association Sco OB1. Dots surrounded by circles are supergiants, and the luminosity classes of the giants are indicated. The Peytremann and Davis (1974) intrinsic colors for main-sequence and giant stars are shown separately by the solid lines.

differ markedly in $U_3 - V$. The star with the largest ultraviolet deficiency is HD 152236 (B1.5Ia+). It is one of the most luminous stars in the Galaxy, and for its absolute visual magnitude $M_V = -8.7$ and bolometric correction of -2.8 (Bradley and Morton, 1969), we derive $M_{bol} = -11.5$, which is the upper limit for stars in the Large Magellanic Cloud (Osmer, 1973). Unfortunately, no $U_3 - V$ color is available for this extremely luminous star.

Table 5. Ground-based and Celescope data for Sco OB1 stars.

HD	B - V	U - B	Sp (MK)	E(B - V)	V	$(U_2 - V)_0$	$(U_3 - V)_0$
148688	0.30	-0.75	B1Ia	0.50	5.32	2.49	–
149404	0.43	–	O9I	0.68	5.49	1.51	–
151003	0.16	-0.79	O9II	0.47	7.11	1.33	1.33
151515	0.14	-0.77	O7	0.46	7.14	1.06	0.80
151564	0.11	-0.73	O9.5IV	0.41	7.96	2.30	–
151804	0.07	-0.85	O8fp	0.38	5.22	1.66	2.92
151932	–	–	WN7-A	0.44	6.47	1.97	1.46
152217	0.16	-0.72	B0III	0.45	8.44	–	-0.36
152218	0.17	-0.76	O9.5IIIn	0.47	7.61	1.08	–
152236	0.46	-0.53	B1.5Ia+	0.62	4.71	2.87	–
152246	0.16	-0.76	O9III	0.47	7.29	2.07	0.46
152247	0.19	-0.74	O9II	0.50	7.16	1.14	–
152268	0.11	-0.75	B0IV	0.41	8.10	1.92	0.64
152333	0.22	-0.68	O9.5IV	0.52	8.02	–	1.01
152405	0.14	-0.78	O9.5Ib	0.41	7.17	2.11	–
152408	0.16	-0.76	O8fp	0.47	5.77	1.62	0.44
152424	0.39	-0.58	O9Ia	0.67	6.27	1.38	–
152667	0.25	-0.68	B0.5Ia	0.47	6.22	–	1.52
152685	0.17	-0.59	B1.5III	0.42	7.43	1.68	1.90
152723	0.10	-0.82	O7	0.42	7.31	1.20	0.32

2. KNOWN PECULIAR STARS

Among the hot stars are several classes with known spectral peculiarities due to chemical-composition anomalies, rotation, or envelope expansion. In this section, we examine the Celescope photometry for some of these interesting groups. Two classes we had hoped to investigate – the old novae and the Fe II emission stars (symbiotic and combination spectra) – were not observed by Celescope.

2.1 The Helium I Stars

A group of stars with strong He I lines has recently been recognized. They have been found from high-dispersion spectra to have helium overabundances of factors of 2 to 4 and excesses of nitrogen and oxygen as well (Lester, 1972; Osmer and Peterson, 1974). As a class, the He I stars are slow rotators and have temperatures of main-sequence B0 to B2 stars.

Celescope and UBV photometry are available for five of the He I stars from the lists of MacConnell, Frye, and Bidelman (1970), Lester (1972), and Osmer and Peterson (1974). Our new UBV and Hβ photometry confirm the finding of Osmer and Peterson that the stars have temperatures and gravities of early main-sequence stars, except for the late-B star HD 37017. One star, HD 36960, is significantly hotter than the remaining three, which we consider the three "classical He I stars."

For the three classical He I stars, we find mean ultraviolet-flux deficiencies relative to normal stars of the same B - V color of $\Delta(U_2 - V) = 0$, $\Delta(U_3 - V) = +0.75$, and $\Delta(U_4 - V) = -0.48$ (one star). The negative deficiency at $U_4 - V$ means an excess of radiation. The deficiency at U_3 can be expected from details of opacity sources at ultraviolet wavelengths. Opacity from neutral helium increases with decreasing wavelength, and an overabundance of helium implies higher opacity. The effects can be seen in models by Klinglesmith (1971), where the abundance of helium was varied in several models having the same effective temperatures and gravity. Unfortunately, Klinglesmith's hottest model is 20000 K, whereas the He I stars are at approximately

T_{eff} = 25000 K. Furthermore, Klinglesmith's models do not include the O II absorption edges, which are likely to become important in stars with large oxygen overabundances.

Insofar as we believe that the Klinglesmith models are applicable, we find that relative to a solar-composition star, a star with a factor of 2-1/2 increase of helium at the expense of hydrogen should be 3% fainter at U_2 and 5% fainter at U_3. For extreme helium enrichment ($X = 0.016$, $Y = 0.984$), the continuum should be depressed relative to a normal star by 21% at U_3 and 11% at U_2. These numbers might be significantly modified by the inclusion of the O II emission edges. However, we cannot explain the U_4 excess in HD 120640.

Because the theoretical models limit our discussion of the He I stars, further models are being developed by Dr. D. Peterson of the State University of New York at Stony Brook. His models will be at the appropriate temperatures and have a detailed calculation of the O II opacity. We plan to publish these results separately in the future.

2.2 Be Stars

Peytremann and Davis (1974) have shown that nonsupergiant Be stars have Celescope photometry normal for stars of the given B - V color. This conclusion is based on all the stars in the Celescope Catalog known to be Be stars. Because many stars cataloged as Be are apparently not markedly different from ordinary B stars, except that they occasionally exhibit Hα emission, we have reexamined this conclusion for a different sample of stars. We felt that since the Be stars show variations in their emission lines with a time scale of ~3 years, it would be relevant to look at stars that showed hydrogen emission at the time the Celescope photographs were being taken. Fortunately, a survey of the entire southern sky was being made with an objective prism on the Curtis-Schmidt telescope at Cerro Tololo from 1967 through 1971, in reasonable coincidence with the Celescope photography. The Be stars active during that time have recently been published by Bidelman and MacConnell (1973).

An important further advantage of working from the Bidelman and MacConnell list is that only the strongest Be stars were picked up in this survey. This is because their survey is on IIa-O plates insensitive to Hα, so only stars having Hβ emission were cataloged. Since Be stars have a large decrement in their Balmer emission, only the more pronounced Be stars have emission at Hβ.

From the list of Bidelman and MacConnell (1973), we have 43 stars with Celescope U_2 or U_3 photometry and also sufficient ground-based data to permit determination of their intrinsic properties. The stars are listed in Table 6, along with their ground-based and Celescope photometry, color excesses, $(U_2 - V)_0$, $(U_3 - V)_0$, and ultraviolet color excesses $E(U_2 - V)$ and $E(U_3 - V)$. The color excesses are derived by subtracting the intrinsic colors appropriate to a star of $(B - V)_0$ from the table of intrinsic colors by Peytremann and Davis (1974). The intrinsic colors were derived by correcting for interstellar reddening by using UBV photometry in the usual way.

Table 6. He I stars.

HD	B - V	U - B	Sp (Q, Hβ)	E(B - V)	$(U_2 - V)_0$	$(U_3 - V)_0$	$(U_4 - V)_0$	$E(U_2 - V)$	$E(U_3 - V)$	$E(U_4 - V)$
36960	-0.25	-1.00	B0V	0.04	0.10	0.11	-0.78	0.65	0.20	-0.15
37017	-0.01	-0.34	B7V	0.13	–	–	2.65	–	–	0.35
64740	-0.23	-0.92	B1V	0.05	–	1.50	–	–	0.85	–
120640	-0.16	-0.77	B2IV	0.09	1.16	–	0.12	0.00	–	-0.48
184927	-0.18	-0.83	B1.5V	0.09	1.10	1.42	–	0.00	0.66	–

Energy distributions of Be stars published by Schild, Chaffee, Frogel, and Persson (1974) indicate that about 20% of the stars with Hβ emission will have their Balmer discontinuities filled in, which will cause their temperatures to be overestimated in our dereddening procedure. Moreover, Schild et al. have shown that when this effect occurs, it is usually pronounced. In averaging the ultraviolet excesses given in the last two columns of Table 7, we have not included stars with excesses (or deficiencies) greater than 1 mag. The 10 ultraviolet colors so excluded are given in parentheses.

Table 7. Be stars.

HD	B - V	U - B	Sp (Q,Hβ)	E(B - V)	V	$(U_2 - V)_0$	$(U_3 - V)_0$	$E(U_2 - V)$	$E(U_3 - V)$
37115	-0.10	-0.57	B4V	0.09	7.10	0.96	1.77	0.94	-0.12
38120	0.04	-0.06	B9.5V	0.09	9.10	2.35	–	0.85	–
42908*	0.04	-0.56	B3V	0.27	8.18	1.67	1.57	-0.17	-0.42
45260	0.07	-0.64	B2V	0.33	9.01	–	0.33	–	-0.52
50850	0.03	-0.57	B3V	0.26	9.29	–	1.67	–	0.78
50938	-0.12	-0.69	B3	0.09	7.66	1.11	0.98	0.59	0.42
52721	0.06	-0.78	B0.5V	0.35	6.59	1.06	–	-0.16	–
53667	0.24	-0.71	B0III	0.53	7.75	–	0.04	–	0.46
54858*	-0.05	-0.24	B8.5	0.05	8.18	–	2.01	–	0.80
55135	-0.05	-0.60	B3V	0.17	7.30	–	0.30	–	(1.00)
55439	0.11	-0.57	B2.5V	0.36	8.47	–	0.46	–	0.66
55538	-0.02	-0.73	B2III	0.23	7.78	0.54	–	0.66	–
56806	0.42	0.16	B9III	0.50	10.21	–	-0.30	–	(3.40)
59281	-0.10	-0.62	B4III	0.08	8.46	1.37	–	0.63	–
60794	0.00	-0.59	B3V	0.23	8.85	–	0.68	–	0.47
68980	-0.12	-0.97	O9.5V	0.19	4.8	1.06	0.31	-0.41	-0.11
71934	0.08	-0.67	B1.5V	0.19	7.54	1.91	0.89	-0.81	-0.14
72551	0.02	-0.95	B3V	0.20	9.35	–	1.36	–	0.19
72754	0.19	-0.71	B0V	0.11	6.89	2.88	2.43	(-2.08)	(-2.03)
73834	-0.02	-0.71	B2V	0.24	8.10	0.67	1.05	0.53	-0.20
79206	-0.09	-0.60	B3.5V	0.12	7.73	1.32	1.51	0.38	-0.11
79778	0.17	-0.75	B0	0.47	8.21	–	-0.12	–	-0.52
80459	-0.01	-0.52	B4V	0.19	7.39	–	1.53	–	-0.02
87203	0.12	-0.63	B1.5V	0.39	8.56	–	0.75	–	-0.19
88661	-0.07	-0.89	B0IV	0.23	5.70	–	1.36	–	(1.04)
90490	-0.08	-0.55	B4V	0.11	6.98	1.83	1.79	-0.07	0.09
90966	-0.06	-0.72	B2V	0.20	6.45	–	0.77	–	-0.08
92027	0.05	-0.76	B2V	0.21	8.53	–	1.00	–	-0.40
92406	-0.03	-0.45	B5.5V	0.14	9.05	–	0.80	–	(-1.10)
95826	0.11	-0.75	B0.5V	0.40	8.53	1.06	-0.08	-0.16	-0.58
97151	-0.11	-0.78	B2V	0.16	7.72	1.02	1.61	-0.08	0.86
97792	-0.05	-0.63	B3V	0.18	8.04	1.13	–	-0.37	–
101974	0.06	-0.74	B0.5V	0.35	8.66	0.84	0.39	0.06	-0.11
105675	0.20	-0.74	O9.5IV	0.51	9.25	–	0.23	–	-0.03
106309	-0.04	-0.82	B0.5V	0.25	7.84	–	0.71	–	-0.21
113573	0.08	-0.57	B2.5V	0.32	8.77	–	0.78	–	-0.27
120958	-0.11	-0.77	B2V	0.15	7.60	1.03	–	0.17	–
139431	0.04	-0.77	B0.5V	0.25	7.34	1.15	1.49	-0.25	(-1.00)
155352	0.10	-0.55	B2.5III	0.13	8.20	–	3.15	–	(-2.00)
155896	0.13	-0.57	B2.5II	0.09	6.75	2.13	2.36	-0.53	(-1.06)
157042	-0.13	-0.81	B2III	0.11	5.24	1.20	0.54	-0.30	0.66
157832	0.02	-0.86	O9.5V	0.28	6.64	0.80	0.89	0.00	-0.49
158864	0.00	-0.91	O8V	0.32	8.15	1.06	1.32	-0.66	(-1.32)

We find that the strong Be stars in our group do not have a significant ultraviolet excess. Our average of $\overline{E}(U_2 - V) = 0.04 \pm 0.49$ (root mean square, rms) for 22 stars and $\overline{E}(U_3 - V) = 0.05 \pm 0.44$ (rms) for 18 stars has an admittedly large scatter. Thus, we confirm the conclusions of Peytremann and Davis that the Be stars have normal ultraviolet colors.

Bidelman and MacConnell's (1973) list of southern Be stars also contains identification of several shell stars, two of which have Celescope and adequate ground-based data, identified by asterisks after their HD numbers in Table 7. The scatter for U_3 is large, and only one star has U_2 photometry. We cannot state any firm conclusion about the ultraviolet colors of stars in their active shell phase.

2.3 P Cygni Stars

The P Cygni stars show evidence of envelope expansion at supersonic velocities in the profiles of their hydrogen lines, and often in the He I lines as well. They are usually considered to be the intrinsically most luminous stars in the Galaxy. It is already known from Peytremann and Davis and from the analysis of stars in Sco OB1 that the ultraviolet magnitudes of intrinsically luminous stars are fainter than those of main-sequence stars. This is believed to be the result of line blocking by multiply ionized light metals. A study of the P Cygni stars may give us a feeling for the the maximum extent of this line-blocking effect.

In Table 8, we list the P Cygni stars from the compilation of Beals (1951) that have Celescope photometry. One star, β Lyrae = HD 174638, is not a supergiant and will not be discussed further. A second star, HD 123385 (A3Ia), is more than a magnitude too bright in U_2 and U_3 for reasons not as yet understood.

Our plots of $(U_2 - V)_0$ and $(U_3 - V)_0$ as a function of MK spectral type (Figures 9 and 10) show the supergiant P Cygni stars generally lying below the mean relation for main-sequence stars (Peytremann and Davis, 1974). The large observational uncertainties in the determination of $E(B - V)$ (which assumes the color-spectrum calibration for normal supergiants) and in the correction for interstellar extinction, especially in U_3, are as expected because of the probable longitude variations in the ultraviolet reddening law (Payne-Gaposchkin and Haramundanis, 1973; Peytremann and Davis, 1974).

Table 8. P Cygni stars.

HD	B - V	U - B	Sp (MK)	E(B - V)	V	$(U_2 - V)_0$	$(U_3 - V)_0$
108	0.16	-0.79	O8	0.46	7.40	0.64	–
13854	0.28	-0.65	B1Iab	0.47	6.50	1.41	0.65
14148	0.30	-0.62	B2Ia	0.44	6.30	–	1.83
34085	-0.03	-0.68	B8Ia	0.00	0.20	2.54	3.91
45910	0.33	-0.68	B2III	0.56	6.76	1.40	0.64
53179	1.17	0.49	–	–	9.26	–	–
151804	0.09	-0.76	O8I	0.38	5.40	0.78	2.64
152236	0.46	-0.53	B1Ia	0.62	4.73	2.32	–
152408	0.16	-0.76	O8fp	0.47	5.77	0.87	0.35
174638	-0.01	-0.57	B7V	0.13	3.43	2.42	2.67
187399	0.17	-0.46	B7Ia	0.21	7.03	2.30	3.92
193237	0.41	-0.58	B1I	0.61	4.82	2.31	1.93
197345	0.09	-0.24	A2Ia	0.11	1.30	4.49	4.74
198478	0.40	-0.46	B3Ia	0.52	4.80	2.66	2.80
223385	0.66	-0.02	A3Ia	0.66	5.42	3.04	3.06

Figures 9 and 10 show the lower envelope of the distribution of Celescope colors for the P Cygni stars. This envelope is of interest because it presumably defines the limit to which line blocking can affect the Celescope colors of supergiants. The usefulness of this line is diminished by the small numbers defining it and by uncertainties in the reddening. Nevertheless, we consider the line to be a useful limit.

2.4 The Wolf-Rayet Stars

The Wolf-Rayet stars are among the most enigmatic ones in the sky. Their emission spectra are of specular strength and radial-velocity width, but their temperatures, luminosities, and evolutionary states are very poorly known. Of the known Wolf-Rayet stars in the list of Roberts (1962), 15 have Celescope photometry. Because of the strength of the emission lines, we have corrected the Wolf-Rayet stars for reddening, as follows.

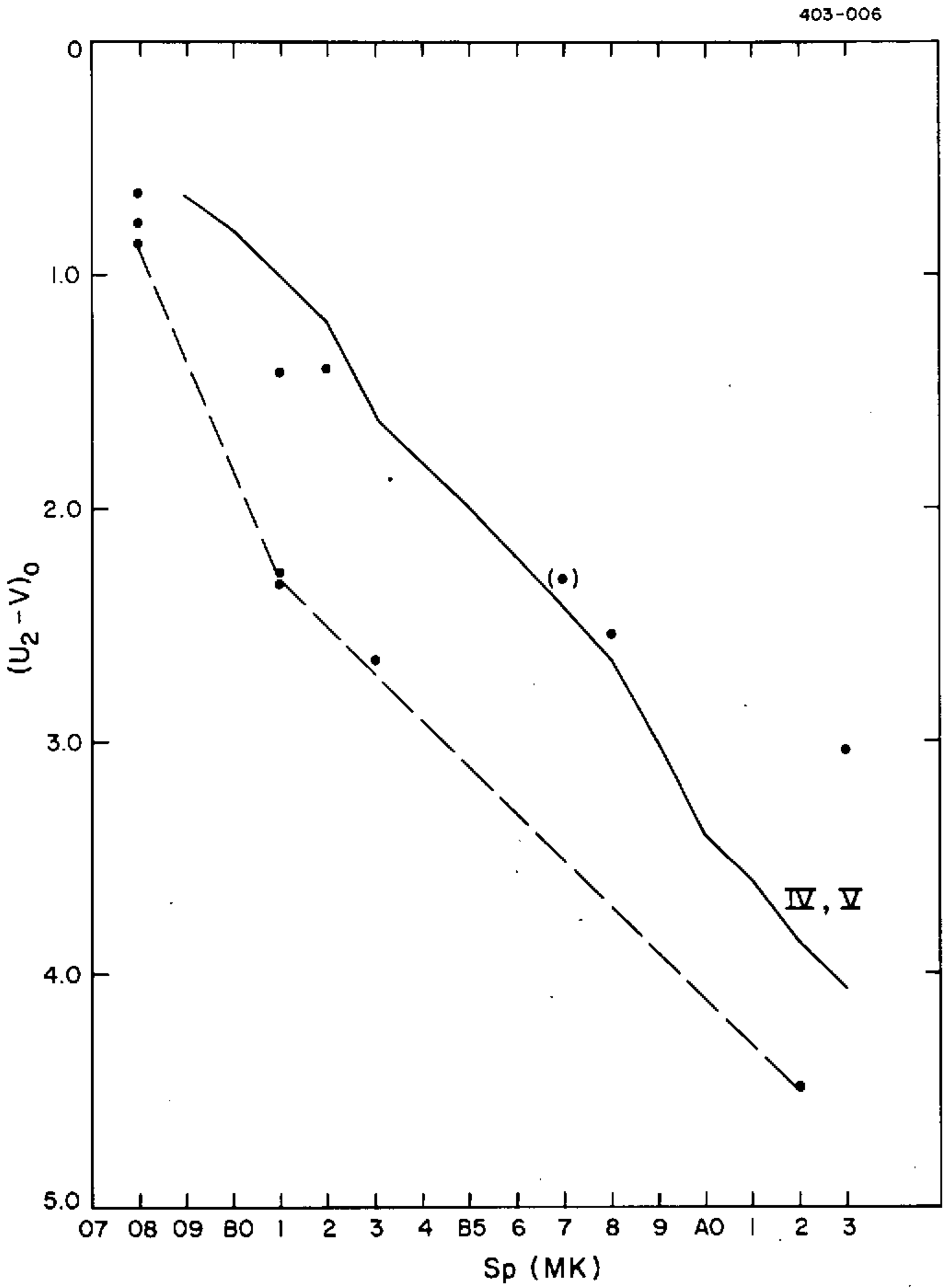

Figure 9. Ultraviolet color $(U_2-V)_0$ as a function of spectral type for the P Cygni stars. The main-sequence relation of Haramundanis and Payne-Gaposchkin (1973) is shown as a solid line. The dashed line is a suggested lower envelope to the data, indicating the maximum effect of line blocking in the ultraviolet for supergiants.

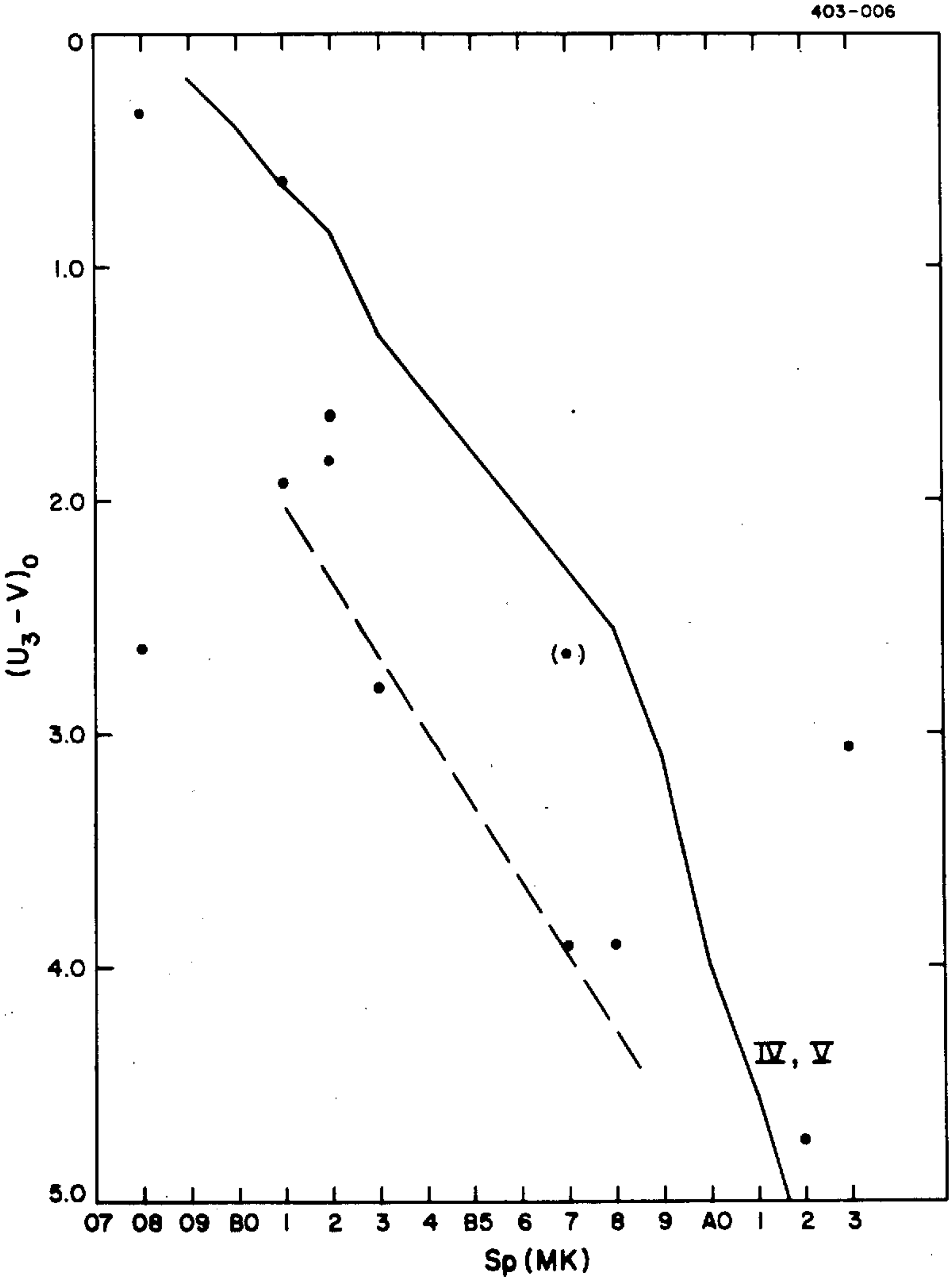

Figure 10. Same as Figure 9, but for $(U_3 - V)_0$.

Spectral classifications are from, in order of preference, Hiltner and Schild (1966), Walborn (1974), and Smith (1968). Corrections to the UBV colors for line emission were taken from Pyper (1966) to derive continuum colors. For stars not having directly determined corrections for the emission lines, mean corrections for the spectral type were used. The continuum color, which may contain significant random and systematic errors, was used to compute color excesses. Following Pyper, we have assumed all WN stars have an intrinsic B - V of -0.32 and all WC stars have B - V = -0.24. These color excesses, due to interstellar extinction, were used to correct the Celescope photometry by the usual procedure. Corrected $U_2 - V$ and $U_3 - V$ data are listed in Table 9. Color excesses ranged from 0.28 to 0.94 in E(B - V).

Table 9. Photometric data for Wolf-Rayet stars.

HD	Spectral type	V	B - V	U - B	Δ(B - V)	E(B - V)	$U_2 - V$	$U_3 - V$	$(U_2 - V)_{corr}$	$(U_3 - V)_{corr}$
50896	WN5-B	6.91	-0.30	-0.80	0.33	0.31	1.10	–	-0.02	–
92740	WN7-A	6.41	0.08	-0.83	0.01	0.41	1.62	1.58	0.14	-0.47
92809	WC6	9.08	0.22	-0.34	0.11	0.56	–	2.38	–	-0.42
93131	WN6-A	6.48	-0.05	-0.91	0.01	0.28	0.02	-1.51	-0.99	-2.91
96548	WN8-A(B)	7.70	0.10	-0.70	0.10	0.52	2.16	–	0.29	–
97152	WC7+OB	8.05	0.04	-0.69	0.07	0.35	2.00	–	0.74	–
151932	WN7-A	6.48	0.30	-0.66	0.01	0.63	3.01	3.57	0.74	0.42
156385	WC7	6.92	0.05	-0.43	0.07	0.36	2.20	1.82	0.90	0.02
190918	WN5.5-A	6.79	0.15	-0.77	0.00	0.44	2.08	2.31	0.50	0.11
191765	WN6-B	8.10	0.00	-0.50	0.27	0.58	2.14	2.33	0.05	-0.57
192103	(WC8)	8.10	0.03	-0.40	0.08	0.34	1.91	2.75	0.69	1.05
192163	WN6-B	7.51	-0.02	-0.40	0.33	0.62	2.83	–	0.60	–
192641	WC7	7.92	0.27	-0.40	0.07	0.56	–	3.87	–	1.07
193793	WC6+OB	6.88	0.40	-0.30	0.05	0.66	–	4.01	–	0.71
219460	WN5.5-A	9.80	0.61	-0.28	0.02	0.94	4.10	–	0.72	–

We have not been able to derive corrections to the ultraviolet Celescope magnitudes for the emission lines, so we simply assume they are negligible. This is not unreasonable, since the Celescope bands are near the peak of the energy distribution for stars of Wolf-Rayet temperatures and since the mechanism driving the Wolf-Rayet envelope expansion and ionization is also powered at the short wavelengths.

We find that HD 93131 has colors too blue to be understood, but that all other stars have ultraviolet colors appropriate to the presumed temperatures of Wolf-Rayet stars. This is shown in Table 10, where we list mean colors of the WN subclasses for the WN-A and WN-B sequences separately. Also given is an approximate spectral type corresponding to the ultraviolet colors, extrapolated from the calibration of Peytremann and Davis (1974).

Table 10. Average ultraviolet colors of WN stars.

Spectral type	$\overline{U_2 - V}$	$\overline{U_3 - V}$	Equivalent spectral type	Number of stars
WN6-A	0.61	0.11	O9	2
WN7-A	0.44	-0.02	O8	2
WN8-A	0.29	–	O7	1
WN5-B	-0.02	–	O5	1
WN6-B	0.32	-0.57	O6	2

Our results are unexpected and should be checked with data from more stars. Among the WN-B stars, we find that color temperature is highest for stars having the highest ionization temperatures (WN5-B). On the other hand, the reverse is true for the WN-A sequence, which has more data. We note that most stars in the WN-A sequence are known binaries with determined periods, and it is likely that all the stars in this class are binaries. Could it be true that the secondaries in these systems affect the colors and that the temperature of the secondary is inversely correlated with the ionization of the primary? The temperatures of all the WN stars are compatible with the adopted intrinsic color used to deredden the fluxes ($(B-V)_0 = 0.32$).

The colors of the WC stars show a large amount of scatter, which may be due in part to the presence of binary components and of the emission lines. Also, if it is true that the WC stars are cooler than the WN stars (Pyper, 1966), then a range of intrinsic B-V colors is more likely to apply to them. This is because all stars hotter than 30000 K have essentially the same color, $(B-V)_0 = -0.31 \pm 0.01$, whereas at 15000 K, B-V changes by 0.02 mag per 1000 K. Therefore, our reddening corrections are more likely to be in error.

The mean color of the WC stars appears to indicate a lower mean temperature for WC than for WN stars. However, our dereddening procedure is, in part, responsible for this difference. It can nevertheless be shown that if the WC stars are dereddened to the same color as the WN stars ($B-V = -0.32$), the WC stars still have less ultraviolet flux. The large scatter in the data and the possible effects of emission lines make these conclusions very tentative, and we believe that higher spectral resolution will be needed to solve the problem.

2.5 Other Peculiar Stars

We have searched the Celescope Catalog for peculiar stars discovered in recent surveys of the Southern Milky Way. In particular, we have looked for all the sources in Sanduleak and Stephenson's (1973) table of strong-emission-line objects. Because the stars in this list tend to be faint, typically 12th mag in V, only one star with Celescope photometry was found. That star is AG Carinae = HD 94910 = MWC 216 (Be!), for which we have $V = 6.96$, $B-V = 0.61$, $U-B = -0.58$, and $Q = -1.02$. Thus, the star has a bluer continuum than an O5 star does ($Q = -0.93$), and we must assume it has excess Balmer emission. AG Carinae has a P Cygni spectrum and varies in brightness from 6.5 to 8.0. We adopt $E(B-V) = 0.77$ to make its $V-B$ color correspond to no Balmer discontinuity.

We attribute the resultant $B-V = -0.16$ to effects of H^- free-bound continuum radiation in the V filter (Schild et al., 1974). For this $B-V$ color excess, we derive $E(U_3-V) = 3.85$, or $-0.85 \leq (U_3-V) \leq +0.65$, depending on the visual magnitudes of AG Carinae at the time of observation. This color is consistent with a very hot object, but nothing further can be said.

3. IDENTIFICATION OF ANOMALOUS SOURCES

The greatest difficulty encountered in checking the Celescope Catalog for possible new types of sources anomalously bright in the ultraviolet has been the lack of good ground-based data for most of the objects identified from the Celescope frames. To remedy this situation, a very large fraction of our energy has gone into securing UBV and $H\beta$ photometry for all identifications in the Catalog. Our new photometry has been the basis for the analysis of cluster and peculiar stars (Sections 1 and 2) and remains the basis for our continuing studies of sources in the Celescope Catalog. We offer to submit at NASA's request an updated tape version of the Celescope Catalog, which contains the results of our UBV and $H\beta$ photometry.

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