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THE SPECTROSCOPIC PARALLAX OF STOCK 14*

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We have determined the spectroscopic parallax of Stock 14 based on MK classification of the 14 brighter stars. Of these, two are spectroscopic nonmembers and one is the supergiant V810 Cen. We find a mean color excess of E_{B-V} = $2^{m}26$ ± 0.12 kpc (s.e. mean for 11 stars), fully consistent with Turner (1982), whose results are based mainly on *UBV* photometry and fitting to the slightly evolved main sequences of NGC 3293. Our independent determination confirms Turner's result, especially with respect to the absolute magnitude and probable membership of the pseudo-cepheid V810 Cen.

Key words: open cluster—MK classification—cepheid variable.

I. Introduction

Recently Turner (1982) has published *UBV* photoelectric photometry of stars in the southern open cluster Stock 14 (ℓ = 295°23, b = −0°63) which considerably supplements the earlier photometry of Moffat and Vogt (MV, 1975). The cluster is important because of the presence of the supergiant variable V810 Centauri (= HR 4511 = HD 101947) and its blue companion, discussed by Parsons (1981), Turner (1982), and others referenced therein. The classification of the blue companion as a B0.5–1 supergiant by Parsons suggested that this star might be at a greater distance than that ascribed by MV for the cluster. For this reason Turner extended the photoelectric sequence and redetermined the distance photometrically in a rather unusual way, because "not enough true ZAMS objects could be identified" (Turner), by fitting to the slightly evolved main sequence of NGC 3293, and by using Hβ and spectroscopic distances of six of the most luminous stars.

Accurate determination of the cluster distance is clearly desirable because it would provide the absolute magnitude of the pseudo-cepheid V810 Cen, which could be an important point on the cepheid period-luminosity-color (PLC) law, provided the star is shown to be a low-amplitude cepheid of ∼ 130.2-day period (Turner). It should be noted that the reality of a regular period is not firmly established; see for instance the radial-velocity study of Balona (1982).

V810 Cen has the advantage of lying within the cluster boundary as defined by stars brighter than $V = 11^{m}$, and is therefore very likely to be a member. As noted by Turner, however, variable extinction is present in the field, at least for stars fainter than $V = 11^{m}$; stars brighter than this have a uniform extinction of $E_{B-V} = 0^{m}26$ ± $0^{m}03$ (s.d.). Furthermore the nonuniformity of the stellar background renders it difficult if not impossible to establish cluster membership statistics fainter than this limit. Thus the only certain members of the cluster could all be evolved, and the existence of the faint main sequence could even be called into doubt. Because of the importance of V810 Cen we therefore thought it important to make an independent determination of the distance of Stock 14.

II. Observations, MK Classification, and Reduction

As part of an extensive program at Waterloo on the properties of intermediate to young open clusters, we have obtained a total of 14 spectra of stars in Stock 14, using the Garrison Image-Tube Spectrograph at an inverse dispersion of 128 Å mm^{-1}. This instrument was attached to the 0.6-meter telescope of the University of Toronto at the Las Campanas Observatory of the Carnegie Institute of Washington.

Each spectrum has been classified independently three times, once by M.L.M. at Waterloo using a binocular microscope, and twice by M.P.F. at the Dominion Astrophysical Observatory using the Boller and Chivens spectrum comparator. The internal agreement, in the sense (M.L.M. − M.P.F.) was 0.4 ± 0.7 (s.d., 13 spectra) in temperature subclass, and −0.3 ± 0.8 in luminosity class, based on one classification. Stars for which disagreement was present were reexamined by M.P.F. and an adopted class assigned. An extensive grid of MK standards was used, taken with the same instrument; this covered nearly all MK classes in the O and B range. Standard stars were taken from Hiltner, Garrison, and Schild (HGS 1969) for the O to A2 stars, and from the revised MK system for the O to M stars.

The adopted classifications are given in Table I, using the numbering system of Turner and MV. Also given are the *spectroscopically* (Sp) derived color excesses E_{B-V}, in-

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TABLE I

Spectroscopic Distance Moduli in Stock 14

Star #	HD or CPD	Spectrum	E_{B-V}	$(B-V)_o^{Sp}$	V_o	$V_o - M_v^{Sp}$	Photometric spectral type	Notes
1	101944	B0 III-IV	0.275	-0.295	8.07	12.97	*b0 IV*	
2	101993	B2 IV-V	0.25	-0.24	8.85	11.65	*b1 V*	
3	101964	B0 III	0.275	-0.295	7.49	12.59	*b0 IV*	
4	101947	G1 Ia + B?	(0.26)		(4.23)	(12.23)	*g9 Ia + b0 III-I*	1
5	102009	B1 III-IV	0.215	-0.265	8.19	12.09	*b1 III-IV*	
6	-61° 2558	B2 IV	0.23	-0.24	9.41	12.21	*b1 V*	
7	102053	B8 V p(Si)	0.17:	-0.09:	9.85	10.10:	*b8.5*	2
8	308003	B2 IV	0.23	-0.24	9.66	12.46	*b1 V*	
9	308002	B6 V	0.27	-0.15	9.45	10.35	*b6*	2
11	308004	B2.5 IV	0.22	-0.22	10.19	12.94	*b2 V*	
12	101837	B0.5 IV	0.24	-0.28	7.72	11.65	*b0.5 IV*	3
13	101794	B0.5 IV ne	0.31:	-0.28:	7.69:	11.62:	*b0.5 III-IV*	4
14	101838	B0 III	0.305	-0.295	7.45	12.55	*b0 IV*	5
17		B6 V	0.15	-0.15	11.73	12.35	*b5 V_0*	6

Notes

1 V810 Centauri: E_{B-V} = 0.26 is assumed, as is $(U-B)_o$ = -1.06 for the B0.5 companion. From this we derive for the B star: M_v = -4.47, V_o = 7.82, $(B-V)_o$ = -0.286, and for the G supergiant M_v = -8.02, V_o = 4.27, $(B-V)_o$ = 0.61 and $(U-B)_o$ = 0.455. This gives the photometric classes stated. A cepheid with period 130.2 days (Turner) has an M_v = -8.16 using the PLC law of Sandage and Tammann (1969).

2 Foreground star.

3 Hernandez and Sahade (1978) discuss this Algol-type spectroscopic binary, classifying it ~ B5 V with a barely visible secondary spectrum, using the MKK atlas alone for comparison.

4,5 Garrison et al (1977) classify these stars B1 IV ne and B1 II-III respectively.

6 MV's photometry was used for this star, otherwise that given by Turner was used.

trinsic color indices $(B-V)_0^{Sp}$, magnitudes V_0, distance moduli $(V_0 - M_v^{Sp})$, and remarks. The latter include the expected photometric spectral class derived from Turner's solution, which we have also derived independently using the magnitudes and extinction relations of Schmidt-Kaler (SK 1982) and colors of FitzGerald (1970). Our result is essentially the same as Turner's, though it too is uncertain for the reasons cited in the introduction. For the spectroscopically derived results we used the above relations, but assigned absolute magnitudes and color indices solely on the basis of the assigned MK class, ignoring $(U-B)$.

In addition to the above 'pure' spectroscopic parallaxes given in Table I, we de-reddened the stars photometrically to the appropriate intrinsic two-color line of FitzGerald for the luminosity class assigned. Distance moduli were then derived from the absolute magnitudes of SK as a function of MK class. We find this a preferable method when both colors are available. Color excesses found this way differ little from Turner's, being (Turner minus us) $-0^m.006 \pm 0^m.005$ (s.d.), and even this could arise from his more general use of the intrinsic two-color relation for class III stars. This latter method we term the *photometric-spectroscopic* (pMK) technique.

III. Discussion and Results

Of the 14 stars for which we have spectrograms, numbers 7 and 9 are foreground stars rejected on both spectroscopic and photometric grounds, and number 4 is V810 Cen. Other identifications and notes are given in the table. Averaging the results for the remaining eleven stars gives $E_{B-V}^{Sp} = 0^m.25 \pm 0^m.05$ (s.d.), $(V_0 - M_v^{Sp}) = 12^m.27 \pm 0^m.48$ for the 'pure' spectroscopic modulus; and $E_{B-V}^{pMK} = 0^m.26 \pm 0^m.04$, $(V_0 - M_v^{pMK}) = 12^m.31 \pm 0^m.30$ for the pMK technique. The former has higher internal error because it does not use the more accurate photometric de-reddening. As may be seen our resultant distance modulus, corresponding to 2.88 ± 0.12 (s.e. mean) kpc, is in full agreement with Turner's, despite the use of substantially different approaches to determine the parameters.

Two stars deserve individual comment, first the faintest star observed by us, number 17, for which we used MV's photometry. Our spectral class is not consistent with Turner's photometry, which suggests a photometric solution of B3 from the colors, whereas MV's photometry dictates a class of B8 V_0 where the subscript indicates a ZAMS star. We suggest it is B5 to B6, and is barely if at all evolved from the ZAMS. Its spectrum compares well with HR 9049 (B6 V, HGS), moderately well with HR 7257 (B5 V, HGS) and unfavorably with HR 2986 (B7 V, HGS). It is the earliest spectroscopically identified star on the ZAMS.

The second star of interest is the pseudo-cepheid V810 Cen, which we have classified as G1 I*a* + B?. Our class is later than the G0 quoted elsewhere, including Keenan and Pitts (KP 1980) who classified it G0 O–I*a* Fe I, and Houk and Cowley (1975) who assign it a range of F5 to G0 I*a*. Our result is based on two plates taken on JD2443536.801 and JD2443556.712, respectively 105.6 and 125.5 days from minimum light using Turner's ephemeris. The spectrum is definitely cooler and more luminous than that of HR 8232 (β Aquarii: G0 I*b*; KP); not distinguishable (except as noted below) from that of R Puppis (G2 O–I*a*; KP, JD2442882.5 and JD2442884.5), which was found to be nonvariable in light by Bidelman (class G0 I*a*, 1951), and slightly variable in light by Stift (1979); and is earlier and more luminous than HD 96746 (G2 I*ab*–I*b*; KP). It is possible that the second spectrum is marginally earlier than the first. It is not too surprising that we find the star with this late a spectral type, since cepheids tend to be coolest at about phase 0.85 from minimum light, and we have observed at phases 0.81 and 0.96 from minimum.

Close examination of the ultraviolet end of our spectrum (seen to about H12 in OB stars) shows the blue region of V810 Cen to be stronger than in any of the above supergiants beyond H and K; H8 to H11 are present, and possibly He I λ3820, though it is much less certain. If we assume that this extended UV spectrum does come entirely from the B0.5–1 star discussed by Parsons (1981), then the hydrogen-line profiles will only allow luminosity classes between I*b* and III. Consistent with Turner and Parsons, our deconvolution of the combined magnitudes and colors of V810 Cen, assuming $E_{B-V} = 0^{m}.26$ and $(U-B)_0 = -1.06$ for the blue star, suggest a photometric classification of F9 Ia + B0.5 III–IV at minimum light.

IV. Conclusions

We confirm the distance found by Turner for Stock 14 on a spectroscopic basis, independent of any assumptions about the evolutionary state of the cluster. Thus our mean distance modulus of $V_0 - M_v = 12^{m}.29 \pm 0^{m}.12$, based on the more luminous evolved stars, corroborates his work, and gives $M_v = -8.02$ for the G0 supergiant, consistent with the PLC law of Sandage and Tammann (1969), though the nature of the star as a small-amplitude cepheid is by no means certain.

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