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Alessi 95 and the short-period Cepheid SU Cassiopeiae

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ABSTRACT

The parameters for the newly discovered open cluster Alessi 95 are established on the basis of available photometric and spectroscopic data, in conjunction with new observations. Colour excesses for spectroscopically observed B- and A-type stars near SU Cas follow a reddening relation described by $E(U-B)/E(B-V) = 0.83 + 0.02E(B-V)$, implying a value of $R = A_V/E(B-V) \simeq 2.8$ for the associated dust. Alessi 95 has a mean reddening of $E(B-V)(\text{B0}) = 0.35 \pm 0.02$ s.e., an intrinsic distance modulus of $V_0 - M_V = 8.16 \pm 0.04$ s.e. (± 0.21 s.d.), $d = 429 \pm 8$ pc, and an estimated age of $10^{8.2}$ yr from zero-age main sequence (ZAMS) fitting of available *UBV*, CCD *BV*, NOMAD, and Two Micron All Sky Survey JHK_s observations of cluster stars. SU Cas is a likely cluster member, with an inferred space reddening of $E(B-V) = 0.33 \pm 0.02$ and a luminosity of $\langle M_V \rangle = -3.15 \pm 0.07$ s.e., consistent with overtone pulsation ($P_{\text{FM}} = 2.75$ d), as also implied by the Cepheid's light-curve parameters, rate of period increase and *Hipparcos* parallaxes for cluster stars. There is excellent agreement of the distance estimates for SU Cas inferred from cluster ZAMS fitting, its pulsation parallax derived from the infrared surface brightness technique and *Hipparcos* parallaxes, which all agree to within a few per cent.

Key words: stars: individual: SU Cas – stars: variables: Cepheids – open clusters and associations: individual: Alessi 95.

1 INTRODUCTION

When van den Bergh (1966) compiled a list of relatively bright stars visible in the National Geographic Palomar Observatory Sky Survey (POSS) that are associated with reflection nebulosity, he noted that the distance and luminosity for one such star, the 1.949 d Cepheid SU Cas, might be estimated using spectroscopic and photometric observations of the nearby B-type stars HD 17138 and HD 17443, which appear to illuminate a portion of the same dust complex. His discovery was very important, given the complete lack in existing surveys of Galactic clusters lying within several degrees of the Cepheid that might serve as distance indicators. Curiously, the field of SU Cas was not surveyed in van den Bergh's earlier search of the POSS for previously undetected star clusters (van den Bergh 1957).

The sparse group of B stars was subsequently designated as Cas R2, and used by Racine & van den Bergh (1970) with other R-associations to map local spiral structure in the Galaxy. An initial estimate for the distance to the dust complex by Racine (1968) yielded a value of $d = 310 \pm 30$ pc from spectroscopic distance moduli for the three B-type stars HD 17327, HD 17443 and HD 17706, and the bright M giant HD 23475. A later study by Schmidt (1978) using Strömgren and Hβ photometry implied that HD 17327 and HD 17443 were closer than HD 17706, at a mean distance of ∼275 pc, versus ∼440 pc for the latter. Schmidt's result found support in an independent earlier survey by Havlen (1971) of

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B-type stars lying within ∼6° of SU Cas. Only a few were found to lie at distances comparable to that expected for SU Cas, provided it was assumed to be either a fundamental mode or overtone pulsator. A more detailed study of Cas R2 stars by Turner & Evans (1984) included an additional star, HD 16893, associated with reflection nebulosity and an A-type companion to HD 17327, yielding a small group of five stars, with five additional candidates, lying at an estimated distance of 261 ± 21 pc. It was noted that background B-type stars were plentiful in the field, with most, including HD 17706, congregating at distances of 401 ± 38 pc.

The inferred luminosity for SU Cas requires an estimate of its reddening, but the immediate field of the Cepheid was surveyed by Turner (1984, see also Turner & Evans 1984), and the field reddening appeared to be fairly well established, although with some dependence on localized dust obscuration. Several of the surveyed companions to SU Cas were found to have intrinsic distance moduli $V_0 - M_V$ near 8.0, but there were no suspicions at the time that the Cepheid might be embedded in an anonymous open cluster. The situation changed dramatically a few years ago when Bruno Alessi discovered a sparse cluster of stars surrounding SU Cas and centred at J2000.0 coordinates 02:52:15.1, +68:53:19 (Alessi, unpublished data), as shown in Fig. 1. The cluster, designated Alessi 95, has nuclear and coronal radii of 24 and 50 arcmin, respectively, and was discovered from an analysis of online data bases (see Alessi, Moitinho & Dias 2003; Kronberger et al. 2006). The colour image (Fig. 1) emphasizes the large number of blue stars (B- and A-type) dominating the central regions of the cluster, and also provides a clear picture of the relationship between SU Cas and its reflection nebula with the surrounding dust.

This study was initiated in order to provide additional information about Alessi 95 – its reddening, distance and age – based upon available observational material, and to discuss what it reveals about SU Cas. For example, the revised *Hipparcos* parallax of 2.53 ± 0.32 mas for SU Cas (van Leeuwen 2007) implies a distance of 395 ± 50 pc to the Cepheid, consistent with intrinsic distance moduli near 8.0 found for several of its optical companions. It may therefore be possible to establish the distance to SU Cas via trigonometric, open cluster and pulsation parallaxes, which would solidly anchor the short-period end of the Galactic calibration of the Cepheid period–luminosity relation and strengthen the relationship established by Turner (2010) from open clusters and associations.

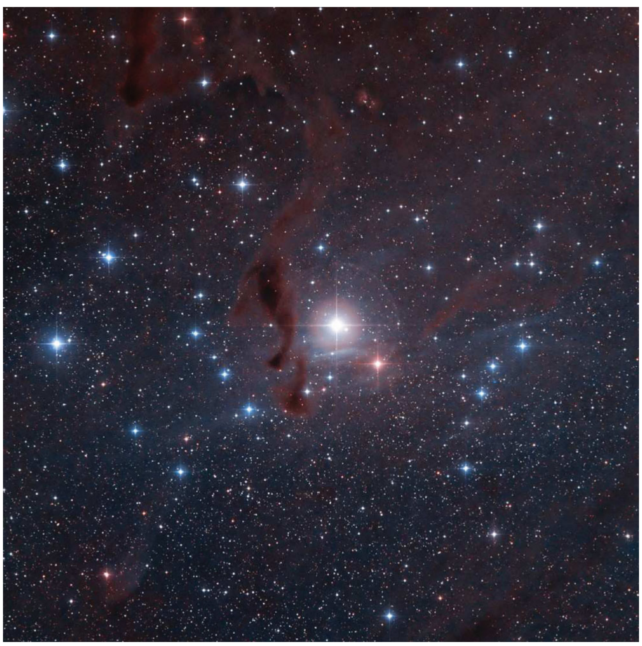

Figure 1. A composite colour 60 × 60 arcmin^2 image of Alessi 95 centred on 2000.0 coordinates 02:52:15.1, +68:53:19, compiled by Noel Carboni from Palomar Observatory Sky Survey-2 blue, red and near-infrared images. SU Cas is the bright star near the centre of the image; the red star south-west of it is the K0 III star TE 10.

2 OBSERVATIONAL DATA AND ANALYSIS

An informative set of observations for bright B-type stars in the field of SU Cas was obtained four decades ago by Havlen (1971), who made photoelectric *UBV* measures for 31 of 33 stars lying within ∼6° of the Cepheid on two nights in 1968 September with the 0.9-m telescope at Stewart Observatory. Spectroscopic observations for 25 of the stars (up to three spectrograms) were obtained at a dispersion of 63 Å mm^{-1} with the No. 1, 0.9-m telescope at Kitt Peak National Observatory (KPNO) during the summer of 1968. The spectra were measured for radial velocity and classified by Havlen (1971) using the facilities of KPNO, and also remeasured for radial velocity using the PDS microdensitometer at the University of Toronto, and reclassified by the lead author, for use in the study by Turner et al. (1985). Part of the latter study included Strömgren and Hβ photometry for the stars obtained by Forbes using the automatic photometer on the 0.76-m telescope of the Behlen Observatory at the University of Nebraska, the same facility used in the study by Schmidt (1978).

For the present study we have combined the original *UBV* measures by Havlen (1971), Aveni & Hunter (1972), Feltz & McNamara (1976) and Turner & Evans (1984) with *UBV* photometry obtained by transforming the available Strömgren photometry (Feltz & McNamara 1976; Schmidt 1978, and Forbes, unpublished) using the relationships of Turner (1990). For a few fainter objects in the sample there are *BV* data from the *Hipparcos/Tycho* data base. The data are summarized in Table 1 along with MK spectral types for the same stars obtained from the literature (see Havlen 1971), the studies of Aveni & Hunter (1972) and Turner et al. (1985), or from new CCD spectra obtained at dispersions of 60 and 120 Å mm^{-1} in 2011 November and December using the 1.8-m Plaskett telescope of the Dominion Astrophysical Observatory. Stars designated as 'FM' are numbered by Feltz & McNamara (1976), those as 'TE' by Turner & Evans (1984) and, for completeness, stars designated as 'T' are numbered from the *Tycho* catalogue along with their *BV* data. The data for HD 23475 are from the literature (Racine 1968), although, like many of the stars in Table 1, it appears to be unrelated to SU Cas according to the present study.

Colour excesses, $E(B-V)$ and $E(U-B)$, were derived for stars in Table 1 with reference to an unpublished set of intrinsic colours for early-type stars established by the lead author through a melding of published tables by Johnson (1966) and FitzGerald (1970), subsequently confirmed through applications to stars in a variety of Galactic star fields (e.g. Turner 1989). The resulting values are plotted in Fig. 2. Intrinsic $(U-B)_0$ colours for post-main-sequence late-B-type stars (e.g. Johnson 1966; FitzGerald 1970) are particularly uncertain, which may account for some of the scatter in the diagram, notably scatter towards systematically small values of $E(U-B)$. Excess Balmer continuum emission can also account for such effects in Be stars (Schild & Romanishin 1976). As noted by Turner (1989), the colour excess data for stars in constrained regions of sky otherwise describe reddening lines with a typical curvature term of +0.02, but with a slope ranging between extremes of +0.55

Table 1. Photometric and spectroscopic data for stars in the region of SU Cas.

Star	V	$B-V$	$U-B$	Spec. type	$E(B-V)$	$E(U-B)$
HD 11529	4.98	−0.09	−0.42	B7 IV	0.03	0.05
HD 11744	7.82	+0.38	−0.31	B3 III:	0.58	0.47
HD 12301	5.61	+0.38	−0.28	B7 Ib	0.44	0.30
HD 12509	7.09	+0.34	−0.53	B1 II	0.58	0.46
HD 12567	8.32	+0.39	−0.54	B0.5 III	0.67	0.50
HD 12882	7.58	+0.37	−0.50	B6 Iae	0.45	–
HD 13590	8.01	+0.38	−0.37	B2 IIIe	0.62	0.53
HD 13630	8.80	+0.36	+0.06	B8 V	0.45	0.36
HD 14010	7.14	+0.60	−0.10	B8 Iab	0.63	0.43
HD 14863	7.76	+0.06	−0.40	B5 V	0.22	0.18
HD 14980	9.10	+0.42	+0.02	A0 III:	0.42	–
HD 15472	7.88	+0.06	−0.61	B3 Ve	0.26	–
HD 15727	8.25	+0.50	−0.20	B3 III:nn	0.70	0.58
HD 16036	8.19	+0.44	+0.27	B9 Vn	0.50	0.45
HD 16393	7.59	+0.04	−0.31	B7 Vnn	0.16	0.11
HD 16440	7.89	+0.75	+0.10:	B3 Vn	0.95	0.81
HD 16831	8.96	+0.32	+0.17	A5 Vp	0.16	0.07
HD 16893	8.53	+0.39	+0.37	A3 V	0.30	0.26
HD 16907	8.39:	+0.13	−0.07	B9.5 V	0.16	–
HD 17179	7.92:	+0.26:	−0.39:	B3 Vn	0.46	–
HD 17327	7.49	+0.35	−0.03	B8 III	0.44	0.40
HD 17327b	10.33	+0.51	–	A2 Vn	0.45	–
HD 17443	8.74	+0.30	+0.13	B9 V	0.36	0.31
HD 17706	8.45	+0.38	−0.18	B5 IV	0.54	0.43
HD 17856	8.71	+0.31	+0.18	B9.5 Vn	0.34	0.25
HD 17857	7.75	+0.79	+0.03	B8 Ib	0.82	–
HD 17929	7.84	+0.29	−0.15	B9 III	0.35	0.19
HD 17982	8.07	+0.43	+0.39	A1 V	0.40	0.34
HD 19065	5.90	−0.02	−0.13	B9 V	0.04	0.05
HD 19856	8.85	+0.21	−0.25	B6 III	0.35	0.34
HD 20226	8.62	+0.25	−0.17	B7 IV	0.37	0.30
HD 20336	4.86	−0.13	−0.75	B2 Vne	0.11	0.11
HD 20566	8.08	+0.38	−0.24	B3 Vne	0.58	0.47
HD 20710	7.61	+0.08	−0.19	B8 V	0.17	0.11
HD 21267	8.00	+0.00	−0.29	B7.5 V	0.11	0.09
HD 21725	9.12	+0.21	+0.10	B9.5 V	0.24	0.17
HD 21930	8.44	+0.19	+0.02	B9 VmA3	0.25	0.20
HD 23475	4.47	+1.88	+2.13	M2 IIa	0.27	–
BD+68°193	9.48	+0.32	+0.02	B9.5 IV	0.35	–
BD+68°194	10.06	+0.39	+0.22	A1 V	0.36	–
BD+68°195	10.20	+0.31	+0.01	B9 III-IV	0.37	0.31
BD+68°201	9.68	+0.21	−0.06	B9 III-IV	0.27	0.24
BD+68°203	10.22	+0.25	+0.13	B9 V	0.28	0.20
TE 1	11.03	+1.56	+1.37	G5 III	0.66	–
TE 2	12.60	+0.74	+0.27	F3 V	0.33	0.28
TE 3	11.06	+0.47	+0.37	A0 V	0.47	0.37
TE 5	10.70	+0.75	+0.07	B5 II	0.89	0.78
TE 6	12.51	+0.85	+0.71	A0 V	0.85	0.71
TE 7	11.99	+0.75	+0.65	A0 VmA5	0.75	0.65
TE 8	13.80	+0.98	+0.59	F2 V	0.63	0.58
TE 10	8.15	+1.49	+1.59	K0 III	0.48	–
FM C	11.28	+0.34	+0.32	A2 V	0.28	0.23
FM G	11.29	+0.63	+0.36	A8 V	0.39	0.30
FM K	10.91	+0.50	+0.36	B9.5 V	0.53	0.43
T4313−918	10.19	+0.42	–	B6 V	0.56	–
T4313−863	10.53	+0.22	–	B9.5 IV	0.25	–

Note. HD 16907 = eclipsing binary TW Cas; HD 17179 = V793 Cas, double-lined spectroscopic binary.

and +0.85, depending upon the line of sight along which one is viewing. The data for the majority of stars near SU Cas closely fit a reddening relation described by $E(U-B)/E(B-V) = 0.83 + 0.02E(B-V)$, provided that the three most deviant objects are omitted, similar in slope to what was found for Cyg OB2 (Turner 1989). That relation was adopted for subsequent analysis. Reddening slope and R value are closely correlated for nearby dust clouds in the first and second Galactic quadrants (Turner 1989, 1996), and in the present case imply a value of $R = A_V/E(B-V) = 2.8$, which was also adopted in the analysis.

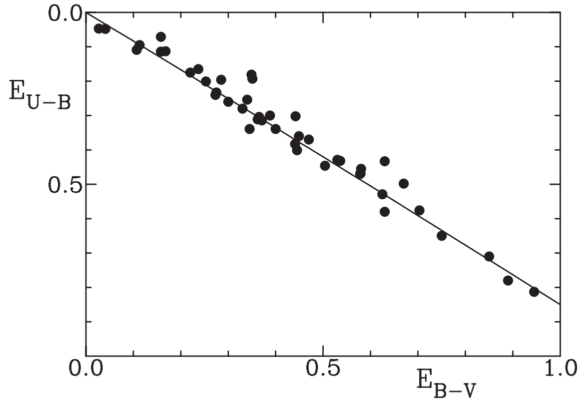

Figure 2. The reddening relation for stars near SU Cas derived from spectroscopic colour excesses. The plotted relation is described by $E(U-B)/E(B-V) = 0.83 + 0.02E(B-V)$.

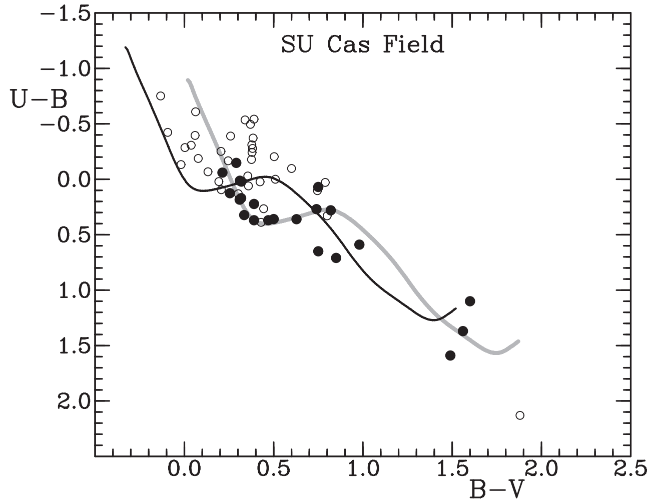

Figure 3. Colour–colour diagram for stars in the SU Cas field, with stars lying within $\sim 1^\circ$ of the Cepheid plotted with filled symbols. The black curve is the intrinsic relation for dwarfs, while the thick grey curve represents the intrinsic relation reddened by $E(B-V) = 0.35 \pm 0.02$.

The last result is important for establishing the distance to Alessi 95, so was examined carefully. At first glance it appears to conflict with the results of an earlier survey of the region by Turner (1976b), who found that the typical reddening law for star clusters near the Galactic longitude of SU Cas ($\ell = 133\overset{\circ}{.}4675$) had a slope $E(U-B)/E(B-V)$ close to 0.75–0.76, with values of R averaging 3.0–3.1. In the study of Turner & Evans (1984) a value of $R = 3.1$ was, in fact, adopted for the reddening corrections. Yet a re-examination of the variable-extinction data in that study (their fig. 4) indicates that an extinction ratio of $R = 2.8$ provides a much better fit to the observations than is the case for the larger value. Since the large reddening slope evident for stars near SU Cas (Fig. 2) cannot be reduced to 0.75–0.76, it appears that our adoption of $R = 2.8$ for those objects is a reasonable assumption. The origin of the difference relative to the Turner (1976b) results may lie in the location of SU Cas well away from the Galactic plane ($b = +8\overset{\circ}{.}5195$), where a localized pocket of dust has different properties from that for dust lying closer to the Galactic equator.

The reddening and distance to SU Cas and its associated dust cloud were established previously by Turner (1984) and Turner et al. (1985) using star counts and derived reddenings for stars near the Cepheid with *UBV* photometry, in conjunction with a technique developed by Herbst & Sawyer (1981) tied to star counts for totally opaque dust globules. Given the new information that the Cepheid lies in the core of a previously unnoticed open cluster, the use of star counts may no longer be appropriate for the study of extinction and distance, leaving the question of the reddening for the Cepheid and cluster open to further examination.

The colours of stars in the SU Cas field are plotted in Fig. 3, with filled circles used to denote stars lying in relatively close proximity to SU Cas. Reddenings have also been derived for four additional stars lying near the Cepheid from *BV* data and spectral types by Aveni & Hunter (1972) along with two stars from Table 2, four of the six appearing to lie at similar distances to SU Cas. The derived mean reddening for the collection of 13 stars lying in close proximity to the Cepheid, and not projected against an obvious dust cloud, is $E(B-V)(\mathrm{B0}) = 0.35 \pm 0.02$ s.e. (± 0.05 s.d.), which also appears to apply to a few stars in the Table 1 collection (see mean reddening adopted in Fig. 3). There is noticeable differential reddening in the field according to the observations, that near SU Cas being associated with the visible dust clouds around the Cepheid. The mean reddening of the central regions of Alessi 95 can be solidly established as $E(B-V)(\mathrm{B0}) = 0.35 \pm 0.02$ s.e., however, with $E(B-V) = 0.33 \pm 0.02$ s.e. inferred for the space reddening of a star with the observed colours of SU Cas (see Fernie 1963).

The inferred reddening for the Cepheid is a close match to an estimate of $E(B-V) = 0.32$: established by Turner, Leonard & English (1987) from published spectrophotometric *KHG* photometry for SU Cas in conjunction with intrinsic values established from Cepheids of well-established space reddening. The reddening also agrees reasonably well with an estimate of $E(B-V) = 0.296 \pm 0.026$ obtained by Kovtyukh et al. (2008) from stellar atmosphere model fitting, in this case linked to derived intrinsic colours and effective temperatures for bright stars of little to no reddening. A reddening of $E(B-V) = 0.28$ was derived by Laney & Caldwell (2007) from BVI_c photometry for SU Cas linked to a calibration based on space reddenings for Cepheids, but that included the earlier estimate of $E(B-V) = 0.27 \pm 0.03$ s.e. by Turner (1984). Given that SU Cas is the shortest period Cepheid in the sample of pulsators with established space reddenings, the small offset of the Laney & Caldwell (2007) reddening with the present result is presumably linked to the original underestimate of reddening for SU Cas obtained by Turner (1984).

Potential members of Alessi 95 were assembled from stars lying within the cluster boundaries: photoelectrically observed stars (Table 1), stars in the *Hipparcos/Tycho* data base (ESA 1997; van Leeuwen 2007), stars brighter than $V = 17$ in the NOMAD data base (Zacharias et al. 2005), recalibrated to the Johnson *BV* system using faint stars from Turner (1984) as reference standards, and stars near the Cepheid with new CCD *BV* observations (see below). Obvious 'ringers' among the faint stars in NOMAD were omitted from the analysis, and the resulting data are plotted in Fig. 4, which represents the colour–magnitude diagram for Alessi 95 uncorrected for differential reddening or detailed membership selection. Included are a best-fitting zero-age main sequence (ZAMS, see below) and a model isochrone from Meynet, Mermilliod & Maeder (1993) for $\log t = 8.2$, which appears to fit the data for cluster stars and the Cepheid SU Cas reasonably well. Note that late-type dwarfs are only encountered in this direction at the distance of Alessi 95 and beyond, so the cluster cannot be less distant than implied from the ZAMS fit, for example, at the distance of 258 ± 3 pc derived for the foreground dust complex (Turner & Evans 1984).

Table 2. Abbey Ridge Observatory *BV* observations for stars near SU Cas.

Star	RA (2000)	Dec. (2000)	V	$B-V$	Star	RA (2000)	Dec. (2000)	V	$B-V$
1	42.6032	68.9848	11.29	0.59	33	42.6618	68.8036	15.32	2.17
2	43.5207	68.8292	11.94	0.58	34	42.5644	68.7939	15.41	1.87
3	42.5635	68.8747	12.28	0.62	35	42.7140	68.8649	15.53	2.20
4	42.5214	68.9379	13.15	0.74	36	42.6204	68.8376	15.57	1.43
5	43.4562	68.8101	13.58	0.86	37	42.8804	68.8988	15.62	1.39
6	42.7422	68.9688	13.64	0.96	38	42.9933	68.9558	15.67	1.69
7	42.9819	68.9792	13.67	0.92	39	43.3421	68.7724	15.71	2.68
8	42.7272	68.8951	13.75	1.23	40	42.8359	68.8794	15.72	1.72
9	42.6903	68.7487	13.83	0.80	41	42.6393	68.8148	15.80	2.02
10	43.4705	68.8416	13.91	1.12	42	42.5626	68.7751	15.82	1.40
11	43.1982	68.7507	14.30	2.18	43	43.2426	68.7531	15.83	1.46
12	43.4667	68.9085	14.43	0.99	44	42.6391	68.9859	15.89	1.76
13	42.5669	68.8139	14.49	0.91	45	43.4950	68.9855	15.94	1.39
14	43.1307	68.8611	14.73	1.28	46	43.0456	68.9040	15.99	1.78
15	42.7000	68.9516	14.75	1.07	47	42.7820	68.8385	16.08	1.51
16	43.4772	68.7904	14.79	0.93	48	43.3109	68.8668	16.09	1.53
17	42.6767	68.8458	14.81	1.02	49	42.8790	68.7889	16.15	2.01
18	43.5128	68.9190	14.90	2.00	50	43.2876	68.8010	16.20	1.69
19	43.1200	68.9134	14.91	1.33	51	42.9461	68.9348	16.22	2.06
20	43.0688	68.8097	14.91	1.14	52	42.5290	68.8124	16.29	1.79
21	42.5517	68.8297	15.00	0.88	53	43.1040	68.9229	16.32	2.05
22	43.2084	68.9804	15.04	1.47	54	43.3733	68.8587	16.42	1.49
23	43.2299	68.8139	15.04	2.99	55	42.6019	68.9187	16.43	1.80
24	43.5362	68.8662	15.07	2.29	56	43.5272	68.8812	16.44	1.66
25	43.4419	68.7818	15.08	1.19	57	42.6220	68.9404	16.49	1.71
26	42.5198	68.7896	15.12	1.02	58	42.8224	68.8314	16.49	1.80
27	42.7201	68.7484	15.13	2.29	59	42.6265	68.9563	16.51	1.55
28	43.3182	68.7498	15.13	1.08	60	42.7998	68.9394	16.60	1.67
29	42.7834	68.9211	15.18	1.38	61	43.0472	68.7603	16.77	1.98
30	43.5239	68.9916	15.21	0.99	62	42.6304	68.7652	16.84	2.53
31	43.0970	68.7965	15.23	1.33	63	42.6872	68.7974	16.94	1.71
32	42.8776	68.8835	15.24	1.05	64	42.9295	68.8324	17.01	1.59

Note. ARO 3 = TYC 4313−355, spec. type = F1 V. ARO 4, spec. type = A3 V.

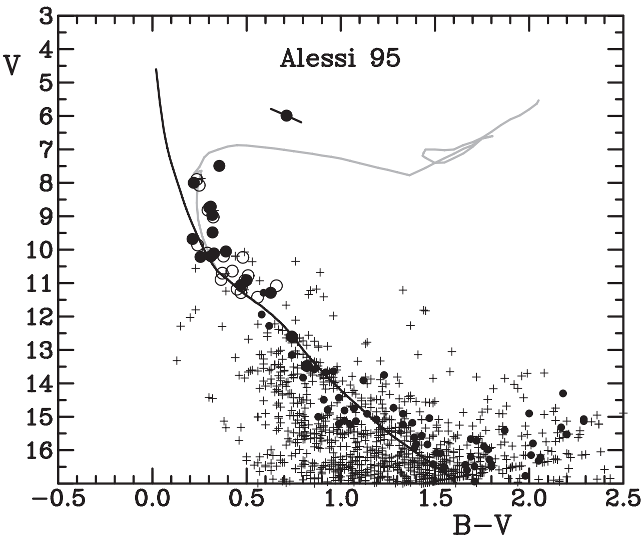

Figure 4. Uncorrected colour–magnitude diagram for Alessi 95, with photoelectric data identified by large filled circles, stars from the *Hipparcos/Tycho* data base by open circles, stars from the ARO survey by small filled circles, stars from NOMAD lying in the inner 30 arcmin of the cluster by small plus signs and SU Cas by a filled circle with bars to indicate its range of variability. The black relation is the ZAMS for $V - M_V = 9.11$, and a grey curve is a model isochrone for $\log t = 8.2$.

CCD observations of the central 15 × 22 arcmin^2 region surrounding SU Cas were made through Johnson system *BV* filters in 2011 September with the SBIG ST8XME camera on the Celestron 35-cm telescope of the robotic Abbey Ridge Observatory (see Lane 2008). The observations were calibrated using previously published photoelectric *UBV* photometry for stars in the field (see Turner 1984; Turner & Evans 1984), and are included in Fig. 4.

The reddening for individual stars was established using the reddening relation found from the spectroscopic observations (Fig. 2) through standard dereddening techniques (see Turner 1976a,b). For stars with *BV* data only, colour excesses were inferred from the spatial trend of reddening across the field, except for those objects closely associated with the opaque dust clouds near the Cepheid. In all cases the B0-star reddenings averaged for spatially adjacent stars were adopted for individually dereddened stars, then adjusted for the colour dependence of reddening to that appropriate for the inferred intrinsic colour of each object (see Fernie 1963). In a few cases it was possible to infer an independent reddening from the spectral classification for the star. Each star was corrected for extinction using its inferred B0-star reddening in conjunction with the adopted value of $R = 2.8$.

The resulting data are plotted in Fig. 5 along with similarly derived data for six stars in Table 1 that appear to share comparable space motions and parallaxes with SU Cas. Observed radial velocities (see Turner & Evans 1984; Turner et al. 1985), proper motions (van Leeuwen 2007) and parallaxes (van Leeuwen 2007) were used

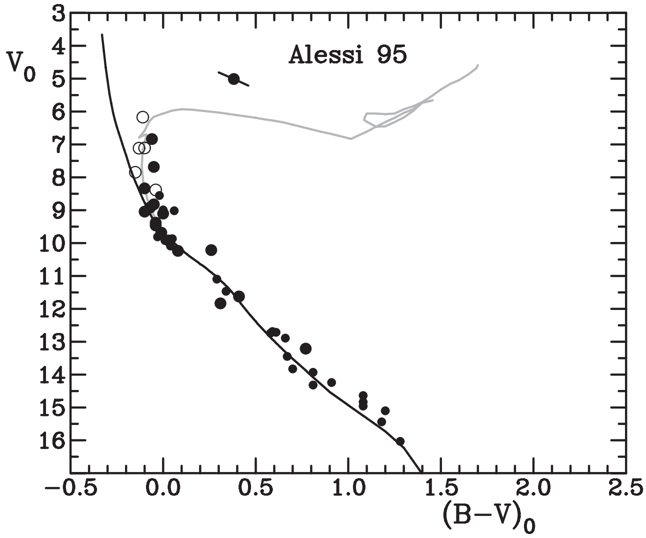

Figure 5. Reddening and extinction-free colour–magnitude diagram for Alessi 95, with photoelectric data identified by large filled circles, stars from the ARO survey and *Hipparcos/Tycho* data base by small filled circles, and SU Cas as in Fig. 4. Open circles denote the six stars from Table 1 that may be outlying cluster members. The black relation is the ZAMS for $V_0 - M_V = 8.16$, and the grey curve is a model isochrone for $\log t = 8.2$.

Table 3. *Hipparcos* parallax data for members and potential outlying members of Alessi 95.

Hipparcos	Star	$\pi_{\rm abs}$ (mas)	$\pm\sigma_\pi$ (mas)
11633	BD+68° 170	2.31	1.46
12434	HD 16228	2.80	1.23
12567	HD 16393	3.03	0.52
12924	HD 16841	3.08	1.01
13138	BD+70° 205	1.04	1.02
13208	HD 17327	0.98	0.77
13219	BD+69° 181	1.82	1.20
13367	SU Cas	2.53	0.32
13465	BD+68° 201	0.89	1.34
13595	BD+69° 186	0.82	1.47
13728	HD 17929	2.84	0.64
13956	BD+69° 189	2.36	1.40
14442	BD+70° 224	0.60	1.10
14483	BD+67° 243	−0.97	1.99
14714	HD 19287	1.02	1.32
15138	HD 19856	1.13	1.09
15959	HD 20710	4.19	0.61
16633	HD 21725	0.86	1.25

Note. BD+68° 201 = FM-A.

to identify only *bona fide* potential outlying cluster members on the basis of similarity of the values to those for SU Cas.

The reddening for individual members of Alessi 95 is well enough established for 26 likely ZAMS members of the cluster to derive a mean intrinsic distance modulus of $V_0 - M_V = 8.16 \pm 0.04$ s.e. (±0.21 s.d.). The ZAMS adopted here is that of Turner (1976a, 1979), and the fit corresponds to a distance of $d = 429 \pm 8$ pc, with the cited uncertainty representing the standard error of the mean. A model isochrone for $\log t = 8.2$ from Meynet et al. (1993) fits the data reasonably well, with a likely uncertainty in $\log t$ no larger than ±0.1. It is possible to use alternate evolutionary isochrones from the literature, but they do not match the adopted ZAMS nearly as well. The isochrone fit for Alessi 95 is not ideal for SU Cas, but that problem could be resolved by accounting for the opacity effects of CNO mixing in the envelopes of post-supergiant stars (see Xu & Li 2004). A more typical solution to the problem of a compressed blue loop for core helium-burning stars is to adopt a metallicity for the isochrone that is smaller than the solar value, but that does not appear to be justified in the case of Alessi 95, given that the derived metallicity of SU Cas (and two associated stars) from stellar atmosphere models is close to solar [$\langle$[Fe/H]$\rangle = -0.12, +0.02, -0.01$ and $+0.06$ according to Kovtyukh et al. (1996), Usenko et al. (2001), Andrievsky et al. (2002) and Luck et al. (2008), respectively].

Three of the bright members of Alessi 95, as well as 15 other stars lying within a few degrees of SU Cas sharing similar space motions (proper motions and in a few cases radial velocities) with the Cepheid and with colours and magnitudes consistent with the $\log t = 8.2$ isochrone in Fig. 4, are catalogued in the *Hipparcos* catalogue (van Leeuwen 2007). The stars are collected in Table 3, along with their cited parallaxes and uncertainties. The weighted mean parallax for the group is $\pi_{\rm abs} = 2.38 \pm 0.19$ mas, corresponding to a distance of 420 ± 33 pc. An attempt was also made to include the less precise parallaxes from the *Tycho* catalogue (ESA 1997) in the result. A further 15 stars were considered in such fashion, but the resulting mean parallax and distance remained unaffected, since the extra stars add negligible weight to the overall solution because of their large parallax uncertainties. In both cases the parallax solution is in excellent agreement with the cluster distance of 429 ± 8 pc derived from ZAMS fitting.

A further consistency check on the results was made using JHK_s photometry (Cutri et al. 2003) from the Two Micron All Sky Survey (2MASS; Skrutskie et al. 2006) for Galactic star fields. Stars lying within 50 arcmin of the centre of Alessi 95 with proper motions similar to that of SU Cas are plotted in colour–colour and colour–magnitude diagrams in Fig. 6 in the manner adopted by Turner (2011). Also included are similar data for the stars from Table 1 and Fig. 5 selected on the basis of comparable space motion with SU Cas. Most of the scatter in the observations can be attributed to photometric uncertainties, yet the data are a reasonably close match to the results inferred from the *UBV* analysis, namely the implied reddening and distance modulus.

A project was also completed in 2012 January to obtain JHK_s photometry of greater precision for the field of Alessi 95 using queue observing with the near-infrared imager (CPAPIR) of l'Observatoire du Mont-Mégantic (OMM; Artigau et al. 2010). The details of that study, to be presented elsewhere, provide much stronger confirmation of the optical results than is the case for the less precise 2MASS data, and also provide information on the extreme lower end of the cluster main sequence.

The nuclear and coronal radii for Alessi 95 implied by its distance derived from ZAMS fitting are 3 and 6.3 pc, respectively. Both values are reasonable, although a larger tidal radius is expected, which would explain the presence of outlying cluster members a few degrees from SU Cas.

3 SU Cas AS A MEMBER OF Alessi 95

In the studies by Schmidt (1978) and Turner & Evans (1984) of stars associated with the dust complexes near SU Cas, it was noted that the dust clouds lie at different distances. The two main clouds at the declination of SU Cas and south of it are at distances of 258 ± 3 and 401 ± 38 pc according to the Turner & Evans (1984) study. SU Cas was assumed to lie at the distance of the former, according to a

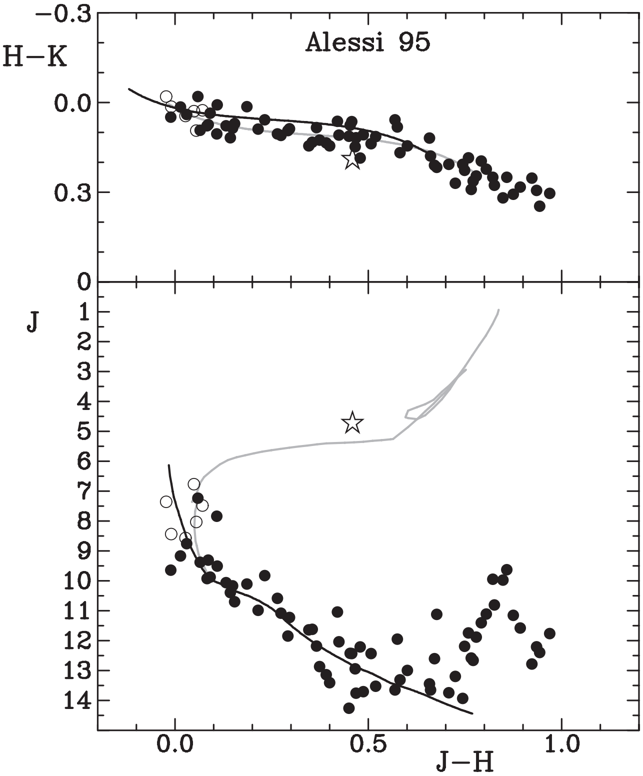

Figure 6. *JHK*$_s$ colour–colour diagram (upper) and colour–magnitude diagram (lower) for stars in Alessi 95 (filled circles) and outlying stars (open circles), indicated to be potential cluster members from proper motion data. SU Cas is denoted by a star symbol. The black relation in the upper diagram is the intrinsic relation for dwarfs, while the grey relation corresponds to a reddening of $E(B-V) = 0.35$. The black relation in the lower diagram is the ZAMS for $V_0 - M_V = 8.16$, and the grey curve is a model isochrone for $\log t = 8.2$.

perceived connection on POSS plates of the SU Cas dust complex with that associated with HD 16893 and HD 17443, which were calculated to be 258 pc distant.

The deeper POSS images used for the production of Fig. 1 indicate that such an assumption cannot be correct. The reflection nebulae illuminated by SU Cas that lie south of the Cepheid display no association with the opaque dust cloud east of it that continues further to the north-east. Strands of the same opaque cloud are seen to the west and south of SU Cas, connecting with the clouds illuminated by HD 16893 and HD 17443, but the main cloud east of SU Cas displays no evidence for associated reflection nebulosity, so must lie foreground to the Cepheid. The true geometry of the stars and dust is revealed by those members of Alessi 95 that, from their large reddenings, must be viewed *through* the dust extinction of the main cloud. SU Cas and Alessi 95 therefore lie beyond the main dust complex located at 258 pc. Indeed, the derived distance of 429 ± 8 pc to Alessi 95 agrees closely with the previous estimate (Turner & Evans 1984) for the distance to the further dust complex in the field.

The derived luminosity for SU Cas as a member of Alessi 95, including the uncertainty in its field reddening, is $\langle M_V \rangle = -3.15 \pm 0.07$ s.e., where the Cepheid's magnitude (Berdnikov 2007) has been adjusted for contamination by an unseen B-type companion 4.2 mag fainter (Evans & Arellano Ferro 1987; Evans 1991). The result is more than a magnitude more luminous than expected for a classical Cepheid with a mean period of $P = 1.949\,322$ d, as used in studies of the star's period changes (Berdnikov et al. 1997; Berdnikov, Mattei & Beck 2003; Turner, Abdel-Sabour Abdel-Latif & Berdnikov 2006). The Cepheid must therefore be an overtone pulsator, as argued previously (e.g. Gieren 1976, 1982). According to the empirical relationship between fundamental mode and first overtone pulsation periods established for double-mode Cepheids by Szabados (1988), the undetected mean period for fundamental mode pulsation in SU Cas must be 2.754 776 d.

An independent distance estimate for SU Cas is possible from its radius and inferred mean effective temperature, using the infrared surface brightness variant of the Baade–Wesselink method, as noted by Storm et al. (2011). The estimated distance to SU Cas in that study is 418 ± 12 pc for a pulsation period of 1.95 d. With the revised space reddening found here for SU Cas and a local ratio of total-to-selective extinction of $R = 2.8$, the derived distance becomes 414 ± 12 pc for fundamental mode pulsation ($P = 2.75$ d). The distance estimates are not completely independent, but the methodologies are. The close agreement in the pulsation parallax, trigonometric parallax and cluster parallax estimates for the distance to Alessi 95 and SU Cas (414 ± 12, 420 ± 33 and 429 ± 8 pc, respectively, all of which agree to within their derived uncertainties) provides strong confirmation of their validity.

The implied mean radius of SU Cas according to the Cepheid period–radius relation of Turner et al. (2010), which is tied to the almost identical slopes for the Cepheid period–radius relation in studies by Gieren, Barnes & Moffett (1989), Laney & Stobie (1995), Gieren, Fouqué & Gómez (1998) and Turner & Burke (2002), is 25.0 $R_\odot$. By comparison, the surface brightness technique yields a mean radius of $28.0 \pm 0.8\,R_\odot$, while an independent Baade–Wesselink analysis using infrared colours by Milone, Wilson & Volk (1999) produced an estimate of $33.0 \pm 1.1\,R_\odot$. The last study also summarizes previous estimates for the mean radius of SU Cas derived from variants of the Baade–Wesselink method, most of which lie in the range 30–45 $R_\odot$. Systematic effects cannot be discounted, given the small amplitude of the light variations in SU Cas and the fact that Milone et al. (1999) adopted a projection factor of $p = 1.39$ in their study. Laney & Joner (2009) find a value of $p = 1.277$ to be more suitable for SU Cas, which would reduce the Milone et al. (1999) value to $30.3 \pm 1.0\,R_\odot$. The *VJK* photometry used by Laney & Joner (2009) leads to a mean radius of 28.5 $R_\odot$ for SU Cas, while Turner & Burke (2002) obtained a radius of $19.0 \pm 0.7\,R_\odot$ using a Baade–Wesselink analysis tied to *KHG* photometry. The last three estimates are closer to the value predicted by the Cepheid period–radius relation, and it may be that the star's small pulsation amplitude and contamination by its B-type companion limit further improvement.

With the period of fundamental mode pulsation in SU Cas indicated by its membership in Alessi 95, one can estimate independently the age of the Cepheid from existing period–age relations. A model-based relationship derived by Bono et al. (2005) yields an age of $\log t = 8.0$ for a solar metallicity Cepheid with $P = 2.75$ d, while a relationship by Efremov & Elmegreen (1998) calibrated by isochrone fits to open clusters yields a similar age of $\log t = 8.3$. Both cited relationships display a dispersion in $\log t$ of ± 0.1, so are consistent with the cluster age inferred from the model isochrones of Meynet et al. (1993). Additionally, the implied age of $\log t = 8.2$ for SU Cas from its membership in Alessi 95 provides a key point at the short-period end of a semi-empirical period–age relationship for cluster Cepheids developed by Turner (2012), where again the dispersion is no larger than ± 0.1 in $\log t$ and the relationship is generated by isochrone fits to clusters containing Galactic Cepheids.

The luminosity of SU Cas inferred from cluster membership, namely $\langle M_V \rangle = -3.15 \pm 0.07$, can be compared with a value of $\langle M_V \rangle = -2.77$ predicted from its inferred radius and effective temperature via the methodology described by Turner & Burke (2002) and Turner et al. (2010). The 0.38 mag offset from the empirical estimate is comparable to the offsets observed for other cluster Cepheids (Turner 2010), and can be partially explained by the nature of SU Cas: a small-amplitude Cepheid lying near the high-temperature side of the instability strip, as also argued by its overtone pulsation. SU Cas has an unseen B9.5 V companion detected by *IUE* (Evans & Arellano Ferro 1987; Evans 1991), and the luminosity inferred for the Cepheid according to the implied magnitude difference between SU Cas and the B star in ultraviolet spectra is $M_V = -3.1 \pm 0.1$ (Evans 1991), closely coincident with the result from cluster membership. The companion, which may also be an Ap star (Turner 2003), has otherwise only a small effect on the overall visual brightness and colours of SU Cas.

Confirmation of the location of SU Cas towards the blue edge of the Cepheid instability strip is provided by its observed rate of period change of $+0.024\ \mathrm{s\,yr^{-1}}$ (Berdnikov et al. 1997, 2003; Turner et al. 2006). That implies a rate of evolution for the Cepheid that is more than twice as rapid as what is typical of fundamental mode pulsators with periods of $\sim$2.75 d near the centre of the instability strip (Turner et al. 2006). The consistency in the implied parameters for SU Cas found from such diverse observational material provides further validation of the present results.

4 DISCUSSION

This first detailed photometric and spectroscopic study of Alessi 95, the sparse open cluster surrounding the Cepheid SU Cas, produces empirical estimates for the reddening and luminosity of a *bona fide* Cepheid calibrator. Estimates for the distance to SU Cas and Alessi 95 from ZAMS fitting, *Hipparcos* parallaxes (van Leeuwen 2007) and the Cepheid's pulsation parallax (Storm et al. 2011, adjusted here) agree closely to within a few per cent, to our knowledge the first such instance of a tight consensus in distance estimates by these diverse methods. Future improvement to the cluster ZAMS fit might be possible, for example, through a more detailed analysis that accounts implicitly for the metallicity of SU Cas and Alessi 95 members. That affects ZAMS fitting through small offsets in the zero-point, which is currently calibrated for solar metallicity stars. Given present knowledge of the near-solar chemical composition for Alessi 95 stars (Usenko et al. 2001), however, only a very minor improvement would be expected.

The inferred field reddening of $E(B - V) = 0.33 \pm 0.02$ found here for SU Cas agrees reasonably well with other independent estimates (Turner et al. 1987; Laney & Caldwell 2007; Kovtyukh et al. 2008), and the effective temperature of 6620 K for SU Cas inferred from its colour via the semi-empirical technique described by Turner & Burke (2002) and Turner et al. (2010) is only slightly greater than the values obtained by Usenko et al. (2001) from stellar atmosphere models. Any discrepancies between the present results and those of previous studies appear to be minor, except for the inferred luminosity of $\langle M_V \rangle = -3.15 \pm 0.07$ s.e., which differs from that found in the earlier study by Turner & Evans (1984), primarily because of an erroneous selection of reflection nebulosity stars associated with the Cepheid in that paper. Future work may improve the situation, since *Hipparcos* parallaxes, pulsation parallaxes and cluster parallaxes are all susceptible to systematic effects that are the subject of ongoing study. It should be evident, however, that there is no longer a need to rely on the Cepheid's membership in Cas R2 to derive its intrinsic parameters (e.g. Turner & Evans 1984; Usenko et al. 2001; Turner 2010).

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