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SPECTROSCOPIC INVESTIGATIONS OF GALACTIC CLUSTERS WITH ASSOCIATED CEPHEID VARIABLES. II. NGC 5662 AND V CEN

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ABSTRACT. We present the results of a spectroscopic and photometric investigation of 15 objects from the open cluster NGC 5662, which contains the Cepheid V Cen. Besides the Cepheid, we studied one G-supergiant, two K-giants, four B-giants, and seven main sequence stars. Radial velocities (RV), v sin i, $T_{\rm eff}$, log g, and [Fe/H] were determined using model fitting. We have derived the color-excesses, reddenings, and intrinsic colors for these stars to determine their true $T_{\rm eff}$ and log g from comparison to the atmosphere models, especially for hot stars, and to determine their absolute magnitudes. RV and GAIA DR2 2018 parallax/distance values for these stars allowed us to determine their membership in the cluster and to construct it 3D kinematic models. These parallaxes and reddenings led to the distances in a range of 700–875 pc, while photometric M_V gave the distances of 550–660 pc. Two objects from our list were found to be non-members of the cluster, and two other objects to be background stars. All members have [Fe/H] $= -0.1 \pm 0.04$ dex. The main sequence stars and B-giants have abundances of C, N, and Na close to the solar one, while the cool supergiants and giants show a deficit of carbon, an overabundance of nitrogen, and a small overabundance or close to the solar sodium content. Two Li-rich K-giants, HD 127733 and HD 127753, were discovered in the cluster.

АБСТРАКТ. Ми презентуємо результати спектроскопічних та фотометрічних дослідів 15 об'єктів розсіяного скупчення NGC 5662 з цефеїдою V Cen. Окрім цефеїди ми дослідили один G-надгігант, два K-гіганти, чотири B-гіганти та сім зір головної послідовності. За допомогою модельного фіттінгу були отримані оцінки радіальних швидкостей (RV), v sin i, $T_{\rm eff}$, log g, та [Fe/H]. Ми розрахували надлишки кольору, почервоніння та справжні кольори для цих зір, щоб знайти їх справжні $T_{\rm eff}$ та log g шлляхом порівнення з моделями атмосфер, особливо для гарячих зір, та абсолютні магнітуди. Оцінки RV та паралакс/відстань з каталогу GAIA DR2 2018 для цих зір дозволяють виявити їх належність до скупчення та збудувати його кінематичні 3D-моделі. Ці паралакси та почервоніння дають оцінки відстаней у межах 700-850 пс, тоді як фотометрічні M_V давали оцінки у 550–660 пс. Два об'єкти з нашого списку виявилися не членами скупчення, та ще два - біля меж скупчення. Усі члени мають [Fe/H]$= -0.1 \pm 0.04$ dex. Зорі головної послідовності та B-гіганти мають вміст C, N, та Na близьким до сонячного, тоді як холодні надгіганти та гіганти показують дефіціт вуглецю, надлишок азоту, та маленький надлишок, або сонячний вміст натрію. У скупченні були відкриті два багатих літієм K-гіганта - HD 127733 та HD 127753.

Key words: Open clusters: radial velocities; Stars: abundance; GAIA parallaxes; Cepheids; Lithium giants; individual: NGC 5662, V Cen, HD 127733, HD 127753.

1. Introduction

The open cluster NGC 5662 belongs to the Centaurus section of the Milky Way. Being the Trumpler class II3m, it consists of a central grouping in the northern part and a southern one with the Cepheid V

Cen and a loose concentration of B- and A-type stars (Turner, 1982). According to Claria et al. (1991), the earliest spectral type stars in it is B7, $E_(B-V)$ = 0.31, $V-M_V = 9.80$, $d = 790 \pm 5$ pc, [Fe/H] = −0.03, and an age near 7.9×10^7 yr. Kharchenko et al. (2016) give a [Fe/H] = 0.03 for this cluster. NGC 5662 has not been carefully studied spectroscopically except for V Cen. Therefore, the main goals of our investigation are as follows: 1) to measure the radial and rotational velocities of the cluster's stars, 2) to determine the atmosphere parameters, metallicities, CNO, and Na abundances and compare the abundances between the objects of different spectral types, and 3) to determine the distances using GAIA DR2 parallaxes and RV data and to construct a 3D cluster's kinematic model.

2. Observations

All observations were taken using the 11m SALT (Southern African Large Telescope) equipped with HRS (High Resolution Spectrograph). HRS is a dual-beam (3700-5500 & 5500-8900 Å) fiber-fed, white-pupil, échelle spectrograph, which uses VHP gratings as cross dispersers. We obtained one spectrum for each object using the *medium mode* with the spectral resolving power R = 40000, an average S/N of over 100, which it is enough to reach our observational goals. These spectra will be used to derive the atmosphere parameters and chemical abundances for some elements of the open cluster members. The data were reduced using the *échelle* context in *MIDAS*. Also, the *feros* package developed for échelle data reduction from the Fiber-fed Extended Range Optical Spectrograph (FEROS) was used. Both FEROS and HRS provide very similar échelle data.

We used the DECH30 package (Galazutdinov, 2007) designed to use the spectra in FITS format to measure the line depths and their equivalent widths. The radial and rotational velocities were measured by fitting of the observed spectrum with a model from Coelho (2014). The object IDs, their magnitudes, spectral types, and measured radial and rotational velocities for each spectrum are given in Table 1. It should be noted that our results are consistent with those from other sources: RV = −21.74 $km\,s^{-1}$ (Mermilliod et al., 2008) and −20.89 $km\,s^{-1}$ (GAIA DR2, 2018) for HD 127427; −21.02 $km\,s^{-1}$ (Mermillod et al., 2008), and −21.31 $km\,s^{-1}$ (GAIA DR2 2018) for HD 127753, respectively.

3. Results and Analysis

3.1. Color-indices, color-excesses, reddenings, and atmosphere parameters

Since the objects of NGC 5662 from our list have different spectral types, masses, and evolutionary status, we have used different methods to determine their atmosphere parameters. First, for the $T_{\rm eff}$, log g, and [Fe/H] determination, as mentioned above, model fitting was performed. Next, the $T_{\rm eff}$estimates were verified using the Gray (1992) calibrations for color-indices. A final determination of the atmosphere parameters was performed in the following way. We have used the $U-B$ and $B-V$ intrinsic color-indices for luminosity types and metallicity based on the Kurucz (1993) models from Bessel et al. (1998) to determine $T_{\rm eff}$ and log g for the B- and A-type stars. For more evolved stars of *FGK* spectral types with a large number of narrow metallic absorption lines we have used the lines depth relation to derive $T_{\rm eff}$ (Kovtyukh, 2007), a Fe ionization balance to derive log g, and the absence of an Fe abundance dependence upon the equivalent width to derive V_t. It is obvious that we needed correct $(U-B)_0$ and $(B-V)_0$ not only for $T_{\rm eff}$ and log g, but also M_V data for our stars distance and radius determination. Therefore in Table 2 we show color-excess, intrinsic color, reddening, and extinction data that we have determined. As seen from Table 2, the majority of stars have close values of the color-excesses and reddenings, except for HD 127818 and HD 127733. Table 3 presents the results of the atmosphere parameters determination. As seen from this Table, the best agreement is achieved between all the methods of the $T_{\rm eff}$ determination for all stars as a whole, although there are discrepancies for some cool stars. The same can be said about the log g determinations.

Figure 1 represents a relation between the rotational velocity and $T_{\rm eff}$. It shows that all main-sequence stars as well as cool giants and supergiants found the

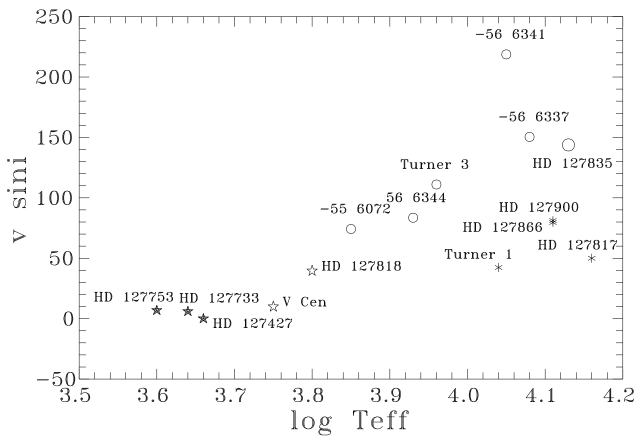

Figure 1: Relation between the rotation velocity and $T_{\rm eff}$for the NGC 5662 open clusters' objects. Open circles show the main sequence stars, filled five-point stars show K-supergiants, open five-point stars show FG-supergiants, and six-point stars show B-giants.

Table 1: General data for the observed objects in NGC 5662 and derived RVs.

Object	V	Sp.type	RV, $\mathrm{km\,s^{-1}}$	v sin i, $\mathrm{km\,s^{-1}}$
V Cen	6.930	F5 Ib-II	-23.50 ± 0.50[1]	10.4 ± 0.1
HD 127427	7.744	G8 II-III	-21.86 ± 0.02	0.0 ± 0.0
HD 127866	8.287	B7 III	-22.25 ± 0.14	79.6 ± 0.3
CPD $-56°6337$	10.659	A1 V	-58.16 ± 0.21	150.4 ± 0.5
HD 127817	9.157	A0 V	-18.57 ± 0.09	50.0 ± 0.2
HD 127753	7.043	K5 III	-22.53 ± 0.03	6.9 ± 0.1
HD 127835	9.375	B8 V	-15.37 ± 0.12	143.8 ± 0.4
HD 127900	8.817	B8 II-III	-20.82 ± 0.10	81.2 ± 0.2
CPD $-56°6341$	10.787	B9 V	-14.97 ± 0.22	218.7 ± 0.7
CPD $-55°6072$	11.296		-37.55 ± 0.08	74.2 ± 0.2
CPD $-56°6344$	11.347		-24.83 ± 0.15	83.5 ± 0.2
HD 127818	9.485	F6/8 IV-V	-10.62 ± 0.06	40.0 ± 0.1
HD 127733	8.599	K2/3 III	$+7.35\pm0.03$	6.0 ± 0.1
HD 127199 (Turner 1)	10.620	B5/7 III	-27.84 ± 0.09	42.3 ± 0.2
Turner 3	12.030		-46.99 ± 0.17	111.0 ± 0.4

1 - Phase $0.^P575$ according to GCVS (1985)

Table 2: Observed colors, color-excesses, intrinsic colors, reddenings, and extinctions for the NGC 5662 objects.

Star	B-V	U-B	$(B-V)_0$	E_{B-V}	$(U-B)_0$	E_{U-B}	A_V	V_0	R
V Cen	0.91	0.60	0.60	0.31	0.36	0.24	1.18	5.75	3.80
HD 127427	1.45	1.30	1.04	0.45	1.03	0.37	1.11	6.39	3.00
HD 127866	0.16	−0.24	−0.12	0.28	−0.45	0.22	0.92	7.45	2.97
CPD $-56°6337$	0.25	−0.02	−0.08	0.33	−0.26	0.22	0.99	9.68	3.00
HD 127817	0.20	−0.25	−0.14	0.54	−0.49	0.24	0.99	8.13	2.99
HD 127753	1.86	2.04	1.33	0.60	1.75	0.27	1.11	5.23	3.00
HD 127835	0.13	−0.29	−0.13	0.26	−0.48	0.20	0.81	8.60	3.00
HD 127900	0.14	−0.26	−0.14	0.28	−0.46	0.20	0.87	7.98	3.00
CPD $-56°6341$	0.33	0.10	−0.06	0.40	−0.18	0.27	1.14	9.61	3.80
CPD $-55°6072$	0.57	0.24	0.29	0.29	-	-	0.88	10.42	3.00
CPD $-56°6344$	0.42	0.26	0.19	0.24	0.01	0.21	0.71	10.64	3.02
HD 127818	0.57	0.16	0.36	0.22	-	-	0.65	8.84	3.02
HD 127733	1.70	1.85	1.29	0.47	1.56	-	1.94	7.20	3.46
HD 127199 (Turner 1)	0.26	0.06	−0.07	0.34	−0.18	0.24	0.96	9.61	3.10
Turner 3	0.61	0.29	0.38	0.35	0.05	0.24	0.99	11.00	3.20

Table 3: Atmosphere parameters for the NGC 5662 objects.

	T_{eff}					log g				V_t
Star	Gray	Fit	Phot	AMod	Adopted	Fit	Phot	AMod	Adopted	
V Cen		5824		5596	5596	0.70		1.80	1.80	3.10
HD 127427	4771	4937		4610	4620	2.24		1.40	1.40	2.00
HD 127866	13537	12912	12891		12891	3.57	3.22		3.22	3.80
CPD $-56°6337$	11863	11712	12000		12000	4.22	4.25		4.25	2.70
HD 127817	14607	14000	14230		14230	3.89	3.90		3.90	3.50
HD 127753	4229	4134		3840	3840	1.27		0.40	0.40	2.20
HD 127835	14049	13347	13400		13400	3.75	3.75		3.75	3.80
HD 127900	14049	13000	13000		13000	3.74	3.50		3.50	3.50
CPD $-56°6341$	11205	14416	11300		11300	4.33	4.30		4.30	3.50
CPD $-55°6072$	6994	7000			7000	3.48			3.48	
CPD $-56°6344$	7534	8415	8375		8375	4.35	4.00		4.00	5.50
HD 127818	6704	6600		6355	6355	3.92		3.40	3.40	2.00
HD 127733	4296	4472		4350	4350	2.75		2.00	2.00	1.80
HD 127199 (Turner 1)	11521	14000	10467		10467	4.13	4.10		4.10	2.50
Turner 3	7040	9556	9050		9050	3.30	4.00		4.00	3.50

Gray - according to Gray (1992); Fit - using fitting;
Phot - from photometry; AMod - using atmosphere models.

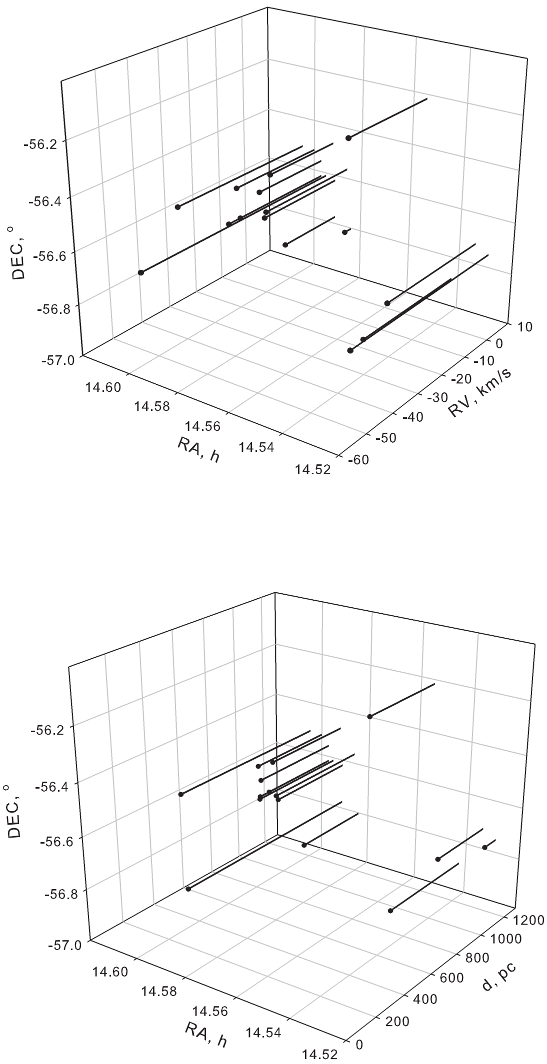

Figure 2: A 3D view of the NGC 5663 cluster by distance and radial velocities.

clear dependence, while blue giants form a separate region.

3.2. Parallaxes, absolute magnitudes, distances, and radii

Table 4 contains the GAIA DR2 parallaxes for our stars as well as absolute magnitudes and distances determined from them, and next to compare, - data from photometric observations. As can be seen from the Table, the parallax-based distances for 12 objects lie in a range of 700–875 pc, and they are close to the 790±5 pc value from Claria et al. (1991). According to these authors, CPD $-55°6072$ and HD 127818 are non-members of the cluster, and this fact is confirmed in this Table. Similar to V Cen, HD 127199 (Turner 1) and Turner 3 are located in the cluster's background. However the distance to the Cepheid is close to the average one for the cluster, while the hot stars are much more distant. At the same time, the distance problem for Turner 1 and Turner 3 is eliminated by using the distances of 550–660 pc derived from the absolute magnitudes, although there are still uncertainties with M_V for two cool giants and supergiant. The results for the stellar radii differ slightly for the main-sequence stars (except for Turner 1 and Turner 3), but for K–giants these discrepancies are significant.

Figure 2 represents kinematic 3D models of NGC 5662. The majority of our list stars are the cluster members, while CPD $-55°6072$ and HD 127818 are definitely non-members and Turner 1 and Turner 3 are the clusters' background stars.

3.3 Chemical abundances

When the atmospheric parameters were derived, we used the VALD oscillator strengths (Kupka et al., 1999) and LTE model atmospheres from Castelli & Kurucz (2004) for determination of the element abundances. Table 5 presents the iron content, which was determined using fitting of the entire spectrum to a model spectrum and the atmosphere models method, and abundances for the "key"-elements of yellow supergiants stellar evolution - carbon, nitrogen, oxygen, and sodium. It shows that the [Fe/H] abundances determined using atmosphere models lie in a range from -0.1 to $+0.04$ dex for all the stars (except for HD 127818) that is in good agreement with the results from Claria et al. (1991) and Kharchenko et al. (2016). The carbon abundance is close to than of the Sun or a little higher for the main-sequence stars and hot giants and shows a moderate deficit for the cool giants and supergiants, except for HD 127753 with the lowest value. The nitrogen abundance is close to solar one or little higher for the main-sequence and hot giant stars except for HD 127818, but all the cool giants and supergiants have a typical overabundance. The oxygen content varies from a small deficit to the solar one. A very interesting situation is seen with sodium: a noticeable overabundance has only HD 127733, while the Cepheid and other cool stars as well as two main-sequence stars have a content close to the solar, again except for HD 127818.

3.4 Lithium rich giants

Two K-giants, HD 127733 and HD 127753, were found as the lithium-rich stars. Using the synth approximation with the atmosphere parameters

Table 4: Comparison between absolute magnitudes, distances, and radii determined using GAIA DR2 parallaxes and photometric data.

	PLX (GAIA DR2)				Photometry		
Object	π (mac)	Mv	d (pc)	R ($R_\odot$)	Mv	d (pc)	R ($R_\odot$)
V Cen	1.340±0.045	−3.60±0.08	740±27	50.2±1.9	−3.24	628	43[1]
HD 127427	1.244±0.039	−2.86±0.08	796±27	52.6±1.8	−2.85[2]	787	52
HD 127866	1.271±0.054	−2.06±0.08	780±28	4.7±0.1	−1.70	652	4.0
CPD −56°6337	1.334±0.046	+0.37±0.05	738±17	1.8±0.0	+0.85	581	1.4
HD 127817	1.231±0.042	−1.33±0.07	809±26	2.7±0.1	−0.85	637	2.2
HD 127753	1.402±0.044	−3.28±0.07	704±23	87.6±2.1	−2.00[3]	385	51
					−4.27[2]	1096	146
HD 127835	1.256±0.042	−0.86±0.05	776±17	2.5±0.1	−0.30	594	1.9
HD 127900	1.207±0.038	−1.61±0.08	828±30	3.7±0.2	−1.20	676	3.1
CPD −56°6341	1.258±0.041	+0.12±0.08	802±29	2.2±0.1	+0.56	658	1.8
CPD −55°6072	2.573±0.345	+2.49±0.28	386±46	2.0±0.3	+1.37	646	3.3
CPD −56°6344	1.133±0.088	+0.93±0.16	875±8	2.8±0.2	+1.68	619	2.1
HD 127818	4.910±0.034	+2.32±0.01	201±1	2.6±0.0	+3.26	131	1.7
HD 127733	1.143±0.040	−2.98±0.05	863±20	62.6±1.5	+0.80[3]	149	11
					−2.30[2]	619	46
HD 127199 (Turner 1)	1.077±0.042	−0.16±0.10	920±41	2.7±0.1	+0.95	552	1.8
Turner 3	0.832±0.042	+0.72±0.10	1197±54	2.7±0.1	+2.07	622	1.4

1 - Phase $0.^P575$ according to GCVS (1985)

2 - M_V according to Claria et al. (1991)

3 - M_V according to FitzGerald et al. (1979)

Table 5: Chemical abundances for NGC 5662 objects

	[Fe/H]		[C/H]	[N/H]	[O/H]	[Na/H]
Object	Fit	AtMod				
V Cen	−0.24	−0.04	−0.30	0.37	−0.10	0.10
HD 127427	−0.11	−0.06	−0.43	0.56	−0.27	−0.02
HD 127866	−0.33	−0.05	0.18	0.05	−0.39	–
CPD −56°6337	−0.63	−0.03	–	–	−0.31	–
HD 127817	−0.36	−0.05	0.22	−0.12	−0.26	–
HD 127753	−0.27	0.04	−0.93	0.73	−0.52	−0.09
HD 127835	−0.28	0.00	0.02	−0.12	−.26	0.00
HD 127900	−0.50	−0.07	–	0.22	−0.03	–
CPD −56°6341	−0.17	−0.03	–	–	0.08	–
CPD −55°6072	−0.28	–	–	–	–	–
CPD −56°6344	−0.18	−0.10	–	−0.12	−0.36	0.00
HD 127818	−0.20	−0.12	−0.43	−0.30	0.03	0.17
HD 127733	−0.20	−0.02	−0.16	0.18	−0.01	0.42
HD 127199 (Turner 1)	−0.18	0.03	0.02	0.15	0.00	–
Turner 3	−0.41	−0.04	–	–	−0.27	–

from Table 3, we obtained $\log A(\mathrm{Li}) = 1.27$ dex and $\log A(\mathrm{Li}) = 0.72$ dex, respectively (see Figures 3 and 4).

4. Summary

1. According to the derived RV, color-indices, and distances only 13 of the 15 objects we investigated are confidently members of NGC 5662.

2. The fitting method used to determine radial and rotational velocities of the cluster stars yields results with an accuracy of 0.5 $\mathrm{km\,s^{-1}}$ in RV and 0.7 $\mathrm{km\,s^{-1}}$ for v sin i.

3. We have revised color-excesses and reddenings for these objects, and it allowed us to refine their intrinsic colors, especially for the hot stars.

4. The atmosphere parameters of the hot stars were determined initially by fitting and finally refined using the atmosphere models based on the intrinsic colors. A good agreement is found for T_{eff} and log g determined by both methods.

5. The atmosphere parameters of the cool supergiants and giants were determined exclusively by

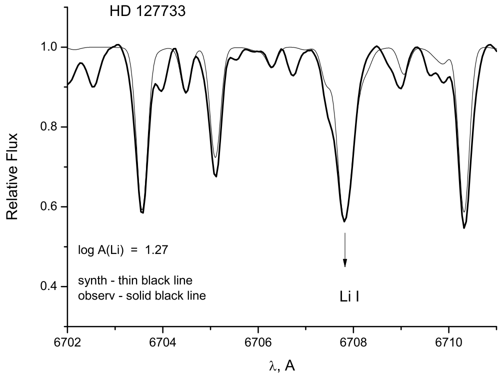

Figure 3: Li sc I 6707 Å absorption line in the atmosphere of HD 127733 and its approximation by synth.

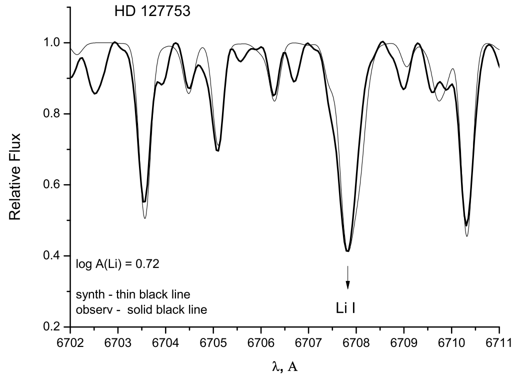

Figure 4: Li I 6707 Å absorption line in HD 127753 atmosphere and its approximation by synth.

the method of atmosphere models. Their final results differ significantly from those derived by fitting.

6. The distances of the most cluster stars determined from the GAIA DR2 2018 parallaxes lie in a range of 700–875 pc that roughly correspond to the mean cluster distance determined by Claria et al. (1991) using photometry, 790±5 pc, with problematic results for Turner 1 and Turner 3. However, the distances found using the visual absolute magnitudes M_V lie in a range of 550–660 pc and are problematic for the cool supergiant and giants.

7. The radii determined from our $T_{\rm eff}$ and the distances found by the two methods differ slightly for the hot stars and significantly for the cool giants.

8. According to kinematic 3D cluster models, 11 objects are the cluster members, Turner 1 and Turner 3 are cluster background stars, and CPD $-55°6072$ and HD 127818 are non-members of the cluster.

9. The [Fe/H] estimates determined by fitting differ significantly from those determined using atmosphere models.

10. All the cluster members have [Fe/H] from -0.1 to $+0.03$ dex that is close to the photometrically estimated ones.

11. The contents of carbon and nitrogen in the hot stars turned out to be close to the solar one, while for the cool supergiants and giants there is a deficit of C and an overabundance of N. This fact indicates that the FGK-type objects have already passed through the "first dredge-up" stage. The sodium content is determined only for two main-sequence stars, and it is close to the solar one. The cool supergiants and giants have either a near-solar content or a small overabundance.

12. Two K-giants from the cluster are lithium-rich stars.

13. Distances to NGC 5662 objects should be further revised.

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