DOI: http://dx.doi.org/10.18524/1810-4215.2018.31.145379

SPECTROSCOPIC INVESTIGATIONS OF GALACTIC CLUSTERS WITH ASSOCIATED CEPHEID VARIABLES. I. POLARIS CLUSTER AND α UMI.

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ABSTRACT. We present the results of an analysis of the spectra of nine so called Polaris cluster $A-FV$ stars obtained during 2016-2018. Radial velocities (RV) and GAIA DR 18 parallaxes-distances for these stars allow us to determine their membership in the cluster and to construct its 3D kinematic model. However $T_{\rm eff}$ for four stars determined spectroscopically give cause for doubts about the GAIA DR 18 parallaxes accuracy. The comparison between their M_V and distances with the those from Pecaut & Mamajek (2013) calibrations shows significant differences for the objects with parallaxes less than 8 mas. The differences in distances increase exponentially with decreasing parallax. These facts indicate an unreliability of the GAIA DR2 parallx measurements of less than 10 mas. We estimated the distance to Polaris B to be 104.2 pc.

АБСТРАКТ. Ми надаємо результати аналізу спектрів дев'яти зір спетрального класу $A-FV$ з так званого "скупчення Полярної", що були отимані на протязі 2016-2018 років. Радіальні швидкості та відстані, що отримані по паралаксах GAIA DR 18 для цих зір дозволяють нам встановити їх належність до скупчення за збудувати їх кінематичну 3D-модель. Але оцінки $T_{\rm eff}$, що отримані спектроскопічно для чотирьох зір надають причину для сумніву у точності значень паралаксів GAIA DR 18. Порівняння з їх M_V та відстанями з подібними, взятими з калібровок Pecaut & Mamajek (2013) показують значні розбіжності для об'єктів з паралаксами меньше ніж 8 mac Ці розбіжності у відстанях зростають експоненційно зі зменьшенням паралаксу. Ці факти викривають ненадійність оцінок паралаксів GAIA DR 18 меньше ніж 10 mac. Ми оцінили відстань до Полярної B у 104.2 парсека.

Key words: Open clusters: Stars: radial velocities; GAIA parallaxes; Cepheids and main-sequence stars: effective temperatures; distances; Cepheids: α UMi

1. Introduction

In a recent paper of Engle et al. (2018) the authors determined the distance to the Polaris AB system of 137.1±0.53 pc based on an estimate of the GAIA DR2 parallax for Polaris B of 7.292±0.03 mas. This distance assumes the Cepheid's radius near 47–50 $R_\odot$, although the "canonical" $P-R$ (period versus radius) relationship (Gieren et al. 1998) gives nearly 33 $R_\odot$. Such a parallax measurement is close to 132±9 ps determined by HIPPARCOS (ESA 1997). It is known that the HIPPARCOS parallax data for Cepheids have been repeatedly questioned, and the GAIA project was aimed at resolving these doubts. On the other hand, based on HIPPARCOS photometric data Turner (2009) established that field stars in the Polaris region belong to a poorly-populated star cluster. Most of these stars have parallaxes that correspond to a distance of 99±2 pc. A colour-magnitude diagramme for possible Polaris cluster stars constructed from 2MASS data suggests a distance of 106±7 pc for a colour-excess of $E_{B-V} = 0.02$ mag (Turner 2009). Usenko & Klochkova (2008) determined spectroscopically $T_{\rm eff}$ = 6900±50 K for Polaris B and assuming an $F3V$ main-sequence star radius of 1.4 $R_\odot$ derived its $M_V = +3.30$ mag and a distance of 109.5 pc. This result is an ideal agreement with 110 pc derived by Kamper (1996) using astrometric methods. Such a significant discrepancy in the estimates

and the radius of Polaris create grounds for a speculation about its evolutionary status and pulsational mode. In addition, Polaris is the nearest Cepheid to the Sun and determining the exact distance to it and its radius, respectively, is an important step in establishing the "$P-L$" relationship for Cepheids.

To resolve this problem we performed spectroscopic observations of the Polaris cluster main-sequence stars in order to determine their RV (to establish their membership in the cluster) and effective temperatures (to determine the radii and distances from known spectral types). These objects were taken from Turner et al. (2005). In addition to our RV measurements, combination with their GAIA DR2 parallaxes makes it possible to construct a kinematic 3D cluster model.

2. Observations

Nine spectra were taken during 2016 – 2018 with the 0.81 m telescope of the Three College Observatory (TCO), located in central North Carolina, USA. They were obtained with an échelle spectrograph manufactured by Shelyak Instruments[1] in a spectral range from 4250 to 7800 Å with a spectral resolving power of $R \sim 12000$ and no gaps between the spectral orders. The data were reduced using the *échelle* package in IRAF.

The DECH30 package (Galazutdinov, 2007) was used to measure the line depths and radial velocities using spectra in FITS format. Lines depths were used to determine the effective temperature (a method based on the spectroscopic criteria – Kovtyukh, 2007). Objects, their magnitudes, color-indices, and derived RVs for each spectrum are given in Table 1. V, $B-V$ and spectral types are taken from SIMBAD database, RV were measured using the metals (RV (met)) and hydrogen (H_α, H_β) absorptional lines.

3. Results and Analysis

Since the investigated objects are A-F main sequence stars, the radii and luminosities of which show an almost linear relation on the effective temperatures (intrinsic colors), we can compare our values of $(B-V)$ and $T_{\rm eff}$ with the ones calculated by Pecaut & Mamajek (2013) for a specific spectral type. This paper allows us to move from $(B-V)$ and $T_{\rm eff}$ to the radii of the stars, and hence to the distances to them. In Table 2 we represent the $(B-V)$ estimates from Turner et al. (2005). For the intrinsic color-indices $(B-V)_0$ we used the $(B-V)$ data for from Pecaut & Mamajek (2013). This way the color-excesses and reddenings were determined for each star. In addition, in Table 2 we included the reddening and distance for each object, defined taking into account the color-excess $E_{B-V} =$ 0.04 from Turner (2009). As can be seen from Table 2, for 6 stars from the list the difference in distance estimates varies from 11 to 45 pc. This indicates that the color-excesses for most of the cluster stars need to be refined.

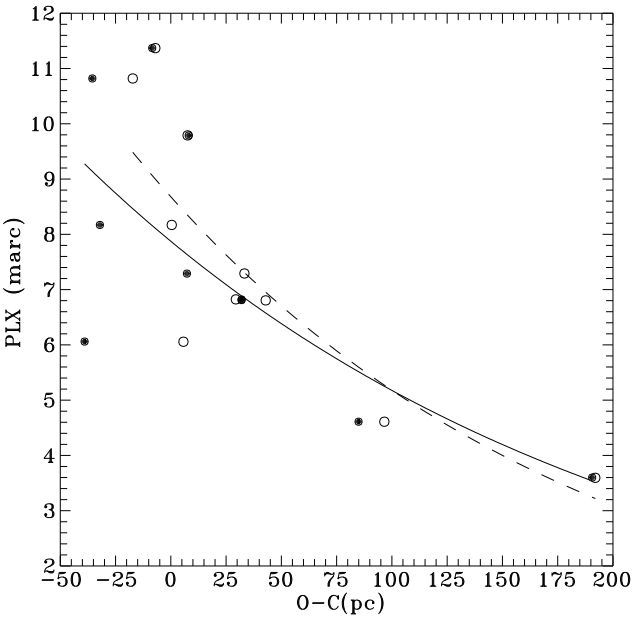

Figure 1: (O-C) distances - GAIA DR2 parallaxes relationship for the Polaris cluster stars. Open circles – calculated with E_{B-V} and A_V according to the intrinsic color-indices from Pecaut & Mamajek (2013), filled circles – calculated with $E_{B-V} = 0.04$ according to Turner (2009).

For four stars from the list, there are estimates of $T_{\rm eff}$, determined spectroscopically: HD 5914 - Teff = 8800±50 K (Usenko et al., 2008) and Polaris B - $T_{\rm eff}$ = 6900±50 K (Usenko & Klochkova, 2008) from hydrogen line profiles; HD 209556 - $T_{\rm eff}$ = 6301± 17 K and HD 163988 - $T_{\rm eff}$ = 6369±20 K from the ratio of the metal absorption line depths (Kovtyukh, 2007). Unfortunately, the latter method works only for stars of the spectral types later than F4 V. Nevertheless, according to Table 2, the difference between the radii determined from the spectroscopic estimates of $T_{\rm eff}$ and the values of Pecaut & Mamajek (2013) for this spectral type is approximately$\sim$0.1 $R_\odot$. In this case, the difference in the value of $T_{\rm eff}$ of 250 K gives an error in the distance is about 5.4 pc. Thus, the data from Pecaut & Mamajek (2013) can be used for calibration of the distances to the cluster stars.

Table 3 shows the GAIA DR2 parallaxes (except for HD 66368) for stars from the list and the absolute magnitudes and distances determined from them, as well as the data according to Pecaut & Mamajek (2013) for comparison. As can be seen from this Table, the smallest discrepancies in distances are found for the stars with parallaxes larger 8 mas. Figure 1 shows the rela-

[1] http://www.shelyak.com

Table 1: Polaris cluster objects. Observational list and RV.

Object	V	$B-V$	SpT	RV, km s^{-1}				
				RV (met)	NL	H_α	H_β	Reference
HD 5914	6.46	0.10	*A3V*	+0.1±3.3	110	+1.7	-2.1	
HD 66368	7.13	0.14	*A0V*	-7.9±2.8	86	-4.4	-2.0	
HD 11696	8.13	0.27	*A3V*	+8.3±0.6	56	-5.0	-	
HD 224687	6.74	0.06	*A0V*	-16.3±2.1	30	-13.6	-8.4	
HD 224991	7.84	0.30	*F0V*	+3.1±2.4	57	-1.9	+3.0	1
				-5.7±4.1	88	-	-	
HD 16335	7.84	0.36	*F0V*	-22.8±2.9	57	-30.1	-28.4	1
				-31.6±3.2	104	-	-	
Polaris B	8.20	0.57	*F3V*	-18.9±3.6	63	-16.6	-	2
HD 14369	8.11	0.35	*F0V*	-8.5±2.1	157	-7.8	-6.4	
HD 209556	8.37	0.45	*F5V*	-8.7±2.4	51	-13.5	-14.4	
HD 163988	8.11	0.47	*F5V*	-12.2±2.2	33	-1.0	-4.8	

NL - number of lines

[1] - two groups of absorption lines of metals, probably a spectroscopic binary star.

[2] - RV data according to Usenko & Klochkova (2008).

Table 2: Intrinsic colors, reddenings, effective temperatures, absolute magnitudes, distances, and radii are determined using data from Pecaut & Mamajek (2013).

Star	$B-V$	SpT	$(B-V)_0$	E_{B-V}	A_V	A_V (T)	$T_{\rm eff}$	M_V	d	d (T)	R	R($T_{\rm eff}$)
HD 5914	0.10	*A3V*	0.090	0.010	0.057	0.067	8550	1.55	93.5	93.0	2.01	1.90
HD 66368	0.14	*A0V*	0.000	0.140	0.585	0.067	9700	1.11	120.5	153.0	2.09	-
HD 11696	0.27	*A3V*	0.090	0.180	0.609	0.067	8550	1.55	157.8	202.5	2.01	-
HD 224687	0.06	*A0V*	0.000	0.060	0.272	0.067	9700	1.11	118.5	130.2	2.09	-
HD 224991	0.30	*F0V*	0.300	0.000	0.020	0.068	7220	2.51	115.9	113.3	1.79	-
HD 16335	0.36	*F0V*	0.294	0.066	0.288	0.068	7220	2.51	102.4	113.3	1.79	-
Polaris B	0.57	*F3V*	0.389	0.181	0.570	0.067	6720	2.99	104.2	128.4	1.60	1.52
HD 14369	0.35	*F0V*	0.294	0.056	0.404	0.068	7220	2.51	108.9	127.2	1.79	-
HD 209556	0.45	*F5V*	0.438	0.012	0.101	0.067	6510	3.40	94.2	95.6	1.46	1.57
HD 163988	0.47	*F5V*	0.438	0.032	0.124	0.067	6510	3.40	83.8	85.2	1.46	1.53

A_V (T) and d (T) - reddening and distance from $E_{B-V} = 0.04$ (Turner, 2009)

Table 3: Comparison between absolute magnitudes and distances determined using GAIA DR2 parallaxes and Pecaut & Mamajek (2013) data.

	PLX (GAIA DR2)			P & M	
Object	π (mac)	M_V	d (pc)	M_V	d (pc)
HD 5914	9.7893±0.0418	1.37±0.01	101.1±0.4	1.55	93.5
HD 66368	8.17[1]±0.55	1.62±0.15	120.9±8.0	1.11	120.5
HD 11696	6.0574±0.0319	2.02±0.01	163.5±1.1	1.55	157.8
HD 224687	4.6108±0.0363	0.02±0.03	215.1±2.5	1.11	118.5
HD 224991	6.8234±0.0305	1.97±0.03	145.3±2.0	2.51	115.9
HD 16335	6.8055±0.0259	1.97±0.01	145.3±0.6	2.51	102.4
Polaris B	7.2920±0.0280	2.87±0.01	135.7±0.6	2.99	104.2
HD 14369	10.8196±0.0291	3.22±0.01	91.7±0.4	2.51	108.9
HD 209556	11.3687±0.0869	3.60±0.02	87.2±0.2	3.40	94.2
HD 163988	3.5955±0.0321	0.85±0.02	275.8±2.5	3.40	83.8

[1] - value from van Leeuven (2007)

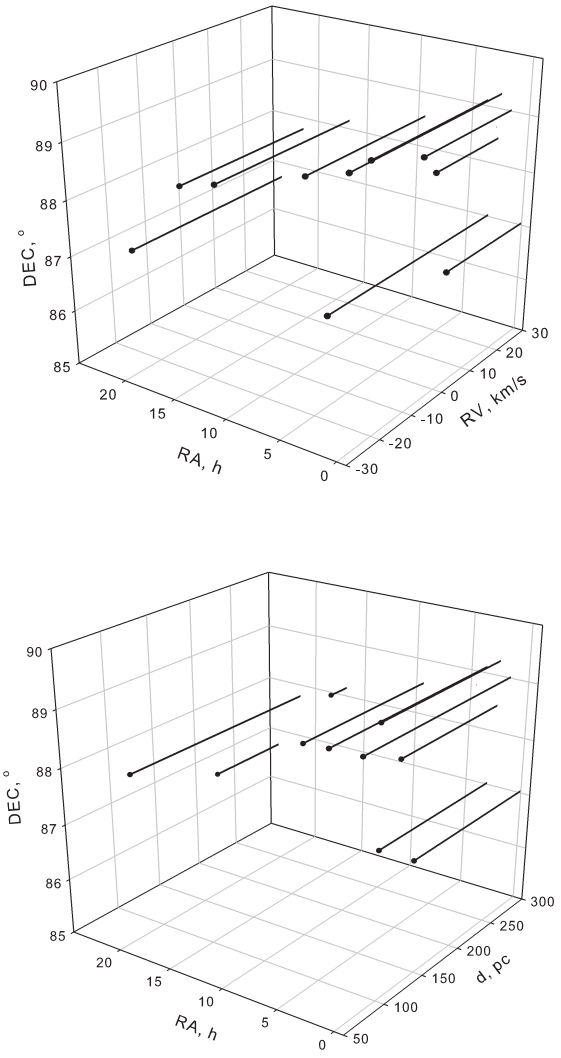

Figure 2: Polaris cluster 3D view by distance (bottom) and RV (top).

tionships of (O-C) in distances - GAIA DR2 parallaxes for two different cases of estimates of the color-excess of cluster stars. To construct this relationship calculated distances (C) were derived using data from Pecaut & Mamajek (2013), while the observed (O) ones came from the GAIA DR2 parallaxes. As can be seen from the Figure, both dependences are close to one another and are of exponential character, indicating that the errors in the distance determination to the cluster stars increase with decreasing parallaxes. This fact means that the GAIA DR2 parallaxes of less than 8 mas are unreliable. This is especially true for the assessment of Polaris B which is used to calibrate the distance for the Cepheid Polaris.

Nevertheless as seen from Figure 2, a 3D view of the Polaris cluster composed from our RV measurements and GAIA DR2 distances show the membership of our objects to the cluster.

4. Summary

1. According to RV values all these stars belong to the same moving group.
2. The distances of these stars determined from Pecaut & Mamajek (2013) calibrations and GAIA DR2 parallaxes indicate that these objects belong to the same cluster.
3. This fact is also evidenced by the distances determinated for four stars (HD 5914, Polaris B, HD 163988, HD 209556) by means of their radii and $T_{\rm eff}$.
4. The distances determined from GAIA DR2 parallxes show significant differences - the smaller the parallax, the greater the distance to the star.
5. (O-C) - Parallax relation, there O, - distance in Pecaut & Mamajek (2013) calibration, and C - on parallxes, has an exponential character.
6. The greatest differences between O and C begin after parallax estimates in 8 mas.
7. These facts indicate the unreability of the estimates of GAIA DR2 parallxes of less than 10 mas.
8. Estimating the distance to Polar B in 137 pc should be revised. Its realistic value within the bounds of 100-110 pc (Usenko & Klochkona, 2008; Turner, 2009).

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