POLARIS ($\alpha\ UMi$),- MULTISTELLAR SYSTEM IN THE OPEN CLUSTER

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ABSTRACT. We present the results of our analysis of high-resolution spectroscopic observations of Cepheid α UMi (Polaris A) and main-sequence type stars Polaris B and HD 5914, - optical companion and a member of Polaris open cluster. The last ones are objects with high projected rotational velocities v $\sin i$ = 110 km s^{-1} and 100 km s^{-1}, respectively. The derived atmosphere parameters are: Polaris A: T$_{eff}$=6022 K; $\log g$=2.2; V$_t$=4.3 km s^{-1}; Polaris B: T$_{eff}$=6900 K; $\log g$=4.3; V$_t$=2.5 km s^{-1}; HD 5914: T$_{eff}$=8800 K; $\log g$=4.0; V$_t$=2.0 km s^{-1}. C, Na and Mg content in last two stars is close to solar, whereas Polaris A demonstrates its that is typical for Cepheid after the first dredge-up stage. The distances to Polaris B and HD 5914 are 109.5 and 108 pc, respectively. The RV pulsational amplitude of Polaris A decreased to 0.6 s^{-1} in 2005 and increased to 7.5 km s^{-1} in 2003

Key words: Stars: abundances - Stars: distances - Stars: Cepheids - Stars: main-sequence stars - Stars: individual - α UMi (Polaris A), Polaris B, HD 5914

1. Introduction

S-Cepheid (DCEPS) α UMi named Polaris is an unique object for astrophysical research due to the following:

1. It is the nearest (d = 99 (Turner, 2005) - 132 pc (ESA 1997)) yellow supergiant and Cepheid in the Galaxy.
2. Polaris is a well-known multiple system with three visual components (Polaris B (BD+88°9, C and D) that are main-sequence stars (Fernie 1966), and the spectroscopic one (Polaris Ab with an orbital period 29.71 yrs (Turner et al. 2006).
3. Polaris is a member of an anonymous open cluster, which contains late A-type and early F-type main sequence stars.
4. Polaris, - one from four nearest Cepheid with the radius, 46±3 $R_\odot$, determined by means of optical interferometry (Nordgren et al. 1999).
5. CNO-abundances analysis data for Cepheid agree well with theoretically predicted ones for 3rd (or 5th) crossing of the Cepheids instability strip.

Thus, the main task consist in:

1. To obtain the high-resolutioned spectra of Polaris ($F6 - F8I$), its the nearest visual companion Polaris B ($F3V$), and the brightest main-sequence member of Polaris cluster HR 5914 ($A3V$) to determine its atmospheric parameters, chemical composition, absolute magnitudes, masses and distances, respectively.
2. To measure the radial velocities of Polaris A during the lond observational period (1999-2006) to determine its pulsational amplitude changes.

2. Observations

Observations of these objects have been realized using:

1. 1m telescope - Ritter Observatory, University of Toledo (Toledo, OH, USA) - fiberfed echelle spectrograph 1150×1150 pixel CCD ($\lambda\lambda$ 5800-6800 Å).
2. 2.1m Otto Struve telescope -McDonald Observatory (Texas, USA) - SANDIFORD spectrograph (McCarthy et al. 1993) 1200×400 pixel CCD ($\lambda\lambda$ 5500-7000 Å).

Table 1: Observational data of Polaris cluster's objects

Object	HJD	NS	T_{eff}	$\log g$	V_t
α UMi	2449513-9649 (1994)		5968±29	2.2	4.35
	2451240-2192 (1999)	4	5973±15	2.1	4.30
	2452416-2515 (2002)	9	6011±25	2.2	4.60
	2452782-2986 (2003)	11	6018±25	2.2	4.30
	2453005-3367 (2004)	10	6027±15	2.2	4.30
	2453686-3693 (2005)	6	6063±10	2.3	4.00
	2453751-4169 (2006)	7	6055±30	2.2	4.00
	Mean	53	6022±21	2.2	4.30
Polaris B		1	6900±50	4.3	2.50
HD 5914		1	8800±50	4.0	2.00

Table 2: Radial velocity data of α UMi during 2005-2006

HJD 2400000+	Number of orders	RV (km s^{-1})	σ	NL
53686.615	20	-17.68	1.05	198
53687.614	27	-17.82	1.00	616
53689.647	27	-18.24	1.20	589
53690.109	27	-17.80	1.13	566
53691.633	27	-17.82	1.06	550
53693.124	27	-17.93	1.06	549
53751.121	27	-16.83	1.21	581
53808.277	27	-18.78	1.55	933
53904.350	27	-17.87	1.09	506
53980.589	27	-17.40	1.29	569
54073.589	27	-18.43	1.15	579
54077.651	27	-17.58	1.21	406

3. 6m telescope BTA - SAO RAS(Russia) - LYNX(Panchuk et al. 1999), PFES(Panchuk et al. 1998), NES(Panchuk et al. 2002) spectrometers ($\lambda\lambda$ 5050 - 7100 Å.)

The reduction was made using IRAF software, MIDAS software, DECH20 software (Galazutdinov, 1992). The observational log is given in Table 1. In Table 2 we present new radial velocity data of Polaris A, obtained during 2005-2006. Our preceding RV data are given in Table 1 of Usenko et al. (2005a) paper

2. Atmosphere parameters and chemical composition

Atmosphere parametrs were determined:

1) T_{eff}: line deph ratio (Kovtyukh & Gorlova, 2000) for Polaris (accuracy: 15 - 70 K); $(B-V)$-T_{eff}, $\log g$ and SYNTH for Polaris B and HD 5914 (accuracy: 50 K);

2) $\log g$: by adopting the same iron abundance for Fe I and Fe II lines. (accuracy: 0.15 dex) for Polaris; $(B-V)$-T_{eff}, $\log g$ and SYNTH for Polaris B (H_β); see Figure 1) and HD 5914 (H_α; see Figure 2)(accuracy: 0.15 dex);

3) V_t - by assuming abundances of the Fe II lines independent of the W_λ for Polaris (accuracy: 0.25 km/s). For Polaris B and HD 5914 these V_t data were selected using SYNTH.

The mean atmosphere parametrs are given in Table

Table 3: Average abundances for Polaris cluster's objects

Elements	Polaris	Polaris B	HD 5914
[C/H]	-0.17±0.10	-0.00±0.05	-0.01
[N/H]	+0.42±0.00	+0.00	+0.00
[O/H]	-0.00±0.15	-0.00	-0.02±0.09
[Na/H]	+0.09±0.11	+0.03	-0.02
[Mg/H]	-0.21±0.12	+0.04±0.12	-
[Fe/H]	+0.07±0.10	+0.07±0.15	+0.05±0.15

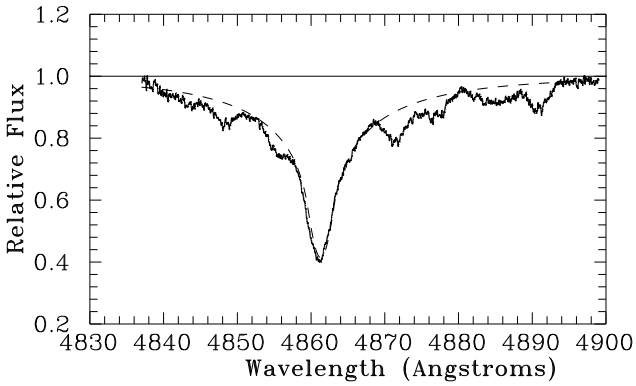

Figure 1: Fragment of Polaris B spectrum in the range 4930-4943 ÅÅwith synthetic spectrum (dashed line) for T_{eff} = 6900 K; $\log g$ = 4.3; V_t = 4.30 km s^{-1} and v $\sin i$ = 110 km s^{-1} is shown for comparison.

1. It is necessary to note that Polaris B and HD 5914 are high-rotating objects with v $\sin i$ = 110 km s^{-1} and 100 km s^{-1}, respectively (see Figures 1 and 2).

As seen from Table 3, a comparison of chemical abundances (CNO-elements, sodium, magnesium and iron) for Cepheid, its visual companion and main-sequence star from open cluster reveals some interesting features. All three stars display essentially identical abundances of iron, thereas Polaris B and HD 5914 appears to have a solar carbon content. The same fact noticeable for sodium and manganise content for these stars. On the other hand Cepheid Polaris A exhibits an obvious deficit of carbon, overabundance of nitrogen, small overabundance of sodium and noticeable deficit of manganese. These features agrees well with theoretically predicted abundances for 5 $M_\odot$ star after 3rd or 5th crossing of the Cepheid instability strip (Usenko et al. 2005).

3. Colour-Excess and Reddening

The use of the line depth ratio method for the T_{eff} determination allows us to obtain the accurate E_{B-V} colour-excesses. Knowning the average T_{eff} and $(B-V)$ for the Cepheid and using the Gray's (1992) $(B-V)$ vs. T_{eff} relationship, we can calculate

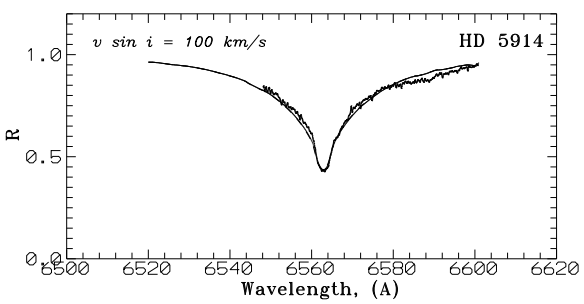

Figure 2: Fragment of HD 5914 spectrum in the range 6500-6620 ÅÅwith synthetic spectrum (dashed line) for T_{eff} = 8800 K; $\log g$ = 4.0; V_t = 2.00 km s^{-1} and v $\sin i$ = 100 km s^{-1} is shown for comparison.

the intrinsic colour $(B-V)_0$, colour-excess E_{B-V}, and reddening A_V. For the mean T_{eff} = 6021 K we have E_{B-V} = 0.034 mag; A_V = 0.102 mag, R = 3.0 (Arellano Ferro, 1984) BC=0.01 mag (Bessell, Castelli, & Plez 1998).

4. Distances, Luminocities, Radii and Masses

As known (Usenko et al. 2005) the distance determination for Polaris system is problematical, - different methods give unequal estimates, - from 99 pc (Turner, 2005) to 132 pc (ESA 1997, Norgren et al. 1999). Known that Polaris B is $F3V$ main-sequence star, then its radius is near 1.38 $R_\odot$ (Straižys, 1982). Using our T_{eff} we can obtain its luminosity of 3.868 $L_\odot$, equivalent to an absolute magnitude $M_V = +3.30$ mag. Using our A_V = 0.102 mag we have obtained a distance d = 109.5 pc. This result coincide with Kamper's (1996) one of 110 pc, determined by astrometrical methods.

As known, for main-sequence stars $\log(L/L_\odot) = 4\log(M/M_\odot)$. Using our gravity and radius values for Polaris B, we can obtain its mass of 1.39 $M_\odot$, that agrees well with Polaris Ab $F4V$ type spectroscopic companion, - 1.38±0.61 $M_\odot$ (Evans et al. 2007).

In the case of HD 5914 we have obtained its radius of 2.14 $R_\odot$, M_V = +1.3 mag, d = 108 pc, and M = 1.66 $M_\odot$, respectively. Therefore, for Polaris A, in the case of distance d = 109.5 pc and T_{eff} = 6021 K, we have: M_V = -3.31 mag, $\log(L/L_\odot)$ = 3.232, R = 38 $R_\odot$, and M = 5 $M_\odot$, respectively.

5. RV Pulsational Amplitude Changes

As seen from Figures 3-7 RV pulsational amplitude of Polaris during 2002-2006 undergoes the changes. It is interesting that it increased from 3 to 7.5 km s^{-1} during 2002-2003, after that we can see a decreasing from 2 to 0.6 km s^{-1} during 2004-2005, and new

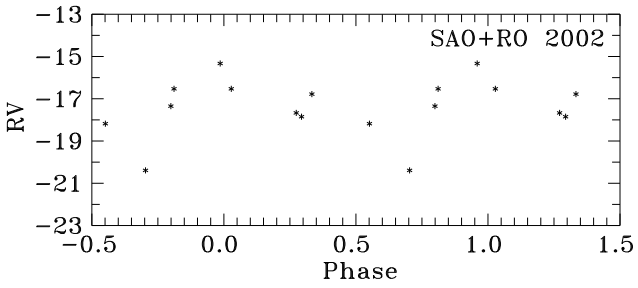

Figure 3: Radial velocity curve for Polaris A in 2002

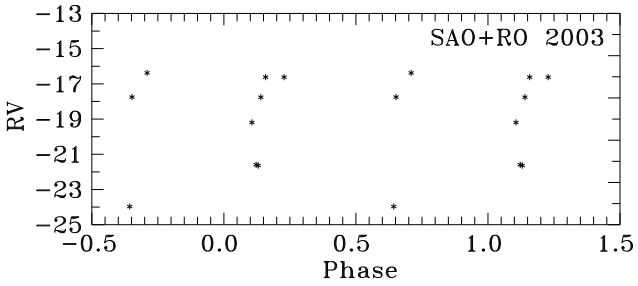

Figure 4: Radial velocity curve for Polaris A in 2003

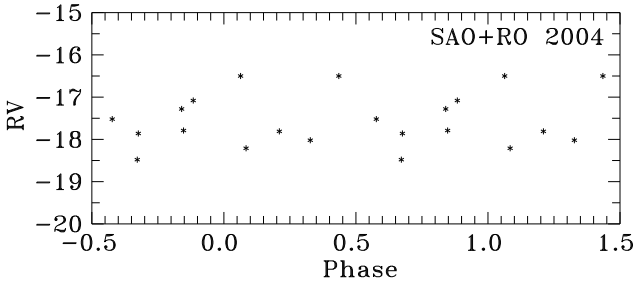

Figure 5: Radial velocity curve for Polaris A in 2004

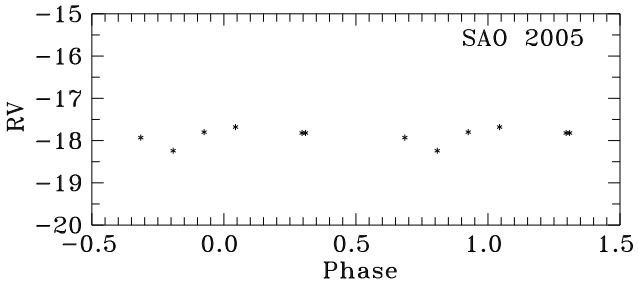

Figure 6: Radial velocity curve for Polaris A in 2005

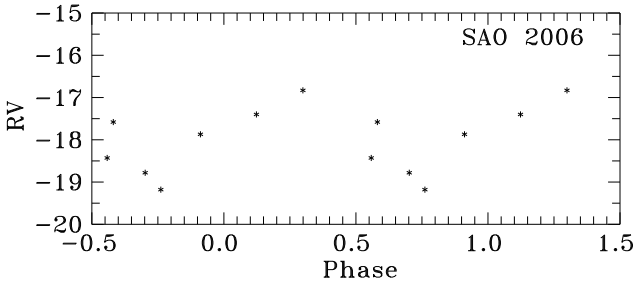

Figure 7: Radial velocity curve for Polaris A in 2006

increasing to 2 km s^{-1} in 2006.

6. Conclusions

We can summarize the results of our investigations as follows.

1. A large projected rotational velocity v $\sin i$ = 110 km s^{-1} for Polaris B is an evidence that Polaris system is young and Polaris B is likely to be single, since most binaries of $A-F$ types have slow rotation, the angular momentum being tied up in orbital motion. Moreover, the rapid rotation's observation could be mean that we see the star nearly equator-on. Atmosphere parametres, obtaines for Polaris B are typical for $F3V$ star.

2. The same conclusions we can sum up for HD 5914 with its projected rotational velocity v $\sin i$ = 100 km s^{-1} and typical $A3V$ spectral type.

3. The majority of Polaris B and HD 5914 chemical elements shows abundances, equal to Polaris A and close to solar one. But carbon, sodium and magnesium in these stars close to solar content, therefore Polaris A demonstrates a typical for the first dredge-up yellow supergiants deficit of C and Mg and overabundance of N and Na (Usenko et al. 2005). Therefore we are eye-witnesses of evolutional history of three stars with different masses in the same stellar system.

4. Absolute magnitude +3.30 mag for Polaris B is equal to one from Fernie (1966). Spectroscopically determined T_{eff} = 6900 K combinating with radius of 1.38 $R_\odot$ give the distance near 109.5 pc, - a fine agreement with Kamper's (1996) one near 110 pc. This result is quite unexpected, because Turner (2005) denoted 101±3 pc to this object and Polaris system as a whole. Whereas HIPPARCOS parallax (ESA 1997) and optical interferometry (Nordgren et al. 1999) results give 132±9 pc to the Polaris A.

5. For HD 5914 we have the absolute magnitude +1.30 mag and for spectroscopically determined T_{eff} = 8800 K and radius of 2.14 $R_\odot$ the desired value of distance come to 108 pc. It is a real confirmation that this star is a member of Polaris open cluster.

6. The obtained mass of Polaris B near 1.39 $M_\odot$ has been founded as unexpected close to one of Polaris Ab spectroscopic companion, - 1.38±0.61 $M_\odot$ (Evans et al. 2007), which is a main-sequence star of earlier than $F4V$ spectral type (Evans et al. 2002). The mass of HD 5914 near 1.66 $M_\odot$ is a typical for main-sequence early $A-$ type stars.

7. If the distance to Polaris A of 109.5 pc is true, then in case of mean T_{eff} = 6021 K its absolute magnitude is -3.31 mag, radius is near 38 $R_\odot$ and mass is equal to 5 $M_\odot$, respectively.

8. *RV* pulsational amplitude of Polaris A during last years undergoes sporadical changes minimized to 0.6 km s^{-1} in 2005 and culminated to 7.5 km s^{-1} (like before 1950 (Roemer, 1965)) in 2003. In last year we can see its new increasing.

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