STELLAR INVESTIGATION IN THE OPEN CLUSTER OF POLARIS

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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, an 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}=6020 K; $\log g$=2.2; V_t=4.2 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 for Polaris A these values are 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 increased to 7.5 km s^{-1} in 2003, decreased to 0.6 km s^{-1} in 2005 and increased anew to 2.5 s^{-1} in 2007.

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 is 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: [C/H]=-0.17 (predicted -0.18 dex), [N/H]=+0.42 (predicted +0.40 dex), [O/H]=-0.00 (predicted -0.02 dex) for evolutionary mass in ranges of 4.9 – 5.2 $M_\odot$ (Usenko et al, 2005).

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 (for the key evolutional elements), absolute magnitudes, masses and distances, respectively.

2. To measure the radial velocities of Polaris A during the lond observational period (1999-2007) 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 ($\lambda\lambda$ 5800-6800 ÅÅ).

Table 1: Observational data of Polaris cluster's objects

Object	HJD	NS	T_{eff}	$\log g$	V_t
α UMi	2449513-9649 (1994)	6	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
	2454169-4426 (2007)	4	6043±10	2.2	4.00
	Mean	57	6020±20	2.2	4.20
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 2005-2007

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
54169.638	27	-19.18	1.09	415
54225.228	27	-18.92	1.25	592
54344.551	27	-19.41	1.04	464
54426.183	27	-16.65	1.19	603

2. 2.1m Otto Struve telescope – McDonald Observatory (Texas, USA) – SANDIFORD spectrograph ($\lambda\lambda$ 5500-7000 ÅÅ).
3. 6m telescope BTA – SAO RAS (Russia) – LYNX, PFES and NES spectrometers ($\lambda\lambda$ 5050-7100 ÅÅ).

The reduction was made using IRAF, MIDAS and 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 2005-2007.

3. Atmosphere parameters and chemical composition

Atmosphere parametrs were determined:

1) Effective temperature T_{eff}: by line depth 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) Surface gravity $\log g$: 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) Microturbulent velocity 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.

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

The mean atmosphere parametrs are given in Table 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, whereas 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).

4. Colour-Excess and Reddening

Knowing 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 the intrinsic colour $(B-V)_0$, colour-excess E_{B-V}, and reddening A_V. For the mean $T_{eff} = 6020$ 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).

5. Distances, Luminocities, Radii and Masses

The distance determination for Polaris system is problematical (Usenko et al. 2005), because the 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 mean T_{eff} value 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 $\log(L/L_\odot) =$

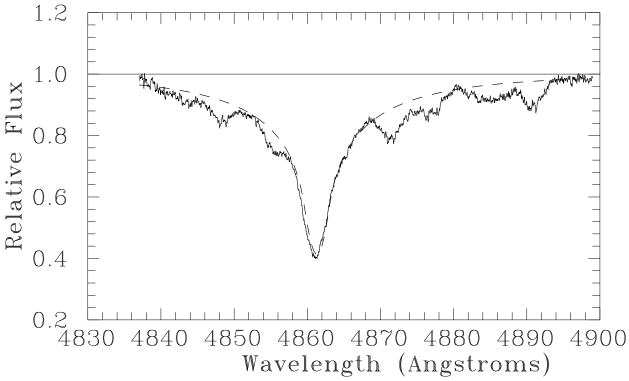

Figure 1: Fragment of Polaris B spectrum in the range 4930-4943 ÅÅwith synthetic spectrum (dashed line).

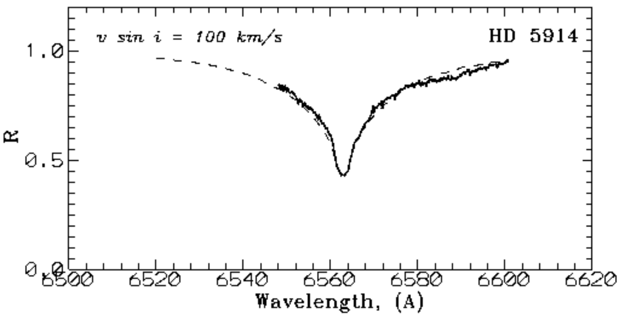

Figure 2: Fragment of HD 5914 spectrum in the range 6500-6620 ÅÅwith synthetic spectrum (dashed line).

$4\log(M/M_\odot)$. 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} = 6020 K, we have: M_V = -3.31 mag, $\log(L/L_\odot)$ = 3.232, R = 38 $R_\odot$, and M = 5 $M_\odot$, respectively.

6. RV Pulsational Amplitude Changes

As seen from Figures 3-8 RV pulsational amplitude of Polaris during 2002-2007 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 increasing to 2 km s^{-1} in 2006 and to 2.5 km s^{-1} in 2007.

7. Conclusions

We can summarize the results of our investigations as follows.

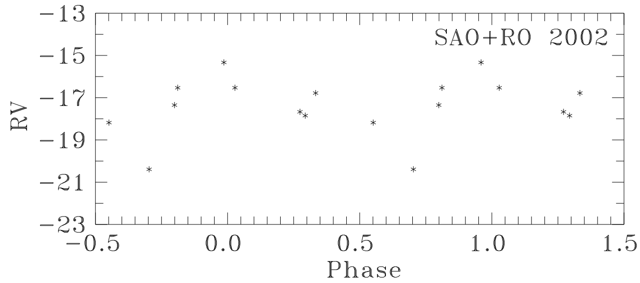

Figure 3: Radial velocity curve for Polaris A in 2002

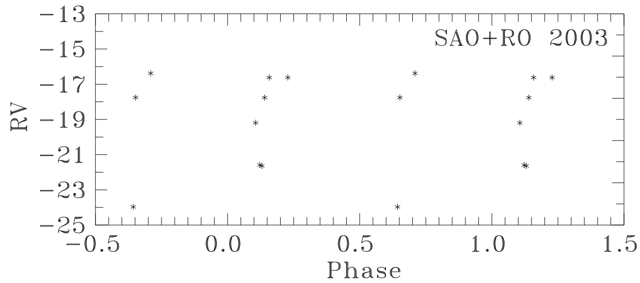

Figure 4: Radial velocity curve for Polaris A in 2003

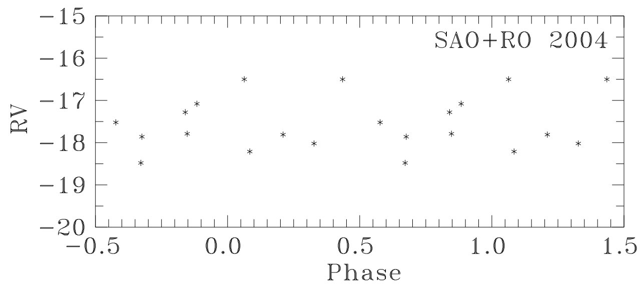

Figure 5: Radial velocity curve for Polaris A in 2004

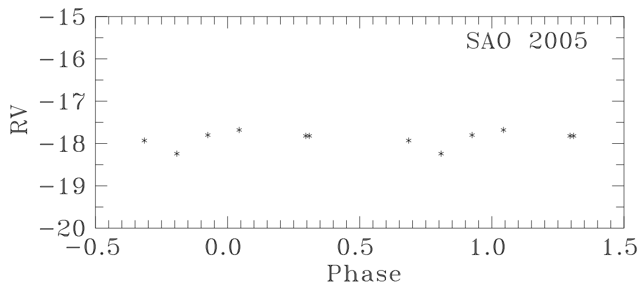

Figure 6: Radial velocity curve for Polaris A in 2005

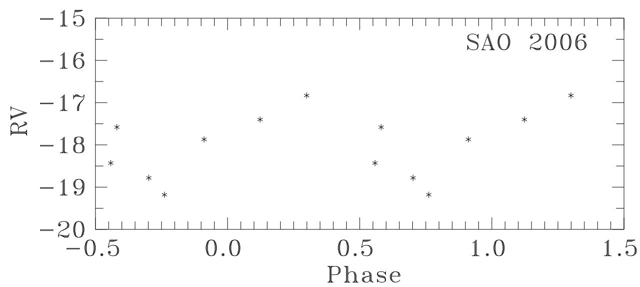

Figure 7: Radial velocity curve for Polaris A in 2006

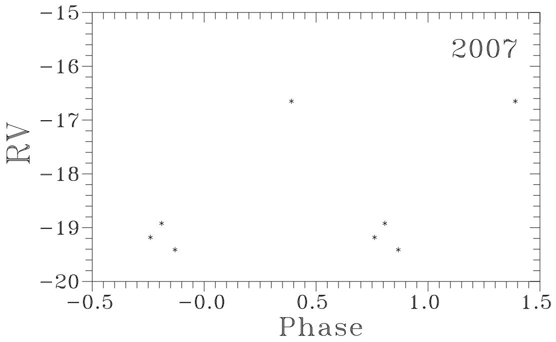

Figure 8: Radial velocity curve for Polaris A in 2007

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 parameters, 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$_{eff}$ = 6020 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) in 2003. In last year we can see its new increasing to 2.5 km s^{-1}.

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