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Pulsational activity changes in the Cepheid Polaris (α UMi) during 2017–2018: a new amplitude decrease

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ABSTRACT

We present an analysis of 67 recent spectra of α UMi (Polaris) obtained in 2017 August–2018 May. Frequency analysis reveals an increase in the pulsation period to $3\overset{\mathrm{d}}{.}970662$ relative to our 2016/17 observations. The radial velocity amplitude was found to be 3.87 km s^{-1} in the last half of 2017, but dropped to 2.80 km s^{-1} during the first half of 2018. In comparison with 4.16 km s^{-1} observed by us in 2015, the observations reveal a new decrease in pulsation amplitude. Such a result is unexpected given that a gradual amplitude growth was evident during the last decade. The average values of T_{eff} were found to be 6017 K and 6039 K, respectively, but the T_{eff} amplitude has increased despite the decrease in radial velocity amplitude. Possibly that could be explained by the presence of starspots on the Cepheid's surface.

Key words: stars: variables: Cepheids – stars: atmospheres – techniques: radial velocities – stars: individual: α UMi.

1 INTRODUCTION

Polaris is the nearest Cepheid in the Galaxy, and also the most mysterious. As a small-amplitude pulsator (DCEPS), the variable presents many difficulties for observers because of its proximity to the north celestial pole, its brightness ($V = 2$), and the lack of suitable comparison stars in its immediate vicinity. The last creates problems for photometric observations of Polaris. Discovered in the middle of the XIXth century, the brightness variations of Polaris led to further problems, because it was difficult to derive the amplitude from visual observations alone. The actual period of variability, near 4 d, was deduced from radial velocity measurements (Campbell 1899), a method found to yield very precise measures of the pulsational period and amplitude variations during more than a century of observation.

Over that interval Polaris demonstrated specific features testifying to its peculiar character:

(1) An abrupt decrease in pulsational amplitude during ∼40 yr from 5–6 km s^{-1} prior to 1950 (Roemer 1965) to 0.05 km s^{-1} in the 1980s (Fernie, Kamper & Seager 1993), and the beginning of an increase during the next 20 yr from 1.5 km s^{-1} in 1987 to 2.4 km s^{-1} in 2007 (Dinshaw et al. 1989; Kamper 1996; Hatzes & Cohran 2000; Bruntt et al. 2008; Lee et al. 2008).

(2) According to Turner et al. (2005), both photometric and radial velocity (RV) data obtained from 1896 to 2004 indicate an increase in pulsation period by 4.45 ± 0.03 s yr^{-1} (from $3\overset{\mathrm{d}}{.}966\,942$ to $3\overset{\mathrm{d}}{.}970\,691$). Except for what seems to be an abrupt short-term decrease in the rate of period increase during 1963–1966, the rate of period change is evidence of the redward evolution of Polaris across the Cepheid instability strip (hereafter CIS). Photometric observations of Spreckley & Stevens (2008) showed an increase of the peak-to-peak amplitude from 2003 to 2005 and confirmed the growth of the pulsational period. These authors suggested that this period has undergone a recent decline and, combined with the increased amplitude, this could imply evolution away from an overtone pulsation mode into the fundamental mode.
According to Lee et al. (2008), the pulsation period increased by 86 s in 2005–2007 (from $3\overset{\mathrm{d}}{.}973\,000$ to $3\overset{\mathrm{d}}{.}973\,94$) while the pulsation amplitude increased to 2.2 km s^{-1}.

(3) Previous frequency analyses of the radial velocity data for 1987/88 (Dinshaw et al. 1989), 1992/93 (Hatzes & Cohran 2000), 1996 (Kamper 1996), 2005/07 (Lee et al. 2008) revealed the possible presence of additional periodicities in the star of 45.3, 40.2, 34, and 119 d, respectively, in addition to the main pulsational period of 3.97 d. Such additional periods have been alternatively explained

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by the rotation of Polaris, the existence of cool or macroturbulent velocity spots, or non-radial pulsation.

Unfortunately, radial velocity observations of Polaris after 2008 were episodic in character. To continue the careful study of the star, we began a spectroscopic monitoring campaign in 2015 August. In previous papers (Usenko et al. 2016, 2017), we found that:

(a) During 2015 September–December (21 spectra), the pulsation period and radial velocity amplitude of Polaris increased. The former was up 8.6 min longer in comparison with the 2007 value, and the latter became 4.16 km s^{-1} (twice that of 2007). The average $T_{\rm eff}$ was 6017 K with an amplitude of 82 K;

(b) During 2016 August–December (37 spectra) and 2017 January–March (12 spectra), the pulsation period decreased by perhaps 17.3 min in comparison with the 2015 data. The radial velocity amplitude decreased to 3.43 km s^{-1} in 2016 and to 3.31 km s^{-1} at the beginning of 2017. The average $T_{\rm eff}$ was 6021 K with amplitudes of 54 and 70 K, respectively.

2 OBSERVATIONS AND FREQUENCY ANALYSIS

67 spectra were obtained for the present observational data set: 29 in 2017 August–December and 38 in 2018 January–May. All observations were obtained with the 0.81 m telescope of the Three College Observatory (TCO) and 0.6 m telescope of the Kernersville Observatory (KO) located in western North Carolina, U.S.A. Both telescopes were equipped with the same model of échelle spectrograph manufactured by Shelyak Instruments[1] in the spectral range from 4150 to 7900 Å with a spectral resolving power of $R \sim 12\,000$ and no gaps between spectral orders. The average S/N ratio in the continuum was 150–200, while most spectral lines used in our analysis were taken from the range 4900–6800 Å. The data were reduced using the *échelle* package in IRAF.

The DECH 30 software package[2] was used to measure the line depths and radial velocities using spectra in FITS format. Radial velocities were measured by cross-correlation and parabolic fitting methods. The precision of the *RV* measurements is between 1 and 1.8 km s^{-1}. Line depths were used to determine the effective temperature – a method based on the depth ratios of selected pairs of spectral lines most sensitive to the temperature (Kovtyukh 2007). The method provides an internal accuracy of the $T_{\rm eff}$ determination of ∼10–30 K (the uncertainty of the average).

Derived values of $T_{\rm eff}$ and radial velocity measured from hydrogen and metal lines for each spectrum are given in Table 1.

The next step in the analysis was to use the PERIOD04 program (Lenz & Breger 2005), which employs Fourier and Fast Fourier Transform analysis and minimizes the residuals of sinusoidal fits to the data.

3 RESULTS

A Fourier power spectrum was obtained over a frequency range from 0–1 d^{-1} with a resolution of 0.000 02 d^{-1}. The largest amplitude at 1.50 corresponds to a frequency of 0.251 847 ± 0.000 181 d^{-1}, corresponding to a pulsation period of $3\overset{\rm d}{.}970\,662 \pm 0\overset{\rm d}{.}002\,849$.

The systemic velocity (γ velocity) is −11.19 ± 1.23 km s^{-1}.

The following ephemeris has been computed from the radial velocity values:

$$\mathrm{RV_{min}} = \mathrm{HJD}\,2458047.179 + 3.970662 \times E \qquad (1)$$

Fig. 1 represents phase curves for the Polaris RV (lower panel) and $T_{\rm eff}$ (upper panel) variations between the last half of 2017 and the first half of 2018. As seen in the figure, the data from the last half of 2017 correspond to a larger amplitude relative to the 2018 data. For approximations to the data by sine waves, the mean amplitudes for the radial velocity curves are 3.81 and 2.80 km s^{-1}, respectively.

The $T_{\rm eff}$ variations display an unusual characteristic – data from the last half of 2017 exhibit an amplitude near 31 K while those from 2018 display a larger value near 68 K. The average values are 6010 ± 17 K and 6039 ± 18 K for the last half of 2017 and 2018, respectively.

4 DISCUSSION

Fig. 2 plots the variations in RV amplitude for the last ∼125 yr. In particular, the amplitude in 2016 and the first half of 2017 were smaller than in 2015. Yet it was larger in the last half of 2017 and smallest in 2018. Both tendencies suggest that Polaris is undergoing a new decrease in pulsation amplitude.

The pulsation period of Polaris has behaved surprisingly: following a steady growth in period length until 2015, it appears to have undergone an abrupt decrease during the 2016/2017 observing season to $3\overset{\rm d}{.}961\,92$, with a renewed growth during the 2017/2018 observing season. The presently derived period of $3\overset{\rm d}{.}9706\,62$ is still less than the value $3\overset{\rm d}{.}979\,872$ observed in 2015.

The $T_{\rm eff}$ amplitude variations are very unusual as well: a decrease from 82 K in 2015 to 54 K in 2016, with a small growth to 70 K in the first half of 2017 (see Usenko et al. 2016, 2017). It was followed by a rapid decrease to 31 K and a return to the previous value. The growth of the amplitude in $T_{\rm eff}$ was accompanied by a decrease in the RV amplitude during the last observational dataset.

The peculiar character of the pulsational period change of Polaris in 2015–2018 is very similar to its abrupt change near 1963 (Turner et al. 2005). Bruntt et al. (2008) noted the non-linear character of such a change. The RV amplitude has decreased relative to that observed in 2007, while the average $T_{\rm eff}$ was still growing. It is very surprising, because (Usenko et al. 2005) noted that the lowest average $T_{\rm eff}$ = 5866 K occurred in 1993 at the same time as the smallest radial velocity amplitude (Hatzes & Cohran 2000). Similar secular changes of the pulsational periods for δ Cep, η Aql, and ζ Gem were noted earlier by Berdnikov et al. (2000).

Fig. 3 represents a modified version of Fig. 2 from Usenko et al. (2005). It is evident that the average value of $T_{\rm eff}$ undergoes secular changes. The observed RV amplitude decrease and the $T_{\rm eff}$ amplitude and average value increase detected during the last observing season are both unusual. A possible explanation may be the presence of starspots and their activity on the surface of the Cepheid. This explanation has been suggested previously (Dinshaw et al. 1989). Also worthy of consideration is what may be a periodicity in the radial velocity amplitude of the last 30 yr comparable to the orbital cycle of the Cepheid Polaris about its companion (Turner 2009). Alternative explanations for short-period Cepheids include the Blazhko effect, secular radius variations, non-radial pulsations, strange pulsational modes (Anderson 2014), and first overtone pulsation (Poleski 2008).

[1] http://www.shelyak.com
[2] http://www.gazinur.com/DECH-software.html

Table 1. Observational data of α UMi (NL – number of lines).

HJD 2450000+	$T_{\rm eff}$ K	σ K	Phase	RV (km s^{-1}) Metals	σ	NL	H α	H β	H γ
7971.6410	5986	27	0.024	– 12.36	1.32	158	– 12.66	– 13.07	– 12.91
7990.5788	5989	19	0.255	– 10.28	1.74	149	– 9.17	– 11.57	– 12.00
7993.6103	6049	20	0.491	– 9.41	1.58	179	– 9.08	– 9.24	– 8.72
8000.5570	6008	19	0.742	– 10.84	1.13	157	– 11.56	– 11.17	– 13.03
8001.6289	5993	13	0.472	– 9.30	1.05	167	– 8.59	– 9.40	– 9.38
8004.6070	6028	14	0.722	– 10.76	1.11	187	– 10.81	– 11.15	– 11.54
8005.6179	6014	16	0.467	– 9.41	1.15	175	– 8.60	– 9.07	– 7.70
8006.6376	6088	15	0.210	– 11.40	0.99	159	– 11.26	– 11.52	– 11.57
8013.5632	6036	16	0.466	– 9.78	1.41	169	– 8.71	– 9.20	– 9.02
8014.5600	6054	17	0.215	– 11.39	1.01	151	– 12.05	– 11.99	– 12.02
8020.5176	5936	17	0.715	– 11.42	1.34	156	– 10.45	– 11.01	– 10.66
8042.5072	6065	19	0.177	– 12.03	1.32	157	– 12.00	– 11.65	– 11.42
8044.6000	5955	19	0.650	– 9.90	1.42	151	– 10.22	– 9.69	– 10.42
8045.5167	6018	15	0.419	– 9.90	1.27	164	– 9.50	– 9.75	– 9.53
8046.6300	6051	18	0.138	– 12.64	1.20	151	– 12.96	– 12.78	– 12.69
8047.6580	6056	16	0.121	– 12.42	1.34	151	– 12.64	– 12.31	– 12.54
8057.5897	6030	19	0.622	– 9.38	1.78	154	– 8.45	– 8.97	– 8.58
8060.5157	5963	17	0.359	– 10.15	1.50	174	– 10.23	– 10.27	– 9.57
8068.6419	5957	20	0.405	– 9.60	1.22	192	– 9.81	– 9.28	– 8.64
8080.6621	5994	19	0.433	– 8.57	1.23	153	– 7.03	– 8.82	– 7.13
8084.4794	5950	19	0.394	– 9.63	1.34	187	– 7.47	– 8.78	– 8.86
8085.6274	5990	19	0.683	– 10.92	1.05	158	– 10.32	– 10.04	– 8.52
8099.5297	5987	16	0.184	– 11.26	0.99	158	– 11.06	– 11.07	– 8.31
8099.5474	5957	18	0.189	– 11.91	1.04	153	– 12.02	– 11.90	– 12.57
8101.5172	6006	16	0.685	– 10.67	1.13	159	– 11.09	– 9.48	– 8.06
8102.5377	6042	13	0.942	– 14.23	1.00	157	– 14.29	– 13.30	– 9.86
8103.5821	5975	13	0.205	– 11.55	1.11	163	– 11.12	– 11.14	– 6.30
8106.6466	6020	18	0.977	– 12.95	1.19	166	– 13.08	– 11.87	– 9.29
8109.5208	6079	19	0.701	– 10.83	1.09	168	– 9.88	– 10.68	– 7.10
8120.5087	6014	17	0.468	– 9.40	0.84	190	– 9.09	– 8.61	– 4.86
8123.5578	6041	16	0.236	– 11.71	1.18	184	– 11.79	– 11.29	– 5.55
8125.6148	6077	16	0.754	– 11.27	1.13	180	– 10.68	– 10.22	– 7.63
8139.5300	6014	14	0.258	– 11.69	1.06	182	– 11.26	– 12.15	– 7.16
8142.5830	6118	21	0.027	– 12.40	1.24	153	– 14.64	– 12.83	– 10.14
8144.5423	6071	20	0.521	– 10.43	1.24	177	– 10.47	– 9.16	– 6.69
8149.5713	6027	18	0.787	– 11.88	1.18	174	– 11.36	– 11.23	– 6.70
8150.7136	6036	16	0.075	– 12.85	1.20	178	– 13.27	– 13.11	– 8.84
8155.7074	6045	19	0.333	– 10.89	1.38	200	– 10.91	– 10.23	– 7.01
8158.5487	6057	19	0.048	– 13.54	1.14	158	– 13.91	– 13.64	– 9.83
8173.5518	6059	17	0.827	– 12.65	1.25	161	– 13.13	– 13.24	– 8.44
8180.6860	6032	17	0.623	– 11.74	1.16	162	– 11.10	– 11.96	– 8.13
8181.6784	6086	20	0.873	– 12.86	1.21	165	– 12.97	– 13.20	– 8.44
8182.6549	6057	19	0.119	– 12.59	0.96	157	– 13.86	– 13.51	– 9.08
8183.6249	5942	19	0.364	– 11.33	0.96	157	– 10.96	– 10.45	– 5.85
8185.6576	6046	18	0.875	– 12.96	1.06	154	– 13.34	– 13.37	– 8.46
8192.5937	6024	18	0.622	– 10.76	1.07	161	– 11.64	– 10.29	– 6.80
8194.5937	6014	19	0.126	– 12.61	1.15	159	– 12.31	– 12.51	– 8.77
8200.6486	6010	15	0.651	– 10.90	0.99	172	– 10.45	– 10.76	– 6.63
8201.6911	6122	15	0.913	– 12.69	1.24	163	– 15.03	– 12.36	– 10.47
8204.5760	6014	17	0.640	– 10.58	1.11	159	– 9.99	– 9.38	– 6.22
8214.5724	5974	15	0.158	– 12.33	1.16	170	– 12.79	– 12.23	– 8.53
8219.6336	6007	16	0.432	– 10.54	1.16	160	– 10.02	– 9.75	– 6.08
8221.5498	6056	21	0.915	– 12.48	1.29	163	– 12.99	– 12.98	– 14.26
8222.5757	6035	19	0.173	– 12.14	1.22	172	– 13.27	– 12.73	– 7.92
8226.5961	6035	18	0.186	– 12.06	1.17	155	– 13.18	– 11.96	– 8.05
8227.6207	6024	16	0.444	– 10.69	1.30	177	– 9.89	– 10.57	– 7.22
8228.5956	6060	18	0.689	– 11.34	1.06	186	– 10.85	– 10.79	– 8.57
8229.5797	6037	15	0.937	– 14.21	1.97	149	– 16.78	– 15.94	– 12.00
8236.6174	6037	17	0.710	– 11.06	1.36	186	– 11.22	– 10.71	– 2.59
8237.5792	6116	13	0.952	– 12.22	1.30	150	– 11.50	– 9.71	– 6.19
8238.5785	5922	19	0.203	– 12.00	1.21	168	– 11.98	– 12.28	– 13.55
8240.5739	5974	18	0.706	– 11.00	1.27	159	– 9.62	– 10.01	– 10.85
8241.6073	6091	21	0.966	– 12.18	1.41	152	– 12.62	– 12.08	– 13.49

Table 1 – *continued*

HJD 2450000+	T_{eff} K	σ K	Phase	RV ($km\,s^{-1}$) Metals	σ	NL	H α	H β	H γ
8242.5793	6060	20	0.211	– 11.95	1.46	152	– 11.59	– 12.68	– 12.09
8245.5895	6060	16	0.969	– 12.88	1.47	154	– 12.47	– 11.61	– 14.63
8247.5934	6042	15	0.474	– 10.35	1.29	162	– 9.78	– 9.27	– 6.05
8248.5947	6029	17	0.726	– 11.32	1.42	155	– 11.70	– 10.83	– 7.17

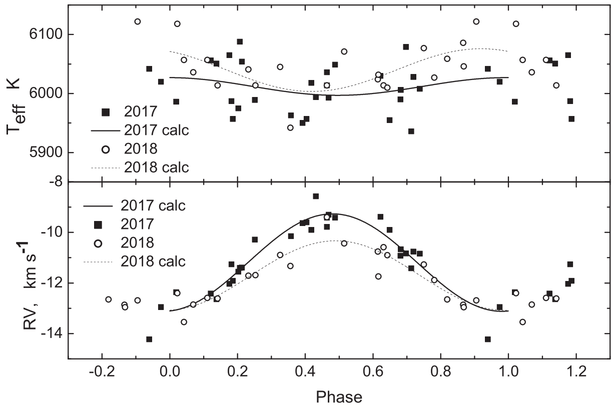

Figure 1. The effective temperature and radial velocity variations of Polaris during its pulsational period.

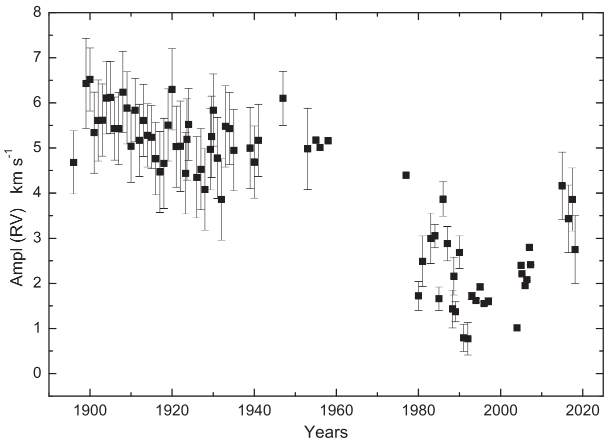

Figure 2. Radial velocity amplitude variations of Polaris over the last ~125 yr.

5 SUMMARY

(i) Spectroscopic observations of Polaris in 2017–2018 indicate that its pulsation period has increased relative to what was observed a decade earlier, although the measures obtained in 2016/first half of 2017 exhibit a period that is smaller than that derived from the 2015 data set.

(ii) The mean amplitude of the radial velocity (RV) in the last half of 2017 increased by nearly 0.4–0.5 $km\,s^{-1}$ relative to the 2016/first half of 2017 data. Yet the mean value for 2018 is smaller by ~1 to 2.80 $km\,s^{-1}$, and is close to the amplitude observed in 2007. A tendency for a decreasing pulsation amplitude is evident from a comparison with the 2015 amplitude of 4.16 $km\,s^{-1}$, i.e. by 67 per cent.

(iii) The mean amplitude for the observed variations in T_{eff} during the last half of 2017 is more than twice as small in comparison with the 2018 data, although the RV amplitude is larger. Such a peculiarity might be explained by the starspots on the surface of Polaris.

(iv) The mean T_{eff} for Polaris in our data sets averages 6010 and 6039 K, respectively. The first value is close to 6015–6021 K determined for our 2015–2017 data (Usenko et al. 2016, 2017), but the 2018 result is somewhat higher and close to what was observed in data from 2004–2007 (Usenko et al. 2008). It seems likely that the mean T_{eff} for Polaris undergoes secular changes connected with the close companion Polaris Ab (Usenko et al. 2005).

(v) In conjunction with previous observations, we emphasize the significance of continued spectroscopic and photometric observations of Polaris for understanding the nature of this peculiar Cepheid.

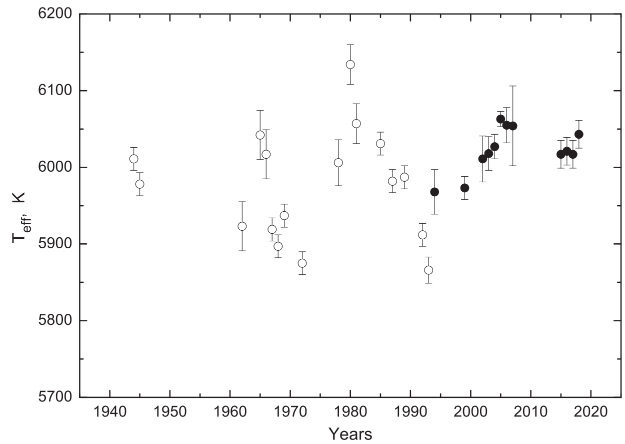

Figure 3. Variations of the mean effective temperature of Polaris during the last 74 yr. Open circles – values from the $(B - V)$ versus T_{eff} relationship by Gray (1992), filled circles – values from lines depth ratios (Kovtyukh 2007).

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