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# EFFECTIVE TEMPERATURE AND RADIAL VELOCITY OF THE SMALL-AMPLITUDE CEPHEID POLARIS ( $\alpha$ UMi) IN 2015

I. A. Usenko<sup>1,2</sup>, V. V. Kovtyukh<sup>1</sup>, A. S. Miroschnichenko<sup>3</sup>, S. Danford<sup>3</sup>

<sup>1</sup> Astronomical Observatory, Odessa National University, Shevchenko Park, Odessa 65014, Ukraine, [igus99@ukr.net](mailto:igus99@ukr.net)

<sup>2</sup> Mykolaiv Astronomical Observatory, Mykolaiv 54030, Ukraine

<sup>3</sup> Dept. of Physics and Astronomy, University of North Carolina at Greensboro, Greensboro, NC, USA

**ABSTRACT.** We present the results of an analysis of 21 spectra of  $\alpha$  UMi (Polaris) obtained in September – December 2015. Frequency analysis shows an increase of the pulsation period up to 8.6 min in comparison to the 2007 observational set. The radial velocity amplitude comes to  $4.16 \text{ km s}^{-1}$ , and it is approximately twice the one found in 2007. The average  $T_{\text{eff}} = 6017 \text{ K}$ , and it is close to the value determined for the 2001–2004 set. Therefore Polaris moves to the red edge of the Cepheid instability strip (CIS).

**Key words:** Stars: radial velocities; Cepheids: overtone pulsations; Cepheids: companions; Cepheids:  $\alpha$  UMi

## 1. Introduction

Polaris is the nearest Cepheid to us in the Galaxy. Being a small-amplitude pulsator (DCEPS) it has some specific features which testify about its peculiar character:

1. An abrupt decrease of the pulsation amplitude during forty years ( $5\text{--}6 \text{ km s}^{-1}$  before 1950 (Roemer, 1965) to  $0.05 \text{ km s}^{-1}$  in the 1980's (Ferne, Kamper & Seager, 1993)) and the beginning of its increase during the next 20 years (Dinshaw et al. 1987; Hatzes & Cochran 2000; Kamper 1996; Bruntt et al. 2008; Lee et al. 2008), – from  $1.5 \text{ km s}^{-1}$  in 1987 to  $2.4 \text{ km s}^{-1}$  in 2007.
2. According to Turner et al. (2005), both photometry and radial velocity data taken in 1896–2004 suggest an increase of the pulsation period by  $4.45 \pm 0.03 \text{ yr}^{-1}$  (from 3.966942 to 3.970691 days), except for a short-term slowdown of  $4.28 \pm 0.73 \text{ yr}^{-1}$  in 1963–1966. The period increase is an evidence of Polaris' redward crossing

of the Cepheid instability strip (hereafter CIS). According to Lee et al. (2008), the pulsation period increased up to 86 seconds in 2005–2007 (from 3.973000 to 3.97394 days), while the pulsation amplitude increased to  $2.2 \text{ km s}^{-1}$ .

3. Previous frequency analyses of the radial velocity data sets of 1987/88 (Dinshaw et al., 1989), 1992/93 (Hatzes & Cochran, 2000), Kamper (1996), Lee et al. (2008) revealed the presence of additional periods of 45.3, 40.2, 34, and 119 days, respectively, in addition to the main pulsation period of 3.97 days. These additional periods have been explained by the rotation of Polaris, existence of cool or macroturbulent velocity spots, or non-radial pulsations.

## 2. Observations and frequency analysis

Twenty one spectrum were taken in September–December 2015 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<sup>1</sup> in a spectral range from 4250 to 7800 Å with a spectral resolving power of  $R \sim 10000$ . There are no gaps between the spectral orders. The data were reduced using the *échelle* package in IRAF.

The DECH30 package (Galazutdinov 2007) allows 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). Derived values of the  $T_{\text{eff}}$  and radial velocity for each spectrum are given in Table 1.

In the next step we used the PERIOD04 program (Lenz & Breger, 2005) to calculate a Fourier power

<sup>1</sup><http://www.shelyak.com>

Table 1: Observational data of  $\alpha$  UMi

HJD 2450000+	$T_{\text{eff}}$ K	Phase	Metals	$RV$ ( $\text{km s}^{-1}$ )			
				NL	$H_{\alpha}$	$H_{\beta}$	$H_{\gamma}$
7283.656	6083±15	0.854	-17.57±1.48	149	-19.27	-17.18	-17.20
7284.715	6059±23	0.120	-19.10±1.63	139	-20.12	-17.79	-17.73
7311.627	6048±20	0.890	-11.93±1.38	104	-11.27	-10.04	-10.93
7312.630	6064±20	0.142	-18.73±1.71	114	-19.50	-17.67	-16.97
7313.632	6007±15	0.394	-15.00±1.59	129	-16.72	-15.51	-15.20
7314.583	5997±16	0.633	-15.83±1.19	119	-16.43	-14.96	-15.93
7316.650	6070±17	0.153	-18.19±1.72	121	-19.31	-17.13	-17.44
7317.625	5967±16	0.398	-15.52±1.56	91	-16.44	-14.48	-14.81
7318.599	6001±18	0.643	-14.93±1.29	118	-15.57	-14.18	-15.27
7319.535	6077±16	0.879	-17.36±1.36	118	-18.90	-16.85	-17.11
7337.676	5962±17	0.442	-16.08±1.08	132	-17.69	-15.21	-16.11
7338.548	6006±19	0.661	-15.35±1.67	125	-16.09	-14.61	-14.35
7339.657	6025±20	0.940	-18.54±1.45	141	-20.36	-17.74	-17.90
7340.667	6037±15	0.194	-17.65±1.35	134	-19.13	-16.87	-17.36
7343.559	6058±18	0.922	-18.55±3.36	139	-20.42	-18.33	-17.77
7349.546	5990±14	0.428	-15.15±1.37	138	-16.73	-14.34	-15.01
7350.581	6034±16	0.688	-14.43±1.62	123	-15.59	-15.06	-14.38
7365.541	6025±17	0.451	-15.14±1.47	147	-15.71	-14.34	-14.72
7366.563	5973±19	0.708	-15.20±1.52	121	-15.94	-14.26	-14.42
7372.638	5975±15	0.236	-17.76±1.48	154	-19.27	-17.18	-17.20
7376.586	6022±14	0.229	-16.60±1.34	161	-18.27	-15.92	-12.20

Phase is calculated using the ephemeris (1)

NL represents the number of metal lines whose radial velocities were measured

spectrum. It uses the Fourier and Fast Fourier Transform analysis with minimization of residuals of sinusoidal fits to the data.

The power spectrum was calculated over the frequency range  $0-1 \text{ d}^{-1}$  with a resolution of  $0.00002 \text{ d}^{-1}$ . The highest amplitude of  $1.70$  corresponds to a frequency of  $0.25126439 \text{ d}^{-1}$ , or  $3.97987156$  days, respectively. This period exceeds by  $8.5$  minutes the period of  $3.97394$  days determined from the 2007 observational set. The systemic velocity ( $\gamma$  - velocity) is equal to  $-16.70 \text{ km s}^{-1}$ .

The following ephemeris has been computed based on the radial velocity values:

$$RV_{\text{min}} = HJD 2457284.237 + 3.97987156 \times E \quad (1)$$

The radial velocity data for each spectrum folded with this period are given in Table 1.

The radial velocity and effective temperature of Polaris are shown in Figures 1 and 2 (data from the last three months of 2015).

The data were fitted with the sinusoidal curves. However, one value of  $-11.93 \pm 1.3 \text{ km s}^{-1}$  obtained on HJD 2457311.627 was excluded from the analysis. According to this approximation, the mean amplitude of the radial velocity curve is  $4.16 \text{ km s}^{-1}$ .

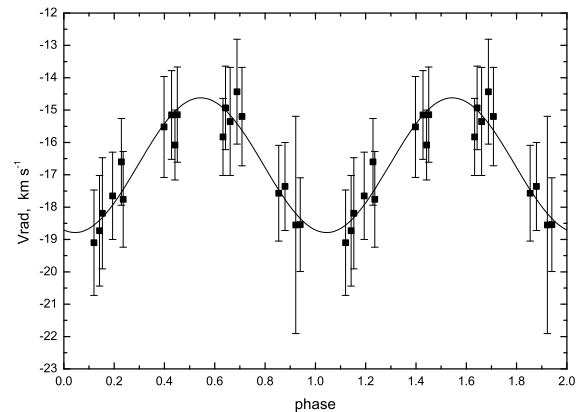


Figure 1: The radial velocity variations of Polaris during its pulsation period.

### 3. Summary

1. As seen from the results of our observations, the pulsation period of Polaris shows a considerable increase in comparison with estimates obtained in 2007 (Lee et al., 2008). This fact confirms the assumption that Polaris is moving to the red edge of the CIS;
2. The mean amplitude of the radial velocity nearly

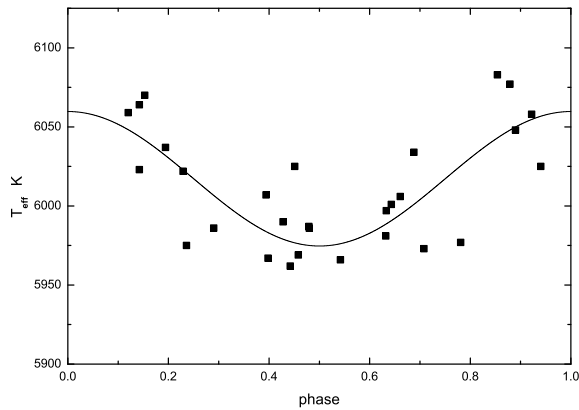


Figure 2:  $T_{\text{eff}}$  of Polaris during its pulsation period.

doubled during the last eight years in comparison to the 2007 observations by Lee et al. (2008).

3. The effective temperature of Polaris for this data set averages 6017 K. This value is close to 6015 K determined for the set of 2001–2004 data (Usenko et al., 2005).

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