Polaris: History of Pulsation Activity since Discovery

By: I.A. Usenko, V.V. Kovtyukh, A.S. Miroshnichenko, S. Danford

Usenko, I.O., Kovtyukh, V.V., Miroshnichenko, A.S., Danford, S. (2017). Polaris: History of Pulsation Activity since Discovery. *Nauka ta Innovacii, 13*(1). 109-113. doi: 10.15407/scin13.01.109

Made available courtesy of Vydavnychyi Dim Akademperiodyka:
http://dx.doi.org/10.15407/scin13.01.109

Abstract:

The pulsation activity of small-amplitude Cepheid Alpha UMi (Polaris) during the period of its radial velocity observations has been analyzed. In the 20th century, Polaris was known to demonstrate a decrease in radial velocity amplitude to the minimum, in the 1980s. Thereafter, the amplitude has increased. The observations of September-December 2015 (21 spectra) obtained by 81cm telescope TCO with spectrograph have showed that radial velocity amplitude comes to 4.16 km/s and is approximately twice higher than the estimates made in 2007, with pulsation period adding 8.6 min.

Keywords: Cepheids | pulsation periods | radial velocities | stars | variable amplitude | α Umi

*****Note: Full text of article below**

ISSN 1815-2066. Nauka innov. 2017, 13(1): 109—113 doi: https://doi.org/10.15407/scin13.01.109

Usenko[1,2], I.A., Kovtyukh[1], V.V., Miroshnichenko[3], A.S., and Danford[3], S.

[1] Astronomical Observatory, Odessa National University, 1B, Marazlievskaya St., Odesa, 65014, Ukraine, tel. +38 (048) 722-03-96
[2] Research Institute «Mykolaiv Astronomical Observatory», 1, Observatorna St., Mykolaiv, 54030, Ukraine, tel. +38 (0512) 47-70-14
[3] Department of Physics and Astronomy, University of North Carolina at Greensboro, P.O. Box 26170, Greensboro, NC 27402, USA

POLARIS: HISTORY OF PULSATION ACTIVITY SINCE DISCOVERY

The pulsation activity of small-amplitude Cepheid Alpha UMi (Polaris) during the period of its radial velocity observations has been analyzed. In the 20th century, Polaris was known to demonstrate a decrease in radial velocity amplitude to the minimum, in the 1980s. Thereafter, the amplitude has increased. The observations of September-December 2015 (21 spectra) obtained by 81cm telescope TCO with spectrograph have showed that radial velocity amplitude comes to 4.16 km/s and is approximately twice higher than the estimates made in 2007, with pulsation period adding 8.6 min.

Keywords:stars, radial velocities, variable amplitude, Cepheids, pulsation periods, and α UMi.

INTRODUCTION

Polaris is the nearest Cepheid to the Earth in the Galaxy and a small-amplitude pulsator (DCEPS). The observations of this variable are very difficult because its proximity to the North celestial pole, its brightness and the lack of suitable check and comparison stars in its immediate vicinity. The last factor complicates Polaris photometric observations. Discovered by Seidel [1] the light variations of Polaris contribute to the problem insofar as it is difficult to find the amplitude using visual estimates only. Therefore, the actual period of variability of near 4 days was deduced from radial velocity estimates by [2]. In particular, this method was established to be more precise to detect the pulsation period and amplitude changes during the last longer than a century interval of observations. Over this interval, Polaris demonstrated some specific features that testify to its peculiar character:

1) An abrupt decrease in the pulsation amplitude during forty years (from 5—6 km/s before 1950 [3] to 0.05 km/s in the 1980s [4] and its increase during the next 20 years ([5—9]), from 1.5 km/s in 1987 to 2.4 km/s in 2007.

2) According to [10], both photometric data and radial velocity estimates assume an increase of the pulsation period by 4.45 0.03 s/year (from 3.966942 to 3.970691 days), in 1896—2004, except for a short-term lowdown of 4.28 0.73 s/year, in 1963—1966, with the period increase being an evidence of Polaris redward crossing of the Cepheid instability strip (hereafter, CIS). According to [9], the pulsation period increased up to 86 seconds in 2005—2007 (from 3.973000 to 3.97394 days) while the pulsation amplitude grew up to 2.2 km/s.

3) The previous frequency analysis of the radial velocity data sets of 1987/88 ([5]), 1992/93 ([6]), 1994/95 [7], and 2007 [9] has 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.

Fig. 1. TCO building

Fig. 2. First floor and operator's room of TCO

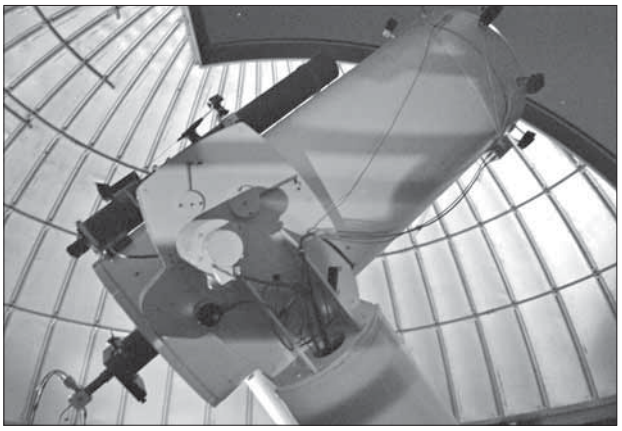

Fig. 3. TCO 81cm telescope

Fig. 4. TCO spectrograph

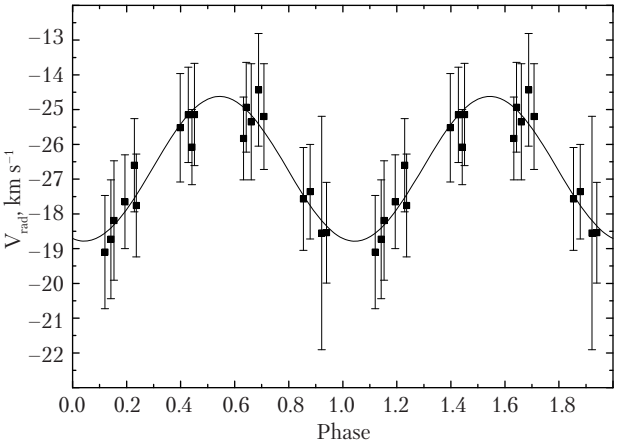

Fig. 5. The radial velocity variations of Polaris during its pulsation period

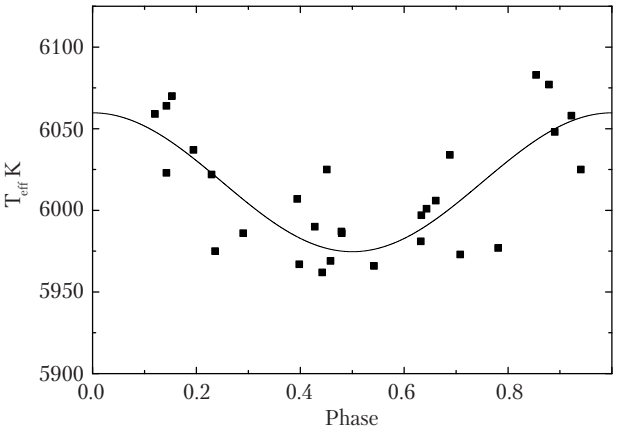

Fig. 6. *T*eff variations of Polaris during its pulsation period

OBSERVATIONS

Observatory

Three College Observatory (TCO) is situated in the middle of North Carolina, 183 m height above sea level. Being located so low, the space particles practically do not distort the images during 20 minutes either. Coordinates are 35 56 latitude North, 79 24 24 longitude West. The Observatory was built at the end of the 1970s (Figs. 1, 2).

Telescope and Spectrograph

A 0.81m telescope equipped with echelle- spectrograph manufactured by *Shelyak Instruments*, at the end of 2011. Resolution is near of 12000, spectral range is 4275—7890 A in 24 orders. Detector ATIK-460EX is a commercial CCD matrix 2200 × 2200 pixels (one pixel corresponds to

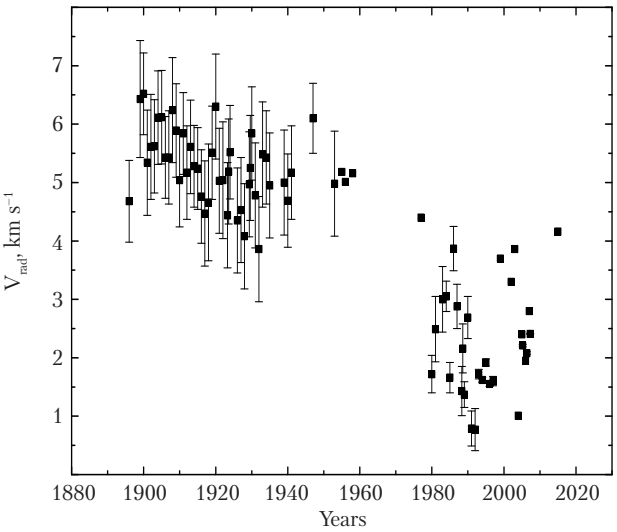

Fig. 7. RV amplitude variations of Polaris during last 120 years

Table 1

Observational Data of α UMi

HJD	Teff	σ	Phase	RV (km/s)					
2450000+	K	K		Metals	σ	NL	Hα	Hβ	Hγ
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

4.5 × 4 microns); spectral exposure with binning of 2 × 2. In the case of Polaris, it has been exposed about 10—30 times during 15—30 s (Figs. 3, 4).

Observational Criteria for Polaris

Since Polaris is a Cepheid with pulsation period of about 4 days, it should be necessary to obtain one or two spectra per night during 1—3 observational months to cover its pulsation curve as much as possible. During the observational period from the end of September to the end of December 2015, twenty-one spectra were taken. The log and observational data are given in Table 1.

Data Reduction

ThAr lamp has been used as a reference spectrum. All images were reduced using the echelle package in IRAF. For each spectrum, from 500 to 700 spectral lines were identified. The accuracy of associating to the wavelength scale was near 1 km/c. Every night, before Polaris observations, the spectra of reference stars (radial velocity references) were exposed. The DECH 30 package [11] enabled to measure the line depths and radial velocities using spectra in FITS format. Line depths were used to determine effective temperature (a method based on the spectroscopic criteria [12]). Derived values of T_{eff} and radial velocity for each spectrum are given in Table 1.

At the next stage, PERIOD 04 program [13] was used to calculate a Fourier power spectrum. The Fourier and Fast Fourier Transform analyses with minimization of sinusoidal residuals fit to the data. The power spectrum was calculated over the frequency range 0—1 d^{-1} with a resolution of 0.00002 d^{-1}. The highest amplitude 1.70 corresponds to frequency of 0.25126439 d^{-1} or 3.97987156 days. This period exceeds by 8.5 minutes the period of 3.97394 days determined from the 2007 observational set. The systemic velocity (γ- velocity) is equal to -16.70 km/s.

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

$$RV_{min} = HJD2457284.237 + 3.97987156 \times E.$$

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

The radial velocity and effective temperature of Polaris are showed in Figs. 5 and 6 (data from the last three months of 2015). The data are fitted with the sinusoidal curves. However, one value of −11.93±1.3 km/s obtained on HJD 2457311.627 was excluded from the analysis. According to this approximation, the mean amplitude of radial velocity curve is 4.16 km/s (Fig. 7).

SUMMARY

1. The pulsation period of Polaris shows a considerable increase in comparison with estimates obtained in 2007 ([9]). This fact confirms the assumption that Polaris moves to the red edge of the CIS.

2. The mean amplitude of radial velocity nearly doubled during the last eight years in comparison with the 2007 observations [9].

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 ([14]).

REFERENCES

1. Seidel L. *Polaris*, IIK1, D.K. Akad. Wiss. Munchen. 1852. 6: 564.
2. Campbell W.W. The variable velocity of alpha Ursae Minoris in the line of sight. *Astroph. J.* 1899. 10: 180.
3. Roemer E. *Orbital Motion of Alpha Ursae Minoris from Radial Velocities*. 1965. 141: 1415.
4. Fernie J.D., Kamper K.W., Seager, S. Goodbye to Polaris the Cepheid. *Astroph. J.* 1993. 416: 820.
5. Dinshaw N., Matthews J.M., Walker G.A.J., Hill G.M. The radial-velocity variations of Polaris — A Cepheid leaving the instability strip? *Astron. J.* 1989. 98: 2249.
6. Hatzes A.P., Cohran W.D. The Radial Velocity and Spectral Line Bisector Variability of Polaris. *Astron. J.* 2000. 120: 979.
7. Kamper K.W. Polaris Today. *Journal Roy. Astr. Soc. Canada*. 1996. 90: 140.
8. Bruntt H., Evans N.R., Stello D., Penny A.J., Eaton J.A., Buzasi D.L., Sasselov D.D., Preston H.L., Miller-Ricci E. Polaris The Cepheid Returns: 4.5 Years Of Monitoring From Ground And Space. *Astroph. J.* 2008. 683: 433.
9. Lee B.-C., Mkrtichian D.E., Han I., Park M.-G., Kim K.-M. Presize Radial Velocities Of Polaris: Detection of Amplitude Growth. *Astron. J.* 2008. 135: 2240.

10. Turner D.G., Savoy J., Derrah J., Sabour M.A., Berdnikov L.N. The Period Changes Of Polaris. *Astron. J.* 2005. 117: 207.
11. Galazutdinov G.A. *DECH 30 Package*. http://gazinur.com/DECH-software.html. 2007.
12. Kovtuykh V.V. High-Precision Effective Temperatures of 161 FGK Supergiants From Line Depth Ratios. *Monthly Not. Roy. Astr. Soc.* 2007. 378: 617.
13. Lenz P., Breger M. Period04 User Guide. *Commun. Astroseismology*. 2005, 146: 53.
14. Usenko I.A., Miroshnichenko A.S., Klochkova V.G., Yushkin M.V. Polaris, the Nearest Cepheid in the Galaxy: Atmosphere Parameters, Reddening and Chemical Composition. *Monthly Not. Roy. Astr. Soc.* 2005. 362: 1219—1224.

І.А. Усенко [1,2], В.В. Ковтюх [1], А.С. Мірошниченко [3], С. Денфорд [3]

[1]Астрономічна обсерваторія,
Одеський національний університет,
вул. Маразліївська, 1В, Одеса, 65014, Україна,
тел. +38 (048) 722-03-96
[2] Науково-дослідний інститут
«Миколаївська астрономічна обсерваторія»,
вул. Обсерваторна, 1, Миколаїв, 54030, Україна
[3] Кафедра фізики та астрономії,
Університет Північної Кароліни у Грінсборо,
П.О. 26170, Грінсборо, Північна Кароліна 27402, США

ПОЛЯРНА: ІСТОРІЯ ПУЛЬСАЦІЙНОЇ АКТИВНОСТІ ПІСЛЯ ЇЇ ВІДКРИТТЯ

Проаналізована пульсаційна активність малоамплітудної цефеїди α UMi (Полярної) на протязі періоду спостережень її радіальної швидкості. Відомо, що протягом XX ст. Полярна демонструвала зниження амплітуди радіальної швидкості до мінімуму у 80-ті роки. Після цього амплітуда почала зростати. Спостереження протягом вересня—грудня 2015 року (21 спектр), отримані за допомогою 81см телескопу ТСО з спектрографом, показали, що амплітуда радіальної швидкості досягла 4,16 км/с, що приблизно вдвічі більше оцінки, встановленої в 2007 році, та пульсаційний період зріс на 8,6 хв.

Ключові слова: зорі, радіальні швидкості, змінна амплітуда цефеїди, пульсаційні періоди, α UMi.

И.А. Усенко [1,2], В.В. Ковтюх [1], А.С. Мирошниченко [3], С. Дэнфорд [3]

[1]Астрономическая обсерватория,
Одесский национальный университет,
ул. Маразлиевская, 1В, Одесса, 65014, Украина,
тел. +38 (048) 722-03-96
[2] Научно-исследовательский институт
«Николаевская астрономическая обсерватория»,
ул. Обсерваторная, 1, Николаев, 54018, Украина
[3] Кафедра физики и астрономии,
Университет Северной Каролины в Гринсборо,
П.О. 26170, Гринсборо, Северная Каролина, 27402, США

ПОЛЯРНАЯ: ИСТОРИЯ ПУЛЬСАЦИОННОЙ АКТИВНОСТИ ПОСЛЕ ЕЕ ОТКРЫТИЯ

Проведен анализ пульсационной активности малоамплитудной цефеиды α UMi (Полярной) на протяжении периода наблюдений ее лучевой скорости. Известно, что на протяжении XX ст. Полярная демонстрировала снижение амплитуды лучевой скорости до минимума в 80-е годы. После этого амплитуда начала возрастать. Наблюдения на протяжении сентября—декабря 2015 года (21 спектр), полученные при помощи 81см телескопа ТСО со спектрографом, показали, что амплитуда лучевой скорости достигла 4,16 км/с, что приблизительно вдвое больше оценки, определенной в 2007 году, а пульсационный период вырос на 8,6 мин.

Ключевые слова: звезды, лучевые скорости, переменная амплитуда, цефеиды, пульсационные периоды, α UMi.

Стаття надійшла до редакції 21.11.16