The Impact of Large-Scale Surveys on Pulsating Star Research
ASP Conference Series, Vol. 203, 2000
L. Szabados & D. W. Kurtz, eds.

The Pulsation Mode of Polaris

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Abstract. Polaris (α UMi) is the only classical Cepheid with *Hipparcos* parallax determined to better than 10% (Feast & Catchpole 1997). The correct identification of its pulsation mode is therefore crucial for calibrating the Cepheid period–luminosity relation. We show that Polaris is an overtone pulsator. Our analysis confirms the finding of Feast & Catchpole, but is entirely independent of the distance estimation.

Polaris pulsates with $P = 3.97$ d. At this period, Fourier phase ϕ_{21} is a clear-cut indicator of the pulsation mode (Antonello & Poretti 1986; Kienzle et al. 1999). Unfortunately, Polaris is a small amplitude, almost sinusoidal variable and measuring its ϕ_{21} is not an easy task. Nevertheless, we have been able to detect the harmonic with the recently published velocity data of Kamper & Fernie (1998). The data consist of 212 measurements grouped into several short "chunks" (observing runs) lasting several days. Phasing the data with $P = 3.97235$ d, we find a sinusoidal velocity curve with dispersion of $\sigma = 0.12$ km s^{-1}. A close examination of the residuals of this fit reveals that they are *systematically different for each data chunk.* Therefore, in the next step we divide the data into separate chunks, lasting from 3 to 10 days, and for each chunk assume an individual zero point correction, to be determined by the least squares minimization. The procedure yields corrections varying from -0.14 km s^{-1} to $+0.28$ km s^{-1} and significantly improves the solution ($\sigma = 0.05$ km s^{-1}). The first harmonic is now detectable at 5σ level, with the amplitude $A_2 = 0.0237 \pm 0.0048$ km s^{-1} and phase $\phi_{21} = 3.89 \pm 0.38$.

The pulsation mode of a classical Cepheid can also be identified with the first order phase lag, $\Delta\phi_1$ (Ogłoza et al. 2000). Reliable determination of $\Delta\phi_1$ requires *simultaneous* photometry and radial velocity data. This is particularly important for Polaris, which is known for its strong period variability. We have identified two datasets suitable for phase lag measurement. From the data of Meyer (1935) and Roemer (1965) we find $\Delta\phi_1 = -0.453 \pm 0.059$ (Epoch 1934.6) while the data of Brown & Bochonko (1994) and Kamper (1996) yield $\Delta\phi_1 = -0.44 \pm 0.10$ (Epoch 1993.0). The two values are identical within the error bars, despite a threefold amplitude decrease between 1934 and 1993. The weighted average of the two measurements is $\Delta\phi_1 = -0.447 \pm 0.051$.

$\Delta\phi_1$ can be determined even more accurately from the O$-$C diagram. Such a diagram is usually constructed by combining the time residuals of maximum light and of minimum observed velocity (Kamper & Fernie 1998), the latter shifted by $\Delta t_0 = \mathrm{HJD}(V_{\max}) - \mathrm{HJD}(\mathrm{RV}_{\min})$. It is easy to check that $\Delta\phi_1 = (2\pi/P)\Delta t_0$. Because different values of Δt_0 have been used in the literature, we have decided to determine this parameter anew. To this effect, we fit the

https://doi.org/10.1017/S0252921100057638 Published online by Cambridge University Press

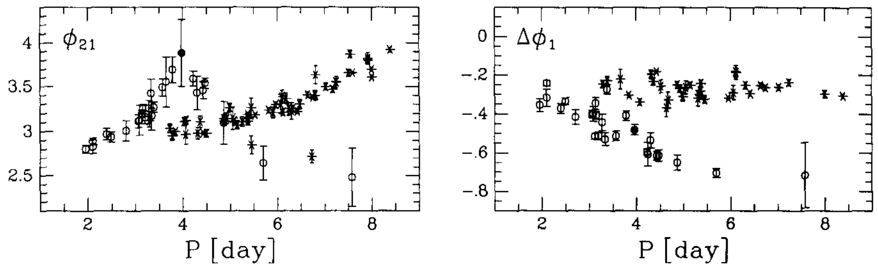

Figure 1. a) velocity ϕ_{21} (from Kienzle et al. 1999) and b) phase lag $\Delta\phi_1$ (from Ogłoza et al. 1999) vs. pulsation period for classical Cepheids. Fundamental mode and overtone Cepheids are plotted with asterisks and open circles, respectively. Polaris is marked with a filled circle.

combined light and velocity O−C data with a polynomial, treating Δt_0 as a *free parameter* to be determined through the least square minimization. We find $\Delta t_0 = -0.304 \pm 0.017$ day, which corresponds to $\Delta\phi_1 = -0.481 \pm 0.027$. We adopt this value as our final estimate of the phase lag of Polaris.

In Fig. 1 we present the plots of velocity ϕ_{21} and of $\Delta\phi_1$ vs. period, where we display Polaris (filled circle) together with other classical Cepheids of known pulsation mode. On both plots Polaris is firmly placed among the overtone Cepheids and is 2σ away and 4σ away, respectively, from the sequence of fundamental-mode Cepheids. We conclude that Polaris is an overtone pulsator.

Being an overtone Cepheid with $P = 3.97$ d, Polaris is not far from the center of $\omega_4 = 2\omega_1$ resonance. Indeed, from Eq.(4) of Kienzle et al. (1999) we find for Polaris $P_4/P_1 = 0.51$. It is tempting to speculate that this proximity to the resonance is the reason behind the intriguing amplitude variability observed in this star. A 2:1 resonance is capable of producing a periodic, or quasi-periodic amplitude modulation with the time scale of years (e.g. Moskalik 1986). Whether such a resonant mechanism actually works in Polaris remains to be checked.

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