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ON THE PERIOD AND AMPLITUDE CHANGES IN POLARIS AND OTHER SHORT-PERIOD CEPHEIDS

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ABSTRACT

The observed modulation of the period and amplitude of Polaris, the short-period classical Cepheid, may be cyclical, though irregular, and superimposed on the continuing evolutionary changes of this star. If so, it curiously resembles the Blazhko effect seen in RR Lyrae stars, as Evans and her colleagues have noted. The present author's recent theory of the Blazhko effect based on a solar-like magnetoconvective cycle in the stellar envelope is here applied to Polaris, with some limited success. The theory may also explain the slow cycle seen in another short-period Cepheid, V473 Lyr. It is therefore possible to predict, tentatively, an entire new class of short-period "Blazhko Cepheids."

Key words: stars: interiors – stars: magnetic fields – stars: oscillations – stars: variables: other – turbulence

1. INTRODUCTION

Polaris (α UMi) is a low-amplitude classical Cepheid with a period of 3.97 days. As the nearest and brightest Cepheid, its parallax has been measured by *Hipparcos* and the resulting luminosity suggests that the star is pulsating in the first-overtone mode (Feast & Catchpole 1997; van Leeuwen et al. 2007). However, the star also is associated with a small cluster of A and F dwarfs, possibly members of the Pleiades moving group, for which main-sequence fitting and *Hipparcos* parallaxes suggest a fainter luminosity, more consistent with fundamental-mode pulsation (Turner et al. 2005). The star's sinusoidal light curve does not necessarily reflect anything other than low amplitude, and is therefore not a clear indicator of pulsational mode. Since Turner et al. (2005) have cast suspicion on the accuracy of the astrometrically measured parallax of Polaris, the issue of mode remains unresolved.

What makes Polaris an unusual Cepheid is its rapid decline of amplitude (in both light and radial velocity) between 1972 and 1985, and then its increase of amplitude since 1994 (Arellano Ferro 1983; Fernie et al. 1993; Kamper & Fernie 1998; Turner et al. 2005; Bruntt et al. 2008). Meanwhile its period has been lengthening since at least 1844, although between 1963 and 1966 a glitch occurred when the period suddenly decreased and the amplitude started to behave erratically (Turner et al. 2005). At other times the amplitude has wobbled somewhat, but whether the period fluctuated in concert has not been determined.

Before the recent rise of amplitude, it was thought that Polaris was rapidly approaching the red edge of the instability strip in the course of one of several evolutionary blue-to-red crossings (Arellano Ferro 1983). Because Polaris is now believed by some researchers to lie well inside the instability strip for fundamental-mode pulsators (Fernie et al. 1993; Evans et al. 2002; but see Turner et al. 2005 for a contrary view) as well as to have escaped a condition of imminent stability, the current view is that some of the observed changes must be pulsational, not evolutionary, in character. Kamper & Fernie (1998) and Spreckley & Stevens (2008) have proposed that Polaris is switching from first-overtone pulsation to either purely fundamental or possibly double-mode behavior, with some transitional readjustment. However, their data reveal no trace of more than one mode being present, and the surprising change from falling to rising amplitude has occurred relatively smoothly. Similar objections have been raised by Bruntt et al. (2008), who regarded the remarkable change of amplitude as being cyclic and possibly due to the beating of two very close periods. Although Arellano Ferro (1983) had already made essentially the same suggestion, he rejected it because the beat period would have to be of the order of a century long, which is unrealistic. However, the overall period increase seems to be largely evolutionary in nature, consistent with a first crossing of the instability strip (Turner et al. 2005).

The superimposed irregular behavior of Polaris resembles, in some ways, the Blazhko effect in RR Lyrae stars, as Evans et al. (2004) and Bruntt et al. (2008) have noted. Recently, a new theory of the Blazhko effect has been proposed (Stothers 2006) that may also explain Polaris. In this paper, we explore our speculative idea and apply it to what may be a new class of "Blazhko Cepheids."

2. NEW THEORY

According to the newly proposed theory, turbulent convection in the stellar envelope (where the pulsational motions largely take place) cyclically weakens and strengthens on a time-scale considerably longer than the pulsation period. This modulation of convection must, of course, be distinguished from the rapid modulation that occurs during the course of a single pulsation cycle. The unknown forcing mechanism for the slow modulation is speculated to be the growth and decay of a magnetic field, built up by either turbulent or rotational dynamo action. The magnetic field need not be, and is unlikely to be, strong enough to directly affect the pulsation period to a significant extent. Rather, it is the field's effect on convection that changes both the period and the amplitude of the pulsation.

The physical picture is as follows. As the magnetic field grows in strength, it tends to weaken convection. Eventually, however, turbulent shredding of the stretched field lines and the accompanying ohmic losses break down the field. Convection regains vigor as a consequence. Then the magnetoconvective cycle begins anew. As in the case of the Sun, this process is not likely to be strictly periodic; some degree of stochasticity can be expected.

Convection in the stellar envelope sharply reduces the pulsation amplitudes in published nonlinear models of RR Lyrae stars (Deupree 1977; Stellingwerf 1984; Gehmeyr 1992; Feuchtinger

1999; Di Criscienzo et al. 2004) as well as in classical Cepheid models (Deupree 1980; Bono et al. 1999; Natale et al. 2008). There is an associated change of pulsation period that is the net outcome of a competition between the hydrostatic adjustment of the model's structure at fixed radius (which tends to increase P) and the shrinkage of the stellar radius (which tends to lower P). For hot stellar envelopes, where convection is not very vigorous, the period increases, while for cool envelopes the period shortens. At some intermediate effective temperature, the period remains unchanged (Stothers 2006).

Based on linear and nonlinear models of RR Lyrae stars pulsating in the fundamental mode, the theoretical crossover point with $\delta P/P = 0$ occurs at ∼6400 K—with some dependence on model parameters (Stothers 2006). Cogan (1979), in a study of observed period changes in classical Cepheids, previously found a similar theoretical shortening of the period as envelope convection strengthens. His linear models cover the cool temperature range 5130–5750 K. A slight extrapolation of his results indicates that $\delta P/P = 0$ would occur at an effective temperature of ∼5850 K. Since classical Cepheids possess a higher luminosity-to-mass ratio than RR Lyrae stars, a cooler crossover effective temperature is to be expected (Stothers 2006). No theoretical models for this specific purpose have been calculated in the case of the first overtone. However, in view of the robustness of the P_1/P_0 period ratio for theoretical models of such stars, the crossover effective temperature should not differ very much from that for the fundamental mode.

3. POLARIS

Observations of the Blazhko effect in RR Lyrae stars appear to support, or at least not to contradict, a crossover effective temperature of ∼6400 K (Stothers 2006). With this empirical check, we can now apply the same theory to Polaris, the classical Cepheid. Usenko et al. (2005) have listed seven published estimates of Polaris's effective temperature that were derived from stellar atmosphere models; all lie in the range 5950–6200 K. Since these estimates are significantly hotter than the theoretical crossover effective temperature of ∼5850 K, we predict that the pulsation period should increase as the amplitude declines as a result of the strengthening of convection. Conversely, the period is expected to decrease as the amplitude rises.

The problem with applying these predictions to Polaris is the star's low amplitude and fast evolution (neither of which affects the RR Lyrae stars). The rapid evolutionary period change may mask the Blazhko period change, while at low amplitude the convective motions become comparable with the pulsational motions, perhaps leading to some irregularity and intermittency of the Blazhko effect. All we can say for now is that the glitch between 1963 and 1966 is suggestive of intermittent Blazhko behavior; otherwise the period decline is difficult to explain. The recent rise of amplitude also suggests the Blazhko effect, especially if the period increase has slowed down or become disturbed (but this is still uncertain). A more careful examination of existing data may be able to test our basic predictions. At least, the observed relative amplitude of the period change $|\delta P/P|$ is $\sim 10^{-3}$, in agreement with theoretical models. Although the ratio of the slow cycle time to the pulsation period cannot yet be predicted, its observed value seems to be $\sim 10^3$. In comparison, RR Lyrae stars show ratios of ~ 10–10^3 (Smith 1995; Jurcsik et al. 2005). Therefore, Polaris is rather sluggish, but not unduly so.

4. V473 LYR

Another classical Cepheid showing a slow modulation of its light and radial-velocity amplitudes is V473 Lyr (HR 7308) (Percy & Evans 1980; Burki & Mayor 1980). This low-amplitude variable appears to be a purely radial pulsator (in an uncertain mode) and has the shortest pulsation period known for a classical Cepheid, 1.49 days. The period of amplitude modulation is ∼1200 days. Although a long-term period increase is also observed, no obvious period variation occurs during the modulation cycle (Berdnikov & Pastukhova 1994; Koen 2001). The amplitude modulation has been explicitly likened to the Blazhko effect in RR Lyrae stars (Burki & Mayor 1980; Koen 2001). A number of theories proposed for the behavior of V473 Lyr have been listed by Koen (2001), but it was Breger (1981) who suggested, as an alternative to the beating of two very close periods, a pure amplitude modulation arising from unspecified changes in the stellar envelope with a three-year cycle. We agree with this suggestion.

Our present proposal to explain Polaris can now also be applied to V473 Lyr. Both Cepheids possess short radial pulsation periods, high effective temperatures of ∼6100 K (for V473 Lyr, see van Genderen 1981; Burki et al. 1982), small pulsation amplitudes, and long amplitude modulation cycles. Since V473 Lyr lies between Polaris and the RR Lyrae stars on the Hertzsprung–Russell (H–R) diagram, the theoretical crossover temperature near this location can be expected to fall somewhere between 5850 and 6400 K. If it is indeed close to 6100 K, this might explain the observed lack of noticeable period modulation in V473 Lyr.

5. DISCUSSION

Turner et al. (2006) have found that nearly all well-studied classical Cepheids with periods shorter than ∼4 days have rates of period change that are roughly an order of magnitude faster than expected from evolutionary models for second and third crossers of the instability strip. They therefore proposed that these Cepheids are in a first or post-third crossing. Could a subset of these short-period stars be "Blazhko Cepheids"? Polaris and V473 Lyr at least suggest this possibility. Owing to the steep slope of the instability strip in the H–R diagram, Polaris and V473 Lyr possess high effective temperatures, which may provide a clue to their peculiarities.

Why, from the point of view of the present theory, should a slow cycle of invigoration and subsequent damping of turbulent convection occur in such hot stars? If the ultimate cause is a solar-like magnetoconvective cycle, a similar explanation to what we proposed previously for RR Lyrae stars might hold here, namely, that the cooler (longer-period) variables have envelope convection which is always too strong to be significantly modulated by a magnetic field. Therefore, only the hotter variables could exhibit a noticeable Blazhko effect. Variables, however, that are so hot that envelope convection is unimportant at all times would not display this effect. Nevertheless, considerable scatter must exist among the stars that are potential Blazhko variables, because the seed magnetic field, the rotation rate, and other relevant parameters doubtless vary much from star to star even at the same location on the H–R diagram. Further observations are clearly needed.

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REFERENCES

Arellano Ferro, A. 1983, ApJ, 274, 755
Berdnikov, L. N., & Pastukhova, E. N. 1994, Astron. Lett., 20, 720
Bono, G., Marconi, M., & Stellingwerf, R. F. 1999, ApJS, 122, 167
Breger, M. 1981, ApJ, 249, 666
Bruntt, H., et al. 2008, ApJ, 683, 433
Burki, G., & Mayor, M. 1980, A&A, 91, 115
Burki, G., Mayor, M., & Benz, W. 1982, A&A, 109, 258
Cogan, B. C. 1979, Science, 204, 1078
Deupree, R. G. 1977, ApJ, 211, 509
Deupree, R. G. 1980, ApJ, 236, 225
Di Criscienzo, M., Marconi, M., & Caputo, F. 2004, ApJ, 612, 1092
Evans, N. R., Buzasi, D., Sasselov, D., & Preston, H. 2004, BAAS, 36, 1429
Evans, N. R., Sasselov, D. D., & Short, C. I. 2002, ApJ, 567, 1121
Feast, M. W., & Catchpole, R. M. 1997, MNRAS, 286, L1
Fernie, J. D., Kamper, K., & Seager, S. 1993, ApJ, 416, 820
Feuchtinger, M. U. 1999, A&A, 351, 103
Gehmeyr, M. 1992, ApJ, 399, 272
Jurcsik, J., Szeidl, B., Nagy, A., & Sódor, A. 2005, Acta Astron., 55, 303
Kamper, K. W., & Fernie, J. D. 1998, AJ, 116, 936
Koen, C. 2001, MNRAS, 322, 97
Natale, G., Marconi, M., & Bono, G. 2008, ApJ, 674, L93
Percy, J. R., & Evans, N. R. 1980, AJ, 85, 1509
Smith, H. A. 1995, The RR Lyrae Stars (Cambridge: Cambridge Univ. Press)
Spreckley, S. A., & Stevens, I. R. 2008, MNRAS, 388, 1239
Stellingwerf, R. F. 1984, ApJ, 284, 712
Stothers, R. B. 2006, ApJ, 652, 643
Turner, D. G., Abdel-Sabour Abdel-Latif, M., & Berdnikov, L. N. 2006, PASP, 118, 410
Turner, D. G., Savoy, J., Derrah, J., Abdel-Sabour Abdel-Latif, M., & Berdnikov, L. N. 2005, PASP, 117, 207
Usenko, I. A., Miroshnichenko, A. S., Klochkova, V. G., & Yushkin, M. V. 2005, MNRAS, 362, 1219
van Genderen, A. M. 1981, A&A, 99, 386
van Leeuwen, F., Feast, M. W., Whitelock, P. A., & Laney, C. D. 2007, MNRAS, 379, 723