Variable Stars in the Local Group
ASP Conference Series, Vol. 310, 2004
Donald W. Kurtz & Karen R. Pollard, eds.

Magnetic models can not explain the Blazhko effect in RR Lyrae stars

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Abstract. We report a new series of high-precision Stokes V profiles and longitudinal magnetic field measurements of RR Lyrae, obtained with the MuSiCoS spectropolarimeter over a period of four years. These data provide no evidence whatsoever for a strong magnetic field in the photosphere of RR Lyrae, which is consistent with Preston's (1967) results, but inconsistent with apparent magnetic field detections by Babcock (1958) and Romanov et al. (1987, 1994). Following discussion of these disparate results, we conclude that RR Lyrae is a *bona fide* non-magnetic star, a conclusion which leads to the general falsification of models of the Blazkho effect requiring strong photospheric magnetic fields.

1. Introduction

Up to now the magnetic field measurements of RR Lyrae pulsating stars have yielded ambiguous results. The investigation of their magnetic fields is extremely important for understanding the nature of pulsations, and more particularly for understanding the physical origin of the Blazhko effect, a periodic amplitude modulation shown by some 20–30% of the RR Lyrae stars. The Blazhko effect does not yet have a generally accepted explanation.

As already discussed by Kovács (2001), one of the most plausible models to explain the Blazhko effect predicts the dependence of the Blazhko amplitude upon the strength of a magnetic field of the order of 1 kG in the stellar photosphere (Cousens 1983; Shibahashi & Takata 1995). Unfortunately, the existence of such a magnetic field in the atmosphere of an RR Lyrae star has never been confirmed. The first search for a magnetic field in RR Lyrae was made by Babcock (1958), who reported detection of a strong longitudinal field showing variations between $B_e = -1580$ and $+540$ G with reported errors of less than 220 G. Later, Preston (1967) failed to detect any magnetic field on RR Lyrae

https://doi.org/10.1017/S0252921100011283 Published online by Cambridge University Press

with 50 photographic observations obtained over two years (1963 and 1964). More recently, using an achromatic circular polarization analyzer, Romanov et al. (1987, 1994) obtained 83 Zeeman spectrograms with the 6-m telescope of the Russian Special Astrophysical Observatory on several nights in 1978, 1982, 1983 and 1984 with reported $1\,\sigma$ uncertainties between 100–500 G. They observed a field with amplitude around 1.5 kG. They reported that the magnetic field presents a periodic variation over the pulsation cycle (0.567 d), while its average intensity shows a periodic long-term variation corresponding to the 40.8 d Blazhko period which perhaps corresponds to the stellar rotation period.

2. Observations and spectropolarimetric measurements of Stokes V and longitudinal magnetic field

Twenty-seven Stokes V spectra of RR Lyrae were obtained over four years (1999, 2000, 2001 and 2002) at various pulsation and Blazhko phases using the MuSiCoS spectropolarimeter mounted at the 2-m Bernard Lyot telescope at Pic du Midi Observatory. All spectra were reduced using the ESpRIT reduction package (Donati et al. 1997). Total exposure times for a full Stokes V exposure (4 subexposures) was typically 40–60 minutes, leading to signal-to-noise ratios (S/N) in the range 600–1000. The Least-Squares Deconvolution (LSD, Donati et al. 1997) multiline analysis procedure was employed to extract high-precision mean Stokes I and V profiles from each spectrum. The longitudinal magnetic field values and the associated uncertainties were inferred from the extracted LSD Stokes I and V Zeeman profile sets by numerical integration, using the first-order moment method (Wade et al. 2000b). The Blazhko and pulsation phases have been calculated respectively from the ephemerides given by Chadid & Gillet (1997). The longitudinal field measurements of RR Lyrae are by far the best ever obtained, with $1\,\sigma$ uncertainties between 33–144 G, and a median value of 80 G. The strongest longitudinal field measured is $B_\ell = +280 \pm 107$ G, obtained at minimum Blazhko phase, whereas the smallest is $B_\ell = -5 \pm 53$ G, also obtained at minimum Blazhko phase. None of our measurements of RR Lyrae represents a significant detection – the most significant measurement, as characterized using the $z = |B_\ell/\sigma_{\rm B}|$ parameter, has $z = 2.60$.

3. Discussion

Romanov et al. (1987, 1994) obtained 83 circular polarization observations of RR Lyrae on several nights in 1978, 1982, 1983 and 1984, with $1\,\sigma$ uncertainties between 100–500 G. According to these authors, RR Lyrae exhibits a longitudinal magnetic field which varies approximately sinusoidally, with a maximum value of $\sim$ 1800 G and an amplitude of the field variation of $\sim$ 1000 G , when phased according to the pulsation period of 0.567 days. We point out that the phase of strongest positive longitudinal magnetic field obtained by Romanov et al. corresponds to the phase of primary shock wave passage ($\phi = 0.95$) just before the phase of maximum light.

Fig. 1 shows a comparison of our 27 RR Lyrae longitudinal magnetic field measurements with those obtained by Romanov et al. (1987) during 1982 September 25–28, phased according to the pulsational ephemeris. It is clear that our

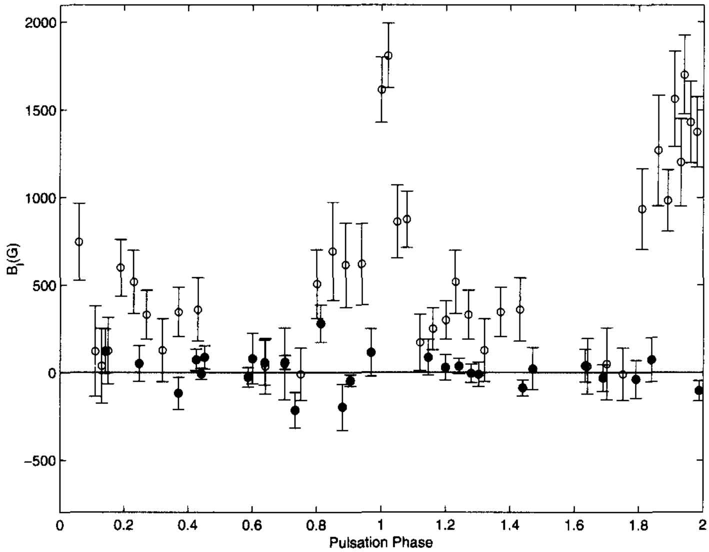

Figure 1. Comparison of our longitudinal magnetic field measurements (solid circles) of RR Lyrae with the magnetic field variation reported by Romanov et al. (1987) (open circles).

new measurements are in strong conflict with those of Romanov et al., especially at phase $\phi = 0.95$ where Romanov et al. obtain a mean magnetic field around 13 times larger than our typical sigma.

Romanov et al. (1987, 1994) also claimed that the average strength and the polarity of the longitudinal field vary according to the 40.8-d Blazhko period: B_ℓ is strongest and positive at Blazhko phase maximum. However, our measurements do not reveal any systematic magnetic variability according to the Blazhko phase, in strong contrast with those of Romanov et al.

In none of our RR Lyrae LSD Stokes V profiles is a significant signal detected. Specifically, we find no evidence of any circular polarization (with a Z upper limit of 1.5) in the mean Stokes profiles of RR Lyrae at phases corresponding to either maximum light or maximum Blazhko effect.

How can these new results be reconciled with the apparent field detections by Babcock (1958) and Romanov et al. (1987, 1994)? The answer may lie in the fact that both Romanov et al. and Babcock employed photographic spectra in their analysis of RR Lyrae. As was pointed out by Preston (1967), uncertainties associated with longitudinal field measurement obtained using photographic spectra are frequently underestimated by factors of up to 300%. This phenomenon is supported explicitly by the results of Wade et al. (1997), and implicitly by the large values of the χ^2 parameter obtained by Wade et al. (1996) for photographic measurements obtained using the Main Stellar Spectrograph at the Russian Special Astrophysical Observatory.

We point out that this same telescope and instrument were employed by Romanov et al. (1987, 1994) to obtain their data. Therefore it would not be surprising if their uncertainties were underestimated by a factor of at least 2. This would render their detection marginal. Even if we allow this marginal detection, we need to consider possible sources of systematic error. As is described by Wade et al. (2002), magnetic measurements of pulsating stars can be complicated by the passage of shock waves through the stellar atmosphere. In RR Lyrae, two strong shock waves are observed (Chadid & Gillet 1996): the first around pulsation phase 0.95 (the primary shock originating from the κ-mechanism expansion) and a second weaker shock around phase 0.65 (the "rebound" shock). These shocks can lead to rapid differential changes in the line profiles (broadening and doubling phenomena), and may result in spurious polarization signatures. Therefore the correspondence between the passage of the primary shock wave and the peak of B_ℓ as obtained by Romanov et al. (1987), rather than indicating the presence of a strong magnetic field at this phase, may simply indicate important spurious contributions to the Stokes V profiles due to shock-related variations.

4. Conclusions

Although we are unable to completely dismiss the apparent detections of magnetic fields in RR Lyrae by Babcock (1958) and Romanov et al. (1987, 1994), we propose that the lack of detection of a field by Preston (1967), the potential of the Babcock and Romanov et al. data for underestimated uncertainties and important spurious polarization signatures, and the lack of detection of any significant magnetic field from our four years of high-precision circular polarization measurements with the MuSiCoS spectropolarimeter suggest very strongly that RR Lyrae is not a magnetic star.

References

Chadid, M., Gillet, D. 1996, A&A, 308, 481

Chadid, M., Gillet, D. 1997, A&A, 319, 154

Chadid, M., Wade, G.A., Shorlin, S.L.S, Landstreet, J.D. 2003, A&A, in press

Cousens, A. 1983, MNRAS, 203, 1171

Donati, J.F., Semel, M., Carter, B.D, Cameron, A.C. 1997, MNRAS, 291, 658

Kovacs, G. 2001, in Stellar pulsation–nonlinear studies, eds. M. Takeuti and D.D. Sasselov, Astrophysics and Space Science library, Vol. 257, p. 61

Preston, G.W. 1967, The Magnetic and Related Stars, ed. R.C. Cameron, (Mono Book Corporation, Baltimore), p. 26

Romanov, Yu.S., Udovichenko, S.N., Frolov, M.S. 1987, Sov. Astr. Lett., 13, 29

Romanov, Yu.S., Udovichenko, S.N., Frolov, M.S. 1994, Sp. Astro. Obs. 38, 169

Shibahashi , H., Takata, M. 1995, ASP Conf. Ser., 83, 42

Wade, G.A., Elkin, V., Landstreet, J.D., Leroy, J.-L., Mathys, G., Romanyuk, I.I. 1996, A&A, 313, 209

Wade, G.A., Elkin, V., Landstreet, J.D., Romanyuk, I. 1997, MNRAS, 292, 748

Wade, G.A., Donati, J.F., Landstreet, J.D., Shorlin, S. 2000, MNRAS, 313, 851