A&A 392, L17–L20 (2002)
DOI: 10.1051/0004-6361:20021084

Astronomy
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Astrophysics

No magnetic field variations with pulsation phase in the classical Cepheid star η Aquilae*

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Received 23 May 2002 / Accepted 24 July 2002

Abstract. We report new high resolution Stokes V spectropolarimetry and ultra-high precision longitudinal magnetic field measurements of the pulsating classical Cepheid η Aql which fail to corroborate the report by Plachinda (2000) of a ~100 G magnetic field in this star.

Key words. stars: atmospheres – stars: variable: δ Cep – stars: individual: η Aql – stars: magnetic fields – polarisation

1. Introduction

The appearance of magnetic fields in the atmospheres of radially pulsating stars would appear to be a rather natural consequence of their strong sustained atmospheric velocity fields. The literature does indeed contain a number of claims of field detections in such stars, beginning with that of Babcock (1958) who published measurements of RR Lyr showing a longitudinal magnetic field as strong as ~1600 G. To our knowledge, none of these claims has ever been confirmed[1]; in fact, Babcock's claim has recently been convincingly refuted by Chadid et al. (2002).

Recently, Plachinda (2000) reported the detection of a ~100 G longitudinal magnetic field in the photosphere of the classical Cepheid η Aql (= HR 7570 = HD 187929, spectral type F6–G4 Iab, $m_V = 4.08{-}5.36$). Plachinda claims that the field varies approximately sinusoidally according to the pulsation ephemeris. Most remarkably, he pointed out an apparent discontinuity in the field variation (around phase $\phi = 0.62$) which he attributed to an abrupt change in the magnetic field configuration associated with the passage of a shock wave through the atmosphere. The quality of the data, along with the apparent coherence of the phased field measurements, makes Plachinda's detection the most convincing to date. We therefore set out to obtain new longitudinal magnetic field observations of η Aql with the aim of testing the reproducibility of Plachinda's detection.

2. Observations

During the nights of 2001 July 10–13 UT we obtained 14 new Stokes V spectra of η Aql using the MuSiCoS spectropolarimeter at Pic du Midi observatory. To check the instrument performance, we also obtained 3 observations (1 per night) of the magnetic Ap standard α^2 CVn. The spectra span a total range of 450–660 nm, with a typical resolving power of 35 000. Details of the instrument, and of the observing and reduction procedures are provided by Wade et al. (2000a). The observation log is reported in Table 1.

3. Stokes V Zeeman signatures and longitudinal magnetic field measurements

No significant circular polarisation is detected within spectral lines in the circular polarisation spectra. This result is illustrated in Fig. 1, and is further supported by a comparison with a numerical simulation. Using the polarised line synthesis code ZEEMAN2 (Landstreet 1988; Wade et al. 2001) we have synthesised the Stokes I and V spectrum of η Aql in the approximate

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* Based on observations obtained using the MuSiCoS spectropolarimeter at Pic du Midi observatory.

[1] Although the existence of magnetic fields have been well-established in the non-radially pulsating roAp stars, it is accepted that the fields are fossil and are likely not produced as a consequence of pulsation.

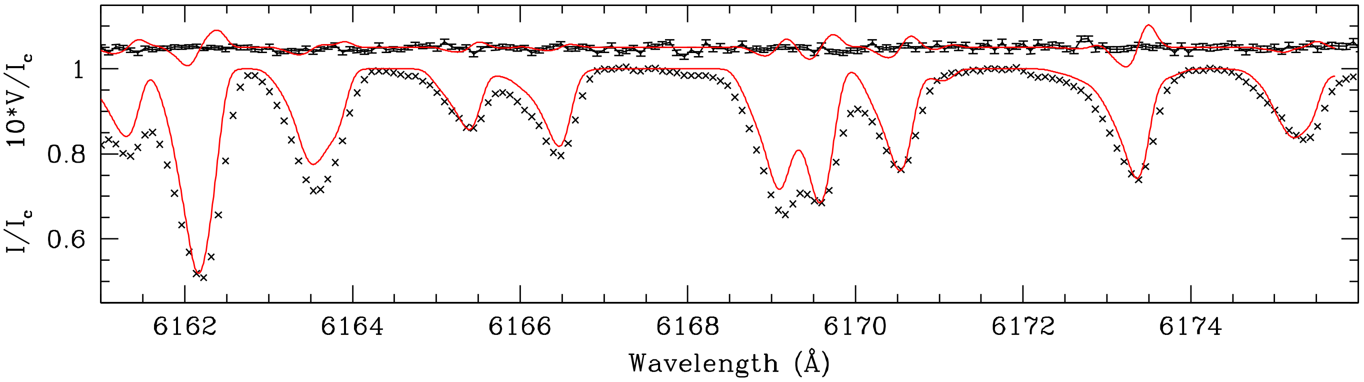

Fig. 1. Averaged observed (crosses and error bars) and synthesised (smooth line) Stokes I (lower) and V (upper) spectra of η Aql, obtained on 10–11 July 2001 UT (pulsation phase ~0.8). The calculated spectrum corresponds to a longitudinal magnetic field of −70 G, as expected at this phase based on Plachinda's results. Various predicted Stokes V Zeeman signatures which should be easily detectable in individual spectral lines in this region are clearly absent in the observed spectrum. Asymmetries in the observed Stokes I spectrum are due to the pulsation velocity field, which is accounted for kinematically in the model (as per Donati et al. 2001). We have employed $v \sin i = 13.3$ km s^{-1}, $\xi = 4$ km s^{-1}, a solar abundance table and 14.92 km s^{-1} and 7.29 km s^{-1} for the first- and second-order Fourier coefficients of the pulsational radial velocity variation. Note that Stokes V has been magnified 10× and shifted up by +1.05 for display purposes.

Table 1. Observation log and inferred longitudinal magnetic field of η Aql obtained from LSD profiles. HJD is the heliocentric Julian Date, S/N is the peak signal-to-noise ratio in the reduced spectrum, $N_{\rm LSD}$ is the mean noise level in the associated LSD profile, and $B_z \pm \sigma_B$ is the inferred longitudinal magnetic field and its standard error. Phases are according to the pulsation ephemeris JD = 2450100.861 + 7.176726 · E of Kiss & Vinkó (2000).

HJD −2 450 000	Pulsation phase	S/N	$N_{\rm LSD}$ (%)	$B_z \pm \sigma_B$ (G)
2101.436	0.759	760	3.6×10^{-3}	6 ± 4
2101.480	0.765	760	3.6×10^{-3}	−7 ± 4
2101.518	0.770	680	4.0×10^{-3}	0 ± 5
2101.548	0.774	650	4.3×10^{-3}	3 ± 5
2101.578	0.779	620	4.6×10^{-3}	4 ± 5
2101.608	0.783	660	4.2×10^{-3}	−8 ± 5
2101.638	0.787	620	4.5×10^{-3}	−8 ± 5
2102.558	0.915	860	3.3×10^{-3}	−9 ± 5
2102.603	0.921	790	4.5×10^{-3}	−13 ± 4
2102.647	0.928	710	4.1×10^{-3}	−14 ± 5
2103.405	0.033	1050	2.3×10^{-3}	−7 ± 3
2103.445	0.039	1040	2.3×10^{-3}	−6 ± 3
2103.554	0.054	1060	2.3×10^{-3}	−6 ± 3
2103.655	0.068	750	3.6×10^{-3}	−1 ± 4

spectral region employed by Plachinda (2000) for his magnetic field measurements, assuming a dipole field configuration which produces a longitudinal magnetic field of approximately −70 G (the value measured by Plachinda 2000 at the depicted phase). Although the detailed *shape* of the computed Stokes V depends on the adopted model magnetic configuration (a dipole), its *amplitude* is representative of any field configuration producing a −70 G longitudinal field. Comparing this synthesis with both the individual and averaged observed spectrum at phase ~0.8, *we find that predicted Stokes V Zeeman signatures which should be easily detectable in many individual lines in this region are completely absent in our observed spectrum.*

We have also applied the Least-Squares Deconvolution (LSD) multiline analysis technique (Donati et al. 1997) to further refine our attempt to detect a magnetic field. From each observed spectrum of η Aql we extracted LSD mean Stokes I and V profiles using a line mask constructed using VALD (Piskunov et al. 1995) line lists corresponding to $T_{\rm eff}$ = 6000 K, $\log g$ = 2.0 and a solar abundance table. LSD profiles of α^2 CVn were also extracted using the procedure described by Wade et al. (2000a). This line mask includes all lines with unbroadened central depths above 10% predicted to appear in the MuSiCoS spectrum of η Aql (more than 4000 lines). More information about the extraction of LSD profiles and the construction of LSD line masks is provided by Shorlin et al. (2002). None of the η Aql LSD profiles show any significant circular polarisation, and our most conservative upper limit on circular polarisation in the mean spectral lines of η Aql during 10, 11 and 12 July 2001 is 0.01% (3 σ, peak-to-peak). Representative mean Stokes I and V profiles of η Aql are shown in Fig. 3.

Finally, the longitudinal magnetic field B_z and its formal uncertainty σ_B were inferred from each of the extracted LSD Stokes I/V profile sets by numerical integration, using the expression:

$$B_z = -2.14 \times 10^{11} \frac{\displaystyle\int v V(v)\, {\rm d}v}{\lambda z c \displaystyle\int [I_c - I(v)]\, {\rm d}v}, \quad (1)$$

(Wade et al. 2000b) where the wavelength λ is in nm and B_z is in Gauss. The Landé factor z is a mean value obtained from all lines used to compute the LSD profile. The accuracy of this technique for determining high-precision longitudinal field measurements has been demonstrated by, e.g. Wade et al. (2000b), Donati et al. (2001) and Shorlin et al. (2002).

The longitudinal field measurements of η Aql represent some of the best ever obtained, with 1σ *formal* uncertainties

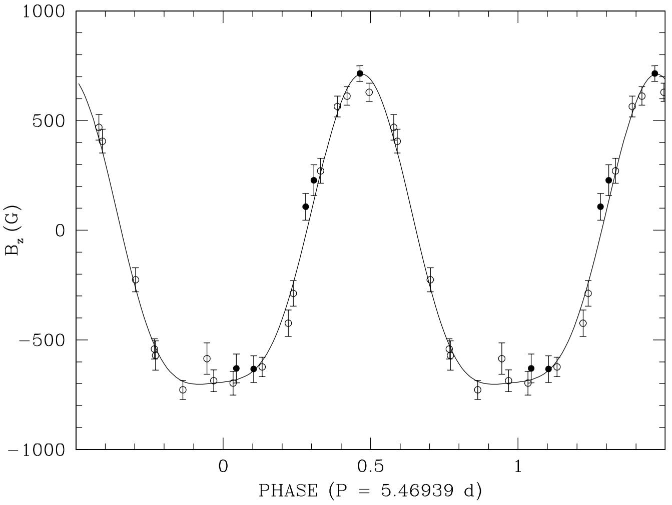

Fig. 2. Longitudinal magnetic field variation of the prototypical magnetic Ap star α^2 CVn, observed as a magnetic standard within the context of this study. Shown are observations reported by Wade et al. (2000b, open circles), and those obtained within the context of this study and an analogous study of RR Lyr (Chadid et al. 2002, filled circles). The solid curve is a least-squares fit.

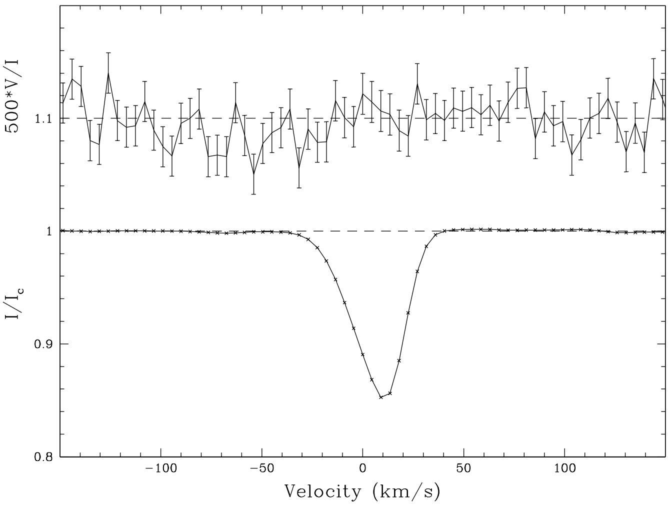

Fig. 3. Representative LSD mean Stokes I and V signatures of η Aql from spectra obtained on 10 July 2002 (JD 2452101.480, phase 0.765). No significant circular polarisation is detected. Note that Stokes V has been enlarged by a factor of 500 and shifted upward by 1.1 for display purposes.

of 3–5 G. The largest longitudinal field measured has $B_z = 14\pm5$ G, and the most significant measurement is $B_z = 13\pm4$ G, ($3.3\,\sigma$). These measurements (in particular the validity of the error bar) will be discussed further in Sect. 6. The B_z measurements of α^2 CVn are also very precise, have uncertainties in the range 35–70 G, and are completely consistent with the field variation of this star as determined by Wade et al. (2000b, see Fig. 2).

The inferred values of the longitudinal field of η Aql are reported in Table 1.

4. Comparison with Plachinda's (2000) results

Many classes of radially-pulsating stars are known to exhibit atmospheric shock waves (e.g. Breitfellener & Gillet 1993; Chadid & Gillet 1996). Typically, two strong shocks are observed, the first around phase 0.9 (the primary shock originating as a result of κ-mechanism expansion) and the second around phase 0.65 (a weaker secondary "rebound" shock). By convention, phase 0.0 represents the phase of maximum lumonosity. Plachinda (2000) observed an apparent rapid increase in the strength of the longitudinal magnetic field corresponding to the phase of the rebound shock, and developed a schematic model to explain this phenomenon.

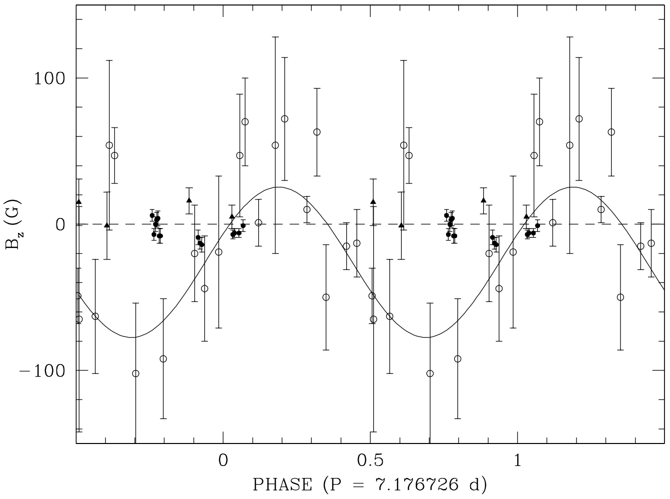

Fig. 4. Comparison of our longitudinal magnetic field measurements (solid circles) of η Aql, and those of Borra et al. (1981, solid triangles), with the field variation reported by Plachinda (2000, open circles and curve). Around phase 0.8, our results are strongly inconsistent with those of Plachinda.

We note a typo in the ephemeris as cited by Plachinda (2000). He uses the emphemeris of Kiss (1998), which should read JD = 2432926.749 + 7.176641 · E. A more recent ephemeris is provided by Kiss & Vinkó (2000; JD = 2450100.861 + 7.176726 · E); this ephemeris is employed for all further analysis. Now, as indicated in Sect. 3, not one of the 14 LSD Stokes V profiles or longitudinal field measurements of η Aql provides any strong evidence for a magnetic field. This is consistent with the results of Borra et al. (1981). These authors, using a measurement procedure conceptually similar to LSD, failed to detect a longitudinal magnetic field in η Aql from 4 measurements with formal uncertainties in the range 8–23 G. To provide a direct comparison with the results of Plachinda (2000), we have phased our new B_z data, as well as those of Borra et al. (1981), according to the pulsation ephemeris of Kiss & Vinkó (2000) and we show them, along with those of Plachinda, in Fig. 4. Clearly, these measurements are in strong conflict with those of Plachinda, most notably around phase 0.8.

We therefore conclude that neither our longitudinal field measurements nor our Stokes V spectra are consistent with the presence of the ~100 G magnetic field reported by Plachinda (2000) to exist in the photosphere of η *Aql.*

5. A weak magnetic field in η Aql?

Although our results do not support the specific conclusions of Plachinda (2000), do they provide any evidence for the existence of weaker magnetic fields? The detection significance $z = |B_z|/\sigma_B$ of our longitudinal field measurements ranges from 0 to 3.3, and the reduced χ^2 of the sample as compared to a zero field model is 3.3. This value is somewhat larger than the maximum reduced χ^2 (2.6 at the 99.9% level) expected for 14 measurements, suggesting that a zero field model may not be an adequate description of the data. The reduced χ^2 is however strongly influenced by two measurements (-14 ± 5 and -13 ± 4 G) obtained on JD 2452102 (excluding these two measurements, the reduced χ^2 is just 2.3). It may be that these two measurements (and the general trend of negative longitudinal field after JD 2452101.608) reflect the presence of weak (~10 G) magnetic field (with characteristics apparently very different from the field claimed by Plachinda). However, we point out that the phase at which these two measurements were acquired (phase 0.92) is precisely the phase at which we expect the largest velocity fields in the atmosphere of η Aql, due to passage of the primary shock wave. In fact, whereas we observe no detectable systematic change in radial velocity amongst the spectra obtained on 10 July (phase 0.759–0.787) or 12 July (phase 0.033–0.068), on 11 July (phase 0.915–0.928) we observe a clear systematic change of the *RV* of the mean line of about 4 $\mathrm{km\,s^{-1}}$. Although our observing and reduction procedure is designed to minimise spurious signatures due to stellar variability (among other causes), it is certainly clear that such rapid variability makes the danger of systematic errors much more severe. Therefore we note the apparent marginal detection of a weak magnetic field around phase 0.92, although we tentatively ascribe it to systematic error, pending further observations.

6. Conclusions

New MuSiCoS circular polarisation observations and ultra-high precision determinations of the longitudinal magnetic field of the Cepheid variable η Aql show no convincing evidence of a photospheric magnetic field. This result is in agreement with measurements by Borra et al. (1981), and in conflict with recent claims by Plachinda (2000). At present, the simplest conclusion is that η Aql is a non-magnetic star, at least at the level of ~10 G.

Acknowledgements. This work has taken advantage of the Vienna Atomic Line Database (VALD). GAW acknowledges grant support from the Natural Sciences and Engineering Research Council of Canada, and the Canadian Department of National Defence. WWW acknowledges support by the *Fonds zur Förderung der wissenschaftlichen Forschung* (P14984) and the *Hochschuljubiläumsstiftung der Stadt Wien*. We also acknowledge the referee, C. Johns-Krull, for useful comments leading to the improvement of this manuscript.

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