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Monitoring magnetic fields of sharp-lined Ap stars with the 6 m telescope

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Abstract.
We report results of an ongoing programme aimed at measuring the longitudinal magnetic fields of a sample of approximately 20 Ap stars with sharp, magnetically-split spectral lines, using the 6 m telescope at the Special Astrophysical Observatory.

Key words: stars: magnetic fields – stars: peculiar – methods: observational

1 Introduction

This talk represents a progress report of a programme of long-term monitoring of longitudinal magnetic fields of sharp-lined magnetic stars. These stars have been identified by the resolved splitting of Zeeman components in their spectra, primarily in the Zeeman doublet of Fe II at 6149.3 Å, and were reported primarily by Mathys et al. (1997).

The sharp lines of these stars (with intrinsic widths < 3 km s^{-1} after magnetic broadening is taken into account) imply small projected rotational velocities $v_{\rm e} \sin i$. For those sharp-lined stars with relatively short rotational periods, it is the combination of moderate equatorial rotational velocity $v_{\rm e}$ and significant inclination $\sin i$ that lead to their sharp lines. However, for those stars with rotational periods longer than about 50 days, their sharp lines are entirely attributable to slow rotation, notwithstanding the inclination of the stellar rotational axis. These ultra-slow rotators represent about one-half of the known sample of Ap stars with resolved, magnetically-split lines, and their measured and estimated rotational periods extend to years, and in some cases (HD 201601=γ Equ) decades.

The rotational angular momentum of an Ap star with a rotational period of 50 d ($v_{\rm e} \simeq 3$ km s^{-1}) is less than 2% of that of a typical normal A star rotating with $v_{\rm e} \sin i = 120$ km s^{-1}; that of an Ap star with a rotational period of 50 years is less than 5×10^{-3}%. It is of enormous physical interest to decipher the mechanism by which these stars have shed the vast majority of their angular momentum (e.g. Stepien & Landstreet 2002). Unfortunately, their extremely long rotational periods make them poorly suited to study.

With the de-commissioning of the CASPEC spectropolarimeter on the ESO La Silla 3.6 m telescope, the Special Astrophysical Observatory provides essentially the only facility worldwide adapted technologically and philosophically to continued study of the magnetic fields of ultra slowly-rotating Ap stars. Since 1996, we have been observing a sample of about 20 of these stars in circular spectro-polarisation, using the main stellar spectrograph on the 6 m telescope. In the remainder of this paper, we describe the properties of the sample, and present some of the first results of our study.

2 Bulk properties of the sharp-lined Ap stars

The sample of sharp-lined Ap stars studied within the context of this programme, roughly divided into "shorter period" and "long period" stars, is reported in Table 1. Of the 23 stars listed in Table 1, we have completed detailed studies for 5, and the results are reported in the refereed literature. For an additional 4 stars, complete but as yet unpublished magnetic phase curves have been obtained. Finally, for another 12

Table 1: List of targets. Individual columns give the object designation, rotational period (if known), apparent visual magnitude, the average value of the mean magnetic field modulus as measured by Mathys et al. (1997), the number of observations obtained in this programme, and comments regarding published models and binarity, and completeness.

Object	Rotational period	m_V	$\langle H \rangle_{AV}$ (kG)	# obs.	Comments
		Shorter period ($P_{\rm rot} < 50$ d)			
HD 12288	34.9 d	7.8	8.0	10	Wade et al. (2000a), SB1
HD 14437	26.9 d	8.3	7.5	30	Wade et al. (2000a)
HD 81009	34.0 d	7.2	8.4	6	Wade et al. (2000b), SB1
HD 119027	$\sim$ 1 month	10.0	3.1	0	incomplete
HD 134214	4.17 d?	7.5	3.1	10	incomplete
HD 142070	3.37 d	8.0	5.0	12	SB1, complete
HD 165474	2.54 d?	7.5	6.5	11	complete
HD 192678	6.42 d	7.4	4.7	12	Wade et al. (1996a)
HD 335238	49 d?	9.2	9.7	12	complete
		Long period ($P_{\rm rot} > 50$ d)			
HD 965	$>>$ 2 y	8.6	4.4	6	incomplete
HD 9996	21: y	6.4	4.4	6	SB1, incomplete
HD 18078	?	8.3	3.7	14	complete
HD 47103	long	9.2	17.5	10	incomplete
HD 50169	$>>$ 4 y	9.0	4.7	3	SB1, incomplete
HD 59435	1360 d	8.0	3.1	5	SB2, incomplete
HD 61468	long	9.8	7.2	0	SB1
HD 110066	4900: d	6.4	4.1	11	incomplete
HD 116114	$>>$ 3 y	7.0	6.0	9	SB1, incomplete
HD 137949	$>$ 75 y ?	6.7	4.7	4	
HD 200311	52.01 d	7.7	8.7	11	Wade et al. (1997)
HD 188041	223.9 d	5.6	3.7	3	incomplete
HD 201601	$>$ 70 y	4.7	3.8	7	incomplete
HD 216018	$>>$ 3 y	7.6	5.6	1	SB1

stars some magnetic data has been obtained (ranging from a single observation in the case of HD 216018, to 11 observations in the case of 110066). In total, as of the date of this meeting, approximately 300 measurements of the longitudinal magnetic fields of the programme stars have been obtained.

The histogram of rotational periods of these stars is shown in Fig. 1. Stars to the left in this figure are characterised, as described above, by shorter periods and larger inclinations. For the majority of these stars, full rotational phase coverage has been obtained and their periods are well-determined. On the other hand, stars to the right in this diagram represent true slow rotators. The majority of these stars have poorly determined rotational periods, and in particular the values reported in the figure tend to be lower limits (as indicated by the red arrow). Therefore, the marginal separation of these two populations evident in Fig. 1 is very probably much more significant, and it would not be unreasonable to assume that they are representative of two independent distributions.

The programme stars have been located on the HR diagram, with effective temperatures determined using Geneva and Stromgren photometry. Heliocentric distances and luminosities were inferred using Hipparcos trigonometric parallaxes (no Lutz-Kelker correction has been applied). Finally, masses and ages were inferred by locating each star on the $(\log T, \log L)$ Hertzsprung-Russell diagram and comparing with the model predictions of Schaller et al. (1992). The resultant HR diagrams for all programme stars and for those stars with well-determined Hipparcos parallaxes ($\sigma_\pi/\pi < 0.2$) are shown in Fig. 2.

Hubrig et al. (2000) reported that the sharp-lined Ap stars appear preferentially away from the ZAMS. Our analysis confirms this general result. However, our analysis also suggests that this may not be true for lower mass stars (e.g. HD 134214, HD 216018). This may suggest that there is a minimum age of stars

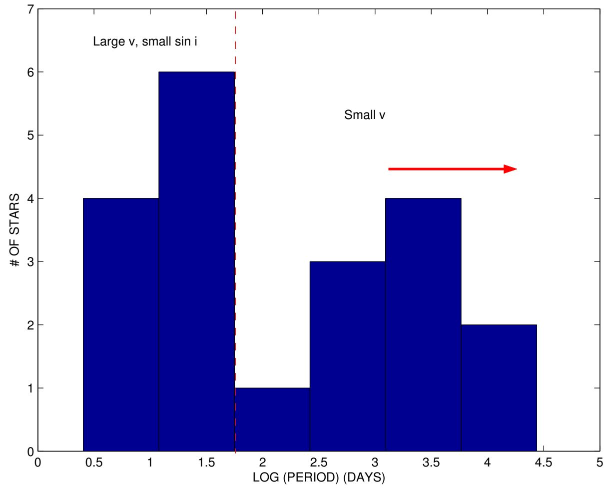

Figure 1: *Period histogram. The dash line separates true slow rotators (to the right) from stars with generally moderate rotational speeds and low inclinations (to the left).*

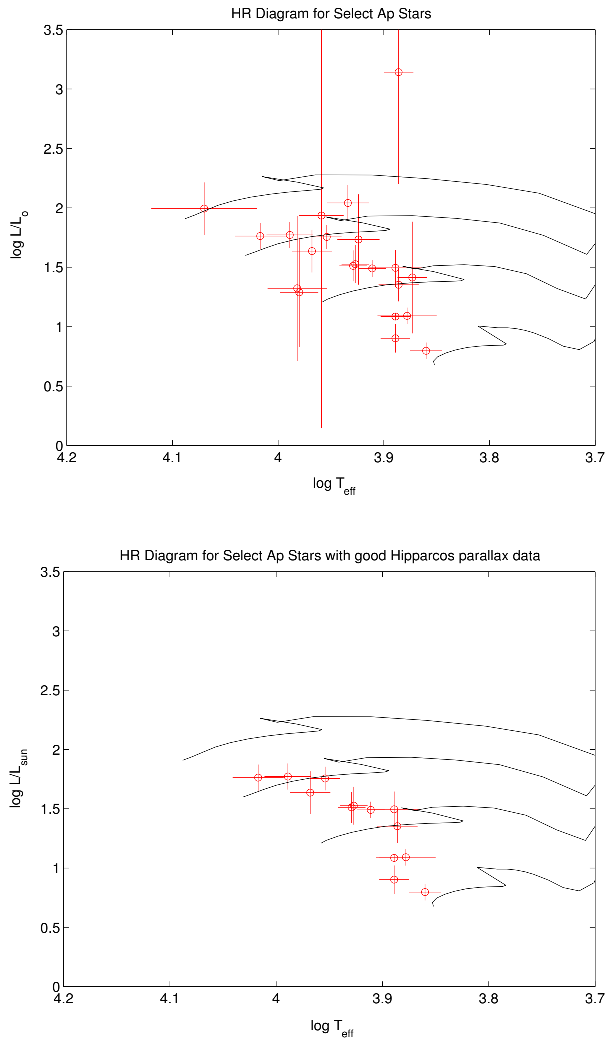

Figure 2: *Derived HR diagrams for the observational sample.* Upper frame – *all stars.* Lower frame – *stars with well-determined Hipparcos parallaxes. Note the general tendency for these stars to reside away from the ZAMS.*

included in this sample. We also find that no clear distinction exists on the HR diagram between long-period and shorter-period sharp-lined stars. There may exist a marginal tendency for long-period stars to have lower masses. However, this is clearly not a firm rule (exceptions include HD 9996, HD 110066).

3 Results for individual stars

In this section we highlight results for 3 stars in our sample: HD 142070, HD 335238 and HD 59435.

3.1 HD 142070

HD 142070 is an intermediate-mass Ap star with an effective temperature of about 8400 K. Mathys et al. (1997) find a mean field modulus of 5.0 kG averaged over the rotational cycle of 3.3748 days. Landstreet & Mathys (2000) show phased field modulus and longitudinal field measurements of this star. Our 12 new measurements of the longitudinal magnetic field are well phased according to a period of 3.3714 days, somewhat shorter than the period adopted by Mathys et al. (1997). The results are illustrated in Fig. 3.

3.2 HD 335238

HD 335238 is an intermediate-mass Ap star with an effective temperature of about 9100 K. Mathys et al. (1997) find a mean field modulus of 9.7 kG averaged over a supposed rotational cycle of 44 days. To our knowledge, apart from a single measurement by Mathys & Hubrig (1997), no other longitudinal field data have been obtained. Our 12 new measurements of the longitudinal magnetic field are well phased according to a period of 49 days, somewhat longer than the period proposed by Mathys et al. (1997). The results are illustrated in Fig. 4.

3.3 HD 59435

HD 59435 is an intermediate-mass Ap star with an effective temperature of about 8600 K, and a member of a double-lined spectroscopic binary. Wade et al. (1996) studied this system in detail, deriving the mean field modulus variation and a rotational period of 1360 days. To our knowledge, no measurements of the longitudinal magnetic field have ever been published. Our 5 new measurements agree well with the period proposed by Wade et al. (1996b), although continued observation is clearly necessary. The results are illustrated in Fig. 5.

4 Summary

New longitudinal field observations have been obtained for 21 sharp-lined Ap stars using the 6 m telescope. Multipolar magnetic field models have been published for 5 of these stars, and firm new period constraints have been obtained for an additional 4 shorter-period stars. Preliminary data have been obtained for an additional 12 stars, 11 of which have rotational periods estimated to be longer than 50 days. In order to obtain significant constraints on the magnetic fields of these extremely slowly-rotating Ap stars, observations continuing on timescales of months, to years and possibly to decades will be required.

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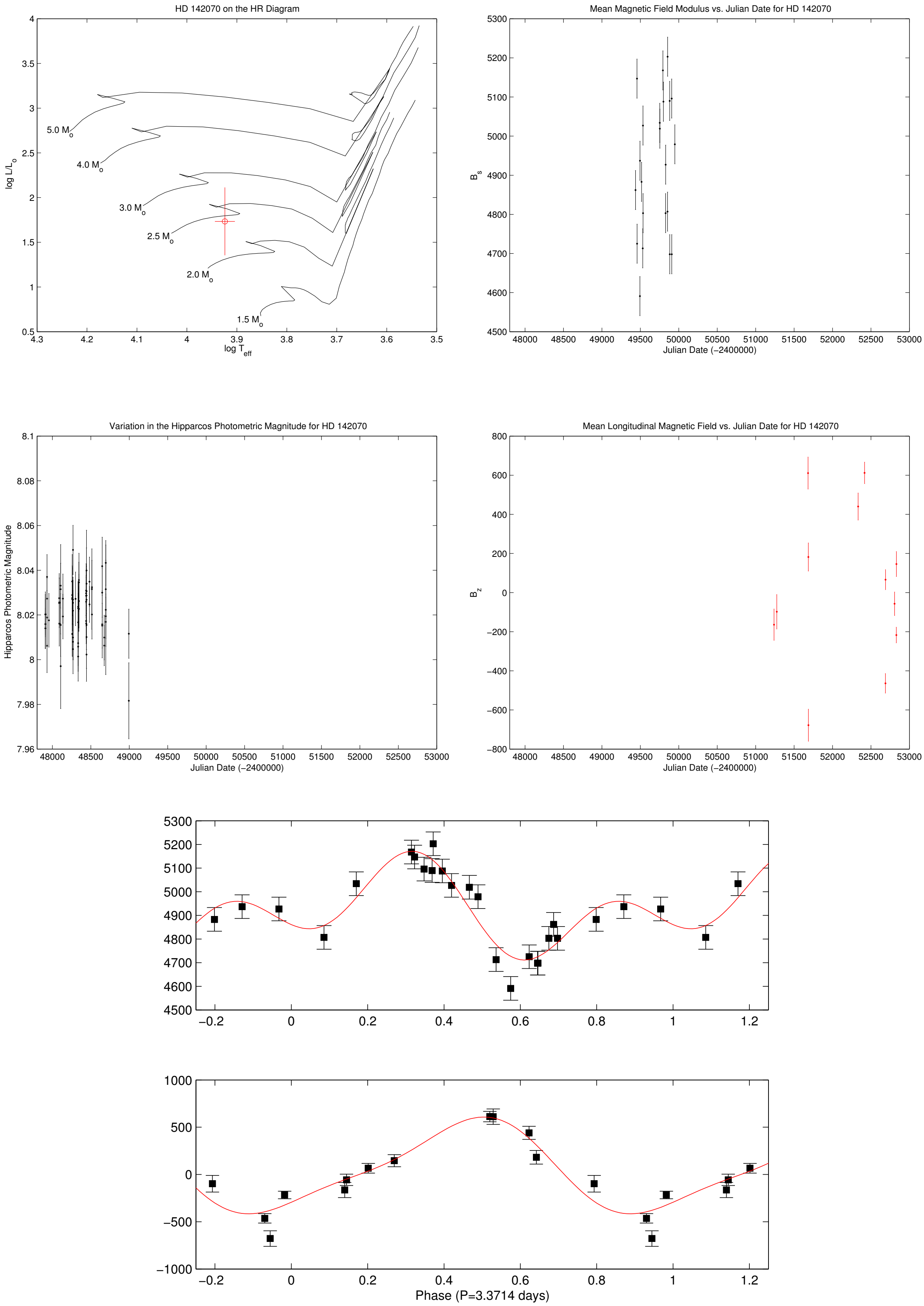

Figure 3: *HD 142070.* Upper frame – *HR diagram position, and time variations of Hipparcos magnitude, mean field modulus (Mathys et al. 1997) and longitudinal field (this work).* Lower frame – *phased field modulus and longitudinal magnetic field measurements.*

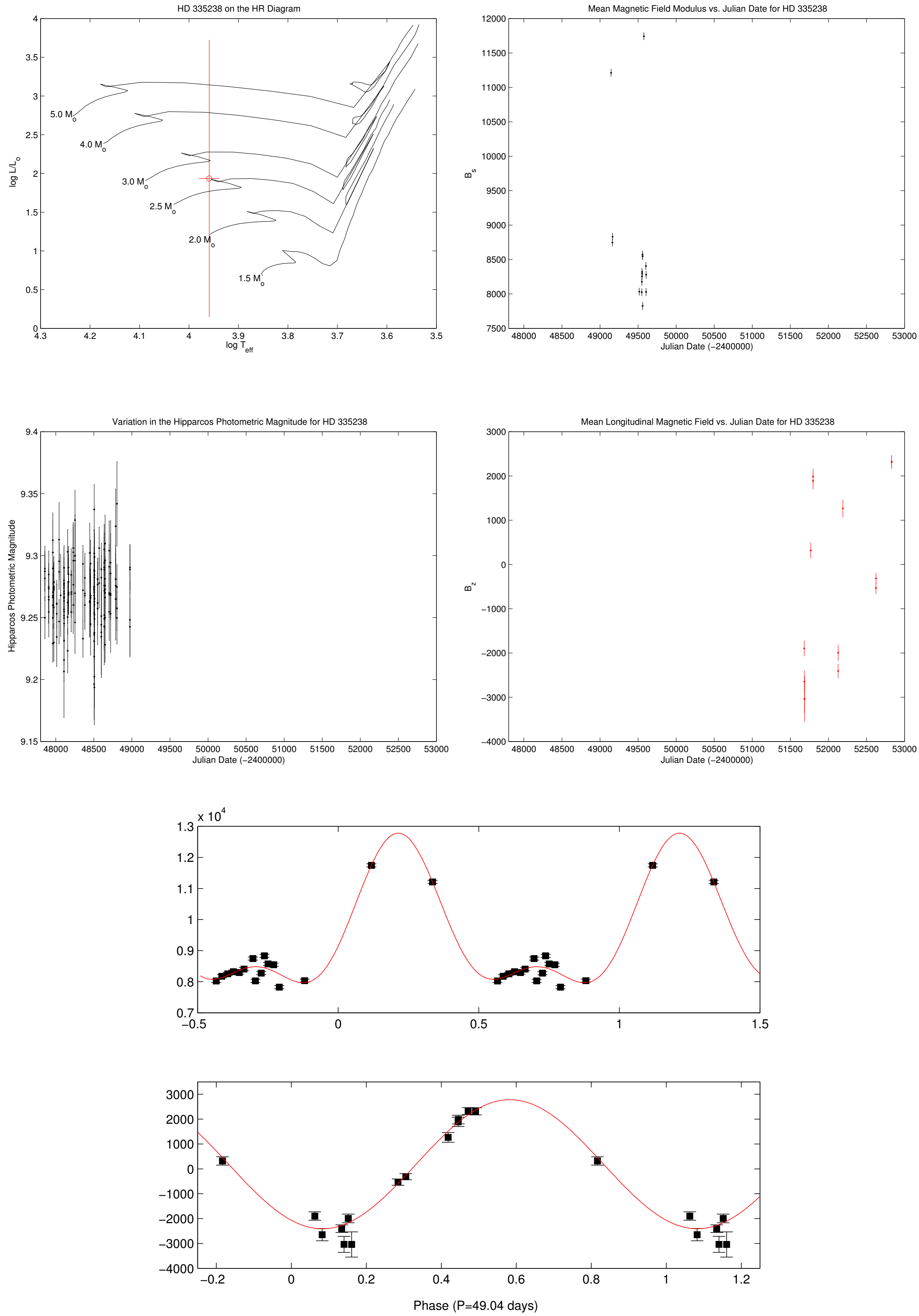

Figure 4: *HD 335238*. Upper frame – *HR diagram position, and time variations of Hipparcos magnitude, mean field modulus (Mathys et al. 1997) and longitudinal field (this work)*. Lower frame – *phased field modulus and longitudinal magnetic field measurements.*

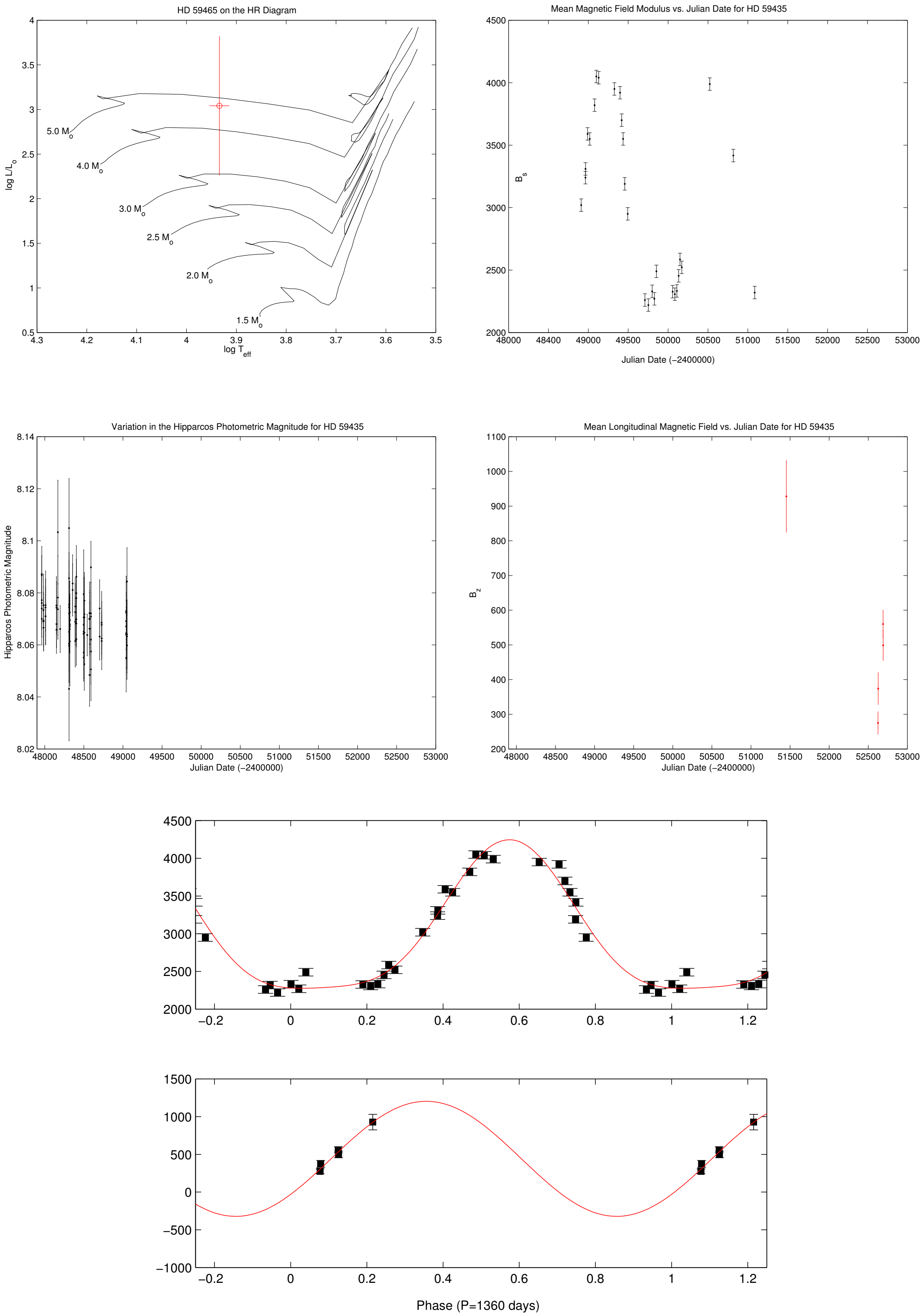

Figure 5: *HD 59435.* Upper frame – *HR diagram position, and time variations of Hipparcos magnitude, mean field modulus (Mathys et al. 1997) and longitudinal field (this work).* Lower frame – *phased field modulus and longitudinal magnetic field measurements.*