Magnetic fields and chemical peculiarities of the very young intermediate-mass binary system HD 72106

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ABSTRACT

The recently discovered magnetic Herbig Ae and Be stars may provide qualitatively new information about the formation and evolution of magnetic Ap and Bp stars. We have performed a detailed investigation of one particularly interesting binary system with a Herbig Ae secondary and a late B-type primary possessing a strong, globally ordered magnetic field. Twenty high-resolution Stokes $V$ spectra of the system were obtained with the ESPaDOnS instrument mounted on the CFHT. In these observations we see clear evidence for a magnetic field in the primary, but no evidence for a magnetic field in the secondary. A detailed abundance analysis was performed for both stars, revealing strong chemical peculiarities in the primary and normal chemical abundances in the secondary. The primary is strongly overabundant in Si, Cr, and other iron-peak elements, as well as Nd, and underabundant in He. The primary therefore appears to be a very young Bp star. In this context, line profile variations of the primary suggest non-uniform lateral distributions of surface abundances. Interpreting the 0.63995 ± 0.00009 day variation period of the Stokes $I$ and $V$ profiles as the rotational period of the star, we have modeled the magnetic field geometry and the surface abundance distributions of Si, Ti, Cr and Fe using Magnetic Doppler Imaging. We derive a dipolar geometry of the surface magnetic field, with a polar strength $B_d = 1230$ G and an obliquity $\beta = 57^\circ$. The distributions Ti, Cr and Fe are all qualitatively similar, with an elongated patch of enhanced abundance situated near the positive magnetic pole. The Si distribution is somewhat different, and its relationship to the magnetic field geometry less clear.

Key words: stars: magnetic fields, stars: abundances, stars: chemically peculiar, stars: evolution, stars: individual: HD 72106

1 INTRODUCTION

Strong, globally organised magnetic fields have recently been reported in a few Herbig Ae and Be (HAeBe) stars (Donati et al. 1997, Hubrig et al. 2004, Wade et al. 2005, 2007, Catala et al. 2007, Alecian et al. 2008). HAeBe stars are pre-main sequence stars of intermediate-mass which evolve to become main sequence A and B stars. HAeBe stars have A or B spectral classes, display emission lines and infrared excesses, and are usually found with nebulosity nearby (Vieira et al. 2003). The detection of magnetic fields in HAeBe stars is of particular interest as it hints at a connection to the main sequence magnetic, chemically peculiar Ap and Bp stars.

Ap and Bp stars display strong magnetic fields, with typical strengths of a few hundred gauss up to a few tens of
kilogauss, and globally ordered geometries of approximately dipolar topology. These stars also display strong and distinctive chemical peculiarities, particularly overabundances of Si and iron peak elements, occasionally in excess of 2 dex, and even greater overabundances of some rare earth elements.

The source of the magnetic fields observed in Ap/Bp stars is not well understood. The two major competing field origin theories propose, on the one hand, that the field is a relic of an earlier stage of stellar evolution, now frozen into the plasma of the star or, on the other hand, that the field is generated contemporaneously by a dynamo. Also unknown are the details of the formation of the observed chemical peculiarities. Chemical peculiarities are believed to be the result of atomic diffusion leading to a chemically stratified stellar envelope (Michaud 1970; Michaud et al. 1981). However, the details of this process, particularly for individual elements, and the impact of magnetic fields are not fully understood (e.g. Alecian & Stift 2007). In this context it is of great interest to identify and characterize the evolutionary progenitors of Ap/Bp stars, as these objects can provide critical information on both the origin of magnetic fields and the formation of chemical peculiarities.

The recently discovered magnetic HAeBe stars have been proposed to be pre-main sequence progenitors of Ap/Bp stars (Wade et al. 2003). Thus a detailed investigation of these stars can shed light on these questions, as well as potentially provide some information about magnetic braking and magnetospheric accretion in intermediate-mass stars.

2 HD 72106

HD 72106 is a double star system in the constellation Vela, with a 0.805 arcsec separation between components (ESA 1997). The brighter star, HD 72106A (‘the primary’), was identified as a magnetic star by Wade et al. (2007), while the fainter star, HD 72106B (‘the secondary’), was identified as a HAeBe star by Vieira et al. (2003). The HD 72106 system was observed by Hipparcos (ESA 1997), and included in the recent re-reduction of Hipparcos data by van Leeuwen (2007a,b) who found a parallax of 3.60 ± 1.14 mas, placing the system at a heliocentric distance of 278 ± 67 pc. The system was identified as having an infrared excess, based on IRAS (the Infrared Astronomical Satellite) data, by Oudmaijer et al. (1992). Torres et al. (1995) observed HD 72106 and noted the presence of emission in the Hα Balmer line of the combined spectrum of the system. Schötz et al. (2003) obtained infrared spectroscopy of HD 72106 system and examined circumstellar abundances of a number of dust grain species. Vieira et al. (2003) associated the system with the Gum Nebula star forming region. They observed weak Hα emission and a small contribution from dust in the spectral energy distribution of HD 72106B. This, they hypothesized, was due to HD 72106B being an evolved HAeBe star that has cleared most of its circumstellar envelope.

The discovery of a magnetic field in in HD 72106A by Wade et al. (2005) was based on spectropolarimetry from FORS1 (FOcal Reducer/l ow dispersion Spectrograph) at the Very Large Telescope and from ESPaDOnS (Echelle SpectroPolarimetric Device for the Observation of Stars) at the Canada France Hawaii Telescope. A longitudinal field of 195 ± 40 G (i.e. 4.9σ) was deduced from the FORS1 spectrum. No significant magnetic field was detected in the secondary (65 ± 55 G was observed). Although the average longitudinal field in the ESPaDOnS spectrum of the primary was consistent with zero, a clear circular polarization signature was detected with a very high degree of significance, unambiguously indicating the presence of a surface magnetic field.

A more conservative re-analysis of the same FORS1 data by Wade et al. (2007) did not confirm the longitudinal magnetic field detection at 3σ confidence. Wade et al. (2007) reported longitudinal fields in HD 72106A of 166 ± 70 G from Balmer lines and −11 ± 91 G from metallic lines, and fields in HD 72106B of 52 ± 90 G from Balmer lines and 3 ± 122 G from metallic lines. However they stressed that ESPaDOnS observations show a clear circular polarization signal, implying that HD 72106A is definitely magnetic.

Due to its young age, probable binarity, and magnetic properties, the HD 72106 system is a compelling target for further study. While other binary systems containing a magnetic intermediate-mass star are known, the apparently very young age and wide visual separation of HD 72106 make this system uniquely interesting. We therefore obtained 20 high-resolution spectropolarimetric (Stokes I and V) observations of the system, with the aim of studying the system’s binarity, rotational properties, magnetic field, chemical abundances, and surface abundance distributions.

3 OBSERVATIONS

Observations used in this paper were obtained with the ESPaDOnS instrument on the 3.6 m Canada-France-Hawaii Telescope (CFHT). ESPaDOnS is a high resolution echelle spectropolarimeter, with a resolving power of about 65000 in spectropolarimetric mode, and nearly continuous wavelength coverage from 370 to 1050 nm. This instrument uses a fiber fed design, with a polarimeter module mounted at the Cassegrain focus of the CFHT and an echelle spectrograph located in the Coudé room.

Twenty Stokes I and V spectra were obtained over a period of two years, and are summarized in Table 1. “Normal” readout in spectropolarimetric mode was used, and the atmospheric dispersion corrector was employed for all observations. Magnetic and non-magnetic standard stars were observed as part of this campaign, and produced results in excellent agreement with the literature.

With careful guiding and monitoring, observations of the individual components of HD 72106 were acquired on a few nights with particularly good seeing. This was challenging, however, as the double star system has a separation of only 0.805 arcsec and ESPaDOnS has a pinhole with a diameter of 1.6 arcsec. On most nights the atmospheric conditions were not good enough for us to resolve the individual components of the double star system. In these cases the photocenter of the system was observed, providing combined spectra of the system.

1 See http://www.cfht.hawaii.edu/Instruments/Spectroscopy/Espadons/ for details.
The observations were reduced with Libre-ESpRIT (Donati et al. 1997, and in preparation). This is a near-automated dedicated data reduction package for ESPaDOnS, which performs a complete calibration and optimal spectrum extraction. Continuum normalization of the resulting unnormalized spectra was performed manually, first by computing a running average on each order of an observed spectrum, then selecting points in the continuum (i.e. maxima) of the smoothed order, and fitting a polynomial (typically of degree 4 or 5) through the selected points. The original observation was then divided by the polynomial to produce a normalized spectral order, and fitting a polynomial (typically of degree 4 or 5) through the selected points. The original observation was then divided by the polynomial to produce a normalized spectral order, and the process was repeated for each order in the echelle spectrum. Similarly, Stokes V spectra were normalized by the Stokes I continuum polynomial, producing a V/I spectrum.

4 SPECTRUM RECONSTRUCTION

4.1 Procedure

The two individual spectra of HD 72106A show strong metallic lines with significant variability. In the two observations of HD 72106B on its own we see no metallic absorption line variability, down to the level of the noise in our observations. However, we do see emission in two lines of HD 72106B: clear, variable, emission is present in Hα, and a small amount of emission in the O i 7771 Å triplet, as shown in Figure 1. Thus we confirm the spectroscopic properties of the secondary leading to its classification as a HAeBe star.

The emission in HD 72106B varies detectably from night to night. Stronger variations are observed on timescales of months to years. No detectable change is observed between observations obtained on the same night. A period analysis of the emission line variations yields no significant periodicity in Hα.

As a consequence of the ∼0.8 arcsec angular separation between the components of HD 72106, the majority of our spectra of HD 72106A & B are of the combined light from the system rather than light from the individual components. The analysis of observed spectra is much more tractable when one is dealing with light from only one object. Thus we attempted to reconstruct the spectrum of one star from the combined spectra of the system.

As the spectrum of the secondary does not appear to vary (outside of emission lines), we can subtract from it the combined spectra and reconstruct the spectrum of the variable primary. We begin by modeling the normalized flux $I_{\lambda,T}$ at any point in the combined spectrum according to:

$$I_{\lambda,T} = I_{\lambda,1} L_1 + I_{\lambda,2} L_2,$$

where $I_{\lambda,1}$ and $I_{\lambda,2}$ refer to the normalized flux spectrum of the primary and secondary respectively at wavelength $\lambda$, and $L_1$ and $L_2$ refer to the luminosity of the primary and secondary respectively. Thus the product $I_{\lambda,1} L_1$ gives the total flux of the primary. $I_{\lambda,T}$ and $L_T$ are the observed normalized flux spectrum of the system and the total luminosity of the system respectively. The total luminosity can be writ-

| UT Date   | HJD (-2 450 000) | Component (HD 72106) | Integration Time (s) | Peak S/N | $B_2$ (G) | LSD Detection |
|-----------|------------------|----------------------|----------------------|----------|----------|---------------|
| 22 Feb. 05| 3423.9248        | A&B                  | 2400                 | 201      | 228 ± 50 | D             |
| 09 Jan. 06| 3745.02967       | A&B                  | 2400                 | 219      | 345 ± 42 | D             |
| 11 Jan. 06| 3747.02034       | A&B                  | 3200                 | 143      | 261 ± 76 | MD            |
| 12 Jan. 06| 3747.99629       | A                    | 1200                 | 149      | -13 ± 44 | MD            |
| 12 Jan. 06| 3748.01496       | B                    | 1200                 | 76       | 2 ± 168  | N             |
| 11 Feb. 06| 3777.87860       | A&B                  | 2000                 | 238      | 231 ± 40 | D             |
| 11 Feb. 06| 3777.95149       | A&B                  | 2400                 | 253      | 124 ± 37 | D             |
| 12 Feb. 06| 3778.86172       | A&B                  | 2400                 | 282      | 282 ± 34 | D             |
| 13 Feb. 06| 3779.87202       | A&B                  | 2400                 | 184      | 170 ± 53 | D             |
| 13 Feb. 06| 3779.98127       | A&B                  | 2400                 | 128      | 157 ± 156| N             |
| 02 Mar. 07| 4161.77282       | A&B                  | 2400                 | 254      | 350 ± 36 | D             |
| 02 Mar. 07| 4161.80256       | A&B                  | 2400                 | 265      | 297 ± 34 | D             |
| 02 Mar. 07| 4161.90282       | A&B                  | 2400                 | 297      | 214 ± 30 | D             |
| 03 Mar. 07| 4162.85713       | A&B                  | 2400                 | 208      | 246 ± 44 | D             |
| 04 Mar. 07| 4163.85361       | A&B                  | 2400                 | 322      | 202 ± 27 | D             |
| 05 Mar. 07| 4164.84650       | B                    | 3200                 | 209      | -51 ± 55 | N             |
| 05 Mar. 07| 4164.88387       | A                    | 2400                 | 248      | 320 ± 23 | D             |
| 05 Mar. 07| 4164.90961       | A&B                  | 1600                 | 277      | 374 ± 32 | D             |
| 09 Mar. 07| 4168.85791       | A&B                  | 2400                 | 283      | 304 ± 33 | D             |
| 09 Mar. 07| 4168.90947       | A&B                  | 2400                 | 272      | 252 ± 34 | D             |
The magnitude ratio must approximately correspond to the wavelength dependence is not strong, and thus has been neglected. Nevertheless, the magnitudes used to calculate the luminosities at $\lambda = 5000 \, \text{Å}$, $T = 2000 \, \text{K}$ (see Section 5.2, or Wade et al. 2007) the wavelength ratio should also depend on wavelength, however since the two components differ in temperature by only $7\%$ (of the total observed flux) for the observation of the primary and $0.7$ arcsec for the secondary), we obtained a theoretical worst-case contamination of $6\%$ (of the 0.9 arcsec for the primary and 0.7 arcsec for the secondary), we obtained a theoretical worst-case contamination of $6\%$ (of the total observed flux) for the observation of the primary and $7\%$ (of the total observed flux) for the observation of the secondary. For contamination by a typical strong line (10%...
Using the procedure described in Section 4. A good match of the spectrum to the observation of the primary can be seen in the core (upper left) and wings (upper right) of Hβ. The reconstructed spectrum of HD 72106A (light gray/green) obtained B (dark gray/blue, 11 January 2006), and the corresponding red (black, 5 March 2007), a combined observation of HD 72106A & Figure 2. Determining whether the HD 72106 system is truly a binary is robust, and yields high-precision spectra of the primary. Thus we conclude that the spectrum reconstruction yields good agreement with observations of the secondary on its own. Thus we conclude that the spectrum reconstruction is robust, and yields high-precision spectra of the primary.

Figure 2. Comparison of an observation of just HD 72106A (black, 5 March 2007), a combined observation of HD 72106A & B (dark gray/blue, 11 January 2006), and the corresponding reconstructed spectrum of HD 72106A (light gray/green) obtained B (dark gray/blue, 11 January 2006), and the corresponding reconstructed spectrum to the observation of the primary can be seen in the core (upper left) and wings (upper right) of Hβ, as well as in weakly variable metallic lines (lower panel).

5 BINARITY AND EVOLUTIONARY STATE

5.1 Binarity

Determining whether the HD 72106 system is truly a binary or just an optical double star (i.e., an accidental conjunction of 2 stars at different distances along the line of sight) is critical. If the system is a coeval binary, this fact allows us to constrain the age of the primary much more accurately than would otherwise be possible. Additionally, it suggests that both components formed from approximately the same material, making HD 72106 an interesting system from the point of view of stellar magnetic and chemical evolution.

The system has a projected separation of 0.805 arcsec, and is thus fairly widely separated. Given the Hipparcos parallax of 3.60 ± 1.14 mas, this implies a minimum physical separation of 224 ± 71 AU.

The Hipparcos observations were solved as a binary system producing a “good quality” solution for the system. This implies that the stars have the same parallaxes and proper motions, at the precision of the Hipparcos observations. Hipparcos finds a large proper motion in right ascension of −6.41 ± 0.82 mas yr$^{-1}$ and in declination of 7.97 ± 1.23 mas yr$^{-1}$ (van Leeuwen 2007a). In the spectrum fitting procedure, described in Section 4 we included heliocentric radial velocities for each star as a free parameter. From this fitting, we found identical radial velocities of 22 ± 1 km s$^{-1}$ for both components. Thus it appears that the stars are at the same point in space and moving together in three dimensions, strongly suggesting that they are in fact physically associated.

Dr. Brian Mason at the United States Naval Observatory kindly provided a record of separation and position angle observations from the Washington Double Star Catalog (WDS), dating back to 1902 (private correspondence, Mason, 2008). These have been compiled from a number of sources in the literature, some of which are no longer readily accessible. These observations indicate no significant change in the separation of the components in 89.37 years, but show a clear and systematic increase in the position angle of the stars of ∼10.5°, illustrated in Figure 3. This relative motion was not noted by Wade et al. (2003), presumably because they examined only a subset of these observations. The change in position angle occurs at a rate of 0.117 ± 0.0075 yr$^{-1}$. In contrast, there is no trend in the set of separation measurements, with an average separation of 0.786 arcsec and a standard deviation of 0.074 arcsec. This kinematical behavior, together with the identical radial velocities and consistent parallaxes of the components, makes it high likely that the system is a true binary.

For the system to be a true binary it must be gravitationally bound. We have therefore verified that the observed

![Figure 3. Position angle measurements of the HD 72106, extracted from the WDS, together with their best fit line.](image-url)
properties are consistent with binarity. We assumed circular orbits, that the minimum possible separation is the true separation (224 ± 71 AU), and used the evolutionary masses derived in Section 3.3. These assumptions are necessary, as we cannot determine the true separation and orbit of the binary without much more accurate observations over a much longer period of time. In this geometry, the relative velocity of the stars is 4.1 ± 0.7 km s⁻¹ and the orbital period is 1600 ± 600 years. This relative velocity is larger than observed, implying that the orbital plane is not parallel to the line of sight, or that the stars’ physical separation is larger than we have assumed (which it almost certainly is). If the orbital plane of the stars is in the plane of the sky, the orbital period implies that an observed change in position angle of 0.219 ± 0.079° yr⁻¹ should be seen, which is roughly consistent with the WDS observed rate of change. Thus we conclude that a wide range of orbits are consistent with the observed radial velocities and position angle change. One example of an orbit that is consistent with all observations is a circular orbit with a semimajor axis of 350 AU (implying a period of 3200 years), with an inclination of the orbital plane to the line of sight of 44.5°, and a position angle of the orbital axis of 200°. In this scenario, the two components would both be crossing the line-of-sight at the current epoch, yielding zero relative radial velocity. The change in position angle would be 0.112° yr⁻¹ and a apparent separation would be 0.807 arcsec. In this example, in 800 years the components would achieve their maximum difference in relative radial velocity of 2.3 km/s, and their maximum apparent separation of 1.151 arcsec. Of course, there is no reason to prefer this particular solution over the many others that are consistent with observations.

When placed on the Hertzsprung-Russell (H-R) diagram, as discussed in Section 3.2, the stars are found to have positions that allow for a range of coeval solutions. Thus according to the H-R diagram positions, it is quite possible for the stars to have formed and evolved together, further supporting the binary hypothesis.

Thus we conclude that HD 72106 is very likely a true binary system. The stars are at the same position in space, moving in the same (three dimensional) direction at the same velocity, allow for a wide range of gravitationally bound orbits, and appear to be consistent with coeval evolution.

5.2 Fundamental Physical Properties

Effective temperature and surface gravity for both components of HD 72106 were determined by fitting Balmer lines. Unfortunately, no intermediate-band photometry of the components of HD 72106 was available. The Hα Balmer line in HD 72106B is clearly contaminated with emission, and hence was not considered in this analysis. The other Balmer lines of both stars appear to be free of emission, and lines of each star can be well-fit with a single model atmosphere.

Wade et al. [2003] performed Balmer line fitting for both components of HD 72106 using observations from the FORS1. For the primary they found: $T_{\text{eff}} = 11000 ± 1000$ K and $3.5 \leq \log g \leq 4.5$, (best fit $T_{\text{eff}} = 11000$ K log $g = 4.0$). For the secondary they found $T_{\text{eff}} = 8000 ± 500$ and $4.0 \leq \log g \leq 4.5$, (best fit $T_{\text{eff}} = 8000$ K log $g = 4.5$).

We repeated the fitting procedure with the FORS1 spectra, using the method outlined above. Solar abundance ATLAS9 model atmospheres were used [Kurucz 1993] to produce the synthetic Balmer lines and the model lines were convolved with a Gaussian instrumental profile of appropriate width to match the observations. We arrived at results identical to Wade et al. [2003] for the primary. For the secondary we find the temperature range 7500 K to 9000 K and the log $g$ range 4.0 to 4.5 more realistic, with a best fit value of 8000 K at log $g = 4.5$. These values from the FORS1 observations are also consistent with those determined from Balmer line fitting of our ESPaDOnS spectra.

In Section 7 we performed detailed spectrum synthesis of both components of HD 72106 and found that the atmospheric parameters of the secondary derived from Balmer lines are not compatible with the metallic line spectrum. In particular, we were unable to simultaneously fit lines of Fe I and Fe II, Cr I and Cr II, and Ti I and Ti II, suggesting a problem with the local thermodynamic equilibrium (LTE) ionization balance of these species. Including $T_{\text{eff}}$ and log $g$ as free parameters in the spectrum fit allowed us to satisfactorily match the metallic line spectrum, provided that $T_{\text{eff}} \sim 8750$ K and log $g \sim 4.0$. While these values produce a somewhat poorer fit to the Balmer lines, the fit to metallic lines is improved substantially. Hence we conclude that the higher temperature and lower log $g$ provide a better description of the atmosphere of HD 72106B.

Including the full range of $T_{\text{eff}}$ and log $g$ which provide acceptable fits to both the metallic line spectra and the Balmer lines of HD 72106B, we adopt $T_{\text{eff}} = 8750 ± 500$ K and log $g = 4.0 ± 0.5$.

Using the Hipparcos parallax of the HD 72106 system and the Tycho magnitudes [Fabricius & Makarov, 2000] we determined the luminosities of both components of HD 72106. To convert the observed Tycho V magnitudes ($V_T = 9.00 ± 0.01$ for the primary and $V_T = 9.62 ± 0.02$ for the secondary) into a Johnson V magnitudes ($V$) we used the empirical relation [ESA, 1997]:

$$V = V_T + 0.09(B_T - V_T),$$

(3)

where $B_T$ is the Tycho B magnitude. For the secondary, the bolometric correction for main sequence stars from Gray [2004] was used, yielding a value of 0.01 ± 0.06 mag. For the primary, the bolometric correction relation of Landstreet et al. [2007] was used, yielding a value of −0.37 ± 1.9 mag. This calibration is tailored specifically for magnetic chemically peculiar A and B type (Ap and Bp) stars. As will be shown, the primary has properties very similar to those of a Bp star, thus the calibration of Landstreet et al. [2007] is more appropriate. From this procedure we find that the luminosity of the primary is $22.2^{+0.5}_{-0.2}$ $L_\odot$, and the luminosity of the secondary is $9.2^{+0.4}_{-0.2}$ $L_\odot$. From the Stefan-Boltzmann equation we find identical radii, given our uncertainty, of $1.3 ± 0.5 R_\odot$ for the primary and $1.3 ± 0.5 R_\odot$ for the secondary (with 1σ error bars).

With the luminosity and effective temperature determined, we can place the stars on the H-R diagram, as shown in Figure 4 and compare their positions with theoretical evolutionary tracks and isochrones. Using the pre-main sequence evolutionary model calculations from CESAM (version 2K; Morel [1997]) and the birthline of Palla & Stahler [1993], we find the mass of the primary to be $2.4 ± 0.3 M_\odot$.
and mass of the secondary to be $1.9 \pm 0.2 M_\odot$ (with 1σ error bars). From this we derive an evolutionary log $g$ of 4.6 ± 0.3 for the primary, and 4.5 ± 0.3 for the secondary, both of which are consistent with (although systematically higher than) the spectroscopic values. We determine the binary’s age to be between 6 and 13 Myr (measured from the birth line), based on the position of the secondary in the H-R diagram and assuming a protostellar accretion rate of $10^{-5} M_\odot$ yr$^{-1}$. In doing this we have assumed, as most investigators do, that the presence of circumstellar material implies that the HAeBe secondary is on the pre-main sequence, and thus that we can constrain its age with pre-main sequence evolutionary tracks. Given the derived admissible range of age and mass, the primary could still be on the pre-main sequence, reaching the zero-age main sequence (ZAMS) in less than 1 Myr. The most likely case (from ‘best fit’ positions) is that the system is $\sim$10 Myr old, and the primary has just entered the main sequence, while the secondary is on its final approach to the ZAMS. In this case the primary would have spent $\sim$6 Myr on the main sequence, giving it a fractional age on the main sequence ($\tau$) of 0.01. In the oldest limiting case, the secondary is just reaching the ZAMS and the primary has been on the main sequence for $\sim$9 Myr giving it a fractional age of 0.015. Further observations, particularly a more accurate distance measurement, are necessary to more precisely determine the evolutionary status of the primary. Regardless, while HD 72106A may not be on the pre-main sequence, it is certainly one of the youngest known main sequence stars of its type.

The physical properties we derive for both stars are summarized in Table 2. It is worth noting that, while the absolute luminosities of the components are poorly determined, their ratio ($L_A/L_B = 2.3 \pm 0.4$) is very well determined. This is because the major uncertainty in the absolute luminosity is the distance to the stars, and the stars are located at the same distance. Thus the values of the radii or masses derived for the two stars are not independent, since spacing between the components in log $L$ on the H-R diagram must remain fixed.

### 6 LEAST SQUARES DECONVOLUTION AND STELLAR ROTATION

#### 6.1 LSD and Longitudinal Magnetic Field

In order to measure the magnetic fields of HD 72106A & B, we employed Least Squares Deconvolution (LSD; Donati et al. 1997). This cross correlation technique uses a table of input atomic data (the line mask) to produce a deconvolved mean line profile from an observed spectrum. Using a large number of lines, $\sim$7000 for our spectra, can result in dramatic improvements in S/N. LSD was performed on all our observations of the individual components of HD 72106, as well as the reconstructed spectra of HD 72106A. The full set of LSD profiles in Stokes $I$ and $V$ for HD 72106A, calculated using specific elements, are presented in Section 3 in Figure 10.

The line mask used for the primary was calculated assuming an effective temperature of 11000 K, log $g$ of 4.0, typical Ap star abundances, and a line depth cutoff of 0.1 (as a fraction of the continuum). This produced LSD profiles with a mean wavelength of 523.4 nm, a mean Landé factor of 1.27, and a mean excitation potential of 5.97 eV, with small variations between observations. These mean values represent the average values of the lines used in the computation of the LSD profile, weighted by the S/N of the lines. The computed LSD profiles are relatively insensitive to variations or errors in the line mask in temperature or abundance (e.g. Shorlin et al. 2002). For the secondary, a $T_{\text{eff}} = 8750$ K, log $g$ = 4.0 line mask was used with solar abundances and a line depth cutoff of 0.1. With this mask we found a mean wavelength of 533 nm, a mean Landé factor of 1.21, and a mean excitation potential of 3.99 eV.

The longitudinal magnetic field was then measured from each set of LSD profiles, using Eq. (1) of Wade et al. (2000). Integration was performed through the portion of the line profile that exceeded 15% of the total line depth, with an additional 5 km s$^{-1}$ on either end. The longitudinal field data are presented in Table 4. We find a maximum longitudinal field for HD 72106A of $374 \pm 32$ G.
In the secondary, in contrast, we detect no longitudinal field, with error bars of 50–150 G. Moreover, the LSD profiles of HD 72106B yield no evidence of a magnetic field. The analysis of HD 72106B by Wade et al. (2005), discussed in Section 2, found no magnetic field in either the Balmer lines or metallic lines with error bars of ∼ 100 G. Thus we conclude that if the secondary has a magnetic field, its longitudinal component never exceeds ∼ 200 G.

### 6.2 Rotation Period of HD 72106A

Variability in the spectrum of HD 72106A was noted by Wade et al. (2003). A careful reexamination of their data shows that most of their reported spectrum variability was due to the lack of atmospheric dispersion correction during the acquisition of one of their spectra. However, we do see substantial metal line variability in all of our spectra of the primary, with a variation timescale on the order of a day. We do not confirm the rotational period of approximately 2 years, and the period consistent with the star’s rotational period derived for variability physically consistent with rotation. For a physically sensible rotational variation, features must move smoothly across the profile from blue to red, and there must not be large changes in the profile with small changes in phase. Upon careful examination, the period of 0.63995 days was the only period to produce a physically sensible phasing of the $I$ and $V$ profiles. Thus we adopt the rotational ephemeris (with maximum longitudinal field at zero phase) for HD 72106A:

$$HJD = (2453747.017 ± 0.013) + (0.63995 ± 0.00009) \cdot E.$$

The LSD profiles phased according to this ephemeris are shown in Figure 10. This period is notable in that it is one of the shortest rotation periods seen in any magnetic intermediate-mass star.

### 7 SPECTRUM SYNTHESIS

The ZEEMAN2 spectrum synthesis code was used to model the observed spectra of HD 72106A & B. This code solves the polarized radiative transfer equations in local thermodynamic equilibrium. In order to find the best fit model of the observed spectrum, a Levenberg-Marquardt $\chi^2$ minimization routine was implemented. This routine consistently produced high quality, stable solutions with good efficiency. The results were, in all cases, carefully examined by eye to verify that they represented both a physical solution and the best fit model, rather than a local minimum in $\chi^2$.

Chemical abundances (in the form $[X/Fe]$), assuming $N_{B}/N_{\odot} = 0.098$, were determined for variability physically consistent with rotation. For a physically sensible rotational variation, elements must move smoothly across the profile from blue to red, and there must not be large changes in the profile with small changes in phase. Upon careful examination, the period of 0.63995 days was the only period to produce a physically sensible phasing of the $I$ and $V$ profiles. Thus we adopt the rotational ephemeris (with maximum longitudinal field at zero phase) for HD 72106A:

$$HJD = (2453747.017 ± 0.013) + (0.63995 ± 0.00009) \cdot E.$$

The LSD profiles phased according to this ephemeris are shown in Figure 10. This period is notable in that it is one of the shortest rotation periods seen in any magnetic intermediate-mass star.
Figure 6. Periodograms for HD 72106A based on longitudinal field measurements (left panel) and LSD profile variability (right panel) in Stokes I and V. A few minima in each periodogram fall below the 99% confidence limit (horizontal line), however the deepest minimum is at 0.64 days in all cases.

since there is not much change in equivalent widths between spectra, the observation of HD 72106A used is approximately representative of the global average for all elements, even those with patchy distributions.

Microturbulence is not expected in the primary, due to its strong magnetic field. By analogy to Ap/Bp stars, the magnetic field would likely suppress microturbulence, thus microturbulence was fixed at 0 km s\(^{-1}\) for HD 72106A. This did not produce any detectable discrepancies between our model and observed spectra. For the primary we adopted the magnetic field model derived from the Stokes V LSD profiles in Section 5.2, this model provided a poor fit to the observed stellar spectrum, and hence \(T_{\text{eff}}\) and \(\log g\) were included as free parameters in our fit. Chemical abundances, \(v \sin i\), and microturbulence were also included as free parameters in the fit, while the magnetic field was set to zero. From this procedure we found a best fit \(T_{\text{eff}}\) of 8750 ± 500 K and \(\log g = 4.0 ± 0.5\). Sample best fit synthetic spectra can be seen in Figure 7 compared with the observed spectrum used in the fitting process we found a best fit procedure we found a best fit abundances and \(v \sin i\), with uncertainties, are given in Table 3. The abundances are presented graphically, relative to solar abundances, in Figure 8.

Remarkably strong overabundances of Si, Cr, Fe and Nd are found in HD 72106A. The Si and Fe abundances appear to be above solar by \(\sim 1\) dex, and Cr appears to be enhanced by \(\sim 2\) dex, whereas He appears to be \(\sim 1.5\) dex underabundant. A number of elements, such as Al, Sc and Sr appear to have solar abundances. A couple of elements, particularly Mg and O, hint at possible peculiarity but require further study before concrete conclusions can be drawn. We find \(v \sin i = 41.0 \pm 0.7 \text{ km s}^{-1}\), which is fairly low for a main sequence B star, but within the normal range for Bp stars. The strong overabundances in Si, Cr, Fe, and Nd, as well as the underabundance in He, are common features of cooler Bp stars (Jaschek & Jaschek 1993).

### 7.2 Abundances in HD 72106B

HD 72106B was initially modeled with an effective temperature of 8000 K and \(\log g = 4.5\). However, as discussed in Section 5.2, this model provided a poor fit to the observed stellar spectrum, and hence \(T_{\text{eff}}\) and \(\log g\) were included as free parameters in our fit. Chemical abundances, \(v \sin i\) and microturbulence were also included as free parameters in the fit, while the magnetic field was set to zero. From this procedure we found a best fit \(T_{\text{eff}}\) of 8750 ± 500 K and \(\log g = 4.0 ± 0.5\). Sample best fit synthetic spectra can be seen in Figure 8 compared with the observed spectrum used in the fitting process. The average best fit abundances, \(v \sin i\), and microturbulence derived for HD 72106B are presented in Table 3 and the abundances are shown graphically relative to solar abundances in Figure 8.
Figure 7. Sample best fit synthetic spectra for HD 72106A (left panels) and HD 72106B (right panels) in two independently fit spectral windows. The observations of the individual stellar components from Mar. 5, 2007 are used for both stars. Major contributors to each line have been labeled, in order of importance. The smooth solid line is the best fit spectrum in this region, the dashed line is a spectrum computed with solar chemical abundances. Dots represent the observations.

The large majority of elements are consistent with solar abundances, within 2σ at most. A few elements appear to depart marginally from solar values, with a significance slightly greater than 2σ. C appears to be overabundant with ~2σ significance, whereas Sc is underabundant by ~3σ. Under abundances of Sc and Ca are characteristic of Am stars. However, since the Ca abundance is approximately normal in HD 72106B, and iron peak elements are not overabundant, HD 72106B is not an Am star. Thus, nearly all the elements are within 2σ of solar abundance, and no elements display the strong peculiarities seen in HD 72106A. This result is consistent with the approximately solar abundances seen in most HAeBe stars (Acke & Waelkens 2004). It is of possible importance that the best fit abundances are consistently below solar, albeit with small significance levels. However there remains a large uncertainty in our best fit temperature and log g. An increase in the adopted temperature by 250 K to 9000 K would systematically increase the best fit abundances by 0.1 dex or 0.2 dex, essentially eliminating this trend.

8 MAGNETIC DOPPLER IMAGING

The observed metallic line variability with rotation strongly suggests that there are horizontal chemical abundance inhomogeneities in the atmosphere of HD 72106A. In an effort to determine the structure of these inhomogeneities, as well as the magnetic field structure, we performed Magnetic Doppler Imaging (MDI) on HD 72106A. Doppler Imaging is a method for inverting a timeseries of variable line profiles at known rotational phases in order to reconstruct the surface distributions that give rise to the observed variations. In MDI, polarized line profiles are also included in the inversion, allowing for the reconstruction of a magnetic field through the Zeeman effect.

We used the MDI code INVERS10, developed by O. Kochukhov and N. Piskunov (Piskunov & Kochukhov 2002) for surface chemical abundance mapping and magnetic field reconstruction. This program performs accurate polarized LTE spectrum synthesis, using pre-calculated model stellar atmospheres. INVERS10 allows for simultaneous modeling of multiple chemical elements and multiple wavelength regions, and takes into account blended lines. Tikhonov regularization is used (Tikhonov 1963; Piskunov & Kochukhov 2002), to constrain abundance gradients in the surface map. While Tikhonov regularization can be applied to the magnetic field as well, we opted for multipolar regularization (Kochukhov et al. 2002), due to the lack of Stokes Q and U spectra and the relatively low S/N in the Stokes V spectra.

Figure 8. Abundances relative to solar for HD 72106A (circles) and HD 72106B (squares), averaged over all spectral windows modeled. The dashed line at 0 represents solar abundance, based on Grevesse et al. (2005). Points marked with an arrow indicate the value is an upper limit only. Strong departures from solar abundance can be seen for HD 72106A, whereas HD 72106B has largely solar abundances.
Table 3. Averaged best fit chemical abundances, \( v \sin i \) and microturbulence (\( \xi \)) for HD 72106A and B as well as solar abundances from Grevesse et al. (2005). Entries marked by an * are based on only a few lines.

| Element | HD 72106A | HD 72106B | Solar |
|---------|-----------|-----------|-------|
| He      | -2.8 ± 0.2 * | -1.07 |       |
| C       | -3.40 ± 0.08 | -3.61 |       |
| O       | -3.0 ± 0.15 * | -3.34 |       |
| Mg      | -4.0 ± 0.3 | -4.60 ± 0.16 | -4.47 |
| Al      | -5.8 ± 0.2 * | -5.63 |       |
| Si      | -3.60 ± 0.14 | -4.7 ± 0.3 | -4.49 |
| Ca      | -5.1 ± 0.3 * | -6.0 ± 0.2 | -5.69 |
| Sc      | -8.6 ± 0.2 * | -9.13 ± 0.08 | -8.83 |
| Ti      | -6.04 ± 0.10 | -7.24 ± 0.09 | -7.10 |
| Cr      | -4.33 ± 0.13 | -6.32 ± 0.19 | -6.36 |
| Mn      | -6.7 ± 0.3 * | -6.61 |       |
| Fe      | -3.49 ± 0.07 | -4.64 ± 0.17 | -4.55 |
| Ni      | -6.3 ± 0.3 | -5.77 |       |
| Sr      | -8.7 ± 0.4 * | -9.2 ± 0.4 * | -9.08 |
| Y       | ≤ -8.5 * | -10.2 ± 0.4 * | -9.83 |
| Ba      | ≤ -9.0 * | -10.30 |       |
| Ce      | ≤ -9.2 * | -10.54 |       |
| Nd      | -7.5 ± 0.3 * | ≤ -9.2 * |       |

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Table 4. Mean atomic data for the element specific LSD profiles used in Magnetic Doppler Imaging.

| Element | Si | Ti | Cr | Fe |
|---------|----|----|----|----|
| mean wavelength (Å) | 5580 | 4970 | 5190 | 5310 |
| mean excitation (eV) | 7.68 | 2.03 | 5.65 | 6.46 |
| log mean \( g_f \) | -0.17 | -0.63 | -0.26 | -0.35 |
| mean Landé factor | 1.35 | 1.12 | 1.29 | 1.27 |

Input into the MDI model of HD 72106A included the adopted effective temperature and surface gravity from Section 5.2: \( T_{\text{eff}} = 11000 \) K and \( \log g = 4.0 \). The inclination angle of the star’s rotation axis to the line of sight (\( i \)) was calculated using the radius determined in Section 5.2. The rotation period from Section 6.2, and the \( v \sin i \) determined from spectrum fitting in Section 7.1, giving an angle of \( i = 24 \pm 10^\circ \). The phasing of observations was determined from the adopted ephemeris. An initial \( v \sin i \) of 41 km s\(^{-1}\) and abundances, for the treatment of blended lines, were taken from the results of our abundance analysis of HD 72106A, presented in Section 7.1. The initial magnetic field geometry was assumed to be a dipole.

Initially, five Si II lines at 4128 Å, 4130 Å, 5056 Å, 5041 Å, and 6371 Å were considered for Doppler Imaging. However, the S/N of the observations was insufficient to produce high quality Doppler maps for Si, as well as for all other elements.

In order to improve the S/N of our observations we calculated LSD profiles for individual chemical elements, and then performed MDI using those profiles. The use of LSD profiles to determine magnetic field geometries, stellar pulsation, and surface structure (Donati et al. 2006, 2001) is well established. LSD profiles of individual elements were obtained by creating LSD line masks containing only lines of the element of interest. The line masks used were derived from the 11000 K Ap star line mask discussed in Section 6. Doppler Imaging was then performed using the LSD profiles for each element as described above. The elements Si, Ti, Cr, and Fe were used in this process. Due to the low S/N in Stokes V for the purposes of MDI, even in the LSD profiles, the magnetic field geometry was determined from the higher S/N Cr and Fe profiles, and held fixed for the lower S/N Si and Ti profiles. Additionally, the multipolar magnetic field regularization was restricted to to \( l = 1 \) modes, effectively providing a ‘dipolar regularization’. Mean LSD profile atomic data were used for the Doppler Imaging process, providing wavelengths and excitation potentials, shown in Table 4. Since the depth of the LSD profile is a complex function of the lines used in the analysis, the mean \( g_f \) value may not represent a realistic oscillator strength for the LSD profile. As a consequence, the absolutely abundance scale of the Doppler images is somewhat uncertain.

The final abundance maps, and magnetic modulus and vector maps, are shown in Figure 9. The corresponding best fits to the LSD line profiles are presented in Figure 10. In this process we have assumed that the LSD profile behaves like a real spectral line, and that the mean atomic data is approximately representative of the LSD profile. Additionally, unaccounted for line blends in the LSD process could slightly distort the LSD profiles, adding some uncertainty to the finer details of the map, as well as the absolute abundance scale. Similarly, the use of LSD profiles to reconstruct the magnetic field geometry through MDI could potentially introduce some systematic uncertainty into the derived geometry. However, the magnetic geometry derived through MDI is fully consistent with the longitudinal magnetic field variability and nearly identical to that we derive by directly modeling the LSD Stokes V profiles with a simple dipole.

Strong inhomogeneities are reconstructed for all four elements. Ti, Cr, and Fe all seem to share similar abundance patterns, though Cr appears to have somewhat larger, more elongates spots. The similar distributions are reflected in the similar phase variations of the LSD profiles in Figure 10. A large patch of overabundance centered near phase 0 is apparent in all three maps, with another somewhat smaller overabundance spot about 180° away in longitude, at the same latitude, around phase 0.6. The Si map shares the larger spot but not the smaller, and this is reflected in the Si LSD profiles. There appears to be a large overabundance spot of Si at the equator (seen near the limb) near phase 0, although the sensitivity of the map is poor in that region due to its small projection. Note that the fits to the relatively noisy Si LSD profiles are somewhat poorer than the fits for the other elements analyzed, thus the results for Si are somewhat more uncertain. The magnetic field geometry derived, shown in Figure 9, is essentially described by a dipole with a strength at the magnetic pole (\( B_p \)) of 1230 ± 80 G, and an obliquity angle of the magnetic dipole with respect to the rotation axis (\( \beta \)) of 57° ± 5. This dipole magnetic field
Figure 9. Surface maps of Si, Ti, Cr, and Fe abundances, as well as the magnetic field, for HD 72106A. The maps are all based on fits to LSD profiles. The ‘X’ represents the rotational pole, the thick line circle indicates the rotational equator. The scale on the right in the abundance maps is in units of log $N_X/N_{tot}$. The map of the magnetic field intensity is labeled ‘a’ and the magnetic field direction is ‘b’ (shown as arrows).

geometry is in full agreement with the observed longitudinal magnetic field variability. If there are any departures from a purely dipolar field geometry, they are not evident in our data. When the magnetic field geometry is compared to the abundance maps, it appears that the positive magnetic pole lies near the large spot of overabundance at phase 0 in all four maps. However, the magnetic pole is offset from the center of the abundance spot, being nearer the rotational equator and at a slightly different latitude, thus the relationship is not entirely clear.

Interestingly, the pattern of abundances seen here for HD 72106A bear some similarities to those obtained for $\epsilon$ Ursae Majoris by Lueftinger et al. (2003). $\epsilon$ Ursae Majoris (HD 112185) is a 9000 K ($g = 3.6$) late main sequence Ap star with ~5 day period and a dipole field strength of several hundred gauss. Lueftinger et al. (2003) constructed Doppler maps of Ti, Cr and Fe, as well as Ca, Mg, Sr, and Mn. They found distributions of Cr and Fe very similar to each other, with two large spots of overabundance near the longitude of the magnetic poles. Ti was roughly anti-correlated with Fe and Cr, displaying two large spots of underabundance at the same positions as the overabundance spots of Cr and Fe. We see little variability in Ca, and have insufficient S/N in Ca, Mg, Sr, and Mn to construct Doppler maps for comparison with Lueftinger et al. (2003). The results for Fe and Cr are qualitatively very similar to what we see for HD 72106A, however the results for Ti differ significantly. The significance of these similarities and differences is unclear, as the evolution of chemical abundance spots over a star’s main sequence lifetime is not understood.

9 DISCUSSION AND CONCLUSIONS

We have analyzed 20 high resolution spectropolarimetric observations of the HD 72106 system. In these observations we see clear evidence for a magnetic field in HD 72106A. We also confirm that HD 72106B is a HAeBe star, based on emission
in Hα and the O i 7771 Å triplet, and that it displays no magnetic field.

There is strong evidence that the HD 72106 system is a true binary system. Both stars have the same proper motions, the same radial velocities, and Hipparcos solution to the system places both stars at the same distance. Although the separation of the components has remained constant in the past 90 years, there has been a slow systematic increase in the position angle observed. Additionally, there is a wide range of possible bound orbits consistent with all available observations.

We find the age of the system to be between 6 and 13 Myr, based on the H-R diagram position of the secondary (and assuming that, as a HAeBe star, the secondary is a pre-main sequence star). Thus the system is fairly evolved, for a pre-main sequence system. In the youngest limit, the primary would within 1 Myr of the ZAMS. However, in the oldest limit the primary would have reached the main sequence 9 Myr ago, but it would have only passed about 1.5% of its main sequence lifetime. Thus, while it may not be on the pre-main sequence, HD 72106A is certainly very young. While it is possible that the system is not coeval and instead was formed by capture, the data available (consistent H-R diagram positions and the young age of the secondary) suggests that the system truly coeval. Even with the large uncertainty in age, only a few known Ap/Bp stars approach the maximum fractional age of HD 72106A (Bagnulo et al. 2004; Landstreet et al. 2007). Given its evolutionary status, HD 72106A appears to represent a link between magnetic HAeBe stars and the Ap/Bp stars.

HD 72106A possesses a strong, predominantly dipolar, magnetic field. We find that a centered dipole with a po-

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Figure 10. Fits of synthetic Stokes I (for Si, Ti, Cr, and Fe) and Stokes V (for Cr and Fe) LSD profiles to observed LSD profiles. The profiles are labeled according to element, phase and mean wavelength. The bars near the bottom of the figure indicate the vertical and horizontal scale, 0.5% of the continuum and 0.5 Å respectively. Generally good fits can be seen, ranging from the high S/N Fe profiles at the best to the noisy Si profiles at the worst.
72106A to those of the magnetic HAeBe stars HD 104237 and HD 190073. HD 104237 was observed to possess a magnetic field by Donati et al. (1997) and confirmed by Donati (2000) and Alecian et al. (2008a), with a longitudinal field strength of \( \sim 50 \) G (Donati, private communication). HD 104237 has a mass of about \( 2.3 \, M_\odot \) and an age of about 2 Myr (van den Ancker et al. 1998). Acek & Waelkens (2004) performed an abundance analysis of HD 104237 using equivalent widths, and found approximately solar abundances for a range of elements, including Si, Cr, and Fe. The star HD 190073 was reported to possess a magnetic field by Catala et al. (2007), with a longitudinal field strength of \( 74 \pm 10 \) G. Catala et al. (2007) derive a mass of \( 2.85 \pm 0.25 \, M_\odot \) and an age of \( 1.2 \pm 0.6 \) Myr (measured from the birth line) for this star. Acek & Waelkens (2004) also studied the surface chemistry of this star and found roughly solar abundances.

Thus it appears that the majority of known magnetic HAeBe stars are chemically normal, though some peculiar stars seem to exist (such as NGC 6611 W601, Alecian et al. 2008a). This is in contrast to main sequence Ap/Bp stars, in which magnetic fields are nearly always found with chemical peculiarities. More analysis of chemical abundances in magnetic HAeBe stars must be performed, with an eye to identifying chemically peculiar objects. Interestingly, the young chemically peculiar stars HD 72106A and NGC 2244 334 display no emission, while HD 104237 and HD 190073 both display significant emission in their spectra. This suggests that HD 104237 and HD 190073 may still be undergoing significant accretion or mass loss while HD 72106A and NGC 2244 334 are not. Thus it may be that accretion or mass loss mixes the stellar atmosphere, inhibiting the build-up of chemical peculiarities through diffusion. However, once accretion halts chemical peculiarities may arise quickly.

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REFERENCES

Acek B., Waelkens C., 2004, A&A, 427, 1009
Alecian E., Catala C., Wade G. A., Donati J.-F., Petit P., Landstreet J. D., Böhm T., Bouret J.-C., Bagnulo S., Folsom C., Grunhut J., Silvester J., 2008a, MNRAS, 385, 391
Alecian E., Wade G. A., Catala C., Bagnulo S., Boehm T., Bohlender D., Bouret J.-C., Donati J.-F., Folsom C. P., Grunhut J., Landstreet J. D., 2008b, A&A, 481, L99
Alecian E., Wade G. A., Catala C., Folsom C., Grunhut J., Donati J.-F., Petit P., Bagnulo S., Marsden S. C., Ramirez J., Landstreet J. D., Boehm T., Bouret J.-C., Silvester J.,...
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2008c, in Proceedings of the CP#AP Workshop Vol. 38 of Contributions of the Astronomical Observatory Skalnate Pleso, Magnetism in pre-MS intermediate-mass stars and the fossil field hypothesis. pp 235–244

Alecian G., Stift M. J., 2007, A&A, 475, 659

Bagnulo S., Hensberge H., Landstreet J. D., Szeifert T., Wade G. A., 2004, A&A, 416, 1149

Carrier F., North P., Udry S., Babel J., 2002, A&A, 394, 151

Catala C., Alecian E., Donati J.-F., Wade G. A., Landstreet J. D., Böhm T., Bouret J.-C., Bagnulo S., Folsom C., Silvester J., 2007, A&A, 462, 293

Donati J.-F., 2000, Thèse d’habilitation, Observatoire Midi-Pyrénées

Donati J.-F., Mengel M., Carter B. D., Marsden S., Collier Cameron A., Wichmann R., 2000, MNRAS, 316, 699

Donati J.-F., Semel M., Carter B. D., Rees D. E., Collier Cameron A., 1997, MNRAS, 291, 658

Donati J.-F., Semel M., Rees D. E., 1992, A&A, 265, 669

Donati J.-F., Wade G. A., Babel J., Henrichs H. F., de Jong J. A., Harries T. J., 2001, MNRAS, 326, 1265

ESA, 1997, The Hipparcos and Tycho Catalogues, ESA SP-1200

Fabricius C., Makarov V. V., 2000, A&A, 356, 141

Gray D. F., 2005, The Observation and Analysis of Stellar Photospheres, 3rd edn. Cambridge University Press, Cambridge, UK

Grevesse N., Asplund M., Sauval A. J., 2005, in Alecian G., Richard O., Vauclair S., eds, Element Stratification in Stars: 40 Years of Atomic Diffusion Vol. 17 of EAS Pub. Ser., The New Solar Chemical Composition. p. 21

Hensberge H., Pavlovski K., Verschueren W., 2000, A&A, 358, 553

Hubrig S., Schöller M., Yudin R. V., 2004, A&A, 428, L1

Jaschek C., Jaschek M., 1995, The behavior of chemical elements in stars. Cambridge University Press, Cambridge

Kochukhov O., Piskunov N., 2002, A&A, 389, 868

Kochukhov O., Piskunov N., Ilyin I., Ilyina S., Tuominen I., 2002, A&A, 389, 420

Kupka F., Piskunov N., Ryabchikova T. A., Stempels H. C., Weiss W. W., 1999, A&AS, 138, 119

Kurucz R., 1993, CDROM Model Distribution, Smithsonian Astrophys. Obs.

Landstreet J. D., Bagnulo S., Andretta V., Fossati L., Mason E., Silaj J., Wade G. A., 2007, A&A, 470, 685

Lueftinger T., Kuschnig R., Piskunov N. E., Weiss W. W., 2003, A&A, 406, 1033

Michaud G., 1970, ApJ, 160, 641

Michaud G., Charland Y., Megessier C., 1981, A&A, 103, 244

Morel P., 1997, A&AS, 124, 597

Oudmaijer R. D., van der Veen W. E. C. J., Waters L. B. F. M., Trams N. R., Waellens C., Engelsman E., 1992, A&AS, 96, 625

Palla F., Stahler S. W., 1993, ApJ, 418, 414

Piskunov N., Kochukhov O., 2002, A&A, 381, 736

Press W. H., Teukolsky S. A., Vetterling W. T., Flannery B. P., 1992, Numerical Recipes in FORTRAN, 2nd edn. Cambridge University Press, Cambridge

Schütz O., Meeus G., Sterzik M. F., 2005, A&A, 431, 165

Shorlin S. L. S., Wade G. A., Donati J.-F., Landstreet J. D., Petit P., Sigut T. A. A., Strasser S., 2002, A&A, 392, 637

Stibbs D. W. N., 1950, MNRAS, 110, 395

Tikhonov A. N., 1963, Soviet Math. Dokl., 4, 1624

Torres C. A. O., Quast G., de La Reza R., Gregorio-Hetem J., Lepine J. R. D., 1995, AJ, 109, 2146

van den Ancker M. E., de Winter D., Tjin A Djie H. R. E., 1998, A&A, 330, 145

van Leeuwen F., 2007a, Hipparcos, the New Reduction of the Raw Data. Springer

van Leeuwen F., 2007b, A&A, 474, 653

Vieira S. L. A., Corradi W. J. B., Alencar S. H. P., Mendes L. T. S., Torres C. A. O., Quast G. R., Guimarães M. M., da Silva L., 2003, AJ, 126, 2971

Wade G. A., Bagnulo S., Drouin D., Landstreet J. D., Monin D., 2007, MNRAS, 376, 1145

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

Wade G. A., Drouin D., Bagnulo S., Landstreet J. D., Mason E., Silvester J., Alecian E., Böhm T., Bouret J.-C., Catala C., Donati J.-F., 2005, A&A, 442, L31