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The photospheric magnetic field and coronal structure of HD 171488

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Abstract. From spectropolarimetric observations of the young, single early G-dwarf HD 171488, we have used Zeeman Doppler imaging to reconstruct brightness and magnetic maps of the star. The inclusion of a solar-like differential rotation law into the imaging process has enabled the measurement of the star's surface differential rotation from the brightness features. In addition, we have created a coronal structure for HD 171488 based on the surface magnetic field distribution.

Key words. Stars: activity – Stars: imaging – Stars: individual: HD 171488 – Stars: magnetic fields – Stars: spots – Stars: coronae

1. Introduction

The nature of X-ray emission from rapidly rotating solar-type stars is still not well understood. Observations show that for active stars X-ray emission increases with increasing rotation rate, until it reaches a maximum for rotation rates of about $v\sin i \sim 20$ km/s. Stars rotating more rapidly than this show no increase in X-ray emission. This is called "saturation".

The exact cause of X-ray saturation is unknown. There are a number of competing suggestions, such as saturation of the magnetic dynamo itself, complete coverage of the star in active regions, or the centrifugal stripping of the corona in rapid rotators (Jardine & Unruh 1999; Jardine 2004).

In this article we present a reconstruction of the coronal magnetic structure of a young early-G star (HD 171488) in the "saturation" regime based on an extrapolation of the surface magnetic field of the star. HD 171488 is a magnetically active star having been detected with the ROSAT EUV wide field camera (Pounds et al. 1993) with count rates indicating an active corona. This is the first early-G dwarf for which such coronal reconstruction has been done. In addition, the previously determined surface differential rotation measurement for the star is placed in context with other young solar-type stars.

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2. Photospheric magnetic field

HD 171488 is a young rapidly rotating early-G dwarf. The stellar parameters are given in Table 1. The photospheric magnetic field of the star was determined by Marsden et al. (2006) with the method briefly outlined below. HD 171488 was observed over a five-night period in September 2004 at the Anglo-Australian Telescope using the high resolution SEMPOL spectropolarimeter (Semel, Donati, & Rees 1993). The observations were taken in circularly polarised light.

The technique of Least-Squares Deconvolution (LSD, Donati et al. 1997) was then used to combine the signal in each of several thousand photospheric lines in each echelle spectrum into a single high S/N LSD profile. This was done for both the Stokes I and Stokes V data and resulted in a multiplex gain in S/N of ∼18 for the Stokes I data and ∼38 for the Stokes V data. Zeeman Doppler Imaging (ZDI, Donati et al. 1997) was then used to recreate photospheric brightness and magnetic field maps of HD 171488 from the Stokes I and Stokes V LSD profiles respectively. The resultant maps are shown in Figure 1 of Marsden et al. (2006).

3. Surface differential rotation

A solar-like differential rotation law was incorporated into the imaging process for the Stokes I data:

$$\Omega(l) = \Omega_{\rm eq} - d\Omega sin^2 l, \qquad (1)$$

where $\Omega(l)$ is the rotation rate at latitude l, $\Omega_{\rm eq}$ is the equatorial rotation rate, and $d\Omega$ is the shear between the equator and poles. Treating $\Omega_{\rm eq}$ and $d\Omega$ as free parameters (after, Petit, Donati, & Collier Cameron 2002) the following measurement for the surface differential rotation of HD 171488 was obtained: $\Omega_{\rm eq} = 4.786 \pm 0.013$ rad/d and $d\Omega = 0.402 \pm 0.044$ rad/d (from Marsden et al. (2006)).

This value of $d\Omega$ is over twice that of other early-G dwarfs observed using this method and is much higher than predicted by theory for early-G dwarfs (Kitchatinov & Rüdiger 1999). The value is significantly above that indicated by the differential rotation-temperature relationship of Barnes et al. (2005) and is similar to that seen on F stars (Marsden et al. 2007; Mengel et al. 2007; Reiners 2006). It appears that a "jump" in the differential rotation rate of active dwarf stars occurs around the early-G spectral type. This can be clearly seen in Fig. 1.

4. Coronal structure

Using the coronal X-ray modelling technique of Jardine et al. (2002) we have been able to reconstruct the coronal structure of HD 171488 from the ZDI image of the radial magnetic field. The technique extrapolates the coronal field from the surface map by using a potential field-source surface method which assumes that the magnetic field is forced open by the outward pressure of the coronal gas at the source surface radius (taken here as ∼3 stellar radii). The closed field line map and corresponding X-ray structure are given in Fig. 2.

The X-ray structure shows little emission from the lower latitude regions around phase 0.00 (due to poor observations at this phase), however, other phases show bright regions at lower latitudes that are eclipsed as the star rotates. This implies that HD 171488 should have rotationally modulated X-ray emission. Fuhrmeister & Schmitt (2003) found no period in HD 171488's ROSAT X-ray emission, how-

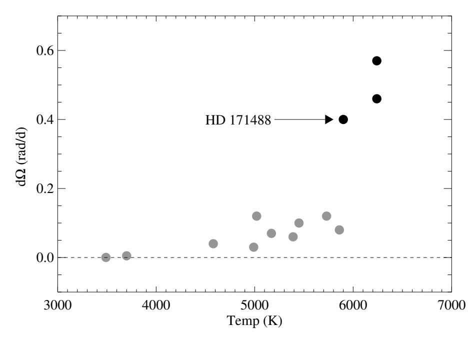

Fig. 1. Surface differential rotation vs. stellar temperature for active dwarf stars. Based on data from Barnes et al. (2005) and new observations (represented by darker symbols, (Marsden et al. 2006, 2007; Mengel et al. 2007)).

Table 1. Stellar parameters for HD 171488 (Marsden et al. 2006; Strassmeier et al. 2003).

Sp. Type	Age (Myr)	Mass ($M_\odot$)	Radius ($R_\odot$)	Equatorial Period (d)	$v\sin i$ (km/s)	Incl. angle, i
early G	30 – 50	1.06 ± 0.02	1.15 ± 0.08	1.313 ± 0.004	37.5 ± 0.5	60° ± 10°

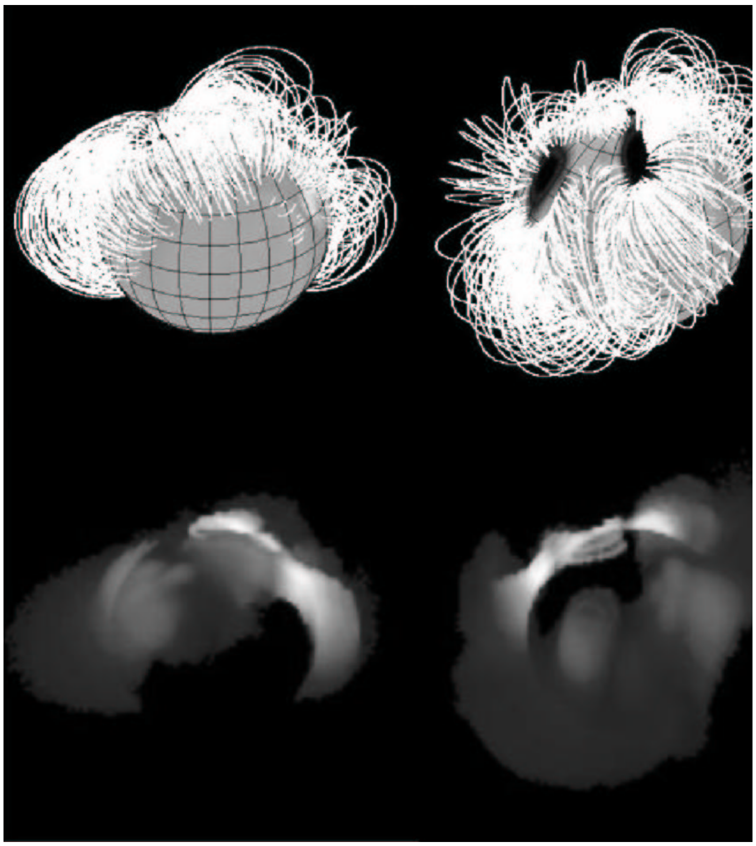

Fig. 2. Calculated coronal structure of HD 171488 based on the radial magnetic field map of Marsden et al. (2006). The images show HD 171488 at phases 0.00, 0.25, 0.50, and 0.75 (from left to right) with the top images showing the closed field lines (in white) that are capable of containing emitting gas and the bottom images showing the corresponding X-ray structure of the corona, created assuming a coronal temperature of $2\text{x}10^7$ K.

ever, as they conclude, it is difficult to find rotationally modulated X-ray emission in single stars, possibly due to their intrinsic variability.

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