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The Exceptional Herbig Ae star HD 101412

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Abstract. A few months ago we obtained multi–epoch polarimetric spectra of HD 101412 with the FORS2 to search for a rotation period and to constrain the geometry of the magnetic field. The search of the rotation period resulted in $P = 42.076 \pm 0.017$ d. Using stellar fundamental parameters and the longitudinal magnetic field phase curve, we discuss the magnetic field geometry. According to the near–infrared imaging studies, the star is observed nearly edge–on. The magnetic field geometry can likely be described by a centered dipole with a polar magnetic field strength $B_{\rm d}$ between 1.5 and 2 kG and an inclination β of the magnetic axis to the rotation axis of $84 \pm 13°$.

Key words: stars: pre–main–sequence – stars: atmospheres – stars: individual: HD 101412 – stars: magnetic fields – stars: rotation – stars: variables: general

1 Introduction

In our previous studies we reported detections at a level higher than 3σ for three out of seven Herbig Ae stars observed with the low–resolution spectropolarimeter FORS1 at the VLT (Hubrig et al., 2004, 2006, 2007). In our most recent spectropolarimetric study of 21 Herbig Ae/Be stars and six debris disk stars carried out two years ago, magnetic field detections were achieved in six Herbig Ae stars (Hubrig et al., 2009). The largest mean longitudinal magnetic field, $\langle B_{\rm z}\rangle = -454 \pm 42$ G was measured in the $\sim$2 Myr old Herbig Ae star HD 101412 = V1052 Cen (Fig. 1, left). It is quite possible that this star belongs to a visual binary system (Fig. 1, right). High–resolution spectra of this star reveal a strong increase of metal line intensity at some phases, and the presence of circumstellar disk lines of Fe I and Fe II (Fig. 2).

2 Rotation Period and Magnetic Field

In the UVES and HARPS spectra (Hubrig et al., 2010), a few lines appear resolved, indicating the presence of a rather strong surface magnetic field varying in the range from 2.5 to 3.5 kG (Fig. 3).

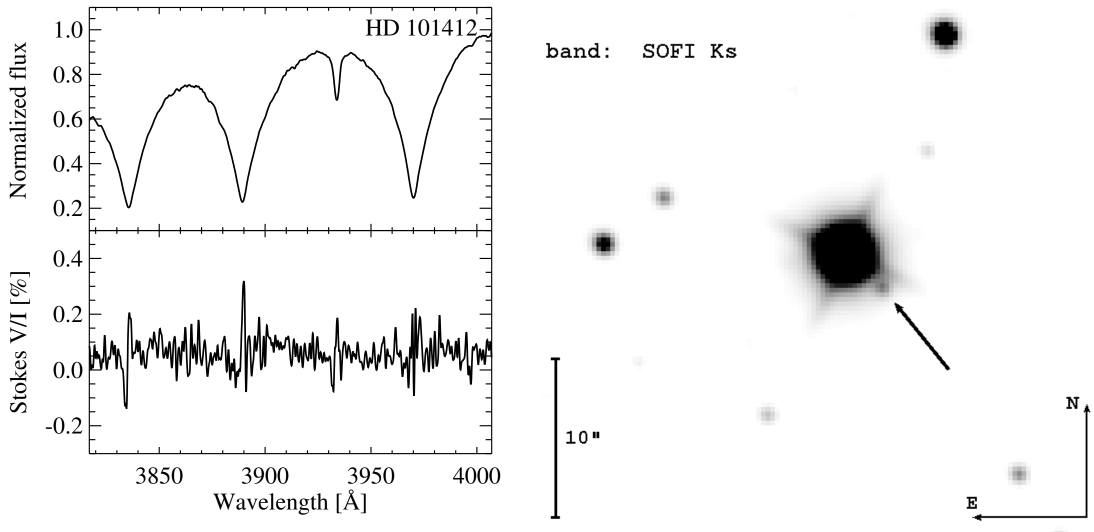

Figure 1: *Left:* FORS1 Stokes I and V spectra of the Herbig Ae star HD 101412, with clear Zeeman features in H_9, H_8, Ca II H&K, and Hϵ profiles. *Right:* SOFI Ks–band image of a potential faint companion to HD 101412. The spatial resolution is $0\farcs29$/pix and the separation amounts to $3\farcs3\pm0\farcs2$.

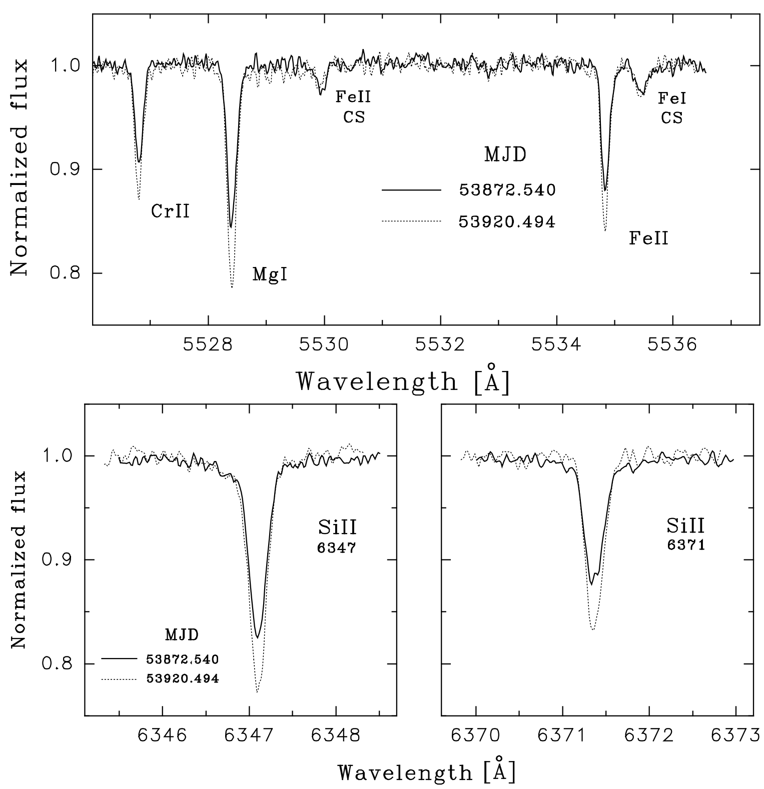

Figure 2: The UVES spectra of the Herbig Ae star HD 101412 in the spectral regions $\lambda\lambda$ 5526 – 5538 Å around the Cr II, Mg I, and Fe II lines *(upper)* and around two Si II lines at λ 6347 *(lower left)* and λ 6371 *(lower right)*. CS lines of Fe I and Fe II are clearly visible in the left spectrum. Note a strong increase of the line intensities at MJD 53920.494.

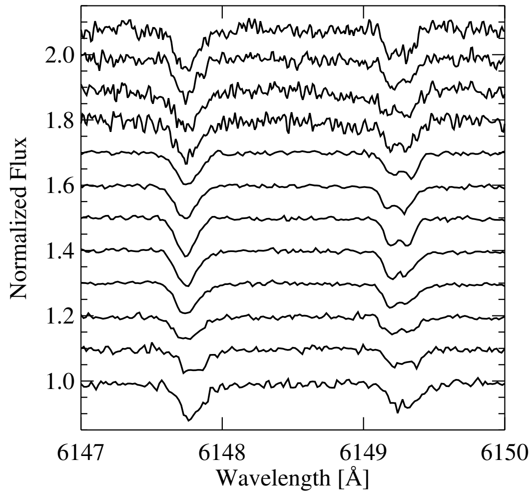

Figure 3: Line profile variations of the Zeeman doublet Fe II $\lambda\,6149.258$ in the UVES and HARPS spectra obtained at different epochs. The spectra are presented with dates increasing from bottom to top.

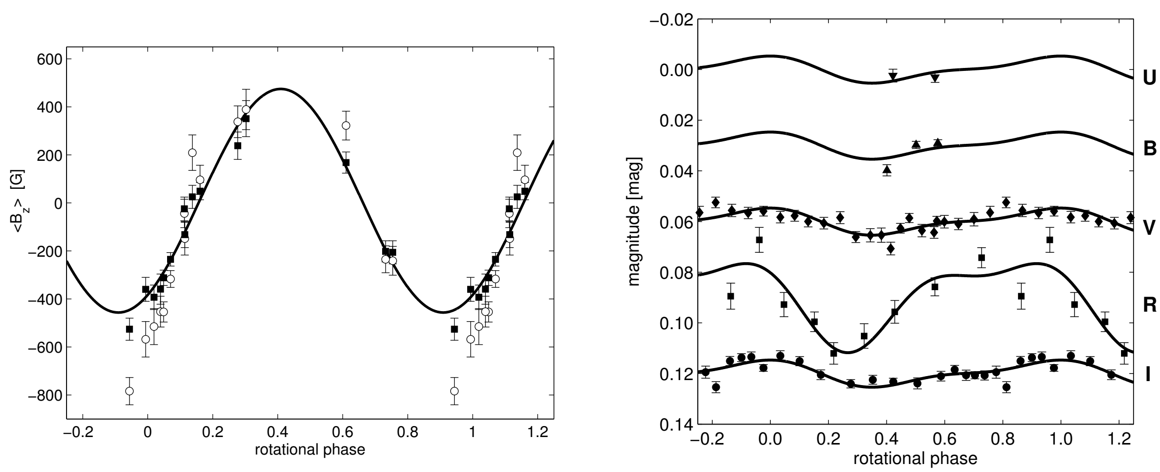

Figure 4: *Left:* Phase diagram with the best sinusoidal fit for the longitudinal magnetic field measurements using all lines (filled squares) and hydrogen lines (open circles). *Right:* $U\,B\,V\,R$, and I light curves of HD 101412. Solid lines present the simplest periodic functions representing the observed photometric variations. Due to a large scatter of individual measurements, the standard technique of normal points (as averages of several tens of phase–adjacent measurements) was used. The light curves are shifted along the y–axis for clarity.

Furthermore, a pronounced variability was detected in the spectral lines of He, Si, Mg, Ca, Ti, Cr, Fe, Sr, Y, and Zr. The character of variability is different for different elements, as it is usually observed for a horizontal inhomogeneous element distribution over the stellar surface in Ap stars. This is the first time the presence of element spots is detected on the surface of a Herbig Ae star. Thirteen new multi–epoch magnetic field measurements were obtained in the last months with the FORS2 (Hubrig et al., 2011). We used a frequency analysis technique to compute best–fit curves to determine the period of variations. The magnetic data were used simultaneously with photometric data that include 920 V and 539 I observations from the ASAS and 1426 R observations from the Pi of the Sky. The phase diagram for the magnetic data using a period of 42 days is presented in Fig. 4 (left). Photometric variations with the same period are shown in Fig. 4 (right). The behaviour of the light curve in the R–band is most asymmetrical, probably due to the fact that this band includes the variable Hα emission. Assuming an oblique rotator model and an inclination of the accretion disk around HD 101412 of $i = 80 \pm 7°$ (Fedele et al., 2008), we obtain an inclination of the magnetic dipole axis of $\beta = 84 \pm 13°$. The fact that the dipole axis is located close to the equatorial plane is very intriguing in view of the generally assumed magnetospheric scenario that magnetic fields channel the accretion flows towards the stellar surface along the magnetic field lines. As was shown by Romanova et al. (2003), the topology of channelled accretion critically depends on the tilt angle between the rotation and magnetic axes. For a large β many “polar” field lines thread the inner region of the disk, while the closed lines cross the path of the disk matter, causing a strong magnetic braking.

3 Summary

For the first time rotation–modulated longitudinal magnetic field measurements and photometric observations were used to determine the rotation period in a Herbig Ae star. The detection of a large–scale, organised, predominately dipolar magnetic field on the surface of the young Herbig Ae star HD 101412 confirms the scenario that the accretion phenomenon in young stellar objects consists in magnetospheric accretion. Due to the presence of a rather strong magnetic field in the atmosphere of HD 101412, and a very low $v \sin i$ value of 3 ± 1 km/s, this star is perhaps one of the most suitable targets to study its environment, including magnetosphere, accretion disk, and the disk wind, altogether producing prominent emission features in the hydrogen line profiles.

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