Measurements of magnetic fields in intermediate mass stars with disks

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Abstract

Contrary to the advance achieved in magnetic studies of T Tauri stars, not so much is known about magnetic fields in Herbig Ae stars. The major advantage of using low-resolution spectropolarimetry with FORS 1 at the VLT is that polarization can be detected in relatively fast rotating Herbig stars as we measure the field in the hydrogen lines. Our recent magnetic field observations demonstrated that magnetic fields in Herbig Ae stars should be rather weak, of the order of a few hundred Gauss and less. Here we report about additional measurements of the Herbig Ae star HD 139614, the δ Scuti variable Herbig Ae star HR 5999 (HD 144668) and of another PMS δ Scuti star: V351 Ori (HD 38238). Studies of pre-main sequence δ Scuti stars are of special interest as they allow to analyze the internal stellar structure and its evolution in the PMS phase. Such studies provide unprecedented constraints for further development of theoretical models of PMS stars. We also searched for a magnetic field in two Vega-like stars with an optically thin disk around them. Although many Vega-like stars are very young (less than 50 Myr) and some of the recently discovered properties clearly indicate that they could be magnetically active, the presence of magnetic fields in these stars is not yet convincingly tested observationally and theoretically. A detection of magnetic fields in Herbig Ae and Vega-like stars is especially important in view of our recent results that no magnetic Ap star of mass below $3M_{\odot}$ can be found in the vicinity of the zero-age main sequence.

Observations and data reduction

Using FORS 1 at the VLT in service mode during the last two years, new longitudinal field determinations have been obtained for approximately 50 Ap and Bp stars, including also normal stars, HgMn stars, He weak Si stars, PGa stars and Slowly Pulsating B (SPB) stars. In addition, we included in our sample a few Herbig Ae stars and Vega-like stars. As potential progenitors of the magnetic Ap stars, Herbig Ae and Vega-like stars provide an excellent opportunity to study the early evolution of magnetic fields in stars of similar mass. A detection of magnetic fields in these stars is especially important in view of our recent results that Ap magnetic stars of mass below $3\,M_{\odot}$ are significantly evolved and concentrated towards the centre of the main-sequence band, and practically no magnetic star of mass below $3\,M_{\odot}$ can be found close to the zero-age main sequence (Hubrig et al. 2000, ApJ 539, 352; Hubrig et al. 2005, Astronomical Polarimetry: Current Status and Future Directions, ASP, *in print*).

FORS 1 is a multi-mode instrument which is equipped with polarization analyzing optics comprising super-achromatic half-wave and quarter-wave phase retarder plates, and a Wollaston prism with a beam divergence of $22''$ in standard resolution mode. For the measurements of the PMS δ Scuti stars HR 5999 and V351 Ori carried out in the year 2004 we used the GRISM 600B in the wavelength range 3480–5890 Å to cover all hydrogen Balmer lines from H_β to the Balmer jump, and the narrowest available slit width of $0''.4$ to obtain a spectral resolving power of R$\sim$2000. For the most recent observations of the Herbig Ae star HD 139614 and the two Vega-like stars HD 109085 and HD 115892 in February 2005 we have used the new GRISM 1200g. With this grism we could cover the H Balmer lines from H_β to H_8 at a spectral resolution of R$\sim$4000. The major advantage of using low-resolution spectropolarimetry with FORS 1 is that polarization can be detected in relatively fast rotators as we measure the field in the hydrogen Balmer lines. The determination of the mean longitudinal fields using FORS 1 is described in detail in Hubrig et al. (2004, A&A 415, 661).

The basic data of the studied Herbig Ae stars are presented in Table 1. The first nine columns indicate, in order, the HD number of the star, another identifier, the visual magnitude, the spectral type, the stellar parameters, their sources and the modified Julian date of mid-observation. The last column lists our determination of the mean longitudinal magnetic field $\langle\mathcal{B}_z\rangle$. The mean longitudinal magnetic field is the average over the stellar hemisphere visible at the time of observation of the component of the magnetic field parallel to the line of sight, weighted by the local emergent spectral line intensity.

Our previous observations of the Herbig Ae stars HD 139614, HD 144432 and the δ Scuti variable Herbig Ae star HR 5999, published last year, revealed a definite longitudinal magnetic field in the star HD 139614 at $4.8\,\sigma$ level: $\langle\mathcal{B}_z\rangle = -450 \pm 93$ G (Hubrig et al. 2005, A&A 428, L1). This is the largest magnetic field ever diagnosed for a Herbig Ae star. It was obtained from the slope of a linear regression of V/I versus the quantity $-g_{\rm eff}\,\Delta\lambda_z\lambda^2\frac{1}{I}\frac{{\rm d}I}{{\rm d}\lambda}\,\langle\mathcal{B}_z\rangle + V_0/I_0$. A hint of a magnetic field was found in the other two stars, HD 144432 and HR 5999, for which magnetic fields were measured at the $\sim1.6\,\sigma$ and $\sim2.5\,\sigma$ level, respectively. Our new observations of the δ Scuti variable Herbig Ae star HR 5999 and V351 Ori conducted during last year show a presence of a weak magnetic field in HR 5999 and in V351 Ori at the $\sim2.9\,\sigma$ and $\sim2.0\,\sigma$ level, respectively. Observations of the Herbig Ae star HD 139614 with the new GRISM 1200g in February 2005 confirm the presence of the magnetic field at the $\sim3.2\,\sigma$ level. The magnetic field in the Vega-like star HD 109085, if present at all, is less than 50 G and is certainly below the detection limit of spectropolarimetric measurements with FORS 1. Another Vega-like star, HD 115892, is probably very weakly magnetic with a measured field of about 70 G which is also well below the $3\,\sigma$ detection limit. Spectra of the recently observed three Herbig Ae stars, HD 38238 (=V351 Ori), HD 139614, HD 144668 (=HR 5999), and the two Vega-like stars, HD 109085 and HD 115892, in integral light in the spectral region around the Ca II K line and close-by H Balmer lines are presented in Fig. 1. The corresponding Stokes V spectra are shown in Fig. 2.

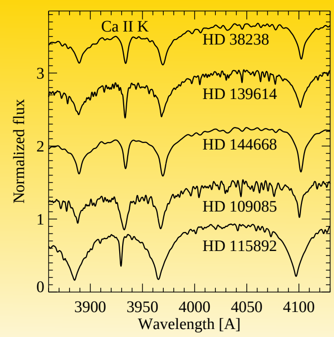

Figure 1: Stokes I spectra.

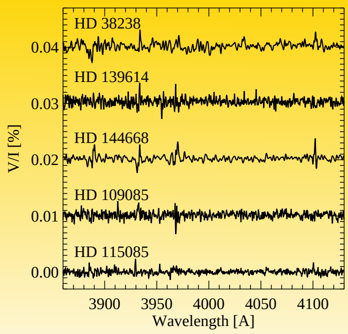

Figure 2: Stokes V spectra.

Table 1: Basic data of the studied Herbig Ae stars.

HD	Other	V	Sp. Type	$T_{\rm eff}$	log g	v sin i	Ref.	MJD	$\langle\mathcal{B}_z\rangle$
139614	CD-27 10778	8.2	A7Ve	8250	4.5	13	1	52904.04	-450 ± 93 G
139614	CD-27 10778	8.2	A7Ve	8250	4.5	13	1	53404.37	-103 ± 32 G
144432	CD-42 10650	8.2	A9Ve	7750	4.5	54	1	52900.99	-94 ± 60 G
144668	HR 5999	7.0	A7IVe	7800	3.5-4.0	180	2	52901.01	-118 ± 48 G
144668	HR 5999	7.0	A7IVe	7800	3.5-4.0	180	2	53120.25	-108 ± 37 G
38238	V351 Ori	8.9	A7III	7500	3.0	100	3	53249.37	-89 ± 44 G

(1) Meeus et al. 1998, A&A 329, 131
(2) Grady et al. 1994, Ap&SS 212, 107
(3) Balona et al. 2002, MNRAS 333, 923

Discussion

Although magnetic fields are believed to play a crucial role in controlling accretion onto, and winds from, Herbig Ae stars, contrary to the advance achieved in magnetic studies of T Tauri stars, there is still no observational evidence demonstrating the strength, extent, and geometry of their magnetic fields. The absence of A stars with magnetic fields close to the ZAMS (Hubrig et al. 2000, ApJ 539, 352; Hubrig et al. 2005, Astronomical Polarimetry: Current Status and Future Directions, ASP, *in print*) and the absence of strong magnetic fields in Herbig Ae stars might be seen as an argument against the fossil-field theories. To properly assess the role of magnetic fields in the star formation process it is important to carry out magnetic field studies of a large sample of Herbig Ae stars and to try to establish the magnetic field strength and the magnetic field geometry by monitoring over several rotation cycles. The existence of δ Scuti type pulsation amongst intermediate mass PMS stars has been confirmed by several studies (e.g., Kurtz & Marang 1995, MNRAS 276, 191; Donati et al. 1997, MNRAS 291, 658) and has stimulated theoretical investigations of the PMS instability strip (Marconi & Palla 1998, ApJL 507, 141; Breger & Pamyatnykh 1998, A&A 332, 958). Obtaining observational evidence of the magnetic fields in the PMS δ Scuti stars for which stellar parameters and their evolution in the PMS phase are studied by astroseismology should be an important goal of future studies.

For a number of Vega-like stars, near-IR photometry revealed excess near-IR emission with colours resembling those of Herbig Ae/Be systems (e.g. Sylvester et al. 1996, MNRAS 279, 915). One of the prototypes of Vega-like stars, β Pictoris, shows evidence of a complex stellar environment with dense and hot regions. It was argued that the observed broad emission from the highly ionized species C III and O IV may originate from a solar-like extended chromosphere or from magnetospheric accretion (Deleuil et al. 2001, ApJ 557, L67). Recent models assume that the disk of this star is truncated at some inner radius from the star and infalling gas from the disk is channeled by an axisymmetric dipole magnetic field connecting the disk to the star (e.g. Hartmann et al. 1994, ApJ 426, 669). If solar-like activity is responsible for the observed highly ionized species, a theoretical framework to explain the origin and evolution of these phenomena remains to be built. At the moment, the presence of magnetic fields in Vega-like stars is not convincingly tested observationally and theoretically. Further spectropolarimetric observations should provide clues for the understanding of processes taking place in the atmospheres of these stars.