Magnetic Stars, 2011, pp. 435 – 439

Dynamical Spot Evolution in HD 11753

Korhonen H.[1], Hubrig S.[2], Briquet M.[3], González J. F.[4], Savanov I.[5]

[1] European Southern Observatory, Garching bei München, Germany
[2] Astrophysikalisches Institut Potsdam, Potsdam, Germany
[3] Instituut voor Sterrenkunde, Katholieke Universiteit Leuven, Leuven, Belgium
[4] Instituto de Ciencias Astronomicas, de la Tierra y del Espacio (ICATE), San Juan, Argentina
[5] Institute of Astronomy, Russian Academy of Sciences, Moscow, Russia

Abstract. Our recent studies of HD 11753, a late B–type star showing a HgMn peculiarity for the first time revealed the presence of a fast dynamical evolution of chemical spots on the surface of this chemically peculiar early–type star. These observations suggest a hitherto unknown physical process operating in stars with outer radiative envelopes. Furthermore, we have also discovered existence of magnetic fields on HgMn stars that were up to now considered non–magnetic. Here we will discuss the dynamical spot evolution in HD 11753 in detail, and also summarize our new results on the magnetic fields of the AR Aur binary system.

Key words: stars: atmospheres, chemically peculiar, early–type, magnetic fields, spots

1 Introduction

Recently, Kochukhov et al. (2007), using the Doppler Imaging technique, reported a discovery of secular evolution of mercury distribution on the surface of the HgMn star α And. However, this result was never verified by other studies due to the lack of observational data. Until very recently, the only other HgMn star with a published surface elemental distribution was AR Aur (Hubrig et al., 2006a), where the discovered surface chemical inhomogeneities are related to the relative position of the companion star. The elements Y and Sr are strongly concentrated in the equatorial ring, which has a gap exactly in the area, permanently facing the secondary.

HD 11753 is a single–lined spectroscopic binary with an effective temperature of 10612 K (Dolk et al., 2003). In Briquet et al. (2010) we published two sets of surface maps for this star, showing HgMn peculiarity. These surface maps are separated only by approximately two months and are obtained from three different elements: Y II, Ti II and Sr II. The maps based on the Y II 4900 Å line (see Fig. 2) exhibit a high abundance region at phases 0.5 – 1.0, extending from the latitude 45° to the pole, with an extension to the equator around the phase 0.8. The Y II abundance distribution also shows a high–latitude lower abundance spot around phases 0.2 – 0.4. A clear evolution in the surface features is present during the two months, separating the datasets. The lower abundance high–latitude feature at phases 0.2 – 0.4 becomes more extended and less prominent in the second set, while the abundance of the high–abundance spot at phases 0.6 – 1.0 gets more prominent with time.

We have also obtained measurements of the magnetic field strength with the moment technique using several elements in a circularly polarised high–resolution spectrum of another HgMn star, AR Aur. These observations revealed the presence of a longitudinal magnetic field in both stellar

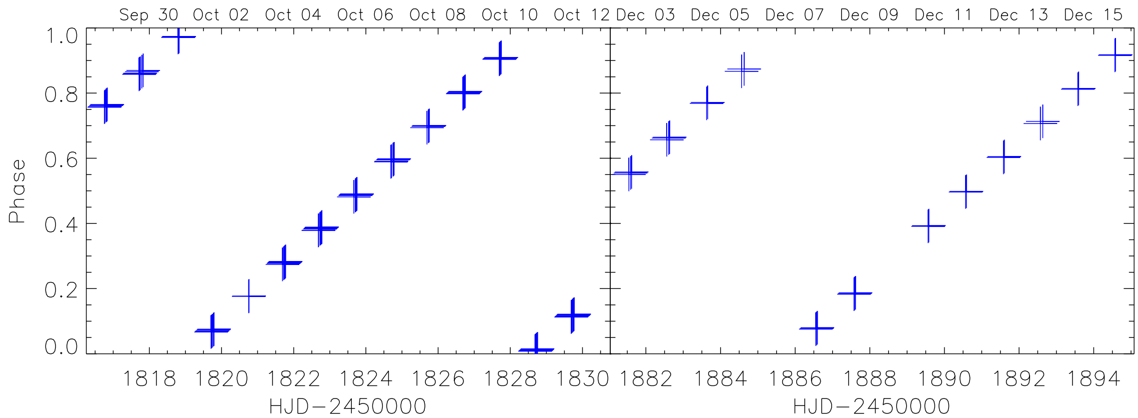

Figure 1: Phases of the HD 11753 observations for both data sets obtained in 2000 (October 2000 on the left, and December 2000 on the right)

components (Hubrig et al., 2010).

Here, we continue the investigation of HD 11753 using the newer CORALIE data from 2009 and 2010, and discuss the magnetic field measurements of AR Aur.

2 Observations

A large number of spectra of a sample of HgMn stars were obtained with the CORALIE spectrograph at the 1.2–m Euler telescope in La Silla during a programme, dedicated to the search for SPB–like pulsations in B–type stars. In Briquet et al. (2010) we published two sets of surface maps of HD 11753 based on these data. To further study the dynamical spot evolution we have obtained more data in August 2009 and January 2010, also using the CORALIE spectrograph. The phase coverage of the data, is good, especially for the 2000 observations, as is shown in Fig. 1.

Nine spectra of AR Aur, observed at the European Southern Observatory with the UVES spectrograph at UT2 in 2005 were for the first time presented at the IAU Symposium 259 by Savanov et al. (2009). To prove the presence of a dynamical evolution of spots also on the surface of AR Aur, we obtained new spectroscopic data with the Coudé Spectrograph of the 2.0–m telescope of the Thüringer Landessternwarte and the SES spectrograph of the 1.2–m STELLA–I robotic telescope at the Teide Observatory. A number of SOFIN spectra of AR Aur were obtained in 2002 at the Nordic Optical Telescope, which we also used in our analysis. In addition to the high resolution spectra mentioned above, spectropolarimetric observations of AR Aur at the rotation phase 0.622 were obtained in December 2009 with the low–resolution camera of SOFIN ($R \approx 30\,000$) at the Nordic Optical Telescope.

3 Spot Evolution in HD 11753

According to our observations, the orbital period of the HD 11753 binary system would be long, and the projected rotational velocity is $v\sin i = 13.5$ km/s (Briquet et al., 2010). After adding the new 2009 and 2010 datasets, the rotational period is improved to $P = 9\overset{\mathrm{d}}{.}531$ (Korhonen et al., 2010).

We have obtained Doppler images of HD 11753 from the CORALIE spectra for four different epochs. In the Doppler imaging, spectroscopic observations at different rotational phases are used to measure the rotationally–modulated distortions in the line profiles. These distortions are produced

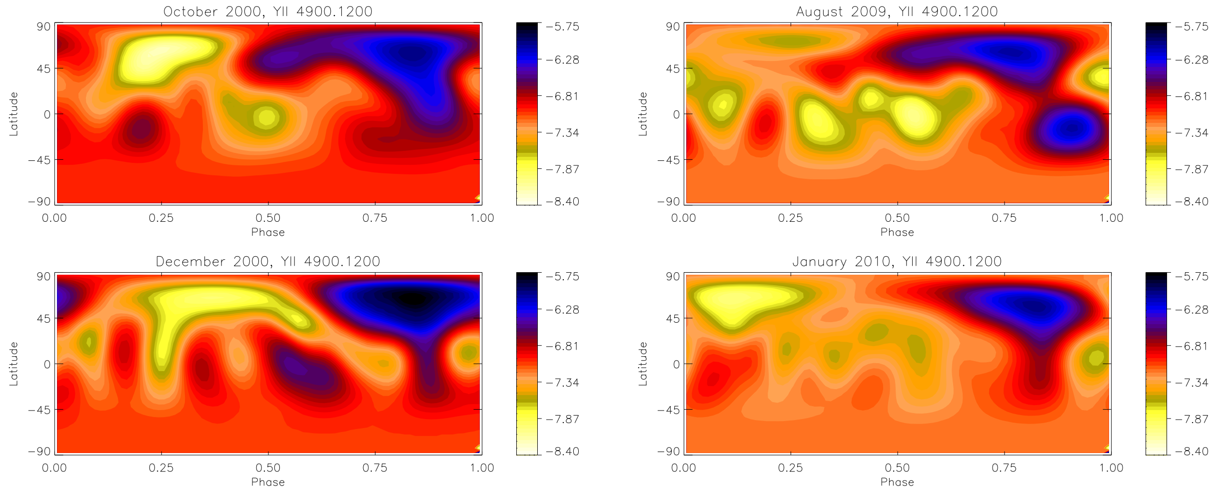

Figure 2: Chemical surface maps of HD 11753 from the Y II 4900 Å line at four different epochs. In the maps the abscissa is the longitude in phases and the ordinate is the latitude in degrees. Colour indicates different abundances, darker colours denoting higher abundances.

by an inhomogeneous distribution of a given surface characteristic, e. g., surface temperature or element abundance. Surface maps are constructed by combining all the observations from different phases and comparing them with synthetic model line profiles. For accurate Doppler imaging the shape and changes of the line profile have to be well defined. This requires a high resolving power and high signal–to–noise ratio.

The Doppler images of HD 11753 using the Y II 4900 Å line are shown in Fig. 2. The two first maps, both from 2000, have 65 days in between them. Clear temporal evolution of the chemical spots occurs even on such short timescales. The high–abundance spot around the phase 0.75 gets more concentrated with time, and the lower–abundance spot around the phase 0.25 is more extended. These two maps were already published by Briquet et al. (2010), but the August 2009 and January 2010 maps are previously unpublished. These latter maps have approximately four and a half months in between them, and again they show temporal evolution of surface structures. The high–abundance spot of phase 0.75 at high latitudes is much more extended in August 2009 than in January 2010. Also, the equatorial high–abundance spot seen at phase 0.85 in the August 2009 map has disappeared before January 2010. The lower–abundance spot of phase 0.0 − 0.4 is almost non–existent in August 2009, but clearly present in January 2010. However, the August 2009 dataset has a large phase gap, 0.17 − 0.47, close to the phase of the lower–abundance spot. Our tests show, though, that a phase gap of 0.3 in phase does not affect the recovery of such large surface features (see Korhonen et al., 2010).

All in all, chemical spots retain their position on the stellar surface stably over an almost 10 year period, covered by our observations. The exact shape changes, though, and this change happens even on the time scales of months.

4 Magnetic Field in AR Aur

Typically, inhomogeneous chemical abundance distributions are observed only on the surface of magnetic chemically peculiar stars with organised large–scale magnetic fields. In these stars, the abundance distribution of certain elements is non–uniform and non–symmetric with respect to the rotation axis. The HgMn stars were assumed in the past not to possess magnetic fields or to exhibit spectral line variability such as that shown by chemically peculiar magnetic Ap and Bp stars. However, due to our extensive studies it now became clear that weak magnetic fields and spectral line variability do exist in these stars.

The most widespread method to detect a magnetic field is to obtain polarimetric spectra, recorded in left and right–hand polarised light to measure the mean longitudinal magnetic field. Another approach to study the presence of magnetic fields in the upper main sequence stars is to determine the value of the mean quadratic magnetic field, which is determined from the study of the second-order moments of the line profiles recorded in unpolarised light (that is, in the Stokes parameter I). Using this method, Mathys & Hubrig (1995) could demonstrate the presence of quadratic magnetic fields in two close double–lined systems with HgMn primaries, 74 Aqr and χ Lup. A magnetic field of the order of a few hundred Gauss was recently detected in four other HgMn stars by Hubrig et al. (2006b) using low–resolution ($R = 2000$) circular polarisation spectra obtained with the FORS1 at the VLT. This small sample of HgMn stars also included the spectrum of a variable HgMn star α And, for which a magnetic field of the order of a few hundred Gauss was detected. It appears that the structure of the measured field in HgMn stars must be sufficiently tangled, so that it does not produce a strong net observable circular polarisation signature.

The double–lined spectroscopic binary AR Aur has an orbital period of 4.13 d. It is a young system with the age of only $4 \cdot 10^6$ yr. Its primary, showing a HgMn peculiarity, is exactly on the Zero Age Main Sequence, while the secondary is still contracting towards it. Variability of spectral lines associated with a large number of chemical elements was reported for the first time for the primary component of this eclipsing binary by Hubrig et al. (2006a).

Doppler maps for the elements Mn, Sr, Y, and Hg using nine spectra of AR Aur, observed at the European Southern Observatory with the UVES spectrograph at UT2 in 2005 were for the first time presented at the IAU Symposium 259 by Savanov et al. (2009). To prove the presence of a dynamical evolution of spots on the surface of AR Aur, observations were made in 2008 – 2010 at various telescopes. The observations show clear variations in the spectral line profiles and also on the surface abundance maps, obtained using the Doppler imaging techniques (Hubrig et al., 2010). These variations are secular in nature, though, and no dynamical evolution in the AR Aur spectra obtained in late 2009 – early 2010 are seen.

To pinpoint the mechanism, responsible for the surface structure formation in HgMn stars, we carried out spectropolarimetric observations of AR Aur, and investigated the presence of a magnetic field during the rotational phase of a very good visibility of the spots of overabundant elements. The spectropolarimetric observations of AR Aur at the rotation phase 0.622 were obtained with the low–resolution camera of the SOFIN ($R \approx 30\,000$) at the Nordic Optical Telescope. Since most elements are expected to be inhomogeneously distributed over the surface of the primary of AR Aur, the magnetic field measurements were carried out for the samples of Ti, Cr, Fe, and Y lines separately. Among the elements showing the line variability, the selected elements have numerous transitions in the observed optical spectral region, allowing us to sort out the best samples of clean unblended spectral lines with different Landé factors.

Our magnetic field measurements, which are discussed in detail by Hubrig et al. (2010), were done using the formalism described by Mathys (1994). A longitudinal magnetic field at a level higher than 3σ of the order of a few hundred Gauss is detected in Fe II, Ti II, and Y II lines, while a quadratic magnetic field $\langle B \rangle = 8284 \pm 1501$ G at 5.5σ level was measured in Ti II lines. No crossover at the 3σ confidence level was detected for the elements studied. Further, we detect a weak longitudinal magnetic field, $\langle B_z \rangle = -229 \pm 56$ G, in the secondary component using a sample of nine Fe II lines. The main limitation on the accuracy, achieved in our determinations is set by the small number of lines that can be used for magnetic field measurements. The diagnosis of the quadratic field is more difficult than that of the longitudinal magnetic field, and it depends much more critically on the number of lines that can be used for the analysis. Interestingly, in analogy to the presented detection of a kG quadratic magnetic field in the primary, and a weak longitudinal magnetic field in the primary and the secondary of AR Aur, Mathys & Hubrig (1995) reported the detection of a weak magnetic field in the secondary of another SB2 binary, χ Lup, while in the same work they discovered a quadratic magnetic field of 3.6 kG in the primary component of 74 Aqr. The secondaries in both the AR Aur and χ Lup systems are mentioned in the literature to have the characteristics very similar to the early Am stars.

5 Summary

The fast dynamic evolution of the spots on the surface of HD 11753 implies a hitherto unknown physical mechanism operating in the outer envelopes of late B–type stars with a HgMn peculiarity and the detection of the magnetic field in AR Aur shatters the traditional view that HgMn stars do not exhibit magnetic fields. For the proper understanding of the nature of these stars, we need accurate information on the element spot configuration and underlying magnetic fields in a sample of HgMn stars to determine a link between these properties and such fundamental stellar parameters as the rotation rate, temperature, evolutionary state, stellar mass, multiplicity and orbital parameters. It is clear that the time–series of high resolution spectropolarimetric observations are needed to solve the puzzle these stars represent.

References

Briquet M., Korhonen H., González J. F., Hubrig S., Hackman T., 2010, A&A, 511, A71

Dolk L., Wahlgren G. M., Hubrig S., 2003, A&A, 402, 299

Hubrig S., González J. F., Savanov I., Schöller M., Ageorges N., Cowley C. R., Wolff B., 2006a, MNRAS, 371, 1953

Hubrig S., North P., Schöller M., Mathys G., 2006b, Astron. Nachr., 327, 289

Hubrig S., Savanov I., Ilyin I., González J. F., Korhonen H., Lehmann H., Schöller M., Granzer T., Weber M., Strassmeier K. G., Hartmann M., Tkachenko A., 2010, MNRAS, 408, L61

Kochukhov O., Adelman S. J., Gulliver A. F., Piskunov N., 2007, Nature Physics, 3, 526

Korhonen H., González J. F., Briquet M. et al., 2010, A&A, in prep.

Mathys G., 1994, A&AS, 108, 547

Mathys G., Hubrig S., 1995, A&A, 293, 810

Savanov I. S., Hubrig S., González J. F., Schöller M., 2009, IAU Symp. 259, 401