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Binaries Among Magnetic CP Stars: Some Observational Results

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Abstract. We present the recent results of observations of binary systems with magnetic components. Spectral and speckle interferometric observations, carried out mostly with the 6–m telescope of the SAO RAS have revealed several new, earlier unknown close stellar systems. The ratio of multiple stars resolved by speckle interferometry is more than 20%. Some binaries were studied spectroscopically. Results presented in this paper have a preliminary character.

Key words: star – binary techniques – speckle interferometry – atmosphere – abundance

1 Introduction

It is a well known fact that binarity plays a very important role in stellar life. The presence of companions, especially close enough so that the accretion processes can start might change the rate and direction of stellar evolution. For instance, close binary systems with neutron stars are the typical progenitors of type I supernovae. The study of close binary systems is also interesting because complex processes may occur in their atmospheres.

Many scientists who study the problem of duplicity of magnetic CP stars agree that the frequency of close stellar systems is lower than the one for normal non–magnetic stars. The most famous work devoted to spectroscopic searches of binaries among Ap stars was made by Abt & Snowden (1973), who found that only about 20% of Si and SrCrEu stars from their sample may have companions, while for hotter HgMn stars the frequency of spectral binaries (40%) is close to normal. These authors also supposed that the frequency of visual binaries for magnetic and non-magnetic stars is approximately the same.

The next significant observational work was carried out by Gerbaldi with his collaborators (Gerbaldi et al., 1985). They reexamined the frequency of binaries among Ap/Bp stars and were the first, who have considered the duplicity of stars with helium abundance anomalies. The observed lack of spectral binaries among He–w, Si and Si+ stars is the main conclusion of the above authors. At the same time, Gerbaldi et al. note that the binary ratio for the coolest Ap stars (46%) is approximately the same as for normal stars.

The latest observational survey was carried out by Carrier et al. (2002). These scientists examined the spectral duplicity of 113 cool chemically peculiar A stars. This work differs from other similar investigations because it is based on the analysis of a most homogeneous and reliable sample. After all corrections for observational biases, authors found that the binary frequency of considered stars is about 43%, which is very close to that found by Gerbaldi et al. (1985). Another important result is an almost total lack of binaries with orbital periods shorter than 3 days.

Table 1: Description of the filter set installed in the speckle interferometer of the 6-m BTA telescope. The highlighted filters were used in our observations most frequently.

λ_{central}, nm	FWHM, nm
550	20
600	40
650	40
700	40
800	100

We can also mention a couple of papers by Hubrig et al. (2008), Schöller et al. (2010), and Schöller et al. (this conference), where multiplicity of non–magnetic HgMn stars was considered.

Despite of the important results obtained early in surveys listed above, our knowledge about magnetic CP binaries is still incomplete to make a detailed statistical analysis.

2 Speckle Interferometry on the 6–m Telescope

Speckle interferometry as a technique of attaining the diffraction resolution on large telescopes was initially proposed by Labeyrie (1970). Taking very short exposure images of astronomical objects, preferably point–like sources or those, having small angular sizes, and then processing them with refined mathematical methods we can remove the effects of astronomical seeing. Moreover, unlike the adaptive optics, efficient in the near IR spectral range, speckle interferometry can be implemented in the visual and even in the near UV range. This is one of the most efficient methods allowing to achieve the highest optical resolution on a telescope with the single main mirror. With a speckle interferometer we can study the stellar pairs, which are too wide to be resolved spectroscopically but still close enough to be a "single" star visually.

The first speckle interferometer for the 6–m telescope BTA was built in the early 1980–s in the Special Astrophysical Observatory by a group of scientists headed by Yu. Yu. Balega. The first interferometer has used photographic film as a registering system. Further improvements of detection techniques have finally led to the implementation of CCDs in interferometers. The latest modification of the speckle interferometer for 6–m telescope uses a high–speed EMCCD detector with 512×512 px size and is equipped with a filter set and a compensator of atmospheric dispersion. Filters, installed during the observations are listed in Table 1.

A comprehensive description of all technical capabilities of the speckle interferometer was done by Maximov et al. (2009).

3 Speckle Interferometric Survey of Magnetic Stars

In order to prepare a sample of magnetic stars suitable for observations at the BTA site, we have analysed the catalogue of mCP stars compiled by Romanyuk & Kudryavtsev (2008). Since the stars available for speckle observations should be brighter than 15 magnitudes, while the faintest magnetic stars are about 12 mag, the only selection criterion is the stellar declination. Finally, we have selected approximately 325 CP stars and started the observations in December 2009. At the time (as of October 2010) about 160 stars from our sample were observed at least once. Reduction of data and positional measurements were completed only for the data collected before July 2010. Below we present only the preliminary measurements for the resolved stars, their component separations

Table 2: Measured parameters of some resolved stars

HD	ρ, arcsec	Δm, mag
965	0.2	≈ 3
5797	0.14	3
6757	0.6	1
51418	0.15	3
258686	1.7	1.5

and magnitude differences. Accurate data on the positional parameters and photometry will be published later as a separate paper.

From the total amount of about 160 magnetic stars 35 pairs were successfully speckle–interferometrically resolved i. e. approximately 20%. Additionally, several observed stars, which are suspected in binarity are not included in this paper until we have careful measurements of them. Among the resolved pairs, 13 belong to stars with SrCrEu peculiarities, 14 — to Si/Si+ stars, and 6 with helium anomalies. Also we have discovered visual components of a famous HgMn star κ Cnc and a HoDy star HD 51418. We have resolved for the first time 7 new binaries, 5 other systems had previously been suspected by some researchers to be multiple.

There is an open question whether all the binaries discovered in our work are indeed gravitationally linked. Considering faint He and Si/Si+ stars we can expect that the distance to those stars is greater than 300 – 350 pc. The presence of wide ($\rho \geq 1''$) companions in such pairs with a magnitude difference of more than 4^m may be the product of incidental projection of a more distant star. It is more probable that the less distant and cooler SrCrEu stars, as some silicon stars form physical systems and with the lapse of time we can detect their orbital motion.

As typical values, we present some estimations of angular separation and Δm for several binaries (Table 2).

For most of other stars the value of ρ varies from about $0''.02$ (lower limit) to $2''$, which correspond to the size of field of view of a micro objective with maximal magnification.

In the following section we shall present the results of a detailed spectroscopic study of the stars HD 5797 and HD 6757 from Table 2.

4 Spectroscopic Study of Some Magnetic Binaries

4.1 Evolved Stars HD 5797 and HD 40711

A couple of stars from the current study were earlier under investigation with the 6–m telescope. For example, magnetic and chemical properties of stars HD 5797 and HD 40711 were studied in detail by Semenko et al. (2011). Both these objects belong to the group of evolved stars with a strong overabundance of iron and chromium. At the same time, the lines of rare earth elements (REE), usually strong in the spectra of magnetic CP stars are very weak. A weak surface magnetic field is also a business card of evolved CP stars.

Our determination of stellar positions on the HR diagram shows that both HD 5797 and HD 40711 are close to the end of the hydrogen burning stage (Fig. 1).

We have as well estimated the abundances for many chemical elements, including rare earths. The results of study are illustrated by the Figure 2.

Studying HD 5797 and HD 40711 we assumed that both of them are single stars or, at least, the contribution from second components are negligible. HD 40711 was a known spectral binary system

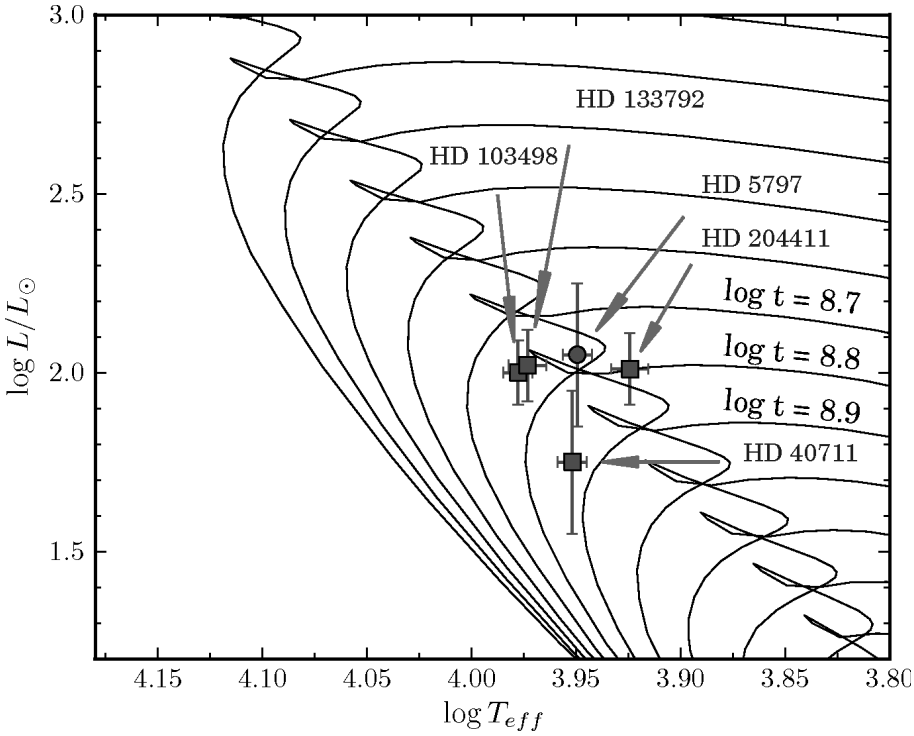

Figure 1: Position of stars HD 5797 and HD 40711 on the theoretical HR diagram. Isochrones were taken from Girardi et al. (2000).

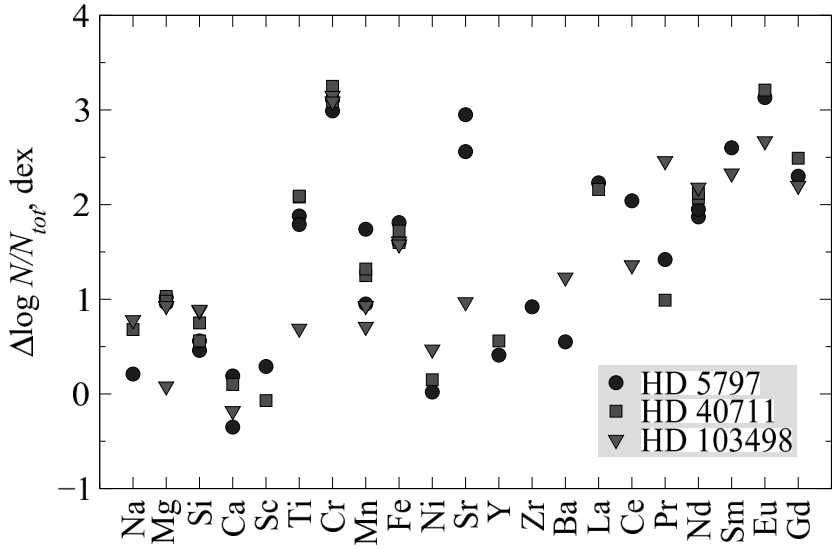

Figure 2: Chemical composition of atmospheres of HD 5797, HD 40711 and HD 103498 (Joshi et al., 2010) compared to the Sun

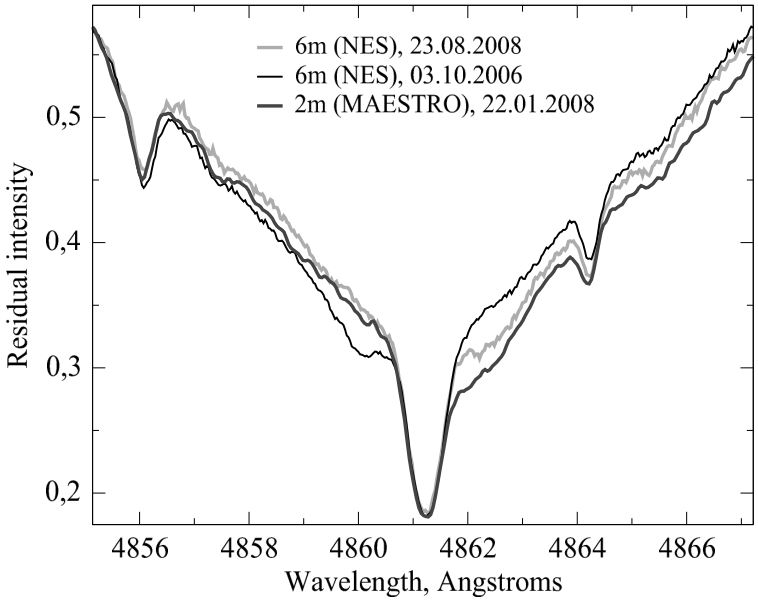

Figure 3: Spectra of HD 6757 near the Hβ line at different moments of time

with the orbital period slightly greater than 1200 days (Carrier et al., 2002). Duplicity of HD 5797 had become known few months after the article was sent to the journal. But even so, we carefully checked the spectrum on variability and on the presence of lines of possible invisible companions. Radial velocities of HD 5797 seem to be constant.

The fact of multiplicity of many systems, containing weakly magnetic stars which show mild excess of REE and strong overabundance of Fe and Cr, may require some additional investigations. We expect that other magnetic stars having similar characteristics can expand group of evolved stars. Among such a candidates are HD 8441, ε UMa, and others, including few of newly discovered but still not published mCP stars.

4.2 HD 6757 — a Possible Triple System

This object was found as magnetic by Kudryavtsev et al. (2006).Further observations had revealed small variability of longitudinal magnetic field. Despite on continuous zeeman observations with 6–m telescope, we still can not to determine rotational period of the star. Between single measurements, when magnetic field varies from about 2300 G to 2900 G, we have a lot of big gaps, which make unreliable study of behaviour of the longitudinal component of stellar field.

In order to clarify the situation with the strength of magnetic field of HD 6757, we have obtained a set of high resolution echelle spectra with the NES spectrometer (Panchuk et al., 2009) of the 6–m telescope, and with the MAESTRO spectrometer, mounted on 2–m telescope of the Peak Terskol Observatory. In both cases the spectral resolution was practically the same: $R = 40000$ for NES, and $R = 45000$ for the MAESTRO spectrometer. The broadening of magnetically insensitive lines is small and corresponds to $v \sin i = 7$ km/s. A complete lack of any kind of photometry suitable to determine the effective temperature and gravitational acceleration of the star prompted us to make such estimations using the hydrogen lines in the spectrum. We have found that the effective temperature is about 9200 K and $\log g \approx 3.7$. The main source of uncertainties is the accuracy of continuum normalisation. A couple of magnetically resolved lines were found in the spectra. Using the lines of Nd III 6145 Å and Fe II 6149 Å, we obtained the value of the surface magnetic field of HD 6757. In the measured spectra B_s varies from 9 to about 12 kG, i. e. we find a field strong enough to be taken into account in the abundance study.

Table 3: Positional and photometric measurements of HD 6757

500/20 nm	800/100 nm
$\rho = 0\farcs618 \pm 0.002$	$0\farcs617 \pm 0.002$
$\theta = 265\fdg1 \pm 0.3$	$265\fdg1 \pm 0.3$
$\Delta m = 1.01 \pm 0.02$	0.73 ± 0.02

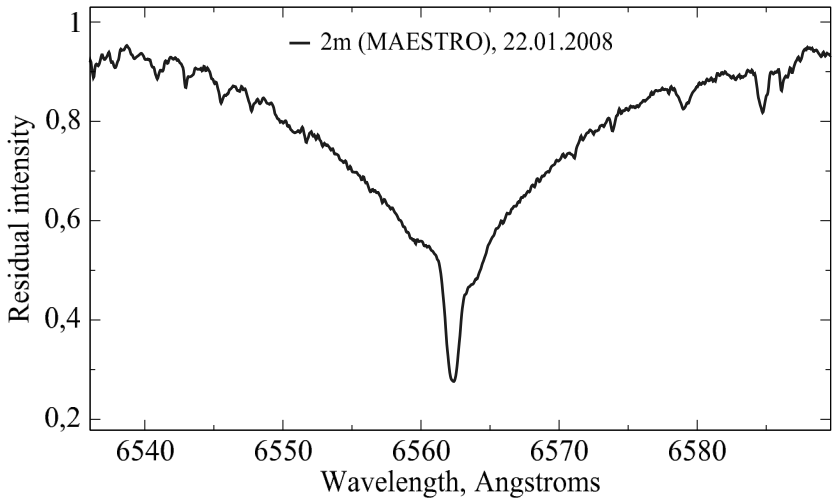

Figure 4: Spectra of HD 6757 near the Hα line

We could not perform a detailed study of HD 6757 due to some problems that have emerged when we got the spectrum with the NES in October 2006. In the hydrogen line Hβ we have found a curvature which can be treated as the lines of the second component (Fig. 3). Later observations with the 2–m telescope and with the BTA have confirmed our assumption. It will be very interesting to apply the existing disentangling methods for obtaining separate spectra of the components, but as yet we have an insufficient number of spectra appropriate for such kind of analysis.

The fact of duplicity of HD 6757 was known before. This star was resolved for the first time in 1876 (Dommanget et al., 2002). Later HD 6757 has often become the target for interferometric observations. The Forth Interferometric catalogue (Hartkopf et al., 2001) contains a lot of data related to this star. We also carried out speckle interferometric observations of HD 6757 using two filters: 500/20 nm and 800/100 nm. The corresponding results are presented in Table 3.

Our results are in perfect agreement with the existing measurements. Such a close pair for our equipment under the typical seeing even less than 1 arcsec would look like a single star. We can assume that a faint companion is not gravitationally linked with the main magnetic star and has a large radial velocity (about 50 – 70 km/s), however, this is very doubtful. Then one of the curvatures can be explained by the orientation of the star in the spectrograph slit. But the shape of the hydrogen line like that in Fig. 4 still requires a presence of a third body in the stellar system for a correct representation. So, obviously, we have yet another triple CP star with a strong magnetic field.

5 Conclusions

Speckle interferometric observations carried out on the 6–m telescope by the Group of High Angular Resolution Methods in Astronomy of the SAO RAS shows that there are many wide binaries among the known "single" magnetic stars. The special significance of the work lies in the fact that such objects look like single stars in the spectral observations, meaning that we can consequently obtain wrong chemical peculiarities from the analysis. The capabilities of the speckle interferometric technique allow us to fill up the range of component separation, which can not be obtained neither from the spectroscopy, nor from the visual observations.

In order to extract the data about the astrometric orbit and masses of closest binaries we shall continue our observations. However, we shall also study the most outstanding binaries with the spectral devices of the 6–m SAO telescope and possibly other instruments.

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