The A-Star Puzzle
Proceedings IAU Symposium No. 224, 2004
J. Zverko, J. Žižňovský, S.J. Adelman, & W.W. Weiss, eds.

DOI: 10.1017/S1743921304004685

A search for SB2 systems among selected Am binaries

I.Kh. Iliev[1], M. Feňovčík[2], J. Budaj[3,4], J. Žižňovský[4], J. Zverko[4], I. Barzova[1] and I. Stateva[1]

[1]National Astronomical Observatory, Bulgarian Academy of Sciences,
P.O.Box 136, BG-4700 Smolyan, Bulgaria
e-mail: iliani@astro.bas.bg

[2]Pavol Jozef Šafárik University, 040 01 Košice, Slovak Republic

[3]Department of Astronomy and Astrophysics, Pennsylvania State University,
Davey Lab. 525, University Park, 16802 PA, USA

[4]Astronomical Institute, Slovak Academy of Sciences,
059 60 Tatranská Lomnica, Slovak Republic

Abstract. We report on the detection of secondary spectra in five spectroscopic binary systems: HD 434, HD 861, HD 108642, HD 178449, and HD 216608. High signal-to-noise high resolution spectroscopic observations were carried out at the Bulgarian NAO Rozhen as part of an extended project concerned mainly with Am stars in binary systems. Our knowledge about early type binaries has serious gaps. This is true especially when it is only based on older photographic techniques. We concluded that photographic data involving longer orbital periods (where Doppler shifts due to the orbital motion are comparable or even less than the rotational broadening of the spectral lines) and early type stars (that have only a few and usually broad lines) should be revisited or at least used with caution. We demonstrate that for the five systems how CCD observations made with 2-m class telescopes can discover the binary nature or secondary spectra of many currently unresolved SB1 systems. Important astrophysical information such as the atmospheric parameters and the mass ratios are used to unravel previous misinterpretations of the data leading often to spurious orbits.

Keywords. Stars: binaries: spectroscopic, stars: chemically peculiar, stars: individual: (HD 434, HD 861, HD 108642, HD 178449, HD 216608)

1. Introduction

Am stars are very often found in binary systems (North *et al.* 1998, Debernardi *et al.* 2000). They offer a unique possibility to study the role of tides and tidal interactions on the stellar hydrodynamics and the diffusion processes in stellar atmospheres. Recently we found indications (Budaj 1996, Budaj 1997, Iliev *et al.* 1998) that the observed Am abundance patterns may depend on the orbital elements of a binary system. It is more pronounced in systems with higher eccentricities and possibly also with longer orbital periods. Some years ago we started an observing project concerned especially with Am stars in binary systems. Its main goal is to collect sufficient high quality spectroscopic data to fulfill the rigid requirements of the spectrum synthesis procedures. The first results of this project have been already presented by Feňovčík *et al.* (2005). Soon after the start of the observations we found that spectra of some target stars exhibited clear signs of secondary components. Here we report on the new SB2 systems discovered among our selected Am binaries.

2. The observations

Our spectroscopic observations were made with the 2-m RCC telescope of the Bulgarian National Astronomical Observatory Rozhen. A Photometrics AT200 camera with a SITe S1003AB chip ($1024 \times 1024, 24\mu$m pixels) was used in the Third camera of the coudé spectrograph to provide spectra in two 100 Å wide spectral regions centered at 6440 Å and 6720 Å with a resolving power $R \sim 32\,000$. A typical S/N ratio is about 300. Standard IRAF procedures were used for bias subtraction, flat-fielding and wavelength calibration. Hot, fast rotating stars were used for telluric lines removal. Continuum fitting and measurements of the radial velocities and equivalent widths were performed using the EQWREC2 code of Budaj & Komžík (2000).

Twenty-six Am binaries from Budaj (1997) were selected which: 1) are brighter than 7 th magnitude in V, 2) have declinations greater than $+10°$, and 3) have orbital periods between 10 and 180 days. This assures a full range of systems with original eccentricities which did not undergo circularization on the main sequence. We put no constraints on the rotational velocities and included an additional broad line "normal" star to test the spectrum synthesis procedure on highly rotating stars.

3. The results

3.1. *HD 434*

HD 434 (HIP 728, $m_V = 6.5, v \sin i = 60$ km s^{-1}) is known as SB1 system. A preliminary orbit has been reported by Hube & Gulliver (1985). Thirty-eight photographic spectra with a dispersion of about 15 Å mm^{-1} were used for this purpose. Later Sreedhar Rao & Abyhankar (1992) used 33 spectra with 33 Å mm^{-1} and determined that $P = 34.26$ days, $e = 0.475$, $\gamma = 2.6$ km s^{-1}, and $K = 24.1$ km s^{-1}. Their radial velocity curve, however, differs significantly in γ- and K-velocities from those of Hube & Gulliver (1985). Our recent observations (Iliev *et al.* 2001a, Budaj *et al.* 2003) discovered a pronounced secondary spectrum (Fig. 1). The combination of high eccentricity, high $v \sin i$, and low K-velocity results in the heavy blended spectrum (Sp. No. 1) seen during the most of the orbital period. Spectral lines of the secondary are isolated only in the very short phase interval during the maximum separation of the components (Sp. No. 2). We found a mass-ratio $q = M_1/M_2 = 1.19 \pm 0.06$, while $\gamma = +12.0$ km s^{-1}. With these values the K_1-velocity should be greater than 31 km s^{-1}. Finally, the Hube & Gulliver (1985) orbital elements satisfy our spectroscopic data better than those of Sreedhar Rao & Abyhankar (1992). But their γ-velocity is smaller than ours.

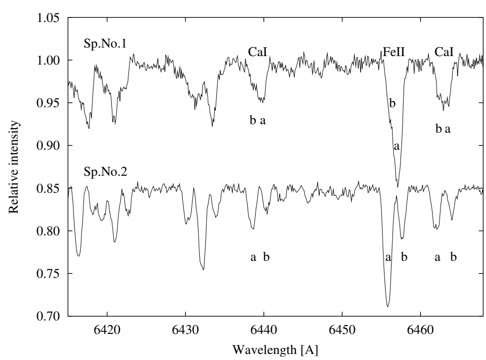

Figure 1. Two spectra of HD 434 are shifted for convenience along the intensity axis. Lines are marked with "a" for the primary, and with "b" for the secondary component.

https://doi.org/10.1017/S1743921304004685 Published online by Cambridge University Press

3.2. *HD 861*

Although bright and close HD 861 (HIP 1063, $m_V = 6.6, v \sin i = 35$ km s^{-1}) is a rarely studied SB1 system. The orbital elements originated from Acker (1971): $P = 11.2153$ days, $e = 0.22$, $\gamma = -12.5$ km s^{-1}, and $K = 43.8$ km s^{-1}. Our observations (Budaj *et al.* 2004) reveal two systems of lines and evidence of orbital motion (Fig. 2). Sharp and weak details are seen only around the Ca I and the Fe I lines. Synthetic spectrum calculations for the primary spectrum show that no predicted theoretical lines can be identified with such details. Thus, the secondary component is substantially cooler, fainter, and less massive than the primary. Its rotation is much slower. Our radial velocity measurements lead to a mass-ratio $q \sim 2$.

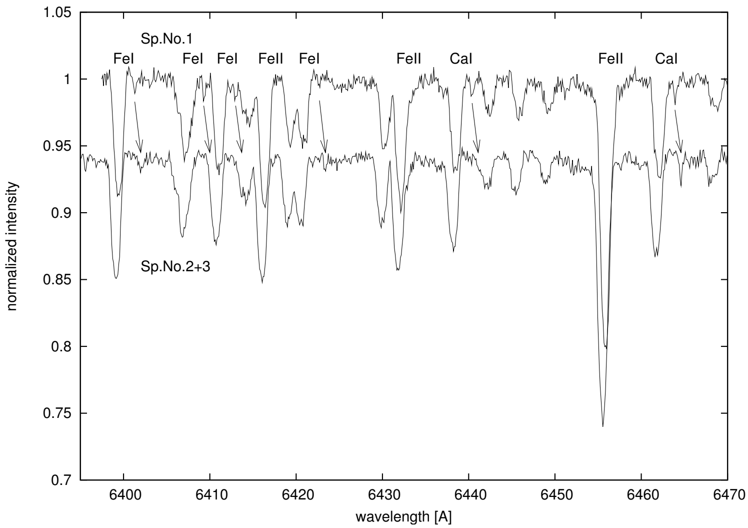

Figure 2. The two successive spectra of HD 861 are separated for convenience by 0.05. While the strong and well isolated lines of the primary are shifted blueward, weak and sharp lines apparently belonging to the secondary are shifted to the red. This is indicated by arrows.

3.3. *HD 108642*

HD 108642 (HIP 60890, $m_V = 6.5$) is a well-known SB1 system. The most recent orbital elements are by Abt & Willmarth (1999): $P = 11.7843$ days, $e = 0.0$, $\gamma = -0.7$ km s^{-1}, and $K = 41.14$ km s^{-1}. According to Abt & Morell (1995) $v \sin i = 13$ km s^{-1}, while Landstreet (1998) obtained $v \sin i < 4.5$ km s^{-1}. Magnetic field measurements by Shorlin *et al.* (2002) permit us to estimate as a by-product that the mass-ratio $M_1/M_2 = 1.9 \pm 0.1$ and $\gamma = -2 \pm 2$ km s^{-1} via polarimetric least-square deconvolution profiles. Two of our observations (Budaj *et al.* 2003) are presented in Fig. 3, where a small part of the spectrum of HD 108642 centered at the Ca I 6439 Å line is shown. For the mass-ratio we obtained $M_1/M_2 = 1.82 \pm 0.01$ which agrees with Shorlin *et al.* (2002). For the γ-velocity we found $\gamma = -0.4$ km s^{-1}, a value very close to that of Abt & Willmarth (1999) who were able to measure only the radial velocity of the primary.

3.4. *HD 216608*

The next star HD 216608 (HIP 113048) is the visual binary system ADS 16345AB. The V magnitudes of A and B components are 6.0 and 7.8, respectively. The brightest member HD 216608A is a SB1 star. Its Am characteristics were found by Walker (1966). Companion B is a F6V star that orbits the primary with a period of about 105 years and has a

https://doi.org/10.1017/S1743921304004685 Published online by Cambridge University Press

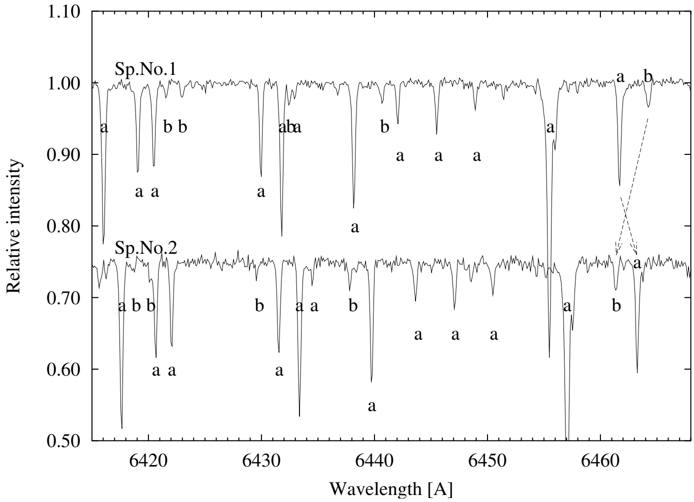

Figure 3. The spectrum of HD 108642 on two different nights. Its SB2 nature is demonstrated by the two line systems, "a" and "b", exchanging places between the first and the second night.

separation of less than one arcsecond. In addition there is an optical C companion, a faint 10.7 star, 28 arcseconds away. Data about the projected rotational velocity of the primary component are a bit controversial. While Walker (1966) measured 50 km s^{-1}, Abt & Morell (1995) determined 46 km s^{-1}, but Abt & Moyd (1973) reported 35 km s^{-1}. Orbital elements come from Abt & Levy (1985): $P = 24.1635$ days, $e = 0.2$, and $K = 10.1$ km s^{-1}. Photographic spectra with a dispersion of about 17 Å mm^{-1} were used.

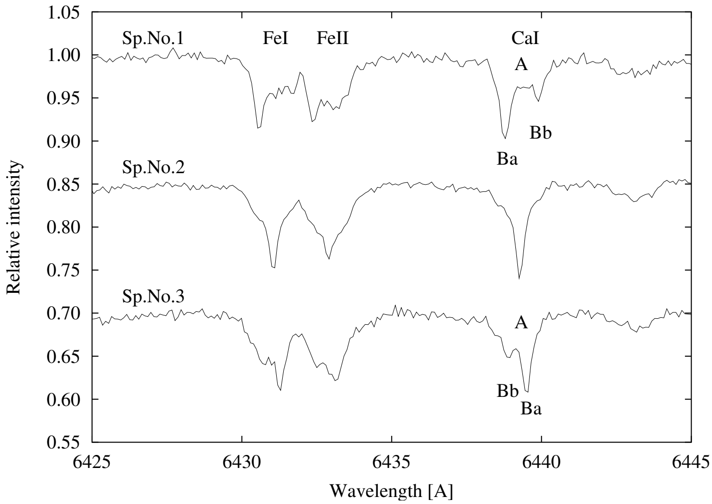

Figure 4. Three successive spectra of HD 216608. Note that while both sharp components marked with Ba and Bb apparently exchange their places due to orbital motion, the wide and shallow lines marked with A do not move.

Our observations of HD 216608 (Iliev *et al.* 2001b) disclose variable spectra that include three line systems. Fig. 4 illustrates how the spectrum changes on three successive nights. A "first sight" interpretation would assign the sharp moving details to the SB1 system HD 216608, while the broad lines could belong likely to the B companion. But the A component is brighter and hotter than the B component, and it is unlikely that its lines would be much sharper. Although well-determined these sharp lines make only a small contribution to the total equivalent width of the ternary blends. This is true especially for the iron lines. The most plausible explanation is that the sharp details belong to the visual B component which seems to be a newly discovered SB2 system HD 216608B. Thus, the wide lines obviously originate from the A component. Synthetic spectrum calculations confirm our suggestions. The mass-ratio $M_{Ba}/M_{Bb} = 1.4$, and the $v \sin i$ values of the A, Ba, and Bb components are 43, 9, and 5 $\mathrm{km\,s^{-1}}$, respectively. Sharp Ba and Bb lines are heavily blended with the broad lines of the primary, thus affecting all foregoing radial velocity measurements made at low resolution. Orbital elements of the system, previous mass estimates, and the SB1 nature of the HD 216608A have to be revisited as well.

3.5. *HD 178449*

17 Lyr (HD 178449, HIP 93917, $m_V = 5.2, v \sin i = 125$ $\mathrm{km\,s^{-1}}$) is a SB1 system, the primary component of ADS 12061. Component B is a 9.1 star 4 arcseconds away from A. The first orbital elements were by Abt & Levy (1976), but they were wrong and the data were analyzed by Dworetsky (1983). Abt & Morell (1995) classified HD 178449 as a mild Am star. It was in our initial target list mainly to test the synthetic spectrum analysis procedures at higher rotational velocities. During the observations we found it extremely interesting and observed it frequently. Very weak sharp absorption details in the bottom of many spectral lines are probably the most intriguing features in its spectrum (Fig. 5). Budaj & Iliev (2003) reported that both the broad and the sharp line systems did not change their radial velocities during the observations (22 months time span) within an error window of $1\sigma \sim 1.5$ $\mathrm{km\,s^{-1}}$. The sharp details are constantly shifted blueward by about 5 $\mathrm{km\,s^{-1}}$.

Three possibilities for the origin of these sharp details are: 1) interstellar, 2) shell (circumstellar), and 3) secondary companion. The first possibility can be eliminated as many sharp lines originate from excited energy levels. To check for a shell we made special observations in the spectral region containing the Ca II K, Ca II H, and Ti II 3913 Å lines. No shell patterns have been found. A further argument against the shell nature of these details is that HD 178449 is rather cool. A stellar origin of the details can be suggested as there are no sharp Fe II lines. Only Ca I and Fe I lines can be seen in Fig. 5. Synthetic spectrum calculations clearly show that the sharp additional spectrum can be reproduced fairly well if a $T_{\mathrm{eff}} = 5000\,\mathrm{K}, \log g = 4.5$, and solar abundance atmosphere for the secondary is assumed. This corresponds to a G-dwarf star which is about 4.2 fainter than the primary at 6450 Å. With this model we can conclude that the secondary would be 4.4 fainter in V, and 4.7 fainter at 3920 Å. It would be very difficult to detect such weak lines if the photographic plates are used. What if the secondary spectrum is produced by visual B component? It is 3.9 fainter and has small angular separation that probably could contaminate the spectrum of the primary. We think this is not the case. If we assume a circular orbit, then the orbital period could be at least 1200 years, but the largest radial velocity difference would be less than we observe. Assessing carefully all arguments we conclude that the weak sharp lines belong to the newly found spectroscopic component of the system.

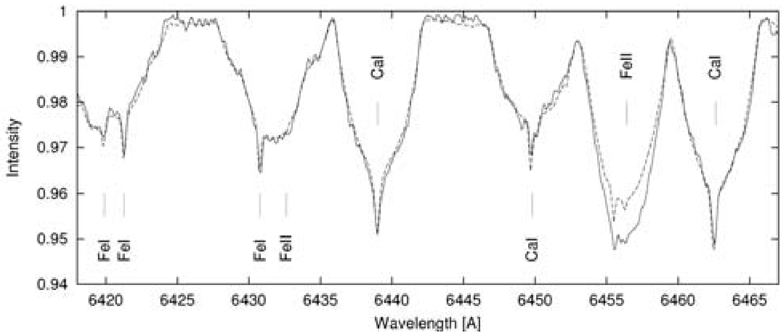

Figure 5. Observed (solid line) and computed (dashed line) spectra of HD 178449.

Acknowledgements

II and IS acknowledge the support provided by the SOC and the LOC of the Symposium. JB gratefully acknowledges grant support from Penn State University (NSF-NATO fellowship: NSF DGE-0312144) and partial support by the VEGA grant No. 3014 and the Science and Technology Assistance Agency under the contract No. 51-000802.

References

Abt, H.A., Levy, S.G. 1976, *ApJS*, 30, 273
Abt, H.A., Levy, S.G. 1985, *ApJS*, 59, 229
Abt, H.A., Morell, N.I. 1995, *ApJS*, 99, 135
Abt, H.A., Moyd, K.I. 1973, *ApJ*, 182, 809
Abt, H.A., Willmarth, D.W. 1999, *ApJ*, 521, 682
Acker, A. 1971, *A&A*, 14, 189
Budaj, J. 1996, *A&A*, 313, 523
Budaj, J. 1997, *A&A*, 326, 655
Budaj, J., Iliev, I.Kh. 2003, *MNRAS*, 346, 27
Budaj, J., Iliev, I.Kh., Barzova, I.S., Žižňovský, J., Zverko, J., Stateva, I. 2003, *IBVS*, 5423
Budaj, J., Iliev, I.Kh., Feňovčík, M., Barzova, I.S., Richards, M.T., Geordzheva, E. 2004, *IBVS*, 5509
Budaj, J., Komžík, R. 2000, `http://www.ta3.sk/~budaj/software`
Debernardi, Y., Mermilliod, J.-C., Carquillat, J.-M., Ginestet, N.J. 2000, *A&A*, 354, 881
Dworetsky, M.M. 1983, *MNRAS*, 203, 917
Feňovčík M., Budaj., I., Iliev, I., Richards, M.T., Barzova, I. 2005, *These Proceedings*, FP20
Hube, D.P., Gulliver, A.F. 1985, *JRASC*, 79, 49
Iliev, I.Kh., Budaj, J., Zverko, J., Barzova, I.S., Žižňovský, J. 1998, *A&AS*, 128, 497
Iliev, I.Kh., Budaj, J., Zverko, J., Žižňovský, J. 2001a, *IBVS*, 5051
Iliev, I.Kh., Budaj, J., Žižňovský, J., Zverko, J., Stateva, I., Geordzheva, E. 2001b, *IBVS*, 5199
Landstreet, J.D. 1998, *A&A*, 338, 1041
North, P., Ginestet, N., Carquillat, J.-M., J., Carrier, F., Udry, S. 1998, *CAOSP*, 27, 179
Shorlin, S.L.S., Wade, G.A., Donati, J.-F., Landstreet, J.D., Petit, P. *et al.* 2002, *A&A*, 392, 637
Sreedhar Rao, S., Abyhankar, K.D. 1992, *MNRAS*, 258, 819
Walker, E.N. 1966, *The Observatory*, 86, 154

Discussion

Dworetsky: It is good to see such intensive detective work on stars that appeared to be well-determined. It shows how important these sorts of efforts can be. I expect to see many more such discoveries in the not-to-distant future.

https://doi.org/10.1017/S1743921304004685 Published online by Cambridge University Press