H_α observations of the W UMa star FI Boo

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Abstract. We obtained a new radial velocity solution of FI Boo on the basis of H_α observations. The analysis of our observations reveals that: (a) the two component of FI Boo are considerably oversized for their masses in respect to the mass-radius relation for MS stars and the binary has near-contact configuration; (b) the mass of the secondary star is quite small for its temperature; (c) presence of transient compact source of H_α absorption which contribution does not correlate with the orbital phase.
Key words: stars, double, eclipsing, spectral

H_α наблюдения на W UMa-тип звездата FI Boo

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В статията е представено ново решение на кривата на лъчевите скорости на звездата FI Boo, получено на базата H_α наблюдения. Анализът на нашите наблюдателни данни показва, че: а) двете компоненти на FI Boo имат размери, които значително надвишават тези на звездите от ГП със същите маси; б) масата на вторичната компонента е твърде малка за нейната температура; в) има компактен източник на H_α absorption, приносът на който не е свързан с орбиталната фаза.

Introduction

The W UMa-type binaries provide good tests for the processes of mass transfer, mass loss and angular momentum loss at the late stellar evolution. In order to realize these possibilities accurate fundamental stellar parameters of the close binaries should be available, especially the mass ratios, provided by their spectral study.

The W UMa-type binary FI Boo (HD 234224, HIP 75203) was assumed as a new discovery from the Hipparcos mission (ESA 1997) with a period of 0.195 days although earlier Duerbeck (1977) reported for the EW nature of its light curve and included the star in the list of possible contact binaries.

The Hipparcos parallax 9.52 mas of FI Boo yields a distance 105 pc. Its visual magnitude $V_{max} = 9.57^m$ (Hog et al. 2000) lead to an absolute magnitude $M_V = 4.41^m$ of the system.

Spectroscopic observations by Lu et al. (2001) showed FI Boo to be a double-lined spectroscopic binary with spectral type G3V, mass ratio q=0.37 and a period of 0.39 days. Thus the spectroscopic period turned out twice of the Hipparcos period.

The small amplitude of 0.15^m of the FI Boo light curve (ESA 1997) suggested a low orbital inclination and a grazing eclipses. Selam (2004) modelled Hipparcos photometry of FI Boo with orbital inclination $i = 45^0$, mass ratio q=0.35 and W-subtype configuration. However, Terrell et al. (2006) performed simultaneous analysis of their UBVRI photometry, the Hipparcos photometry and the Lu et al. (2001) radial velocity data and established an A-subtype of FI Boo.

The observed photoelectric minima of FI Boo (Pribulla et al. 2002, Karska & Maciejewski 2003, Pribulla et al. 2005, Hubscher et al. 2005, Krajci 2005, Hubscher 2007) allowed improving of its ephemeris.

The kinematic data of the star are: X=7 pc; Y=63 pc; Z=84 pc; U=-33 km/s; V=-20 km/s; W=-21 km/s (Bilir et al. 2005).

D'Angelo et al. (2006) detected a faint third component in the FI Boo spectra with the flux ratio f_3/f_{12}=0.012 and mass ratio M_3/M_{12}=0.31.

One of the goals of our study of FI Boo was to find the reason for the discrepancy of its subtype (W or A). We aimed also to obtain a new radial velocity solution and to search for appearances of chromospheric activity and/or third component in the H_α spectra.

1 Observations

We obtained 40 spectra of FI Boo in the spectral range around the H_α line (6470-6670 A) with resolution 0.19 A/pixel (R=35000). We used a CCD Photometrics AT200 camera with the SITe SI003AB 1024x1024 pixels chip mounted on the Coude spectrograph (grating B&L632/14.70) on the 2-m telescope of the National Astronomical Observatory at Rozhen. The exposure time was 15 min. We used β Vir as a radial velocity standard.

The bias frames and flat-field integrations were obtained at the beginning and at the end of each night. All stellar integrations were alternated with Th-Ar comparison source exposures for wavelength calibration. The spectral data were reduced in a standard way using the PCIPS (Smirnov & Piskunov 1995) software packages by bias substraction, flat-field division and wavelength calibration.

Our data were phased according to the spectroscopic ephemeris of Lu et al. (2001)

$$HJD(MinI) = 2451718.3951 + 0.389998 * E. \qquad (1)$$

The normalized spectra of FI Boo from 2007 are shown in Figs. 1-2.

2 Analysis of the spectra

Figures 1-2 illustrate the orbital variations of the spectra of FI Boo. The H_α line is the strongest line in our observational range. The depths and widths of the H_α profiles of the two components are close. Initially we will call "primary" the star that is eclipsed at phase 0.0 according to the ephemeris (1).

We noted two peculiarities of the H_α profiles.

(a) The H_α line at phase 0.98 on August 7 2007 is very deep while the rest lines are even shallower (Fig. 1). In order to check if this behavior is permanent we obtained 3 additional spectra at the primary minimum of FI Boo on May 27 2008 (Table 1). They revealed that the depth of the H_α line at the same phase 0.98 was around 2 times smaller than in August 2007 while the depths of the rest lines were the same or even bigger (Fig. 3). This means

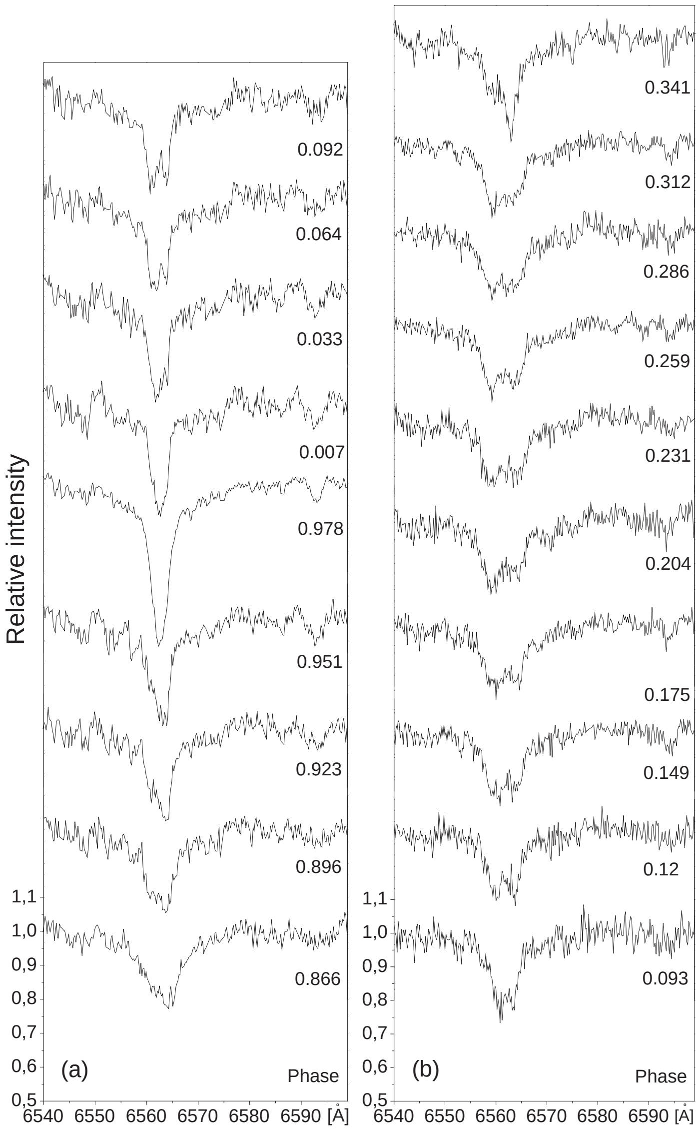

Fig. 1. The spectra of FI Boo from (a) August 7 2007; (b) December 21 2007

that the big H_α absorption on August 7 2007 does not correlate with the orbital phase. The third component in FI Boo detected by D'Angelo et al. (2006) might be the additional compact source of H_α absorption.

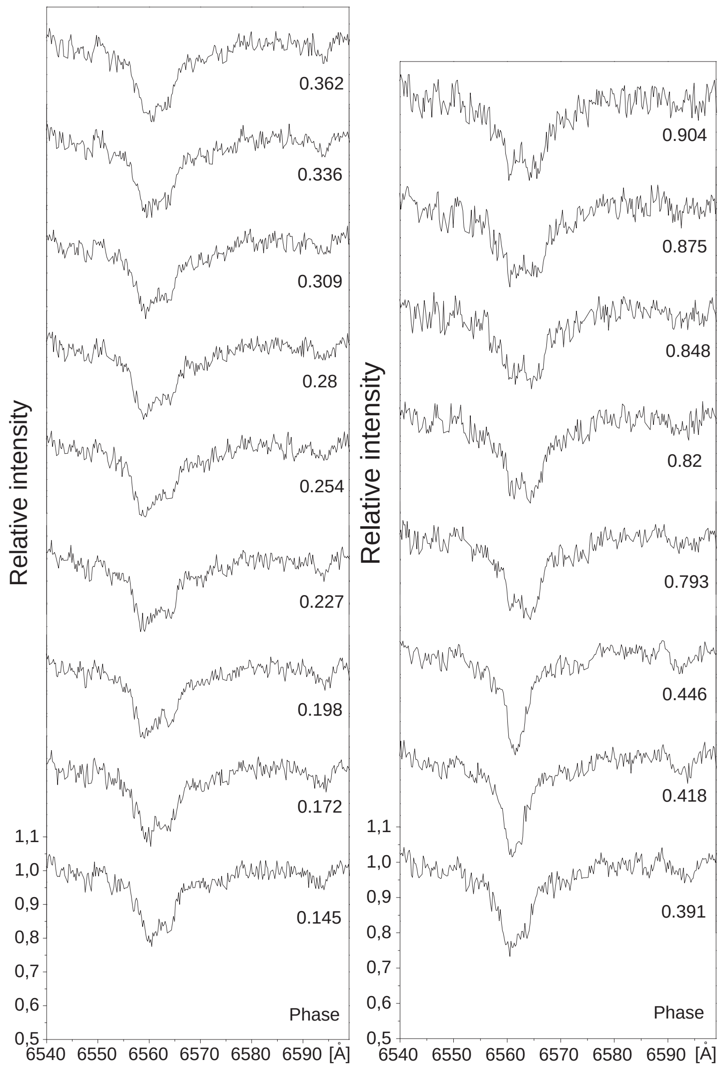

Fig. 2. The spectra of FI Boo from August 8 2007

(b) The depth of the secondary's H_α line increased near 2 times while the primary's H_α line weakened at phase 0.34 on December 21 2007 (Fig. 1).

To perform measurement of the radial velocities of FI Boo we fitted the H_α profiles (mainly from Aug 8 2007 because they cover almost whole cycle) with sums of two Lorenzians (Fig. 4). The obtained values are plotted in Fig. 5. They were fitted by sinusoids with semi-amplitudes K_1^i =

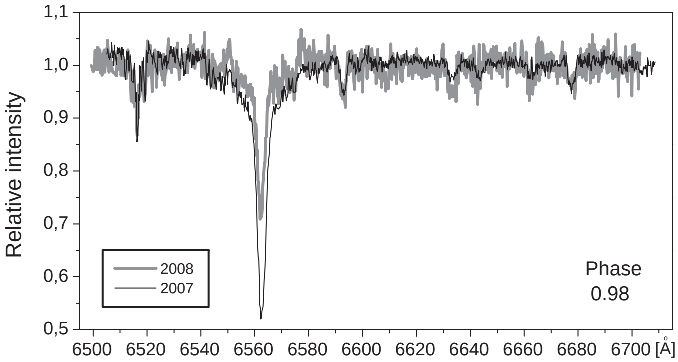

Fig. 3. The different depth of the H_α line of FI Boo at the same phase in 2007 and 2008

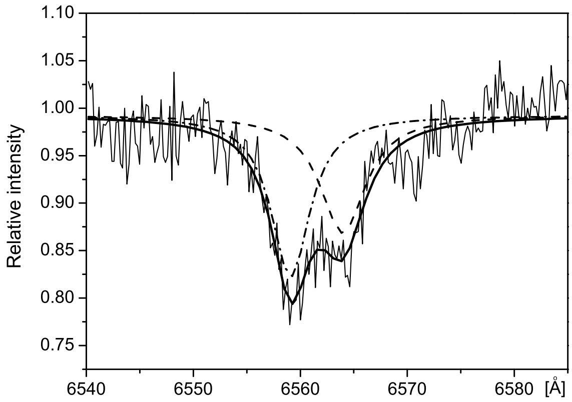

Fig. 4. The fitting of the H_α profiles by sums of two Lorenzians

$V_1^{orb} sin i$=148.9±2.1 km/s, $K_2^i = V_2^{orb} sin i$=57.1±1.9 km/s and $V_0 = -27.9\pm2.3$ km/s (the superscript i corresponds to the initial ephemeris (1). On the basis of obtained semi-amplitudes we calculated $a \sin$=1.59±0.02 $R_\odot$ and $(M_1 + M_2) sin^3 i = 0.351 \pm 0.015 M_\odot$.

Our radial velocity solution is quite close to that of Lu et al. (2001) which values are K_1=148.65 km/s, K_2=55.27 km/s, $V_0 = -30.6$ km/s. Taking into account that the two radial velocity solutions use the same ephemeris (1) we should confirm the conclusion of Lu et al. (2001) about the W subtype of FI Boo (the less massive star is eclipsed at the primary minimum).

However one should remember that the determination of the subtype of the W UMa stars is difficult when the two eclipses have almost equal depths, as in the case of FI Boo. We noted that Selam (2004) used the spectroscopic ephemeris (1) to fit the Hipparcos light curve with slightly deeper primary

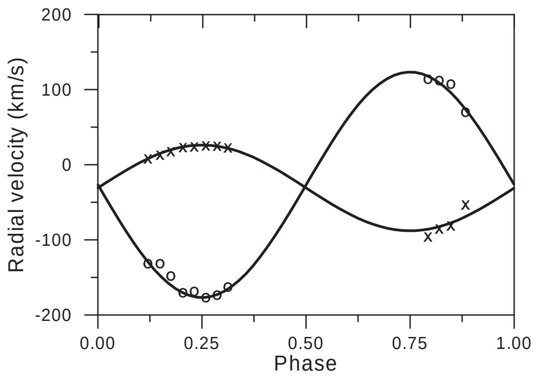

Fig. 5. Radial velocity curves of FI Boo and their fits

eclipse (depths 0.094 and 0.093 in light units) while Terrell et al. (2006) derived a new ephemeris of FI Boo

$$MinI = 2453142.0857 + 0.38999879 * E \tag{2}$$

on the basis of their photometric BVI data. The new ephemeris reversed the identities of the primary and secondary eclipses of the previous studies. This explains the phase shift of 0.5 of the radial velocity curve of Lu et al. (2001) showed in Fig. 4 of Terrell et al. (2006) as well as their conclusion that FI Boo is an A-subtype W UMa system.

According to the ephemeris (2) we renumbered the stellar components and correspondingly obtained K_2=K_1^i = 148.9± 2.1 km/s and K_1=K_2^i = 57.1±1.9 km/s. The determined mass ratio $q = M_1/M_2 = K_2/K_1$=0.384±0.01 is in the middle of the mass ratio range q=0.2-0.5 for the W UMa stars and corresponds to A-subtype of the binary.

3 Global parameters and activity

To determine the global parameters of FI Boo we need the orbital inclination from the light curve solutions. There were two close values of this parameter in the literature: i=45^0 of Selam (2004) and i=43.1^0 of Terrell et al. (2006).

We tried to reproduce the eclipse depths of the photometric observations of Terrell et al. (2006) using our q=0.384 and their parameters T_1=5528 K, T_2=5119 K, r_1=0.47, r_2=0.30. Our tests revealed that the best fit corresponds to orbital inclination i=47.5^0.

Using this value we determined a=2.15±0.03 $R_{\odot}$; M_1=0.635±0.02 $M_{\odot}$; M_2=0.24±0.02 $M_{\odot}$; R_1=1.01±0.02 $R_{\odot}$; R_2=0.65±0.03 $R_{\odot}$; $g_1/g_{\odot}$=0.62±0.03; $g_2/g_{\odot}$=0.57±0.03; L_1=0.85±0.02 $L_{\odot}$; L_2=0.26±0.03 $L_{\odot}$.

These values of the global parameters reveal that: (a) the masses of the components are quite small for their temperatures (especially for the secondary star) that implies mass loss from the system; (b) the components of

FI Boo are considerably oversized for their masses in respect to mass-radius relation for MS stars (especially for the secondary star) indicating that the system is evolved; (c) the binary configuration is almost contact.

The measured mean rotational broadenings of the H_α lines of the two components of FI Boo correspond to equatorial velocity V_1^{rot}=124 km/s and V_2^{rot}=105 km/s. The fast rotation is the natural consequence of spin-orbit synchronization due to strong tidal interactions between the components of the W UMa stars.

The big rotational velocity is requirement for a high star activity. The comparison of the profiles and depths of the H_α lines of FI Boo with those of nonactive stars of the same spectral type reveal that they are filled-in. This is sign of the chromospheric activity of the stellar components.

We calculated the orbital angular momentum of the target by the expression (Popper 1977)

$$J_{rel} = M_1 M_2 P^{1/3} (M_1 + M_2)^{-1/3} \tag{3}$$

where P is in days and M_i are in solar units.

The obtained value $\log J_{rel}$=-0.94 of FI Boo is not only considerably smaller than those of the RS CVn binaries and detached systems which have $\log J_{rel} \geq$+0.08 but it is also smaller than those of the contact systems which have $\log J_{rel} \geq -0.5$.

The small orbital angular momentum of FI Boo implies existence of past episode of angular momentum loss during the binary evolution after MS as a result of the period decrease or/and mass loss. This conclusion is supported by its oversized components. Though the unusual small mass of the secondary of FI Boo remains quite exotic peculiarity of this binary.

Another explanation of the small orbital angular momentum of FI Boo is existence of third component. Firstly the presence of a tertiary of FI Boo is suspected from the stochastic residuals in Hipparcos measurements. In fact the Hipparcos parallax error increases if an unseen component causes a transverse motion of the star on the sky. Pribulla & Rucinski (2006) assumed the parallax error of FI Boo as indicator of multiplicity of contact binary. The Hipparcos astrometric solution of FI Boo showed unexplainable jitter indicating a possible short period of triple.

Conclusion

The main results of our high-resolution H_α observations of the W UMa-type star FI Boo might be summarized as follows.

(1) The radial velocity solution of our data together with a fitting of the light curve of Terrell et al. (2006) lead to the following global parameters of the system: M_1=0.74 $M_\odot$; M_2=0.26 $M_\odot$; R_1=1.03 $R_\odot$; R_2=0.66 $R_\odot$; a=2.18 $R_\odot$; V_1^{rot}=124 km/s; V_2^{rot}=105 km/s.

(2) The two component of FI Boo are considerably oversized for their masses in respect to the mass-radius relation for MS stars and the binary has near-contact configuration. The mass of the secondary star is quite small for its temperature.

(3) The obtained value log J_{rel} =-0.94 of FI Boo is considerably smaller than those of the RS CVn binaries and detached systems which have log $J_{rel} \geq$+0.08. The orbital angular momentum of FI Boo is smaller even than those of the contact systems which have log$J_{rel} \geq$ -0.5.

The small orbital angular momentum of FI Boo implies existence of past episode of angular momentum loss during the binary evolution as a result of the period decrease. It means also that FI Boo is past-MS object. This means that the orbital period of FI Boo is stable.

(4) Our spectra show presence of transient compact source of H_α absorption which contribution does not correlate with the orbital phase.

Acknowledgements

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Fig. 6. A view to Shumen and to the hill of the monument "1300 Years Bulgaria" from the terrace of the University Astronomical Center

Fig. 7. Nikola Petyrov, Joanna Kokotanekova and Dimitar Kokotanekov on the terrace of the University Astronomical Center

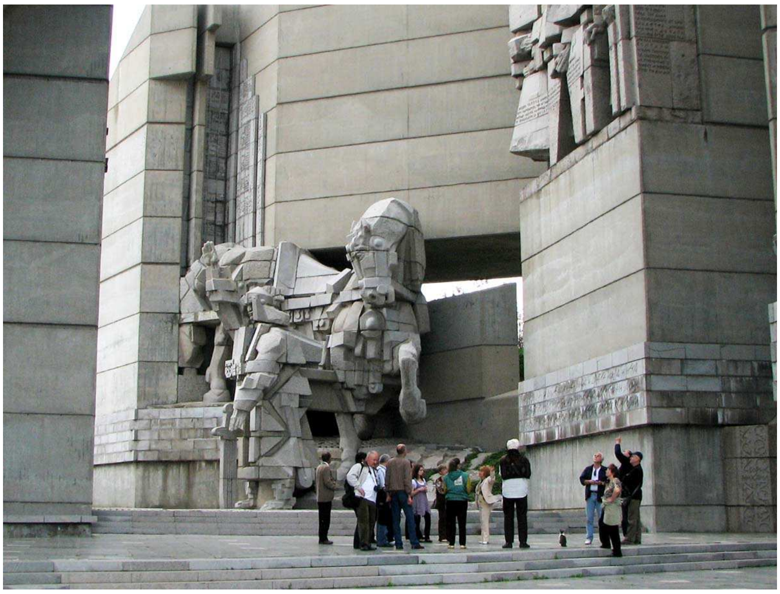

Fig. 8. At the pedestal of the monument "1300 Years Bulgaria"

Fig. 9. At the pedestal of the monument "1300 Years Bulgaria"