*Magnetic Stars, 2011, pp. 366 – 373*

# Spectral Variability of the Be Star HD 152478: Evidence for Magnetized Wind?

**Pogodin M. A.**[1], **Drake N. A.**[2], **Jilinski E. G.**[1,3,4], **Ortega V. G.**[3], **de la Reza R.**[3]

[1] Pulkovo Observatory, St. Petersburg, Russia
[2] Sobolev Astronomical Institute, St. Petersburg State University, St. Petersburg, Russia
[3] Observatório Nacional/MCT, Rio de Janeiro, Brazil
[4] Instituto de Física, Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brasil

**Abstract.** Results of a spectroscopic investigation of the southern Be star HD 152478 are presented. Five spectra of the object were obtained in 2007 – 2009 with the high–resolution ($R = 48\,000$) FEROS spectrograph installed at the 2.2–m telescope of the European Southern Observatory (ESO) in Chile. Notable variations of line profiles have been found for a number of elements (H I, He I, Fe II, etc.). The analysis of the variability has shown that the widely accepted hypothesis of "one–armed perturbation" drifting in the equatorial gaseous disk is not confirmed by the observations. We suggest an alternative interpretation of the observed variability in the assumption of a variable magnetized stellar wind of flattened geometry, flowing close to the equatorial disk.

**Key words:** Stars: Be: circumstellar matter – stars: spectroscopy – stars: individual: HD 152478

## 1 Introduction

The southern Be star HD 152478 was included in the program of identification and investigation of possible past supernovae events, taking place in the region of the Scorpius–Centaurus OB association (Hoogerwerf et al., 2001). According to a later spectroscopic study by Jilinski et al. (2010), this object may be considered as an eventual runaway star.

Nevertheless, this Be star demonstrates an unusual spectral behaviour. The goal of the present study was to investigate the spectroscopic activity of this star seen in a number of spectral lines.

In this report we consider the large–scale profile variability, observed in the optically–thick H$\alpha$ and H$\beta$ lines, and in several optically–thin Fe II lines.

## 2 Observations

Five high–resolution spectra were obtained in 2007 – 2009 using the echelle Fiber–fed Extended Range Optical Spectrograph (FEROS) installed at the 2.2–m telescope of ESO at La Silla, Chile. The FEROS spectral resolution is $R = 48\,000$, and the wavelength coverage is from 3600 Å to 9200 Å. The typical $S/N$ ratio was from 100 to 200 depending on the spectral region. The times of observations are given in Table 1.

Table 1: Observing dates

| N | Date | MJD |
|---|---|---|
| I | June 2, 2007 | 54253.162 |
| II | Feb 23, 2008 | 54519.356 |
| III | May 25, 2008 | 54611.154 |
| IV | May 14, 2009 | 54965.118 |
| V | July 28, 2009 | 55040.982 |

## 3 Spectral Classification

We used the echelle spectra of the object to improve its former spectral classification, published by Levenhagen & Leister (2006). Contrary to these authors, who used a rather limited number of observational criteria, we analyzed a series of spectral parameters, such as:

- profiles of a number of helium lines in the blue part of the spectrum;
- numerous blends of such elements as ionized O, Fe, Si, etc.;
- wide absorption wings of the Balmer lines, free from the circumstellar (CS) influence.

Synthetic spectra, calculated with the code of Piskunov (1992), based on the LTE models of stellar atmospheres of Kurucz, were used for comparison with the observed spectra. Results of our estimates as well as the model parameters of Levenhagen & Leister (2006) are given in Table 2.

Table 2: Parameters of the atmosphere

| Model | $T_{\rm eff}$ (K) | $\log g$ | $v \sin i$ (km/s) |
|---|---|---|---|
| Former result | 19 800 | 3.75 | 295 |
| Our result | 25 000 | 4.25 | 370 |

According to our estimates, the star is considerably hotter and rotates more rapidly than recognized earlier. In addition to that, a notable He overabundance has been found. In the first approximation, the excess of He abundance is about $[\mathrm{He/H}] = +0.35$. A more accurate determination of this parameter requires an application of a specific model of stellar atmosphere taking into account the anomalous He abundance.

The results of our spectral study of HD 152478 speak in favor of the assumption that this object can be a runaway star, ejected from a binary as a result of a supernova outburst. According to Hoogerwerf et al. (2001), runaways would have enhanced helium abundances and large rotational velocities.

## 4 Variability of Line Profiles

The temporal behaviour of the H$\alpha$ profile is shown in Fig. 1. Four fragments illustrate the profiles, observed on dates II − V, as compared with the double–peaked and symmetric profile, obtained on date I (dotted line). The synthetic atmospheric profile is also given in this Figure (marked by the

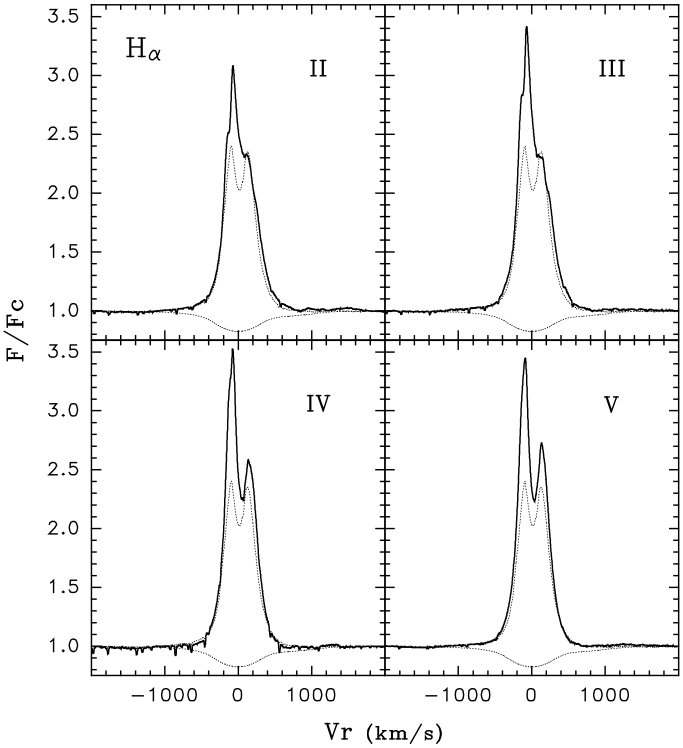

Figure 1: Normalized Hα profiles for dates I−V. The profile for date I is shown by the dotted line.

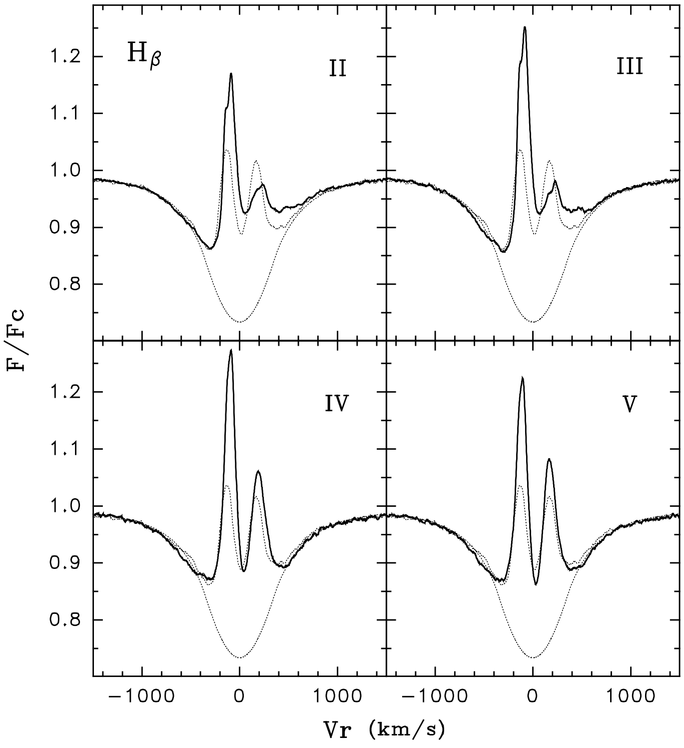

Figure 2: The same as in Fig. 1 but for Hβ line profiles

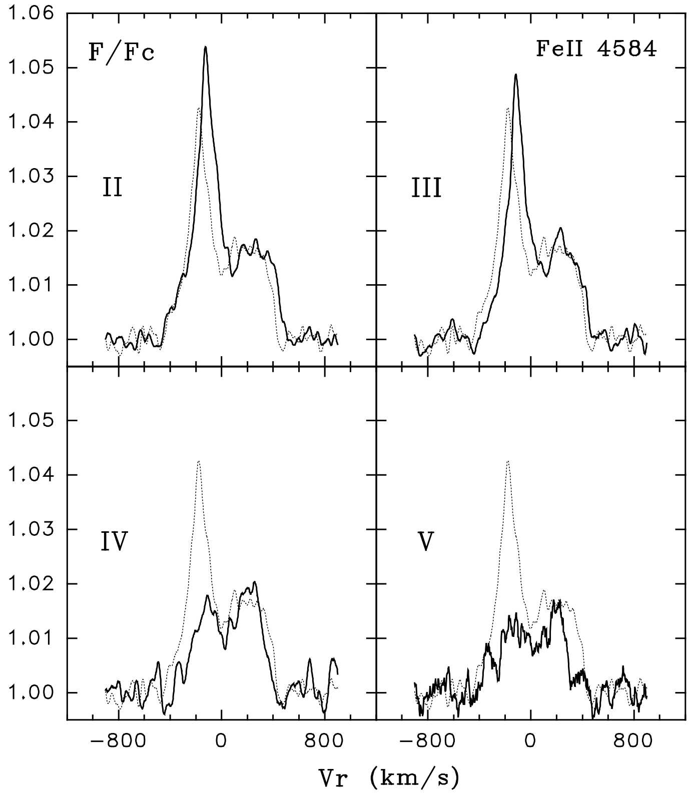

Figure 3: The same as in Fig. 1 but for the Fe II 4584 Å line profile

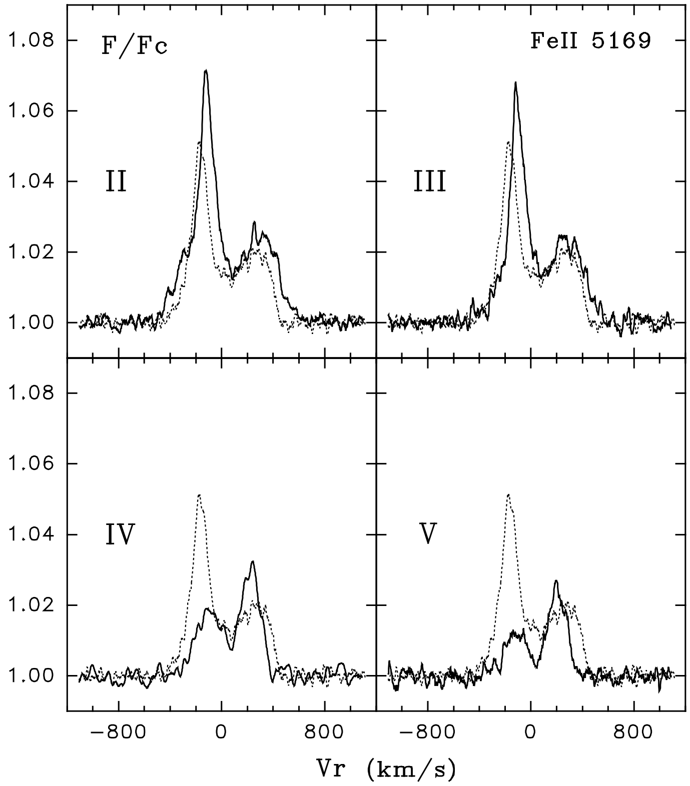

Figure 4: The same as in Fig. 1 but for the Fe II 5169 Å line profile

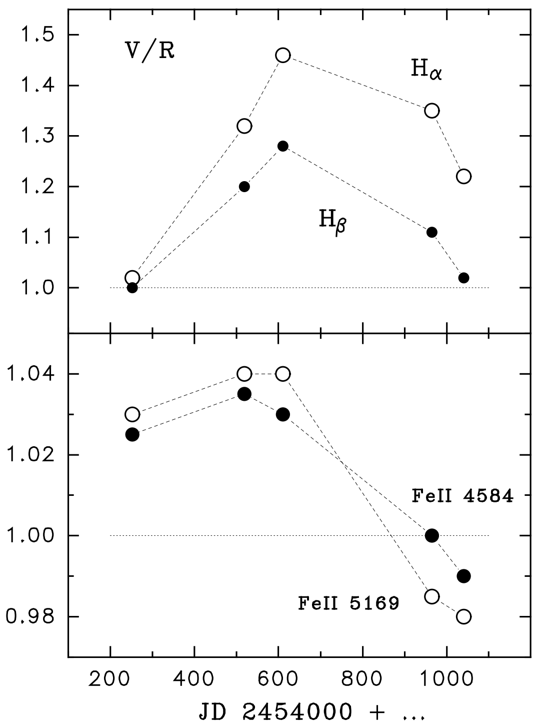

Figure 5: The $V/R$ ratio variations observed in the Balmer and the Fe II lines

dotted line too). One can see that on dates II and III, the emission profile becomes very asymmetric. The blue peak increases strongly in intensity, and the red wing shows an increase in its extension. In turn, on dates IV and V the red emission peak starts to rise, while the red wing again looks as on date I.

Temporal behaviour of the H$\beta$ line profile is similar to the behaviour of the H$\alpha$ profile (see Fig. 2).

However, the character of the variations observed in the optically–thin Fe II lines is quite different. The emission profiles of these lines are asymmetric already on date I with the blue peak being of greater intensity, than the red one. On dates II and III, the profiles remain approximately the same, but on dates IV and V the line intensity decreases, and the blue peak becomes even lower than the red one. As an example, this variability is illustrated in Figs. 3 and 4 for the Fe II $\lambda$ 4584 and $\lambda$ 5169 Å lines.

## 5 Possible Interpretations of Spectral Behaviour

The variability observed in HD 152478 is typical for a classical rapidly rotating Be star. In recent times, a prominent change of the $V/R$ ratio is most commonly interpreted as a result of a drift of the so–called one–armed perturbation, arising in the equatorial gaseous disk. According to the theory of global oscillations in disks of classical Be stars, large–scale density and velocity inhomogeneities can be formed in the disk, which is not co–rotating with the gas, but is a precessing retrograde with a period of several years (Kato, 1983; Okazaki, 1991). Its drifting modulates the profiles of CS lines, and a cyclic $V/R$ ratio variability is observed.

In the paper of Hanuschik et al. (1995) it has been shown that:

- the $V/R$ ratio variability takes place in the same phase in the optically–thick H$\alpha$ and H$\beta$ lines, as well as in optically–thin Fe II lines;

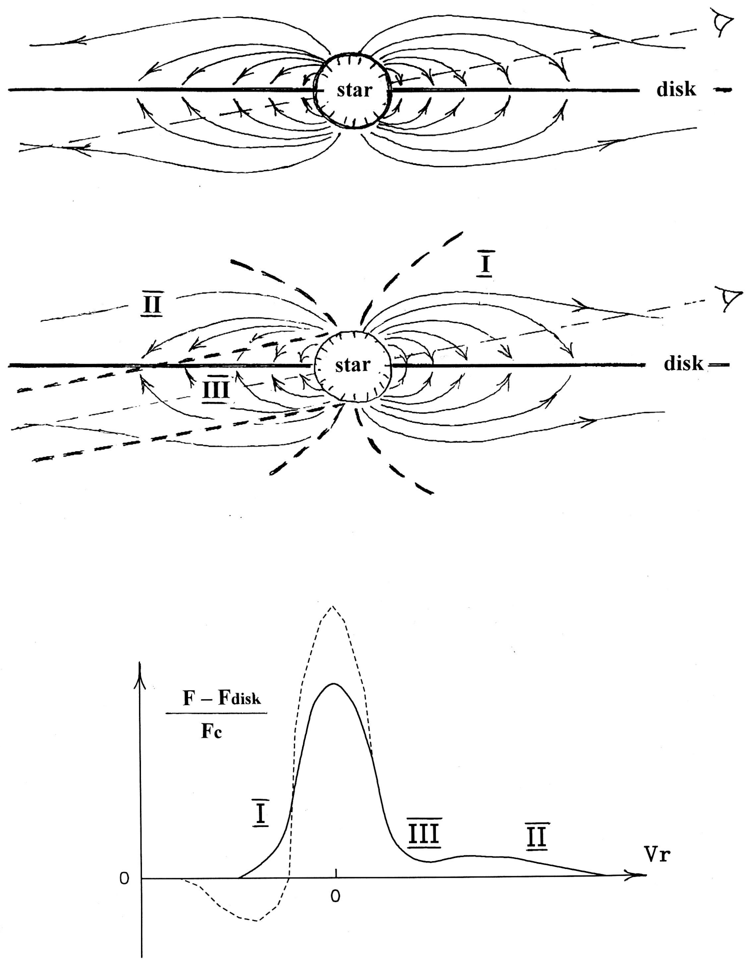

Figure 6: A simplified scheme of the geometric structure of a magnetized stellar wind (Porter, 1997) corresponding to the field $B = 100\,\mathrm{G}$ (*top*), and the expected profile of an emission line, formed in this wind (*bottom*)

- these variations are not followed by any changes of the equivalent width (EW) of emission lines.

As seen in Fig. 5, the $V/R$ ratio, observed in the Balmer and Fe II lines in the spectrum of HD 152478 shows variations, which can be assumed as corresponding to long–term cyclic variations, connected with the drifting of a large–scale perturbation. But they do not occur in the same phase. A phase shift is clearly seen here. The model of a drifting perturbation alone cannot explain this phenomenon. Moreover, the observed profile transformations are followed by a high–amplitude change in the EW (see Figures 1 − 4). Besides, these variations are not predicted by the oscillation theory either. Finally, on dates II and III, when the Balmer line profiles become very asymmetric, the red emission wing becomes very extended (up to 1800 km/s for H$\alpha$). Such high velocities cannot exist in a nearly–Keplerian disk. The maximum velocity of the rotating gas near the inner boundary of the disk is only 650 km/s for a typical B1 V star. On the other hand, such a large velocity can be achieved in a radiatively–driven stellar wind, flowing from a Be star at intermediate latitudes. This circumstance allows us to consider an alternative interpretation of the spectral behaviour of HD 152478 in the framework of the assumption of a variable stellar wind.

Some time ago it was shown that the Wind–Compressed Disk (WCD) theory of disk formation

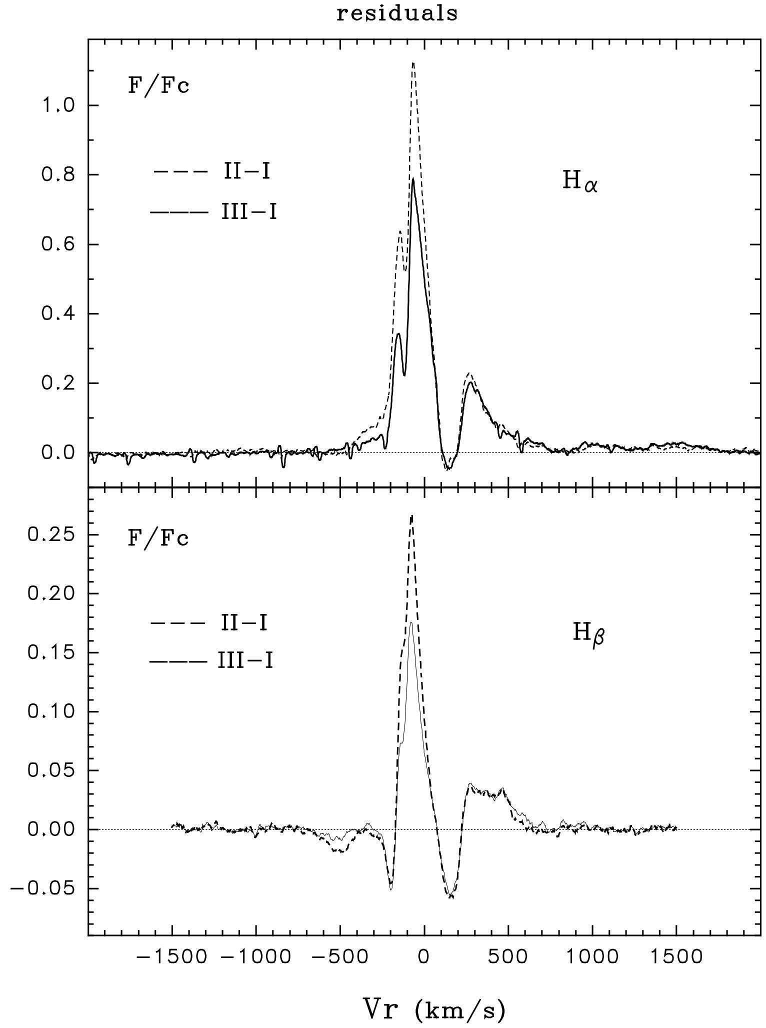

Figure 7: Residual H$\alpha$ and H$\beta$ profiles for dates II and III constructed by subtraction of the profiles for date I.

around Be stars (Bjorkman & Cassinelli 1993), together with a magnetic field of the order of 100 G introduced into the WCD model by Porter (1997) leads to a better agreement between the theory and the observational data of Be stars. It should be mentioned that such fields were already revealed in several classical Be stars, using the spectropolarimetric method (Hubrig et al., 2009). According to the calculations by Porter (1997), the wind zone, in the WCD model, in the presence of a magnetic field becomes flattened and concentrated towards the equator.

We tried to estimate the contribution of such a magnetized wind in the whole emission line profile. In general, this task is rather difficult. It requires model calculations with many free parameters describing physical and kinematical conditions in all regions of the CS gas, including the wind, the disk and the region of their interaction. Such a task cannot be solved without speculations. Nevertheless, we can estimate the wind contribution in a qualitative level.

Fig. 6 (*top*) schematically illustrates the geometric structure of the magnetized wind in projection on the plane, containing the rotation axis and the line of sight of the observer. Here the orientation of the object is close to “edge–on” taking into account the large $v \sin i$ (370 km/s) of HD 152478. The expected profile of an emission line formed in the wind is shown at the bottom of the figure. It is clear that the red wing of the profile is more intense and extended, than the blue wing because the optically thick gas, flowing towards the observer screens the star. Even a P Cyg–type structure would be expected in the blue wing. Besides, a local fall in intensity at moderate positive velocities can be expected in the red emission wing. This is connected with the fact that a considerable amount of the emitting gas, flowing outwards the observer is screened by the stellar limb. This effect can be significant in the case of flattened magnetized winds and negligible for a spherically symmetric geometry of the wind zone.

Fig. 7 shows the observational profiles of H$\alpha$ and H$\beta$ for dates II and III, corresponding to the wind contribution to the whole emission profile, obtained by simply subtracting the observed profile for date I. It is hereby assumed that namely on date I, the symmetric double-peaked profiles were formed mainly in the disk, and on dates II and III, the wind contribution was maximal. Actually, this procedure is not correct for an accurate quantitative analysis since: a) the disk contribution can be different in different observing dates; and b) the gas in the wind is not optically–thin in Balmer lines and the emission of the disk and the wind is not additive. Nevertheless, our goal here is only to reveal specific features of an emission line profile, expected for the magnetized wind contribution (see Fig. 6, *bottom*). One can see in Fig. 7, that the constructed residuals contain all the principal features expected for a flattened magnetized stellar wind.

Therefore, we are putting forward the assumption of a variable magnetized wind as a possible interpretation of spectral behaviour of HD 152478.

**Acknowledgements.** M. Pogodin would like to remark that his contribution to this work was sponsored by the Program of the Presidium of the RAS № 4, OFN RAS Program № 10104, RFBR (grant № 07–02–00535a) and Sci. School № 3645.2010.2. We also thank Dr. A. Tarasov of the Crimean Astrophysical Observatory for useful remarks during the discussion of our results.

## References

Bjorkman J. E., Cassinelli J. P., 1993, ApJ, 409, 429
Hanuschik R. W., Hummel W., Dietle O., Sutorius E., 1995, A&A, 300, 163
Hoogerwerf R., de Bruijne J. H. J., de Zeeuw P. T., 2001, A&A, 365, 49
Hubrig S., Schöller M., Savanov I., Yudin R. V., Pogodin M. A., Stefl St., Rivinius Th., Curé M., 2009, Astron. Nachr., 330, 708
Jilinski E. G., Ortega V. G., Drake N. A., de la Reza R., 2010, ApJ, 721, 469
Kato S., 1983, Pub. of the Astron. Society of Japan, 35, 249
Levenhagen R. S., Leister N. V., 2006, MNRAS, 371, 252
Okazaki A. T., 1991, Pub. of the Astron. Society of Japan, 43, 75
Piskunov N. E., 1992, in: Glagolevskij Yu. V., Romanyuk I. I. (eds), Proc. Int. Conf., "Stellar Magnetism", 92
Porter J. M.: 1997, A&A, 324, 597