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VARIABILITY OF THE He I 6678 EMISSION IN δ Sco

POLLMANN, ERNST

International Working Group ASPA, Emil-Nolde-Str. 12, 51375 Leverkusen, Germany

Introduction

δ Scorpii (HD143275, HR5953) is a 2.3 magnitude Be binary star whose binarity was discovered interferometrically by McAlister (1978). But its binary nature was first reported by Innes (1901). The star was first classified as a Be star when it showed an emission profile on the wings of an absorption core of a spectrum taken in 1990 by Coté & van Kerkwijk (1993) and is now considered to be a typical B0.3 IV star.

This binary system with its large eccentric orbit ($e > 0.9$) (Tango et al. 2009) exhibits a strong mass loss that has resulted in a circumstellar gaseous disk formation. He I lines are good tracers of matter very close to the star, where temperature and density are the highest and ionisation is the strongest. The He I 6678 line profile of δ Sco suggests that one sees some optically-thick outflow and a lot of matter in the line of sight. The outflow should add more mass to the disk and as a result, the disk will gradually grow outwards. This is very interesting since the inclination angle of the circumstellar disk is about 45°[36°, Miroshnichenko et al. (2013); 38°± 5°Miroshnichenko et al. (2001); 48.5°± 6.6°Hartkopf et al. (1996); 70°, Bedding (1993)].

During each periastron (period = 10.8 years) some ring material may flow from the primary's Roche lobe into the secondary's Roche lobe. During that process the disk becomes denser and single-, double- or triple peak profiles may be observable. Outside of each periastron the He 6678 line is emitted in an extended rotating elliptical disk or ring around the central star, where the ring is not centered on the central star.

The situation might be more complex since the companion is triggering the disk/ring formation or destruction through tidal effect on the circumstellar disk/ring. There seems to be two physical effects going on in δ Sco: one is the ejection of material from the photosphere, the other is the formation of "blobs" of gas in the disk or ring(s) probably from viscosity effects. The blobs rotate in a more or less Keplerian mode, eventually to fall back closer to the star (Miroshnichenko, personal communication 07/2004).

As to further studies of the physical properties of δ Sco's disk, I refer to the following important publications: Properties of the δ Sco circumstellar disk from continuum modelling, Carciofi et al. (2006); Disk geometry and kinematics before the 2011 periastron, Maillard et al. (2011); Imaging disk distortion of Be binary system δ Scorpii near periastron, Che et al. (2012); The circumstellar disk evolution after the periastron, Meilland et al. (2013).

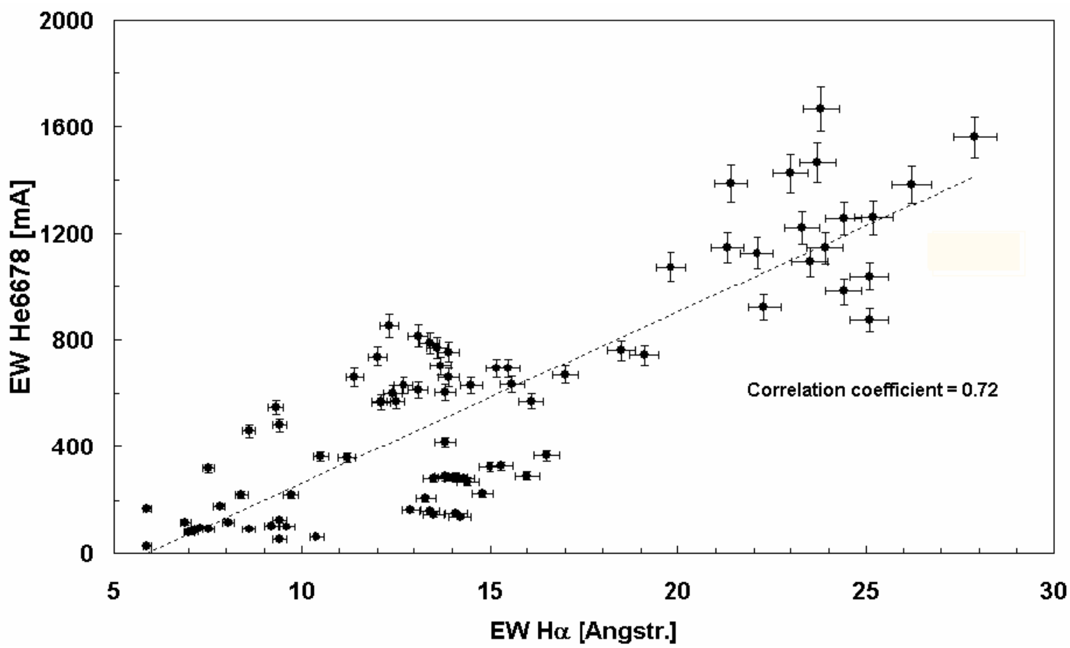

Figure 1. Correlation between the equivalent width of He I 6678 and Hα from April 2005 to April 2016.

Observation and results

Following the generally accepted assumption that the disk of this binary system is being fed due to outbursts of matter ejected from the stellar surface (Miroshnichenko et al., 2003), and since the He I 6678 line forms near the photosphere of the primary component one can expect a correlation between the equivalent width (EW) of the Hα and and He I 6678 lines (Fig. 1). Such a correlation might be interpreted as a result of a disk feeding process. However we cannot exclude that this reflects only contemporaneous density variations within the line formation zones.

This study of a correlation between Hα and He I 6678 EWs (Fig. 1) and of the behaviour of the He I 6678 line profiles have been performed by the author at the observatory of the Vereinigung der Sternfreunde Köln (Germany) with a C14 40 cm Schmidt-Cassegrain-telescope, the slit-grating-spectrograph LHIRES III with a spectral resolving power $R \sim 17000$ and a CCD-camera (768×512 pixel, pixel size 9 μm, this instrumental configuration provides spectra within the range from 6500 to 6700 Å), in collaboration with observers of the ARAS group[1] at different locations, different telescopes (apertures between 20 and 40 cm) and different spectrographs with spectral resolving powers of 10000 to 20000 (signal-to-noise ratios, S/N of these spectra are ca. 200–300).

With exposure times of 300 to 350 sec for an individual spectrum, the S/N in a sum spectrum of 10 individual spectra reached values mostly more than 1000. The spectra have been reduced manually with standard procedures (instr. response, normalisation,

[1] http://www.astrosurf.com/aras

wavelength calibration) by using the programs Maxim-DL[2], VSpec[3] and MK32[4].

Since April 2005, during every observing season, the observed correlation impressively supports the existence of this disk-feeding process, in which the slope of the linear fit shown in Fig. 1 reflects the quantitative correlation.

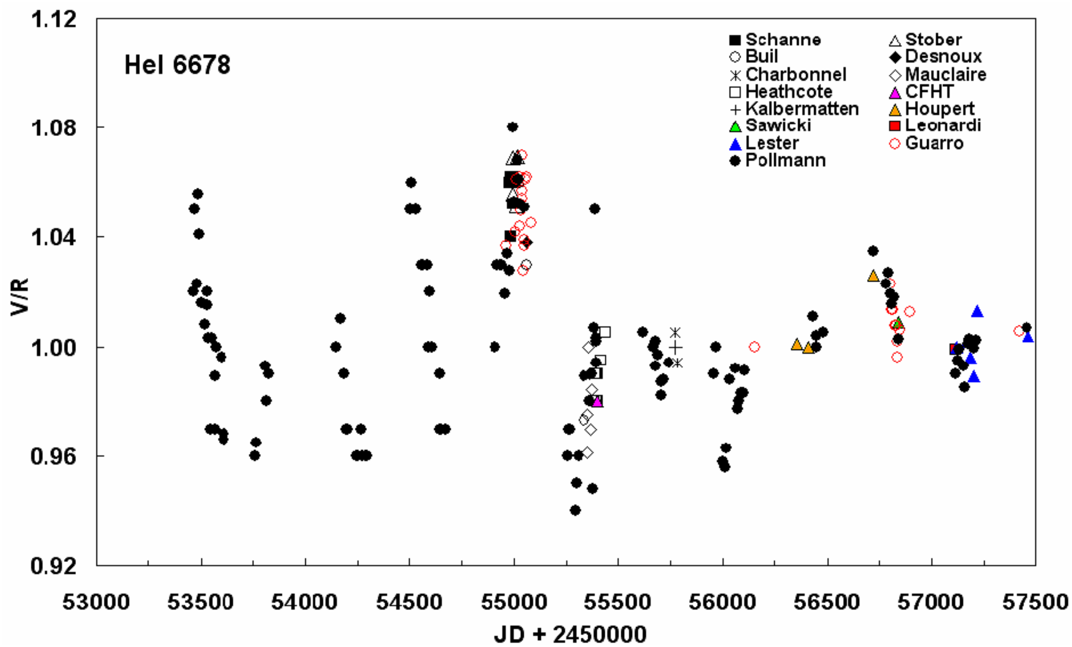

Figure 2. Long-term monitoring of the V/R ratio from April 2005 to March 2016.

In addition to the variability of the EWs (measured and analysed in the same spectra) the He I 6678 line double-peaked profile exhibits a variable V/R ratio that is the relative intensity of the violet component I_V to the red component I_R. For the first time it was possible to analyse eleven complete cycles of the V/R variations from April 2005 to March 2016 (Fig. 2). In the earlier seasons, merely the descent could be measured. On this occasion I emphasize that, among others, members of the ARAS group, made a significant contribution to the frequent observations.

The V/R measurements of these eleven cycles presented here permitted an analysis of possible periodicities. For the analysis of the period (Fig. 3) and the phase diagram (Fig. 4) the method of the PDM [phase dispersion minimization of Stellingwerf (1978)] within the program package AVE[5] was used.

As very clear result the period of 553 d (± 2.3) with the output epoch T_0 = JD 2453794 (± 7.8) could be found. The V/R ratio has been measured of course only in the spectra for which the double peak profiles are apparent. In the light of that result it is interesting to have a look on the cyclic behaviour of the Hα EW within our long-term monitoring of that star from July 2000 to May 2015 (see Fig. 5). After subtracting the long-term wave of approx. 9 years in the upper left panel of Fig. 5, I could derive a period of 509 days (lower left, upper and lower right panels of Fig. 5), which is very close to the period of

[2]`http://www.cyanogen.com`
[3]`http://www.astrosurf.com/vdesnoux`
[4]`http://www.appstate.edu/ grayro/spectrum/spectrum276/`
[5]`http://astrogea.org/soft/ave/aveint.htm`

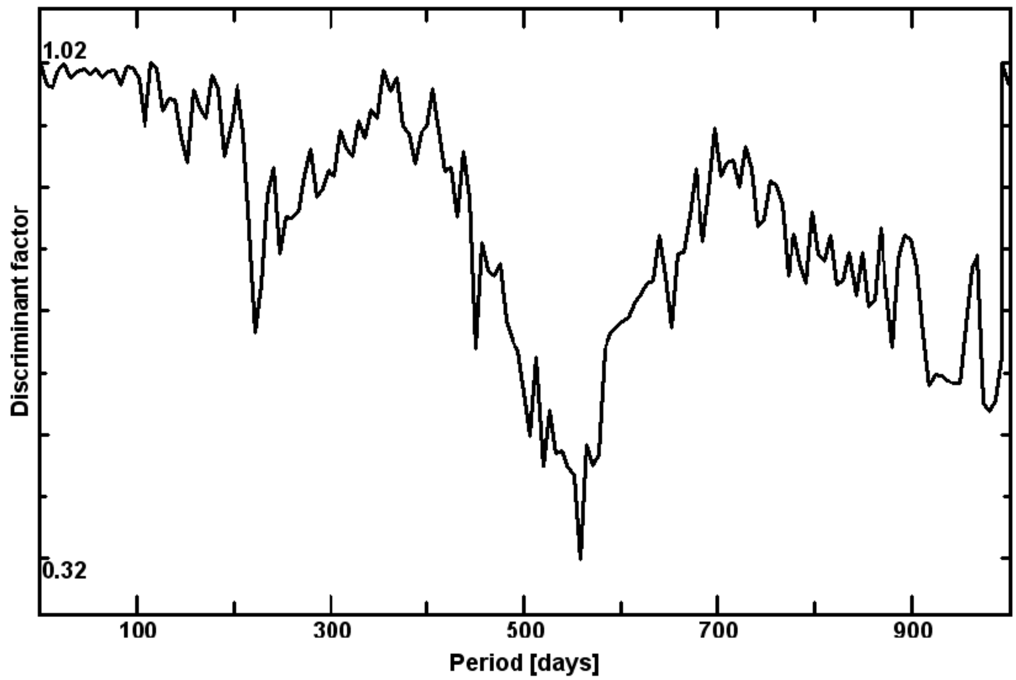

Figure 3. The method of the PDM analysis revealed a period of 553 d in the V/R data in Fig. 2.

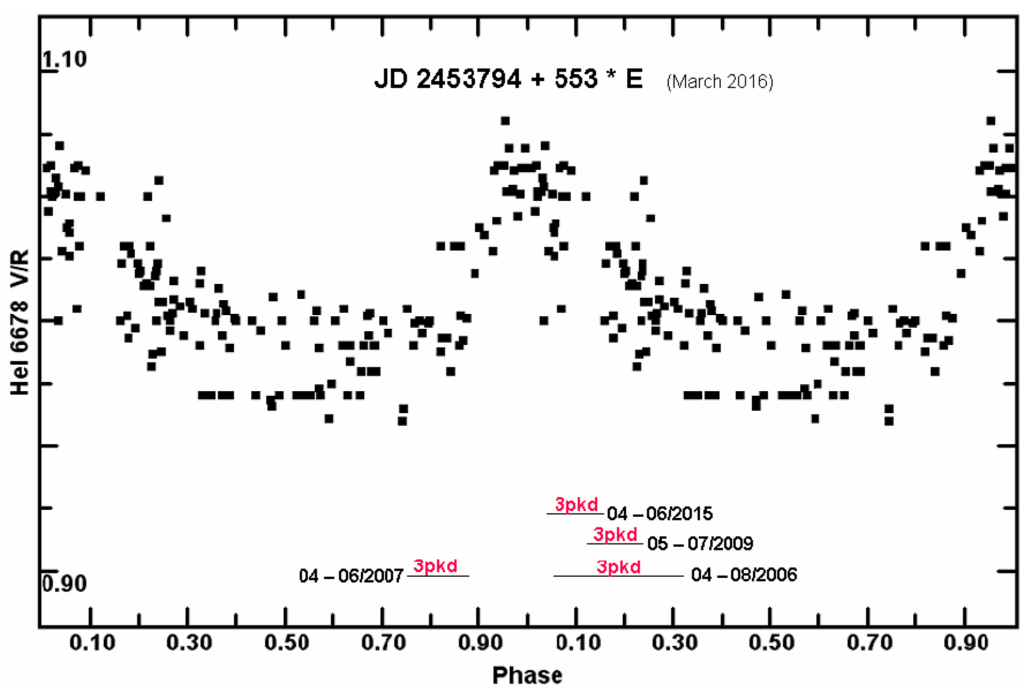

Figure 4. Phase diagram of the V/R data folded on the period of 553 d with $T_0 = 2453794$ and the marked phase sections of the triple-peak appearance (3pkd).

He I 6678 derived in this paper. These close coincidences of the periodic behaviour led to the suspicion of identical physical causes. The long-term behaviour of the Hα emission of δ Sco might be studied in a further paper.

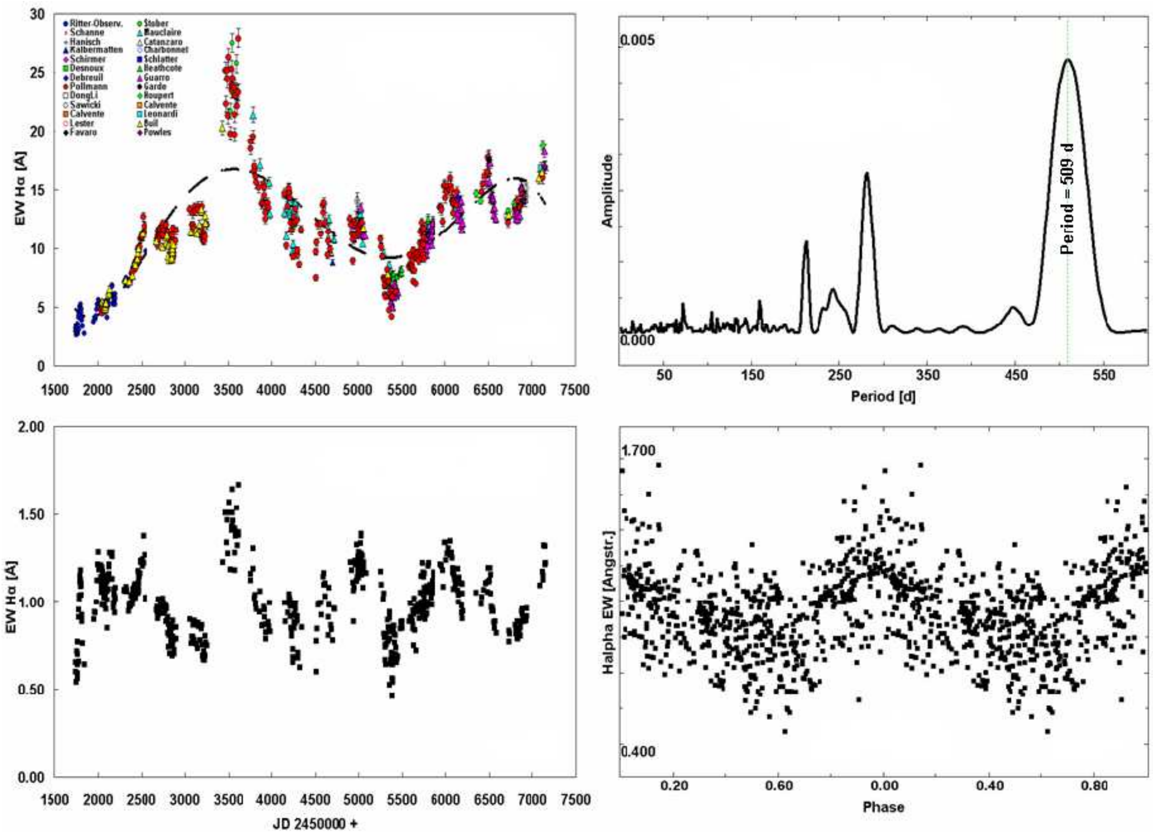

Figure 5. (Upper left) δ Sco Hα monitoring and long-term variations (period approx. 9 years). (Lower left) Long-term variation removed EW of Fig. 1 divided through the long-term variation. (Upper right) Period analysis of the long-term removed data in the lower left panel. (Lower right) Phase diagram of the 509 d period.

An inspection of the spectra shown in Fig. 6 shows that the third emission component (the triple-peak profile) was observed within the phase intervals ~ 0.06 to ~ 0.3 (04-08/2006), ~ 0.75 (04/2007), ~ 0.1 to ~ 0.24 (05-07/2009) and ~ 0.03 to ~ 0.13 (04-06/2015). marked (in red, as 3pkd) in Fig. 4. The last triple peak phase from April to June 2016 (approx. JD 2457114 to 2457175) was observed very weakly as a consequence of the very low emission intensity.

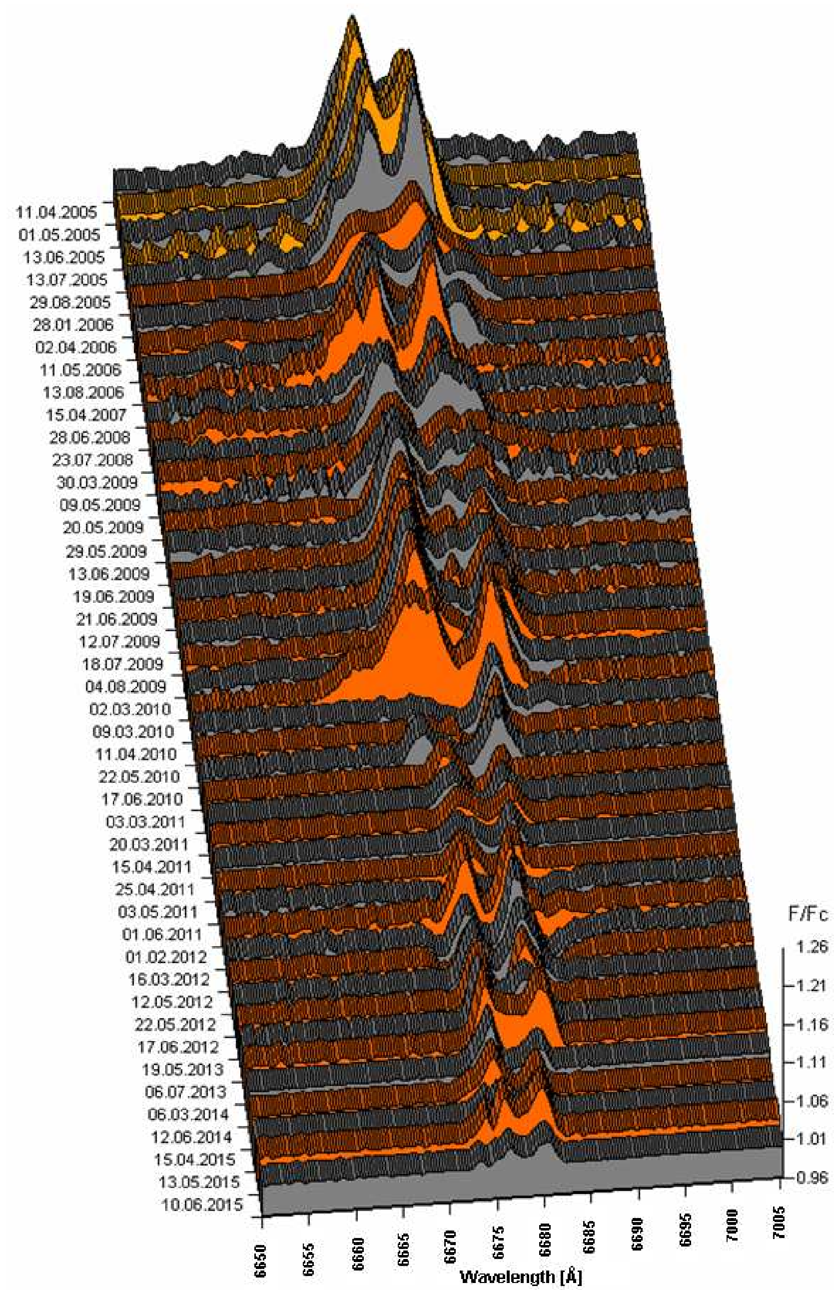

Figure 6. Three-dimensional plot to show the appearance of the third emission component (the triple-peak profile), observed within the phase interval ~ 0.06 to ~ 0.3 (04-08/2006), ~ 0.75 (04/2007), ~ 0.1 to ~ 0.24 (05-07/2009) and ~ 0.03 to ~ 0.13 (04-06/2015).

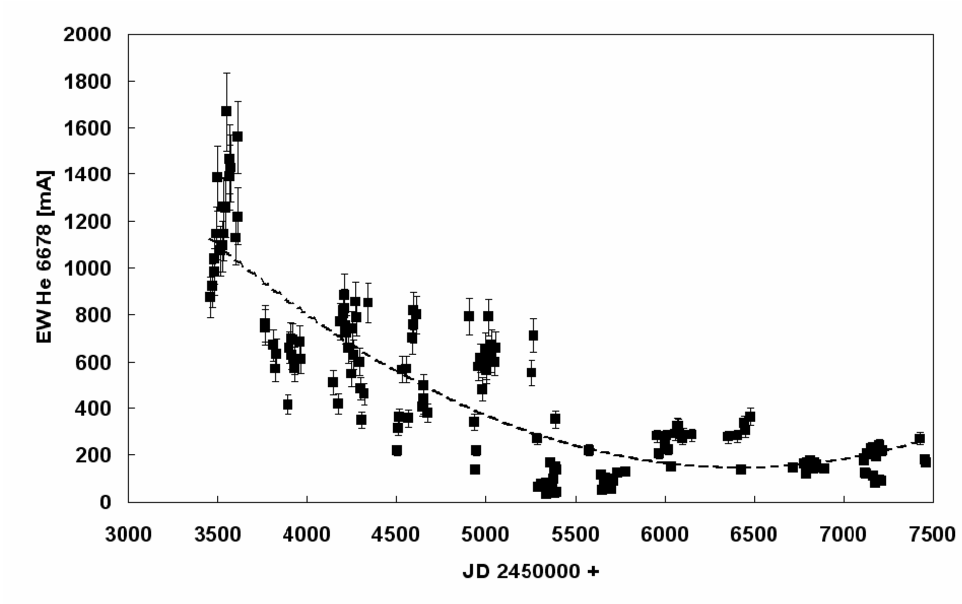

Figure 7. Long-term monitoring of the He I 6678 emission line EW from April 2005 to March 2016.

The plot of the emission intensity long-term monitoring as EW of He I 6678 versus time in Fig. 7 confirms this fact with the EW being at minimum at that time. One can state that there is no certain phase preference for the appearance of this bizarre and mystery line profile characteristics, in the He I 6678 emission of the spectra of δ Sco. This might be due to the presence of a density enhancement sometimes in front of the star and sometimes hidden behind it at other phases.

References:

Bedding, T., R., 1993, *AJ*, **106**, 768

Carciofi, A. C. et al., 2006, *ApJ*, **652**, 1617

Che, X. et al., 2012, *ApJ*, **757**, 29

Coté, J., van Kerkwijk, M. H., 1993, *A&A*, **274**, 870

Hartkopf, W. L., Mason, B., D., McAlister, H., A., 1996, *AJ*, **111**, 370

Innes, R. T. A., 1901, *MNRAS*, **61**, 414

McAlister, H. A., 1978, *ApJ*, **225**, 932

Meilland, A. et al., 2011, *A&A*, **532**, A80

Miroshnichenko, A. S., Fabregat, J., Bjorkman, K. S. Knauth, D. C., Morrison, N. D., Tarasov, A., E., Reig, P., Negueruela, I., Blay, P., 2001, *A&A*, **377**, 485

Miroshnichenko, A. S. et al., 2003, *A&A*, **408**, 305

Miroshnichenko, A. S. et al., 2013, *ApJ*, **766**, 119

Stellingwerf, R. F., 1978, *ApJ*, **224**, 953

Tango, W. J. Davis, J., Jacob, A. P., Mendez, A., North, J. R., O'Byrne, J. W., Seneta, E. B., Tuthill, P., G, 2009, *MNRAS*, **396**, 842

*This version of the paper contains corrections, and differs from the one appeared on-line originally. Date of last modification: Aug 24 08:41:17 CEST 2016