Chapter 5

Spectral profiles analysis of δ-Scorpii

5.1 THE OPTICAL SPECTRUM OF DELTA-SCORPII AT A GLANCE

The optical spectrum of δ-Sco was observed in the range of λ4300–7100Å using an Echelle spectrograph with wavelength dispersion of 0.1Å. Apparently, the spectrum exhibits many lines in the emission profile with broad features, which are the general characteristics of rapid rotators with a circumference disc revolving around a star at the centre. Figure 5.1 shows one of the Echelle data observed in 2010 for the selected regions of this study. Most of the prominent lines appear in the blue region from λ4300Å to λ4950Å. In visual region (λ4950–5900Å) only sodium lines are present and a few significant lines appear in the red region (λ6200–7500 Å). The first three lines of the Balmer series: H_αλ6562, H_βλ4861 and H_γλ4340 show strong emission lines with a double-peaked profile. The other lines that also appear in the emission are *HeI*λ5012, 5876, 6678, 7065 and *SiII*λ6347, 6371. The absorption lines, such as *HeI*λ4387, 4922, 4388, 4471, OII λ4414, 4649, *HeII*λ4685 and *MgII*λ4481 are found in the blue region, which are broadened owing to the rapid rotation of the star at the centre. There are no lines of interest in the other regions from λ5060Å to λ6300Å and λ6700Å to λ6900Å; hence, there were not used in this study.

The Echelle data provides a full coverage on optical range whereby the studies of metallic lines, in addition to the Hydrogen and Helium lines, can be carried out. In addition, the database provides data through a constant monitoring, specifically on H_α, from 2007 to 2011. The changes or variations of this line might give a direct view of the characteristics or behaviour of the disc surrounding the star.

Owing to a very strong emission line with a very high peak of *E/C* ~ 3.4, the photospheric absorption wing of $H_\alpha$was invisible. The photospheric absorption wing on the other hand was apparently seen in H_β with a rather small emission peak of *E/C* ~ 1.5 and in the H_γ line, it shows a broad photospheric absorption line with a tiny emission line appearing at the centre. The strength of an emission line affects the appearance of the line profile, as shown in Figure 5.2.

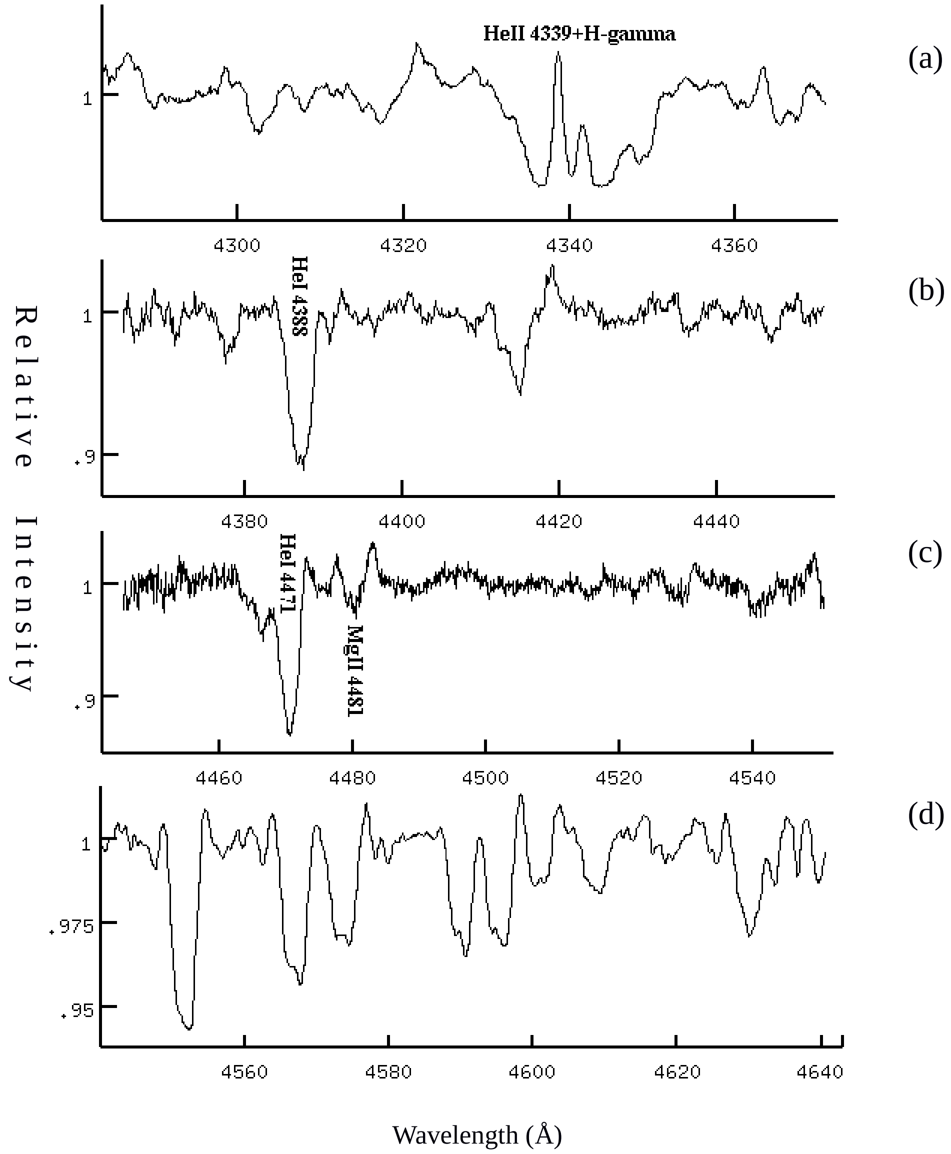


Figure 5.1 – Line identification in optical region of δ-Sco. The spectra were taken on Feb. 21, 2010 at Castanet Observatory using the eShel instrument.

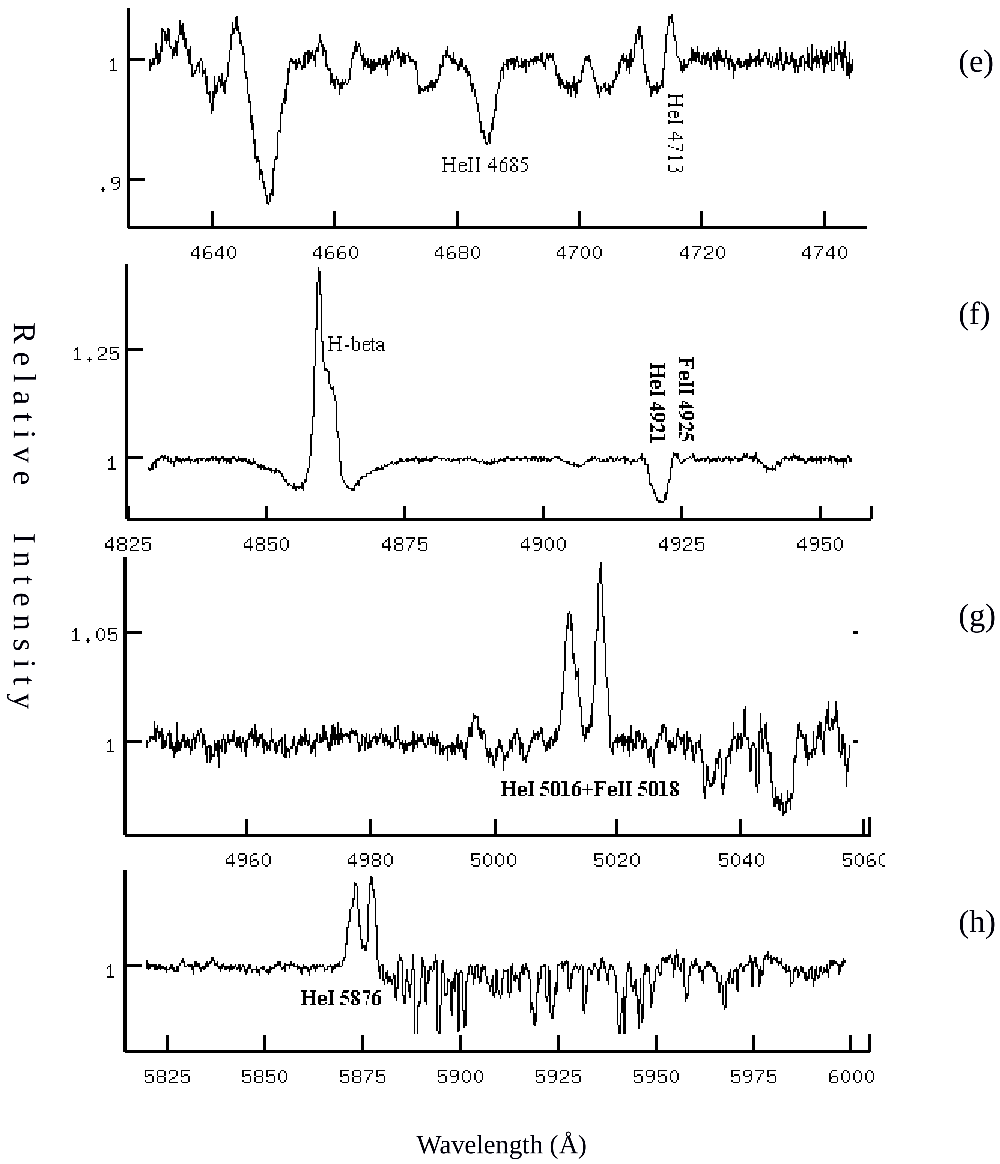


Figure 5.1 - continue

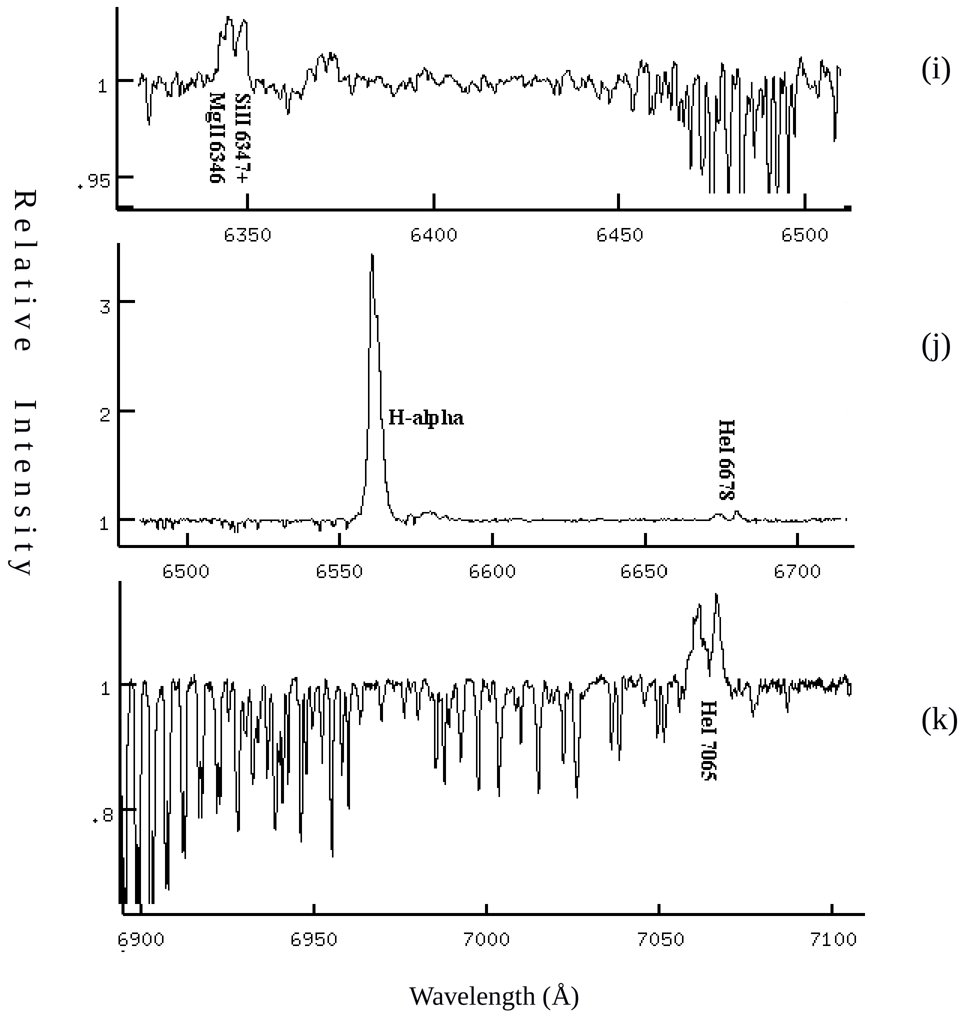


Figure 5.1 - continue

Some of the lines suffer from blending with other lines as a consequence of line broadening. *HeI* λ4471 and *MgII* λ4481 are visible in the absorption and found blended with other lines at λ4466 and λ4479, respectively (Figure 5.3a-bottom). However, we suspect that the blending could be a signature of a binary system, because we knew δ-Sco is a binary star. The *HeI* λ4921 and *FeII* λ4925 lines are just separable visually (Figure 5.3a-top). The *HeII* λ4339 and H_γ λ4340 lines (Figure 5.1(a)) are the emission lines, which also experience blending. Furthermore, a number of other lines appear in the emission in addition to the Balmer lines. *HeI* λ5016 and *FeII* λ5017 (Figure 5.1(g)) are found in the emission and are close to each other, yet clearly separated.

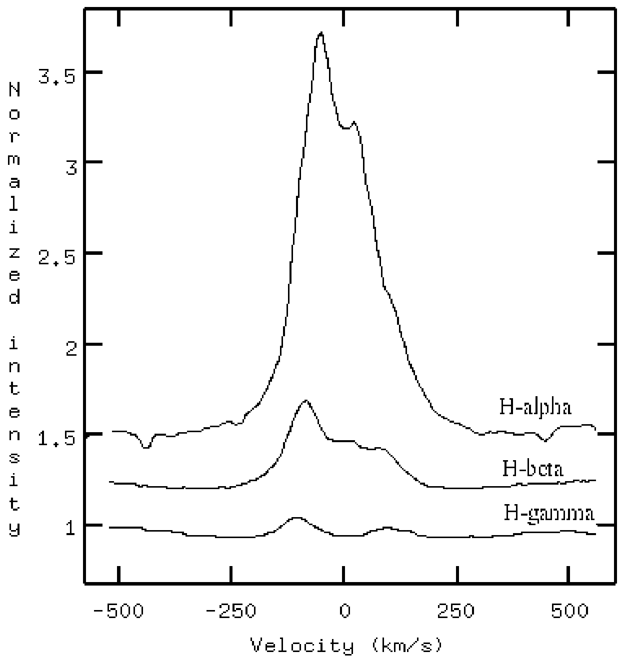
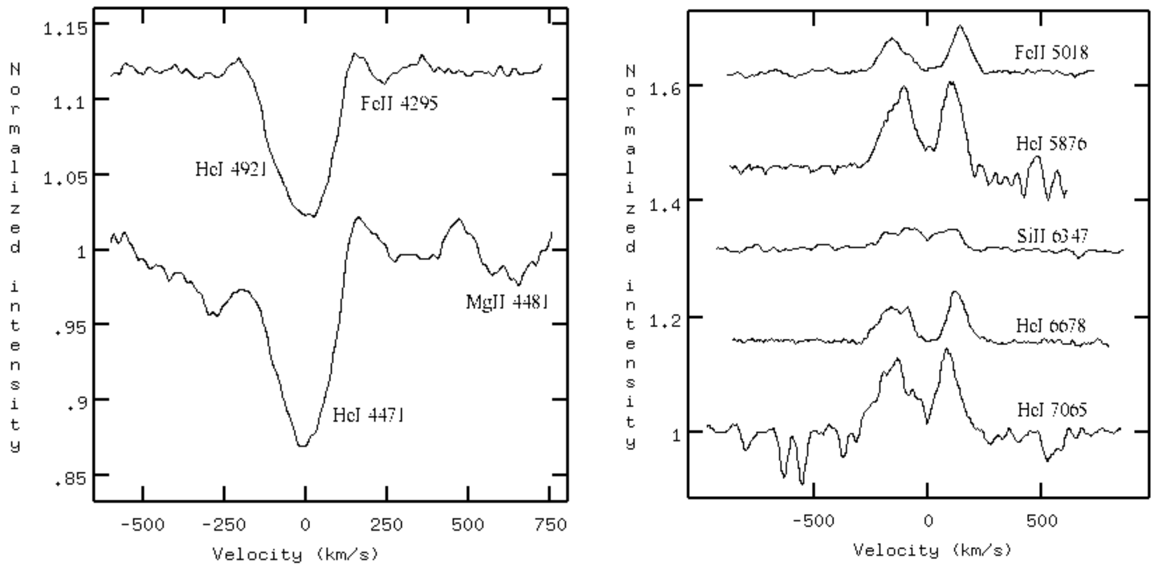


Figure 5.2 – Profiles of Balmer lines of δ-Sco in comparison to relative normalised intensity.

HeI λλ5876, 6678, 7065 and *SiII* λ6347 also appear in an emission line with a double-peaked profile (Figure 5.3b). We also identified sodium lines in the spectra, *NaI* λλ5890 and 5896 (Figure 5.1(h)). These lines belong to an interstellar medium, because no noticeable variations have been identified either in their strength or radial velocity; thus, these lines were not used in this study.



(a) (b)

Figure 5.3 – Blended absorption lines (a) and the double-peaked emission lines (b).

5.2 DOUBLE PEAK PROFILE

As shown in Section 5.1, many lines appear in the emission profile in the optical spectra of δ-Sco. These optical emission lines of Be stars originate in the disc-like circumstellar envelopes. In the hypothesis of a Keplerian disc, the discis supposed to form at the equatorial region of the stars. The emission lines from the circumstellar disc are usually in the form of a double-peaked profile. From the double-peaked emission line profile, we know that the star is rotating at a certain angle with respect to line of sight of the observers from the Earth. Miroshnichencko (2001) found that the angle, called the inclination angle, of δ-Sco isi = 38º ± 5º.

Huang (1972), Hirata and Kogure (1984) and Hummel and Vrancken (1995) have shown that the separation of the double-peaked profileΔV_p has a relationship with the outer radius r of the emitting disc as follows:

$$\Delta V_{peak} = \frac{2v \sin i}{r^j} \tag{5.1}$$

where j is a parameter describing the velocity law inside the circumstellar disc: j = 1 for the case of angular momentum conversation and j = ½ for Keplerian rotation, r is in the units of the radius of the underlying star. Hummel &Vrancken (2000) concluded that the relationship of eq.(5.1) for Be stars gives a valid approximation if Keplerian rotation is applied. Hence, eq.(5.1) can be written as eq.(5.2) as follows:

$$\frac{R_d}{R_*} = \left(\frac{2v \sin i}{\Delta V_p}\right)^2 \tag{5.2}$$

where R_d/R_* is the ratio of the disc and stellar radii, $v \sin i$ is the rotational velocity of the star and ΔV_p is the separation of the double-peaked profile. The measurements of the peak separation and relative disc radii will be carried out in the analysis part of this study.

The features of a double-peak profile that are used in the analysis are the blue or violet peak, red peak, blue and red wings and central reversal. Figure 5.4 illustrates the typical features of a double-peak emission line profile.

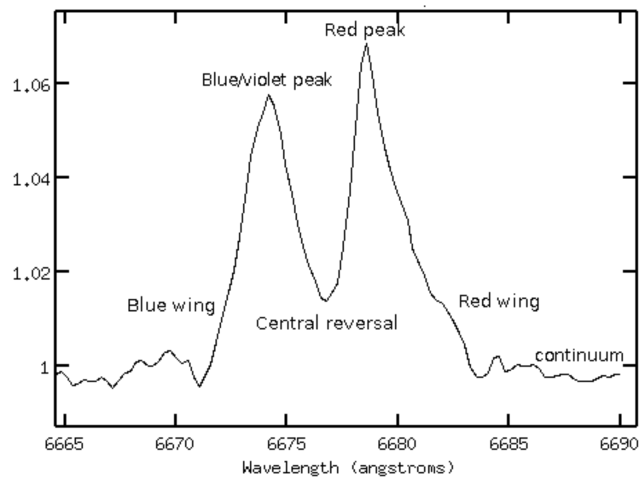


Figure 5.4 – Features of double-peak emission line

In order to study the motion behaviour of the emitting regions that are represented by the double-peak profile, we measure the radial velocity by simply applying a Doppler shift equation as below:

$$\frac{(\lambda - \lambda_o)}{\lambda_o} = \frac{\nu}{c} \tag{5.3}$$

We used the central reversal or centre absorption line of the double peak as λ to justify the line's shift, λ_o is the wavelength at rest, ν is the radial velocity and c is the speed of light. In order to obtain the true radial velocity of the emitting disc region, we performed a heliocentric correction to remove the effects of the motion of the Earth around the Sun.