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 4300–7100Å 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 4300Å to 4950Å. In visual region (4950–5900Å) only sodium lines are present and a few significant lines appear in the red region (6200–7500 Å). The first three lines of the Balmer series: Hαλ6562, Hβλ4861 and Hγλ4340 show strong emission lines with a double-peaked profile. The other lines that also appear in the emission are HeIλ5012, 5876, 6678, 7065 and SiIIλ6347, 6371. The absorption lines, such as HeIλ4387, 4922, 4388, 4471, OII λ4414, 4649, HeIIλ4685 and MgIIλ4481 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 5060Å to 6300Å and 6700Å to 6900Å; 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 Hₐ, 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 $E/C \sim 3.4$, the photospheric absorption wing of Hₐ was invisible. The photospheric absorption wing on the other hand was apparently seen in Hᵦ with a rather small emission peak of $E/C \sim 1.5$ and in the Hᵧ 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
Some of the lines suffer from blending with other lines as a consequence of line broadening. $\text{HeI} \, \lambda 4471$ and $\text{MgII} \, \lambda 4481$ are visible in the absorption and found blended with other lines at $\lambda 4466$ and $\lambda 4479$, respectively (Figure 5.3a-bottom). However, we suspect that the blending could be a signature of a binary system, because we knew $\delta$-Sco is a binary star. The $\text{HeI} \, \lambda 4921$ and $\text{FeII} \, \lambda 4925$ lines are just separable visually (Figure 5.3a-top). The $\text{HeII} \, \lambda 4339$ and $\text{H}_\gamma \, \lambda 4340$ 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. $\text{HeI} \, \lambda 5016$ and $\text{FeII} \, \lambda 5017$ (Figure 5.1(g)) are found in the emission and are close to each other, yet clearly separated.
HeI $\lambda 5876$, 6678, 7065 and SiII $\lambda 6347$ also appear in an emission line with a double-peaked profile (Figure 5.3b). We also identified sodium lines in the spectra, NaI $\lambda 5890$ 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.

Figure 5.2 – Profiles of Balmer lines of $\delta$-Sco in comparison to relative normalised intensity.
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 disc is 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. Miroshnichenko (2001) found that the angle, called the inclination angle, of δ-Sco is $i = 38^\circ \pm 5^\circ$.

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

![Figure 5.3 – Blended absorption lines (a) and the double-peaked emission lines (b).](image)
\[ \Delta V_{peak} = \frac{2v \sin i}{rj} \]  \hspace{1cm} (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 \( j = \frac{1}{2} \) 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:

\[ \frac{R_d}{R_*} = \left( \frac{2v \sin i}{\Delta V_p} \right)^2 \]  \hspace{1cm} (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 \( \Delta V_p \) 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.
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:

$$\frac{(\lambda - \lambda_o)}{\lambda_o} = \frac{v}{c}$$  \hspace{1cm} (5.3)

We used the central reversal or centre absorption line of the double peak as $\lambda$ to justify the line’s shift, $\lambda_o$ is the wavelength at rest, $v$ 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.

Figure 5.4 – Features of double-peak emission line