In 2011, δ-Sco once again went through the periastron passage. The effect of the close encounter was detected by the reduction of its radial velocity when the companion moves closer to the primary, as shown in Figure 4.35. We also recognised the changes of *V/R* variations in the double-peaked line profiles. The value of *V/R* has been reduced to the smallest ratio, i.e.,$V<<R$ during the recent periastron, which occurred during the 4^{th} to 5^{th} of July. The relative disc sizes of most of the emitting regions were also reduced during the periastron, as depicted in Figure 7.9.

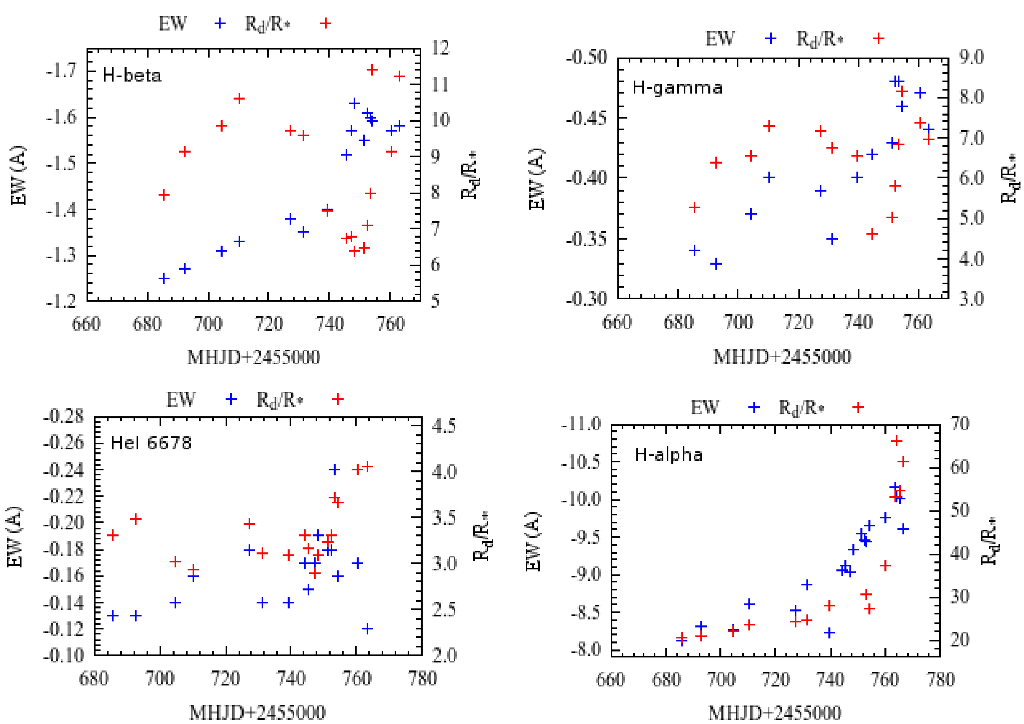

Figure 7.9 – Evolution of disc radii with time in different emitting regions during the periaston passage 2011.

However, from Table 5.5, there were no measurements of the disc size for the H_α emitting region during the periastron owing to the 'missing' double-peaked profile. The supposed H_α exhibits a double-peaked profile as in other emitting regions; however, because of the increment of the line width *FWHM* in the $H_\alpha$line, as shown in Figure 7.10, the double-peak has merged (at the resolution). Thus, during periastron, the $H_\alpha$line profile exhibits a broad asymmetrical single-peak profile.

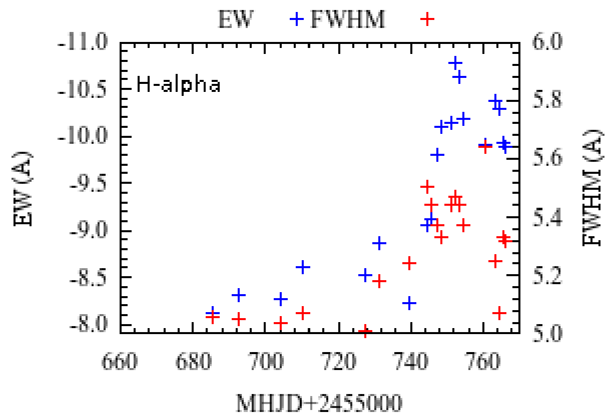

Figure 7.10 – Correlation of *EW* and *FWHM* during periastron 2011.

We expect that the radius of the H_α emitting region would extend to a certain limit, equivalent to the increment of *EW* and line broadening; the *V/R* ratio (if the profile shows a double-peak) will reach a minimum value at the most blue-shifted radial velocity. However, the *V/R* ratios observed in 2011 do not vary correspondingly with the radial velocity, if the one-armed model is considered. The radial velocities, which have been measured continuously, show evidence of moving towards the blue-shift region, even though *V/R*> 1. In this case, we suggest that the outer disc region of δ-Sco has been affected by the tidal effect of the companion as the cycle disorder occurs during the period of the companion close encounter. However, it needs close investigation in order to study the mechanism.

7.4 EVOLUTIONARY STUDY

In the evolutionary study, we tried to evolve the program star, δ-Sco from ZAMS to TAMS as a single star, because there was no clear evidence from previous work for mass transfer to occur between δ-Sco and its companion, the 8M⊙ secondary. In addition, all the trials in evolving the star as a binary star were unsuccessful because the mass transfer was unable to occur during each evolution process.

In this work, our attempt is to identify the current status of δ-Sco on the Hertzsprung-Russell (HR) diagram model based on the *log Teff* that we adopted in this study. From the evolutionary process, other information is generated, such as mass, core temperature, rotational velocity, age, etc., which could be used to estimate the current status based on the physical characteristics studied by other people. By using the EV stellar evolution code, we evolved the star at the centre with certain initial parameters: the initial mass M_{ini} and initial rotational velocity $Vrot_{ini}$ with metallicity Z = 0.01 and 0.02. We found that not only was the evolutionary track model run at $Vrot_{ini}$ = 270 km/s and M_{ini} = 12.5 M⊙ with Z = 0.01 successful in reaching the Red Giant phase, as shown in the HR diagram (Figure 6.2) but that it also showed the most approximate value of *log Teff* to the current value adopted from Miroshinichenko et al. (2001). Furthermore, the rotational velocity ν_{rot} = 265 km/s of the current status in this model is consistent with the observed rotational velocity of the star on its axis, which is about 268 km/s, if the inclination angle, *i* = 38°± 5° (Miroshinichenko etal., 2001) is true.

7.5 CONCLUSIONS

From the studies of the characteristics or behaviours of the Be disc of δ-Sco, based on the monitored spectra in the optical region from 2007 to 2011, we found that the Be disc of the program star is dynamically moves in addition to the rotation which follows the Keplerian rotation.

The decrease in the strength of the circumstellar disc regions has been detected from 2007 to 2010. However, the strengthening of the Balmer lines during the periastron passage and onwards indicates that the close encounter of the 8M⊙ companion at about 14 stellar radii influences the increase of the circumstellar matter around the primary star. Therefore, we suggest that the effect of the gravitational pull from the companion during the periastron passage plays an important role in the survival of the Be disc of δ-Sco.

A weak emission line of H_{α}has also been reported during the periastron of 1990. Then, in the last periastron of 2000, the strength of the emission line has been observed at nearly half that of the recent periastron. We suggest that the tidal interaction during the close encounter of the 8M⊙ companion on each periastron has potentially caused the δ-Sco to gradually change into a Be star.

On the rotation of the disc, based on the cycle of the *V/R* variation of the H_{α} line, we show that the disc is consistent with the one-armed oscillation disc model from 2007 – 2010 but incompatible in 2011 during the periastron passage. It is clear that the tidal effect from the companion influenced the disc's rotation.

In the second part of this study, we present a few stellar evolution models, especially in the main sequence band, to represent the evolutionary track of the program star δ-Sco. One of our findings is that at initial mass of 12.5 $M_\odot$, the evolution process in solar metallicity Z = 0.02 or Z = 0.01 has been found to have stopped at an earlier phase such as at the terminal age main sequence or the shell hydrogen burning phase, if the initial rotational velocity is 345 km/s or higher, or if the rotation rate is about 0.6. In addition, at this initial rotation rate, the star rotates much faster than the critical rotation and the rotational velocity keeps on increasing, which causes the stellar evolution process to breakdown.

Based on the evolutionary models that ran, the model that evolved at $Vrot_{ini}$ = 270 km/s, M_{ini} = 12.5$M_\odot$ with Z = 0.01 resulted in the closest value of $log\ T_{eff}$ to the current value, which we had adopted in this study. Taking into consideration other parameter values, e.g., *log L*, rotational velocity, mass, *log R* and age, as shown in Table 6.2, we suggest that this model can represent the evolutionary track of δ-Sco. Hence, the current values of those physical parameters that we considered for this star, as stated in section 6.5.2, are recommended for its current physical properties.

According to Townsend (2004), Porter (1996) and Chauville et al. (2001), the star is supposed to have to rotate at about $0.7\nu_{cr}$ or faster for the Be phenomenon to occur. However, from this work, we show that the star is rotating at about $0.5\nu_{cr}$ less than it should be from their suggestions and yet, the Be phenomenon has been noticed in this star since 1990. Based on the observations in 1990, the year of the periastron passage, whereby a weak emission line of H_α was first noticed, followed by the observations during the last periastron passage in September 2000, in which the relative intensity of H_α emission line increased by about half of that of the recent periastron passage that happened in July 2011, the increment of the relative intensity of H_α is one of the lines that indicates the existence of a circumstellar disc surrounding the star during the periastron passage. Hence, we suggest that the close encounter of the 8 $M_\odot$ companion to the primary did have an influence on the appearance of the Be phenomenon of δ-Sco. Although its rotation rate to the critical velocity is only about 0.5, the outside factor such as the effect of the periastron passage which had occurred several times could eventually contributes to the appearance of Be phenomenon in δ-Sco.

Furthermore, we show indirectly that Eggleton's stellar evolution code, used in developing a model of the evolutionary track of a fast rotating star, was successfully executed in carrying out the task jobs. For this study, very few parameters were considered in developing the model track of a fast rotating star but we believe that task jobs that are more complicated could be carried out under this code in the effort to study the relationship of Be stars at the centre and the appearance and disappearance of the surrounding envelope.

As a whole conclusion we suggest that the rotation rate of B type stars can be as low as 0.5 V_{cr} for the Be phenomenon to appear and does not necessarily of 0.7 V_{cr} provided that there should be an outside factor to directly or indirectly trigger the material of the star at centre to be ejected onto the orbit.

7.6 SUGGESTIONS FOR FUTURE WORK

The studies on the effects of periastron on the increase of material in the circumstellar disc should be carried out continuously, because we might be able to determine for how long the effect of the 8 solar mass companion can be detected before it has moved too far from the primary star. In addition, the effect of periastron should be applied to other binary system where no mass transfer is believed to have occurred.

However, if every periastron passage of δ-Sco does influence the change from a B to a Be star, why is a weak H_α emission line of the star only reported after the periastron in 1990 and no emission line of the star published prior to this? This suggests the idea that other factors or mechanisms in conjunction with the periastron passage in1990 could eject mass into orbit.

Further research on δ-Sco should be carried out for other wavelength regions in addition to the optical range, such as UV and infra-red, in order to study the effects of the stellar wind and mass-loss rate on the evolution of the circumstellar disc, specifically during the close encounter of the companion.