6.5 THE MODEL EVOLUTIONARY TRACKS OF δ-SCORPII

The model tracks of δ-Sco's stellar evolution has been calculated using EV stellar evolution code (Eggleton, 2002) where rotation was the main factor used to distinguish between Be stars and normal B type stars. The program star evolved with different sets of parameters, as explained in the previous sections, at solar metallicity, Z = 0.02 and Z = 0.01 from ZAMS to TAMS and up to red giant phase. Table 6.1 presents the sets of parameter and the evolutionary phases of the evolution process at a given equal number of time-steps of the evolution process.

Table 6.1 – Evolutionary phases of δ-Sco at various sets of parameters with the same number of timesteps at each evolution process.

M_{ini}	Z	$Vrot_{ini}$(km/s)	Stage of evolution
12.5	0.02	345	ZAMS→TAMS
		300	ZAMS→TAMS→ SHBP
		270	ZAMS→TAMS→ SHBP → SHNP → RGP
		0	ZAMS→TAMS→ SHBP → SHNP → RGP
	0.01	345	ZAMS→TAMS→ SHBP
		300	ZAMS→TAMS→ SHBP → SHNP → RGP
		270	ZAMS→TAMS→ SHBP → SHNP → RGP
		0	ZAMS→TAMS→ SHBP → SHNP → RGP

Notes:
ZAMS – Zero Age Main Sequence
TAMS – Terminal Age Main Sequence
SHBP – Shell Hydrogen Burning Phase
SHNP – Shell Hydrogen Narrowing Phase
RGP – Red Giant Phase

At a higher rotational velocity, the evolution process was found to stop at an earlier phase than with lower rotational velocity. For example, at high initial rotations of 345 km/s and 300 km/s with solar metallicity, Z = 0.02, the evolution process can be carried out only up to the stage of hydrogen burning in a thick shell. The same thing happened for an initial rotational velocity of 345 km/s with metallicity, Z = 0.01; the star can only be evolved over one third of the given time steps before the evolution breaks down at the shell hydrogen burning phase. It shows that the star cannot take the initial condition given in the evolution process. The models of the Hertzsprung-Russell diagram (HRD) or the evolutionary tracks of δ-Sco at Z=0.02 and 0.01 are shown in Figure 6.2.

We suggest that with an initial mass of 12.5 M⊙, the star was unable to evolve at the high initial rotational velocities of 300 to 345 km/s or more for Z = 0.02 and 0.01. In this study, we only focused on the evolution of δ-Sco from the ZAMS to the TAMS and specifically on the theoretical evolution relative to the rotational velocity. Our attempts focused successfully on identifying the current location of the star on the model tracks based on the adopted effective temperature log T_{eff} ~ 4.4314 (Miroshinichenko et al., 2001). The radius of this star has also been estimated from the effective temperature using the Bolometric method where we estimate R = 5.99 R⊙. The suggested position of the current status of the star was marked with a solid triangle on each model track in Figure 6.3, which shows the model of the evolutionary tracks from the ZAMS to the TAMS. From Figure 6.3, the main sequence phase is marked from A to B, which is the hydrogen-burning phase and is supposed to be the longest phase in the lifetime of a star; B–C is the overall contraction phase, where in B, the core hydrogen becomes a very low fraction of the central hydrogen abundance by mass, 0.01–0.04.

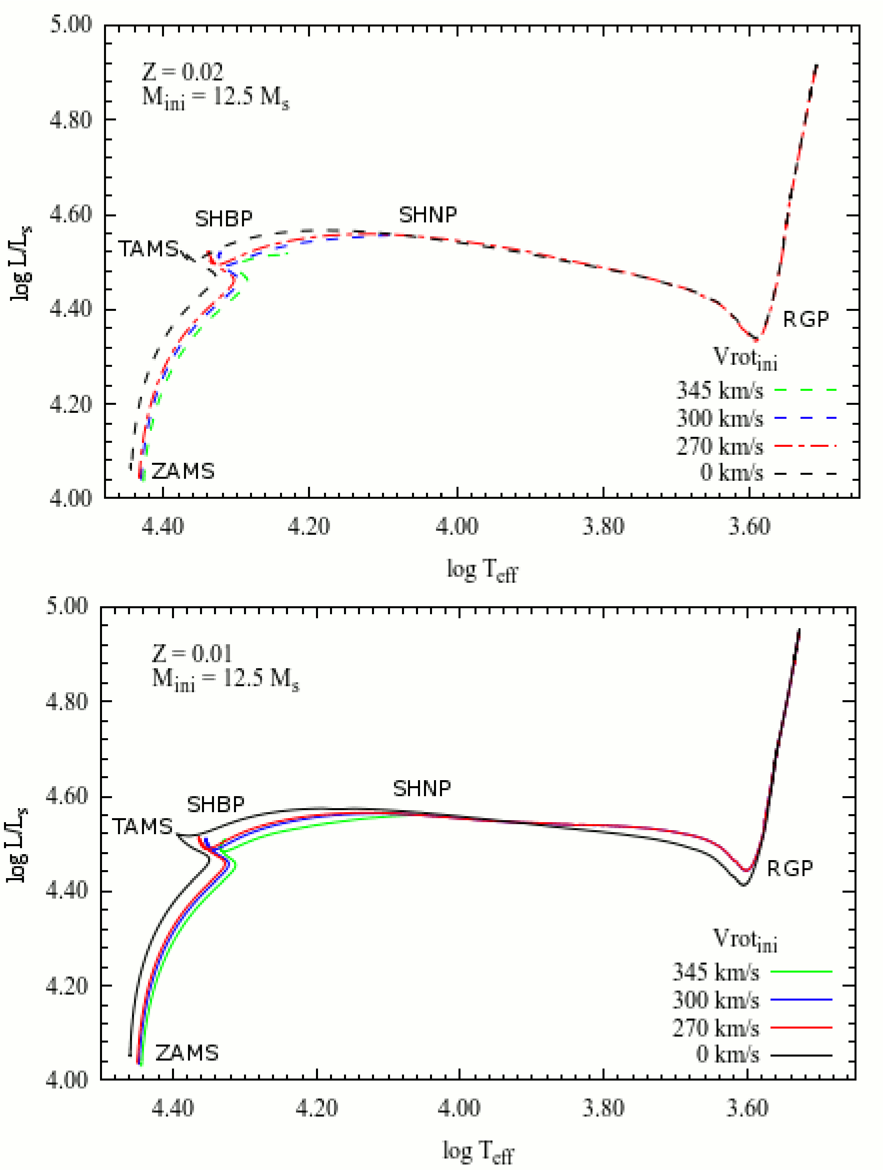

Figure 6.2 – Models of evolutionary track of δ-Sco at 345, 300 and 270 km/s initial rotation velocities. The model tracks are also compared with a normal star, which was assumed a non-rotating star. The models of HR diagram for Z = 0.02 (above) and Z = 0.01 (below) at an initial mass of 12.5 M⊙.

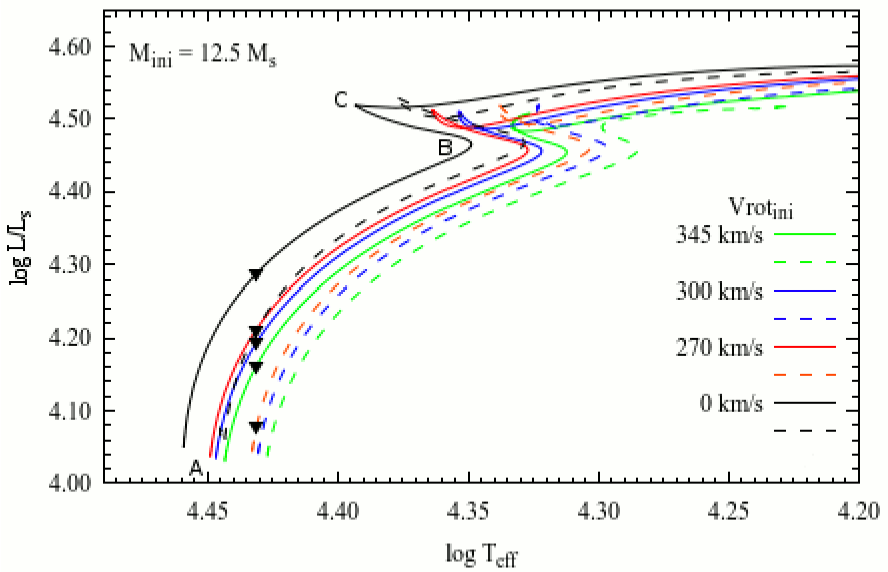

Figure 6.3 – Models of main sequence phase of δ-Sco at different initial rotational velocities. Tracks in solid lines represent Z = 0.01 and dashed lines Z = 0.02. Triangle on the tracks estimate the current status of δ-Sco based on the effective temperature log T_{eff} = 4.4314.

In this phase, the energy is supplied by the contraction process in the core and the entire star, which causes the star's radius to decrease. The hydrogen core becomes exhausted and a helium core is formed. We found that the green and blue dashed line model tracks of the 345 and 300 km/s rotational velocity, respectively, with Z = 0.02 were unable to meet the log T_{eff} of the star and hence, it is not a good model. The evolutionary track of $Vrot_{ini}$ = 345 km/s with Z = 0.02 was unsuccessful in evolving the star up to the red giant phase. Hence, those model tracks cannot fit with the log *Teff* and/or are unsuccessful to evolve, are considered unsuitable to represent the model evolutionary track of δ-Sco.

On the other hand, the current status of δ-Sco can be plotted on the model evolutionary tracks that evolved at lower metallicity Z = 0.01 for all the initial rotational velocity values: 345, 300 and 270 km/s. However, among the model tracks, the green solid line that represents $Vrot_{ini}$ = 345 km/s was found unsuccessful in developing the evolution process to at least the red giant phase. Thus, the initial parameters for this evolution are also considered unsuitable for this star. For solar metallicity Z = 0.02, only the model track for $Vrot_{ini}$ = 270 km/s is able to generate the adopted log T_{eff} of δ-Sco, as shown in Figure 6.3. The black solid line representing the non-rotating model track indicates the model track of a normal B type star. From Figure 6.3, we show that the star is currently in the middle of the main sequence phase, which is consistent with Fabregat&Torrejon (2000), who suggested the Be phenomenon will start to develop only in the second half of a B star's main sequence lifetime owing to the structural changes in the star. The physical parameters of the star at the current status, points B and C on the model tracks, namely *logT*, *log L*, age, mass, *log R*, *Prot* and V_{rot}, *R*, V_{cr} and V_{rot}/V_{cr} generated from the numerical calculations are listed in Table 6.2. Hence, our findings are congruent with those of Fabregat&Torrejon (2000).