5.3.3 H_β and H_γ variability behaviour

The physical parameters that we considered for the study of the star's variability in behaviour of the H_β and H_γ emitting regions are the equivalent width (*EW*), radial velocity (*RVcr*), *V/R* ratio, peak separation (*ΔVp*) and relative disc radii (*Rd/R**). All these parameters are listed in Table 5.2. Figure 5.13a shows the variations of *EW* and relative disc radii with time in the H_β and H_γ emitting regions. The graph shows that the *EWs* of H_β decreased in 2008 with increasing relative disc radii. In 2009, the line strength also shows a decreasing pattern with small changes in the relative disc radii. The decreasing of *EW* in H_β became worst in 2010; however, the disc radii show significant extension. For the H_γ emitting region, the *EW* and *Rd/R** show the same trend as that of H_β.

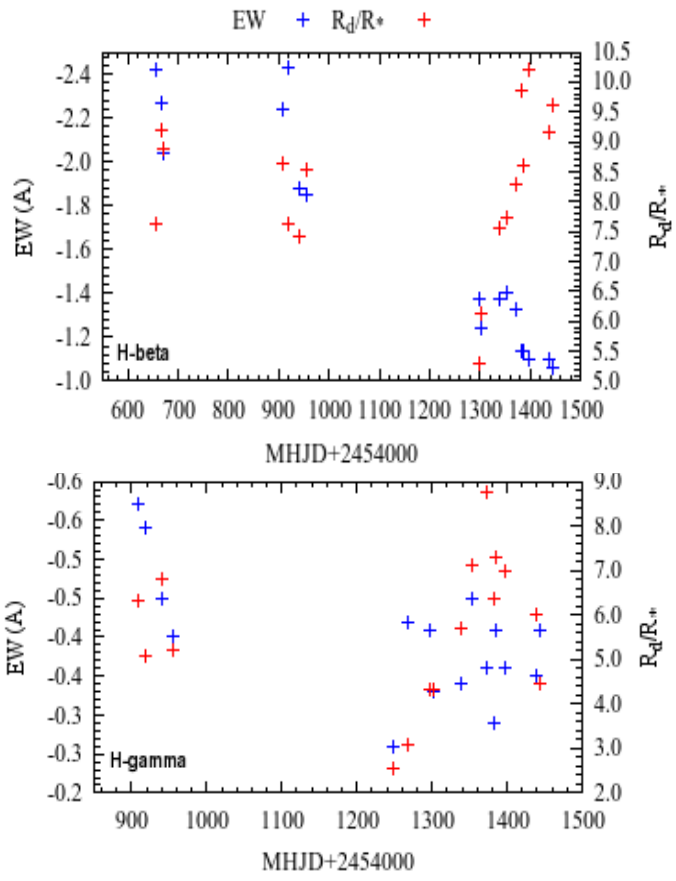

Figure 5.13a- Variation of line strength and relative disc radii with time of H_β (top panel) and H_γ (lower panel).

In the relationship between the relative disc radii and *V/R* variation, we observed that a higher *V/R* ratio corresponds to a smaller disc radius in all Balmer emitting regions (H_α, H_β and H_γ). This relationship is shown in Figure 5.13b.

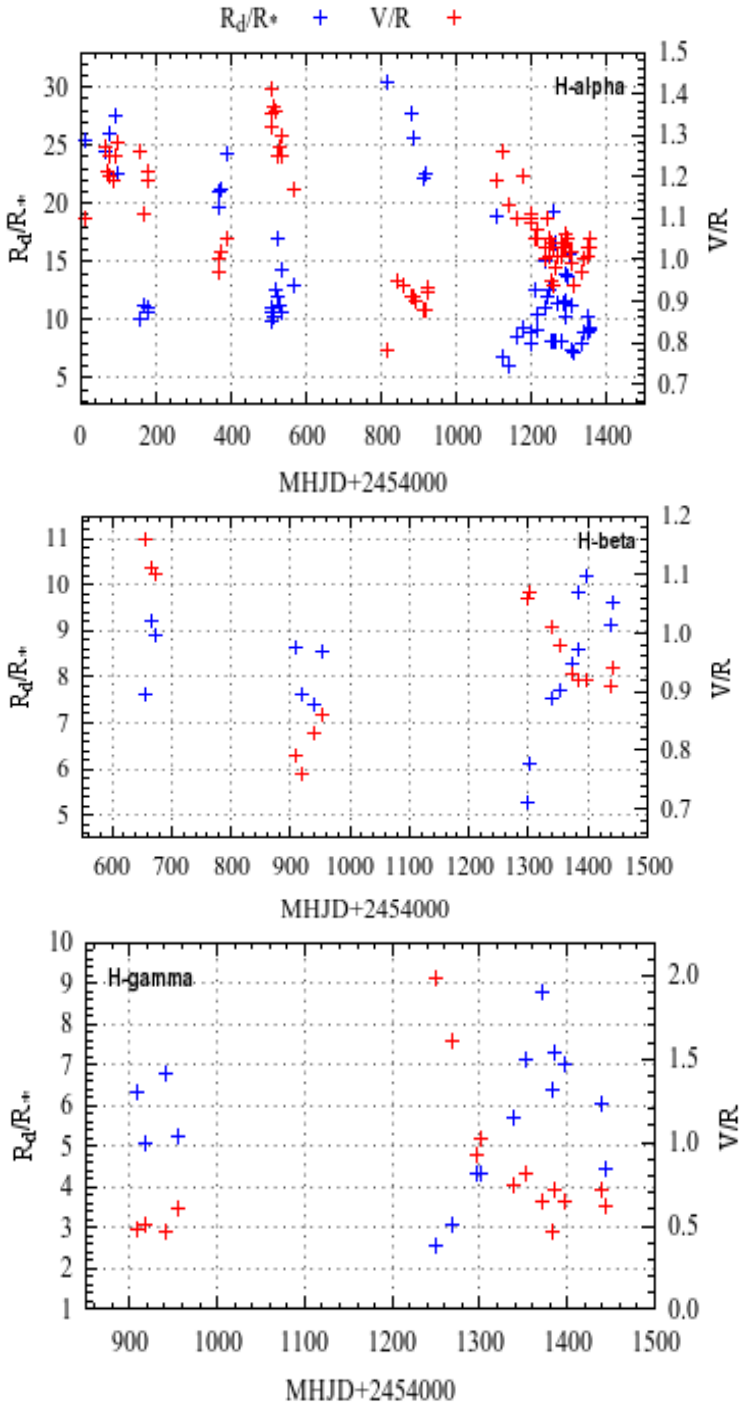

Figure 5.13b – Correlation and evolution of the relative disc radii and *V/R* ratio of Balmer lines.

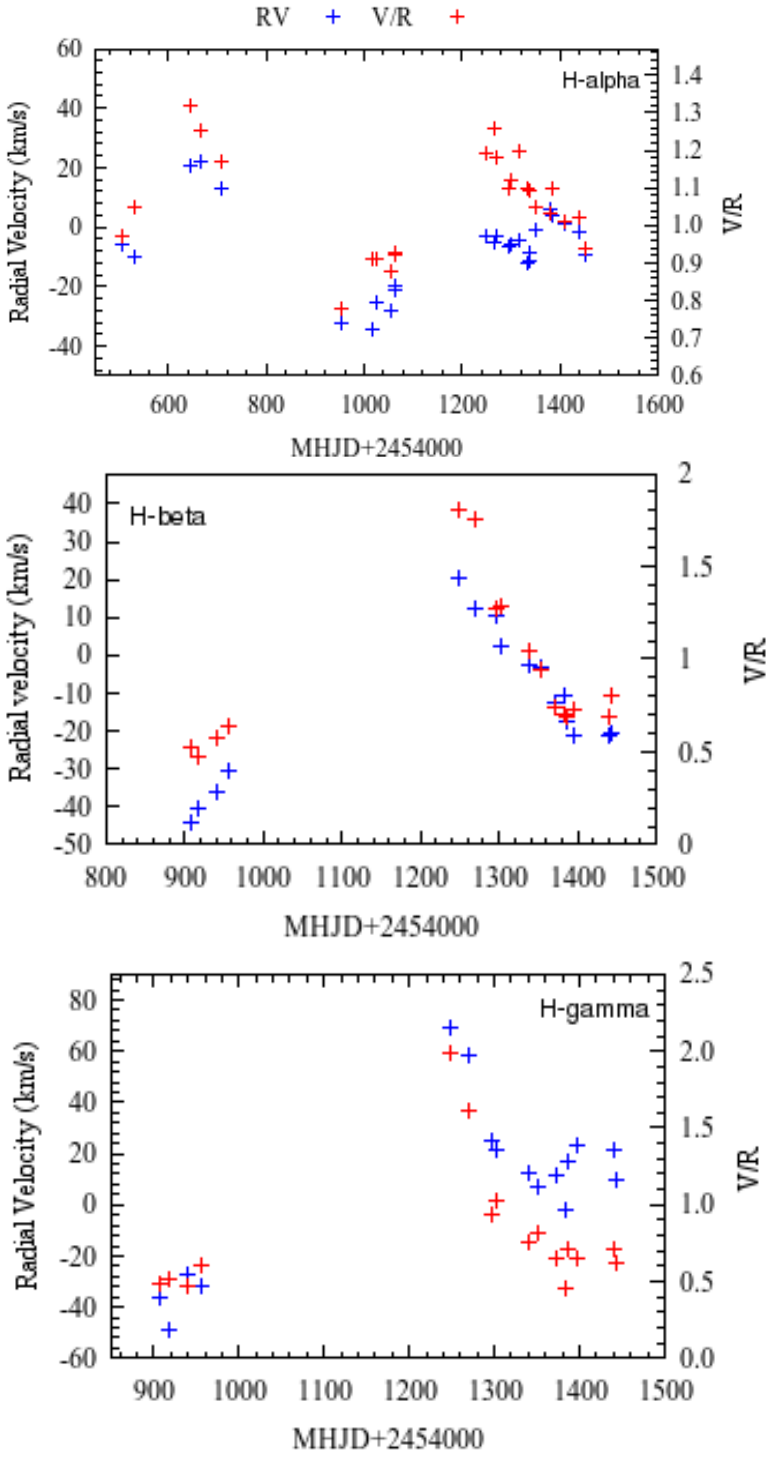

Figure 5.13c – Correlation of the radial velocity (*RVcr*) and *V/R* ratio with time in H_{α}, H_{β} and H_{γ}.

The rotation of the Be disc of δ-Sco with respect to the observer creates the approaching and receding parts of the disc that can be represented by the *V/R* ratio. Therefore, the relation of the radial velocity (from eq.5.3) of the emission lines with *V/R*

ratio can be studied. We found that in the H_α, H_β and H_γ emitting regions, the radial velocity is shifted towards a shorter wavelength when $V<R$ and shifted towards a longer wavelength when $V>R$; except for H_α in 2010, the relation of which seems incompatible with the variation pattern. In Figure 5.13b (top), the graph shows that the relative disc radii for H_α were getting increased in 2010 or in other words, the disc size became larger. Figure 5.7c (in section 5.3.1) shows that the line is broaden larger than the previous years. The broadening supposed had related with the rotation speed of the disc region. If the broadening of H_α can represent all of other emission line regions, then it shows that the disc is rotating faster. Otherwise, it would be only H_α emitting region that experience such a faster rotation which caused the larger disc size. For *V/R* ratio, we found it varies accordingly following its cycle. In overall, there was a size reduction of H_α emitting region in 2010 compared from previous years but the size of the emitting region is in increasing pattern for 2010. Other emitting regions were slightly larger compared from previous years.

5.4 HELIUM LINES: *HEI*λ6678 EMISSION LINE

In stellar spectral classification, the presence of Helium lines in the spectrum can be used as a benchmark for hot stars. The star is of type B if only *HeI* present and it is of type O if only *HeII* is present in the spectrum of the stars. The star is possibly in a transition phase from late O type and early B type, if both the neutral and singly ionised lines are present in the spectrum. These are due to the temperature of the stars. The hotter stars, O-type, are more capable of ionising the Helium element than are B-type stars. In Be star studies, the Helium lines can be used as a tool to diagnose the characteristics or behaviour of their circumstellar discs.

As the central star in δ-Sco system is an early B type star, B0.3IV, the presence of neutral Helium *HeI* lines are represented more than the singly ionised Helium *HeII* lines. Figure 5.1 shows that the *HeI* lines present are λλ4387, 4471, 4713, 4921, 5876, 6678 and 7065 and that the *HeII* lines present are λλ4339 and 4685. Almost all Helium lines in the red wavelength region are emission lines, which originate from the circumstellar disc and most of *HeI* lines are absorption lines, which arise from the photospheric region. In this work, we focused on *HeI* λ6678 because no other emission lines have been found close to this line.

Table 5.3 – Summary of the HeI λ6678 observations of δ-Sco from Feb 2007 to Oct 2010. First and second columns are the observation in Gregorian date dan Modified Heliocentric Julian Date (MHJD) respectively. Column 3 list the V/R ratio, column 4 presents the equivalent width, EW. The radial velocity, *RVcr* in column 5 has been measured with respect to its central reversal (cr) of the double peak profile. Column 6 and 7 are peak separation in different unit. Column 8 is the relative disk radii and the last column is the information on the spectral dispersion, in unit of Å/pixel. The hash, #, marks the line profile that appeared in the P-Cygni profile.

Delta Scorpii : HeI 6678 2007 - 2010

Date	MHJD+ 2450000	V/R	EW (Å)	RVcr (km/s)	ΔVp (Å)	ΔVp (km/s)	Rd/R*	dw
20070216	4147.65	1.004	-1.552	-41.944	5.026	225.781	2.136	0.25
20070312	4171.62	1.012	-0.783	-45.313	4.414	198.288	2.770	0.24
20070326	4185.62	0.990	-1.088	-54.163	4.747	213.248	2.395	0.25
20070408	4198.56	0.967	-1.032	-38.036	4.373	196.447	2.822	0.24
20070412	4202.56	0.970	-1.151	-38.934	4.462	200.445	2.710	0.25
20070415	4205.57	0.977	-1.314	-30.489	4.409	198.064	2.776	0.24
20070420	4210.52	0.962	-1.153	-35.745	4.390	197.210	2.800	0.25
20070425	4216.51	0.956	-0.991	-28.018	4.152	186.519	3.130	0.24
20070506	4226.54	0.970	-1.075	-28.512	5.040	226.410	2.124	0.24
20070523	4244.48	0.961	-0.720	-12.295	4.128	185.441	3.167	0.24
20070601	4253.47	0.956	-0.987	-10.633	5.045	226.635	2.120	0.24
20070605	4257.43	0.973	-0.860	-10.678	5.086	228.476	2.086	0.24
20070618	4270.44	0.976	-1.372	11.379	5.642	253.453	1.695	0.25
20070621	4273.39	0.959	-1.245	-10.453	5.532	248.512	1.763	0.24
20070707	4289.42	0.969	-0.639	3.383	5.577	250.533	1.735	0.24
20070717	4299.40	0.963	-0.645	16.320	5.006	224.883	2.153	0.24
20080208	4504.68	1.050	-0.686	-65.798	4.940	221.918	2.211	0.24
20080212	4508.69	1.049	-0.592	-29.501	4.929	221.424	2.221	0.24
20080217	4513.67	1.046	-0.522	-50.255	4.696	210.957	2.447	0.24
20080305	4530.63	1.051	-0.574	-90.865	5.378	241.594	1.866	0.24
20080401	4557.61	1.031	-0.704	-91.449	4.701	211.181	2.442	0.24
20080429	4585.58	1.028	-0.646	-38.171	4.575	205.521	2.578	0.24
20080501b	4588.47	1.004	-1.147	8.055	4.498	202.062	2.667	0.24
20080508	4595.50	1.002	-1.002	22.205	4.342	195.054	2.862	0.24
20080509	4596.51	1.011	-0.157	20.184	4.189	188.181	3.075	0.24
20080512	4599.44	1.007	-0.859	25.709	4.118	184.991	3.182	0.24
20080521	4607.51	0.991	-0.801	27.237	4.017	180.454	3.344	0.24
20080524	4611.50	0.996	-0.877	40.983	4.184	187.956	3.083	0.24
20080604	4622.43	0.997	-0.491	45.790	4.179	187.732	3.090	0.24
20080618	4636.39	0.976	-0.159	56.436	4.849	217.830	2.295	0.24
20080621	4639.41	0.979	-0.306	27.686	5.208	233.957	2.362	0.24
20080625	4643.38	0.986	-0.404	67.038	3.210	144.202	2.701	0.24
20080628b	4646.41	0.969	-0.374	25.305	5.425	243.705	1.980	0.24
20080629	4647.44	0.981	-0.309	93.093	3.497	157.094	1.947	0.12
20080701	4649.40	0.969	-0.469	54.370	4.767	214.146	2.375	0.24
20080703	4651.41	0.946	-0.419	81.503	4.285	192.493	2.869	0.12
20080717	4665.29	0.957	-0.566	56.841	6.032	270.973	1.900	0.34
20080723	4671.37	0.964	-0.376	65.780	4.093	183.868	2.932	0.24
20080724	4672.37	0.975	-0.234	54.819	5.416	243.301	2.091	0.24
20080830	4709.32	#	#	90.982	#	#	#	0.12
20090215	4877.75	0.992	-0.308	-65.933	4.329	194.470	2.880	0.26
20090228	4890.63	0.990	-0.395	-70.515	4.339	194.919	2.866	0.26
20090318	4908.65	1.000	-0.900	-145.805	4.577	205.611	2.576	0.24
20090330	4920.63	1.020	-0.850	-143.110	4.611	207.138	2.538	0.24
20090415	4936.61	1.027	-0.370	-30.938	4.878	219.132	2.211	0.25
20090422	4943.55	1.023	-0.214	-17.776	3.970	178.343	2.332	0.25

Table 5.3 - Continue

Delta Scorpii : HeI 6678 2007 - 2010

Date	MHJD+ 2450000	V/R	EW (Å)	RVcr (km/s)	ΔVp (Å)	ΔVp (km/s)	Rd/R*	dw
20090424	4945.56	0.695	-0.217	-22.268	4.628	207.902	2.519	0.25
20090509	4961.46	1.021	-0.462	-17.327	6.076	272.950	1.462	0.25
20090520	4972.52	1.028	-0.585	-27.704	6.072	272.770	1.464	0.25
20090529	4981.39	1.029	-0.523	31.055	6.434	289.032	1.304	0.25
20090612	4995.41	1.069	-0.698	54.325	6.906	310.236	1.235	0.25
20090621b	5004.40	1.047	-0.565	100.281	6.471	290.694	1.289	0.25
20090712	5025.38	1.059	-0.590	166.272	6.926	311.134	1.125	0.25
20090718	5031.36	1.049	-0.545	48.665	6.687	300.397	1.207	0.25
20090804	5048.35	1.049	-0.595	149.291	6.814	306.103	1.174	0.25
20090810	5054.37	1.040	-0.702	115.330	6.810	305.914	1.164	0.12
20090812	5056.36	1.050	-0.828	151.897	6.569	295.097	1.098	0.12
20090818	5063.36	1.031	-0.623	101.000	6.786	304.845	1.269	0.34
20090819	5063.36	1.048	-0.595	76.472	6.698	300.892	1.281	0.34
20100405	5291.58	0.991	-0.292	110.164	5.863	263.381	1.570	0.11
20100424	5310.53	#	#	55.044	#	#	#	0.11
20100603	5350.64	0.966	-0.228	5.135	4.829	216.931	2.607	0.11
20100606	5353.57	0.967	-0.126	0.508	4.907	220.435	2.059	0.11
20100608	5355.52	0.967	-0.187	10.705	4.766	214.101	2.266	0.11
20100617	5365.51	0.987	-0.145	22.654	4.923	221.154	2.227	0.11
20100624	5371.51	0.970	-0.264	31.369	4.735	212.709	2.407	0.11
20100630	5378.40	0.973	-0.258	29.932	4.117	184.946	3.184	0.69
20100706	5384.39	0.845	-0.154	22.834	4.637	208.306	2.510	0.69
20100707	5385.36	0.996	-0.118	54.684	4.394	197.390	2.795	0.34
20100709	5387.35	0.975	-0.182	64.747	4.148	186.339	3.136	0.34
20100712	5390.02	0.991	-0.143	57.604	4.563	204.982	2.592	0.34
20100713	5391.39	0.986	-0.125	70.362	4.594	206.374	2.557	0.19
20100715	5393.35	0.996	-0.137	47.137	4.434	199.187	2.745	0.34
20100725	5403.06	0.983	-0.142	61.198	4.456	200.175	2.718	0.19
20100809	5417.99	0.995	-0.131	56.077	4.422	198.648	2.760	0.19
20100822	5431.01	0.994	-0.124	77.101	4.175	190.247	3.009	0.19
20100827	5436.33	0.999	-0.123	79.616	4.226	189.843	3.022	0.34
20100830	5438.98	1.003	-0.169	44.352	4.674	209.968	2.470	0.19
20100910	5449.93	1.001	-0.136	54.235	4.782	214.820	2.360	0.19
20101005	5474.93	1.009	-0.099	44.846	4.675	210.013	2.469	0.19
20101021	5490.91	1.019	-0.129	42.780	4.718	211.945	2.424	0.19
20101025	5494.90	1.015	-0.128	42.825	4.346	195.234	2.857	0.19
20101027	5496.91	1.024	-0.098	31.369	4.080	183.284	3.242	0.19