Chapter 2

Literature Review

2.1 BE STARS IN GENERAL

B type stars are classified as an early type and among the hot stars, whose spectrum shows absorption lines. On the other hand, Be stars are B type stars whose spectra show, or have shown at some time, one or more Balmer lines in emission. Included under this loose definition of Be stars are HerbigAe/Be stars, peculiar Btype stars, Oe and Ae type stars, βCep, Btype super- and hypergiant stars, which are also classified as luminous blue variables (LBVs) and also some planetary nebula. The Be stars that are considered in this study are classified as classical Be stars, which are defined as “non-supergiant, Btype stars whose spectrum shows or has shown at some time, hydrogen lines in emission” (Collins, 1987). This definition of classical Be star is consistence with Jaschek etal. (1981), confining them to stars of luminosity class V–III (giant or subgiant), which are then called classical Be stars or simply, Be stars.

It is generally accepted that Be stars share at least one of the following general properties (Dachs, 1987):

1. The underlying (central) early type stars on average are among the fastest known rotators.
2. There are emission lines in the optical and near infrared spectra.
3. Profiles of resonance absorption lines in the UV spectra of earlytype Be stars usually reveal variable stellar wind with typical velocities of 500 to 1000

km/s and electron temperature exceeding the effective temperature of the stars.

4. Virtually all Be stars show strong irregular variation in their visual spectra and optical brightness on various timescales.
5. Appearance of emission lines in the spectrum of an early type Be star represents a transient phase in the life of the star; transitions from the normal B phase of the central star with a pure absorption spectrum, to a Be phase of usually limited duration are common phenomenon.

The presence of emission lines in their spectra indicate that the stars were surrounded by an extended envelope, where the gas is ionised by the ultraviolet radiation of the star; thus, producing a recombination spectrum (Struve, 1931). As with the B spectral type stars, Be stars are located at or near the main sequence band in the Hertzsprung-Russell (HR) diagram indicating that they are still burning hydrogen at their core.

The brightness and spectral profile of these stars varies in time, which is highly related to the activities of the circumstellar material encompassing the stars. The variation in both brightness and spectral profile are correlated to the phase-changing variation between B ↔ Be, Be ↔ Be-shell and B ↔ Be-shell, on timescalesof hours up to several decades. These phase-changing variations, the so-called Be phenomenon, is due to the episodic ejection of mass at the star's equator. The B or Be normal phase is observed during the absence of circumstellar material surrounding the star, whereas the Be and Be-shell phases are observed during the presence of circumstellar material or a disc. The Be and Be-shell stars differ in their spectral profiles in that Be stars show a single emission line, whereas Be-shell stars show a profile of sharp and deep absorption components in the centre of double-peaked emission lines. Figure 2.1 shows the variety of H_α profiles of normal B, Be and Be-shell stars.

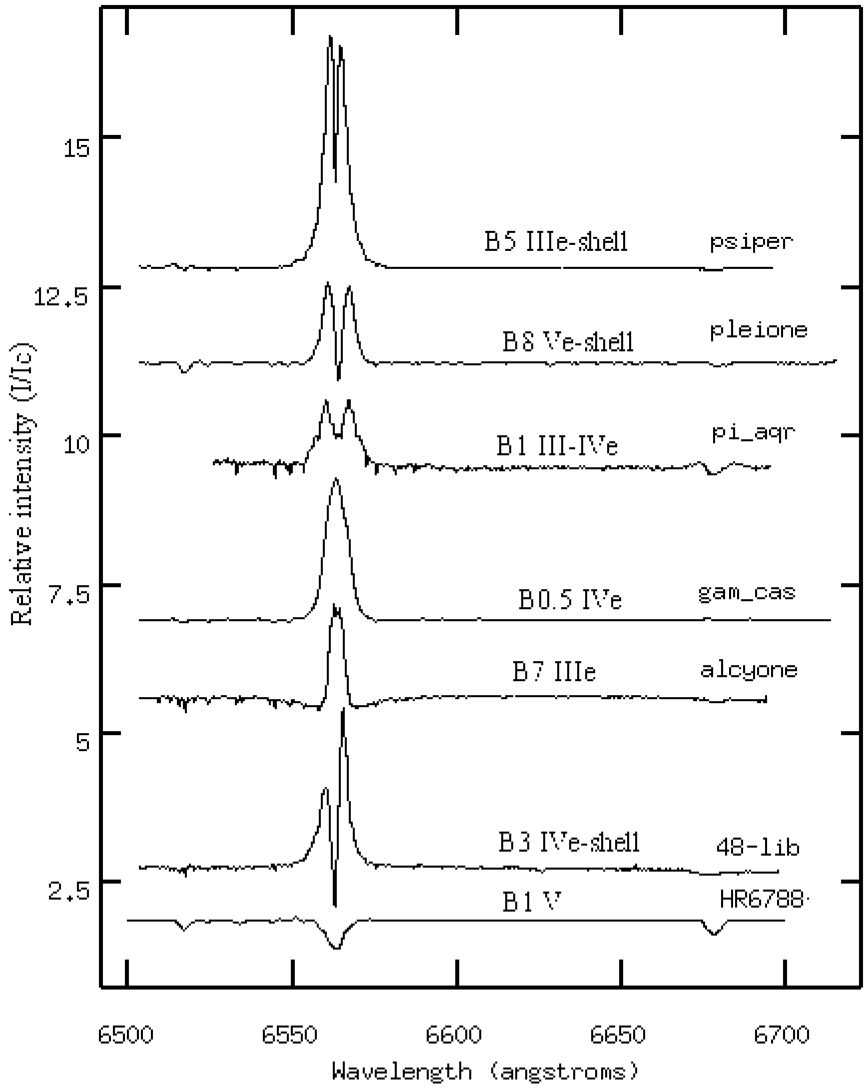

Figure 2.1 – Phases of H_α profile: normal B (HR6788), Be (Alcyone,γ-Cas, π-Aqr) and Be-shell (φ-Per, Pleione, 48-Lib).

2.2 PHYSICAL CHARACTERISTICS OF CIRCUMSTELLAR DISC OF BE STARS

2.2.1 Geometry

The studies of polarisation by McLean & Brown (1978) indicated that the geometry of circumstellar gas is not spherically symmetric and work by Poeckert& Marlborough (1978a, 1978b) detected a strong intrinsic linear polarisation from Be stars owing to electron scattering modified by hydrogen opacity in the envelope. The preferred model of the circumstellar envelope is an axisymmetric geometry (Shakovskoi 1965, McLean 1979) and Keplerian disc (Hanuschik, 1994). Doazan (1987) proposed an ellipsoidal geometry model to improvise the spherically symmetric model. However, it was unacceptable because stellar rotation has only a minor effect on the envelope in the ellipsoidal model. The case for an elliptical or a least oval structure is more convincing when the Be stars are a member of a binary system (Poeckert, 1982).

The first interferometric observation of a Be star ψ Per, using the very large array (VLA), confirmed that the geometry of the emitting circumstellar region was not spherically symmetric; the radio emission of ψ Per has an axial ratio of less than 2 (Dougherty & Taylor, 1992). Furthermore, the technique of optical interferometry has confirmed that the geometry of the circumstellar envelope of Be stars is indeed disc-like. Based on the observations of ζ Tau, the vertical extent of the envelope was limited to no more than 20° and the size of the envelope ranged from 3 to 12 stellar radius (Quirrenbach etal., 1997).

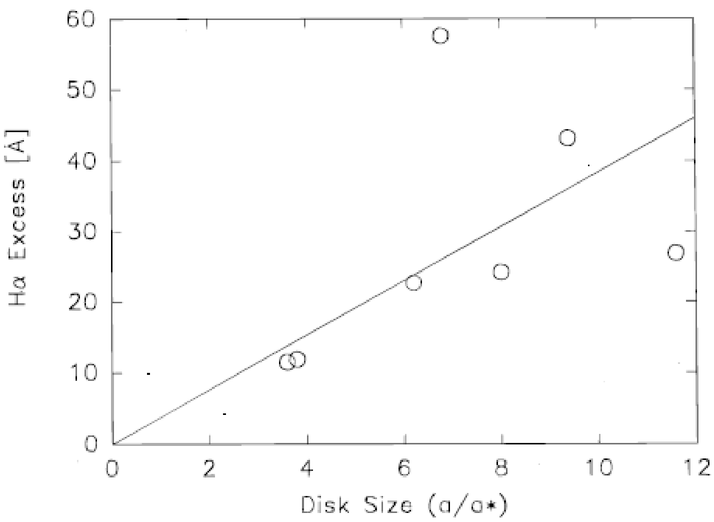

Figure 2.2 - H_α excess as a function of envelope size (*a/a**), *a* is the disc diameter and *a** is the photospheric diameter (Quirrenbach etal., 1997).

The thickness of the disc's envelope or opening angle has been determined from statistical studies of Be-shell stars to be 5° (Porter, 1996) and 13° (Hanuschick, 1996) with an upper limit of 20° (Quirrenbach etal., 1997). Wood et al. (1997) calculated an opening angle of 2.5° for ζTauri from polarisation; a technique that is sensitive to the inner regions only. If the disc flares, it will probe to the larger disc radii whereby the opening angle is an increasing function of radius (Hanuschick, 1996). From statistical analysis, Yudin (2001) concluded that the half-opening angles lie in the range 10–40°. In summary, interferometric studies have confirmed that the geometry of the circumstellar envelope is disc-like and relatively thin.

2.2.2 Kinematics

The appearance of hydrogen emission line indicates the presence of ionized circumstellar gas which is believed to be formed in an equatorial disc-like structure. The rotation mechanism of the disc was very hard to be determined from spectroscopic data alone, whether it follows Keplerian rotation, angular momentum conserving or of a type in between. The interferometric observations in the optical and infrared wavelengths have provided a unique insight of the structure of the disc. Hence, information on the gas kinematics of the disc region particularly, H_{α}, can be revealed. It was found an evidence that the disc around classical Be stars exhibit a near-Keplerian rotation profile (e.g. Quirrenbach et al. 1994; Tycner et al. 2005). In the Keplerian disc, the specific angular momentum increases as the disc radius, $r^{½}$, and the Be disc is formed from inside by material ejected from the central star. Thus, the angular momentum has to be transferred from the inner part to the outer part.

Wide observational evidence for the non-radial pulsation (NRP) has been accumulated for Be stars as early as 1980s (Baade 1987). Typical behaviour of the NRP in B and Be stars is the rapid variation of line profiles in the form of subfeatures (bumps or dips) travelling through the profiles. Variations of subfeatures suggest the occurring and travelling of hot or cold regions on the photospheric surface. Osaki (1999) suggested a possible role of non-radial oscillation that large-amplitude non-radial waves give rise through wave-breaking phenomenon to drive the equatorial mass-loss, which forms a viscous decreation-disc around Be stars. Optical or infrared spectroscopic observations have revealed non-radial pulsations of Be star, which might provide a way to feed material from the photosphere to the inner disc (e.g., Rivinius et al. 1998).

2.3 FORMATION OF THE BE DISC

In an astrophysical accretion system, the disc is a gas disc found around various types of celestial object ranging from newborn stars to massive black holes. This disc transports gas to the object at the centre from the interstellar medium or from another star. However, this is unlikely for the case of Be stars because it is supposed that Be discs originate from the ejection of mass from the underlying star owing to the lack of an outside source of material, because they are not generally found in a close mass-exchange binary system. Furthermore,it is observed that the discs or envelopes are formed and destroyed on timescales of days to decades. Hence, the mechanisms responsible for the ejection of gas or material from the underlying star are one of the puzzles in studying Be stars. Regardless ofby what mechanism the gas or material is ejected from the photosphere, it must generate a region in the star's equatorial plane sufficiently dense to facilitate the continuum and emission lines. The general requirement for propelling gas or material from the rotating surface of the star at the centre into orbit can be understood simply by means of launching terrestrial satellites, which is easiest when the launch occurs from near the equator and into the direction of rotation.

The mechanism of the formation of a disc around Be stars, especially single Be stars is still unknown. However, there are several suggested possibilities to explain the ejection of gas from the photosphere:

1. Radiatively driven wind – a wind driven by stellar radiation will be aspherical with a higher velocity at the equator than at the poles. Hot stars (T_{eff}> 10^4 K) can sustain a flow driven by line absorption and scattering of stellar photons (Porter &Rivinius, 2003). These winds accelerate the gas through the sonic point close to the star and achieve terminal velocities of 1000 km/s and a mass-loss rate of 10^{-8} to 10^{-10} $M_{\odot} yr^{-1}$ (Snow, 1981, 1982 and Grady et al., 1987).
2. Photospheric pulsation – pulsation might induce turbulent motions at the photosphere and lead to angular momentum deposition in the photospheric regions producing super-Keplerian speeds that will lift gas off the star.

2.3.1 Models of disc formation

There are several commonly suggested mechanisms in simulating or modelling the formation of the discof Be stars: first, stellar wind compression that may channel supersonically out-flowing gas from mid-latitudes to the equatorial plane through the conservation of angular momentum (Bjorkman&Cassinelli, 1993; Bjorkman, 2000);second, episodic ejections from some point on the star with some material being propelled forward into orbit and some falling back onto the star (Kroll &Hanuschik, 1997; Owocki& Cranmer, 2002);third, magnetic forces that can channel gas towards the equatorial plane and provide sufficient torque to spin up a disc (Cassinelli etal., 2002; Brown etal., 2004).

2.3.1.1 Wind Compressed Discs Model

The Wind Compressed Disc (WCD) model introduced by Bjorkman&Cassenelli (1993) originates from the principle of spherically symmetric flow for non-rotating OB stars line-driven winds. When a stream of gas is expelled by the photosphere, it is acted upon by gravity and radiation and thus, it flows along radial streamlines. In the case of rotating stars, the rotation of the radiation-driven wind produces flow towards the equator and this wind streamline stays in its orbital plane. AsBe stars are very fast rotators, the rotation is sufficiently large for the streamlines to cross the equatorial plane. The same procedure happensin the opposite hemisphere and thus, both streamlines intercept each other at the equatorial plane. This produces a shock that forms a dense region of disc confined to the equatorial plane.

At first, this model naturally produces an equatorial disc and infact, the initial dynamical simulation undertaken by Owocki, Cranmer and Blondin (1994) confirmed much of the basic WCD paradigm. However, subsequent work by Owocki, Cranmer and

Gayley (1996) has shown that non-radial (poleward) components of the driving can effectively inhibit the formation of any disc. The other reasons why WCD was ultimately found to fail in modelling disc formation are that the outflow from a subcritical rotating star lacks the angular momentum for a stationary orbit. Thus, material in the inner disc is pulled back onto the star by gravity, while material in the outer disc flows outward with the stellar wind. Moreover, the radial flowing WCD material remains unchanged for only a few days; hence, it is incapable of explaining the long-term (several years) variation of the spectral profile of Be stars.

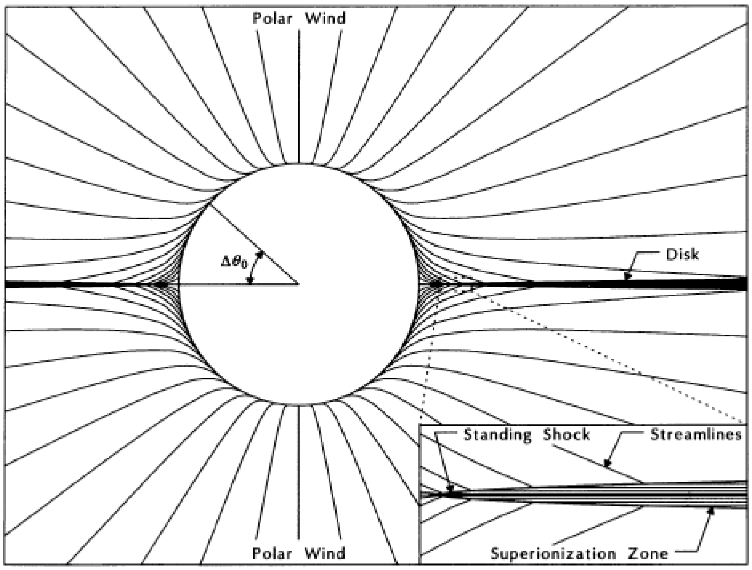

Figure 2.3 – Orbital plane of each streamline inclined with respect to the equatorial plane by the initial latitude of streamline. This model requires high rotation rate and wind pressure for the dense disc to be formed at the equatorial plane (Bjorkman &Cassinelli, 1993).

2.3.1.2 Magnetically Torqued Disc

The possible role of magnetic fields in producing a Be disc has often been ascribed to that of controlling the out-flowing gas (Poe & Friend, 1986; Ignace, Cassinelli&Bjorkman, 1996). Havnes&Goertz (1984) and Babel &Montmerle (1997a) have discussed the time-dependent accumulation of stellar wind matter channelled by strong magnetic fields. Their idea was then extended towards other hot stars and the Be star phenomenon by Babel & Montmerle (1997b) and Donati etal. (2001). However, these works did not consider the contribution of the rotation to the dynamics of the magnetically channelled wind. The Magnetically Torqued Disc model (MTD) addresses the regime in which the rotational term is dominant and where the field provides sufficient torque to produce a dense disc with quasi-Keplerian speeds (Cassiinelli etal., 2002).

The fact that near mainsequence B stars have a mass outflow and that the channelling of that flow can lead to shock-compressed disc material has been applied to this model. In this model, an aligned field of dipole-like shape for the basic magnetic topology $B(r,\theta)$ with r parametric dependence is used. The gas is assumed to be confined by the magnetic field and its azimuthal velocity $v_\phi(d)$ in the equatorial plane at radial distance d, is considered to find the field needed to transfer angular momentum to the material or gas that is driven up from the star by line-driven wind forces and to redirect that flow towards the equatorial plane.

Figure 2.4 depicts the principle of the MTD model. The closed field will channel the gas to a specific radial distance $d(l)$ that depends on the latitude $l$and the field tube at the stellar surface; larger values of$l$ correspond to larger values of d. For $l>\pi/4$, field lines near the poles would intercept the equator at very large distances but the wind energy density will exceed the field before it reaches the equatorial plane; therefore, the field would no longer be magnetically dominated.

In this model, they had calculated the effect of a dipolar stellar magnetic field on the wind flow, which for the region where the magnetic energy dominates over the kinetic energy density the flow streamlines follow the magnetic field lines. For the closed magnetic loops near the equator, this forces the gas to flow towards the equatorial plane from both hemispheres and results in a shocked region that creates the disc.

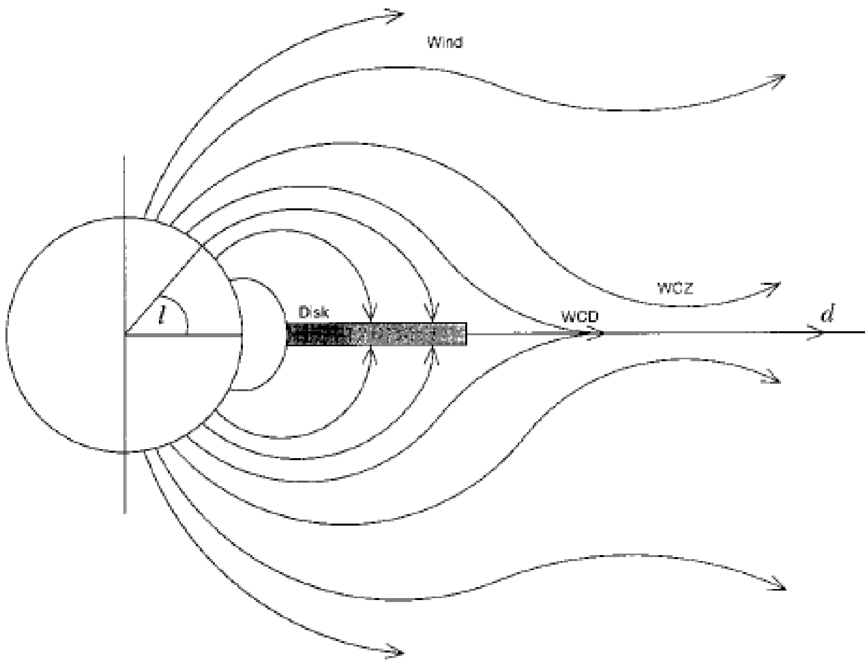

Figure 2.4 – Schematic diagram for MTD model (Cassinelli et al., 2002).

This model seems reliable in forming the disc in the equatorial plane because numerical magnetohydrodynamic simulations on this model appear consistent with the expectation for non-rotating stars (Ud Doula & Owocki, 2002). However, simulations including the stellar rotation appropriate for Be stars do not produce such a magnetically torqued disc capable of explaining the Be phenomenon (Owocki&Ud Doula, 2003).

2.3.1.3 Viscous Disc Model

In the viscous disc model (Lee etal., 1991), gas and angular momentum are added to the inner regions before being diffused outwards under the action of turbulent magnetohydrodynamic viscosity. The role of angular momentum is to increase the disc's velocity to Keplerian speed. Therefore, the equatorial regions of the stellar atmosphere are spun-up to slightly super-Keplerian rotation speeds. The gas or material in the disc self-interacts through viscosity and if the gas or material is continually supplied with angular momentum that is conducted outward, it will be lifted from the stellar surface and continue to move further away from the star. Hence, a disc could be built up with rotational speeds very close to Kelperian and subsonic radial velocities. However, the mechanism of how to supply the angular momentum to the disc is still to be determined in this model. One possibility is through the Smoothed Particle Hydrodynamics (SPH) simulation by Kroll & Hanuschik (1997). In this simulation, they consider the effect of an undirected explosive ejection of material from a localised equatorial region of rapidly rotating surface. The material that happens to be propelled in the direction of rotation gains sufficient velocity to achieve circumstellar orbit, whereas material ejected in other directions falls back on to the star almost immediately.

The viscous disc model has apparently been found successful in describing the observed Be stars (e.g., *V/R* variations in the emission lines, Okazaki, 1997); nevertheless, a good explanation for the input angular momentum s still required.

2.4 MASS LOSS IN THE BE STARS

Mass loss is a common feature in luminous stars, namely O type stars, giant and supergiant OB stars, as well as in late type stars such as type M. The mass loss rates and the underlying physical mechanism, however, differ greatly for the different types of stars. Observations reveal that mass loss rates of hot luminous stars are correlated with the stellar luminosity (De Loore& Doom, 1992).

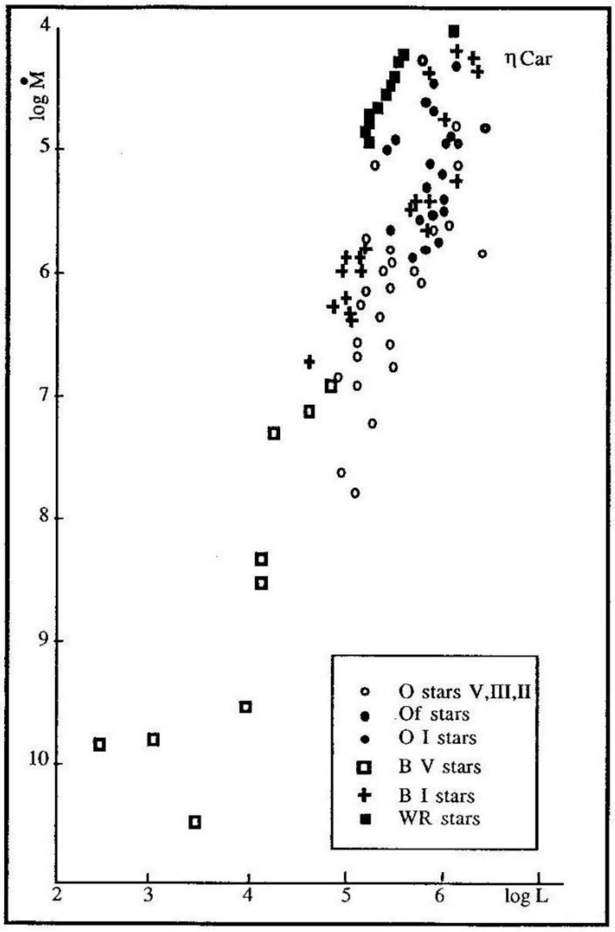

Figure 2.5 – Correlation of massloss rate and luminosity of the stars.(De Loore& Doom, 1992).

We know that gravitational force and pressure compete with each other in the stars to gain the balances for the stars to survive until the end of their life. The competition eventually results a stellar wind, which leads to the ejection of mass from the stars. There are four main physical processes presently known capable of directly accelerating matter from the stellar surface to escape velocities: radiative pressure, centrifugal force, thermal expansion and hydromagnetic waves (Strafella etal., 1998).

Radiation pressure is generated by the exertion of a force on a surface hit by photons. We know that a photon possesses an energy E, which also carries a momentum of $p = E/C$. The momentum will be transferred from the photon emerging from the star to the particles of the stellar atmosphere as the energy being transported from the core towards the surface by means of radiation and thus, thisleads to the radiative pressure that causes the mass ejection. This mass-loss mechanism is only efficient for O type stars that are hot and have highluminosity in the range of $L_* \sim 10^5 - 10^6 L_\odot$ (Castor et al., 1975). For intermediatemass stars of B, A and F spectral types, this mechanism is not expected to be significant in ejecting the mass from the stars. Hence, in the case of Be stars, radiation pressure alone cannot produce a considerable mass loss.

Centrifugal force represents the effect of inertia arising in connection with rotation, which is experienced as an outward force away from the centre of rotation. This centrifugal force that results from rotation of the stars would cause the stars to produce an equatorial bulge. In the case of Be stars that are rotating rapidly, the effect of centrifugal force distorts the spherical shape of the stars, causing them to become oblate and thus, undergo gravity darkening. As a result, the stars have higher surface gravity and thus, temperature and brightness at the polescompared with the equator. The fast rotation of Be stars might result in centrifugal effects that could possibly cause the stars to lose their mass and generate a stellar wind. Snow (1981) found that mass loss from early Be stars ranged between 10^{-11} and 3×10^{-9} $M_\odot$ yr^{-1} and this value only caused the massloss of about 10^{-3} $M_\odot$ over the hydrogen-burning lifetime of the stars, which typically takes a few times 10^7 years. This amount of loss could be considered small and to have aninsignificant impact on the evolution.

2.5 ROTATION OF BE STARS

The underlying Be star is probably identical to a normal B type star of similar spectral type. However, the fact that Be stars as a class are rapidly rotating cannot be neglected; in fact, the rotation speed is faster than other classes of non-degenerate stars. The star rotates on its axis at a certain inclination angle *i* with respect to the line of sight from Earth. The rotational velocity $v_{rot} sin\ i$ at this angle is described in Figure 2.6. According to Porter (1996), the value of $v_{rot} sin\ i$ is not the fundamental rotational parameter for a rotating star but rather it is the rotational velocities of the star as a fraction of break-up velocity $\omega = v_{rot}/v_{cr}$, where v_{cr} is the critical rotational velocity or break-up velocity of the star (Porter, 1996).

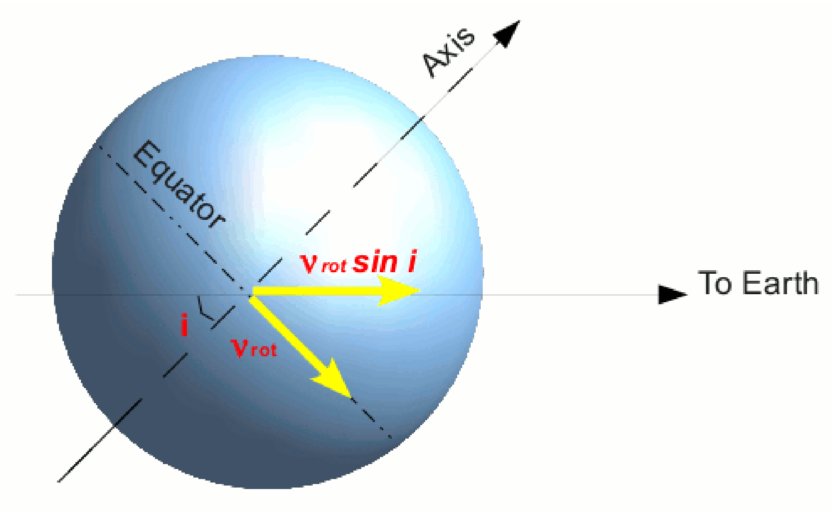

Figure 2.6 – Schematic diagram of rotational velocity of a star rotating at inclination angle *i* with respect to the observer on Earth.

It has been well established that Be stars have higher rotational velocities than that of normal B stars, although Be stars do not rotate at their break-up velocities (Slettebak, 1979). It was first hypothesised by Struve (1931) that the equatorial rotational velocities v_{rot} might be sufficiently close to the critical velocity to allow material to leak into the disc. This hypothesis was then scrutinised quantitatively by Slettebak and others, establishing the current view that the rotation of Be stars is significantly subcritical with $\omega = v_{rot}/v_{cr} \cong 0.7 - 0.8$ (e.g.,Chauville etal., 2001; Townsend etal., 2004). The critical rotational velocity can be calculated using equation (2.1) as follows:

$$\nu_{cr} = \sqrt{\frac{GM*}{Req}} \qquad (2.1)$$

where G is the universal gravitational constant, M_* is the mass of the star and Req is the equatorial radius of the star at breakup. The equatorial radius is equal to 3/2 times the polar radius at breakup. The value of ν_{cr} increases with spectral subtype from B0 (ν_{cr} ~ 540 km/s) to B9 (ν_{cr} ~ 390 km/s) (Porter, 1996). Observations of Be stars suggest that rapid rotation is a key ingredient for a B type star to become a Be star. However, the fact that many rapidly rotating B stars without emission lines are known and the fact that Be stars can lose their H_α emission at irregular intervals, suggests that rapid rotation is not the only parameter involved (Pols et al., 1991).

2.6 LINE PROFILE VARIATIONS

It is widely accepted that the ionised regions in the envelope or circumstellar disc of Be stars are responsible for the appearance of the emission lines. The features or profiles of these emission lines are often strongly variable, for example, the emission lines sometimes disappear and reappear and their intensity often varies with time. Most of the variations in Be stars are treated as Be phenomena rather than as a special type of stars. Four types of line profile variation that may occur in Be stars are:

a- Phase change

b- *V/R* variation

c- *E/C* variation

d- Radial velocity (*RV*) variation

2.6.1 Phase change

The phase change in Be stars is the change from B to Be, Be to Be-shell and B to Be-shell or vice-versa. The variations occur usually on time-scales of years to decades as the changes are were due to the formation and destruction of the circumstellar disc for B stars become Be or Be-shell stars and vice-versa, which is a long-term process. Generally, the difference between aBe star and a Be-shell star is the orientation of its rotational axis as viewed from the Earth; a Be star rotates at an angle whereas a Be-shell star rotates near equator-on. However, this cannot be applied in the case of the interchange between the Be and Be-shell phase as the rotational axis of the star must be conserved. The transformation from Be to Be-shell or vice-versa is due usually to the change in structure of the envelope, which is a long-term process.

2.6.2 *V/R* variation

V/R variation is the change in ratio of the intensity of the violet and red peaks with time. For Be stars, which are viewed at an angle of the inclination axis or equator-on, the emission lines happen to have a double-peaked profile. This double-peaked profile is the violet and red peaks of intensity above the underlying photospheric absorption profile. The intensity of both peaks is often observed to vary with time. The variation of *V/R* can be explained by an elliptical disc or ring model (Ballereau 1989). In this model, a rotating elliptical disc or ring is considered, in which gas undergoes Keplerian motion. Gas particles located near the periastron passage will move faster than near the apoastron passage. This would cause a greater accumulation of gas particles near apoastron passage with stronger emission lines than near the periastron passage.

Poeckert (1982) and Hirata (1984) studied the spectral features of Be stars and found that the profile of *V/R* variation are attributed to cool equatorial discs surrounding the star. Hubert etal. (1987) and Dach (1987) outlined the typical features of these long-term *V/R* variations as follows:

1- Periods range from years to decades.

2- Periods are not sensitive to spectral types of the star at the centre.

3- The entire profile shifts blue-ward when the red component is stronger and shifts red-ward when the violet component is stronger.

4- In addition to the above-mentioned common features, phase differences or phase lags among *V/R* curves of individual lines are observed in some Be stars.

The *V/R* variation along the rotation of the envelope can be observed if the ring or elliptical disc rotates around the star by some long-term apsidal motion. Kato (1983) reformed this model as a one-armed oscillation of rotating disc and suggested that one-armed, low-frequency waves could exist stably in the geometrically thin, nearly Keplerian disc. This theory was then developed by Okazaki (1991, 1996) and named the global one-armed oscillation of equatorial discs for explaining the *V/R* variation in Be stars. In this model, the oscillation is considered in the form of $exp[i(\omega t - m\varphi)]$, where $\omega = 2\pi\nu$ is the circular frequency, φ is the phase and m is the mode of oscillation. For one-armed oscillation, $m = 1$. The model is highlighted by the enhancement of the surface density, which is expressed by $\sigma_o + \sigma_1$, where σ_o denotes the undisturbed density and $\sigma_1$the disturbed part. Figure 2.7 shows the one-armed oscillation disc model for explaining the *V/R* variations.

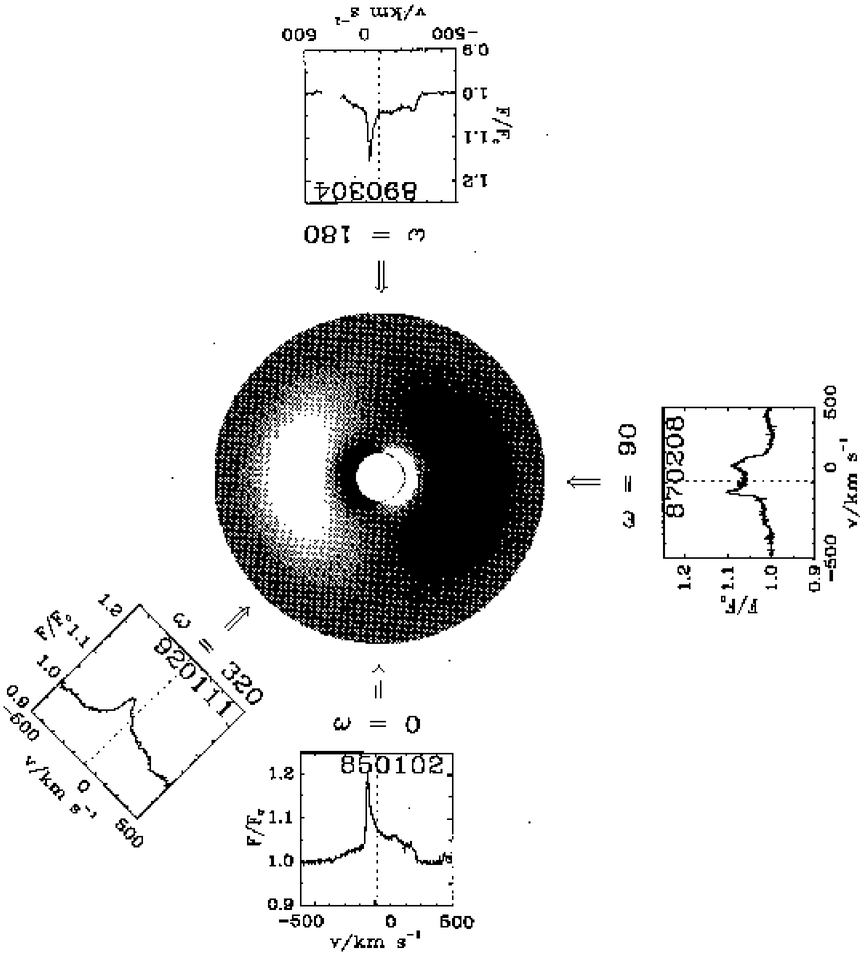

Figure 2.7 – Variation of line profile can be explained by the one-armed oscillation disc model. The profiles of μ Cen have been found to meet with the model (Okazaki, 1991).

2.6.3 *E/C* variation

E/C variation is the time variation of emission line intensities *E*, relative to the adjacent continuum *C*. The change of the emission line intensity is probably because the line radiation itself changes, or because the star becomes brighter or dimmer, which causes the variation in continuum level. Whatever the causes, this variation simply represents the variation in strength of the Be phenomenon. One cycle of *E/C* variation changing from the maxima to the minima of *E/C*might varies for different stars and for different epochs of observation. Figure 2.8 show one example of the *E/C* variation of H_α in μ Cen.

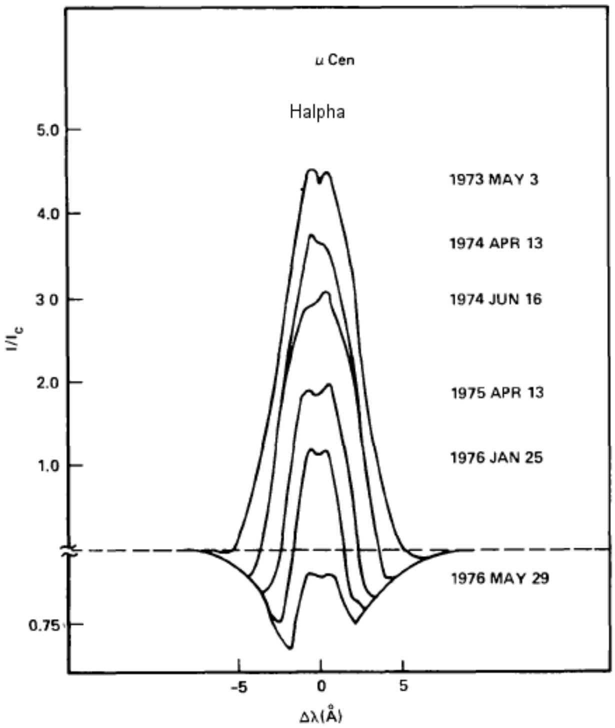

Figure 2.8 – The *E/C* variation of Hα in μ Cen from May 1973 to May 1976. The decrease of the intensity has been observed parallel with line width. The change of line width here is not correlated to the rotational velocity of the star.

2.6.4 Radial velocity variation

Information on radial velocity variation can be related to the binarity system of stars. For the emission lines or shell lines, this variation can be used as an indicator of the motion in the envelope, i.e., whether it is expanding, contracting or stationary, provided the radial velocity of the star is known. The radial velocity of a star can be determined by using the photospheric lines, which are not affected by the absorption or emission lines from the envelope.

Early studies of Be stars have established that the variation of the velocity as a function of the number of lines in the series can define the progression. In addition, many stars exhibit different radial velocities of different lines in the Balmer series. If we can pinpoint the area in which the various lines in the series are formed, then the progression would indicate whether the expansion or contraction is accelerated or decelerated. Therefore, the progression of lines in a series such as the Balmer lines could provide information regarding the motion in the envelope.

The variation in radial velocity can also be related to the phase change in the Be phenomena. The radial velocities usually have a large variation when the star changes from a shell phase to a Be phase. This effect was shown in Pleione, in which the disappearance of the shell was associated with a large increment in the expansion velocity for the higher members of the Balmer series. However, the behaviour could be different for different stars. For example, for*59Cyg*, the maximum expansion velocity was observed at the highest strength of its shell phase. The expansion velocity decreased afterwards and returned to its initial value when the shell lines disappeared (Barker 1979). Therefore, the behaviour of Be stars is unique. Different stars have different behaviour, which cannot be considered as a general behaviour of all Be stars. The study of radial velocity in the visible region provides information only on the motion of the cool envelope with respect to the photosphere of the Be stars.

2.7 Be BINARY

Kříž and Harmanec (1975) proposed that a large proportion of Be stars are interacting binaries undergoing mass transfer from the secondary component filling of its Roche lobe. Owing to insufficient data on secondary components in Be stars, Harmanec (1985) introduced another method of mass transfer originating from a rotationally unstable secondary contracting towards the helium main sequence. Pols et al. (1991) suggested that Be stars could also be post-mass exchange binaries in which they owe their rapid rotation to angular momentum transfer. Nevertheless, the present disc is not due to accretion from the companion because the companion has evolved to a compact object that accretes mass from the disc. It is the B star that somehow has to manage the formation of the disc and became a Be star.

The idea of post-mass transfer binaries was proposed previously by Rappaport & van de Heuvel (1982), in which the rotation of Be stars is increased by means of binary transfer and where the donor or primary star explodes as a supernova if the mass is sufficient, leaving a Be + neutron star (NS) system.

Be binaries can be categorised into four groups (Gies, 2001): (1) hot Algol, i.e., interacting binaries that pertain to the hypothesis of Křĭž and Harmanec (1975), (2) Be + He stars, (3) Be X-ray binaries and (4) Be + white dwarf. A number of studies of Be stars has found insufficient evidence to support a general relevance of binarity for Be stars (Porter and Rivinius, 2003; Basikalo etal., 2006). However, they have admitted that binarity is an important aspect of the Be phenomenon. For example, in the past, the companion might have had influence on the Be star as a result of previous mass transfer and the companion of the Be star might have lessened or enhanced the mass loss from the primary into the disc (Harmanec etal., 2002).