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Be Stars: Messengers of Stellar Disk Physics

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Abstract

Be Stars are massive stars with the presence of material around them in the form of a disk. Be stars provide an excellent opportunity to study circumstellar disks. Spectra of Be Stars show interesting emission lines of different elements such as hydrogen, helium, iron, oxygen and calcium, silicon, magnesium, nitrogen on rare occasions. Spectroscopic studies of these emission lines provide an important insight to the geometry and kinematics of the disk. In this article, we provide an introduction to the various observable properties of Be Stars, effect of metallicity on those properties and discuss the major breakthroughs, till date in Be Star research.

Keywords: Be Star, Emission Lines, Variability, Be phenomenon, Metallicity

1. Introduction

The tiresome job of classifying stars by their spectral properties started in the late 19th century in the basement of the Harvard College Observatory. Under the leadership of the astronomer

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Edward Pickering, the then Director of the Observatory, dozens of women and computers were involved in this significant work. Annie Jump Cannon and Cecelia Payne-Gaposchkin initially arranged stars according to the strength of the hydrogen Balmer lines (with A being the strongest). Then, when a physical explanation for spectral line formation was found, they rearranged the spectral classes according to temperature. The sequence that was finally adopted begins with the hottest stars, class O, which show ionised helium lines in their spectra, and proceeds from hot to cool in the order: O, B, A, F, G, K, and M. Most stars of the visible universe can be classified into these groups. For finer discrimination, each of the classes are subdivided from 0 to 9 (from hot to cool). The Sun, for example, is classified as a G2 star.

Later, two other astronomers - Morgan and Keenan added a luminosity class to this system using Roman numerals. It is useful because stars of different luminosities may have the same temperature in their photosphere. These designations are 0 for hypergiants, I for supergiants, II for bright giants, III for regular giants, IV for sub-giants, V for main sequence stars, VI for sub-dwarfs, and VII for white dwarfs. Since the Sun is a main sequence star, fusing hydrogen into helium, its full designator is G2V.

Most of the hot stars show absorption lines in their spectra. But surprisingly, some of them also show emission lines of various elements. Broadly known as emission line stars, they indicate the presence of a circumstellar disk. Be Stars belong to this group of emission line stars which also show various interesting emission lines in their spectra. A Be Star is a special class of massive B-type main-sequence star surrounded by a geometrically thin, equatorial, gaseous, decretion disk which orbits the star in a near Keplerian rotation. Collins (1987) defined a classical Be (CBe) Star as: "a non-supergiant B Star whose spectrum has, or had at some time, one or more Balmer lines in emission". It is estimated that around 15-20 % of all B-type stars in our Milky Way are Be Stars. They belong within the luminosity classes III-V and their corresponding masses and radii range within $M_Y \sim 3.6 - 20\ M_\odot$, and $R_Y \sim 2.7 - 15\ R_\odot$ (Cox 2000).

2. Be Phenomenon

Be Stars provide an excellent opportunity to study circumstellar disks. Unlike protoplanetary dust disks surrounding young stars, Be Star disks are not shrouded in dust thus being more directly accessible for observation. Moreover, the disks are temporary, forming and dissipating on a timescale of years to decades which help in studying disk evolution. However, though various studies have been done, the disc formation mechanism of Be Stars- the 'Be phenomenon', is still not understood clearly. Naturally, most of the studies on Be Stars have focussed on solving the mystery of the Be phenomenon. Rapid rotation, non-radial pulsation (NRP), stellar wind, binary interaction and so on are some mechanisms that have been proposed to explain the Be Phenomenon. The physical model which best describes these disks so far is the viscous decretion disk (VDD) model (Lee et al. 1991; Carciofi 2011).

Clues have come that stellar evolution and metallicity may even play important roles in Be phenomenon. The role of stellar evolution in Be phenomenon was first claimed by Schmidt and Kaler (1964). They proposed that Be Phenomenonn occurs during the overall contraction phase following the exhaustion of hydrogen in the core. This claim was doubted by Hardorp and Strittmatter (1970). Several other authors have also studied the possible role of stellar evolution in Be Phenomenon in later years. Presently, it is thought that the Be Phenomenon occurs in the latter part of a B star's Main Sequence lifetime (Mathew et al. 2008; McSwain and Geiss 2005; Maeder and Meynet 2001; Fabregat and Torrejon 2000; Meynet and Maeder 2000). Metallicity has also been suggested to be a factor influencing Be Phenomenon. Effects of metallicity in Be stars have been discussed in section 5.

Over 150 years have passed since the discovery of the first Be Star Gamma Cas by Father Angelo Sechhi in 1866 (Sechhi, 1867). Most of our present knowledge about Be Stars have been obtained through spectroscopic studies of various emission lines observed in their spectra. The key indication of the presence of a gaseous disk surrounding a Be Star also comes by spectral analysis of the emission lines present in their spectra. Spectral survey of Be Stars is important to understand the nature of their disks as a whole. Till date, several spectroscopic surveys have been carried out both in the optical (for example Jaschek et al., 1980; Slettebak, 1982; Andrillat and Fehrenbach, 1982; Dachs et al., 1986; Hanuschik, 1986; Hanuschik, 1987; Andrillat et al., 1988; Dachs et al., 1992; Banerjee et al., 2000; Mennickent et al., 2002; Keller, 2004; McSwain and Geiss, 2005; Sabogal et al. 2005; Mathew et al., 2008; Koubsky et al., 2012) and in the near-infrared (for example Clark and Steele 2000; Steele and Clark 2001) regime to characterise Be star disks.

Apart from spectroscopic surveys, there exists the BeSS (Be Star Spectra) database which contains the complete catalogue of classical Be stars, Herbig Ae/Be stars, and B[e] supergiants. Maintained at the LESIA laboratory of the Observatoire de Paris-Meudon, this database currently assembles 210273 Be stars spectra obtained by professional and amateur astronomers for 1211 different Be Stars (http://basebe.obspm.fr/basebe/). Still, they remain among the most mysterious stars of the universe. Intense studies have been done, and are still on to understand these enigmatic stars. Naturally, one might wonder and ask what is the necessity to study Be Stars even now? Let us now discuss in brief the importance of studying Be Stars.

2.1 Importance of Studying Be Stars

First, the central star itself is of great interest. Be stars are among the fastest rotating non-degenerate stars in the universe. They rotate (on an average) with speeds between 70- 90% of their critical limit where the centrifugal force balances gravity (Townsend et al., 2004; Porter, 1996; Chen and Huang, 1987). Rotation, however, is the only fundamental parameter of stars that is still not understood clearly. It is the biggest unknown in our present understanding of stellar evolution; especially in the case of hot stars (Maeder and Meynet 2000). Such high rotation rates of Be Stars certainly place them in the centre of discussions of angular momentum evolution, making them one of the most prominent testbeds for rotationally induced instabilities (Maeder and Meynet 2000 and references therein).

Secondly, as mentioned earlier, Be Stars are the testbeds to study circumstellar disks. Although the Be Phenomenon can be observed in some of the late O and early A-type stars but it is mainly confined to stars of B spectral type. The mystery of Be phenomenon can be understood by studying Be stars in various locations like clusters and fields. Spectra of Be Stars show various interesting emission lines of hydrogen, helium, oxygen, calcium, iron, and so on. Spectroscopic analysis of these lines provides abundant information about the geometry of the gaseous disk and several other properties of the central star. Hence, understanding the Be Phenomenon can provide new insights to study disk physics of protoplanetary disks and for other astrophysical objects which also possess circumstellar disks like planetary nebulae, supernova remnants and so on. Apart from their vital role in massive star evolution studies, Be Stars also offer prospects for astroseismology studies of the hottest objects examined so far.

For all these research areas, solutions to Be Star problems are essential as that may offer new clues to all (hot) stars and vice verse. Though Be Stars are still shrouded in mystery, intense research in this area for over a century has provided information about various interesting properties of Be Stars and their disks. We will now look into some major observational properties of Be Stars in the next section followed by their disk characteristics.

3. Observational Properties of Be Stars

Most of the knowledge about Be Stars have been obtained through spectroscopic studies of emission lines visible in their spectra. These spectral lines can originate from three regions: the star itself, the actual disk surrounding the Be Star and the circumstellar environment above the disk up to the polar regions.

3.1 The Appearance of Emission Lines

All Be Stars show emission lines in the Balmer series. For the first discovered Be Star, Gamma (γ) Cassiopeiae, Padre Angelo Secchi noticed a bright emission line in place of the expected absorption line at Hβ (Secchi 1867). Gradually, it became clear that every Be Star emits at Hα. Though Hβ emission is also common, it is not a universal property of Be Stars. Wherever both Hα and Hβ emission are present, the higher-order Balmer series members have also been seen in emission as well, though Hα emission is always the strongest. Jaschek and Jaschek (1987) found that emission strengths decrease for the higher-order Balmer transitions. It seems that the region emitting H*a* is the largest and higher-order lines occur in the inner disk regions. This satisfactorily explains why H*a* emission is the most prominent spectral feature of all Be stars. Furthermore, it appears that the equivalent width of H*a* emission lines reach a maximum at B2 spectral type and markedly decrease towards the late-type Be Stars. This suggests that the early-type Be Stars have more developed circumstellar envelopes than late-type Be Stars (Kogure and Leung, 2007).

Be Stars are usually classified into three categories based on their H*a* line profiles. These are:

i. Pole-on: they show a single peak H*a* profile superimposed on the absorption lines of the underlying photosphere.

ii. Normal Be Stars: they are characterised by double-peaked profiles and are the most common type of Be Stars observed.

iii. Shell stars: Be stars showing deep and sharp absorption components in the centre of the double-peaked emission lines belong to this category.

The explanation for the origin of such profiles was given by Struve (1931). He proposed that these emission lines are produced in a circumstellar equatorial disk of the rapidly rotating Be Stars. From this point of view, the difference in the observed three types of line profiles can be explained simply by changing viewing angles of the observer for the star's rotational axis. This is shown schematically in Fig. 1. The observer A looking from pole-on position ($i = 0^{\circ}$) will see a Pole-on Be Star. Observers B and C will observe a normal Be Star viewing from an angle ($i > 0^{\circ}$ but $< 90^{\circ}$) whereas observer D looking from $i = 90^{\circ}$ will see a Shell Star.

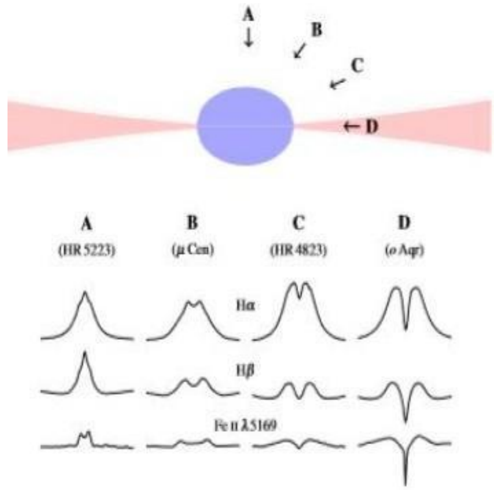

Figure 1: A schematic diagram depicting different H*a* profiles of Be stars with respect to the angle of sight of an observer. The lower portion shows the example of H*a* profiles from pole-on to shell Be Stars. Figure from Rivinius et al. (2013)

Apart from Balmer lines, Paschen lines of higher-order (like P10 or P11 onwards to around P23), singly ionised metals and in some cases neutral helium are also found in emission in Be Star optical spectra. Though neutral helium lines (especially λ = 5876 ˚A) may appear in the earliest Be Stars but Fe II emission lines are more common. Fe II lines appear in stars of spectral types within B0 and B5. Jaschek and Jaschek (1987) found that the intensity of both Fe II and Balmer emission lines strengthen and weaken simultaneously. Even emission lines of other singly ionised metals, such as Si II, Mg II and Ti II, are rarely found in Be Star optical spectra (Porter and Rivinius, 2003). Moreover, Paschen lines of the lower order (Paschen*a* to P9), Bracket series lines, and Pfund series are observed in the Infrared spectra of Be Stars.

3.2 Rapid Rotation

One of the most vital physical characteristics of Be Stars is their rapid rotation rate. They are among the fastest rotating non-degenerate stars in the universe. Such rotation produces large photospheric absorption lines widths that, when converted to velocity units correspond to hundreds of km. These line-width velocity measurements represent the rotational velocity of the star v multiplied by the sine of the inclination angle of the pole to the viewer's line of sight, or vsini.

The average rotation speed (i.e. vsini value) of Be Stars are found to range within 200 - 250 km/s (Slettebak, 1982). This rapid rotation was once suggested to be the cause of formation of the circumstellar disk around Be Stars by ejecting material from the central star (Struve, 1931). Though Be Stars rotate faster than normal B stars, Slettebak (1979) showed that they do not rotate at break-up velocity. In later researches, it has been found that Be Stars rotate only at 70% of their critical velocity (v_{crit}) (Chen and Huang 1987; Porter, 1996). Despite these findings, the rapid rotation is still considered to play a vital role in the disk formation as it has been proposed that vsini is systematically underestimated for the fastest rotating stars (Collins&Truax, 1995). Gravity darkening can affect such stars. It is the phenomenon where the fast rotation of a star produces equatorial stretching, that induces non-uniform surface gravity and temperature distributions (Zeipel, 1924). Considering the effects of equatorial gravity darkening Townsend et al. (2004) suggested that Be stars may be rotating close to their critical velocity (0.95 v_{crit}). Cranmer (2005) and various other authors (Yudin 2001; Zorec and Briot 1997; Slettebak 1982; Fukada 1982) have found that rotation rate increases for the late-type Be Stars (B3 and later) while early types rotate at 40 - 60% of the critical value.

3.3 Variability

Another striking property of almost every Be Star is variability. Any Be Star which exhibits no or little variation in its line profiles from one epoch of observation to another is a rare exception. They show either short-term (that occur on timescales of minutes to days) or long-term variations (that occur on timescales of years to decades) in their spectra.

3.3.1 Short-term variations

Variations which occur on timescales from minutes to days, and the spectral lines which exhibit such variations, seem to indicate either the photosphere or the immediate circumstellar region as their formation region (Porter and Rivinius 2003). Studying short-term variations are extremely important as they provide the clues of the additional mechanism necessary to transform a rapidly rotating B-type star into a Be Star. There are three main types of short-term variations, viz: (1) pulsation, (2) rotational modulation, and (3) transient features and X-ray flares.

Non-radial pulsation (NRP) explains significant line profile variability (LPV) on timescales ranging from hours to several days (Baade 1982). Porter and Rivinius (2003) found that in at least 80% of early-type Be Stars, NRP can explain LPV. Though stellar spots (Balona 1990) and corotating clouds (Balona 1995) have also been proposed to explain LPV, various studies of some well-observed objects support NRP as a prevalent cause. The rotational modulation seems to be of most importance in case of a few exceptional Be Stars that are not adequately described by NRP. Furthermore, numerous Be Stars show spectral variations on even shorter timescales than those already discussed. Such variations are known as transient features. Many stars show blue-shifted absorption features which may form in less than 10 minutes and have typical lifetimes of around one hour.

3.3.2 Long-term Variations

Many Be Stars undergo phase changes from Be to normal B type Stars and back again. These phase changes occur usually on time scales ranging from several years to several decades and can be readily understood as the formation and dissipation of disks. Other long-term variations take place within the emission or Be phase, like transitions between singly and doubly peaked line profiles or even a transformation between Be and Be Shell Stars. As discussed earlier, according to the classical view, various line profile shapes originate due to the inclination angle of the star's rotational axis to the observer.

A different type of long-term variation often occurs in Be Stars showing double-peaked emission. This is also of great importance. These are termed as V/R (violet-to-red) variations due to the cyclic asymmetry shown by the changing peak heights in the violet (V) and red (R) components of the stellar spectrum. Occurring in timescales of years to decades (Hanuschik et al., 1996), it is estimated that about one-third of all Be Stars show V/R variations. Detail studies and evidence suggests that such cyclic variations are caused by a one-armed density oscillation processing in the disk (Okazaki, 1991, 1996). This is also known as the global oscillation model. Theoretical calculations by Okazaki (1996) and later observations of the CBe stars δ Cen (Hanuschik et al., 1995) and ζ Tauri (Carciofi et al., 2009) supported the relevance of this model in explaining the observed V/R variations in Be Stars.

4. Be Star Disks

The term "classical Be Star" is now inextricable from the idea of a circumstellar disk. The presence of a disk has now become a well accepted view for a Be Star. Every model currently used to reproduce or predict Be Star observables have accepted the presence of such a disk. This section describes the geometry and kinematics of the disk which are used to study the observed properties of Be Stars.

4.1 Disk Geometry

Struve (1931) proposed that Be Stars are surrounded by a circumstellar flattened, equatorial, gaseous disk. Views of alternate geometries (mainly spherical shells) for the circumstellar material started emerging during the 70's and 80's. Disk geometry of Be stars became a matter of intense debate in the upcoming years. Fig. 2 shows a schematic diagram representing the structure of a Be Star envelope.

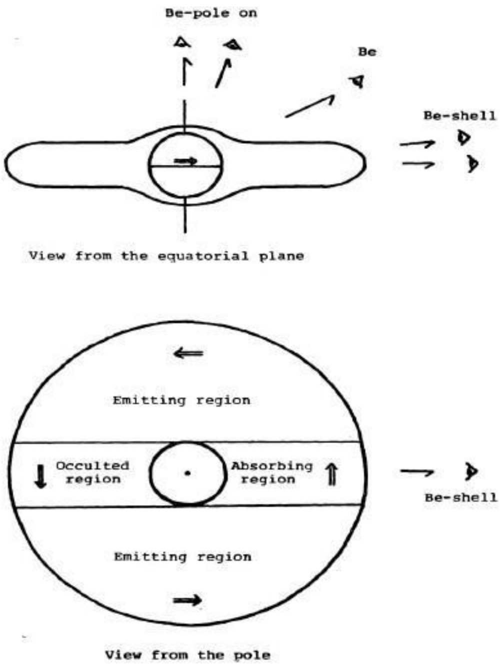

Figure 2: A schematic diagram showing the structure of a CBe star envelope. Figure from Kogure and Leung (2007)

Interferometric studies of the Be Star ψ Persei at radio wavelengths done by Dougherty and Taylor (1992) showed that the radio emission originates from a non-spherical distribution of thermally radiating gas. This confirms the aspherical geometry of the emitting region. Numerous other studies have also supported the non-spherical geometry of the circumstellar disk (Stee, 2011; Tycner et al., 2005; Quirrenbach et al., 1997; Stee, 1995).

4.1.1 Disk Size

Though one can determine the size of the emitting region of a given line in a Be Star disk, it is challenging to obtain the physical extent of the disk observationally and has not yet been determined unambiguously for any Be Star till now. Using interferometric observations, it was found that the size of the Hα-emitting region is directly related to the star's spectral type, with stars of earlier spectral type having larger Hα-emitting regions (Tycner et al., 2005). This is due to the amount of ionising radiation received from the central star. For the well-known Be Star δ Sco (Delta Scorpii), Millan-Gabet et al. (2010) measured the size of the Hα-emitting region to be 14.9 R_* (for R_* = 7 $R_\odot$) using spectro-interferometry. Hα luminosity also shows a clear dependence on the linear size of the envelope implying that the Hα emission originates in an optically thick region of the circumstellar disk.

4.1.2 Disk Density

Waters (1986) examined the IR continuum excesses of Be Stars and suggested that the density distribution of the circumstellar disk can be approximated by a power-law with an index n as follows:

$$\rho(r) = \rho_0 (r/ R_*)^{-n}$$

Here, ρ_0 denotes an initial density at the stellar surface; R_* is the stellar radius, and $r \geq R_*$ is the radial distance. Waters et al. (1987) found the value of n is typically between 2 and 3.5. Adopting this ad-hoc description of the density, many authors have shown to reproduce the average properties of Be Star observables. It has been determined from other studies that the base density of the disk lies between the range of around 10^{-12} to a few times 10^{-10} g/cm^{-3}. Radial density slopes are usually in the range 2 – 4, with a peak in the range 3 – 4.

4.2 Disk Kinematics

As the picture of the disk became clear, the kinematics needed to be understood. How the disk rotates can throw light on its formation mechanism therefore, understanding the disk kinematics observationally is of immense importance.

4.2.1 Disk Rotation

Over time, two main cases were considered for Be Star disks, viz. (i) angular momentum conserving disks, and (ii) disks undergoing Keplerian rotation. The first evidence that the disks must be in Keplerian rotation emerged from the V/R variations, which are understood as a one-armed density oscillation precessing in the disk. In the subsequent years, Hummel and Vrancken (2000) provided additional support for Keplerian rotation. Recent observational results from spectroastrometry of emission lines and spectrally resolved interferometry have finally confirmed Keplerian rotation (Kraus et al., 2012; Wheelwright et al., 2012; Delaa et al., 2011, Meilland et al., 2007).

But to form and maintain a circumstellar disk and also to prevent reaccretion, angular momentum must be supplied continuously at the ~ inner disk boundary, since in Be Star disk systems, the central stars do not seem to be rotating at their critical velocities. It is now clear that the central star possesses ~10^{10} times the specific angular momentum of the disk taking into account that the mass of the star is on average, ~ 10 M_* while the disk mass is typically 10^{10} or 10^9 M_*, and the rotational velocities of the star and disk are of the same order of magnitude even if they are not exactly equal. Hence it seems reasonable that the star can supply the necessary angular momentum to the disk. However, the actual mechanism responsible for angular momentum transfer from the star to the disk is still unclear.

5. Metallicity Effects in Be Stars

Modern telescopes equipped with sophisticated instruments have enabled us to study individual stars in other galaxies. Large and Small Magellanic Clouds (LMC and SMC) being the nearest galaxies to us, have helped immensely to observe and build large databases of Be Stars in these galaxies. Distance to LMC and SMC are around 1,70,000 (Pietrzynski et al., 2013) and 2,20,000 (Graczyk et al., 2012, 2013) lightyears respectively. Analysing their photometric and spectroscopic behaviour provided a better understanding of stellar physics at low metallicity regions. It has been a major question that whether the parameters and stellar evolutionary paths of extragalactic Be Stars are affected by different metallicity (Z) or not. To study this, Be Stars have been observed in different galaxies like Milky Way (MW), LMC and SMC with respective metallicities of around Z = 0.020, 0.008, and 0.004 (Westerlund 1997 and references therein).

5.1 Metallicity Effect on Stellar Rotation

Observational studies have confirmed that Be Stars rotate faster in low metallicity environments; their rotation speed is higher in the SMC than in the LMC and likewise faster in the LMC than in the

MW (Hunter et al., 2008; Martayan et al., 2006a, 2007b; Keller, 2004). This is because the radiatively driven stellar winds become less efficient (Puls et al., 2008) at low metallicity regions. A comparative study confirmed the existence of a gradient of mass-loss with metallicity (Mokiem et al., 2007). As mass-loss is lesser due to weaker winds, less angular momentum loss will occur which in turn will force the stars to rotate faster.

5.2 Metallicity Effect on Incidence

Due to the higher rate of rotation, it is expected that the fraction of Be Stars will increase in the LMC/ SMC than in the MW. This has been indeed observed by Maeder et al. (1999) that on average, the fraction of Be Stars is increasing with lower metallicity in open clusters, though the scatter is very large between individual clusters. Later studies with much larger samples have confirmed this finding (Martayan et al. 2006b,± 2007a; Wisniewski & Bjorkman,± 2006). It has been found that in clusters, between 26 and 40 ±4% of all the B type Stars are Be ± Stars in the SMC (Martayan et al., 2007a), while in the LMC this fraction is between 20 and 17.5 ± 2.5% (Martayan et al., 2006b). In MW; for field stars, this incidence is around 17% across the whole B range, and 34 1% for B1 Stars (Zorec & Briot, 1997).

Martayan et al. (2010a) noticed that the frequency of Be stars among the early-type stars (B0 – B3) is around 3 - 5 times higher in the SMC than in our MW as obtained by Mathew et al. (2008) and McSwain and Gies (2005). Studies in the SMC by Martayan et al. (2007b, 2010a) suggest that some Be Stars may be born as Be Stars, and if in low metallicity, they can maintain their status throughout the main sequence life.

5.3 Effect of Metallicity and Rotation on Stellar Pulsations

It is generally accepted that Be Stars pulsate more than normal B-type stars and is independent of metallicity. Be stars are thought to pulsate due to opacity driven factors. At low metallicity, it would naturally become much harder to drive pulsations in this manner. So one may expect a higher fraction of Be pulsators in the SMC than in the LMC. Faster rotation in Be Stars is supposed to either favour pulsation mechanisms or increases the amplitude (Diago et al. 2009b), which can explain the larger fraction of pulsating Be Stars in the SMC. Recently, galactic Be Star studies by Neiner et al. (2012a) found that rotation may indeed cause the amplitude of pulsations to increase. But, it is to be noted that after searching, no classical Be pulsator has yet been found spectroscopically in LMC or SMC (Baade et al. 2002).

6. Binarity in Be Stars

It has been found that most massive stars ($M_* \geq 8M_\odot$) ≥ are either binaries (about 75%) or were so at some point of time during ± their evolution (Sana 2017, Sana et al. 2012). Various types of binary star systems with B-type primary components are known. The most prominent are Algol and W UMa (Ursa Majoris) type variables which are eclipsing contact or semi-detached systems. Here the secondary fills the Roche lobe and the accretion onto the primary gives rise to the emission lines. Among B-type stars in the LMC galaxy, the fraction of spectroscopic binaries in 408 studied systems was reported to be 0:58 ± 0:11 (Dunstall et al. 2015). Consequently, Be Stars can also be expected to reside in binary systems.

Binarity is common in Be Stars as well. At one time, the properties of interacting binaries seemed to explain the observed spectral changes in Be Stars so well that Kriz and Harmanec (1975) hypothesised that probably all Be Stars are binary systems, with most having unseen counterparts. They suggested that the mechanism of Roche lobe overflow is responsible for producing Be Stars in general. But till date, no CBe Star having a Roche lobe filling companion has been detected. Moreover, infrared observations since then showed evidence that did not support this hypothesis. Binary systems which experienced past mass transfer and a spin-up of the present-day Be component include Be X-ray type binaries (BeXRBs) and Be+sdOB systems. BeXRBs consist of one Classical Be and a compact, post-supernova objects (black hole i.e. BH, neutron star i.e. NS, or white dwarf i.e. WD) and are sources of characteristic X-ray radiation, which makes them fairly easy to detect (Reig, 2011). Mainly CBe+NS systems were detected so far (81 according to Shao and Li 2014), while WD companions, although thought to be common, still remain elusive. Thought to be rare and hard to detect using conventional X-ray surveys, only one CBe+BH system was confirmed so far (Casares et al., 2014).

Binarity has been suggested previously as a possibility to explain Ca II line formation region in Be Stars (Polidan & Peters, 1976). They proposed that Ca II lines are formed in the expelled gas of an unseen binary companion in Be Stars. Later, Porter and Rivinius (2003) claimed that only one-third of the Be Stars are binary in nature. A recent analysis of 57 Be Stars by Klement et al. (2019) suggests that many if not all Be Stars have close companions influencing their outer disks. If confirmed to be subdwarf companions, the mass transfer spin-up scenario might explain the existence of the vast majority of classical Be stars. Since binarity is not confirmed in many Be Stars, it is now generally accepted that Be Stars can be formed as single stars and in binaries as well.

7. Research on Be Stars at CHRIST (Deemed to be University)

This article provides an introduction to the various observable properties of Be Stars, effect of metallicity on those properties and discuss about some major works done till date in Be Star studies. Apart from what is discussed here, intense research has been done in various aspects of Be Stars over the time (Rivinius et al. 2013; Porter & Rivinius, 2003). But as mentioned before, these enigmatic stars are still shrouded in mystery.

CHRIST (Deemed to be University) hosts an active research group (probably the largest in India) dedicated in studying various aspects of Be Stars since over six years now. Mathew et al. (2008) studied 152 Galactic cluster Be stars for the Northern Hemisphere clusters as a follow-up work done by McSwain and Geiss (2005) who performed a survey of a sample of Galactic cluster Be stars for the Southern Hemisphere clusters. We expect to obtain a comprehensive picture about the Be phenomenon by combining these two works. Followed by this, Paul K T (PhD Thesis) performed the analysis of these stars focussing mainly on spectral line identification and some correlation studies between Hα, Hβ, O I λ 7772 and λ 8446 lines. Hα line variation studies for Be stars have been done as well (for example Paul et al. 2017, 2012, Bhat et al. 2016).

Though many large surveys have been carried out till date, still one might not find any spectroscopic survey which has looked into over 100 Be stars covering the whole spectral range of 3800 - 9000˚A region, perhaps except the study by Mathew et al. (2008). Motivated by this work, we followed up with a survey of 118 Galctic field Be stars to study more about all major emission lines present in their spectra (Banerjee, G; MPhil thesis, 2019). To the best of our knowledge, such a large and detailed survey to study all major emission lines for a sample of 118 field Be stars has not been done till date. After identifying all prominent spectral lines necessary for our study, we have done Fe II and Ca II emission line analysis followed by Balmer decrement studies for our sample stars to check disc opacity in Be stars. In the process, we have developed a new technique to deblend Ca II emission line components from Paschen lines (which gets blended with Ca II lines) in Be stars using the equivalent width of Paschen lines P12 - P19. Moreover, as far as we know, we have carried out the largest sample survey of field Be stars till date to estimate their Balmer decrement (D_{34} and D_{54}) values,which is indicative of disc opacity. This is presently an ongoing work with various other projects on Be star studies been running at the same time at our university.

We have proposed observation programs with facilities such as the 2.1-m Himalayan Chandra Telescope (HCT), operated by the Indian Institute of As- trophysics (IIA, Bangalore) and located at Hanle, Ladakh; the 2.34-m Vainu Bappu Telescope (VBT) and the 1-m telescope at Vainu Bappu Observatory (VBO), Kavalur, Tamil Nadu. The 1-m telescope is primarily used for the tran- sient nature studies of Be stars, whereas spectroscopic surveys of cluster and field Be stars are done using the other facilities. Our work is like a small step to probe Be star disc geometry using new techniques and approaches which has the potential to initiate further studies of Be stars, putting into test our technique and approaches, thus improving our understanding of Be stars and stellar disc physics as a whole.

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