SURFACE INHOMOGENITIES AND MULTIPERIODIC PHENOMENA IN Be AND Bp STARS

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Abstract

Some similar photometric and spectroscopic properties of Be and Bp stars have been confirmed by the observations in the last decade. The rapid variations in Be stars seem to have rotational origin rather than explanations by non-radial stellar pulsation according to the latest models. Thus, similarly to Bp stars, photospheric spots and inhomogeneous shell are supposed to be responsible for rapid photometric and spectroscopic variations in Be stars. The rotator model of Be stars reduces the number of the assumed non-radial pulsators among them. Multiperiodic variations have been confirmed neither in Bp nor in Be stars. A comparison of the properties of Be and Bp stars is shown. A unified theory of both classes of stars is not excluded.

1. INTRODUCTION

Besides many different properties these two classes of B type stars, as numerous investigations confirmed, show much similar photometric and spectroscopic behaviour. The similar character of the rapid (0.5 to 2-3 days) variation of the Be and Bp stars became known due to the extended photometric observations, especially on the Be stars in the last decade. In the recent years Balona and Engelbrecht (1986) (and the references therein) carried out extended photometric observations on different B type and Be stars, and determined the periods of variations if it was possible. Percy (1987) reported on 40 Be stars varying in this range. On the other hand different types of magnetic Bp stars have been observed photometrically earlier by Pedersen and Thomsen (1977), Vető et al. (1980), Waelkens (1985) and so on. The photometric variations observed are similar to those in Be stars according to their shape and amplitude, but the periods of the variations are longer, they range between 1 to 20 days.

Comparing the reviews on the far UV spectral properties of Be and Bp stars, by Snow (1987) and Barker (1986) remarkable similarities are also present in the character of the absorption lines of CIV and SiIV ions. There are several examples among the He-strong magnetic Bp stars in which Hα emission has been found, widening the scale of the variety of physically more heterogeneous class of Be stars. It seems to be worth to consider the question, are the Be stars (or a part of them) spotted oblique rotators with appropriate envelope, but without global ordered magnetic fields? Keeping in mind this question, a parallel discussion on the properties of Be and Bp stars is given.

2. OBSERVATIONAL PROPERTIES AND MODELS

2.1 Bp stars

The Bp stars are main sequence B type stars which have been classified according to their peculiar absorption line spectra. Bp stars consist of two main groups, the Ga-P and Hg-Mn or CP3 stars, which are late B type stars with strong lines of the given elements besides deficiency of He in their spectra. These stars are regarded as higher temperature analogy of the Am (CP1) stars. The other main group of the Bp stars is formed by the magnetic Bp, He-peculiar or He-spectrum variable stars in other terminology CP4 stars. They are magnetic stars with peculiar He and several strong metallic lines, known as hotter relatives of Ap (CP2) stars.

The general observational properties of Bp stars have been reviewed in recent years by Underhill and Doazan (1982), Bolton (1983), Hunger (1986), etc. The basic difference between Hg-Mn and magnetic Bp stars is the presence of the often variable, strong magnetic field and the variable line and continuous spectra in latter, and their absence in Ga-P and Hg-Mn stars.

In the following I characterise the magnetic Bp stars, because their variation are similar to those of Be stars, as will be shown in this paper. The magnetic Bp stars form two subclasses which are the He-weak and He-strong stars according to their He line strength. The He-weak stars are B8-B9 stars according to their He-lines, but B5-B6 if we look their colour or H-lines, while He-strong stars are early, BO-B2 stars. The rotational velocity ranges to 170 km/s in He-strong and it is something less in He-weak stars. Their uniform property is the periodic profile and strength variation of the He-lines, which is often coupled with a photometric variation of a few hundredth of a magnitude. Variable, peculiar metallic lines (SiII, SrII, TiII) occur mainly in He-weak stars, while in several He-strong stars Hα emission was detected (Bohlender et al. 1987 and Hirata et al. 1987). There are several stars, (a Cen, HD 175362 for example) whose He-line strength varies between He-strong to He-weak or He-normal to He-weak.

Magnetic Bp stars are the earliest type stars to possess observable simple structured magnetic field. Magnetic field measurements on Bp stars are known from Landstreet and Borra (1978). Borra et al. (1983) observed He-weak, while Bohlender et al. (1987) He-strong stars. The variable magnetic field strength observed in the majority of both the He-strong and He-weak stars varies in the range of several hundred to a few thousand Gauss, can be well interpreted by a rotating dipole in agreement with the oblique rotator model. Constant magnetic fields occur in pole on stars, in one He-strong star HD 37776 quadrupole field structure was found (Thompson and Landstreet, 1985).

Far UV observation of magnetic Bp stars detected slightly variable absorption of highly ionized (CIV, SiIV) atoms with several hundred km/s radial velocity, indicating the presence of a hot stellar wind region. This kind of stellar wind was observed in all He-strong and three He-weak stars, as referred by Barker (1986) and references therein. All variances in the different stellar parameters proceed with the same period which prove to be the period of rotation, as the relationship of the rotational velocities and periods indicates.

Models of Bp stars

The kinematic models of magnetic Bp stars suppose inhomogeneous distribution of temperature and chemical elements in the photosphere causing the photometric and spectroscopic variation due to the stellar rotation. The magnetic field governs the formation of the inhomogeneities in the photosphere and the extended region of the hot stellar wind or magnetosphere, which corotates with the star. In the emission Bp stars there is a shell similar to those of Be stars where the emission lines emerges.

Such a kinematic model was suggested by Groote and Hunger (1982) for the prototype of emission Bp stars σ Ori E, who supposed one He-strong area in the photosphere. Barker (1986) challenged its property concerning the phase of CIV absorption lines. Bolton et al. (1987) corrected the model with two corotating emission region on the basis of double nature of the Hα emission line observed. Recently Bohlender and Landstreet (1988) modeled the He distribution on the star with two He enhanced areas. Models for surface distribution of He have been calculated by Vető et al. (1990) for eight magnetic Bp stars on the basis of the strength variation of the HeIλ 4026 lines, observed as R-index variation by Pedersen and Thomsen (1977) and Pedersen (1979). According to these models three different kinds of He surface distribution was found, in 3 stars one extended He-strong area, in 4 stars two He-strong spots have been found, in HD 37776 a He-strong belt (or two He-weak spots) is probable, in comparison to the rest part of the surface. In this last star quadrupole magnetic field has been detected. In six of the eight stars it was possible to compare the He distribution with the magnetic field geometry of the star (Vető, 1990). In 2 stars He-strong spots are placed at both magnetic poles, in a further one star only at negative magnetic pole is a He strong spot. In two stars remarkable distances are proved between the magnetic poles and He-strong areas. The first star (σ Ori E) has two, while the other one (a

Cen) only one He-strong spots displaced from the magnetic poles. The sixth star, HD 37776 has its He-strong belt inclined with 60 degrees to the rotational equator, but the geometry of the magnetic quadrupole is unknown.

According to the spectroscopic and photometric observation of magnetic Bp stars one can establish that photometric variations are not present in all spectroscopic variables. When existing, the spectroscopic and photometric variations are usually in antiphase, light maximum occurs at He line strength minimum. Mihalas (1973) called the attention, that this effect can not be interpreted by inhomogeneous temperature and He content distribution in the atmosphere only, also different gravity is needed.

In the dynamical models the formation of inhomogeneities in the photosphere is explained by the simultaneous effect of stellar wind, diffusion and magnetic field. The first attempt to model overabundances of peculiar metallic lines in Ap stars originates from Michaud (1970). Later Vauclair (1975), recently Michaud et al. (1987) have modeled the formation of anomalous distribution of He in magnetic Bp stars. Their quantitative model explains the formation of He-deficient, as well as He-enhanced areas in the case of appropriate stellar wind and temperature. The only contradiction to the kinematic models is, that the model proposed by Michaud et al. predicts He enhancement at the magnetic equator regions, and according to the kinematic models He-strong areas are much more probable at magnetic poles. One can establish that not everything has been explained yet about Bp stars.

Multiperiodicity

Schöneich (1981) reported on all kinds of variations of Ap and Bp stars. The magnetic Bp stars are regular variables with a constant period. All the variable stellar parameters vary with this period. This period has been considered as the rotational period of the star. The variation is generally present in the absorption lines of the visible spectrum, in UV resonance CIV and SiIV lines in the brightness and magnetic field and in the appearance of the Hα emission lines in several He-strong Bp stars.

The line strength and photometric light curves often show double maxima in a period (double wave curves), but the rotational origin even of the more difficult time variation is evident.

One He-strong star HD 37776 was referred as possible β Cep variable but later observation proved it to be simple spotted rotator (Pedersen and Thomsen, 1977). Since then no other magnetic Bp star has been classified as β Cep variable. Actually, two kinds of multiperiodicity could be admitted in Bp stars. The magnetic field plays a deterministic role in the physics of the Bp stars. A recurrent variation of the stellar magnetism on a longer time scale could cause an apparent variation in the observable parameters of the star leading to the first kind of multiperiodicity. Such a long time scale variation of stellar magnetism has not been investigated yet and because of the lack of sufficient magnetic observations there are no concrete facts to confirm this suspicion. The only remarks on the stars a Cen and HD 217833 are that in a time scale of several years the period of these stars seems to be constant, but there are some signs indicating a slight variation of the shape of the HeI λ4026 line strength and U colour light curve, when comparing the HeI λ4026 line strength measurement by Norris (1971) and R-index by Pedersen and Thomsen (1977) for a Cen, and the U colour observations of HD 217833 (Vető el al. 1980) and the new unpublished observations in 1988-89 respectively.

The other possibility of multiperiodicity supposed in Bp stars is similar to those short time variations in magnetic Ap stars reported by Kurtz (1988). In several Ap stars photometric and radial velocity variations have been found with a period $\leq 1^h$ caused by stellar pulsation.

Searches for such variations in Bp stars have been also carried out. See the references in Kurtz (1988). No short time scale variation has been found in stars earlier than A2-3. The only magnetic Bp star which has a second photometric period of P=140 min (Gerth et al. 1984) is ET And. The origin of this light and radial velocity variation is quite uncertain, the cited authors argue for a third, close companion in ET And, where anyway ET And is a binary system with a period of 48 days in the radial velocity. A possible unique multiperiodic Hg-Mn! star is α And according to Zverko et al. (1987). Panov (1984) observed several short periods for ET And and another He-weak Bp star HD 183339 in the range of a few minutes. Also I have taken an attempt to observe rapid variation in HD 183339 and the He-strong star HD 184927. The peaks appearing at different frequencies in the Fourier spectra of both stars do not exceed 3 mmag I interpreted as the noise of the observations (Vető, 1988). In Bp stars the variation on the time scale of one or several days are undoubtedly caused by stellar rotation. Any short time light variations are very uncertain, because no β Cep or short periodic oscillating magnetic Bp stars have been found yet.

2.2 Be stars

Generally, Be stars are B type stars in which Balmer emission lines have been observed at least one time. Be stars are present in all subclasses of B stars, but they are most frequent among the B2-3, V-IV stars. Detailed review is given on all our knowledge about Be stars by Underhill and Doazan (1982) and more recently in "Physics of Be Stars", Proceedings of the 92d IAU Colloquium (1987) eds. Slettebak and Snow. I briefly summarise the main observational properties of Be stars:

1. Be stars are fast rotators, their typical rotational velocity range is $175km/s \leq vsini \leq 325km/s$, and the mean value of vsin i = 200 km/s for all spectral subclasses.

2. The characteristic property of Be stars is the strong variability of the line and continuous spectrum on different time scales. Variable or occasionally present shell spectrum lines of H, metals or rarely HeI occur invoking emission line. The concrete appearance of the variability in a given star can have very different features. A long time kind of variation is the semi regular reappearance of shell and emission lines in the spectrum and radial velocity variation in range of several years to month. The short time (called often as rapid) variation in Be stars shows more complex feature. The time scale of this variation ranges from several tenth to a few days and concernes the profile and equivalent widths of spectral lines as well as (or not) light variation. The profile variations appear in form of V/R variations, in travelling bumps in the lines during a period. The light variation ranges at most 0.2 magnitudes, but in certain cases they are absent.

3. Highly ionised CIV, NV, OVI resonance lines in the far-UV spectra indicate a stellar wind which is stronger and contains higher ionized particles than the same spectral type of normal OB stars, as reported by Snow (1987).

4. According to the magnetic field measurements by Barker (1987) the global magnetic field strength does not exceed 1-2 hundred Gauss. On the basis of polarimetric observations Clarke and McGeel (1987) the presence of local magnetic fields without global ordered structure are not excluded and if there are, they could explain several questions in the modeling of Be stars.

Models of Be stars

The kinematic models are developed in order to describe the atmosphere and its structure and to reconstruct the general spectral properties of the stars. The observational facts can be geometrically interpreted by a dense, cool envelope around the objects in question. In this kinematic model the emission lines observed originate from the edges of this outer atmosphere (envelope), while the absoption shell lines are seen in that part of this envelope which is placed between the stellar disc and the observer. This envelope is sorrounded by a thin, hot stellar wind region, which is responsible for the UV resonance lines. The long time scale variations of Be stars are interpreted as recurrences of these envelopes by outburts in the stellar atmosphere. The kinematic models of emission lines have got three main types, which more or less explain the spectral behaviour of Be stars - or most of them. The model atmospheres and their structures have been discussed by Poeckert (1982).

These are in historical sequence:

1. Elliptical ring model
2. Disc models
3. Non-spherical extended envelopes

To explain the origin of rapid variations till now no model is generally accepted, because there are different interpretations for different stars. Three proposed models are competing:

1. Spots and spokes in the stellar atmosphere

This model explains the rapid variations in the frame of the oblique rotator, as spots and spokes pass the visible hemisphere of the star causing line profile, equivalent width and light variation with the period of rotation. This model was discussed and rejected by Vogt and Penrod (1983) in modeling of 13 Oph, because no ligth variation was detected during the strong line profile variation of HeI λ6678 line. Balona and Engelbrecht (1986) pointed out the exclusive possibility of spotted rotator model in some Be stars considering their photometric observation on Be stars in young clusters. Harmanec (1987) pointed out that the presence of light variation in spots spokes model is not basically required, and later (Harmanec, 1989) proved the property of the spotted rotator models in 13 Oph and 45 Per.

2. Non-radial pulsation

The concurrent model of rapid variation in Be stars is similar to those in β Cep and 53 Per variables is non-radial pulsation. Bolton (1982) suggested the variations observed in λ Eri might be caused by pulsation, because radial velocity variation was coupled with only very weak 0.02 mag light variation. Vogt and Penrod modeled 13 Oph as non-radial pulsator because of the lack of light variation. Since then rapid variations of Be stars as λ Eri, o And, 13 Oph, 2 Vul (Penrod, 1987) are supposed to be non-radial pulsators. Baade (1987) gave a wide review of non-radial pulsation models of Be stars. The lack of this model is that can not explain light variation larger than 0.05 mag, and very extreme pulsational modes have to be supposed excited.

3. Interacting binaries

Harmanec (1987) pointed out that interacting binary models are able to explain the rapid variation of Be stars. Furthermore the binary models of Be stars are more general then explaining only rapid variation, but they involve potentially the spots and spokes as well as the non- radial pulsation models. In this sense the interacting binary model belongs to the dynamical models explaining non-radial pulsation caused by tidal forces or the formation of matter outflow through the outer lagrangian point spiralling up like spokes in a contact binary system. The only problem with the binary models is the lack of eclipsing binaries among Be stars.

Table

Comparison of Be and Bp stars

	Be stars	**magnetic Bp stars**
Spectral type	among all BV-III, mainly B2-3	among all BV-III, B0-2 He-strong, B8-9 He-weak
Spectral anomalies	shell and emission lines	peculiar lines of He (strong, weak) and strong lines of certain metals
Rotation	fast rotation, $175 km/s \leq vsini \leq 350 km/s$	intermediat rotation $vsini \leq 170 km/s$
UV features	strong CIV,NV,OVI resonance lines	CIV,SiIV resonance lines, mainly in He-strong stars
Variations		
long time	variation of the emission and shell lines	no
rapid	line profile, line strength light variation A ≤0.2 mag, $0.3^d \leq P \leq 2^d$	line profile, line strength light variation A ≤ 0.1 mag, $0.9^d \leq P \leq 20^d$
short time	no	no
multiperiodic	μ Cen, KY And?	no
Magnetic field	no observable global field strength, B ≤ 200 G	strong dipole or quadrupole field, 400 G ≤ B ≤ 6 kG
Kinematic models	oblique rotator (with spots and spokes), or non radial pulsation	oblique rotator (with spots)
Dynamic models	interacting binaries, mass outflow and magnetic field or fast rotation and non-radial pulsation	stellar wind, magnetic field and diffusion

The dynamical models are to provide explanation for the existence of emission line atmospheres and for processes leading variations detected in Be stars.

1. Binary hypothesis (Harmanec, 1982)
2. Magnetic Be star model (Underhill, 1983)
3. Fast rotating non-radial pulsator model (Baade, 1987)

Underhill (1983) has opened a new period in the dynamical modeling Be stars with her theory of magnetically heated mantle around Be stars. This model has been combined by strong rotation responsible for leting in non-radiative energy in the mantle. Harmanec (1989) suggested a model of spiral circumstellar spokes in Be stars. According to his model there are equatorial spots corotating with the stellar disc, where the "spokes" of dense circumstellar material emerge, leading to spiral structured inhomogeneities. The envelope formed in this way is responsible for the discrete components seen in the UV resonance lines as well as for the shell lines in the visual spectral region. Harmanec has (1989) tested the model on the Be stars 13 Oph and 45 Per, and traced back their rapid variation to the stellar rotation instead of the rather problematic non-radial pulsation. The fast rotator non-radial pulsator model of Baade (1987) explains Be stars dynamically as coupling between rotation and non-radial pulsation. The outward flow of momentum leads to ejecting shells in the outer layer of the star.

Multiperiodicity

Harmanec (1983) gave an overview of the variation observed in Be stars, which occur on different time scales. There seems to be physical connections between long time and rapid variations in Be stars, for example between the appearance of emission lines and the amplitude of rapid variations, as Koubsky (1987) reported. This kind of multiperiodicity is undoubtedly present in Be stars, but any multiperiodic rapid variation is questionable. Here only the rapid multiperiodic variations will be discussed.

The question of presence of this last kind of multiperiodicity in Be stars is an important feature because it could be decisive in the competition of different interpretations of rapid variations. All variable Be stars which have two comparable frequencies in the Fourier spectrum of their variation are probable non-radial pulsators.

In the past decade different arguments were confronted concerning the multiperiodic behaviour of Be stars. Many of the Be stars show periodic photometric variability on a 0.2 to 2 days time scale. In several cases the amplitude of variation does not exceed the observational limit, and lot of the light curves show two (or more) maxima in a period. The Fourier spectra of such light curves contain a large number of frequency components and alias frequecies during the period analysis, thus a single period can be interpreted as multiperiodic variation. Hence there were uncertainties with the multiperiodic character of several Be stars, as HR 9070, 25 Cyg, 13 Oph and so on. The multiperiodicity of several Be stars have been suspected, but in no cases have been confirmed. Baade (1988) reported μ Cen as multiperiodic non-radial pulsator, with periods of 0.505, 0.391 days period and also a third period is possible. A new candidate for multiperiodicity is the Be star KY And, as Pavlovski (1987) reported. Harmanec (1989) has shown the rotator properties of spectral and photometric variation of 13 Oph and 45 Per. The pulsational interpretation can not reconcile some spectroscopic observational facts. He pointed out that the different peaks in the Fourier- spectrum of these stars can be interpreted as the rotational period and its related peaks, and modeled the variation by a common oblique rotator.

Due to Harmanec's work the rotational models of Be stars came into prominence which interpret the rapid variation of Be stars similar to those of the magnetic Bp stars, the shorter periods indicate faster rotation in Be stars.

3. DISCUSSION

When comparing the spottedness and multiperiodicity of Be and magnetic Bp stars one first thinks on physical differences between the two classes of stars. The basic physical character of the Be stars is the fast stellar rotation, inducing the formation of strong stellar wind and dense envelopes. In Bp stars the strong global ordered magnetic field governs the processes in the stellar atmosphere.

Combining now the magnetic hypothesis of Underhill (1983) and the model proposed by Harmanec (1989) I suppose that the similarities and differences of the Be and Bp stars are rather the results of the similar or different effects of their magnetic fields. As the magnetic observaions have proved, there are strong magnetic dipole or quadrupole fields in Bp stars, but the presence of weaker and less systematic structured magnetic fields has not been excluded even in Be stars. The effect of the supposed magnetic field in the Be stars' atmosphere helps the formation of structures suggested by Harmanec (1989). The magnetic field hypothesis could serve explanation for similarities of the UV spectra of Be and Bp stars, due to a magnetically heated hot stellar wind region. Also the differences in the shell and emission spectra could be interpreted as a weaker formation of circumstellar spokes in Bp stars because of the slower rotation and the fewer magnetic sources of mass streams there.

It is worth noting again that even early, fast rotating, He-strong, magnetic Bp stars show variable Hα emission, but only those, in which because of the strong stellar wind and the fast rotation the formation of such shells is helped. The class of Be stars is probably more general than Bp stars. Inside of their envelopes they may contain perhaps close, interacting binaries, non-radial pulsating β Cep variables or spotted rotators with corotating circumstellar matter. According to the new tendencies the number of the spotted rotator Be stars will increase. If the local magnetic field hypothesis proves to be correct, a unified theory of Bp and Be stars will also be possible.

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