AN IMPROVEMENT OF OUR KNOWLEDGE ABOUT Be AND B[e] STARS USING GAIA

D. Briot[1], A.M. Hubert[2], F. Vakili[3], M. Floquet[2], H. Hubert[2]

[1] Observatoire de Paris, URA 335 du CNRS/DASGAL, 75014 Paris, France
[2] Observatoire de Paris, Section de Meudon, URA 335 du CNRS/DASGAL, 92195, Meudon Cedex, France
[3] OCA-Fresnel-GI2T, 06460 Caussols, France

ABSTRACT

GAIA will provide accurate distances and absolute magnitudes for the first time for many early Be stars. Absolute magnitudes of Be stars in open clusters of different ages will allow us to test evolutionary tracks. Determination of absolute magnitudes of B[e] stars, which are strongly embedded in dust and circumstellar matter, will enable us to study their position in the HR diagram and define their evolutionary state: whether they are pre-main sequence stars or evolved stars. The location of Be stars on one hand in open clusters, and on the other hand in galactic plane will teach us about the population of Be stars as compared with B stars. Progress will be made in the detection of Be binary systems and in the determination of their orbital parameters (orbits of the primary and/or of the secondary). Furthermore Be stars are well known to present photometric and spectral variations with different time scales (tens of hours, tens of days, years) which are generally superimposed, but the sample observed from ground remains very small. With an intensive survey over 5 years, in multicolour photometry, detailed information will be obtained for a very large sample, essentially of early Be stars which are the most active, on the frequency of enhancement of mass loss and on the evolution of envelope structure.

Key words: Be stars, HR diagram, distances, binaries

1. INTRODUCTION

We first recall briefly the main characteristics of Be and B[e] stars.

Be stars are B stars which present, or presented at least on one occasion, some emission in the hydrogen lines, and principally in the Hα line. Emission can be seen also in Fe II lines for early and mid Be-type stars with strong emission features and in He I lines for the hottest ones. This emission originates from an extended envelope. As can be seen from ground based interferometric observations and also from models, the radius of the envelope can be estimated as several stellar radii: Re<20 R$\star$ in the wavelength of Hα.

The presence of deep absorption lines for stars with large $V \sin i$ as well as polarization measurements (up to 2%) indicate a flattened shape of the circumstellar envelope. These stars show a very large rotational velocity; actually, they are the fastest rotators that we know among the non-degenerate stars. As B stars, they show some evidence for stellar winds at various wavelengths, but the wind characteristics are stronger for Be stars than for B stars. An infrared excess is often observed, and is attributed to a thermal emission in the envelope (free-free radiation and free-bound radiation).

One of the main characteristics of Be stars is the variability: Be stars display a lot of variation both in the lines and continuum, on time scales of hours, days, weeks, months, years and decades. Every emission feature can vary and even disappear and re-appear again. So a Be star can appear at some times like a non-emission B star. On average, the strengths of emissive characteristics and of the variability level are correlated with the temperature of the central star, i.e., decrease from B0e to B9e.

What is the origin of the envelope? Several hypotheses co-exist, but actually they cannot explain up to now all the characters observed in Be stars. The role of the stellar rotation is certainly important, but is insufficient to cause by itself the formation of the envelope. An attractive hypothesis uses the non-radial pulsations of the central star, deduced from rapid line profile variations observed, i.e., moving dips/bumps. Non-radial pulsations can accelerate the equatorial zone of the star up to the rotational instability and give rise to mass loss. This model would offer a nice opportunity to explain episodic mass loss.

An alternative hypothesis is based on the stellar duplicity where the envelope is formed by the matter transferred to the B star from an overflowing Roche lobe companion. Though this model of interactive binaries is certainly effective in some cases, it cannot be applied to any Be star.

As well as the permitted emission lines of 'classical' Be stars, B[e] stars, sometimes called peculiar Be stars (Bep), show forbidden emission lines of: [Fe II], [O I], [N II], [S II] and [Fe III]. They are characterized by a strong UV and visible absorption of the order of several magnitudes, and also a large IR excess which is attributed to a dust and thermal envelope. This population of stars is not well known so far and a problem of detection subsists: less than 100 such stars are recorded. The link with 'classical' Be stars is yet to be studied. A lot of new results are expected from infrared surveys in progress. Additional and update information about Be stars can be found in proceedings of recent IAU meetings (Slettebak & Snow, 1987; Balona et al. 1994).

It is important to emphasize that Be stars are fundamental objects for the study of stellar and galactic evolution. They are one key for understanding the process of ejection of material by stars. By studying the formation and variations of envelopes of Be stars, it would be possible to precise the role of several parameters: temperature and gravity of the star, stellar rotation, non-radial pulsations or instabilities in the star, and binarity with mass exchange.

The population of B emission line stars is approximatively 17% of all B stars, this being even higher for some early type stars, that is a non-negligible proportion among B stars. It means that when studying B stars, Be stars have to be taken in consideration to avoid to study an inhomogeneous sample.

Though Be stars have been known for a long time, the origin of the Be phenomenon is yet unexplained. Actually, we do not know if it represents a distinctive phase in the evolutionary track of all B stars, or only of some B stars, or if it depends on the initial conditions during star formation. The part of duplicity is also to be clarified. With GAIA, it will be possible to determine several fundamental parameters of Be stars so far unknown, and to obtain answers to many questions.

2. EXPECTED PROGRESS ON DETERMINATION OF FUNDAMENTAL PARAMETERS

Being a minor constituent of the galactic disc, B and Be stars are scarce in the solar neighbourhood, most are quite remote and beyond reach of current parallax measurements.

2.1. Absolute magnitudes

The accurate determination of distances first will give new determinations of absolute magnitudes of Be stars, and B stars.

Now, we know that Be stars have a larger luminosity, or the same luminosity, than B stars of same temperature. The excessive luminosity of Be stars, as compared with B stars, is directly correlated with the temperature of the central star, the hottest stars being the most overluminous (Zorec & Briot, 1991). Absolute magnitude is certainly a necessary parameter for the understanding of the Be phenomenon.

Several possible causes can explain the location of Be stars in the HR diagram. The presence of the circumstellar envelope implies an energy redistribution. This over-luminosity depends also of the inclination of the star because of the lack of spherical symmetry of the envelope.

The location of Be stars in the HR diagram interpreted as an evolutionary effect needs to be discussed. This type of study is generally based on cluster Be stars (Bessel & Wood, 1992; Mermilliod, 1982). However, some arguments exist against using only this interpretation. We know since Hardorp & Strittmatter (1970) that because of their large number, Be stars are not confined to the secondary contraction phase as proposed by Crampin & Hoyle (1960). The number of Be stars among B stars of the same spectral type and luminosity class is not larger for stars of luminosity class III than for stars of luminosity class V. Actually, there exist a lot of Be stars of luminosity class V. Moreover the possibly transient emission prevents an explanation of the Be phenomenon only in evolutionary terms.

The fast rotation of the central star can shift the star above the main sequence. Actually this shift is complicated to determine: it depends not only on the rotational velocity V, but also on the angle between the stellar rotational axis and the line of sight i (Collins et al. 1991). This determination is also greatly affected by the rotational model used: rotation as a solid body, or various cases of differential rotation. Moreover, the rotation of the star modifies the evolutionary track in the HR diagram, in different ways when considering some rotational mixing (Fleigner & Langer, 1994).

It will be of great value for the understanding of the Be phenomenon to more closely relate absolute magnitudes of Be stars with their spectroscopic and photometric properties. A study of the variations of absolute magnitudes is also needed.

As far as the absolute magnitudes of galactic B[e] stars are concerned, everything is to be discovered both in observations and in theory. These stars are strongly embedded in dust and circumstellar matter. We do not know if they are pre-main sequence stars or evolved stars. Only the study of these stars in the HR diagram will enable us to clarify their evolutionary status. Information obtained will have to be related with infrared data which will be known at this time.

2.2. Determination of the distances of Be stars

As can be seen above, the Be state cannot be only a certain phase in the evolutionary track of a B star. It then depends on the conditions of formation of the star. As young stars, they are yet close to their birth place. So it would be of great importance to know the location of field B and Be stars in the galactic plane with respect to the spiral arms.

It will be the same for B and Be stars in clusters: the location of Be stars as compared with B stars will give important information about the formation of the stars.

2.3. Duplicity of Be stars

The detection of binaries among Be stars is an essential point to be investigated. The similarity of Be envelopes to the discs in some close binaries has been often pointed out (Harmanec & Kriz, 1976). However even this very day, the role of duplicity in the Be phenomenon is unknown.

The detection of Be binaries by spectroscopy is limited by the inaccuracy in the radial velocity measurements of photospheric lines of the primary B star, which are broadened by high rotation and in addition disturbed by circumstellar emission and absorption features. Furthermore the amplitude of the variation of the radial velocity of lines of the B star, which is the more massive in such systems, is rather small (K about 10 km/s). The non linear motion of the photocentre of unresolved systems measured by GAIA will allow the detection of many Be binaries up to about 2 kpc distant. If a photocentric orbit could be obtained in different colours, an estimation of the nature of the companion could be deduced.

Be binaries with highly eccentric orbits will enable detection of Be star X-ray candidates in so far as the theory has predicted such properties for these systems. Be stars presumed binaries, for which the orbital motion or the period value is a subject of controversy could be confirmed or disproved as binaries. In any case, our knowledge of frequency of binaries among Be stars should be highly improved.

Though an increasing number of Be stars exhibit strictly periodic spectral variations which can be explained in the framework of interacting binaries, the detection of the secondary star in such systems remains very limited and the proof of mass exchange between the stellar components has to be made. The identification of a companion to a Be star by photometry (variations or anomalous energy distribution) and spectroscopy (radial velocity variations) is not easy due to the contamination by the circumstellar envelope.

High accuracy spatial interferometry will enable the systematic detection of Be binaries for which the angular separation of components is between 1–2 mas to several tens of mas, much increasing the number of detections of Be binaries provided by spectroscopy, ground based interferometry and lunar occultations. The access to systems with orbital periods ranged between several tens of days to several hundreds of days will be highly favoured. These systems are the most interesting ones for the search of a possible link between the Be phenomenon and the late stages of mass transfer (case B) in the evolution of binary systems, especially in the case of non continuous or variable mass transfer.

Components of Be binary stars separated by about 100 solar radii could be detected up to 400 pc, if the magnitude difference was moderate. Combined with spectroscopic data, the distance, linear separation and masses of each component should be available, which is of a great interest for studying the interaction of such systems, in the case of a cool giant companion overflowing its Roche lobe. In this framework the envelope is the result both of the stellar wind from the hot star and of the mass transfer from the secondary.

3. ADDITIONAL INFORMATION TO BE OBTAINED

3.1. What can be obtained from a five-year photometric monitoring

Three time scales are often present and superimposed in photometric variations of Be stars: a short-term (hours, days) variability of low amplitude (several hundredths of magnitude) described hereinafter as microvariability; a mid-term (weeks) variability whose the amplitude goes up to 0.2 magnitude; a long-term (years, decades) variability whose the amplitude goes up to 0.8 magnitude.

Microvariability: Intensive and often multi-site photometric campaigns have revealed that the short-term variability occurs in more than half of monitored Be stars; it is quite clear in early-type Be stars which are the most active among Be stars. The detection is poor among late-type Be stars probably because the amplitude of light variation is weak (of the order of 1 millimag). Two physical interpretations have been suggested to explain variability of a few hours or days: the rotational modulation of photospheric spots and the presence of non-radial pulsations in the star, the latter being the more frequent explanation. New opacity data have been able to show that in B stars two distinct categories of modes could be driven by the opacity mechanism. The short-term variability in Be stars could be explained by high-order g-mode non-radial pulsations present from O9.5 to B9; according to Dziembowski (1994) the instability domain in the HR diagram is very sensitive to metal content. The expected accuracy in photometry of GAIA (0.2 millimag in B and V for a $V = 10$ mag star) will allow the detection of microvariability among late Be stars if observations can be repeated within 24 hours, otherwise the distinction from other time scale variability will not be feasible. As the presence of non-radial pulsations is strongly dependent on [Fe/H] content, the search for pulsators among B and Be stars in open clusters of different metallicity is very much needed to test the validity of the opacity mechanism as an explanation of rapid variability.

Mid-term variability: Quasi periodic oscillations in colour variations have been detected in several Be stars. They seem to occur prior to fading events and could be precursors of development of shell phases or mass loss episodes (Mennickent et al. 1994). Such new observations obtained in Strömgren differential photometry through a monitoring programme at the European Southern Observatory (Long-Term Photometry of Variables) have been reported only for a small sample of Be stars.

Long-term variability: Long-term photometric variations are often reported for Be stars. Changes in the mass-loss rate and in the radiative flux are thought to introduce variability in the opacity, the size and the geometry of the envelope giving rise to an alternation between a quasi-normal phase, and a Be or a Be-shell phase, as is commonly observed for many stars. The cycle duration seems to be longer for active late Be stars than for early ones (Hirata & Hubert-Delplace, 1981). Quasi-cyclic photometric variations as well as quasi-cyclic spectroscopic variations provide information on changes in physical and geometric parameters of the envelope. Details on dimensions, anisotropy, opacity and temperature of the envelope, estimate of the inclination of the star, information about the region of variations (photosphere or envelope) could be drawn from study of colours and colour indices if the Hα emission strength is also available. They should provide good tests for quantitative envelope models.

Finally, 5 year-photometric monitoring represents an excellent opportunity for: detecting microvariability in late Be stars; collecting information on recurrent mass-loss episodes in early Be stars, the most active ones; constraining envelope models.

3.2. Complementarity of ground-interferometry and space-astrometry for studying Be stars

Diameters of Be star envelope and photosphere: Be stars are favourite objects for ground-based optical interferometric observations (Vakili et al. 1994; Quirrenbach, 1994). At the time GAIA will be launched, planned aperture synthesis arrays with kilometric baselines will certainly approach 0.1 mas and beyond in terms of 2D imaging angular resolution. With such possibilities the circumstellar envelope of Be stars within 5 kpc can be fully resolved in Balmer emission lines and the nearest ones mapped with 5×5 pixels across the photospheric disc (e.g., γ Cas with 1 km baseline interferometer).

Only with the high accurate determination of distances of Be stars expected with GAIA, true dimensions of Balmer emitting envelope will be, for the first time, known. This information will be of a high order for the knowledge of Be stars and will constrain models of envelope.

In a similar way the true diameter of the photosphere of the nearest Be stars will be obtained. The direct comparison of dimensions of B and Be stars will be probably pertinent and will give information on the rotational distortion effect.

Finally, notice that for those of Be stars which are members of binary systems, the angular diameter of the components obtained from long baseline optical interferometry could be combined with the distance of the binary from GAIA and provide directly the surface gravity of the components.

Asymmetry of Balmer emitting envelopes: Quasi-cyclic variations of the ratio of the violet to red emission peaks in the first Balmer emission lines, often reported in long-term spectroscopic changes of Be stars, are not well understood; they have been sometimes explained by the apsidal motion of an asymmetric disc-shaped envelope. In this picture the photocentre of the envelope does not correspond with the photocentre of the star. This point would be easily clarified if a narrow-band Hα filter was added to the photometric system. The existence of the non-axisymmetry of the envelope is one of the most fundamental results that GAIA will be able to bring about Be stars.

4. AUXILIARY INSTRUMENTATION NEEDED: Hα FILTER

An additional narrow-band Hα filter is highly desirable for the study of Be and B[e] stars, as well as for other emission-line star studies.

Firstly, it will permit the detection of any Be star, so avoiding the mixing of B and Be stars. It will give a measure of the strength of the Hα emission line throughout the astrometric survey, a careful indication for the study of the envelope influence on absolute magnitudes. Then, it will allow an extensive study of Hα variations, simultaneously with photometric variations, which is highly desirable for an exhaustive work of envelope variability modelling. In particular it will provide direct evidence of asymmetric envelopes in many Be stars. This later point concerns also any star with an emitting hydrogen envelope.

5. COMPLEMENTARY OBSERVATIONS

The spectral classification will of course be needed for any star. In the case of Be stars the determination from spectra is more accurate. It has been shown that the Q index derived from UBV photometry and commonly used for the classification of B stars cannot be a good indicator of spectral type for Be stars with strong emission characteristics and Be stars with strong shell features.

The determination of $V \sin i$ is required as an important parameter in the physics of Be stars and particularly it influences the absolute magnitudes. The [Fe/H] content in clusters is a parameter which can help the understanding of the efficiency of non-radial pulsations.

At least the very difficult task of determination of stellar radial velocity of Be stars will be necessary. All these requirements need the dedication of ground based large collectors to fundamental parameter acquisition of distant stars.

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