STUDY OF INTERSTELLAR ABSORPTION OF BE STARS

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RESUMEN. Debido a la existencia de un enrojecimiento intrínseco en las estrellas Be, los procedimientos clásicos de desenrojecimiento, pueden conducir a una sobreestimación de su absorción interestelar. Para evitar este inconveniente, el enrojecimiento interestelar de las estrellas Be es frecuentemente estimado a partir de la banda de absorción en 2200 Å. En este trabajo hemos comparado los resultados obtenidos usando esta banda de absorción, con el enrojecimiento obtenido a partir de las estrellas circundantes. Para ello, hemos establecido primero un método de desenrojecimiento de referencia, usando estrellas B normales y el sistema fotométrico UBV, junto con el sistema espectrofotométrico BCD. Con este método de referencia, hemos controlado dos procedimientos de desenrojecimiento, ambos basados en la banda de absorción en 2200 Å, y el método basado en las estrellas normales circundantes. Para determinar la absorción interestelar de las estrellas Be con las estrellas circundantes, hemos determinado previamente sus magnitudes visuales absolutas y las magnitudes visuales aparentes, correspondientes a sus fases sin emisión, con el objeto de calcular sus distancias.

Comparando finalmente los enrojecimientos interestelares de las estrellas Be, obtenidos con la banda en 2200 Å y con las estrellas circundantes, se observa que la banda en 2200 Å conduce a una sobreestimación de la absorción interestelar. Las causas de esta sobreestimación son discutidas someramente.

ABSTRACT. Owing to their intrinsic reddening, Be stars may be "over-dereddened" when they are corrected for interstellar absorption by classical photometric methods. So a dereddening method often used for these stars is to take the interstellar bump at 2200 Å. We tested this method by comparing its results with the interstellar reddening obtained from surrounding stars.

For this, we first established a standard dereddening method for normal B stars both from UBV photometric observations and from observations of the Balmer discontinuity (BCD method). By using this standard method, we could test with normal B stars, firstly the various dereddening methods from the 2200 Å bump, and secondly the dereddening method from the surrounding stars. To determine the interstellar absorption of Be stars from the surrounding stars, it is necessary to determine the absolute magnitude of Be stars and their apparent visual magnitudes corresponding to a non-emission phase, with the aim of obtaining their distance. The comparison of interstellar reddenings of Be stars obtained from the 2200 Å bump and from the surrounding stars shows that the interstellar reddening obtained from the 2200 Å band have a tendency to be slightly overestimated. Some likely physical explanations are suggested.

I. INTRODUCTION

The determination of interstellar reddening of *classical* Be stars -the type of stars studied in this paper- is a very delicate matter. *Classical* Be stars being intrinsically luminous, some of those which are usually studied are very distant, while they are very near the galactic plane. So their interstellar absorption can be strong, and cannot be neglected. On the contrary, it is important to study it carefully.

1. Problems in determining the interstellar absorption of Be stars

The presence of circumstellar matter around Be stars can modify the observed colors of the stars. Be stars often are redder than B stars of the same spectral type. The reddening of a Be star as compared with a non-reddened B star is partly a result of the intrinsic colors of the object and partly a result of the absorption by interstellar matter. When interstellar absorption of Be stars is determined in the usual way, that is to say, from photometric observational data as compared with colors of normal B stars which are assumed unreddened, the presence of an intrinsic reddening can result in an *over-dereddening*. This overestimate is difficult to evaluate because intrinsic colors of Be stars are probably different from star to star. So it appears more advisable to use other methods for the determination of the interstellar absorption of Be stars and the aim of this study is to test the validity of these methods when applied to the latter.

2. Principle of the approach followed here

Having ruled out the methods of interstellar dereddening from photometric observations, the interstellar absorption will be determined using spectral features assumed to be independent of the star studied and depending only on the interstellar medium. The ultraviolet absorption feature located at 2200 Å seems to show the best correlation with interstellar reddening (Dorschner 1975, Nandy *et al.* 1975, 1976). Actually the interstellar dereddening method from the 2200 Å band is usually used for Be stars and it is important to test its validity by comparing it with a method assumed to be independent of the properties of the stars studied. So we compare the interstellar absorptions determined, on the one hand, by an *intrinsic* method, the use of the 2200 Å bump, and, on the other hand, by an *extrinsic* method, the determination of the interstellar absorption from the stars in the same part of the sky as the star studied.

Before being applied to the Be stars, each of these two methods will be tested here using normal B stars. Therefore, our first aim is to establish a standard dereddening method for normal B stars.

This method is explained in section II. Then, in section III, we study the dereddening method using the 2200 Å bump. We tested this method on B stars without emission by comparing its results with those of the standard method defined in section II, and then we apply the former to the Be stars. In the same way we study the dereddening method from the surrounding stars (section IV). This method is first tested on B stars without emission and is then applied to Be stars. Finally, testing the reliability of the 2200 Å bump dereddening method when applied to Be stars, we compare the results obtained by this method for Be stars with the results obtained using the surrounding stars (section V).

II. DEFINITION OF A STANDARD DEREDDENING METHOD FOR B STARS WITHOUT EMISSION

The interstellar dereddening method which we call a standard method for B stars without emission, proceeds from *classical* methods since the latter are applicable to normal B stars. The sample of normal B stars studied here is taken from the sample of normal B stars given in Zorec *et al.* (1983). It is composed of MK system standard stars which were also classified in the BCD system or whose spectral types were established in a very accurate way by Underhill *et al.* (1979). These stars were never reported as having some emission.

We express the interstellar reddening in the usual way, that is to say, by the color excess E(B-V). This color excess was determined for B stars by two different approaches. The first one used photometric observations in the UBV broad band system (Johnson *et al.* 1966) and FitzGerald's (1971) intrinsic colors. We call the color excess so determined $E(B-V)_{UBV}$. The second approach used the Barbier-Chalonge-Divan method (BCD method) as defined in Chalonge and Divan (1973) based on the value and location of the Balmer discontinuity. We call the color excess so determined $E(B-V)_{UBV}$. The agreement between these two approaches is satisfying and we used as standard color excess due to the interstellar reddening, for B stars, the following mean color excess

$$E(B-V)_{UBV+BCD} = \frac{1}{2}\left[E(B-V)_{UBV} + E(B-V)_{BCD}\right] \quad (1)$$

III. DEREDDENING METHODS OF B AND BE STARS FROM THE 2200 Å BAND

Now we determine the interstellar absorption from the central depth of the 2200 Å feature. Of course, this method is available only for stars observed in the ultraviolet range. Two types of measurement were made to determine the central depth of the 2200 Å feature. Its central depth from an interpolated pseudo-continuum was found as done by Beeckmans and Hubert-Delplace (1980). Alternatively we took Lorentz profiles fitted to the observational data in the 2200 Å range by Gürtler *et al.* (1982) so as to give central depths.

1. Determination of the central depth of the 2200 Å feature from an interpolated pseudo-continuum

A study of interstellar reddening of Be stars from the determination of the central depth of the 2200 Å band was made by Beeckmans and Hubert-Delplace (1980) from observations of the TD-1 satellite. They obtain for normal B stars a relation between the color excess $E(m^{i}_{2100} - V)$ and E(B-V), as well as a relation between the color excess $E(m^{i}_{2100} - V)$ and m_{2200}, m_{2200} being the central depth of the 2200 Å bump measured from a pseudo-continuum drawed by interpolation between 1670 Å and 2500 Å. However, this last relation is not very well defined and the physical reason of the scatter of values in the $E(m^{i}_{2100} - V)$ vs. m_{2200} diagram for main sequence stars and giantsremains partly unexplained. A reason may be that, as can be seen from interstellar reddening curves, such as those of Sapar and Kuusik (1978) or Savage and Mathis (1979), the 2500 Å region is still in the absorption wing of the 2200 Å bump. Observational data of the TD-1 satellite every 20 Å, from which the bump at 2200 Å is studied, do not, however extend longward of 2540 Å.

To test this dereddening method, we applied it, as described by Beeckmans and Hubert -Delplace (1980), to B stars without emission (we verify from Be stars already studied by Beeckmans and Hubert-Delplace (1980) that our reddening determinations agree with theirs). We called $E(B-V)_{BHD}$ the color excess to determined, and we compared these quantities with the $E(B-V)_{UBV+BCD}$ color excesses determined using the standard dereddening method described in section II.

To obtain a good agreement between color excesses determined by these different methods, it is necessary to apply the following correction

$$E(B-V)^{cor}_{BHD} = 1.189\ E(B-V)_{BHD} - 0.025 \quad (2)$$

(this relation is determined at 97%).

2. Determination of the central depth of the 2200 Å feature by fitting with a Lorentz' profile

We then used another method to study the 2200 Å absorption feature. This involved the γ parameter representative of the central depth of the 2200 Å bump and given by Gurtler *et al.* (1982). This parameter is obtained through fitting a Lorentz profile to the 2200 Å bump, the observational data being here also those of the TD-1 satellite. We calibrated the γ parameter as a function of the color excess $E(B-V)_{UBV+BCD}$ obtained by the standard dereddening method described in section II, using a sample of B stars. So we defined a color excess $E(B-V)\gamma$. This color excess was determined for Be stars from their γ parameter, as given in Gurtler *et al.* (1982).

We plotted for Be stars, $E(B-V)_{\gamma}$ as a function of $E(B-V)^{cor}_{BHD}$ as defined in section III.1. The agreement is satisfactory as it can be seen in Fig. 1. The correlation is defined at 98%. Then we adopted for each of the Be stars studied, a mean value of the color excess due to interstellar absorption determination from the 2200 Å band. This mean value is defined by

$$E(B-V)_{BHD+\gamma} = \frac{1}{2}\left[E(B-V)^{cor}_{BHD} + E(B-V)_{\gamma}\right] \quad (3)$$

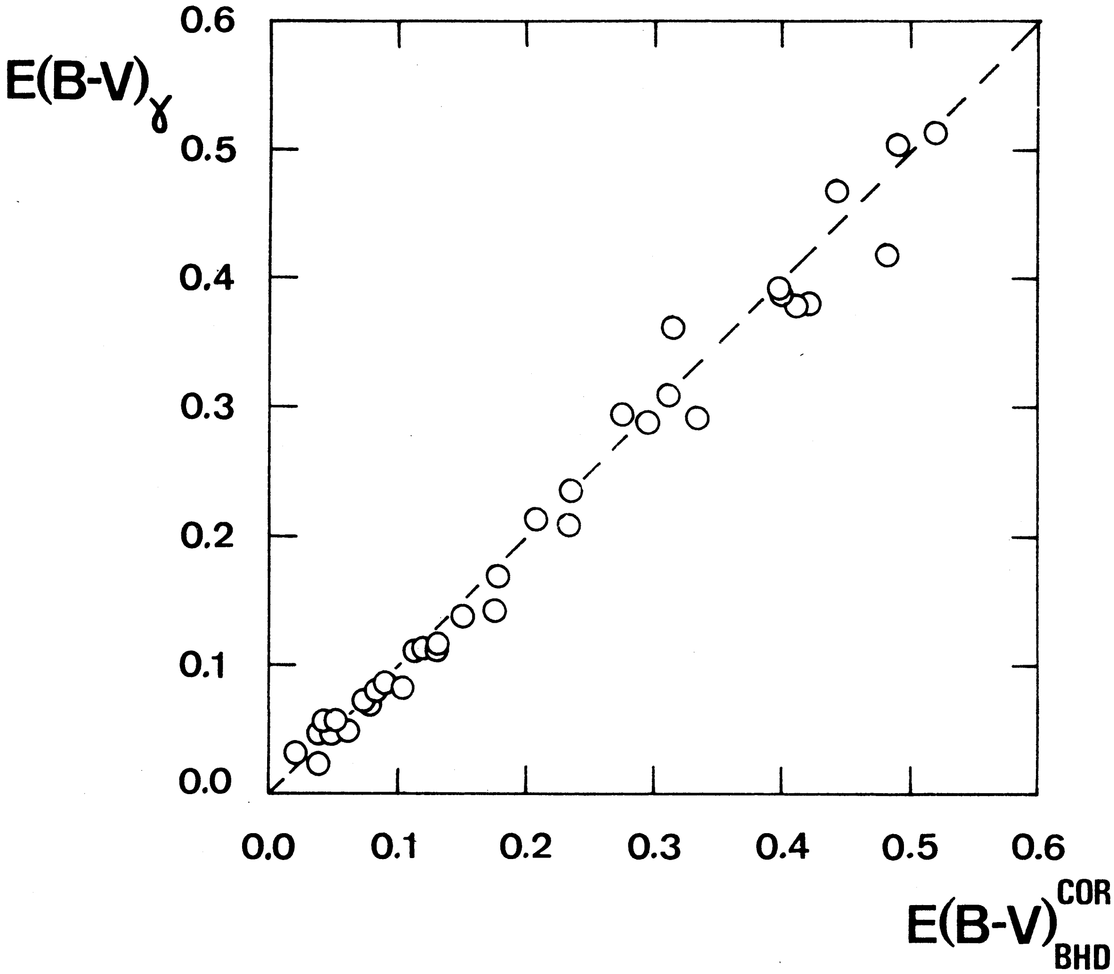

Fig. 1. Comparison of the $E(B-V)_{\gamma}$ and the $E(B-V)^{cor}_{BHD}$ color excess determinations for normal B stars.

IV. DEREDDENING METHOD OF B AND BE STARS FROM SURROUNDING STARS

Our purpose is now to determine the interstellar absorption of Be stars by an extrinsic method, and, therefore, independent of Be star characteristics. The extrinsic method we used is the determination of the interstellar absorption from that of stars located in the same galactic direction. We first established this method for normal B stars to test its reliability and then we applied it to Be stars. By comparing interstellar absorptions of Be stars determined by this extrinsic method and those determined from the 2200 Å band we can see if the emission of Be stars has some influence on the 2200 Å band.

1. Definition of the method for B stars

We studied the interstellar aborption of surrounding stars for normal B stars taken from the sample described in section II and for which we had enough information in the catalogue of the galactic distribution of interstellar absorption by Deutschman *et al.* (1976). We examined the stars located in a region centered on each B star studied. This region is defined by a radius of 2° around the B star each time this was possible and by a radius of 5° in the worst cases. By using the $E(B-V)_D$ reddening and the distance, as given in the Deutschman *et al.* (1976) catalogue for the various stars of the region considered, we determined, for each of these regions, the interstellar reddening law expressed by the color excess as a function of the distance of stars in the region considered:

$$E(B-V)_D = f(d) \qquad (4)$$

By using this interstellar reddening law obtained from surrounding stars, and knowing the distance of the B star on which is centered each of the regions studied, we obtained the interstellar reddening of this B star. We call $E(B-V)_{sur}$ the reddening so determined of the B star. For the B stars of our sample, we compared this reddening both with the *standard* reddening established for the B stars $E(B-V)_{UBV+BCD}$, and with the reddening determined from the 2200 Å bump $E(B-V)_{BHD+\gamma}$. In each of these cases, the agreement is satisfactory. We obtain a 45° correlation line defined at 98%, but the $E(B-V)_{sur}$ is overestimated in 0.02 mag. This is due to the $(B-V)_o$ intrinsic colors of the Deutschman's *et al.* (1976) calibration, which are systematically bluer in 0.02 mag than the intrinsic colors used in defining the standard dereddening method in section II.

2. Application of the method to Be stars

After testing on B stars without emission the reliability of the interstellar reddening determination method from surrounding stars, we now apply it to Be stars. The sample studied is made of 55 Be stars. It is important to note that the application of this method to Be stars raises more problems that for B stars. Now the interstellar absorption is determined from the distance of the star studied while the absolute magnitudes, and hence the distances are much worse known for Be stars than for B stars. According to numerous studies, Be stars are intrinsically more luminous than B stars of the same spectral classification (see references in Briot and Hubert-Delplace, 1982). Moreover we know from Underhill (1960) and, principally, Feinstein (1968), that the magnitudes of Be stars present some irregular variability. The study of a given Be star during its variations shows that the V magnitude is correlated to the strength of the emissive phenomenon, the star is more luminous in V when the emission is stronger (Divan *et al.* 1982, 1983). So it is first necessary to make a determination of the absolute magnitudes of Be stars and their apparent visual magnitudes that corresponds to a non-emission phase, to obtain their distances.

We assumed that the total luminosity of Be stars remains constant during the observed variations of the star and that it is the same as the total luminosity of a B star without emission of the same spectral classification. This hypothesis is based on the following observational facts.

As known from Barbier and Chalonge (1939), Be stars can present two Balmer discontinuities. The first discontinuity at longer wavelengths has a location corresponding to the discontinuity of a normal B star and is attributed to the photosphere of the central star. The second discontinuity is at shorter wavelengths and originates in a lower density medium. It appears either in emission for Be stars showing strong emission characteristics, or in absorption for Be stars showing strong shell characteristics. This second discontinuity is attributed to the circumstellar envelope and may show numerous variations when the luminosity, colors or line intensities of the Be star vary. These variations can involve the complete disappearance of the second discontinuity in the case when all the emission characteristics disappear and when the star appears like a *normal* B star. It was shown by Divan (1979) for Be stars with the second Balmer discontinuity in emission, and by Divan and Zorec (1982a) for Be stars with the second Balmer discontinuity in absorption, that these changes do not affect the central star classification determined from the first Balmer discontinuity attributed to the central star photosphere (BCD classification system). Therefore, it appears that, during the observed variations of the Be star, the effective temperature of the central star remains constant and corresponds to that of a normal star of the same BCD spectral classification. This is also the case for the total luminosity of the star, as was verified by Divan and Zorec (1982b) in the case of 59 Cygni.

From these results it can be concluded that, when the Be star loses every emission characteristics, its visual absolute magnitude corresponds to that of a normal B star of same spectral classification. It is also known that the visual magnitude is linearly correlated to the strength of the emission in the Balmer continuum, the star being brighter when the emission is stronger (Divan *et al.* 1982, 1983).

Therefore, we attempted, for each of the Be stars studied, to determine its apparent visual magnitude during a phase when the star has lost its emission. Each time we had at our disposal the necessary observational data, i.e., for each star for which the Balmer discontinuity was observed during variations, we establish the relation

$$V = V(D) \quad (5)$$

where V is the apparent visual magnitude and D the total Balmer discontinuity, that is to say, the amount of the two Balmer discontinuities as defined above. So it is possible to determine the apparent visual magnitude that the star would have during a non-emission phase.

For the stars for which we have not enough observations of the Balmer discontinuity, we used photometric data. For each of the stars in this category, we studied how the apparent visual magnitude varies as a function of colors during the stellar variations and we established the relations

$$V = V\left[(B-V)_o\right] \quad (6)$$

and

$$V = V\left[(U-B)_o\right] \quad (7)$$

$(B-V)_o$ and $(U-B)_o$ are the colors of the star after interstellar reddening correction according to the method used by Beeckmans and Hubert-Delplace (1980) revised according to formula (2).

From each of the two formulae (6) and (7), and by extrapolation to the values of $(B-V)_o$ and $(U-B)_o$ corresponding to the dereddened colors of normal stars of the same BCD spectral classification, an estimate of the apparent visual magnitude which the Be star would have during a phase without emission is obtained. As a value of V, we adopted the mean of the values, of V determined from formula (6) and from formula (7).

The spectroscopic distance d is estimated from the relation

$$\log_{10} d_{pc} = 0.2 \left[V-M-3.1\ E(B-V)^{cor}_{BHD} + 5\right] \quad (8)$$

where M is the absolute visual magnitude of a normal B star of the same spectral classification as given in Deutschman *et al.* (1976). The error in this formula will be discussed and estimated in section V.2.

Using the distance of the B star so obtained, we determined, from surrounding stars, for each of the Be stars studied, the interstellar reddening law that corresponds to its region, as we did for B stars without emission (section IV.1). As above, we call $E(B-V)_{sur}$ the color excess that corresponds to this interstellar reddening.

V. COMPARISON OF INTERSTELLAR REDDENINGS OF BE STARS DETERMINED FROM THE 2200 Å BUMP AND FROM SURROUNDING STARS

1. Comparison and results

We plot in Fig. 2, $E(B-V)_{sur}$ versus $E(B-V)_{BHD+\gamma}$ for the sample of Be stars studied here. We see that the distribution of points in the $E(B-V)_{sur}$ vs. $E(B-V)_{BHD+\gamma}$ diagram is not symmetric around the 45° line. The stars are located, on the average, on and below the 45° line, i.e., $E(B-V)_{BHD+\gamma} > E(B-V)_{sur}$. The 45° line is displaced taking into account the systematic overestimation of the $E(B-V)_{sur}$ compared to the $E(B-V)_{BHD+\gamma}$ for normal stars, as pointed out in section IV.1.

2. Discussion about the validity of the results

The examination of Fig. 2 shows that one may consider as meaningful the fact that the interstellar absorption determined from the surrounding stars has a tendency to be smaller than the interstellar absorption determined from the 2200 Å band. It is important to know whether the difference between the results obtained by each dereddening method comes from an underestimate of the interstellar absorption determined from the surrounding stars or from an overestimate of the interstellar absorption determined from the 2200 Å bump. The error in the determination of the interstellar absorption of Be stars from the surrounding stars comes mainly from the errors in the distance determination of Be stars, which are due, as can be seen from relation (8), on one hand, to the inaccuracy in the determination of absolute magnitudes of Be stars and, on the other hand, to the inaccuracy in the determination of the V magnitude at a phase without emission. The sum of these two errors can be estimated as ± 0.5 mag. From this value, the error bars of Fig. 2 were calculated. We see in this Figure that the errors in the distances

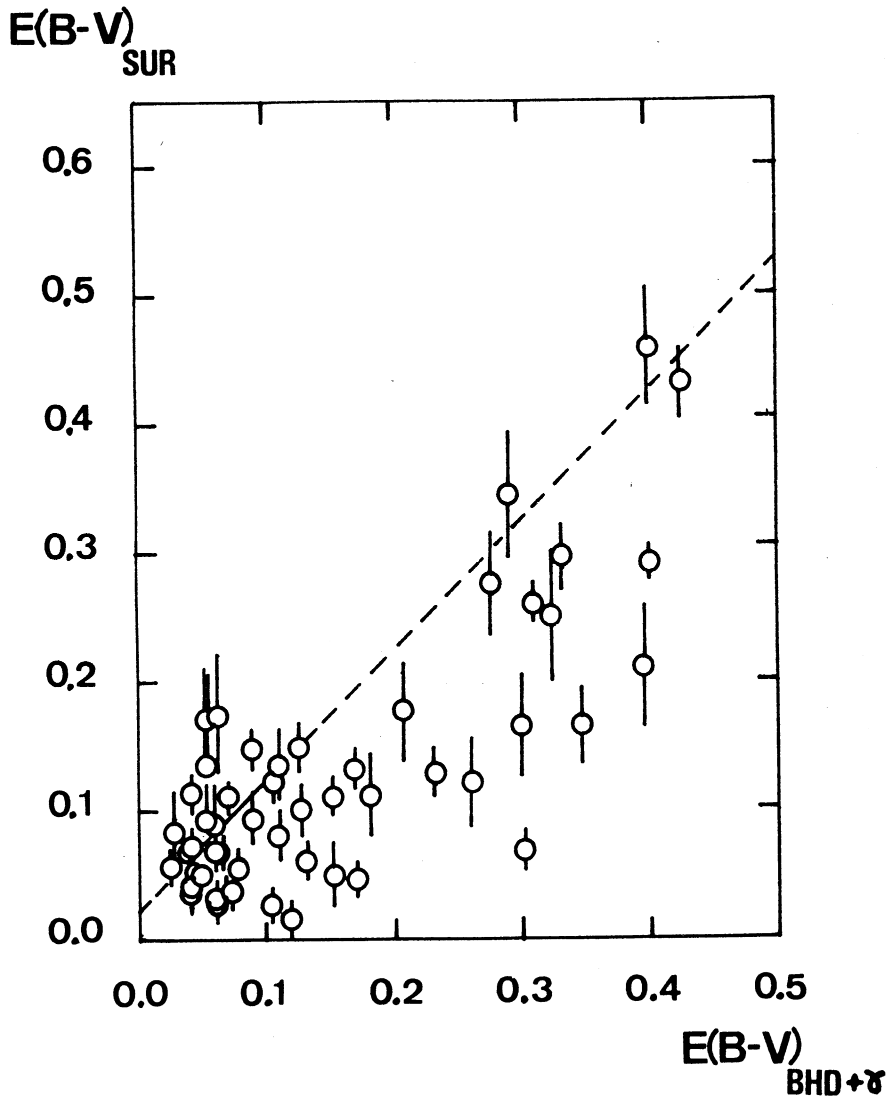

Fig. 2. Comparison of the $E(B-V)_{sur}$ color excesses with the $E(B-V)_{BHD+\gamma}$ color excesses for Be stars.

of Be stars are not sufficient to justify the deviation from the 45° line, that is to say, the difference between the interstellar absorption determined from the surrounding stars and the one determined from the 2200 Å absorption bump.

We can also consider that this difference is due to an overestimate of the interstellar absorption determined from the 2200 Å band.

However, some points with $E(B-V)_{BHD+\gamma} < 0.1$ mag lie above the 45° line. These points correspond to stars classified by Zorec *et al.* (1983) as *strong* emission stars. We searched for a correlation between the deviation from the 45° line, as observed in Fig. 2, and the properties of Be stars such as, in particular, the emission strength, but up to now, no correlation has been found. So, the influence of the emission phenomena on the depth of the 2200 Å bump, in particular for stars having low interstellar absorption, is not clear.

3. Some physical reasons of the overestimate of the interstellar absorption determined from the 2200 Å band

We briefly enumerate some of the physical reasons which may be at the origin of the tendency to overestimate the interstellar absorption determined from the 2200 Å bump. One can presume that in the case of Be stars, the 2200 Å bump is produced not only by interstellar matter but also that, in some way, there is a contribution from the circumstellar matter forming the envelope. The main physical reasons may be of two kinds, namely,

i) On one hand, there exists a great number of lines of Fe II, Fe III, Ni II, CrIII, etc. around the 2200 Å wavelength (Beeckmans and Hubert-Delplace, 1980).

ii) On the other hand, it is possible that the absorption properties of the circumstellar matter are more or less similar to those of interstellar matter and so that circumstellar matter contributes to the 2200 Å bump.

VI. CONCLUSION

An *intrinsic* method currently used to correct Be stars for interstellar absorption is to derive the correction from the 2200 Å bump. The aim of this paper was to test the reliability of this *intrinsic* dereddening method, when applied to Be stars, by comparing its results with those from an as-much-as-possible *extrinsic* method. The *extrinsic* method used in this study is the determination of interstellar absorption from the surrounding stars.

First, we defined a standard dereddening method from classical dereddening methods applicable to normal B stars. Such methods are based,on one hand, the use of broad band photometric observations, knowing the intrinsic stellar colors and, on the other hand, the use of the Balmer discontinuity as observed in the BCD system. We could, therefore, test using normal B stars, both the interstellar dereddening method from the 2200 Å bump and the *extrinsic* method. Each dereddening method was then applied to Be stars and the results were compared to each other. The method using the surrounding stars served as a test of the method based on the 2200 Å absorption feature.

The final result is that the interstellar reddening determined from the 2200 Å bump has a tendency to be slightly larger than that determined from the surrounding stars. It would seem that the circumstellar matter forming the envelopes of Be stars contributes somehow or other to the 2200 Å bump.

The results published here may be considered as preliminary. A more detailed study is now in progress.

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