VARIABILITY OF B AND Be STARS WITH GAIA

C. Neiner[1,2], A.-M. Hubert[2], Y. Frémat[3], M. Floquet[2]

[1]RSSD, ESTEC, ESA, Keplerlaan 1, 2201 Noordwijk ZH, The Netherlands
[2]Observatoire de Paris, GEPI / CNRS UMR 8111, 92195 Meudon cedex, France
[3]Royal Observatory of Belgium, 3 avenue circulaire, 1180 Brussels, Belgium

ABSTRACT

In this paper, we present the kind of information that can be derived for variable B (β Cep and SPB) and Be stars from the five-year photometric monitoring and medium resolution near-IR spectra that Gaia will obtain after 2011.

First of all, Gaia will provide a deep survey of variability of about one million B and Be stars in young galactic clusters, in the field of the Galaxy and in the Magellanic Clouds. Therefore, we will be able to study the influence of age and metallicity upon variability. Moreover, the high accuracy of photometry will allow us to detect micro-variability predicted in late B stars but undetected with ground-based observations.

In addition, we will extend, to a much larger sample, the results regarding the outbursts of bright Be stars derived from Hipparcos photometry. We will then be able to test the hypothesis concerning the origin of the recurrence of Be stars among B-type stars.

Finally, Gaia will make a significant contribution for the discovery of new variable stars, in particular SPB stars. Emission in Paschen lines and the use of a medium band filter in the Hα region will also allow us to separate Be stars from B stars. Exotic objects such as B[e], Ae/Be, symbiotic and proto-planetary nebulae stars will be easily distinguished thanks to the presence of iron emission lines combined to the IR emission lines.

Key words: Stars: Be, β Cephei, SPB; Stars: pulsations; Stars: circumstellar environment.

1. INTRODUCTION: β CEP, SPB AND BE VARIABLES

1.1. Pulsations

In the last decade, the update of atomic data and opacities has allowed the prediction of a large region of instability in the main-sequence B band, due to the κ mechanism. Two distinct groups could be explained by this mechanism: β Cep stars characterized by low-order pressure and gravity modes with periods between 0.1 and 0.3 day, and Slowly Pulsating B (SPB) stars characterized by high-order gravity modes with periods between 0.5 and 4 days. As mentioned by Dziembowski (1994), this new instability domain nearly bridges the gap in spectral types between δ Scuti and β Cephei stars. Be stars are also located in this part of the HR diagram: early-type Be stars are located at the instability strip of the β Cephei stars, while mid- and late-type Be stars are mixed with SPB stars (Figure 1).

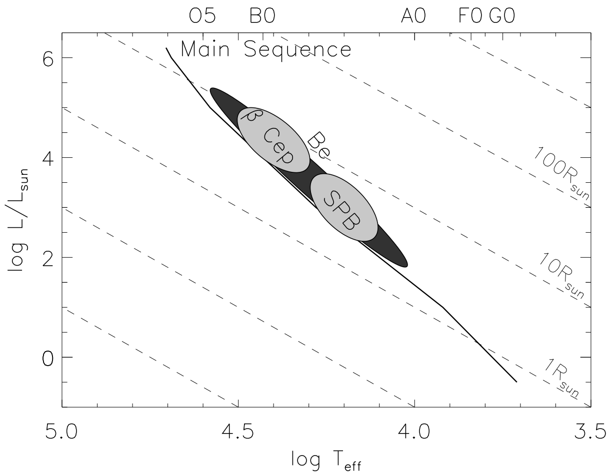

Figure 1. Upper HR diagram showing the regions covered by the β Cep and SPB stars (two grey ellipses) and the location of Be stars (black ellipse).

From the observational point of view, many β Cep, SPB and Be stars are known to host pulsations (p or g modes) with periods ranging from a few hours to several days. Several very early Be stars are also reported as β Cep stars while less massive and less luminous Be stars show longer periods of variations such as SPB stars. Short-term periodic variability of B and Be stars can thus be explained as the consequence of non-radial pulsations. In addition, variations due to rotation and wind are also observed in the optical and UV spectral domains.

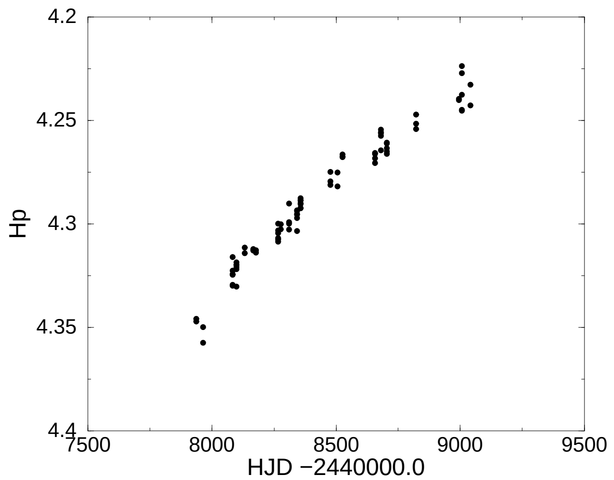

Figure 2. Long-term trend of the Be star ψ Per, observed with Hipparcos (Hubert & Floquet 1998).

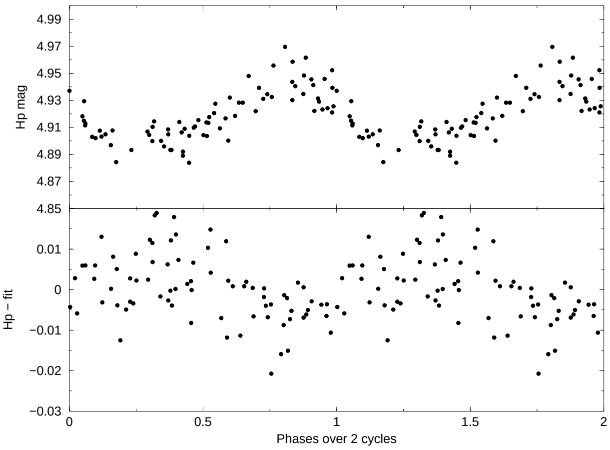

Figure 3. Variations of the magnitude of 19 Mon from Hipparcos data. Upper panel: folded in phase with P_1 = 0.191 d. Lower panel: folded in phase with P_2 = 0.204 d after removing P_1.

1.2. Circumstellar Disc of Be Stars

Be stars have a circumstellar equatorially concentrated envelope, or clouds, fed by discrete mass-loss events. The presence of emission in optical and infrared spectral lines and in the near-IR continuum, which is also called the 'Be phenomenon', is attributed to this excretion disc. About 20% of all B-type stars in our Galaxy show this phenomenon. Its magnitude can vary with time and B and Be phases are thus commonly observed to alternate in such stars.

How outbursts can occur and create a circumstellar disc has remained a mystery since the discovery of Be stars 140 years ago. It has been proposed (Ando 1986, Osaki 1986, Lee & Saio 1989, 1993) that non-radial pulsations coupled to the high rotation of Be stars (at least 80% of the critical rotation velocity) could help to trigger episodic mass-loss phases in Be stars. Alternatively, the ejection process could be related to magnetic activity, since a handful of pulsating B stars, including two Be stars (Henrichs et al. 2000, Neiner et al. 2003), also host a magnetic field of a few hundred Gauss.

2. VARIABILITY

2.1. Current Status

Photometric variability in Be stars is rather complex. Three timescales are often superimposed: (i) a short-term (hours, tens of hours) variability of low amplitude (several hundredths of magnitude) due to non-radial pulsations and temporarily orbiting clouds, (ii) a mid-term (weeks, tens of weeks) variability with amplitudes up to 0.2 mag, (iii) a long-term (years, decades) variability for which the amplitude goes up to 0.8 mag, due to global changes of the physical and geometrical parameters of the disc.

Short periods have been commonly detected in photospheric line profile and photometric variations of B and Be stars, except in late sub-classes. For Be stars, Hipparcos showed a strong dependence of this variability on effective temperatures: short-term variability is present in the quasi-totality (86%) of early-Be stars, in 40% of mid-types (B4e-5e) and in only 18% of late-Be stars (Hubert & Floquet 1998). Up to now, a hundred Be stars have been claimed as short-term periodic variables, and their number still increases.

Multi-periodicity has also been detected in light curves (Hubert & Floquet 1998, Aerts 2000) of a fraction of B and early Be stars as well as in photospheric line profile variations (numerous references in IAU Coll. 175, 2000, ASP Conf. Series 214). An example of short-term multiperiodic variability detected by Hipparcos is shown in Figure 3.

2.2. Variability with Gaia

Gaia will provide a deep survey of variability of B and Be stars in young galactic clusters and in the field of the Galaxy. With the Besançon model of stellar population synthesis of the Galaxy (Robin et al. 2003), it is estimated that Gaia will observe about one million B-type stars in our Galaxy. Information could also be derived for B and Be stars located in the less crowded regions of the Magellanic Clouds. Therefore, Gaia will allow us to study the influence of age and metallicity upon variability.

Moreover, the high photometric accuracy of Gaia (1 mmag for a V = 10 star at 100 pc) will allow us to detect micro-variability ($\leq$ a few mmag) predicted in late B and Be stars but difficult to detect with ground-based observations as amplitudes barely exceed the limit of detectability.

Finally, photometric data of Be stars also show long-term trends combined with the short-term variations (Fig-

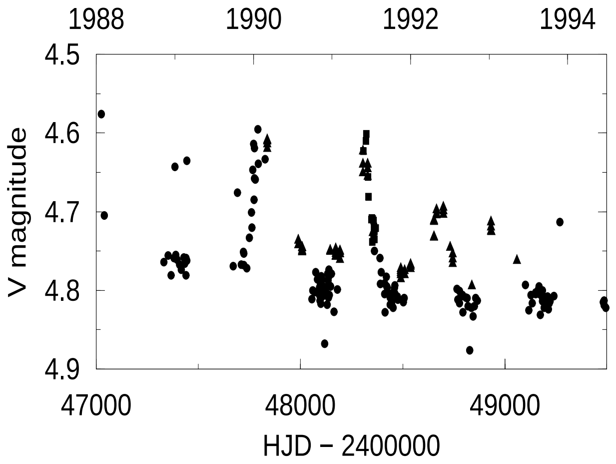

Figure 4. Short-lived outbursts of the Be star 66 Oph (Floquet et al. 2002), observed by Hipparcos (triangles) and other instruments (circles and squares).

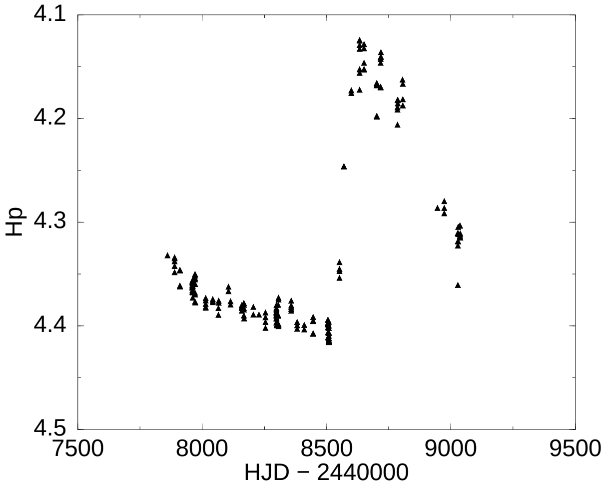

Figure 5. Long-lived outburst of the Be star υ Cyg (Hubert & Floquet 1998; Neiner et al. 2004), observed by Hipparcos.

ure 2). Due to the length of the Gaia mission, these trends will be easily removed from the data to improve the study of short-term variations, such as pulsations and rotational modulation. On the other hand, these long-term trends also reflect changes in the physical parameters of the disc of Be stars and their study could therefore provide insights onto the ‘Be phenomenon’.

3. STUDY OF BE OUTBURSTS

The disc of Be stars is fed by discrete mass-loss events, called outbursts. These ejections of matter are thus a key ingredient to understand the ‘Be phenomenon’. Hipparcos allowed us to study outbursts in several bright Be stars: recurrent short-lived and long-lived light outbursts have been observed (Figures 4 and 5 respectively; and see Hubert & Floquet 1998, Hubert et al. 2000). Outbursts have been preferentially detected with a high level (delta V up to 0.3 mag) in early Be stars with a low to moderate $v \sin i$. At the opposite, fading events seem to be more conspicuous in stars with higher $v \sin i$. Thus, fadings are thought to be the negative image of short-lived outbursts seen in rather low to moderate $v \sin i$ Be stars. Both phenomena probably have the same origin and can be explained by discrete high density emitting plasma events seen under various inclination angles above or inside an anisotropic envelope (disc).

Gaia will extend these results on outbursts of Be stars to a much larger sample: about 200 000 Be stars will be observed with Gaia. In particular, Gaia will observe a large amount of Be stars in interior and exterior galactic clusters. Clusters are ideal laboratories to study the underlying physical causes of the presence of a disc around Be stars. These allow the isolation of several parameters thought to be of relevance, such as metallicity or age. A natural line of research is therefore to study the occurrence rate of Be stars with cluster environment. For example, Fabregat & Torrejón (2000) proposed that Be stars are more numerous in clusters of 10 to 25 million years but Maeder et al. (1999) proposed that the ‘Be phenomenon’ is favored in stars of low metallicity. These theories will be easily tested with the statistics provided by Gaia.

4. DISCOVERY OF NEW B VARIABLES, BE STARS AND EXOTIC OBJECTS

4.1. The Contribution of Hipparcos and Gaia

Hipparcos made a significant contribution to the discovery of new SPB candidates. It raised their number from 12 to 84 stars (Waelkens et al. 1998). We expect that Gaia will make a significant contribution for the SPB stars as well, and that it will probably also discover new β Cep stars.

Moreover, many B stars classified as ‘unsolved variables’ by Hipparcos appeared to host pulsations and additional long-term variations and turned out to be Be stars. Long-term variability in B stars (Figure 2) is thus an indirect method for a pre-selection of Be stars (Hubert & Floquet 1998). It is particularly useful for the Be stars with weak emission and which can not be detected as Be stars with a Hα filter only.

4.2. Identification of B and Be ariables

Early Be stars usually exhibit emission in Paschen lines (Figure 6). This will allow us to separate Be stars from B stars observed with Gaia and, in this way, discover new Be stars. The use of a medium band filter in the Hα region is necessary to extend the detection of Be stars towards the late sub-types that do not show Paschen emission.

The Hα filter is also very useful to separate Be stars from pre-main sequence Ae/Be and B[e] stars, which have

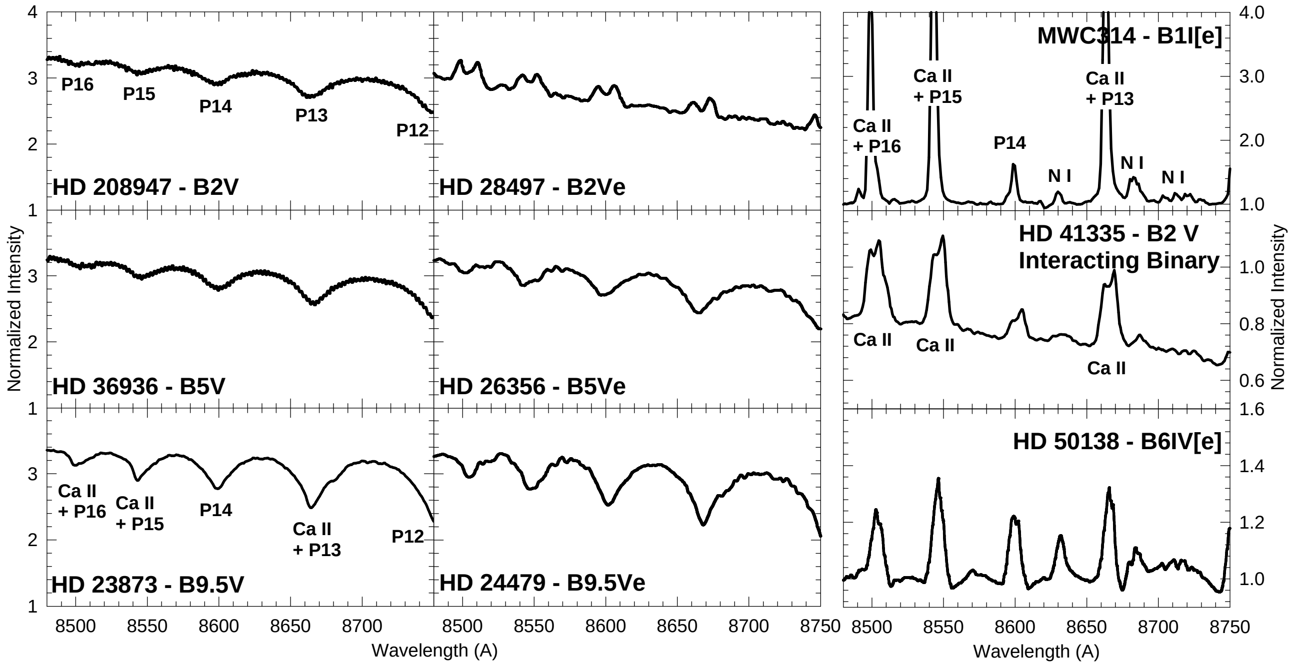

Figure 6. Examples of spectra of B (left), Be (middle), B[e] stars and an interacting binary (right) in the wavelength domain of Gaia.

stronger emission than classical Be stars. Furthermore, exotic objects such as Herbig Ae/Be, B[e], symbiotic and proto-planetary nebulae stars will be easily identified thanks to the presence of FeII and Fe[II] emission lines in addition to the IR CaII and Paschen emission lines (see Figure 6).

5. CONCLUSIONS

Gaia will be a major tool to study the variability of B and Be stars on different timescales, the influence of age and metallicity upon variability, as well as micro-variability.

It will also allow us to study short-lived and long-lived outbursts of Be stars and the ‘Be phenomenon’ on a large sample of stars and in different environments.

Finally, Gaia will certainly discover many new β Cep, SPB and Be stars, as well as exotic objects such as B[e], Ae/Be or symbiotic stars.

REFERENCES

Aerts C. 2000, ‘The Be Phenomenon in Early-Type Stars’, IAU Coll. 175, ASP Conf. Ser. 214, eds M.A. Smith and H.F. Henrichs, 192

Ando, H. 1986, A&A 163, 97

Dziembowski, W.A., 1994, in Pulsation, Rotation and Mass Loss in Early Type Stars, IAU Symp. 162, p. 55

Fabregat, J., Torrejón, J.M., 2000, A&A, 357,451

Floquet, M., Neiner, C., Janot-Pacheco, E., et al., 2002, A&A 394, 137

Henrichs, H.F, de Jong, J.A., Donati J.-F., et al., 2000, ‘The Be Phenomenon in Early-Type Stars’, IAU Coll. 175, ASP Conf. Ser. 214, eds M.A. Smith and H.F. Henrichs, p.324

Hubert, A.-M., & Floquet, M., 1998, A&A 335, 565

Hubert, A.-M., Floquet, M., Zorec, J., 2000, ‘The Be Phenomenon in Early-Type Stars’, IAU Coll. 175, ASP Conf. Ser. 214, eds M.A. Smith and H.F. Henrichs, 348

Lee, U., Saio, H., 1989, MNRAS, 237, 875

Lee, U., Saio, H., 1993, MNRAS, 261, 415

Maeder, A., Grebel, E.K., Mermilliod, J.-C., 1999, A&A 346, 459

Neiner, C., Floquet, M., Hubert, A.-M., et al., 2004, A&A in press

Neiner, C., Hubert, A.-M., Frémat, Y., et al., 2003, A&A 409, 275

Osaki, Y., 1986, PASP 98, 30

Robin, A.C., Reylé, C., Derrière, S. & Picaud, S., 2003, A&A 409, 523

Waelkens, C., Aerts, C., Kestens, E., et al., 1998, A&A 330, 215