EMISSION LINE STARS IN THE FRAMEWORK OF GAIA

I. Kolka, T. Eenmäe, A. Hirv, T. Tuvikene, M. Kama
Tartu Observatory, 61602 Tõravere, Estonia

ABSTRACT

Emission line stars will comprise only a small part among Gaia objects. However, several types of them are at critical evolutionary stages and the Gaia mission should, in principle, discover many new members of these distinct stellar families which will serve as wanted targets for further ground–based observations. Taking the example of WR, Be and HAeBe stars, we investigate the possibilities to separate these peculiar objects from 'ordinary stellar targets' using proposed Gaia photometric systems (PSs). To simulate PS fluxes we use empirically determined spectral energy distribution templates of typical WR, Be and HAeBe stars. In addition, we estimate to which extent Gaia will provide classification capabilities inside broad spectral types mentioned above. We consider especially the case of the Gaia medium band photometry without the dedicated filter for the H_α spectral region.

Key words: Gaia; Stars: WR, Be, HAeBe; SED; synthetic photometry.

1. INTRODUCTION

The scientific goals of the Gaia mission are one of the main factors which determine the design of it's instruments. The aim to study the chemical and dynamical evolution of the Galaxy at different galactocentric distances poses the constraint to optimize the performance of instruments for 'main' stellar targets which represent the galactic populations in the best way. For example, for the evaluation of proposed photometric systems (PSs) the term 'scientific targets' has been introduced for such objects, and certain quantified priorities have been assigned to them (cf. Jordi 2005). Gaia should be able to recognize and classify them down to the faint limiting magnitude. In this context, all types of emission line stars represent minorities in the world of Gaia objects and have no priority in defining instruments' characteristics. However, if possible, Gaia should distinguish emission line stars from other objects assigning a special 'peculiarity flag' and performing in suitable cases the classification task.

The Spectro instrument on the Gaia satellite contains the Radial Velocity Spectrometer (RVS) which will record short segments of spectra around 860 nm at a resolution $\sim 10^4$. In principle, this option would be the most suitable to recognize objects with emission lines (Munari 1999) but the limiting magnitude for RVS is V $\sim$ 17–18 (Katz 2005) while for broad–band and medium–band photometry it is several magnitudes fainter (Perryman et al. 2001). Therefore, it is natural to consider expected photometric data as the primary source for separation of stars with peculiarities, and spectral data as a complementary one.

The investigations of stars with emission lines will benefit from Gaia observations in two ways: from one side new high quality data on already known objects will refine our knowledge on their physical parameters and evolutionary stage but the discovery of new objects of a certain type would be another valuable result which would provide new targets for subsequent ground–based studies. Both, 'known' and 'new' objects should be equally recognizable to Gaia because this mission has been designed not to have a pre–defined list of targets.

In the following, we make an attempt to estimate the capability of the proposed Gaia PSs to recognize and classify emission line objects in the case of WR, Be and HAeBe stars. In the next sections we describe the compilation of empirical spectral energy distributions (SEDs) for these types of stars and the results of synthetic photometry using these SEDs. We point to a sample of photometric indices capable for the task described above.

2. EMPIRICAL SPECTRAL ENERGY DISTRIBUTIONS

The aim of this investigation has been to find out which photometric indices in the proposed Gaia PSs can be used for the separation and classification of emission line stars. The method of synthetic photometry was selected for this task, and it was decided that typical empirical SEDs of sufficient spectral resolution can be used for the simulation of PSs fluxes. For the medium–band photometric system (MBP) the proposed interference filters have transparency curves with slopes of width of a few nanometers. Accordingly, the reasonable spectral resolution of SEDs should be 1 – 2 nm. We decided to compile the empirical SED templates for selected targets using publicly available photometric and spectrophotometric data. If necessary, we added our own spectroscopic observations of suitable resolution ($\sim$ 4 Å/pix). We have used for this task the 1.5 m telescope of Tartu Observatory equipped with the Cassegrain spectrograph and cryogenically cooled CCD camera Orbis–1. These spectra were flux–calibrated by corresponding (spectro)photometric data. The calibration procedure is reliable enough thanks to the smooth continuum curves and small number of spectral lines in the case of hot stars selected for investigation (a different approach has been used for WR stars, see below). In the following, we indicate separately on each type of considered stars which data bases have been the sources for SED compilations. We notice that WR, Be and HAeBe stars are known as possible irregular variables, both in continuum and (especially) in line strengths. In these circumstances we can not claim that final SEDs compiled from various sources represent a certain state of selected targets accurately in details but we suppose that they can be used as reliable templates representing the variety of objects inside the stellar types under investigation.

2.1. Be Stars

Our sample of Be stars (cf. Table 1 part 3, spectral types from Steele et al. 1999 and Jaschek & Egret 1982) has been selected to cover different spectral subclasses and different emissivity from their gaseous discs (various strengths of H_α line). Be stars have been quite extensively observed in the 13–colour photometric system (Johnson & Mitchell 1975, Schuster & Alvarez 1983) which is well calibrated in absolute fluxes. On the majority of our objects, we have found a good agreement between 13–colour fluxes and SEDs from the Kharitonov et al. spectrophotometric catalogue (Kharitonov et al. 1988). Using these two data sets we have formed the calibrated reference SEDs which were complemented in selected cases by our spectra normalized to the continuum. In a few cases of southern Be stars, we have incorporated the spectrophotometric data published by Kaiser (1987) and Dachs et al. (1989). For the characterization of Be stars the importance of H_α line is natural. In this context, we have found very useful to take into account the spectroscopic observations of Be stars in the H_α region made publicly available by Ch. Buil[1]. We notice that the eight visually brightest Be stars ($V < 3$) have been included to form a subsample of supposedly marginally reddened objects. In addition, five main sequence (MS) B stars belong to our sample for comparison purposes (Table 1 part 4). We depict our compilation results by two characteristic examples in Figure 1 (panel a) demonstrating the influence of disc emission power on the details of SED (line intensities and the form of the Balmer jump).

2.2. HAeBe Stars

This type of hot pre–main sequence stars is represented presently by seven objects only (cf. Table 1 part 2, spectral types from van den Ancker et al. 1998). However, they are of various spectral types, and preliminary conclusions on their place in the Gaia framework can be made (see next section).

To form the SED templates for HAeBe stars we have used photometric data from uvby–beta catalogue (Hauck & Mermilliod 1997) and measurements in Vilnius photometric system (Eimontas & Sūdžius 1998). In the long wavelength region Johnson R, I and J filter fluxes were incorporated, too (Hillenbrand et al. 1992). We checked the reliability of our compilations against the spectrophotometric data by Garrison (1978) presented in graphical form. In Figure 1 (panel b) two SEDs on HAeBe stars with different spectral classes are depicted.

Table 1. Emission line objects used to compile the data base of empirical SEDs.

Star name	Sp. class	Star name	Sp. class
WR2	WN2	WR152	WN3
WR1	WN4	WR128	WN4
WR149	WN5	WR134	WN6
WR136	WN6	WR158	WN7
WR156	WN8	WR105	WN9
WR108	WN9	BR8	WC4
WR4	WC5	WR5	WC6
WR68	WC7	WR135	WC8
WR92	WC9	WR121	WC9
HD 259431	B1Ve	BD+40°4124	B2Ve
HD 200775	B2.5IVe	HD 250550	B4-5IIIe
V594 Cas	B8eq	AB Aur	A0Ve
BD+46°3471	A4e		
HD 4180	B2.5Ve	HD 5394	B0.5IVe
HD 6811	B5IIIe	HD 9709	B8Ve
HD 10144	B3Ve	HD 18552	B7Ve
HD 21641	B9Ve	HD 22192	B4Ve
HD 23630	B7IIIe	HD 25940	B2.5Ve
HD 37795	B7IVe	HD 58715	B8Ve
HD 105435	B2IVe	HD 127972	B1.5Ve
HD 149757	O9.5Ve	HD 158427	B2Ve
HD 168797	B2.5Ve	HD 171406	B4Ve
HD 183362	B2Ve	HD 183656	B6e
HD 193009	B1.5Ve	HD 206773	B0Ve
HD 210129	B6Ve		
HD 36512	B0V	HD 74280	B3V
HD 147394	B5IV	HD 87901	B7V
HD 114330	A1V		

2.3. WR Stars

In the case of WR stars both WC and WN spectral sequences are presented (cf. Table 1 part 1, star names and spectral classes from van der Hucht 2001). The sources for the SED compilation have been the spectrophotometric atlases by Torres & Massey (1987, 1988), and the continuum normalized spectra made available by W.–R. Hamann[2]. These data bases have the long–wavelength limit at $\sim$ 730 nm and we have filled the remaining gap

[1] www.astrosurf.com/buil/us/bestar.htm

[2] ftp.astro.physik.uni–potsdam.de/pub/wrhamann/WNatlas

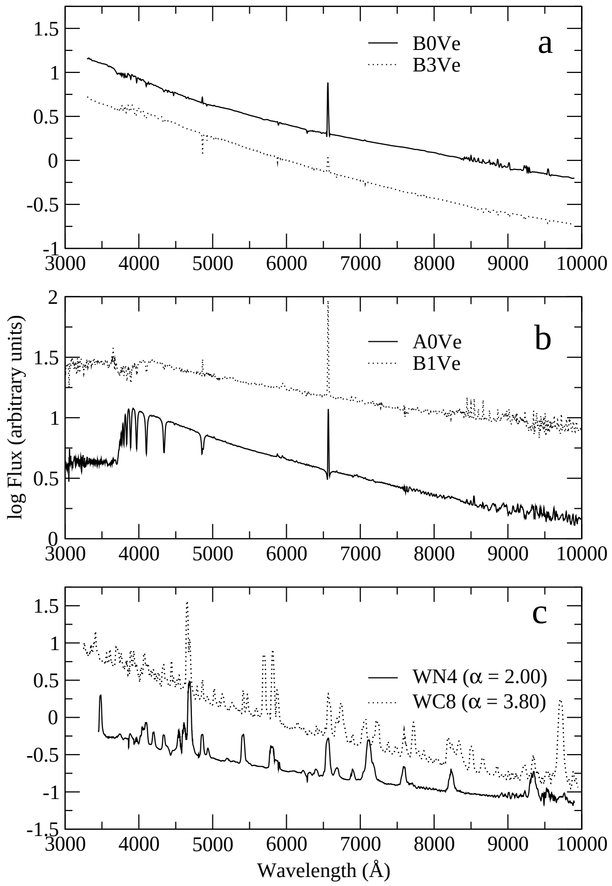

Figure 1. The examples of empirical SED curves for Be stars (panel a), HAeBe stars (panel b) and WR stars (panel c).

up to 1000 nm with spectra obtained by us at Tartu Observatory. This NIR region covers many telluric spectral features, and the correction of target spectra for their influence is never fully satisfactory (see e.g., Conti et al. 1990). Our final SED templates suffer from the same inaccuracy. To compile the SEDs for WR stars we have taken into account the results on their continuum energy distributions by Morris et al. (1993). According to that paper the intrinsic continua of single WR stars independent of their spectral type may be represented by a power law with a single spectral index for the wavelength interval 150 – 1000 nm. With high probability, all single WR stars can be described by a spectral index α inside the interval 2.0 – 3.8 if the continuum flux is set proportional to $\lambda^{-\alpha}$. In this way, in our set of WR SED templates every continuum normalized target spectrum is combined with two extreme continuum slopes having α = 2.0 and 3.8. Two examples of this dependence are shown in Figure 1 (panel c).

3. RESULTS OF SYNTHETIC PHOTOMETRY

The following analysis considers three PSs proposed for Gaia: 2X (Vansevicius 2004) and 3F (Jordi et al. 2004a) as medium band systems, and 4B (Lindegren 2003) as a broad band one. It is natural to suppose that suitably selected photometric indices of Gaia PSs can be sensitive to specific spectral features of emission line stars if some of the PS filters have suitable characteristics (position in the wavelength scale and width). Simple visual comparisons of SEDs and filter curves can give the first hint, and subsequently we checked the situation using the method of synthetic photometry. We have used the program package *fluxGAIA2* provided kindly by C. Jordi who uses the same software (Barcelona's simulator) for the testing of PSs against 'scientific targets' mentioned above (see the Photometry Working Group web site[3]). This program requires SEDs in relative units as input and calculates filter fluxes and colours corresponding to transmission curves which take into account all instrumental factors influencing its shape. The magnitudes and colours are given in a system which uses the Kurucz model flux of Vega as a standard.

In search of suitable photometric indicators to selected types of emission line stars it is preferable to use (if possible) indices free of interstellar reddening. In the case of Be and HAeBe stars it is straightforward to try to construct a photometric H_α index. Indeed, combining the proposed medium band filter 3F656 or 2X655 with the broad band filter 4B650 (all centered near H_α line) we have got a reddening-free H_α index. The expected result is shown in Figure 2 demonstrating the tight correlation between the equivalent width of H_α and the derived photometric index. The higher sensitivity of 3F index arises from the smaller full–width of 3F656 band. In both cases normal B stars are well distinguished from emission line ones. This index reveals the peculiarity of WR stars, too (Figure 2), but the dependence of its value on the strength of the blended emission line (HI + HeII + CII(CIV)) near 656 nm is less well determined due to additional emission lines residing inside the 4B650 band. In spite of promising results with H_α index we have looked for additional Be/HAeBe stars indicators. This has been caused by discussions in the Gaia photometry working group to drop the medium band filter at 656 nm as unimportant for 'main targets' and to use this slot of focal plane CCDs for some other band. It was shown (see e.g., Dachs et al. 1989 and Garrison 1978) that the value of the Balmer jump and the flux level in the Balmer continuum can be different in normal and emission line stars and correlated with the H_α equivalent width. Figure 3 demonstrates that the situation is more complicated than with H_α index above. Both colours (one measuring the jump (upper panel) and another the continuum level (lower panel)) must be corrected for the stellar photospheric contribution to reveal the existence and strength of the disc component which would then be the indicator of peculiarity. This would be an additional and sophisticated procedure which should be avoided if possible.

Considering WR stars we notice the favourable positioning of two medium bands 3F467 and 3F585 against the classification lines in WR spectra. The first measures the strength of HeII (main contributor) and NIII/V (or CIII/IV) lines between 460 and 470 nm, the second the strength of CIII and CIV lines between 560 and 590 nm. By the interpolation of the continuum level into

[3]http://gaia.am.ub.es/PWG/

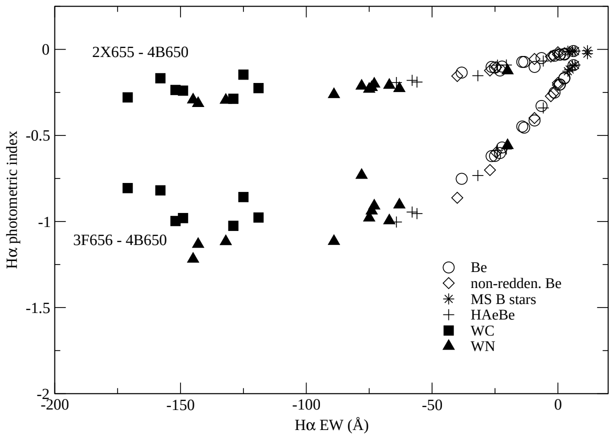

Figure 2. The photometric index calculated by the combination of broad band and medium band H_α fluxes defines the location of emission line stars. The performance of two MBP systems is depicted.

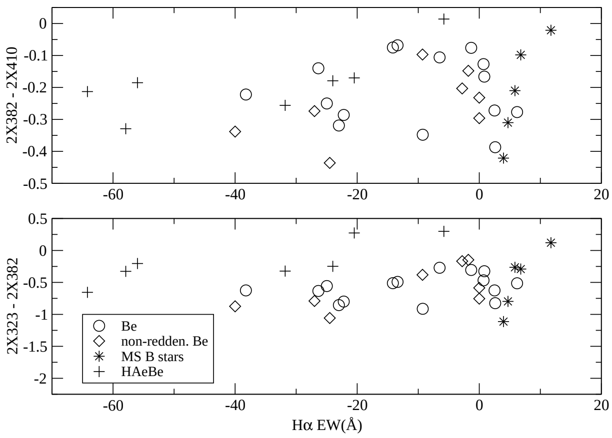

Figure 3. Two UV region colour indices in 2X MBP system indicate that both emission line and normal stars cover similar colour intervals and a more sophisticated analysis of UV fluxes is needed to separate peculiar objects.

these bands we could get two reddening-free photometric indices which separate WR stars from other stellar targets and are able to distinguish WN and WC sequences. We have estimated that the continuum at 3F467 (C467) can be calculated as C467 $=$ 3F386 $-$ 0.67(3F386 $-$ 3F508) and the continuum at 3F585 (C585) as C585 $=$ 3F508 $-$ 0.25(3F508 $-$ 3F891). These formulae are reasonable approximations as far as the continuum flux in magnitudes can be described by a linear slope inside the selected spectral intervals. We notice that the bands 3F386, 3F508 and 3F891 selected for continuum interpolation contain in the case of WR SEDs relatively weak emission lines only, and can be used as acceptable continuum representatives for our purposes. The two colour diagram (3F467 – C467 versus 3F585 – C585) in Figure 4 demonstrates that the WN and WC sequences occupy different regions and their separation is achievable independent of expected intrinsic continuum slopes. The same is true for reddened

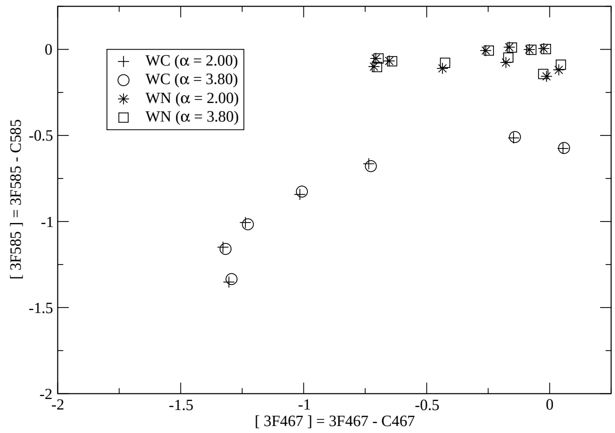

Figure 4. The suitably selected emission line photometric indices on WR stars (see text for more explanations) are able to distinguish clearly WN and WC sequences.

WR SEDs, too, thanks to the approximate linearity of continuum curves as mentioned above.

4. CONCLUSIONS

We have presented the results of the first step to assess the performance of Gaia PSs in the field of emission line stars. Presently, before the final decision on the PSs has been made we conclude that the proposed systems 2X, 3F and 4B give the possibility to derive reddening-free photometric indices (see above) which can be used to recognize Be, HAeBe and WR stars amongst other stellar targets, separate WR objects and classify them into WN and WC sequences. We suggest not to drop MBP filter at H_α line. We notice in this context the recent paper by Barrado y Navascues & Martin (2003) which demonstrates the definite role of H_α emission line strength in the classification of T Tauri stars and their substellar analogs. This enhances the importance of the corresponding photometric index inside the final PS for Gaia.

Special comments are needed on the performance of MBP at low galactic latitudes where the bulk of emission line stars should be detected. According to recent estimates (see Jordi et al. 2004b) the most crowded areas near the galactic plane ($|b| < 2°$) may remain unobserved by MBP due to its nonsufficient angular resolution. However, as it was pointed out by Evans (2004) the usage of PSF fitting with accurate PSFs and astrometric information from the Astro instrument could provide accurate MBP photometry in these areas. Our conclusion is that despite the fact that crowded regions remain to be studied in more detail the final PS for Gaia should keep its sensitivity in the field of emission line stars. We plan to investigate the final system by the method outlined above, and to assess its ability for more refined classification of emission line objects.

ACKNOWLEDGEMENTS

This research is supported in part by the Estonian Science Foundation grant No. 5003. The authors acknowledge the stimulating discussions with M. Grenon, C. Jordi and V. Vansevicius. MK acknowledges financial support from the LOC and SOC of this Symposium.

REFERENCES

Barrado y Navascues, D., Martin, E.L., 2003, AJ, 126, 2997

Conti, P.S., Massey, P., Vreux, J.–M., 1990, ApJ, 354, 359

Dachs, J., Poetzel, R., Kaiser, D., 1989, A&AS, 78, 487

Eimontas, A., Sūdžius, J., 1998, Baltic Astron., 7, 407

Evans, D.W., 2004, Gaia technical report PWG–DWE–001

Garrison, L.M., 1978, ApJ, 224, 535

Hauck, B., Mermilliod, M., 1997, uvby–beta Catalogue (CDS II/215)

Hillenbrand, L.A., Strom, S.E., Vrba, F.J., Keene, J., 1992, ApJ, 397, 613

Jaschek, M., Egret, D., 1982, Catalogue of Be stars (CDS III/67A)

Johnson, H.L., Mitchell, R.I., 1975, Rev. Mex. Astron. Astrofis., 1, 299

Jordi, C., 2005, ESA SP-576, this volume

Jordi, C., Figueras, F., Torra, J., Carrasco, J.M., 2004a, Gaia technical report UB–PWG–016

Jordi, C., Knude, J., Carrasco, J.M., Figueras, F., 2004b, Gaia technical report UB–PWG–015, v1.2

Kaiser, D., 1987, A&AS, 67, 203

Katz, D., 2005, ESA SP-576, this volume

Kharitonov, A.V., Tereshchenko, V.M., Knyazeva, L.N., 1988, Spectrophotometric Catalogue of Stars, Alma–Ata, Nauka, 484 p.

Lindegren, L., 2003, Gaia technical report GAIA–LL–51

Morris, P.W., Brownsberger, K.R., Conti, P.S., et al., 1993, ApJ, 412, 324

Munari, U., 1999, Baltic Astron., 8, 73

Perryman, M.A.C., de Boer, K.S., Gilmore, G., et al., 2001, A&A, 369, 339

Schuster, W.J., Alvarez, M., 1983, PASP, 95, 35

Steele, I.A., Negueruela, I., Clark, J.S., 1999, A&AS, 137, 147

Torres, A.V., Massey, P., 1987, ApJS, 65, 459

Torres–Dodgen, A.V., Massey, P., 1988, AJ, 96, 1076

van den Ancker, M.E., de Winter, D., Tjin A Djie, H.R.E., 1998, A&A, 330, 145

van der Hucht, K.A., 2001, New Astron. Rev., 45, 135

Vansevičius, V., 2004, Gaia technical report GAIA–VIL–014