ABSTRACT

The spectroscopic features to be measured, their dependence as a function of $T_{\text{eff}}$, $\log g$ or [M/H] for the various types of stars leading us to the design of the medium passbands, central wavelength and their blue and red limits are described. The design specially accounts for the scientific key targets for the study of the origin and history of our Galaxy. This paper focusses on the Geneva-Barcelona medium-band photometric system.

Key words: Gaia; ESA; photometry; filter definition; astrophysical parameters.

1. INTRODUCTION

The Gaia mission must provide the physical properties ($T_{\text{eff}}$, luminosity, chemical composition, peculiarities, anomalies, etc), with an accuracy sufficient for the quantitative description of the chemical and dynamical evolution of the Galaxy over all galactocentric distances.

The bands proposed by the Geneva-Barcelona team for the Gaia mission (Grenon et al. 1999a, 1999b, Jordi et al. 2003, 2004), are a compromise to have at the same time a performing classification tool for early, intermediate and late type stars up to the $G$-limiting magnitude. This performance was achieved by adopting bandwidths as broadest as possible, without significant degradation of the physical information. We took special care to assure that abundances, gravities and temperatures at the needed accuracy could be derived for the scientific goals (ESA-SCI(2000)4).

For the optimization of the bands, synthetic photometry was realized using ATLAS9 (Kurucz 1991, 1994), BaSeL-2.2 (Lejeune et al. 1998) and PHOENIX team (Hauschildt et al. 1999, Allard et al. 2001) stellar atmosphere models.

Presently, this system is being optimized for the reddening determination and tested for possible improvements of chemical abundances determination by learning from other medium-band proposals for Gaia (Vansevicius, 2004, Knude & Høg, 2004, Straizys, 2004). See Jordi & Høg (2004), for a detailed discussion of photometric system performances evaluation.

2. THE GAIA PHOTOMETRY

The UV domain contains the most useful information on gravity for early type stars (see Fig. 1) and on metallicity for F, G, K stars (see Fig. 2 and Cayrel et al. 1999). In early type stars spectra, the Balmer continuum is devoid of absorption features. In ground based photometry, the $U$ band is naturally limited on the UV-C side, by saturated terrestrial $O_3$ bands. In space the $F_{33}$ band should extend to the QE-CCD limit. This improves the determination of [M/H] for G and K stars because of the presence of very many atomic lines. Any overlap of $F_{33}$ with the Balmer jump would result in a loss of sensitivity to gravity for B and A stars.

The $F_{41}$ filter is designed to measure Balmer lines for late B and A type stars, in the range from the Balmer jump up to H$_\alpha$, see again Fig. 1. For F type stars and cooler, the $F_{41}$ filter measures the break short of 430 nm, due to a strong concentration of atomic and molecular lines, see Fig. 2. In addition, the $F_{41}$ band contains CN bands, strong CaII lines, the Q and R branches of CH radical and the P branch, less intense. When the abundance of...
The flux measured in the F$_{14}$ bandpass increases the abundance of CH decreases, thus the side was defined to avoid certain CH contamination. With used to derive elements abundances.

The F$_{17}$ filter measures a domain where the absorption by atomic and molecular lines is minimum, see Fig. 2. The flux in that domain corresponds to a pseudo-continuum, used with the F$_{59}$ or F$_{75}$ fluxes to derive $T_{\text{eff}}$. The blue side was defined to avoid certain CH contamination. With a red limit at 484 nm, the perturbation by H$_{\beta}$ at 481 nm is small. This red limit is also imposed by the presence of the MgH band in particular for K dwarfs.

The F$_{51}$ filter was designed to measure the complex MgH+Mg b, which is the best gravity indicator for late G to early M stars. It must be investigated if this band can be used to derive $\alpha$-elements abundances.

The F$_{59}$ band measures a pseudo-continuum with very low absorption by metallic lines, except by Na D which becomes very strong in SMR stars. F$_{59}$ is limited on the blue side by the numerous metallic lines and on the red side by that of a strong TiO band. The cut at 615 nm avoids an excessive contamination by the TiO $\gamma$ system bands. For stars later than K4, the F$_{59}$ band becomes contaminated by TiO.

In very metal poor low luminosity dwarfs, the MgH band remains strong whereas TiO bands vanish completely. Red colours, low TiO and strong MgH are typical signatures of halo counterparts of M dwarfs.

The original purpose of the F$_{65}$ band was the detection (when present) of emission features in the spectrum, thus allowing to detect peculiar objects (such as Be stars, T-Tau stars, etc.). The band width (653-659 nm) was chosen to the detection of both H$_{\alpha}$ and [N I] 655/658 nm even in high-radial velocity stars. Since the strength of the line is sensible to effective temperature for early type stars, this band combined with a broad band centred at the same effective wavelength may provide an almost reddening free index. This option is under investigation.

CN increases the abundance of CH decreases, thus the flux measured in the F$_{14}$ bandpass remaining a very good indicator of the global metallicity. F$_{39}$ filter is introduced to better isolate CH from CN.

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The distinction between M and C stars is realized with the F$_{75}$, F$_{78}$, F$_{83}$ and F$_{89}$ bands (see again Fig. 3). At a given temperature, the fluxes are similar in the F$_{78}$ and F$_{89}$ for O-rich stars (the M sequence) and for C-rich stars (the C sequence), but very different in the F$_{75}$ and F$_{83}$ bands, namely because of strong CN bands. The separation between M and C stars is indeed possible even if they are heavily reddened.

Finally, the F$_{86}$ band covers the wavelength range of the
RVS spectrometer. This passband is important for classification of heavily reddened early-type stars, when they are too faint to be well measured in the ultraviolet.

3. ASTROPHYSICAL PARAMETERS DERIVATION

3.1. Luminosity determination

The MgH+Mg b band intensity is nearly invariant as a function of [M/H] for G and K dwarfs and subgiants. This behaviour allows to separate luminosities down to the G-limiting magnitude (see Fig. 4), specially in the Galactic poles direction. Its intensity reaches a maximum around K7V. It is also useful to discriminate between M dwarfs and cool white dwarfs.

The Balmer jump, measured by C_{33−41} versus T_{eff} (Fig. 5 left), also helps on the determination of luminosity. The amplitude of variation is of ~0.8 mag for a log g change from 4.5 to 1.5 leading to accurate estimates of log g down to G = 19 (σ_{log g}~0.05 dex).

We also have to take into account the valuable information coming from the extremely accurate trigonometric parallax, that will provide a direct determination of luminosity for many of the observed stars.

3.2. Abundance determination

Figure 5 (right) demonstrates the capability of the F_{41} band to derive global abundances through the reddening-free parameter Q_{I_{41}} = Q_{>41477889}. The errors of Q_{I_{41}} slightly decrease with C_{59−75} while the sensitivity to [M/H] increases. A good metallicity discrimination (σ_{[M/H]} < 0.1 dex) may be obtained down to V ~ 18 for typical red giants. σ_{[M/H]} ≈ 0.17 dex for a star of 4200 K and G=19 (G − V ~ −0.14). Even, the metallicities for the horizontal branch stars of the LMC (V ~ 20) will be accessible.

Figure 4. Reddening-free Q_{I_{33−41}} derived from Kurucz’s (thin solid lines) and PHOENIX’s (without dust: thin dotted lines, with dust: dashed line) theoretical models for stars with solar metallicity, as well as for empirical (thick solid lines) spectra (Pickles 1998). Error bars correspond to a star of [M/H]=−2.0 at the end of the mission.

Figure 5. Left: The Balmer jump as measured by the C_{33−41} index for solar metallicity stars. Error bars correspond to a G = 19 mag at the end of the mission. Right: Reddening-free index Q_{I_{41}} = Q_{>41477889} for stars with log g=3 vs. θ for different metallicities using PHOENIX models. Error bars give the errors for a G = 19 star at the end of the mission.

An analogous reddening-free Q_{I_{TiO}} is also suitable, although the estimated error is larger.

Figure 6 (left) shows the reddening-free Q_{I_{TiO}} as a function of T_{eff}. The Q_{I_{TiO}} measures the TiO band intensity around 780 nm, relative to the F_{75} and F_{90} pseudo-continua. For late K and M dwarfs, I_{TiO} shows a strong dependence on [M/H], allowing a precise determination of [Ti/H]. The figure shows that although the PHOENIX models predict a thinner range of Q_{I_{TiO}} values than Kurucz’s models, this index is still providing astrophysical information down to low temperatures (C_{59−75} ~ 3 corresponds to T_{eff} ~ 2500 K). Thus, the Q_{I_{TiO}} allows an easy separation of SMRs, old and thick disk stars. Estimated uncertainties using Kurucz and PHOENIX SEDs differ in 0.05 dex and 0.08 dex at V=18 and 20 mag, respectively.

[Ti/H] may be defined with σ_{[Ti/H]} < 0.1 dex, down to V = 18.5 or 20, depending on the models, for M dwarfs with T_{eff} = 3500 K, see Fig. 6 right. Even with the less favourable predictions given by PHOENIX models, σ_{[Ti/H]} is ± 0.075 dex at V=18, i.e. G ~ 16.5, sufficient enough to identify moving group members. It is still possible to distinguish thin and thick disk M2–M3 dwarfs at
3.3. Temperature determination

The colour indices sensitive mainly to \( T_{\text{eff}} \), are almost linear functions of the reciprocal temperature \( \theta = 5040/T_{\text{eff}} \). It is why colour indices will be plotted versus \( \theta \) rather than \( T_{\text{eff}} \). For stars cooler than 10,000 K, metallicity effects on the colours are function of [M/H], \( T_{\text{eff}} \) and \( \log g \). \( C_{59-75} \) is the temperature estimator, by far the less sensitive to [M/H] for dwarfs in the range 10,000 to 3500 K, as shown in Fig. 6 (right).

The colour index \( C_{47-59} \) shows metallicity residuals, growing with decreasing \( T_{\text{eff}} \). These residuals are still acceptable for A,F,G dwarfs, because they are brighter in \( F_{59} \) band than in \( F_{75} \) band, and also because \( C_{47-59} \) is less sensitive to reddening than \( C_{59-75} \). A slight contamination by TiO is noticeable for \( \theta > 1.25 \) (\( T_{\text{eff}} < 4000 \) K).

For M stars and cooler, \( C_{75-89} \) is the best temperature estimate. Although not fully independent on [M/H], it shows a monotonic growth with \( \theta \). It could be corrected for [M/H] through the TiO index described below, although this step is not a must since iso-[M/H] and iso-\( T_{\text{eff}} \) lines will be drawn in the colour-colour diagrams.

The errors on temperature are dependent on the stars colours and apparent magnitude. An excellent \( T_{\text{eff}} \) estimation with \( \sigma_{T_{\text{eff}}} < 50 \) K (1.4\%) is obtained down to \( V = 20 \) when \( C_{59-75} \) and \( C_{75-89} \) indices are used for the M dwarf, being the second more precise below 3500 K and so, suitable for cool M dwarfs and brown dwarfs.

For solar type stars, the accuracy on \( T_{\text{eff}} \) is slightly better when the \( C_{47-59} \) index is used rather than \( C_{59-75} \) index, although more sensitive to reddening. The threshold \( \sigma_{T_{\text{eff}}} = 100 \) K (1.7\%) is reached for \( V = 19 \). When ages are determined from turn-off temperatures alone, 100 K error leads to errors on the age up to 2 Gyr at age \( = 10 - 14 \) Gyr.

4. FUTURE DEVELOPMENT

Our immediate goal is to improve the present proposal of this MBP system still on the basis of scientific key targets in collaboration with the other members of the PWG, studying how the different [\( \alpha/\text{Fe} \)] abundances (variable with galactocentric distance and metal content) or the violet CNO anomalies may affect the global metallicity determination. The performance of the system for those type of stars not yet considered (WR, with H\(_{\alpha}\) emission, Be, S, flare, white dwarfs, T-Tauri, metal-deficient M dwarfs, ...) and non-stellar objects (QSO, solar system objects, ...) will be evaluated.

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