A Possible Photometric System for FAME

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Abstract. I describe a possible semi-broad band photometric system for the FAME mission. A χ^2-based classification method is used to determine the stellar parameters and interstellar extinction. A useful application is the calibration of photometric parallaxes via $log(g)$. Astrometric and photometric parallaxes are compared.

Keywords: FAME, Photometric Systems, 3D Classification, Interstellar Extinction, Photometric Parallax

1. Introduction

FAME is the first US astrometric satellite and will operate for 5 years from its launch in 2004 or 2005. FAME, a NASA MIDEX mission, will be in a geosynchronous orbit and will scan the sky in a HIPPARCOS-like manner with spin and precession periods of 40 minutes and 20 days, respectively. A Cassegrain telescope is used to image the sky through two viewports. The expected mission-end (ME) parallax accuracies will reach 50 and 500 μas, at V=9 and 15, respectively (FAME, 2001). FAME's photometric bands are designed to determine the chromaticity corrections to the astrometry. Two CCDs with SDSS r' and i' filters (York *et al.*, 2000) yield $\delta r'_{ME} \sim 8.5$ mmag at V=15.

This contribution describes a possible six-band system in a four-CCD system for FAME and its utility for the determination of stellar parameters and interstellar extinction.

2. A Possible Six-band Photometric System for FAME

This study only includes effects due to stellar parameters ($X_\star$, ie, temperature (T_{eff}), composition ($[Fe/H]$), gravity [$log(g)$]), and extinction parameters (the total extinction A_V and the ratio of selective to total extinction, R_V). To determine five parameters, at least five data points are required. I use six: the SDSS g', r' and i' bands, and three narrower bands: wide Strömgren (1966) v and b and a very red band.

3. Classification Methods

I developed a simple method to estimate the 5D classification accuracy of such photometric systems (Olling, 2001a,b,c) that employs a library of (N_M=15,937) model atmospheres (Le Jeune *et al.*, 1997) covering a

Table I. Properties of a proposed FAME filter set. The columns designate: 1) name, 2) wavelength, 3) bandwidth, 4) mission-end measurement precision for an A0 star, 5) Number of CCDs (such that the total equals 4, minus filter-glue losses). The last entry, a narrow-band TiO-continuum filter, was used as a neutral density filter for bright stars.

filter name (1)	λ_0 [nm] (2)	$FWHM$ [nm] (3)	$\delta m_{V=15}$ [mmag] (4)	N_{CCD} (5)	Remarks (6)
F411	411	50	9.1	1.14	wide Strömgren v
F466	466	50	9.8	0.73	wide Strömgren b
g'	480	141	7.9	0.40	SDSS
r'	625	139	7.6	0.40	SDSS
i'	769	154	7.9	0.40	SDSS
Pa/Ca	875	85	9.8	0.73	Paschen Jump, Ca II triplet
(TiO$_C$	745	30	6.4	3.00	TiO-continuum ; bright star filter)

wide range in stellar parameters: this is the "training set." The spectra are normalized by the SDSS r' band, while Vega serves as the zero point. For each model spectrum, errors are assigned to each band according to the flux distribution and the product of the bandpass and the spectrum. A 5 mmag ME error per chip is used for an A0V star at V=15 in the average of the SDSS r' and i' bands. Each band is assigned a number of CCDs (ie, observations) so as to minimize the range in errors between the bands. Errors in color-indices include the errors from both bands. I define an N_P-dimensional vector $\overline{P} = (P_1, ..., P_k, ..., P_{N_P})^T$ for each model atmosphere i, where P_k is an observable (apparent flux, color, etc.). The best results are obtained employing the individual fluxes plus the colors constructed from adjacent bands (see Olling 2001a,b). The to-be-classified models j are perturbed by noise $[\delta P_k(j)]$ and compared, in the χ^2 sense, with each model i in the training set:

$$\chi^2_i(j; A_V, R_V) \ = \ \sum_{k=1}^{k=N_P} [[P_k(j) - P_k(i; A_V, R_V)]/\delta P_k(j)]^2 \qquad (1)$$

for all N_A (N_R) values of A_V (R_V), and $N_A \sim 10 \sim N_R$. The stellar parameters and extinction are determined in a two-step process: 1) at each (A_V, R_V) combination, the parameters X of the training models yield average values $\overline{X\star}(A_V, R_V) = \sum_{i=1}^{N} X_\star(i)/\chi^2(i)$ and $\overline{\chi^2}(A_V, R_V) = 1.0/[\sum_{i=1}^{N} 1/\chi^2(i)]$, where the models i are sorted such that χ^2 increases with i, 2) the M averages with the smallest $\overline{\chi^2}(A_V, R_V)$ values are selected to yield $\overline{\chi^2}$-weighted averages for all parameters ($N \sim 18, M \sim 10$). Figure 1 shows that, at V=15, T_{eff}, can be determined to 4%, and

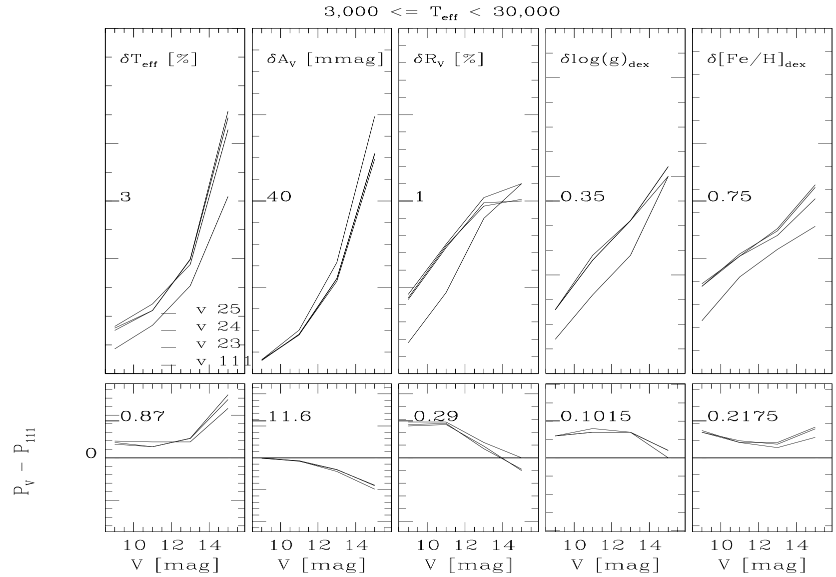

Figure 1. 5D classification results for various 6(+1) band filter systems without a band bluewards of 400 nm ("UV" band). In the top panels, I plot the classification errors for T_{eff}, $A_V, R_V, log(g)$ and $[Fe/H]$, from left to right. In each panel the half-way point of the vertical scale is indicated (all start at zero). In the bottom panels, I plot the classification results with respect to #111, which has a UV band.

A_V and R_V to (0.06 mag and 1%)/A_V. The gravity and metallicity results (0.4 and 0.75 dex) are not very good, and depend on T_{eff} (Olling, 2001a). Note that any co-variances between the parameters are not uncovered by this method. Different filter sets yield different results (the various lines in fig. 1), and better results could be obtained if a UV band were included. All sets show that the classification is a strong function of magnitude (signal-to-noise), a consequence of the fact that all parameters affect the global shape of the spectrum sufficiently to be detectable at the mmag level (in well-positioned semi-broad bands). The numerical values for the errors on $X_\star$ are consistent with results obtained by Bailer-Jones (2000) via an entirely different method.

However, the χ^2 results are sub-optimal since this classifier weights the parameters by the noise, irrespective of the "classification resolution." The classification resolution of a photometric system is a combination of the range in the to-be-classified parameter and the signal-to-noise. For example, models with $[T_{eff}, log(g)] = [4,500, 4.5]$ and $\Delta[Fe/H] = 3$, have a 681 mmag range in the F411-F625 color, or 34.8 times the expected FAME error in F411-F625 ($N_\sigma = 34.8$). Thus, the classification resolution, ρ, equals 0.09 dex ($\rho \equiv \Delta[Fe/H]/N_\sigma = 3/34.8$). Other colors perform worse (e.g., $\rho_{r'-i'} \sim$1 dex), and should be down-weighted accordingly. With N_C colors, I use a weight $w_\ell = 1/\rho_\ell^2$

for each color ℓ in the determination of each parameter X_ℓ. The best value of parameter X equals the weighted sum of the X_ℓ's: $\overline{X} = \sum_\ell w_\ell X_\ell / \sum_\ell w_\ell$, and the classification resolution ($\delta\overline{X}$) is given by:

$$\delta X \;\sim\; 1.0 / \sqrt{\sum_{\ell=1}^{N_C} \frac{1}{\rho_\ell^2(X)}} \tag{2}$$

With this scheme, I find that the classification errors are potentially one to four times better than displayed in figure 1 (Olling, 2001b,c).

4. The Photometric Parallax

The stellar distance (d) is related to its flux (ℓ), effective temperature and radius (R), as well as gravity and mass (M). With σ the constant of Stefan-Boltzmann, G Newton's constant, $\ell = \sigma T_{eff}^2 R^2/d^2$ and $g = G\,M/R^2$, I find $d^2 = \sigma\, T^4\, G\, M/(\ell\, g)$ and

$$\frac{\Delta d^2}{d^2} \;=\; \sqrt{\left(4\frac{\Delta T}{T}\right)^2 + \left(\frac{\Delta \ell}{\ell}\right)^2 + \left(\frac{\Delta g}{g}\right)^2} \tag{3}$$

$$\left.\frac{\Delta d}{d}\right|_{phot} \;\sim\; \frac{\ln 10}{2}\Delta \log g \;\sim\; 1.15\,\Delta \log g \;\sim\; 0.46\frac{(V-8)}{7}\,, \tag{4}$$

(the last relation follows from fig. 1). For FAME, with $V \leq 15$, the photometric parallax errors are always smaller than 46%. If the distance at which FAME's astrometric accuracy equals X percent is given by: $d_{X\%} \;=\; 20\, X_{\%} \sqrt{2.512^{15-V}}$, then the distance at which the photometric and astrometric parallax errors are equal is: $d_{AST=PHOT} = \Delta d/d|_{phot} \times 10^6/(500\sqrt{2.512^{V-15}})$ parsec. The 10% distance is about half as large as $d_{AST=PHOT}$, and about 20% of stars would have better photometric parallaxes than astrometric distances (Olling, 2001c), if a six-band photometric system can be adopted for FAME.

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