A Proposal For Additional Photometric Bands, III

Blue Filter Trades

Astrometric and Photometric Parallaxes Compared in FAME Light

Rob Olling

USNO/USRA, Washington, DC

ABSTRACT

This memo on photometry follows up on FTM2001-07 and FTM2001-03. Here I detail some of the differences and trades that exist for 6+1 and 7+1 filter sets that do no contain a u' filter. The "best" 6+1 filter set (F411, F466, Mg b, r', TiO_C, i', PaJ/Ca II) does not contain the g' filter. A pseudo g' filter could be constructed from F466 and Mg b. The detailed results of this study are valid for the original (CSR) design ("FAME Classic"). It is found that the photometric errors employed in FTM2001-03 and FTM2001-07 for the 5D-classification method were over-estimated by a factor of $\sqrt{2}$. Similar results can be obtained with the descoped mission ("FAME Light"), but only if 4 or more CCDs are assigned to photometry. I also investigate the accuracy of photometric distances, and compare the results with those obtained from traditional astrometry. Photometric parallaxes with $\Delta\pi/\pi = 0.1 - 0.5$ could be obtained for the stars with low-precision astrometric parallaxes, but only if a $\geq$5-band photometric system is adopted. From signal-to-noise considerations it follows that implementing such a photometric scheme requires $\gtrsim 4$ photometric CCDs, and would yield $\Delta\pi/\pi_{phot} \lesssim 0.46$, for *all* stars and possibly two to four times better. With $\Delta\pi/\pi_{phot} \lesssim 0.46/2$, I find that 42% of main-sequence stars would have $\Delta\pi_{phot} \lesssim \Delta\pi_{ast}$, while the photometric parallax is superior to π_{ast} for practically all (sub/super) giants. *Version 3 (current) of this memo differs from version 2 in that I included the effects of the newly adopted 50% overall throughput value for FAME Light.*

1. Introduction

In previous memos (FTM2001-03 and FTM2001-07) three photometric filter sets were introduced: an 8-band system without a u' filter, a 6+1 set with a u' filter, and a 6+1 combination without a u' filter. The latter two sets have 6 primary filters plus one narrow-band (30 nm) filter centered on a spectral region between two TiO absorption features.

In this memo, I concentrate on 6+1 and 7+1 filter sets that do not include the u' band. The question asked here is whether to include a filter centered on the Mg b feature at 516 nm. I investigate this question using the "resolution classification method" described in FTM2001-07, section 3.1.

Given that the physical parameters of stars can be determined accurately, I investigated how well these parameters can be used to determine distances to stars. The 6+1 band system described here and in previous memos can be used to determine distances to 10-50% accuracy, independent of the actual distance. I have not re-run a filter system optimized for the FAME Light case.

This memo is organized as follows: in section 2, I discuss the "Blue Filter Trades." Section 3, is devoted to FAME Light considerations, while the photometric & astrometric parallaxes are compared in section 4

2. Blue Filter Deliberations for FAME Classic/Light

In table 1, I enumerate all filters that were considered. Most entries are self-explanatory. The single-measurement accuracy is obtained as follows: 1) assume that the mission-end average photometric accuracy of the g', r', and i' is 5 mmag at V=15 for the SDSS-only filter set with 75.6 observations each, 2) the single-measurement accuracy for the case of SDSS-filters only is derived by dividing 5 mmag by $\sqrt{75}$ to get $\delta m_{S,SDSS}(15) = 43$ mmag, 3) then the single measurement in the other bands follows from throughput and bandwidth scaling. These are the accuracies that one gets if the total number of photo-electrons in the full bandpass (400-900 nm) equals 950,000 for a 9^{th} mag A0V star. In that case: $N_\nu \sim \frac{\Delta\lambda}{563\mathrm{nm}} \times 950,000 \times 2.512^{9-V}$ photo electrons. For classification purposes, I *do* us the spectral shape the determine the exact number of photons in the bands.

For FAME Classic, as per FTM2001-14-v8, the assumption of 950k photo-electrons in the unfiltered band for a V=9 A0 star has been revised downward to 815k. The effects of this revision and the descope will be discussed below.

For a 6+1 set, we should always use: F411, r', TiO_C, i' and Ca II. The remaining two bands must be chosen from F466, g' and Mg b. In figures 1 through 3 I present the classification results for the F466+g', F466+Mg b and g'+Mg b combinations.

These figures show that the g'+Mg b combinations has the worst classification perfor-

Table 1: Enumeration of the elements of a FAME filter set that does not contain a u' filter. The first four columns designate: name, central wavelength, FWHM and band-averaged total throughput of the filters. In column # 5, I list $\delta m_S(15)$: the single-measurement accuracy at V=15. The last column contains some other information on the filters. Note that these values are valid for the FAME Classic case (with 950k electrons in the wide-open band for a V=9 A0 star). For FAME Light, $\delta m_S(15)$ is about twice worse and $< QE * TP >$ must be multiplied by a factor 0.50/0.75 ~ 0.66

filter name (1)	λ_0 [nm] (2)	$FWHM$ [nm] (3)	$< QE * TP >$ (4)	$\delta m_S(15)$ [mmag] (5)	Remarks (6)
F411	411	50	0.56	83	wide Strömgren v
F422	422	50	0.62	79	wide Strömgren v, shifted
F466	466	50	0.76	71	wide Strömgren b
g'	480	141	0.76	42	SDSS
Mg b	516	50	0.83	67	DDO52 look-alike
r'	625	139	0.83	41	SDSS
TiO_C	745	30	0.73	93	TiO-continuum ; bright star filter
i'	769	154	0.68	43	SDSS
Ca II	875	85	0.45	71	Ca II triplet, Pachen Jump, pseudo SDSS-z'

mance: about 0.2 dex worse $log(g)$ for 5,000K $\lesssim T_{eff} \lesssim$ 6,000K.

Comparison of the F466+g' and F466+Mg b results (figs. 1 and 2) shows that the overall performance is comparable, except for the following: 1) F466+g' is 0.05 dex better for [Fe/H] of hot stars, 2) F466+Mg b is about 0.02 dex worse for 5,500K $\lesssim T_{eff} \lesssim$ 6,000K and 3) F466+Mg b is about 0.05 dex better for 4,200K $\lesssim T_{eff} \lesssim$ 5,000K, in particular for the metal-rich stars.

In figure 4, I present the 7+1 combination that includes F466, g' and Mg b. Below 10,00K, this filter combination performs as well as the best of the (F466+Mg b) and (F466+g') sets, but is only as good as F466+Mg b above 10,000K. The reason for the latter fact is probably the lower signal-to-noise ratios in the 7+1 set as compared to the 6+1 set.

In figure 5, I present a 6+1 filter combination that has neither F411 nor F422 filter. The results are dramatically worse than for sets that do include F411/F422. Dropping a F411/F422 filter is about as bad for the classification procedure as not having any u' data.

3. Errors & FAME-Light Considerations

After the research described in the previous sections of this memo was completed, I realized that I have been somewhat pessimistic in the determination of the photometric errors. The "problem" lies in the normalization of the model spectral energy distributions (SEDs), or in-band fluxes. In the work presented before in FTM2001-03 and FTM2001-07, I normalized all SEDs by the flux in the SDSS r' band.

However, it is much better to normalize by the flux in the astrometric band: 1^{st}) the band is about twice wider and has hence a twice larger photon count per observation, 2^{nd}) there are about 14/0.5 times more observations in the astrometric chip at mission-end than in the photometric bands (14 astrometric chips versus ~0.5 photometric chip per band in FAME Classic with the 6+1 band system[1].). The error propagation works as follows: normalizing the counts in band F_1 by the counts in the "normalization" band (F_n), we get: $F_1' = F_1/F_n$ and:

$$\left(\frac{\Delta F_1'}{F_1'}\right)^2 = \left(\frac{\Delta F_1}{F_1}\right)^2 + \left(\frac{\Delta F_n}{F_n}\right)^2 \approx 2\left(\frac{\Delta F_1'}{F_1'}\right)^2 , \tag{1}$$

where the last equality holds for that case that $F_n \sim F_1$. I have followed that procedure in FTM2001-03 and FTM2001-07 where I normalized measurements by the counts in the r' band. Thus for FTM2001-03 and FTM2001-07, the fractional error on F_1' is $\sqrt{2}$ times larger than $\Delta F_1/F_1$.

However, when normalizing by the narrow astrometric band (N) with a twice large photon count (F_N), the contribution to the error on F' from the normalization process is reduced by a factor $\sqrt{2}$. Further, for FAME Classic there are roughly 14/1 times more observations in the astrometric than in the SDSS r' band, the mission-end error on F_N is only: $\Delta F_N/F_N = 1/\sqrt{2 \times 14/0.5}\,\Delta F_n/F_n \sim 0.133\,\Delta F_n/F_n$. As a result, we obtain:

$$\left(\frac{\Delta F_1''}{F_1''}\right)^2 = \left(\frac{\Delta F_1}{F_1}\right)^2 + \left(\frac{\Delta F_n}{7.5\,F_n}\right)^2 \sim \left(\frac{\Delta F_1}{F_1}\right)^2 . \tag{2}$$

Thus, normalization by the astrometric band does not increase the error on the photometric bands. Thus, the analysis that I presented in FTM2001-03 and FTM2001-07 employs error estimates that are too large by a factor $\sqrt{2}$ for the FAME Classic concept. My previous was build upon the *assumption* of 5 mmag errors at V=15 for the case of a 4-SDSS band FAME Classic mission. As shown above, I really worked with the case of $5 \times \sqrt{2} \sim 7.1$ mmag errors.

[1]For FAME Light, the numbers would be only slightly different

3.1. 5D Classification Results in FAME Descoped

In the current FAME design (20011029), the number of photons per transit is only 70% of that for the FAME Classic design, whereas the assumed average throughput in the 550-850 nm band has been reduced to 50% [from 75% (factor 0.66)]. These degradations are partly compensated by more observations: the FAME Light mission is 5 years rather than FAME Light's 2.5 yr. Combining these factors, the mission-end photon-count in an SDSS band for FAME Light is 93.3% of that for FAME Classic.

Some other changes have degraded the expected mission-end photometric error of 5 mmag in the FAME Classic design: 1^{st}) It appears that the number of photon-electrons (950k) in the unfiltered FAME band as expected at CSR time was an over-estimate, current calculations only yield 93% of that number, 2^{nd}) only 93% of the stellar photons land in the FAME raster of 13x24 pixels, 3^{rd}) degradation of the photometric accuracy due to read-noise was not included in the CSR estimates. Including all these effects, the current-best estimate for the FAME Classic mission-end photometric precision should be 7.4 mmag rather than 5 mmag at V=15 (FTM2001-14, table 27, for an A0V star in an SDSS band).

Due to my over-estimation of the photometric errors discussed in the previous subsection, the results of FTM2001-03 and FTM2001-07 were really based on an assumption of 7.1 mmag errors are V=15, and better at brighter magnitudes according to photon statistics.

How do the results of FTM2001-03 and FTM2001-07 fare with the sensitivities valid for FAME Light? If we assume that the overall quantum efficiency and throughput in FAME Light is 66% of that of FAME Classic *at all wavelengths*, then the comparison depends only on the magnitude error as a function of apparent magnitude. For FAME Light, I recalculate the expected errors including all the known degradation factors discussed above. I find 8.5 mmag at V=15 (FTM2001-14, table 13, A0V star), or significantly worse than the value assumed in FTM2001-03 and FTM2001-07 (5 mmag [or equivalently 7.1 mmag for classification comparisons]). In FTM2001-03 and FTM2001-07 I *assumed* that the errors improve according to photon statistics, or to 4.48 mmag at V=14 from 5 mmag at V=15. *However,* at faint magnitudes the photometric errors scale according to read-noise statistics and improve more rapidly towards bright magnitudes[2]. Including the read-noise effects for the FAME Light case and scaling from the classification-equivalent photometric error of 7.1 mmag, I find 4.05 mmag at V=14: better than the photon-statistics scaling for the FAME Classic case.

Thus, *for classification purposes,* the proper error treatment as discussed in the previ-

[2]proportional to $1/N$ rather than $1/\sqrt{N}$, cf. FTM2001-14, eqn. (4).

ous subsection "gains more photons" than the "loss of photons" due to the smaller mirror dimensions and more conservative throughput assumptions in the FAME Light concept (for $V \lesssim 14.5$). As a result, the 5D classification results obtained in FTM2001-03 and FTM2001-07 are approximately valid for the current FAME design: FAME Light will do slightly better at bright and slightly worse at very faint magnitudes. This conclusion is sensitive to the actual level of the readnoise of the photometric chips: a 50% reduction (increase) in the readnoise level reduces (increases) the photometric errors at V=15 by about 30% (FTM2001-14).

Without performing detailed calculations, I have shown above that the achievable 5D classification results for a descoped FAME with 4 photometric CCDs will be comparable to those reported in previous memos: FTM2001-03 and FTM2001-07.

4. Photometric & Astrometric Parallaxes Compared

In FTM2001-14 I have shown that almost 70% of the stars in the FAME catalog will have parallax measurements that are less accurate than 10%. Is it possible that photometric parallaxes might be more accurate than astrometric parallaxes? Below I will argue that this the case, at least for a subset of stars.

Assuming that stellar effective temperature and surface gravity can be determined to several percent and to 0.1-0.4 dex in $\log g$, respectively (FTM2001-03). These accuracies were obtained with a relatively inadequate method. In FTM2001-07 and in this memo, I argued that a good method of analysis might reach up to four times better accuracies for $log(g)$. Furthermore, the attainable T_{eff} $\log(g)$ accuracies vary with stellar temperature. No attempt has been made to include the modifications resulting from the T_{eff} effects.

4.1. Photometric Parallaxes

As it turns out, the classification uncertainties in T_{eff} and $\log(g)$ relate directly to a distance uncertainty. From first principles we have:

$$\ell \;=\; \sigma T_{eff}^2 \frac{4\pi R^2}{4\pi d^2}\,, \tag{3}$$

where ℓ is the observed flux, σ the Stefan-Boltzmann constant, and R the radius of the star. Employing the relation for surface gravity ($g = G\,M/R^2$) with N Newton's constant and M the mass of the star, it is possible to eliminate the stellar radius, and solve for the distance and it's error:

$$d^2 = \frac{\sigma T^4 G M}{\ell g} \tag{4}$$

$$\frac{\Delta d^2}{d^2} = \sqrt{\left(4\frac{\Delta T}{T}\right)^2 + \left(\frac{\Delta \ell}{\ell}\right)^2 + \left(\frac{\Delta g}{g}\right)^2} . \tag{5}$$

Employing $\frac{\Delta d}{d} = \frac{1}{2}\frac{\Delta d^2}{d^2}$, $\ln g = \ln 10 \log g$, and $\frac{\Delta g}{g} = \ln 10 \Delta \log g$, eqn. (5) simplifies to:

$$\left.\frac{\Delta d}{d}\right|_{phot} = \frac{\ln 10}{2}\Delta \log g \sim 1.15\,\Delta \log g \sim 1.15 \times 0.4\frac{(V-8)}{7} , \tag{6}$$

where the last equality describes the approximate relation found in FTM2001-07. To arrive at equation (6), I have neglected the relative uncertainties in the effective temperature and the observed flux since they are both much smaller ($\lesssim 0.03$ and $\lesssim 0.01$) than the log(g) term (0.1-0.4).

The relation between apparent magnitude (V) and absolute magnitude (M_V) on the one hand and expected astrometric accuracy are given by equations (5), (6) and (7) in FTM2001-14. For convenience, I copy those results. Below, d is the distance at which a star of absolute magnitude M_V has apparent magnitude V. These results are graphically displayed in figure 6 for two cases: 1) no extinction (full lines) and 2) an extinction of 1 magnitude per kpc (dotted lines). Further, $d_{X\%}$ corresponds to the distance at which the astrometry is determined to X percent.

$$d = 10^{(V-M_V+5)/5} \quad [pc] \tag{7}$$

$$d_{X\%} = X_{\%}\; MIN\,(17.1\;\alpha(V)\,, 200) \quad [pc] \tag{8}$$

$$\alpha(V) \equiv \frac{\delta x_0^A(V=15)}{\delta x_0^A(V)} = \frac{\delta x_0^P(V=15)}{MAX(\,1/350,\; \delta x_0^P(V, PEF)\,)} \tag{9}$$

where the factor 17.1 arises due to the 585 μas mission-end FAME parallax error at V=15 and the fact that X is expressed in percent, $\alpha(V)$ describes the astrometric error as a function of magnitude and PEF-factor (the spectral-type dependent photon-enhancement factor[3] ,see FTM2001-14, table 5). The limiting value for $[17.1\alpha(V)]$ is set by the assumed best possible 10% astrometric parallax of 50 μas (ie, $d_{10\%} \leq 2000$ pc). At bright magnitudes, $\alpha(V)$ follows from photon-statistics, at faint magnitudes ($V \gtrsim 13.5$), read-noise dominates the behavior.

Equation (6) above shows that the fractional photometric distance error is linearly proportional to the apparent magnitude. The relative astrometric error on the other hand

[3]The PEF-factor is of order 1.5, for the average star in the Tycho catalog.

decreases according to the square-root of the photon count (roughly proportional to square of the magnitude) and increases linearly with radius [cf. eqn. (8)]. That is to say, for distant and faint stars, the relative photometric parallax error may be smaller than the astrometric error. Below I show that the distance effect is most important for the current application.

Employing eqns. (8) and (6), one can find the distance at which the astrometric and photometric parallaxes accuracies are equal to one another:

$$d_{AST=PHOT} \quad = \quad \left.\frac{100\Delta d}{d}\right|_{phot} \times MIN\,(17.1\;\alpha(V)\,,200\,) \qquad [\mathrm{pc}]\,. \tag{10}$$

In figure 6, I over-plot the $\Delta\pi_{AST} = \Delta\pi_{PHOT}$ line as the full (black) line as a function of apparent magnitude. Stars that are more distant than $d_{AST=PHOT}$ would have better photometric than astrometric parallaxes. I also plot the 10%-astrometry relation [$d_{10\%}$, cf., eqn. (8)] as the dashed (black) line. The break in the curves around V=11 is due to the lower limits to the assumed parallax error of 50 μas. Because $d_{10\%}$ is smaller than $d_{AST=PHOT}$ at most apparent magnitudes, there is a region in space where the astrometric parallaxes are worse than 10%, but better than the photometric distances.

As discussed above, a better analysis of the photometry could yield up to four times better parallaxes. In that case, $\Delta d/d|_{phot}$ will be 4 times smaller, so that the $d_{AST=PHOT}$-relation of equation (10) will be four times smaller. The fraction of stars for which the astrometric parallax is better determined than the photometric parallax is a strong function of the ability to photometrically determine $log(g)$. The results are tabulated in table 2 below.

Inspection of table 2 shows that the utility of photometric parallaxes is largest for bright stars at large distances: for the worst possible 5D classification method ($\gamma_{15} = 0.46$) only 90% of B stars would have better photometric than astrometric parallaxes. This fraction decreases rapidly towards later spectral types, while the catalog-averaged value equals 16.7%. This catalog-averaged fraction increases rapidly for better classification schemes: to 41%, 55% and 62% for twice, three-times and four-times better $\Delta log(g)/log(g)$.

In figure 6, I also plot the the relations between distance and apparent magnitude [cf., eqn. (7)] for the case of no extinction (full lines) and 1 mag/kpc (dashed lines)[4]. All stars closer to the Sun than these lines will be part of the FAME catalog. These lines illustrate in a graphical manner what can be inferred from table 4 or FTM2001-14: the region of allowed parameter space where photometric parallaxes are superior to astrometric parallaxes is rather large, particularly for the intrinsically bright stars, and in low-extinction regions.

---

[4]The extinction is included by replacing V by $V + A_{V,kpc} \times d$ in equation (7), where $A_{V,kpc}$ is the extinction per kpc, in the V band. In that case, equation (7) becomes non-linear, but can be solved numerically.

Table 2: Astrometric and Photometric parallaxes compared. The first through third columns list the absolute magnitude, approximate spectral type and percentage of the FAME input catalog (for main-sequence stars). The next eight columns are the distance ($d_{a=p}$) at which the astrometric parallax equals the photometric parallax (# 4,6,8,10) and the percentage ($P^{MS}_{\pi AbP}$) of stars for which the astrometric parallax accuracy is better than the photometric parallax accuracy (# 5,7,9,11). Four groups with increasingly better $\gamma_{15} = \Delta log(g)/log(g)$ determination accuracy are presented, from the default value of 0.46 at V=15 to 0.46/4 as the best possible classification accuracy. The calculations pertinent to this table include the PEF factor as well as an extinction of 1 mag/kpc.

			γ_{15} =0.46/1		γ_{15} =0.46/2		γ_{15} =0.46/3		γ_{15} =0.46/4	
M_V (1)	Type (2)	F^{MS}_{cat} (3)	$d_{a=p}$ (4)	$P^{MS}_{\pi AbP}$ (5)	$d_{a=p}$ (6)	$P^{MS}_{\pi AbP}$ (7)	$d_{a=p}$ (8)	$P^{MS}_{\pi AbP}$ (9)	$d_{a=p}$ (10)	$P^{MS}_{\pi AbP}$ (11)
-1.2	B5	5	2099	10.1	1377	2.2	100	0.0	100	0.0
1.9	A5	7	1358	37.1	990	14.0	792	7.5	660	4.6
3.5	F5	24	1080	79.3	802	33.8	657	19.9	563	13.4
5.1	G5	28	820	100.0	614	72.8	509	45.5	442	32.2
7.4	K5	14	563	100.0	426	100.0	358	100.0	314	100.0
10.0	M2	5	100	100.0	263	100.0	222	100.0	197	100.0
all MS		83	-	83.3	-	58.5	-	44.6	-	38.0

According to equation (6), if FTM2001-7's photometric classification efficiency can be achieved [0.4 dex for log(g) at V=15], all stars in the FAME catalog would have their photometric parallax determined to better than 46%. For a slightly more optimistic classification scheme, 41% of all stars would have superior photometric parallaxe errors. Of course, the relation that yields the distance as a function of stellar mass, temperature and surface gravity [eqn. (4)] needs to be calibrated using objects with accurate known astrometric distances.. Again note that π_{phot} can be determined at *any* distance, where the accuracy only depends on V.

4.2. Practical Implementation?

In the current baseline for the descoped FAME, only two CCDs and two photometric bands are assigned to photometry. Two CCDs are not sufficient to define a photometric system that is capable of determining π_{phot} due to the lack of sensitivity (too little Silicon, too many filters). Furthermore, at least 5 bands (plus the astrometric band to normalize the photometry) are required for 5D spectral classification of stars. A system with 4 CCDs (preferably 5 or 6) and 5 [6] filters (F411/F422, F460, g', r' and i' [PaJ/CaII[5]]) would suffice for the accurate determination of log(g) and T_{eff}. I have not investigated the detailed requirements for the numbers of CCDs and whether or not the PaJ/Ca II filter can be dropped from the list for the FAME Light case. Such filters, spread around on the focal plane might also greatly aid in the determination of the color terms of the optical distortions.

Currently, it seems that there are two routes that might lead to ≥4 photometric CCDs for FAME Light. *First,* there is room in the focal plane to add two additional CCDs at the outer edges in the cross-scan direction. The locations of these CCDs would have poor optical quality, but this would not be required for aperture photometry. On the down side, it appears (20011101), that there is not enough power to operate these two extra CCDs. However, with the larger bus (FAME Heavy), it might be possible to increase the instrument power by a factor (13+2)/13=1.15 to accommodate two extra CCDs. *Second,* it may be possible to devote to photometry 2 or 3 CCDs that are currently diverted from bright-star to faint-star astrometry. That would be a valid scheme if a small loss in faint-star astrometry (factor $\sqrt{11/9} \sim 1.1$) is judged to be less important than the huge amount of additional photometric information (eg π_{phot}). Also note that photometric CCDs can be used for astrometry albeit that the *instrumental* parameters are less well calibrated due to the reduced photon counts and reduced number of "colored CCDs." On the other hand, each photometric band approximates an "independent" instrument and their results could serve to estimate systematic effects in the data reduction scheme.

5. Conclusions

The differences between the various filter sets combinations are smaller than 0.1 dex (except for the bad G', Mg b combination). Some optimization according to scientific preference is possible. For FAME Light, these conclusions are approximately valid, but no fine-tuning has been performed.

- Filter combinations with F422 rather than F411 perform about 0.1 dex worse for [Fe/H] for $T_{eff} \gtrsim$ 5,000K and up to 0.05 dex worse in $log(g)$.
- F422 should only be considered if the blue response of the system is significantly worse than assumed in table 1.

[5]Dropping the PaJ/CaII filter reduces the ability to determine extinction and log(g) for early-type stars.

- It is important to have decent QE and throughput values between 400 and 450 nm (or better, between 390 and 440 nm)
- The best 6+1 set for $T_{eff} \gtrsim$10,000K is : F411, F466, g', r', TiO_C, i', Ca II
- The best 6+1 set for $T_{eff} \lesssim$10,000K is : F411, F466, Mg b, r', TiO_C, i', Ca II
- The best 6+1 set for late F, early G is : F411, F466, g', r', TiO_C, i', Ca II
  These stars are good targets to probe the star formation history and stellar evolution in general.
- The best 6+1 set for late G, K is : F411, F466, Mg b, r', TiO_C, i', Ca II
  These stars are suitable for rotation curve and K_z studies.
- A pseudo g' band might be constructed from F466 and Mg b
- The best 7+1 set is : F411, F466, g', Mg b, r', TiO_C, i', Ca II
- The 7+1 set would probably perform better than a 6+1 filter set at the task of determining interstellar extinction.

Without performing detailed calculations, I have shown above that the achievable 5D classification results for a descoped FAME with 4 photometric CCDs will be comparable to those reported earlier.

Of course, memos FTM2001-03, FTM2001-07 and the current one only apply if $\geq$ 4 CCDs can be assigned to photometry. When comparing the accuracies in astrometric and photometric parallaxes, one finds that the worst-case photometric-parallax error is of order 46%, at V=15. For brighter stars, $\Delta\pi/\pi_{phot}$ decreases approximately linearly to 6.5% at V=9. A more sophisticated method of analysis could reduce the photometric parallax uncertainties by up to a factor of four. For "reasonable" gravity classification results [$\Delta log(g)/log(g)$=0.46/2], the photometric parallax accuracy would be better than the astrometric parallax errors for about 43% of main-sequence stars in the FAME input catalog.

In the FAME Light design, there exist opportunities for a system with $\geq$ 4 photometric CCDs. One of these schemes involves two additional CCDs in locations of poor optical quality. A decision as to include such 3xtra photometry-only CCDs needs to be made before the instrument and bus designs are cast in stone.

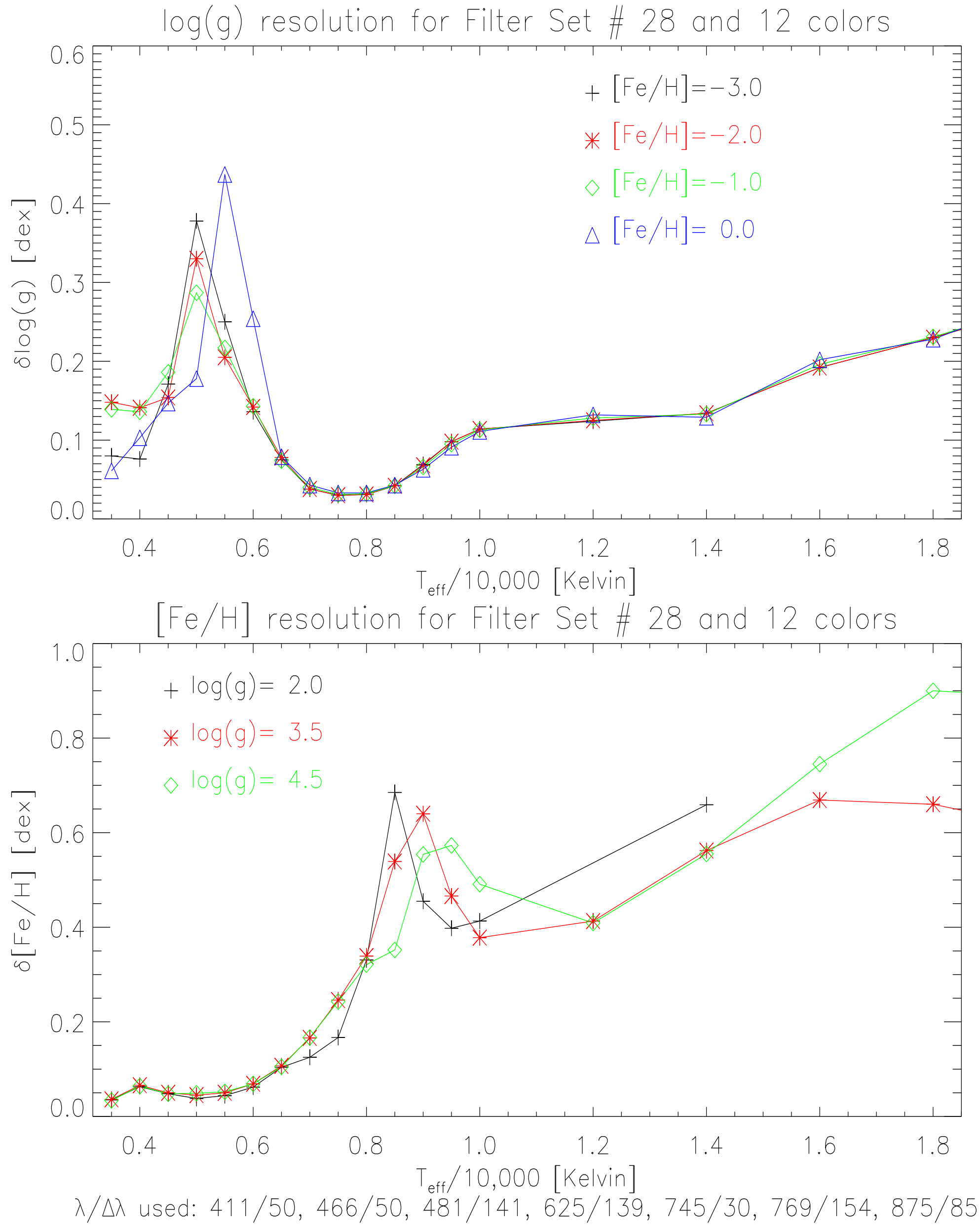

Fig. 1.— "Best possible" classification results for a 6+1 filter set: **with F466 and g'**. The central wavelengths and bandwidths of the filters used are enumerated below the bottom plot. In the top panel, I present the attainable surface-gravity results at fixed metallicity, at four $[Fe/H]$ values. In the lower panel, the metallicity results at fixed surface gravity are presented.

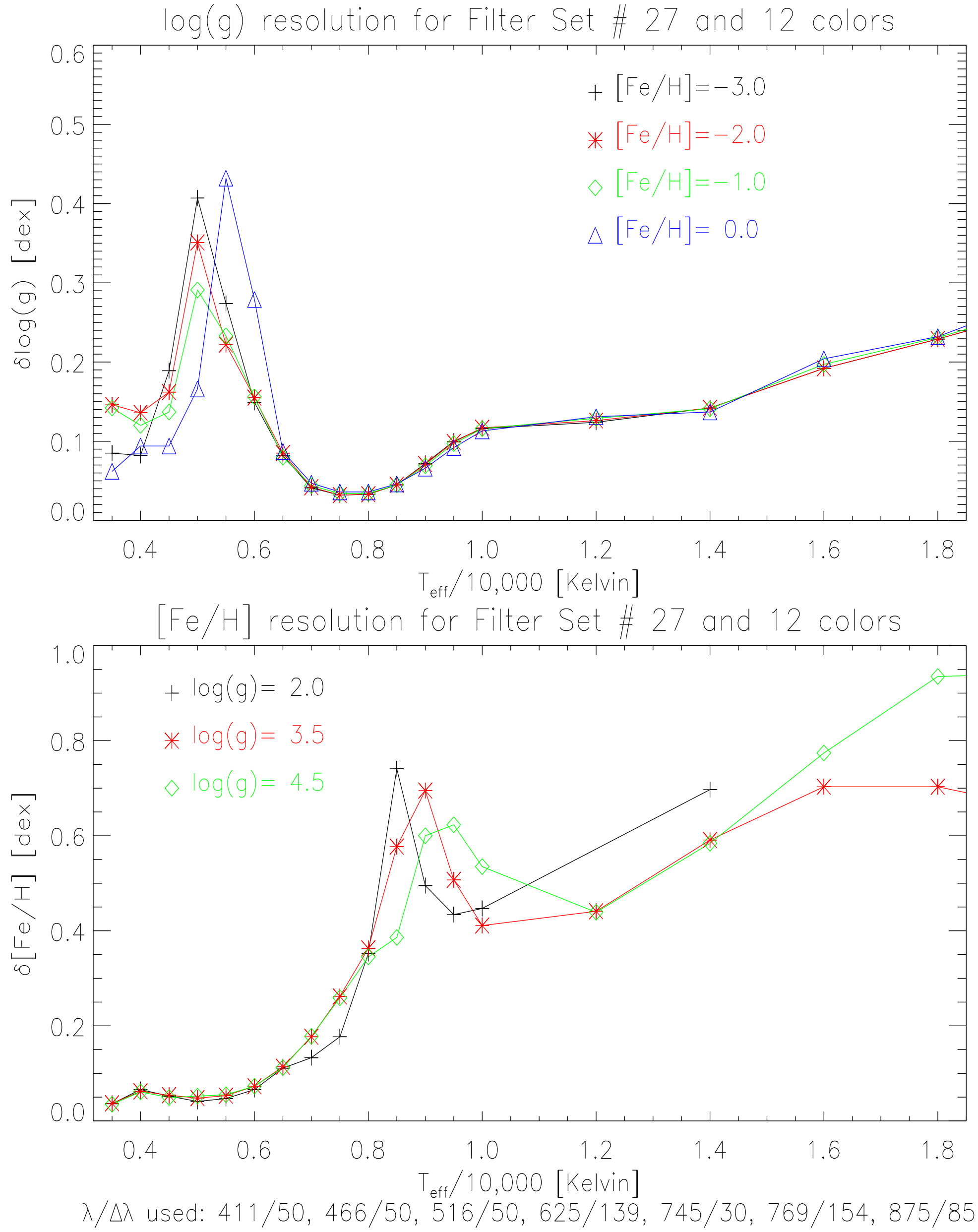

Fig. 2.— As figure 1, but **with F466 and Mg b**.

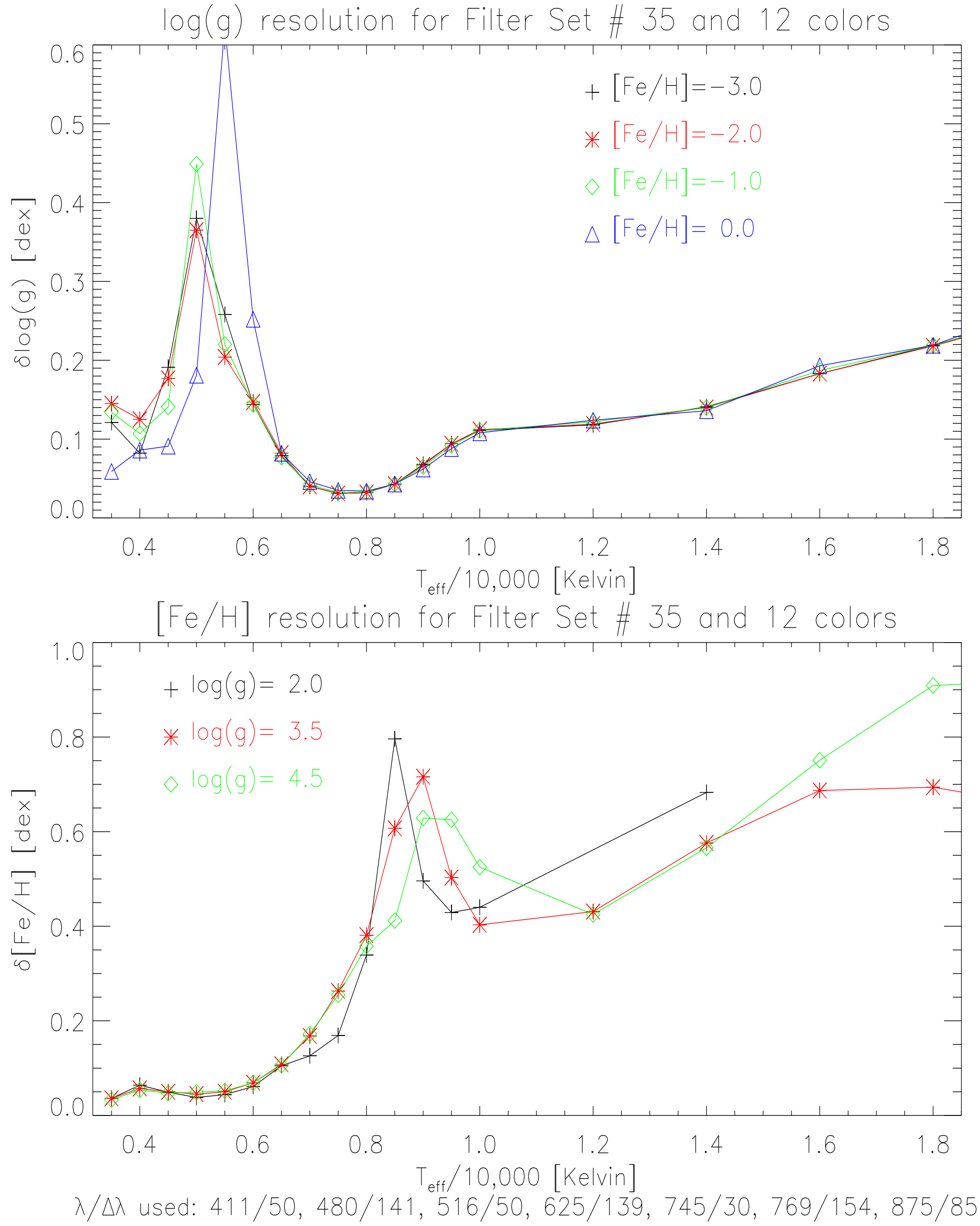

Fig. 3.— As figure 1, but **with g' and Mg b**.

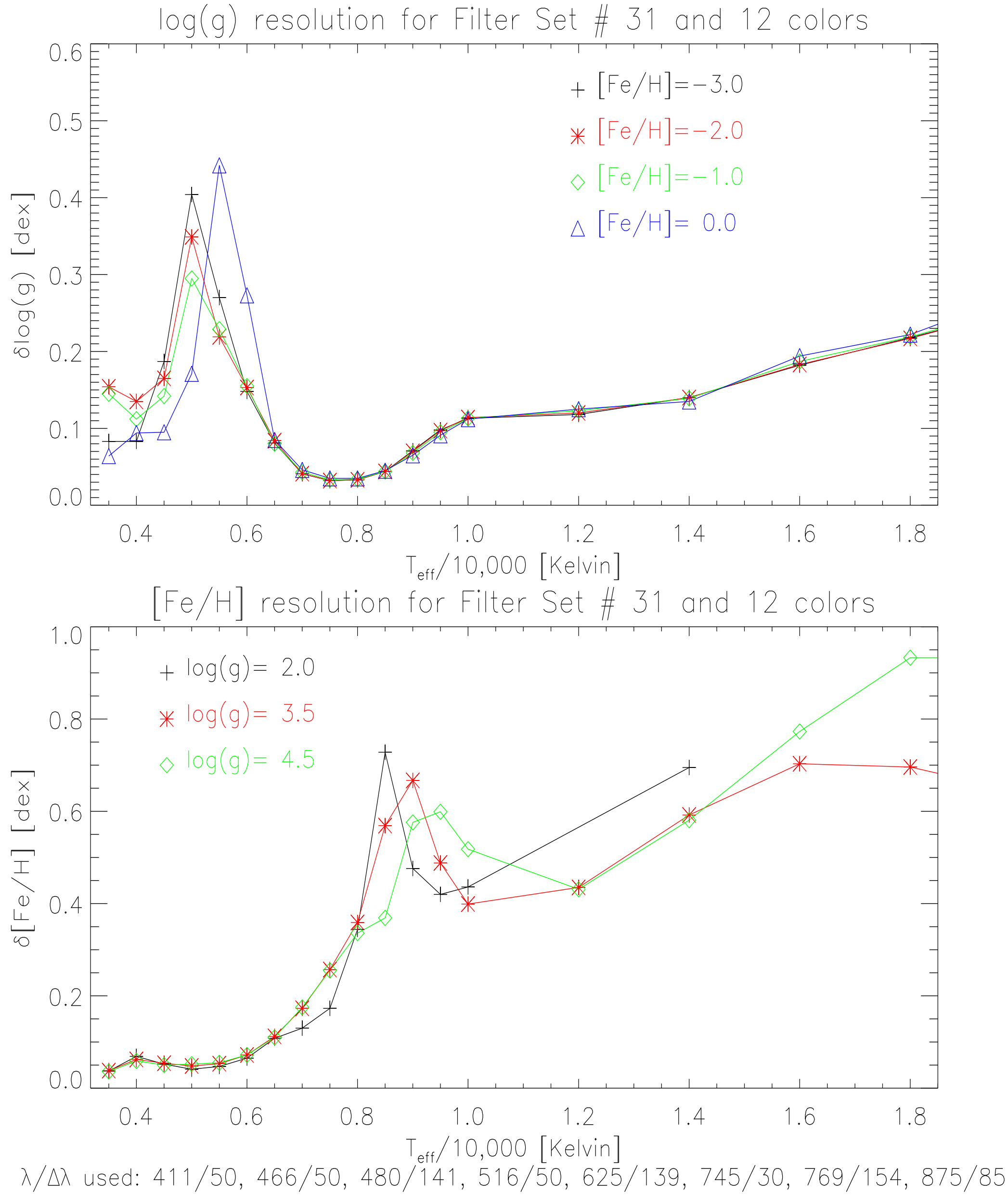

Fig. 4.— As figure 1, but a 7+1 filter set **with F466, g' and Mg b**.

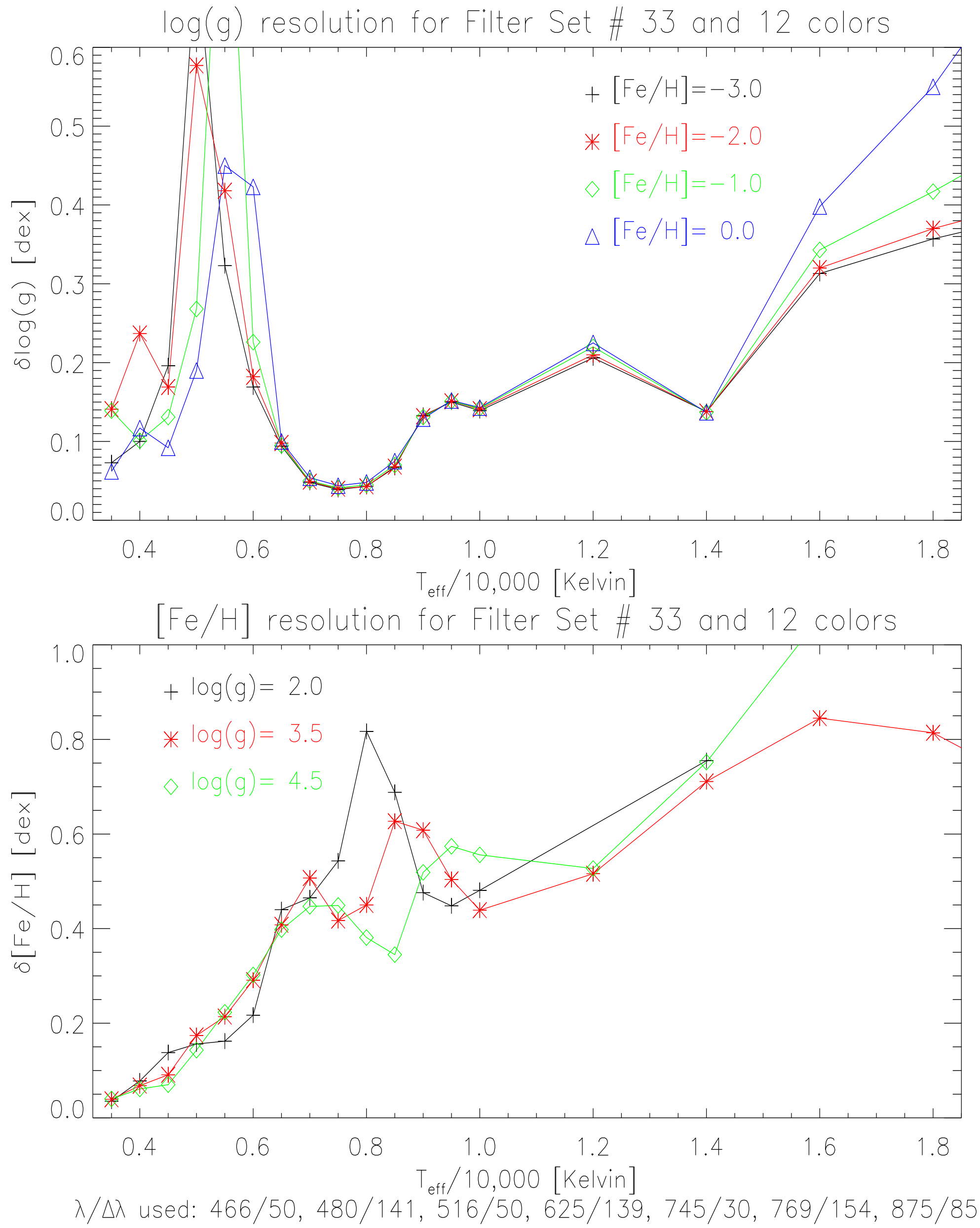

Fig. 5.— As figure 4, but a 6+1 filter set **without F411** . The classification results are dramatically worse.

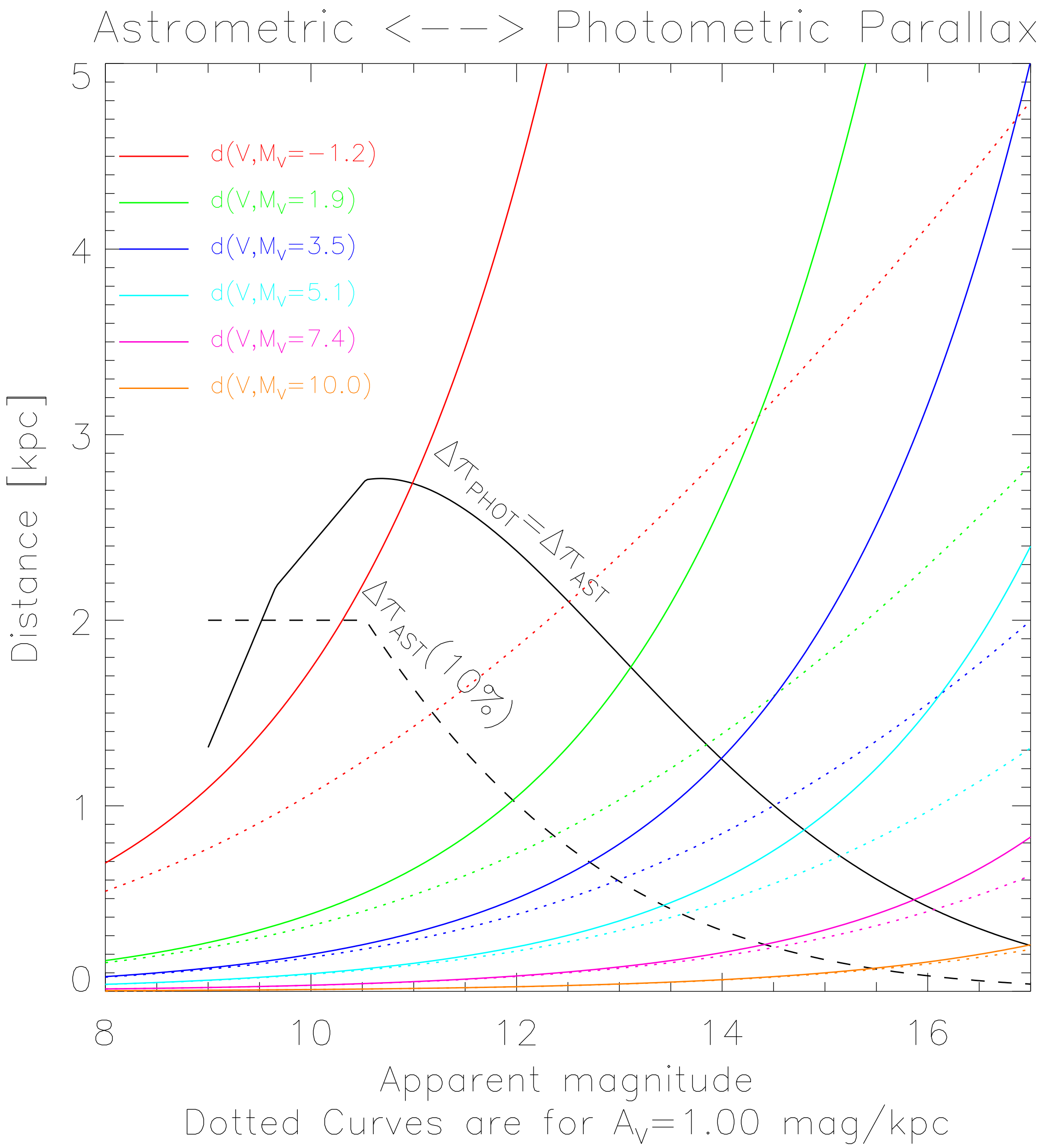

Fig. 6.— As a function of apparent magnitude, I present the 10%-astrometric distance limit (dashed black line), and the distance at which the photometric parallax error equals the astrometric distance error (full black line). I also plot the distances as a function of V, for various absolute magnitude. If the photometric parallax accuracy can be improved by a factor Y, the $d_{AST=PHOT}$ line shifts down by a factor Y. Note that Y is expected to be of order 1-4 (see section 4). The break around V=11 is due to the lower limit on the astrometric accuracy of 50 μas.