Harvard-Smithsonian Center for Astrophysics

Precision Astronomy Group

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Subject:	FAME mission accuracy		

In another memo [Phillips 1999a], detailed consideration is given to the various sources of bias in single FAME observations. Here, I discuss the extent to which this single-measurement bias will average over the mission, and present estimates for mission accuracy.

The precision to be expected in centroiding a FAME observation has been calculated in covariance studies [Phillips 1998], and the standard deviation of the centroid positions, for the current FAME parameters[1], as a function of V magnitude, are given as the "σ_{cent}" column of Table 1. The "A post" column is the *a posteriori* error, i.e., the error in a single observation after correcting with models based on all mission and other data, for example, using the final estimates of the parameters of the models of optical distortion and CCD errors. The various contributions to *a posteriori* error are functions of, for example, the phase of the measurement with respect to the pixel boundary ("pixel phase") and the instrument temperature. Half of the observations of a

Table 1. FAME mission accuracy.

				SST			Filters					
V	σ_{cent}	A post	Bias	σ_1	Obs	σ_M	Atten	σ_1	chips	frac	Obs	σ_M
	μas	μas	μas	μas		μas		μas				μas
2	19	113	10	115	1360	11						
3	30	113	10	117	1360	11						
4	47	113	10	122	1360	11	40	319	3	0.7	143	39
5	75	113	10	135	1360	11	40	486	3	1	204	49
6	118	113	10	164	1360	12	7	333	3	0.75	153	39
7	188	113	10	219	1360	13	7	509	3	1	204	51
8	297	113	10	318	1360	16	1	318	14	0.7	666	20
9	471	113	10	485	1360	21	1	485	14	1	952	24
10	751	113	10	759	1360	31	1	759	14	1	952	36
11	1202	113	10	1207	1360	47	1	1207	14	1	952	56
12	1940	113	10	1943	1360	75	1	1943	14	1	952	90
13	3187	113	10	3189	1360	123	1	3189	14	1	952	146
14	5403	113	10	5404	1360	207	1	5404	14	1	952	248
15	9663	113	10	9664	1360	371	1	9664	14	1	952	443
16	18646	113	10	18646	1360	715	1	18646	14	1	952	855

[1] Focal length is 15 m, aperture is 0.6×0.5 m (the 0.5 m direction is divided into two portions 0.25 m in height by the complex mirror), and other values are as they will appear in the June, 1999 MIDEX phase A report.

star can be regarded as contributing to the estimate of its position in each direction. Thus, 72-680 observations contribute. The *a posteriori* error is expected to average down over the mission, as observations with a range of pixel phases are included, for example. The "Bias" column is the estimate of the correlated portion of the error, and is thus the asymptotic level to which the *a posteriori* errors would average after a large number of measurements.

Two instrument configurations are considered here, one in which bright stars are handled via "Start-Stop Technology (SST)", and the other in which neutral density filters are placed over some CCD's. The error estimates differ in the two cases.

The magnitude at which saturation sets in is between V=9 and 10, in the simplifying worst case that the star goes down the center of the column, that precession does not smear the observation (most observations are smeared), and neglecting the effect of charge spreading in the CCD [Ando 1975 and references therein; Tulloch 1998]. When the above effects are taken into account, one finds that there are unsaturated observations of stars brighter than V=9 in the faint-star CCD's, to as bright as V~7.

In the SST case, all chips are available for all observations, and all photons from a star contribute to mission precision (except for a negligible fraction that fall in the "trails" between images) [Phillips 1999b]. Under "SST" in Table 1, the single-observation accuracy is the "σ_1" column, and is calculated as the RSS of the centroiding precision and the *a posteriori* error. The centroiding precision assumes that the clock is gated N_{SS} times to keep the image from saturating, creating a "ribbon of data": N_{SS} images spread out in the column direction, separated by trails. The precision stated assumes that all of the N_{SS} images are usable. (The ribbon occupies only a fraction of the length of the column. There is only one image in a ribbon for V=9 -- the brightest no-gating case -- and there are 128 for V=4.) The number of observations is the number of ribbons, and is given in the "Obs" column. The mission accuracy estimate is the "σ_M" column, and is calculated as the RSS of the single-observation accuracy divided by the square root of half the number of observations, and the bias.

Even if there is an unforseen problem with the gating, such that only one useful image can be obtained for each passage of a bright star, the mission accuracy requirement is met: it is met for V=9, which is the precision obtained with a single image that is near full-well.

In the filter case, 3 chips are covered with filters passing 1/40 of the light impinging on them, and these chips are used for observations of 4th and 5th magnitude stars. Three more chips are covered with filters passing 1/7 of the light, and these are used for 6th and 7th magnitude stars. While a star of V=8 that is unsmeared laterally by precession would saturate in the unfiltered chips, 70% of stars experience sufficient smearing that they do not saturate, and the unfiltered chips can be used. While the 3 chips with 7× attenuating filters will also observe V=8 stars, the information from those observations is reduced both because there are fewer chips and because those chips see fewer photons, so in aggregate those observations are 6 times less precise, and their weight in determining the positions of V=8 stars is negligible. (Similarly, the chips with 40× attenuating filters will also see those stars, but their contribution to aggregate precision is $\sqrt{6}$ times smaller still.) The same holds for stars of V=6: the observations with greatest weight in determining their position are smeared observations of stars with 7× attenuating filters. Finally, smearing is the only way to observe V=4 stars with this filter scheme.

Note that observations of stars of V=6 and 7 in the bright star chips (NDa filters) will be needed in order to calibrate the offset of these chips with respect to the medium-bright chips (NDb filters). While these observations by themselves would not suffice to locate individual stars of these magnitudes, in the aggregate there is sufficient information to calibrate the NDa chips with respect to the NDb. In turn, stars of the other intermediate magnitude range (V=8 and 9) will be used to calibrate NDb chips with respect to the main battery of faint-star chips.

For the filter case, under "Filters" in Table 1, the attenuation in use at that magnitude is given in the "Atten" column. The single-measurement accuracy is the "σ_1" column, and is calculated as the RSS of the centroiding precision (allowing for attenuation) and the *a posteriori* error. The number of chips used is given as the "chips" column. For V=8, V=6, and V=4, smearing is used to avoid saturation, and the "frac" column indicates the usable fraction of observations. (No "frac" column is needed in the SST case, because SST does not rely on precession-induced smearing to avoid saturation.) The number of usable observations (neglecting the observations of negligible weight discussed above) is given in the "Obs" column. The mission accuracy estimate is the "σ_M" column, and is calculated as the RSS of the single-observation accuracy divided by the square root of half the number of observations, and the bias.

Traditionally in astrometry, one might expect to cover 5 magnitudes with a single choice of filter. The reason that one cannot in this case is that at V=9, the required precision is within a factor of a few of the photon statistics limit, and so for V=8, for example, a filter dark enough to permit observations at V=5 gives a photon statistics limit that prevents reaching the required mission accuracy.

References

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Distribution

R.W. Babcock
J.F. Chandler
FAME website *via* M. Murison & S. Horner
R.D. Reasenberg
I.I. Shapiro