Astrometric properties of the SOFI imager

Rizzi, L., E.V. Held, Gullieuszik, M.

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1 Computation of the astrometric solution

The astrometric properties of an imaging camera can be mapped by constructing an astrometric solution, which is basically a way to convert pixel positions into world coordinate positions. The general form of an astrometric solution is:

$$f(x, y) = \alpha, \delta \tag{1}$$

were x and y are the pixel positions and α and δ are the world coordinates. The actual shape of the f function can be quite complex, and might contain high order terms. Moreover, such a function can be filter-dependent if the filters have a small yet non-negligible optical power.

The standard way to map this function is to correlate the pixel coordinates of a large number of stars with their world coordinates, and to fit a suitable function to the resulting pairs. Since the precision of the output funtion is closely related to the precision of the world coordinates, this procedure requires very accurate coordinates, such as those provided by astrometric catalogs. In particular, our past experience with astrometry suggests that the use of astrometric fields taken from the list of Stone, Pier, & Monet (1999) provide the best solution. For these reasons, such observations were taken with SOFI in Large Field Mode on the night of February 25, 2003. J, H, and K exposures of the FIELD E were obtained.

Unfortunataly, we soon verified that the astrometric catalogs could not provide a sufficiently high number of stars to properly map the astrometric solution, and decided to prepare a catalog of secondary standards. To this aim, we relied upon observations of the same astrometric field obtained with the WFI@2p2 wide field camera. Once those observations were astrometrically calibrated (using up to 2000 stars), we searched for stars on the whole WFI mosaic and computed their absolute position. Using a relatively high detection threshold (10 σ) we detected $\sim$ 15000 stars. Scaling down this value to the SOFI field of view, the expected number of stars for the astrometric calibration is ~ 500, a factor of 10 larger than the original astrometric catalog.

The final computation was perfomed using our reduction package (`wfpred`, *Wide Field Padova Reduction Package*) following this procedure. First, the astrometric information contained in the image header was extracted and stored in an IRAF standard astrometric database[1] This is done to allow a recentering of the default astrometric solution, which is usually slightly

[1] An astrometric database is a text file containing all the astrometric information of an image and it is generated by the `ccmap` task.

Filter	a	b	d	e	ξ rms	η rms
J	3.6545E-4	-0.28824	-0.28829	-1.8249E-4	0.05371	0.05929
J (ESO)	2.084E-4	-0.2883	-0.2882	-6.946E-5	0.069	0.098
H	2.2081E-4	-0.28836	-0.28833	-1.8763E-4	0.05183	0.05249
H (ESO)	2.314E-4	-0.2883	-0.2883	-9.973E-5	0.069	0.096
K	2.4077E-4	-0.28828	-0.28837	-1.8758E-4	0.08474	0.07416
K (ESO)	2.360E-4	-0.2884	-0.2883	-9.788E-5	0.064	0.085

Table 1: Linear astrometric coefficients.

offset due to small pointing errors. Such a recentering is performed by the task `wfpzero`, using either the astrometric catalog or the USNO catalog. The actual computation of the f function is done using the `wfpastro` task. This task reads an input catalog of stars, converts the celestial coordinates into pixel positions, and performs a recentering of the stars. The result is a file in which the pixel coordinates of each stars are coupled with its celestial coordinates. A polynomial fit is then performed, and the results are stored in a new astrometric database.

After a few tests, we confirmed that a linear fit is the best approximation of the astrometric solution for SOFI, as stated in the SOFI website. The astrometric databases we computed for the J, H, and K filters are in Appendix A. The `surface1` section of these files gives the linear terms of the transformation expressed as:

$$\xi = a + bx + cy \qquad \eta = d + ex + fy \tag{2}$$

The values we computed are presented in Table 1. Values computed by ESO are also shown for comparison. Basically, there is a substantial agreement between the previously available values and the values presented here.

2 Image combination

It is quite common in the case of SOFI to observe a series of contiguous fields to cover large sky areas. The standard procedure to combine the resulting exposures is to find a number of common stars near the edges and to compute the corresponding offsets (`imalign`, `imcombine`). The availability of astrometric databases offer a valid alternative to this procedure. Once images are astrometrically calibrated, the IRAF task `imcombine` is able to automatically compute the required offsets.

The only complex step is the adjustment of the astrometric calibration. Basically, all the astrometric information we can deduce from the image header is stored in the `RA` and `DEC` keywords, which are not precise enough to obtain a satisfactory combined image (due, basically, to pointing errors). To correct for this effect, we need a catalog of reference stars whose coordinates are compared to their actual position on the ccd to compute an offset correction. The astrometric solution is then written into the image headers taking into account this offset.

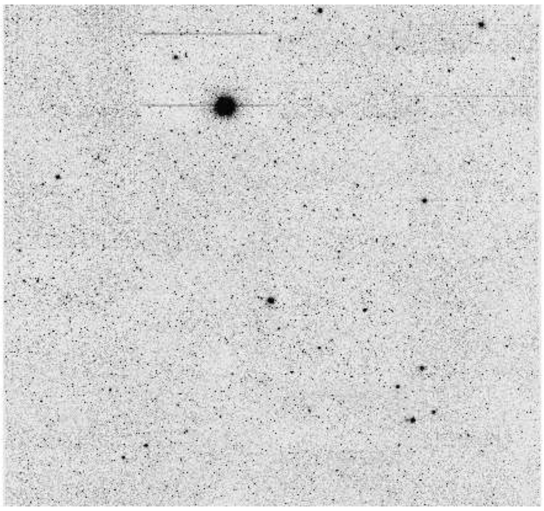

Figure 1: Combined image obtained using 16 overlapping pointings on the Fornax dSph

The first step is then to obtain a good reference catalog. The USNO catalog could be a solution but the star density appears to be too low for a good calibration. Moreover, USNO stars were originally detected on blue plates, and their magnitude distribution is completely different from that of the actual stars on SOFI images. A good alternative could be the 2MASS point source catalog (we did not test this solution). The best solution, when available, is to have wide field observations of the same area obtained with a camera for which the astrometric properties are well known, such as the WFI@2p2. In this case, the WFI image is used to detect a large number of stars, and the SOFI mosaic is constructed using this resulting catalog.

An effective solution to perform all these steps is offered by the `mscred` package (Valdes, F. G. , 1998). The offset between the RA DEC keywords can be computed computed using either the task `msczero` (for large offsets) or the task `msccmatch` (for small offsets). In most cases, the `msccmatch` task should be enough. This tasks automatically finds stars in the SOFI image, then uses a triangular algorithm to compute a linear relation between the observed positions and the catalog coordinates. The final absolute precision of the calibration is of the order of 0.1 arcsec, but the relative precision is much higher, at the level of a tenth of the pixel scale.

The task `mscstack` can then be used to compute the final combined image. An example of the combination of 16 overlapping images is presented in Figure 1. An enlargement view of one of the intersection regions is presented in Figure 2. Measurements of the FWHM on the overlap region show no difference with respect to the FWHM of the single images.

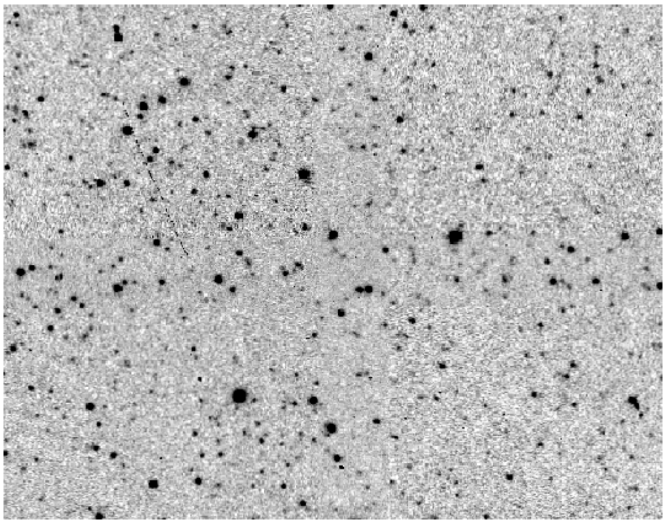

Figure 2: A zoom view of Figure 1 on one of the intersection regions between the 16 pointings

A Astrometric databases for the J, H, and K filters

A.1 J filter

```
# Fri 16:59:32 27-Jun-2003
begin im0
xrefmean 512.7927027027027
yrefmean 474.4797297297298
lngmean 7.237299039039035
latmean -0.008490990990991054
pixsystem logical
coosystem j2000
projection tnx
lngref 7.237222
latref -0.007080000000000001
lngunits hours
latunits degrees
xpixref 495.3081574252892
ypixref 489.0432218572437
geometry general
function polynomial
xishift 140.8044294429155
etashift 142.8594613590964
xmag 0.2882454604893144
ymag 0.2882883612170909
xrotation 89.92735754978339
yrotation 269.9637299876502
wcsxirms 0.05371551293784979
wcsetarms 0.05929121250782031
xirms 0.05371551293784979
etarms 0.05929121250782031
surface1 11
3. 3.
2. 2.
2. 2.
0. 0.
22.63 22.63
996.2799999999999 996.2799999999999
38.48 38.48
1006.52 1006.52
140.8044294429155 142.8594613590964
3.654518898605283E-4 -0.2882452288202064
-0.2882883034544233 -1.824954963902736E-4
surface2 0
```

A.2 H filter

```
# Fri 17:11:39 27-Jun-2003
begin im0
xrefmean 542.8370212765956
yrefmean 447.8244680851065
lngmean 7.237438102836877
latmean -0.01086684397163125
pixsystem logical
coosystem j2000
projection tnx
lngref 7.237222
latref -0.007080000000000001
lngunits hours
latunits degrees
xpixref 495.1659394460838
ypixref 488.4724639977454
geometry general
function polynomial
xishift 140.733251481772
etashift 142.8761787766227
xmag 0.2883570057531704
ymag 0.2883327732122537
xrotation 89.95612511197164
yrotation 269.9627149089339
wcsxirms 0.05183439072726812
wcsetarms 0.05249544574593631
xirms 0.05183439072726812
etarms 0.05249544574593631
surface1 11
3. 3.
2. 2.
2. 2.
0. 0.
22.58 22.58
996.1400000000001 996.1400000000001
37.89 37.89
1003.5 1003.5
140.733251481772 142.8761787766227
2.208126010443817E-4 -0.288356921208299
-0.2883327121617643 -1.876318472178195E-4
surface2 0
```

A.3 K filter

```
# Fri 17:02:54 27-Jun-2003
begin im0
xrefmean 574.1092592592591
yrefmean 442.2968518518518
lngmean 7.237472716049383
latmean -0.01340910493827168
pixsystem logical
coosystem j2000
projection tnx
lngref 7.237222
latref -0.007080000000000001
lngunits hours
latunits degrees
xpixref 494.9617082706224
ypixref 489.3638368448355
geometry general
function polynomial
xishift 141.000996287969
etashift 142.7793863027755
xmag 0.2882801567828467
ymag 0.288374804216878
xrotation 89.95214584445694
yrotation 269.9627296942896
wcsxirms 0.08474035334261634
wcsetarms 0.07416464681691515
xirms 0.08474035334261634
etarms 0.07416464681691515
surface1 11
3. 3.
2. 2.
2. 2.
0. 0.
22.45 22.45
995.78 995.78
10.35 10.35
1004.34 1004.34
141.000996287969 142.7793863027755
2.407751840712499E-4 -0.2882800562336101
-0.2883747432059056 -1.875847827836264E-4
surface2 0
```

B Secondary astrometric standard

Secondary astrometric standards were obtained for the E field of the list of Stone, Pier, & Monet (1999). Their absolute precision is $0.05''$. Here, we only report the first few stars we detected, the whole catalog is available upon request.

```
7:15:03.235 0:00:42.16       1
7:14:53.820 0:00:42.93       2
7:14:46.207 0:00:43.56       3
7:14:56.221 0:00:44.00       4
7:14:57.227 0:00:44.06       5
....
```

Contents

References

Stone, R. C., Pier, J. R., & Monet, D. G. 1999, AJ, 118, 2488

Valdes, F. G., ASP Conf. Ser. 145: Astronomical Data Analysis Software and Systems VII, 1998, 7, 53