

## Examinations of the Relative Alignment of the Instruments on SOT

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**Abstract.** We report the results of the examination about the relative alignment among the instruments on SOT. We employ a test data set obtained in the natural sun-light test in May 2005, which has had a grid pattern over the entire FOV. SOT has the filtergraph (FG) and the spectro-polarimeter (SP). The FG consists of six broadband filter imagers (BFI) and six narrowband filter imagers (NFI). We examined the displacements among the images taken with different filters to an accuracy of better than 0.1 pixel corresponding to 0.02". It is important to know relative displacements and plate scales of these instruments for accurate alignment of observational data. We note that the values measured in our work are relative and it is needed to decide the absolute values with another way.

### 1. Data Set

Table 1. FG data

	BFI	NFI
filter	CN bandhead (3883Å)	Mg I (5172Å)
	Ca II H line (3968Å)	Fe I (5250Å)
	G band (4305Å)	Fe I (5576Å)
	Blue continuum (4504Å)	Na I (5896Å)
	Green continuum (5550Å)	Fe I (6302Å)
	Red continuum (6684Å)	H I (6563Å)
size	2048×1024	2048×1024
plate scale	0.108"/pix (2×2 summing)	0.160"/pix (2×2 summing)
number of grids	21 (7×3)	55 (11×5)
focus position	2009~2043	1999~2039

The data used in this paper were summarized in Table 1. In Figure 1, the grid pattern was located at the position where the OTA focus was simulated

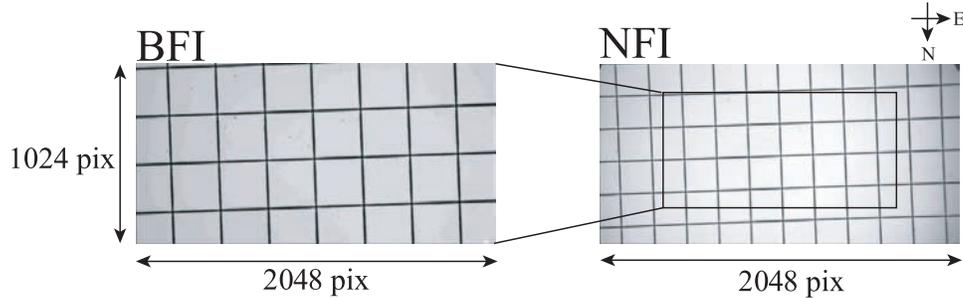


Figure 1. Images of BFI (left) and NFI (right).

before installation of FPP. The images of the pattern were taken through all the filters of the FG. We measured positions of all the crosses in the grid pattern, and derived relative displacements and pixel scales. It is noted that all FG pixels in this paper refer to the larger image pixels, which have been summed (2x2) from the smaller original CCD pixels.

## 2. Alignment of Filtergram (FG)

### 2.1. Displacements and Plate Scales among BFIs and NFIs

To measure displacements and plate scales among the filters, we performed the following procedures: (1) Determine grid positions for each filter of the focus position 2009, (2) Plot relative shifts of the grid positions with respect to the positions on the 5550Å and 5576Å image in the case of BFI and NFI, respectively (left panel in Figure 2 in the case of BFI), (3) Calculate average displacements (DX, DY) between two filters by averaging the relative shifts of the grid positions (see Table 2), (4) Correct the average displacements, and then plot the grid positions again (right panel in Figure 2), (5) Get difference of the pixel scale among the images with respect to the 5550Å and 5576Å image (see Table 2).

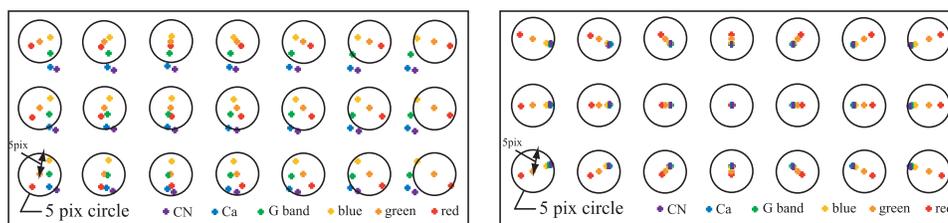


Figure 2. *left*: Relative shifts of the grid positions. *right*: Grid positions after the average displacements are corrected. These figures are in the case of BFI.

### 2.2. Alignment between BFI and NFI

The relative displacement of the center positions of BFI 5550Å with respect to NFI 5576Å are 2.07'' and 1.09'' in the X- and Y-directions, respectively. The

Table 2. Average displacements DX and DY. The error is less than 0.12 pix.

filter	BFI				filter	NFI			
	displacement		pixel scale			displacement		pixel scale	
	DX	DY	in X	in Y		DX	DY	in X	in Y
3883	-0.2	-5.4	1.0049	1.0044	5172	0.0	-0.3	1.0014	1.0012
3933	-2.0	-4.7	1.0050	1.0048	5250	-0.2	-0.6	1.0008	1.0008
4305	-1.6	-1.6	1.0047	1.0045	5576	0.0	0.0	1.0000	1.0000
4504	-0.8	2.1	1.0039	1.0037	5896	-1.0	-1.2	0.9984	0.9981
5550	0.0	0.0	1.0000	1.0000	6302	1.4	0.9	0.9975	0.9972
6684	1.1	-1.9	0.9966	0.9968	6563	1.7	0.7	0.9971	0.9969

relative pixel scale among the images of BFI (5550Å) and NFI (5576Å) is 0.6732, while it is designed as 0.6750.

### 2.3. Dependence on Focus Position

The bottom figures in Figure 3 show the displacements of the grid points in the X-direction as a function of the focus positions. The displacements represent the shifts from the grid positions obtained at focus position 2009. The images taken with BFI 5550Å and NFI 5576Å are used here. Only the grids in the middle row are plotted (see the color rectangles in the top panels in Figure 3).

We notice two features from the figures: (i) The grid positions show periodic variations with an amplitude of several pixels in a period of 18, (ii) The distance between two grids of the images becomes smaller as the focus position is larger. This means the pixel scale is larger at the larger focus positions.

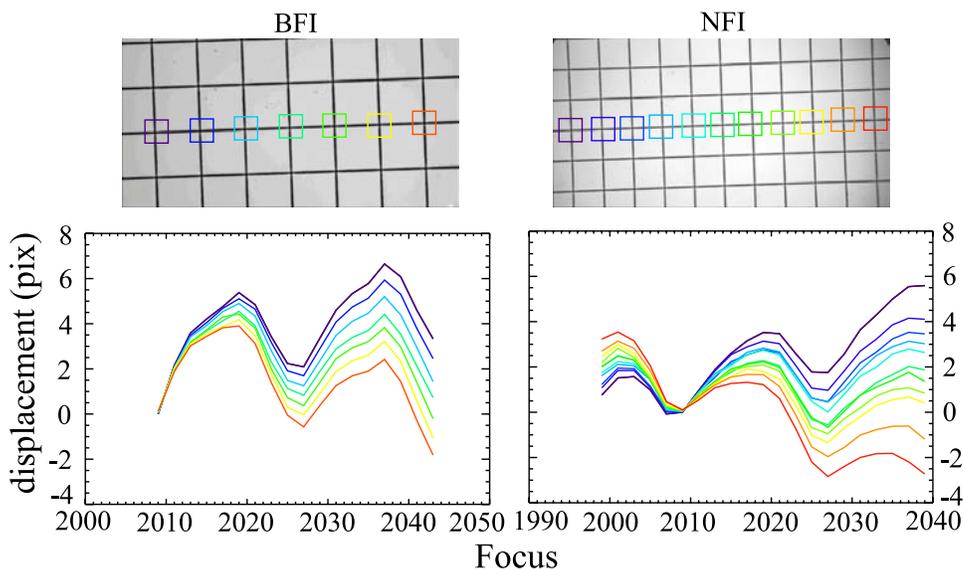


Figure 3. Dependence on focus position. *top*: Images of BFI and NFI. *bottom*: Displacements of the grid points in the X-direction as a function of the focus positions. The color lines in the bottom panels correspond to the grid positions surrounding color rectangles in the top panels.

### 3. Displacements and Plate Scales between SP and NFI

We examine the pixel scale and alignment of SP along the slit and in the direction of scanning with respect to NFI (see Table 3). SP data is scanned on the FOV with 101 steps. We select one wavelength of SP and make an image that has  $101 \times 1024$  pix size (the left panel in Figure 4). The center-top panel in Figure 4 indicates an NFI image that is scanned on the FOV of NFI 6302Å image with 101 uniform steps at intervals of 20. According to these figures, the scanned steps of SP are non-uniform and the pixel scale of SP and NFI is different.

Table 3. SP data

plate scale	0.16"/pix along slits
step scale	0.16"/step along scanning
sampling	-1000~1000 steps on FOV (at interval of 20)
focus position	2019

After correcting distortion and rotation (0.2 degree counterclockwise with respect to SP) of NFI image, we analyzed uniformity of scanning steps. Using vertical lines, we examined the position on NFI image corresponding to each slit of SP. The result is shown in the center-bottom panel and right panels in Figure 4. According to these figures, we can see the periodic residual component and the non-uniformity of scanning steps. To measure them with higher accuracy, it is necessary to analyze data having smaller step size than 20 steps. The summary about SP alignments with respect to NFI is listed in Table 4. The SP scan step is about 10% smaller than the NFI pixel.

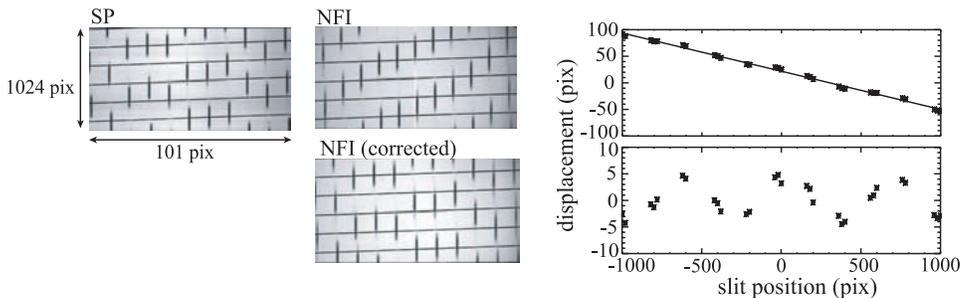


Figure 4. *left*: SP image. *center*: NFI image with uniform steps (top) and corresponding to each slit of SP (bottom). *right*: Displacement of the slit position with respect to the uniform steps (top) and the residual component (bottom).

Table 4. Summary about SP.

relative scanning step	$0.906 \pm 0.106$
rotation	0.2 degree
relative pixel scale	$0.9964 \pm 0.0016$
relative shift	8.7 pix