WHIRC Report III

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Introduction

During the nights of 15 and 21 April 2008, Pat Knezek and Dick Joyce obtained several datasets for evaluating WHIRC performance, including:

- Observations of standard star flux and sky background through all 13 filters
- Observations of dome flats in all 13 filters
- Observations of a globular cluster (M13) and a standard star on a 10 × 10 grid to investigate photometric performance, flatfielding, and scaling.

Signal and Background Levels

As noted in Report II (2 April 2008), the observations of FS23 on 18 March 2008 were all taken with the star at the same location on the array because this test was being carried out in conjunction with WTTM testing. This location was unfortunately near a bad pixel, which had to be corrected in the analysis; in addition, no data were obtained in the Pa β filter at that time. Pat Knezek repeated this test using the standard FS 28, this time at three positions on the array, through all of the filters. The results, which are the average of the signals at the three array locations, are shown in Table 1, compared with the results from March. The agreement is quite satisfactory, particularly for the broadband filters.

It is important to emphasize that these are raw signal levels, designed to allow users to estimate exposure times and performance in preparing for observing runs. Since the stars were on different locations on the array, one anticipates some variation in signal level. The April data were also possibly compromised by the detector pattern noise, which had reappeared on that night.

The higher background level, particularly in the K band filters, is significant, and is a consequence of the high emissivity of the optical train and the higher ambient temperature in April. We plan to continue to obtain background data over the wide temperature range encountered throughout the year, since this will need to be considered in the implementation of the exposure time calculator for WHIRC.

The top set of data in Table 1 are those for FS23 on 18 March 2008, the bottom set those obtained for FS28 on 21 April 2008. The raw signal levels for FS28 were taken using 5 s integrations for the broadband filters and 60s for the narrowband filters. These data have been incorporated into the WHIRC website.

Table 1 WHIRC Signal/Background Levels

FILTER	BG ADU/s	star0	star1	0.0 ADU/s	0.0 ADU/s
LOW_AIR	0.45	833	1630	1.32E+08	1.15E+08
HE_I	0.53	590	1072	9.35E+07	7.56E+07
J	5.54	11199	25040	1.77E+09	1.76E+09
PA_B_4500	1.07	902	1894	1.43E+08	1.33E+08
FE_II	2.03	1113	2500	1.07E+08	1.02E+08
FE_II_4500	2.86	1198	2723	1.15E+08	1.11E+08
H	25.32	19614	43874	1.88E+09	1.79E+09
H2	2.90	800	1741	7.15E+07	6.49E+07
BR_G	3.76	864	1969	7.73E+07	7.34E+07
BR_G_4500	5.70	965	2150	8.63E+07	8.01E+07
KS	73.73	12094	28512	1.08E+09	1.06E+09
CO	7.77	664	1394	5.94E+07	5.19E+07
LOW_AIR	0.44	463848		1.53E+08	
HE_I	0.56	303656		1.00E+08	
J	9.19	460146		1.83E+09	
PA_B	2.00	461734		1.53E+08	
PA_B_4500	1.12	407974		1.35E+08	
FE_II	2.69	334794		1.01E+08	
FE_II_4500	3.52	367377		1.11E+08	
H	45.88	538411		1.95E+09	
H2	5.24	227537		6.60E+07	
BR_G	7.71	247067		7.17E+07	
BR_G_4500	10.86	282793		8.21E+07	
KS	154.80	313642		1.09E+09	
CO	16.61	195819		5.68E+07	

Flatfielding

During the April run, we established the proper flatfield lamp setting for all 13 filters, under the conditions of the Fowler-1 mode and 5 s integration time. We have not yet established whether one must obtain flatfields in Fowler-4 mode to reduce observations taken in that mode, but we did take some flat observations in a couple of the narrowband filters. A suggested rule of thumb is to utilize a 16 s integration in Fowler-4 mode, using a numerical lamp setting approximately 2/3 that used for a 5 s flat in Fowler-1 mode. The suggested lamp settings have been incorporated into the User Manual.

Dome vs Sky Flats

Because of the low sky background in the narrowband filters, it will always be necessary to use the dome screen for obtaining flatfields. In the broadband filters, the sky background is sufficiently high (for reasonably long integration times) so that dark-subtracted sky frames can theoretically be used for flatfielding. The 10 x 10 grid of standard star observations in the Ks filter is a useful test of both methods, since one may obtain a reasonably low-noise flatfield by averaging (with median filtering) the 100 observations, even though the sky background was relatively small (1000 ADU) in each observation. This experiment is also a good test of evaluating the effects of the pupil ghost, since the standard star under photometric conditions represents a good sampling of the actual array sensitivity at each of the 100 locations.

The sky flat was fabricated by averaging the 100 observations using median rejection to eliminate any stars from the result, then subtracting a dark frame obtained at the same integration time (the dark frame was the average of 10 individual darks). The dome flat was obtained from the difference of the average of five observations of the dome screen with the lamps on and five with the lamps off. This subtracts out not only the dark current, but also the background thermal signal from the dome screen itself. Both flats were normalized to 1.0 over a representative area and extreme pixel values were set to 1.0 to avoid big spikes in the flatfielded images.

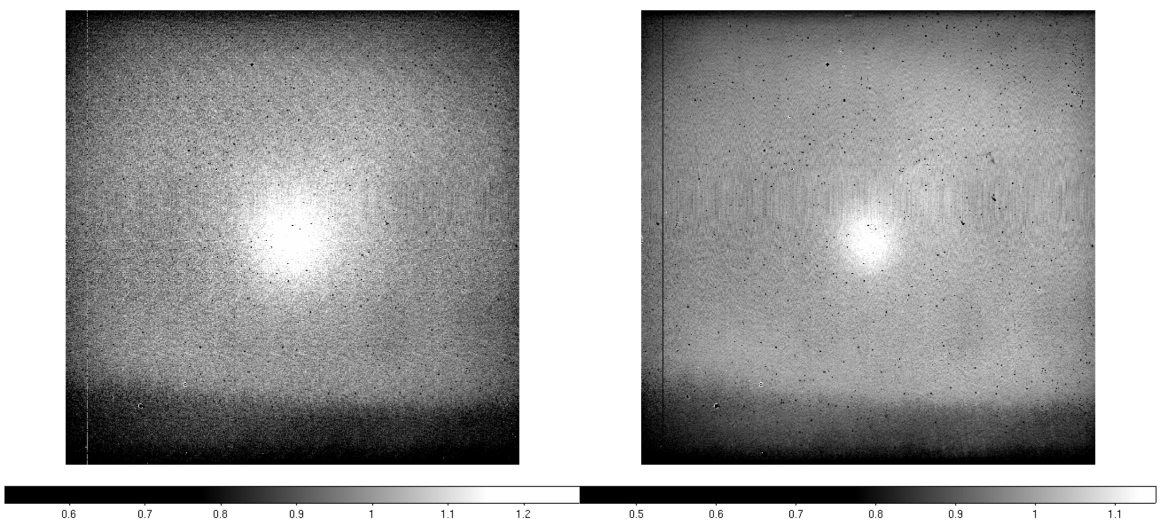

Figure 1: Normalized Ks flats using the sky (left panel) and the dome screen (right panel). Note that the pupil ghost is more apparent in the sky flat.

One can see a significant difference in the two flats (Fig. 1). The sky flat does still show some residual noise from the detector pattern noise, but more importantly, the pupil ghost is much more evident in both extent and relative intensity (35% vs. 17%) over the "continuum" by comparison to the dome flat. Interestingly, the "lights off" dome flat was similar in appearance to the sky flat, suggesting that the emission from the WTTM optics, which is the bulk of the signal for the sky flat, produces the broader pupil ghost. This also argues for using the dome flat, rather than the sky flat for Ks, since the signal from the latter does not originate from the sky, but from warm optics at various distances from the pupil.

Figure 2 shows the measured signals from FS28 (on a magnitude scale) using a generous 2.4 arcsec diameter aperture. The results are plotted for the raw data and for flattening

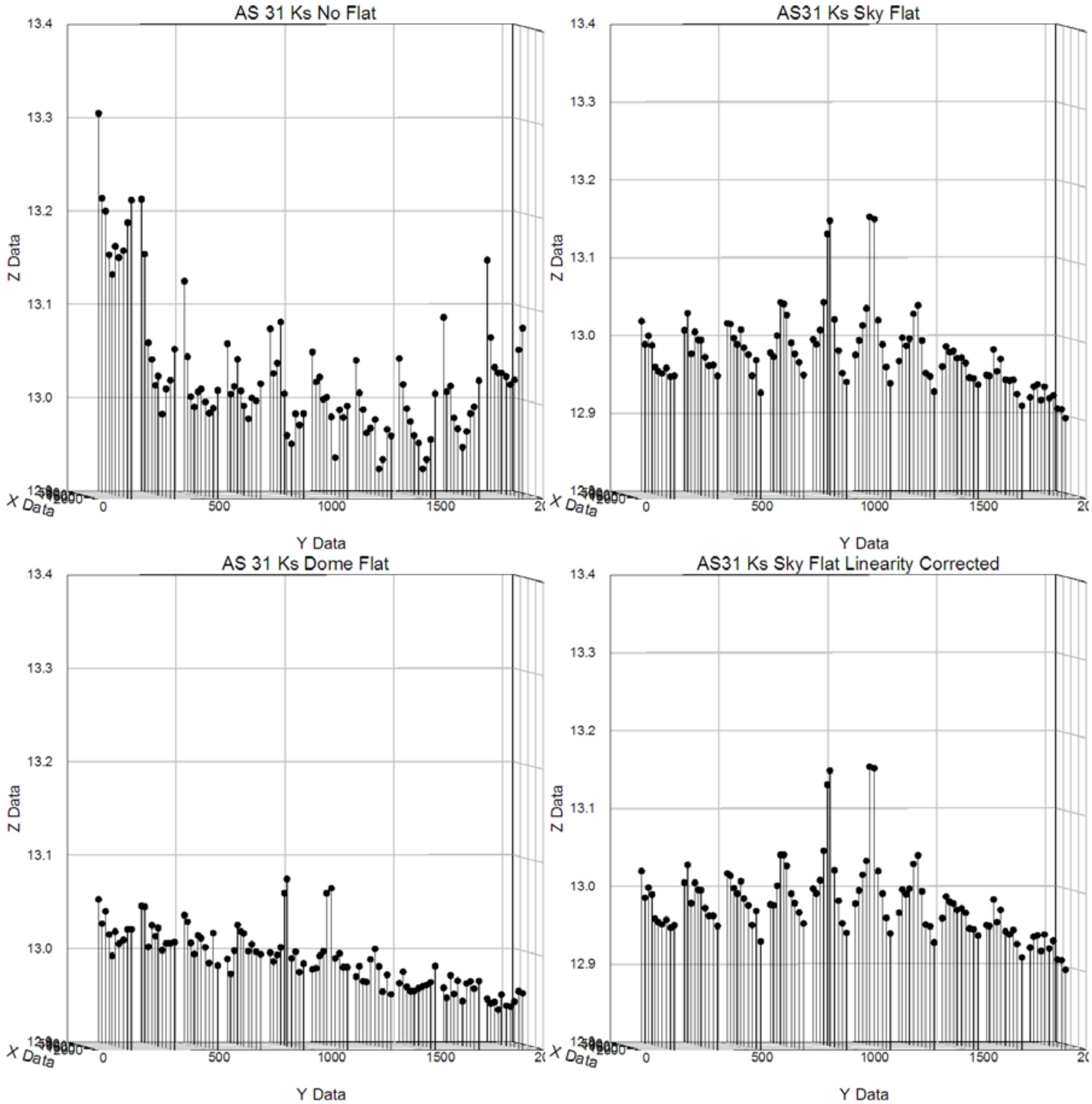

Figure 2: Three-dimensional plots of relative magnitude for FS28 in a 10 × 10 grid covering the WHIRC field of view. X and Y scales are in pixels. The view is heavily foreshortened in X to make all of the measurements visible. The pupil ghost produces the depressed signal (higher magnitude) in the center of the array; the effect is significantly larger in both amplitude and extent for the sky flat. The linearity correction produced no detectable effect at the observed signal levels.

with both sky and dome flats. In addition, we show the results of linearity correction for the sky flattened data, which produced no detectable effect.

With the exception of the pupil artifact, the dome flattened data show promise. Along the rows, the p-p variation is on the order of 2 – 4%. However, there is a low spatial frequency "tilt" of 5 – 6% long the column direction which is still unexplained. This is not a time-dependent effect, because the data were taken in four 5 × 5 quadrants over a 30 minute time frame and each "row" consists of two datasets separated by 15 minutes.

These results suggest that future efforts concentrate on the use of dome flats rather than sky flats and understanding/modeling the pupil ghost so it can be removed as part of the standard data reduction.

A second set of observations obtained on 15 April 2008 was of images of the globular cluster M13 at various locations on the array. This approach has the advantage of a large number of calibrated 2MASS stars spread over the array, so one can investigate the combined effects of flatfielding and linearity. This analysis is only beginning; however, the initial efforts have allowed us to refine the pixel scaling on the WHIRC detector.

Image Scale Measurements

In the initial attempts to identify targets in M13 for photometry to evaluate the flatfielding accuracy, it was evident that the plate scale parameters in the WHIRC header were significantly in error. Attempts to overlay region or catalog files showed significant differential errors up to 7 arcsec across the array. We used the IRAF task ccmap to establish a solution using a grid of 22 stars over the field (a larger grid of 59 stars gave almost identical solutions for H, so the smaller grid was used for convenience at both J and Ks).

The results are shown in Table 2. The parameters CRPIX1 and CRPIX2 are simply zero point offsets which represent any error in the TCS coordinates and are not important. The four parameters CD1_1, CD2_1, CD1_2 and CD2_2 represent the transformation matrix elements for the conversion from pixel to astrometric units. The off-axis values CD1_2 and CD2_1 are effectively the pixel scale in X and Y; the small but non-zero values of CD1_1 and CD2_2 indicate that the two coordinate systems are not exactly 90º apart in rotation. In addition, the known "keystoning" of the WTTM image (C. Claver, private communication) could contribute to these coefficients.

Table 2. Scaling Solutions for WHIRC at J, H, and Ks

	Original Values	M13-J	M13-H	M13-Ks
CRPIX1	1066	968	932	972
CRPIX2	1034	1050	1007	1053
CD1_1	5.591060E-07	4.344570E-07	4.423750E-07	4.201739E-07
CD2_1	-2.784990E-05	-2.691327E-05	-2.690456E-05	-2.690389E-05
CD1_2	-2.689920E-05	-2.782711E-05	-2.783065E-05	-2.781849E-05
CD2_2	-5.499160E-07	-5.016059E-07	-4.714078E-07	-4.709654E-07
scale x	0.10026	0.09688	0.09685	0.09685
scale y	0.09684	0.10017	0.10019	0.10015

The most obvious result is that the default first-order scaling parameters in the image header were reversed. The 3% difference in pixel scale in the two axes (presumably a consequence of the WTTM optics) will clearly result in a mismatch with a template field if the two are reversed. An encouraging conclusion from this test is the confirmation of the highly achromatic performance of the WHIRC optics.