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WFC3 SMOV Proposal 11442: Alignment of the WFC3/UVIS Apertures to the FGS Coordinate Frame

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ABSTRACT

Target placement and the execution of offsets are implemented for an HST instrument using information in the Science Instrument Aperture File (SIAF). Exposures of an astrometric stellar cluster are used to measure the location and orientation of the detector in the spacecraft V2,V3 frame, and to provide aperture locations and orientations for the SIAF. Observations of the open cluster NGC 188, made in SMOV program 11442, were used to produce a SIAF file for the WFC3/UVIS detector that took effect on 3 August 2009. The location of the detector in the V2,V3 frame was shifted by (-0.57", +2.71") and its orientation was rotated by -0.074 degrees relative to the placement defined in the previous SIAF, which was determined from ground-based tests and modelling. The rms errors in the shift and rotation are (0.011",0.015") and 0.027 degrees.

Introduction

SMOV program 11442 was performed to fine-tune the placement of targets on the WFC3/UVIS apertures. Until the on-orbit performance of the pointing is checked and adjusted for a science instrument, target placement can be expected to be off by up to several arcseconds, and offsets executed with POSTARGs or patterns may have a small angular error.

The location of the reference pixel and the extent and orientation of the aperture in the V2,V3 spacecraft coordinate system is listed for every aperture on an HST instrument in the SIAF (Science Instrument Aperture File) for that instrument. (See Section

6.4.3 of the WFC3 Instrument Handbook for a discussion of coordinate systems.) A geometric distortion solution relating pixel positions to positions on the tangential plane on the sky is also included for each aperture. The SIAF is used to determine how to place the target at the reference pixel, or to place it at an offset position specified by POSTARGs or patterns, when a phase 2 proposal is prepared for execution. It also affects the population of position-related keywords in the headers of science data, such as ORIENTAT (position angle of image Y axis) and WCS (World Coordinate System) parameters. Finally, it affects the display of exposures in APT (Astronomers Proposal tool). (See Cox, ISR TEL 2008-01.)

For the initial observations made with an HST instrument, the parameters in the SIAF are estimates derived from a combination of ground testing of the instrument and optical modelling. Early in the SMOV (Servicing Mission Observatory Verification) program, the science instrument team performs observations of an astrometric stellar field that are used along with V2,V3 positions of the astrometric stars determined from FGS data and modelling to improve the parameters in the SIAF. Support activities are coordinated so that the new SIAF takes effect in the execution of pointings and in the production of headers in the data pipeline on the same date, in this case 3 August 2009. The production of the first WFC3/UVIS SIAF to be based on on-orbit measurements, and the consequent changes in UVIS exposures, are described in this document.

Data

The data for this project were acquired in SMOV program 11442 to support SMOV activity WFC3-29. Images of an area near the center of the open cluster NGC 188, an astrometric field, were obtained with the UVIS detector using astrometric guide stars. Positions of stars in this field have been measured in the GSC1 reference frame and compiled in STScI NGC-188 Special Plate Catalog ”ZZZZ” (van Altena, 1988). The relative astrometry of the stars in this catalog is accurate to an rms of 30 mas, but depending on proper motion errors and given the long time baseline over which they are applied ($\sim$20 years), the relative errors for individual stars may be approaching 0.1 arcsec.

The observations were made on 12 July 2009, after the completion of the UVIS optical alignment programs (11424, 11434). The target was star 58 in the astrometric catalog. Three CR-SPLIT exposures (iab001011, iab001021, iab001031) of length 228 sec were made in a single visit with aperture UVIS and filter F410M: one exposure on the target star, one with POSTARG (-15,0), and one with POSTARG (0,-25). The catalog numbers and positions of the astrometric stars included in the exposures are listed in Table 1. The locations of each astrometric star on the detector in the three exposures is shown in Figure 1.

Table 1. Catalog numbers and positions of the observed astrometric stars in the NGC 188 field

ID #	RA (J2000)	PM (sec/yr)	DEC (J2000)	PM (”/yr)
48	00 46 23.033	-0.0027	+85 17 12.58	-0.0139
58	00 47 04.453	-0.0025	+85 16 32.70	-0.0112
59	00 47 03.784	-0.0041	+85 15 26.78	-0.0126
61	00 47 13.350	-0.0030	+85 16 39.00	-0.0137
64	00 47 19.585	-0.0023	+85 17 35.13	-0.0122

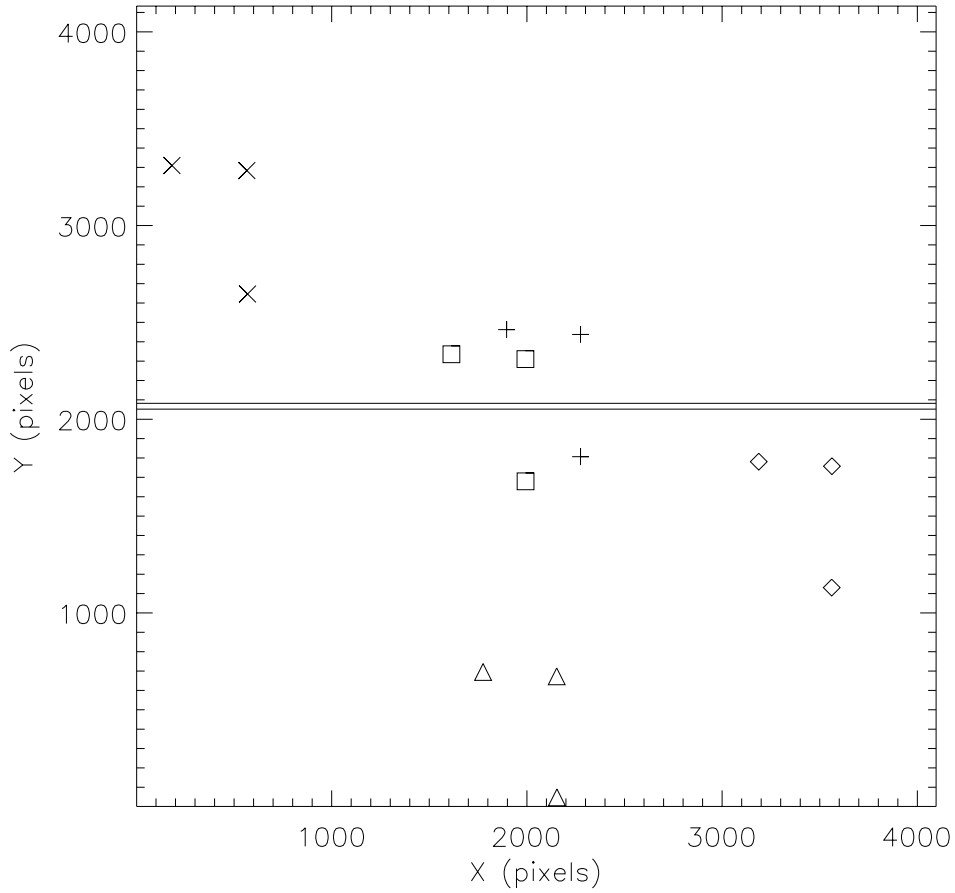

Figure 1. *Location of each astrometric star on the detector in the 3 dithered exposures. Each star is represented by a different symbol. The target star is indicated by a square.*

Analysis

Stellar Positions in the V2,V3 Frame

The RA and Dec of the observed NGC 188 astrometric stars and guide stars, corrected for proper motion, and the time range of the visit were submitted to the Flight Operations Sensors and Calibrations group at GSFC, lead by Ed Kimmer. Kimmer's group took the guide star raw observations and applied the latest FGS distortion and alignment matrices to obtain the V2,V3 locations of the guide stars. They then fit these two positions to the corresponding RA and Dec to obtain the pointing solution. Using this, they provided a list of the V2,V3 values associated with each of the observed astrometric field stars at short time samples throughout the time range of the visit. From this list, we extracted the V2,V3 values of the stars at the times of the exposures.

Stellar Positions in the Detector Frame

We measured the X and Y positions of the astrometric stars on each calibrated (crj) image using the procedure described by Dulude and Dressel (ISR WFC3 2009-11). We determined the X and Y centers separately by analyzing a flux profile along each axis. We summed 7 rows centered on a PSF to form a profile along X, and summed 7 columns centered on the PSF to form a profile along Y. The IDL function GAUSSFIT was used to fit a gaussian to each profile, thus providing us with Gaussian-fit centers. We made a second set of measurements by smoothing the X and Y profiles with a 3-point sliding boxcar prior to performing the Gaussian fit. This choice of smoothing was based on our experience with measuring the spatial center of the trace of a stellar spectrum in STIS spectral images (Dressel, ISR STIS 2007-03). A Gaussian is not a good fit to a PSF that has been undersampled by the pixels. Boxcar-smoothing the PSF along the slit in a spectral image convincingly removes artifacts from the Gaussian-fit center of the trace as it crosses the detector. We used the centers determined from the smoothed profiles in this analysis. They differed from the centers measured from the unsmoothed profiles by up to 0.04 pixels.

Location and Orientation of Apertures in the V2,V3 Frame

At this point we had a set of X,Y positions on the images for the astrometric stars and their corresponding V2,V3 positions. These positions are shown in Table 2. The X,Y positions were converted to predicted V2,V3 coordinates using the aperture definition and the preliminary geometric distortion solution in the SIAF that was in effect for these observations. We computed the shift (-0.57", +2.71") and rotation (-0.074 degrees) that best aligned the predicted V2,V3 coordinates with the V2,V3 coordinates provided by the group at GSFC, with rms errors (0.011",0.015") and 0.027 degrees. This shift and rotation were used to update the geometric distortion solution relating X,Y to V2,V3. Using this new solution, the V2,V3 coordinates of the reference pixels and the angles of

the detector axes with respect to the V2,V3 frame were updated for all of the UVIS apertures in a new SIAF. This SIAF has been used for executing pointings and for populating header keywords in the science pipeline since 3 August 2009.

Table 2. X,Y positions of astrometric stars in the crj images and corresponding V2,V3 positions in the spacecraft frame

Exposure [extension]	ID #	X (pixel)	Y (pixel)	V2 (arcsec)	V3 (arcsec)
iab001011[1]	48	2151.48	671.73	-40.097	-40.321
iab001011[4]	58	1991.50	227.61	+9.867	+0.959
iab001011[4]	59	564.50	1200.67	+74.077	-14.036
iab001011[4]	61	2273.76	354.80	+6.095	+13.032
iab001011[1]	64	3561.56	1756.31	-47.101	32.564
iab001021[1]	48	1774.42	694.24	-29.468	-50.907
iab001021[4]	58	1612.32	252.39	+20.497	-9.627
iab001021[4]	59	180.97	1226.86	+84.707	-24.620
iab001021[4]	61	1895.08	379.65	+16.724	+2.448
iab001021[1]	64	3186.52	1780.03	-36.472	+21.980
iab001031[1]	48	2152.76	46.84	-57.737	-58.037
iab001031[1]	58	1991.96	1678.35	-7.770	-16.756
iab001031[4]	59	568.06	563.46	+56.441	-31.750
iab001031[1]	61	2273.58	1805.81	-11.543	-4.682
iab001031[1]	64	3560.31	1129.78	-64.739	14.850

Effect of the SIAF Update on Science Data

The SIAF update took effect during the SMOV calibration period. Identical visits made before and after the update will show a difference in the placement of the target in the aperture. In Figure 2, we show the superposition of two exposures (iaau51u4q_flt, iaau61i1q_flt) from program 11426 made on 29 July 2009 and 4 August 2009. The star GRW+70D5824 was observed near a corner of the detector in the UVIS1-C512A-SUB aperture with the F343N filter. The position of the star in the two exposures was measured by profile fitting as described above. It changed by +60.3 pixels in X and +41.1 pixels in Y. The expected change due to the use of the different SIAF files is +61.2 pixels in X and +36.8 pixels in Y. The extra observed shift of (-1 pixels,+4 pixels) is greater than the fractional pixel errors in the frame shift and rotation used in the SIAF update, and can be accounted for by errors in pointing and target position.

Each of these visits used the same dominant guide star in the same FGS, but a different roll guide star, and the aperture orientation differed by 6 degrees. The rms pointing repeatability should be comparable to or slightly greater than that of different visits that use the same guide stars and the same orientation: 0.05 to 0.1 arcsec, or

Figure 2. *Superposition of two exposures (iaau51u4q_flt, iaau61i1q_flt) of a star made on a 513x512 subarray before and after the SIAF update. The star is higher and to the right in the later exposure.*

$\sim$1.3 to $\sim$2.5 pixels, enough to account for the extra shift seen above. An error in the relative astrometry of the target and the guide stars can also affect pointing repeatability in different visits. Even for visits made with the same SIAF and guide stars, a target with a position error relative to the guide stars will rotate around the reference pixel from one visit to the next if the aperture orientation changes. The offset of the target from the reference pixel in the second observation (1.6" in X) is consistent with the stated position uncertainty in the proposal, and could account for rotational motion $\sim$4 pixels in Y for a 6 degree change in orientation.

The STIS SIAF was found to be sufficiently accurate that no update was needed during SMOV. A check of STIS target acquisitions of GRW+70D5824 confirms a target position specification error of nearly 2" in the WFC3 exposures. STIS calibration program 11860 specified a position 0.9"W, 1.4"S of the position used in the WFC3 program 11426. The STIS acquisition exposures (ob8702elq, ob87n2gkq) showed that an adjustment of $\sim$0.3" was needed to the position, making the corrected position 0.9" W, 1.7" S of the position used in 11426. Given the position angle of the UVIS aperture in exposure iaau61i1q (-58 degrees), this indicates that the star was displaced nearly along the X axis by $\sim$1.9", or about 48 pixels. The measured offset of the star from the reference pixel was 41 pixels in X. The predicted shift due to the SIAF update has thus been confirmed to within 4 pixels ($\sim$0.15"), and the post-update placement of the target at the reference pixel has been confirmed to within 7 pixels ($\sim$0.3").

Conclusions

Observations of the open cluster NGC 188, made in SMOV program 11442, were used to produce a SIAF file for the WFC3/UVIS detector that took effect on 3 August 2009. The location of the detector in the V2,V3 frame was shifted by (-0.57",+2.71") and its orientation was rotated by -0.074 degrees relative to the placement defined in the previous SIAF, which was determined from ground-based tests and modelling. The rms errors in the shift and rotation are (0.011",0.015") and 0.027 degrees. The resulting change in target placement and the accuracy of target placement using the updated SIAF were verified to within 0.15" and 0.3", respectively, in a check of repeated exposures of one star.

References

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