SPACE TELESCOPE SCIENCE INSTITUTE
Operated for NASA by AURA

WFC3 Instrument Science Report 2009-36

WFC3 SMOV Proposal 11443: Alignment of the WFC3/IR Apertures to the FGS Coordinate Frame

L. Dressel, C. Cox, and M. Lallo
November 12, 2009

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 11443, were used to produce a SIAF file for the WFC3/IR detector that took effect on 3 August 2009. The location of the detector in the V2,V3 frame was shifted by (-0.98", +6.18") and its orientation was rotated by -0.151 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",0.019") and 0.064 degrees.

Introduction

SMOV program 11443 was performed to fine-tune the placement of targets on the WFC3/IR 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 7.4.3 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/IR SIAF to be based on on-orbit measurements, and the consequent changes in IR exposures, are described in this document.

Data

The data for this project were acquired in SMOV program 11443 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 IR 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 13 July 2009, after the completion of the IR optical alignment programs (11425, 11435). The target was star 58 in the astrometric catalog. Three exposures (iab101aaq, iab101acq, iab101aeq) of length 44 sec (RAPID sequence, 15 frames) were made in a single visit with aperture IR-FIX and filter F128N: 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 location of each astrometric star in the second and third exposures, used in the analysis, is shown in Figure 1. (V2,V3 positions were not available for the first exposure at the time of the analysis. One star was off the detector in the second exposure.)

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)
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

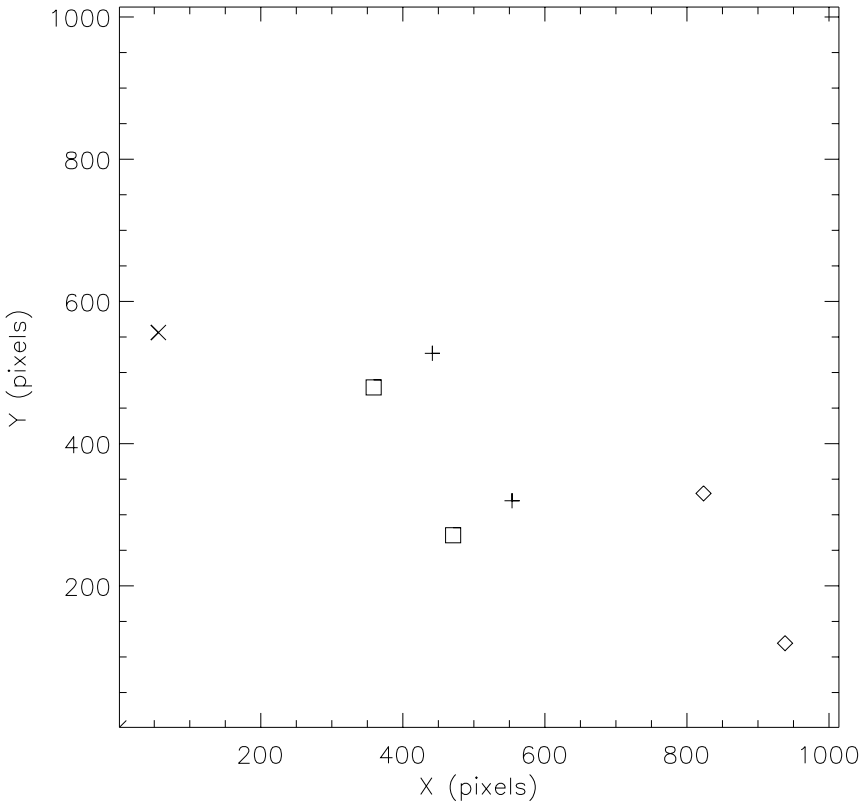

Figure 1. *Location of each astrometric star in the two dithered exposures used in the analysis. Each star is represented by a different symbol. The target star is indicated by a square.*

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, except for a time range including the first exposure when TDRS was unavailable to send the data. From this list, we extracted the V2,V3 values of the stars at the times of the second and third exposures.

Stellar Positions in the Detector Frame

We measured the X and Y positions of the astrometric stars on each calibrated (flt) 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 0.05 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 in all 3 exposures, and their corresponding V2,V3 positions in the second and third exposures. The V2,V3 positions of the stars in the first exposure were obtained later, and are presented here for use in later SIAF updates. The positions for all of the astrometric stars in all of the exposures 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 (-0.98", +6.18") and rotation (-0.151 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",0.019") and 0.064 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 IR 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 flt images and corresponding V2,V3 positions in the spacecraft frame

Exposure	ID #	X (pixel)	Y (pixel)	V2 (arcsec)	V3 (arcsec)
iab101aaq	58	469.86	479.66	+2.354	-6.568
iab101aaq	59	57.05	761.17	+66.546	-21.637
iab101aaq	61	552.28	527.44	-1.406	+5.511
iab101aaq	64	934.74	329.82	-54.578	+25.105
iab101acq	58	358.97	479.11	+12.958	-17.174
iab101acq	61	441.60	527.05	+9.199	-5.096
iab101acq	64	823.37	330.00	-43.974	+14.498
iab101aeq	58	470.82	271.22	-15.323	-24.246
iab101aeq	59	55.91	556.29	+48.87	-39.315
iab101aeq	61	553.72	319.70	-19.082	-12.167
iab101aeq	64	938.10	119.39	-72.254	+7.427

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 (iaac23g2q_flt, iaac24ktq_flt) from program 11451 made on 21 July 2009 and 11 August 2009. The star GD153 was observed near the center of the detector in the IRSUB128 aperture with the F140W filter. The position of the star in the two exposures was measured by profile fitting as described above. It changed by +49.4 pixels in X and +42.4 pixels in Y. The expected change due to the use of the different SIAF files is +47.4 pixels in X and +40.3 pixels in Y. (This shift includes a change in the definition of the reference pixel, moving it away from the intersection of the 4 quads, with an increment of (+10,+10) pixels.) The extra observed shift of (+2 pixels,+2 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 specification.

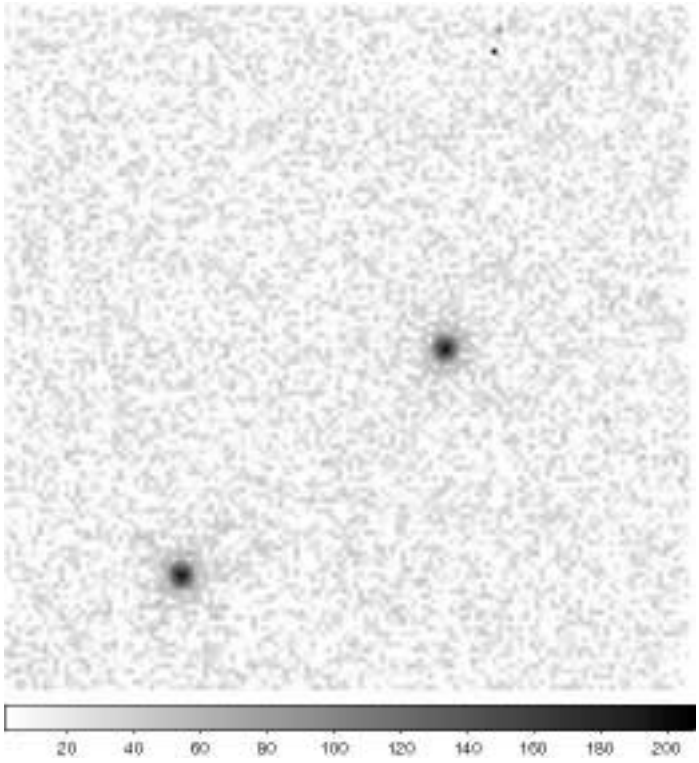

Figure 2. *Superposition of two exposures (iaac23g2q_flt, iaac24ktq_flt) of a star made on a 128x128 subarray before and after the SIAF update. The star is higher and to the right in the later exposure.*

Each of these visits used the same dominant guide star and roll guide star in the same FGSes; the aperture orientation differed by 12 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 $\sim$0.4 to $\sim$0.8 pixels, which could account for some of 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 (1.7”) could account for rotational motion $\sim$3 pixels for a 12 degree change in orientation, equal to the difference between prediction and measurement that we are attempting to account for.

A check of STIS target acquisitions of GD153 confirms a target position error of about 2” in the WFC3 exposures. STIS SMOV calibration proposals 11393 and 11394 included the proper motion in the target position specification, which amounts to (-0.44”,-1.96”) in (RA,Dec) in the 9.6 years since epoch 2000. The initial STIS pointings were found to need adjustments in (x,y) of only (0.11”,0.12”) for 11393 (exposure

oa8d02n3q) and (0.11”,0.09”) for 11394 (exposure oa8e02xwq). Had the proper motion been included in the WFC3 target position specification, the target would have been placed (-11.5,+10.1) pixels relative to the measured placement. It would have thus been placed within (2.6,0.4) pixels of the reference pixel after the SIAF update, a distance of 0.35”. The predicted shift due to the SIAF update and the placement of the target at the reference pixel after the update have thus both been confirmed to within 0.35”.

Conclusions

Observations of the open cluster NGC 188, made in SMOV program 11443, were used to produce a SIAF file for the WFC3/IR detector that took effect on 3 August 2009. The location of the detector in the V2,V3 frame was shifted by (-0.98”, +6.18”) and its orientation was rotated by -0.151 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 confirmed to within 0.35” in a check of repeated exposures of one star.

References

Bond, H. E., and Kim Quijano, J., et al. 2007, ”Wide Field Camera 3 Instrument Handbook, Version 1.0” (Baltimore: STScI).

Cox, C., 2008, ISR TEL 2008-01, ”The Wide Field Camera 3 Science Instrument Aperture File”.

Dressel, L., 2007, ISR STIS 2007-03, ”Time Dependent Trace Angles for the STIS First Order Modes”.

Dulude, M., and Dressel, L., 2009, ISR WFC3 2009-11, ”First-Order Test of WFC3/IR Imaging: from Phase 2 Proposal to MultiDrizzle Product”.

van Altena, W.F, 1988, private communication to STScI.