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The Two-Gyro Pointing Stability of HST, Measured with ACS

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Abstract. We present the results of the pointing stability tests for HST, as measured with the ACS/HRC during the two-gyro test program conducted in February 2005 and the validation tests performed after the transition to two-gyro mode in August 2005. We have measured the shifts of 301 exposures obtained of the globular clusters NGC1851, NGC2298, NGC6341, NGC6752, and Omega Centauri, obtained over a total of 21 orbits during these two test programs, and compare the measured pointings to those that were commanded in the observing program. We find in all cases that the measured shifts and rotations have the same level of accuracy as those executed in three-gyro mode. Specifically, the pointing offsets during an orbit relative to the first exposure can be characterized with distributions having a dispersion of 2.1 - 2.3 milliarcseconds for shifts and 0.0007 - 0.00097 degrees for rotations, thus less than 0.1 HRC pixels, and agree extremely well with similar values measured for comparable exposures obtained in three-gyro mode. In addition, we successfully processed these two-gyro test data through the MultiDrizzle software which is used in the HST pipeline to perform automated registration, cosmic ray rejection and image combination for multiple exposure sequences, and we find good agreement with similar exposures obtained in three-gyro mode. In summary, we find no significant difference between the quality of HST pointing as measured from these two-gyro test data, relative to the nominal behavior of HST in regular three-gyro operations.

1. Introduction

As part of the options for extending the lifetime of the Hubble Space Telescope (HST), a new attitude control system was activated in August 2005 that enables the telescope to point using only two gyroscopes instead of the nominal three by using additional information from the Fine Guidance Sensors, thereby allowing one of the gyroscopes to be turned off to conserve its life for possible future use. The February two-gyro test (F2G) was carried out during 20 − 23 February 2005 to investigate the feasibility of this mode, and based on its results the decision was made to transition to two-gyro mode (TGM) on 28 August 2005, with a second set of validation tests performed during 28 − 31 August 2005.

One of the principal motivations for these tests was to examine the pointing stability of HST, since a possible concern with TGM operations is the need to determine whether the pointing stability is significantly worse than with three gyroscopes. If so, this could potentially impact the tracking accuracy of HST during an exposure, as well as the accuracy of dither offset maneuvers from one exposure to the next, and the accuracy of guide star re-acquisitions from one orbit to the next. In addition to degrading the resolution of the final image, a decrease in pointing stability can also affect the degree of accuracy with which sub-pixel sampling is achieved with dithering. Therefore, an extensive set of observations was obtained during both test periods to verify and measure the pointing stability of HST under TGM. All results from these tests indicate that the two-gyro pointing performance of HST is not significantly different from that under nominal three-gyro operations.

2. Observational Design and Methodology

The observational methodology is described in detail in ACS ISR 2005-07 (Koekemoer et al. 2005) and Sembach et al. (this volume), and is summarized here. Three principal questions need to be addressed concerning the pointing stability of HST in two-gyro mode:

1. Maintaining stability within an orbit, so that successive exposures during an orbit are either located at the same position (if no dithering is used), or are dithered accurately according to the commanded offsets, particularly if sub-pixel shifts are required.

2. Maintaining sufficient re-acquisition accuracy from one orbit to the next to enable multi-orbit observations to be successfully obtained, particularly if sequences of exposures or dither patterns are spread across multiple orbits.

3. Ensuring that the pipeline processing system, specifically MultiDrizzle image registration, cosmic ray rejection and image combination, can successfully process the data.

The observations described here were obtained in programs 10443 and 10458 during February and August 2005, respectively. These contained a wide variety of exposures, using a range of exposure times, dither offset strategies and different types of guide stars, to quantify in detail the behavior of the telescope in TGM. The proposals used the HRC camera (1024x1024 pixels), which has small pixels (26 milliarcseconds) and can very accurately measure the HST pointing accuracy. The 10443 observations were spread over 13 orbits, obtaining 155 exposures of the globular cluster NGC6341 and 32 exposures of Omega Centauri at a 10° off-nominal roll. The 10458 program covered 8 orbits and obtained 18 exposures of NGC1851, 18 exposures of NGC6752, and 78 exposures of NGC2298. A companion three-gyro program, 10455, was obtained in February 2005 using a subset of the exposures in 10443 with the same observing configuration, therefore providing useful exposures that could be directly compared with those obtained in two-gyro mode.

The observations used a range of guide stars with magnitudes V=11, 13, and 14. The exposure times were 10 seconds, 100 seconds and 500 seconds, and were obtained in a variety of configurations including CRSPLIT sequences of 2, 4 and 5 exposures (with no dithering) as well as 2-point and 4-point dither patterns, with some of the 2-point patterns containing a 2-exposure CRSPLIT pair at each location. Most of the observations used the F555W filter, with additional F330W observations obtained in February 2005.

3. Analysis and Results

3.1. Initial Processing and Distortion Correction

All the exposures were first processed through standard ACS calibration, including gain correction, bias and dark current removal, and flat field correction. The resulting calibrated FLT files were then transformed onto an undistorted output frame using the MultiDrizzle software (Koekemoer et al. 2002), which makes use of Drizzle (Fruchter & Hook 2002) to remove the ACS geometric distortion using the most up-to-date distortion files (IDCTAB) and distortion residual images (DGEOFILES), as specified in the image headers (ACS ISR 2004-15, Anderson & King 2005). This step also accounts for slightly different distortion terms in different filters (F555W and F330W), and removes small additional scale changes due to velocity aberration resulting from changes in the motion of HST along the line of sight to the target during an orbit. Thus, exposures from different times and with different filters could be directly compared with one another. The resulting set of drizzled images, one for each exposure, were all examined in detail to verify that there were no problems, before continuing with the pointing measurements.

3.2. Catalog Generation

The pointing accuracy was measured for all the exposures, regardless of whether they had been obtained as part of a CRSPLIT or NUMEXP sequence with no dithering, or whether a dither pattern had been used. The goal was to measure how well each exposure aligned with the commanded pointing of the telescope. This was measured by first creating a catalog for each exposure using the IRAF DAOFIND software (Stetson 1987), with parameters optimized for centroiding on unresolved stellar sources. For the clusters NGC2298, NGC1851, NGC6341, and NGC6752, the images typically contained $\sim 1000 - 2,500$ stars that could be matched between all the exposures (10, 100 and 500 seconds) while the F330W images contained $\sim 800 - 1,100$ stars that could be matched. For Omega Centauri, only $\sim 50 - 60$ stars were matched so this dataset served more as a consistency check. Cosmic rays were generally not a problem; most of the exposures were short enough to have a low number of cosmic rays, and the number of stars was generally large enough that occasional stars affected by cosmic rays would show up as significant outliers and could be easily rejected.

3.3. Shift Measurement Results

We used the catalogs to iteratively solve for shifts, rotations and possible scale changes. All scale changes from velocity aberration were successfully removed, and no significant additional time-dependent scale changes were present. The only remaining scale change is between short and long exposures, along the y-axis to the level of a few times 10^{-5}. This is accounted for by a known effect related to CTE (charge transfer efficiency) which produces slight changes in the centroids of stars. However, this scale change is not time-dependent, and comparisons between exposures of the same length showed no significant scale changes during the observations. No other geometric changes were found and the final analysis was conducted by solving for shifts and rotations, keeping other terms fixed. The resulting measurements for each exposure represent the difference between the commanded HST pointing and the actual pointing obtained. All of these can be presented relative to the first exposure in each orbit, and are shown in Figure 1.

The results show that the stability of the telescope is generally very good, with each exposure aligning to within a few milliarcseconds of the commanded offsets. While some orbits show a slight gradual change with time up to $\sim 4 - 5$ milliarcseconds, this is also found to occur in three-gyro mode and is interpreted as the result of thermal changes within the telescope. It should be recalled that the orbits during each test were not contiguous but obtained over several days, during which other targets at different sun angles were also observed, therefore slight changes in tracking due to thermal effects might be expected. However, the principal result is that the translational and rotational stability of the telescope remains good and shows no dramatically different behavior to three-gyro mode.

We also compared these results to three-gyro data from program 10455 and Cycle 12 program 9750 (PI: K. Sahu), which used ACS/WFC over 105 orbits to observe the galactic bulge (TEL ISR 2005-02, Gilliland et al. 2005). Since the telescope becomes thermally stable after about a day, we chose the first 20 orbits of this program as being representative of three-gyro data. In Figure 2 we show a histogram summarizing the relative offsets that were presented in Figure 1 for two-gyro mode, along with the similar measurements obtained for the comparable data from program 9750. In all cases, the shifts and rotations represent the differences from the commanded pointings for all exposures within an orbit, relative to the first exposure in the orbit. From the figure it is apparent that the distributions are not significantly different, and this is also borne out by the quantitative comparison between the two distributions when we characterize each distributions in terms of its r.m.s. dispersion. This was verified independently by A. Riess and the other team members. The results are presented in Table 1. We also find that the pointing repeatability for guide star re-acquisitions between orbits does not appear significantly worse than in three-gyro mode, although we were only able to verify this for a few orbits.

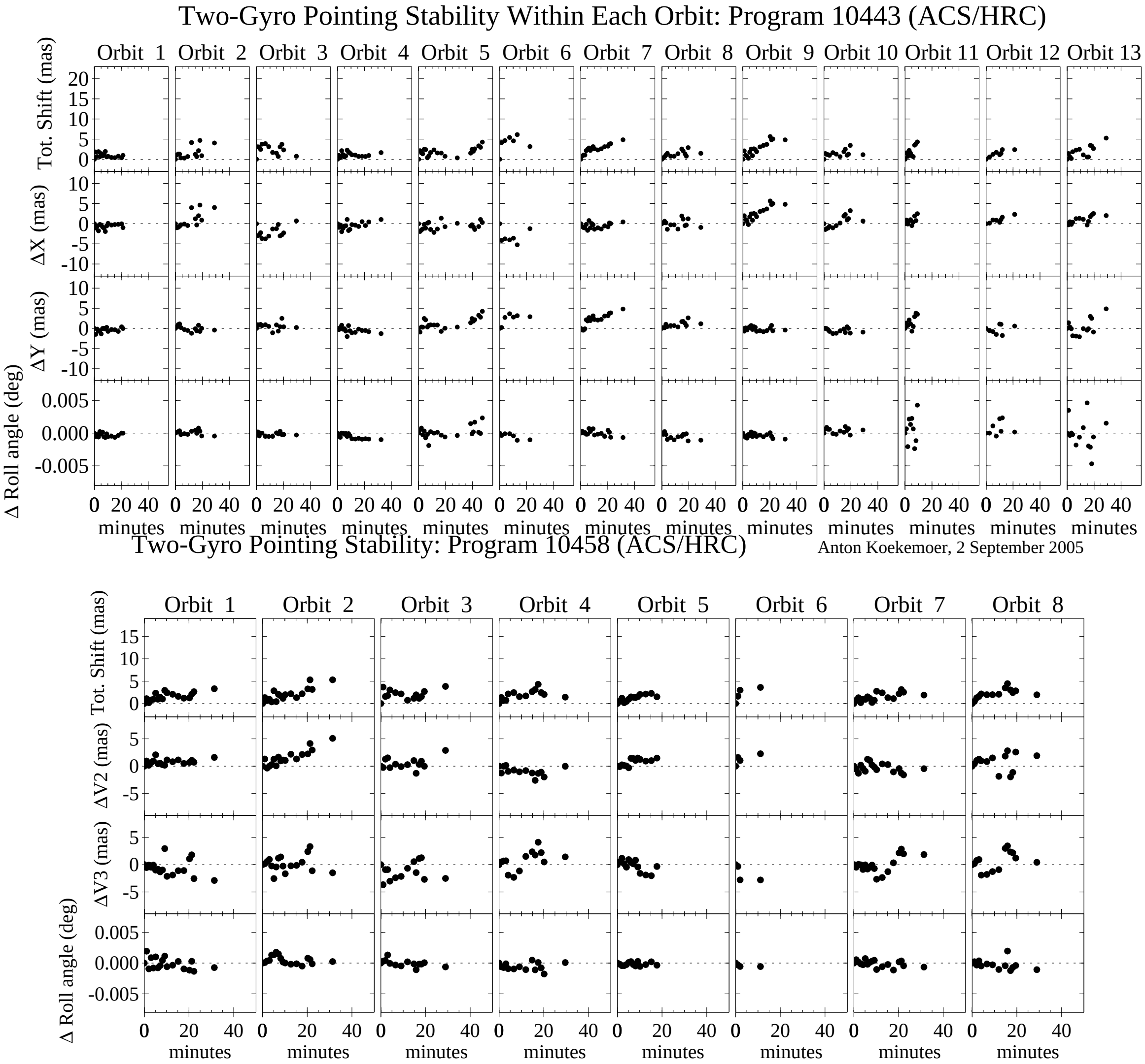

Figure 1: Relative pointing accuracy of HST for the observations obtained in February 2005 (top) and August 2005 (bottom), for a total of 301 exposures, including dither patterns. The offsets represent the difference between the commanded and actual pointing, to quantify the stability of HST during an orbit. It can be seen that the stability is very good to the level of a few milliarcseconds, which is comparable to three-gyro performance.

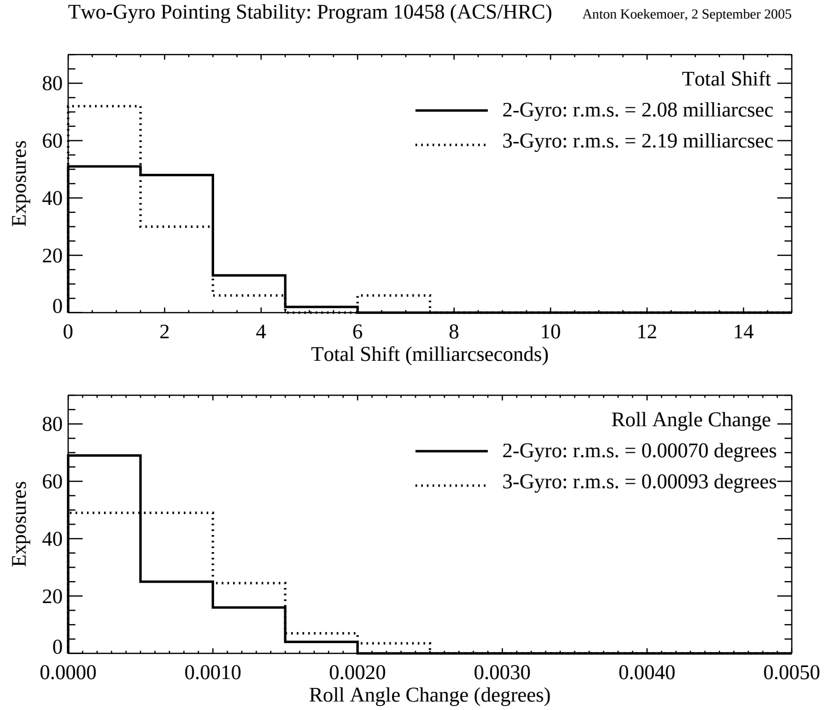

Figure 2: A comparison of the histogram distribution of shifts and rotational offsets between the two-gyro test data and comparable three-gyro data. These offsets represent the differences between commanded and measured pointings, as plotted in Figure 1. There is no significant difference between two-gyro and three-gyro data for either shifts or rotations.

Table 1: HST Pointing Stability Summary: ACS/HRC

	Total Shift r.m.s. (milliarcseconds)	Roll Angle r.m.s. (degrees)
Two-gyro (February 2005)	2.29	0.00097
Two-gyro (August 2005)	2.08	0.00070
Three-gyro (nominal)	2.19	0.00093

3.4. Processing Two-Gyro Data through MultiDrizzle

As a final test, we processed the two-gyro exposure sequences through the MultiDrizzle software (Koekemoer et al. 2002), which is used in the HST pipeline to automatically register images based on their headers, perform cosmic ray cleaning and create a final combined image using Drizzle. A variety of multiple exposure sequences were obtained in the two-gyro test, including those specified using CRSPLIT, NUMEXP, and dither patterns. As an initial test, the images were processed through MultiDrizzle using only their header astrometry as a basis for registration, thus ignoring the offsets of a few milliarcseconds that were shown in Figure 1. This is the current behavior of the pipeline, in the sense that the images are registered based on their commanded offsets. The results from these tests showed that there is no significant degradation in the quality between the images, which was confirmed quantitatively by measuring the PSF of stars in the images in each case.

This agreement is consistent with the fact that the offsets of the exposures as shown in Figure 1 were found to be only a few milliarcseconds, or less than about 0.1 HRC pixels. Therefore, these two-gyro images can generally be combined directly to the same degree of accuracy as three-gyro data, using the astrometric headers information. If it is ever necessary to incorporate measured shifts, as demanded by certain types of scientific programs, then this can be done by means of the ”Tweakshifts” script which uses the techniques described here to solve for shifts and apply them to the image headers, prior to image combination.

4. Summary

We have presented the results of the pointing stability tests for HST, as measured with the ACS/HRC during the Two-Gyro test program conducted in February 2005 as well as the verification observations in August 2005. We have measured the shifts of 301 exposures of the globular clusters NGC1851, NGC2298, NGC6341, NGC6752, and Omega Centauri, obtained over a total of 21 orbits, and have compared the measured pointings to those that were commanded in the observing program. We find in all cases that the measured offsets of shifts and rotations agree with those that were commanded to the same level of accuracy as in three-gyro mode. Specifically, the differences between commanded and actual pointings during an orbit relative to the first exposure can be characterized with distributions having dispersions of $\sim 2.1 - 2.3$ milliarcseconds for shifts and $\sim 7.0 - 9.7 \times 10^{-4}$ degrees for rotations, thus less than 0.1 HRC pixels, and agree extremely well with similar values measured for comparable exposures obtained in three-gyro mode. In addition, we successfully processed these two-gyro test data through the MultiDrizzle software which is used in the HST pipeline to perform automated registration, cosmic ray rejection and image combination for multiple exposure sequences, and we find excellent agreement with similar exposures obtained in three-gyro mode. In summary, we find no significant difference between the quality of HST pointing as measured from these two-gyro test data, relative to the nominal behavior of HST in regular three-gyro operations.

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