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WFC3 TV2 Testing: Image Stability

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ABSTRACT

I review the image stability tests performed during the second thermal-vacuum (TV) campaign of WFC3. In the first TV campaign, significant drifts were seen in both channels in response to induced thermal changes in the instrument, but subsequent analysis indicated that the induced temperature variations were unrealistically large (compared to on-orbit conditions). In the current tests, the magnitude of the thermal variations was reduced to approximate conditions that will be seen on orbit. During those times when conditions provided a realistic simulation, the image stability was within specifications for some, but not all, of the time. Specifically, the image stability was acceptable during cold-case simulations of orbital cycling and telescope slewing, but not during hot-case simulations of these variations. During hot orbital cycling, the drift rates in the UVIS and IR channels were up to 1.3x that in the CEI specifications, while during hot orbital cycling and slewing, the UVIS drift rates were up to 2x that in the specification, and the largest IR drift rates were still at 1.3x the specification. The stability test was also run for significant periods when the thermal variations were much larger than anticipated on orbit, and during these times, the image drift rate often exceeded specifications.

Background

The thermal environment in HST varies significantly on a variety of timescales, including orbital variation, slews from target to target, seasonal variations, and the long-scale degradation of thermal blankets. These temperature variations can induce image drift in scientific instruments, with two primary impacts on scientific observations: drift within an exposure will degrade the image resolution, while drift between exposures will hamper efforts to resample the point spread function (PSF) through dithering. For these reasons, the Contract End Item (CEI) specification for WFC3 image stability calls for less than 10 mas (0.25 pixels) of drift in 200 min (approximately 2 orbits) on the UVIS channel, and less than 20 mas (0.16 pixels) of drift on the IR channel in 200 min.

During the first round of thermal-vacuum (TV) tests, WFC3 appeared to violate its CEI specifications for stability (Brown 2005a, WFC3 ISR 2005-11), but subsequent analysis at GSFC found that thermal variations in the test enclosure did not accurately simulate the conditions that will be encountered on orbit. For this reason, the thermal variations were reduced during the image stability tests of the second TV campaign. The simulations of orbital cycling and telescope slewing were performed for both cold and hot cases, with these cases representing the extreme conditions that might be encountered on orbit. The stability test was also run during periods where conditions were not realistic, as when WFC3 was transitioned rapidly from one extreme case to the other; violations during these periods should not be considered an actual problem with the instrument.

The WFC3 image stability was tested on both channels during the current campaign, taking place in the summer of 2007, in a manner similar to that done in the first thermal vacuum campaign. The test was run in three periods: Jul 5-7, Jul 17-19, and Aug 3. During each period, the thermal environment was modulated using the cryopanels placed around the instrument.

In the first TV campaign, two types of test were employed to track image stability: one involving a point source from the optical stimulus (CASTLE), and another that placed the channel select mechanism (CSM) in an intermediate position, to isolate the motion in WFC3 components downstream of the pick-off mirror (POM). That latter CSM version of the test was introduced to troubleshoot the large image drifts seen in the standard image stability tests, and it was not used in the current TV campaign. All of the stability data described herein involved observations of the CASTLE point source with interleaved observations in the IR and UVIS channels, commanded by SMS UV12S03 and CASTLE script UV12C03. CASTLE illuminated the WFC3 detectors with a 10 micron fiber fed by the tungsten lamp. During the stability tests, WFC3 images were obtained in rapid sequence, alternating between channels, with 10 UVIS/F814W images, 3 IR/F128N images, 10 UVIS/F814W images, etc. The UVIS images were 400x400 pixel subarrays of 10 sec each, while the IR images were 512x512 pixel subarrays of 4.2 sec each (read in a RAPID sequence of 6 images). A total of 2,791 WFC3 images were obtained in all. No intentional changes were made to the optical stimulus during the test, and the only mechanical changes to WFC3 were motions of the CSM, which is known to be very repeatable (Brown et al. 2005b, ISR WFC3 2005-18). The "quad-cell" detector on CASTLE was used to record motion intrinsic to CASTLE, enabling subtraction of such motion from the WFC3 images, thus approximately isolating motions intrinsic to WFC3.

Analysis

The series of images in each test were analyzed using IDL software written during the first TV campaign (see Brown et al. 2005a). The software was updated to reflect conditions during the current TV campaign (image source position, image intensity, IR reads used, etc.), and to update the transformation between IR, UVIS, and CASTLE reference frames. In particular, it is worth noting that the IR images are now rotated 90 degrees with respect to their orientation in the first TV campaign, so that their orientation on the sky is approximately the same as that of the UVIS images. Furthermore, a dark subtraction is now made on all of the IR images, given the large number of hot pixels in the current IR detector (FPA129, also known as IR1), which can bias the centroid of the CASTLE source. All of the analysis is done in a common reference frame, arbitrarily tied to the UVIS detector. The position of the source was determined from a two-iteration centroid on a small median-subtracted subsection of each subarray image. This subsection was 20x20 pixels on the UVIS channel, and 5x5 pixels on the IR channel.

Two transformations are required to put all of the data (UVIS, IR, and CASTLE) in the UVIS reference frame (R. Telfer, priv. comm.). The transformation from CASTLE to UVIS frame is:

$X_{UVIS} = -0.9784\ X_{CASTLE} - 0.9707\ Y_{CASTLE}$ $\qquad Y_{UVIS} = +1.0398\ X_{CASTLE} - 0.9101\ Y_{CASTLE}$.

The transformation from IR to CASTLE frame is:

$X_{CASTLE}=-1.46456\ X_{IR}+1.30856\ Y_{IR}$ $\qquad Y_{CASTLE}=-1.46456\ X_{IR} -1.30856\ Y_{IR}$.

The code performs these transformations in microns on each of the detectors in question (because CASTLE quadcell data are given in microns). The UVIS and IR pixels are 15 and 18 microns wide, respectively. The UVIS and IR plate scales in X are 39.7 mas/pixel and 135.5 mas/pixel, respectively, while the UVIS and IR plate scales in Y are 39.5 mas/pixel and 121.1 mas/pixel, respectively.

Results

The image drift in each channel for each of the three test runs is shown in Figures 1-3. Plots are shown first without the CASTLE motion subtracted (to give an idea of how large the intrinsic CASTLE variations were with respect to the motions we are trying to track in WFC3) and then with the CASTLE motion subtracted (to approximate motion intrinsic to WFC3 alone). Ideally, one would want the CASTLE motion to be smaller than 10 mas in 200 min, so that the measured WFC3 motion was not subject to a correction significantly larger than the signal we are trying to detect. In practice, the CASTLE was not sufficiently isolated from the changes in the thermal environment, and the measurements of WFC3 motion were often subject to a significant correction for CASTLE motion ($\lesssim$175 mas).

Although the instrument stability was within CEI specifications during the “cold orbital cycling” and “cold orbital cycling and slewing” simulations (Figure 1), the stability violated CEI specifications during the “hot orbital cycling” and “hot orbital cycling and slewing” simulations (Figure 2), possibly due to the *much* larger temperature swings induced in the hot case. The drift rate on the UVIS channel was 1.3x the CEI specification during “hot orbital cycling” and 2x the CEI specification during “hot orbital cycling and slewing.” The drift rate on the IR channel was 1.3x the CEI specification during both “hot orbital cycling” and “hot orbital cycling and slewing.” However, the conditions were not strictly flight-like during the entire period of “hot orbital cycling,” due to cryopanel adjustments made on the fly, and if one considers only the flight-like subset of the “hot orbital cycling” data, no violations occurred. The violations of the CEI specification were not at all random in the sense of the image drift; to help isolate which part of the instrument might be responsible, Figure 4 shows the spatial distribution of all CEI specification violations (whether they occurred during realistic flight conditions or not).

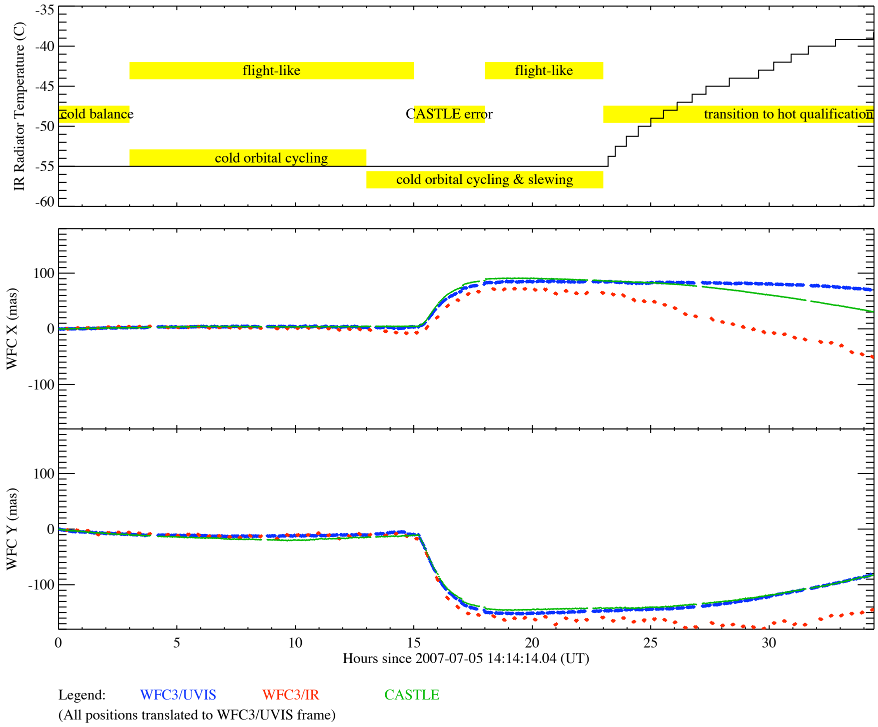

Figure 1a: The image stability test data from Jul 5-7, shown without correction for CASTLE motion. The top panel in each plot shows the temperature of the IR radiator, to give an indication of large changes made in the thermal environment; conditions are annotated (*yellow*); many other temperatures are available in the engineering headers of the WFC3 images, but this temperature provides a good proxy for the gross changes in the cryopanels. The middle panel shows the image motion in the UVIS images (*blue points*), IR images (*red points*), and CASTLE quad cell (*green points*), in the X-axis of the UVIS reference frame. The bottom panel shows these motions in the Y-axis of the UVIS reference frame. From 0 to 3 hours, the instrument was stable in cold thermal balance, after which cold orbital cycling began. To simulate orbital cycling, the cryopanels were cycled from -120 to -140 ^{o}C, although these changes were too small to significantly impact the IR radiator temperature. During the period from 13 to 23 hours, orbital cycling was simulated on top of a telescope slew (where the enclosure was warmed by approximately 3 ^{o}C). At 23 hours, the instrument was transitioned to the "hot qualification" case (note the large change in the IR radiator temperature); that transition was not a realistic flight condition. Thus, from a thermal perspective, flight conditions existed only from 3 to 23 hours in this test. However, due to a CASTLE error, CASTLE itself suffered a significant shift at 15 hours (reflected also in the WFC3 image data), and this disturbance did not settle down until 18 hours. The CASTLE disturbance exceeded the stability specification by more than an order of magnitude, so this period from 15 to 18 hours cannot be considered a realistic flight condition, either. Flight conditions were only present from 3 to 15 hours, and then from 18 to 23 hours.

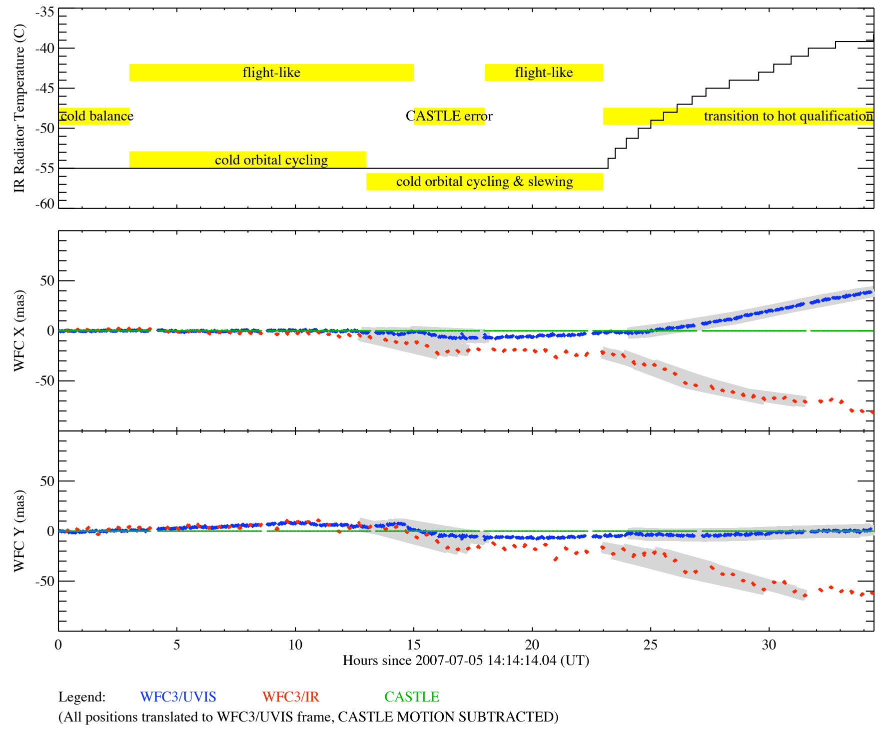

Figure 1b: The same as in Figure 1a, but the motion intrinsic to CASTLE has been subtracted from the source drift in the WFC3 images. A thick grey line connects all pairs of datapoints that violate the CEI specification; i.e., they fall on the same detector within a 200 minute window and indicate a total drift exceeding 10 mas (UVIS) or 20 mas (IR), where the total drift is the quadrature sum of the drift in each axis. Fortunately, the only violations involve points affected by unrealistic flight conditions; either the points themselves fall within an unrealistic flight condition, or the points are paired with those in an unrealistic flight condition. If the periods of 3 to 15 hours and 18 to 23 hours are considered in isolation, no violations of the CEI specification occurred. Thus, WFC3 image stability was within CEI specifications for both “cold orbital cycling” and “cold orbital cycling and slewing” cases.

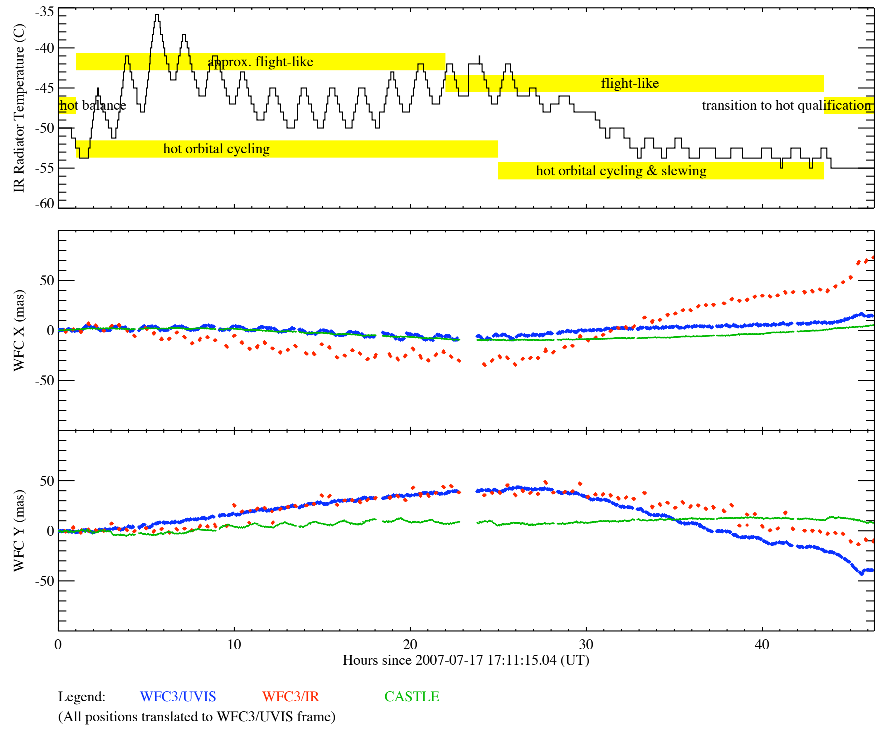

Figure 2a: The same as in Figure 1a, but for the period of Jul 17 to 19. Simulated flight conditions begin 1 hour into this dataset. From hours 1 to 25, the "hot orbital cycling" case was simulated, with temperature variations 7 to 8x larger than those induced than those in the cold case; this is because in the hot case, the WFC3 radiator experiences a range from full Earth view to deep space view, while in the cold case, the radiator has a roughly constant and partial view of the Earth. For the first few hours, the cryopanels were varied from -180 to -20 °C, but then the hot extreme was cooled, giving a variation of -180 to -43 °C. That temperature correction was done in order to compensate for reduced heat pipe functionality, compared to the expectations prior to the test, and in that sense it is not strictly a flight-like variation. From 22 to 25 hours, there were three repeated thermal cycles that were realistic, but WFC3 data were not obtained for that entire 3-hour window. At 25 hours, orbital cycling was simulated on top of a telescope slew, with the enclosure environment cooled by approximately 3 °C. During this slew, the cryopanel variation was not as extreme, ranging from -120 to -75 °C. At 43.5 hours into the test, the environment was transitioned to "cold qualification" in a manner not realistic for flight. CASTLE was fairly stable during this entire dataset.

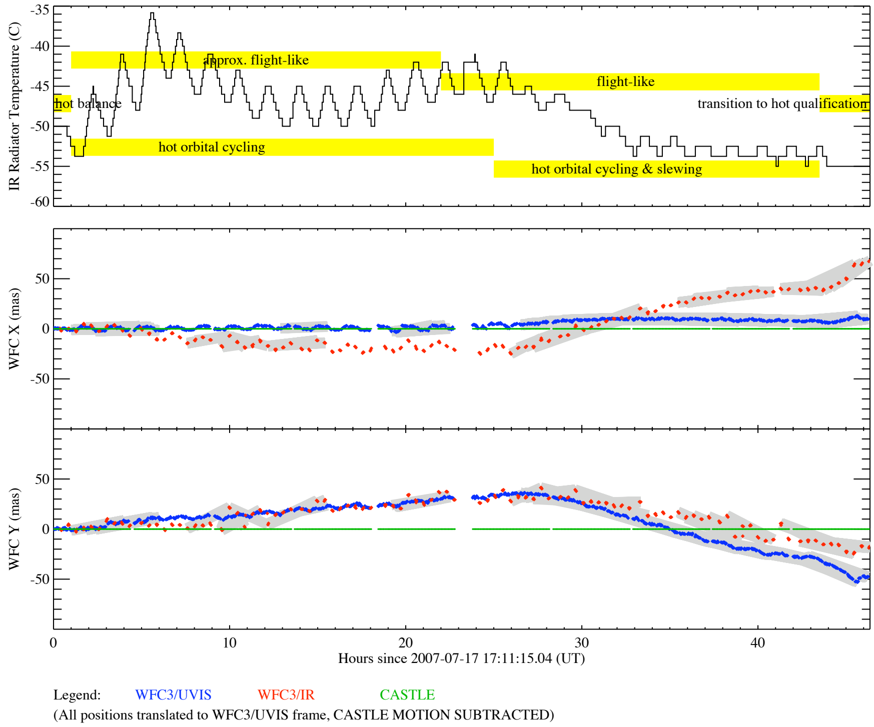

Figure 2b: The same as in Figure 1a, but for the period of Jul 17 to 19. Some of the CEI spec violations (*grey*) involve datapoints that do not reflect realistic flight conditions (before 1 hour or after 43.5 hours). Unfortunately, most of the violations occur when conditions were realistic for flight, or at least close to realistic. The largest such violations occur during the simulations of orbital cycling on top of telescope slewing (25 to 43.5 hours); here, pairs of images can be constructed within 200 minute windows showing the source moving by 19.4 mas in the UVIS channel (twice the CEI specification) and 26.3 mas in the IR channel (1.3 times the CEI specification). During the time frame when only orbital cycling occurred (1 to 25 hours), the UVIS violations were significantly reduced, with the largest at 13.0 mas, but the largest of the IR violations were only slightly reduced, at 25.4 mas. Strictly speaking, the "hot orbital cycling" simulation was only realistic from 22 to 25 hours, and if one considers only the data within that time frame, there were no violations of the CEI specifications on either channel. In short, during "hot orbital cycling," both channels failed the CEI specification by a factor of 1.3, while during the "hot orbital cycling and slewing" simulations, the UVIS channel failed by a factor of 2 and the IR channel failed by a factor of 1.3.

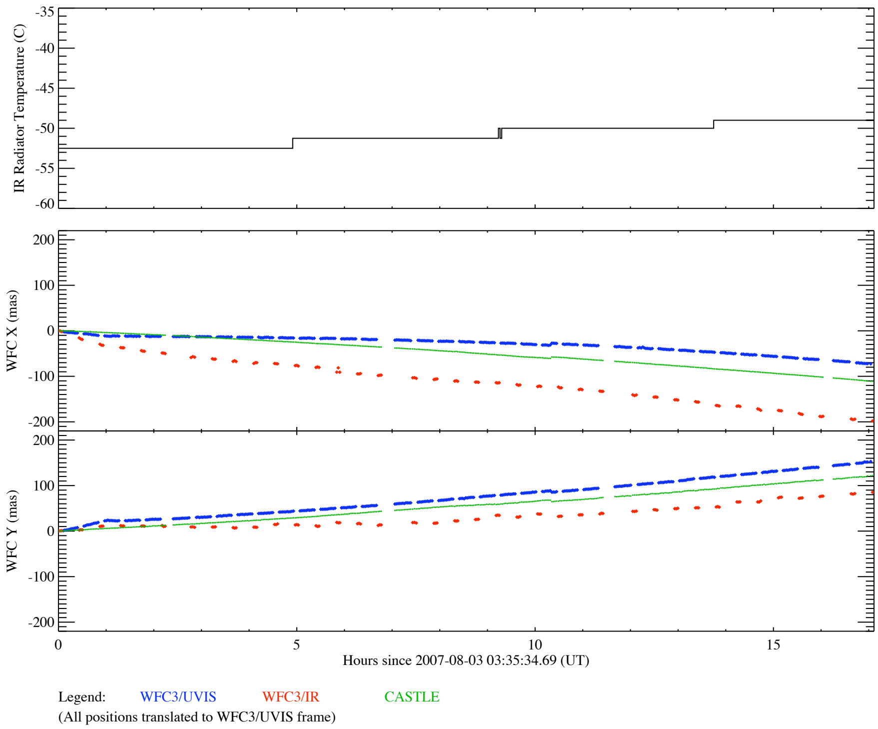

Figure 3a: The same as in Figure 1, but for the image stability tests run on Aug 3. During this entire period, the conditions were not a realistic representation of those on orbit. CASTLE itself was undergoing extremely large drifts (exceeding by more than an order of magnitude those stability in the CEI specification), and the thermal environment was being transitioned from "Cold Operate" to "Hot Qualification" configuration.

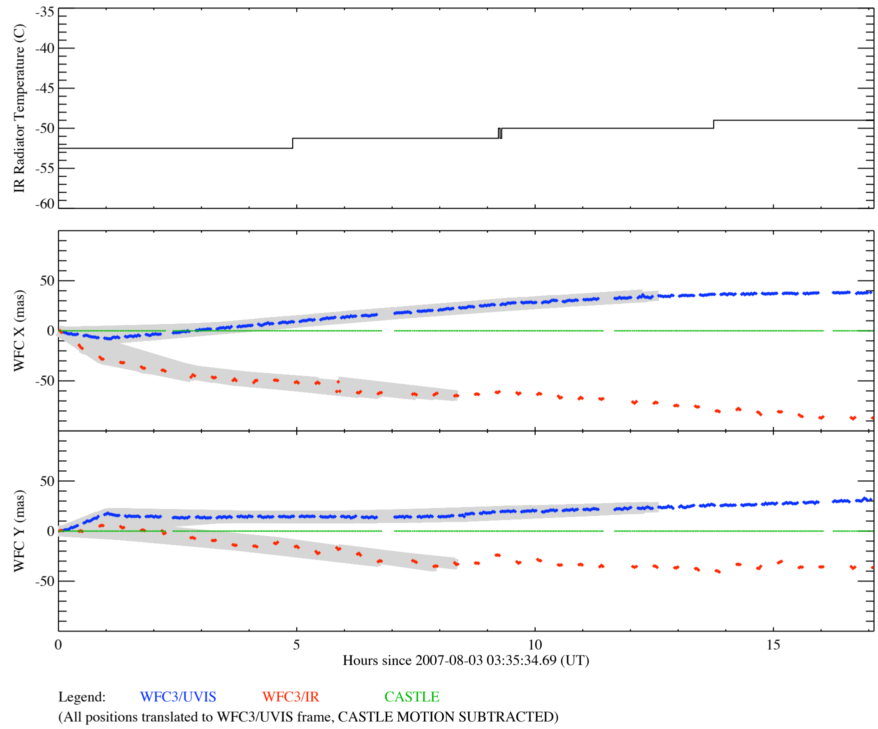

Figure 3b: The same as in Figure 1b, but for the image stability tests run on Aug 3. Although there are long periods where the drift on WFC3 was larger than that allowed under CEI specifications (*grey*), this entire time period was one where conditions were not a realistic approximation of those on orbit.

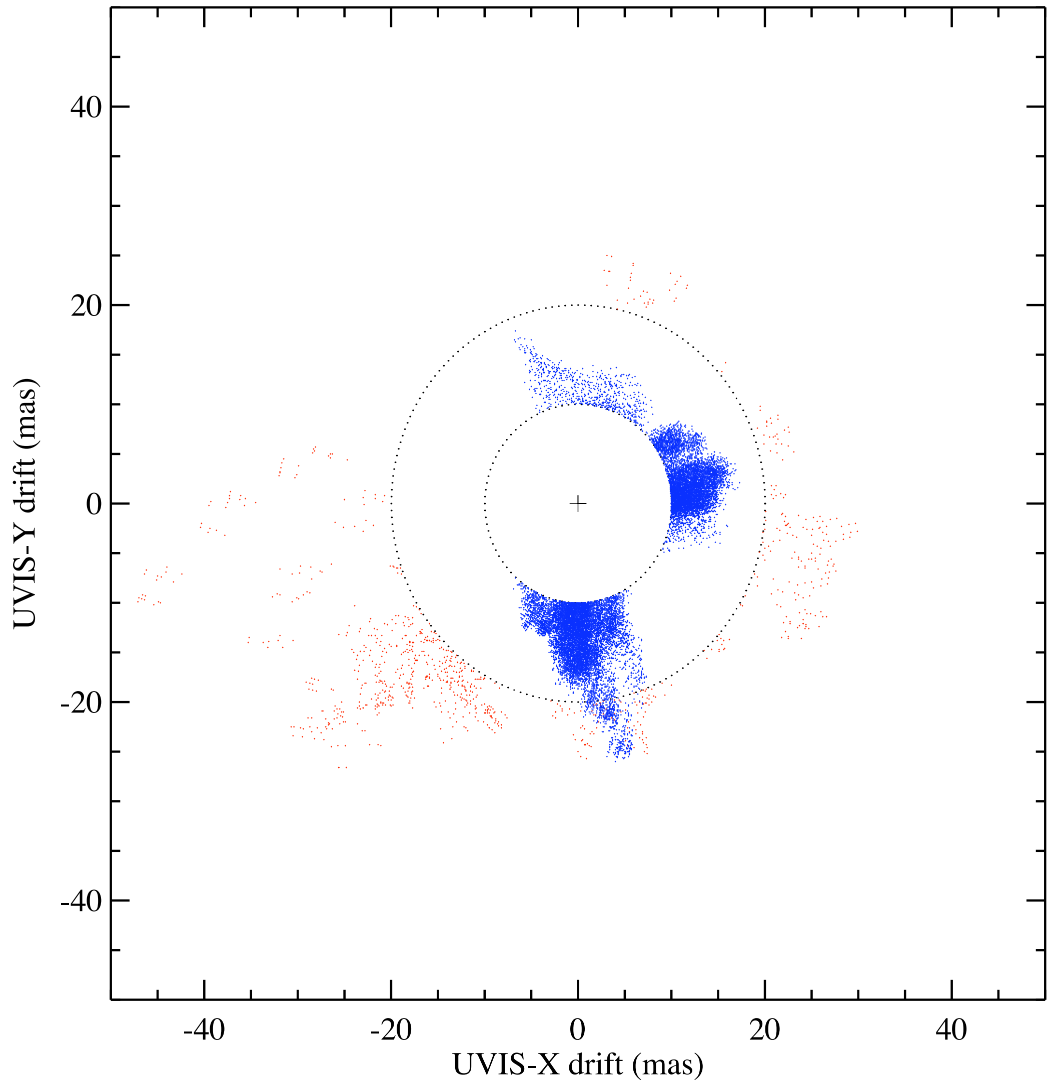

Figure 4: The spatial distribution of drifts that exceeded the CEI specification for the UVIS (*blue points*) and IR (*red points*) images. **All violations from the image stability tests are shown, whether the conditions were flight-like or not.** The CEI specification for each channel is also shown (*dotted lines;* UVIS = 10 mas = 0.25 pix; IR = 20 mas = 0.16 pix). Each point represents a pair of images falling within a 200 minute window, with the sense of the drift corresponding to the motion forward in time.

Acknowledgments

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