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WFC3 SMOV Program 11798: UVIS PSF Core Modulation

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ABSTRACT

The image quality analysis carried out during the third thermal-vacuum campaign (TV3) revealed that vibrations of the UVIS shutter cause changes in the width and in the central pixel flux of point sources in short exposures. During the Servicing Mission Observatory Verification (May-August 2009) we observed the flux standard star GD153 with a series of 0.5 sec, 1.0 sec, 3.0 sec, 10.0 sec and 20.0 sec exposures to investigate the impact of the shutter vibration on data acquired in orbit. Our analysis shows that in the very short exposures (<3.0-10.0 sec) the PSF is significantly degraded, but that the flux is preserved.

Introduction

An anomaly in the characteristics of the WFC3/UVIS point spread function (PSF) was discovered during the ground tests in the TV3 campaign. In series of short exposures the width of the PSF and the peak signal fraction for a point source were observed to modulate for alternate exposures. This behavior was strongly dependent on exposure time, with the greatest modulation occurring at 0.5 sec exposures (the shortest exposure time possible) and was ascribed to vibration of optical train components induced by the UVIS shutter mechanism (Hartig 2008).

Accelerometer measurements showed that whenever the shutter servo electronics were enabled, a significant amount of vibration was induced in the optical bench (Rossetti et al. 2008). These ground tests showed that, on the ground, the amplitude of the vibration depended on the orientation of the instrument and led the engineering team to conclude that on-orbit effect could be as much as 3 times that observed from the ground (Hartig 2008).

Proposal CAL-11798 was designed to evaluate the impact the shutter vibration on the stellar PSF in the on-orbit data. This proposal was executed during the 4^{th} Servicing Mission Observatory Verification (SMOV4) that followed the Servicing Mission 4 (SM4) in May 2009 during which WFC3 was installed on HST. In this ISR we describe the exposures, the analysis of the data and discuss the impact of the PSF modulation on science data.

Data

Five series of short exposures of the flux standard star GD153 were acquired during SMOV4 as part of Proposal CAL-11798, to measure the impact of the shutter vibration on the quality of the photometry. Table 1 summarizes the observations: in total we acquired 49 0.5 sec and 51 1.0 sec exposures in the F606W filter, 50 3.0 sec exposures in the F505W filter, 44 10.0 sec exposures in the F698M filter and 37 20 sec exposures in the F645N filter.

Images were acquired using the standard 512x512 pixel subarray in quadrant A to minimize the impact of buffer dumping, with no dithering. Each exposure was bias and dark subtracted and flat fielded using the standard calibration pipeline CALWF3[1] and, since no calibration files from space were available, the most updated version of calibration files aquired in TV3 were applied.

Analysis

For each exposure we measured several parameters using different pyraf routines: in particular we measured the full width half maximum (FWHM) with *imexam*, the sharpness with *daofind*, and the magnitude of the star within an aperture radius of 3, 5, 7, and 10 pixels using *phot*.

Figure 1 shows the variation of the stellar FWHM and sharpness in the 0.5 and 1.0 sec

[1] A complete description of CALWF3 is provided in the HST Data Handbook for WFC3 v1.0, Quijano et al. 2009)

Dataset	Start Time	End Time	Exp. Time (s)	Filter	# Exp
IABV01011	2009-07-23 07:06:46	2009-07-23 08:10:12	0.5	F606W	24
IABV01021	2009-07-23 08:11:06	2009-07-23 08:33:07	0.5	F606W	25
IABV01031	2009-07-23 08:34:01	2009-07-23 08:56:02	1.0	F606W	25
IABV01041	2009-07-23 09:39:39	2009-07-23 10:02:35	1.0	F606W	26
IABV01051	2009-07-23 10:12:54	2009-07-23 11:22:33	3.0	F555W	25
IABV01061	2009-07-23 11:23:27	2009-07-23 11:46:18	3.0	F555W	25
IABV01071	2009-07-23 11:47:23	2009-07-23 13:01:58	10.0	F689M	22
IABV01081	2009-07-23 13:02:52	2009-07-23 13:25:26	10.0	F689M	22
IABV02011	2009-07-29 13:24:18	2009-07-29 15:04:45	20.0	F645N	37

Table 1: *Logbook of the observations: the 1^{st} column reports the name of the association table, the 2^{nd} and 3^{rd} columns list when the observation started and ended, the used filter is reported in column 4, and the number of observations acquired is listed in column 5.*

long exposures. Results from the ground data are also shown for comparison. The same odd/even modulation (Hartig 2008) observed in the ground data is present also in the data acquired from the space. In the 0.5 sec exposures this modulation is ~ 2 times higher than in the ground data, in the 1.0 sec exposures the odd/even modulation is clearly visible, and it is ~ 14 times stronger than in the ground data acquired at the same exposure time.

Figure 2 shows the results for the 3.0 sec and 10 sec exposures from space. The odd/even effect is still present, but is strongly attenuated, especially in the 10.0 sec exposures. The most striking feature in this plots is the jump occurring around the $\sim 20^{th}$ exposure visible in both series of observations. Because of coma, stars in the four corners of the UVIS detector are elongated. During its orbit around the earth, HST is subject to temperature changes that cause variations in its focus. This behavior is called telescope breathing. Because of the breathing the PSF of each HST instrument changes within an orbit. The jump visible around the $\sim 20^{th}$ exposure is due to the telescope breathing and to the fact that the observations for each time series were not acquired within the same orbit (images before the jump were acquired at the end of one orbit, when the telescope is on focus, and images after the jump were acquired at the beginning of the following orbit, when the effect of breathing is maximum). This effect is illustrated in Figure 3 where two 0.5 sec images of GD153 in the F606W filter are compared. At the beginning of the orbit (left panel) GD153 is elongated along the top-left/bottom-right diagonal direction. At the end, on the contrary, the star

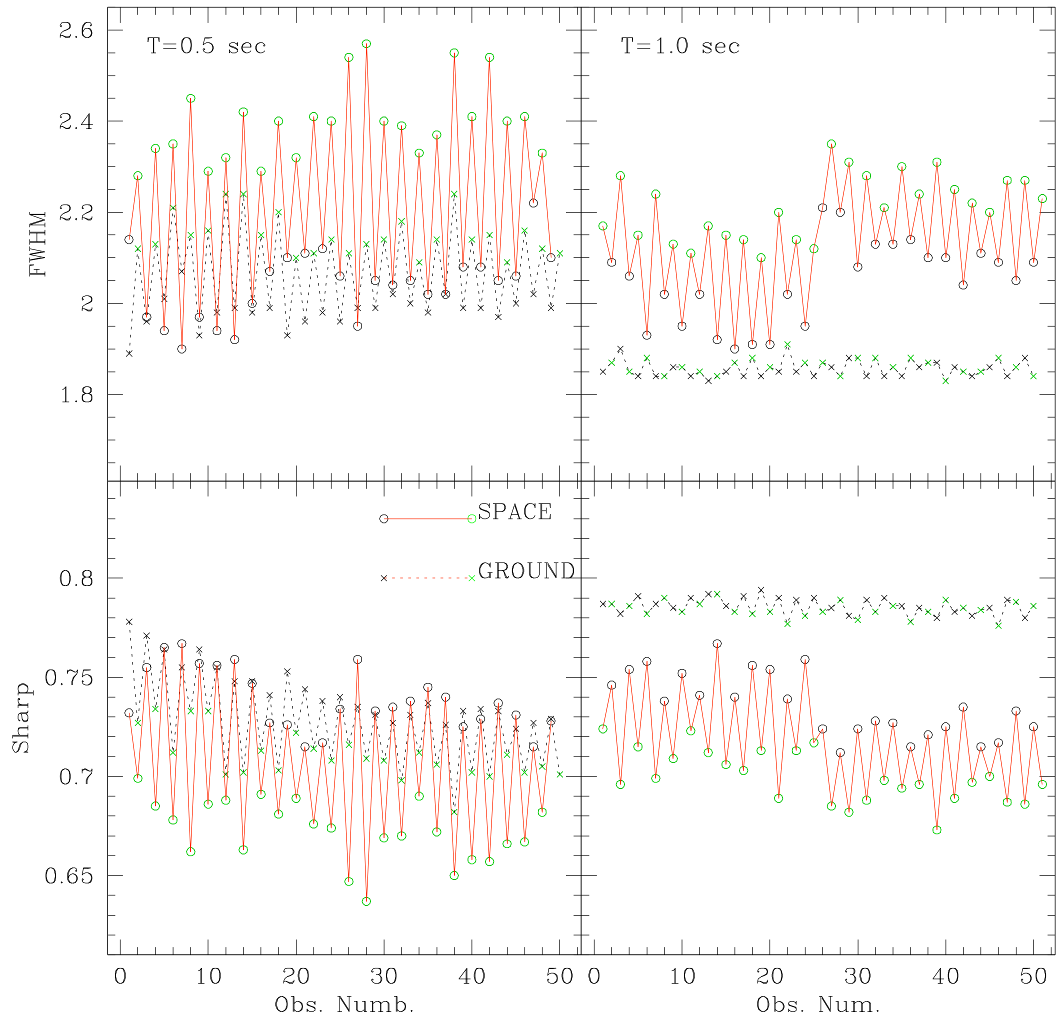

Fig. 1.— *Stellar FWHM and sharpness as function of exposure number for 0.5 sec (left panels) and the 1.0 sec (right panels) exposures. Open circles and red continuous lines are for the space data, x points and dotted black lines for the ground. Green points refers to side B of the shutter, black points to side A.*

looks more symmetrical (right panel). Both the images have been acquired with side B configuration.

Table 2 summarizes the impact of the shutter vibrations on the PSF FWHM. In particular it shows that in the 0.5 sec exposures from the space the FWHM is 15% broader on side B with the respect to side A. In the 1.0 sec exposures the difference in the FWHM is 7.3%, and (once the impact of breathing is taken into account) 2.4% in the 3.0 sec exposures. At

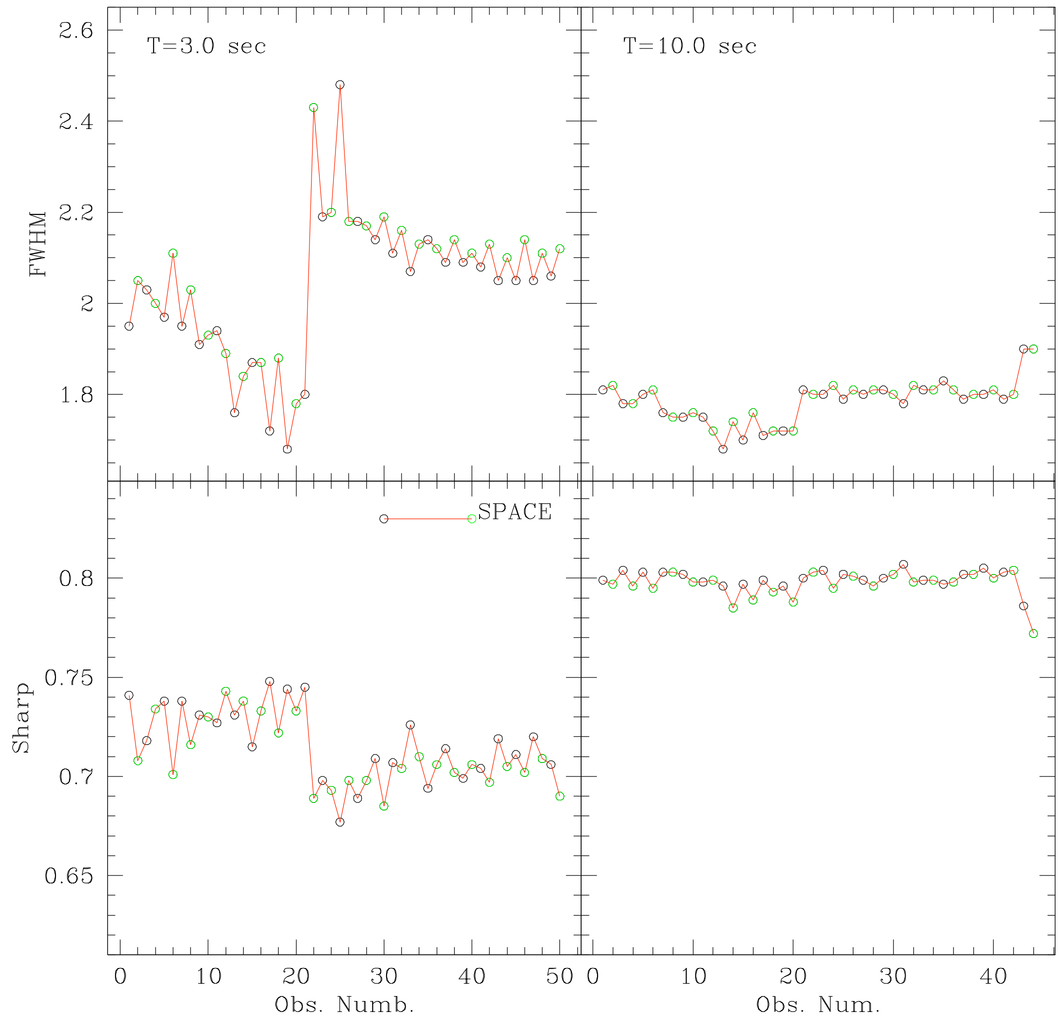

Fig. 2.— *Stellar FWHM and sharpens as function of the exposure number for the 3.0 (left panels) and the 10.0 sec (right panels) exposures. Green circles refers to side B of the shutter, black to side A.*

10.0 sec the difference is less then 0.5%.

In order to evaluate the impact of the odd/even effect on the photometry for each data-set, we measured the magnitude of the star at 3, 5 7 and 10 pixel radii using aperture photometry. Figure 4 shows the magnitude variations for the various exposure times. For each set of exposures the impact of breathing on the quality of the photometry is clearly evident in the set of analysis performed with the smallest aperture radius (3 pixels). These

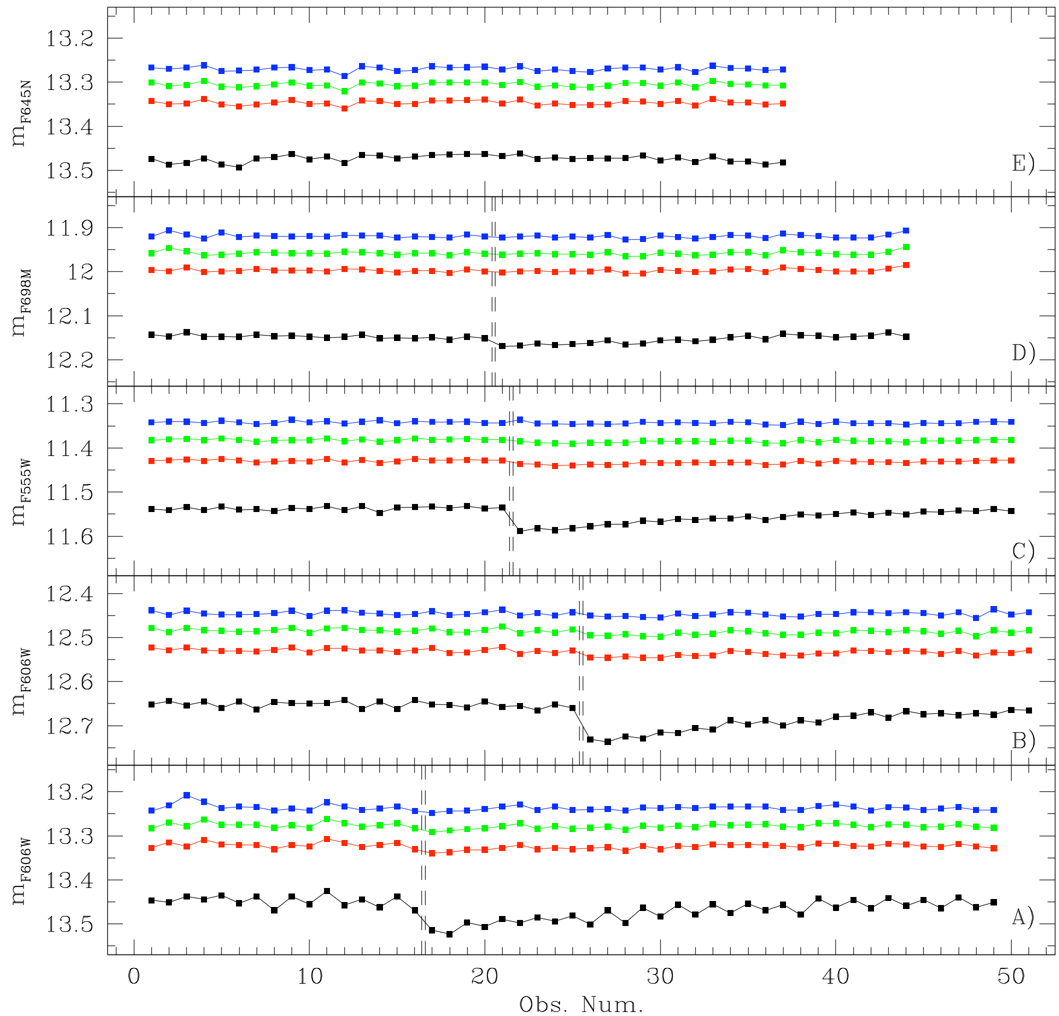

Fig. 3.— *Magnitude of the GD153 star as derived from a 3 (black), 5 (red), 7 (green), and 10 (blue) pixel aperture photometry for the 0.5 sec (A panel), 1.0 sec (B panel), 3.0 sec (C panel), 10.0 sec (D panel) and 20.0 exposures (E Panel). The dashed lines mark where an orbit ends and a new one begins.*

plots show that although the flux from the star is preserved, but because of the broadening of the PSF, there is an uncertainty of 2% in the magnitude of GD153 in the 0.5 sec exposures when an aperture of 3 pixels is used. However at r=5 pixel the uncertainties is 0.8%, and in the 1.0 sec and longer exposures the uncertainties in the r=3 pixel aperture photometry is always less than 0.7%. Figure 3 also shows that for the shortest exposures, 0.5 sec, telescope breathing and shutter vibrations have comparable impact on the quality of the photometry in

Exp. Time.	FWHM (side A)	FWHM (side B)
0.5	2.04±0.08	2.40±0.08
0.5*	1.98±0.03	2.15±0.05
1.0	2.05±0.08	2.21±0.07
1.0*	1.85±0.02	1.86±0.02
3.0	2.01±0.17	2.07±0.14
$3.0^{\otimes}$	2.08±0.03	2.13±0.03
10.0	1.78±0.05	1.79±0.04
$10.0^{\otimes}$	1.80±0.01	1.81±0.01
20.0	1.83±0.04	1.85± 0.05

Table 2: *Average FWHM measured in images acquired with different exposure time and different side of the shutter. Values marked with an asterisk are for ground based data for 0.5 and 1.0 exposures. The* $^{\otimes}$ *symbol indicates the values obtained before taking into account the telescope breathing.*

the 0.5 sec exposures, and that in relatively short exposures (e.g. 1.0 and 3.0 sec) breathing is the dominant source of uncertainties. Figure 5 shows the variation in ellipticity of GD153 as function of time for different exposure times. The passage from one orbit to the next is clear.

Conclusions

We measured the impact of shutter vibrations on the quality of photometry of a point source using observations of the flux standard star GD153. The star was observed in quadrant A with a standard 512×512 pixels subarray. Our analysis shows that in very short exposures (T=0.5 sec) the vibration of the shutter introduce an uncertainty of $\geq 2\%$ in the magnitude of the star when an aperture of radius smaller than 5 pixel is used and that the FWHM of stars acquired with shutter on side B is systematically larger than that acquired on side A. As a consequence stars will appear fainter in the corners of the detector if measured with a small aperture radius.

We confirm that shutter vibrations have less effect for longer longer exposure times, and that already for exposure times$\geq$ 1.0 sec the uncertainties induced by the odd/even effect are less then 1%. Our analysis shows also that telescope breathing increases the astigmatism that affects UVIS data in the corners, and that in short exposures acquired at the beginning

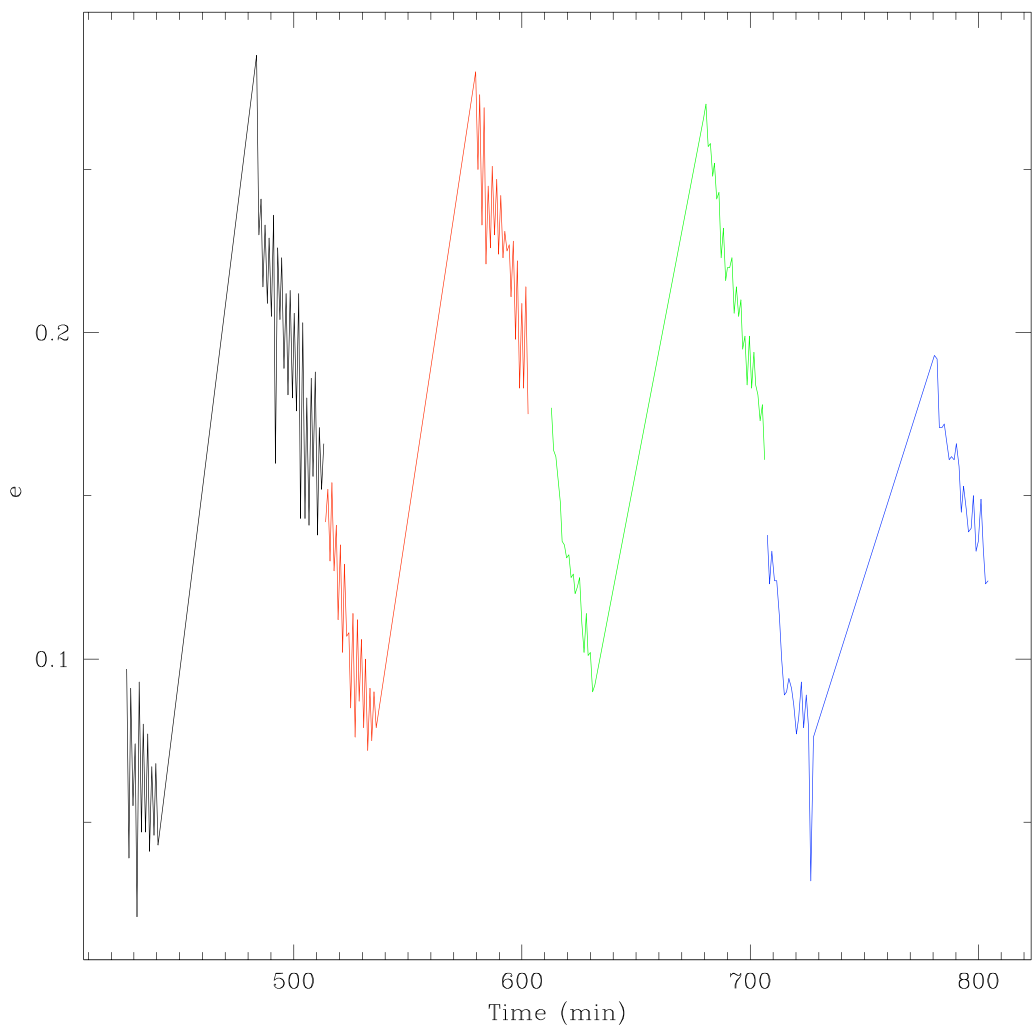

Fig. 4.— *Ratio between the minor and the major axis of GD153 as function of the observing time. Values obtained for the 0.5 sec exposures are in black, for the 1.0 sec exposures in red, green is for the 3.0 sec exposures and and blue for the 10.0 sec exposures.*

of an orbit sources in the four corners of the detector will be fainter than in exposures acquired with the same exposure time at the end of the orbit if using photometric aperture with a radius smaller than 4 pixels.

Acknowledgments

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References

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