No Evidence Found for WFC3/UVIS QE ‘Overshoot’

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ABSTRACT

Ground tests of WFC3/UVIS spare flight detectors showed that a QE instability can occur wherein the detector sensitivity is greater immediately following a super-saturated exposure relative to the sensitivity measured a few hours later. Dubbed QE ‘overshoot’, the low-level short-lived effect occurred when saturation levels reached at least 7 times the full-well amount and fluxes of ∼6100 e-/s. The Bowtie Monitoring program serves as a useful check for possible cases of QE ‘overshoot’ on-orbit. The majority of WFC3/UVIS images do not achieve the extreme saturation and flux levels that could potentially cause a QE ‘overshoot’ over large areas of the detector. However, we identified five science exposures which meet the QE ‘overshoot’ criteria and have bowtie observations taken within the first few hours following the saturating exposure. Inspections of image ratios between the first bowtie image after the saturating exposure and nominal reference bowtie images show no visible or quantifiable QE ‘overshoot’ features. Down to the detection threshold (∼0.5%), these data show no evidence of ‘overshoot’ in response to extreme saturation and flux levels. However, the data do not allow us to rule out ‘overshoot’ occurring at levels below a few tenths of a percent and/or with extremely fast decay times (<5 minutes).

Introduction

Several WFC3 calibration programs are employed annually to serve as a monitor of the overall health and stability of the WFC3/UVIS detector. One such program is the WFC3/UVIS Bowtie
Monitor, which has been in operation since the first on-orbit WFC3 images were taken and is used to detect and mitigate intermittent low-level Quantum Efficiency (QE) deficits (also known as detector hysteresis) across each UVIS CCD chip. A series of three UVIS internal flat field images are acquired every three days as part of the bowtie program: (1) An unsaturated image to check for the presence of hysteresis features and/or global QE deficits, (2) a saturated ‘pinning’ exposure to neutralize any QE offsets, and (3) another unsaturated image to allow for verification of the efficacy of the neutralizing exposure. Further details on the Bowtie Monitoring program can be found in WFC3 ISR 2013-09 (Bourque & Baggett 2013).

Testing of flight spare detectors at the Goddard Space Flight Center (GSFC) Detector Characterization Laboratory (DCL) revealed that a QE ‘overshoot’ can occur wherein the detector sensitivity is greater immediately after the saturated ‘pinning’ exposure relative to the sensitivity measured 1-2 hours later. This QE ‘overshoot’ occurred when two conditions were met: (1) when the detector was saturated to at least 7 times the full-well amount and (2) when the lamp flux reached $\sim 6100$ e-/second. Such a scenario resulted in a $\sim 2\%$ overshoot that slowly decayed over two hours (Collins et al. 2009). The QE ‘pinning’ exposures used in the Bowtie Monitoring program do saturate the CCD by $\sim 8$ times the full well amount but have count rates of only $\sim 3000$ e-/s/pix and do not cause and QE ‘overshoots’.

With the knowledge that QE instability can occur in the first few hours following images that meet the two ‘overshoot’ criteria in the spare detector, we search for any evidence of such an instability occurring with the WFC3/UVIS flight detector on-orbit. Any ‘overshoot’ in the flight detector, if present, is expected to be very low-level and short-lived, given the excellent long-term photometric stability ($<0.4\%$) measured on-orbit (Kalirai et al., 2010). Here we describe the on-orbit observations identified to have met the ‘overshoot’ criteria, as well as the analysis to determine if they caused any QE instability.

Analysis

We identified several external observations that meet the criteria for potentially causing QE ‘overshoot’ and have a bowtie observation taken within several hours following the saturating exposure. These observations are listed in Table 1 and originate from two GO programs: (1) program 13055 (Orbital Evolution and Stability of the Inner Uranian Moons, PI M. Showalter, Cycle 20) and program 13414 (Reading the Record of Cometary Impacts into Jupiter’s Rings, PI M. Showalter, Cycle 21). With the aid of HST schedulers, three bowtie visits were purposely scheduled to immediately follow observations of Jupiter’s Rings; this provides the best QE ‘overshoot’ test case to date, as the potential for any QE ‘overshoot’ to decay beyond detection was minimized.
Table 1: On-orbit WFC3/UVIS images that (1) met the QE ‘overshoot’ criteria and (2) had a bowtie observation taken within the first few hours after the highly-saturated external exposures. Observation dates and times reflect when the particular exposure commenced. Delta Time lists the amount of time between the end of the saturating exposure and the start of the proceeding bowtie exposure. Saturations are measured in full well amounts (e.g. 100 x the full well). Bowtie images ic4582t5q and ic450aa1q are from program 13072 (UVIS Bowtie Monitor, Cycle 20, PI M. Bourque), while bowtie images ice029gmq, ice028e8q, and ice027g6q are from program 13555 (UVIS Bowtie Monitor, Cycle 21, PI M. Bourque).

The saturation levels of the Uranus observations were determined by modeling the extended source via the Exposure Time Calculator (ETC), using a composite spectrum gathered from The Planetary Atmospheres Data Node (PDS) (http://atmos.pds.nasa.gov/). The count rates of the Uranus observations were calculated by dividing the estimated total number of observed electrons by the exposure time. The count rates of the Jupiter observations were determined by calculating the fluxes of previously observed unsaturated WFC3/UVIS Jupiter images. The saturation levels were then calculated by scaling up the fluxes by the exposure time.

Uranus

To detect any possible QE ‘overshoot’ features, we visually inspected image ratios between the first bowtie images following the saturating Uranus exposures and a reference bowtie image (iac702kkq from program 11808 (WFC3 UVIS Bowtie Monitor, Cycle 17, PI J. MacKenty) which was taken early in the mission and used as a reference image throughout the bowtie monitoring program). Particular attention was directed to the area of the detector in which the saturation occurred; images ic0451smq and ic0450oaq utilize the 512x512 UVIS2-C512C subarray located near the amplifier in quadrant C on UVIS chip 2 (FITS extension 1), and the extended source was nearly centered in the subarray aperture. With the bowtie image being 3x3 binned, we carefully examined the 171x171 sized image area in the lower-left hand corner of chip 2 and saw no features that were atypical of the nominal bowtie image ratio features described in WFC3 ISR 2013-09. The 171x171 image area corresponding to the UVIS2-C512C subarray for these two bowtie image ratios, as well as a nominal bowtie image ratio, are shown in Figure 1. For the nominal bowtie image ratio, we chose the iac777rdq/iac702kkq image ratio.
Fig. 1.—Two bowtie image ratios (left: ic4582t5q/iac702kkq, center: ic450aa1q/iac702kkq) using the first bowtie image proceeding the saturating Uranus exposures and one nominal bowtie image ratio (right: iac777rdq/iac702kkq) to be used as a visual comparison. Each figure shows the 171x171 image area in the lower left corner of chip 2 of the 3x3 binned bowtie image, corresponding to the 512x512 UVIS2-C515C subarray in which the saturating exposures were taken. The green circles represent the approximate location of where saturated Uranus source fell on the 3X3 binned frame. Greyscale stretch is +/-5%.

In addition to visual inspections, for all three bowtie image ratios, we plotted the average of selected rows across the detector versus each column (shown in Figure 2) in order to detect any possible QE ‘overshoot’ features. Selected rows are based on where the saturating source fell on the detector in the saturating image. In this case, we plot the average of rows 83-93 for the 170 columns corresponding to the UVIS2-C512C subarray. If there were to be QE ‘overshoot’ present, one would expect an increase in pixel values in the bowtie image following the saturated exposure, and thus an increase in the image ratio surrounding the saturating area (columns 60-120). However, no such features are seen. ‘Overshoots’ of 0.5% and higher would have been clearly and unambiguously detected if present, based on an analysis of test images with simulated ‘overshoot’ regions added. Thus, while the saturating Uranus exposures did not cause any QE ‘overshoot’ of 0.5% or more, we cannot rule out the presence of a very low-level ‘overshoot’. In addition, any short-lived effect (<34 minutes, the shortest delta-time between the Uranus exposure and the bowtie image used to check for ‘overshoot’) would have been undetectable with these datasets. Note that there are vertical offsets between the image ratios across the entire frame (i.e. both inside and outside of the region where Uranus was imaged); these are due to a slow decline in lamp output over time, as described in WFC3 ISR 2013-09.
Jupiter Rings

Like that of the Uranus observations, we analyzed the first bowtie images following the saturating Jupiter exposures by means of visually inspecting and plotting average row values around the saturation location. The Jupiter observations also utilized the 512x512 UVIS2-C512C subarray located in quadrant C, however, since the science goals of the program required observations of Jupiter’s rings, Jupiter was positioned slightly outside of the subarray imaging area as to avoid saturation in the subarray itself. With Jupiter’s rings being positioned at the mid-right-edge of the science subarray, and with the diameter of Jupiter being ≈400 pixels in the 3X3 binned frame, we estimate that the saturating source spans columns 250-650 and rows 0-285 in the 3x3 binned frame.
Three bowtie image ratios for each of the bowtie images immediately following the saturating Jupiter exposures, each using iac702kkq as a reference bowtie image, are shown in Figure 3. The corresponding average pixel plots can be seen in Figure 4; these plot the average row values of rows 0-285 for every column in the 3x3 frame for both the bowtie image ratio following the saturated exposures and the nominal bowtie image ratio. Again, no evidence of QE ‘overshoot’ is seen in the ratio images or the plots, as there are no distinct features or elevated pixel values surrounding the saturated area. We also examined the averages of smaller ranges of rows that surround the center of the saturating source and obtained similar results. Thus, the three highly-saturated Jupiter images did not cause any QE instability down to the detection threshold (∼0.5%). If there had been an ‘overshoot’ which decayed, it would have been extremely short lived (<5 minutes, the shortest delta time between the Jupiter exposure and the subsequent bowtie image). Given instrumental overheads, the delta-time in this case is effectively the shortest time possible between two images from different proposals; a dedicated calibration proposal would be required to achieve even shorter delta-times.
Fig. 4.—Average pixel values of rows 0-285 for all columns for each post-saturation bowtie ratio image (green) and reference bowtie ratio image (blue). The gray shaded region represents the approximate columns in which the saturating Jupiter source fell on the 3x3 binned frame.
Conclusion

We searched for possible cases of QE ‘overshoot’ occurring in WFC3/UVIS on-orbit, given that ground testing with the flight spare device revealed that QE instability can occur immediately following super-saturated images. We identified five on-orbit WFC3/UVIS exposures that (1) met the criteria for potentially causing QE ‘overshoot’ by having saturation levels greater than 7 times the full well amount and count rates beyond $\sim 6100 \text{ e-}/s$, and (2) had a bowtie observation taken within two hours after the saturating observation. Analysis of bowtie images following super-saturated external exposures by 5 minutes up to 1.5 hours later failed to identify any evidence of QE ‘overshoot’ down to the $\sim 0.5\%$ detection threshold: signal levels remained nominal and no distinct QE instability features were seen. Thus, within the parameters of the available data, the WFC3/UVIS detector has not experienced QE instability on-orbit due to the ‘overshoot’ effect. However, the available data do not allow us to rule out QE ‘overshoots’ at very low levels ($<0.5\%$) and/or ‘overshoots’ of very short duration ($<5$ minutes). We will continue to monitor for possible cases of QE ‘overshoot’ on-orbit by identifying any new super-saturated WFC3/UVIS exposures and performing a similar analysis of any such QE ‘overshoot’ candidate images.

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References

