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IR Detector Timing and Persistence

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ABSTRACT

The IR detector on WFC3 exhibits after images, known as persistence, following exposure to light that exceeds half saturation of individual pixels of the detector. The IR channel of WFC3 has no shutter and therefore light from bright objects reaches the detector between science exposures. For estimating persistence, the time that is important is the time between pixel resets. In intervals between science exposures, all pixels are discharged or reset every 2.91 s. For full-frame exposures, the time between resets is the science exposure time (EXPTIME) plus 5.82 s. Since full-frame exposures are usually much longer than 5.82 s, the difference between the time between resets and the science exposure time is usually not a significant problem for estimating persistence in full-frame exposures. However, the science exposure time for certain sub-array sequences can be considerably shorter than the time between resets, and in these cases, the persistence can be much greater than one expects if the time between resets is not correctly calculated. Here we discusses details of detector timing in order to allow a more accurate estimate of the effective persistence exposure time during an observation.

Introduction

Bright objects do not cause permanent damage to the the IR detector on WFC3, but bright objects do generate after images, known as persistence, which can compromise the science associated with observations that occur within a few hours of the exposure in which the bright object was observed. The persistence image is primarily a function of the level (measured in electrons) to which a pixel is exposed. Persistence is noticeable at exposure levels that exceed half saturation of individual pixels of the detector. Once the exposure level exceeds saturation, the amount of persistence rises although the rise is a relatively weak function of the exposure. The primary effect of very bright stars is that the number of pixels affected by a single star increases as more and more pixels become saturated.

In calculating persistence, the time that matters is the time between pixel resets. As an example, in 2010 December, a spectacular, and unexpected, persistence image was found in one of the Multi-Cycle Treasury (MCT) program images (See Figure 1). The persistence was due to an earlier grism exposure. The nominal exposure time for the grism observation was 0.23 s and in that 0.23 s, the grism spectra were only modestly saturated. Normally, one would not have expected a large persistence signal from such an object. However, prior to each multi-accum exposure obtained with WFC3/IR, the detector is flushed twice (reset to bias level) and during this period the effective exposure was 2.91 seconds, which means that in fact during this period, much more light accumulated on the detector than during the science exposure itself. Furthermore, during the science portion of the exposure the time between resets was even larger, 3.23 s. As a result, the actual exposure levels during this observation were many times saturation. To make an estimate of the detector illumination as a function of time, one needs to take into account all of the opportunities for the detector to be exposed.

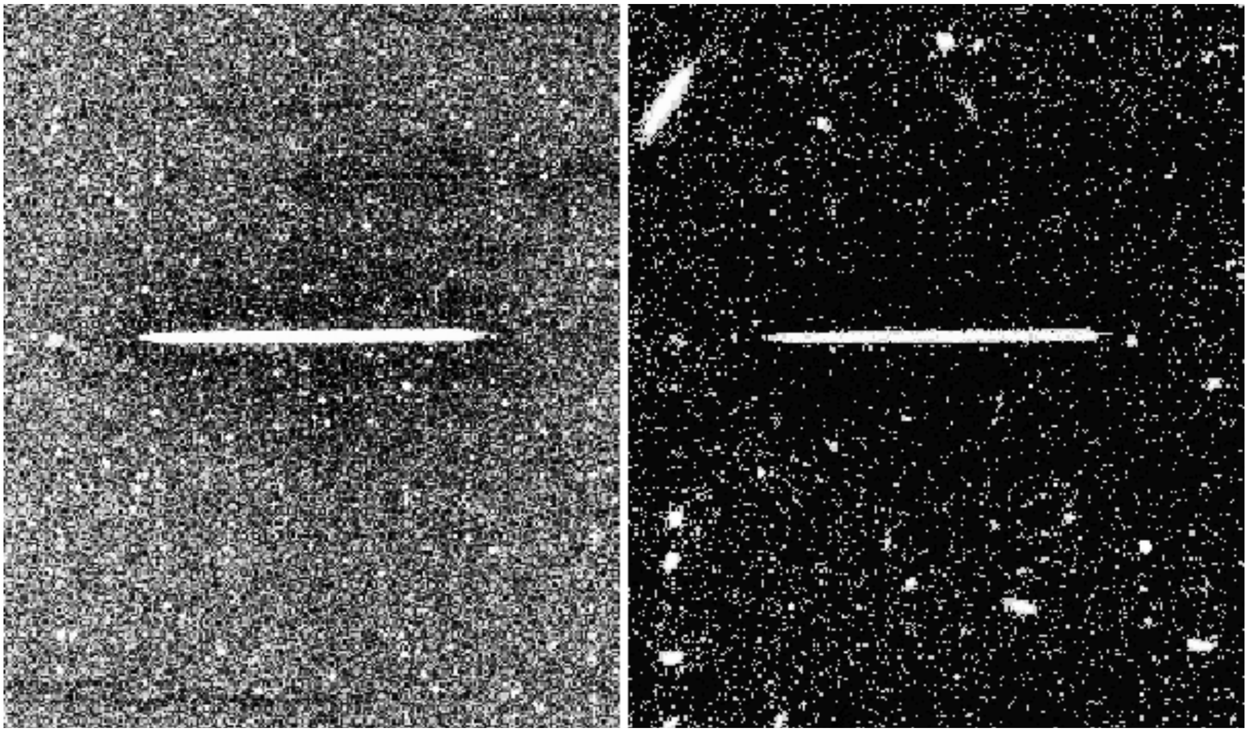

Figure 1 – An example of persistence seen in dataset ibew0y030 in one of the Multi-Cycle Treasury observations from program 12064 due to a set of very short grism exposures that preceded the MCT observation. The figure shows the effects of persistence on a "guard-dark" (left) designed to check for persistence prior to the science exposure (right). The grism observations toook place about an hour earlier and consisted of a long series of IR subarray exposusres (IRSUB128). The individual exposures had an EXPTIME of 0.23 s, but the time between resets was 3.23 s. Thus, the time pixels were exposed to light between resets was more than 14 times the science exposure time.

Timing of the IR detector

The IR detector on WFC3 is segregated into four quadrants, each with an independent off-chip readout amplifier. In normal operations, the detector is either in multi-accum mode, that is cycling through the pixels of each quadrant simultaneously and reading their values non-destructively, or it is in flush mode, that is cycling through the pixels of each quadrant again simultaneously and resetting them to their bias level. The time to non-destructively read the entire array, a full frame, is 2.91 s; the time to reset the entire array is also 2.91s. Only one of these two processes can be occurring at any one time. The fact that these two times are identical minimizes the differences in the heat loads on the detector in the two modes. The IR detector is maintained in flush mode between IR observations. The resets that occur during these periods prevent charge from accumulating on the pixels during idle periods, slews, SAA passages, and to keep the heat loads on the detector as constant as possible.

Timing for Full Frame Exposures

A multi-accum exposure consists of the following sequence of events.

Array reset: This is a fast calibration of the analog-to-digital (A-to-D) converters and where all pixels are set to the detector bias level. Two complete reset cycles precede every exposure.

Array read: The charge in each pixel is measured non-destructively, A-to-D converted, and stored in WFC3's on-board memory. This read, which is referred to as the zeroth read, is done immediately after the array reset. This allows subtraction of the reset noise.

Multiple integration-read cycles: Using one of the predefined multi-accum sample sequences, the detector integrates for a specified time and then each pixel is non-destructively readout. This process can be repeated up to a total of 15 times following the zeroth read during the muti-accum sequence. All frames are individually stored in WFC3's memory.

Continuous reset mode: After the final read of an exposure the detector returns to the continuous reset (a.k.a. flush) in order to prevent charge build-up and to limit the formation of residual images.

It is important to remember that none of the operations occurring during the science exposure, i.e., **Array read** or **Multiple integration-read cycles,** resets the pixels to the bias level. Reseting the pixels only occurs in flush mode.

The science exposure time (recorded as EXPTIME in the headers of the data files) is the time between the end of the zeroth read and the end of the last non-destructive read of the detector. However, persistence is most likely determined by the maximum amount of charge that accumulates on a pixel and this is not set by the science exposure but by the time between resets. For a full-frame exposure, T_{per} is the sum of the time from the end of the pre-exposure flush to the zero read (2.91s), plus the science exposure time (EXPTIME), plus the time of the first post exposure flush (2.91 s), which is EXPTIME+5.82 s. This is shown diagrammatically in Figure 2.

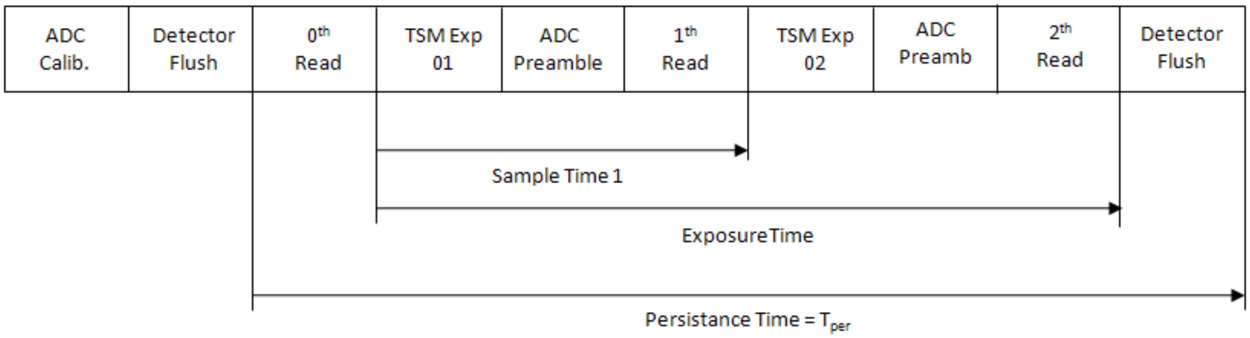

Figure 2. Illustration of a two-sample IR MULTIACCUM exposure. The persistence time, T_{per}, is shown: $T_{per} = 0^{th}$ *Read + Exposure Time + Detector Flush*. This formula applies to full-frame as well as sub-array exposures.

Full-frame exposure times on WFC3 range from 2.93 to 2800 s. For the longer exposures, the correction factor to account for the difference between the science exposure time and the time between resets is obviously quite small. That said, and since the persistence is a fairly strong function of the number of electrons in a pixel when the charge is near full well, it would be prudent to add 5.8 sec to the exposure time for persistence related calculations when full-frame exposures are involved.

Timing for Subarray Exposures

All full-frame exposures with the IR detector on WFC3 have exposure times of at least 2.93 seconds, e. g., a single read in Rapid mode. This is because it takes this amount of time to read all 1024 x 1024 pixels of the detector. However, sub-array readouts, which are designed to allow one to observe very bright sources, can be made in considerably less time.

The overall structure and timing of the steps within a sub-array exposure is similar to that of full-frame exposures, with a couple of important exceptions. As is the case for full-frame exposures, sub-array exposures are preceded and followed by two complete reset cycles of all the pixels in the detector. The non-destructive readouts within the exposure, however, are effectively only performed for the pixels within the sub-array, with the remaining pixels being skipped. More correctly, the pixels outside the sub-array are still addressed, but not digitized, as part of each readout, and so the time spent on these pixels is very short (short enough to ignore). There are four sizes of sub-arrays for the IR channel: 64 x 64, 128 x 128, 256 x 256, and 512 x 512 pixels. The time to read the pixels in the sub-arrays is approximately proportional to the subarray size: 0.011, 0.045, 0.1825, and 0.73 s, respectively. The achieved readout intervals are somewhat larger - 0.040, 0.092, 0.257, and 0.832 s - because of overheads not counted in a simple proportional model.

The one complicating factor with sub-array exposures is the fact that the reset cycles are performed for all pixels in the detector (the same as in full-frame exposures), while the readouts are performed for only the pixels within the sub-array. This has the effect of making the time elapsed between the pre-exposure reset and zeroth read variable for different pixels of the sub-array. Similarly, the time elapsed between the final read and post-exposure reset also varies across the sub-array. Because of the order in which the pixels are addresed, the elapsed time between the pre-exposure reset and zeroth read is much longer for pixels in the top and bottom rows of the sub-array than it is for pixels in rows at the center. The timing differences are reversed at the end of the exposure: the time elapsed between the final read and the post-exposure reset is shorter for pixels in rows at the top and bottom of the sub-array than for those near the center. Fortunately, these differences in timing cancel out in that the total amount of extra time that a pixel is exposed to light between resets at the beginning and end of an exposure is constant across a sub-array. For the four available sub-array sizes, the total amount of extra exposure time is ~2.95 s (64x64), ~3.00 s (128x128), ~3.17 s (256x256), and ~3.74 s (512x512). Thus, a good approximation to the time between the pre- and post-exposure resets for a sub-array is given by EXPTIME + δ where δ is 2.95, 3.00, 3.17 and 3.74 s for the various sub-array modes.

Since the nominal science exposure time (EXPTIME) tends to be small for sub-array exposures, the difference between the science exposure time and the time between resets is likely to be more of a concern for sub-arrays than for full-frame exposures. Indeed there are a number of likely exposure sequences (SAMP_SEQ) involving either RAPID or STEP sequences, particularly with the smaller sub-arrays, that have times between resets that are more than a factor of 2 longer than the EXPTIME would indicate. Since persistence depends on the degree to which a pixel is saturated, and hence the time between resets, it is particularly important to use the time between resets modelling persistence in situations involving sub-arrays.

The fact that the pixels begin to fill immediately after a reset affects the non-linearity corrections for WFC3/IR images. This is already incorporated into calwf3. Specifically, the time elapsed between the pre-exposure reset and zeroth read is already included in the standard calibration of WFC3/IR images by calwf3, where the “zsigcorr” step estimates the amount of signal accumulated in each pixel between the reset and zeroth read. This signal offset is then taken into account in the subsequent non-linearity correction (“nlincorr”) step to perform accurate saturation checks and non-linearity corrections.

Conclusions

Persistence in the IR detector on WFC3 depends primarily on the exposure level reached between detector resets. Therefore, it is important to estimate this time accurately when trying to estimate the likely importance of persistence in an image or to remove it from an image.

The relationship between the science exposure time (EXPTIME) and the effective persistence time (t_{per}) for the purposes of calculating persistence are approximately as follows:

Full frame	t_{per} = EXPTIME + 5.82 s
64 x 64 subarray	t_{per} = EXPTIME + 2.95 s

128 x128 subarray	t_{per} = EXPTIME + 3.00 s
256 x 256 subarray	t_{per} = EXPTIME + 3.17 s
512 x 512 subarray	t_{per} = EXPTIME + 3.74 s

The current version of the bright object tool in APT does not make an allowance for this factor; a change is needed. Ideally, the change would be to simply add a variable delta-time to the exposure time based on the aperture.[1]

The detailed effects associated with detector timing are already properly taken into account within the calibration pipeline for WFC3.

References

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[1] A modification of APT is currently underway and should be in place in time for preparation of Phase II proposals for Cycle 19.