Persistence in the WFC3 IR Detector

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Abstract. As is the case for most if not all modern IR arrays, bright sources observed with the IR detector in WFC3 leave faint residual images in subsequent exposures. This image persistence has been observed not only in dithered exposures by one observer of a single target within an orbit but also and more often in exposures of a different target by another observer in subsequent orbits. The amount of image persistence in the WFC3 IR detector is a function of the degree of photo-generated charge saturation of a pixel and time since the pixel was (over)exposed. The persistence decays roughly as a power law with time, and is typically $0.3 \text{ e s}^{-1}$ for a pixel that was highly saturated 1000 s earlier. Here, we show examples of persistence which have been observed and characterize the effect. We also describe ways for observers to find the pixels that are likely to have been affected by persistence, and to mitigate the effects of persistence when planning observations and reducing their data.

1. Introduction

Persistence is a residual image observed in most types of IR arrays after they have been exposed to signals that fill individual photodiodes, or pixels, to a substantial fraction of the full-well. Persistence has been observed on HST’s first IR instrument, NICMOS (Daou & Skinner 1997), which like the IR detector incorporated into WFC3 is a HgCdTe device. Persistence has also been observed in images taken with the IR detector on WFC3. The time scale for the persistence to decay in the HgCdTe detector on WFC3 is sufficiently long that persistence can be observed not only within an orbit as the source is dithered but also on subsequent orbits. This means that the persistence signature on the array can on occasion reflect an observation by another observer of a completely different region of the sky. The characteristics of the persistence in orbit are similar to those measured in thermal vacuum tests (McCullough & Deustua 2010).

Persistence is understood to arise from traps in the material that comprises the active area of the detector, especially regions of the photodiode that become accessible to free electrons and holes when the depletion region changes location due to photo-generated charge (Smith et al. 2008). Persistence primarily reflects the total number of photo-generated electrons accumulated from the beginning of an exposure to the end; thus persistence is seen from bright sources exposed for a short period of time or less bright sources exposed for a longer period of time. Other factors, such as the amount of time spent in a specific charge-state, also affect the amount of persistence in some HgCdTe devices, but have not yet been investigated systematically in on-orbit observations with the IR detector incorporated into WFC3.

In the remainder of this report, we describe what has been learned about persistence in the WFC3 detector since observations began shortly after it was installed into HST, our initial attempts to identify persistence in on-orbit data and to develop a protocol to remove persistence in subsequent images.
Figure 1: An observation of a field well out of the galactic plane which followed several dithered observations containing saturated stars.

2. The nature of persistence in the WFC3 array

An example of persistence as seen in the WFC/IR array is illustrated in Figure 1. The frame being shown is the first image of a sequence of 1300 s exposures of a high latitude field observed with the F160W filter. The image is displayed in histogram equalization mode that emphasizes faint features and shows very clear signatures of at least two dither sequences from observations in earlier orbits. These observations contained a number of very bright stars that produced heavily saturated images. Since persistence is a function of pixel exposure the previous dither pattern is imprinted on the array several hours later. The brightest persistence in this image is about 0.09 e s⁻¹, and corresponds to about 120 electrons.

A plot of persistence (measured in e s⁻¹) as a function of earlier illumination (measured in e) is shown in Figure 2a. In this case, the observation that caused the persistence contained a single extremely bright star and the persistence is seen in the pixels in the array that are included in the wings of the point spread function (PSF) of the star. The persistence image was obtained about 14 minutes after the original exposure. Persistence in the WFC3 array is minimal in regions of the detector where the exposure, measured in electrons, is less than 50,000 e, rises rapidly as the exposure grows to 100,000 e, and rises only slowly for values that are larger than this.¹ The turnover at 100,000 e reflects the full-well depth of the pixels in the WFC3 array.

The rate at which persistence decays, as measured in a calibration program in which a sequence of darks were obtained after first illuminating the array with the Tungsten flat-field lamp, is shown in Figure 2b. The various curves are for lamp exposures ranging from 50,000 to 1,500,000 e. At times greater than 100 s, the persistence decays roughly as a power law with a slope of about -2. The decay rate appears to vary somewhat as a function of illumination, but the decay is not a strong function of the illumination.

¹In describing exposures of greater than the well-depth, we mean the product of the instantaneous rate and the exposure time.
3. Finding persistence in WFC3 images

As indicated in Figure 1, one simple way to inspect images for evidence of persistence, especially persistence from observations taken at a different position on the sky, is to display the first image of a visit in histogram equalization mode. Another very good way to find persistence is to construct difference images of exposures taken at different dither positions in your observation. A convenient way to do this, if your own images are well-dithered, is to use MultiDrizzle (Fruchter et al. 2009) to produce individually drizzled, distortion-corrected images from each exposure (single_sci.fits files) projected to the same coordinate and pixel scale. Subtracting any two images that you have dithered will reveal the persistence since the signature of the field you were observing will be largely removed by this procedure, but due to the offset, the persistence will not. An example of this is shown in Figure 3. In this case observations of a high latitude field were preceded, unbeknownst to the observer, by a calibration observation of the outskirts of 47 Tuc.

Self-induced persistence, that is persistence occurring within a single visit, is often harder to detect than persistence from earlier visits involving other astronomical targets. This is because many observers use dither patterns involving steps that are small compared to the wings of the PSF of a bright star. This is a good strategy from the point of persistence since it confines persistence to small regions of the detector that are usually not part of the primary science of an observer. However, if an observer uses larger steps, as one might to mosaic a larger field or to step over macroscopic features on the detector (such as the “Death Star” or IR blobs), then persistence can be an issue. In this case, a simple way to check for persistence is to simply step through images displayed in image coordinates and

\[2\] If one suspects persistence induced by earlier observations or indeed if one wishes simply to check whether persistence is a possibility, one can obtain a time history of WFC3 IR exposures using a search form located at http://archive.stsci.edu/hst/history_search.html (If you copy and paste this link, make sure the ‘?’ appears in your browser.)
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Figure 3: a) An image that looks fairly normal until one actually checks for persistence b) The difference of the first and last single_sci.fits files from this observation. The two images were dithered on the sky and so the persistence, which is tied to a pixel instead, shows up as a positive and negative signals which are separated by the size of the dither.

Look for features that gradually fade as you step through the images beginning of course with the image that contained a bright star. An example of this is shown in Figure 4.

Figure 4: A sequence of images obtained with WFC3/IR when a bright star was observed and the following exposures involved large dither steps from the initial position.

4. Mitigating the effects of persistence

From the point of view of planning observations, the best way to mitigate persistence is to avoid it. The best strategies for this are to use as short a series of exposures as is possible, consistent (usually) with the desire to avoid time gaps for storing the data. This will minimize the number of pixels that are any image that are saturated or close to saturation. This is especially important if one’s science involves crowded star fields or very bright diffuse objects. Obviously, one should also be sure to make sure that dithers do not bring the areas on the sky that contain the prime science into regions of the detector that have been previously exposed to bright stars. Observers need to be especially careful in situations where they are looking for faint targets in fields crowded with moderately bright stars. An exposure of an 18th magnitude star with WFC3/IR using the broadband filters, e. g. F110W that lasts about 150 s will saturate the central pixel to an effective depth of 100,000 e. Estimates of which stars will saturate in WFC3 are available using the Bright Object Protection in APT.

At first glance one might suggest that a good strategy to reduce the effects of persistence would be to order the exposures such that the “thinnest” exposures occur first, however usually, observers balance exposure times so that all of the images are comparably deep.
In many instances, one cannot avoid persistence in images. The STScI does attempt to screen observations for the targets and exposures that will cause the worst persistence and to prevent IR exposures taken too close in time to these observations, but to do so with all IR observations would reduce overall scheduling efficiency of HST, and in most cases the regions of the IR detector that are affected by persistence in a subsequent observation are small, comparable to or less than the areas of the detector that are marked as being less than optimal data quality for other reasons.

It is also possible to at least partially remove the effects of persistence from images if one has access to the earlier images. Tools to correct for persistence are currently under development at STSCI; our prototype software assumes that persistence $P(x,y,t)$, measured in $e\text{s}^{-1}$, can be modeled as

$$P(t) = P_{1000} \left( \frac{t}{1000\text{s}} \right)^{-\gamma} \left( \frac{1}{e^{\frac{\delta z}{z_0}} + 1} \right)$$

where $P_{1000}$ is the maximum persistence at a fiducial time of 1000 s and characteristic exposure level $z_0$, measured in electrons. Here $\delta z$ describes the scale of exposure over which the persistence rises from a minimal to maximal value. We measure $t$ from the end of a previous exposure to the mid-point of the current exposure. (This is not a perfect description of the persistence as it does not track the slow rise in persistence as the image becomes extremely heavily saturated, but at present pixel to pixel variations in persistence is likely a larger problem.) If, as is often the case, there are multiple earlier images that potentially contribute to persistence in the current exposure, we assume that only the image contributing the maximum persistence matters. Based on this model, we calculate a persistence image and subtract it from the current FIT file. The persistence image for our first example (Figure 1) is shown in Figure 5, along with the persistence subtracted image (again displayed in histogram equalization mode). In this case, we have set $z_0$ to be 80,000 $e$ and $\delta z$ to be 20,000 electrons and $P_{1000}$ to be 0.3 $e\text{s}^{-1}$. Most of the persistence has been subtracted. Whereas persistence peaked at 0.09 $e\text{s}^{-1}$ previously, it now peaks at less than 10% of this, so about 90% has been removed.

Figure 5: a) An estimate of the persistence affecting the image shown in Figure 1, using the model described here. The image is plotted on a linear scale. b) The image shown in Figure 1 now with the persistence removed. The image is displayed in the same histogram equalization mode as Figure 1.
5. Summary and Future Work

Persistence is a residual image seen in most if not all HgCdTe detectors and is seen in the IR detector on WFC3. In particular, the WFC3 IR detectors exhibit persistence whenever the photo-generated charge is a substantial fraction of the full-well. This persistence can be observed in exposures within a single visit or in exposures which follow observations (by others) of completely different star fields by several hours. It can be both scientifically and cosmetically deleterious, but can be reduced by the averaging process that takes place when dithered images are “drizzled” and/or when models based on the time history of exposures are used to subtract the persistence from images.

We are continuing to investigate persistence in the IR, including quantifying pixel by pixel variations in persistence and attempting to determine how to model effects due to the length of time a pixel is near full well. We do not yet have a complete model for persistence but are working with individual observers on removing persistence from their images. We are considering the possibility of producing persistence images on a routine basis for observers, but in the meantime observers who find significant persistence in their images are encouraged to contact helpstsci.edu, and we will, on a case by case basis, work with them to see if persistence can be removed from their images. The latest information on image persistence will be posted on http://www.stsci.edu/hst/wfc3/ins_performance/persistence/.

References