Mitigation of H2RG persistence with image illumination

Brian A. McLeod*[a], Roger Smith[b]
[a]Harvard-Smithsonian Center for Astrophysics, 60 Garden St., Cambridge, MA 02138; [b]Caltech Optical Observatories, California Institute of Technology, MC105-24, 1200 E. California Blvd, CA 91125, USA

ABSTRACT

Residual charge generation, or image persistence, in infrared detectors is a problem that affects many low-light astronomical instruments. The HAWAII-2RG in the MMT & Magellan Infrared Spectrograph shows significant persistence when first powered up. We describe here how we reduce the persistence sensitivity of this detector by exposure to light.

Keywords: infrared detectors, persistence, HAWAII-2RG

1. INTRODUCTION

Image persistence is a ubiquitous problem in calibrating astronomical data taken with infrared arrays. It is particularly problematic in instruments that can see a large range of flux levels on the same region of the detector from one exposure to the next. A given pixel in a multi-object slit spectrograph may see highly variable levels of illumination as the instrument is operated in imaging mode for initial alignment, with calibration lamp spectra, and with night sky spectra that alternate between bright OH lines and dark regions in between. These patterns change location on the detector as the slit pattern changes from one target field to the next. Space-based imagers may similarly see bright stars on one exposure and dark-current limited background in the next. Persistence results in a spurious time variable signal superposed on top of the faint signals that is difficult to subtract out.

Image persistence is understood as a filling of traps when the pixel is filled with charge and then discharge of those traps after the pixel is reset. This discharge occurs on timescales of hundreds of seconds. A detailed model of this process has been developed by Smith et. al.[1,2]

Subtracting out the persistence signal from a pixel is challenging because it depends on the recent time history of the signal on that pixel. Furthermore, the persistence sensitivity varies significantly from pixel to pixel. Recent efforts in characterizing persistence have concentrated on the Teledyne HAWAII2-RG detector, a 2048x2048 HgCdTe photodiode array in broad use in the astronomical community. The Hubble WFC3 team has recently invested significant effort to understand the time dependence of the persistence signal, and the data pipeline products now include information on persistence. Despite these efforts, the correction is still not perfect.[3,4]

In this paper, instead of attempting a detailed understanding of persistence, we present some evidence that persistence can be reduced by exposing the detector to levels of illumination that saturate the pixels. It is unknown at this point whether this phenomenon applies generally to all HAWAII2-RG arrays, or is in some way special to the detector we studied.

*bmcleod@cfa.harvard.edu

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2. DISCOVERY

In 2014 we prepared a HAWAII-2RG system to replace the HAWAII-2 infrared array in the MMT and Magellan Infrared Spectrograph (MMIRS)[5], then installed at the Magellan Clay Telescope at Las Campanas, Chile. Characterization of the array in a test dewar in our lab in Cambridge, MA showed no apparent problems with persistence. Once the array was installed in Chile we found that the level of persistence was much larger than we expected it to be. We performed several tests but were unable to resolve the problem, and even suspected that the array was not resetting properly. Faced with an upcoming observing run we decided to revert back to the original HAWAII-2 array and return the H2RG to the US. Once back in our lab test dewar, the performance once again seemed normal. We then shipped the array back to Chile and tried again. Back in the spectrograph we were again faced with high persistence levels. The key to understanding the difference arose with the set of images shown in Figure 1. The left image shows an image of a MMIRS slit mask taken with no disperser. The middle image was taken with a grism in the beam resulting in spectra dispersed vertically. Finally the right hand image was taken showing the persistence signal. The persistence signal is lower in the regions where the bright non-dispersed slit images appeared previously. Thus we concluded that exposure to bright light provides inoculation against persistence. We then also realized why the lab results showed much less persistence: The 870nm LED in our test dewar was controlled by the analog output of a Lakeshore temperature controller, which spiked upon power-up, saturating the H2RG in less than a second. This brief flash, we concluded, was what mitigated the persistence in our lab experiments.

Armed with this basic discovery we provided increasing amounts of signal to try and reduce the persistence level with the array installed in the instrument. Each inoculation exposure must be followed by period of ~12 hours of rest to let the initial persistence signal dissipate. And then the persistence measurement itself takes a few hours before the signal fully dissipates. We were again under time pressure to return the instrument into operation so we were not able to fully characterize the behavior. Subsequently we have not had the resources to perform further characterization.

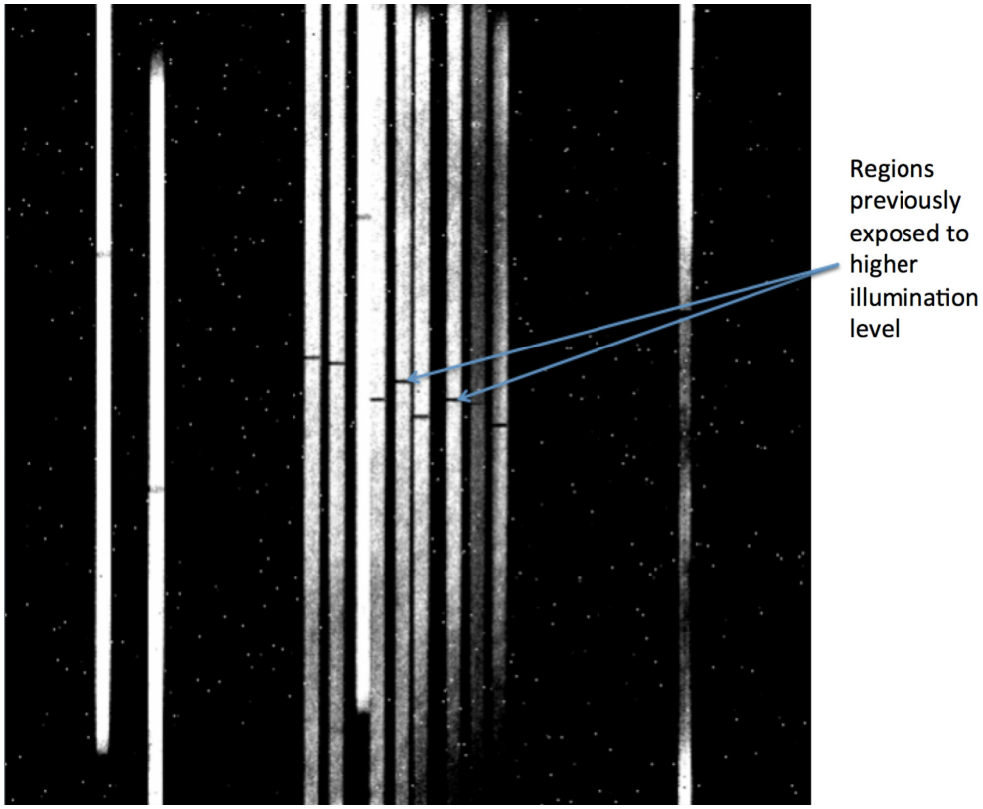

Figure 1. The bright vertical bands are persistence from recently illuminated regions. They are interrupted by dark bands that had previously been exposed to stronger illumination.

3. RESULTS

3.1 Time dependence of persistence signal

In Figure 2 we show an example of the measured integrated signal of a sequence of 300 dark frame frames taken after exposure to light, and sampled up-the-ramp every 1.4 seconds. We find that the persistence rate is well fit by the form $R=A(t-t_0)^{\alpha}$ as has been suggested previously.[6] We perform a non-linear least squares fit to the measured integrated signal, solving for A, t_0, and α, as well as the reset level at the start of each 300 sec ramp. The resulting fit to the integrated signal is also shown in Figure 2. The fitted parameters are A=12 e-/sec, t_0=11.5s, and α=-0.55. As has been previously reported[6], resetting the array has no impact on the persistence signal. The value of t_0 resulting from the fits is typically within a few seconds of the time when the array was reset to remove the illumination image. The slope α=-.55 of the decay is shallower than has been reported for other arrays, typically $\alpha \sim -1$. [6]

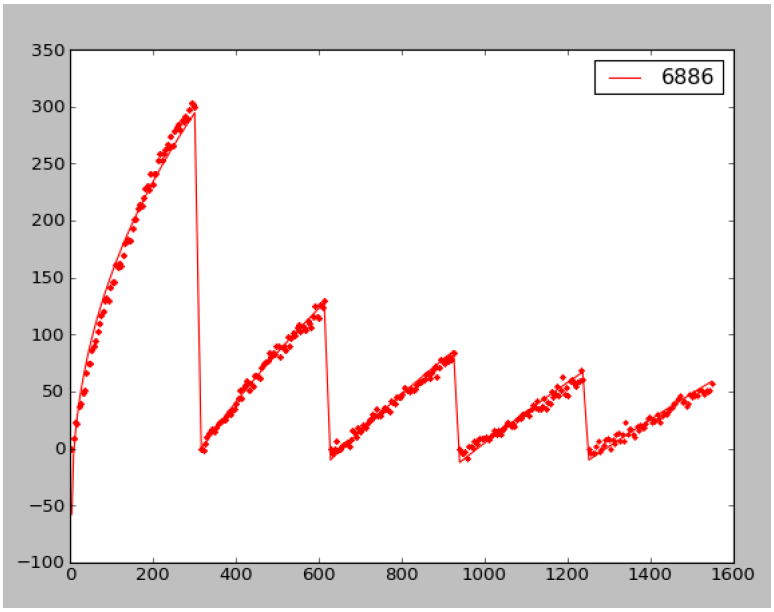

Figure 2. Persistence signal data [e-] vs time [sec] and fit resulting after exposure to light.

3.2 Persistence signal relationship to illumination rate

We took images of Argon lamp spectra which exhibit significant variation in illumination from one pixel to the next over a relatively small area of the detector. This lamp was on during the first 5 seconds of a 30 second exposure. This was followed immediately by a 300 second dark exposure. In Figure 3 we show the relation between the mean persistence during the 300 second dark exposure plotted against the integrated illumination level. The persistence appears roughly linear for illumination levels up to 500e-, with a break in slope there, and again linear up to the maximum of 6000e- that we had in the exposure.

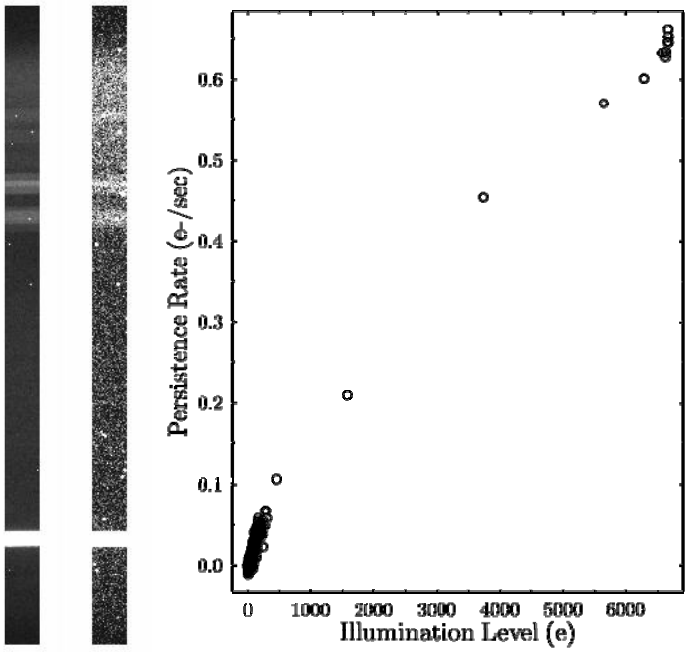

Figure 3. On the left, a section of the illumination image which is an Argon spectrum, and the resulting persistence image. On the right, the mean persistence rate during the first 300 seconds versus the illumination level.

3.3 Spatial dependence of persistence

The persistence varies significantly across the array, varying by more than a factor of 10 across the array. This is significantly larger than the 10's of percent variations reported for other arrays.[4,6] In Figure 4 we show the result of applying even illumination across the array and then taking a 300 sec dark image. The results in the following section were measured at the locations marked.

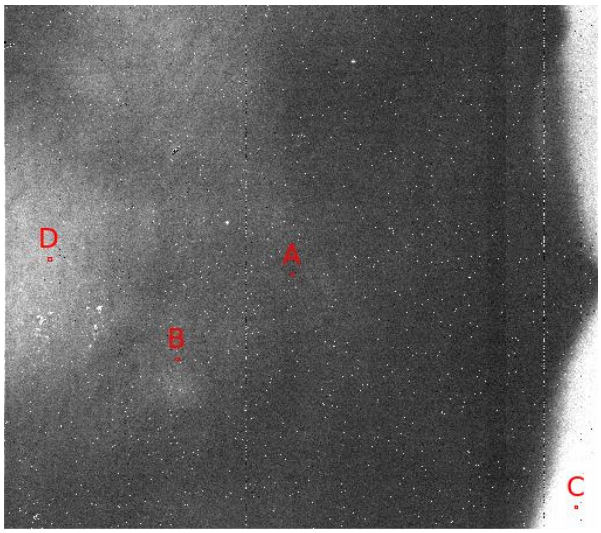

Figure 4. Persistence across the array.

3.4 Reduction of persistence by exposure to light

Once the basic property had been discovered we made some quantitative exploration of the effect. As a metric we use the persistence rate 300 or 1800 seconds after the removal of light, as computed from the derived least squares parameters. We first provided an inoculation exposure that lasted 60 seconds with no resets during the exposure with an illumination that provided a photoelectron signal as listed in Table 1. Then we waited several hours to let the initial persistence decay. We then measured the dark signal before applying any additional illumination. This is indicated in the second column. Then we measured the persistence resulting from lower level illumination by applying 2 seconds of illumination just prior to the end of a 30 second exposure. Immediately after that we acquired five 300sec dark frames, sampling up the ramp every 1.4 sec. The resulting persistence levels are shown in Table 1 and in Figure 5. The quantities tabulated are: the power law index, α; and the persistence signal at times t=300s and t=1800s as evaluated from the fit parameters.

The "bright flash" data were acquired in August 2014 in the lab. The inoculation was the result of a power-up transient of our test dewar's illumination LED. The duration and brightness of the flash are unknown but are suspected to be less than a second, but brighter than the 7×10^6 e-/sec illumination that we were able to provide once installed in the MMIRS instrument.

The remaining lines in the table are for data acquired in September 2014 with the detector installed in MMIRS at Las Campanas Observatory. Illumination was provided using the MMIRS calibration lamp system.

As the inoculation exposure was increased, the subsequent persistence susceptibility decreased several fold in all measured regions except "B", the region on the edge with very high persistence. In this region there was an initial reduction but then no further improvement as the illumination level was increased. In the lab we were able to measure the persistence after the bright flash only in region "A" due to the fact that only a small area of the detector was illuminated.

Table 1. Persistence rate at the locations shown in Figure 4. Rates have been normalized to an illumination exposure level of 10000e-. The actual illumination level in e- is shown for reference. The wavelength refers to the inoculation exposure. R300 and R1800 are the persistence signal in e-/sec 300 and 1800 seconds after illumination as determined from the least squares solution.

Inoculation exposure	Wavelength	Dark	Illumination	A			B			C			D		
[e-/pix/sec]	[um]	[e-/sec]	[e-]	alpha	R300	R1800	alpha	R300	R1800	alpha	R300	R1800	alpha	R300	R1800
Brief but bright flash	0.87		4500	-0.49	0.044	0.025									
<10^4	?	0.008	7000	-0.504	0.194	0.078	-0.553	1.36	0.5	-0.38	0.302	0.152			
10^4 x 60 sec	1.17-1.33		7000	-0.51	0.115	0.045	-0.618	0.617	0.198	-0.456	0.18	0.079	-0.6	0.251	0.083
5 x 10^5 x 60 sec	0.97-1.07	0.053	7000	-0.23	0.092	0.062	-0.595	0.612	0.205	-0.326	0.111	0.061	-0.505	0.184	0.074
7 x 10^6 x 60 sec	0.8-2.5	0.03	9000	-0.24	0.058	0.037	-0.643	0.588	0.183	-0.538	0.076	0.031	-0.467	0.148	0.062

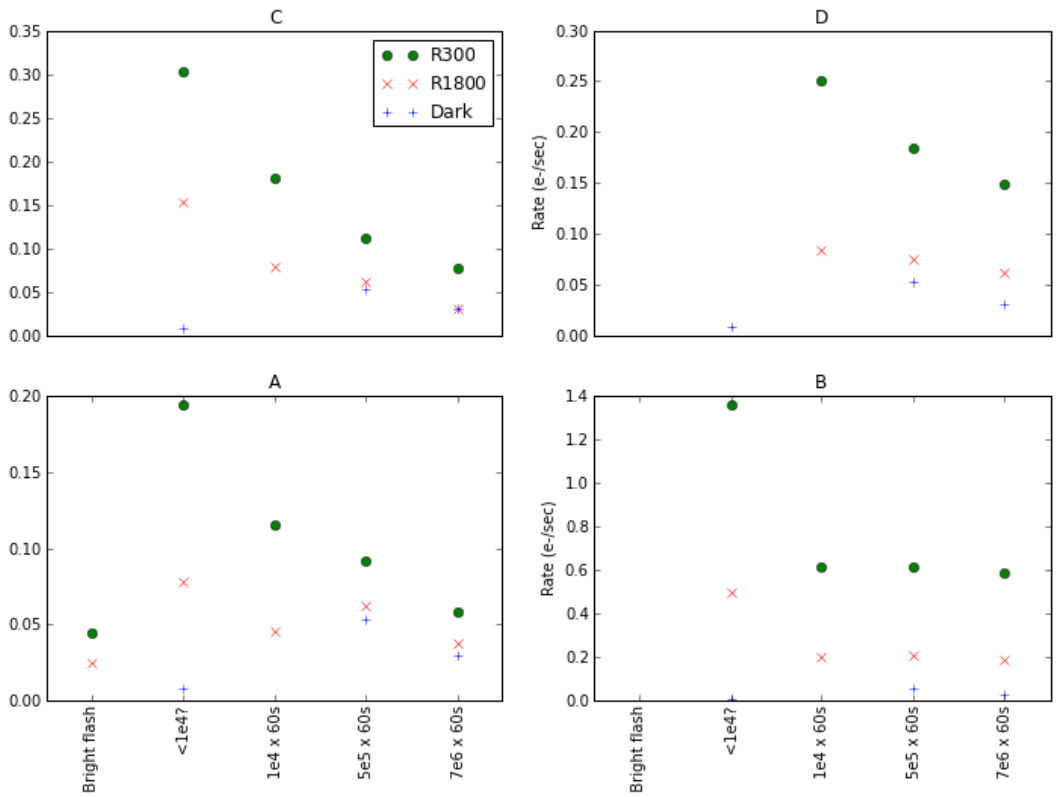

Figure 5. Graphical representation of the persistence signal data shown in Table 1.

3.5 Longevity of persistence reduction

We made a single remeasurement of the persistence level 30 days after the initial post-inoculation measurement during which time the instrument was cold and in use. We found that the persistence had increased by a factor of 1.5, which means that the inoculation remains effective on a timescale of weeks.

4. DISCUSSION

The theory developed by Smith et al. attributes persistence to the capture of charge by traps at the edge of the depletion region as it moves inwards in response to accumulation of photogenerated charge. This trapped charge is released after the return of the depletion width to its maximum width by the diode reset (i.e. during subsequent exposures). Persistence behavior maps to diode voltage changes whether due to photogenerated charge or reset voltage changes.

The mechanism for the inoculation is not understood by the authors. While it is tempting to think that traps might be filled by the strong illumination, and thus removed as available sites to capture and release charge, we know of no mechanism for keeping those traps full, and indeed we witness these traps emptying in the form of image persistence.

Furthermore, the penetration length of the 870 nm photons used for inoculation is only about 120 nm, so photon interactions must be limited to the back surface. A determination that the persistence can be affected by changing the state of the back surface would have major ramifications for our understanding of the persistence mechanism, which has thus far been attributed to the interaction of charge with traps in the region of the diode implant which of course is on the "front" (i.e. multiplexor) side.

To test whether the inoculation effect is due to the electrical state of the diode junction or due to the interaction of photons at the back surface, one could apply the same bright illumination while holding the reset switch closed. If the inoculation effect goes away when the electrical state of the diode is preserved by the reset, then the effect must be electrical.

The converse test would be to show that the same inoculation effect could be induced by driving the photo-diodes into forward bias through manipulation of the VRESET voltage. This test is particularly important since it suggests that persistence could be prevented merely through a special clocking sequence executed in sufficient time for the array to full recover prior to start of observing.

5. CONCLUSIONS

- This array has significantly larger spatial variation of persistence than other studied arrays.
- Illumination reduces persistence in the MMIRS HAWAII2-RG array. The reduction plateaus in the region of largest persistence
- It is not known whether this behavior is seen in other arrays.
- Further testing of this array has been limited due to the fact that it has been installed in the operational instrument and to limited manpower.
- Several tests have been suggested which might move us closer to understanding the underlying physics, but as yet we have no good theory.
- Even in the absence of an understanding of the physics, it may prove possible to harness the inoculation effect to reduce the impact persistence either through periodic intense illumination or brief forward bias of the photodiodes. Such a procedure would induce its own persistence but, remarkably, the benefits seem to outlive the persistence decay resulting from the inoculation.

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