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Bright Point Source Saturation Response and Persistence Properties of the Roman Wide Field Instrument from Thermal-Vacuum Testing: Interim Results

Dana R. Louie [1,2,3] Robert F. Wilson [4,2,3] Joshua E. Schlieder [2] and Thomas Barclay [2]

[1] *Catholic University of America, Department of Physics, Washington, DC, 20064, USA*
[2] *Exoplanets and Stellar Astrophysics Laboratory (Code 667), NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA*
[3] *Center for Research and Exploration in Space Science and Technology II, NASA/GSFC, Greenbelt, MD 20771, USA*
[4] *Department of Astronomy, University of Maryland, College Park, MD 20742, USA*

1. INTRODUCTION

Roman's Wide Field Instrument (WFI) underwent its second thermal vacuum (TVAC) test, referred to here as TVAC2, in a space-like environment at BAE Systems, Inc., Space & Mission Systems in Boulder, CO between March and May 2024 (J. E. Schlieder et al. 2024). As part of this TVAC2 campaign, the WFI Bright Star Saturation test was conducted to characterize how WFI Sensor Chip Assemblies (SCAs) respond to saturation from a wide range of bright, in-focus point sources, similar to those expected during Roman's science surveys.

A telescope simulator was used to project nine point sources designed to approximate stars with magnitudes ranging from ∼4 to ∼18 mag through the F146 filter, onto a uniformly spaced grid of locations on SCAs 4 and 11. To measure associated persistence, interleaved dark exposures (e.g. with the illumination from the telescope simulator turned off) were taken with the F146 filter in place following each illuminated exposure. Following all illuminated source and interleaved dark exposures, a series of 18 dark exposures were taken with the filter wheel Dark element in place to monitor long term persistence that may be present after illumination.

A comprehensive description of the test and subsequent analyses regarding both saturation and persistence behavior will be presented in a future publication. Herein, we provide a more limited description of select saturation and persistence results from that work to provide a general overview of Roman SCA performance when illuminated with bright point sources. In addition to this document, we have made available a small subset of the bright star test data in a mini-release webpage[5]. This webpage provides TVAC2 data that approximate point sources of brightness ∼7 and ∼17 magnitude on SCA 11, as well as a presentation with a test set-up and procedure overview and example quicklook analysis plots. For additional information on the persistence performance and other properties of individual Roman WFI SCAs, please visit the Roman WFI Performance webpage[6] under the *Focal Plane System* tab.

2. DATA ANALYSIS SUMMARY

For the Bright Star Saturation test, all illuminated and dark exposures consisted of 56 frames spanning ∼180 s of integration time, where the first frame is the reset-read frame. To mitigate $1/f$ noise, we began our analysis by applying the Improved Roman Reference Correction algorithm (IRRC, S. K. Betti et al. 2024, Rauscher et al., in prep) to all exposures. We subtracted a superbias frame from all data as part of the IRRC correction. A superbias is a high-quality, low-noise reference bias frame created by combining many individual bias exposures. We created our superbias frame by taking the median of the final three post-test dark exposures, which were found to be free from any lingering persistence so long after illumination. Following IRRC application, we multiplied each individual frame by per pixel gain values. Specific methods used for the illuminated frames and the interleaved dark frames are discussed in Sections 3 and 4, respectively.

3. SATURATION RESULTS

Figure 1 shows the growth of saturation over time when the detector is illuminated by the equivalent of a ∼12 mag point source on SCA 11. The top panels show three different image frames throughout the exposure, the middle panels

Email: dana.r.louie@nasa.gov

[5] https://asd.gsfc.nasa.gov/roman/WFI_Bright_Star/
[6] https://roman.gsfc.nasa.gov/science/WFI_technical.html

show the instantaneous slope compared to the mean slope at each of the three different frames, and the bottom panel tracks individual pixel fluxes as the saturation region spreads. The pixels corresponding to the slopes/curves plotted in the lower panel are designated by "X" symbols with matching colors in the top and middle panels. Hard saturation is indicated for a given pixel when the slope becomes horizontal. Note that pixel slopes increase when the leading edge of the saturation region is adjacent to them (the "saturation front"), impacting linearity. This slope change in the vicinity of a saturated pixel is likely due to charge leakage and has been previously observed by T. D. Brandt et al. (2017) who reported a similar effect in CHARIS H2RG detectors. When a pixel saturated they found the four nearest neighbor pixels received an immediate/compensating influx of electrons, while pixels located diagonally to the saturated pixel also received a significant increase. Such an effect may need to be taken into account in an analysis of saturated source photometry. Figure 1 also shows that after 54 frames of illumination (≈170 s), the saturation region of the ∼12 mag source grows to about 15 pixels in diameter. For comparison, the saturation region of the ∼4 mag source grows to about 150 pixels in diameter after the same number of frames.

4. PERSISTENCE RESULTS

Figure 2 shows persistence decay curves for illumination that approximates magnitude 7, 12, 14, and 15 point sources on SCA 11. For each source, we plot points for the first interleaved dark following the illuminated exposure, followed by each subsequent interleaved dark exposure available in each case. Due to the sequence of each illuminated exposure, the brightest sources have the most subsequent interleaved darks available for analysis. For example, for the ∼7 mag source, we compute persistence for the ensuing 8 interleaved darks, while for the ∼15 mag source, only 4 interleaved darks are available.

In this analysis, we first created a saturation mask for each illumination level by flagging pixels with electron counts between 100,000 and 130,000 in the last frame of the illuminated data. For each interleaved dark exposure, we estimated persistence by computing the slope in e^-/s for each pixel within the saturation mask for each magnitude. Additionally, for each interleaved dark, we subtracted both local stray light background within a region of interest (ROI) surrounding each saturation mask and additional contaminating flux from the telescope simulator projector fibers.[7] The background was computed by finding the median value of all pixels within the ROI, but outside the saturation mask. This background subtraction was necessary to deal with the effects of faint and structured stray light from the telescope simulator. The fiber contamination was subtracted from each interleaved dark using the per pixel fiber contribution measured during the final interleaved dark. This fiber contamination was outside the saturation region of the ∼18 mag source and was effectively free of persistence post-illumination. The persistence decay curves shown in Figure 2 are the median values within each saturation mask as a function of time after these corrections. The error bars are computed as the average of the Interquartile Range for all pixels. For all sources regardless of magnitude, the persistence values in the first interleaved dark agree within the error bars, and the persistence decays to background levels after about 20 minutes post-illumination. These results are also broadly consistent with those measured using flat field illumination to approximately twice full well during the same WFI TVAC2 campaign.[8]

REFERENCES

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Brandt, T. D., Rizzo, M., Groff, T., et al. 2017, Journal of Astronomical Telescopes, Instruments, and Systems, 3, 048002, doi: 10.1117/1.JATIS.3.4.048002

Schlieder, J. E., Barclay, T., Barnes, A., et al. 2024, in Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, Vol. 13092, Space Telescopes and Instrumentation 2024: Optical, Infrared, and Millimeter Wave, ed. L. E. Coyle, S. Matsuura, & M. D. Perrin, 130920S, doi: 10.1117/12.3020622

[7] Please see the slides presented on the bright star mini-release webpage for visualizations of the local stray light background and fiber contamination. Direct link to slides: https://asd.gsfc.nasa.gov/roman/WFI_Bright_Star/TVAC2_Bright_star_saturation_summary_release.pdf

[8] https://roman.gsfc.nasa.gov/science/WFI_technical.html under the *Focal Plane System* tab

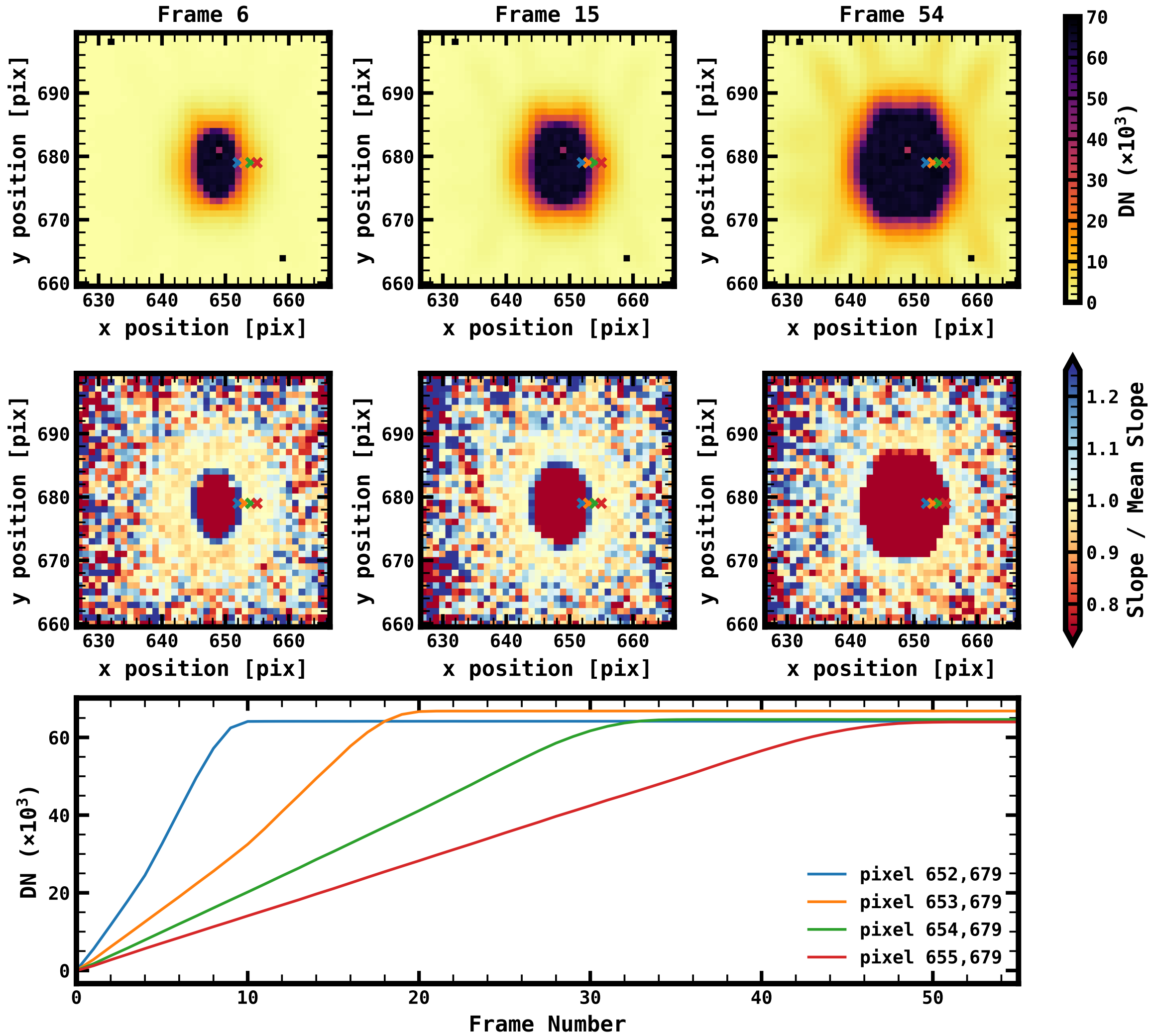

Figure 1. Pixels adjacent to saturated regions show pronounced non-linear behavior. The saturation response for an approximately 12 mag source on SCA 11 is shown here. Top row: total accumulated signal in the indicated frame. Middle row: instantaneous slope, computed as the difference between the indicated frame and the preceding frame, divided by the best-fit ramp slope derived from frames acquired before neighboring pixels saturate. Bottom panel: accumulated signal for specific pixels across all frames with corresponding pixels marked by “X” in the other panels. The local slopes increase when the leading edge of the saturated region – the “saturation front” – approaches a pixel, producing deviations from linearity. For example, as the pixel marked with the blue X (652, 679) approaches saturation, the pixel marked with the orange X (653, 679) shows a clear change in slope. This effect appears in the left-most middle panels as a ring of elevated instantaneous slopes surrounding the saturated core. As the saturation front expands, the instantaneous slope increases compared to the mean slope measured prior to the saturation of adjacent pixels.

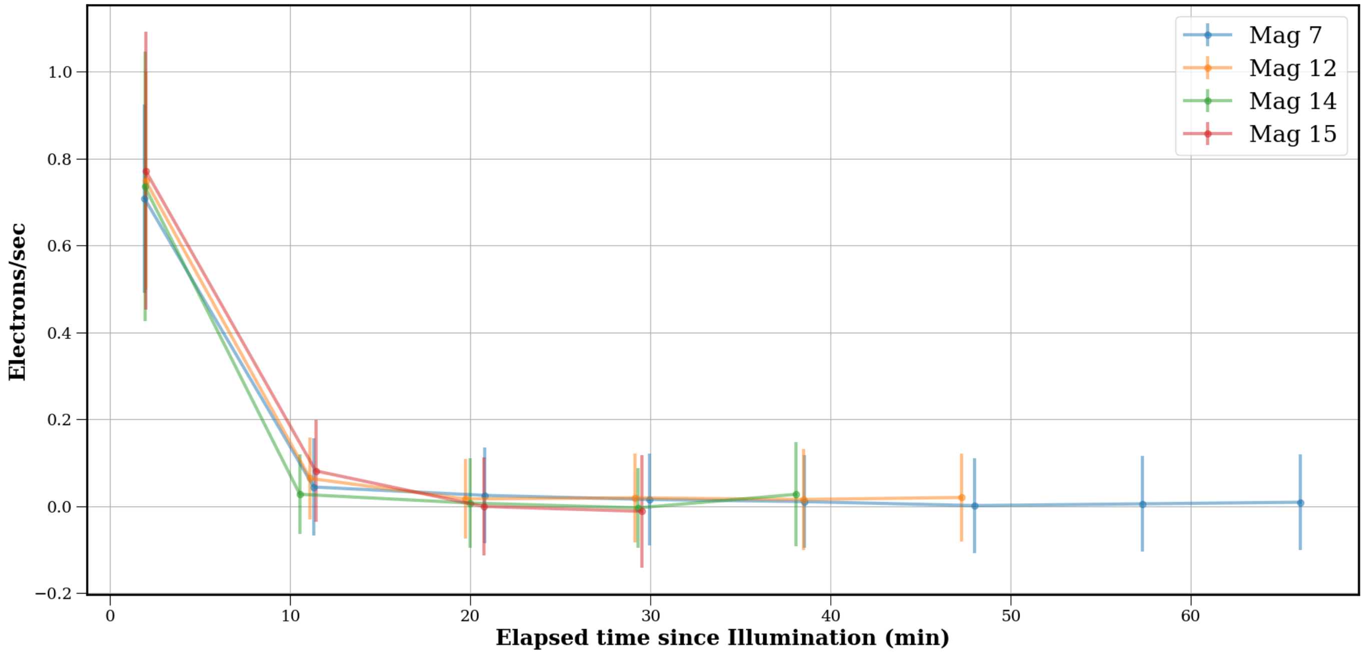

Figure 2. Persistence decay curves for approximately 7, 12, 14, and 15 mag sources. These measurements have been corrected for both local background and telescope simulator fiber contamination. For all sources, persistence values in the first interleaved dark agree within the error bars and decay to background levels within 20 minutes after illumination. This is broadly consistent with the persistence performance measured after flat field illumination during the same WFI TVAC2 test campaign.