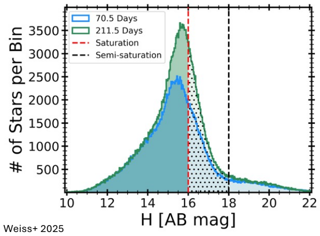
A saturated photometry approach for asteroseismology in the Galactic Bulge Time Domain Survey

Lauryn James (1), Adam Ballas (2), Timothy R. Bedding (3), Kaili Cao (2), Noah Downing (4), Scott Gaudi (2), Marc Hon, Madeline Howell (2), Daniel Huber, Jennifer Johnson, Matthew Penny, Marc Pinsonneault (2), Sanjib Sharma, Dennis Stello, Trevor Weiss (10), and Joel C. Zinn

(1) Department of Physics and Astronomy, California State University, Long Beach; (2) Ohio State University; (3) University of Sydney; (10) New Mexico State University

CALIFORNIA STATE UNIVERSITY LONG BEACH

Why should we extract photometry for saturated targets in the GBTDS?



Weiss+ 2025

Distribution of simulated stars per H-band for 70.5- and 211.5-day baselines.

Saturated stars produce PSF wing flux and persistence signals that bleed into neighboring ensemble pixels across exposures

A large fraction of GBTDS asteroseismic targets (and some microlensing targets) will be saturated (H < 18)

Differential photometry is needed for both science cases

Saturated: Pixel reaches full well within first resultant.

Semi-saturated: pixel reaches full well later in the ramp, before exposure ends.

F146 = 11

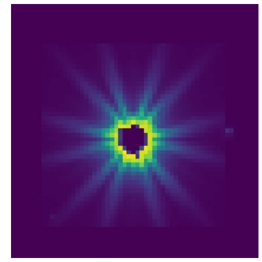


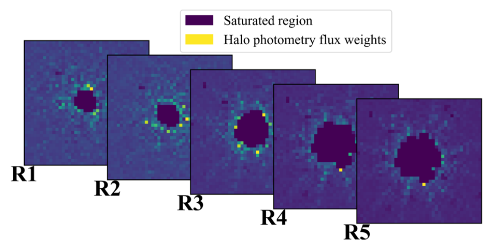
Image of an 11 MAG saturated star simulated using Romanisim

How should we extract differential saturated photometry?

A SATURATION PIPELINE

1) Reject saturated pixels and their neighbors in resultant 1 in every exposure
2) Weight each non-saturated pixel to minimize the exposure-by-exposure scatter for the sum of pixels --- ***halophot*** method demonstrated in K2 saturated data (White+ 2017; Pope+ 2019)
3) Sum flux from weighted pixels in resultant 1 for each exposure
4) Repeat for other resultants --- one light curve possible for each resultant
5) Add in quadrature the differential signal across light curves

Tested using ***romanisim*** and built in the *Roman Research Nexus*



`halophot` pixel weights for each of the BGTDS resultants for a saturated star.

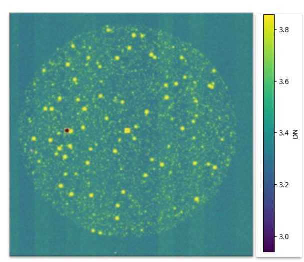
CROWDING CONSIDERATIONS

halophot is not able to reject flux from pixels contaminated by background sources

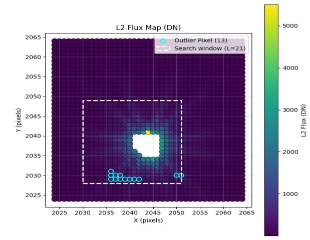
We flag and mask contaminating point sources using outlier rejection adapted from Popowicz & Smolka (2016):

For each pixel, the algorithm searches for an increasing brightness out to the edge of a window size L.

Steps smaller than $k \cdot \sqrt{(I + \sigma^2)}$ are treated as noise, where σ is the read noise and k is a tunable sensitivity parameter (larger k yields fewer false positives)



A Romanisim L2 generated image depicting a central focused 11 MAG (saturated) star with background sources (outliers).



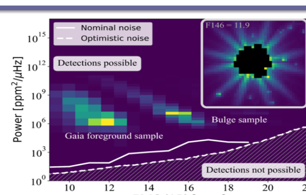
Outlier rejection algorithm results, with cyan circles indicating flagged outliers.

What noise level do we achieve?

Noise taken to be RMS of resulting light curve for one resultant

Noise level amenable to asteroseismology of red giants in the bulge

This method is PSF agnostic yet performs comparably to an ideal PSF method



Resulting RMS of single-resultant light curve (solid white) achievable with the saturated PSF photometry pipeline described here. A saturated photometry method using PSF fitting is more optimistic (dashed white; R. Wilson et al., in prep.). The expected asteroseismic power for foreground samples and the bulge are above the noise floor and therefore expected to be detectable.

Acknowledgments

We thank Tom Barclay, Joshua Schlieder, and the Roman Team for their insight on the project.

Where do we go from here?

Further validate outlier rejection performance

Cross validate simulation results against Roman WFI TVAC2 bright star saturation test data (Schielder et al. 2024; Paine et al. 2025: Roman Project Science Team 2025).

Assess impact of outlier rejection on photometry light curve RMS

Include realistic slew patterns for realistic persistence

References

Roman Observations Time Allocation Committee (2025) Roman Community Forum, https://roman.gsfc.nasa.gov/science/ccs/ROTAC-Report-20250424-v1.pdf
Roman Science Team (2025) Roman WFI Technical Overview, https://roman.gsfc.nasa.gov/science/WFI_technical.html
Wilson, R. et al. (2023) The Astrophysical Journal, 987, 181
Romanisim Team (n.d.) Romanisim Documentation, https://romanisim.readthedocs.io/en/latest/index.html
Paine, J. et al. (2025) TVAC2 Bright Star Saturation Test Summary, NASA GSFC, https://asd.gsfc.nasa.gov/roman/WFI_Bright_Star/TVAC2_Bright_star_saturation_summary_release.pdf
Schlieder, J. et al. (2024) Proceedings of SPIE, 13092, 0SS
Roman Project Science Team (2025) Roman WFI TVAC2 Bright Star Saturation Test Data Mini-Release, https://asd.gsfc.nasa.gov/roman/WFI_Bright_Star/
Popowicz, A. & Smolka, B. (2016) A method of complex background estimation in astronomical images. *Monthly Notices of the Royal Astronomical Society*, arXiv:1608.02700