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Original Publication Information

G. Bruce Berriman *et al.* "TESS as a Low-surface-brightness Observatory: Cutouts from Wide-area Coadded Images." 2021 *Research Notes of the AAS* 5(7): 1-5.

Draft version February 2, 2022
Typeset using LaTeX **manuscript** style in AASTeX631

TESS As A Low Surface Brightness Observatory: Cutouts From Wide-Area Co-Added Images

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ABSTRACT

We present a mosaic of those co-added Full Frame Images acquired by the TESS satellite that had been released in April 2020. The mosaic shows substantial stray light over the sky. Yet over spatial scales of a few degrees, the background appears uniform. This result indicates that TESS has considerable potential as a Low Surface Brightness Observatory. The co-added images are freely available as a High Level Science Product (HLSP) at MAST and accessible through a Jupyter Notebook.

Keywords: Diffuse radiation(383) — Low surface brightness galaxies (940) — Computational methods (1965) — Astronomy software (1855)

1. INTRODUCTION

The Transiting Exoplanet Sky Survey (TESS) instrument has a simple unobstructed light path, with four cameras each housing seven lenses; fast optics, with a focal ratio of f/1.4; and wide-field detectors, with four large-format CCD cameras (2048 $\times$ 2048 pixels) having a 24° x 96° field of view

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(Ricker et al. 2015). This design, intended for the discovery of exoplanets, is also ideal for studies of the low-surface brightness (LSB) environments of galaxies. A major complication in such studies is, however, the impact of stray light in the images. We present here a mosaic, covering two-thirds of the sky, derived from co-adds of images covering roughly two-thirds of the sky, that offer insight into the effects of stray light for LSB studies that use TESS data. An earlier mosaic, derived near the South Ecliptic Pole for one camera, is too small to address this issue (Berriman et al. 2019).

2. CREATING THE TESS CO-ADDED IMAGES AND MOSAIC

An overview of the TESS observing cadence is useful in understanding the construction of the mosaic. In Mission Year 1, the four TESS cameras observed the sky in swaths $24^\circ \times 96^\circ$ in size, stretching from the South Ecliptic Pole to ecliptic latitude $\beta = -6^\circ$. The satellite covered the sky in 13 partially overlapping swaths, or sectors, with a 30-minute cadence, for a total of 27.5 days per sector. This strategy generated sky coverage in the southern hemisphere where the South Ecliptic Pole was observed continuously for 351 days, and the sectors nearest the ecliptic equator were observed for 27.5 days. In Mission Year 2, TESS is completing a survey of the northern sky, albeit with some modifications to the cadence: some of the sectors start at a higher ecliptic latitude and extend farther over the pole. Full Frame Images (FFIs) for successive sectors are released at regular intervals through the mission archive at the Barbara A. Mikulski Archive for Space Telescopes (MAST).

We present a mosaic derived from the co-addition of all FFIs acquired in sectors 1 through 21 acquired by all four cameras; these are the data that had been released to the public by April 2020. The data set comprises 13 sectors in the south and eight sectors in the north. As in Berriman et al. (2019), the mosaic was created with the Montage image mosaic engine (Berriman and Good 2017). It preserves the calibration and astrometric fidelity of input FITS images, models smoothly varying image backgrounds across images, and rectifies these backgrounds to a common level. Montage is, to our knowledge, unique in using this approach to handling backgrounds.

The computations were performed on 21 high-performance servers of the Amazon Web Services (AWS) Elastic Compute Cloud (EC2); the servers employed a total of 336 virtual CPUs. The raw and processed data were stored on AWS Elastic File Storage (EFS; essentially a shared network file system) for performance, and the processing time of the production run was approximately two wall clock hours. Each input image was re-projected to a reference frame for its sector, and over-sampled at 6.0 arcseconds (rather than the original 21 arcseconds) to preserve all the information associated with the overlap between pixels. These re-projected images were then co-added to create the mosaic. A total of 40,000 images were processed, with approximately 700 images excluded because their astrometric solutions contained errors.

3. CHARACTERISTICS OF THE MOSAIC AND THE CREATION OF CUTOUTS

Figure 1 shows the mosaic. The galactic plane is most easily seen as a horizontal band across the right side of the image; below it, near the South Galactic Pole, are the the Large and Small Magellanic Clouds. The most striking feature across the image is the highly variable residual stray light, even after rectification by Montage. This is most likely caused by light from the Earth appearing over the satellite sunshade, a consequence of the geometry of the spacecraft's orbit (RK. Vanderspek; private communication). It can be removed in a subsequent mosaic by excluding images where this contamination is present. Despite the prevalence of stray light, the cutouts of the four galaxies in Figure 1 show that on spatial scales of 1 to 2 degrees, the background is smooth. The sets of three vertical stripes in the cutouts are associated with the strapping in the CCD. They are localized to specific pixel columns, and therefore a one-dimensional smooth background removal should leave the extended objects unaffected. Altogether, the mosaic indicates the TESS image mosaics are indeed suitable for LSB studies in the environments of galaxies. Future processing of FFIs that excludes stray light from the Earth are likely to show smooth backgrounds over larger spatial scales than are evident here.

The co-added image files are hosted at MAST as a High Level Science Product at 10.17909/t9-ebg0-3a45 and freely accessible through a Jupyter Notebook.

4. CONCLUSIONS

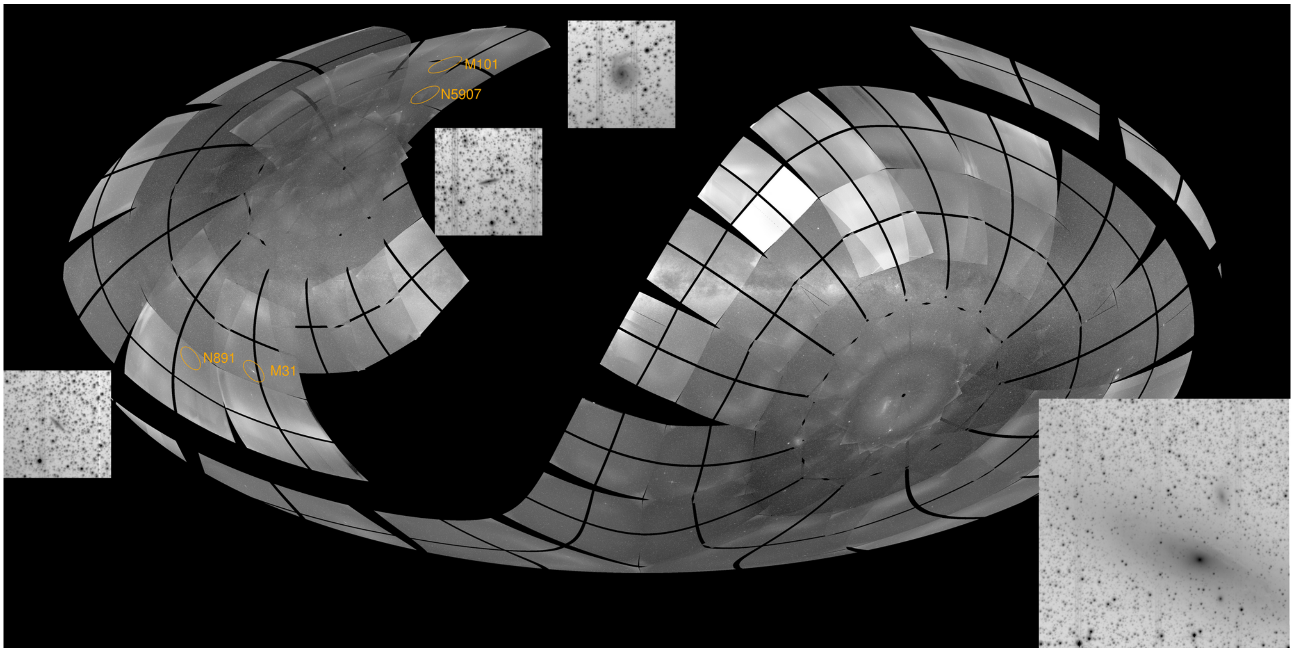

Figure 1. Mosaic in galactic coordinates presented in an Aitoff projection derived from co-adds of TESS FFIs from sectors 1 through 21 that had been publicly released in April 2020. The figure includes cutouts of four galaxies: N891 (bottom left; 1 degree square), M31 (bottom far right; 2.3 degrees square), N5907 (upper-left center; 1 degree square), M101 (upper-right center; 1 degree square). The sets of three vertical stripes in the cutouts are associated with the strapping in the CCDs. .

The data presented here indicate TESS data are adequate for LSB astronomy. They can be used in tests of Λ-CDM galaxy formation scenarios; derivation of stellar halo fractions for galaxies of different masses and morphologies; identification of some stellar streams around these galaxies and other galaxy cannibalism leftovers; and detection of ultra-diffuse galaxies as companions to bigger galaxies (Holwerda 2018).

This paper includes data collected with the TESS mission, obtained from the MAST data archive at the Space Telescope Science Institute (STScI). Funding for the TESS mission is provided by the NASA Explorer Program. STScI is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS 5–26555. The images were processed with MontageIt is funded by the National Science Foundation under Grant Numbers ACI-1440620,1642453 and 1835379The images were processed on the Amazon Elastic Cloud 2 (EC2) of Amazon Web Services (AWS). We thank the AWS Public Sector Cloud Credit for Research Program for a generous allocation of research credits. We thank Roland Vanderspek for valuable discussions.

Facilities: TESS, MAST

Software: Montage (Berriman and Good 2017); code repository at https://github.com/Caltech-IPAC/Montage .

REFERENCES

Berriman, G. B., Good, J. C., Christiansen, J. L., et al. 2019, Research Notes of the American Astronomical Society, 3, 94. doi:10.3847/2515-5172/ab3051

Berriman, G. B. & Good, J. C., 2017, PASP, 129, 058006

Holwerda B. W., 2018, Research Notes of the American Astronomical Society, 2, 53

Ricker, G. R.; Winn, J. N; Vanderspek, R.; et al. Journal of Astronomical Telescopes, Instruments, and Systems. 1 (1). 014003.