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The NASA GSFC TESS Full Frame Image Light Curve Data Set

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Abstract

We present a data set containing the light curves of all stars brighter than 16th magnitude in the TESS full frame images from the primary mission (Years 1 and 2; Sectors 1–26). This includes a total of over 150 million light curves, making it the largest set of TESS light curves released to date.

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1. Introduction

The Full Frame Images (FFIs) from the Transiting Exoplanet Survey Satellite (TESS) (Ricker et al. 2015) present an enormous and largely unexploited opportunity for discovery. Some TESS FFI light curve data sets have been produced and archived on the Mikulski Archive for Space Telescopes (MAST), including those described in Caldwell et al. (2020) and Huang et al. (2020). While vast, these data sets still comprise less than 20% of the stars observed in the FFIs down to TESS's limiting magnitude of ~ 16 .

If a user were interested in light curves of any other stars, some tools exist to allow them to create their own. Two common choices are the specially developed *eleanor* pipeline (Feinstein et al. 2019) or *lightkurve* (Lightkurve Collaboration et al. 2018), both relying on TESSCut (Brasseur et al. 2019) to provide Target Pixel Files (TPFs) of the requested star. This can work well for individual stars but scales poorly.

Here we present precomputed *eleanor* light curves for all stars in the FFIs brighter than 16th magnitude: a total of over 150 million light curves available through MAST as a High Level Science Product, *gsfc-eleanor-lite*.¹¹ Our light curve construction process can be summarized as a parallelized, offline implementation of the *eleanor* pipeline. The construction of this data set was made possible through the use of the NASA Center for Climate Simulation (NCCS) *Discover* supercomputer.¹²

2. Light Curve Creation

2.1. Target List

Targets are selected from the TESS Input Catalog (TIC, Stassun et al. 2019) version 8.2, with the only criteria being the aforementioned magnitude limit. In order to determine the sectors in which each star

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We downloaded the TIC from MAST,¹³ then used *Discover* to perform the tess-point operation in parallel, which returned the sectors in which each star is present. We grouped the returned TIC numbers by sector, eventually combining them all into a single target list, with characteristics shown in Figure 1.

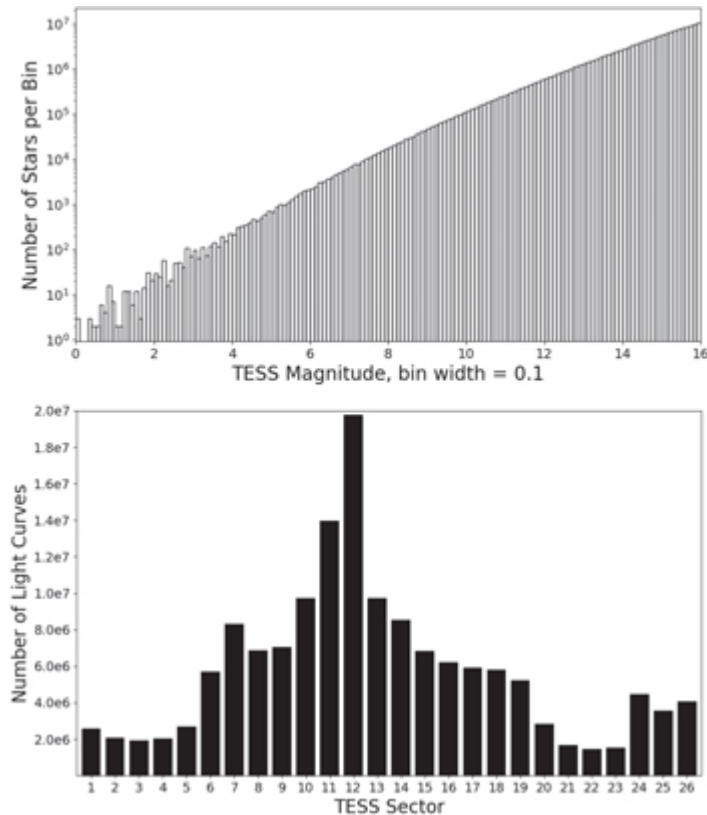


Figure 1. (Top panel) Histogram of the TESS magnitudes of the stars in the data set. (Bottom panel) Number of light curves in the data set (or number of stars brighter than 16th magnitude) by TESS sector.

2.2. Raw Data

MAST provides scripts for bulk downloads of the FFIs.¹⁴ Upon download, we organized the FFIs by camera and chip.

2.3. Eleanor

The *eleanor* package is presented in full in Feinstein et al. (2019), but here we briefly describe our process and how we ran the package locally on *Discover*. All light curves were built with *eleanor* version 2.0.3 and the accompanying *eleanor-tools* package.¹⁵

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2.3.1. Intermediate Products

Pointing Models—Following the scripts from Feinstein et al. (2019), we create a pointing model for each sector using isolated, bright-but-unsaturated stars to account for spacecraft motion and precisely translate coordinates into positions on the chip at every cadence.

Postcards and Backgrounds—Using the *eleanor-tools* scripts, we create postcards and background files: a small cutout of the FFIs, stacking all cadences into a data cube storing the fluxes and inferred background levels over time for those pixels.

Light Curves—Once the pre-processing is complete, we invoke the *eleanor* function `TargetData`, which builds the raw, corrected, and PCA light curves as described in Feinstein et al. (2019). Though it is possible to construct the PSF light curve as well, we avoid this option due to time constraints.

2.3.2. The Eleanor-lite Format

Each light curve is saved and provided for public release on MAST as a FITS file in the "eleanor-lite" format. The lite format was introduced as a data-saving measure for bulk downloading of light curves. Here we document the differences.

1. In the original save method, the target's TPF and errors were saved (a data cube of fluxes for all pixels and cadences used as well as one for its flux errors). In the lite format, only the median pixel file and median error (median flux and error of each pixel across all cadences) are saved.
2. The original FITS file contains all apertures used and tested by *eleanor*, of which only one is selected as optimal and used to create the light curve. In the lite version, we only save the name and values of this optimal aperture, discarding the rest.
3. Finally, the original FITS files contain a third extension that holds the raw, corrected, and flux errors of every aperture that *eleanor* tested, which lite discards and only provides the optimal aperture's light curve.

All of the above choices were made with the expectation that *gsfc-eleanor-lite* light curves will be downloaded in bulk for vast searches for specific astrophysical signals (e.g., planets, eclipses, flares) and that only a small subset of these targets will merit closer investigation, at which point it becomes feasible for the user to manually recreate the full *eleanor* light curves themselves. In all, the *gsfc-eleanor-lite* FITS files are 19.2× smaller than the originals, allowing for quicker bulk downloads and less strain on disk storage in searching these millions of stars.

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3. Caveats

Here we reiterate that our target selection was purely a 16th magnitude cut. However, TESS has large pixels, and in crowded fields it is unlikely that a 16th magnitude star is isolated enough from brighter neighbors to create a reliable light curve. We make no corrections for dilution or flux contamination, which may be so severe as to make the light curve unusable. Users should consult the optimal aperture as well as other eleanor functions or third-party tools in order to conduct pixel-level investigations or make appropriate corrections.

4. Summary

We have provided a data set of over 150 million TESS FFI light curves for public release, available through MAST. Large-scale studies or machine learning techniques, in addition to visual surveying, could be powerful tools in examining the light curves.

Resources supporting this work were provided by the NASA High-End Computing (HEC) Program through the NASA Center for Climate Simulation (NCCS) at Goddard Space Flight Center.

This paper includes data collected by the TESS mission, which are publicly available from the Mikulski Archive for Space Telescopes (MAST). Funding for the TESS mission is provided by NASA's Science Mission directorate.

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Footnotes


11 DOI 10.17909/j2yt-t417

12 <https://www.nccs.nasa.gov/systems/discover>

13 https://archive.stsci.edu/tess/tic_ctl.html

14 https://archive.stsci.edu/tess/bulk_downloads/bulk_downloads_ffi-tp-lc-dv.html

15 <https://github.com/afeinstein20/eleanor-tools>

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