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TESS in the Solar System: Refining asteroid light curves with long-baseline photometry

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Abstract

Last summer, the Transiting Exoplanet Survey Satellite (TESS) began science operations, with the promise of delivering an impressive yield of new transiting exoplanet candidates around nearby stars. The data products generated by the mission provide new and interesting avenues of research in Solar System studies as well. In particular, rotational light curve studies of small bodies serve to benefit greatly from the continuous high-cadence long-baseline photometry, following the legacy of similar work done using images from the *K2* mission, I will discuss the various data products from the TESS mission relevant for small body studies and describe techniques for extracting photometry, as well as the unique challenges inherent in using the TESS images. As a specific example, I will present new rotational light curves of two objects — Eurybates and Polymele — which will be visited as part of the NASA *Lucy* fly-by mission to the Jupiter Trojans.

1. Introduction

Launched in April 2018, TESS lies on a highly-elliptical orbit around Earth, completing an orbit every $\sim$13.7 days. As part of the 2-year primary mission, the telescope divides the Southern and Northern sky into 13 Sectors each, observing every Sector continuously for two spacecraft orbits. The instrument is equipped with four CCD cameras with adjacent fields-of-view, arranged in a vertical north-south configuration to produce a total viewable area of $24° \times 96°$ in a single shot. The positions of each Sector are chosen so as to avoid the ecliptic, with each Sector extending from 6° ecliptic latitude to the ecliptic pole. Nevertheless, a large number of high-inclination asteroids will be visible in the full-frame images.

2. Working with TESS data

2.1 Data products

TESS images the entire field-of-view with 2-second exposures. The detector bandpass spans the 600–1000 nm region, centered on Cousins *I*-band. Individual exposures are stacked into Full Frame Images (FFIs) at 30-minute cadence onboard the spacecraft. Over 1200 of these FFIs are obtained for each Sector and are downlinked at the end of each spacecraft orbit.

The raw FFIs are fed into a dedicated pipeline at the Science Processing Operations Center (SPOC) at NASA Ames, which calibrates the images following similar methods applied to data from the *Kepler* mission. Once these data products are processed and passed to the TESS Science Office, they are released to the public at regular intervals onto the Mikulski Archive for Space Telescopes (MAST, located at the Space Telescope Science Institute, STScI). Both raw and calibrated FFIs are available, along with an array of meta-data and data quality products.

2.2 Extracting moving object photometry

Each FFI contains a reliable astrometric solution, allowing for easy cross-referencing of stars and identification of moving objects with known orbits. Extraction of asteroid photometry proceeds through standard techniques that have been developed for small body studies using previous *Kepler* images [1]. Starting from the calibrated FFIs, which have been corrected for cosmic rays and various flat-field and instrumental effects, a median image is subtracted from the full array to produce a difference image with non-saturated stars removed. The pixel size of the detectors is 21 arcseconds, and we have found that over intervals ranging from several days to an entire spacecraft orbit, the pointing of the TESS telescope is stable to within one pixel. This means that simple pixel arithmetic is usually sufficient to produce clean difference images without the need to realign and interpolate the images prior to subtraction.

Next, we query the HORIZONS ephemerides service for the positions of a known asteroid and identify the corresponding source on each difference image. Due to the 30-minute exposure time for each FFI, Near-Earth, Main Belt, as well as Jupiter-resonant asteroids will be non-negligibly streaked on the images, requiring photometric extraction through elongated apertures. This produces the photometric light curve for the object.

There are several challenges inherent to working with TESS FFIs. The most notable one is stray light on the detector. This effect is most problematic for Camera 1, which is located closest to the ecliptic. Although the instrument is equipped with a specially-designed lens hood to mitigate scattered light from the Earth or Moon, a non-negligible amount of stray light falls onto the detector, with the distribution and magnitude of the contamination varying with each exposure depending on the instantaneous relative position of those bright sources. We will discuss various techniques to characterize and reduce stray light effects in the extracted photometric series.

3 Summary

The TESS mission promises to be a watershed moment for both exoplanet and solar system science. The wide-field, continuous photometry provided by the spacecraft provides numerous applications in the field of small body astronomy, in particular in the study of time-domain processes like rotational light curves. With 10% relative photometric precision down through 17th-18th magnitude, an enormous number of asteroids will be observable in the Full Frame Images, allowing for efficient survey analyses, with huge implications for many fundamental questions in solar system science.

References

[1] Pál, A., Molnár, L., and Kiss, C.: TESS in the Solar System, PASP, Vol. 130, 114503, 2019.