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TESS Data Release Notes: Sector 7, DR9

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Acknowledgements

These Data Release Notes provide information on the processing and export of data from the Transiting Exoplanet Survey Satellite (TESS). The data products included in this data release are full frame images (FFIs), target pixel files, light curve files, collateral pixel files, cotrending basis vectors (CBVs), and Data Validation (DV) reports, time series, and associated xml files.

These data products were generated by the TESS Science Processing Operations Center (SPOC, [Jenkins et al., 2016](#)) at NASA Ames Research Center from data collected by the TESS instrument, which is managed by the TESS Payload Operations Center (POC) at Massachusetts Institute of Technology (MIT). The format and content of these data products are documented in the [Science Data Product Description Document \(SDPDD\)](#)¹. The SPOC science algorithms are based heavily on those of the Kepler Mission science pipeline, and are described in the Kepler Data Processing Handbook ([Jenkins, 2017](#)).² The Data Validation algorithms are documented in [Twicken et al. \(2018\)](#) and [Li et al. \(2019\)](#). The TESS Instrument Handbook ([Vanderspek et al., 2018](#)) contains more information about the TESS instrument design, detector layout, data properties, and mission operations.

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This report is available in electronic form at
<https://archive.stsci.edu/tess/>

¹<https://archive.stsci.edu/missions/tess/doc/EXP-TESS-ARC-ICD-TM-0014.pdf>

²<https://archive.stsci.edu/kepler/manuals/KSCI-19081-002-KDPH.pdf>

1 Observations

TESS Sector 7 observations include physical orbits 21 and 22 of the spacecraft around the Earth. Data collection was paused for 1.66 days during perigee passage while downloading data. In total, there are 22.80 days of science data collected in Sector 7.

Table 1: Sector 7 Observation times

	UTC	TJD ^a	Cadence #
Orbit 21	2019-01-08 02:59:37	1491.62553	190203
Orbit 21 end	2019-01-19 12:53:3	1503.03803	198420
Orbit 22 start	2019-01-21 04:43:36	1504.69775	199615
Orbit 22 end	2019-02-01 14:01:3	1516.08524	207814

^a TJD = TESS JD = JD - 2,457,000.0

The spacecraft was pointing at RA (J2000): 110.2559°; Dec (J2000): -32.6344°; Roll: 166.4476°. Two-minute cadence data were collected for 20,000 targets, and full frame images were collected every 30 minutes. See the TESS project [Sector 7 observation page](#)³ for the coordinates of the spacecraft pointing and center field-of-view of each camera, as well as the detailed target list. Fields-of-view for each camera with all two-minute targets can be found at the TESS Guest Investigator Office [observations status page](#)⁴.

1.1 Notes on Individual Targets

Five very bright stars ($T_{\text{mag}} \lesssim 2$) with large pixel stamps were not processed in the photometric pipeline. Target pixel files with raw data are provided, but no light curves were produced. The affected TIC IDs are 322899250, 64602863, 255559489, 38877693, 280310048.

Three stars (110798661, 300015238, and 354825493) had very bright stars nearby (110798652, 300015239 and 354825513 respectively). The contaminating flux for these objects is very large, and the pipeline assigns them disjoint photometric apertures that likely cause uncorrected systematic errors in the light curves.

Four targets (80466973, 124751941, 156934909, and 269407223) had apertures selected (25x25 pixels) that did not fully capture the bleed trails.

1.2 Spacecraft Pointing and Momentum dumps

The reaction wheel speeds were reset with momentum dumps every 3.125 days. FFIs taken during these times are marked with bit 6 (Reaction Wheel Desaturation Events) set. Only one or two FFIs are affected by each momentum dump. Figure 1 summarizes the pointing performance over the course of the sector based on Fine Pointing telemetry.

³<https://tess.mit.edu/observations/sector-7>

⁴<https://heasarc.gsfc.nasa.gov/docs/tess/status.html>

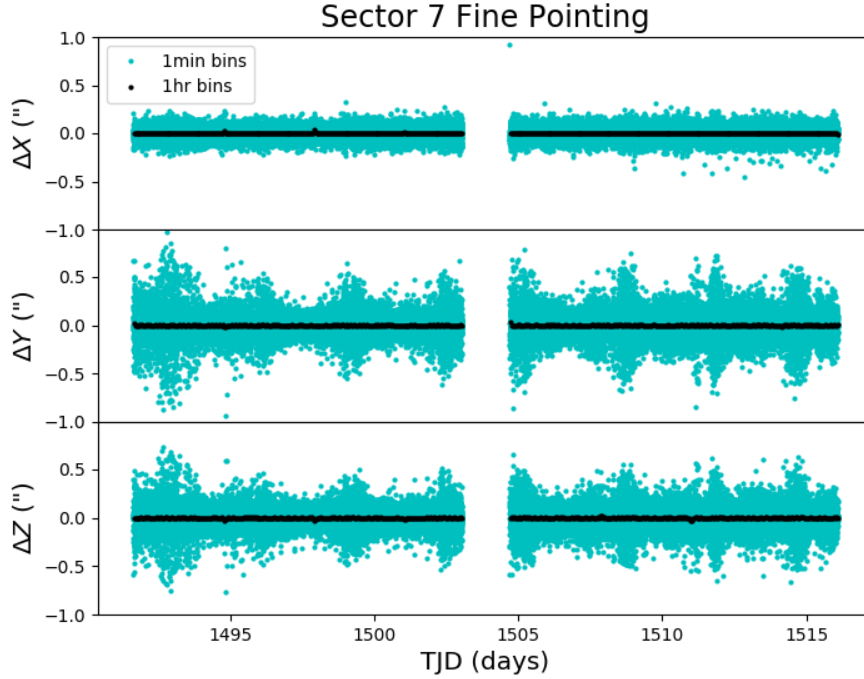


Figure 1: Guiding corrections based on spacecraft fine pointing telemetry. The delta-quaternions from each camera have been converted to spacecraft frame, binned to 1 minute and 1 hour, and averaged across cameras. Long-term trends (such as those caused by differential velocity aberration) have also been removed. The $\Delta X/\Delta Y$ directions represent offsets along the detectors’ rows/columns, while the ΔZ direction represents spacecraft roll.

1.3 Scattered Light

Figure 2 shows the median value of the background estimate for all targets on a given CCD as a function of time. Figure 3 shows the angle between each camera’s boresight and the Earth or Moon—this figure can be used to identify periods affected by scattered light and the relative contributions of the Earth and Moon to the image backgrounds. In Sector 7, the main stray light features are caused by the Earth and Moon rising above the sunshade at the end of orbit 21, which continues through the start of orbit 22.

2 Data Anomaly Flags

See the SDPDD (§9) for a list of data quality flags and the associated binary values used for TESS data, and the Instrument Handbook for a more detailed description of each flag.

The following flags were not used in Sector 7: bits 1, 2, 7, 9, 11, and 12 (Attitude Tweak, Safe Mode, Cosmic Ray in Aperture, Discontinuity, Cosmic Ray in Collateral Pixel, and Straylight).

Cadences marked with bits 3, 4, and 6 (Coarse Point, Earth Point, and Reaction Wheel Desaturation Event) were marked based on spacecraft telemetry.

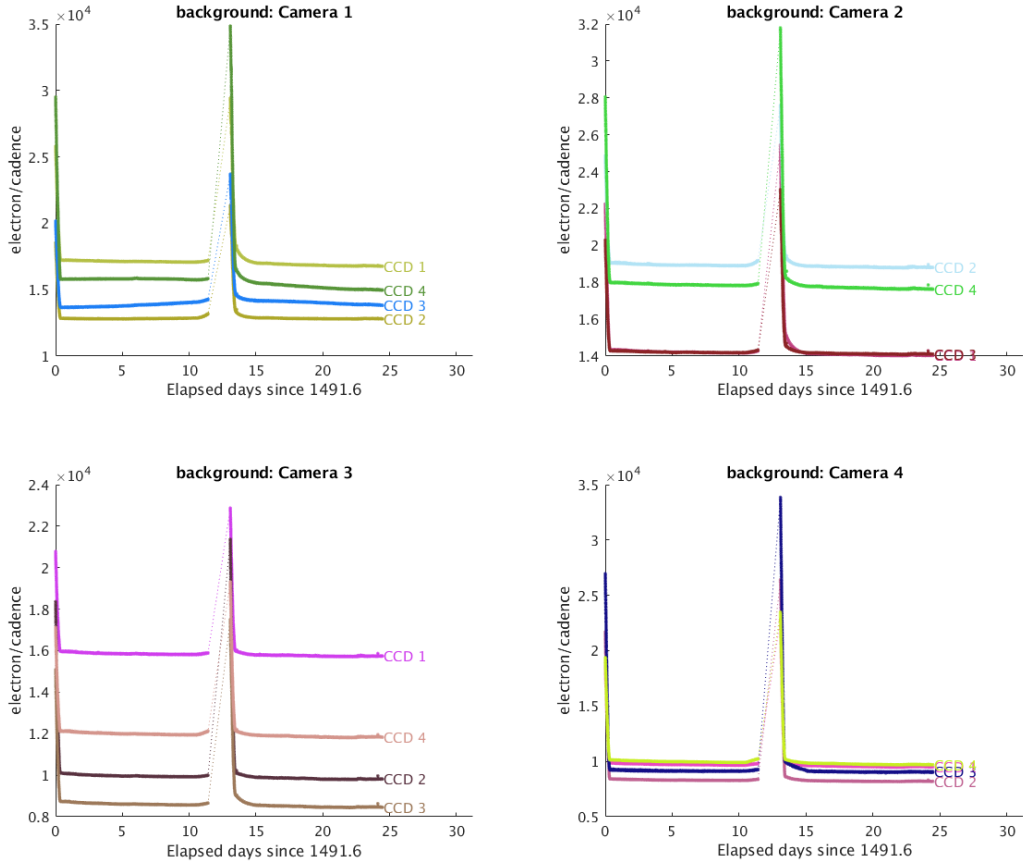


Figure 2: Median background flux across all targets on a given CCD in each camera. The changes are caused by variations in the orientation and distance of the Earth and Moon. The peak between orbits was caused by the Earth and Moon rising above the sunshade.

Cadences marked with bit 5 and 10 (Argabrightening Events and Impulsive Outlier) were identified by the SPOC pipeline. Bit 5 marks a sudden change in the background measurements. In practice, bit 5 flags are caused by rapidly changing glints and unstable pointing at times near momentum dumps. Bit 10 marks an outlier identified by PDC and omitted from the cotrending procedure.

Cadences marked with bit 8 (Manual Exclude) are ignored by PDC, TPS, and DV for cotrending and transit searches. In Sector 7, these cadences were identified using spacecraft telemetry from the fine pointing system. All cadences with pointing excursions >21 arc-seconds (~ 1 pixel) were flagged for manual exclude. See Figure 4 for an assessment of the performance of the detrending based on the final set of manual excludes.

FFIs were only marked with bit 6 (Reaction Wheel Desaturation Events). Only one or two FFIs are affected by each momentum dump.

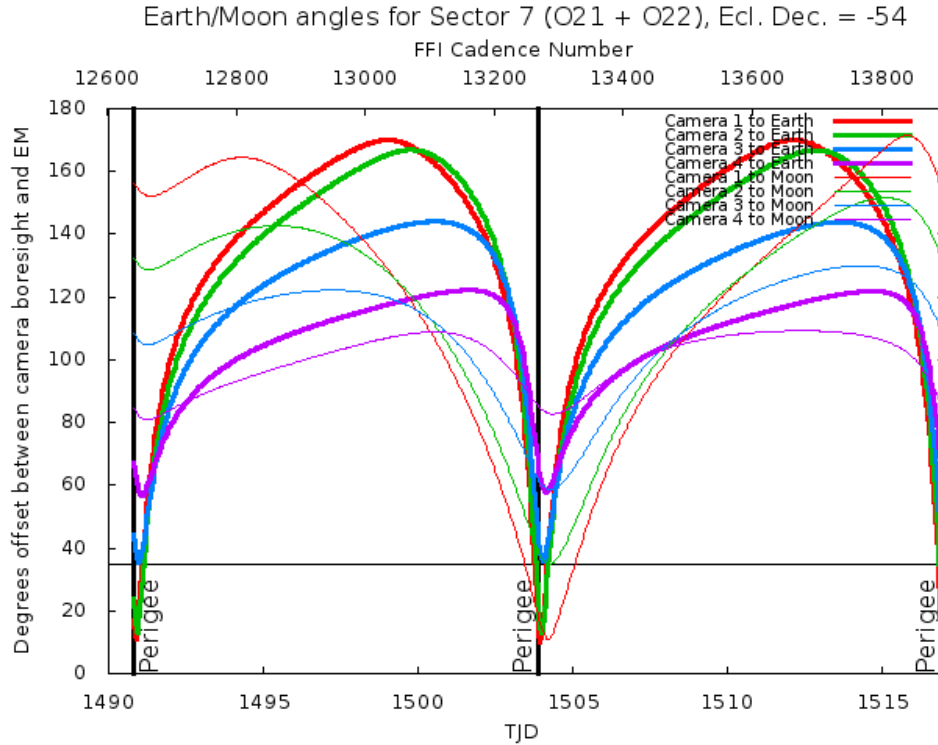


Figure 3: Angle between the four camera boresights and the Earth/Moon as a function of time. When the Earth/Moon moves within 37° of a camera's boresight, scattered light patterns and complicated features such as glints may appear. At larger angles, low level patchy features may appear. This figure can be used to identify periods affected by scattered light and the relative contributions of the Earth and Moon to the background. However, the background intensity and locations of scattered light features depend on additional factors, such as the Earth/Moon azimuth and distance from the spacecraft.

3 Anomalous Effects

3.1 Smear Correction Issues

The following columns were impacted by bright stars in the science frame and/or the upper buffer rows, which bleed into the upper serial register resulting in an overestimated smear correction.

- Camera 1, CCD 4, Columns 623-626, Star Procyon A
- Camera 2, CCD 4, Columns 2068-2092, Star Sirius A

3.2 Black Level Residuals

The Sector 7 data from some channels show a small non-zero residual in the mean black level after calibration that is either static (e.g., camera 3, CCD 2, output D) or slowly time varying (e.g., camera 4, CCD 1, all outputs and camera 4, CCD 3, all outputs). The level of

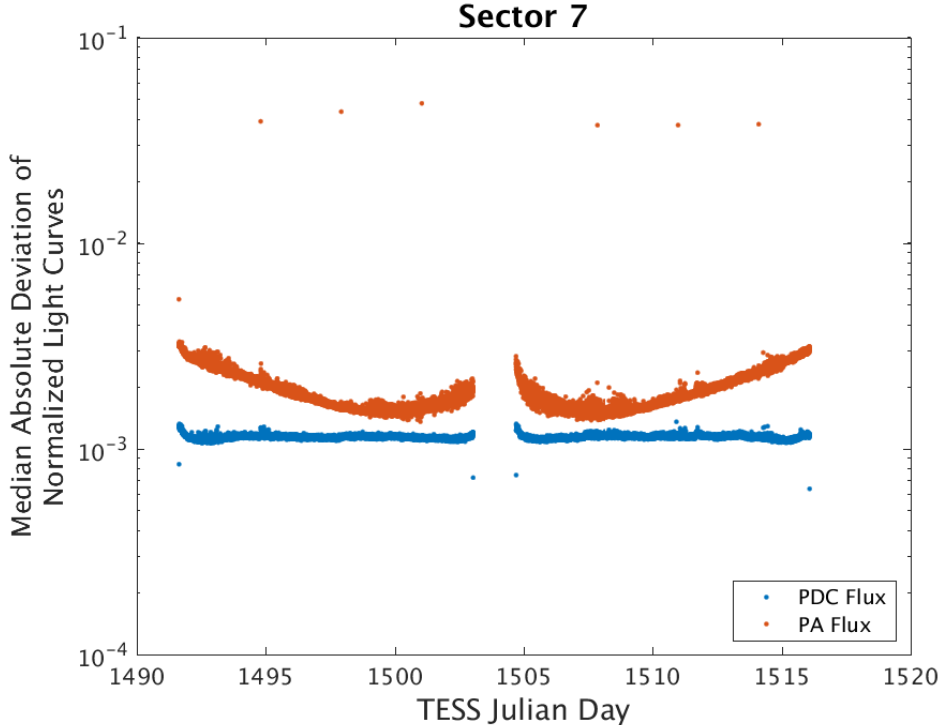


Figure 4: Median absolute deviation (MAD) for the 2-minute cadence data from Sector 7, showing the performance of the cotrending after identifying Manual Exclude data quality flags. The MAD is calculated in each cadence across stars with flux variations less than 1% for both the PA (red) and PDC (blue) light curves, where each light curve is normalized by its median flux value. The scatter in the PA light curves is much higher than that for the PDC light curves, and the outliers in the PA light curves are largely absent from the PDC light curves due to the use of the anomaly flags. Note that the first and last cadences in each orbit are treated as gaps by PDC.

these residuals is ~ 1 ADU/read and the timescale of variation is of order 5–10 days. Given the low levels and slow variation of the residuals, we do not expect them to impact most science investigations. However, the Sector 7 data were calibrated using the updated 1-D black method (see the [Sector-5 Data Release Notes, § 4.1⁵](#)), from which we do not expect such time-varying residuals. We are investigating the cause of these residuals.

Flutter and popcorn noise in the mean black level was observed in a small number of cameras, consistent with previous sectors. The current calibration removes these signals from the pixel data.

3.3 Fireflies and Fireworks

Table 2 lists all firefly and fireworks events for Sector 7. These phenomena are small, spatially extended, comet-like features in the images that may appear one or two at a time (fireflies) or in large groups (fireworks). See the Instrument Handbook for a complete description.

⁵https://archive.stsci.edu/missions/tess/doc/tess_drn/tess_sector_05_drn07_v01.pdf

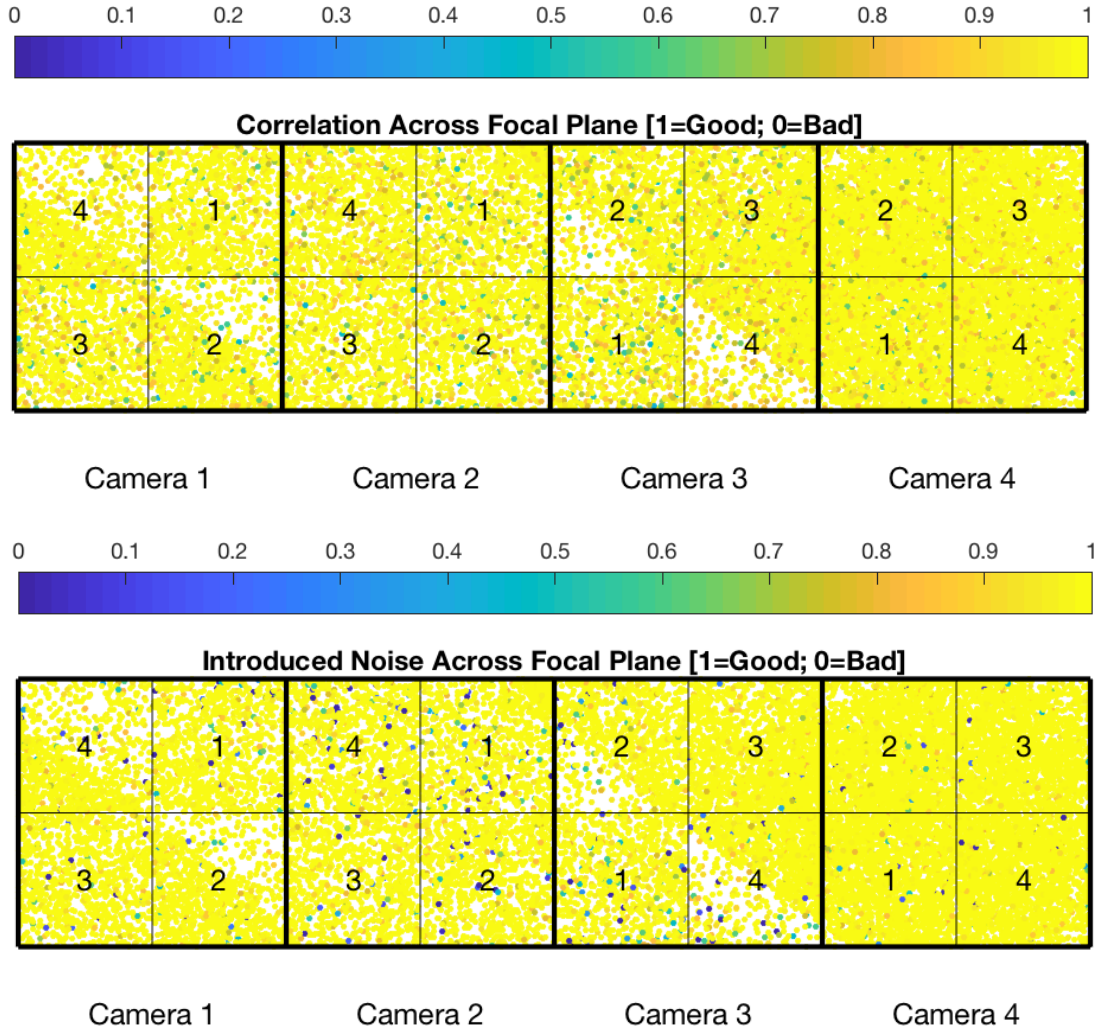


Figure 5: PDC residual correlation goodness metric (top panel) and PDC introduced noise goodness metric (bottom panel). The metric values are shown on a focal plane map indicating the camera and CCD location of each target. The correlation goodness metric is calibrated such that a value of 0.8 means there is less than 10% mean absolute correlation between the target under study and all other targets on the CCD. The introduced noise metric is calibrated such that a value of 0.8 means the power in broad-band introduced noise is only slightly above the level of uncertainties in the flux values.

3.4 TJD Calculation

As of Sector 7, the spacecraft clock kernel has been updated. The estimated accuracy of the TJD values in all products associated with this data release is 50 ms.

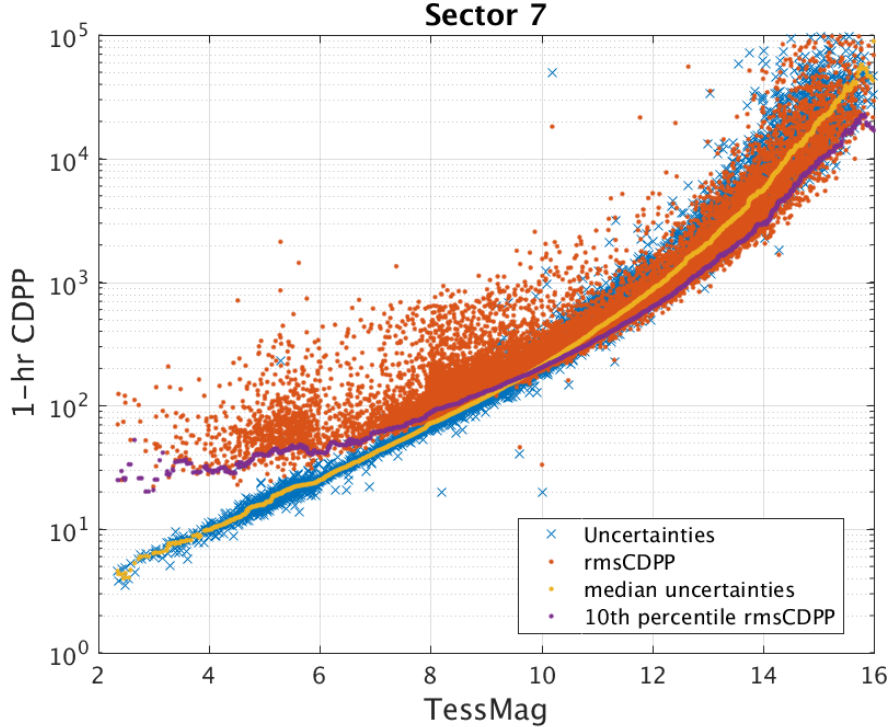


Figure 6: 1-hour CDPP. The red points are the RMS CDPP measurements for the 19,995 light curves from Sector 7 plotted as a function of TESS magnitude. The blue x’s are the uncertainties, scaled to 1-hour timescale. The purple curve is a moving 10th percentile of the RMS CDPP measurements, and the gold curve is a moving median of the 1-hr uncertainties.

Table 2: Sector Fireflies and Fireworks

FFI Start	FFI End	Cameras	Description
2019021155936	2019021162936	1, 2, 3	Fireflies
2019032052936	2019032055936	2, 3, 4	Fireflies

4 Pipeline Performance and Results

4.1 Light Curves and Photometric Precision

Figure 5 gives the PDC goodness metrics for residual correlation and introduced noise on a scale between 0 (bad) and 1 (good). The performance of PDC is very good and generally uniform over most of the field of view. Figure 6 shows the achieved Combined Differential Photometric Precision (CDPP) at 1-hour timescales for all targets.

4.2 Transit Search and Data Validation

In Sector 7, the light curves of 19,995 targets were subjected to the transit search in TPS. Of these, Threshold Crossing Events (TCEs) at the 7.1σ level were generated for 813 targets.

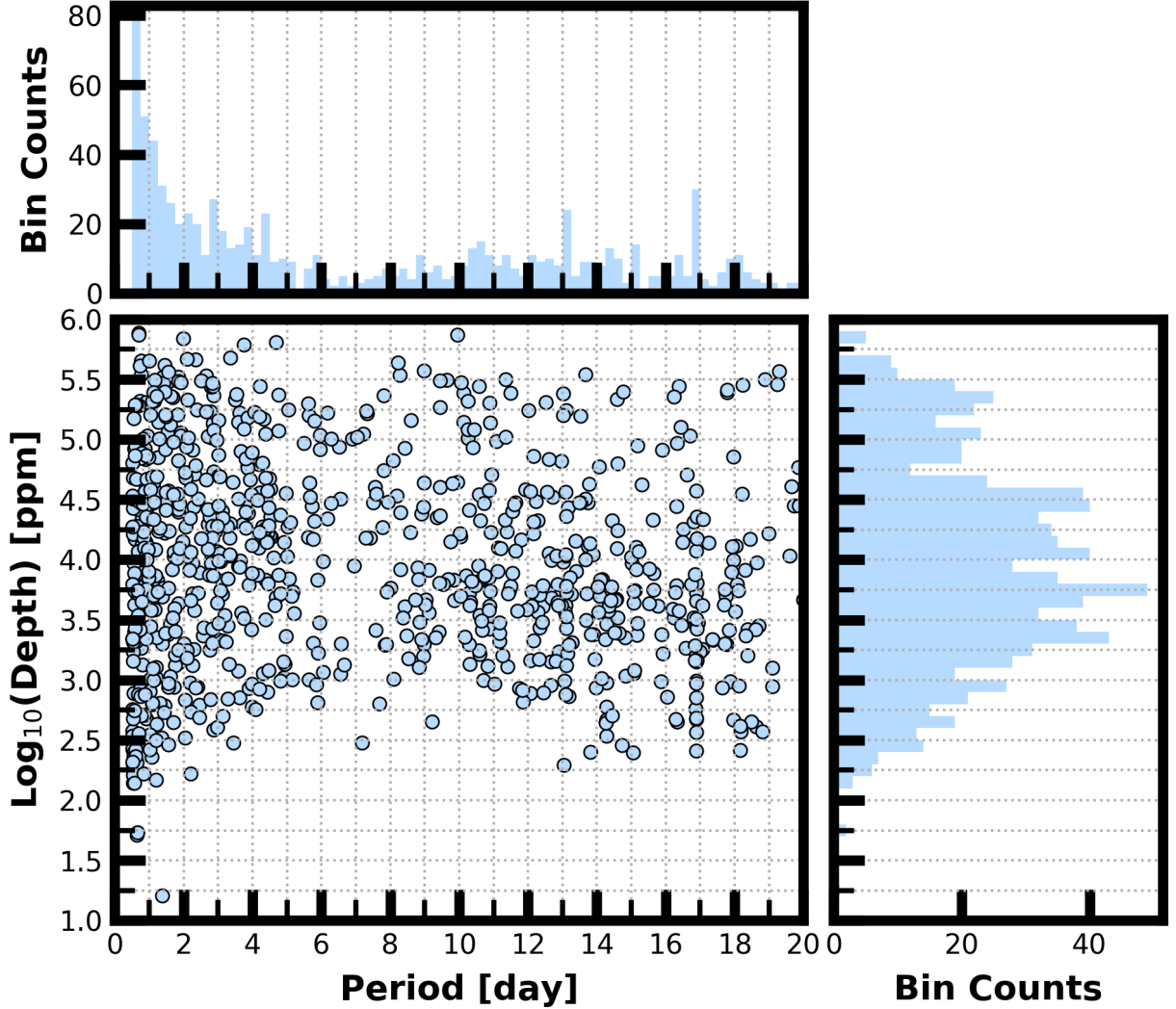


Figure 7: Lower Left Panel: Transit depth as a function of orbital period for the 1140 TCEs identified for the Sector 7 search. For enhanced visibility of long period detections, TCEs with orbital period <0.5 days are not shown. Reported depth comes from the DV limb darkened transit fit depth when available, and when not available, the DV trapezoid model fit depth. Top Panel: Orbital period distribution of the TCEs shown in the lower left panel. Right Panel: Transit depth distribution for the TCEs shown in the lower left panel.

The top panel of Figure 7 shows the distribution of orbital periods for the TPS TCEs found in Sector 7. Narrow peaks in the histogram occur at approximately 3, 13, and 17 days. These periods are mainly caused by pointing excursions associated with the second, third, and seventh momentum dumps. Figure 8 shows the number of TCEs at a given cadence that exhibit a transit signal—the isolated peaks show a strong correspondence to the periods of increased jitter in Figure 1. The 17 day period excess of TCEs corresponds to the time separation between the two most populated peaks in Figure 8.

The vertical histogram in the right panel of Figure 7 shows the distribution of transit depths derived from limb-darkened transiting planet model fits for TCEs. The model

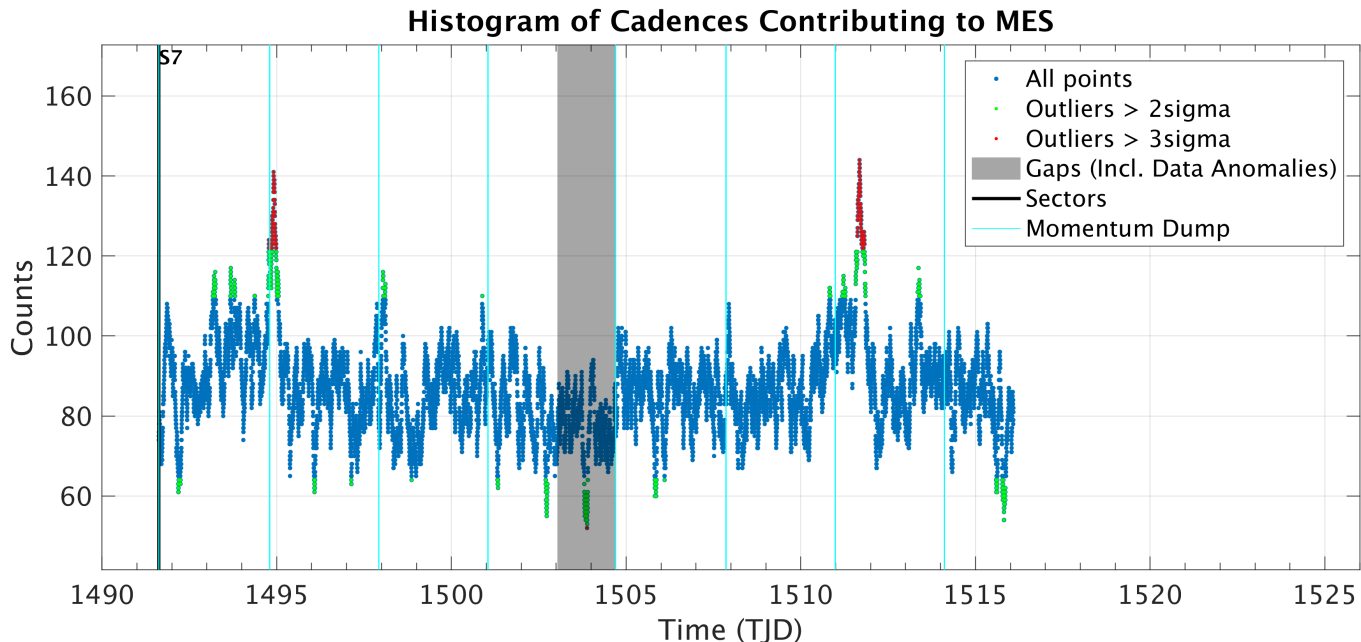


Figure 8: Number of TCEs at a given cadence exhibiting a transit signal. Isolated peaks are caused by a single event and result in spurious TCEs. The peaks typically align with pointing instabilities and strong background variations. The main features to be aware of are cadences near TJD epoch 1495.0 and 1511.6.

transit depths range down to the order of 100 ppm, but the bulk of the transit depths are considerably larger.

A search for additional TCEs in potential multiple planet systems was conducted in DV through calls to TPS. A total of 1140 TCEs were ultimately identified in the SPOC pipeline on 813 unique target stars. Table 3 provides a breakdown of the number of TCEs by target. Note that targets with large numbers of TCEs are likely to include false positives.

Table 3: Sector 7 TCE Numbers

Number of TCEs	Number of Targets	Total TCEs
1	542	542
2	224	448
3	40	120
4	5	20
5	2	10
–	813	1140

References

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Acronyms and Abbreviation List

BTJD	Barycentric-corrected TESS Julian Date
CAL	Calibration Pipeline Module
CBV	Cotrending Basis Vector
CCD	Charge Coupled Device
CDPP	Combined Differential Photometric Precision
COA	Compute Optimal Aperture Pipeline Module
CSCI	Computer Software Configuration Item
CTE	Charge Transfer Efficiency
Dec	Declination
DR	Data Release
DV	Data Validation Pipeline Module
DVA	Differential Velocity Aberration
FFI	Full Frame Image
FIN	FFI Index Number
FITS	Flexible Image Transport System
FOV	Field of View
FPG	Focal Plane Geometry model
KDPH	Kepler Data Processing Handbook
KIH	Kepler Instrument Handbook
KOI	Kepler Object of Interest
MAD	Median Absolute Deviation
MAP	Maximum A Posteriori
MAST	Mikulski Archive for Space Telescopes
MES	Multiple Event Statistic
NAS	NASA Advanced Supercomputing Division
PA	Photometric Analysis Pipeline Module

PDC Pre-Search Data Conditioning Pipeline Module

PDC-MAP Pre-Search Data Conditioning Maximum A Posteriori algorithm

PDC-msMAP Pre-Search Data Conditioning Multiscale Maximum A Posteriori algorithm

PDF Portable Document Format

POC Payload Operations Center

POU Propagation of Uncertainties

ppm Parts-per-million

PRF Pixel Response Function

RA Right Ascension

RMS Root Mean Square

SAP Simple Aperture Photometry

SDPDD Science Data Product Description Document

SNR Signal-to-Noise Ratio

SPOC Science Processing Operations Center

SVD Singular Value Decomposition

TCE Threshold Crossing Event

TESS Transiting Exoplanet Survey Satellite

TIC TESS Input Catalog

TIH TESS Instrument Handbook

TJD TESS Julian Date

TOI TESS Object of Interest

TPS Transiting Planet Search Pipeline Module

UTC Coordinated Universal Time

XML Extensible Markup Language