NASA/TM—2019—220463

TESS Data Release Notes:
Sector 17, DR24

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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 Products 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.

The TESS Mission is funded by NASA's Science Mission Directorate.

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 17 observations include physical orbits 41 and 42 of the spacecraft around the Earth. Data collection was paused for 1.43 days during perigee passage while downloading data. An instrument reset also occurred in orbit 42—no data were collected for six minutes between TJD 1789.18374 and 1789.18790. In total, there are 23.51 days of science data collected in Sector 17.

Table 1: Sector 17 Observation times

	UTC	TJD[a]	Cadence #
Orbit 41 start	2019-10-08 04:15:26	1764.67891	386801
Orbit 41 end	2019-10-19 19:01:26	1776.29418	395164
Orbit 42 start	2019-10-21 05:19:26	1777.72335	396193
Orbit 42 end	2019-11-02 04:37:25	1789.69417	404812

[a] TJD = TESS JD = JD - 2,457,000.0

The spacecraft was pointing at RA (J2000): 351.2381°; Dec (J2000): 57.8456°; Roll: 41.9686°. Two-minute cadence data were collected for 20,000 targets, and full frame images were collected every 30 minutes. See the TESS project Sector 17 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 and the Guest Investigator two-minute target list can be found at the TESS Guest Investigator Office observations status page[4].

1.1 Notes on Individual Targets

Three bright stars (Tmag $\lesssim$ 1.8) 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 174500619, 306349516, and 260614141.

Six target stars (445258206, 441804565, 341873045, 91329517, 91329515, 91329512) are blended with comparably bright stars—the contaminating flux for these objects is very large, and the resulting photometry for such targets is expected to be unreliable.

One target star (445258198, Tmag = 5.92) lies within the same pixel of a very bright star (445258206, Tmag = 2.8). In this case, no optimal aperture was assigned. A target pixel file with raw data is provided, but no light curve was produced.

One target (445258206) had a pixel stamp that did not fully capture the bleed trails.

1.2 Spacecraft Pointing and Momentum dumps

In Sector 17, the spacecraft pointing returned to the nominal mission pointing with Camera 4 centered on the North Ecliptic Pole. Camera 4 alone was used for guiding in both orbit 41 and orbit 42.

[3] https://tess.mit.edu/observations/sector-17

[4] https://heasarc.gsfc.nasa.gov/docs/tess/status.html

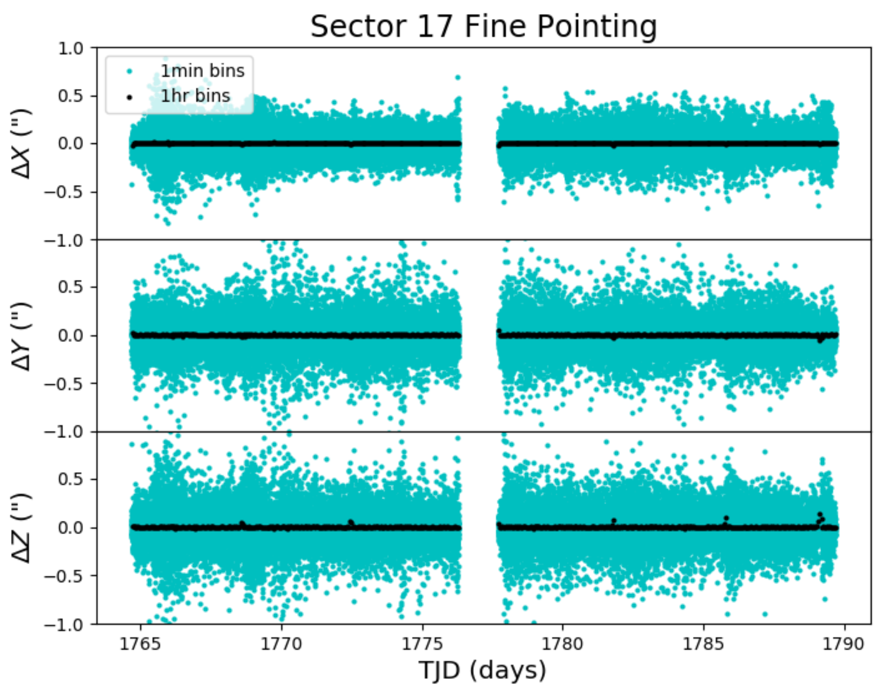

Figure 1: Guiding corrections based on spacecraft fine pointing telemetry. The delta-quaternions from each camera have been converted to spacecraft frame, binned to 1 minute and 1 hour, and averaged across cameras. Long-term trends (such as those caused by differential velocity aberration) have also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

The reaction wheel speeds were reset with momentum dumps every 3.875 (orbit 41) or 4.0 days (orbit 42). Figure 1 summarizes the pointing performance over the course of the sector based on Fine Pointing telemetry.

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 17, the Moon and Earth move into the field of view of Camera 1 towards the end of each orbit.

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 TESS Instrument Handbook for a more detailed description of each flag.

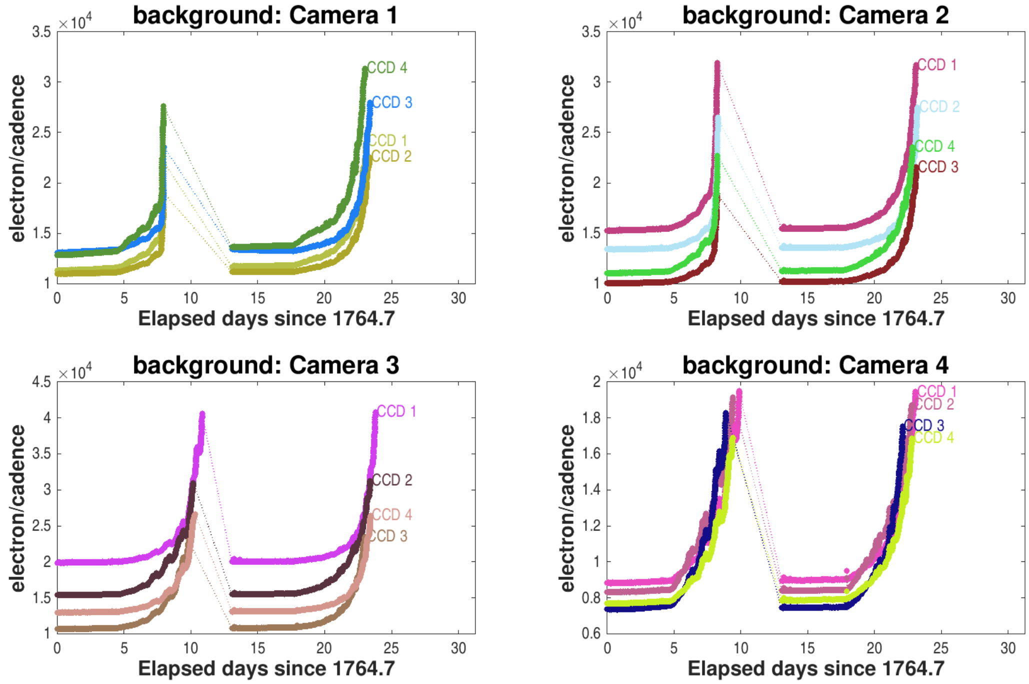

Figure 2: Median background flux across all targets on a given CCD in each camera. The changes are caused by variations in the orientation and distance of the Earth and Moon.

The following flags were not used in Sector 17: bits 1, 2, 7, 9, and 11 (Attitude Tweak, Safe Mode, Cosmic Ray in Aperture, Discontinuity, Cosmic Ray in Collateral Pixel).

Cadences marked with bits 3, 4, 6, and 12 (Coarse Point, Earth Point, Reaction Wheel Desaturation Event, and Straylight) were marked based on spacecraft telemetry. Note that the Straylight flag (bit 12) marks periods for when certain cameras are not suitable for guiding and do not necessarily indicate problematic data for other cameras. We suggest that users inspect the light curves before removing data in their analyses when this bit is set.

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 17, these cadences were identified using spacecraft telemetry from the fine pointing system. All cadences with pointing excursions >7 arcseconds (∼0.3 pixel) were flagged for manual exclude. See Figure 4 for an assessment of the performance of the cotrending based on the final set of manual excludes.

In Sector 17, bit 13 (value 4096, "Scattered Light") was set based on the observed background measurements for targets on each CCD, in order to mask cadences that would negatively affect the systematic error removal in PDC and the planet search in TPS.

FFIs were only marked with bits 3, 6 and 12 (Course Point, Reaction Wheel Desaturation

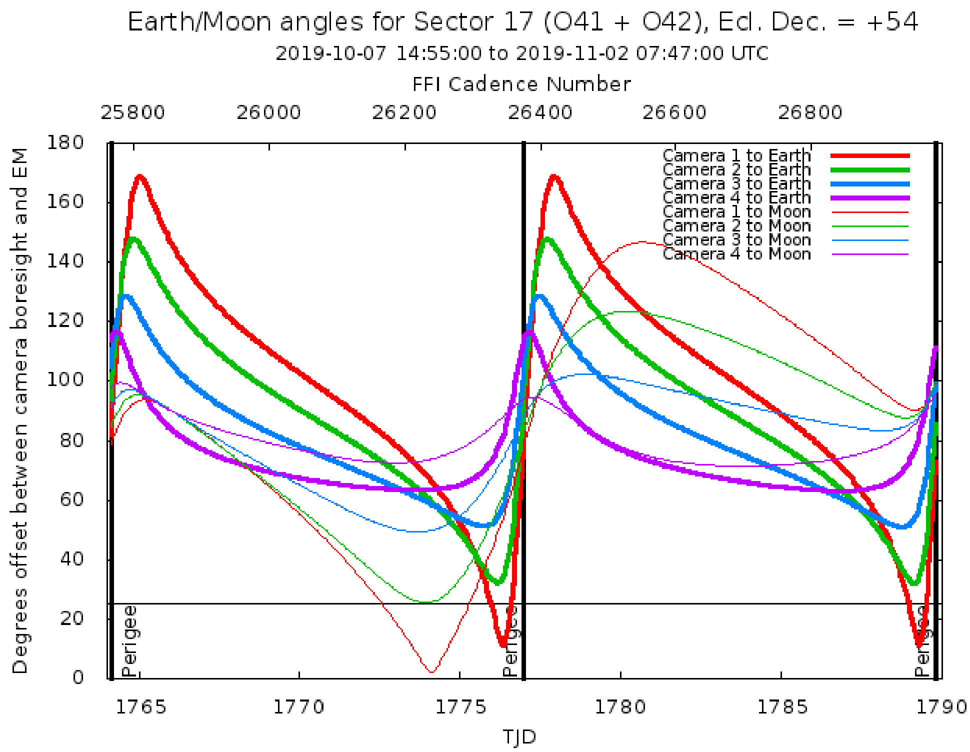

Figure 3: Angle between the four camera boresights and the Earth/Moon as a function of time. When the Earth is within $\sim 25^\circ$ of a camera's boresight, transiting planet searches may be compromised by high levels of scattered light. At larger angles, up to $\sim 35^\circ$, scattered light patterns and complicated structures may be visible. At yet larger angles, low level patchy features may be visible. Scattered light from the Moon is generally only noticeable below $\sim 35^\circ$. 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.

Events and Straylight). Only one FFI is affected by each momentum dump. There are no WCS coordinates for FFIs that coincide with momentum dumps.

3 Anomalous Effects

3.1 Smear Correction Issues

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

- Camera 1, CCD 3, Column 1179, Star Zeta Andromedae
- Camera 3, CCD 1, Column 1995, Star Xi Cephei

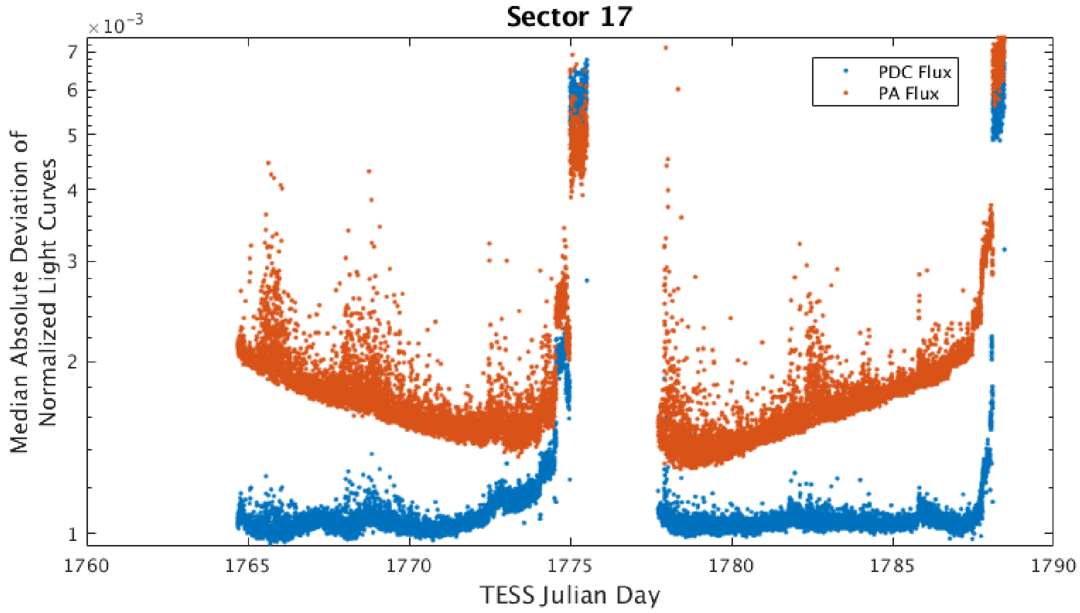

Figure 4: Median absolute deviation (MAD) for the 2-minute cadence data from Sector 17, showing the performance of the cotrending after identifying Manual Exclude data quality flags. The MAD is calculated in each cadence across stars with flux variations less than 1% for both the PA (red) and PDC (blue) 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.

3.2 Fireflies and Fireworks

Table 2 lists all firefly and fireworks events for Sector 17. These phenomena are small, spatially extended, comet-like features in the images—created by sunlit particles in the camera FOV—that may appear one or two at a time (fireflies) or in large groups (fireworks). See the TESS Instrument Handbook for a more complete description.

Table 2: Sector Fireflies and Fireworks

FFI Start	FFI End	Cameras	Description
2019296012926	2019296015926	3	Firefly
2019299022926	2019299025926	2, 3, 4	Fireflies
2019302065926	2019302072926	1	Firefly

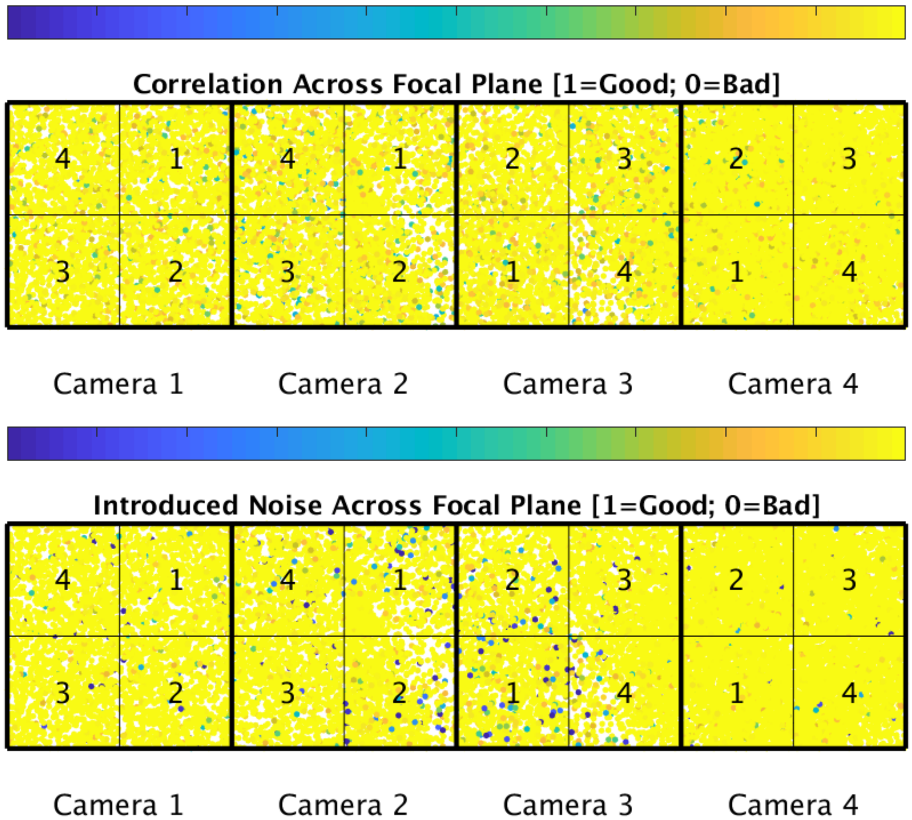

Figure 5: PDC residual correlation goodness metric (top panel) and PDC introduced noise goodness metric (bottom panel). The metric values are shown on a focal plane map indicating the camera and CCD location of each target. The correlation goodness metric is calibrated such that a value greater than 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 greater than 0.8 means the power in broad-band introduced noise is below the level of uncertainties in the flux values.

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 17, the light curves of 19996 targets were subjected to the transit search in TPS. Of these, Threshold Crossing Events (TCEs) at the $7.1\,\sigma$ level were generated for 702 targets.

We employed an iterative method when conducting the Sector 17 transit search. The top panel of Figure 7 shows the number of TCEs at a given cadence that exhibit a transit

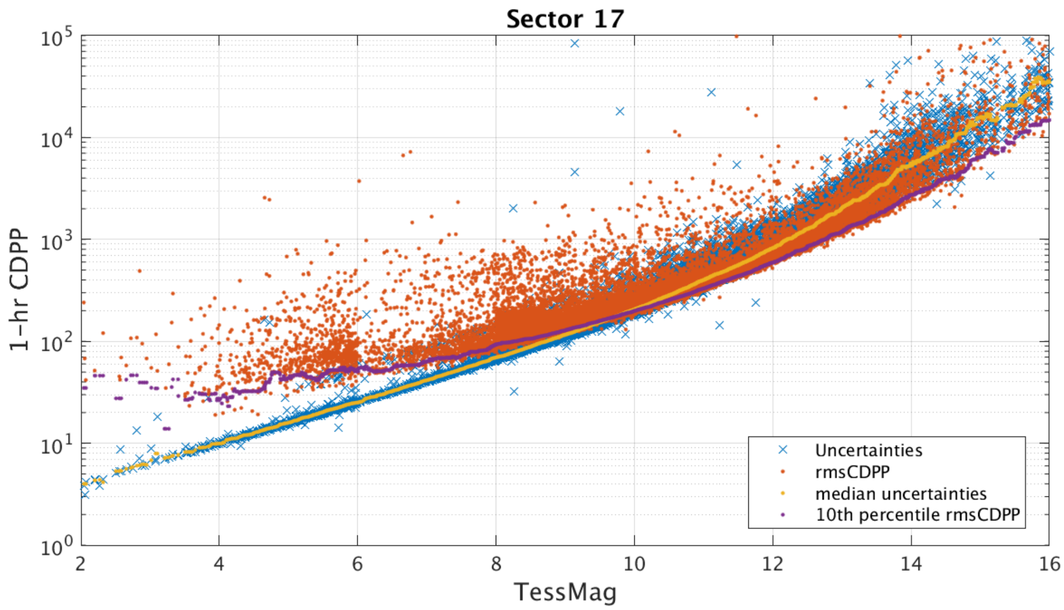

Figure 6: 1-hour CDPP. The red points are the RMS CDPP measurements for the 19996 light curves from Sector 17 plotted as a function of TESS magnitude. The blue x's are the uncertainties, scaled to 1-hour timescale. The purple curve is a moving 10th percentile of the RMS CDPP measurements, and the gold curve is a moving median of the 1-hr uncertainties.

signal from an initial run of TPS. The $3\,\sigma$ peaks were used to define deemphasis weights for a second run of TPS, the results of which are shown in the bottom panel of Figure 7. The final set of TCEs and the results reported here are based on the second run of TPS. The values of the adopted deemphasis weights are provided in the DV timeseries data products for targets with TCEs.

The top panel of Figure 8 shows the distribution of orbital periods for the final set of TCEs found in Sector 17. The vertical histogram in the right panel of Figure 8 shows the distribution of transit depths derived from limb-darkened transiting planet model fits for TCEs. The model 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 1005 TCEs were ultimately identified in the SPOC pipeline on 702 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 17 TCE Numbers

Number of TCEs	Number of Targets	Total TCEs
1	471	471
2	175	350
3	43	129
4	11	44
5	1	5
6	1	6
–	702	1005

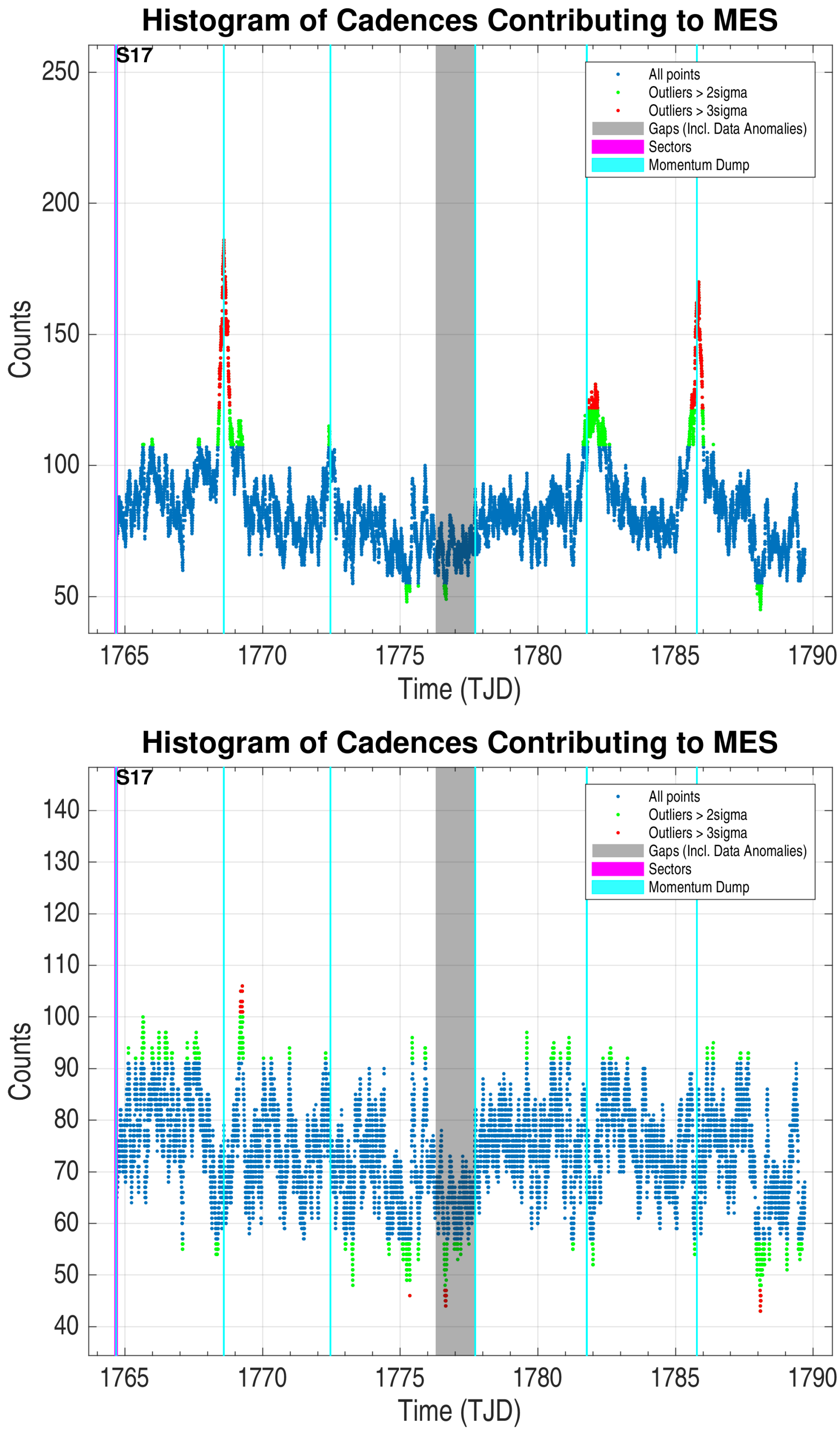

Figure 7: Top panel: Number of TCEs at a given cadence exhibiting a transit signal, based on an initial run of TPS. Any isolated peaks are caused by single events that result in spurious TCEs. These peaks were used to define deemphasis weights that suppress problematic epochs for the transit detection statistics in a second iteration of TPS. Bottom panel: Results from the second run of TPS.

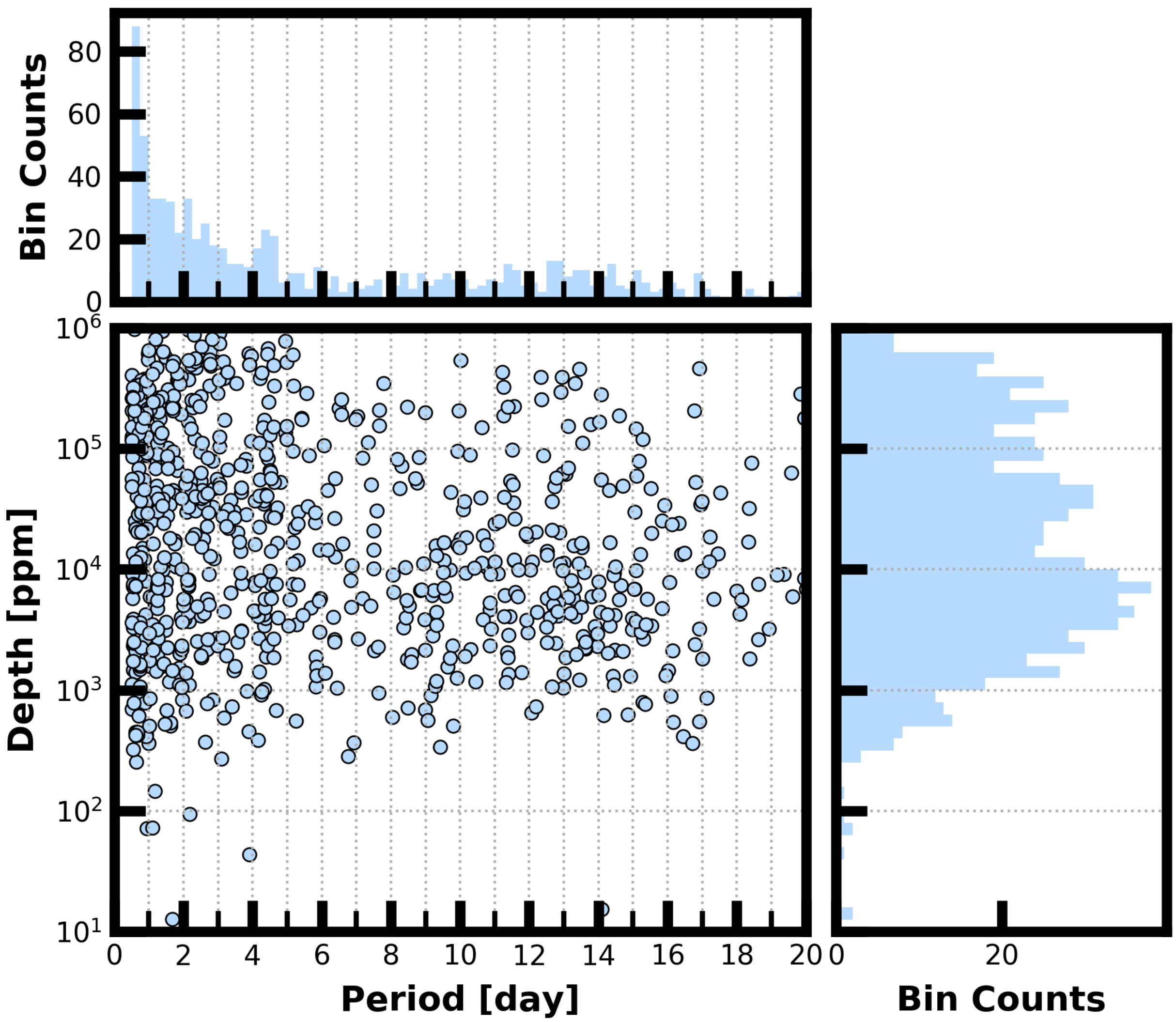

Figure 8: Lower Left Panel: Transit depth as a function of orbital period for the 1005 TCEs identified for the Sector 17 search. For enhanced visibility of long period detections, TCEs with orbital period <0.5 days are not shown. Reported depth comes from the DV limb darkened transit fit depth when available, and the DV trapezoid model fit depth when not available. 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.

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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

WCS World Coordinate System

XML Extensible Markup Language