NASA/TM—20230013469

TESS Data Release Notes:
Sector 61, DR86

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February 24, 2023

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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, 2020).[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-Rev-F.pdf

[2] https://archive.stsci.edu/kepler/manuals/KSCI-19081-003-KDPH.pdf

1 Observations

TESS Sector 61 observations include physical orbits 129 and 130 of the spacecraft around the Earth. Data collection was paused for a total of 0.63 days to download data. Data were downloaded approximately every seven days, once near apogee of each orbit and once near perigee.

In total, there are 24.80 days of science data collected in Sector 61.

Table 1: Sector 61 Observation times

	UTC	TJD[a]	Cadence #
Orbit 129a start	2023-01-18 07:00:40	2962.79362	1249444
Orbit 129a end	2023-01-24 19:56:40	2969.33251	1254152
Orbit 129b start	2023-01-25 01:00:40	2969.54362	1254304
Orbit 129b end	2023-01-30 16:42:39	2975.19778	1258375
Orbit 130a start	2023-01-30 21:44:39	2975.40750	1258526
Orbit 130a end	2023-02-06 16:32:39	2982.19083	1263410
Orbit 130b start	2023-02-06 21:34:39	2982.40056	1263561
Orbit 130b end	2023-02-12 17:22:39	2988.22555	1267755

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

[b]The horizontal black lines mark gaps in the light curves for data downlink.

The spacecraft was pointing at RA (J2000): 118.0446°; Dec (J2000): −36.0902°; Roll: 162.2198°. See the TESS project Sector 61 observation page[3] for the coordinates of the spacecraft pointing and center field-of-view of each camera. Fields-of-view for each camera can be found at the TESS Guest Investigator Office observations status page.[4] The detailed target list for both 2-minute and 20-second data, as well as the Guest Investigator target lists, can be found at the Sector 61 observation page and the observations status page.

1.1 Notes on Individual Targets

There are no issues with missing light curves in the 20-second data products. There were 2177 targets chosen for 20-second cadence observations, including 400 PPA stars.

For the 2-minute cadence data, 12216 targets were selected. Five bright stars (Tmag $\lesssim$ 1.8) with large pixel stamps were not processed in the photometric pipeline. The target pixel files with original and calibrated pixel data are provided, but no light curves were produced. Note that the TPF files do not include a background correction for stars without light curves. The affected TIC IDs are 255559489, 342884451, 38877693, 22942488 and 134501440.

Five target stars (354825493, 300015238, 110798652, 110798661, 100205079) are blended with comparably bright stars—the contaminating flux for these objects is very large, and the resulting photometry is expected to be unreliable.

[3]https://tess.mit.edu/observations/sector-61

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

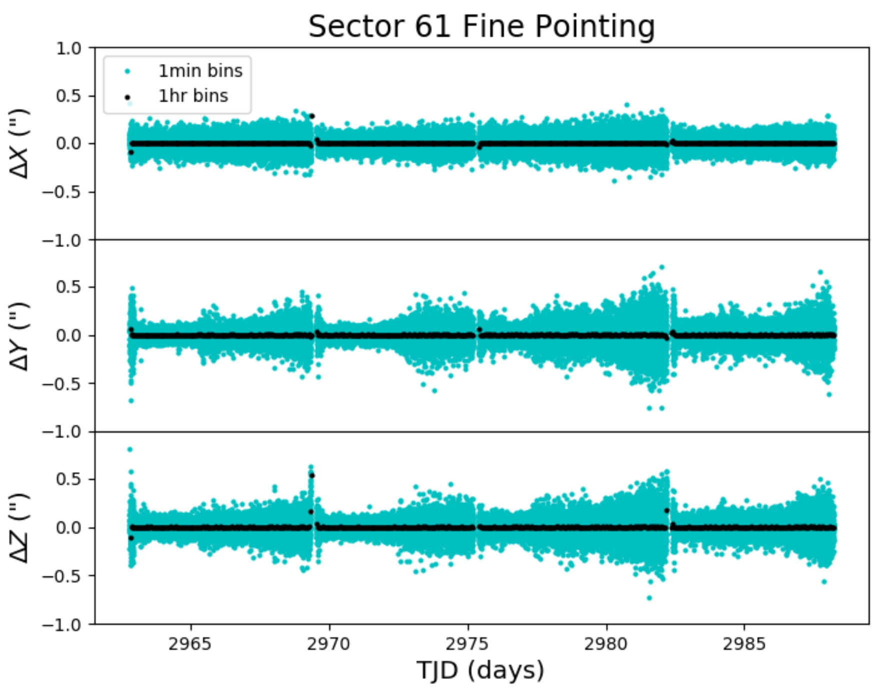

Figure 1: The delta-quaternions from each camera have been converted to spacecraft frame, binned to 1 minute and 1 hour. Long-term trends (such as those caused by differential velocity aberration) have also been removed. The $\Delta X/\Delta Y$ directions represent offsets along the detectors' rows/columns,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

1.2 Spacecraft Pointing and Momentum dumps

The pointing in Sector 61 was set at -55.5 degrees in ecliptic latitude. Camera 4 alone was used for guiding in the first half of orbit 129 and orbit 130. Camera 1 and Camera 4 were both used for guiding in the second half of each orbit. One momentum dump was performed in each orbit, at the end of each data downlink just before data collection resumed. 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 61, the Earth introduces scattered light signals at the start and end of each orbit.

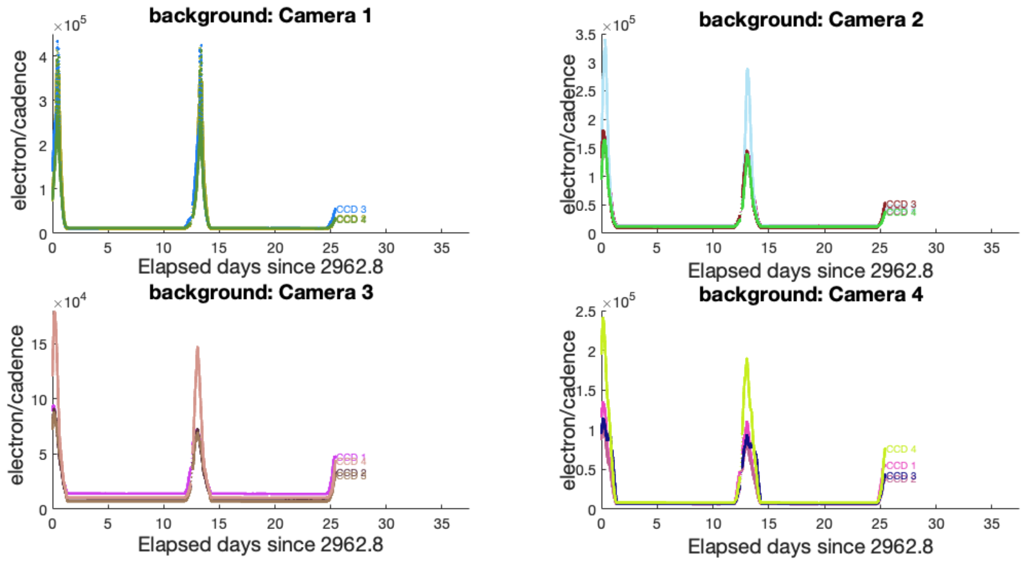

Figure 2: Median background flux across all targets on a given CCD in each camera. The changes are caused by variations in the orientation and distance of the Earth and Moon.

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.

The following flags were not used in Sector 61: bits 1, 2 and 9 (Attitude Tweak, Safe Mode, and Discontinuity).

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. Cadences marked with bits 2 and 4 (Safe Mode and Earth Point) have timestamps and data marked with `NULL` in the target-pixel files and light curve files.

Note that just after the data downlinks near apogee (midpoint of each orbit), the spacecraft pointing is still settling for 20 to 60 seconds after data collection resumes. Cadences during this time are marked with bit 8 (Manual Exclude, described below).

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.

The 20-second data mode includes cadences marked with bit 7 and 11 (Cosmic Ray in Optimal Aperture and Cosmic Ray in Collateral Pixel). These flags indicate cadences affected by cosmic rays that are removed by the pipeline, and can be found in both the TPF and LC files. The data provided in the archive products are corrected for cosmic rays, and a `FITS` table extension in the TPF and Collateral Pixel File details the cosmic rays identified and removed by the pipeline at the pixel level.

Cadences marked with bit 8 (Manual Exclude) are ignored by PDC, TPS, and DV for

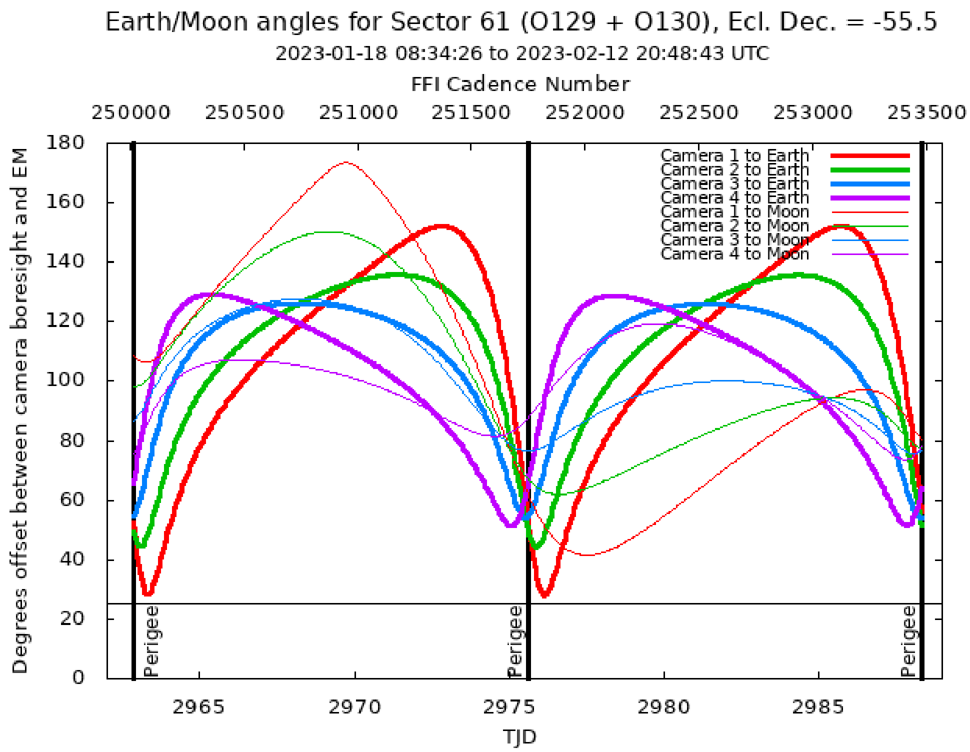

Figure 3: Angle between the four camera boresights and the Earth/Moon as a function of time. When the Earth is within ∼25° of a camera's boresight, transiting planet searches may be compromised by high levels of scattered light. At larger angles, up to ∼35°, scattered light patterns and complicated structures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

cotrending and transit searches. In Sector 61, these cadences were identified using spacecraft telemetry from the fine pointing system. All cadences with pointing excursions >7 arcsec (0.3 pixel) were flagged for manual exclude. Figure 4 shows an assessment of the performance of the cotrending based on the final set of manual excludes.

The predicted stray light flag (bit 12, value 2048) is marked in the FFIs and flags times when the Earth/Moon are near the camera FOVs and may interfere with guiding or saturate the detectors. We strongly recommend that users inspect the FFI data before removing images marked with bit 12, because this bit is set based on predictions from mission planning and is known to be conservative with respect to the quality of data usable for analysis.

The predicted stray light flag (bit 12) is disabled for the 2-minute and 20-second data products. The scattered light exclude flag (bit 13, value 4096) identifies cadences at which individual targets are affected by scattered light

If the Earth/Moon interference is strong enough to saturate the detector, all targets on a CCD slice will be affected and the data are unusable. Cadences with bad calibrations due to saturation are now explicitly marked with bit 15 (value 16384, "Bad Calibration Exclude").

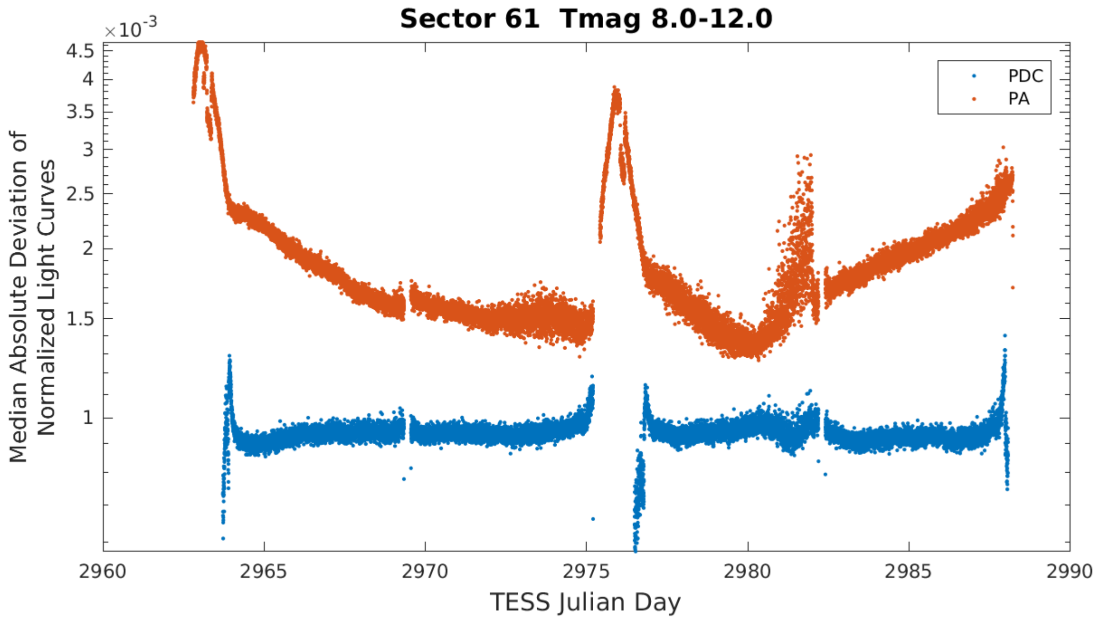

Figure 4: Median absolute deviation (MAD) for the two-minute cadence data from Sector 61, showing the performance of the cotrending after identifying Manual Exclude data quality flags. The MAD is calculated in each cadence across stars with flux variations less than 1% for both the PA (red) and PDC (blue) 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.

For some cadences, the majority of targets on a CCD may be flagged for scattered light and not enough valid data remains to derive cotrending basis vectors in PDC. No systematic error correction can be applied at these times. This situation is identified by bit 16 (value 32768, "Insufficient Targets for Error Correction Exclude").

FFIs were only marked with bits 3, 6, 8, 12, and 15 (Coarse Point, Reaction Wheel Desaturation Events, Manual Exclude, Straylight, and Bad Calibration Exclude). There are no WCS coordinates for FFIs that coincide with momentum dumps.

3 Anomalous Effects

Smear Correction Issues

The following columns were impacted by bright stars in the science frame, and/or upper buffer rows, and/or lower science frame rows, which bleed into the upper serial register resulting in an overestimated smear correction. In addition, Camera 3, CCD 3, Column 1408 (slice C) is impacted by intra-camera crosstalk from the bright star Nu Puppis located on slice A (see Section 6.8.6 of the TESS Instrument Handbook).

- Camera 1, CCD 1, Column 1877 - Star HD 71343
- Camera 1, CCD 2, Column 741 - Star HD 75490

- Camera 1, CCD 2, Column 1233 - Star HD 77266
- Camera 1, CCD 3, Column 886 - Star HD 77410
- Camera 1, CCD 4, Column 293 - Star HD 71295
- Camera 1, CCD 4, Column 1080 - Star HD 67614
- Camera 3, CCD 3, Column 385 - Star Nu Puppis
- Camera 3, CCD 3, Column 459 - Star HD 48150
- Camera 3, CCD 3, Column 1408 - Intra-camera Crosstalk from star Nu Puppis
- Camera 3, CCD 3, Column 1720 - Star HD 56813
- Camera 4, CCD 3, Column 917 - Star HD 33539
- Camera 4, CCD 3, Column 963 - Star WZ Doradus
- Camera 4, CCD 3, Column 1491 - Star HD 271253

4 Pipeline Performance and Results

4.1 Light Curves and Photometric Precision

Figure 5 gives the PDC goodness metrics for the two-minute cadence data, with residual correlation goodness and introduced noise goodness shown 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 two-minute targets.

4.2 Transit Search and Data Validation

In Sector 61, the two-minute light curves of 12211 targets were subjected to the transit search in TPS. Of these, Threshold Crossing Events (TCEs) at the $7.1\,\sigma$ level were generated for 1211 targets.

We employed an iterative method when conducting the Sector 61 transit search. The top panel of Figure 7 shows the number of TCEs at a given cadence that exhibit a transit signal from an initial run of TPS. The 3-σ peaks were used to define de-emphasis 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 de-emphasis 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 61. The bimodal nature of the period distribution is due to a large number of two-transit detections with periods ranging from 8 to 20 days, many of which are

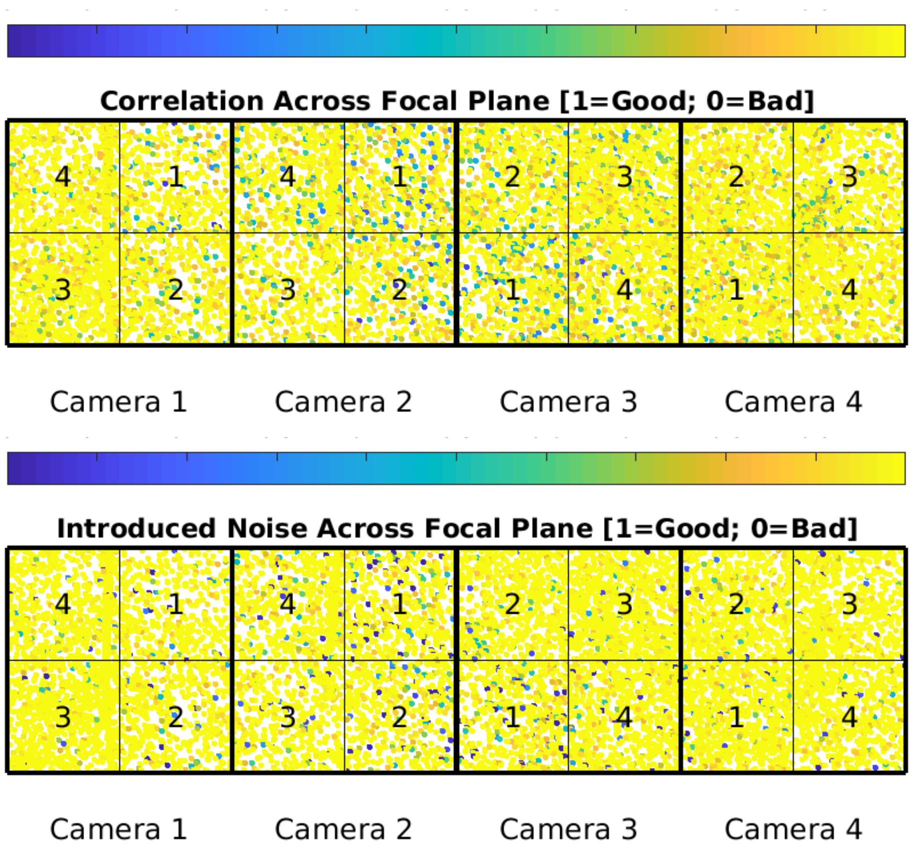

Figure 5: PDC residual correlation goodness metric (top panel) and PDC introduced noise goodness metric (bottom panel) for the two-minute cadence data. The metric values are shown on a focal plane map indicating the camera and CCD location of each target. The correlation goodness metric is calibrated 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.

likely false positives. Two-transit TCEs can be identified with the `NTRANS` keyword in the headers of the dv-timeseries FITS files. 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 1618 TCEs were ultimately identified in the SPOC pipeline on 1211 unique target stars. Table 2 provides a breakdown of the number of TCEs by target. Note that targets with large numbers of TCEs are likely to include false positives.

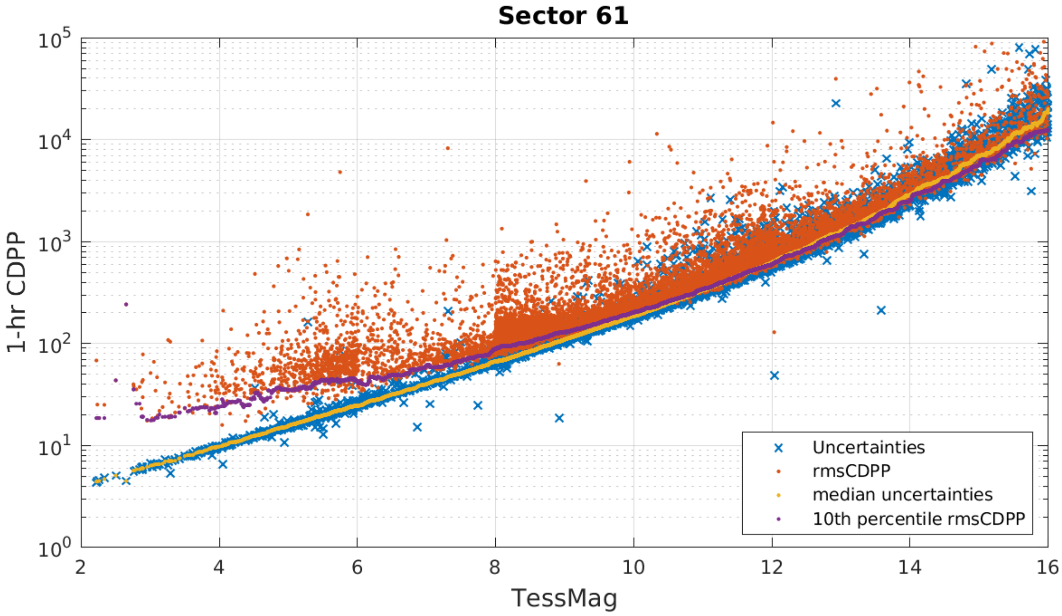

Figure 6: 1-hour CDPP. The red points are the RMS CDPP measurements for the 12211 light curves from Sector 61 plotted as a function of TESS magnitude. The blue x's are the uncertainties, scaled to 1-hour timescale. The purple curve is a moving 10th percentile of the RMS CDPP measurements, and the gold curve is a moving median of the 1-hr uncertainties.

Table 2: Sector 61 TCE Numbers

Number of TCEs	Number of Targets	Total TCEs
1	876	876
2	280	560
3	42	126
4	10	40
5	2	10
6	1	6
–	1211	1618

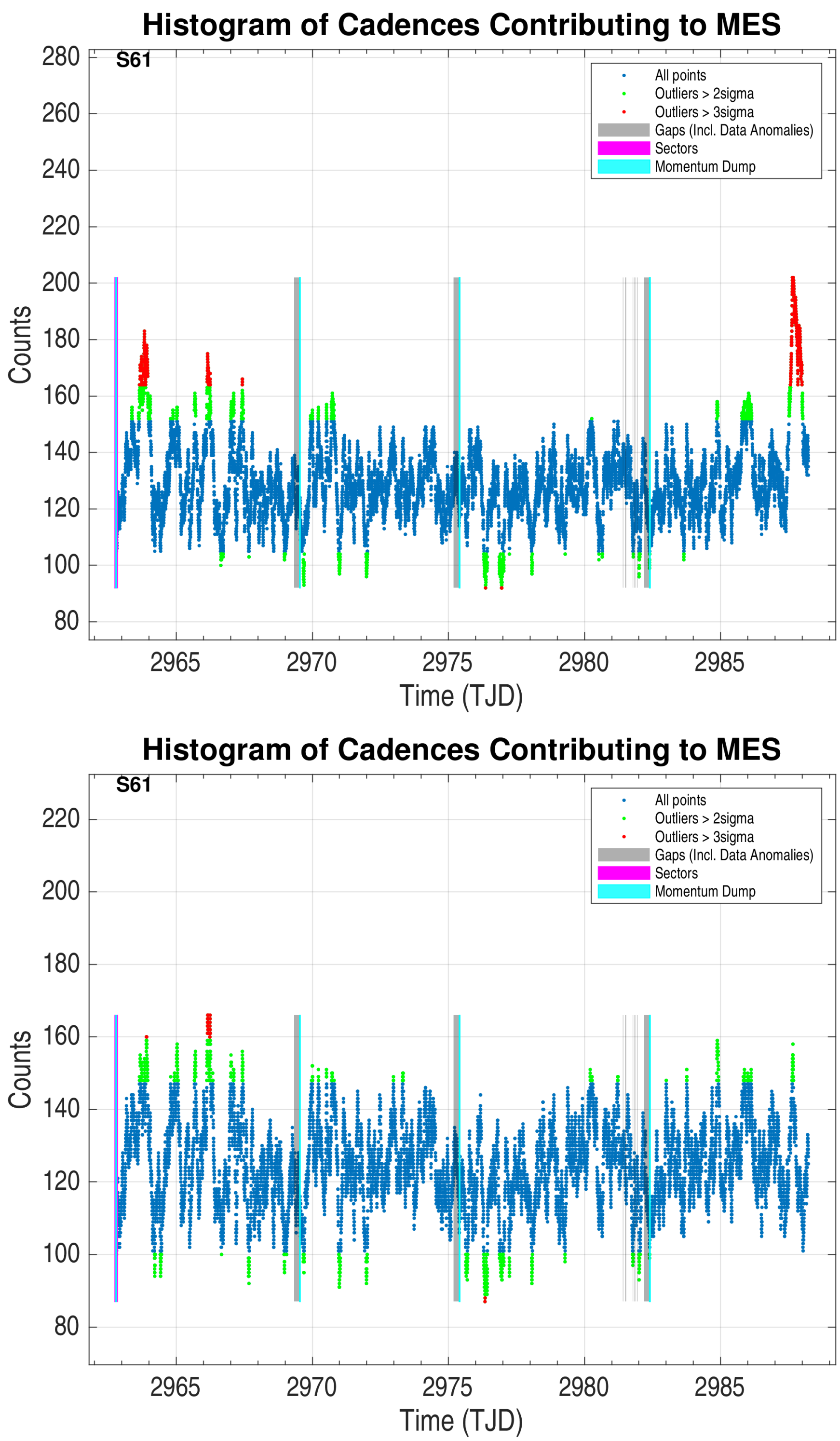

Figure 7: Top panel: Number of TCEs at a given cadence exhibiting a transit signal, based on an initial run of TPS. Any isolated peaks are caused by single events that result in spurious TCEs. These peaks were used to define de-emphasis weights that suppress problematic epochs for the transit detection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

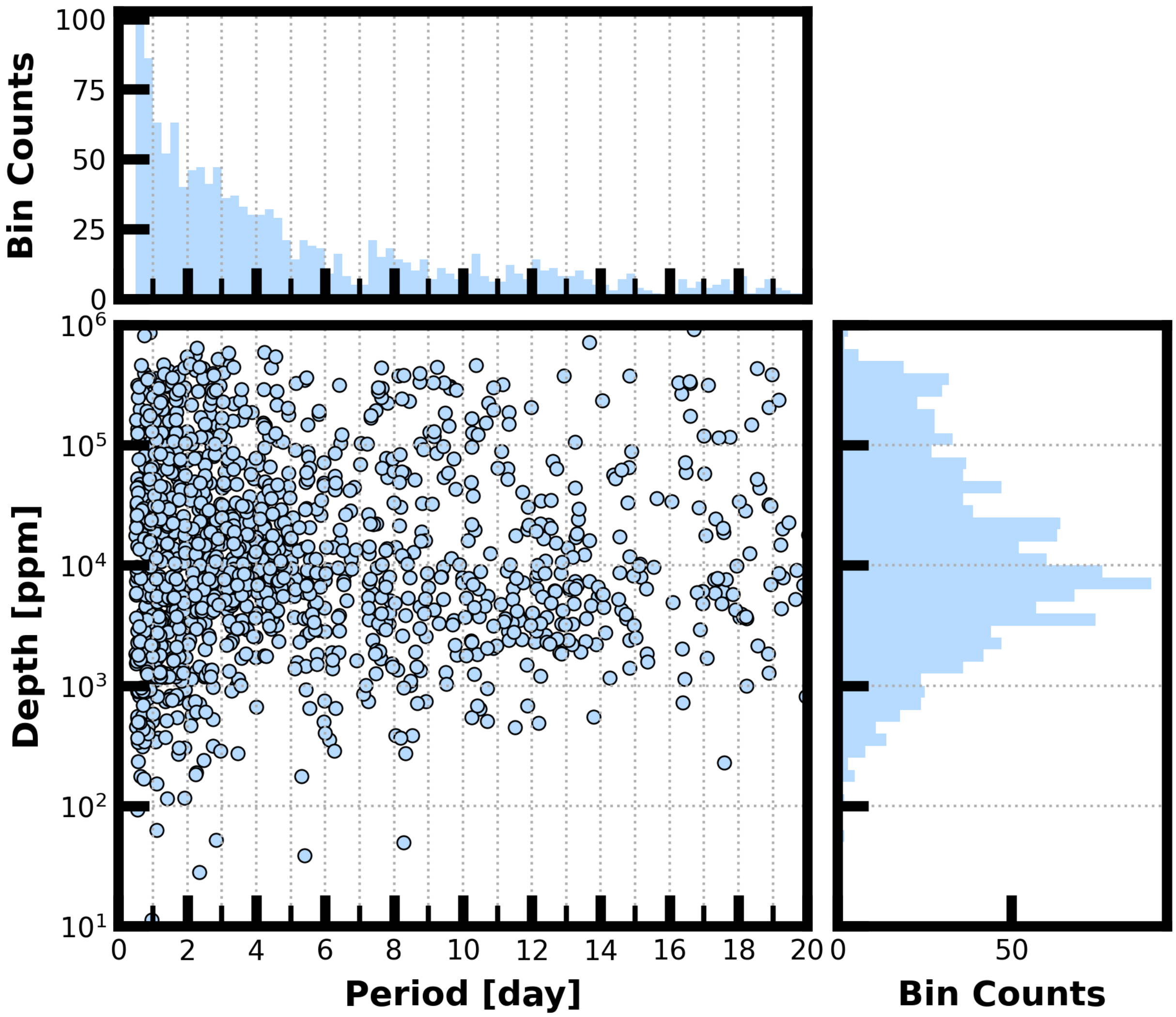

Figure 8: Lower Left Panel: Transit depth as a function of orbital period for the 1618 TCEs identified for the Sector 61 search. For enhanced visibility of long period detections, TCEs with orbital period <0.5 days are not shown. Reported depth comes from the DV limb-darkened transit fit depth when available, 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.

References

Jenkins, J. M. 2020, Kepler Data Processing Handbook: Overview of the Science Operations Center, Tech. rep., NASA Ames Research Center

Jenkins, J. M., Twicken, J. D., McCauliff, S., et al. 2016, in Proc. SPIE, Vol. 9913, Software and Cyberinfrastructure for Astronomy IV, 99133E, doi: 10.1117/12.2233418

Li, J., Tenenbaum, P., Twicken, J. D., et al. 2019, *PASP*, 131, 024506, doi: 10.1088/1538-3873/aaf44d

Twicken, J. D., Catanzarite, J. H., Clarke, B. D., et al. 2018, *PASP*, 130, 064502, doi: 10.1088/1538-3873/aab694

Vanderspek, R., Doty, J., Fausnaugh, M., et al. 2018, TESS Instrument Handbook, Tech. rep., Kavli Institute for Astrophysics and Space Science, Massachusetts Institute of Technology

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

PPA Photometer Performance Assessment

ppm Parts-per-million

PRF Pixel Response Function

RA Right Ascension

RMS Root Mean Square

SAP Simple Aperture Photometry

SDPDD Science Data Products 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