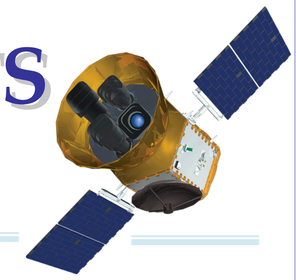
First Year Threshold Crossing Events in the TESS SPOC Transit Search



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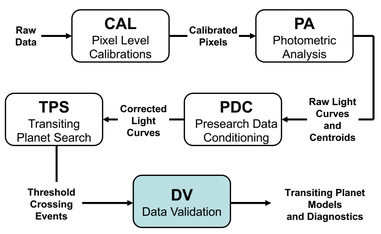
Abstract

The Transiting Exoplanet Survey Satellite (*TESS*) mission was designed to survey bright stars in the greater Solar neighborhood in search of transiting exoplanets. Science operations began in the southern (ecliptic) hemisphere on July 25, 2019. Observation sectors overlap at the ecliptic poles so that target stars near the poles in each hemisphere may be observed continuously for one year. Data are acquired at a 2-minute cadence for 16,000 – 20,000 pre-selected target stars in each observation sector. The 2-minute target data are processed in the Science Processing Operations Center (SPOC) pipeline at NASA Ames Research Center. The photometry pipeline produces a systematic error corrected light curve for each target star. Light curves are searched for transiting planet signatures in the Transiting Planet Search (TPS) component of the SPOC pipeline. Light curves are searched by sector for all target stars, and separately for target stars observed in multiple sectors. Potential transit signals that exceed the pipeline transiting planet detection threshold and pass a series of transit consistency tests are referred to as Threshold Crossing Events (TCEs). Light curves with TCEs are processed in the Data Validation (DV) component of the pipeline. TCEs are characterized in DV with limb-darkened transiting planet models. The residual light curves after transits are removed are iteratively searched for signatures of additional transiting planets. We present an overview of the single- and multiple-sector results of the SPOC pipeline transit search as of July 2019. The full TCE population and the population of SPOC TCEs that were later identified as *TESS* Objects of Interest (TOIs) are both highlighted. Characteristics of the TCE populations implied by the transiting planet model fits are also presented. SPOC pipeline archive products are delivered to the Mikulski Archive for Space Telescopes (MAST; archive.stsci.edu/tess) for access by the community. Funding for the *TESS* mission has been provided by the NASA Science Mission Directorate.

TESS SPOC Science Pipeline

Data Flow



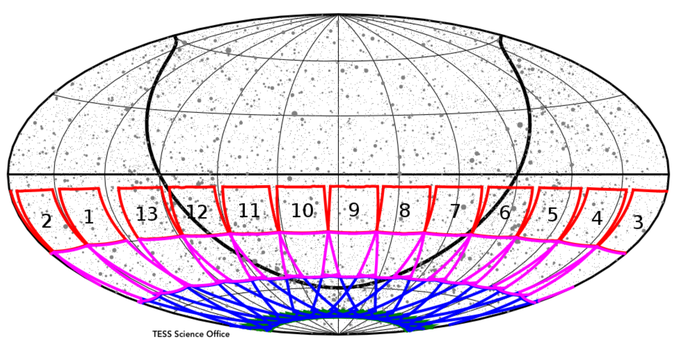
Science data from 16,000 – 20,000 stellar targets per 27.4-day observing sector are processed in the Science Pipeline. Cadence data (sampled at 2 minutes) are processed from Calibration (CAL) through Data Validation (DV). Full Frame Images (FFIs) acquired at 30 minute intervals are also calibrated in the pipeline.

Components and Primary Functions

CAL	Calibrate science pixels (collateral and target) for each cadence
PA	Extract raw flux and compute photocenter (centroid) for each target and cadence from associated target pixels
PDC	Correct systematic and other errors in raw light curves, remove excess flux due to aperture crowding, and condition light curves for the transiting planet search
TPS	**Perform transiting planet search and return Threshold Crossing Events (TCEs) for candidate planet detections**
DV	**Fit transiting planet model to light curves with TCEs, search for additional transiting planets, and perform diagnostic tests to support vetting of candidate planets**

TESS Observations

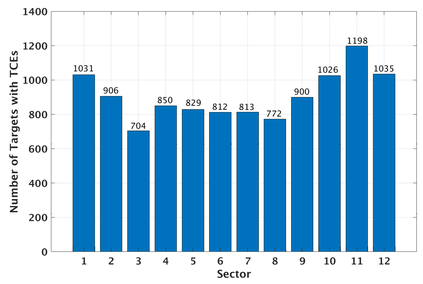
Sector Map



Sector map for the first year of the *TESS* mission is shown in ecliptic coordinates. The thick black curve marks the galactic plane. *TESS* is equipped with four wide-field cameras. Regions imaged by Camera 1 are outlined in red; regions imaged by Camera 2 are outlined in magenta; regions imaged by Camera 3 are outlined in blue; regions imaged by Camera 4 are outlined in green. The northern ecliptic hemisphere will be observed in the second year of the mission.

Single-Sector Results

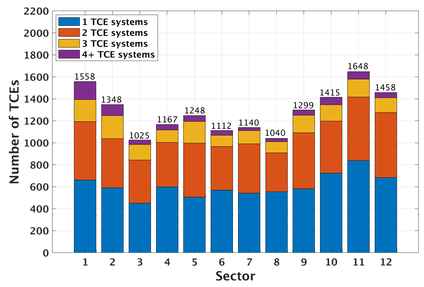
TCE Counts



SPOC Pipeline TCE:

- Transit detection statistic exceeds threshold (7.1σ) for associated orbital period, epoch of first transit, and trial transit pulse duration
- Detection statistic is largest that satisfies all transit consistency checks

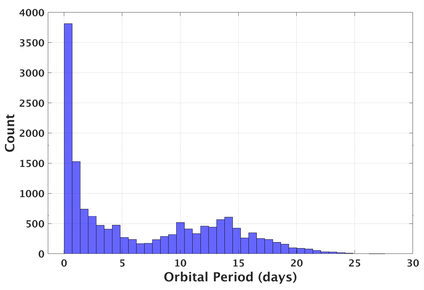
The number of target stars with at least one SPOC pipeline TCE is displayed above for each of the first twelve observing sectors. 16,000 target stars were observed with 2-minute cadence in Sectors 1 – 3, whereas 20,000 targets were observed per sector with 2-minute cadence beginning in Sector 4. Light curves were generated for all targets with Tmag > 2 in each observing sector, and were searched for transiting planet signatures. The SPOC pipeline criteria for generating TCEs are also shown above; TCEs represent potential transit signals.

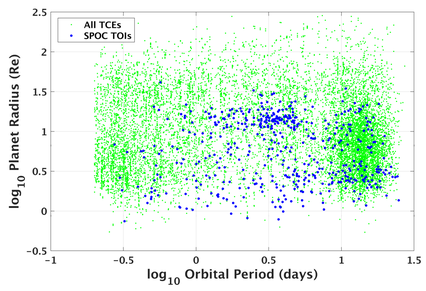


The total number of SPOC pipeline TCEs is displayed above for each of the first twelve observing sectors. Transit signals associated with each TCE are fitted with a transiting planet model and removed from the respective light curves. The light curves are searched for additional TCEs identifying potential multiple-planet systems. Colors specify the multiplicity of TCEs on the host targets.

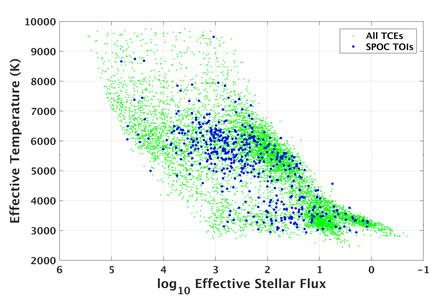
Orbit and Planet Characteristics

A histogram of orbital period for all single-sector TCEs is shown on the right. The bulk of TCEs have short orbital period (the minimum period searched in the SPOC pipeline is 0.2 days). There is an excess of TCEs with orbital period > 7 days; the excess is non-physical. Many of these TCEs were triggered by one transit-like event in each of the two *TESS* orbits in the given observing sector. *TESS* TCEs may be triggered by two transits only; in contrast, the *Kepler* SOC pipeline was configured to require a minimum of three transits to produce a TCE.



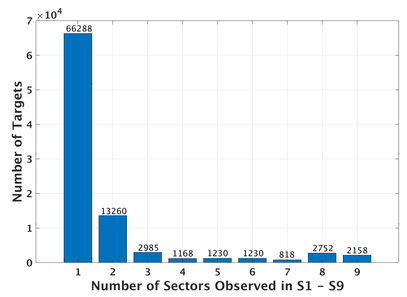


TCEs are characterized in the SPOC pipeline with a limb-darkened transiting planet model. Stellar parameters are obtained from the *TESS* Input Catalog (TIC) version 7. Planet radius is displayed versus orbital period above. Single-sector TCEs with S/N > 7.1σ are marked in green and SPOC TCEs with orbital period < 25 days that were promoted to *TESS* Object of Interest (TOI) status by July 2, 2019 are shown in blue. Effective temperature for target stars < 10000 K is displayed below versus effective stellar flux (i.e., insolation relative to the Solar flux incident at the top of Earth's atmosphere) for the same TCEs and TOIs.



Multiple-Sector Results

Target Stars and TCEs

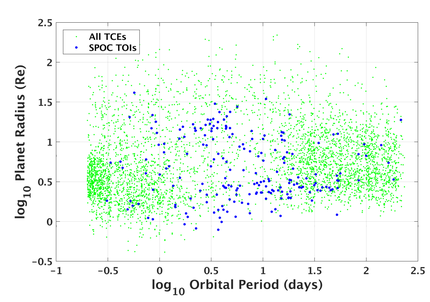


Multiple-sector transit search:

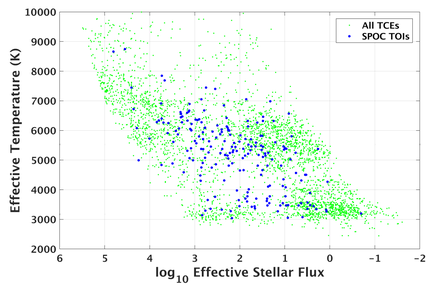
- Sectors 1 – 9
- 25,961 target stars
- 3159 unique targets with TCEs
- 5690 total TCEs

Multiple-sector transit search results are available now for Sectors 1 – 9. The count of target stars observed with 2-minute cadence in these sectors is displayed above by number of sectors observed. All targets observed in two or more sectors were subjected to a multiple-sector transit search in the SPOC pipeline. Another southern hemisphere multiple-sector search will be performed after Sector 13.

Orbit and Planet Characteristics



Planet radius is displayed versus orbital period above. Multiple-sector TCEs with S/N > 7.1σ are marked in green and SPOC TCEs associated with multiple-sector targets that were promoted to TOI status by July 2, 2019 are shown in blue. Effective temperature for target stars < 10000 K is displayed versus effective stellar flux below for the same populations of TCEs and TOIs.



Confirmed TESS Planets

Source: NExScI[1]

TOI Number	Planet Name	First Author	Publication
118.01	HD 219666 b	M. Esposito	AA 2019
120.01	HD 1397 b	L. Nielsen	AA 2019
123.01	HD 202772A b	S. Wang	AJ 2019
135.01	HD 2685 b	M. Jones	AA 2019
136.01	LHS 3844 b	R. Vanderspek	ApJL 2019
144.01	π Mensae c	D. Gandolfi	AA 2018
144.01	π Mensae c	C. Huang	ApJL 2018
174.01	HD 23472 c	T. Trifonov	AA 2019
174.02	HD 23472 b	T. Trifonov	AA 2019
175.01	L 98-59 c	V. Kostov	AJ 2019
175.02	L 98-59 d	V. Kostov	AJ 2019
175.03	L 98-59 b	V. Kostov	AJ 2019
186.02	GJ 143 c	D. Dragomir	ApJL 2019
197.01	HD 221416 b	D. Huber	AJ 2019
216.01	TOI 216 c	D. Kipping	MNRAS 2019
216.02	TOI 216 b	D. Kipping	MNRAS 2019
402.01	HD 15337 b	X. Dumusque	AA 2019
402.01	HD 15337 b	D. Gandolfi	ApJL 2019
402.02	HD 15337 c	X. Dumusque	AA 2019
402.02	HD 15337 c	D. Gandolfi	ApJL 2019

Confirmed planets in the table above were identified with pipeline TCEs and promoted to TOI status by the *TESS* Science Office. The TOIs were disseminated to the community with SPOC pipeline Data Validation reports and TCE summaries.

[1]exoplanetarchive.ipac.caltech.edu (July 9, 2019)