<image> **TESS Science Processing Operations Center Pipeline and Data Products** JON M. JENKINS (NASA AMES RESEARCH CENTER) AND THE SPOC TEAM



ABSTRACT

TESS launched 18 April 2018 to conduct a two-year, near all-sky survey for at least 50 small, nearby exoplanets for which masses can be ascertained and whose atmospheres can be characterized by ground- and space-based follow-on observations. TESS just completed its survey of the southern hemisphere, identifying >900 candidate exoplanets and unveiling a plethora of exciting non-exoplanet astrophysics results, such as asteroseismic oscillations, asteroids, and supernovae. The TESS Science Processing Operations Center (SPOC) processes the data downlinked every two weeks to generate a range of data products hosted at the Mikulski Archive for Space Telescopes (MAST). For each sector (~1 month) of observations, the SPOC calibrates the image data for both 30-min Full Frame Images (FFIs) and up to 20,000 pre-selected 2-min target star postage stamps. Data products for the 2-min targets include simple aperture photometry and systematic error-corrected flux time series. The SPOC also conducts searches for transiting exoplanets in the 2-min data for each sector and generates Data Validation time series and associated reports for each transit-like feature identified in the search. Multi-sector searches for exoplanets are conducted periodically to discover longer period planets, including those in the James Webb Continuous Viewing Zone (CVZ), which are observed for up to one year. Data products also include co-trending basis vectors (CBVs) and calibration files, such as the Pixel Response Functions across the field of view of each of TESS's four cameras. To maximize the usability, the TESS science data products are modeled after those for *Kepler*, including Target Pixel Files and Light Curve files.

e TESS Mission is funded by NASA's Science Mission Directorate as an Astrophysics Explorer Mission.

Data Type Uncalibrated full frame image Calibrated full frame image Target pixels Light curves Collateral target pixel files Cotrending basis vectors Full data validation report TCE summary report Data validation results DV Results XML Schema Definition	Naming Convention tessyyydddhhmmss-ssctr-cam-ccd-scid-cr_ffir.fits.gz tessyyydddhhmmss-ssctr-cam-ccd-scid-cr_ffic.fits.gz tessyyydddhhmmss-ssctr-tid-scid-cr_tp.fits.gz tessyyydddhhmmss-ssctr-tid-scid-cr_lc.fits.gz tessyyydddhhmmss-ssctr-type-cam-ccd-output-scid-cr_col.fits.gz tessyyydddhhmmss-ssctr-cam-ccd-scid-cr_cbv.fits tessyyydddhhmmss-sstartsctr-sendsctr-tid-pin_dvr.pdf tessyyydddhhmmss-sstartsctr-sendsctr-tid-pin_dvs.pdf tessyyydddhhmmss-sstartsctr-sendsctr-tid-pin_dvr.xml.gz tessyyydddhhmmss_startsctr-sendsctr-tid-pin_dvr.xml.gz tessyyydddhhmmss_startsctr-sendsctr-tid-pin_dvr.xml.gz	File Type FITS+GZIP FITS+GZIP FITS+GZIP FITS+GZIP FITS PDF PDF XML XML Schem	e)))))))))))))			Date Stamp in UTCyyyy4 digit yearddd3 digit day of year [001,366]hh2 digit hour [00,23]mm2 digit minute [00,59]ss2 digit second [00,60]
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com cod - Comoro # ($C \cap H$		1	1	Y	Attitude Tweak
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scid := spacecraft config	uration		3	4	Y	Spacecraft is in Coarse Point
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	on performed? 'x': no, 's': spacecraft, 'a': SPOC		4	8	Y	Spacecraft is in Earth Point
nineline 'h' hoth	on performed? 'x': no, 's': spacecraft, 'a': SPOC		4 5	8 16	Y Y	Spacecraft is in Earth Point Argabrightening event
pipeline, 'b': both	on performed? 'x': no, 's': spacecraft, 'a': SPOC		4 5 6 7	8 16 32	Y Y Y	Spacecraft is in Earth Point Argabrightening event Reaction Wheel desaturation Event
pipeline, 'b': both output := CCD output #	on performed? 'x': no, 's': spacecraft, 'a': SPOC 'A', 'B', 'C' or 'D'		4 5 6 7	8 16 32 64	Y Y N	Spacecraft is in Earth Point Argabrightening event Reaction Wheel desaturation Event Cosmic Ray in Optimal Aperture pixel
<pre>pipeline, 'b': both output := CCD output # pin := monotonically inc</pre>	on performed? 'x': no, 's': spacecraft, 'a': SPOC 'A', 'B', 'C' or 'D' reasing index for each SPOC pipeline run		4 5 6 7 8	8 16 32 64 128	Y Y N Y	Spacecraft is in Earth Point Argabrightening event Reaction Wheel desaturation Event Cosmic Ray in Optimal Aperture pixel Manual Exclude. The cadence was excluded because of an anomaly.
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<pre>pipeline, 'b': both output := CCD output # pin := monotonically inc pn := planet number for tid := TESS input catalog type := type of collatera</pre>	on performed? 'x': no, 's': spacecraft, 'a': SPOC 'A', 'B', 'C' or 'D' reasing index for each SPOC pipeline run each target star system number I data included: "Ivcol", "tvcol", "smrow", or "vrow".		4 5 6 7 8 9 10 11 11 12	8 16 32 64 128 256 512 1024 2048	Y Y N Y N Y	Spacecraft is in Earth Point Argabrightening event Reaction Wheel desaturation Event Cosmic Ray in Optimal Aperture pixel Manual Exclude. The cadence was excluded because of an anomaly. Discontinuity corrected between this cadence and the following one. Impulsive outlier removed before cotrending. Cosmic ray detected on collateral pixel row or column. Straylight from Earth or Moon in camera FOV.

List of Data Products and Data Quality Flags

Uncalibrated full frame image Calibrated full frame image Target pixels Light curves Collateral target pixel files Cotrending basis vectors Full data validation report TCE summary report Data validation results DV Results XML Schema Definition Data validation time series	tessyyyyddhhmmss-ssctr-cam-ccd-scid-cr_fhr.fits.gz tessyyyyddhhmmss-ssctr-cam-ccd-scid-cr_ffic.fits.gz tessyyyyddhhmmss-ssctr-tid-scid-cr_tp.fits.gz tessyyyyddhhmmss-ssctr-type-cam-ccd-output-scid-cr_col.fits.gz tessyyyyddhhmmss-ssctr-cam-ccd-scid-cr_cbv.fits tessyyyyddhhmmss-ssctr-sendsctr-tid-pin_dvr.pdf tessyyyyddhhmmss-sstartsctr-sendsctr-tid-pin_dvs.pdf tessyyyyddhhmmss-sstartsctr-sendsctr-tid-pin_dvr.xml.gz tessyyyyddhhmmss_dvr.xsd	FITS+GZII FITS+GZI FITS+GZI FITS+GZI FITS+GZI FITS PDF PDF XML XML Sche FITS+GZI	D P P P P P			Date Stamp in UTCyyyy4 digit yearddd3 digit day of year [001,366]hh2 digit hour [00,23]mm2 digit minute [00,59]ss2 digit second [00,60]
ssctr, sstartsctr, sendsct	r := sector, start/end sector		Bit	Value	FFI	Attitude Tweek
cam.ccd := Camera #. (CD #		2	2	N	Safe Mode
scid - concoraft confic	uration		3	4	Y	Spacecraft is in Coarse Point
sciu spaceciait comig			4	8	Ý	Spacecraft is in Earth Point
cr := cosmic ray mitigati	on performed? 'X': no, 's': spacecraft, 'a': SPOC		5	16	Y	Argabrightening event
pipeline, 'b': both			6	32	Y	Reaction Wheel desaturation Event
output := CCD output #	Ϋ́A', 'B', 'C' or 'D'		7	64	N	Cosmic Ray in Optimal Aperture pixel
nin ·= monotonically inc	reasing index for each SPOC nineline run		8	128	Y	Manual Exclude. The cadence was excluded because of an anomaly.
print interior connecting inte	and target star system		9	256	N	Discontinuity corrected between this cadence and the following one.
pri := planet number for	each laigei staí system		10	512	N	Impulsive outlier removed before cotrending.
tid := TESS input catalog	number		11	1024	Y	Cosmic ray detected on collateral pixel row or column.
			10	2040	V	Straulight from Earth or Moon in consers EOV

Science Processing Operations Center Architecture



event/issue

See the Science Data Products Description Document https://heasarc.gsfc.nasa.gov/docs/tess/documentation.html

Target Pixel Files

- Contains calibrated, background-subtracted pixel data time series for each 2-minute target
- One file per sector, per target

Number of pixels collected per target (typically 11x11) and the aperture HDU is always a bounding box around the collected pixels

			33 => 100001	= >
Bit	Value	Description		te: 060
1	1	Pixel was collected by the spacecraft.	37 => 100101 = >	
2	2	Pixel was in optimal aperture.	Collected, Output A,	-19100
3	4	Pixel was used in background calculation.	Used for background calc.	
4	8	Pixel was used to calculate the flux weighted centroid.		
5	16	Pixel was used to calculate the PRF centroid.		-19+01 w1 hel he
6	32	Pixel is on CCD output A		
7	64	Pixel is on CCD output B	43 => 101011 => Collected Output A In	
8	128	Pixel is on CCD output C	Optimal Aperture, Used for	-
9	9 256 Pixel is on CCD output D		flux-weighted centroid	-19+00



- SAP_FLUX: Simple Aperture Photometry, background subtracted
- PDC_FLUX: Pre-search Data Conditioning: removal
- of instrumental systematics
- Goodness metrics
- CDPP
- other quality metrics
- PSF_CENTR#: PSF-fitted centroids (only for PPA targets) Better, but not for every target
- MOM_CENTR#: Flux-weighted (moment-derived) centroid motion
 - Available for (almost) every target

Coming soon for FFIs!

Cotrending Basis Vectors (CBVs)

- CBVs represent the systematic trends present in the data per CCD. They are singular vectors from an SVD analysis.
- Several types of CBVs available:
 - Single-Scale
- Multi-Scale
- Spike
- Every effort made so that the CBVs only contain systematic signals ("Entropy Cleaning") and Bayesian







Data Release Notes

Ebilelos -19:00 2012e05s RA (deg)

Pointing Quality, Background, Scattered Light



Cadences affected by fireflies/fireworks noted. Cadences excluded due to scattered light also noted:

Table 2: Cadence ranges for data excludes due to scattered light

Cam	CCD	Orbit 31	Orbit 32
1	1	286196 - 288125	297056-298530
1	2	286196 - 288125	297056-298542
1	3	286196 - 288125	297056-298375
1	4	286196 - 288125	297056 - 298543

uality of Flux Time Series





- Priors used to regularize the fits in PDC
- But overfitting can still occur.
- You can perform your own fit to CBVs if PDC did not perform well on your target.

Coming soon for FFIs!



ShortPeriod-sig: N/A

LongPeriod-sig: 100.0% [22.16 sigma] ModelChiSquare2-sig: 79.4%

Epoch = 1625.2777 [0.0019] BTJD Rp/R* = 0.0275 [0.0152]





Sectors 12 - 12

Target 307210830 / Flux Time Series / Sector

