NASA/TM—20205008729

TESS Science Data Products Description Document

EXP-TESS-ARC-ICD-0014 Rev F

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September 2020

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September 2020

CM FOREWORD

This document is a TESS controlled document. Check https://ehpdmis.gsfc.nasa.gov to verify that this is the correct version prior to use. Changes to this document require prior approval from the TESS Program Office. Proposed changes shall be submitted to the TESS Configuration Management Office (CMO), along with supportive material justifying the proposed change.

Questions or comments concerning this document should be addressed to:

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Scott Fleming, TESS Operations Lead at MAST, STScI	Date
Jason Tumlinson, Head of the STScI Community Mission Office, STScI	Date

Contents

List of Figures

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Todo list

Change Date	Notes
10 Mar 2014	Initial commit.
19 Mar 2014	Cleanup useless repetition. Center some tables.
25 Mar 2014	Use autogenerated table contents for revision history.
26 Mar 2014	Add Tess Mission System Interfaces diagram. Generate files in build instead of along side the latex files. Print stack trace instead of relying on gradle to print something useful.
9 Apr 2014	Add flat field and pixel response function file descriptions. Add flat field and pixel response function files. Use correct datatypes for timestamps and stellar catalog parameters. Include DV time series file as a deliverable to the MAST. Change TSO deliverables to use pipeline instance number as part of their naming convention.
10 Apr 2014	Explain PDCMETHD and related keywords. Cleanup header files (incorrect constants, table formatting, missing keywords, references to short and long cadence). Move data quality bits to end. Assume that we will add bits later as needed rather than having so many outstaning TODOs.
14 Apr 2014	Official document numbers.
23 Apr 2014	Use inline TODO syntax.
9 Jun 2014	Document numbers.
14 Jun 2014	Added ext.docId to all the docs/sources build.gradle files. Modified the build task to create build/doc-id.sty files specific to each tex document and in turn modified those documents to use it. Modified the publish task to put the docId into the published pdf filenames.
16 Jun 2014	Change wording describing data quality flags.
13 Aug 2014	There are several kinds of changes rolled into this... 1) There are some merge failures that I've encountered and needed to commit these changes in order to resolve these merge conflicts. 2) Removing static variables that would prevent multiple instances of the ADB server from ever existing in the same process. 3) Clean up of some of the server shutdown code so that the caller can know that the server has shutdown. 4) A new way to create instances of the file store server for in-process test purposes.
15 Aug 2014	File versioning information. Increase the number of digits used to represent a target identifier.
7 Sep 2014	Start making changes that deal with collateral that is not addressed as part of CCD science pixels.
8 Sep 2014	Specify the CCD output the target pixel belongs to. Encode the collateral geometry in the FFI headers.
9 Sep 2014	Fix gain, readnoise, and mean black keywords for all HDUs that use them. Correct cosmic ray table's cosmic ray value encoding.
12 Sep 2014	FFI cosmic ray table FITS header.
13 Sep 2014	Refer to correct import file in main latex document. Initial specification of collateral FITS tables and headers. Cleaned CCD related keywords in light curve and target pixel files.
14 Sep 2014	Complete specification of collateral pixel file.
15 Sep 2014	Embed PRF centers as keywords rather than using columns to represent the centers. Cotrending basis vector FITS headers.
23 Oct 2014	Use length of history entry to estimate the number of lines needed for the history entry. Modify documents to use new automatic editing history.
2 Nov 2014	Remove full frame cosmic rays a distinct delivery.
28 Nov 2014	Allow signature page to handle additional signatures. Incorporate changes suggested by Daryl Swade. Fix table and section references. Remove extra back slashes. Fix some of the wording used to describe the collateral pixels and the PRF.
1 Dec 2014	Minor corrections suggested by Daryl and Roland. Consolidate calibrated and uncertaintiy FFI into one file. FFI diagram.
2 Dec 2014	Diagram for target pixel files.
3 Dec 2014	CBV file diagram. Small corrections to various FITS headers. Updated CBV section. Collateral pixel diagram. Some FFI HDUs refer to header when it should refer to data. Light curve file diagram.

Change Date	Notes
4 Dec 2014	Spelling. Add manifest file description.
11 Dec 2014	Make the SOC the top signatory. Labels and references. Integrate all the diagrams. Diagrams, FITS headers. Initial revision.
15 Dec 2014	Remove Error Handling and Recovery section as this can be covered in the ICDs themselves. Clarify file versioning. Remove PRF and flat field. These are defined in the POC-SPOC ICD.
16 Dec 2014	Correct keplerMag to tessMag. Using tess mag until I hear otherwise. Minor corrections to the DV time series file. Make KIC -> TIC, MJD -> TJD, KOI -> TOI corrections in the dv results file. Fix duplicated HDUs in collateral pixel file. Define acronyms. Remove references to data delivery and other ICD specific wording. Spelling. Define pn.
8 Jan 2015	Shorten list of TIC keywords exported to just the keywords used by the SPOC for processing. Remove SIP-WCS TODO since I've not heard back about it.
9 Jan 2015	Still a WIP. Added Acknowledgements to the TESS Science Data Products Description Document. Refactored spoc-poc-icd.tex in order to extract the manifest-{purpose,composition,filenames}.tex and reuse them in the formats.tex. Extracted the file-transfer.tex from the spoc-poc-icd.tex file.
11 Jan 2015	Fix latexisms. Clarify reference space and time used for WCS. Specify which WCS coordinate system are used. Specify which data quality flags apply to FFIs.
13 Jan 2015	Catchup with Kepler 9.3 DV result outputs: trapezoidalFit, ghost diagnostic. Multi Quarter (MQ) to MultiSector (MS). KOI to TOI.
16 Jan 2015	Added dictionary for DV results XML file.
21 Jan 2015	Added missing Acknowledgement example to formats.tex. Updated several of the common tex files. Updated the spoc-poc-icd.tex file. WIP
23 Jan 2015	Make dvTargetResults the top level element in the DV results file and move several attributes and elements from planetResults into this element. Fix more Keplerisms in the DV results file.
26 Jan 2015	Removed TODO for UKIRT images since this can be handled internally at the SPOC. Fix PROCVER example value to reflect the SPOC use of git. Small changes suggested by Daryl. Remove TODOs that have been resolved internally, delivery of known exoplanet ephemerides, time slice keyword.
27 Jan 2015	Fix references to tables and figures. Fix references from text to the figures and tables. Update signatures. Update BJDREFF and BJDREFI keyword values to their correct constants. Add RESIDUAL_LC_ERR column to dv time series file. Assign document id.
29 Jan 2015	Use the same set of signatories for the data products document, soc-mast and soc-tso icds. Add D. Latham, S. Jones, V. Moran and J. Volosin.
5 Feb 2015	Reconfigure build to pickup the renamed sdp file. Rename formats to sdp (science data products).
12 Feb 2015	Feedback from Daryl. Commas, wording.
20 Feb 2015	Specify BTJD when we are correcting for light arrive time at the target level. Update collateral pixel files to use the correct collateral regions. Remove modified julian date. Either replace references to "target table" with "pixel table" or omit it completely. Remove mention of on-board comsic ray removal. Add provenance keywords for TIC keywords.
20 Mar 2015	Use RA decimal degrees everywhere. Remove manifest. Remove DV results schema section.
21 Mar 2015	Reorder signatories. Spelling. Fix calibrated FFI description.
23 Mar 2015	Some rewording of the aperture mask HDU section and the collateral pixel section. Remove todo.
31 Mar 2015	Add DCT_TIME and DATSETNM todo.
1 Apr 2015	Remove MMNTMDMP and FINE_PNT keywords since these are redundant with DQUALITY. Move FFI IMAGTYPE keyword to the image HDU. Clarify NULL encoding for WCS keyword values.
7 Apr 2015	Remove DATE-OBS TODO. Daryl and Susan confim that most FITS files have these keywords and so should these files.
24 Apr 2015	Use TJD for cotrending basis vector header keywords. Large update to DV results XML file.
27 Apr 2015	Add CCD output columns to collateral keyword definition. Update collateral pixel information with latest CCD layout. Some fixes to CBV headers.
28 Apr 2015	Remove fluxType todo.

Change Date	**Notes**
26 May 2015	Change FFI to one file per CCD per FFI cadence. Rather than all CCDs per FFI cadence. Remove remaining TODOs.
5 Jun 2015	Remove draft notification.
2 Jul 2015	Spelling.
20 Aug 2015	Remove chiSquare1 from DvPlanetCandidate since it is not useful and was only being maintained by Kepler for backwards compatibility with NEXSCI. In DV results: move star as a parent of targetResults, add toi matched and correlation attributes, remove sector dependent fields from limb darkening model.
21 Aug 2015	Fix numbering of dv time series columns. DV time series file: transit period and epoch keywords to TEPOCH and TPERIOD to avoid conflicting with other FITS uses, fix TCE column units, add PCD_SAP_FLUX_ERR to stat columns, fix TFIELDS. Cotrending basis vector file: remove OBSMODE keyword (a relic of Kepler), table 24 will now show there are 19 columns, NAXIS1 value was incorrect, NAXIS2 is not a constant. Apeture mask image incorrectly makes the dimensions of the image constant. Rename FITS keywords in the target pixel file headers GAINV and GAINF to GAINC and GAIND for CCD outputs C and D. Rename TVCE1 keyword to TVCEA to indicate it is for CCD output A. Remove DCT_TIME from FFI primary header. Fix NEXTEND values in FFI primary header. From the DV results schema remove: pixel correlation results and single transit fits. Add to the DV results documentation: bootstrap results.
26 Aug 2015	Fix pixel column FITS display formats. Remove CAMERA and CCD columns from the FFI cosmic ray binary table header.
27 Aug 2015	DV time series file: RESIDUAL_LC_ERR does not exist.
5 Jan 2016	Cosmic ray mitigation changes: file names, FTIS keyword additions, new cosmic ray mitigation section.
9 Jan 2016	Include spacecraft config id in some file names so we can have more cosmic ray cosmic ray mitigation related variants. Modify meanings of cosmic ray related FITS keywords. Change from TJD to JD.
4 Mar 2016	Cleanup draft and proposed markings.
11 Apr 2016	Remove DATSETNM from FFI. This removes the DATSETNM FITS keyword from the TESS data products.
17 Apr 2016	Remove the multiple TIC provenance keywords and replace them with TICVER. Fix FITS data types for CREATOR FILEVER TELESCOP INSTRUME CAMERA RA_OBJ DEC_OBJ OBJECT and TICID.
18 Apr 2016	Verification and validation plan.
1 May 2016	Fix the PDF title metadata.
6 May 2016	New version 05062016 of SDP document with comments from Dean addressed
12 May 2016	New comments from Roland addressed
15 Jun 2016	Changes in SDP document about TPS pulse duration values
16 Jun 2016	Change in TPS pulse durations
18 Oct 2016	Science Data Products updates in: Tables 7 (Target Pixel File Primary Header), Table 9 (Target Pixel File Pixels Binary Extension Header), Table 11 (Target Pixel File Target Cosmic Ray Binary Extension Header), Table 12 (Light Curve File Primary Headers), Table 14 (Light Curve File Lightcurve Binary Extension Header), Table 16 (Target Pixel File and Light Curve File Aperture Extension Header)
21 Oct 2016	Changes is various tables: * Updated the description for CRSPOC in table 3. * Updated TSTART and TSTOP entries in tables 4, 9, 14, 20, 25, 48 and 50: * Updated TICID in tables 7, 9, 12, 14, 16, 46. * Removed entries: RA_OBJP, DEC_OBJP, PMRAP, PMDECP, PMTOTALP, TESSMAGP, TEFFP, LOGGP, FEHP, RADIUSP in tables 7, 12 and 46 * Updated PRMA, PMDEC and PMTOTAL entries in tables 7, 12 and 46. * Updated CAMERA entries in tables 7, 12 and 25 * Updated SECTOR entries in tables 7 and 17. * Added entries: PXTABLE, TICVER in tables 7, 12 and 46. * Table 9: Removed entries CDPP3_0, CDPP6_0 and CDPP12_0 and added entries CDPP1_0, CDPP0_5 and CDPP2_0 * Table 11: Added entries for EXTNAME and TUNIT4 * Table 14: Updated the entries NSPSDDET * Section 14.4: Updated the definition of pulse duration in the second paragraph.
13 Sep 2017	Updated Table 1. "Calibrated full frame image" file name now displays the spacecraft id; scid.

Change Date	Notes
14 Sep 2017	Updated Table 1 in sections 2.1. The file name for the collateral pixel export file used to be defined as: tessyyyydddhhmmss-cam-ccd-scid-cr _col.fits.gz. However, a decision was made to divide up the collateral pixel export by CCD output. Therefore, the file name was changed to include an output indicator: tessyyyydddhhmmss-cam-ccd-output-scid-cr _col.fits.gz, where ''output'' is one of ''a'', ''b'', ''c'', or ''d''.
18 Sep 2017	* Updated DV report schema and example. * In sections 2.1 the DV schema export file name used to be define as: ''tesspin_dvr.xsd'', where ''pin'' was the pipeline instance ID that generated the file. But this was not correct because a pipeline instance does not create this file. It is created manually. But we still need a way to indicate the version of the schema. A timestamp should be sufficient and so changed to file name format to: ''tessyyyydddhhmmss_dvr.xsd''
21 Sep 2017	updating SDP
22 Sep 2017	replacing reaction wheel zero crossings with Argabrightening events for bit 5 of the data quality flags.
25 Sep 2017	Clarified that collateral pixel values for FFIs are stored in the FFI FITS files rather than in the collateral FITS files.
26 Sep 2017	Fixing typo in 8.1 to ad an 'an' before 'ensemble' Fixed relationship of TIME to TIMECORR in description of binary table contents for target pixel files (4.2.2), light curve files (5.2.2), and the DV time series files (14.3).
13 Oct 2017	updating time units in DV time series statistics header description in Table 49 updating sdp to reflect time units in TCE headers in table 47 updating TIME units in Table 8 for Target Pixel Files
15 Oct 2017	removing 'barycenter corrected' from descrtipion of TIME units in collateral binary table headers in table 19
16 Oct 2017	Updated Section 10 (Data Validation Results) with major changes to 10.4 (Dictionary).
17 Oct 2017	Updated description of composition of TCE summary report (11.2.1) and swapped TESS specific one-page summary for Kepler one-page summary in Figure 7 (11.2.2).
18 Oct 2017	Updated description of full data validation report (12.2.1 - 12.2.6). Added new sections: TCE model fit and diagnostic test results (12.2.7) and Appendices (12.2.8). Swapped TESS-specific dashboard for Kepler dashboard in Figure 8 (12.2.4), and swapped TESS specific difference image for Kepler difference image in Figure 9 (12.2.5).
19 Oct 2017	Updates to text in Data Validation Time Series section (14): Purpose (14.1), Per TCE HDU (14.3), Statistics HDU (14.4). Updates to Table 49 (CREATOR, OBJECT, DVVERSN) and Table 52 (QUALITY, SES_CORR_pulse, SES_NORM_pulse).
20 Oct 2017	Updated metallicity keyword from FEH to MH in all applicable tables. Updated OBJECT data type to C20 in all applicable tables. Noted that sectorsObserved string begins with sector 0 in Table 27.
24 Oct 2017	Fixing pdftitle command so that correct title shows up on windows in pdf viewers
30 Oct 2017	Fixing collateral file name convention in Table 1
8 Nov 2017	Adding Scott Dynes as signatory to all ICDs updating signatories for new versions
15 Nov 2017	Removed duplicate entry on signature page.
17 Nov 2017	In table 26, section 9, page Fixed 46 changed the entry for Bit 10 to say ''Impulsive outlier removed before cotrending'' rather than ''Impulsive outlier removed after cotrending''.
8 Feb 2018	Added mean stellar density to DV Results Dictionary (10.4): Table 27 DV target results and Table 33 model parameters. Added mean stellar density to TCE Summary Cmposition (11.2).
13 Feb 2018	Updated Figures 7-9: TCE summary and DV report examples.
15 Mar 2018	Updated SDP for new CBV structure.
16 Mar 2018	Copied and renamed revision history files to base sdp directory so they could be edited. Added the KDPH to the reference document list. Added info on CBVVALID keyword. Fixed column headers for CBV headers. Updated SDP to document the header contents for multi-scale and spike basis vectors.
18 Mar 2018	Added time and date keywords to CBV primary header table and CBVVALID keywords to single scale and spike header tables.
19 Mar 2018	Removed redundant sec:fileTimestamps label. Correcting the number of systematic error-corrected light curves generated by PDC from three to two per Jeff Smith's comments.
17 May 2018	Updated filenames to include sector numbers. Fixed some table column spacing issues causing overflow into right margin.
27 July 2018	Corrected typo in the use of the leading "s" in the *sctr*, *startsctr*, and *endsctr* variables for use in the archive filenames. Also corrected a typo in the use of the textit macros in Table 1.
31 July 2018	Corrected example value to 3 for number of extensions in a calibrated FITS image header.

Change Date	Notes
20 Aug 2019	Added data quality bits 13 and 14.
10 Jan 2020	Added data quality bits 15 and 16.
26 Feb 2020	Updated primary and binary table header timestamps, added SIMDATA keyword, and added TMOFSTmn keyword to CBV file.
16 Mar 2020	Added fast pixel and FFI-based photometry data products, added mini data validation report product and descriptive section, and added data validation reference documents.
25 Mar 2020	Updated signatories.
27 Mar 2020	Updated naming convention for fast pixel and FFI-based photometry data products.
01 Apr 2020	Removed FFI-based photometry data products.
22 Jul 2020	Corrected errors in Tables 21 (collateral cosmic rays), 24 (cotrending basis vectors), 28 (data quality flags). Updated FITS header definitions for following data products: FFI, target pixel files, light-curve files, collateral target pixel files, cotrending basis vectors, data validation time series.
06 Aug 2020	Updated Section 7 (collateral target pixel files) to describe both standard and fast collateral pixel file formats.
04 Sep 2020	Updated signatories.
08 Sep 2020	Updated KDPH reference document to version 3 and added URL.

1 Introduction

1.1 Purpose and Scope

This document discusses data product formats that are produced primarily by the TESS Science Processing Operations Center (SPOC) at NASA Ames Research Center. Data products are sent to the TESS Science Operations Center (SOC) at MIT where they are disseminated to the Mikulski Archive for Space Telescopes (MAST) and the TESS Science Office (TSO).

1.2 Intended Audience

This document is intended to be read by people concerned with the contents and formatting of the final TESS mission data products.

1.3 Related Documents

1.3.1 Compliance Documents

This data formats document will be compliant with the requirements found in the following specification documents.

- Software Requirements Document (SRD) (EXP-TESS-ARC-RQMT-0010)
- TESS Science Office Level 3 Requirements Document (EXP-TESS-MKI-RQMT-0006)

1.3.2 Reference Documents

- Specification for FITS, version 3, as published in "Astronomy and Astrophysics" in 2010 (http://www.aanda.org/index.php?option=com_article&access=doi&doi=10.1051/0004-6361/201015362&Itemid=129).
- rfc1952, GZIP file format specification version 4.3 (http://tools.ietf.org/html/rfc1952).
- System Architecture Document (EXP-TESS-ARC-SW-0003).
- SPOC to TSO Interface Control Document (EXP-TESS-ARC-ICD-0008).
- Representations of World Coordinates in FITS (Paper I), Greisen, E. W., and Calabretta, M. R., Astronomy and Astrophysics, 395, 1061-1075, 2002 (http://fits.gsfc.nasa.gov/fits_wcs.html).
- Representations of celestial coordinates in FITS (Paper II), Calabretta, M. R., and Greisen, E. W., Astronomy and Astrophysics, 395, 1077-1122, 2002 (http://fits.gsfc.nasa.gov/fits_wcs.html).
- Simple Imaging Polynomial FITS WCS Convention (http://fits.gsfc.nasa.gov/registry/sip.html).
- Chi-Square Discriminators for Transiting Planet Detection in Kepler Data,Shawn Seader et al. 2013 ApJS 206 25 (http://iopscience.iop.org/0067-0049/206/2/25/).
- Discovery and Validation Of Kepler-452b: A 1.6 $R\_\oplus$ Super Earth Exoplanet In the Habitable Zone of a G2 Star, Jon M. Jenkins et al. 2015 The Astronomical Journal 150 56 (http://iopscience.iop.org/1538-3881/150/2/56/).
- Kepler Data Validation I – Architecture, Diagnostic Tests, and Data Products for Vetting Transiting Planet Candidates, Joseph D. Twicken et al. 2018 PASP 130 065402 (http://iopscience.iop.org/article/10.1088/1538-3873/aab694).
- Kepler Data Validation II – Transit Model Fitting and Multiple-planet Search, Jie Li et al. 2019 PASP 31 024506 (https://iopscience.iop.org/article/10.1088/1538-3873/aaf44d).
- Kepler Data Processing Handbook: KSCI-19081-003, Jenkins, J. M. (Ed.) (https://archive.stsci.edu/kepler/manuals/KSCI-19081-003-KDPH.pdf).

2 Interface Design

2.1 Summary of File Formats

While referring to table 1 the following conventions hold.

Lettering in *italics* indicate parameters that will be instantiated for some specific instance of a file, for example timestamps and target identifiers. *yyyydddhhmmss*, is covered in section 2.4.1. *tid*, is a 16 digit zero-padded target identifier that refers to an entry in the TESS Input Catalog (TIC). *sctr*, is a 4 digit zero-padded integer indicating the sector in which the data were collected. For multi-sector data files, there will be two instances of *sctr*, *startsctr* and *endsctr* indicating the first and last sectors in the unit of work for multi-sector transit searches and subsequent Data Validation processing. The file may contain a subset of the sectors spanned by the range indicated by *startsctr* and *endsctr*, and the actual sectors included in the data set will be documented in the file itself. *cam*, is a single digit that identifies the camera used to collect the data, and can be "1", "2", "3", or "4". *ccd*, is a single digit that identifies CCD chip, and can be "1", "2", "3", or "4". *pn*, is a zero padded two digit planet number. *pin*, is a zero padded 5 digit pipeline instance number that is a monotonically increasing number that indicates the run of SPOC pipeline used to produce a file. Since different runs of the SPOC pipeline may produce a different set of TCEs for the same target star this allows different runs to be treated as distinct sets of files. *cr*, refers to cosmic ray mitigation. The value of this file name parameter will be "x" if no mitigation at the SPOC was performed, "s" when mitigation was performed on the spacecraft, the value will be "a" to indicate that a SPOC mitigation algorithm was used, and "b" to indicate that both the SPOC algorithm and the the spacecraft algorithm was used. *scid*, is a four digit zero padded identifier of the spacecraft configuration map used to process this data. *output*, indicates the CCD output which could be one of "a", "b", "c", or "d". *type*, indicates the type of collateral data included, which can be one of "lvcol", "tvcol", "smrow", or "vrow". *dset*, is the data set id. This is used by some files for versioning.

Data Type	Naming Convention	File Type	Section
Uncalibrated full frame image	tess*yyyydddhhmmss*-s*sctr*-*cam*-*ccd*-*scid*-*cr*_ffir.fits.gz	FITS+GZIP	3
Calibrated full frame image	tess*yyyydddhhmmss*-s*sctr*-*cam*-*ccd*-*scid*-*cr*_ffic.fits.gz	FITS+GZIP	3
Target pixels	tess*yyyydddhhmmss*-s*sctr*-*tid*-*scid*-*cr*_tp.fits.gz	FITS+GZIP	4
Fast target pixels	tess*yyyydddhhmmss*-s*sctr*-*tid*-*scid*-*cr*_fast-tp.fits.gz	FITS+GZIP	4
Light curves	tess*yyyydddhhmmss*-s*sctr*-*tid*-*scid*-*cr*_lc.fits.gz	FITS+GZIP	5
Fast light curves	tess*yyyydddhhmmss*-s*sctr*-*tid*-*scid*-*cr*_fast-lc.fits.gz	FITS+GZIP	5
Collateral target pixel files	tess*yyyydddhhmmss*-s*sctr*-*type*-*cam*-*ccd*-*output*-*scid*-*cr*_col.fits.gz	FITS+GZIP	7
Fast collateral target pixel files	tess*yyyydddhhmmss*-s*sctr*-*type*-*cam*-*ccd*-*output*-*scid*-*cr*_fast-col.fits.gz	FITS+GZIP	7
Cotrending basis vectors	tess*yyyydddhhmmss*-s*sctr*-*cam*-*ccd*-*scid*-*cr*_cbv.fits	FITS	8
Fast cotrending basis vectors	tess*yyyydddhhmmss*-s*sctr*-*cam*-*ccd*-*scid*-*cr*_fast-cbv.fits	FITS	8
Full data validation report	tess*yyyydddhhmmss*-s*startsctr*-s*endsctr*-*tid*-*pin*_dvr.pdf	PDF	13
Mini data validation report	tess*yyyydddhhmmss*-s*startsctr*-s*endsctr*-*tid*-*pin*_dvm.pdf	PDF	12
TCE summary report	tess*yyyydddhhmmss*-s*startsctr*-s*endsctr*-*tid*-*pn*-*pin*_dvs.pdf	PDF	11
Data validation results	tess*yyyydddhhmmss*-s*startsctr*-s*endsctr*-*tid*-*pin*_dvr.xml.gz	XML	10
DV Results XML Schema Definition	tess*yyyydddhhmmss*_dvr.xsd	XML Schema	Appendix A
Data validation time series	tess*yyyydddhhmmss*-s*startsctr*-s*endsctr*-*tid*-*pin*_dvt.fits.gz	FITS+GZIP	15

Table 1: Summary of File Formats

2.2 File Versioning

Should the data be reprocessed and a new set of export files generated by the SPOC pipeline the file specified in this document will remain unchanged. This is not the case for the files generated by the SPOC data validation process. These files are: full data validation report, TCE summary report, data validation results, and data validation time series.

When files with the same name are produced by the pipeline they are associated with a data release version. This is an increasing integer number that is encoded in the DATAREL keyword present in FITS files. Additional FITS keywords such as PROCVER are associated with the version of the software that produced the file.

Files that are produced infrequently are not associated with a data release and are not given a data release number.

2.3 Heritage

Many of the SPOC deliverables are almost identical to the deliverables delivered by the *Kepler* mission. This section (2.3) is not meant to be a complete enumeration of differences between Kepler and TESS data products, but should highlight some important differences. When changes have been made it has been because there is not an analogous TESS construct, to increase efficiency of data encoding, or to decrease software maintenance costs.

The TESS target pixel file does not contain an image column for cosmic rays. Since this is a sparse data structure a separate HDU encodes this same information for TESS. The TESS target pixel file and the TESS light curve files share the same definition of aperture mask header. Kepler, defines slightly different flags for these images. The SPOC will deliver GZIP compressed versions of some of these files.

The TESS FFI files are are one file per CCD per FFI cadence. The Kepler FFI files are all CCDs per FFI cadence.

Unlike the Kepler CBV files, we generate one per CCD rather than a single file that contains all the CCD channels.

Many of the data products produced by Data Validation (DV) are similar to the Kepler deliverables to Exoplanet Archive (`http://exoplanetarchive.ipac.caltech.edu/`). The major differences are that the DV results are contained in a file per target star rather than one unwieldy XML file. This has been done in order to facilitate efficient generation and consumption of these files and inspection by human beings. The DV files adhere to the TESS SPOC file timestamp convention so that they now reflect something about the data contained in the files rather than the file DV run time. In order to distinguish between different runs of DV for TESS file names also have the SPOC pipeline instance name.

2.4 Time Standards

2.4.1 File Timestamps

File timestamps expressed as *yyyydddhhmmss* are defined as follows. The time system used is UTC. Individual deliverables may define which time is referenced, but it is usually the start of the spacecraft pointing time (i.e the start of the pixel table) unless otherwise noted. The actual start time of the data present in the file may be different. We use this convention in case reprocessing runs change the start time of the data present in the file either due to missing data being retransmitted at a later date or due to detection of bad data which usually occurs during the start or end of a pointing.

If a file does not contain data from the spacecraft, but instead a model file or something else then the timestamp represents the time the file was created. The various components of the timestamp are defined in table 2.

Field	Description
yyyy	4 digit year
ddd	3 digit day of year [001,366]
hh	2 digit hour [00,23]
mm	2 digit minute [00,59]
ss	2 digit second [00,60]

Table 2: File timestamp convention

2.5 FITS

2.5.1 Usage

FITS is a standard for exchanging astronomical data. We will be using version 3 of that standard. FITS has few requirements on the ordering of the appearance of keywords in files. We will adhere to the ordering of keywords where the requirements for ordering is unambiguous. However, keywords not defined by the standard may appear in any order as long as they obey ordering with respect to keywords defined in the FITS standard (e.g. there are not any TESS specific keywords that come before the SIMPLE keyword). Therefore, a consumer of any of these files should not assume that keywords will be delivered in the same order as they appear in this document. A consumer of the files in this document should look for the keyword by name, not by position.

2.5.2 Encoding of NULL Keyword Values

FITS does not have a standard way to encode NULL (i.e. missing values) in header keywords for non-string types. We use the following convention for NULL keyword values. For string data types we use the encoding as specified in the FITS standard section 4.2.1.

```
KEYWORD1= '' / null string keyword
```

For other data types we use the other method specified in section 4.2.1. This method has the disadvantage of not encoding the type information so this could be logical, floating point or integer keyword value.

```
KEYWORD3= / undefined keyword
```

Software consuming these files as input should not break in the presence of new keywords that may be present. This implies that it should not assume any particular length for a FITS HDU.

2.5.3 World Coordinate Systems

The target pixel files, light curve files and full frame image files contain two different world coordinate systems (WCS). Image coordinates are mapped to pixels on the physical CCD chip(s) with alternative WCS coordinates designated with the letter 'P'. The primary WCS maps the image coordinates to the celestial sphere.

Target pixel files and light curve files use the Gnomonic (TAN) projection for celestial coordinates. The reference point of the system is the TIC RA and DEC. Rather than compute the WCS for each cadence in these files, a cadence in the middle of the time series is chosen that does not have any defined data quality problems.

The full frame image files use the Simple Imaging Polynomial (SIP) convention in order to describe field distortion. SIP folds all the rotation, scaling and skew terms into a single matrix represented by keywords (CD1_1, CD1_2, CD2_1, CD2_2). Distortions and their inverse are represented with polynomials encoded in the keywords (A_ORDER, A_p_q, B_ORDER, B_p_q, AP_ORDER, AP_p_q, BP_ORDER, BP_p_q). The SIP convention does not adhere to the FITS 3 standard of naming projection algorithms; it uses 'RA—TAN-SIP' and 'DEC–TAN-SIP'. The reference pixel is chosen to be in the center of the image.

If for some reason WCS keyword values can not be computed then they will not appear at all in the FITS file as they may not have empty values. This is an exception to the NULL encoding rules in 2.5.2.

2.6 XML

XML documents originating from the TESS SPOC will use the XML namespace

```
http://tess-spoc.nasa.gov/
```

with the alias "tess-spoc:" used as the namespace prefix in XML documents or all the elements will be in the default namespace. This uniform resource identifier (URI) need not be active website, but just a bogus name used for the XML namespace. Each XML document is specified by a corresponding XML Schema document. These schema documents can be used to automatically verify that the XML file received is valid.

2.7 Cosmic ray mitigation

Spacecraft cosmic ray mitigation is handled by allowing different versions of files that contain the same type of data for the same time interval, but have a cosmic ray mitigation file identifier in their file names. For FITS files the keywords CRMITEN, CRBLKSZ, and CRSPOC are defined as follows. CRMITEN is true when spacecraft cosmic ray mitigation was applied to the data in the file and false when it was turned off. CRBLKSZ is a parameter used by the spacecraft cosmic ray mitigation algorithm. It is the block size of the number of exposures inspected by the mitigation algorithm. The value of CRBLKSZ is NULL when CRMITEN is false. CRSPOC is true to indicate that the SPOC cosmic ray mitigation algorithm was applied. FITS file types that have HDUs containing cosmic ray detections will have their cosmic ray HDU omitted.

3 Full Frame Image

3.1 Purpose

A Full Frame Image (FFI) file contains all the pixels on a single CCD. These are full images as opposed to sparse images that would be generated if only the target pixels were collected. If a pixel has an unknown value it will be filled with -1 if it is an integer data type else it will be filled with a NaN. Although we expect to have all the pixels in an image, it's possible due to spacecraft anomalies, data transmission problems or unforeseen issues that not all pixels will be available.

There are three types of FFI images that will be delivered: uncalibrated, calibrated and uncertainty. The uncalibrated image is the uncalibrated pixel data taken from the spacecraft; it uses 32-bit, signed integers as its pixel value. The calibrated image will contain the calibrated pixels as single precision (32-bit) floating point values. The uncertainty image will contain the uncertainty in the calibrated pixel values as single precision floating point to encode pixel values. The calibrated image and its associated uncertainty image are stored in the same file.

Collateral pixels are part of each image and stored as extra pixels outside the photometric pixels. Collateral pixel values for FFIs are not stored in the collateral target pixel files, but rather appear in the FFI FITS files in the spatial locations indicated in Figure 5.

The cosmic ray corrections that have been applied to the FFI images are stored in a binary table extension of the calibrated FFI file. Figure 1 shows the structure of the HDUs in the FFI files. This HDU only exists when SPOC cosmic ray mitigation has been enabled.

3.2 Composition

The uncalibrated images are contained in their own separate file. Calibrated image FFI files contains: a calibrated image, their associated uncertainties and the SPOC pipeline cosmic ray detections that have been applied (subtracted) from the calibrated pixels. Figure 1 gives an outline of the different FFI files and the HDUs that are present in those files.

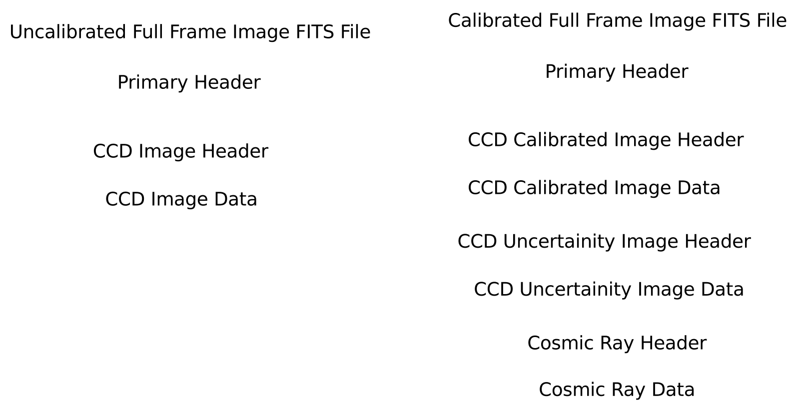

Figure 1: Full Frame Image (FFI) FITS file composition

3.2.1 FFI Primary FITS Header

There is one primary header at the beginning of each of each type of FFI file. It is header only and does not contain any image data. Table 3 contains the definition of this header.

Header Card	Data Type	Example Value	Notes
SIMPLE = T / conforms to FITS standards	L1	const	
BITPIX = 8 / array data type	I4	const	
NAXIS = 0 / number of array dimensions	I4	const	
EXTEND = T / file contains extensions	L1	const	
NEXTEND = / number of standard extensions	I4	3	1(uncal) 3(calibrated)
EXTNAME = 'PRIMARY ' / name of extension	C7	const	
EXTVER = 1 / extension version number (not format version)	I4	const	
SIMDATA = / file is based on simulated data	L1	F	
ORIGIN = 'NASA/Ames' / institution responsible for creating this file	C9	const	
DATE = / file creation date.	C10	2013-06-12	
TSTART = / observation start time in BTJD	R8	1207.27	
TSTOP = / observation stop time in BTJD	R8	1207.29083333333	
DATE-OBS= / TSTART as UTC calendar date	C24	2013-04-08T11:23:43.112	
DATE-END= / TSTOP as UTC calendar date	C24	2013-04-08T11:53:08.571	
CREATOR = / pipeline job and program used to produce this	C50	539245 FfiExporter	
PROCVER = / SW version	C50	spoc-5.0.2-20200714	
ASTATE = / archive state F indicates single orbit processing	L1	T	T indicates should be archived at MAST
FILEVER = / file format version	C8	'1.0 '	
TIMVERSN= 'OGIP/93-003' / OGIP memo number for file format	C11	const	
TELESCOP= 'TESS ' / telescope	C4	const	
INSTRUME= 'TESS Photometer' / detector type	C15	const	
DATA_REL= / version of data release notes for this file	I4	22	
SCCONFIG= / commanded S/C configuration ID	I4	111	
RADESYS = 'ICRS ' / reference frame of celestial coordinates	C4	const	
FFIINDEX= / number of FFI cadence interval	I4	84	
EQUINOX = 2000.0 / equinox of celestial coordinate system	R8	const	
CRMITEN = / spacecraft cosmic ray mitigation enabled	L1	T	
CRBLKSZ = / [exposures] s/c cosmic ray mitigation block size	I4	20	
CRSPOC = / SPOC cosmic ray cleaning enabled	L1	T	
CHECKSUM= / HDU checksum updated 2013-06-12T22:00:23	C16	UkO4ajN4VjN4ajN4	
END			

Table 3: FFI file primary header. This header is used for the uncalibrated file and the calibrated file.

3.2.2 FFI Image Extension HDU

Uncalibrated image pixel values are encoded as signed integer values with -1 indicating a NULL value. Calibrated and uncertainty image pixels are 32-bit single precision floating point. NULL values are encoded as a NaN. The uncalibrated FFI file contains one FFI image extension HDU for a CCD. The calibrated FFI file contains two FFI image extension HDUs for each CCD; one for calibrated pixels the other for the uncertainties in the calibrated pixels.

Table 4 contains the definition of the FITS header for the image HDU. The FITS keyword, DQUALITY, is the data quality keyword; it is the logical AND of the bits from section 9. These bits describe the conditions under which data were collected for the time period covered by a particular FFI file.

Header Card	Data Type	Example Value	Notes
XTENSION= 'IMAGE '/ marks the beginning of a new HDU	C5	const	
BITPIX = / array data type	I2	-32	uncal 32
NAXIS = 2 / NAXIS	I4	const	
NAXIS1 = / length of first array dimension	I4	const	
NAXIS2 = / length of second array dimension	I4	const	
PCOUNT = 0 / group parameter count (not used)	I4	const	
GCOUNT = 1 / group count (not used)	I4	const	
INHERIT = T / inherit the primary header	L1	const	
EXTNAME = / name of extension	C18	'CAMERA.CCD 2.1 cal'	
EXTVER = 1 / extension version number (not format version)	I4	const	
SIMDATA = / file is based on simulated data	L1	F	
TELESCOP= 'TESS '/ telescope	C4	const	
INSTRUME= 'TESS Photometer'/ detector type	C15	const	
CAMERA = / Camera number	I4	2	
CCD = / CCD chip number	I4	2	
TIMEREF = 'SOLARSYSTEM'/ barycentric correction applied to times	C11	const	
TASSIGN = 'SPACECRAFT'/ where time is assigned	C10	const	
TIMESYS = 'TDB '/ time system is Barycentric Dynamical Time (TDB)	C3	const	
BJDREFI = 2457000 / integer part of BTJD reference date	I4	const	
BJDREFF = 0.0 / fraction of the day in BTJD reference date	R4	const	
TIMEUNIT= 'd '/ time unit for TIME, TSTART and TSTOP	C1	const	
TSTART = / observation start time in BTJD	R8	1207.27	
TSTOP = / observation stop time in BTJD	R8	1207.29083333333	
TELAPSE = / [d] TSTOP - TSTART	R8	0.020833333333	
EXPOSURE= / [d] time on source	R8	0.020416666667	
LIVETIME= / [d] TELAPSE multiplied by DEADC	R8	0.0204166666665924	
DEADC = / deadtime correction	R8	0.98	
TIMEPIXR= / bin time beginning=0 middle=0.5 end=1	R8	0.5	
TIERRELA= / [d] relative time error	R8	5.78E-07	
INT_TIME= / [s] photon accumulation time per frame	R8	1.96	
READTIME= / [s] frame transfer time	R8	0.04	
FRAMETIM= / [s] frame time (INT_TIME + READTIME)	R8	2	
NUM_FRM = / number of frames per time stamp	R8	900	
TIMEDEL = / [d] time resolution of data	R8	0.0208333333333333	
DATE-OBS= / TSTART as UTC calendar date	C24	2013-04-08T11:23:43.112	
DATE-END= / TSTOP as UTC calendar date	C24	2013-04-08T11:53:08.571	
BTC_PIX1= / reference col for barycentric time correction	R8	1068	
BTC_PIX2= / reference row for barycentric time correction	R8	1024	
BUNIT = 'electrons/s'/ physical units of image data	C11	const	
BARYCORR= / [d] barycentric time correction	C14	0.0043712342	
BACKAPP = / background is subtracted	L1	F	
DEADAPP = / deadtime applied	L1	T	
VIGNAPP = / vignetting or collimator correction applied	L1	T	
GAINA = / [electrons/count] CCD output A gain	R4	5.2210998	
GAINB = / [electrons/count] CCD output B gain	R4	5.2211999	

GAINC = / [electrons/count] CCD output C gain	R4	5.2213001
GAIND = / [electrons/count] CCD output D gain	R4	5.2213001
READNOIA = / [electrons] read noise CCD output A	R4	11.54385
READNOIB = / [electrons] read noise CCD output B	R4	11.54929
READNOIC = / [electrons] read noise CCD output C	R4	11.55474
READNOID = / [electrons] read noise CCD output D	R4	11.56017
TMOFST<CAMERA><CCD>= / [s] readout delay for camera <CAMERA> and ccd <CCD>	R4	0.5
MEANBLCA= / [count] CCD output A mean black level	I4	6000
MEANBLCB= / [count] CCD output B mean black level	I4	6000
MEANBLCC= / [count] CCD output C mean black level	I4	6000
MEANBLCD= / [count] CCD output D mean black level	I4	6000
NREADOUT= / number of reads per cadence	I4	750
FXDOFF = / compression fixed offset	I4	3355400
LVCSA= / serial register col start, output A	I2	1
LVCEA= / serial register col end, (inclusive) output A	I2	11
TVCSA= / trailing virtual col start, output A	I2	2093
TVCEA= / trailing virtual col end (inc.), output A	I2	2103
SCCSA= / science col start, output A	I2	45
SCCEA= / science col end (inclusive), output A	I2	556
SCICOLHA= / T science cols are read increasing order else dec, output A	L1	T
LVCSB= / serial register col start, output B	I2	12
LVCEB= / serial register col end, (inclusive) output B	I2	22
TVCSB= / trailing virtual col start, output B	I2	2104
TVCEB= / trailing virtual col end (inc.), output B	I2	2114
SCCSB= / science col start, output B	I2	557
SCCEB= / science col end (inclusive), output B	I2	1068
SCICOLHB= / T science cols are read increasing order else dec, output B	L1	F
LVCSC= / serial register col start, output C	I2	23
LVCEC= / serial register col end, (inclusive) output C	I2	33
TVCSC= / trailing virtual col start, output C	I2	2115
TVCEC= / trailing virtual col end (inc.), output C	I2	2125
SCCSC= / science col start, output C	I2	1069
SCCEC= / science col end (inclusive), output C	I2	1580
SCICOLHC= / T science cols are read increasing order else dec, output C	L1	T
LVCSD= / serial register col start, output D	I2	34
LVCED= / serial register col end, (inclusive) output D	I2	44
TVCSD= / trailing virtual col start, output D	I2	2126
TVCED= / trailing virtual col end (inc.), output D	I2	2136
SCCSD= / science col start, output D	I2	1581
SCCED= / science col end (inclusive), output D	I2	2092
SCICOLHD= / T science cols are read increasing order else dec, output D	L1	F
SCIROWS = / science row start	I2	1
SCIROWE = / science row end (inclusive)	I2	2048
VROWS = / virtual row start	I2	2069
VROWE = / virtual row end (inclusive)	I2	2078
SMROWS = / smear row start	I2	2059
SMROWE = / smear row end (inclusive)	I2	2068
BFROWS = / buffer row start	I2	2049
BFROWE = / buffer row end (inclusive)	I2	2058
RADESYS = 'ICRS '/ reference frame of celestial coordinates	C4	const
EQUINOX = 2000.0 / equinox of celestial coordinate system	R8	const
WCSAXES = 2 / number of WCS axes	I4	const
CTYPE1 = 'RA---TAN-SIP'/ Gnomonic projection + SIP distortions	C12	const
CTYPE2 = 'DEC--TAN-SIP'/ Gnomonic projection + SIP distortions	C12	const

CRVAL1 =		/ RA at CRPIX1, CRPIX2	R8	290.61823035494683
CRVAL2 =		/ DEC at CRPIX1, CRPIX2	R8	48.621087449301115
CRPIX1 =		/ X reference pixel	R8	533.0
CRPIX2 =		/ Y reference pixel	R8	521.0
CD1_1 =		/ Transformation matrix	R8	9.25764100696209E-4
CD1_2 =		/ Transformation matrix	R8	6.022306180475121E-4
CD2_1 =		/ Transformation matrix	R8	6.026783497802804E-4
CD2_2 =		/ Transformation matrix	R8	-0.0009261371709987
A_ORDER =		/ Polynomial order, axis 1	I4	2
B_ORDER =		/ Polynomial order, axis 2	I4	2
A_2_0 =		/ distortion coefficient	R8	6.546148956398465E-7
A_0_2 =		/ distortion coefficient	R8	9.124547788606689E-8
A_1_1 =		/ distortion coefficient	R8	5.431307207960112E-7
B_2_0 =		/ distortion coefficient	R8	9.912027909381444E-8
B_0_2 =		/ distortion coefficient	R8	7.034022645952275E-7
B_1_1 =		/ distortion coefficient	R8	4.986667808595385E-7
AP_ORDER=		/ Inv polynomial order, axis 1	I4	2
BP_ORDER=		/ Inv polynomial order, axis 2	I4	2
AP_1_0 =		/ inv distortion coefficient	R8	-2.664439310750E-06
AP_0_1 =		/ inv distortion coefficient	R8	5.864213903597475E-7
AP_2_0 =		/ inv distortion coefficient	R8	-6.473101758615E-07
AP_0_2 =		/ inv distortion coefficient	R8	-9.405092021605E-08
AP_1_1 =		/ inv distortion coefficient	R8	-5.404990510879E-07
BP_1_0 =		/ inv distortion coefficient	R8	2.467515200839062E-6
BP_0_1 =		/ inv distortion coefficient	R8	-1.064303039323E-06
BP_2_0 =		/ inv distortion coefficient	R8	-1.064362625616E-07
BP_0_2 =		/ inv distortion coefficient	R8	-6.927552295741E-07
BP_1_1 =		/ inv distortion coefficient	R8	-4.898721480837E-07
A_DMAX =		/ maximum distortion, axis 1	R8	0.386545739338203
B_DMAX =		/ maximum distortion, axis 2	R8	0.3655951185636468
WCSNAMEP=	'PHYSICAL	'/ name of world coordinate system alternate P	C8	const
WCSAXESP=	2	/ number of WCS physical axes	I4	const
CTYPE1P =	'RAWX	'/ physical WCS axis 1 type CCD col	C4	const
CUNIT1P =	'PIXEL	'/ physical WCS axis 1 unit	C5	const
CRPIX1P =		/ reference CCD column	R8	1
CRVAL1P =		/ value at reference CCD column	R8	0
CDELT1P =		/ physical WCS axis 1 step	R8	1.0
CTYPE2P =	'RAWY	'/ physical WCS axis 2 type CCD row	C4	const
CUNIT2P =	'PIXEL	'/ physical WCS axis 2 units	C5	const
CRPIX2P =		/ reference CCD row	R8	1
CRVAL2P =		/ value at reference CCD row	R8	0
CDELT2P =		/ physical WCS axis 2 step	R8	1.0
RA_NOM =		/ [deg] RA of camera boresight	R8	290.667
DEC_NOM =		/ [deg] declination of camera boresight	R8	44.5
ROLL_NOM=		/ [deg] roll angle of camera	R8	290.0
DQUALITY=		/ data quality flags	I4	128
IMAGTYPE=		/ FFI image type: raw, cal, uncert	C3	cal
CHECKSUM=		/ HDU checksum updated 2013-06-12T21:57:54	C16	bbkPcZhMbahMbYhM
END				

Table 4: FFI image extension header. This header is used for uncalibrated, calibrated, and uncertainty images.

3.2.3 FFI Cosmic Ray Binary Table HDU

In order to compute the calibrated FFI pixel value with cosmic rays the user of this file should add the value in COSMIC_RAY to the specified pixel coordinate. This HDU only exists for the calibrated FFI file. Table 5 describes the columns in the binary table. Table 6 defines the header for this HDU. These corrections are only available if the SPOC cosmic ray detection algorithm has been used. This HDU only exists when SPOC cosmic ray mitigation has been enabled.

Column Number	TYPE	FORM	UNIT	Description
1	RAWX	16-bit signed integer	pixels	Pixel CCD column coordinate.
2	RAWY	16-bit signed integer	pixels	Pixel CCD row coordinate.
3	COSMIC_RAY	32-bit single precision floating point	e^{-}/s	Correction applied to the pixel in the calibrated image.

Table 5: FFI cosmic ray FITS binary table columns.

Header Card	Data Type	Example Value
XTENSION= 'BINTABLE '/ marks the beginning of a new HDU	C8	const
BITPIX = 8 / array data type	I4	const
NAXIS = 2 / number of array dimensions	I4	const
NAXIS1 = 14 / length of first array dimension	I4	const
NAXIS2 = / length of second array dimension	I4	4203
PCOUNT = 0 / group parameter count (not used)	I4	const
GCOUNT = 1 / group count (not used)	I4	const
TFIELDS = 3 / number of table fields	I4	const
TTYPE1 = 'RAWX' / column title: CCD column	C4	const
TFORM1 = 'I '/ column format: signed 16-bit integer	C1	const
TDISP1 = 'I4 '/ column display format	C2	const
TTYPE2 = 'RAWY' / column title: CCD row	C4	const
TFORM2 = 'I '/ column format: signed 16-bit integer	C1	const
TDISP2 = 'I4 '/ column display format	C2	const
TTYPE3 = 'COSMIC_RAY' / column title: cosmic ray correction	C10	const
TFORM3 = 'E '/ column format: 32-bit floating point	C1	const
TDISP3 = 'E14.7 '/ column display format	C5	const
SIMDATA = / file is based on simulated data	L1	F
END		

Table 6: FFI cosmic ray table header.

4 Target Pixel Files

4.1 Purpose

The target pixel files contain all the pixels collected for one target during a sector (two space craft orbits). If a target was observed in more than one sector then multiple files will be created for the target, but they may be delivered in separate deliveries. The images represented in the file have the dimensions of the bounding box of the pixels that were collected. As a result, there may be pixels in the images stored in these files that were never collected. Standard target pixel files (designated by "tp" in the file name) are associated with data acquired at a 2-minute cadence. Fast target pixel files (designated by "fast-tp") are associated with data acquired at a 20-second cadence.

4.2 Composition

The target pixel file is in FITS format with four HDUs. The primary HDU is just the header and contains basic information about the target star such as the brightness of the star and other information that might be found in the TIC. The second HDU contains a binary table with several images for every timestamp along with some information about the quality of the data. The third HDU contains an image that describes the aperture that was used for photometry, if pixels in the target image bounding box were ever collected and the CCD outputs on the target pixel aperture. The fourth and final HDU contains cosmic ray corrections that have been applied to the calibrated image. Figure 2 shows the organization of the HDUs in the target pixel file.

Target Pixel FITS File

Primary Header

Header for Binary Table of Images

Binary Table of Image Data

Aperture Mask Image Header

Aperture Mask Image Data

Cosmic Ray Correction Header

Cosmic Ray Correction Data

Figure 2: Target pixel FITS file composition

4.2.1 Primary HDU

The primary HDU does not contain any data; it is only a header. The primary purpose of the keywords in this section is to describe the stellar parameters of the target star used by the SPOC pipeline to process the data collected for the target star. The aperture mask image HDU (section 6) indicates which pixels were actually collected. Table 7 defines the header for this HDU.

Header Card	Data Type	Example Value
`SIMPLE  = T          / conforms to FITS standards`	L1	const
`BITPIX  = 8          / array data type`	I4	const
`NAXIS   = 0          / number of array dimensions`	I4	const
`EXTEND  = T          / file contains extensions`	L1	const
`NEXTEND = 3          / number of standard extensions`	I4	const
`EXTNAME = 'PRIMARY  '/  name of extension`	C7	const
`EXTVER  = 1          / extension version number (not format version)`	I4	const
`SIMDATA =            / file is based on simulated data`	L1	F
`ORIGIN  = 'NASA/Ames'/  institution responsible for creating this file`	C9	const
`DATE    =            /  file creation date.`	C10	2013-06-10
`TSTART  =            / observation start time in BTJD`	R8	1472.086752
`TSTOP   =            / observation stop time in BTJD`	R8	1557.968852
`DATE-OBS=            /  TSTART as UTC calendar date`	C24	2013-01-12T14:06:28.100
`DATE-END=            /  TSTOP as UTC calendar date`	C24	2013-04-08T11:17:10.783
`CREATOR =            /  pipeline job and program`	C50	535987 TargetPixelExporterPipelineModule
`PROCVER =            /  SW version`	C50	spoc-5.0.2-20200714
`FILEVER =            /  file format version`	C8	'1.0 '

TIMVERSN= 'OGIP/93-003'/ OGIP memo number for file format		C11	const
TELESCOP= 'TESS '/ telescope		C8	const
INSTRUME= 'TESS Photometer'/ detector type		C13	const
OBJECT =	/ string version of TICID	C20	TIC 6541920
TICID =	/ unique TESS target identifier (0 < values < 2^50)	I8	6541920
SECTOR =	/ Observing sector	I4	16
CAMERA =	/ Camera number	I4	1
CCD =	/ CCD number	I4	4
DATA_REL=	/ version of data release notes for this file	I4	22
RADESYS = 'ICRS	'/ reference frame of celestial coordinates	C4	const
RA_OBJ =	/ [deg] right ascension	R8	297.115121
DEC_OBJ =	/ [deg] declination	R8	41.909140
EQUINOX = 2000.0	/ equinox of celestial coordinate system	R8	const
PMRA =	/ [mas/yr] RA proper motion	R4	0.0000
PMDEC =	/ [mas/yr] Dec proper motion	R4	0.0000
PMTOTAL =	/ [mas/yr] total proper motion	R4	0.0000
PXTABLE =	/ pixel table id	I4	2
TESSMAG =	/ [mag] TESS magnitude	R4	13.709
TEFF =	/ [K] Effective temperature	R4	5920
LOGG =	/ [cm/s2] log10 surface gravity	R4	4.467
MH =	/ [log10([M/H])] metallicity	R4	-0.200
RADIUS =	/ [solar radii] stellar radius	R4	0.962
TICVER =	/ TIC Version	R4	8.1
CRMITEN =	/ spacecraft cosmic ray mitigation enabled	L1	T
CRBLKSZ =	/ [exposures] s/c cosmic ray mitigation block size	I4	20
CRSPOC =	/ SPOC cosmic ray cleaning enabled	L1	T
CHECKSUM=	/ HDU checksum updated 2013-06-10T22:41:33	C16	KGGVKE9VKEGVKE9V
END			

Table 7: Target pixel file primary header

4.2.2 Target Pixel Binary Table Extension

For table 8 TYPE, FORM and UNIT refer to the FITS keywords that would describe that column. In FITS parlance "TYPE" is not the data type of the column, but rather its name. "FORM" actually describes the data type for the column which can be, for example, "D", a 64-bit double precision floating point value. Table 9 defines the header for this HDU. Subtracting TIMECORR from TIME will give the light arrive time at the spacecraft rather than at the barycenter.

Column Number	TYPE	FORM	UNIT	Description
1	TIME	64-bit float	Days	BJD - 2457000 (BTJD)
2	TIMECORR	32-bit float	Days	light arrival time correction applied
3	CADENCENO	32-bit integer		timestamp count from start of mission
4	RAW_CNTS	Image 32-bit signed int	ADU	Raw, uncalibrated target image.
5	FLUX	Image 32-bit float	e^-/s	Calibrated, cosmic ray removed, background subtracted target image.
6	FLUX_ERR	Image 32-bit float	e^-/s	Uncertainty of the FLUX.
7	FLUX_BKG	Image 32-bit float	e^-/s	Estimate of the background at every pixel in the target image.
8	FLUX_BKG_ERR	Image 32-bit float	e^-/s	Uncertainty of the FLUX_BKG.
9	QUALITY	32-bit signed integer	Bit field	See table 32.
10	POS_CORR1	32-bit float	pixels	The CCD column local motion differential velocity aberration (DVA), pointing drift, and thermal effects.
11	POS_CORR2	32-bit float	pixels	The CCD row local motion differential velocity aberration (DVA), pointing drift, and thermal effects.

Table 8: Target pixel FITS binary table columns.

Header Card	Data Type	Example Value
XTENSION= 'BINTABLE '/ marks the beginning of a new HDU	C8	const
BITPIX = 8 / array data type	I4	const
NAXIS = 2 / number of array dimensions	I4	const
NAXIS1 = / length of first array dimension	I4	892
NAXIS2 = / length of second array dimension	I4	4203
PCOUNT = 0 / group parameter count (not used)	I4	const
GCOUNT = 1 / group count (not used)	I4	const
TFIELDS = 11 / number of table fields	I4	const
TTYPE1 = 'TIME '/ column title: data time stamps	C4	const
TFORM1 = 'D '/ column format: 64-bit floating point	C1	const
TUNIT1 = 'BJD - 2457000, days'/ column units: Barycenter corrected TESS Julian Date	C19	const
TDISP1 = 'D14.7 '/ column display format	C5	const
TTYPE2 = 'TIMECORR '/ column title: barycentric correction	C8	const
TFORM2 = 'E '/ column format: 32-bit floating point	C1	const
TUNIT2 = 'd '/ column units: day	C1	const
TDISP2 = 'E14.7 '/ column display format	C5	const
TTYPE3 = 'CADENCENO'/ column title: unique cadence number	C9	const
TFORM3 = 'J '/ column format: signed 32-bit integer	C1	const
TDISP3 = 'I10 '/ column display format	C3	const
TTYPE4 = 'RAW_CNTS '/ column title: raw pixel counts	C8	const
TFORM4 = / column format: image of signed 32-bit integers	C3	'36J '
TUNIT4 = 'count '/ column units: count	C5	const
TDISP4 = 'I8 '/ column display format	C2	const
TDIM4 = / column dimensions: pixel aperture array	C10	(6,6)
TNULL4 = -1 / column null value indicator	I4	const
WCSN4P = 'PHYSICAL '/ table column WCS name	C8	const
WCAX4P = 2 / table column physical WCS dimensions	I4	const
1CTY4P = 'RAWX '/ table column physical WCS axis 1 type, CCD col	C4	const
2CTY4P = 'RAWY '/ table column physical WCS axis 2 type, CCD row	C4	const
1CUN4P = 'PIXEL '/ table column physical WCS axis 1 unit	C5	const
2CUN4P = 'PIXEL '/ table column physical WCS axis 2 unit	C5	const
1CRV4P = / table column physical WCS ax 1 ref value	R8	983
2CRV4P = / table column physical WCS ax 2 ref value	R8	94
1CDL4P = / table column physical WCS a1 step	R8	1.0
2CDL4P = / table column physical WCS a2 step	R8	1.0
1CRP4P = / table column physical WCS a1 reference	R8	1
2CRP4P = / table column physical WCS a2 reference	R8	1
WCAX4 = 2 / number of WCS axes	I4	const
1CTYP4 = 'RA---TAN '/ right ascension coordinate type	C8	const
2CTYP4 = 'DEC--TAN '/ declination coordinate type	C8	const
1CRPX4 = / [pixel] reference pixel along image axis 1	R8	4.193741312131351
2CRPX4 = / [pixel] reference pixel along image axis 2	R8	3.431512924394326
1CRVL4 = / [deg] right ascension at reference pixel	R8	297.1151205
2CRVL4 = / [deg] declination at reference pixel	R8	41.90914
1CUNI4 = 'deg '/ physical unit in column dimension	C3	const
2CUNI4 = 'deg '/ physical unit in row dimension	C3	const
1CDLT4 = / [deg] pixel scale in RA dimension	R8	-0.001110042860542
2CDLT4 = / [deg] pixel scale in DEC dimension	R8	0.001110042860542
11PC4 = / linear transformation matrix element cos(th)	R8	-0.8822291555959011
12PC4 = / linear transformation matrix element -sin(th)	R8	-0.48126521856354487
21PC4 = / linear transformation matrix element sin(th)	R8	0.47726131851222925

22PC4 =	/ linear transformation matrix element cos(th)	R8	-0.873141317477748
TTYPE5 = 'FLUX	'/ column title: calibrated pixel flux	C4	const
TFORM5 =	/ column format: image of 32-bit floating point	C4	'36E '
TUNIT5 = 'e-/s	'/ column units: electrons per second	C4	const
TDISP5 = 'E14.7	'/ column display format	C5	const
TDIM5 =	/ column dimensions: pixel aperture array	C10	(6,6)
WCSN5P = 'PHYSICAL	'/ table column WCS name	C8	const
WCAX5P = 2	/ table column physical WCS dimensions	I4	const
1CTY5P = 'RAWX	'/ table column physical WCS axis 1 type, CCD col	C4	const
2CTY5P = 'RAWY	'/ table column physical WCS axis 2 type, CCD row	C4	const
1CUN5P = 'PIXEL	'/ table column physical WCS axis 1 unit	C5	const
2CUN5P = 'PIXEL	'/ table column physical WCS axis 2 unit	C5	const
1CRV5P =	/ table column physical WCS ax 1 ref value	R8	983
2CRV5P =	/ table column physical WCS ax 2 ref value	R8	94
1CDL5P =	/ table column physical WCS a1 step	R8	1.0
2CDL5P =	/ table column physical WCS a2 step	R8	1.0
1CRP5P =	/ table column physical WCS a1 reference	R8	1
2CRP5P =	/ table column physical WCS a2 reference	R8	1
WCAX5 = 2	/ number of WCS axes	I4	const
1CTYP5 = 'RA---TAN	'/ right ascension coordinate type	C8	const
2CTYP5 = 'DEC--TAN	'/ declination coordinate type	C8	const
1CRPX5 =	/ [pixel] reference pixel along image axis 1	R8	4.193741312131351
2CRPX5 =	/ [pixel] reference pixel along image axis 2	R8	3.431512924394326
1CRVL5 =	/ [deg] right ascension at reference pixel	R8	297.1151205
2CRVL5 =	/ [deg] declination at reference pixel	R8	41.90914
1CUNI5 = 'deg	'/ physical unit in column dimension	C3	const
2CUNI5 = 'deg	'/ physical unit in row dimension	C3	const
1CDLT5 =	/ [deg] pixel scale in RA dimension	R8	-0.001110042860542
2CDLT5 =	/ [deg] pixel scale in DEC dimension	R8	0.001110042860542
11PC5 =	/ linear transformation matrix element cos(th)	R8	-0.8822291555959011
12PC5 =	/ linear transformation matrix element -sin(th)	R8	-0.48126521856354487
21PC5 =	/ linear transformation matrix element sin(th)	R8	0.47726131851222925
22PC5 =	/ linear transformation matrix element cos(th)	R8	-0.873141317477748
TTYPE6 = 'FLUX_ERR	'/ column title: 1-sigma calibrated uncertainty	C8	const
TFORM6 =	/ column format: image of 32-bit floating point	C4	'36E '
TUNIT6 = 'e-/s	'/ column units: electrons per second (1-sigma)	C4	const
TDISP6 = 'E14.7	'/ column display format	C5	const
TDIM6 =	/ column dimensions: pixel aperture array	C10	(6,6)
WCSN6P = 'PHYSICAL	'/ table column WCS name	C8	const
WCAX6P = 2	/ table column physical WCS dimensions	I4	const
1CTY6P = 'RAWX	'/ table column physical WCS axis 1 type, CCD col	C4	const
2CTY6P = 'RAWY	'/ table column physical WCS axis 2 type, CCD row	C4	const
1CUN6P = 'PIXEL	'/ table column physical WCS axis 1 unit	C5	const
2CUN6P = 'PIXEL	'/ table column physical WCS axis 2 unit	C5	const
1CRV6P =	/ table column physical WCS ax 1 ref value	R8	983
2CRV6P =	/ table column physical WCS ax 2 ref value	R8	94
1CDL6P =	/ table column physical WCS a1 step	R8	1.0
2CDL6P =	/ table column physical WCS a2 step	R8	1.0
1CRP6P =	/ table column physical WCS a1 reference	R8	1
2CRP6P =	/ table column physical WCS a2 reference	R8	1
WCAX6 = 2	/ number of WCS axes	I4	const
1CTYP6 = 'RA---TAN	'/ right ascension coordinate type	C8	const
2CTYP6 = 'DEC--TAN	'/ declination coordinate type	C8	const
1CRPX6 =	/ [pixel] reference pixel along image axis 1	R8	4.193741312131351

2CRPX6	= / [pixel] reference pixel along image axis 2	R8	3.431512924394326
1CRVL6	= / [deg] right ascension at reference pixel	R8	297.1151205
2CRVL6	= / [deg] declination at reference pixel	R8	41.90914
1CUNI6	= 'deg '/ physical unit in column dimension	C3	const
2CUNI6	= 'deg '/ physical unit in row dimension	C3	const
1CDLT6	= / [deg] pixel scale in RA dimension	R8	-0.001110042860542
2CDLT6	= / [deg] pixel scale in DEC dimension	R8	0.001110042860542
11PC6	= / linear transformation matrix element cos(th)	R8	-0.8822291555959011
12PC6	= / linear transformation matrix element -sin(th)	R8	-0.48126521856354487
21PC6	= / linear transformation matrix element sin(th)	R8	0.47726131851222925
22PC6	= / linear transformation matrix element cos(th)	R8	-0.873141317477748
TTYPE7	= 'FLUX_BKG '/ column title: calibrated background flux	C8	const
TFORM7	= / column format: image of 32-bit floating point	C4	'36E '
TUNIT7	= 'e-/s '/ column units: electrons per second	C4	const
TDISP7	= 'E14.7 '/ column display format	C5	const
TDIM7	= / column dimensions: pixel aperture array	C10	(6,6)
WCSN7P	= 'PHYSICAL '/ table column WCS name	C8	const
WCAX7P	= 2 / table column physical WCS dimensions	I4	const
1CTY7P	= 'RAWX '/ table column physical WCS axis 1 type, CCD col	C4	const
2CTY7P	= 'RAWY '/ table column physical WCS axis 2 type, CCD row	C4	const
1CUN7P	= 'PIXEL '/ table column physical WCS axis 1 unit	C5	const
2CUN7P	= 'PIXEL '/ table column physical WCS axis 2 unit	C5	const
1CRV7P	= / table column physical WCS ax 1 ref value	R8	983
2CRV7P	= / table column physical WCS ax 2 ref value	R8	94
1CDL7P	= / table column physical WCS a1 step	R8	1.0
2CDL7P	= / table column physical WCS a2 step	R8	1.0
1CRP7P	= / table column physical WCS a1 reference	R8	1
2CRP7P	= / table column physical WCS a2 reference	R8	1
WCAX7	= 2 / number of WCS axes	I4	const
1CTYP7	= 'RA---TAN '/ right ascension coordinate type	C8	const
2CTYP7	= 'DEC--TAN '/ declination coordinate type	C8	const
1CRPX7	= / [pixel] reference pixel along image axis 1	R8	4.193741312131351
2CRPX7	= / [pixel] reference pixel along image axis 2	R8	3.431512924394326
1CRVL7	= / [deg] right ascension at reference pixel	R8	297.1151205
2CRVL7	= / [deg] declination at reference pixel	R8	41.90914
1CUNI7	= 'deg '/ physical unit in column dimension	C3	const
2CUNI7	= 'deg '/ physical unit in row dimension	C3	const
1CDLT7	= / [deg] pixel scale in RA dimension	C18	-0.001110042860542
2CDLT7	= / [deg] pixel scale in DEC dimension	R8	0.001110042860542
11PC7	= / linear transformation matrix element cos(th)	R8	-0.8822291555959011
12PC7	= / linear transformation matrix element -sin(th)	R8	-0.48126521856354487
21PC7	= / linear transformation matrix element sin(th)	R8	0.47726131851222925
22PC7	= / linear transformation matrix element cos(th)	R8	-0.873141317477748
TTYPE8	= 'FLUX_BKG_ERR'/ column title: 1-sigma cal. background uncertain	C12	const
TFORM8	= / column format: image of 32-bit floating point	C3	'36E '
TUNIT8	= 'e-/s '/ column units: electrons per second (1-sigma)	C4	const
TDISP8	= 'E14.7 '/ column display format	C5	const
TDIM8	= / column dimensions: pixel aperture array	C10	(6,6)
WCSN8P	= 'PHYSICAL '/ table column WCS name	C8	const
WCAX8P	= 2 / table column physical WCS dimensions	I4	const
1CTY8P	= 'RAWX '/ table column physical WCS axis 1 type, CCD col	C4	const
2CTY8P	= 'RAWY '/ table column physical WCS axis 2 type, CCD row	C4	const
1CUN8P	= 'PIXEL '/ table column physical WCS axis 1 unit	C5	const
2CUN8P	= 'PIXEL '/ table column physical WCS axis 2 unit	C5	const

1CRV8P = / table column physical WCS ax 1 ref value	R8	983
2CRV8P = / table column physical WCS ax 2 ref value	R8	94
1CDL8P = / table column physical WCS a1 step	R8	1.0
2CDL8P = / table column physical WCS a2 step	R8	1.0
1CRP8P = / table column physical WCS a1 reference	R8	1
2CRP8P = / table column physical WCS a2 reference	R8	1
WCAX8 = 2 / number of WCS axes	I4	const
1CTYP8 = 'RA---TAN '/ right ascension coordinate type	C8	const
2CTYP8 = 'DEC--TAN '/ declination coordinate type	C8	const
1CRPX8 = / [pixel] reference pixel along image axis 1	R8	4.193741312131351
2CRPX8 = / [pixel] reference pixel along image axis 2	R8	3.431512924394326
1CRVL8 = / [deg] right ascension at reference pixel	R8	297.1151205
2CRVL8 = / [deg] declination at reference pixel	R8	41.90914
1CUNI8 = 'deg '/ physical unit in column dimension	C3	const
2CUNI8 = 'deg '/ physical unit in row dimension	C3	const
1CDLT8 = / [deg] pixel scale in RA dimension	C18	-0.001110042860542
2CDLT8 = / [deg] pixel scale in DEC dimension	R8	0.001110042860542
11PC8 = / linear transformation matrix element cos(th)	R8	-0.8822291555959011
12PC8 = / linear transformation matrix element -sin(th)	R8	-0.48126521856354487
21PC8 = / linear transformation matrix element sin(th)	R8	0.47726131851222925
22PC8 = / linear transformation matrix element cos(th)	R8	-0.873141317477748
TTYPE9 = 'QUALITY '/ column title: pixel quality flags	C7	const
TFORM9 = 'J '/ column format: signed 32-bit integer	C1	const
TDISP9 = 'B16.16 '/ column display format	C6	const
TTYPE10 = 'POS_CORR1'/ column title: column position correction	C9	const
TFORM10 = 'E '/ column format: 32-bit floating point	C1	const
TUNIT10 = 'pixel '/ column units: pixel	C5	const
TDISP10 = 'E14.7 '/ column display format	C5	const
TTYPE11 = 'POS_CORR2'/ column title: row position correction	C9	const
TFORM11 = 'E '/ column format: 32-bit floating point	C1	const
TUNIT11 = 'pixel '/ column units: pixel	C5	const
TDISP11 = 'E14.7 '/ column display format	C5	const
INHERIT = T / inherit the primary header	L1	const
EXTNAME = 'PIXELS' / name of extension	C6	const
EXTVER = 1 / extension version number (not format version)	I4	const
SIMDATA = / file is based on simulated data	L1	F
TELESCOP= 'TESS ' / telescope	C8	const
INSTRUME= 'TESS Photometer'/ detector type	C15	const
OBJECT = / string version of TICID	C20	TIC 6541920
TICID = / unique TESS target identifier (0 < values < 2^50)	I8	6541920
RADESYS = 'ICRS '/ reference frame of celestial coordinates	C4	const
RA_OBJ = / [deg] right ascension	R8	297.115121
DEC_OBJ = / [deg] declination	R8	41.909140
EQUINOX = 2000.0 / equinox of celestial coordinate system	R8	const
EXPOSURE= / [d] time on source	R8	67.45912770
TIMEREF = 'SOLARSYSTEM'/ barycentric correction applied to times	C11	const
TASSIGN = 'SPACECRAFT'/ where time is assigned	C10	const
TIMESYS = 'TDB '/ time system is Barycentric Dynamical Time (TDB)	C3	const
BJDREFI = 2457000 / integer part of BJD reference date	I4	const
BJDREFF = 0.0 / fraction of the day in BJD reference date	R4	const
TIMEUNIT= 'd '/ time unit for TIME, TSTART and TSTOP	C1	const
TELAPSE = / [d] TSTOP - TSTART	R8	85.88209984
LIVETIME= / [d] TELAPSE multiplied by DEADC	R8	79.06606017

TSTART =	/ observation start time in BTJD	R8	1472.086752
TSTOP =	/ observation stop time in BTJD	R8	1557.968852
DEADC =	/ deadtime correction	R8	0.92063492
TIMEPIXR=	/ bin time beginning=0 middle=0.5 end=1	R8	0.5
TIERRELA=	/ [d] relative time error	R8	5.78E-07
INT_TIME=	/ [s] photon accumulation time per frame	R8	6.019802903270
READTIME=	/ [s] frame transfer time	R8	0.518948526144
FRAMETIM=	/ [s] frame time (INT_TIME + READTIME)	R8	6.538751429414
NUM_FRM =	/ number of frames per time stamp	I4	270
TIMEDEL =	/ [d] time resolution of data	R4	0.02043359821692
DATE-OBS=	/ TSTART as UTC calendar date	C24	2013-01-12T14:06:28.100
DATE-END=	/ TSTOP as UTC calendar date	C24	2013-04-08T11:17:10.783
BACKAPP =	/ background is subtracted	L1	T
DEADAPP =	/ deadtime applied	L1	T
VIGNAPP =	/ vignetting or collimator correction applied	L1	T
GAINA =	/ [electrons/count] CCD output A gain	R4	107.06
GAINB =	/ [electrons/count] CCD output B gain	R4	107.06
GAINC =	/ [electrons/count] CCD output C gain	R4	107.06
GAIND =	/ [electrons/count] CCD output D gain	R4	107.06
READNOIA=	/ [electrons] read noise CCD output A	R4	79.053104
READNOIB=	/ [electrons] read noise CCD output B	R4	79.053104
READNOIC=	/ [electrons] read noise CCD output C	R4	79.053104
READNOID=	/ [electrons] read noise CCD output D	R4	79.053104
TMOFST<CAMERA><CCD>	/ [s] readout delay for camera <CAMERA> and ccd <CCD>	R4	0.5
MEANBLCA=	/ [count] CCD output A mean black level	I4	749
MEANBLCB=	/ [count] CCD output B mean black level	I4	749
MEANBLCC=	/ [count] CCD output C mean black level	I4	749
MEANBLCD=	/ [count] CCD output D mean black level	I4	749
NREADOUT=	/ number of read per cadence	I4	270
FXDOFF=	/ compression fixed offset	I4	419400
CDPP0_5 =	/ RMS CDPP on 0.5-hr time scales	R4	71.25101
CDPP1_0 =	/ RMS CDPP on 1.0-hr time scales	R4	49.6552
CDPP2_0=	/ RMS CDPP on 2.0-hr time scales	R4	37.136634
CROWDSAP=	/ Ratio of target flux to total flux in op. ap.	R4	0.9335
FLFRCSAP=	/ Frac. of target flux w/in the op. aperture	R4	0.8824
CHECKSUM=	/ HDU checksum updated 2013-06-10T22:41:33	C16	KaEOLXELKaELKUEL
END			

Table 9: Target pixel file binary table header

4.2.3 Aperture Mask Image

The third HDU in the target pixel file is the aperture mask image. Section 6 discusses the aperture mask image HDU which shares a common definition with the light curve file.

4.3 Cosmic Ray Binary Table Extension

The fourth HDU in the target pixel file describes the cosmic rays that were identified and subtracted from the target pixels. In order to compute the calibrated pixel value with cosmic rays the user of this file should add the value in COSMIC_RAY to the specified pixel coordinate. These cosmic ray corrections are only available if the SPOC cosmic ray correction algorithm was enabled during processing. Table 10 describes the columns in the binary table. Table 11 defines the header. This HDU only exists when SPOC cosmic ray mitigation has been enabled.

Column Number	TYPE	FORM	UNIT	Description
1	CADENCENO	32-bit signed integer		timestamp count since start of mission
2	RAWX	16-bit signed integer	pixels	Pixel CCD column coordinate.
3	RAWY	16-bit signed integer	pixels	Pixel CCD row coordinate.
4	COSMIC_RAY	32-bit single precision floating point	e^{-}/s	Correction applied to the pixel in the calibrated image.

Table 10: Target pixel FITS binary table columns.

Header Card	Data Type	Example Value
`XTENSION= 'BINTABLE '/  marks the beginning of a new HDU`	C8	const
`BITPIX  = 8          / array data type`	I4	const
`NAXIS   = 2          / number of array dimensions`	I4	const
`NAXIS1  = 12         / length of first array dimension`	I4	const
`NAXIS2  =            / length of second array dimension`	I4	4203
`PCOUNT  = 0          / group parameter count (not used)`	I4	const
`GCOUNT  = 1          / group count (not used)`	I4	const
`EXTNAME = 'TARGET COSMIC RAY'/ name of extension`	C17	const
`TFIELDS = 4          / number of table fields`	I4	const
`TTYPE1  = 'CADENCENO'/  column title: unique cadence number`	C9	const
`TFORM1  = 'J        '/  column format: signed 32-bit integer`	C1	const
`TDISP1  = 'I10      '/  column display format`	C3	const
`TTYPE2  = 'RAWX'     / column title: CCD column`	C4	const
`TFORM2  = 'I        '/ column format: signed 16-bit integer`	C1	const
`TDISP2  = 'I4       '/ column display format`	C2	const
`TTYPE3  = 'RAWY'     / column title: CCD row`	C4	const
`TFORM3  = 'I        '/ column format: signed 16-bit integer`	C1	const
`TDISP3  = 'I4       '/ column display format`	C2	const
`TTYPE4  = 'COSMIC_RAY' / column title: cosmic ray correction`	C10	const
`TFORM4  = 'E        '/ column format: 32-bit floating point`	C1	const
`TDISP4  = 'E14.7    '/ column display format`	C5	const
`TUNIT4  = 'e-/s    '/ column units: electrons per second`	C4	const
`SIMDATA =            / file is based on simulated data`	L1	F
`END`		

Table 11: Target cosmic ray table header

5 Light Curve Files

5.1 Purpose

Light curve files contain the output of the photometric analysis and subsequent cotrending as applied to the light curve. A single file contains the light curves for one target for one sector (two orbits). If a target was observed in more than one sector then multiple files will be created, but these may be delivered in separate deliveries. Standard light curve files (designated by "lc" in the file name) are associated with data acquired at a 2-minute cadence. Fast light curve files (designated by "fast-lc") are associated with data acquired at a 20-second cadence.

5.2 Composition

The primary header contains information about the target that does not vary with the data acquisition time, such as its right ascension and declination. The primary HDU does not have a data table. The second HDU contains a FITS binary table where each row in the table contains the data at some cadence. The definitions of the columns for this table are summarized in table 13. The header for the second HDU contains keywords that are needed to describe binary table and properties of the target object that may vary with the time at which it was observed such as which CCD the target fell on during the observation. The final HDU contains a single image that is the aperture mask for that image. Each pixel value is the product of the bit-wise OR of the flags defined in table 15. Figure 3 shows the relationships among the HDUs in this file.

Light Curve FITS File

Primary Header

Header for Binary Table of Light Curves

Binary Table of Light Curve Data

Aperture Mask Image Header

Aperture Mask Image Data

Figure 3: Light curve FITS file composition

5.2.1 Primary Header

The first HDU only contains keywords and is primarily concerned with stellar parameters. Table 12 defines this header.

Header Card	Data Type	Example Value
SIMPLE = T / conforms to FITS standards	L1	const
BITPIX = 8 / array data type	I4	const
NAXIS = 0 / number of array dimensions	I4	const
EXTEND = T / file contains extensions	L1	const
NEXTEND = 2 / number of standard extensions	I4	const
EXTNAME = 'PRIMARY '/ name of extension	C7	const
EXTVER = 1 / extension version number (not format version)	I4	const
SIMDATA = / file is based on simulated data	L1	F
ORIGIN = 'NASA/Ames'/ institution responsible for creating this file	C9	const
DATE = / file creation date.	C10	2013-07-12
TSTART = / observation start time in BTJD	R8	1472.086752
TSTOP = / observation stop time in BTJD	R8	1557.968852
DATE-OBS= / TSTART as UTC calendar date	C24	2013-01-12T14:06:28.100
DATE-END= / TSTOP as UTC calendar date	C24	2013-04-08T11:17:10.783
CREATOR = / pipeline job and program used t	C50	540344 LightCurveExporterPipelineModule
PROCVER = / SW version	C50	spoc-5.0.2-20200714
FILEVER = / file format version	R8	5.0
TIMVERSN= 'OGIP/93-003'/ OGIP memo number for file format	C11	const
TELESCOP= 'TESS '/ telescope	C4	const
INSTRUME= 'TESS Photometer'/ detector type	C15	const
DATA_REL= / version of data release notes for this file	I4	22
OBJECT = / string version of TICID	C20	TIC 6541920
TICID = / unique TESS target identifier (0 < values < 2^50)	I8	6541920
SECTOR = / Observing sector	I4	16

CAMERA =	/ Camera number	I4	1
CCD =	/ CCD number	I4	4
RADESYS = 'ICRS	'/ reference frame of celestial coordinates	C4	const
RA_OBJ =	/ [deg] right ascension	R4	297.115121
DEC_OBJ =	/ [deg] declination	R4	41.909140
EQUINOX = 2000.0	/ equinox of celestial coordinate system	R8	const
PMRA =	/ [mas/yr] RA proper motion	R4	0.0000
PMDEC =	/ [mas/yr] Dec proper motion	R4	0.0000
PMTOTAL =	/ [mas/yr] total proper motion	R4	0.0000
PXTABLE =	/ pixel table id	I4	2
TESSMAG =	/ [mag] TESS magnitude	R4	13.709
TEFF =	/ [K] Effective temperature	R4	5920
LOGG =	/ [cm/s2] log10 surface gravity	R4	4.467
MH =	/ [log10([M/H])] metallicity	R4	-0.200
RADIUS =	/ [solar radii] stellar radius	R4	0.962
TICVER =	/ TIC Version	R4	8.1
CRMITEN =	/ spacecraft cosmic ray mitigation enabled	L1	T
CRBLKSZ =	/ [exposures] s/c cosmic ray mitigation block size	I4	20
CRSPOC =	/ SPOC cosmic ray cleaning enabled	L1	T
CHECKSUM=	/ HDU checksum updated 2013-07-12T22:34:06	C16	9H6DFH4B9H4BCH4B
END			

Table 12: Light curve primary header.

5.2.2 Light Curve Binary Table Extension Header

For table 13 TYPE, FORM and UNIT refer to the FITS keywords that would describe that column. In FITS parlance "TYPE" is not the data type of the column, but rather its name. "FORM" actually describes the data type for the column which can be, for example, "D", a 64-bit double precision floating point value. Subtracting TIMECORR from TIME will give the light arrival time at the spacecraft rather than on the target's center.

Column Number	TYPE	FORM	UNIT	Description
1	TIME	64-bit float	Days	BJD - 2457000 (BTJD)
2	TIMECORR	32-bit float	Days	light arrival time correction applied
3	CADENCENO	32-bit integer		timestamp count from start of mission
4	SAP_FLUX	32-bit float	e^{-}/s	Simple aperture photometry light curve.
5	SAP_FLUX_ERR	32-bit float	e^{-}/s	1-σ uncertainty of the SAP light curve.
6	SAP_BKG	32-bit float	e^{-}/s	Estimated background flux contribution to the target aperture. Already subtracted from SAP_FLUX.
7	SAP_BKG_ERR	32-bit float	e^{-}/s	1-σ uncertainty of the SAP background light curve.
8	PDCSAP_FLUX	32-bit float	e^{-}/s	PDC corrected SAP light curve.
9	PDCSAP_FLUX_ERR	32-bit float	e^{-}/s	1-σ uncertainty of the PDC corrected SAP light curve.
10	QUALITY	32-bit integer	Bit field	Each bit is a flag defined in table 32.
11	PSF_CENTR1	64-bit float	pixels	CCD column position of of target centroid using a PSF model.
12	PSF_CENTR1_ERR	32-bit float	pixels	1 σ uncertainty of PSF_CENTR1.
13	PSF_CENTR2	64-bit float	pixels	CCD row position of of target centroid using a PSF model.
14	PSF_CENTR2_ERR	32-bit float	pixels	1 σ uncertainty of PSF_CENTR2.
15	MOM_CENTR1	64-bit float	pixels	CCD column position of target's flux-weighted centroid.
16	MOM_CENTR1_ERR	32-bit float	pixels	1 σ uncertainty of MOM_CENTR1.
17	MOM_CENTR2	64-bit float	pixels	CCD row position of target's flux-weighted centroid.
18	MOM_CENTR2_ERR	32-bit float	pixels	1 σ uncertainty of MOM_CENTR2.
19	POS_CORR1	32-bit float	pixels	The CCD column local motion differential velocity aberration (DVA), pointing drift, and thermal effects.
20	POS_CORR2	32-bit float	pixels	The CCD row local motion differential velocity aberration (DVA), pointing drift, and thermal effects.

Table 13: Light curve binary table column summary.

Table 14 defines the FITS header for the light curve binary table HDU. The FITS keyword, PDCMETHD, describes the algorithm used to cotrend the light curve. If the algorithm is "multiScaleMap" then NUMBAND may be greater than one. NUMBAND specifies how many bands are used for the light curve each of which can have different values for the keywords: FITTYPEn, PR_GOODn and PR_WGHTn of which there are 1 ... NUMBAND. Other algorithms may not define these keywords (FITTYPEb, PR_GOODn, PR_WGHTn) and so they may not be present at all in a light curve file.

Header Card	Data Type	Example Value
`XTENSION= 'BINTABLE '/  marks the beginning of a new HDU`	C8	const
`BITPIX  = 8          / array data type`	I4	const
`NAXIS   = 2          / number of array dimensions`	I4	const
`NAXIS1  = 100        / length of first array dimension`	I4	const
`NAXIS2  =            / length of second array dimension`	I4	4203
`PCOUNT  = 0          / group parameter count (not used)`	I4	const
`GCOUNT  = 1          / group count (not used)`	I4	const
`TFIELDS = 20         / number of table fields`	I4	const
`TTYPE1  = 'TIME     '/  column title: data time stamps`	C4	const
`TFORM1  = 'D        '/  column format: 64-bit floating point`	C1	const
`TUNIT1  = 'BJD - 2457000, days'/  column units: Barycenter corrected TESS Julian Date`	C19	const
`TDISP1  = 'D14.7    '/  column display format`	C5	const
`TTYPE2  = 'TIMECORR '/  column title: barycentric correction`	C8	const
`TFORM2  = 'E        '/  column format: 32-bit floating point`	C1	const
`TUNIT2  = 'd        '/  column units: day`	C1	const
`TDISP2  = 'E14.7    '/  column display format`	C5	const

TTYPE3 = 'CADENCENO'/ column title: unique cadence number	C9	const
TFORM3 = 'J '/ column format: signed 32-bit integer	C1	const
TDISP3 = 'I10 '/ column display format	C3	const
TTYPE4 = 'SAP_FLUX '/ column title: aperture photometry flux	C8	const
TFORM4 = 'E '/ column format: 32-bit floating point	C1	const
TUNIT4 = 'e-/s '/ column units: electrons per second	C4	const
TDISP4 = 'E14.7 '/ column display format	C5	const
TTYPE5 = 'SAP_FLUX_ERR'/ column title: aperture phot. flux error	C12	const
TFORM5 = 'E '/ column format: 32-bit floating point	C1	const
TUNIT5 = 'e-/s '/ column units: electrons per second (1-sigma)	C4	const
TDISP5 = 'E14.7 '/ column display format	C5	const
TTYPE6 = 'SAP_BKG '/ column title: aperture phot. background flux	C7	const
TFORM6 = 'E '/ column format: 32-bit floating point	C1	const
TUNIT6 = 'e-/s '/ column units: electrons per second	C4	const
TDISP6 = 'E14.7 '/ column display format	C5	const
TTYPE7 = 'SAP_BKG_ERR'/ column title: ap. phot. background flux error	C11	const
TFORM7 = 'E '/ column format: 32-bit floating point	C1	const
TUNIT7 = 'e-/s '/ column units: electrons per second (1-sigma)	C4	const
TDISP7 = 'E14.7 '/ column display format	C5	const
TTYPE8 = 'PDCSAP_FLUX'/ column title: aperture phot. PDC flux	C11	const
TFORM8 = 'E '/ column format: 32-bit floating point	C1	const
TUNIT8 = 'e-/s '/ column units: electrons per second	C4	const
TDISP8 = 'E14.7 '/ column display format	C5	const
TTYPE9 = 'PDCSAP_FLUX_ERR'/ column title: ap. phot. PDC flux error	C15	const
TFORM9 = 'E '/ column format: 32-bit floating point	C1	const
TUNIT9 = 'e-/s '/ column units: electrons per second (1-sigma)	C4	const
TDISP9 = 'E14.7 '/ column display format	C5	const
TTYPE10 = 'QUALITY'/ column title: aperture photometry quality flag	C11	const
TFORM10 = 'J '/ column format: signed 32-bit integer	C1	const
TDISP10 = 'B16.16 '/ column display format	C6	const
TTYPE11 = 'PSF_CENTR1'/ column title: PSF-fitted column centroid	C10	const
TFORM11 = 'D '/ column format: 64-bit floating point	C1	const
TUNIT11 = 'pixel '/ column units: pixel	C5	const
TDISP11 = 'F10.5 '/ column display format	C5	const
TTYPE12 = 'PSF_CENTR1_ERR'/ column title: PSF-fitted column error	C14	const
TFORM12 = 'E '/ column format: 32-bit floating point	C1	const
TUNIT12 = 'pixel '/ column units: pixel (1-sigma)	C5	const
TDISP12 = 'E14.7 '/ column display format	C5	const
TTYPE13 = 'PSF_CENTR2'/ column title: PSF-fitted row centroid	C10	const
TFORM13 = 'D '/ column format: 64-bit floating point	C1	const
TUNIT13 = 'pixel '/ column units: pixel	C5	const
TDISP13 = 'F10.5 '/ column display format	C5	const
TTYPE14 = 'PSF_CENTR2_ERR'/ column title: PSF-fitted row error	C14	const
TFORM14 = 'E '/ column format: 32-bit floating point	C1	const
TUNIT14 = 'pixel '/ column units: pixel (1-sigma)	C5	const

TDISP14 = 'E14.7 '/ column display format	C5	const
TTYPE15 = 'MOM_CENTR1'/ column title: moment-derived column centroid	C10	const
TFORM15 = 'D '/ column format: 64-bit floating point	C1	const
TUNIT15 = 'pixel '/ column units: pixel	C5	const
TDISP15 = 'F10.5 '/ column display format	C5	const
TTYPE16 = 'MOM_CENTR1_ERR'/ column title: moment-derived column error	C14	const
TFORM16 = 'E '/ column format: 32-bit floating point	C1	const
TUNIT16 = 'pixel '/ column units: pixel (1-sigma)	C5	const
TDISP16 = 'E14.7 '/ column display format	C5	const
TTYPE17 = 'MOM_CENTR2'/ column title: moment-derived row centroid	C10	const
TFORM17 = 'D '/ column format: 64-bit floating point	C1	const
TUNIT17 = 'pixel '/ column units: pixel	C5	const
TDISP17 = 'F10.5 '/ column display format	C5	const
TTYPE18 = 'MOM_CENTR2_ERR'/ column title: moment-derived row error	C14	const
TFORM18 = 'E '/ column format: 32-bit floating point	C1	const
TUNIT18 = 'pixel '/ column units: pixel (1-sigma)	C5	const
TDISP18 = 'E14.7 '/ column display format	C5	const
TTYPE19 = 'POS_CORR1'/ column title: column position correction	C9	const
TFORM19 = 'E '/ column format: 32-bit floating point	C1	const
TUNIT19 = 'pixels '/ column units: pixel	C6	const
TDISP19 = 'E14.7 '/ column display format	C5	const
TTYPE20 = 'POS_CORR2'/ column title: row position correction	C9	const
TFORM20 = 'E '/ column format: 32-bit floating point	C1	const
TUNIT20 = 'pixels '/ column units: pixel	C6	const
TDISP20 = 'E14.7 '/ column display format	C5	const
INHERIT = T / inherit the primary header	L1	const
EXTNAME = 'LIGHTCURVE'/ name of extension	C10	const
EXTVER = 1 / extension version number (not format version)	I4	const
SIMDATA = / file is based on simulated data	L1	F
TELESCOP= 'TESS '/ telescope	C8	const
INSTRUME= 'TESS Photometer'/ detector type	C15	const
OBJECT = / string version of TICID	C20	TIC 6541920
TICID= / unique TESS target identifier (0 < values < 2^50)	I8	6541920
RADESYS = 'ICRS '/ reference frame of celestial coordinates	C4	const
RA_OBJ = / [deg] right ascension	R4	297.115121
DEC_OBJ = / [deg] declination	R4	41.909140
EQUINOX = 2000.0 / equinox of celestial coordinate system	R8	const
EXPOSURE= / [d] time on source	R4	27.06606017
TIMEREF = 'SOLARSYSTEM'/ barycentric correction applied to times	C11	const
TASSIGN = 'SPACECRAFT'/ where time is assigned	C10	const
TIMESYS = 'TDB '/ time system is Barycentric Dynamical Time (TDB)	C3	const
BJDREFI = 2457000 / integer part of BJD reference date	I4	const
BJDREFF = 0.0 / fraction of the day in BJD reference date	R4	const
TIMEUNIT= 'd '/ time unit for TIME, TSTART and TSTOP	C1	const
TELAPSE = / [d] TSTOP - TSTART	R4	85.88209984
LIVETIME= / [d] TELAPSE multiplied by DEADC	R4	79.06606017
TSTART = / observation start time in BTJD	R8	1472.086752
TSTOP = / observation stop time in BTJD	R8	1557.968852
DEADC = / deadtime correction	R4	0.92063492
TIMEPIXR= / bin time beginning=0 middle=0.5 end=1	R8	0.5

TIERRELA=	/ [d] relative time error	R8	5.78E-07
INT_TIME=	/ [s] photon accumulation time per frame	R4	6.019802903270
READTIME=	/ [s] readout time per frame	R4	0.518948526144
FRAMETIM=	/ [s] frame time (INT_TIME + READTIME)	R4	6.538751429414
NUM_FRM =	/ number of frames per time stamp	I4	270
TIMEDEL =	/ [d] time resolution of data	R8	0.02043359821692
DATE-OBS=	/ TSTART as UTC calendar date	C24	2013-01-12T14:06:28.100
DATE-END=	/ TSTOP as UTC calendar date	C24	2013-04-08T11:17:10.783
BACKAPP =	/ background is subtracted	L1	T
DEADAPP =	/ deadtime applied	L1	T
VIGNAPP =	/ vignetting or collimator correction applied	L1	T
GAINA =	/ [electrons/count] CCD output A gain	R4	107.06
GAINB =	/ [electrons/count] CCD output B gain	R4	107.06
GAINC =	/ [electrons/count] CCD output C gain	R4	107.06
GAIND =	/ [electrons/count] CCD output D gain	R4	107.06
READNOIA=	/ [electrons] read noise CCD output A	R4	79.053104
READNOIB=	/ [electrons] read noise CCD output B	R4	79.053104
READNOIC=	/ [electrons] read noise CCD output C	R4	79.053104
READNOID=	/ [electrons] read noise CCD output D	R4	79.053104
TMOFST<CAMERA><CCD>	/ [s] readout delay for camera <CAMERA> and ccd <CCD>	R4	0.5
MEANBLCA=	/ [count] CCD output A mean black level	I4	749
MEANBLCB=	/ [count] CCD output B mean black level	I4	749
MEANBLCC=	/ [count] CCD output C mean black level	I4	749
MEANBLCD=	/ [count] CCD output D mean black level	I4	749
NREADOUT=	/ number of read per cadence	I4	270
FXDOFF=	/ compression fixed offset	I4	419400
CDPP0_5 =	/ RMS CDPP on 0.5-hr time scales	R4	71.25101
CDPP1_0 =	/ RMS CDPP on 1.0-hr time scales	R4	49.6552
CDPP2_0=	/ RMS CDPP on 2.0-hr time scales	R4	37.136634
CROWDSAP=	/ Ratio of target flux to total flux in op. ap.	R8	0.9335
FLFRCSAP=	/ Frac. of target flux w/in the op. aperture	R8	0.8824
NSPSDDET=	/ Number of SPSDs detected	I4	0
NSPSDCOR=	/ Number of SPSDs corrected	I4	0
PDCVAR =	/ Target variability	R4	1.0995078086853027
PDCMETHD=	/ PDC algorithm used for target	C13	multiScaleMap
NUMBAND =	/ Number of scale bands	I4	3
FITTYPE1= 'robust	'/ Fit type used for band 1	C6	const
PR_GOOD1=	/ Prior goodness for band 1	R8	0.0
PR_WGHT1=	/ Prior weight for band 1	R8	0.0
FITTYPE2= 'prior	'/ Fit type used for band 2	C5	const
PR_GOOD2=	/ Prior goodness for band 2	R4	0.9961856603622437
PR_WGHT2=	/ Prior weight for band 2	R4	87.8223876953125
FITTYPE3= 'none	'/ Fit type used for band 3	C4	const
PR_GOOD3=	/ Prior goodness for band 3	C4	-1.0
PR_WGHT3=	/ Prior weight for band 3	C4	-1.0
PDC_TOT =	/ PDC total goodness metric for target	R4	0.9671841859817505
PDC_TOTP=	/ PDC_TOT percentile compared to mod/out	R4	70.68902587890625
PDC_COR =	/ PDC correlation goodness metric for target	R4	0.9984112977981567
PDC_CORP=	/ PDC_COR percentile compared to mod/out	R4	65.72728729248047
PDC_VAR =	/ PDC variability goodness metric for target	R4	0.974346399307251
PDC_VARP=	/ PDC_VAR percentile compared to mod/out	R4	65.5057144165039
PDC_NOI =	/ PDC noise goodness metric for target	R4	0.9020557403564453
PDC_NOIP=	/ PDC_NOI percentile compared to mod/out	R4	34.96445846557617
PDC_EPT =	/ PDC earth point goodness metric for target	R4	0.9971959590911865
PDC_EPTP=	/ PDC_EPT percentile compared to mod/out	R4	76.96773529052734

CHECKSUM= / HDU checksum updated 2013-07-12T22:34:06	C16	4QGk5QDj4QDj4QDj
END		

Table 14: Light curve binary table header.

5.2.3 Aperture Mask Image

The third and final HDU is the aperture mask image. This HDU is described in section 6.

6 Aperture Mask Image HDU

6.1 Purpose

The aperture mask image indicates the pixels that were collected for a target and which of those pixels were used for photometry. Target pixel files and light curve files each contain one of these HDUs.

6.2 Composition

A pixel in the aperture mask image is the bit-wise OR of the bits described in table 15. Table 16 defines the FITS header for this image HDU. It is possible that a pixel is in the bounding box of the image, but was not actually collected by the spacecraft. These pixel values will NOT show as NULL in a FITS viewer. They are filled with the value 0 to indicate all bits are set to false. The value of each pixel is the bit-wise OR of the bits described in 15.

Bit	Value	Description
1	1	Pixel was collected by the spacecraft.
2	2	Pixel was in optimal aperture.
3	4	Pixel was used in background calculation.
4	8	Pixel was used to calculate the flux weighted centroid.
5	16	Pixel was used to calculate the PRF centroid.
6	32	Pixel is on CCD output A
7	64	Pixel is on CCD output B
8	128	Pixel is on CCD output C
9	256	Pixel is on CCD output D

Table 15: Aperture mask image bits

Header Card	Data Type	Example Value
XTENSION= 'IMAGE '/ marks the beginning of a new HDU	C5	const
BITPIX = 32 / array data type	I4	const
NAXIS = 2 / number of array dimensions	I4	const
NAXIS1 = / length of first array dimension	I4	6
NAXIS2 = / length of second array dimension	I4	6
PCOUNT = 0 / group parameter count (not used)	I4	const
GCOUNT = 1 / group count (not used)	I4	const
INHERIT = T / inherit the primary header	L1	const
EXTNAME = 'APERTURE '/ name of extension	C8	const
EXTVER = 1 / extension version number (not format version)	I4	const
SIMDATA = / file is based on simulated data	L1	F
TELESCOP= 'TESS '/ telescope	C6	const
INSTRUME= 'TESS Photometer'/ detector type	C17	const
OBJECT = / string version of TICID	C20	TIC 6541920
TICID= / unique TESS target identifier (0 < values < 2^50)	I8	6541920
RADESYS = 'ICRS '/ reference frame of celestial coordinates	C4	const
RA_OBJ = / [deg] right ascension	R4	297.115121
DEC_OBJ = / [deg] declination	R4	41.909140

EQUINOX = 2000.0	/ equinox of celestial coordinate system	R8	const
WCSAXES = 2	/ number of WCS axes	I4	const
CTYPE1 = 'RA---TAN '	/ right ascension coordinate type	C8	const
CTYPE2 = 'DEC--TAN '	/ declination coordinate type	C8	const
CRPIX1 =	/ [pixel] reference pixel along image axis 1	R4	4.193741312131351
CRPIX2 =	/ [pixel] reference pixel along image axis 2	R4	3.431512924394326
CRVAL1 =	/ [deg] right ascension at reference pixel	R4	297.1151205
CRVAL2 =	/ [deg] declination at reference pixel	R8	41.90914
CUNIT1 = 'deg '	/ physical unit in column dimension	C3	const
CUNIT2 = 'deg '	/ physical unit in row dimension	C3	const
CDELT1 =	/ [deg] pixel scale in RA dimension	C18	-0.001110042860542
CDELT2 =	/ [deg] pixel scale in Dec dimension	R4	0.001110042860542
PC1_1 =	/ linear transformation element cos(th)	C19	-0.8822291555959011
PC1_2 =	/ linear transformation element -sin(th)	C20	-0.48126521856354487
PC2_1 =	/ linear transformation element sin(th)	R4	0.47726131851222925
PC2_2 =	/ linear transformation element cos(th)	C18	-0.873141317477748
WCSNAMEP= 'PHYSICAL '	/ name of world coordinate system alternate P	C8	const
WCSAXESP=	/ number of WCS physical axes	I4	2
CTYPE1P = 'RAWX '	/ physical WCS axis 1 type CCD col	C4	const
CUNIT1P = 'PIXEL '	/ physical WCS axis 1 unit	C5	const
CRPIX1P =	/ reference CCD column	I4	1
CRVAL1P =	/ value at reference CCD column	I4	983
CDELT1P =	/ physical WCS axis 1 step	R8	1.0
CTYPE2P = 'RAWY '	/ physical WCS axis 2 type CCD row	C4	const
CUNIT2P = 'PIXEL '	/ physical WCS axis 2 units	C5	const
CRPIX2P =	/ reference CCD row	I4	1
CRVAL2P =	/ value at reference CCD row	I4	94
CDELT2P =	/ physical WCS axis 2 step	R8	1.0
NPIXSAP =	/ Number of pixels in optimal aperture	I4	8
NPIXMISS=	/ Number of op. aperture pixels not collected	I4	0
CHECKSUM=	/ HDU checksum updated 2013-07-12T22:34:06	C16	X3ppY0mnX0mnX0mn
END			

Table 16: Light curve and target pixel file aperture mask image extension header

7 Collateral Target Pixel Files

7.1 Purpose

The purpose of the collateral target pixel files is to archive the pixel level calibration data collected by the spacecraft during operation. All of the collateral rows and columns are virtual: they do not exist on the chip itself, and are the result of either overclocking (i.e., executing the readout procedure once all of the actual columns of a row, or rows of a CCD, have already been read out) or serial registers (i.e., non-pixel charge "buckets" in the "pig tail" that conveys the charge from the CCD to the output amplifier). The collateral pixels are used to estimate the following effects: non-static readout bias (also known as "black") value; shutterless smear, the result of operating without a shutter and clocking the CCD data out over a finite time interval; and dark current, the charge which the CCD collects in the absence of incident photons. Standard collateral target pixel files (designated by "col" in the file name) are associated with data acquired at a 2-minute cadence. Fast collateral target pixel files (designated by "fast-col") are associated with data acquired at a 20-second cadence.

The full frame image collateral pixels are included in the accompanying FFI as additional rows and columns in the FFI image.

7.2 Composition

There are sixteen FITS files per CCD: one for each CCD output and for each of the four types of collateral data. The four types of data are:

1. Leading virtual Column (lvcol): Measures bias voltage or black level.

2. Trailing virtual Column (tvcol): Measures bias voltage or black level.
3. Smear row (smrow): Measures shutterless smear charge and dark current.
4. Virtual row (vrow): Measures shutterless smear charge and dark current during readout.

There are two extension HDUs per standard collateral pixel FITS file: one pixel data extension plus one cosmic ray extension that lists cosmic rays detected in the collateral data in the file. There are three extension HDUs per fast collateral pixel FITS file: one pixel data extension, one pixel list extension indicating the CCD row and column coordinates of the pixel data, and one cosmic ray extension that lists cosmic rays detected in the collateral data in the file. Figure 4 shows the organization of the HDUs within a standard collateral pixel data file and a fast collateral pixel data file.

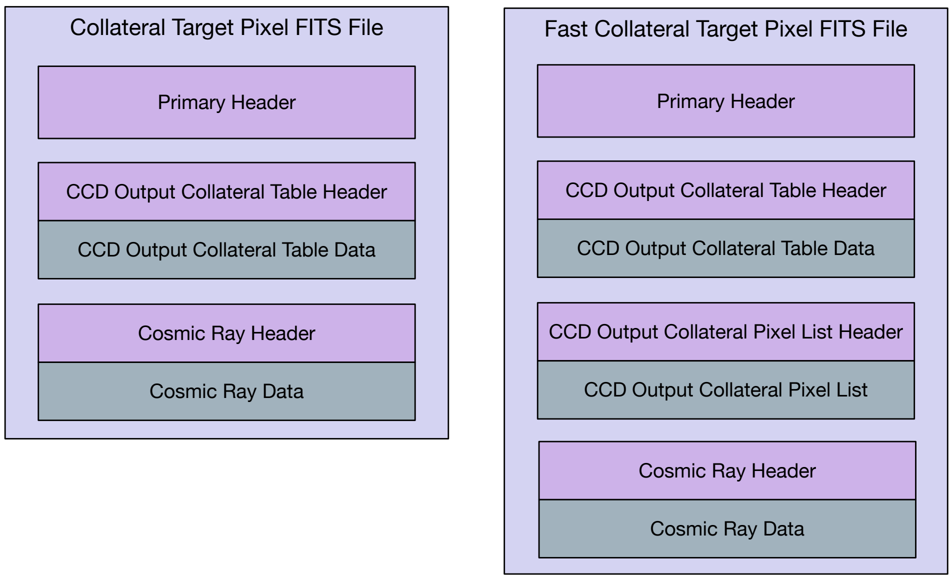

Figure 4: Standard (left) and fast (right) collateral target pixel FITS file composition

7.2.1 Primary header

This FITS HDU contains information about when the file was produced, what software produced it and other information. The primary data section is empty. Table 17 defines the primary header.

Header Card	Data Type	Example Value
`SIMPLE  = T          / conforms to FITS standards`	L1	const
`BITPIX  = 8          / array data type`	I4	const
`NAXIS   = 0          / number of array dimensions`	I4	const
`EXTEND  = T          / file contains extensions`	L1	const
`NEXTEND = 16         / number of standard extensions`	I4	const
`EXTNAME = 'PRIMARY  '/  name of extension`	C7	const
`EXTVER  = 1          / extension version number (not format version)`	I4	const
`SIMDATA =            / file is based on simulated data`	L1	F
`ORIGIN  = 'NASA/Ames'/ institution responsible for creating this file`	C9	const
`DATE    =            / file creation date.`	C10	2013-06-12
`TSTART  =            / observation start time in TJD`	R8	1207.27
`TSTOP   =            / observation stop time in TJD`	R8	1234.27
`DATE-OBS=            /  TSTART as UTC calendar date`	C24	2013-01-12T14:06:28.100
`DATE-END=            /  TSTOP as UTC calendar date`	C24	2013-04-08T11:17:10.783
`CREATOR =            / pipeline job and program used to pr`	C50	538746 CollateralPixelExporterPipelineModule
`PROCVER =            / SW version`	C50	spoc-5.0.2-20200714
`FILEVER =            / file format version`	R8	1.0
`TIMVERSN= 'OGIP/93-003' / OGIP memo number for file format`	C11	const

TELESCOP= 'TESS	'/ telescope	C4	const
INSTRUME= 'TESS Photometer'/	detector type	C15	const
CAMERA =	/ Camera number	I4	1
SECTOR =	/ Observing sector	I4	12
CCD =	/ CCD chip number	I4	2
CCD_OUT =	/ Output for this CCD	C1	A or B or C or D
COLLTRAL=	/ Collateral pixel type	C5	lvcol, tvcol, vrow, or smrow
DATA_REL=	/ version of data release notes for this file	I4	22
CRMITEN =	/ spacecraft cosmic ray mitigation enabled	L1	T
CRBLKSZ =	/ [exposures] s/c cosmic ray mitigation block size	I4	20
CRSPOC =	/ SPOC cosmic ray cleaning enabled	L1	T
CHECKSUM=	/ HDU checksum updated 2013-06-12T17:30:34Z	C16	CT18EQ15CQ15CQ15
END			

Table 17: Collateral pixel primary FITS header

7.2.2 Collateral pixel tables

This FITS HDU contains the uncalibrated pixels, and the "calibrated" collateral pixels. The calibrated pixels are the residual values after removing the estimate of the black values from them. There are keywords in the header to identify the mapping of CCD pixel coordinates to collateral pixels. See figure 5 for a pictorial representation of these different collateral regions. The binary table columns are collateral pixel images or arrays for each cadence. Leading rows or columns are closer to the CCD coordinate origin (at CCD row 1, column 1) than trailing rows or columns. Buffer rows are unmasked, physical CCD rows affected by electronic noise. They are not used for targets and not needed for calibration and so are not part of the collateral pixel file.

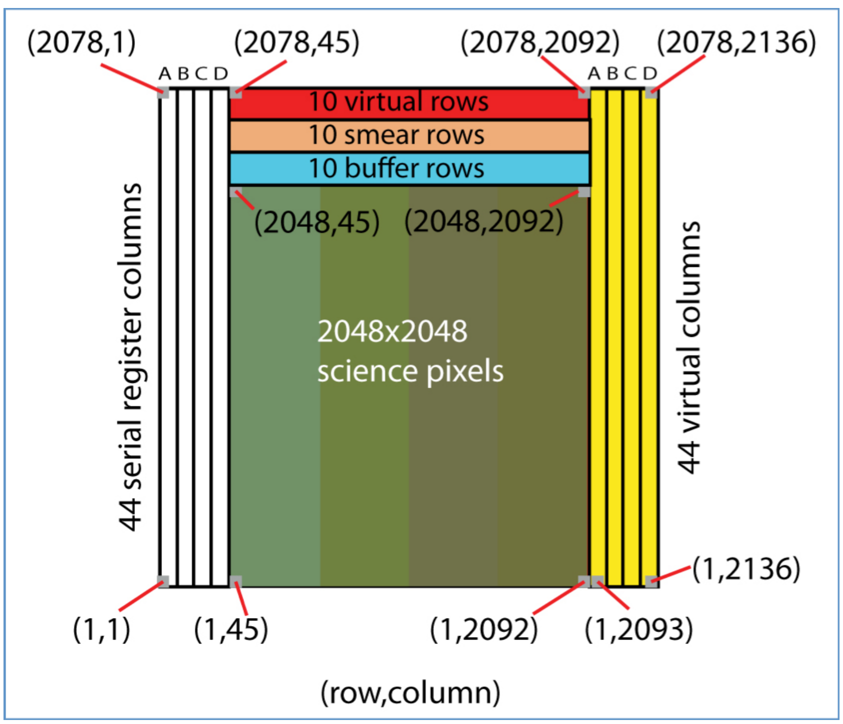

Figure 5: CCD Geometry. Not pictured are the outputs along the bottom row.

Table 18 is an enumeration of the collateral types used to designate the type of collateral being described in a FITS file or this document. Table 19 describes the columns that can be found in the binary table extension of the standard collateral pixel files. Table 20 defines the FITS headers for the binary table extension in each of these files. Table 21 describes the columns that can be found in the binary table extension of the fast collateral pixel files. Table 22 defines the FITS headers for the binary table extension in each of these files. Note that <CAMERA> and <CCD> can take on values in the set {1,2,3,4}, and that <CCD_OUT> can take on values in the set {A,B,C,D}.

Ordinal Value	Collateral Type	Mnemonic
0	Virtual rows	VROW
1	Smear rows	SMROW
2	Leading (serial register) virtual columns	LVCOL
3	Trailing virtual columns	TVCOL

Table 18: Collateral pixel types

Column Number	TYPE	FORM	UNIT	Description
1	TIME	64-bit float	days	TESS Julian Date.
2	CADENCENO	32-bit unsigned integer		timestamp count from start of mission
3	One of { VROW_RAW, SMROW_RAW, LVCOL_RAW, TVCOL_RAW }	image of 32-bit signed int	ADU	images of the uncalibrated collateral pixels
4	One of { VROW_CAL, SMROW_CAL, LVCOL_CAL, TVCOL_CAL}	image of 32-bit float	DN/sec (cols) or e^{-}/s (rows)	images of the calibrated collateral pixels
5	One of { VROW_ERR, SMROW_ERR, LVCOL_ERR, TVCOL_ERR}	image of 32-bit float	DN/sec (cols) or e^{-}/s (rows)	uncertainty of column 4

Table 19: Standard collateral target pixel FITS binary table columns

Header Card	Data Type	Example Value
XTENSION= 'BINTABLE '/ marks the beginning of a new HDU	C8	const
BITPIX = 8 / array data type	I4	const
NAXIS = 2 / number of array dimensions	I4	const
NAXIS1 = / length of first array dimension	I4	17132
NAXIS2 = / length of second array dimension	I4	4203
PCOUNT = 0 / group parameter count (not used)	I4	const
GCOUNT = 1 / group count (not used)	I4	const
EXTNAME = / name of extension	C11	'TVCOL_2_1_A'
EXTVER = 1 / extension version number (not format version)	I4	const
SIMDATA = / file is based on simulated data	L1	F
CAMERA = / Camera number	I4	1
SECTOR = / Observing sector	I4	12
CCD = / CCD number	I4	2
CCD_OUT = / Output for this CCD	C1	'C'
TIMESYS = 'TDB '/ time system is Barycentric Dynamical Time (TDB)	C3	const
TSTART = / observation start time in TJD	R8	1207.27
TSTOP = / observation stop time in TJD	R8	1234.27
JDREFI = 2457000 / integer part of BJD reference date	I4	const
JDREFF = 0.0 / fraction of the day in BJD reference date	R4	const
TFIELDS = 5 / number of table fields	I4	const
TTYPE1 = 'TIME '/ column title: data time stamps	C4	const
TFORM1 = 'D '/ column format: 64-bit floating point	C1	const
TUNIT1 = 'JD - 2457000, days'/ column units: TESS modified Julian date (TJD)	C15	const
TDISP1 = 'D14.7 '/ column display format	C5	const
TTYPE2 = 'CADENCENO'/ column title: unique cadence number	C9	const
TFORM2 = 'J '/ column format: signed 32-bit integer	C1	const
TDISP2 = 'I10 '/ column display format	C3	const

TTYPE3 =	/ column title: raw black counts	C9	'TVCOL_RAW'
TFORM3 =	/ column format: array of 32-bit signed integers	C5	'22858J'
TUNIT3 = 'count	'/ column units: digital numbers	C6	const
TDISP3 = 'I8	'/ column display format	C2	const
TDIM3 =	/ column dimensions: pixel aperture array	C8	(11,2078)
TNULL3 =	/ column null value indicator	C2	-1
TTYPE4 =	/ column title: black residuals	C9	'TVCOL_CAL'
TFORM4 =	/ column format: array of 32-bit floating point	C5	'22858E'
TUNIT4 = 'DN/sec	'/ column units: digital numbers per second	C6	const
TDISP4 = 'E14.7	'/ column display format	C5	const
TDIM4 =	/ column dimensions: pixel aperture array	C6	(11,2078)
TTYPE5 =	/ column title: 1-sigma residual uncertainty	C13	'TVCOL_ERR'
TFORM5 =	/ column format: array of 32-bit floating point	C5	'22858E'
TUNIT5 = 'DN/sec	'/ column units: digital numbers per sec	C6	const
TDISP5 = 'E14.7	'/ column display format	C5	const
TDIM5 =	/ column dimensions: pixel aperture array	C6	(11,2078)
INHERIT = T	/ inherit the primary header	L1	const
DEADC =	/ deadtime correction	R4	0.92063492
TIMEPIXR=	/ bin time beginning=0 middle=0.5 end=1	R8	0.5
TIERRELA=	/ [d] relative time error	R8	5.78E-07
INT_TIME=	/ [s] photon accumulation time per frame	R4	6.019802903270
READTIME=	/ [s] readout time per frame	R4	0.518948526144
FRAMETIM=	/ [s] frame time (INT_TIME + READTIME)	R4	6.538751429414
NUM_FRM =	/ number of frames per time stamp	I4	270
TIMEDEL =	/ [d] time resolution of data	R4	0.02043359821692
DATE-OBS=	/ TSTART as UTC calendar date	C24	2013-01-12T14:06:28.100
DATE-END=	/ TSTOP as UTC calendar date	C24	2013-04-08T11:17:10.783
BACKAPP = F	/ background is subtracted	L1	const
DEADAPP = T	/ deadtime applied	L1	const
VIGNAPP = F	/ vignetting or collimator correction applied	L1	const
GAIN<CCD_OUT> =	/ [electrons/count] CCD output <CCD_OUT> gain	R4	107.06
READNOI<CCD_OUT>=	/ [electrons] read noise CCD output <CCD_OUT>	R4	79.053104
TMOFST<CAMERA><CCD>	/ [s] readout delay for camera <CAMERA> and ccd <CCD>	R4	0.5
MEANBLC<CCD_OUT>=	/ [count] CCD output <CCD_OUT> mean black level	I4	749
NREADOUT=	/ number of reads per cadence	I4	270
FXDOFF =	/ compression fixed offset	I4	419400
LVCS<CCD_OUT>=	/ serial register col start, output <CCD_OUT>	I2	1
LVCE<CCD_OUT>=	/ serial register col end, (inclusive) output <CCD_OUT>	I2	1
SCCS<CCD_OUT>=	/ science col start, output <CCD_OUT>	I2	2
SCCE<CCD_OUT>=	/ science col end (inclusive), output <CCD_OUT>	I2	3
TVCS<CCD_OUT>=	/ trailing virtual col start, output <CCD_OUT>	I2	4
TVCE<CCD_OUT>=	/ trailing virtual col end (inc.), output <CCD_OUT>	I2	5
SCICOLH<CCD_OUT>=	/ T science cols are read increasing order else dec, output <CCD_OUT>	L1	T
SCIROWS =	/ science row start	I2	10
SCIROWE =	/ science row end (inclusive)	I2	11
VROWS =	/ virtual row start	I2	12
VROWE =	/ virtual row end (inclusive)	I2	13
SMROWS =	/ smear row start	I2	14
SMROWE =	/ smear row end (inclusive)	I2	15
BFROWS =	/ buffer row start	I2	16
BFROWE =	/ buffer row end (inclusive)	I2	17
CHECKSUM=	/ HDU checksum updated 2013-06-12T17:30:34	C16	9ITkGFSi9FSiEFSi
END			

Table 20: Standard collateral pixel binary table FITS header

Column Number	TYPE	FORM	UNIT	Description
1	TIME	64-bit float	days	TESS Julian Date.
2	CADENCENO	32-bit unsigned integer		timestamp count from start of mission
3	One of { VROW_RAW, SMROW_RAW, LVCOL_RAW, TVCOL_RAW }	array of 32-bit signed int	ADU	arrays of the uncalibrated collateral pixels (may be empty)
4	One of { VROW_CAL, SMROW_CAL, LVCOL_CAL, TVCOL_CAL}	array of 32-bit float	DN/sec (cols) or e^-/s (rows)	arrays of the calibrated collateral pixels (may be empty)
5	One of { VROW_ERR, SMROW_ERR, LVCOL_ERR, TVCOL_ERR}	array of 32-bit float	DN/sec (cols) or e^-/s (rows)	uncertainty of column 4 (may be empty)

Table 21: Fast collateral target pixel FITS binary table columns

Header Card	Data Type	Example Value
XTENSION= 'BINTABLE '/ marks the beginning of a new HDU	C8	const
BITPIX = 8 / array data type	I4	const
NAXIS = 2 / number of array dimensions	I4	const
NAXIS1 = / length of first array dimension	I4	12012
NAXIS2 = / length of second array dimension	I4	110000
PCOUNT = 0 / group parameter count (not used)	I4	const
GCOUNT = 1 / group count (not used)	I4	const
EXTNAME = / name of extension	C11	'TVCOL_2_1_A'
EXTVER = 1 / extension version number (not format version)	I4	const
SIMDATA = / file is based on simulated data	L1	F
CAMERA = / Camera number	I4	1
SECTOR = / Observing sector	I4	12
CCD = / CCD number	I4	2
CCD_OUT = / Output for this CCD	C1	'C'
TIMESYS = 'TDB '/ time system is Barycentric Dynamical Time (TDB)	C3	const
TSTART = / observation start time in TJD	R8	1207.27
TSTOP = / observation stop time in TJD	R8	1234.27
JDREFI = 2457000 / integer part of BJD reference date	I4	const
JDREFF = 0.0 / fraction of the day in BJD reference date	R4	const
TFIELDS = 5 / number of table fields	I4	const
TTYPE1 = 'TIME '/ column title: data time stamps	C4	const
TFORM1 = 'D '/ column format: 64-bit floating point	C1	const
TUNIT1 = 'JD - 2457000, days'/ column units: TESS modified Julian date (TJD)	C15	const
TDISP1 = 'D14.7 '/ column display format	C5	const
TTYPE2 = 'CADENCENO'/ column title: unique cadence number	C9	const
TFORM2 = 'J '/ column format: signed 32-bit integer	C1	const
TDISP2 = 'I10 '/ column display format	C3	const
TTYPE3 = / column title: raw black counts	C9	'TVCOL_RAW'
TFORM3 = / column format: array of 32-bit signed integers	C5	'1000J'
TUNIT3 = 'count '/ column units: digital numbers	C6	const
TDISP3 = 'I8 '/ column display format	C2	const
TDIM3 = / column dimensions: pixel aperture array	C8	(1000)

TNULL3 =	/ column null value indicator	C2	-1
TTYPE4 =	/ column title: black residuals	C9	'TVCOL_CAL'
TFORM4 =	/ column format: array of 32-bit floating point	C5	'1000E'
TUNIT4 = 'DN/sec	'/ column units: digital numbers per second	C6	const
TDISP4 = 'E14.7	'/ column display format	C5	const
TDIM4 =	/ column dimensions: pixel aperture array	C6	(1000)
TTYPE5 =	/ column title: 1-sigma residual uncertainty	C13	'TVCOL_ERR'
TFORM5 =	/ column format: array of 32-bit floating point	C5	'1000E'
TUNIT5 = 'DN/sec	'/ column units: digital numbers per sec	C6	const
TDISP5 = 'E14.7	'/ column display format	C5	const
TDIM5 =	/ column dimensions: pixel aperture array	C6	(1000)
INHERIT = T	/ inherit the primary header	L1	const
DEADC =	/ deadtime correction	R4	0.92063492
TIMEPIXR=	/ bin time beginning=0 middle=0.5 end=1	R8	0.5
TIERRELA=	/ [d] relative time error	R8	5.78E-07
INT_TIME=	/ [s] photon accumulation time per frame	R4	6.019802903270
READTIME=	/ [s] readout time per frame	R4	0.518948526144
FRAMETIM=	/ [s] frame time (INT_TIME + READTIME)	R4	6.538751429414
NUM_FRM =	/ number of frames per time stamp	I4	270
TIMEDEL =	/ [d] time resolution of data	R4	0.02043359821692
DATE-OBS=	/ TSTART as UTC calendar date	C24	2013-01-12T14:06:28.100
DATE-END=	/ TSTOP as UTC calendar date	C24	2013-04-08T11:17:10.783
BACKAPP = F	/ background is subtracted	L1	const
DEADAPP = T	/ deadtime applied	L1	const
VIGNAPP = F	/ vignetting or collimator correction applied	L1	const
GAIN<CCD_OUT> =	/ [electrons/count] CCD output <CCD_OUT> gain	R4	107.06
READNOI<CCD_OUT>=	/ [electrons] read noise CCD output <CCD_OUT>	R4	79.053104
TMOFST<CAMERA><CCD>	/ [s] readout delay for camera <CAMERA> and ccd <CCD>	R4	0.5
MEANBLC<CCD_OUT>=	/ [count] CCD output <CCD_OUT> mean black level	I4	749
NREADOUT=	/ number of reads per cadence	I4	270
FXDOFF =	/ compression fixed offset	I4	419400
LVCS<CCD_OUT>=	/ serial register col start, output <CCD_OUT>	I2	1
LVCE<CCD_OUT>=	/ serial register col end, (inclusive) output <CCD_OUT>	I2	1
SCCS<CCD_OUT>=	/ science col start, output <CCD_OUT>	I2	2
SCCE<CCD_OUT>=	/ science col end (inclusive), output <CCD_OUT>	I2	3
TVCS<CCD_OUT>=	/ trailing virtual col start, output <CCD_OUT>	I2	4
TVCE<CCD_OUT>=	/ trailing virtual col end (inc.), output <CCD_OUT>	I2	5
SCICOLH<CCD_OUT>=	/ T science cols are read increasing order	L1	T
	else dec, output <CCD_OUT>		
SCIROWS =	/ science row start	I2	10
SCIROWE =	/ science row end (inclusive)	I2	11
VROWS =	/ virtual row start	I2	12
VROWE =	/ virtual row end (inclusive)	I2	13
SMROWS =	/ smear row start	I2	14
SMROWE =	/ smear row end (inclusive)	I2	15
BFROWS =	/ buffer row start	I2	16
BFROWE =	/ buffer row end (inclusive)	I2	17
CHECKSUM=	/ HDU checksum updated 2013-06-12T17:30:34	C16	9ITkGFSi9FSiEFSi
END			

Table 22: Fast collateral pixel binary table FITS header (assuming 1000 TVCOL pixels)

7.2.3 Collateral pixel lists

Collateral pixels are acquired on an as-needed basis for fast (i.e., 20-second) target pixel data because the cadence interval is very short and the number of targets is relatively small. The fast collateral FITS file includes only those pixels of the specified collateral data type that are actually required to calibrate the fast target pixel data. The pixel list extension contains the CCD row and column coordinates of the pixels that are found in the collateral pixel binary table extension of this FITS file. Table 23 describes the columns that can be found in this HDU. Table 24 defines the FITS header. This HDU is empty when the given collateral pixel type has not been acquired.

Column Number	TYPE	FORM	UNIT	Description
1	PIXELCOL	16-bit signed integer	pixels	Pixel CCD column coordinate.
2	PIXELROW	16-bit signed integer	pixels	Pixel CCD row coordinate.

Table 23: Collateral pixel list FITS binary table columns

Header Card	Data Type	Example Value
XTENSION= 'BINTABLE '/ marks the beginning of a new HDU	C8	const
BITPIX = 8 / array data type	I4	const
NAXIS = 2 / number of array dimensions	I4	const
NAXIS1 = 4 / length of first array dimension	I4	const
NAXIS2 = / length of second array dimension	I4	1000
PCOUNT = 0 / group parameter count (not used)	I4	const
GCOUNT = 1 / group count (not used)	I4	const
TFIELDS = 2 / number of table fields	I4	const
TTYPE1 = 'PIXELCOL' / column title: CCD column	C8	const
TFORM1 = 'I '/ column format: signed 16-bit integer	C1	const
TUNIT1 = 'pixel '/ column units: pixels	C5	const
TDISP1 = 'I4 '/ column display format	C2	const
TTYPE2 = 'PIXELROW '/ column title: CCD row	C8	const
TFORM2 = 'I '/ column format: signed 16-bit integer	C1	const
TUNIT2 = 'pixel '/ column units: pixels	C5	const
TDISP2 = 'I4 '/ column display format	C2	const
INHERIT = T / inherit the primary header	L1	const
EXTNAME = / name of extension	C10	'TVCOLPIXELLIST_2_1_A'
EXTVER = 1 / extension version number (not format version)	I4	const
SIMDATA = / file is based on simulated data	L1	F
CHECKSUM= / HDU checksum updated 2016-06-14T21:10:51	C16	2016-06-14T21:10:51
END		

Table 24: Collateral pixel list binary table FITS header (assuming 1000 TVCOL pixels)

7.2.4 Collateral cosmic rays

This FITS binary table extension contains the cosmic ray corrections applied to all the CCD outputs in all the collateral types in the file. Table 25 describes the columns that can be found in this HDU. Table 26 defines the FITS header. This HDU is empty when SPOC cosmic ray mitigation has been disabled.

Column Number	TYPE	FORM	UNIT	Description
1	CADENCENO	32-bit signed integer		timestamp count since start of mission
2	RAWX	16-bit signed integer	pixels	Pixel CCD column coordinate.
3	RAWY	16-bit signed integer	pixels	Pixel CCD row coordinate.
4	COSMIC_RAY	32-bit single precision floating point	e^{-}/s	Correction applied to the calibrated collateral pixel.

Table 25: Collateral cosmic ray FITS binary table columns

Header Card	Data Type	Example Value
XTENSION= 'BINTABLE '/ marks the beginning of a new HDU	C8	const
BITPIX = 8 / array data type	I4	const
NAXIS = 2 / number of array dimensions	I4	const
NAXIS1 = 12 / length of first array dimension	I4	const
NAXIS2 = / length of second array dimension	I4	4203
PCOUNT = 0 / group parameter count (not used)	I4	const
GCOUNT = 1 / group count (not used)	I4	const
TFIELDS = 4 / number of table fields	I4	const
TTYPE1 = 'CADENCENO'/ column title: unique cadence number	C9	const
TFORM1 = 'J '/ column format: signed 32-bit integer	C1	const
TDISP1 = 'I10 '/ column display format	C3	const
TTYPE2 = 'RAWX' / column title: CCD column	C4	const
TFORM2 = 'I '/ column format: signed 16-bit integer	C1	const
UNIT2 = 'pixel '/ column units: pixels	C5	const
TDISP2 = 'I4 '/ column display format	C2	const
TTYPE3 = 'RAWY' / column title: CCD row	C4	const
TFORM3 = 'I '/ column format: signed 16-bit integer	C1	const
UNIT2 = 'pixel '/ column units: pixels	C5	const
TDISP3 = 'I4 '/ column display format	C2	const
TTYPE4 = 'COSMIC_RAY' / column title: cosmic ray correction	C10	const
TFORM4 = 'E '/ column format: 32-bit floating point	C1	const
UNIT2 = 'e-/sec '/ column units: electrons per second	C6	const
TDISP4 = 'E14.7 '/ column display format	C5	const
INHERIT = T / inherit the primary header	L1	const
EXTNAME = 'COSMIC_RAY'/ name of extension	C10	const
EXTVER = 1 / extension version number (not format version)	I4	const
SIMDATA = / file is based on simulated data	L1	F
END		

Table 26: Collateral cosmic ray binary table FITS header

8 Cotrending Basis Vectors

8.1 Purpose

The cotrending basis vectors (CBVs) represent the set of systematic trends present in the ensemble light curve data for each CCD. Specifically, these are the $\mathbf{U}$ matrix, aka the left singular vectors, of a singular value decomposition (SVD) performed on an ensemble of light curves. A light curve user may fit the CBVs to light curves to remove the common instrumental effects from the data when the Presearch Data Conditioning (PDC) light curve (see table 13) is insufficient for their target. Standard cotrending basis vector files (designated by "cbv" in the file name) are associated with data acquired at a 2-minute cadence. Fast cotrending basis vector files (designated by "fast-cbv") are associated with data acquired at a 20-second cadence.

The CBVs in the FITS files include one set of single-scale CBVs, one set of spike basis vectors, and two or more sets of multi-scale CBVs (one for each pass band). The number of multi-scale CBVs is parameterized, but fewer than the nominal three passbands may result in the event of orbits or sectors that are shorter than normal. The actual number of passbands will be determined during early science operations and may be different than three. During processing, PDC uses all these CBVs to generate two different versions of the systematic error-corrected light curve for each target and determines which version provides the best systematic error reduction, which is the version represented in the archival data. More information can be found in the chapter 8 of the Kepler Data Processing Handbook located at https://archive.stsci.edu/kepler/manuals/KSCI-19081-003-KDPH.pdf.

8.2 Composition

This file contains a primary header that describes basic file provenance information and two or more binary table extensions. Figure 6 shows the organization of the HDUs within the CBV file.

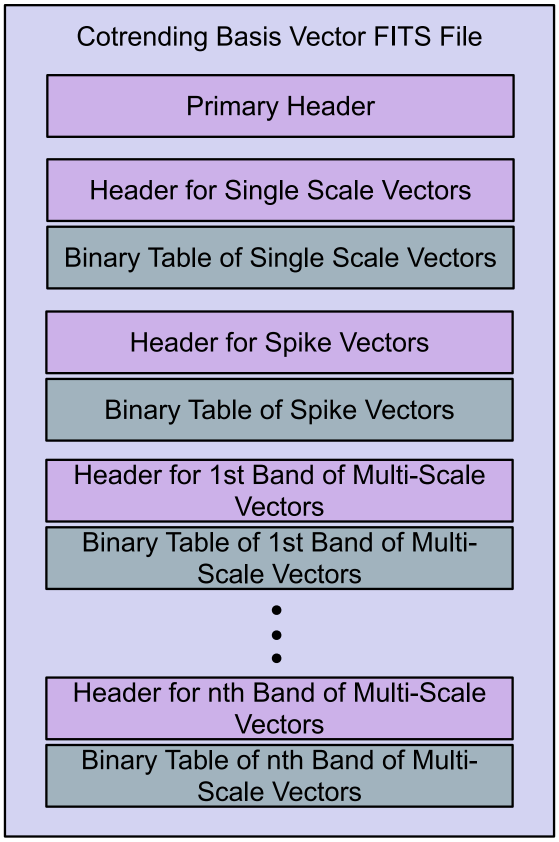

Figure 6: Cotrending basis vector FITS file composition

8.2.1 Primary header

The primary header only contains basic identifying information. Table 27 defines this header.

Header Card	Data Type	Example Value
SIMPLE = T / conforms to FITS standards	L1	const
BITPIX = 8 / array data type	I4	const
NAXIS = 0 / number of array dimensions	I4	const
EXTEND = T / file contains extensions	L1	const
NEXTEND = 5 / number of standard extensions	I4	const
EXTNAME = 'PRIMARY '/ name of extension	C7	const
SIMDATA = / file is based on simulated data	L1	F
EXTVER = 1 / extension version number (not format version)	I4	const
ORIGIN = 'NASA/Ames'/ institution responsible for creating this file	C9	const
DATE = / file creation date.	C10	2018-03-02
TSTART = / observation start time in TJD	R8	1207.27

TSTOP =	/ observation stop time in TJD	R8	1234.57
DATE-OBS=	/TSTART as UTC calendar date	C24	'2018-03-29T18:27:38.816'
DATE-END=	/TSTOP as UTC calendar date	C24	'2018-04-26T01:39:38.816'
CREATOR =	/ pipeline job and program used to	C50	111 CbvExporter
PROCVER =	/ SW version	C50	spoc-5.0.2-20200714
FILEVER =	/ file format version	R8	1.0
TIMVERSN =	/ OGIP memo number for file format	C11	'OGIP/93-003'
TELESCOP= 'TESS '	/ telescope	C6	const
INSTRUME= 'TESS Photometer'	/ detector type	C17	const
SECTOR =	/ Observing sector	I4	15
DATA_REL=	/ version of data release notes for this file	I4	20
CRMITEN =	/ spacecraft cosmic ray mitigation enabled	L1	T
CRBLKSZ =	/ [exposures] s/c cosmic ray mitigation block size	I4	20
CRSPOC =	/ SPOC cosmic ray cleaning enabled	L1	T
CHECKSUM=	/ HDU checksum updated 2014-01-03T17:48:30	C16	YaAkaa4kZa9kaa9k
END			

Table 27: Cotrending basis vector file primary FITS header

8.2.2 Binary Tables

This binary table HDUs contains the basis vectors themselves for each kind of basis vector. Note that the number of basis vectors stored in each HDU is variable except for the single-scale CBVs where there are always 16. Table 28 describes the columns that can be found in these tables. Tables 29, 30, and 31 defines the FITS headers for the single scale, spike and multiscale HDUs. Note that the structure of the binary tables are similar for all three kinds of basis vectors (though the multi-scale header has more information specific to how the band-splitting was accomplished) and that the EXTNAME keyword specifies which type of basis vector is stored in each HDU. EXTNAME has the form 'CBV.<type>.<camera>.<ccd>', where <type> is "single-scale", "spike", or "multiscale-band-<bandno>", and <bandno> is a positive integer. Examples include 'CBV.single-scale-1.2.1', 'CBV.spike.2.1', 'CBV.multiscale-band-1.2.1', 'CBV.multiscale-band-2.2.1'. and 'CBV.multiscale-band-3.2.1'. Note that the CBVVALID keyword is set to 0 in the event that there are no valid basis vectors for a particular HDU. In this case there is only one CBV column and all CBV table values are zero. CBVVALID is set to 1 when the CBVs are valid for this HDU.

Column Number	TYPE	FORM	UNIT	Description
1	TIME	64-bit float	days	TESS Julian Date.
2	CADENCENO	32-bit integer		timestamp count from start of mission
3	GAP	logical		When true a data processing gap occurred on this cadence.
$4 \ldots 4+(N-1)$	VECTOR_$1 \ldots N$	32-bit float		The N basis vectors for this kind of CBV.

Table 28: Cotrending basis vector table summary.

Header Card		Data Type	Example Value
XTENSION= 'BINTABLE '	/ marks the beginning of a new HDU	C8	const
BITPIX = 8	/ array data type	I4	const
NAXIS = 2	/ number of array dimensions	I4	const
NAXIS1 = 77	/ length of first array dimension	I4	const
NAXIS2 =	/ length of second array dimension	I4	4780
PCOUNT = 0	/ group parameter count (not used)	I4	const
GCOUNT = 1	/ group count (not used)	I4	const
TFIELDS = 19	/ number of table fields	I4	const
TTYPE1 = 'TIME '	/ column title: data time stamps	C4	const
TFORM1 = 'D '	/ column format: 64-bit floating point	C1	const
TUNIT1 = 'JD - 2457000, days'	/ column units: TESS modified Julian date (TJD)	C15	const
TDISP1 = 'D14.7 '	/ column display format	C5	const
TTYPE2 = 'CADENCENO'	/ column title: unique cadence number	C9	const
TFORM2 = 'J '	/ column format: signed 32-bit integer	C1	const

TDISP2 = 'I10 '/	column display format	C3	const
TTYPE3 = 'GAP ' /	column title: when true cadence was gapped	C7	const
TFORM3 = 'L '/	column format: 8-bit boolean value	C1	const
TDISP3 = 'L1 '/	column display format	C1	const
TTYPE4 = 'VECTOR_1 '/	column title: co-trending basis vector 1	C8	const
TFORM4 = 'E '/	column format: 32-bit floating point	C1	const
TDISP4 = 'F8.5 '/	column display format	C4	const
TTYPE5 = 'VECTOR_2 '/	column title: co-trending basis vector 2	C8	const
TFORM5 = 'E '/	column format: 32-bit floating point	C1	const
TDISP5 = 'F8.5 '/	column display format	C4	const
TTYPE6 = 'VECTOR_3 '/	column title: co-trending basis vector 3	C8	const
TFORM6 = 'E '/	column format: 32-bit floating point	C1	const
TDISP6 = 'F8.5 '/	column display format	C4	const
TTYPE7 = 'VECTOR_4 '/	column title: co-trending basis vector 4	C8	const
TFORM7 = 'E '/	column format: 32-bit floating point	C1	const
TDISP7 = 'F8.5 '/	column display format	C4	const
TTYPE8 = 'VECTOR_5 '/	column title: co-trending basis vector 5	C8	const
TFORM8 = 'E '/	column format: 32-bit floating point	C1	const
TDISP8 = 'F8.5 '/	column display format	C4	const
TTYPE9 = 'VECTOR_6 '/	column title: co-trending basis vector 6	C8	const
TFORM9 = 'E '/	column format: 32-bit floating point	C1	const
TDISP9 = 'F8.5 '/	column display format	C4	const
TTYPE10 = 'VECTOR_7 '/	column title: co-trending basis vector 7	C8	const
TFORM10 = 'E '/	column format: 32-bit floating point	C1	const
TDISP10 = 'F8.5 '/	column display format	C4	const
TTYPE11 = 'VECTOR_8 '/	column title: co-trending basis vector 8	C8	const
TFORM11 = 'E '/	column format: 32-bit floating point	C1	const
TDISP11 = 'F8.5 '/	column display format	C4	const
TTYPE12 = 'VECTOR_9 '/	column title: co-trending basis vector 9	C8	const
TFORM12 = 'E '/	column format: 32-bit floating point	C1	const
TDISP12 = 'F8.5 '/	column display format	C4	const
TTYPE13 = 'VECTOR_10'/	column title: co-trending basis vector 10	C9	const
TFORM13 = 'E '/	column format: 32-bit floating point	C1	const
TDISP13 = 'F8.5 '/	column display format	C4	const
TTYPE14 = 'VECTOR_11'/	column title: co-trending basis vector 11	C9	const
TFORM14 = 'E '/	column format: 32-bit floating point	C1	const
TDISP14 = 'F8.5 '/	column display format	C4	const
TTYPE15 = 'VECTOR_12'/	column title: co-trending basis vector 12	C9	const
TFORM15 = 'E '/	column format: 32-bit floating point	C1	const
TDISP15 = 'F8.5 '/	column display format	C4	const
TTYPE16 = 'VECTOR_13'/	column title: co-trending basis vector 13	C9	const
TFORM16 = 'E '/	column format: 32-bit floating point	C1	const
TDISP16 = 'F8.5 '/	column display format	C4	const
TTYPE17 = 'VECTOR_14'/	column title: co-trending basis vector 14	C9	const
TFORM17 = 'E '/	column format: 32-bit floating point	C1	const
TDISP17 = 'F8.5 '/	column display format	C4	const
TTYPE18 = 'VECTOR_15'/	column title: co-trending basis vector 15	C9	const
TFORM18 = 'E '/	column format: 32-bit floating point	C1	const
TDISP18 = 'F8.5 '/	column display format	C4	const
TTYPE19 = 'VECTOR_16'/	column title: co-trending basis vector 16	C9	const
TFORM19 = 'E '/	column format: 32-bit floating point	C1	const
TDISP19 = 'F8.5 '/	column display format	C4	const
INHERIT = T /	inherit the primary header	L1	const
EXTNAME = /	name of extension	C20	'CBV.single-scale.2.1'
EXTVER = 1 /	extension version number (not format version)	I4	const
SIMDATA = /	file is based on simulated data	L1	F
CBVVALID= /	nonzero if collateral basis vectors are valid	I4	0

CAMERA = / Camera number	I4	2
CCD = / CCD number	I4	2
TIMESYS = 'TDB '/ time system is Barycentric Dynamical Time (TDB)	C3	const
JDREFI = 2457000 / integer part of BJD reference date	I4	const
JDREFF = 0.0 / fraction of the day in BJD reference date	R4	const
TIMEUNIT= 'd '/ time unit for TIME, TSTART and TSTOP	C1	const
TELAPSE = / [d] TSTOP - TSTART	R8	85.88209984
TSTART = / observation start time in TJD	R8	1207.27
TSTOP = / observation stop time in TJD	R8	1234.27
DATE-OBS= /TSTART as UTC calendar date	C24	'2018-03-29T18:27:38.816'
DATE-END= /TSTOP as UTC calendar date	C24	'2018-04-26T01:39:38.816'
TIMEPIXR= / bin time beginning=0 middle=0.5 end=1	R8	0.5
TIERRELA= / [d] relative time error	R8	5.78E-07
MAPORDER= / order used for MAP fit	I4	0
BVVER = / basis vector software version	C9	'0.0.1 '
TMOFST<CAMERA><CCD> / [s] readout delay for camera <CAMERA> and ccd <CCD>	R4	0.5
CHECKSUM= / HDU checksum updated 2014-01-03T17:47:33	C16	TFFiTD9fTDEfTD9f
END		

Table 29: Single-scale cotrending basis vector FITS binary table header

Header Card	Data Type	Example Value
XTENSION= 'BINTABLE '/ marks the beginning of a new HDU	C8	const
BITPIX = 8 / array data type	I4	const
NAXIS = 2 / number of array dimensions	I4	const
NAXIS1 = 17 / length of first array dimension	I4	const
NAXIS2 = / length of second array dimension	I4	720
PCOUNT = 0 / group parameter count (not used)	I4	const
GCOUNT = 1 / group count (not used)	I4	const
TFIELDS = 4 / number of table fields	I4	const
TTYPE1 = 'TIME '/ column title: data time stamps	C4	const
TFORM1 = 'D '/ column format: 64-bit floating point	C1	const
TUNIT1 = 'JD - 2457000, days'/ column units: TESS modified Julian date (TJD)	C15	const
TDISP1 = 'D14.7 '/ column display format	C5	const
TTYPE2 = 'CADENCENO'/ column title: unique cadence number	C9	const
TFORM2 = 'J '/ column format: signed 32-bit integer	C1	const
TDISP2 = 'I10 '/ column display format	C3	const
TTYPE3 = 'GAP ' / column title: when true cadence was gapped	C7	const
TFORM3 = 'L '/ column format: 8-bit boolean value	C1	const
TDISP3 = 'L1 '/ column display format	C1	const
TTYPE4 = 'VECTOR_1 '/ column title: co-trending basis vector 1	C8	const
TFORM4 = 'E '/ column format: 32-bit floating point	C1	const
TDISP4 = 'F8.5 '/ column display format	C4	const
INHERIT = T / inherit the primary header	L1	const
EXTNAME = / name of extension	C13	'CBV.spike.2.1'
EXTVER = 1 / extension version number (not format version)	I4	const
SIMDATA = / file is based on simulated data	L1	F
CBVVALID= / nonzero if collateral basis vectors are valid	I4	0
CAMERA = / Camera number	I4	2
CCD = / CCD number	I4	1
TIMESYS = 'TDB '/ time system is Barycentric Dynamical Time (TDB)	C3	const
JDREFI = 2457000 / integer part of BJD reference date	I4	const
JDREFF = 0.0 / fraction of the day in BJD reference date	R4	const
TIMEUNIT= 'd '/ time unit for TIME, TSTART and TSTOP	C1	const
TELAPSE = / [d] TSTOP - TSTART	R8	27.3
TSTART = / observation start time in TJD	R8	1207.27

TSTOP = / observation stop time in TJD	R8	1234.57
DATE-OBS= /TSTART as UTC calendar date	C24	'2018-03-29T18:27:38.816'
DATE-END= /TSTOP as UTC calendar date	C24	'2018-04-26T01:39:38.816'
TIMEPIXR= / bin time beginning=0 middle=0.5 end=1	R8	0.5
TIERRELA= / [d] relative time error	R8	5.78E-07
MAPORDER= / order used for MAP fit	I4	0
BVVER = / basis vector software version	C9	'0.0.1 '
TMOFST<CAMERA><CCD> / [s] readout delay for camera <CAMERA> and ccd <CCD>	R4	0.5
CHECKSUM= / HDU checksum updated 2014-01-03T17:47:33	C16	CgKaEZKTCdKYCZKY
END		

Table 30: Spike cotrending basis vector FITS binary table header

Header Card	Data Type	Example Value
XTENSION= 'BINTABLE '/ marks the beginning of a new HDU	C8	const
BITPIX = 8 / array data type	I4	const
NAXIS = 2 / number of array dimensions	I4	const
NAXIS1 = / length of first array dimension	I4	17
NAXIS2 = / length of second array dimension	I4	720
PCOUNT = 0 / group parameter count (not used)	I4	const
GCOUNT = 1 / group count (not used)	I4	const
TFIELDS = 4 / number of table fields	I4	const
TTYPE1 = 'TIME '/ column title: data time stamps	C4	const
TFORM1 = 'D '/ column format: 64-bit floating point	C1	const
TUNIT1 = 'JD - 2457000, days'/ column units: TESS modified Julian date (TJD)	C15	const
TDISP1 = 'D14.7 '/ column display format	C5	const
TTYPE2 = 'CADENCENO'/ column title: unique cadence number	C9	const
TFORM2 = 'J '/ column format: signed 32-bit integer	C1	const
TDISP2 = 'I10 '/ column display format	C3	const
TTYPE3 = 'GAP ' / column title: when true cadence was gapped	C7	const
TFORM3 = 'L '/ column format: 8-bit boolean value	C1	const
TDISP3 = 'L1 '/ column display format	C1	const
TTYPE4 = 'VECTOR_1 '/ column title: co-trending basis vector 1	C8	const
TFORM4 = 'E '/ column format: 32-bit floating point	C1	const
TDISP4 = 'F8.5 '/ column display format	C4	const
INHERIT = T / inherit the primary header	L1	const
EXTNAME = / name of extension	C24	'CBV.multiscale-band-1.2.1'
EXTVER = 1 / extension version number (not format version)	I4	const
SIMDATA = / file is based on simulated data	L1	F
CBVVALID= / nonzero if collateral basis vectors are valid	I4	0
GRPMTHD = / multiscale grouping method	C8	'manual '
SPLTMTHD= / multiscale splitting method	C8	'wavelet '
WVLTTAPS= / number of wavelet taps	I4	12
WVLTFMLY= / wavelet family	C10	'daubechies'
BANDMAX = / maximum cadence grouping length in band	I4	1024
BANDMIN = / minimum cadence grouping length in band	I4	512
CAMERA = / Camera number	I4	2
CCD = / CCD number	I4	2
TIMESYS = 'TDB '/ time system is Barycentric Dynamical Time (TDB)	C3	const
JDREFI = 2457000 / integer part of BJD reference date	I4	const
JDREFF = 0.0 / fraction of the day in BJD reference date	R4	const
TIMEUNIT= 'd '/ time unit for TIME, TSTART and TSTOP	C1	const
TELAPSE = / [d] TSTOP - TSTART	R8	85.88209984
TSTART = / observation start time in TJD	R8	1207.27
TSTOP = / observation stop time in TJD	R8	1234.27
DATE-OBS= /TSTART as UTC calendar date	C24	'2018-03-29T18:27:38.816'

DATE-END=	/TSTOP as UTC calendar date	C24	'2018-04-26T01:39:38.816'
TIMEPIXR=	/ bin time beginning=0 middle=0.5 end=1	R8	0.5
TIERRELA=	/ [d] relative time error	R8	5.78E-07
MAPORDER=	/ order used for MAP fit	I4	0
BVVER =	/ basis vector software version	C9	'0.0.1 '
TMOFST<CAMERA><CCD>	/ [s] readout delay for camera <CAMERA> and ccd <CCD>	R4	0.5
CHECKSUM=	/ HDU checksum updated 2018-03-02T02:56:02	C16	9QGpEODn9ODnEODn
END			

Table 31: Multi-scale cotrending basis vector FITS binary table header

9 Data Quality Flags

Some files include an integer field or table column that describes any anomalies detected in the data for that cadence or image. These integers should be treated as individual bits that have the meanings described in table 32. Implementers should not assume this represents a comprehensive list of flags and that flags not defined here will be available for their use as it is very likely there will be changes to flag values after launch. Undefined bits will be set to zero.

Bit	Value	FFI	Description
1	1	Y	Attitude Tweak
2	2	N	Safe Mode
3	4	Y	Spacecraft is in Coarse Point
4	8	N	Spacecraft is in Earth Point
5	16	Y	Argabrightening event
6	32	Y	Reaction Wheel desaturation Event
7	64	N	Cosmic Ray in Optimal Aperture pixel
8	128	N	Manual Exclude. The cadence was excluded because of an anomaly.
9	256	N	Discontinuity corrected between this cadence and the following one.
10	512	N	Impulsive outlier removed before cotrending.
11	1024	Y	Cosmic ray detected on collateral pixel row or column.
12	2048	Y	Straylight from Earth or Moon in camera FOV (predicted).
13	4096	N	Scattered Light Exclude (spoc-4.0.5 and later).
14	8192	N	Planet Search Exclude (spoc-4.0.5 and later).
15	16384	Y	Bad Calibration Exclude (spoc-4.0.14 and later).
16	32768	N	Insufficient Targets for Error Correction Exclude (spoc-4.0.14 and later).

Table 32: Data quality bits

10 Data Validation Results

10.1 Data Validation Jargon

A Threshold Crossing Event (TCE) is a detection made by the Transiting Planet Search (TPS) algorithm. It represents a statistically significant periodic, transit-like dimming of the target star. The significance of the detection when folded at the detected orbital period is known as the multiple event statistic (MES). Data validation, a SPOC software component, is often referred to as DV. TPS and DV operate on light curves generated by Presearch Data Conditioning (PDC).

10.2 Purpose

Unlike the Kepler DV results files there is one results file per target per DV run. The timestamp on this file indicates the start of the spacecraft pointing associated with the first sector in the transit search. This way targets that happen to be present in multiple pointings can have all their TCE detections recorded in one file.

The DV Results file is a subset of the database stored after a run of DV. Minimally it will include the ephemeris for the TCEs detected around a target. It will include all the TCEs not just the initial TCE detected by TPS. The precise contents of this XML file are specified by a XML Schema definition file. The schema definition file can be used to validate the syntax of any DV results file. The schema is contained in appendix A.

10.3 Composition

The following is an example DV results file for a target that has one planet. Some repeated elements in the example have been truncated. Comments within the XML listing indicate where this has been done. Definitions of the fields in the listing follow.

```xml
<?xml version="1.0" encoding="UTF-8" standalone="yes"?>
<dv:dvTargetResults startCadence="101" endCadence="820" planetCandidateCount="2" pipelineTaskId="117" ticId="364512468" sectorsObserved="001" xmlns:dv="http://www.nasa.gov/2018/TESS/DV">
    <dv:decDegrees provenance="TIC6" value="-50.987933424179" uncertainty="0.0"/>
    <dv:effectiveTemp provenance="TIC6" value="6179.0" uncertainty="194.0"/>
    <dv:limbDarkeningModel modelName="claret_tess_nonlinear_limb_darkening_model" coefficient1="0.4704329" coefficient2="0.3157554" coefficient3="-0.15574454" coefficient4="-6.5638113E-4"/>
    <dv:log10Metallicity provenance="Solar" value="0.0" uncertainty="0.0"/>
    <dv:log10SurfaceGravity provenance="TIC6" value="4.27319" uncertainty="2.00574"/>
    <dv:planetResults detrendFilterLength="76" planetNumber="1">
        <dv:allTransitsFit type="ALL" fullConvergence="true" limbDarkeningModelName="claret_tess_nonlinear_limb_darkening_model" modelChiSquare="473.39288" modelDegreesOfFreedom="191.0" modelFitSnr="1.653213" planetNumber="1" transitModelName="mandel-agol_geometric_transit_model">
            <!-- Most entries deleted from dv:modelParameterCovariance for readability. -->
            <dv:modelParameterCovariance>1.2669299E-4 0.0 0.0 0.08688231 -2.3424514E-6 2.5282016 0.0 0.027153958 0.002767197 41.66609</dv:modelParameterCovariance>
            <dv:modelParameters>
                <dv:modelParameter fitted="true" name="transitEpochBtjd" uncertainty="0.011255798" value="1207.5791170461694"/>
                <dv:modelParameter fitted="false" name="eccentricity" uncertainty="0.0" value="0.0"/>
                <dv:modelParameter fitted="false" name="longitudeOfPeriDegrees" uncertainty="0.0" value="0.0"/>
                <dv:modelParameter fitted="false" name="planetRadiusEarthRadii" uncertainty="106.037796" value="6.53293878409677"/>
                <dv:modelParameter fitted="false" name="semiMajorAxisAu" uncertainty="0.0196784" value="0.011728746871713883"/>
                <dv:modelParameter fitted="true" name="minImpactParameter" uncertainty="3116.0989" value="0.011909914149503252"/>
                <dv:modelParameter fitted="false" name="starRadiusSolarRadii" uncertainty="1.31431" value="1.3143099546432495"/>
                <dv:modelParameter fitted="false" name="transitDurationHours" uncertainty="33.310787" value="0.5051468005541482"/>
                <dv:modelParameter fitted="false" name="transitIngressTimeHours" uncertainty="3.3992136" value="0.02215645378805354"/>
                <dv:modelParameter fitted="false" name="transitDepthPpm" uncertainty="50461.54" value="2380.4200067254274"/>
                <dv:modelParameter fitted="true" name="orbitalPeriodDays" uncertainty="0.01564944" value="0.4264339107334846"/>
                <dv:modelParameter fitted="true" name="ratioPlanetRadiusToStarRadius" uncertainty="0.73762316" value="0.04553111017642167"/>
                <dv:modelParameter fitted="true" name="ratioSemiMajorAxisToStarRadius" uncertainty="662.3717" value="6.769346077034497"/>
                <dv:modelParameter fitted="false" name="inclinationDegrees" uncertainty="26384.58" value="89.89919437425503"/>
                <dv:modelParameter fitted="false" name="equilibriumTempKelvin" uncertainty="2275.1946" value="2886.24503107337"/>
```

```xml
            <dv:modelParameter fitted="false" name="effectiveStellarFlux" uncertainty="51712.93" value="16400.375614891924"/>
            <dv:modelParameter fitted="false" name="starDensitySolarDensity" uncertainty="6727.5503" value="22.917817238722698"/>
        </dv:modelParameters>
    </dv:allTransitsFit>
    <dv:binaryDiscriminationResults>
        <dv:longerPeriodComparisonStatistic planetNumber="0" value="0.0" significance="-1.0"/>
        <dv:oddEvenTransitDepthComparisonStatistic value="3.0623512E-6" significance="0.99860376"/>
        <dv:shorterPeriodComparisonStatistic planetNumber="2" value="19.586588" significance="0.9999904"/>
    </dv:binaryDiscriminationResults>
    <dv:bootstrapResults bootstrapThresholdForDesiredPfa="1.0912158" mesMean="0.05600676" mesStd="0.7437549" significance="0.017413275449277902" transitCount="2.0">
        <dv:histogram>
            <!-- Most entries deleted from dv:statistics for readability. -->
            <dv:statistics>-8.0 -7.898734 -7.797468 -7.6962028 -7.594937 -7.493671 -7.392405 -7.291139 -7.189873 -7.088608 -6.987342</dv:statistics>
            <!-- Most entries deleted from dv:probabilities for readability. -->
            <dv:probabilities>0.0 0.0 0.0 0.0 0.0 2.2000748E-5 0.0 2.2000748E-5 4.4001496E-5 0.0 8.2502804E-5 7.150243E-5</dv:probabilities>
        </dv:histogram>
    </dv:bootstrapResults>
    <dv:centroidResults>
        <dv:differenceImageMotionResults>
            <dv:msTicCentroidOffsets>
                <dv:meanRaOffset value="6.162112" uncertainty="2.8933713"/>
                <dv:meanDecOffset value="-18.067911" uncertainty="4.089354"/>
                <dv:meanSkyOffset value="19.089815" uncertainty="3.9815378"/>
            </dv:msTicCentroidOffsets>
            <dv:msControlCentroidOffsets>
                <dv:meanRaOffset value="8.8529" uncertainty="2.89458"/>
                <dv:meanDecOffset value="-30.823315" uncertainty="4.0893598"/>
                <dv:meanSkyOffset value="32.06946" uncertainty="4.010858"/>
            </dv:msControlCentroidOffsets>
            <dv:summaryQualityMetric qualityThreshold="0.7" numberOfAttempts="1" numberOfMetrics="1" numberOfGoodMetrics="0" fractionOfGoodMetrics="0.0"/>
            <dv:summaryOverlapMetric imageCount="1" imageCountNoOverlap="1" imageCountFractionNoOverlap="1.0"/>
        </dv:differenceImageMotionResults>
    </dv:centroidResults>
    <dv:differenceImageResults numberOfCadenceGapsInTransit="0" numberOfCadenceGapsOutOfTransit="0" numberOfCadencesInTransit="12" numberOfCadencesOutOfTransit="39" numberOfTransits="1" overlappedTransits="false" endCadence="820" sector="2" startCadence="101" targetTableId="9">
        <dv:ccd ccdNumber="1" cameraNumber="2"/>
        <dv:controlCentroidOffsets>
            <dv:rowOffset value="-0.7200021" uncertainty="0.14505492"/>
            <dv:columnOffset value="1.4010327" uncertainty="0.24529545"/>
            <dv:focalPlaneOffset value="1.5752128" uncertainty="0.22386172"/>
            <dv:raOffset value="8.8529" uncertainty="2.7163565"/>
            <dv:decOffset value="-30.823315" uncertainty="3.9652066"/>
            <dv:skyOffset value="32.06946" uncertainty="4.221216"/>
        </dv:controlCentroidOffsets>
        <dv:controlImageCentroid>
```

```xml
                <dv:row value="186.6929" uncertainty="2.7297947E-4"/>
                <dv:column value="941.6705" uncertainty="3.5008762E-4"/>
                <dv:raDegrees value="161.30869177622978" uncertainty="1.890788E-6"/>
                <dv:decDegrees value="-50.9844477782978" uncertainty="1.9165964E-6"/>
            </dv:controlImageCentroid>
            <dv:differenceImageCentroid>
                <dv:row value="185.9729" uncertainty="0.14505467"/>
                <dv:column value="943.0715" uncertainty="0.2452952"/>
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                <dv:decDegrees value="-50.99300980988909" uncertainty="0.0011014446"/>
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            <dv:ticReferenceCentroid>
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            </dv:ticReferenceCentroid>
        </dv:differenceImageResults>
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            transitModelName="mandel-agol_geometric_transit_model">
            <!-- Most entries deleted from dv:modelParameterCovariance for readability. -->
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                -0.020206053 -0.00791647 -24.427214 0.0</dv:modelParameterCovariance>
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                <dv:modelParameter fitted="true" name="transitEpochBtjd" uncertainty="0.010946328
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                <dv:modelParameter fitted="false" name="starRadiusSolarRadii" uncertainty="1.31431" value="1.3143099546432495"/>
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        <dv:oddTransitsFit type="ODD" fullConvergence="true" limbDarkeningModelName="claret_tess_nonlinear_limb_darkening_model" modelChiSquare="486.72223" modelDegreesOfFreedom="188.0" modelFitSnr="1.172342" planetNumber="1" transitModelName="mandel-agol_geometric_transit_model">
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                <dv:modelParameter fitted="false" name="longitudeOfPeriDegrees" uncertainty="0.0" value="0.0"/>
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            <dv:modelParameter fitted="false" name="orbitalPeriodDays" uncertainty="0.0" value="0.4263888895511627"/>
            <dv:modelParameter fitted="true" name="ratioPlanetRadiusToStarRadius" uncertainty="1.3943931" value="0.045650177529544304"/>
            <dv:modelParameter fitted="true" name="ratioSemiMajorAxisToStarRadius" uncertainty="1271.6096" value="6.7962299801215025"/>
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    </dv:oddTransitsFit>
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        <dv:weakSecondary maxMes="0.5975002" maxMesPhaseInDays="-0.05729168" minMes="-0.8666473" mesMad="0.19417827" minMesPhaseInDays="0.21388884" medianMes="-0.010581793" nValidPhases="310" robustStatistic="0.14346346">
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                <dv:modelParameter fitted="true" name="transitDurationHours" uncertainty="-1.0" value="0.7844305024521372"/>
                <dv:modelParameter fitted="true" name="transitIngressTimeHours" uncertainty="-1.0" value="0.011126610021820514"/>
                <dv:modelParameter fitted="true" name="transitDepthPpm" uncertainty="-1.0" value="4002.8077530564015"/>
                <dv:modelParameter fitted="false" name="orbitalPeriodDays" uncertainty="-1.0" value="0.4263888895511627"/>
                <dv:modelParameter fitted="false" name="ratioPlanetRadiusToStarRadius" uncertainty="-1.0" value="0.06326774654637544"/>
                <dv:modelParameter fitted="false" name="ratioSemiMajorAxisToStarRadius" uncertainty="-1.0" value="4.439582546068219"/>
                <dv:modelParameter fitted="false" name="inclinationDegrees" uncertainty="-1.0" value="0.0"/>
                <dv:modelParameter fitted="false" name="equilibriumTempKelvin" uncertainty="-1.0" value="0.0"/>
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            <dv:modelParameterCovariance>1.19786586E-4 0.0 0.0 0.013492465 -1.4540136E-6 0.29487288 0.0 0.0030850167 5.841647E-4 2.8853765</dv:modelParameterCovariance>
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                <dv:modelParameter fitted="false" name="longitudeOfPeriDegrees" uncertainty="0.0" value="0.0"/>
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    </dv:bootstrapResults>
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            <dv:msControlCentroidOffsets>
                <dv:meanRaOffset value="14.335471" uncertainty="4.605982"/>
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            </dv:differenceImageMotionResults>
        </dv:centroidResults>
        <dv:differenceImageResults numberOfCadenceGapsInTransit="0" numberOfCadenceGapsOutOfTransit="0" numberOfCadencesInTransit="22" numberOfCadencesOutOfTransit="76" numberOfTransits="2" overlappedTransits="false" endCadence="820" sector="2" startCadence="101" targetTableId="9">
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            <dv:controlCentroidOffsets>
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                <dv:columnOffset value="1.3274885" uncertainty="0.35679728"/>
                <dv:focalPlaneOffset value="1.3515201" uncertainty="0.3553244"/>
                <dv:raOffset value="14.335471" uncertainty="4.496117"/>
                <dv:decOffset value="-23.285799" uncertainty="7.1724205"/>
                <dv:skyOffset value="27.344728" uncertainty="6.6616125"/>
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            <dv:controlImageCentroid>
                <dv:row value="186.69989" uncertainty="1.9516576E-4"/>
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                <dv:raOffset value="11.813379" uncertainty="4.494815"/>
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                <dv:skyOffset value="15.699501" uncertainty="5.9529595"/>
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                <dv:raDegrees value="161.30987886619914" uncertainty="0.0"/>
                <dv:decDegrees value="-50.98799094573222" uncertainty="0.0"/>
            </dv:ticReferenceCentroid>
        </dv:differenceImageResults>
        <dv:evenTransitsFit type="EVEN" fullConvergence="true" limbDarkeningModelName="claret_tess_nonlinear_limb_darkening_model" modelChiSquare="469.87305" modelDegreesOfFreedom="264.0" modelFitSnr="1.5311277" planetNumber="2" transitModelName="mandel-agol_geometric_transit_model">
            <!-- Most entries deleted from dv:modelParameterCovariance for readability. -->
            <dv:modelParameterCovariance>2.8186225E-4 0.0 0.0 2.0836384 0.0 22.782465 0.0 0.21160989 0.09061734 227.95268 0.0 0.014521852</dv:modelParameterCovariance>
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                <dv:modelParameter fitted="false" name="eccentricity" uncertainty="0.0" value="0.0"/>
                <dv:modelParameter fitted="false" name="longitudeOfPeriDegrees" uncertainty="0.0" value="0.0"/>
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                <dv:modelParameter fitted="false" name="semiMajorAxisAu" uncertainty="0.015383411" value="0.009169815933739762"/>
                <dv:modelParameter fitted="true" name="minImpactParameter" uncertainty="1669.9384" value="0.07807143050883503"/>
                <dv:modelParameter fitted="false" name="starRadiusSolarRadii" uncertainty="1.31431" value="1.3143099546432495"/>
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                <dv:modelParameter fitted="false" name="transitDepthPpm" uncertainty="16986.988" value="2245.484901477024"/>
                <dv:modelParameter fitted="false" name="orbitalPeriodDays" uncertainty="0.0" value="0.2947916922469929"/>
                <dv:modelParameter fitted="true" name="ratioPlanetRadiusToStarRadius" uncertainty="1.0649968" value="0.044243996194932"/>
                <dv:modelParameter fitted="true" name="ratioSemiMajorAxisToStarRadius" uncertainty="676.6383" value="4.711059300710369"/>
                <dv:modelParameter fitted="false" name="inclinationDegrees" uncertainty="20448.926" value="89.05045384652945"/>
                <dv:modelParameter fitted="false" name="equilibriumTempKelvin" uncertainty="2572.834" value="3264.214547302249"/>
                <dv:modelParameter fitted="false" name="effectiveStellarFlux" uncertainty="84591.91" value="26830.933658975504"/>
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        </dv:evenTransitsFit>
        <dv:ghostDiagnosticResults>
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        </dv:ghostDiagnosticResults>
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```xml
        <dv:oddTransitsFit type="ODD" fullConvergence="true" limbDarkeningModelName="claret_tess_nonlinear_limb_darkening_model" modelChiSquare="469.87305" modelDegreesOfFreedom="264.0" modelFitSnr="1.1199957" planetNumber="2" transitModelName="mandel-agol_geometric_transit_model">
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                <dv:modelParameter fitted="false" name="semiMajorAxisAu" uncertainty="0.015384539" value="0.009169846634548035"/>
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                <dv:modelParameter fitted="true" name="ratioSemiMajorAxisToStarRadius" uncertainty="417.06912" value="4.72252468266268"/>
                <dv:modelParameter fitted="false" name="inclinationDegrees" uncertainty="11585.547" value="88.84592637405876"/>
                <dv:modelParameter fitted="false" name="equilibriumTempKelvin" uncertainty="2573.0334" value="3264.209082973736"/>
                <dv:modelParameter fitted="false" name="effectiveStellarFlux" uncertainty="84598.05" value="26830.753998397977"/>
                <dv:modelParameter fitted="false" name="starDensitySolarDensity" uncertainty="4313.6797" value="16.28262543106333"/>
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            </dv:weakSecondary>
```

```
        </dv:planetCandidate>
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        </dv:secondaryEventResults>
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            planetNumber="2" transitModelName="trapezoidal_model">
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            <dv:modelParameters>
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                <dv:modelParameter fitted="false" name="orbitalPeriodDays" uncertainty="-1.0" value="0.2947916922469929"/>
                <dv:modelParameter fitted="false" name="ratioPlanetRadiusToStarRadius" uncertainty="-1.0" value="0.07747115280573284"/>
                <dv:modelParameter fitted="false" name="ratioSemiMajorAxisToStarRadius" uncertainty="-1.0" value="2.359601819727165"/>
                <dv:modelParameter fitted="false" name="inclinationDegrees" uncertainty="-1.0" value="0.0"/>
                <dv:modelParameter fitted="false" name="equilibriumTempKelvin" uncertainty="-1.0" value="0.0"/>
                <dv:modelParameter fitted="false" name="effectiveStellarFlux" uncertainty="-1.0" value="0.0"/>
                <dv:modelParameter fitted="false" name="starDensitySolarDensity" uncertainty="-1.0" value="0.0"/>
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```

```
    <dv:radius provenance="TIC6" value="1.31431" uncertainty="1.31431"/>
    <dv:stellarDensity provenance="TIC6-Derived" value="0.5205854" uncertainty="2.4599795"/>
    <dv:tessMag provenance="TIC6" value="12.429" uncertainty="0.018"/>
</dv:dvTargetResults>
```

10.4 Dictionary

The contents of the DV results file are defined hierarchically in the following tables. Table 33 describes the top level XML element dvTargetResults. These field definitions do not make the distinction between XML attributes which can appear in any order and XML elements which usually have a defined order. The proper ordering of these elements are defined in the XML schema document in appendix A.

Name	Definition	Units
startCadence	Number of first cadence for DV unit of work.	
endCadence	Number of last cadence for DV unit of work.	
planetCandidateCount	The number of planetResults to expect in this file.	
ticId	TESS Input Catalog ID of DV target.	
toiId	This attribute will be present if this target matched a star on the TESS Objects of Interest catalog (TOI).	
matchedToi	One or more of these elements will be present if there were TCE ephemerides that matched known exoplanet ephemerides.	
unmatchedToi	One or more of these elements will be present if there are exoplanet ephemerides present for the target star that were not detected or their ephemeris did not match the detected ephemeris.	
sectorsObserved	String with '1' if target was observed in given sector and '0' if target was not observed. Sector 0 is first element in string.	
pipelineTaskId	ID of DV pipeline task in which target was processed.	
tessMag	Catalog Magnitude for DV target with value, uncertainty and parameter provenance string.	
raDegrees	Catalog Right Ascension of DV target with value, uncertainty and parameter provenance string.	degrees (J2000)
pmRa	Catalog Proper Motion in Right Ascension of DV target with value, uncertainty and parameter provenance string.	millarcseconds per year
decDegrees	Catalog Declination of DV target with value, uncertainty and parameter provenance string.	degrees (J2000)
pmDec	Catalog Proper Motion in Declination of DV target with value, uncertainty and parameter provenance string.	millarcseconds per year
radius	Catalog Radius of DV target with value, uncertainty and parameter provenance string. Optional.	Solar radii
effectiveTemp	Catalog Effective Temperature of DV target with value, uncertainty and parameter provenance string. Optional.	Kelvin
log10SurfaceGravity	Catalog Log (Surface Gravity) of DV target with value, uncertainty and parameter provenance string. Optional.	cm/sec/sec
log10Metallicity	Catalog Metallicity [M/H] of DV target with value, uncertainty and parameter provenance string. Optional.	dex
stellarDensity	Mean stellar density of DV target with value, uncertainty and parameter provenance string. Derived from catalog radius and surface gravity. Optional.	Solar density
limbDarkeningModel	Limb-darkening model name and coefficients. See Table 34.	
planetResults	A set of results per planet. See table 35.	

Table 33: DV results – dvTargetResults

Name	Definition	Units
modelName	String with limb-darkening model name.	
coefficient1	Limb-darkening coefficient c1 (see Claret 2000, Mandel-Agol 2002, Claret-Bloemen 2011).	
coefficient2	Limb-darkening coefficient c2 (see Claret 2000, Mandel-Agol 2002, Claret-Bloemen 2011).	
coefficient3	Limb-darkening coefficient c3 (see Claret 2000, Mandel-Agol 2002, Claret-Bloemen 2011).	
coefficient4	Limb-darkening coefficient c4 (see Claret 2000, Mandel-Agol 2002, Claret-Bloemen 2011).	

Table 34: DV results – limbDarkeningModel

Name	Definition	Units
planetNumber	Index of planet in DV results for given target.	
toiId	This will have exoplanet catalog name if this planetResults's ephemeris was matched against a known exoplanet.	
toiCorrelation	This attribute will have a non-negative value if the planetResult was matched against the ephemeris of a known exoplanet. This is pearson's correlation coefficient.	
detrendFilterLength	The length of the median detrend filter window.	cadences
planetCandidate	Transiting planet search TCE details, statistical bootstrap results, and secondary event results. See Table 36.	
allTransitsFit	Results for limb-darkened transiting planet model fit to all transits for given planet. See Table 38.	
oddTransitsFit	Results for limb-darkened transiting planet model fit to odd transits for given planet. See Table 38.	
evenTransitsFit	Results for limb-darkened transiting planet model fit to even transits for given planet. See Table 38.	
trapezoidalFit	Results for trapezoidal model fit to all transits for given planet. See Table 38.	
reducedParameterFits	Results for limb-darkened transiting planet model fits to all transits for given planet for series of fixed impact parameters. See Table 38.	
binaryDiscriminationResults	Eclipsing binary discrimination test results for given planet. See Table 40.	
bootstrapResults	Statistical bootstrap results for given planet. See Table 41.	
centroidResults	Difference image centroid offset results for given planet. See Table 42.	
differenceImageResults	Results of difference image analysis by sector for given planet. See Table 47.	
ghostDiagnosticResults	Optical ghost diagnostic test results for given planet. See Table 51.	
secondaryEventResults	Secondary event model results for given planet. See Table 52.	

Table 35: DV results – planetResults

Name	Definition	Units
planetNumber	Index of planet in DV results for given target.	
orbitalPeriodInDays	Period of TCE as determined in transiting planet search.	days
epochTjd	Epoch of first transit of TCE as determined in transiting planet search.	TJD (TDB)
trialTransitPulseDurationInHours	Duration of transit pulse employed in transiting planet search to produce TCE.	hours
maxSingleEventSigma	Maximum single event detection statistic at TCE pulse duration.	
maxMultipleEventSigma	Maximum multiple event detection statistic at TCE period and pulse duration. Point estimate of transit SNR.	
maxSesInMes	Maximum single event detection statistic of those combined to form maximum multiple event statistic.	
robustStatistic	Robust detection statistic at TCE period, epoch and pulse duration.	
chiSquare2	Chi-square2 veto statistic (see Seader 2013).	
chiSquareDof2	Degrees of freedom for Chi-square2 veto statistic (see Seader 2013).	
chiSquareGof	Goodness of fit for the chiSquare2.	
chiSquareGofDof	Degrees of freedom for chiSquareGof.	
expectedTransitCount	Number of transits that would have been observed with complete coverage.	
observedTransitCount	Number of transits that were observed.	
suspectedEclipsingBinary	Boolean; true if source of TCE was suspected to be an eclipsing binary (based on transit depth). Limb-darkened model fits are not performed in this case.	
weakSecondary	Detection statistics and secondary event fit results at TCE period and duration computed in absence of primary transits. See Table 37.	
thresholdForDesiredPfa	Transit detection threshold that would have been required to achieve the desired false alarm probability based on the TPS bootstrap. Invalid if value = -1.	
modelChiSquare2	Like chiSquare2, but for the model light curve.	
modelChiSquareDof2	The degrees of freedom for modelChiSquare2.	
modelChiSquareGof	Like chiSquareGof, but for the model light curve.	
modelChiSquareGofDof	The degrees of freedom of the modelChiSquareGof.	

Table 36: DV results – planetCandidate

Name	Definition	Units
maxMesPhaseInDays	Phase of maximum multiple event statistic at period and duration of TCE computed in absence of primary transits. Invalid if mesMad = -1.	days
maxMes	Maximum multiple event detection statistic at period and duration of TCE computed in absence of primary transits. Invalid if mesMad = -1.	
minMesPhaseInDays	Phase of minimum (typically negative) multiple event statistic at period and duration of TCE computed in absence of primary transits. Invalid if mesMad = -1.	days
minMes	Minimum (typically negative) multiple event detection statistic at period and duration of TCE computed in absence of primary transits. Invalid if mesMad = -1.	
medianMes	Median of the multiple event detection statistic at period and duration of TCE computed in absence of primary transits. Invalid if mesMad = -1.	
mesMad	Median absolute deviation of multiple event detection statistics at period and duration of TCE computed in absence of primary transits. Invalid if mesMad = -1.	
depthPpm	Value and uncertainty of fitted depth of secondary event with maximum multiple event detection statistic. Invalid if uncertainty = -1.	ppm
robustStatistic	Robust detection statistic at period and duration of TCE computed in absence of primary transits. Invalid if mesMad = -1.	

Table 37: DV results – weakSecondary

Name	Definition	Units
planetNumber	Index of planet in DV results for given target.	
transitModelName	String with transiting planet model name. Optional.	
limbDarkeningModelName	String with limb-darkening model name.	
type	String with transit fit type. One of: { ALL, ODD, EVEN, REDUCED_PARAMETER, TRAPEZOIDAL }.	
fullConvergence	Boolean; true if full convergence was achieved.	
modelChiSquare	Chi-square for model fit (typically robust). Invalid if modelChiSquare = -1.	
modelDegreesOfFreedom	Number of degrees of freedom for model fit. Invalid if modelChiSquare = -1.	
modelFitSnr	Signal/noise ratio for model fit. Invalid if modelChiSquare = -1.	
modelParameters	List of fitted and derived model parameters. Each parameter includes name, value, uncertainty, and a Boolean flag indicating whether the parameter was fitted (or derived). See Table 39.	
modelParameterCovariance	Covariance matrix for fitted and derived parameters. Displayed as 1-dimensional vector in column major order. Empty for trapezoidal fit which does not produce uncertainties.	

Table 38: DV results – allTransitsFit / oddTransitsFit / evenTransitsFit / trapezoidalFit / reducedParameterFits

Name	Definition	Units
transitEpochBtjd	Barycentric corrected epoch of first transit.	BTJD (TDB)
eccentricity	Orbital eccentricity.	
longitudeOfPeriDegrees	Orbital longitude of periapse.	degrees
planetRadiusEarthRadii	Planet radius.	Earth radii
semiMajorAxisAu	Orbital semi-major axis.	AU
minImpactParameter	Orbital minimum impact parameter.	
starRadiusSolarRadii	Target radius.	Solar radii
transitDurationHours	Duration of transit.	hours
transitIngressTimeHours	Ingress time duration of transit.	hours
transitDepthPpm	Depth of transit.	ppm
orbitalPeriodDays	Period of orbit.	days
ratioPlanetRadiusToStarRadius	Reduced radius.	
ratioSemiMajorAxisToStarRadius	Reduced semi-major axis.	
inclinationDegrees	Orbital inclination angle.	degrees
equilibriumTempKelvin	Planet equilibrium temperature.	Kelvin
effectiveStellarFlux	Insolation relative to top of Earth's atmosphere.	
starDensitySolarDensity	Mean stellar density derived from transit model fit.	Solar density

Table 39: DV results – modelParameters

Name	Definition	Units
shorterPeriodComparisonStatistic	Value and significance of statistic comparing period of planet against planet on same target with next shorter period (where applicable). Significance is computed assuming that statistic is drawn from Chi-squared distribution with one degree of freedom. Invalid if significance = -1.	
longerPeriodComparisonStatistic	Value and significance of statistic comparing period of planet against planet on same target with next longer period (where applicable). Significance is computed assuming that statistic is drawn from Chi-squared distribution with one degree of freedom. Invalid if significance = -1.	
oddEvenDepthComparisonStatistic	Value and significance of statistic comparing depth of fit to odd transits against depth of fit to even transits. Significance is computed assuming that statistic is drawn from Chi-squared distribution with one degree of freedom. Invalid if significance = -1.	

Table 40: DV results – binaryDiscriminationResults

Name	Definition	Units
transitCount	Number of transits employed for bootstrap computation.	
significance	Bootstrap probability of false alarm based on null event statistics and observed number of transits. Invalid if significance = -1.	
histogram	Multiple event statistics and probabilities of occurrence for the associated statistics computed by bootstrap.	
	See Jenkins 2015 appendix A.	
bootstrapThresholdForDesiredPfa	The threshold on the bootstrap distribution that would provide the same false alarm probability as the transit detection threshold on a standard normal distribution.	
mesMean	The mean of the multiple event statistic distribution computed by the bootstrap.	
mesStd	The standard deviation of the multiple event statistic distribution computed by the bootstrap.	

Table 41: DV results – bootstrapResults

Name	Definition	Units
differenceImageMotionResults	Difference image centroid offset results for given planet. See Table 43.	

Table 42: DV results – centroidResults

Name	Definition	Units
msTicCentroidOffsets	Robust mean (over sectors where possible) offsets of difference image centroids with respect to catalog coordinates of target. See Table 44.	
msControlCentroidOffsets	Robust mean (over sectors where possible) offsets of difference image centroids with respect to out-of-transit image centroids. See Table 44.	
summaryQualityMetric	Summary of quality of difference images for the given planet. See Table 45.	
summaryOverlapMetric	Summary of difference images based on overlap between transits of the given planet and transits of other planets on the same target. See Table 46.	

Table 43: DV results – differenceImageMotionResults

Name	Definition	Units
meanRaOffset	Value and uncertainty of robust mean difference image centroid offset in Right Ascension. Invalid if uncertainty = -1.	arcseconds
meanDecOffset	Value and uncertainty of robust mean difference image centroid offset in Declination. Invalid if uncertainty = -1.	arcseconds
meanSkyOffset	Value and uncertainty of magnitude of robust mean difference image centroid offset on sky. Invalid if uncertainty = -1.	arcseconds

Table 44: DV results – msTicCentroidOffsets / msControlCentroidOffsets

Name	Definition	Units
numberOfAttempts	Number of difference images for which PRF-based centroiding was attempted. Invalid if fractionOfGoodMetrics = -1.	
numberOfMetrics	Number of difference images for which PRF-based centroids and quality metrics were successfully computed. Invalid if fractionOfGoodMetrics = -1.	
numberOfGoodMetrics	Number of difference image quality metrics which exceeded the specified quality threshold. Invalid if fractionOfGoodMetrics = -1.	
fractionOfGoodMetrics	Fraction of difference image quality metrics that exceeded the specified quality threshold. Invalid if fractionOfGoodMetrics = -1.	
qualityThreshold	Threshold for establishing good quality difference images. Quality metric correlates each difference image against PRF evaluated at the location of difference image centroid.	

Table 45: DV results – summaryQualityMetric

Name	Definition	Units
imageCount	Number of per sector difference images.	
imageCountNoOverlap	Number of difference images for which transits of given planet do not overlap transits of other planets on the same target.	
imageCountFractionNoOverlap	Fraction of difference images for which transits of given planet do not overlap transits of other planets on the same target. Invalid if imageCountFractionNoOverlap = -1.	

Table 46: DV results – summaryOverlapMetric

Name	Definition	Units
sector	Sector index for which difference imaging has been performed.	
targetTableId	ID of target pixel table for which difference imaging has been performed.	
startCadence	Number of first cadence that target pixel table was in effect.	
endCadence	Number of last cadence that target pixel table was in effect.	
ccd	The camera number and ccd number for the target in given sector.	
ticReferenceCentroid	Catalog position of target in CCD and celestial coordinates. See Table 48.	
controlImageCentroid	Out-of-transit image PRF centroid in CCD and celestial coordinates. See Table 48.	
differenceImageCentroid	Difference image PRF centroid in CCD and celestial coordinates. See Table 48.	
ticCentroidOffsets	Offsets of difference image PRF centroid with respect to catalog position of target for given sector. See Table 49.	
controlCentroidOffsets	Offsets of difference image PRF centroid with respect to out-of-transit image PRF centroid for given sector. See Table 49.	
numberOfTransits	Number of observed transits in given sector.	
numberOfCadencesInTransit	Number of in-transit cadences from which difference image was constructed.	
numberOfCadenceGapsInTransit	Number of missing in-transit cadences that would have been employed in constructing difference image.	
numberOfCadencesOutOfTransit	Number of out-of-transit cadences from which out-of-transit and difference images were constructed.	
numberOfCadenceGapsOutOfTransit	Number of missing out-of-transit cadences that would have been employed in constructing out-of-transit and difference images.	
qualityMetric	Value of difference image quality metric, and Boolean flags indicating whether there was an attempt to compute the PRF-based centroid and whether the metric is valid.	
differenceImagePixelData	Difference imaging results by pixel. See Table 50.	
overlappedTransits	Flag indicating if transits of other planets on the same target overlapped the transits used for difference imaging.	

Table 47: DV results – differenceImageResults

Name	Definition	Units
row	Value and uncertainty of CCD row coordinate of centroid. Invalid if uncertainty = -1.	
column	Value and uncertainty of CCD column coordinate of centroid. Invalid if uncertainty = -1.	
raDegrees	Value and uncertainty of Right Ascension coordinate of centroid. Invalid if uncertainty = -1.	degrees (J2000)
decDegrees	Value and uncertainty of Declination coordinate of centroid. Invalid if uncertainty = -1.	degrees (J2000)

Table 48: DV results – ticReferenceCentroid / controlImageCentroid / differenceImageCentroid

Name	Definition	Units
rowOffset	Value and uncertainty of difference image centroid offset in CCD row. Invalid if uncertainty = -1.	pixels
columnOffset	Value and uncertainty of difference image centroid offset in CCD column. Invalid if uncertainty = -1.	pixels
focalPlaneOffset	Value and uncertainty of magnitude of difference image centroid offset on focal plane. Invalid if uncertainty = -1.	pixels
raOffset	Value and uncertainty of difference image centroid offset in Right Ascension. Invalid if uncertainty = -1.	arcseconds
decOffset	Value and uncertainty of difference image centroid offset in Declination. Invalid if uncertainty = -1.	arcseconds
skyOffset	Value and uncertainty of magnitude of difference image centroid offset on the sky. Invalid if uncertainty = -1.	arcseconds

Table 49: DV results – ticCentroidOffsets / controlCentroidOffsets

Name	Definition	Units
ccdRow	CCD row coordinate for given pixel.	
ccdColumn	CCD column coordinate for given pixel.	
meanFluxOutOfTransit	Value and uncertainty of mean flux level in vicinity of transits in given sector. Invalid if uncertainty = -1.	e-/cadence
meanFluxInTransit	Value and uncertainty of mean flux level in-transit in given sector. Invalid if uncertainty = -1.	e-/cadence
meanFluxDifference	Value and uncertainty of difference between mean flux levels out-of-transit and in-transit in given sector. Invalid if uncertainty = -1.	e-/cadence
meanFluxForTargetTable	Value and uncertainty of mean flux level over all cadences in given sector. Invalid if uncertainty = -1.	e-/cadence

Table 50: DV results – differenceImagePixelData

Name	Definition	Units
coreApertureCorrelationStatistic	Correlation statistic and significance for flux derived from core photometric aperture against transit model light curve. Significance is computed assuming that statistic is drawn from a standard normal distribution. Invalid if significance = -1.	
haloApertureCorrelationStatistic	Correlation statistic and significance for flux derived from halo surrounding core photometric aperture against transit model light curve. Significance is computed assuming that statistic is drawn from a standard normal distribution. Invalid if significance = -1.	

Table 51: DV results – ghostDiagnosticResults

Name	Definition	Units
planetParameters	Planet parameters derived from depth of secondary event. See Table 53.	
comparisonTests	Statistical comparison tests involving planet parameters to help ascertain if TCE is due to occultation of giant planet. See Table 54.	

Table 52: DV results – secondaryEventResults

Name	Definition	Units
geometricAlbedo	Geometric albedo derived from depth of secondary event. Invalid if uncertainty = -1.	
planetEffectiveTemp	Planet effective temperature derived from depth of secondary event. Invalid if uncertainty = -1.	Kelvin

Table 53: DV results – planetParameters

Name	Definition	Units
albedoComparisonStatistic	Statistical comparison of geometric albedo against 1. Invalid if significance = -1.	
tempComparisonStatistic	Statistical comparison of planet effective temperature against equilibrium temperature. Invalid if significance = -1.	

Table 54: DV results – comparisonTests

11 TCE Summary Report

11.1 Purpose

The Threshold Crossing Event (TCE) summary report file is a human readable report in portable document format (PDF). This report contains diagnostic plots for a single TCE rather than all the TCEs on the same target. The report contains the following header information.

11.2 Composition

11.2.1 Report Description

1. TIC catalog identifier
2. Planet number (x of y)
3. Orbital period, epoch of first transit, ratio of the planet radius to host star radius, ratio of semi-major axis to host star radius, impact parameter, and their associated uncertainties, as determined in the DV planet model fit to all transits.
4. Planet radius, semi-major axis, equilibrium temperature, effective stellar flux, mean stellar density, and their associated uncertainties, as derived from the planet model fit parameters.
5. Geometric albedo, planet effective temperature, and their associated uncertainties, as derived from the depth of the largest secondary event at the period and pulse duration of the TCE.
6. Correlation coefficient between the TCE ephemeris and a known planet (e.g., TOI) ephemeris on the same star when an ephemeris match is determined (typically correlation greater than 0.75). The identifier of the known planet is also displayed in the case of an ephemeris match. Note that known planets in the context of DV are those that are provided to DV at the time it is run; DV cannot, for example, match against the ephemerides of TOIs if it is not provided with them.
7. TESS magnitude of the host star.
8. Radius of the host star.
9. Effective temperature of the host star.
10. Surface gravity $log_{10}(g)$ of the host star.
11. Metallicity $log_{10}(M/H)$ of the host star.
12. Mean stellar density of the host star, as derived from radius and surface gravity.

The following plots are available on the summary report.

1. Detrended, sector-stitched, systematic error corrected, relative flux of the target during the DV processing window. Markers indicate the transit events.
2. Phase-folded, detrended, sector-stitched, systematic error corrected, relative flux showing the timings of all transits for all TCEs on the host star. The transiting planet model fit is overlaid on the light curve.
3. Zoom on the phase-folded, relative flux light curve at the phase of the maximum secondary event. The phase, depth and associated uncertainty, and MES of the secondary eclipse are also displayed.
4. Zoom on the phase-folded, relative flux light curve at phase zero. The transiting planet model fit is overlaid.
5. The transiting planet model fit to the phase-folded light curve in the whitened domain, along with the fit residuals. Number of observed transits, MES, transit depth and associated uncertainty, and model fit SNR are also displayed.
6. The phase-folded light curves for the odd and even transits displayed together for comparison. Transit depths and associated uncertainties are displayed for each light curve.
7. Offsets of the difference image centroids relative the out-of-transit centroids for each sector in which the star was observed. Nearby objects are also marked. The 3σ radius of uncertainty is displayed for the mean (over sectors) centroid offset.

The following diagnostic information is available.

1. Statistical comparison of orbital period to longer and shorter period TCEs on the same target star.
2. Statistical comparison of depths of odd and even transits.
3. Statistical comparison of geometric albedo against 1.
4. Statistical comparison of planet effective temperature against equilibrium temperature.
5. Planet model fit χ^2_2 (see Seader 2013).
6. Planet model fit χ^2_{GOF} (see Seader 2013).
7. Bootstrap false alarm probability.
8. Ratio of optical ghost core aperture correlation statistic to halo aperture correlation statistic.
9. Centroid offsets with respect to both out-of-transit centroid and catalog location of target: absolute offsets in arcseconds and their significance.
10. Difference image quality metrics.

11.2.2 Summary Report Example

Figure 7 shows an example one-page summary report for a background eclipsing binary.

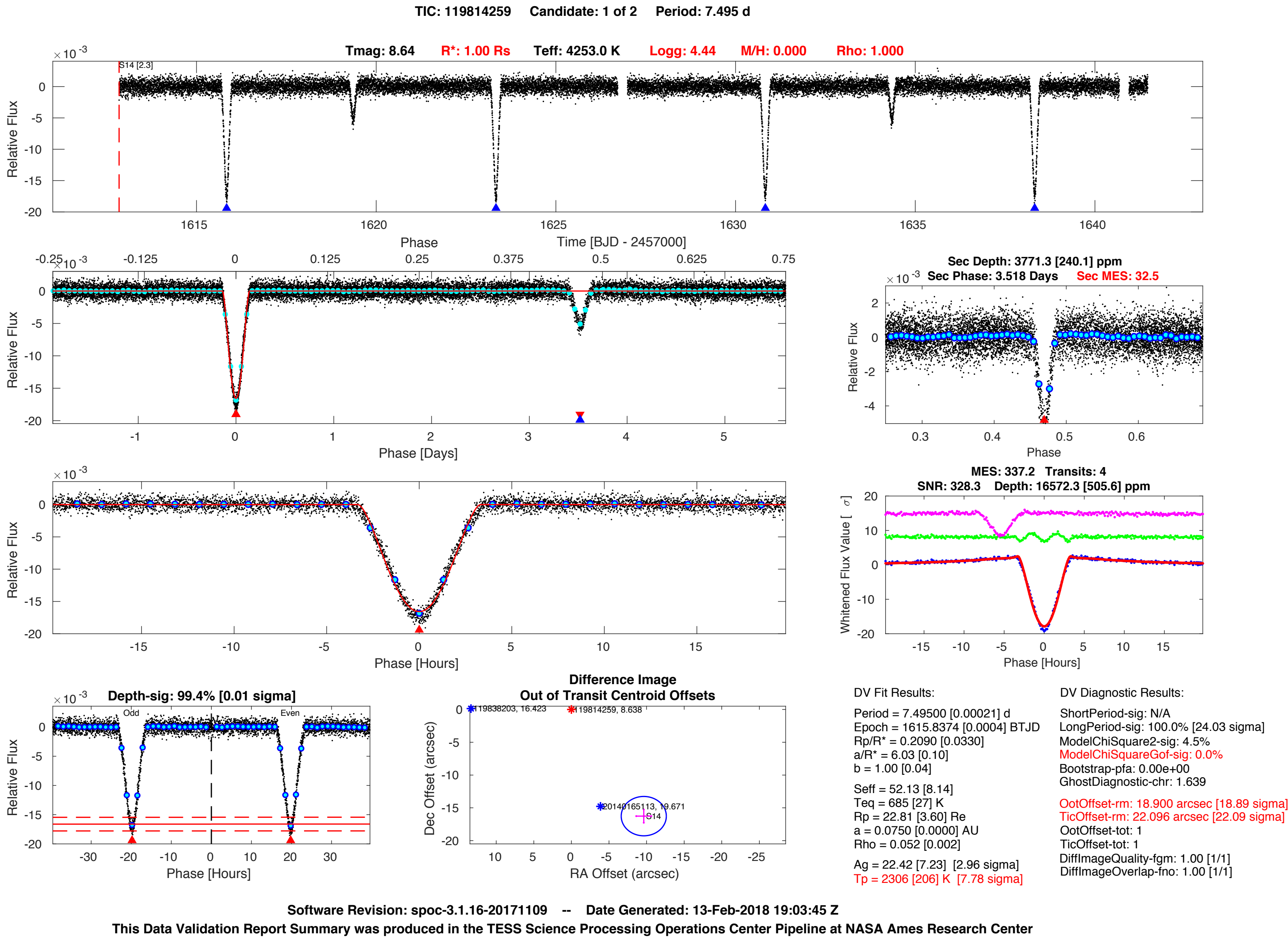


Figure 7: TCE Summary Report

12 Mini Data Validation Report

12.1 Purpose

The mini DV report (also known as DV mini-report) is a human readable report that highlights the key DV results for all TCEs associated with a particular host star. It contains the DV diagnostic information necessary for subject experts to vet TCEs generated in the SPOC pipeline and identify the credible transiting planet candidates for promotion to TOI status.

12.2 Composition

12.2.1 TCE Summaries

The one-page TCE summary reports for all TCEs associated with the host star are displayed sequentially at the beginning of the mini DV report.

12.2.2 Difference Images

Difference images are displayed by sector (in reverse chronological order) and TCE for all TCEs associated with the host star and all sectors in the pipeline transit search. The difference images are obtained from the full DV report, but are redrawn with a 1:1 aspect ratio so that individual pixels appear square.

12.2.3 Centroid Offsets

Centroid offset diagnostic figures are displayed sequentially for all TCEs associated with the host star. Centroid offsets are shown for each sector with observed transits; robust mean centroid offets computed over all sectors are shown as well. Centroid offsets are also overlaid on high resolution Digitized Sky Survey (DSS) red images of the host star and its immediate neighborhood if available. The figures are obtained from the full DV report but are redrawn to display a wider area.

12.2.4 Flux Time Series

SAP flux time series for the host star are displayed by sector. The time series are offset vertically for clarity. Normalized PDCSAP flux time series for the host star are displayed by sector, also offset vertically for clarity. Transit events for all TCEs associated with the host are identified on the PDCSAP time series with colored markers.

12.2.5 Phased Light Curves

Phase-folded light curves are displayed sequentially for all TCEs associated with the host star. For each TCE, a single page includes the phase-folded unwhitened light curve after median detrending, the phase folded whitened light curve, and the phase-folded unwhitened light curve employed in the trapezoidal model fit. The unwhitened transit model, whitened transit model, and trapezoidal transit model are overlaid on the three phase-folded light curves respectively.

12.2.6 Sky Image

A high resolution Digitized Sky Survey (DSS) red image of the host star and its local neighborhood is displayed at the end of mini DV report. The positions of nearby stars (corrected for proper motion) are displayed with colored markers. Relatively bright stars in the celestial neighborhood are also numbered. A table adjacent to the sky image displays TIC ID and TESS magnitude of the numbered stars as well as proper-motion corrected distance from the host star. The numbering system is consistent with that employed to mark nearby stars on the difference images and centroid offsets diagnostic figures in the mini and full DV reports.

13 Full Data Validation Report

13.1 Purpose

The full DV report is a human readable report that details all TCEs associated with a particular host star. It contains much more detail than the summary report.

13.2 Composition

13.2.1 Summary

The summary details the host star's stellar properties and the provenance of those properties. It shows summary information regarding the pipeline software revision, the model files employed in DV, which camera/CCD the host star was observed on during the observation period, photometric aperture metrics by observing sector, and target-specific limb darkening coefficients. A table includes the ephemerides and planet characteristics (e.g., planet radius, equilibrium temperature, and effective stellar flux) for all TCEs detected on the host star.

13.2.2 Sky Image

A Digitized Sky Survey (DSS) red image of the sky centered on the host star's location is displayed if available. This is useful for understanding the celestial neighborhood and assessing possible sources of contamination for the host star.

13.2.3 Flux Plots

A series of plots displays the stitched and normalized stellar flux by observing sector along with the locations of the transits for all TCEs detected on the host star. This is followed by a series of plots showing the raw (i.e., prior to systematic error correction and sector stitching) flux time series by sector with units of e-/cadence.

13.2.4 Planet Candidate Dashboards

There is one dashboard for each TCE detected on the host star. A dashboard is a summary of planet model fit results, eclipsing binary discrimination test results, difference image centroid offset analysis, statistical bootstrap test results, and optical ghost diagnostic test results. Panels in the dashboard are color-coded to provide a quick overview of DV results for the given TCE; the color coding scheme is described in the caption below the dashboard. Figure 8 shows an example dashboard.

3 Dashboards

Planet Candidate 1

Model Fitter

Stellar Radius

1.0 ± 0.0 Solar units

Period = 7.5 ± 0.0 days
Depth = 16572 ± 506 ppm
Planet Radius = 22.8 ± 3.6 Earth radii
Semi-major Axis = 0.1 ± 0.0 AU
Effective Stellar Flux = 52.1 ± 8.1
Equilibrium Temperature = 685 ± 27 Kelvin
Chi-squared/DoF = 1.2
SNR = 328.3

Ghost Diagnostic Test

Core Aperture Correlation Statistic

Value = 129.06
Significance = 100.00%

Halo Aperture Correlation Statistic

Value = 78.72
Significance = 100.00%

Core/Halo Ratio

Ratio = 1.64

Eclipsing Binary Discrimination Test

Odd-Even Depth Comparison Statistic

Value = 5.59e-05
Significance = 99.40%

Shorter Period Comparison Statistic

Value = N/A
Significance = N/A

Longer Period Comparison Statistic

Value = 5.77e+02
Significance = 100.00%

Difference Image Centroid Offsets

Offsets Relative to Out of Transit Centroid

Source RA Offset = -9.63e+00 ± 1.00e+00 arcsec (-9.62 σ)
Source Dec Offset = -1.63e+01 ± 1.00e+00 arcsec (-16.26 σ)
Source Offset Distance = 1.89e+01 ± 1.00e+00 arcsec (18.89 σ)

Offsets Relative to TIC Position

Source RA Offset = -1.11e+01 ± 1.00e+00 arcsec (-11.06 σ)
Source Dec Offset = -1.91e+01 ± 1.00e+00 arcsec (-19.12 σ)
Source Offset Distance = 2.21e+01 ± 1.00e+00 arcsec (22.09 σ)

Bootstrap Test

False Alarm = 0.00e+00
Transit Count = 4
Max Multiple Event Statistic = 337.2

Summary of model fitter results and validation test results for target 119814259, planet candidate 1. In general, green denotes that the candidate is likely a planet, while red denotes that the candidate is unlikely to be a planet. Cyan denotes that no data is available. The color of the Model Fitter block is: green, when the SNR of the fit is greater than or equal to 10; yellow, if the SNR is greater than or equal to 7.1 but less than 10; red, if the SNR is less than 7.1 or if the fitter failed. The color of the Ghost Diagnostic Test and Eclipsing Binary Discrimination Test blocks are: green, when the significance is within 2-sigma; yellow, when the significance is between 2- and 3-sigma; red when the significance is greater than 3-sigma. The color of the Difference Image Centroid Offsets block is: green, when the max offset distance sigma is less than or equal to 2; yellow, when the max sigma is between 2 and 3; red when the max sigma is greater than 3. The color of the Bootstrap Test block is green whenever the false alarm probability is less than 10^{-12}, low enough to limit the total number of false alarms from a four year mission to less than one. If the false alarm probability is greater than 10^{-12}, the color of the Bootstrap Test block is: green, when the false alarm probability is less than or equal to the CCDF of a Gaussian distribution at the observed maximum multiple event statistic; yellow when the false alarm probability is between 1 and 2 times that of a Gaussian distribution at the max multiple event statistic; and red when the false alarm probability is more than 2 times that of a Gaussian distribution at the max multiple event statistic.

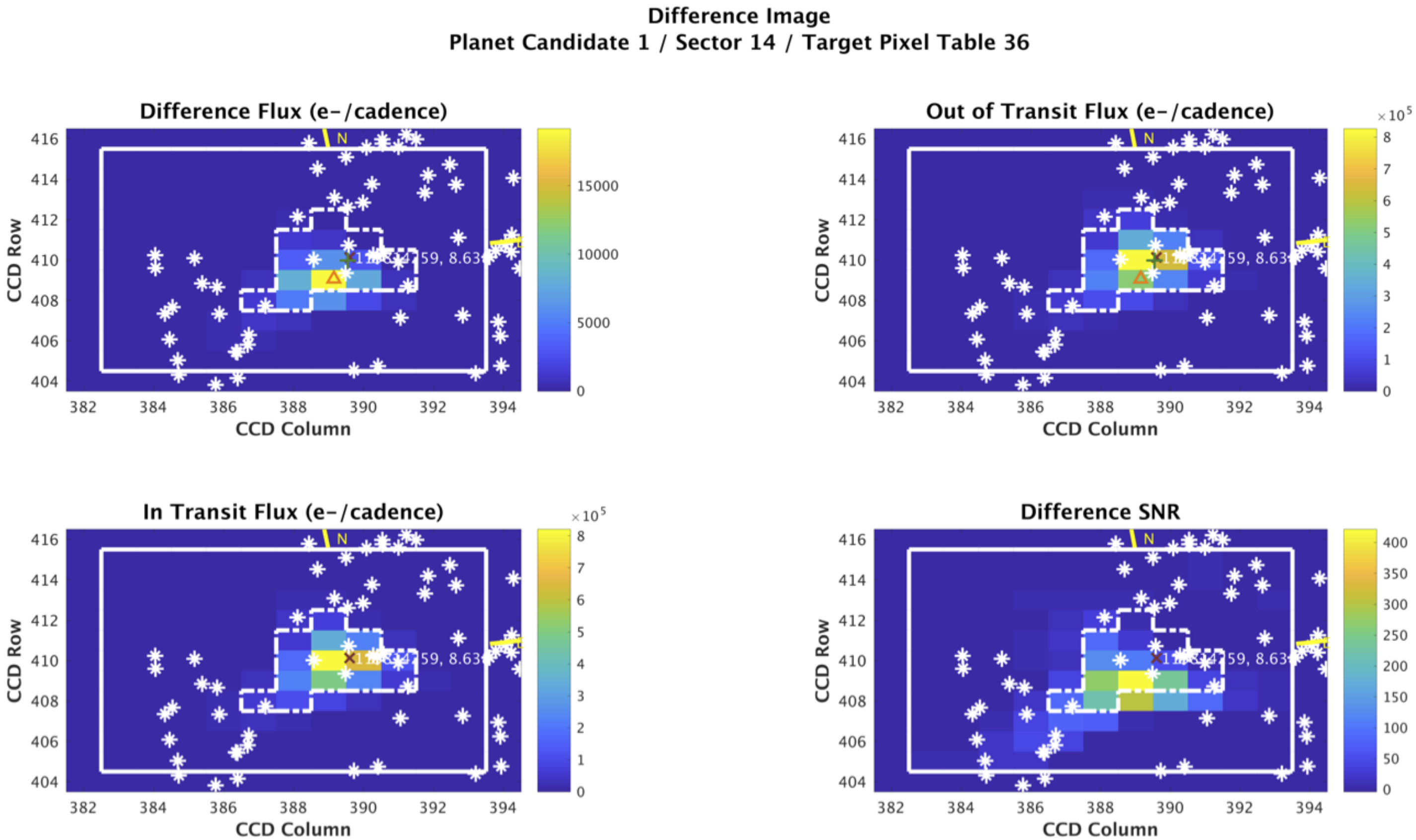
Figure 8: Dashboard Example

13.2.5 Pixel Level Diagnostics

The following information is available for each TCE on the host star. Multiple difference images and centroid offsets may be present if the host star was observed in more than one pointing. Difference imaging and centroid offset analysis is invaluable for identifying TCEs attributable to background objects.

1. Tabulated mean offsets (over observing sectors) in Right Ascension and Declination between difference image centroids representing the location of the transit source and out-of-transit image centroids representing the location of the target star.
2. Tabulated mean offsets (over observing sectors) in Right Ascension and Declination between difference image centroids representing the location of the transit source and catalog coordinates representing the location of the target star.
3. A figure displaying the centroid offsets on the sky between the difference image centroids and the out-of-transit centroids.
4. A figure displaying the centroid offsets on the sky between the difference image centroids and the TIC position of the target.
5. The following pixel images are displayed for each pointing with observed transits: difference flux, in-transit flux, out-of-transit flux and difference SNR, where difference flux is defined as out-of-transit minus in-transit-flux.
6. Tabulated centroids of the PRF fit to the difference and out-of-transit images, and centroid offsets as described above for each pointing with observed transits.

Figure 9 is an example of a difference image described in this section.



Difference image for target 119814259, planet candidate 1, sector 14, target pixel table 36. Upper left: difference between mean flux out-of-transit and in-transit; upper right: mean out-of-transit flux; lower left: mean in-transit flux; lower right: difference between mean flux out-of-transit and in-transit after normalizing by the uncertainty in the difference for each pixel. The optimal aperture is outlined with a white dash-dotted line in each panel and the target mask is outlined with a solid white line. Symbol key: x: target position from TIC RA and Dec converted to CCD coordinates via motion polynomials; *: position of nearby TIC objects converted to CCD coordinates via motion polynomials; +: PRF-fit location of target from out-of-transit image; triangle: PRF-fit location of transit source from the difference image. Number of transits = 4; number of valid in-transit cadences = 314; number of in-transit cadence gaps = 0; number of valid out-of-transit cadences = 1616; number of out-of-transit cadence gaps = 0. Difference image quality metric = 1.00 (good).
Open `./planet-01/difference-image/0000000119814259-01-difference-image-14-036.fig`

Figure 9: Difference Image Example

13.2.6 Phased Light Curves

Phase-folded light curves are displayed for all TCEs associated with the host star in both unwhitened and whitened domains. The unwhitened light curves are median detrended. The transiting planet model fit is overlaid on the light curve associated with each TCE. The transit events for all TCEs are marked below each light curve in a color coded fashion. Planet model fitting is performed in the whitened domain in DV. The light curves and planet models are both distorted in the same fashion by the whitener.

For each TCE, phase-folded, unwhitened light curves with zoom on transit events at phase zero are also displayed separately by sector. This permits a visual consistency check for targets with transits observed in multiple pointings.

13.2.7 TCE Model Fit and Diagnostic Test Results

The DV report includes a separate section with planet model fit and diagnostic test results for each TCE associated with the target star. The results are displayed in tables and captioned figures. The following items are available for each planet candidate identified in the pipeline.

1. A table displaying the TCE parameters determined in the transiting planet search: ephemeris, detection statistics, and veto statistics.
2. A table displaying the transiting planet model fit (to all transits) results: fitted parameters with associated uncertainties, derived parameters with associated uncertainties, model fit SNR, and model fit χ^2 statistics (see Seader 2013).
3. One or more (where applicable) figures displaying the unfolded, unwhitened light curve by sector. The locations of the transit events associated with the given TCE are marked.
4. A figure displaying the phase-folded, whitened light curve associated with the TCE. The whitened, binned and averaged planet model light curve is overlaid. Whitened, binned and averaged fit residuals are displayed with a vertical offset for clarity.
5. A figure displaying the phase-folded, whitened light curve with zoom on transit events at phase zero. Binned and averaged planet model and fit residuals are also displayed. Color coding permits the data points that were excluded from the model fit to be identified.
6. A table displaying the results of a series of reduced-parameter planet model fits, i.e., model fits performed over a range of fixed impact parameters.
7. Figures displaying the results of the reduced-parameter fits as a function of impact parameter.
8. A table displaying the results of a trapezoidal model fit to the light curve associated with the given TCE.
9. A figure displaying the phase-folded, detrended light curve with trapezoidal model fit and fit residuals.
10. A figure displaying the phase-folded, detrended light curve with zoom on transit events at phase zero. The trapezoidal model fit and fit residuals are also displayed.
11. A table displaying the results of the DV weak secondary test.
12. A table displaying the results of the DV eclipsing binary discrimination tests.
13. A table displaying the results of the DV statistical bootstrap.
14. A table displaying the results of the DV optical ghost diagnostic test.
15. A figure displaying the secondary MES versus phase for the given TCE. Maximum and minimum secondary events are marked.
16. A figure displaying the bootstrap false alarm probability versus detection statistic for the given TCE. The false alarm probability for the MES associated with the TCE is indicated. The bootstrap distribution is extrapolated if necessary to determine the TCE false alarm probability. The false alarm probability versus detection statistic for a standard normal noise distribution is also displayed for reference.
17. Figures displaying the phase-folded optical ghost core and halo aperture light curves. The planet model fit is overlaid on the figures.

13.2.8 Appendices

The DV report includes an Appendix for each TCE on the host star with tables and figures displaying robust weights and fit residuals for planet model fits, model fit results for odd and even transits, and some DV diagnostic test results. A final Appendix to the DV report includes all Alerts generated for the target star when DV was run in the pipeline. The pipeline Alerts may indicate off-nominal behavior, but their existence should not directly call into question the validity of any given TCE.

14 DV Results XML Schema Definition

14.1 Purpose

This file contains an XML Schema that can be used to validate the structure and data types of an instance of the schema in this case the Data Validation Results (see appendix A). This file is updated when the structure of the Data Validation Results file changes. It is expected that this schema may change during the course of the mission.

14.2 Composition

Appendix A contains a listing of the complete schema.

15 Data Validation Time Series

15.1 Purpose

This is a FITS file that contains a single statistics HDU with time series for the target as a whole and HDUs for every TCE. The purpose of this file is to archive the time series data related to data validation that are involved with transit search and TCE modeling.

The number of DV light curve files may vary between different runs of DV on the same set of target data. TCEs that appeared in previous runs may not exist in a subsequent run. TCEs may also be found in different orders which will yield different planet numbers for the same TCE. To federate across different runs of DV some kind of ephemeris matching needs to be used; this is outside the scope of this document.

Light curves have the following characteristics:

- Harmonics removed (optional in TPS/DV).
- Edge de-trended.
- Level adjusted.
- Normalized.
- Gap unfilled. During processing gap filling is done to simplify the science algorithms and preserve CDPP which is the noise term in the signal to noise ratio computed by TPS. Model light curves are defined on all cadences and so do not have gaps. Timestamps are defined on all cadences even cadences for which data were not received. This is because model light curves are defined on these cadences.
- Stitched. Stitching only happens between sectors (or quarters for Kepler).

Figure 10 shows the organization of the HDUs in the DV time series file.

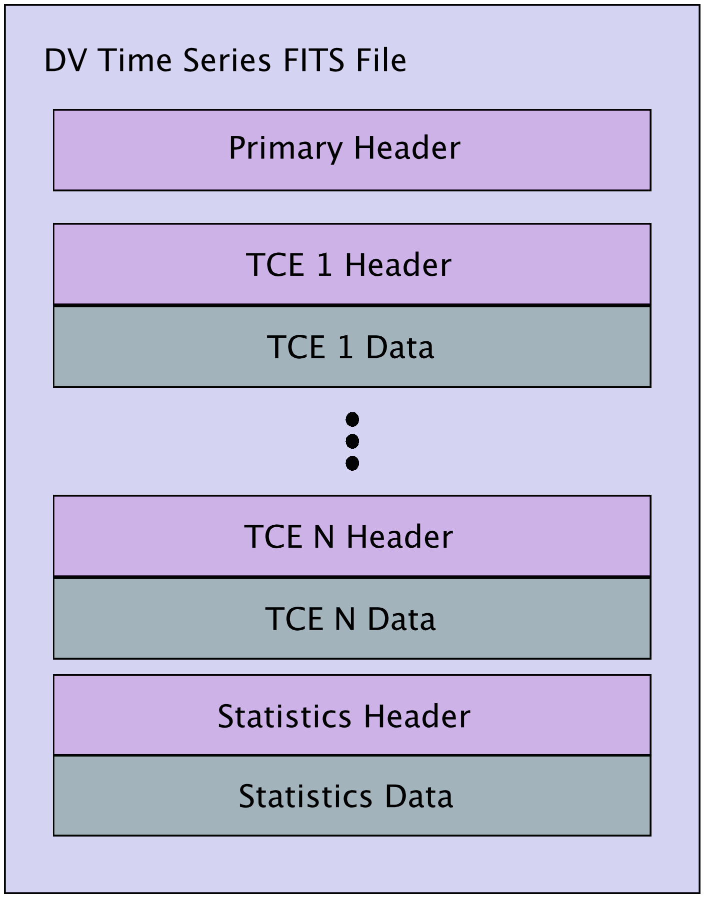


Figure 10: DV Time Series File Composition

15.2 Primary HDU

The primary HDU is defined in table 55. Note that the SECTOR keyword only appears in single sector DV time series FITS files, and not in multi-sector files.

Header Card	Data Type	Example Value
SIMPLE = T / conforms to FITS standards	L1	const
BITPIX = 8 / array data type	I4	const
NAXIS = 0 / number of array dimensions	I4	const
EXTEND = T / file contains extensions	L1	const
NEXTEND = 2 / number of standard extensions	I4	const
EXTNAME = 'PRIMARY '/ name of extension	C7	const
EXTVER = 1 / extension version number (not format version)	I4	const
SIMDATA = / file is based on simulated data	L1	F
ORIGIN = 'NASA/Ames'/ institution responsible for creating this file	C9	const
DATE = / file creation date	C10	2013-07-12
TSTART = / observation start time in BTJD	R8	1207.27
TSTOP = / observation stop time in BTJD	R8	1234.27
DATE-OBS= / TSTART as UTC calendar date	C24	2018-03-29T18:27:38.816
DATE-END= / TSTOP as UTC calendar date	C24	2018-03-30T18:27:38.816
CREATOR = / pipeline job and program used t	C50	643 DvTimeSeriesExporter
PROCVER = / SW version	C10	a0965a4308
FILEVER = / file format version	R8	5.0
TIMVERSN= / OGIP memo number for file format	C11	OGIP/93-003
TELESCOP= 'TESS '/ telescope	C8	const
INSTRUME= 'TESS Photometer'/ detector type	C15	const

OBJECT = / string version of TICID	C20	TIC 6541920
TICID = / unique TESS target identifier (0 < values < 2^50)	I8	6541920
SECTOR = / Observing sector	I4	16
DATA_REL= / version of data release notes for this file	I4	22
RADESYS = 'ICRS '/ reference frame of celestial coordinates	C4	const
RESFILE = / corresponding result file name	C23	tess01234567890_dvr.xml
DVVERSN = / DV Version	C50	'spoc-5.0.2-20201407'
NUMTCES = / number of TCES discovered	I4	2
SECTORS = / sectors observed	C50	'00110000'
RA_OBJ = / [deg] right ascension	R4	297.115121
DEC_OBJ = / [deg] declination	R4	41.909140
EQUINOX = 2000.0 / equinox of celestial coordinate system	R8	const
PMRA = / [mas/yr] RA proper motion	R4	0.0000
PMDEC = / [mas/yr] Dec proper motion	R4	0.0000
PMTOTAL = / [mas/yr] total proper motion	R4	0.0000
PXTABLE = / pixel table id	I4	2
TESSMAG = / [mag] TESS magnitude	R4	13.709
TEFF = / [K] Effective temperature	R4	5920
LOGG = / [cm/s2] log10 surface gravity	R4	4.467
MH = / [log10([M/H])] metallicity	R4	-0.200
RADIUS = / [solar radii] stellar radius	R4	0.962
TICVER = / TIC Version	R4	8.1
CHECKSUM= / HDU checksum updated 2013-07-12T22:34:06	C16	9H6DFH4B9H4BCH4B
END		

Table 55: Data validation time series primary header.

15.3 Per TCE HDU

Table 57 defines the header used for the TCE HDUs. This is a binary table header. The PERIOD and EPOCH keywords can be used to fold the light curves in order to reproduce the figures in the DV reports and to match the TCE against known ephemerides. The PHASE column is used as the x-axis in many of the plots in the TCE summary report. Subtracting TIMECORR from TIME will give the light arrival time at the spacecraft rather than at the solar system barycenter.

Table 56 describes the columns that can be found in this HDU.

Column Number	TYPE	FORM	UNIT	Description
1	TIME	64-bit float	days	BJD - 2457000 (BTJD)
2	TIMECORR	32-bit float	days	light arrival time correction applied
3	CADENCENO	32-bit integer		timestamp count from start of mission
4	PHASE	32-bit float	days	Days relative to the transit period.
5	LC_INIT	32-bit float	relative flux	Detrended initial light curve. This has been gapped.
6	LC_INIT_ERR	32-bit float	relative flux	The uncertainty of LC_INIT. This has been gapped.
7	LC_WHITE	32-bit float	relative flux	Initial, whitened time series. This has been gapped.
8	LC_DETREND	32-bit float	relative flux	Initial, median detrended time series. This has been gapped.
9	MODEL_INIT	32-bit float	relative flux	The fitted model evaluated at every timestamp.
10	MODEL_WHITE	32-bit float	relative flux	A whitened, fitted model light curve.

Table 56: DV time series per TCE time series.

Header Card	Data Type	Example Value
XTENSION= 'BINTABLE '/ marks the beginning of a new HDU	C8	const
BITPIX = 8 / array data type	I4	const
NAXIS = 2 / number of array dimensions	I4	const
NAXIS1 = 44 / length of first array dimension	I4	const

NAXIS2 =	/ length of second array dimension	I4	2
PCOUNT = 0	/ group parameter count (not used)	I4	const
GCOUNT = 1	/ group count (not used)	I4	const
EXTNAME =	/ extension name	C5-6	'TCE_1'
EXTVER = 1	/ extension version number (not format version)	I4	const
SIMDATA =	/ file is based on simulated data	L1	F
TFIELDS = 10	/ number of table fields	I4	const
INHERIT = T	/ inherit the primary header	L1	const
COMMENT Time system keywords			
RADESYS = 'ICRS	'/ reference frame of celestial coordinates	C4	const
RA_OBJ =	/ [deg] right ascension	R4	297.115121
DEC_OBJ =	/ [deg] declination	R4	41.909140
EQUINOX = 2000.0	/ equinox of celestial coordinate system	R8	const
EXPOSURE=	/ [d] time on source	R4	79.06606017
TIMEREF = 'SOLARSYSTEM'	/ barycentric correction applied to times	C11	const
TASSIGN = 'SPACECRAFT'	/ where time is assigned	C10	const
TIMESYS = 'TDB	'/ time system is Barycentric Dynamical Time (TDB)	C3	const
BJDREFI = 0	/ integer part of BJD reference date	I4	const
BJDREFF = 0.0	/ fraction of the day in BJD reference date	R4	const
TIMEUNIT= 'd	'/ time unit for TIME, TSTART and TSTOP	C1	const
TELAPSE =	/ [d] TSTOP - TSTART	R4	85.88209984
LIVETIME=	/ [d] TELAPSE multiplied by DEADC	R4	79.06606017
TSTART =	/ observation start time in BTJD	R8	1207.27
TSTOP =	/ observation stop time in BTJD	R8	1234.27
DEADC =	/ deadtime correction	R4	0.92063492
TIMEPIXR=	/ bin time beginning=0 middle=0.5 end=1	R8	0.5
TIERRELA=	/ [d] relative time error	R8	5.78E-07
INT_TIME=	/ [s] photon accumulation time per frame	R4	1.96
READTIME=	/ [s] readout time per frame	R4	0.04
FRAMETIM=	/ [s] frame time (INT_TIME + READTIME)	R4	2.0
NUM_FRM =	/ number of frames per time stamp	I4	30
TIMEDEL =	/ [d] time resolution of data	R8	0.02043359821692
DATE-OBS=	/ TSTART as UTC calendar date	C24	2018-03-29T18:27:38.816
DATE-END=	/ TSTOP as UTC calendar date	C24	2018-03-30T18:27:38.816
COMMENT TCE Information			
TPERIOD =	/ [day] transit period	R4	365.25
TEPOCH =	/ [days] transit epoch in BTJD	R4	744.3
TDEPTH =	/ [ppm] fitted depth	R4	20.4
TSNR =	/ transit signal to noise	R4	10.4
TDUR =	/ [hour] transit duration	R4	6.5
INDUR =	/ [hour] ingress duration	R4	0.1
IMPACT =	/ impact parameter	R4	.5
INCLIN =	/ [deg] inclination	R4	.01
DRRATIO =	/ ratio of planet distance to star radius	R4	215.0934
RADRATIO=	/ ratio of planet radius to star radius	R4	0.009
PRADIUS =	/ [R_earth] planet radius	R4	1.01
MAXMES =	/ [sigma] maximum multi-event statistic	R4	8.4
MAXSES =	/ [sigma] maximum single event statistic	R4	7.02
NTRANS =	/ number of transits for this TCE	I4	3
CONVRGE =	/ fit converged?	L1	T
MEDDETR =	/ [hour] length of the median detrender in hours	R4	12.0
COMMENT Table column definitions			
TTYPE1 = 'TIME'	/ column title: Time in BTJD	C4	const
TFORM1 = 'D '	/ column format: 64-bit floating point	C1	const
TUNIT1 = 'BJD - 2457000, days'	/ column units: Barycenter corrected TESS Julian Date	C19	const
TDISP1 = 'D14.7'	/ column display format	C5	const
TTYPE2 = 'TIMECORR'	/ column title: Correciton applied to time	C8	const

TFORM2 = 'E ' / column format: 32-bit floating point	C1	const
TUNIT2 = 'days' / column units: days	C8	const
TDISP2 = 'E13.7' / column display format	C5	const
TTYPE3 = 'CADENCENO' / column title: Cadence Numbers	C9	const
TFORM3 = 'J ' / column format: 32-bit floating point	C1	const
TDISP3 = 'J ' / column display format	C5	const
TTYPE4 = 'PHASE' / column title: phase using period and epoch	C5	const
TFORM4 = 'E ' / column format: 32-bit floating point	C1	const
TUNIT4 = 'days ' / column units: [-0.25*period, 0.75*period]	C8	const
TDISP4 = 'E13.7' / column display format	C5	const
TTYPE5 = 'LC_INIT' / column title: sector-stitched light curve	C7	const
TFORM5 = 'E ' / column format: 32-bit floating point	C1	const
TUNIT5 = 'dimensionless' / column units: dimensionless flux	C8	const
TDISP5 = 'E13.7' / column display format	C5	const
TTYPE6 = 'LC_INIT_ERR' / column title: Error in the LC_INIT	C11	const
TFORM6 = 'E ' / column format: 32-bit floating point	C1	const
TUNIT6 = 'dimensionless' / column units: dimensionless flux	C8	const
TDISP6 = 'E13.7' / column display format	C5	const
TTYPE7 = 'LC_WHITE' / column title: Initial whitened time series fit by DV	C8	const
TFORM7 = 'E ' / column format: 32-bit floating point	C1	const
TUNIT7 = 'dimensionless' / column units: dimensionless flux	C8	const
TDISP7 = 'E13.7' / column display format	C5	const
TTYPE8 = 'LC_DETREND' / column title: Initial Median Detrended time series	C10	const
TFORM8 = 'E ' / column format: 32-bit floating point	C1	const
TUNIT8 = 'dimensionless' / column units: dimensionless flux	C8	const
TDISP8 = 'E13.7' / column display format	C5	const
TTYPE9 = 'MODEL_INIT' / column title: model light curve	C10	const
TFORM9 = 'E ' / column format: 32-bit floating point	C1	const
TUNIT9 = 'dimensionless' / column units: dimensionless flux	C8	const
TDISP9 = 'E13.7' / column display format	C5	const
TTYPE10 = 'MODEL_WHITE' / column title: whitened model light curve	C11	const
TFORM10 = 'E ' / column format: 32-bit floating point	C1	const
TUNIT10 = 'dimensionless' / column units: dimensionless flux	C8	const
TDISP10 = 'E13.7' / column display format	C5	const
END		

Table 57: Data validation time series per TCE header.

15.4 Statistics HDU

The statistics HDU includes the systematic error corrected light curve produced for the host star in PDC, time series related to the single event statistic (SES) generated by TPS, and a residual light curve. The SES time series are the SES correlation and SES normalization time series; these are the terms in the numerator and denominator used to compute the multiple event statistic (MES). Combined differential photometric precision (CDPP) is a measure of the noise of the light curve. The CDPP is the inverse of the SES normalization time series multiplied by one million to yield an estimate of the noise in parts per million. The residual light curve is in units relative to the median flux of the light curve. All detected transits have been removed from the residual light curve. The SES time series are also computed in the absence of all transits to support the computation of the bootstrap false alarm rate. Table 58 describes the binary table columns that may be found in the statistics HDU.

Some time series are available for every transit pulse duration searched. These time series are denoted with *pulse*. The pulse duration is expressed in hours. When encoding pulse durations as part of FITS column names the period in the decimal place ('.') is replaced with an underscore ('_') character, e.g. '0_5' and '1_0'.

Table 59 defines the FITS header for this binary table extension.

Column Number	TYPE	FORM	UNIT	Description
1	TIME	64-bit float	days	barycentric corrected TESS Julian Date (BTJD).
2	TIMECORR	32-bit float	days	light arrival time correction applied
3	CADENCENO	32-bit integer		timestamp count from start of mission
4	PDC_SAP_FLUX	32-bit float	e^{-}/s	The input PDC light curve. This has been gapped.
5	PCD_SAP_FLUX_ERR	32-bit float	e^{-}/s	The uncertainty in the input PDC light curve. This has been gapped.
6	RESIDUAL_LC	32-bit float	Relative flux	Remaining residual flux after all identified transits have been removed.
7	DEWEIGHTS	32-bit float		Deemphasis weights. These are the weights applied to the light curve during the transit search. Deemphasized cadences are usually the result of instrumental anomalies.
8	QUALITY	32-bit integer		This field should be interpreted as a bit field. The meaning of these bits is documented in section 9; the same quality bits are present in the light curve files (with the exception that bit 11 is not populated in the DV Time Series file).
9 to 9 + NPULSE - 1	SES_CORR_*pulse*	32-bit float	σ	Single event statistic correlation time series. (signal)
9 + NPULSE to 9 + 2*NPULSE - 1	SES_NORM_*pulse*	32-bit float	σ	Single event statistic normalization time series (noise)

Table 58: DV time series statistics HDU columns.

Header Card	Data Type	Example Value
`XTENSION= 'BINTABLE '/  marks the beginning of a new HDU`	C8	const
`BITPIX  = 8          / array data type`	I4	const
`NAXIS   = 2          / number of array dimensions`	I4	const
`NAXIS1  = 144         / length of first array dimension`	I4	const
`NAXIS2  =            / length of second array dimension`	I4	2
`PCOUNT  = 0          / group parameter count (not used)`	I4	const
`GCOUNT  = 1          / group count (not used)`	I4	const
`EXTNAME = 'Statistics' / extension name`	C10	const
`EXTVER  = 1          / extension version number (not format version)`	I4	const
`SIMDATA =            / file is based on simulated data`	L1	F
`TFIELDS =           / number of table fields`	I4	36
`INHERIT = T          / inherit the primary header`	L1	const
`COMMENT Time system keywords`		
`RADESYS = 'ICRS     '/  reference frame of celestial coordinates`	C4	const
`RA_OBJ  =            / [deg] right ascension`	R4	297.115121
`DEC_OBJ =            / [deg] declination`	R4	41.909140
`EQUINOX = 2000.0     / equinox of celestial coordinate system`	R8	const
`EXPOSURE=            / [d] time on source`	R4	79.06606017
`TIMEREF = 'SOLARSYSTEM'/  barycentric correction applied to times`	C11	const
`TASSIGN = 'SPACECRAFT'/  where time is assigned`	C10	const
`TIMESYS = 'TDB      '/  time system is Barycentric Dynamical Time (TDB)`	C3	const
`BJDREFI = 0          / integer part of BJD reference date`	I4	const
`BJDREFF = 0.0        / fraction of the day in BJD reference date`	R4	const

TIMEUNIT= 'd '/ time unit for TIME, TSTART and TSTOP	C1	const
TELAPSE = / [d] TSTOP - TSTART	R4	85.88209984
LIVETIME= / [d] TELAPSE multiplied by DEADC	R4	79.06606017
TSTART = / observation start time in BTJD	R8	1472.086752
TSTOP = / observation stop time in BTJD	R8	1557.968852
DEADC = / deadtime correction	R4	0.92063492
TIMEPIXR= / bin time beginning=0 middle=0.5 end=1	R8	0.5
TIERRELA= / [d] relative time error	R8	5.78E-07
INT_TIME= / [s] photon accumulation time per frame	R4	6.019802903270
READTIME= / [s] readout time per frame	R4	0.518948526144
FRAMETIM= / [s] frame time (INT_TIME + READTIME)	R4	6.538751429414
NUM_FRM = / number of frames per time stamp	I4	270
TIMEDEL = / [d] time resolution of data	R8	0.02043359821692
DATE-OBS= / TSTART as UTC calendar date	C24	2018-03-29T18:27:38.816
DATE-END= / TSTOP as UTC calendar date	C24	2018-03-30T18:27:38.816
TTYPE1 = 'TIME' / column units: Barycenter corrected TESS Julian Date	C4	const
TFORM1 = 'D ' / column format: 64-bit floating point	C1	const
TUNIT1 = 'BJD - 2457000, days' / column units: barycenter corrected TESS Julian Date	C19	const
TDISP1 = 'D14.7' / column display format	C5	const
TTYPE2 = 'TIMECORR' / column title: barycentric correction	C8	const
TFORM2 = 'E ' / column format: 32-bit floating point	C1	const
TUNIT2 = 'days' / column units: days	C8	const
TDISP2 = 'E13.7' / column display format	C5	const
TTYPE3 = 'CADENCENO' / column title: Cadence Numbers	C9	const
TFORM3 = 'J ' / column format: 32-bit floating point	C1	const
TDISP3 = 'J ' / column display format	C5	const
TTYPE4 = 'PDCSAP_FLUX' / column title: PDC light curve (e/s)	C11	const
TFORM4 = 'E ' / column format: 32-bit floating point	C1	const
TUNIT4 = 'e-/s' / column units: electrons per sec	C4	const
TDISP4 = 'E13.7' / column display format	C5	const
TTYPE5 = 'LC_RESIDUAL' / column title: residual light curve	C11	const
TFORM5 = 'E ' / column format: 32-bit floating point	C1	const
TUNIT5 = 'sigma' / column units: significance	C5	const
TDISP5 = 'E13.7' / column display format	C5	const
TTYPE6 = 'DEWEIGHTS' / column title: Initial De-emphasis Weights	C9	const
TFORM6 = 'E ' / column format: 32-bit floating point	C1	const
TDISP6 = 'E13.7' / column display format	C5	const
TTYPE7 = 'QUALITY' / column title: Quality Flags	C7	const
TFORM7 = 'J ' / column format: 32-bit integer	C1	const
TDISP7 = 'J' / column display format	C5	const
TTYPE8 = 'SES_CORR_1_5' / column title: SES correlation for pulse 1.5	C12	const
TFORM8 = 'E ' / column format: 32-bit floating point	C1	const
TUNIT8 = 'sigma' / column units: significance	C5	const
TDISP8 = 'E13.7' / column display format	C5	const
TTYPE9 = 'SES_NORM_1_5' / column title: SES normalization for pulse 1.5	C12	const
TFORM9 = 'E ' / column format: 32-bit floating point	C1	const
TUNIT9 = 'sigma' / column units: significance	C5	const
TDISP9 = 'E13.7' / column display format	C5	const
TTYPE10 = 'SES_CORR_2_0' / column title: SES correlation for pulse 2.0	C12	const
TFORM10 = 'E ' / column format: 32-bit floating point	C1	const
TUNIT10 = 'sigma' / column units: significance	C5	const
TDISP10 = 'E13.7' / column display format	C5	const
TTYPE11 = 'SES_NORM_2_0' / column title: SES normalization for pulse 2.0	C12	const
TFORM11 = 'E ' / column format: 32-bit floating point	C1	const
TUNIT11 = 'sigma' / column units: significance	C5	const
TDISP11 = 'E13.7' / column display format	C5	const
TTYPE12 = 'SES_CORR_2_5' / column title: SES correlation for pulse 2.5	C12	const

TFORM12 = 'E ' / column format: 32-bit floating point	C1	const
TUNIT12 = 'sigma' / column units: significance	C5	const
TDISP12 = 'E13.7' / column display format	C5	const
TTYPE13 = 'SES_NORM_2_5' / column title: SES normalization for pulse 2.5	C12	const
TFORM13 = 'E ' / column format: 32-bit floating point	C1	const
TUNIT13 = 'sigma' / column units: significance	C5	const
TDISP13 = 'E13.7' / column display format	C5	const
TTYPE14 = 'SES_CORR_3_0' / column title: SES correlation for pulse 3.0	C12	const
TFORM14 = 'E ' / column format: 32-bit floating point	C1	const
TUNIT14 = 'sigma' / column units: significance	C5	const
TDISP14 = 'E13.7' / column display format	C5	const
TTYPE15 = 'SES_NORM_3_0' / column title: SES normalization for pulse 3.0	C12	const
TFORM15 = 'E ' / column format: 32-bit floating point	C1	const
TUNIT15 = 'sigma' / column units: significance	C5	const
TDISP15 = 'E13.7' / column display format	C5	const
TTYPE16 = 'SES_CORR_3_5' / column title: SES correlation for pulse 3.5	C12	const
TFORM16 = 'E ' / column format: 32-bit floating point	C1	const
TUNIT16 = 'sigma' / column units: significance	C5	const
TDISP16 = 'E13.7' / column display format	C5	const
TTYPE17 = 'SES_NORM_3_5' / column title: SES normalization for pulse 3.5	C12	const
TFORM17 = 'E ' / column format: 32-bit floating point	C1	const
TUNIT17 = 'sigma' / column units: significance	C5	const
TDISP17 = 'E13.7' / column display format	C5	const
TTYPE18 = 'SES_CORR_4_5' / column title: SES correlation for pulse 4.5	C12	const
TFORM18 = 'E ' / column format: 32-bit floating point	C1	const
TUNIT18 = 'sigma' / column units: significance	C5	const
TDISP18 = 'E13.7' / column display format	C5	const
TTYPE19 = 'SES_NORM_4_5' / column title: SES normalization for pulse 4.5	C12	const
TFORM19 = 'E ' / column format: 32-bit floating point	C1	const
TUNIT19 = 'sigma' / column units: significance	C5	const
TDISP19 = 'E13.7' / column display format	C5	const
TTYPE20 = 'SES_CORR_5_0' / column title: SES correlation for pulse 5.0	C12	const
TFORM20 = 'E ' / column format: 32-bit floating point	C1	const
TUNIT20 = 'sigma' / column units: significance	C5	const
TDISP20 = 'E13.7' / column display format	C5	const
TTYPE21 = 'SES_NORM_5_0' / column title: SES normalization for pulse 5.0	C12	const
TFORM21 = 'E ' / column format: 32-bit floating point	C1	const
TUNIT21 = 'sigma' / column units: significance	C5	const
TDISP21 = 'E13.7' / column display format	C5	const
TTYPE22 = 'SES_CORR_6_0' / column title: SES correlation for pulse 6.0	C12	const
TFORM22 = 'E ' / column format: 32-bit floating point	C1	const
TUNIT22 = 'sigma' / column units: significance	C5	const
TDISP22 = 'E13.7' / column display format	C5	const
TTYPE23 = 'SES_NORM_6_0' / column title: SES normalization for pulse 6.0	C12	const
TFORM23 = 'E ' / column format: 32-bit floating point	C1	const
TUNIT23 = 'sigma' / column units: significance	C5	const
TDISP23 = 'E13.7' / column display format	C5	const
TTYPE24 = 'SES_CORR_7_5' / column title: SES correlation for pulse 7.5	C12	const
TFORM24 = 'E ' / column format: 32-bit floating point	C1	const
TUNIT24 = 'sigma' / column units: significance	C5	const
TDISP24 = 'E13.7' / column display format	C5	const
TTYPE25 = 'SES_NORM_7_5' / column title: SES normalization for pulse 7.5	C12	const
TFORM25 = 'E ' / column format: 32-bit floating point	C1	const
TUNIT25 = 'sigma' / column units: significance	C5	const
TDISP25 = 'E13.7' / column display format	C5	const
TTYPE26 = 'SES_CORR_9_0' / column title: SES correlation for pulse 9.0	C12	const
TFORM26 = 'E ' / column format: 32-bit floating point	C1	const

TUNIT26 = 'sigma' / column units: significance	C5	const
TDISP26 = 'E13.7' / column display format	C5	const
TTYPE27 = 'SES_NORM_9_0' / column title: SES normalization for pulse 9.0	C12	const
TFORM27 = 'E ' / column format: 32-bit floating point	C1	const
TUNIT27 = 'sigma' / column units: significance	C5	const
TDISP27 = 'E13.7' / column display format	C5	const
TTYPE28 = 'SES_CORR_10_5' / column title: SES correlation for pulse 10.5	C13	const
TFORM28 = 'E ' / column format: 32-bit floating point	C1	const
TUNIT28 = 'sigma' / column units: significance	C5	const
TDISP28 = 'E13.7' / column display format	C5	const
TTYPE29 = 'SES_NORM_10_5' / column title: SES normalization for pulse 10.5	C13	const
TFORM29 = 'E ' / column format: 32-bit floating point	C1	const
TUNIT29 = 'sigma' / column units: significance	C5	const
TDISP29 = 'E13.7' / column display format	C5	const
TTYPE30 = 'SES_CORR_12_0' / column title: SES correlation for pulse 12.0	C13	const
TFORM30 = 'E ' / column format: 32-bit floating point	C1	const
TUNIT30 = 'sigma' / column units: significance	C5	const
TDISP30 = 'E13.7' / column display format	C5	const
TTYPE31 = 'SES_NORM_12_0' / column title: SES normalization for pulse 12.0	C13	const
TFORM31 = 'E ' / column format: 32-bit floating point	C1	const
TUNIT31 = 'sigma' / column units: significance	C5	const
TDISP31 = 'E13.7' / column display format	C5	const
TTYPE32 = 'SES_CORR_12_5' / column title: SES correlation for pulse 12.5	C13	const
TFORM32 = 'E ' / column format: 32-bit floating point	C1	const
TUNIT32 = 'sigma' / column units: significance	C5	const
TDISP32 = 'E13.7' / column display format	C5	const
TTYPE33 = 'SES_NORM_12_5' / column title: SES normalization for pulse 12.5	C13	const
TFORM33 = 'E ' / column format: 32-bit floating point	C1	const
TUNIT33 = 'sigma' / column units: significance	C5	const
TDISP33 = 'E13.7' / column display format	C5	const
TTYPE34 = 'SES_CORR_15_0' / column title: SES correlation for pulse 15.0	C13	const
TFORM34 = 'E ' / column format: 32-bit floating point	C1	const
TUNIT34 = 'sigma' / column units: significance	C5	const
TDISP34 = 'E13.7' / column display format	C5	const
TTYPE35 = 'SES_NORM_15_0' / column title: SES normalization for pulse 15.0	C13	const
TFORM35 = 'E ' / column format: 32-bit floating point	C1	const
TUNIT35 = 'sigma' / column units: significance	C5	const
TDISP35 = 'E13.7' / column display format	C5	const
END		

Table 59: Data validation time series statistics header.

Appendices

A DV Results XML Schema

```
<?xml version="1.0" encoding="UTF-8" standalone="yes"?>
<xs:schema elementFormDefault="qualified" version="1.0" targetNamespace="http://www.nasa.gov
    /2018/TESS/DV" xmlns:dv="http://www.nasa.gov/2018/TESS/DV" xmlns:tns="http://www.nasa.gov
    /2018/TESS/DV" xmlns:xs="http://www.w3.org/2001/XMLSchema">
  <xs:element name="dvTargetResults" type="tns:dvTargetResults"/>

  <xs:complexType name="dvTargetResults">
    <xs:sequence>
```

```
      <xs:element name="decDegrees" type="tns:dvDoubleQuantityWithProvenance"/>
      <xs:element name="effectiveTemp" type="tns:dvQuantityWithProvenance"/>
      <xs:element name="limbDarkeningModel" type="tns:dvLimbDarkeningModel"/>
      <xs:element name="log10Metallicity" type="tns:dvQuantityWithProvenance"/>
      <xs:element name="log10SurfaceGravity" type="tns:dvQuantityWithProvenance"/>
      <xs:element name="matchedToiId" type="xs:string" minOccurs="0" maxOccurs="unbounded"/>
      <xs:element name="planetResults" type="tns:dvPlanetResults" maxOccurs="unbounded"/>
      <xs:element name="pmDec" type="tns:dvQuantityWithProvenance"/>
      <xs:element name="pmRa" type="tns:dvQuantityWithProvenance"/>
      <xs:element name="raDegrees" type="tns:dvDoubleQuantityWithProvenance"/>
      <xs:element name="radius" type="tns:dvQuantityWithProvenance"/>
      <xs:element name="stellarDensity" type="tns:dvQuantityWithProvenance"/>
      <xs:element name="tessMag" type="tns:dvQuantityWithProvenance"/>
      <xs:element name="unmatchedToiId" type="xs:string" minOccurs="0" maxOccurs="unbounded"/>
    </xs:sequence>
    <xs:attribute name="startCadence" type="xs:int" use="required"/>
    <xs:attribute name="endCadence" type="xs:int" use="required"/>
    <xs:attribute name="planetCandidateCount" type="xs:int" use="required"/>
    <xs:attribute name="pipelineTaskId" type="xs:long" use="required"/>
    <xs:attribute name="ticId" type="xs:long" use="required"/>
    <xs:attribute name="sectorsObserved" type="xs:string" use="required"/>
    <xs:attribute name="tessName" type="xs:string"/>
    <xs:attribute name="toiId" type="xs:string"/>
  </xs:complexType>

  <xs:complexType name="dvDoubleQuantityWithProvenance">
    <xs:complexContent>
      <xs:extension base="tns:dvDoubleQuantity">
        <xs:sequence/>
        <xs:attribute name="provenance" type="xs:string" use="required"/>
      </xs:extension>
    </xs:complexContent>
  </xs:complexType>

  <xs:complexType name="dvDoubleQuantity">
    <xs:sequence/>
    <xs:attribute name="value" type="xs:double" use="required"/>
    <xs:attribute name="uncertainty" type="xs:float" use="required"/>
  </xs:complexType>

  <xs:complexType name="dvQuantityWithProvenance">
    <xs:complexContent>
      <xs:extension base="tns:dvQuantity">
        <xs:sequence/>
        <xs:attribute name="provenance" type="xs:string" use="required"/>
      </xs:extension>
    </xs:complexContent>
  </xs:complexType>

  <xs:complexType name="dvQuantity">
    <xs:sequence/>
    <xs:attribute name="value" type="xs:float" use="required"/>
    <xs:attribute name="uncertainty" type="xs:float" use="required"/>
  </xs:complexType>

  <xs:complexType name="dvLimbDarkeningModel">
    <xs:sequence/>
```

```
    <xs:attribute name="modelName" type="xs:string" use="required"/>
    <xs:attribute name="coefficient1" type="xs:float" use="required"/>
    <xs:attribute name="coefficient2" type="xs:float" use="required"/>
    <xs:attribute name="coefficient3" type="xs:float" use="required"/>
    <xs:attribute name="coefficient4" type="xs:float" use="required"/>
  </xs:complexType>

  <xs:complexType name="dvPlanetResults">
    <xs:sequence>
      <xs:element name="allTransitsFit" type="tns:dvPlanetModelFit"/>
      <xs:element name="binaryDiscriminationResults" type="tns:dvBinaryDiscriminationResults"/>
      <xs:element name="bootstrapResults" type="tns:dvBootstrapResults"/>
      <xs:element name="centroidResults" type="tns:dvCentroidResults"/>
      <xs:element name="differenceImageResults" type="tns:dvDifferenceImageResults" maxOccurs="unbounded"/>
      <xs:element name="evenTransitsFit" type="tns:dvPlanetModelFit"/>
      <xs:element name="ghostDiagnosticResults" type="tns:dvGhostDiagnosticResults"/>
      <xs:element name="oddTransitsFit" type="tns:dvPlanetModelFit"/>
      <xs:element name="planetCandidate" type="tns:dvPlanetCandidate"/>
      <xs:element name="reducedParameterFits" minOccurs="0">
        <xs:complexType>
          <xs:sequence>
            <xs:element name="reducedParameterFit" type="tns:dvPlanetModelFit" minOccurs="0" maxOccurs="unbounded"/>
          </xs:sequence>
        </xs:complexType>
      </xs:element>
      <xs:element name="secondaryEventResults" type="tns:dvSecondaryEventResults"/>
      <xs:element name="trapezoidalFit" type="tns:dvPlanetModelFit"/>
    </xs:sequence>
    <xs:attribute name="detrendFilterLength" type="xs:int" use="required"/>
    <xs:attribute name="planetNumber" type="xs:int" use="required"/>
    <xs:attribute name="tessName" type="xs:string"/>
    <xs:attribute name="toiCorrelation" type="xs:float"/>
    <xs:attribute name="toiId" type="xs:string"/>
  </xs:complexType>

  <xs:complexType name="dvPlanetModelFit">
    <xs:sequence>
      <xs:element name="modelParameterCovariance" minOccurs="0">
        <xs:simpleType>
          <xs:list itemType="xs:float"/>
        </xs:simpleType>
      </xs:element>
      <xs:element name="modelParameters">
        <xs:complexType>
          <xs:sequence>
            <xs:element name="modelParameter" type="tns:dvModelParameter" minOccurs="0" maxOccurs="unbounded"/>
          </xs:sequence>
        </xs:complexType>
      </xs:element>
    </xs:sequence>
    <xs:attribute name="type" type="tns:planetModelFitType" use="required"/>
    <xs:attribute name="fullConvergence" type="xs:boolean" use="required"/>
    <xs:attribute name="limbDarkeningModelName" type="xs:string"/>
    <xs:attribute name="modelChiSquare" type="xs:float" use="required"/>
```

```
    <xs:attribute name="modelDegreesOfFreedom" type="xs:float" use="required"/>
    <xs:attribute name="modelFitSnr" type="xs:float" use="required"/>
    <xs:attribute name="planetNumber" type="xs:int" use="required"/>
    <xs:attribute name="transitModelName" type="xs:string" use="required"/>
  </xs:complexType>

  <xs:complexType name="dvModelParameter">
    <xs:sequence/>
    <xs:attribute name="fitted" type="xs:boolean" use="required"/>
    <xs:attribute name="name" type="xs:string" use="required"/>
    <xs:attribute name="uncertainty" type="xs:float" use="required"/>
    <xs:attribute name="value" type="xs:double" use="required"/>
  </xs:complexType>

  <xs:complexType name="dvBinaryDiscriminationResults">
    <xs:sequence>
      <xs:element name="longerPeriodComparisonStatistic" type="tns:dvPlanetStatistic"/>
      <xs:element name="oddEvenTransitDepthComparisonStatistic" type="tns:dvStatistic"/>
      <xs:element name="shorterPeriodComparisonStatistic" type="tns:dvPlanetStatistic"/>
    </xs:sequence>
  </xs:complexType>

  <xs:complexType name="dvPlanetStatistic">
    <xs:complexContent>
      <xs:extension base="tns:dvStatistic">
        <xs:sequence/>
        <xs:attribute name="planetNumber" type="xs:int" use="required"/>
      </xs:extension>
    </xs:complexContent>
  </xs:complexType>

  <xs:complexType name="dvStatistic">
    <xs:sequence/>
    <xs:attribute name="value" type="xs:float" use="required"/>
    <xs:attribute name="significance" type="xs:float" use="required"/>
  </xs:complexType>

  <xs:complexType name="dvBootstrapResults">
    <xs:sequence>
      <xs:element name="histogram" type="tns:dvBootstrapHistogram"/>
    </xs:sequence>
    <xs:attribute name="bootstrapThresholdForDesiredPfa" type="xs:float" use="required"/>
    <xs:attribute name="mesMean" type="xs:float" use="required"/>
    <xs:attribute name="mesStd" type="xs:float" use="required"/>
    <xs:attribute name="significance" type="xs:double" use="required"/>
    <xs:attribute name="transitCount" type="xs:float" use="required"/>
  </xs:complexType>

  <xs:complexType name="dvBootstrapHistogram">
    <xs:sequence>
      <xs:element name="statistics" minOccurs="0">
        <xs:simpleType>
          <xs:list itemType="xs:float"/>
        </xs:simpleType>
      </xs:element>
      <xs:element name="probabilities" minOccurs="0">
        <xs:simpleType>
```

```
        <xs:list itemType="xs:float"/>
      </xs:simpleType>
    </xs:element>
  </xs:sequence>
</xs:complexType>

<xs:complexType name="dvCentroidResults">
  <xs:sequence>
    <xs:element name="differenceImageMotionResults" type="tns:dvDifferenceImageMotionResults"/>
  </xs:sequence>
</xs:complexType>

<xs:complexType name="dvDifferenceImageMotionResults">
  <xs:sequence>
    <xs:element name="msTicCentroidOffsets" type="tns:dvMsCentroidOffsets"/>
    <xs:element name="msControlCentroidOffsets" type="tns:dvMsCentroidOffsets"/>
    <xs:element name="summaryQualityMetric" type="tns:dvSummaryQualityMetric"/>
    <xs:element name="summaryOverlapMetric" type="tns:dvSummaryOverlapMetric"/>
  </xs:sequence>
</xs:complexType>

<xs:complexType name="dvMsCentroidOffsets">
  <xs:sequence>
    <xs:element name="meanRaOffset" type="tns:dvQuantity"/>
    <xs:element name="meanDecOffset" type="tns:dvQuantity"/>
    <xs:element name="meanSkyOffset" type="tns:dvQuantity"/>
  </xs:sequence>
</xs:complexType>

<xs:complexType name="dvSummaryQualityMetric">
  <xs:sequence/>
  <xs:attribute name="qualityThreshold" type="xs:float" use="required"/>
  <xs:attribute name="numberOfAttempts" type="xs:int" use="required"/>
  <xs:attribute name="numberOfMetrics" type="xs:int" use="required"/>
  <xs:attribute name="numberOfGoodMetrics" type="xs:int" use="required"/>
  <xs:attribute name="fractionOfGoodMetrics" type="xs:float" use="required"/>
</xs:complexType>

<xs:complexType name="dvSummaryOverlapMetric">
  <xs:sequence/>
  <xs:attribute name="imageCount" type="xs:int" use="required"/>
  <xs:attribute name="imageCountNoOverlap" type="xs:int" use="required"/>
  <xs:attribute name="imageCountFractionNoOverlap" type="xs:float" use="required"/>
</xs:complexType>

<xs:complexType name="dvDifferenceImageResults">
  <xs:complexContent>
    <xs:extension base="tns:dvAbstractTargetTableData">
      <xs:sequence>
        <xs:element name="controlCentroidOffsets" type="tns:dvCentroidOffsets"/>
        <xs:element name="controlImageCentroid" type="tns:dvImageCentroid"/>
        <xs:element name="differenceImageCentroid" type="tns:dvImageCentroid"/>
        <xs:element name="differenceImagePixelData" type="tns:dvDifferenceImagePixelData"
            maxOccurs="unbounded"/>
        <xs:element name="qualityMetric" type="tns:dvQualityMetric"/>
        <xs:element name="ticCentroidOffsets" type="tns:dvCentroidOffsets"/>
        <xs:element name="ticReferenceCentroid" type="tns:dvImageCentroid"/>
```

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      </xs:sequence>
      <xs:attribute name="numberOfCadenceGapsInTransit" type="xs:int" use="required"/>
      <xs:attribute name="numberOfCadenceGapsOutOfTransit" type="xs:int" use="required"/>
      <xs:attribute name="numberOfCadencesInTransit" type="xs:int" use="required"/>
      <xs:attribute name="numberOfCadencesOutOfTransit" type="xs:int" use="required"/>
      <xs:attribute name="numberOfTransits" type="xs:int" use="required"/>
      <xs:attribute name="overlappedTransits" type="xs:boolean" use="required"/>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>

<xs:complexType name="dvAbstractTargetTableData" abstract="true">
  <xs:sequence>
    <xs:element name="ccd" type="tns:ccdXml"/>
  </xs:sequence>
  <xs:attribute name="endCadence" type="xs:int" use="required"/>
  <xs:attribute name="sector" type="xs:int" use="required"/>
  <xs:attribute name="startCadence" type="xs:int" use="required"/>
  <xs:attribute name="targetTableId" type="xs:int" use="required"/>
</xs:complexType>

<xs:complexType name="dvCentroidOffsets">
  <xs:sequence>
    <xs:element name="rowOffset" type="tns:dvQuantity"/>
    <xs:element name="columnOffset" type="tns:dvQuantity"/>
    <xs:element name="focalPlaneOffset" type="tns:dvQuantity"/>
    <xs:element name="raOffset" type="tns:dvQuantity"/>
    <xs:element name="decOffset" type="tns:dvQuantity"/>
    <xs:element name="skyOffset" type="tns:dvQuantity"/>
  </xs:sequence>
</xs:complexType>

<xs:complexType name="dvImageCentroid">
  <xs:sequence>
    <xs:element name="row" type="tns:dvQuantity"/>
    <xs:element name="column" type="tns:dvQuantity"/>
    <xs:element name="raDegrees" type="tns:dvDoubleQuantity"/>
    <xs:element name="decDegrees" type="tns:dvDoubleQuantity"/>
  </xs:sequence>
</xs:complexType>

<xs:complexType name="dvDifferenceImagePixelData">
  <xs:sequence>
    <xs:element name="meanFluxInTransit" type="tns:dvQuantity"/>
    <xs:element name="meanFluxOutOfTransit" type="tns:dvQuantity"/>
    <xs:element name="meanFluxDifference" type="tns:dvQuantity"/>
    <xs:element name="meanFluxForTargetTable" type="tns:dvQuantity"/>
  </xs:sequence>
  <xs:attribute name="ccdRow" type="xs:int" use="required"/>
  <xs:attribute name="ccdColumn" type="xs:int" use="required"/>
</xs:complexType>

<xs:complexType name="dvQualityMetric">
  <xs:sequence/>
  <xs:attribute name="attempted" type="xs:boolean" use="required"/>
  <xs:attribute name="valid" type="xs:boolean" use="required"/>
  <xs:attribute name="value" type="xs:float" use="required"/>
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</xs:complexType>

<xs:complexType name="ccdXml" final="extension_restriction">
  <xs:sequence/>
  <xs:attribute name="ccdNumber" type="xs:int" use="required"/>
  <xs:attribute name="cameraNumber" type="xs:int" use="required"/>
</xs:complexType>

<xs:complexType name="dvGhostDiagnosticResults">
  <xs:sequence>
    <xs:element name="coreApertureCorrelationStatistic" type="tns:dvStatistic"/>
    <xs:element name="haloApertureCorrelationStatistic" type="tns:dvStatistic"/>
  </xs:sequence>
</xs:complexType>

<xs:complexType name="dvPlanetCandidate">
  <xs:complexContent>
    <xs:extension base="tns:dvThresholdCrossingEvent">
      <xs:sequence/>
      <xs:attribute name="expectedTransitCount" type="xs:int" use="required"/>
      <xs:attribute name="modelChiSquare2" type="xs:float" use="required"/>
      <xs:attribute name="modelChiSquareDof2" type="xs:int" use="required"/>
      <xs:attribute name="modelChiSquareGof" type="xs:float" use="required"/>
      <xs:attribute name="modelChiSquareGofDof" type="xs:int" use="required"/>
      <xs:attribute name="observedTransitCount" type="xs:int" use="required"/>
      <xs:attribute name="planetNumber" type="xs:int" use="required"/>
      <xs:attribute name="suspectedEclipsingBinary" type="xs:boolean" use="required"/>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>

<xs:complexType name="dvThresholdCrossingEvent">
  <xs:sequence>
    <xs:element name="weakSecondary" type="tns:dvWeakSecondary"/>
  </xs:sequence>
  <xs:attribute name="chiSquare2" type="xs:float" use="required"/>
  <xs:attribute name="chiSquareDof2" type="xs:float" use="required"/>
  <xs:attribute name="chiSquareGof" type="xs:float" use="required"/>
  <xs:attribute name="chiSquareGofDof" type="xs:float" use="required"/>
  <xs:attribute name="epochTjd" type="xs:double" use="required"/>
  <xs:attribute name="maxMultipleEventSigma" type="xs:float" use="required"/>
  <xs:attribute name="maxSesInMes" type="xs:float" use="required"/>
  <xs:attribute name="maxSingleEventSigma" type="xs:float" use="required"/>
  <xs:attribute name="orbitalPeriodInDays" type="xs:float" use="required"/>
  <xs:attribute name="robustStatistic" type="xs:float" use="required"/>
  <xs:attribute name="thresholdForDesiredPfa" type="xs:float" use="required"/>
  <xs:attribute name="trialTransitPulseDurationInHours" type="xs:float" use="required"/>
</xs:complexType>

<xs:complexType name="dvWeakSecondary">
  <xs:sequence>
    <xs:element name="depthPpm" type="tns:dvQuantity"/>
  </xs:sequence>
  <xs:attribute name="maxMes" type="xs:float" use="required"/>
  <xs:attribute name="maxMesPhaseInDays" type="xs:float" use="required"/>
  <xs:attribute name="minMes" type="xs:float" use="required"/>
  <xs:attribute name="mesMad" type="xs:float" use="required"/>
```

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    <xs:attribute name="minMesPhaseInDays" type="xs:float" use="required"/>
    <xs:attribute name="medianMes" type="xs:float" use="required"/>
    <xs:attribute name="nValidPhases" type="xs:int" use="required"/>
    <xs:attribute name="robustStatistic" type="xs:float" use="required"/>
  </xs:complexType>

  <xs:complexType name="dvSecondaryEventResults">
    <xs:sequence>
      <xs:element name="comparisonTests" type="tns:dvComparisonTests"/>
      <xs:element name="planetParameters" type="tns:dvPlanetParameters"/>
    </xs:sequence>
  </xs:complexType>

  <xs:complexType name="dvComparisonTests">
    <xs:sequence>
      <xs:element name="albedoComparisonStatistic" type="tns:dvStatistic"/>
      <xs:element name="tempComparisonStatistic" type="tns:dvStatistic"/>
    </xs:sequence>
  </xs:complexType>

  <xs:complexType name="dvPlanetParameters">
    <xs:sequence>
      <xs:element name="geometricAlbedo" type="tns:dvQuantity"/>
      <xs:element name="planetEffectiveTemp" type="tns:dvQuantity"/>
    </xs:sequence>
  </xs:complexType>

  <xs:simpleType name="planetModelFitType">
    <xs:restriction base="xs:string">
      <xs:enumeration value="ALL"/>
      <xs:enumeration value="ODD"/>
      <xs:enumeration value="EVEN"/>
      <xs:enumeration value="REDUCED_PARAMETER"/>
      <xs:enumeration value="TRAPEZOIDAL"/>
    </xs:restriction>
  </xs:simpleType>

</xs:schema>
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