NASA/TM—2018–220036

TESS Science Data Products Description Document
EXP-TESS-ARC-ICD-0014 Rev D

Peter Tenenbaum
SETI Institute, Mountain View California
Ames Research Center, Moffett Field, California

Jon M. Jenkins
Ames Research Center, Moffett Field, California

July 2018

CM FOREWORD

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Questions or comments concerning this document should be addressed to:

EHPD Configuration Management Office
Mail Stop 460
Goddard Space Flight Center
Greenbelt, Maryland 20771

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 Processing Handbook: KSCI-19081-002, Jenkins, J. M. (Ed.)

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
Light curves	tess*yyyydddhhmmss*-s*sctr*-*tid*-*scid*-*cr*_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
Cotrending basis vectors	tess*yyyydddhhmmss*-s*sctr*-*cam*-*ccd*-*scid*-*cr*_cbv.fits	FITS	8
Full data validation report	tess*yyyydddhhmmss*-s*startsctr*-*sendsctr*-*tid*-*pin*_dvr.pdf	PDF	12
TCE summary report	tess*yyyydddhhmmss*-s*startsctr*-*sendsctr*-*tid*-*pn*-*pin*_dvs.pdf	PDF	11
Data validation results	tess*yyyydddhhmmss*-s*startsctr*-*sendsctr*-*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*-*sendsctr*-*tid*-*pin*_dvt.fits.gz	FITS+GZIP	14

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.

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	The pixels' CCD column coordinate.
3	RAWY	16-bit signed integer	pixels	The pixels' 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

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.

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.

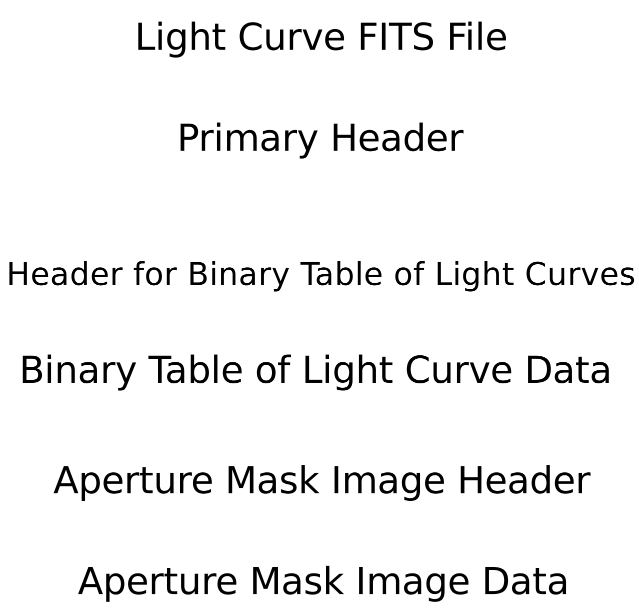

Figure 3: Light curve FITS file composition

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
ORIGIN = 'NASA/Ames'/ institution responsible for creating this file	C9	const
DATE = / file creation date.	C10	2013-07-12
DATE-OBS= / TSTART as UTC calendar date	C24	2013-01-12T14:06:28.100Z
DATE-END= / TSTOP as UTC calendar date	C24	2013-04-08T11:17:10.783Z
CREATOR = / pipeline job and program used t	C34	540344 FluxExporter2PipelineModule
PROCVER = / SW version	C51	cf5f6d9db9889c0259ad09f r-4.0.1
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	I2	1
CCD = / CCD number	I2	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	I4	5
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 2013-07-12T22:34:06Z	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 28.
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	C15	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
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 BJD	R8	1472.086752
TSTOP = / observation stop time in BJD	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	2013-01-12T14:06:28.100Z
DATE-END= / TSTOP as UTC calendar date	C24	2013-04-08T11:17:10.783Z
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> / [seconds] 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 2013-07-12T22:34:06Z	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.