T'DA Data Release Notes

Data Release 4 for TESS Sectors 1+2

TASOC-0004-01

TESS Data for Asteroseismology (T'DA)

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This report is prepared by the Coordinated Activity T'DA of the TESS Asteroseismic Science Consortium (TASC), which is responsible for light curve preparation for asteroseismology.

Raw photometry for 2-min (TPF) and 30-min (FFI) cadence targets from TESS Sectors 1 and 2 are released with this note. The data summarised in this report can be queried via the TESS Asteroseismic Science Operation Center (TASOC)[1] data base. We are in the process of also making the data available as a High Level Science Product (HLSP) on The Mikulski Archive for Space Telescopes (MAST)[2].

We are working hard on the implementation of the co-trending component of the T'DA pipeline, but release raw photometry now to allow the community to have a first look at the full data sets. The TASOC pipeline used to generate the data is open source and available on GitHub[3].

Before using data from this release we strongly recommend you read through this note, and consult the TESS Instrument Handbook (Vanderspek et al. 2018).

[1] https://tasoc.dk
[2] https://archive.stsci.edu/tess/
[3] https://github.com/tasoc

These notes are the collective effort of the 100+ members of the TESS Data for Asteroseismology (T'DA) Coordinated Activity, lead by

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Pointing

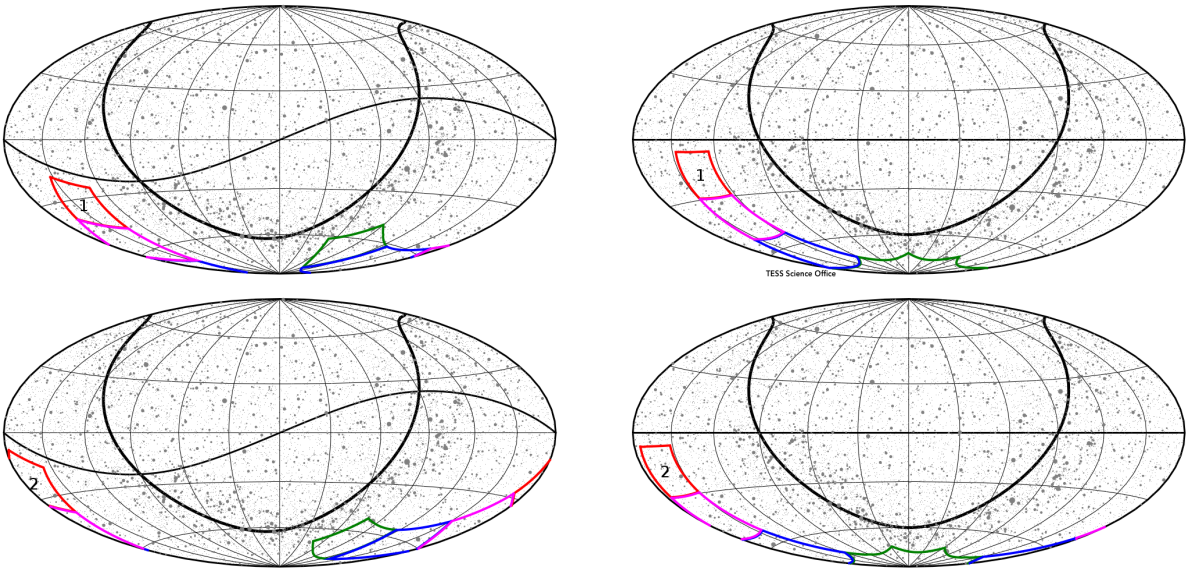

Figure 1: Pointing and FOV for Sector 1+2 observations in celestial coordinates (left) and ecliptic coordinates (right). See Table 3 for detailed pointing information. Camera 1 (red) is annotated by the Sector for reference. Thin black line is ecliptic, thick black line is the galactic plane. Illustrations adopted from tess.mit.edu.

Table 1: Information on timing of observations in Sectors 1+2.

Sector	Orbits	Cadence	First Cadence (TBJD)	Last Cadence (TBJD)	First Candece (UTC)	Last Cadence (UTC)	Nstart	Nend	Ntot
1	9–10	1800s	1325.33	1353.16	25-07-2018 19:37:20	22-08-2018 16:06:51	4697	6033	1336
1	9–10	120s	1325.30	1353.18	25-07-2018 19:09:59	22-08-2018 16:21:27	70444	90519	20075
2	11–12	1800s	1354.11	1381.50	23-08-2018 14:36:05	20-09-2018 00:06:27	6079	7393	1314
2	11–12	120s	1354.11	1381.52	23-08-2018 14:32:48	20-09-2018 00:27:10	91186	110922	19736

Note. – TBJD = "TESS Barycentric Julian Date" (BJD - 2457000); "Nstart" is the cadence number of the first observation; "Nend" is he cadence number of the last observation; "Ntot" is the total number of cadences.

Table 2: Information on the Sector 1 FOV.

	Sector	RA (deg)	DEC (deg)	Roll (deg)	Ecliptic Longitude (deg)	Ecliptic Latitude (deg)
Bore sight	1	352.6844	-64.8531	-137.8468	315.8	-54
Camera 1	1	324.5670	-33.1730	–	315.8	-18
Camera 2	1	338.5766	-55.0789	–	315.8	-42
Camera 3	1	19.4927	-71.9781	–	315.8	-66
Camera 4	1	90.0042	-66.5647	–	315.8	-90

Note – "Bore sight" is the spacecraft centre pointing vector, at the middle of the camera array, midway between cameras 2 and 3. All coordinates are in degrees (J2000).

Table 3: Information on the Sector 2 FOV.

	Sector	RA (deg)	DEC (deg)	Roll (deg)	Ecliptic Longitude (deg)	Ecliptic Latitude (deg)
Bore sight	2	16.5571	-54.0160	-139.5665	343	-54
Camera 1	2	352.0795	-23.0645	–	343	-18
Camera 2	2	5.6956	-44.3080	–	343	-42
Camera 3	2	33.3558	-62.1878	–	343	-66
Camera 4	2	90.0022	-66.5654	–	343	-90

Note – "Bore sight" is the spacecraft centre pointing vector, at the middle of the camera array, midway between cameras 2 and 3. All coordinates are in degrees (J2000).

Targets

For this release both Full-Frame Images (FFI; 30-min) and Target Pixel Files (TPF; 2-min) for Sectors 1+2 have been analysed. Table 4 gives the number of data sets released for the individual sectors, and the number of targets processed. The total number of processed targets is higher that the number of released data sets, because a target being processed might have already been identified as being contained within the aperture of a brighter target. In such a case the fainter target will not be assigned its own data set, but be included in the contamination metric of the brighter target. We have currently limited the FFI processing to a TESS magnitude of 15.

The magnitude distribution for extracted targets is shown in Figure 2.

Data format

Data file format version: 1.4

The primary data format for extracted and corrected light curves is FITS (Flexible

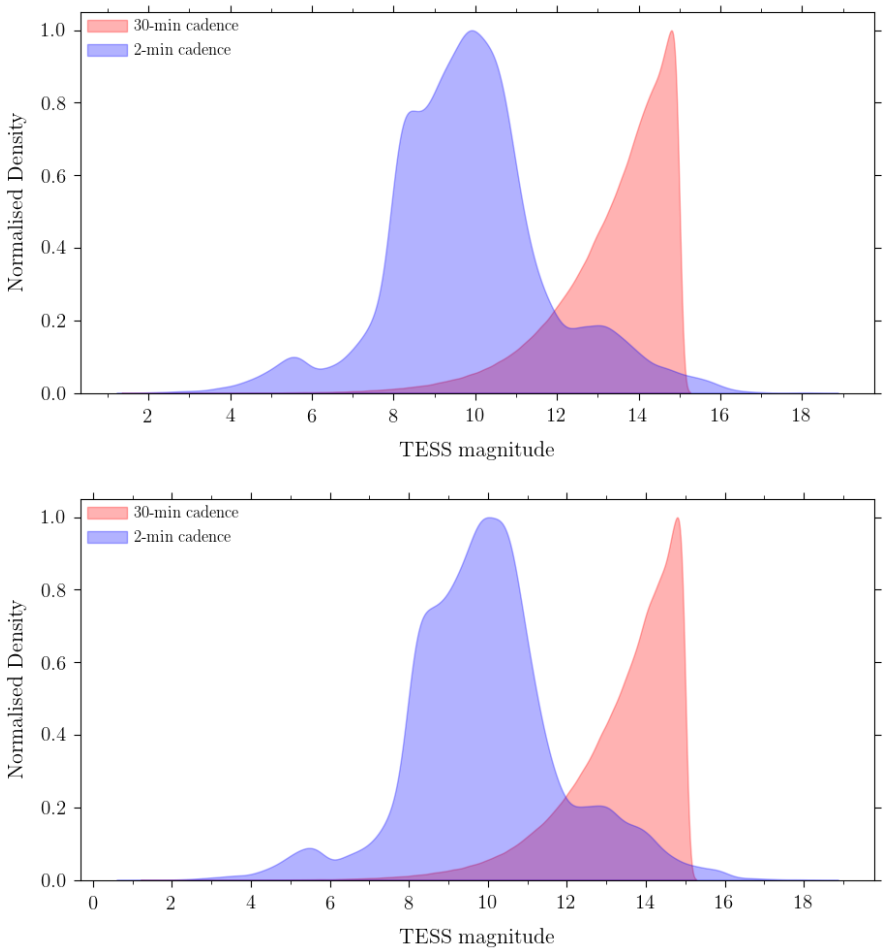

Figure 2: Magnitude distribution for stars covered by this release, normalised to a maximum of 1. Top: Sector 1 targets; Bottom: Sector 2 targets.

Table 4: Number of data sets released and targets processed.

Sector	FFI	TPF	Total	Total Processed
1	937837	15672	953509	1382279
2	764282	15785	780067	1112804
1+2	364814	6969	371783	—

Note – "Total" refers to the sum of released "FFI" and "TPF" targets, while "Total Processed" gives the total number of targets run through the pipeline. The third line indicates the number of targets observed in both Sectors 1 and 2.

Image Transport System), and is provided in a compressed gzip format. A FITS light curve file produced by T'DA and stored on TASOC will be named following the structure:

`tess{TIC ID}-s{sector}-c{cadence}-dr{data release}-v{version}-tasoc_lc.fits.gz`

The "TIC ID" (TESS Input Catalog identifier) of the star is zero (pre-)padded to 11 digits, the "sector" is be zero (pre-)padded to 2 digits, the "cadence" is in seconds and zero (pre-)padded to 4 digits, the "data release" is zero (pre-)padded to 2 digits and refers to the official release of the data from the mission, the "version" is zero (pre-)padded to 2 digits and refers to the TASOC data release (counting from 1). As an example, the star TIC 62483237, observed in sector 1 in 120 second cadence and part of the first data release and first TASOC processing will have the name:

`tess00062483237-s01-c0120-dr00-v01-tasoc_lc.fits.gz`

Each light curve FITS file has four extensions: a "`Primary`" header with general information on the star and the observations; a "`LIGHTCURVE`" table with time, raw flux, corrected flux, etc.; a "`SUMIMAGE`" with an image given by the time-averaged pixel data; and an "`APERTURE`" image. The information provided in the FITS file is intended to mimic that provided in the official TESS products – please consult the "TESS Science Data Products Description"[4] for more information.

Note, targets processed with the Halo photometry option (see the `PHOTMET` key in primary FITS header for the adopted photometry method) have the additional extension "`WEIGHTMAP`" in their FITS file, which gives the weight assigned to each pixel in the Halo photometry method.

From file version 1.3 additional columns have been added to the "`LIGHTCURVE`" table containing quality flags. One of these, "`PIXEL_QUALITY`", contains the quality flag provided by the TESS team. For an explanation to the bit values used here see the TESS Archive Manual. The column "`QUALITY`" gives the quality flags set by the TASOC pipeline, which have the following meanings:

[4] https://archive.stsci.edu/missions/tess/doc/EXP-TESS-ARC-ICD-TM-0014.pdf

With file version 1.4 a few additional keywords have been added to the "`LIGHTCURVE`" header. Of particular notice is the "`XPOSURE`" key, which gives the actual exposure of the observations, taking into account dead-time from readout and from the cosmic ray mitigation (see Berta-Thompson et al. 2015; Vanderspek et al. 2018). Using this value for the integration of measured flux will, for instance, be important for the calculation of signal apodization.

Table 5: TASOC "`QUALITY`" flags.

Bit digit (n)	Value ($2^{(n-1)}$)	Description
0	0	All is OK
1	1	Data point flagged as bad based on quality flag by TESS team (their bits 1, 2, 4, 8, 32, 64, and/or 128)
2	2	Manually excluded by TASOC team
3	4	Data point has been sigma-clipped
4	8	A additive constant jump correction has been applied
5	16	A additive linear jump correction has been applied
6	32	A multiplicative constant jump correction has been applied
7	64	A multiplicative linear jump correction has been applied
8	128	Data point has been interpolated

With this file version a photometric data validation (`DATAVAL`) flag has also been added to the "`Primary`" header. These flags have the following meanings:

Table 6: TASOC "`DATAVAL`" flags.

Bit digit (n)	Value ($2^{(n-1)}$)	Description
0	0	All is OK
2	2	Star has lower flux than given by magnitude relation
5*	16	Star has minimum 2x2 mask
6*	32	Star has smaller mask than general relation
7*	64	Star has larger mask than general relation
9	256	PTP-MDV lower than theoretical
10	512	RMS lower than theoretical
11*	1024	Invalid Contamination
12	2048	Contamination high
13*	4096	Invalid mean flux
14*	8192	Invalid Noise

Bits marked with a "*" in Table 6 have been used internally to identify targets to hold back from being released – these targets will be scrutinised further and may be made available with a subsequent release. Therefore, only non-* bits will actually appear in the released data. The boundaries used for the flags are given in Figures 3–7. We note that a target may have an aperture of 4 pixels (i.e. the minimum allowed aperture) without being flagged with bit 5, because this bit is only set when the aperture definition has failed in some manner and has defaulted to the minimum 2x2.

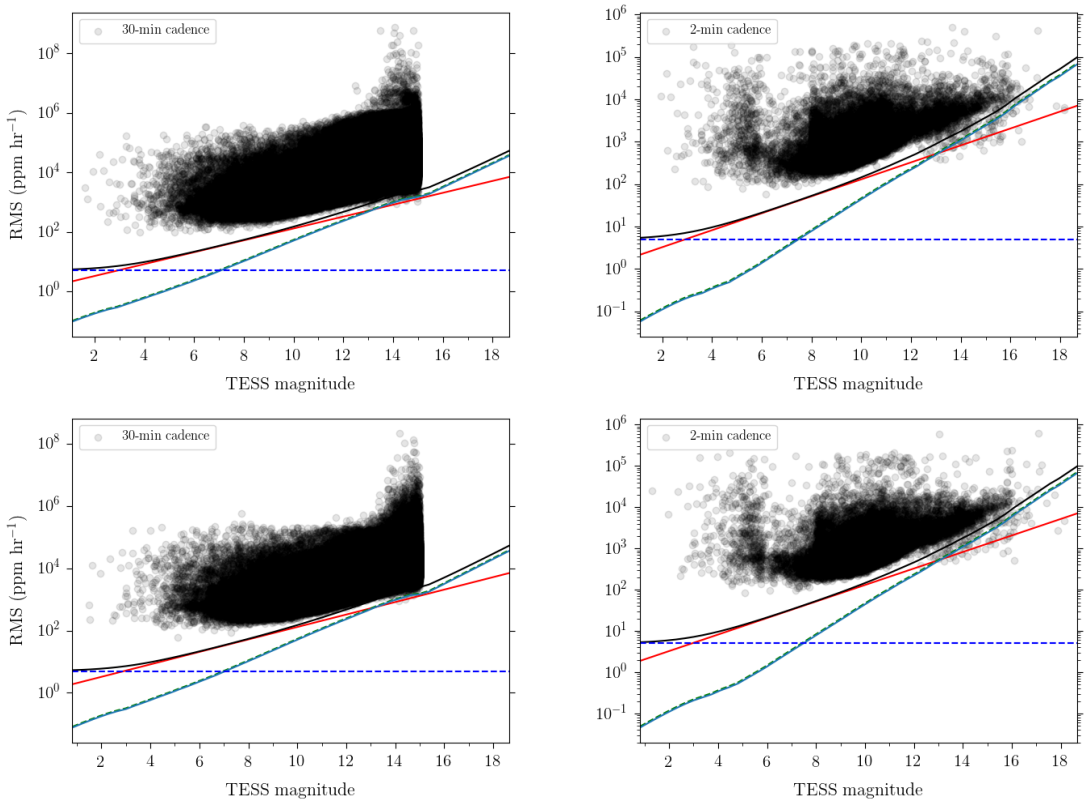

Figure 3: RMS noise on 1 hour time scale for stars covered by this release. The lines give the predicted noise estimates following Sullivan et al. (2015) (red full: shot noise; yellow full: read noise; green dashed: zodiacal noise; black full: total noise).

Make sure to check the photometric data validation (`DATAVAL`) flag of any specific star under study, as well as the aperture and sum-images.

Photometry

Photometry pipeline version: 3.0.0

The photometric quality of the reduced (raw) light curves is summarised in Figures 3-4. Figure 3 shows the 1 hour root-mean-square (RMS) noise in parts-per-million (ppm) as a function of TESS magnitude; Figure 4 gives the point-to-point Median-Differential-Variability (MDV) (corresponding to RMS on time scale of observing cadence). For the expected-noise curves we used relations for mean flux (Figure 7) and number of aperture pixels (Figure 5) as a function of TESS magnitude derived from the processed data. As seen the raw photometry generally follow the expected noise characteristics.

Figure 5 shows the sizes of the defined apertures as a function of TESS magnitude.

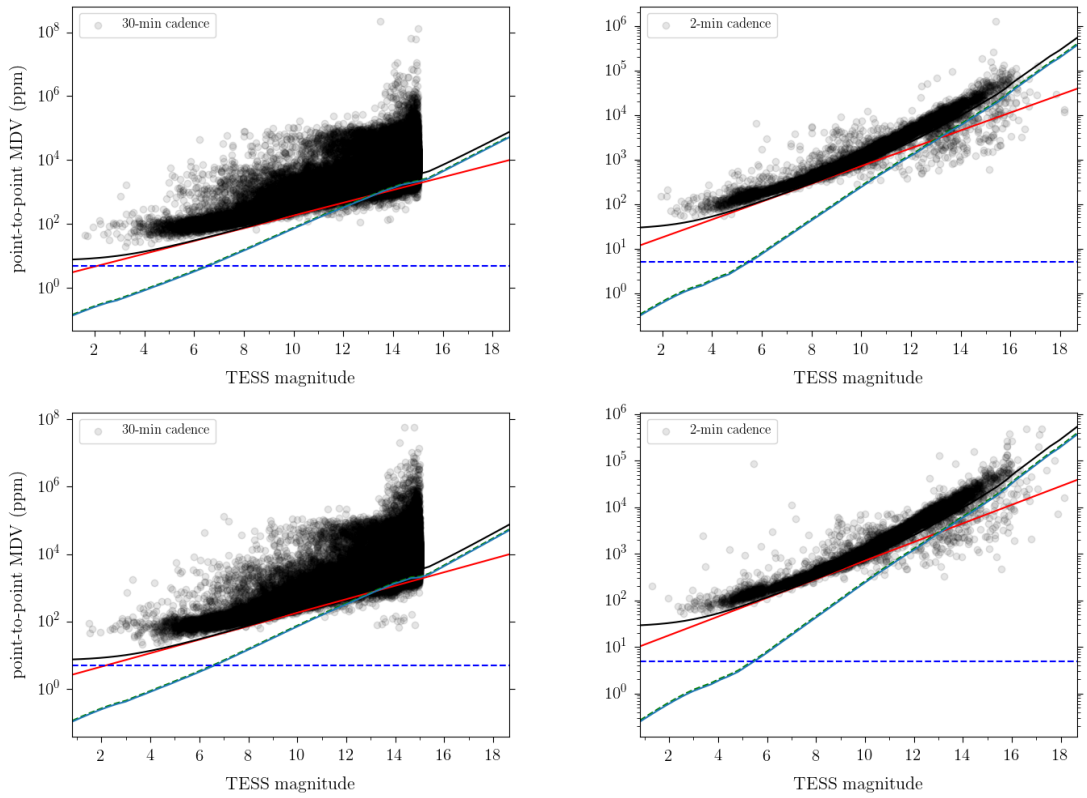

Figure 4: Point-to-point Median-Differential-Variability (MDV) for stars covered by this release (left: 1800 sec cadence; right: 120 sec cadence). The lines give the predicted noise estimates following Sullivan et al. (2015) (red full: shot noise; yellow full: read noise; green dashed: zodiacal noise; black full: total noise).

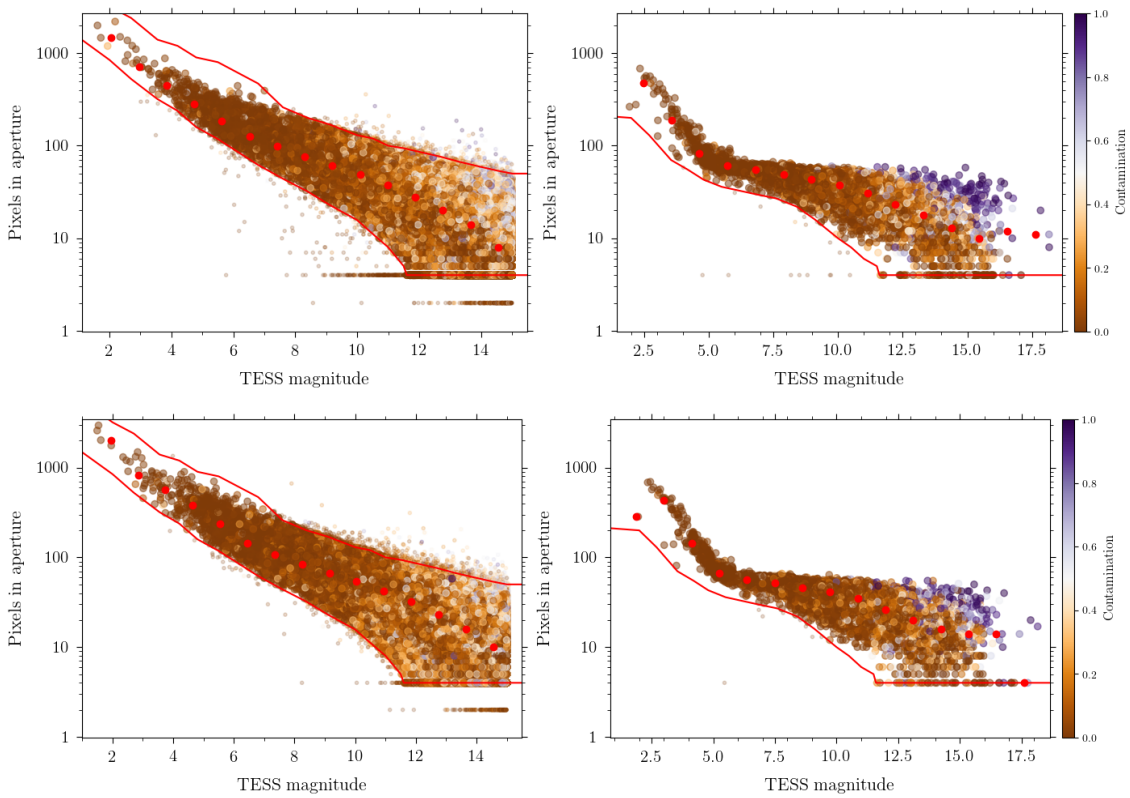

Figure 5: Pixel in apertures as a function of TESS magnitude for Sector 1 (top) and 2 (bottom). The left panels show apertures for 30-min cadence FFI targets, while the right panels show apertures for 2-min TPF target. The individual points are colour-coded by the contamination. The full red lines give the boundaries for the data validation. The red circles give the median binned values for the aperture sizes.

A minimum aperture of 4 pixels has been adopted for the TASOC processing – targets with smaller apertures in Figure 5 are situated on CCD edges and have not been released (cf. Table 6). The full red lines give the boundaries used in the data validation (affected target plotted with small markers). For 2-min cadence targets only a lower bound is used because the upper aperture limit is typically set by the downloaded stamp size. One should be aware of contamination (see below), especially at high magnitudes – as seen from Figure 5 the faint targets with larger-than-average apertures are typically significantly contaminated.

Figure 6 shows the contamination metric (given in the FITS light curve header as `AP_CONT`) for each star as a function of TESS magnitude. Make sure to keep this value in mind when interpreting signals extracted for a given star – the metric gives the fraction of flux in the light curve contributed from stars other than the main one, calculated from the magnitudes of identified stars found within the defined aperture of the main star.

Note therefore that flux in the aperture from a neighbouring star that does not lie within the aperture is not taken into account. The World Coordinate Solution (WCS) provided with the aperture in the FITS file can be used to identify which other stars fall within the aperture of the main star.

Figure 7 shows the relation between the extracted mean flux for a star and it's TESS magnitude. This relation can be described well by the relation:

$$\langle \mathrm{Flux} \rangle \approx 10^{-0.4(\mathrm{T_{mag}}-20.54)} \,. \tag{1}$$

This relation is used for stars with photometry extracted using the Halo method, in order to obtain the correct relative amplitudes. The fit was obtained by considering only targets with a contamination below 0.15, and weighting the individual data points be be inverse of the contamination.

Figure 8 shows the stamp sizes for the cut-outs made around each processed target. For TPF data the stamp provided by the TESS mission is always used. In cases where a defined aperture touches the edge of the pixel stamp (for FFI data), the stamp is allowed to re-size by a in one or both directions by a fixed step of 5 pixels, and the aperture is defined anew. The starting guess for the stamp size (width and height) has been optimised to reduce the number of required re-sizes and thereby also processing time. The maximum number of allowed re-sizes is current set to 5. FFI targets seen to have heights/widths falling below the well-defined relation are found on the edges of the CCDs and, hence have a limited height/width.

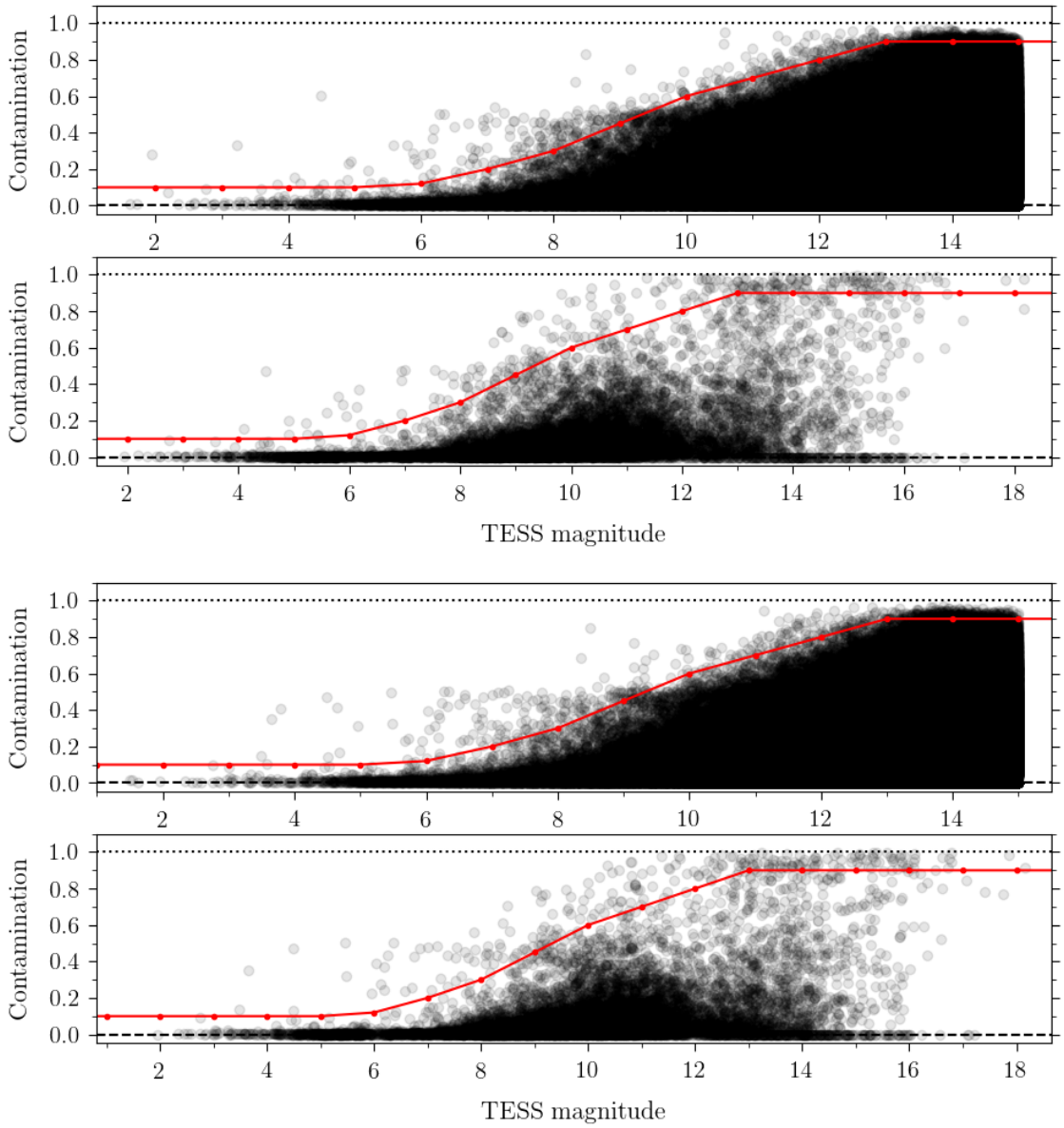

Figure 6: Contamination metric as a function of TESS magnitude in Sectors 1 (top two panels) and 2 (bottom two panels). For each Sector the top (bottom) panel gives contamination for FFI (TPF) data. The red full curve gives the boundary used in the photometry data validation.

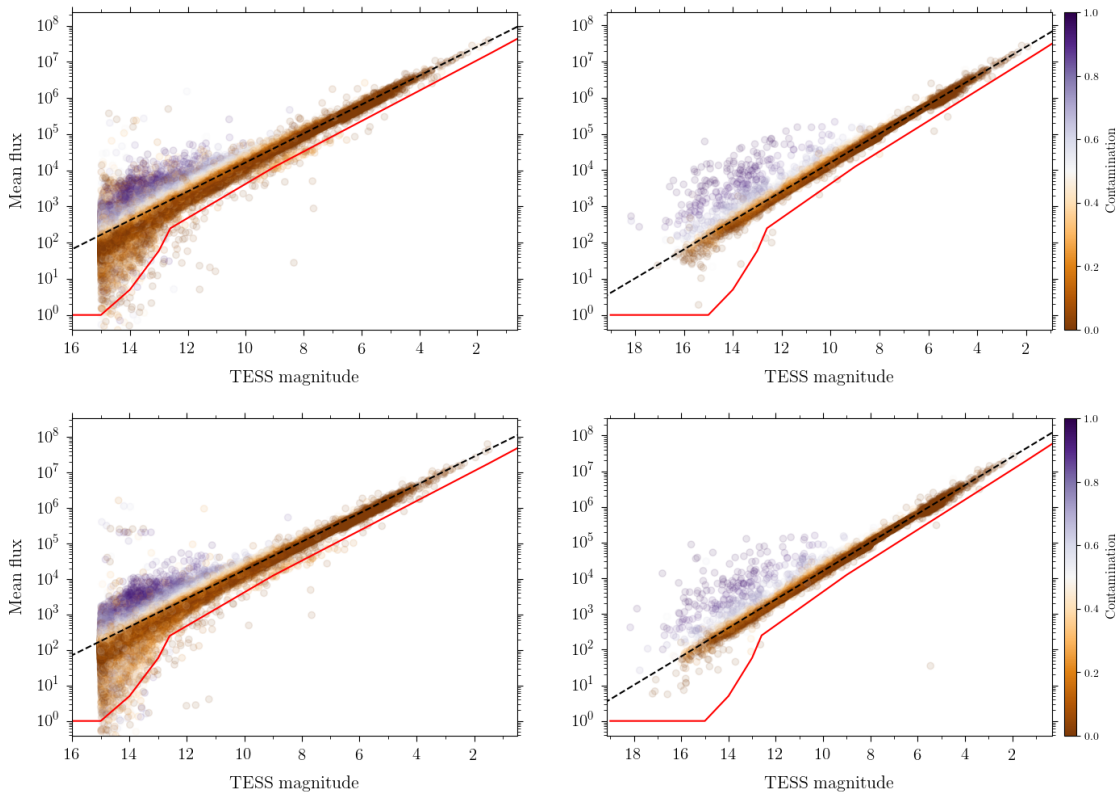

Figure 7: Relation between extracted flux from aperture and the TESS magnitude, colour-coded by contamination. The top (bottom) panels show the values for Sector 1 (2) targets. The left (right) panels show values for 30-min FFI (2-min TPF) data. The black dashed line gives the individual relations obtained following the prescription in Equation 1. The full red line gives the adopted boundary for the data validation.

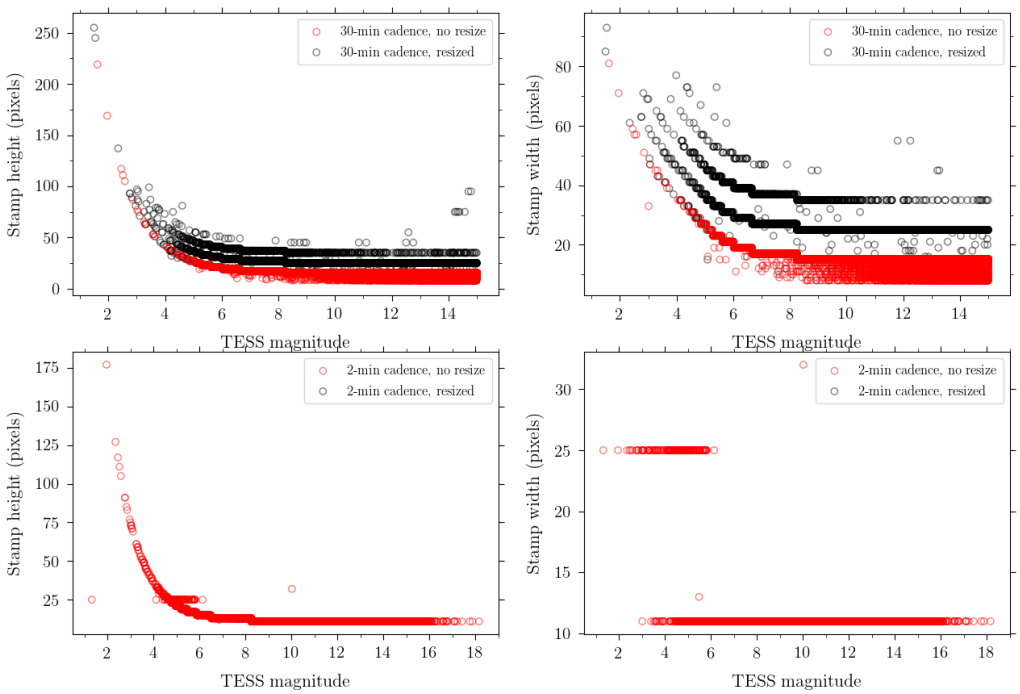

Figure 8: Relation between stamp height (left) and width (right) as a function of TESS magnitude for Sector 2 targets (similar for Sector 1). The top (bottom) panels show the values for 30-min FFI (2-min TPF) data. Red points indicated stamps that have not been re-sized (and show the starting value), while black points show values for re-sized stamps.

Corrections

No corrections have been applied to data released with this note.

References

Berta-Thompson, Z. K., Levine, A., & Sullivan, P. 2015, Cosmic Ray Rejection Strategies for TESS, Tech. rep.

Sullivan, P. W., Winn, J. N., Berta-Thompson, Z. K., et al. 2015, ApJ, 809, 77

Vanderspek, R., Doty, J. P., Fausnaugh, M., et al. 2018, TESS Instrument Handbook, Tech. rep., Kavli Institute for Astrophysics and Space Science, Massachusetts Institute of Technology. https://archive.stsci.edu/missions/tess/doc/TESS_Instrument_Handbook_v0.1.pdf