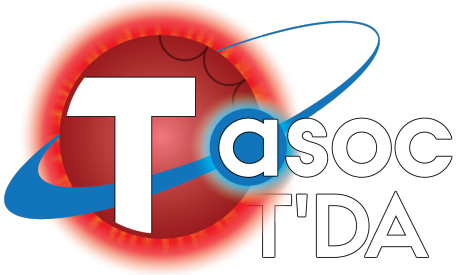


T'DA Data Release Notes

Data Release 5 for TESS Sectors 1–6

TASOC-0005-01

TESS Data for Asteroseismology (T'DA)

Rasmus Handberg, Derek Buzasi & Mikkel N. Lund, Editors

February 18, 2021

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 1–6 are released with this note, in addition to systematics corrected light curves. This is the first TASOC data release containing systematic corrected light curves with two different correction methods, resulting in over 12 million released light curves.

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]. 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, the T'DA pipline papers (Handberg et al. 2021; Lund et al. 2021), 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

Handberg, Rasmus, T'DA Chair, TASC SC.
Buzasi, Derek, T'DA Chair, TASC SC.
Tkachenko, Andrew, T'DA sub-chair for classification, TASC SC.
White, Timothy R., T'DA sub-chair for saturated stars.

The following members deserve a special notice for their important contributions to the T'DA efforts:

Armstrong, David
Audenaert, Jeroen
Bedding, Timothy R.
Bell, Keaton
Bugnet, Lisa
Carboneau, Lindsey
Chontos, Ashley
Garcia, Rafael
Hall, Oliver
Hon, Marc T. Y.
Kuszlewicz, James
Lund, Mikkel N.
Molnár, László
Pereira, Filipe
Pope, Benjamin

Pointing

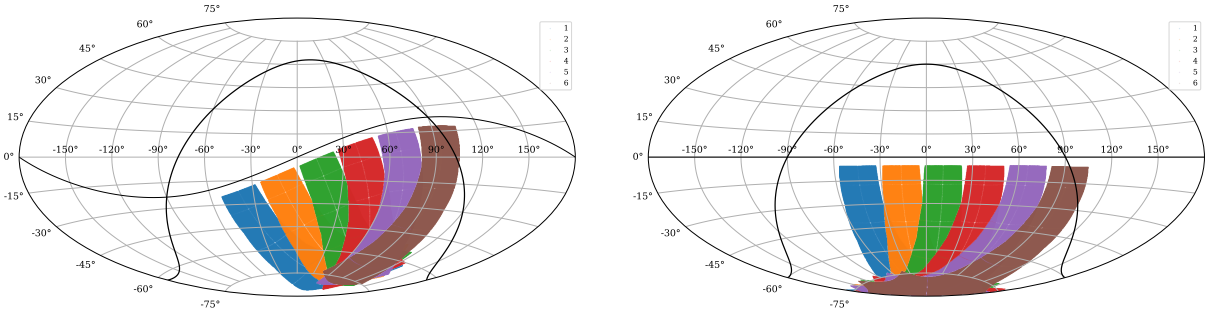


Figure 1: Pointing and FOV observations in equatorial coordinates (left) and ecliptic coordinates (right). See Table 1 for detailed pointing information. Thin black line is ecliptic, thick black line is the galactic plane.

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

Table 1: Information on the FOV of Sectors 1–6 . All coordinates are in degrees.

Sector	Camera 1		Camera 2		Camera 3		Camera 4	
	RA	Dec	RA	Dec	RA	Dec	RA	Dec
1	324.5670	-33.1730	338.5766	-55.0789	19.4927	-71.9781	90.0042	-66.5647
2	352.0795	-23.0645	5.6956	-44.3080	33.3557	-62.1878	90.0021	-66.5654
3	17.1728	-12.2229	28.4640	-33.9055	47.3926	-53.8504	89.9996	-66.5654
4	41.8084	-2.7600	49.8806	-25.4686	61.8676	-47.5211	89.9973	-66.5649
5	67.0563	3.5339	71.1053	-20.1344	76.6971	-43.6751	89.9956	-66.5642
6	92.8145	5.4079	92.3086	-18.5869	91.6247	-42.5799	89.9947	-66.5632

Table 2: Information on timing of observations in Sectors 1–6 .

Sector	Start (TJD)	End (TJD)	Start (UTC)	End (UTC)
1	1325.29198	1353.17698	2018-07-25 19:00:27	2018-08-22 16:14:51
2	1354.10022	1381.51380	2018-08-23 14:24:19	2018-09-20 00:19:52
3	1382.03906	1409.38748	2018-09-20 12:56:15	2018-10-17 21:17:58
4	1410.89894	1436.84837	2018-10-19 09:34:28	2018-11-14 08:21:39
5	1437.82486	1464.39976	2018-11-15 07:47:48	2018-12-11 21:35:39
6	1465.21182	1490.04279	2018-12-12 17:05:01	2019-01-06 13:01:37

Note. – TJD = "TESS Julian Day" = JD - 2457000.

Targets

For this release both Full-Frame Images (FFI; 30-min) and Target Pixel Files (TPF; 2-min) for Sectors 1–6 have been analysed. Table 3 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.

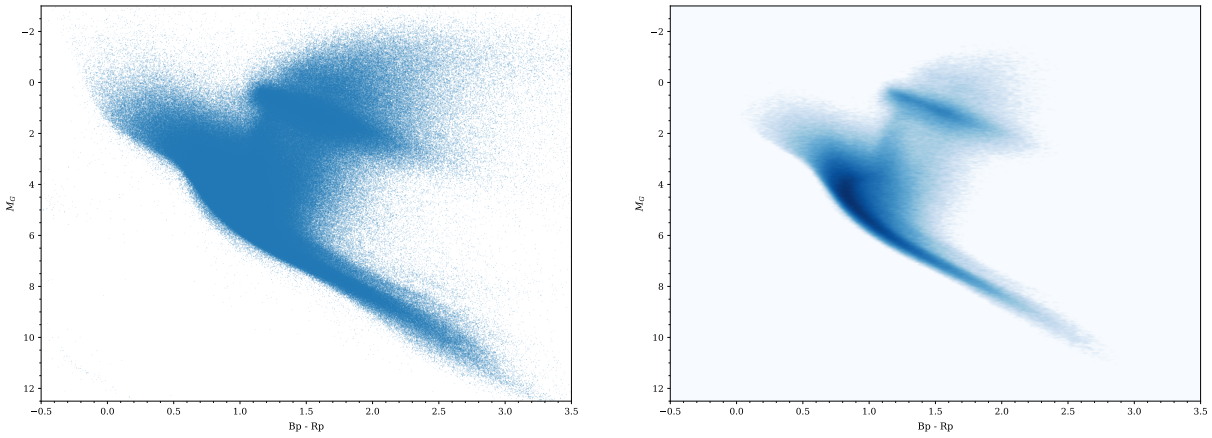


Figure 2: Color-magnitude diagram for the extracted targets in Gaia DR2 colors. Left panel shows the actual positions of each individual target, while the right shows the same as a distribution using a Gaussian kernel density estimation.

Note that we are extracting more targets in the 2-min cadence than the observed number of targets (normally ∼20,000). This is due to the TASOC photometric pipeline being able to extract "secondary" targets if they falls within the observed pixels of another primary target.

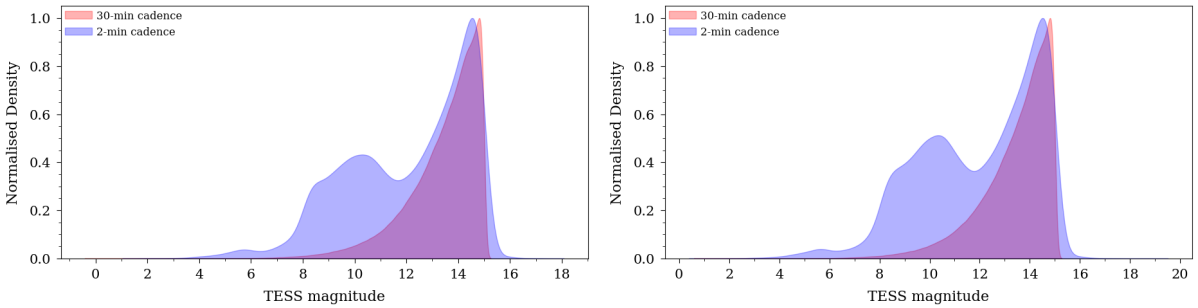
Table 3: Number of data sets released and targets processed.

Sector	Cadence (s)	Processed	Extracted	CBV	Ensemble
1	1800	1,299,346	951,403	951,403	950,181
2	1800	1,042,017	775,988	775,988	774,932
3	1800	979,317	726,782	726,782	723,474
4	1800	1,046,573	782,508	782,508	774,983
5	1800	1,386,086	1,002,881	1,002,880	1,001,101
6	1800	2,866,753	1,652,469	1,652,469	1,651,269
1	120	64,261	34,241	34,241	–
2	120	57,724	31,787	31,787	–
3	120	56,306	31,267	31,267	–
4	120	70,791	40,027	40,027	–
5	120	82,269	44,117	44,117	–
6	120	128,845	59,886	59,886	–
Total		9,080,288	6,133,356	6,133,355	5,875,940

Note – "Processed" and "Extracted" refers to the number of targets processed by the photometric pipeline and the number of extracted raw light curves from them. "CBV" and "Ensemble" refers to the number of released targets in using each correction method. The last line indicates the number of targets observed in all sectors.

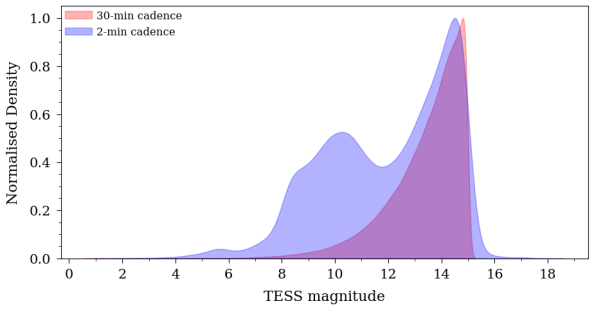
The magnitude distributions for extracted targets is shown in Figure 3.

Figure 3: Magnitude distribution for stars covered by this release, normalised to a maximum of 1.

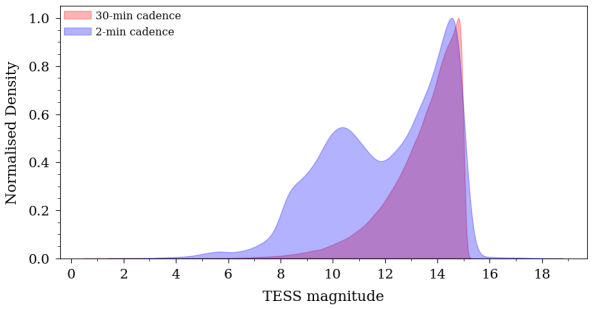


(a) Sector 1.

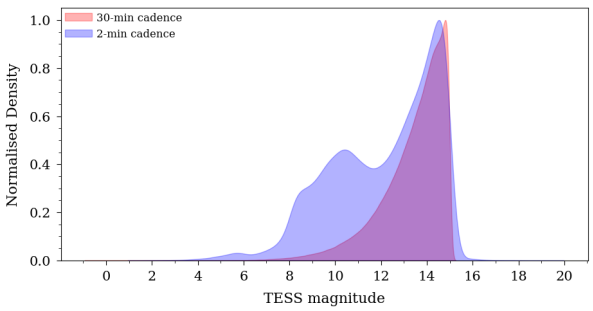
(b) Sector 2.



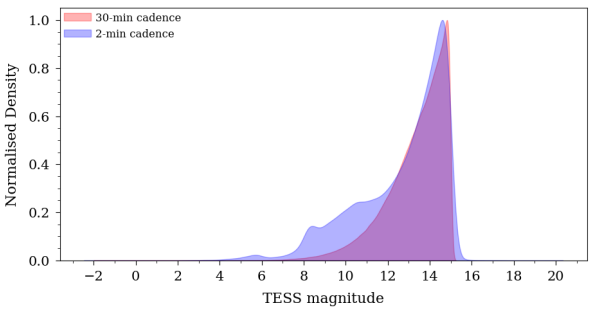
(c) Sector 3.



(d) Sector 4.



(e) Sector 5.



(f) Sector 6.

Photometry

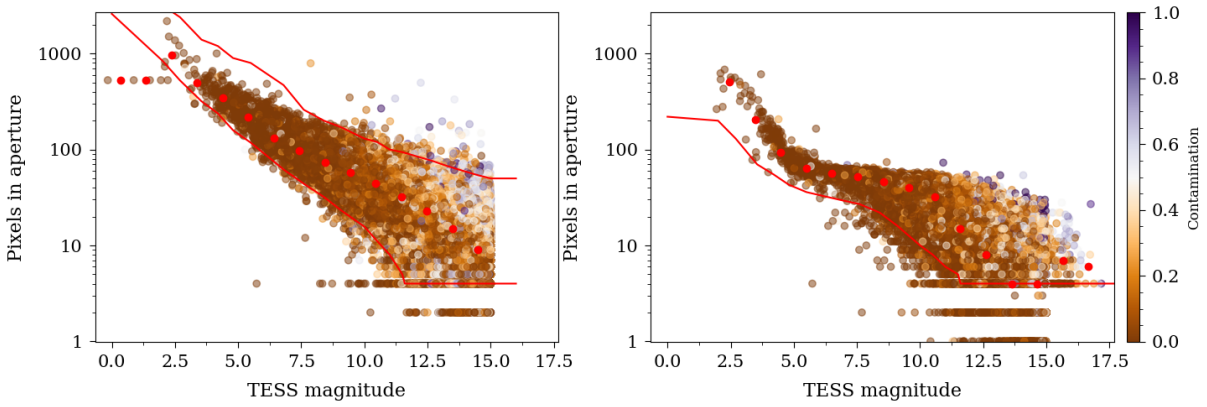
Photometry pipeline version: 5.1

See Handberg et al. (2021) for details.

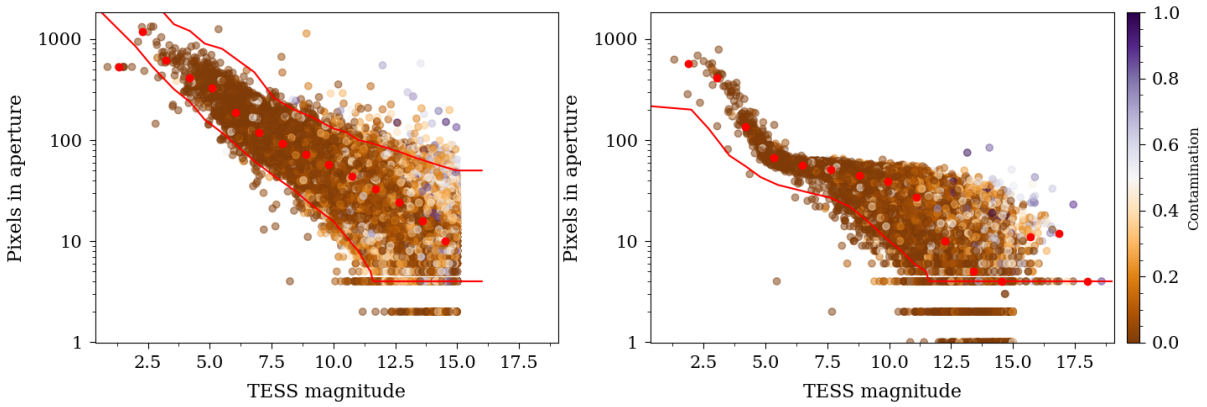
Figure 4 shows the sizes of the defined apertures as a function of TESS magnitude. A minimum aperture of 4 pixels has been adopted for the TASOC processing – targets with smaller apertures in Figure 4 are situated on CCD edges and have not been released. The full red lines give the boundaries used in 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 4 the faint targets with larger-than-average apertures are typically significantly contaminated.

Figure 5 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.

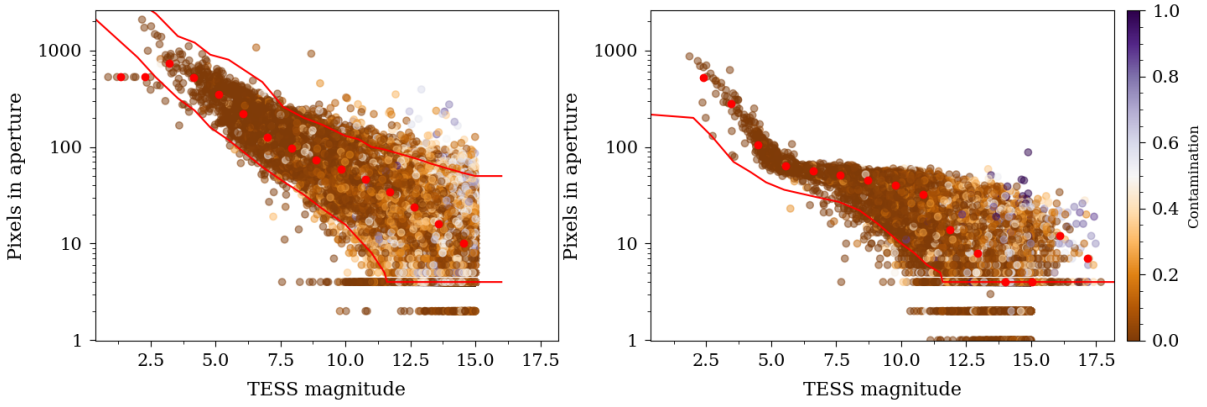
Figure 4: Pixel in apertures as a function of TESS magnitude. The left panels show apertures for 30-min cadence FFI targets, while the right panels show apertures for 2-min TPF target. The individual points are colour-coded by the contamination. The full red lines give the boundaries for the data validation. The red circles give the median binned values for the aperture sizes.



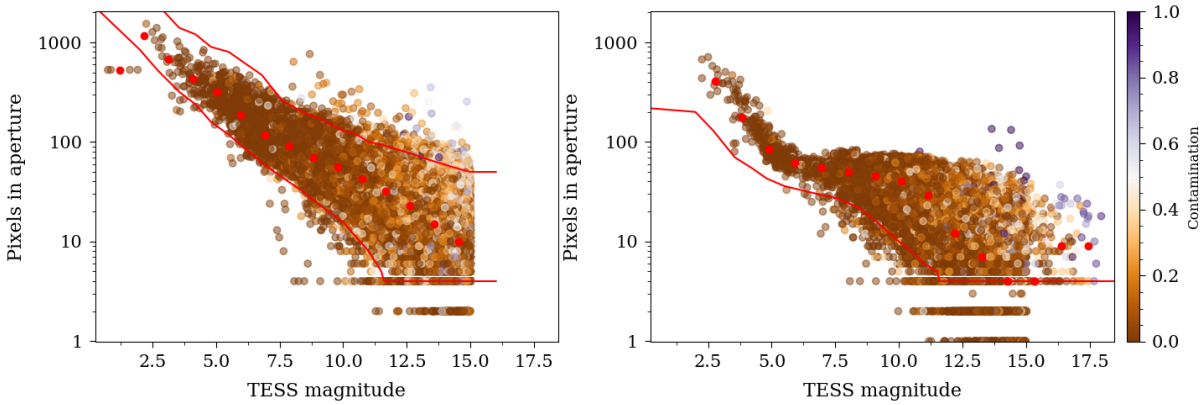
(a) Sector 1.



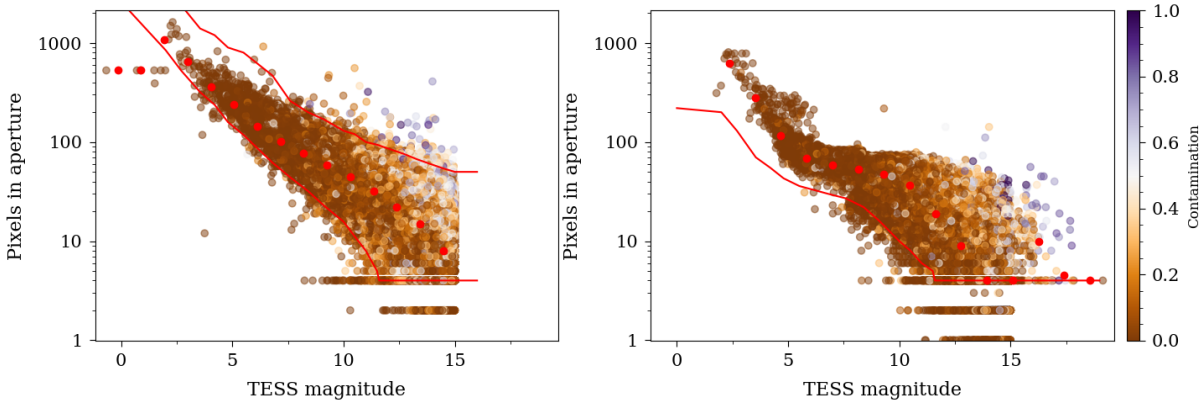
(b) Sector 2.



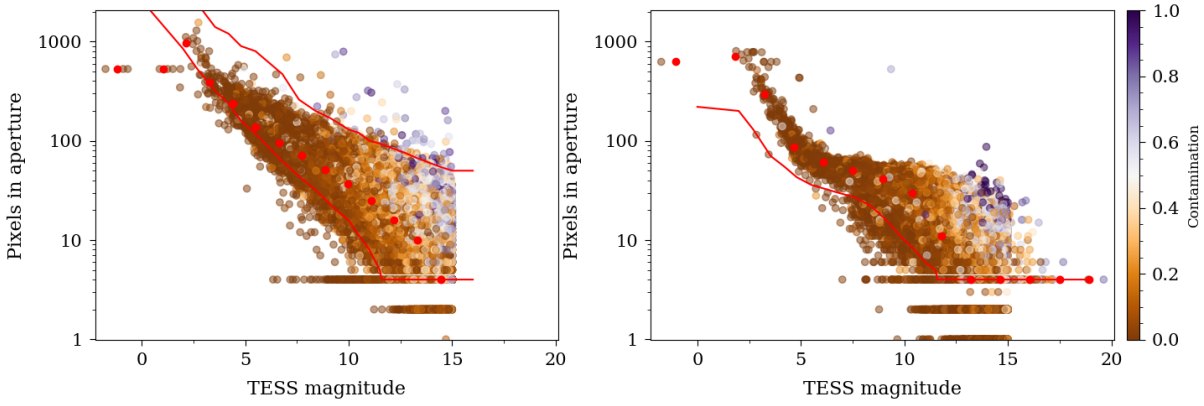
(c) Sector 3.



(d) Sector 4.

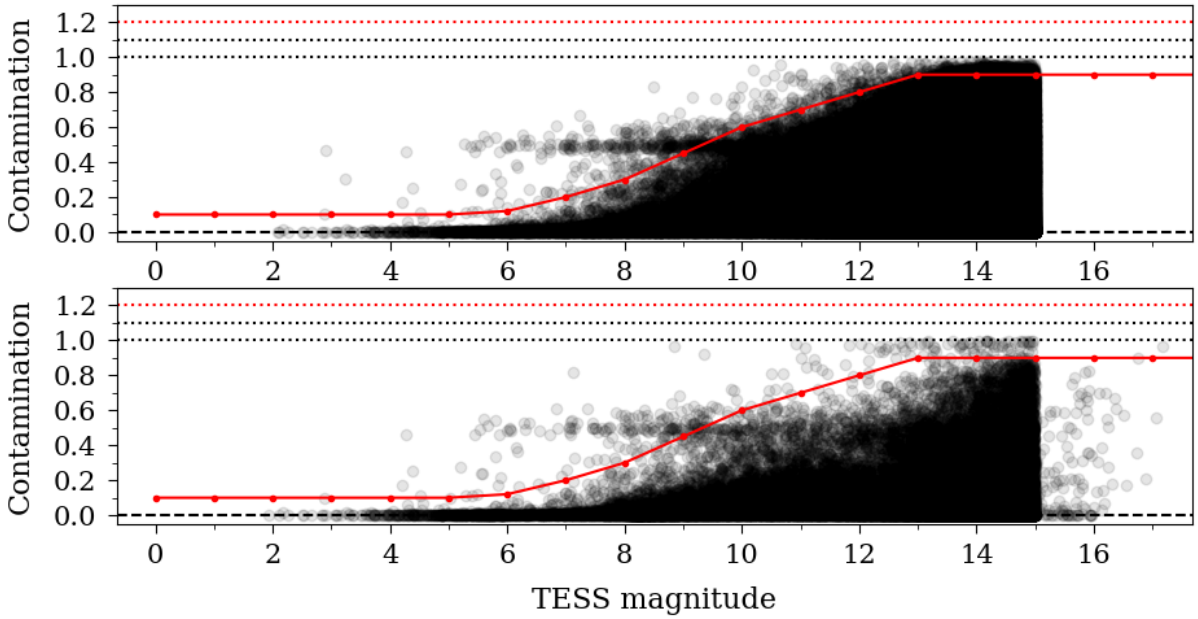


(e) Sector 5.

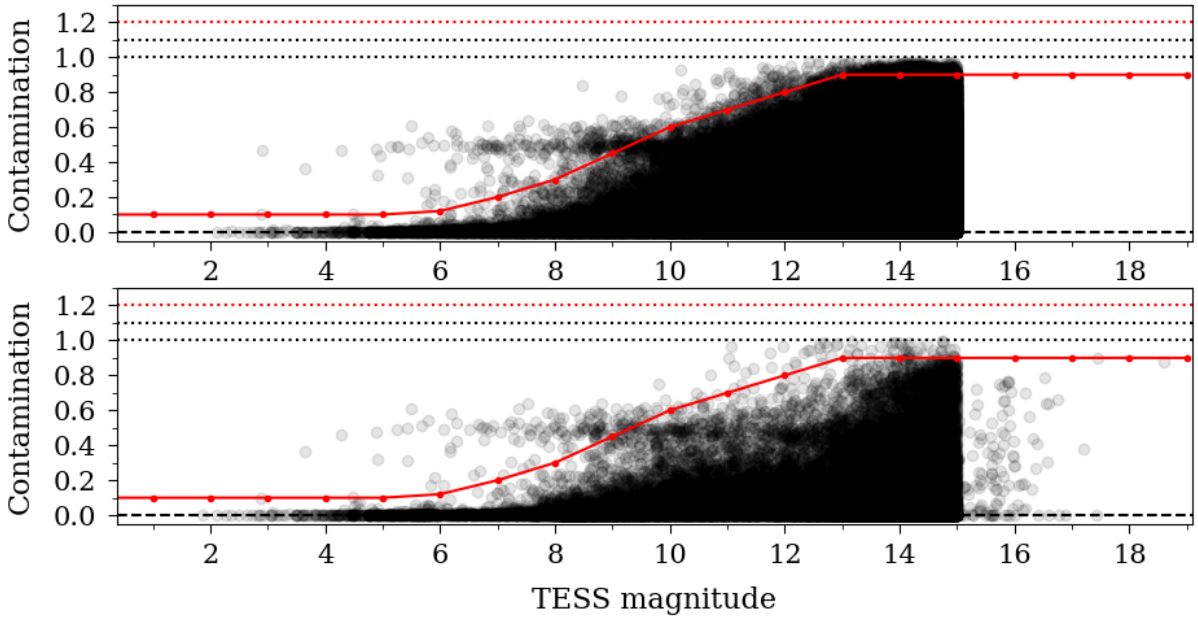


(f) Sector 6.

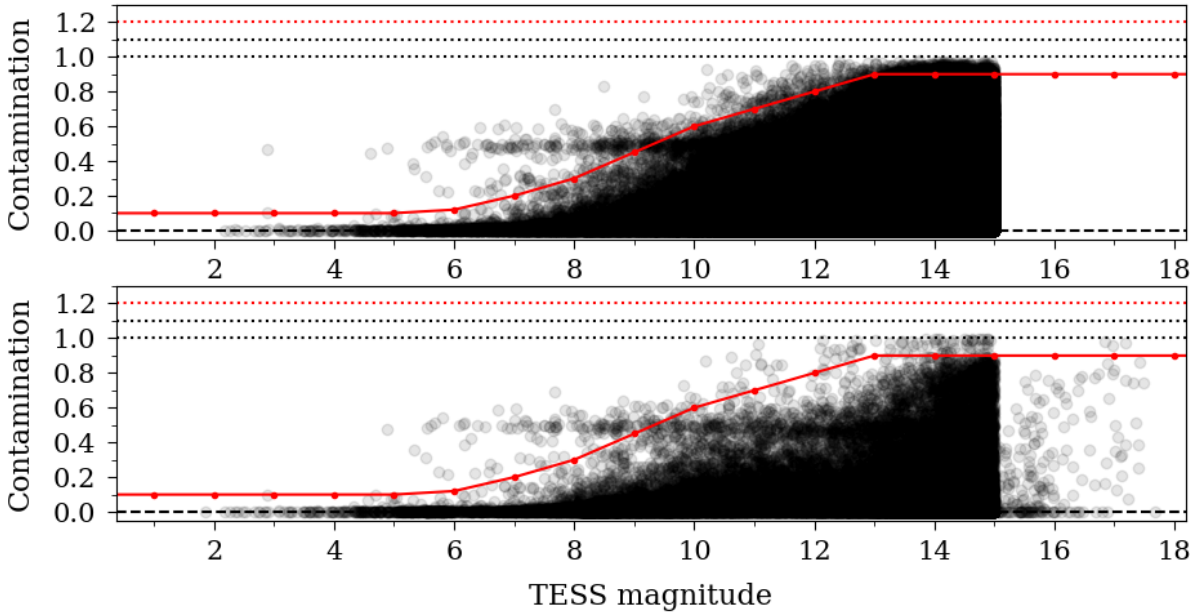
Figure 5: Contamination metric as a function of TESS magnitude. For each Sector the top (bottom) panel gives contamination for FFI (TPF) data. The red full curve gives the boundary used in the photometry data validation.



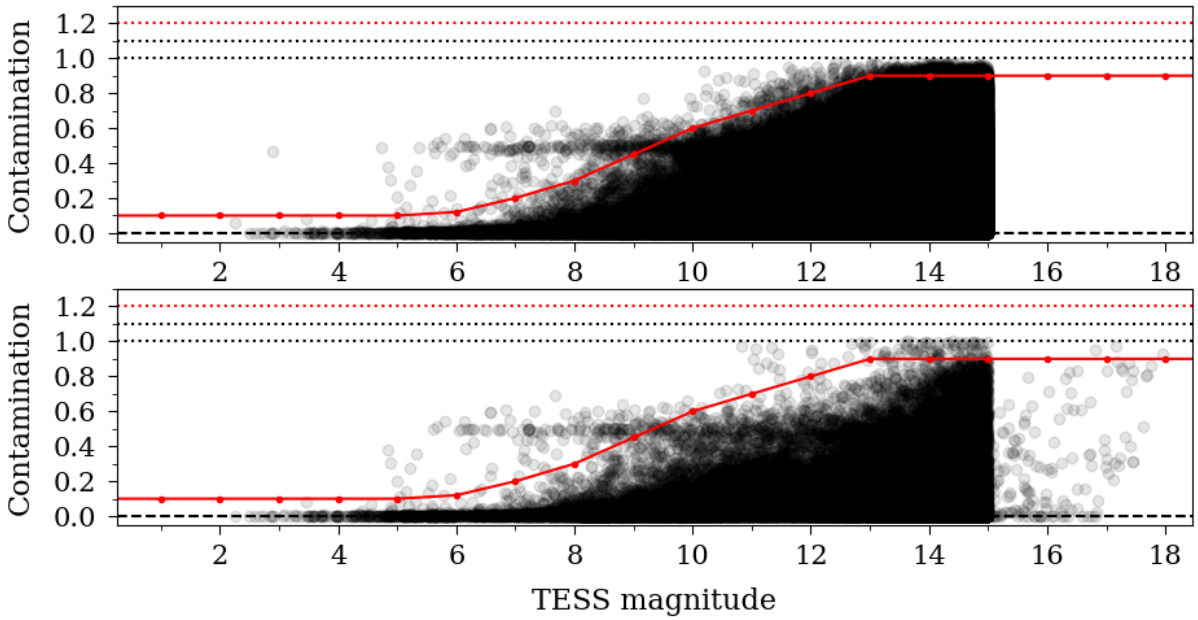
(a) Sector 1.



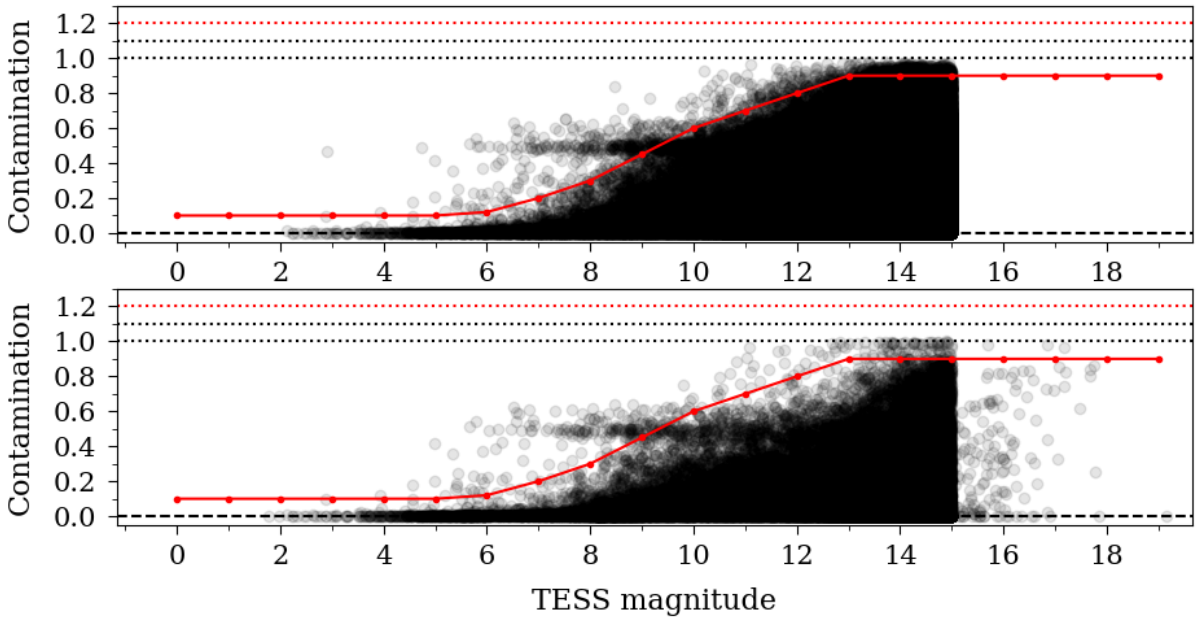
(b) Sector 2.



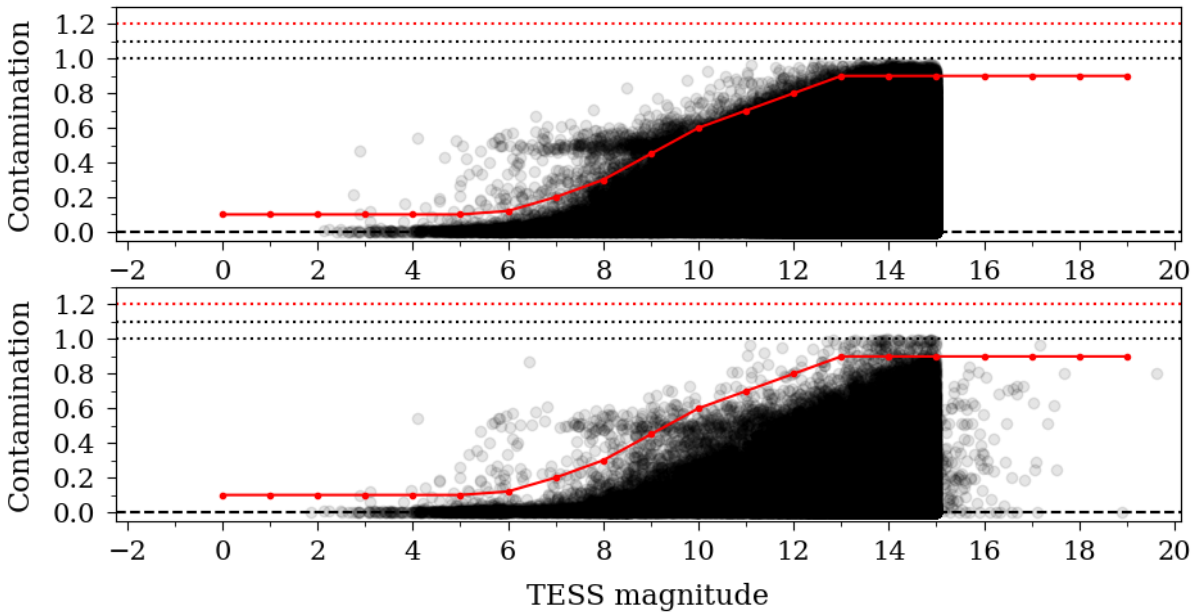
(c) Sector 3.



(d) Sector 4.

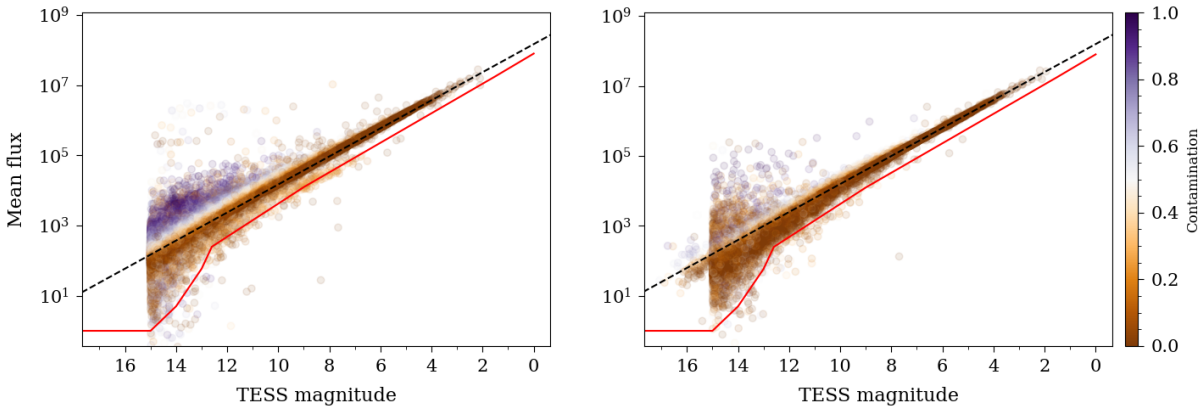


(e) Sector 5.

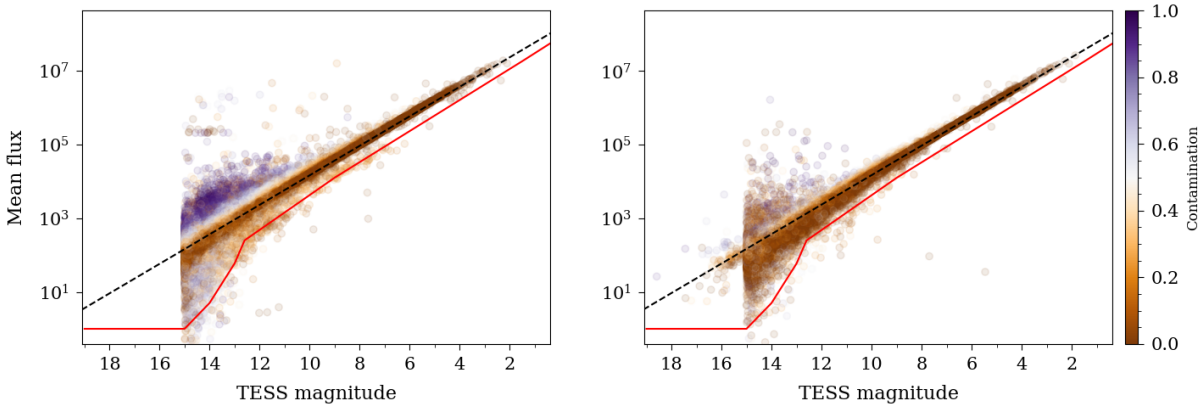


(f) Sector 6.

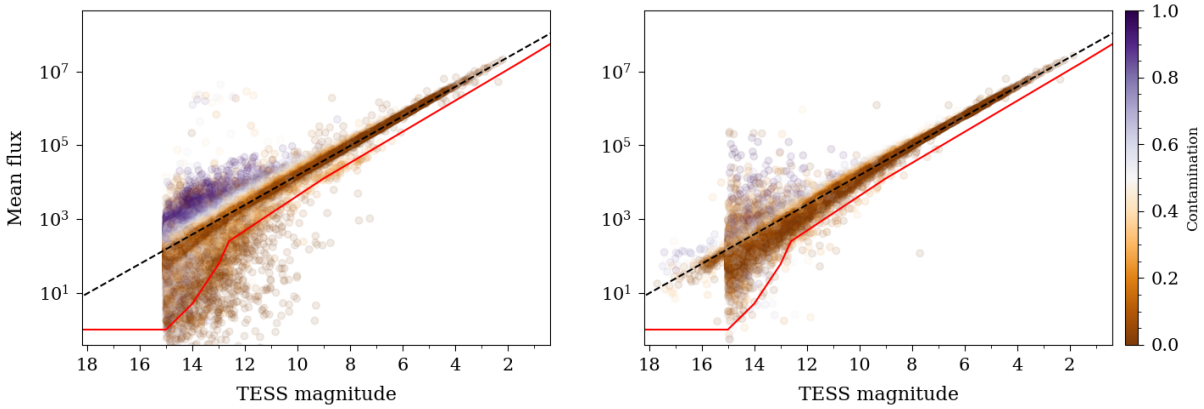
Figure 6: Relation between extracted flux from aperture and the TESS magnitude, colour-coded by contamination. The left (right) panels show values for 30-min FFI (2-min TPF) data. The black dashed line gives the individual relations obtained following the prescription in Handberg et al. (2021). The full red line gives the adopted boundary for the data validation.



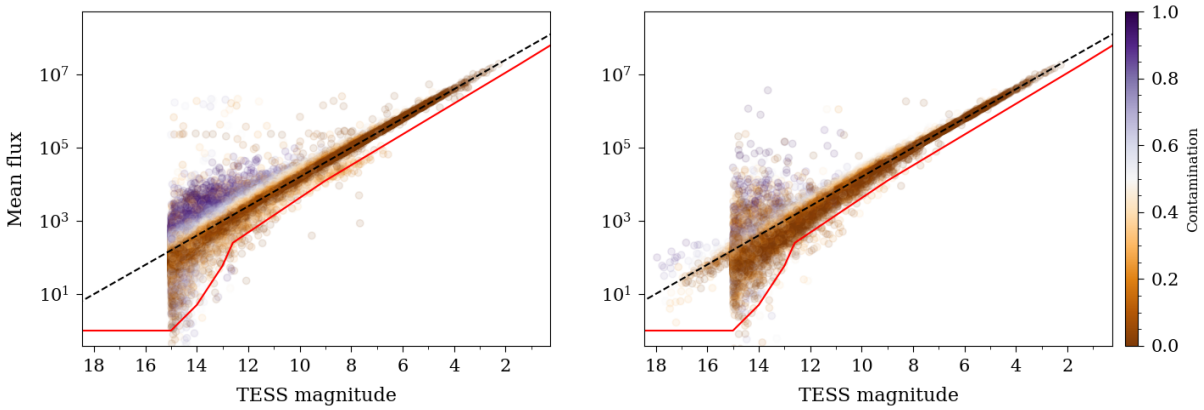
(a) Sector 1.



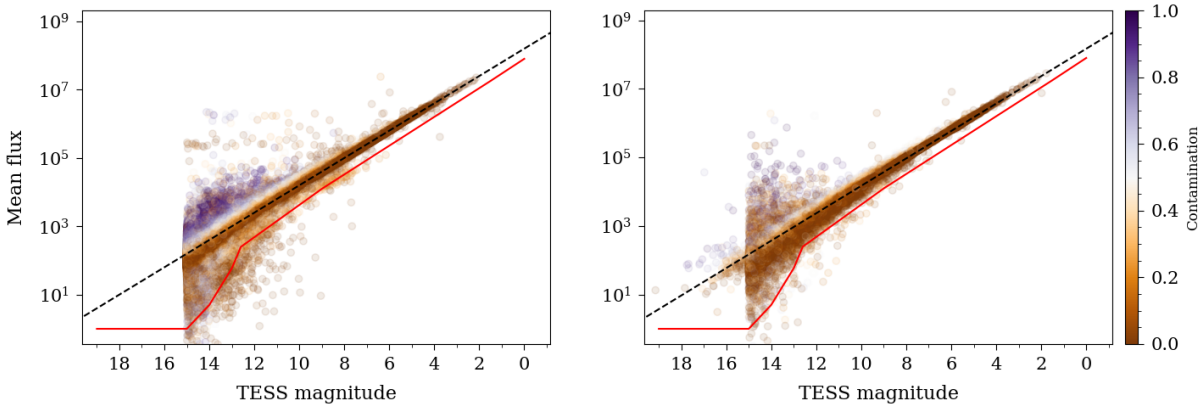
(b) Sector 2.



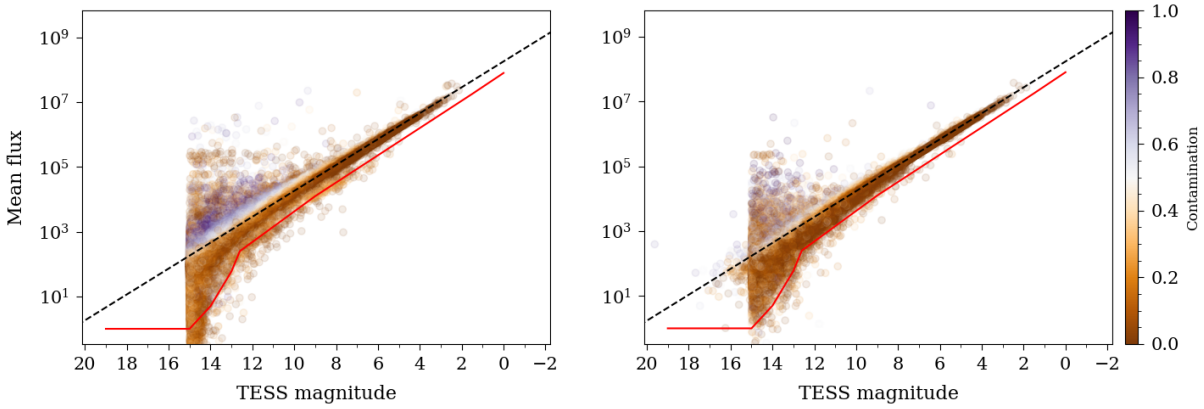
(c) Sector 3.



(d) Sector 4.



(e) Sector 5.



(f) Sector 6.

Corrections

Photometry pipeline version: 1.5

See Lund et al. (2021) for details.

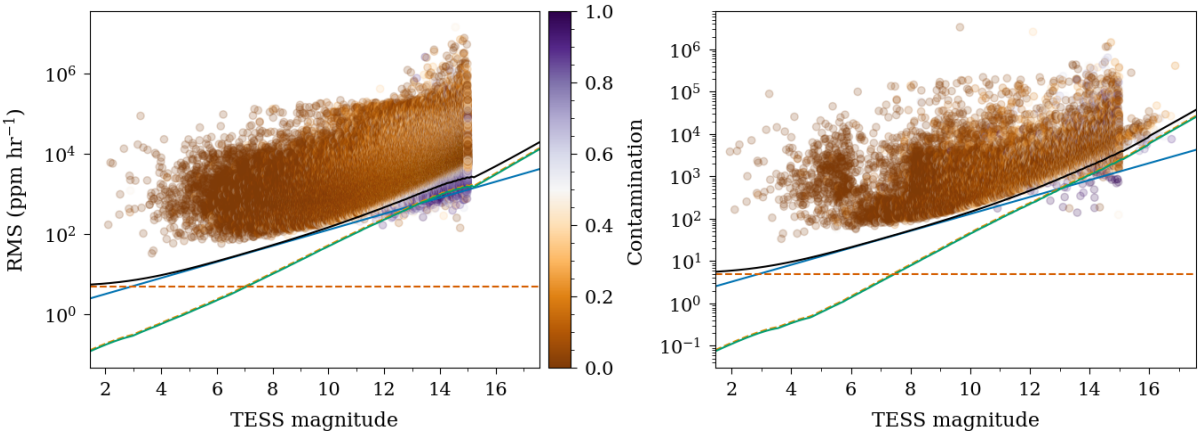
The photometric quality of the corrected light curves is summarized in Figures 7–8. Figure 7 shows the 1 hour root-mean-square (RMS) noise in parts-per-million (ppm) as a function of TESS magnitude; Figure 8 gives the point-to-point Median-Differential-Variability (MDV) (corresponding to RMS on time scale of observing cadence). For the expected-noise curves we used relations for mean flux (Figure 6) and number of aperture pixels (Figure 4) as a function of TESS magnitude derived from the processed data. As seen the extracted light curves generally follow the expected noise characteristics.

Data format

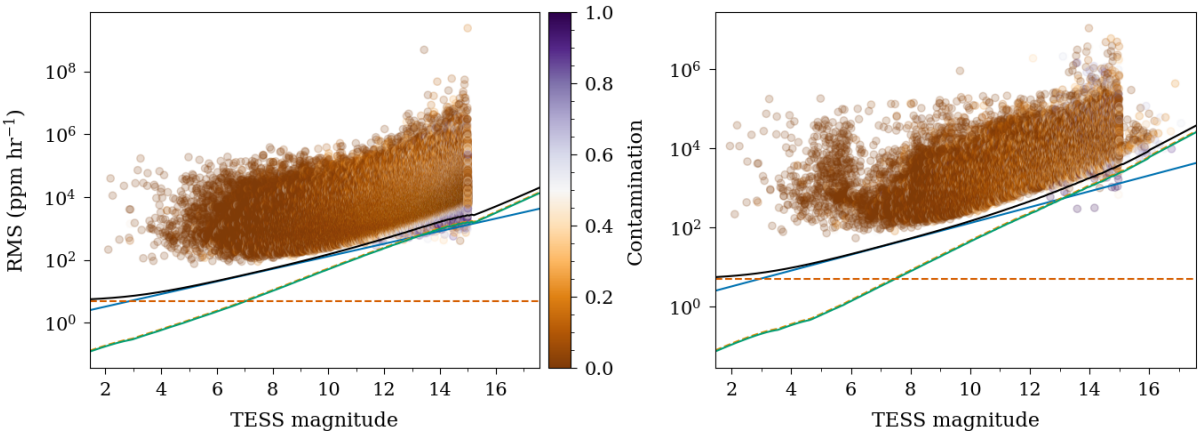
Data file format version: 1.4

See Handberg et al. (2021) and Lund et al. (2021) for details about file formats.

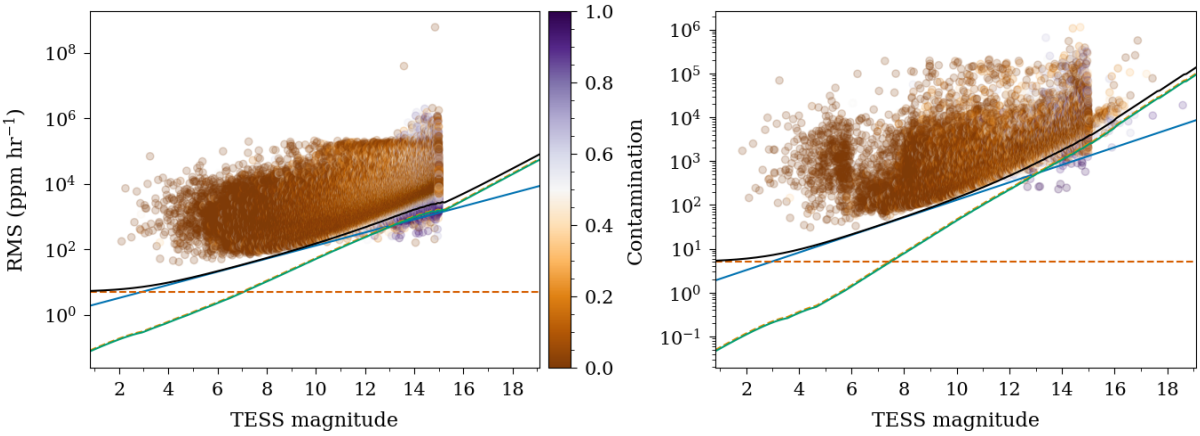
Figure 7: RMS noise on 1 hour time scale for stars covered by this release. The lines give the predicted noise estimates following Sullivan et al. (2015) (red full: shot noise; yellow full: read noise; green dashed: zodiacal noise; black full: total noise).



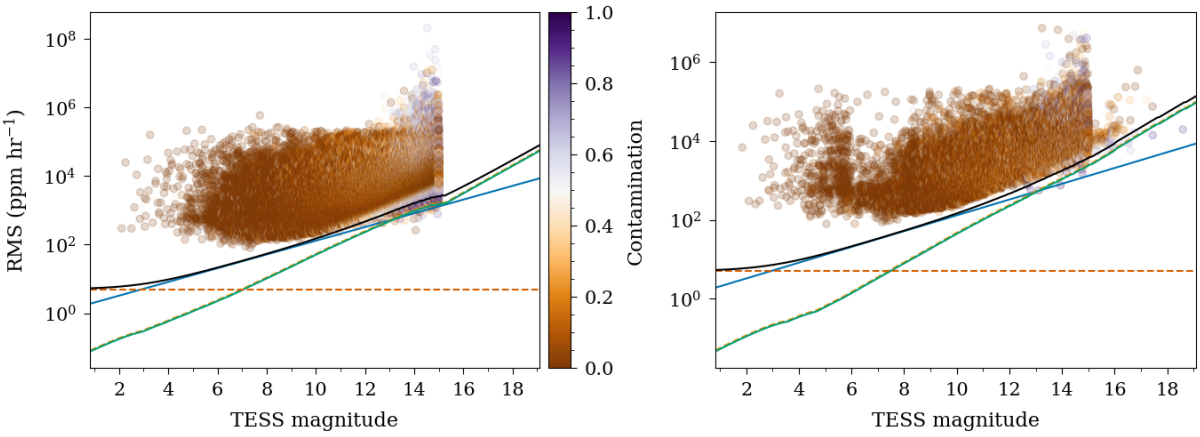
(a) Sector 1, cbv corrected.



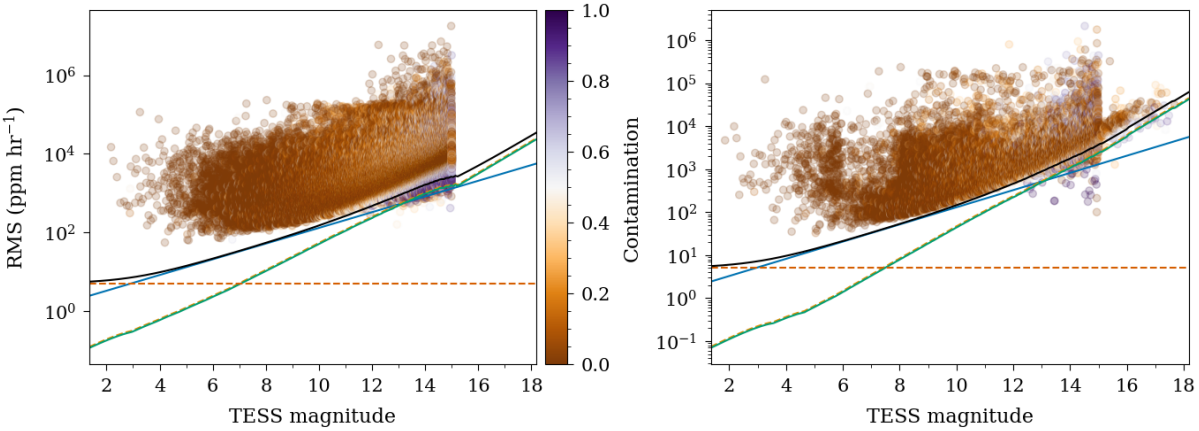
(b) Sector 1, ensemble corrected.



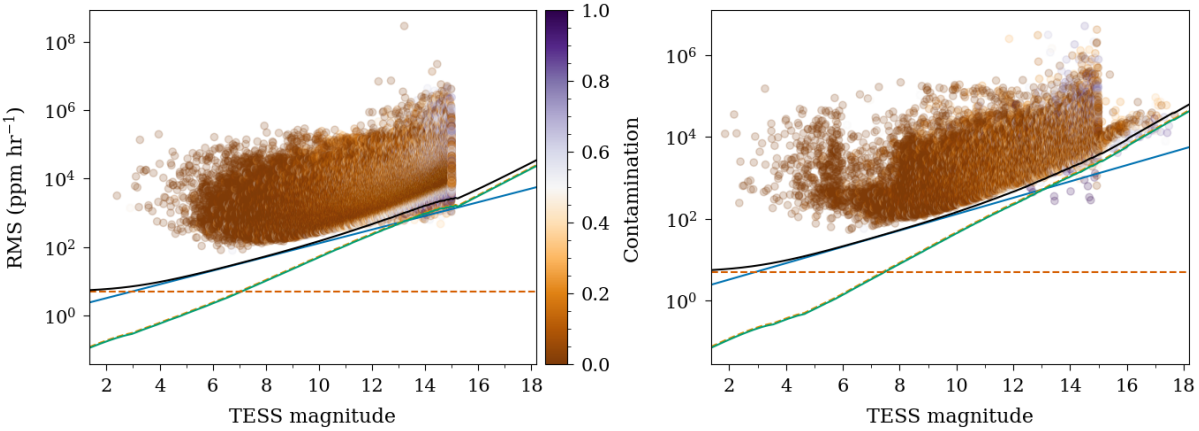
(c) Sector 2, cbv corrected.



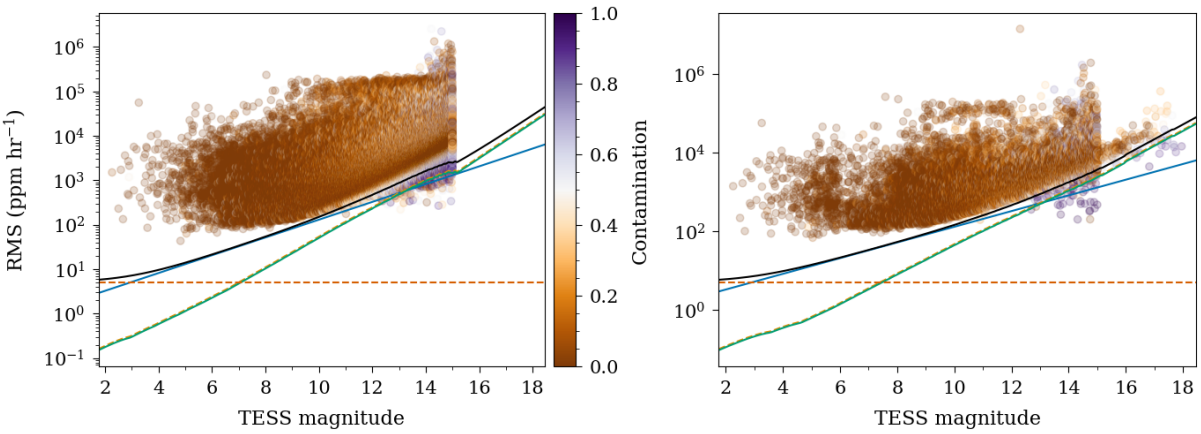
(d) Sector 2, ensemble corrected.



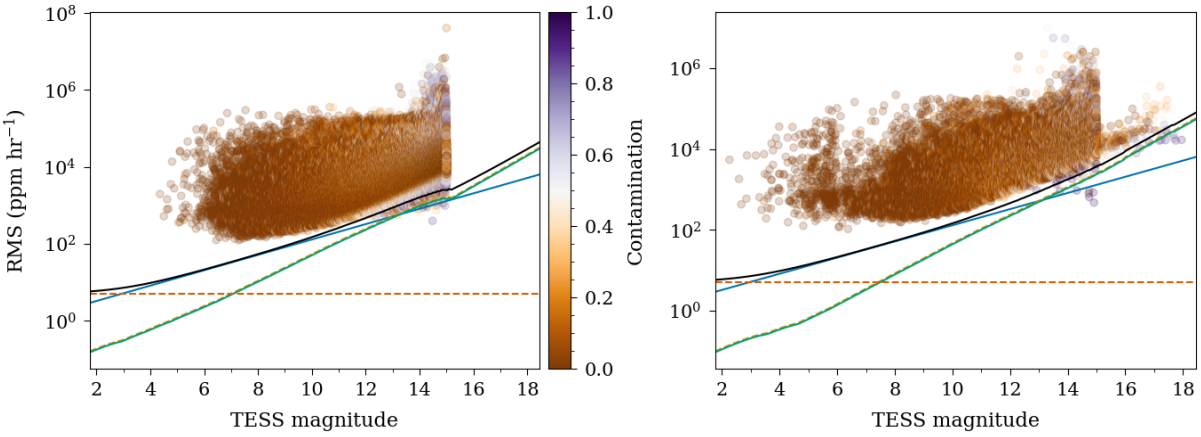
(e) Sector 3, cbv corrected.



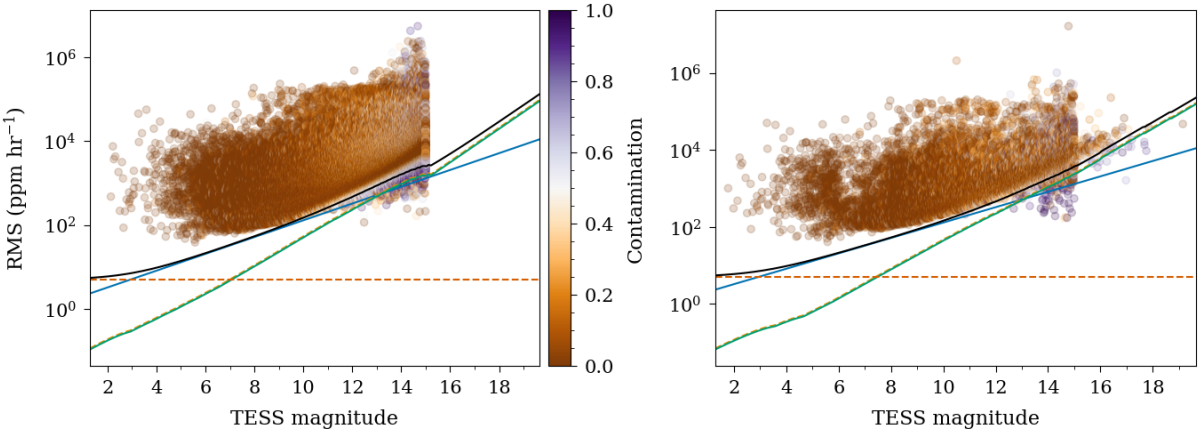
(f) Sector 3, ensemble corrected.



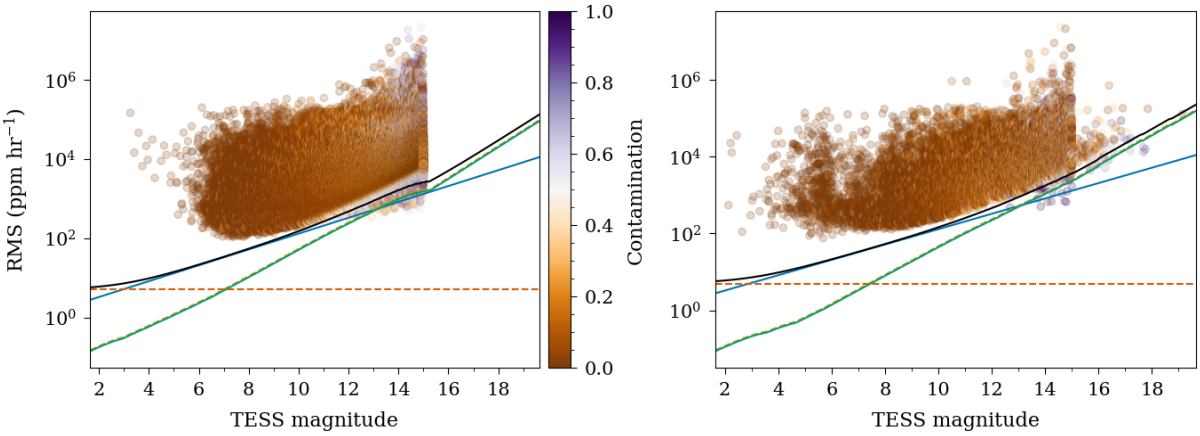
(g) Sector 4, cbv corrected.



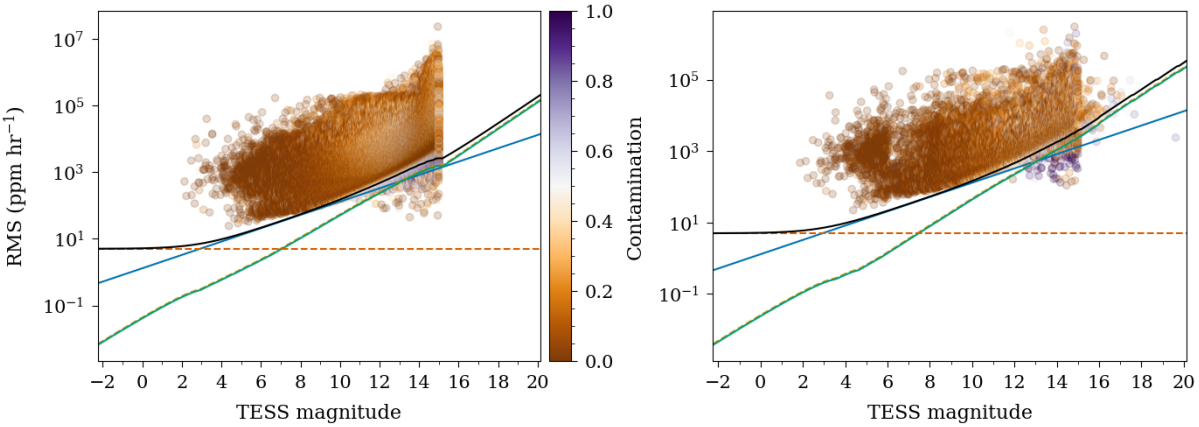
(h) Sector 4, ensemble corrected.



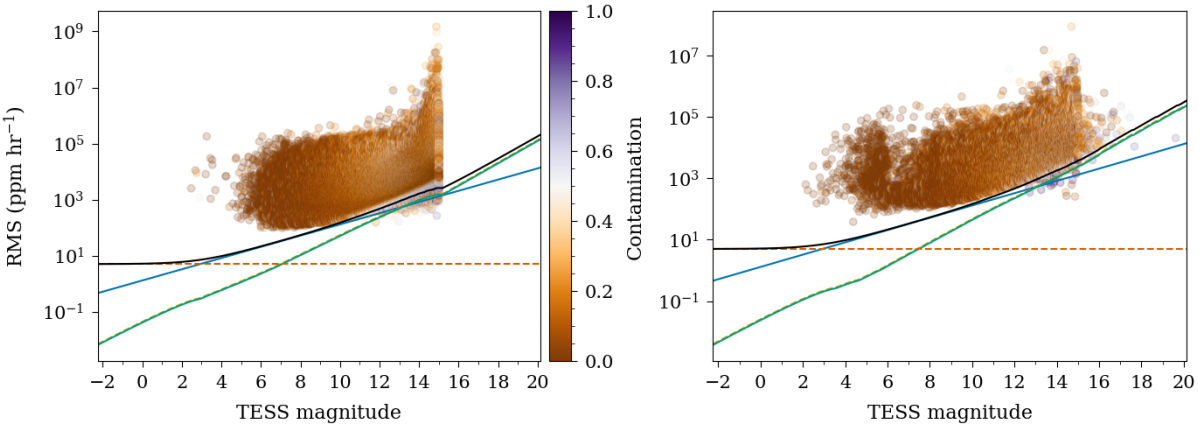
(i) Sector 5, cbv corrected.



(j) Sector 5, ensemble corrected.

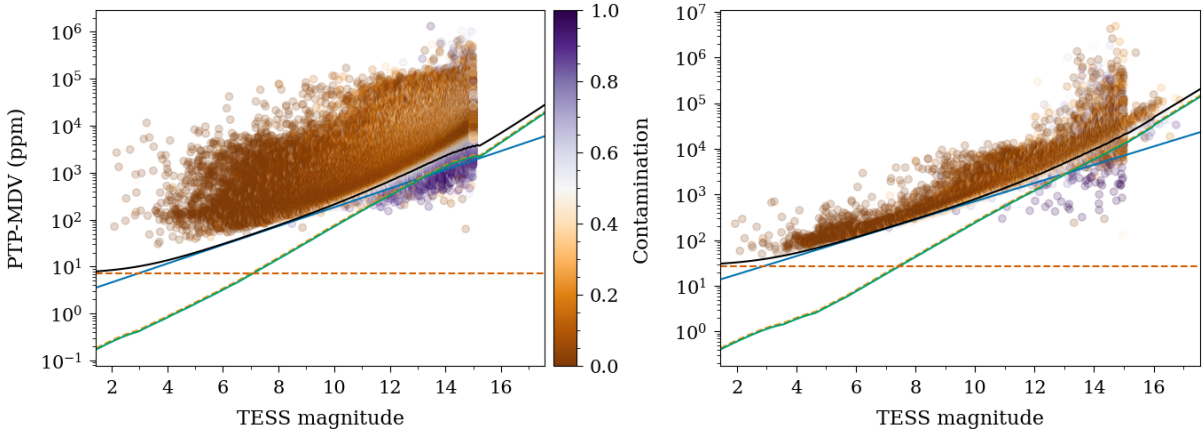


(k) Sector 6, cbv corrected.

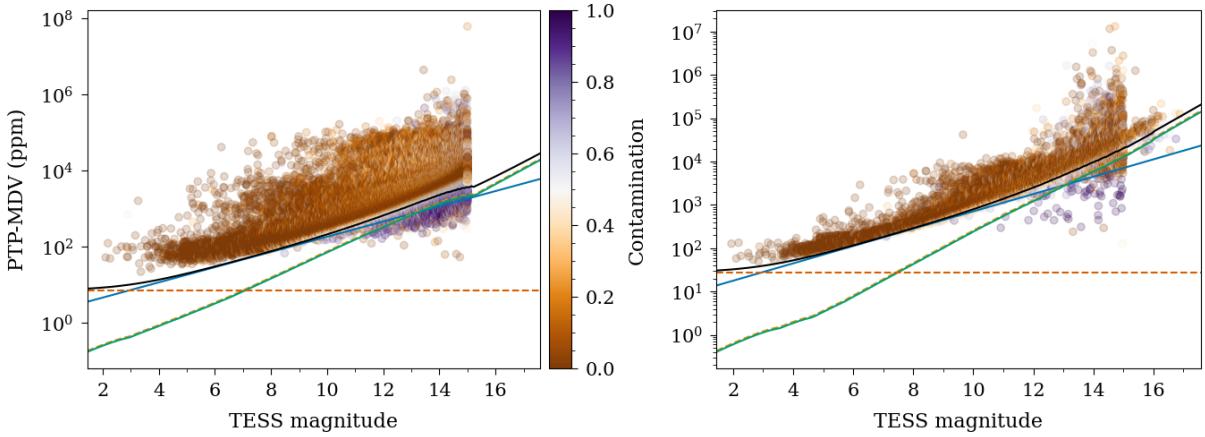


(l) Sector 6, ensemble corrected.

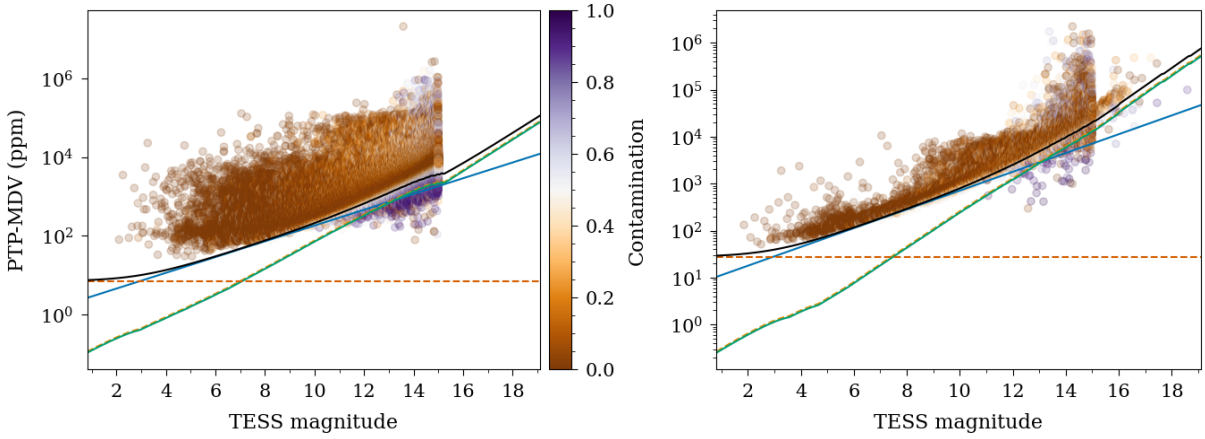
Figure 8: Point-to-point Median-Differential-Variability (MDV) for stars covered by this release (left: 1800 sec cadence; right: 120 sec cadence). The lines give the predicted noise estimates following Sullivan et al. (2015) (red full: shot noise; yellow full: read noise; green dashed: zodiacal noise; black full: total noise).



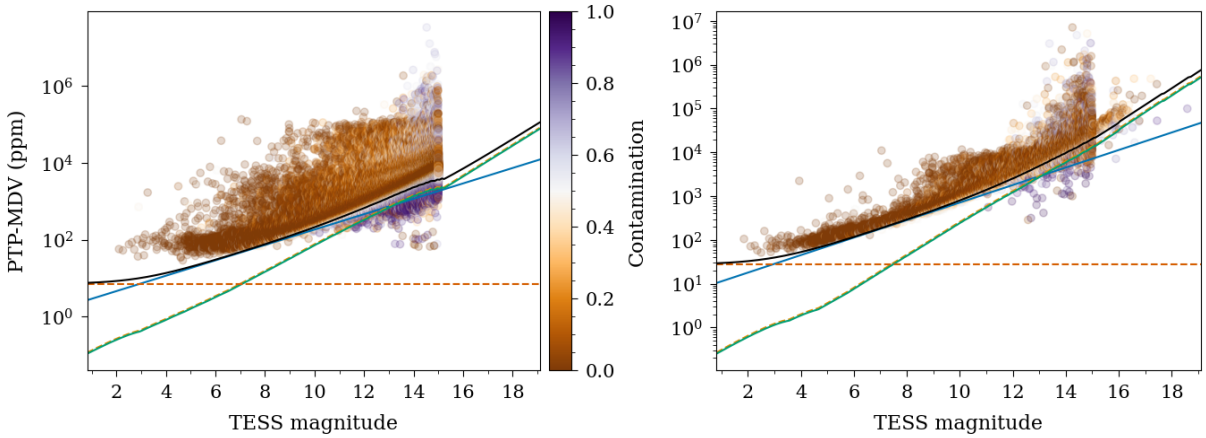
(a) Sector 1, cbv corrected.



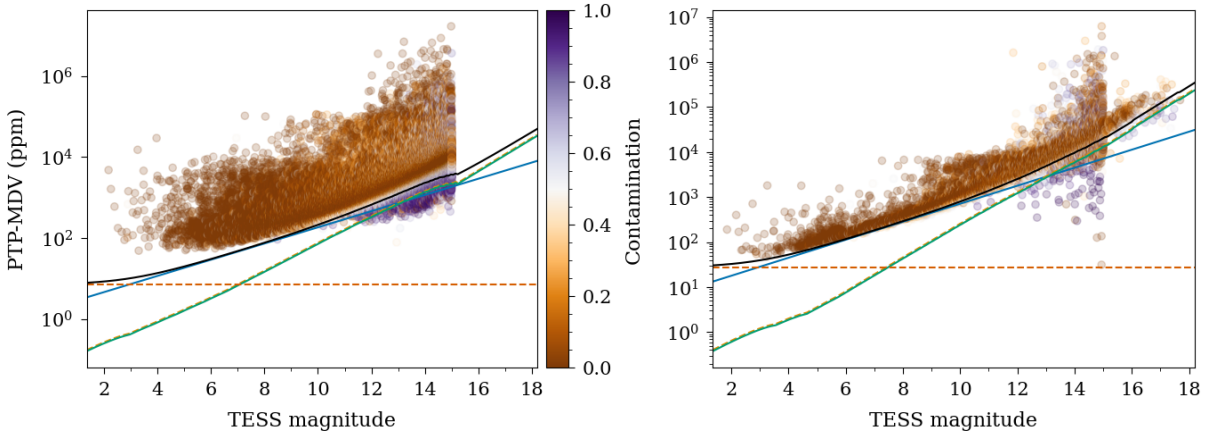
(b) Sector 1, ensemble corrected.



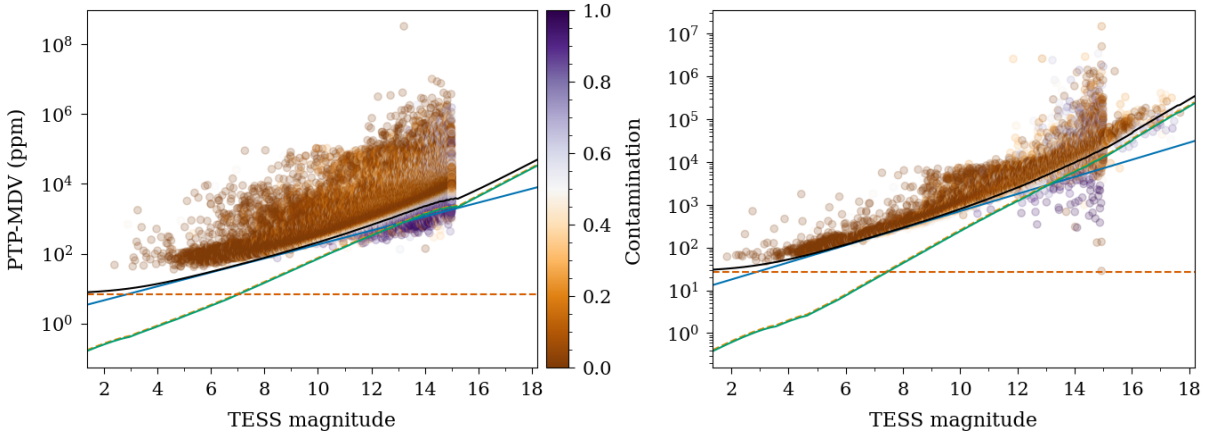
(c) Sector 2, cbv corrected.



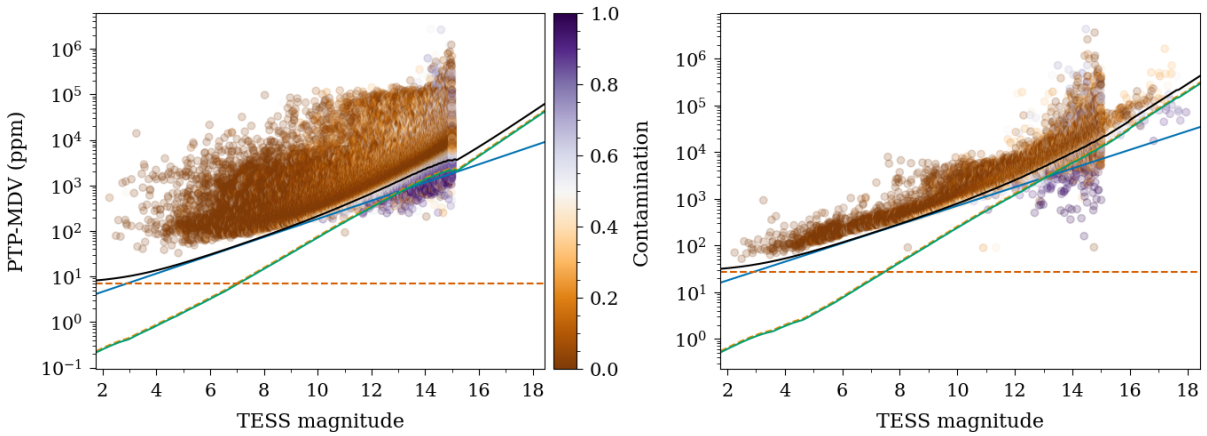
(d) Sector 2, ensemble corrected.



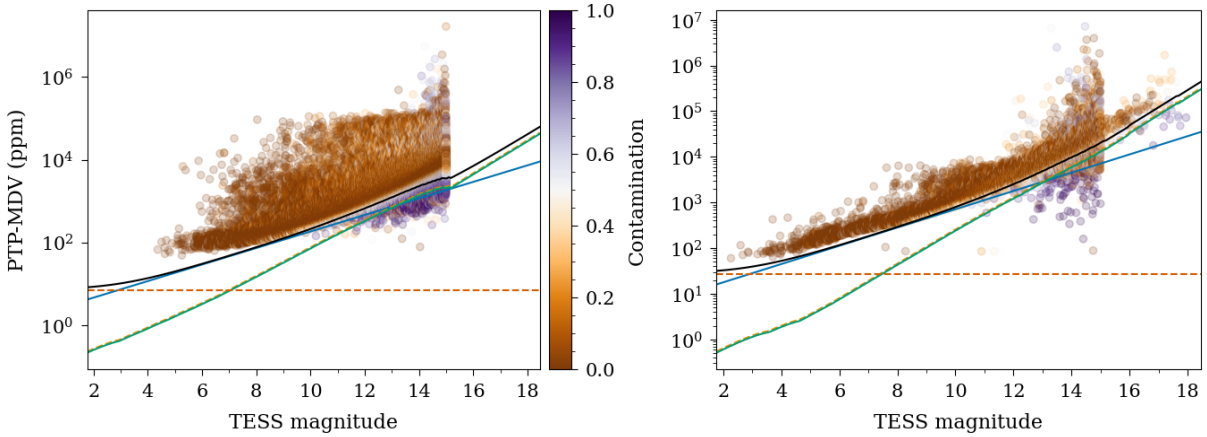
(e) Sector 3, cbv corrected.



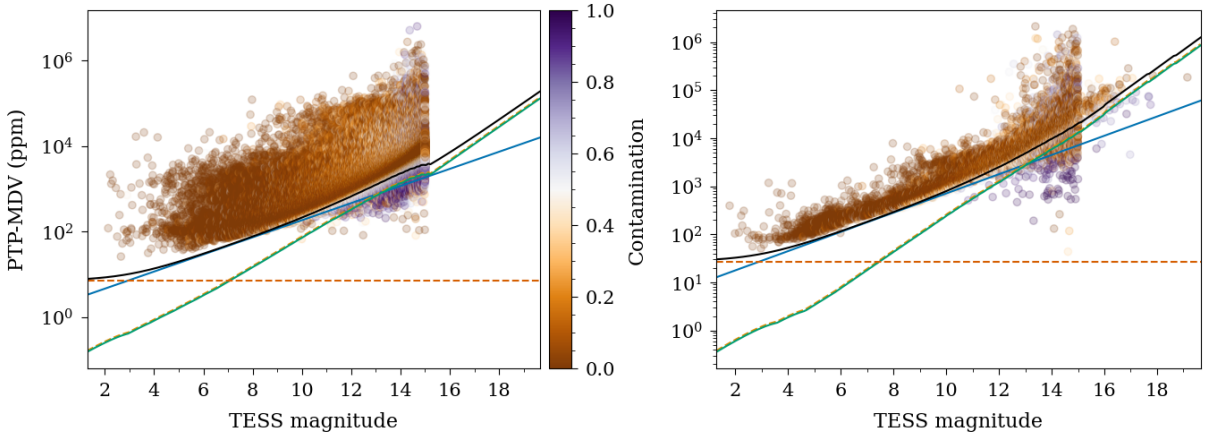
(f) Sector 3, ensemble corrected.



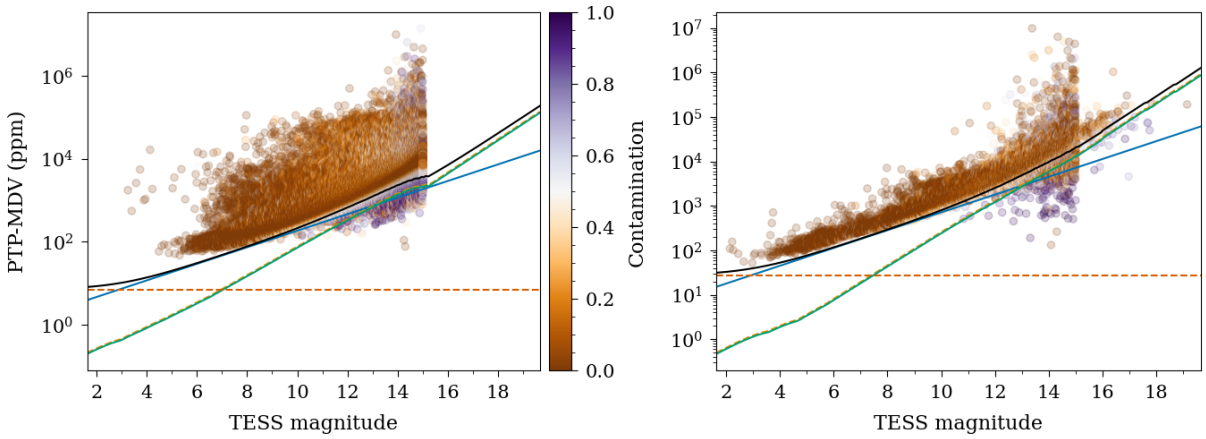
(g) Sector 4, cbv corrected.



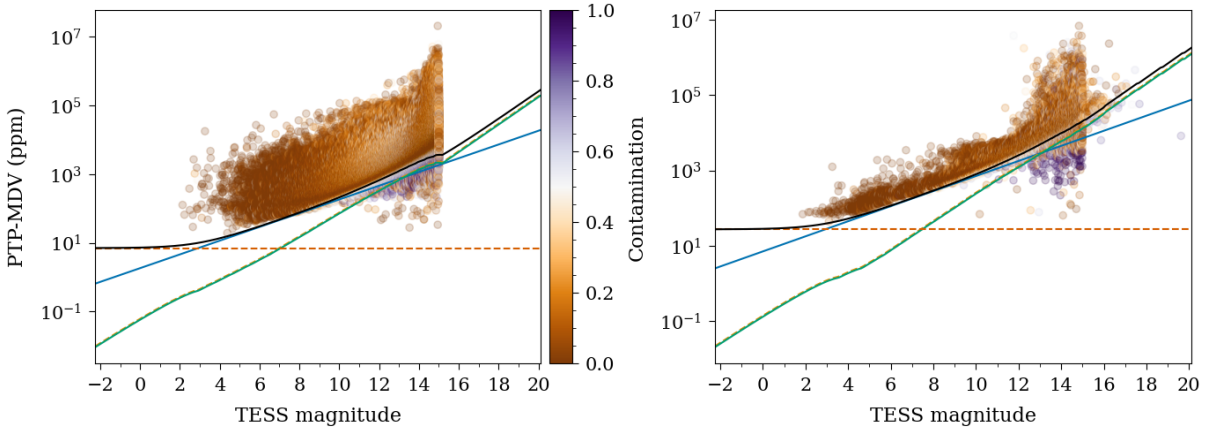
(h) Sector 4, ensemble corrected.



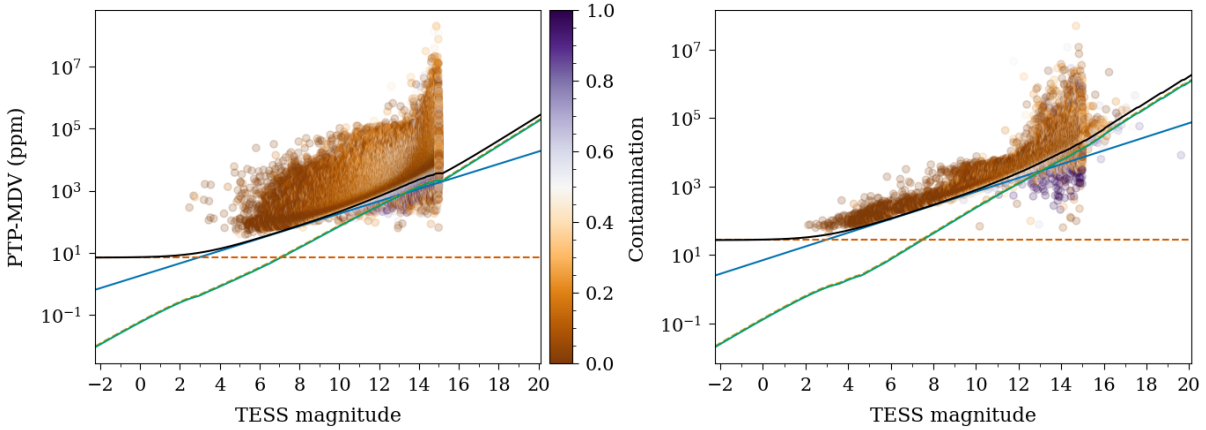
(i) Sector 5, cbv corrected.



(j) Sector 5, ensemble corrected.



(k) Sector 6, cbv corrected.



(l) Sector 6, ensemble corrected.

References

Handberg, R., Lund, M. N., White, T. R., et al. 2021, The Astronomical Journal. https://tasoc.dk/publications/99

Lund, M. N., Handberg, R., Buzasi, D. L., et al. 2021, The Astronomical Journal. https://tasoc.dk/publications/100

Sullivan, P. W., Winn, J. N., Berta-Thompson, Z. K., et al. 2015, The Astrophysical Journal, 809, 77, doi: 10.1088/0004-637X/809/1/77

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