



## *Planet Detection Metrics:*

Window and One-Sigma Depth Functions  
for Data Release 24

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## 1. Introduction

This document describes the window and one-sigma depth functions produced by the Transiting Planet Search (TPS) algorithm in the *Kepler* pipeline (Jenkins 2002). The window function specifies the fraction of phase space over which three transits are observable as a function of orbital period. The one-sigma depth function specifies the depth of a signal (in ppm) for a given light curve that results in a one-sigma detection of a transit signature as a function of orbital period when averaged over phase.

These new planet detection metrics quantify the ability of TPS to detect a transiting planet signature on a star-by-star basis. They are uniquely applicable to a specific *Kepler* data release, since they are dependent on the details of the light curves searched and the functionality of the TPS algorithm used to perform the search. They are available for the first time as part of *Kepler* Data Release 24, which was processed and searched with SOC pipeline version 9.2.

These data products are archived in the NExScI Exoplanet Archive<sup>1</sup> as two separate FITS files per target as described below. They are available for all targets searched for planets by the *Kepler* pipeline (Seader et al. 2015) and can be downloaded as a set, or for individual targets through the interactive interface.

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<sup>1</sup> <http://exoplanetarchive.ipac.caltech.edu/index.html>

## 2. Window Function

The window function for a transit survey specifies the fraction of phase space that permits  $\geq k$  transits to be observed as a function of period for a fixed-length data set (Gaudi 2000; Burke et al. 2006; Burke & McCullough 2014). The *Kepler* pipeline requires  $k \geq 3$  transits for planet detection at each of the fourteen transit durations searched (*i.e.*, 1.5, 2.0, 2.5, 3.0, 3.5, 4.5, 5.0, 6.0, 7.5, 9.0, 10.5, 12.0, 12.5, and 15.0 hrs), so the reported window functions are based on this three-transit criteria.

The FITS files are named `kplr<identifier>_<release>_window.fits`, where `<identifier>` corresponds to the target's *Kepler* Input Catalog (KIC) identification number and `<release>` specifies the *Kepler* data release. Each file contains 14 binary table extensions for the 14 pulse durations searched by TPS. The transit duration is specified by the keyword TDUR in the FITS header for each extension. Each binary table extension has two columns corresponding to the orbital period (in days) and the window function (unitless) for the stated transit duration.

Due to the expected increase in transit duration with orbital period for transiting planet signatures, the entire period range is not searched at all transit durations. The shortest transit durations have an upper limit to the orbital periods searched, and the longest transit durations have a lower limit to the orbital periods searched. Thus, the range of orbital period over which valid window function data is computed by TPS varies with duration.

Several example window functions are provided in the left-hand panels of Figures 1 – 3. These examples illustrate targets that have varying amounts of observational data available. The window function ranges from 0 to 1. It has a value of 1 at short periods, where there is a high probability of having at least 3 transits. The window function then decays to 0 at long orbital periods since there is a decreasing probability that the flux time series is long enough to allow at least 3 transits to be observed. For nearly all *Kepler* targets the window function varies insignificantly with transit duration, so it is typically valid to adopt the results of any small set of durations that spans the full range of periods. This is well illustrated in the left-hand panels of Figures 1 – 3, where all 14 durations are plotted, but only one continuous curve is apparent.

### 3. One-Sigma Depth Function

The detectability of a transit signal is predominately determined by its signal-to-noise ratio (SNR) (Gaudi 2000). One can estimate the transit SNR as  $\Delta\sqrt{N_{\text{tran}}}/\sigma_{\text{cdpp}}$ , where  $\Delta$  is the expected transit depth,  $N_{\text{tran}}$  is the expected number of transits, and  $\sigma_{\text{cdpp}}$  is an averaged noise estimate from the root-mean-square (rms) CDPP (Christiansen et al. 2012). However, this SNR estimate assumes all observations have the same noise properties and that missing or de-weighted data in the flux time series are evenly distributed in time. For the one-sigma depth function, TPS quantifies the transit signal depth that yields a SNR of unity as a function of the orbital period by taking into account the full details of the time varying properties of the noise and accounting for any missing or de-weighted data. When using the one-sigma depth function,  $\Delta_{\text{one}}$ , the transit signal-to-noise ratio is simply  $\text{SNR} = \Delta/\Delta_{\text{one}}$ .

As for the window function, the one-sigma depth function is archived in FITS format. Each file contains 14 binary table extensions giving results for the 14 transit durations searched by TPS. Each binary table extension has two columns corresponding to the orbital period (in days) and the one-sigma depth (in ppm). The file names have the form `kplr<identifier>_<release>_onesigdepth.fits`, where `<identifier>` and `<release>` have the same definitions as for the window function files.

Several examples of one-sigma depth functions are provided in the right-hand panels of Figures 1 - 3. These examples feature targets with varying amounts of missing data to illustrate the impact of incompleteness. In the large  $N_{\text{tran}}$  (*i.e.*, short-period) regime,  $\Delta_{\text{one}}$  increases as  $\sqrt{P_{\text{orb}}}$ , where  $P_{\text{orb}}$  is the orbital period. For small values of  $N_{\text{tran}}$  (*i.e.*, long periods),  $\Delta_{\text{one}}$  deviates from this simple dependence on  $P_{\text{orb}}$  because the noise properties of the full flux time series are not well represented by such sparse sampling.

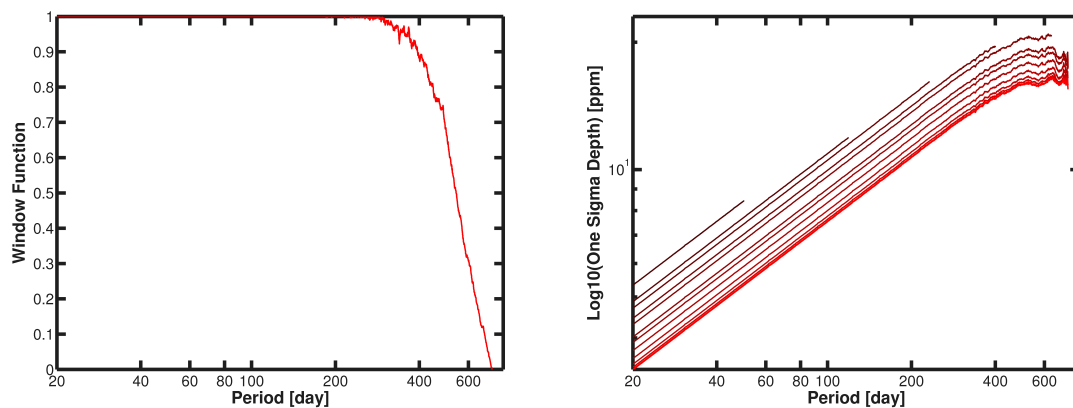


Figure 1. Example planet detection metrics for a target with data available in every quarter (Q1-Q17). This target corresponds to KIC 10593626, the host of *Kepler-22b* (Borucki et al. 2012). **Left:** Window function as a function of orbital period. **Right:** One-sigma depth function as a function of orbital period. The top (bottom) line corresponds to the shortest (longest) transit duration searched for transit signatures.



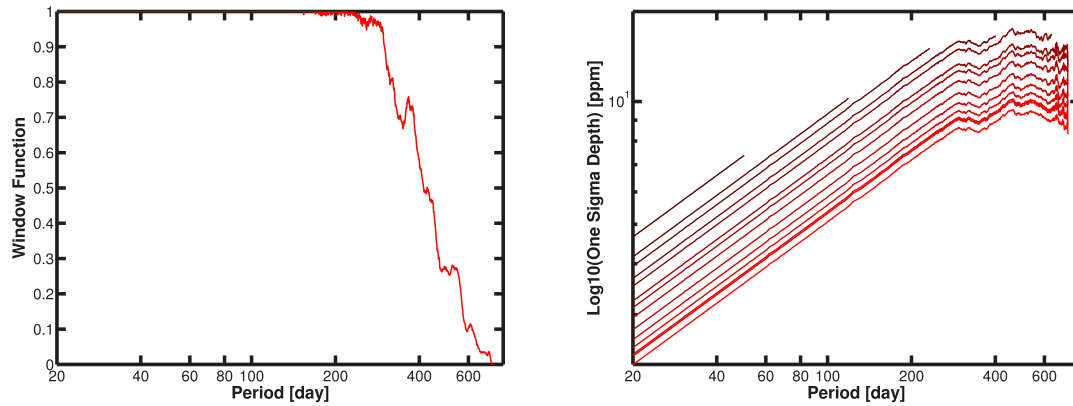


Figure 2. Example planet detection metrics for a target impacted by the loss of Module 3 (*i.e.*, every fourth quarter of data is missing). This target corresponds to KIC 11446443, the host of TrES-2b (O'Donovan et al. 2006). **Left:** Window function as a function of orbital period. **Right:** One-sigma depth function as a function of orbital period. The top (bottom) line corresponds to the (shortest) longest transit duration searched for transit signatures.

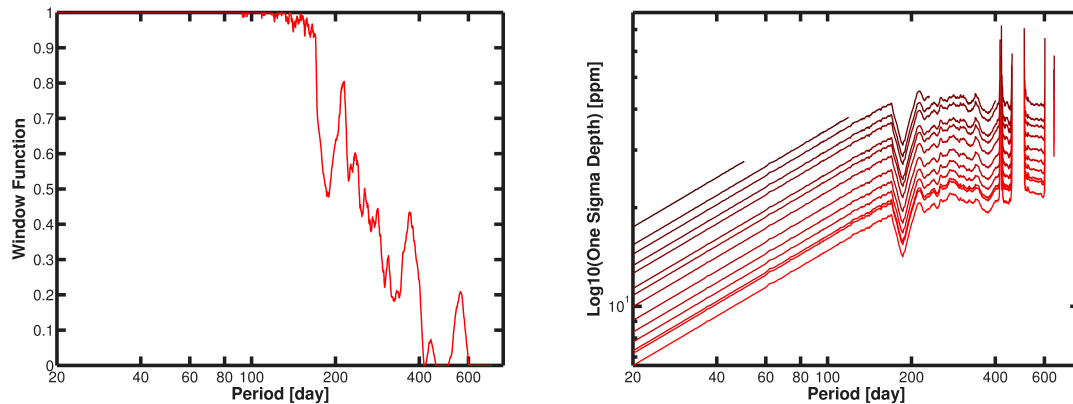


Figure 3. Example planet detection metrics for a target with data missing every other quarter. This target corresponds to KIC 8745553. **Left:** Window function as a function of orbital period. **Right:** One-sigma depth function as a function of orbital period. The top (bottom) line corresponds to the (shortest) longest transit duration searched for transit signatures.

#### 4. Erratum for Window Function

In the process of verifying the DR25 window functions, an error was discovered that impacts the DR24 results. It turns out that in addition to the three-transit criteria described in Section 2, TPS performs an additional check when exactly three transits contribute to a putative detection. In the three-transit case only, each transit is inspected. If more than half of the in-transit cadences are deweighted for any of the three transits that contribute to the detection, then the detection is rejected and does not become a Threshold Crossing Event (TCE).

This three-transit weight check was not included in the DR24 calculation of the window functions, so they are overly optimistic representations of the actual SOC 9.2 pipeline performance. Figure 4 shows the results of the DR25 verification exercise (Burke & Catanzarite 2016), which used Monte Carlo transit injection and recovery tests to infer the window function for selected targets (black lines). These Monte-Carlo-derived window functions are in good agreement with the DR25 window functions (blue lines) once the three-transit weight check is included, but the DR24 window functions (red lines) hosted at NExScI are optimistic by up to 50%. End users of the DR24 results are encouraged to consider how such discrepancies might impact their scientific results.

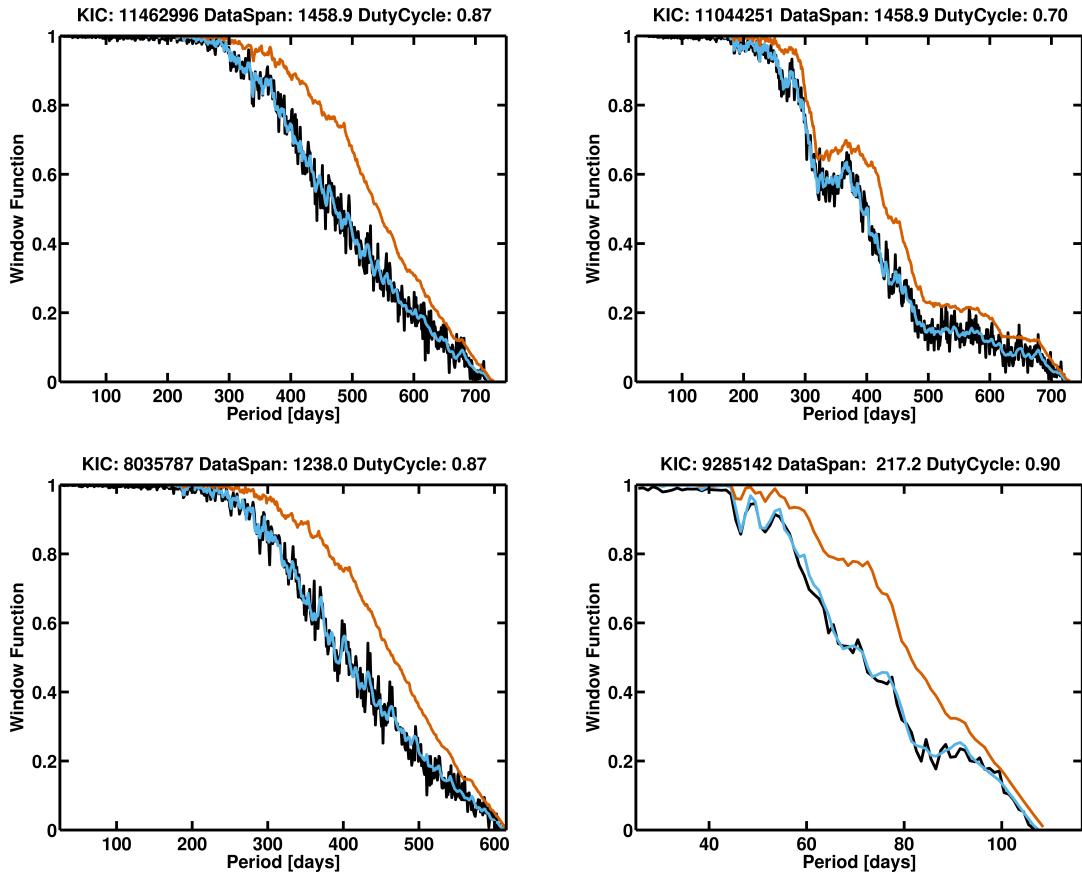


Figure 4. Example window functions for representative targets with varying amounts of observational data. The target's *Kepler* ID, data span, and duty cycle are specified along the top. The DR24 (SOC 9.2) window functions (red lines) are overly optimistic compared to the DR25 (SOC 9.3) window functions (blue lines) when the three-transit weight check is included.

## 5. References

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