Discovery and Vetting of Exoplanets. I. Benchmarking K2 Vetting Tools

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Abstract

We have adapted the algorithmic tools developed during the Kepler mission to vet the quality of transit-like signals for use on the K2 mission data. Using the four sets of publicly available light curves at MAST, we produced a uniformly vetted catalog of 772 transiting planet candidates from K2 as listed at the NASA Exoplanet Archive in the K2 Table of Candidates. Our analysis marks 676 of these as planet candidates and 96 as false positives. All confirmed planets pass our vetting tests. Sixty of our false positives are new identifications, effectively doubling the overall number of astrophysical signals mimicking planetary transits in K2 data. Most of the targets listed as false positives in our catalog show either prominent secondary eclipses, transit depths suggesting a stellar companion instead of a planet, or significant photocenter shifts during transit. We packaged our tools into the open-source, automated vetting pipeline Discovery and Vetting of Exoplanets (DAVE), designed to streamline follow-up efforts by reducing the time and resources wasted observing targets that are likely false positives. DAVE will also be a valuable tool for analyzing planet candidates from NASA’s TESS mission, where several guest-investigator programs will provide independent light-curve sets—and likely many more from the community. We are currently testing DAVE on recently released TESS planet candidates and will present our results in a follow-up paper.

Key words: planets and satellites; general — techniques: photometric

Supporting material: machine-readable table

1. Introduction

From the numerous ground- and space-based studies that have detected exoplanets, it has become evident over the past 20+ yr that planetary systems are not only common but also diverse in nature (e.g., Borucki et al. 2011; Burke et al. 2015; Thompson et al. 2018). NASA’s Kepler mission has shown that the occurrence rate for small planets is high, with almost every low-mass star expected to host at least one small (R < 4R⊕) planet (e.g., Dressing & Charbonneau 2015). While missions like Kepler (Borucki et al. 2010), CoRoT, and various ground-based photometric and radial velocity surveys have successfully expanded our knowledge of exoplanets, there are still regions of parameter space that are largely unexplored. These include planets around nearby stars and small planets around bright stars, systems that K2—the repurposed Kepler mission—is well-suited to explore. The major advantage of observing both bright and nearby stars is that planets can be more than detected—they can be characterized in detail. Such planets can be studied by (a) precise Doppler spectroscopy to get their masses and densities, (b) both emission and transmission spectroscopy to characterize their atmospheric properties, (c) high-contrast direct imaging to search for longer-period planets, and (d) asteroseismology to determine precise stellar properties—essential for precise planetary radii, masses, and equilibrium temperatures.

NASA’s K2 mission has been tremendously successful at finding planets, as demonstrated by a number of published catalogs containing hundreds of planet candidates, with many of them validated or confirmed (e.g., Montet et al. 2015; Adams et al. 2016; Barros et al. 2016; Crossfield et al. 2016; Pope et al. 2016; Vanderburg et al. 2016; Cabrera et al. 2017; Dressing et al. 2017; Rizzuto et al. 2017; Shporer et al. 2017; Livingston et al. 2018; Mayo et al. 2018). Some of these planets are as small as the Earth and transit bright, nearby stars. These targets will be particularly well-suited for follow-up observations with the James Webb Space Telescope (JWST) with the goal of studying their atmospheric composition and density. Such observations will yield a better understanding of the difference between rocky and gaseous planets, particularly how composition varies as a function of planet radius.

A major challenge for transit surveys like K2 targeting a large number of stars is to distinguish false-positive (eclipses/transits not due to planets) and false-alarm (signals unrelated to any eclipsing/transiting astrophysical system) signals from real transit events. An additional complication associated with K2 is the significant systematics due to spacecraft pointing drift (Howell et al. 2014), which introduces a significant difficulty in detecting high-quality planet candidates. Another layer of difficulty is introduced when there are multiple independent data sets per target, each employing a different approach to systematics correction on a star-by-star basis. This is indeed the case for K2, where, as described below, four different teams have produced publicly available light-curve sets. Each

9 a.k.a. Susan E. Thompson.

10 And will be the case for the Transiting Exoplanet Survey Satellite (TESS) as well.
detected planet candidate needs to undergo proper vetting to eliminate instrumental artifacts, nontransiting variable stars, eclipsing binaries, and contamination from variable objects other than the target star. In the absence of radial velocity measurements to confirm the planetary nature of a transit-containing light curve, one has to rely on additional methods to distinguish between a bona fide planet and a false positive. To tackle such obstacles, a number of methods have been developed for the Kepler mission, each tailored to a particular source of potential false positives, over successive catalogs of planet candidates as the data and sources of false alarms and false positives were better understood (e.g., Borucki et al. 2010; Batalha et al. 2011; Mullally et al. 2015; Rowe et al. 2015; Thompson et al. 2015, 2018; Coughlin et al. 2016).

Several automated vetting codes have been developed and applied to Kepler data. For example, Autovetter (Catanzarite 2015) uses a machine-learning random-forest decision tree to classify threshold crossing events (TCEs) as planet candidates, false positives, or nontransiting phenomena. Robovetter (Coughlin et al. 2016) utilizes specifically designed metrics that mimic the decision process of human vetting to assign a TCE as a planet candidate or false positive. Vespa (Morton 2012) uses a probabilistic algorithm designed to determine whether a transit-like signal is statistically likely to be caused by a background eclipsing binary. Astronet (Shallue & Vanderburg 2018) and Exonet (Ansdell et al. 2018) are also machine-learning tools that use deep learning to classify transit signals in Kepler data, including analysis of centroid time series and scientific-domain knowledge.

Here we present a new pipeline designed for the Discovery and Vetting of Exoplanets (DAVE) from K2. DAVE implements vetting tools used for the Kepler mission (e.g., Coughlin et al. 2014; Thompson et al. 2015, 2018; Mullally 2017) to produce a uniformly vetted catalog of K2 planet candidates. The pipeline adapts these tools to K2 data and focuses on applying robotic vetting techniques, formulated as part of the prime Kepler mission, to K2 data. We highlight these techniques and the types of false positives they eliminate and present a robust catalog of uniformly vetted planet candidates and false positives. We have reclassified 60 targets previously listed as planet candidates as false positives and two targets previously listed as false positives as planet candidates (EPIC 211970234.01 and EPIC 212572452.01). DAVE’s key benefit to the community is the potential to reduce the effort expended following up on false positives because we can identify them with Kepler data alone. The DAVE pipeline, including the vetting tools, is publicly available at https://github.com/exoplanetvetting/DAVE.

We note that while K2 and Kepler data are based on the same instrument, the two sets have different characteristics and systematics (e.g., K2 data does not span multiple quarters and has a significant roll motion). Thus, vetting tools trained for Kepler data, such as Autovetter, Astronet, and Exonet, may not be optimal for application to K2 data. Compared to machine-learning algorithms, DAVE has the advantage of well-defined individual tests—thoroughly scrutinized across multiple Kepler planet catalogs—that provide specific reasons for failing a particular planet candidate. With that said, while we have ported over some parts of Robovetter into DAVE (e.g., Modshift), DAVE does not (yet) have the capability to measure the completeness and reliability of the vetting process or the validation power of Vespa.

1.1. Different Light Curves, Different Vetting

Throughout this work, when available, we use four different sets of K2 light curves in our DAVE analyses. The four light-curve reductions used are Aigrain et al. 2015 (AGP; Table 4), Luger et al. (2016; EVEREST), Vanderburg & Johnson (2014; k2sff), and the Kepler/K2 program office-processed light curves (PDC).

The Aigrain et al. (2015) AGP light curves are the result of a three-component Gaussian process used to model the observed stellar flux and remove systematics. The three components include one with a dependence on pixel position, one with a dependence on time, and a white-noise component. The light curves from the Luger et al. (2016, 2018) EVEREST algorithm use a variant of the pixel-level decorrelation technique developed to correct systematics in Spitzer data (Deming et al. 2015). The pixel-level decorrelation procedure removes spacecraft pointing–induced systematics, and a Gaussian process is then used to model time-dependent astrophysical variability. We used the EVEREST light curves as available at the Mikulski Archive for Space Telescopes (MAST) without masking and recomputing. The K2sff light curves use a “self-flat-fielding” (SFF; Vanderburg & Johnson 2014) method to remove photometric variability due to the imprecise pointing of K2. The SFF technique involves an iterative basis-spline fit to low-frequency variability and an iterative procedure to remove position-dependent noise that depends on the arc length of the path a star follows on the detector. The K2 mission creates pre-search data conditioning (PDC) light curves that use a modified version of the Kepler processing algorithm (Smith et al. 2012). The PDC removes systematic errors using a process where flux signatures that are similar across many stars in the same group of modules are removed by fitting basis vectors using a Bayesian approach.

The different approaches inherent to the systematics correction employed in each set of light curves leads to different light-curve properties on a star-by-star basis. This in turn leads to the detection of both the same planet candidates with different properties (signal-to-noise ratio (S/N), transit depth, etc.) and the inhomogeneous detection of different planet candidates depending on which light curves are searched, what planet search algorithm is used, and the details of subsequent human candidate vetting (e.g., Crossfield et al. 2016, 2018). In this work, we attempt to mitigate some of these biases by performing a uniform DAVE analysis on each light curve available for a given planet candidate and provide the lessons learned throughout this process.

This paper is organized as follows. In Section 2, we present our algorithm for generating detrended light curves, our search algorithm, and the different vetting metrics we applied. In Section 3, we outline the K2 target sample and describe our catalog of uniformly vetted planet candidates. Finally, we draw our conclusions in Section 4.

2. DAVE Pipeline

The pipeline consists of several modules, each tailored to particular aspects of the vetting procedures we used. These are broadly split into two categories: (a) photocenter analysis to rule out background eclipsing binaries and (b) flux time-series analysis to rule out odd–even differences, secondary eclipses, low-S/N events, variability other than a transit, and size of the
Figure 1. Example of the centroid vetting module of DAVE, showing a target with a clear photocenter shift (left panels, EPIC 211804579) and another target with no significant photocenter shift (right panels, EPIC 206432863). Upper panels: the small circle symbols (magenta) represent individual difference image photocenter positions, and the large circle symbol represents the average position. The star symbols (cyan) represent the corresponding out-of-transit photocenter positions. The catalog position of the respective EPIC target is marked with a yellow cross. Middle panels: same as upper panels but zoomed in to better show the individual photocenters, which are now also colored by the cadence number (from red to blue), along with the corresponding confidence intervals. Lower panels: respective 1′ × 1′2MASS J-band images, with the A2 target marked with a red circle. The source of the photocenter offset for EPIC 211804579 is clearly visible on the image as a field star to the east of the target star.
transiting object. The metrics these modules produce are described below.

2.1. Vetting Metrics: Centroid Analysis

Measuring the position of the photocenter of light during a planetary transit (or stellar eclipse) is a powerful method to distinguish between a genuine occultation occurring in the target system and an unresolved background source aligned along the same line of sight (e.g., an eclipsing binary). Specifically, a strong indicator of a false positive is a photocenter shift away from the target’s location on the detector during a transit. When applied to the original Kepler mission, this method was successful at identifying such false positives with subpixel precision (Bryson et al. 2010). The roll motion of K2, however, changes the distribution of light on the detector from one cadence to the next, independent of any astrophysical variability. The centroid analysis used in DAVE extends the difference-imaging technique described by Bryson et al. (2013) and is outlined in Christiansen et al. (2017); we summarize it here for completeness.

To compensate for the effects introduced by the roll motion of K2, we calculate the photocenter per in-transit cadence instead of per transit as follows. First, we find the in- and out-of-transit cadences with the same roll angle and separated by a single thruster firing event (to minimize the effects of velocity aberration on the roll axis). Next, we compute the photocenter offsets by fitting a pixel response function model (Bryson et al. 2010) to the out-of-transit and difference images. We note that the repeatability of the K2 roll motion is not perfect; thus, in-transit cadences do not always have corresponding out-of-transit cadences at the same roll angle. Finally, assuming that the measured offsets follow a Gaussian distribution, we estimate the probability that these are statistically significant by averaging the centroid offset over all out-of-transit cadences and their corresponding difference cadences.

An example result from the centroid vetting module is shown in Figure 1, demonstrating one target with a clear
photocenter shift (EPIC 211804579, listed as a false positive and planetary candidate in both the NASA Exoplanet Archive and the Exoplanet Follow-up Observing Program (ExoFOP) at the time of writing) and another with no significant shift (EPIC 206432863, a false positive due to radial velocity (RV) measurements; Shporer et al. 2017).

We note that sometimes bright field stars inside the aperture of the target star may capture the out-of-transit pixel response function (PRF) fit and thus result in a false centroid offset (e.g., KOI-1860; Bryson et al. 2013). Such cases are marked in our catalog as “centroid offset spurious” (COSp); if the separation between the target star and the field star(s) is at least 1 pixel, we use the lightkurve package (Vincius et al. 2018) to extract custom light curves from apertures containing only the target star and field star(s). If the custom light curve demonstrates that the transit signal is coming from the target star, it is listed in our catalog as a confirmed planet. Alternatively, if the field star is the source of the signal, we flag the target as a false positive.

An example of a spurious centroid offset for a planet candidate (EPIC 210957318.01) is shown in the upper panels of Figure 2, where the out-of-transit photocenter is locked on the bright field star in the upper left corner of the aperture instead of on the target star, and the PRF fit to the difference image returns the position of the target star, marking it as the source of the transit signal. This target is listed as a confirmed planet in the NASA exoplanet archive NExScI (Mayo et al. 2018) and as a planet candidate with COSp in our catalog. An example of a spurious centroid offset for a false positive (EPIC 211808055.01) is shown in the lower panels of Figure 2. Here the photocenters of the out-of-transit and difference images are both locked on the bright field star in the upper left corner of the target’s aperture, and DAVE flags the target as a potential false positive based on a centroid offset. However, deeper investigation using the custom apertures and extracted light curves shown in Figures 3 and 4 demonstrates that the transit signal is coming from the field star; thus, the target is listed in our catalog as a false positive with COSp.

Another example of a COSp is when the photocenter can be measured for only two to three points (typically for long-period candidates with few transits). As this is insufficient for a meaningful centroid analysis, such targets are dispositioned as planet candidates, with an added COSp comment. If there are three to four centroid measurements (and thus a defined confidence interval), the centroid offset is at the >3σ level of significance and on the order of a pixel or larger, we add an...
additional comment indicating that the target may be a false positive due to a potential centroid offset (CO).

2.2. Vetting Metrics: Flux Analysis

By design, the DAVE pipeline is fast\(^{11}\) and fully automated—it requires only a target list—easy to test, and impartial. For flux-based vetting of K2 candidates, we analyzed several aspects of the time-series light curves to ensure that (1) the signal is plausibly astrophysical, i.e., due to a planetary transit or stellar eclipse instead of a false alarm due to, e.g., instrument systematics, star spots, or stellar pulsation; and (2) the target is not an eclipsing binary. We examine the same plots and information for every detrending available (i.e., AGP, EVEREST, PDC, and SFF).

2.2.1. Modshift Analysis

The flux-based analysis proceeds as follows. First, in order to minimize the effects of stellar variability, we median filter the light curves with a window size of 50 points. Next, we inspect the phase-folded light curve and a zoomed-in plot of the primary transit. We check whether the signal has a significant S/N compared to any out-of-transit variation and appears transit-shaped rather than V-shaped. Next, we check whether there is a secondary eclipse or out-of-eclipse quasi-sinusoidal variation, which would indicate that the object is an eclipsing binary. We then examine the entire photometric time series—detrended and unphased—with each identified transit highlighted according to the given ephemeris and duration. This is to ensure that the individual transit events do not occur near gap edges or during repointing events or that there are any other anomalies that may indicate the signal is systematic in origin instead of a bona fide astrophysical signal. An example is shown in Figure 5 for the EVEREST light curve of the planet candidate 201345483.01. Next, we inspect zoomed-in plots of all individual transits to check whether (1) the shape and depth of each event is inconsistent with a transiting planet, (2) any transit exhibits an asymmetric depth profile, and (3) a minority of the individual transits have significantly larger depths than the rest. Points (1), (2), and (3) would indicate that the feature is likely not a transit but instead has a systematic origin, such as

\(^{11}\) Processing one K2 light curve for one target for one data set takes 29 s on a standard laptop computer.
Sudden pixel sensitivity drop (SPSD). Next, we study the phase-folded light curve, focused on the primary event, separately for the odd- and even-numbered transits. A significant difference between the two indicates that the target is an eclipsing binary with an orbital period twice that of the detected period. Similarly, we also examine the phase-folded light curve focused on the primary at half of the detected period. If the signal appears coherent in this plot, it indicates that the signal is likely due to a transiting planet detected at twice the true orbital period. An example is shown in Figure 6 for the EVEREST light curve of the planet candidate 201345483.01.

After careful inspection of each of these plots, we then examine the Modshift plots (see A.3.4 of Thompson et al. 2018 for a detailed description). Briefly, Modshift is an automated procedure that convolves the transit model fit with the phase-folded light curve to highlight features that have similar shape, depth, and duration to the primary transit event at phases other than 0.0. This allows a number of quantitative measurements. For example, the strength of the primary event is compared to the systematic red noise out of transit to ensure it is a significant detection. Additionally, the second strongest decrease in flux (aside from the primary) is compared to the systematic red noise to test whether it can be a plausible secondary eclipse due to an eclipsing binary. Any positive events that might suggest that the system is a heartbeat star, self-lensing binary, or other nonplanetary system are flagged and examined as well.

Modshift also performs a quantitative measurement of odd–even differences to examine eclipsing binaries detected at half their true orbital period, as well as a check on the consistency of the individual transit depths. Plots are provided to assist the user to determine whether the data qualitatively agree with the quantitative measurements given. Example results from the Modshift flux vetting are shown in Figures 7–9, demonstrating a planetary candidate (EPIC 201345483), a false positive due to odd–even difference (EPIC 212443457), and a false positive due to a significant secondary eclipse (EPIC 214611894).

By examining the multiple facets of the photometric light curve described above for every available detrending and in a variety of qualitative and quantitative formats, we ensure that a target labeled as a candidate is plausibly due to a transiting planet. These metrics allow us to rule out false positives due to significant, undetrended systematics or eclipsing binaries with either a significant secondary or out-of-eclipse variations. For completeness, we also investigate the calculated size of the transiting object using the stellar radii listed in the catalog of Stassun et al. (2018), cautioning that these could be systematically off. With this caveat in mind, if the calculated size of the transiting object is larger than $2R_{\text{Jup}}$—i.e., about twice the size of an M9V (e.g., Kaltenegger & Traub 2009) and thus potentially a star instead of a planet—the target is marked as a planet candidate but with an added flag of “potential very deep eclipse” (“pVDE”).
Additionally, to avoid potential problems related to particularly challenging candidates (e.g., Shporer et al. 2017), cases where the metrics are not well tuned for K2 data, or cases where the four dispositions for a particular target (based on the four different light curves) differ from each other, we complemented the Modshift analysis with visual inspection of all DAVE dispositions. To minimize the introduction of human bias, the vetters looked for the same features DAVE is analyzing, e.g., odd–even difference, a secondary eclipse, transit-like shape, consistent transit depth, and sufficient S/N. An example where the Modshift module misses a clear secondary eclipse due to strong light-curve variability but human vetting captures it easily is EPIC 206135267, shown in Figure 10. The added benefit of human analysis is marking features that are not part of the vetting procedure but may nevertheless be astrophysically interesting (e.g., flares, self-lensing events, etc.). Overall, if there is no sufficient reason to flag potentially doubtful targets as false positives based on either DAVE’s dispositions or visual inspection, we aim to err on the side of passing them as planet candidates.

Most of the DAVE results are unambiguous; i.e., the different dispositions for a particular target are consistent with each other, and visual inspection agrees with the automated vetting. These dispositions are referred to as “accurate” in Section 3. Targets that required further scrutiny and discussion (85 in total) were inspected by at least two members of our team. Of these targets, 51 were consistently identified as planet candidates by three vetters, and the rest were identified as potential false positives. The dispositions where the human vetters disagreed with DAVE are marked as “not convincing” and marked in the DAVE catalog as “NC.” Overall, of the 2886 individual dispositions produced by DAVE, visual inspection agrees for 2609 cases, or about 90%.

### 2.2.2. Transit-like Analysis

It is not uncommon for transit-searching algorithms to return short-period, quasi-sinusoidal false positives that are caused by stellar spots or contact eclipsing binaries. To detect these, we use locality preserving projection (LPP), a transit-like metric (TLM) that uses dimensionality reduction and k-nearest neighbors to distinguish transit-looking folded light curves from the rest. The LPP algorithm currently implemented by DAVE is the same algorithm as that used for the DR24 KOI Catalog vetting (see Section 3.2.1.1 of Coughlin et al. 2016 and Thompson et al. 2016), and we outline it here for completeness. We note that LPP is similar to the method used by Matijevic et al. (2012), where a local linear embedding is used to distinguish between detached and contact eclipsing binaries. However, LPP differs, as it can be applied to TCEs with parameters outside those of the training set. The output from the LPP TLM is a single number representing the degree of
Figure 7. Modshift results for planetary candidate EPIC 201345483. Upper two rows: folded and folded+convolved EVEREST light curve. Lower two rows: the individual panels, clockwise from upper left, show the model fit to all transits (label “primary”), all odd transits (label “odd”), all even transits (label “even”), most prominent positive feature (label “positive”), most prominent tertiary feature (label “tertiary”), and most prominent secondary feature (label “secondary”). There are no significant odd–even differences, secondary or tertiary eclipses/transits, positive features, or sinusoidal modulations, so this is a solid planet candidate.
Figure 8. Upper panel: phase-folded light curve (AGP detrending). Lower panels: modshift results for false positive EPIC 212443457.01. The target is a false positive due to a significant odd–even difference, indicating an eclipsing binary. We note that while Petigura et al. (2017) marked this target as a planet candidate, they also commented that the transit is deep and irregular and the target is a “possible hierarchical triple.”
similarity between the shape of a TCE and the shape of known transits. The method works as follows.

First, the light curve is folded and binned down to 141 data points. The binning is not uniform, but instead it emphasizes the points around the transit. The algorithm then uses LPP dimensionality reduction (He & Niyogi 2004) to reduce those 141 binned points down to 20. Next, using the k-nearest neighbors in this lower-dimensionality space, the distances to the 15 closest transit signals are averaged. This average distance in 20 dimensions is the value given for the TLM. Lower values indicate that the signal in question is clustered near known transit-like signals and thus it is likely shaped like a transit. DAVE’s TLM relies on the mapping to lower dimensions generated from the population of known transits developed for the DR24 Catalog (Coughlin et al. 2016). We note that signal detrending can have an impact on the effectiveness of the metric, so we feed the TLM median detrended light curves.

An example result from the TLM module is shown in Figure 11, demonstrating a false positive where the signal is consistent with quasi-sinusoidal modulations instead of a transit (EPIC 212454160).

3. A Benchmark Catalog of Uniformly Vetted K2 Planet Candidates

We used the DAVE pipeline to vet the K2 Planet Candidate Catalog hosted at the NASA Exoplanet Archive as of 2018 August 6 utilizing the four publicly available light curves—AGP, EVEREST, PDC, and SFF—that are available as high-level science products at MAST. Capitalizing on this treasure trove of data, we produced a uniformly vetted, publicly

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**Figure 9.** Upper panel: modshift results for false positive EPIC 214611894.01. Lower panels: phase-folded light curve (AGP detrending). The target is a false positive due to a significant secondary eclipse, indicating an eclipsing binary.
The catalog lists the EPIC ID of each K2 planet candidate, transit properties, disposition (planet candidate, “PC,” or false positive, “FP”), reason for the disposition (e.g., centroid offset during transit, “CO”), and additional comments (e.g., presence of field stars in the target’s aperture, “FSAp”). DAVE dispositions for planet candidates are uploaded to the Kepler TCE Review Team website (http://keplertcert.seti.org/DAVE/) and the ExoFOP website hosted by NExScI. Supporting materials, including the searched light curves, will also be provided for each EPIC ID. Overall, the catalog is a

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**Figure 10.** Example of DAVE missing a clear secondary eclipse (EPIC 206135267.01), showing the results from the modshift analysis of the EVEREST data (upper panel) and PDC data (lower panel). Systems like this demonstrate the benefit of complementary manual analysis.

**Figure 11.** Example of the TLM vetting module of DAVE, demonstrating quasi-sinusoidal modulations masquerading as a transit signal (EPIC 212454160.01). The data shown represent the phase-folded AGP light curve.

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12 AGP does not cover Campaign 1.
community-facing product designed to serve as a multipurpose tool for, e.g., (a) providing quick-look results for interesting targets (if the light curves are available at MAST); (b) minimizing or even completely removing the need to wait for an accepted publication, since we will continue to update the DAVE website; (c) facilitating exoplanet confirmation and characterization; and (d) enabling the community to make its own judgment about a particular candidate.

DAVE also provides a utility platform for comparison between light curves produced by different teams, each employing a different approach to systematics correction on a star-by-star basis. For example, when comparing the vetting results for AGP, EVEREST, SFF, and PDC, our analysis shows that about one in three planet candidates do not have sufficient S/N (~5–10, depending on the target) in at least one light-curve set. An example of a low S/N in one light curve but a

Figure 12. Comparison between AGP (left panels) and EVEREST (right panels) light curves for EPIC 211808055.01 (upper panels) and EPIC 210605073.01 (lower panels) in terms of normalized flux as a function of orbital phase. DAVE marks EPIC 211808055.01 as a planet candidate in AGP data and a false positive in EVEREST data due to low S/N, and vice versa for EPIC 210605073.01. The disposition for the former target is accurate for AGP data and inaccurate for EVEREST data, and vice versa for the latter target. EPIC 211808055.01 is listed in our catalog as a false positive due to centroid offset (see Figures 2 and 4), and EPIC 210605073.01 is listed as a planet candidate.

Figure 13. Ratio of planet–star radius, e.g., \((R_{\text{planet}}/R_{\text{star}})_{\text{AGP}}/\sigma \times (R_{\text{planet}}/R_{\text{star}})_{\text{EVEREST}}\), for the candidates that show significant transits in the respective pair of data sets. The legends list the corresponding mean and 1σ values. We do not observe a trend with radius ratio and light-curve detrending pipelines.
clear transit in another is demonstrated in Figure 12, where we compare AGP and EVEREST data for the same target. For the case of EPIC 211808055.01, the transit signal is clearly defined in AGP data and has a low S/N in EVEREST data; for EPIC 210605073.01, it is the other way around. In general, the dispositions can vary between the different light curves on a target-by-target basis; thus, vetting multiple data sets for each target is crucial to distinguish between a bona fide planet candidate and a false positive.

For candidates whose transits have sufficient S/N in at least two data sets, we find that the calculated radius ratios $(\Delta R = R_{\text{planet}}/R_{\text{star}})$ are consistent across the four detrendings (AGP, EVEREST, PDC, and SFF). We compare the radius ratios between the different detrendings in terms of $\delta R = (\Delta R_{\text{AGP}})/(\Delta R_{\text{EVE}})$ in Figure 13. The number of pairs is different because a candidate can have significant transits in as few as two data sets or in as many as four—and on a target-by-target basis. We note that there are several outliers where targets have $\delta R \gg 5$ between two data sets, yet the transits are significant in both, e.g., EPIC 211831378, where the transit depth in PDC is $\sim0.1$ and in SFF $\sim300$ ppm. There is no obvious reason for such differences.

The number of candidates showing transits with sufficient S/N in each detrending pipeline is listed in Table 1. Our analysis shows that $\sim90\%$ of the candidates show significant transits in AGP, EVE, and SFF data and $\sim70\%$ in PDC data. Overall, $\sim67\%$ of the targets show significant transits in all four light-curve sets, $\sim23\%$ in three light-curve sets, $\sim5\%$ in two light-curve sets, $\sim3\%$ in one light-curve set, and $\sim2\%$ in zero light-curve sets. The orbital periods, *Kepler* magnitudes, and stellar gravities of the candidates showing no significant transits in a particular detrending pipeline are shown in Figure 14 as a function of the candidate’s radius ratio as listed in NExScI. Overall, we find that there is no one-size-fits-all recipe for analyzing these candidates. Thus, it is recommended that users examine as many different detrendings as possible when evaluating individual systems and modeling them.

3.1. Comparison between NExScI and DAVE Dispositions

Of the 772 *K2* planet candidates we investigated, NExScI listed 276 as confirmed planets, 61 as false positives, and 435 as
Table 2
Examples of DAVE Dispositions Compared to NExScI Disposition as of 2018 August 6

| EPIC ID   | Period | Epoch       | AGP Disp. | EVE Disp. | PDC Disp. | SFF Disp. | Final Disp. | FP Reason | NExScI Disp. | Comments | DAVE URL |
|-----------|--------|-------------|-----------|-----------|-----------|-----------|-------------|-----------|--------------|----------|----------|
| 201110617 | 0.813  | 2787.557292 | Low S/N   | None      | Low S/N   | None      | PC          | ...       | CP           |          | http://...|
| 201130233 | 0.365  | 2788.542394 | SS        | N/A       | N/A       | SS        | PC          | ...       | CP           | SS NC    | ...      |
| 201155177 | 6.687  | 2015.11927  | None      | Low S/N   | None      | PC        | ...         | CP        | ...          |          | ...      |
| 201166680 | 18.105 | 2783.302493 | CO        | None      | Low S/N   | None      | CP          | AGP COSp   | ...          |          | ...      |
| 201211526 | 21.07  | 2797.621875 | CO        | CO        | CO        | CO        | PC          | ...       | CP           | pCO      | ...      |
| 201629650 | 40.063 | 2019.587878 | ...       | ...       | ...       | ...       | ...         | CP        | pCO, FSAp    | ...      | ...      |
| 2016119924| 4.656  | 2179.540469 | CO        | Low S/N   | Low S/N   | LCMOD     | PC          | ...       | CP           | pCO, FSAp | ...      |
| 211594205 | 16.994 | 2349.48838  | ...       | ...       | ...       | PC        | ...         | CP        | pCO          | ...      | ...      |
| 210954046 | 0.95   | 2263.967875 | CO        | None      | None      | CO        | FP          | CO        | FP (RV)   | No centroid | ...      |
| 206155547 | 24.387 | 2177.271763 | SS        | SS        | None      | SS        | FP          | SS        | FP (RV)   | ...      | ...      |
| 210401157 | 1.316  | 2264.541126 | SS        | SS        | SS        | SS        | FP          | OOTMOD    | FP‡          | pSS      | ...      |
| 210754505 | 0.807  | 2264.106897 | None      | OE        | None      | None      | PC          | ...       | FP (OOTMOD) | pOE, pOOTMOD | ...      |
| 210414957 | 0.97   | 2264.112891 | None      | None      | None      | None      | PC          | ...       | FP (OOTMOD) | pOOTMOD   | ...      |
| 206065006 | 25.277 | 2186.653484 | Low S/N   | Low S/N   | Low S/N   | Low S/N   | PC          | ...       | FP (Vespa) | Low S/N   | ...      |
| 212572439 | 2.582  | 2423.58774  | CO        | CO        | CO        | CO        | FP‡‡         | CO        | PC          | FSApST   | ...      |

Note. The five sections, starting from the top, are as follows: (i) NExScI confirmed planets and DAVE planet candidates, (ii) four NExScI confirmed planets that are marked in the DAVE catalog as planet candidates but may be false positives due to potential centroid offset, (iii) NExScI and DAVE false positives, (iv) NExScI false positives but DAVE planet candidates, and (v) NExScI planet candidates but DAVE false positives. The corresponding columns are EPIC ID; period; epoch; automated false-positive reason for AGP, EVEREST, PDC, and SFF light curves, respectively; final disposition in DAVE catalog; false-positive reason; NExScI disposition; and comments. The corresponding abbreviations are listed in Table 4. (This table is available in its entirety in machine-readable form.)
planet candidates (as of 2018 August 1). We note that eight targets—EPIC 201324549.01, 205990339.01, 206432863.01, 210414957.01, 210754505.01, 211804579.01, 212572452.01, and 228729473.01—are listed as both a planet candidate and a false positive at the time of writing (e.g., Livingston. et al. 2018 and references therein). In addition, EPIC 206135267.01 is listed in NExScI as a planet candidate with a reference to Crossfield et al. (2016) and Vanderburg et al. (2016), yet it is marked as an “Obvious Binary” by Crossfield et al. (2016; their Table 3). Another target, EPIC 212443457.01, is also listed as a planet candidate in NExScI but is marked as a “irregular transit shape” by Petigura et al. (2017).

Our analysis of this sample identifies 676 planet candidates and 96 potential false positives. These are distributed as described below.

### 3.1.1. DAVE Analysis of Confirmed Planets

All 276 targets listed in NExScI as confirmed planets pass our vetting analysis and are marked in the DAVE catalog as planet candidates (“PC”). Their corresponding DAVE dispositions are listed in Table 2. We note that we vet targets independent of any prior knowledge of whether the system is confirmed or not.

Four of the confirmed planets show signs of a potential—but not prominent enough to declare a false positive—photocenter shift, and although they are dispositioned in our catalog as planet candidates, we recommend further investigation. In addition, while DAVE’s automated vetting passes EPIC 212554013.01, visual inspection of the ModShift results indicates that there may be a potential secondary eclipse, very weak (depth of \( \sim 100–200 \) ppm), identified by the module at the same phase (\( \approx 0.38 \)) for the AGP, EVEREST, and SFF light curves, albeit not as a statistically significant feature. However, as the (primary) transit depth indicates a Jupiter-sized object (\( \sim 10R_\oplus \))—and thus the potential secondary feature may be an occultation, and the depth of the potential secondary feature is comparable to the height of the positive features present in the light curve—we list this target as a planet candidate.

The four targets with potential centroid offsets are as follows.

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Figure 15. Measured out-of-transit and difference image centroid positions for EPIC 201211526 (results for PDC data), listed as a confirmed planet in NExScI but indicating a potential centroid offset in DAVE of \( \sim 0.5 \) pixel with a \( \chi^2 \approx 1800. \) The lower left panel shows a 1’ × 1’ 2MASS J-band image.
(i) EPIC 201211526.01. See Figure 15. The centroid offset is most pronounced in the vetting analysis of the PDC data—showing four cadences with measured centroids—and less so in the other three light-curve sets where there are three measured centroids. A query of the 2MASS catalog does not reveal any obvious field stars within the $K_2$ aperture (lower left panel of the figure).

(ii) EPIC 201629650.01. See Figure 16. There are two field stars north and south of the target, the former much brighter. DAVE measures a $>3\sigma$ centroid offset in a northern direction, although it is based on three centroid positions only. Deeper investigation of this target using custom apertures with the lightkurve package (Vincius et al. 2018) was inconclusive (see Figure 17). Nevertheless, given that the magnitude of the measured centroid offset is nearly 1 pixel and the direction is toward the brighter of the field stars, we add a comment indicating a potential centroid offset.

(iii) EPIC 206119924.01. See Figure 18. The measured centroid offset is at the $\sim2\sigma$ level, and the individual difference image photocenters are scattered across the target’s aperture. Closer inspection of the 2MASS $J$-band image (lower left panel) indicates that there is a faint nearby field star north of the target. Two stars are blended within the central 2–3 pixels, and we could not employ custom light-curve extraction to study the photometry of each star individually. The measured difference image photocenter is in the opposite direction of the field star, which suggests that the offset may be spurious. However, for consistency within our catalog and despite its previous confirmation, we list the target as RFS for “recommend further scrutiny.”

(iv) EPIC 211594205.01. See Figure 19. The measured centroid offset is $\sim0.7$ pixel at the $>3\sigma$ level, although it is based on four points. While there are no obvious field stars in the 2MASS images, there is a faint field star southeast of the target on the DSS images, in the opposite direction of the measured photocenter shift. The two stars are blended within the central 2–3 pixels, and we could not employ custom light-curve extraction to study the photometry of each star individually. Thus, we recommend further scrutiny of this target.
3.1.2. Potential False Positives

Of the 96 targets flagged as potential false positives in the DAVE catalog (see Table 3), 60 are listed in NExScI as planet candidates and 36 as false positives. Our dispositions and the corresponding number of targets are listed in Table 3. The most common reason for flagging a target as a false positive (49 targets) is the presence of a secondary eclipse (indicating the target is probably an eclipsing binary; EB). Next is a measured photocenter shift during transit (25 targets, indicating that the target star is not the source of the signal). Seventeen targets exhibit out-of-transit modulations in phase with the detected transits (suggesting an EB), eight targets exhibit nontransit-like features (i.e., stellar variability mimicking transits), and six targets show differences in the measured depths of odd and even transits (indicating an EB at half the proposed period). Nine targets exhibit more than one false-positive indicator.

We note that while DAVE detected secondary eclipses for two targets, EPIC 206036749.01 and EPIC 211705654.01, the depths of the corresponding primary transits indicate a Jovian or smaller orbiting body, and the orbital periods are \( \sim 2–4 \) days. As a result, these secondary eclipses may in fact be planetary occultations, and the targets are thus listed in our catalog as planet candidates. Additionally, the calculated transit depth for 48 targets suggests a transiting object larger than \( 2R_{\text{Jup}} \), and six targets show V-shaped transits—both potentially indicative candidate.
of an EB. These targets are listed in our catalog as planet candidates with an added flag for, respectively, “pVDEs” or “V-shaped transits.”

We note that while 25 of the remaining NExScI false positives pass the automated vetting and are marked as planet candidates in our catalog, 14 are flagged as “pVDEs” or “V-shaped transits,” and visual inspection marks two of them as likely false positives due to potential odd–even differences and/or out-of-transit modulations, in agreement with the results of Adams et al. (2016).14 Eleven are discussed in more detail below.

(i) EPIC 201324549.01 is listed as a false positive and flagged as a “triple star system” in Crossfield et al. (2016) but as a planet candidate by Barros et al. (2016) and Vanderburg et al. (2016). This target passes all of our vetting tests and is marked in the DAVE catalog as a planet candidate.

(ii) EPIC 203581469.01 has an S/N < 4 and is thus automatically flagged as a false positive by DAVE. As described below, for such targets, we use a default disposition of planet candidate.

(iii) EPIC 205990339.01 is also listed as a planet candidate by Vanderburg et al. (2016) but a false positive with a probability of 1 by Crossfield et al. (2016). DAVE marks this target as a false positive in SFF and EVEREST data due to odd–even differences. However, visual inspection marks these as spurious. Since the period is long, there are only three transits; the transit has a short duration and thus is not well-sampled.

(iv) EPIC 206065006.01 has an S/N < 4. By default, we mark such targets as planet candidates even though DAVE flags them as false positives.

(v) The two-planet system EPIC 206432863 (in a 2:1 resonance) is listed in NExScI as confirmed by Crossfield et al. (2016) but refuted by Shporer et al. (2017) based on RV measurements. DAVE flags the inner planet candidate as a false positive due to odd–even differences and centroid offset, but visual inspection does not find these convincing, given the intrinsic light-curve modulations and the scatter in the measured photocenters, and flags the outer planet candidate as a false positive due to secondary

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14. These two were not specially selected for further scrutiny; all DAVE results are inspected by at least one person, regardless of their automatic disposition.
eclipses—again disproved by visual inspection, since these are the transits of the inner candidate.

(vi) EPIC 210414957.01 and EPIC 210754505.01 are listed on NExScI as both false positives due to out-of-transit modulations (Adams et al. 2016) and planet candidates (Barros et al. 2016; Crossfield et al. 2016). Visual inspection of these two suggests that there may indeed be potential out-of-transit modulations in AGP and EVEREST data, as well as a potential odd–even difference for EPIC 210754505.01 in EVEREST data (as flagged by DAVE).

(vii) EPIC 211946007.01 is flagged as a false positive by Gillen et al. (2017) using RV measurements. While DAVE flags this target as a false positive due to odd–even differences, visual inspection did not find the disposition convincing because the transit is not well-sampled due to the very short duration. In addition, there is a field star inside the aperture of EPIC 211946007.01 that captures the out-of-transit photocenters, but the difference image photocenters lock on the target star itself, demonstrating that it is the source of the transit signal—which is also corroborated by custom aperture analysis with lightkurve.

(viii) EPIC 211970234.01 is flagged as a false positive by Dressing et al. (2017) because of “inconsistent transit depth or blended photometry.” DAVE flags this target because the feature does not appear transit-like but visual inspection marks this as spurious since the duration of the transit is very short and the transits are not well-sampled. In addition, there are multiple field stars in the aperture, and the measured centroid from DAVE is spurious because both the out-of-transit and difference image photocenters lock on the brightest of them instead of on the target star. However, using lightkurve, we confirmed that the transit signal is the target star itself and not the field stars. This is shown in Figure 20, where the target’s aperture produces a clear transit signal (left panels), but there is no obvious transit signal coming from the field star (right panels).

(ix) Finally, EPIC 228729473.01 is listed as a planet candidate by Mayo et al. (2018) but a false positive due to RV observations by Livingston et al. (2018).
Overall, these considerations demonstrate that, barring RV measurements, the true disposition of these 11 candidates is quite challenging, and it is thus not unexpected that they are not flagged as false positives in our catalog.

3.1.3. Individual Targets

Targets that happen to fall inside each other’s aperture can be particularly challenging to vet. An example is EPIC 212572439.01 (NExScI candidate) and EPIC 212572452.01 (NExScI false positive). Dressing et al. (2017) identified the latter as a false positive due to light contamination from the former. DAVE flags both targets as false positives due to measured significant photocenter shifts during transit. However, closer investigation indicates that EPIC 212572452.01 is the planet candidate and EPIC 212572439.01 is the false positive. Specifically, as shown in Figure 21, the out-of-transit photocenters for EPIC 212572452.01 lock onto the brighter field star EPIC 212572439.01, while the difference image photocenters lock onto EPIC 212572452.01 itself, indicating it as the true source of the transit signal. In contrast, the out-of-transit photocenters for EPIC 212572439.01 lock onto it, while the difference image photocenters lock onto EPIC 212572452.01, again indicating it as the transit signal. Extracting custom light curves with lightkurve confirms this (see Figures 22 and 23).

3.2. Lessons Learned

During our analysis of the K2 planet candidates, we noticed several issues introduced by the application of an automated vetting pipeline to an inhomogeneous set of light curves. Here we list these “lessons learned.”

(i) In some cases, the center of light can be measured for only one or two cadences at the same roll angle. In such situations, DAVE cannot provide a statistically significant centroid analysis, so we used archival images to rule out potential contamination sources and constrain the offset.
Figure 21. Upper panel: a $1' \times 1'$ 2MASS $J$-band image of EPIC 212572439.01 (brighter) and EPIC 212572452.01 (fainter). Middle and lower panels: DAVE photocenter measurements for EPIC 212572439.01 (middle panels) and EPIC 212572452.01 (lower panels). The two targets fall in each other’s aperture. The pipeline flags both targets as false positives due to a measured centroid offset. As discussed in the text and shown in Figures 22 and 23, closer investigation demonstrates that EPIC 212572452.01 is the true source of the transit signal and EPIC 212572439.01 is a false positive.
Sometimes, the test for odd–even differences fails targets with deep transits that, after careful visual inspection, appear to be bona fide planet candidates. We realized the importance of taking the systematic red noise ($F_{\text{red}}$) into account when computing the statistical significance of the odd–even metric. To account for this complication, we modified the code to include a comparison between the depth of the transits and the red noise of the light curve. For example, we started with automatically failing if $\sigma_{\text{odd–even}} > 4$ but found it too harsh, so we compensated with $(\sigma_{\text{odd–even}}/F_{\text{red}}) > 4$, which was more accurate. While this improved the disposition for most of these targets, there were still a few that could not be reconciled.

To test whether a transit has sufficient S/N, DAVE uses a nominal threshold of S/N = 10. However, given that the different light curves are processed and detrended by different methods, transits in AGP, EVEREST, and SFF often (but not always) have a different S/N (e.g., see Figure 12). Thus, using a single S/N threshold for all four light-curve sets is not optimal; for example, we have found that in general, an S/N = 6–7 works better for PDC. Overall, we note that all automated false-positive dispositions due to low S/N are marked in our catalog as planet candidates, since these candidates may have been discovered in light curves customarily detrended beyond what is publicly available. In addition, if we had K2 transit-injection and recovery experiments, this would help to quantify the detection threshold for each detrending as a function of planet parameters.

4. Conclusions

Capitalizing on our group’s unique expertise accumulated as part of Kepler’s planet candidate vetting team (e.g., Mullally et al. 2015; Coughlin et al. 2016), we have developed the fully automated vetting pipeline DAVE. We have adapted several methods used for vetting Kepler data, i.e., the LPP algorithm (Thompson et al. 2015) and Marshall technique (Mullally et al. 2016), to check whether the event is transit-shaped. In addition, we compared the depth to the red noise in the light curve and searched for secondary events. We have also developed a novel method for measuring centroid shifts in the presence of K2’s
image motion that enables us to measure in-transit image motion at a level approaching that of the Kepler mission.

Using DAVE, we have thoroughly examined 772 K2 targets, eliminating a number of different false positives and false alarms, and produced a benchmark catalog of uniformly vetted planet candidates and false positives. Of these targets, 676, including 276 confirmed planets, pass our vetting tests and are listed in our catalog as planet candidates. Ninety-six targets fail one or more of these tests. Thirty-six of these are known false positives, and the rest are new dispositions. The main source of false positives is a significant secondary, nonplanetary eclipse detected in the light curve (49 targets), followed by a center-of-light offset during transit (25 targets). A smaller number of targets were dispositioned as false positives due to either out-of-transit modulations (17 targets), features that do not appear transit-like (eight targets), or odd–even differences between consecutive transits (six targets). Fourteen targets, while listed in our catalog as planet candidates, are flagged as having either a potentially very deep transit (i.e., a transiting object larger than $2R_{\text{Jup}}$; 48 targets) and/or V-shaped transit signatures (six targets). Two targets that were previously listed as false positives were reclassified as planet candidates (EPIC 211970234.01 and EPIC 212572452.01).

The number of transiting planets is expected to grow significantly in the coming years, especially with the recent launch of TESS (Ricker et al. 2015) and, looking into the future, the Wide Field Infrared Survey Telescope (Spergel et al. 2015) as well. The knowledge gained here will be key when applying DAVE and other vetting diagnostic tools to the large number of planet candidates expected to be found in a multitude of community-produced light curves from the TESS pixel-level data and full-frame images. TESS will produce full-frame images at the same cadence as K2, and these will contain $\sim$25–30 million persistent light sources—among which there will be thousands of transiting planet candidates (Barclay et al. 2018). Quickly vetting these with DAVE will be critical for the rapid follow-up needed to obtain mass measurements, comparing the community light curves, and the development of a uniform catalog of TESS planets. We are currently developing DAVE to be directly applicable to TESS data and are already testing it on recently released planet candidates from TESS. In addition, planet validation will help enable prioritization of the best targets for atmospheric characterization with the Hubble Space Telescope and JWST.

Figure 23. Same as Figure 22 but for the planet candidate EPIC 212572452.01. Here the target star (EPIC 212572452.01) produces a much deeper transit (left panels) compared to the field star (EPIC 212572439.01, right panels), confirming that the former is the source of the signal.
The DAVE catalog will be hosted in a table format by MAST and will be properly maintained, archived, and documented at the archive in perpetuity. We will incorporate any additional candidates found by the community so that all planetary candidates found in K2 data will have a consistent set of statistics and vetting products available. In addition, we hope to continue improving our algorithms, refactor our code to improve readability, and add documentation to lower the barrier to community use while maintaining our open-access policy.

We thank the referee for the insightful comments that helped us improve this manuscript. This paper includes data collected by the K2 mission. Funding for the K2 mission is provided by the NASA Science Mission directorate. The data presented in this paper were obtained from the Mikulski Archive for Space Telescopes (MAST), operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS5-26555. The NASA Exoplanet Archive is operated by the California Institute of Technology, under contract with NASA under the Exoplanet Exploration Program. V.K., E.Q., and J.C. gratefully acknowledge support from NASA via grant NNX16AJ19G. DAVE is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS5-26555.

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Software: DAVE (https://github.com/exoplanetvetting/DAVE), Kepler Science Data Processing Pipeline (https://github.com/nasa/kepler-pipeline), Centroid Robovetter (Mulally 2017), LPP Metric (Thompson et al. 2015), Scipy package (https://www.scipy.org).

Abbreviations

| Abbreviation | Description |
|--------------|-------------|
| AGP         | AGP light curves (Aigrain et al. 2015) |
| CO          | Centroid offset |
| COSp        | Centroid offset spurious |
| CP          | Confirmed planet |
| EVEREST     | EVEREST light curves (Luger et al. 2016, 2018) |
| FP          | False positive |
| FSap        | Field star(s) in aperture |
| FSapST      | Field star(s) in aperture, the source of the transit |
| LCMOD       | Light-curve modulations |
| N/A         | Disposition and/or light curve not available |
| NC          | Not convincing |
| OE          | Odd—even difference |
| OOTMOD      | Out-of-transit modulations |
| PC          | Planet candidate |
| pCO         | Potential centroid offset |
| PDC         | PDC light curves (Smith et al. 2012) |
| pFP         | Potential false positive |
| pOOTMOD     | Potential out-of-transit modulations |
| pSS         | Potential significant secondary |
| RFS         | Recommend further scrutiny |
| SFF         | SFF light curves (Vanderburg & Johnson 2014) |
| S/N         | Signal-to-noise ratio |
| TESS        | Transiting Exoplanet Survey Satellite |
| TLM         | Transit-like metric |
| pVDE        | Potentially very deep eclipse |
| VSHAPE      | V-shaped transit |

The DAVE catalog will be hosted in a table format by MAST and will be properly maintained, archived, and documented at the archive in perpetuity. We will incorporate any additional candidates found by the community so that all planetary candidates found in K2 data will have a consistent set of statistics and vetting products available. In addition, we hope to continue improving our algorithms, refactor our code to improve readability, and add documentation to lower the barrier to community use while maintaining our open-access policy.

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