Light-curve Modulation of Low-mass Stars in K2. I. Identification of 481 Fast Rotators in the Solar Neighborhood

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Received 2017 January 4; revised 2017 October 20; accepted 2017 October 25; published 2017 December 15

Abstract

The K2 mission is targeting large numbers of nearby (d < 100 pc) GKM dwarfs selected from the SUPERBLINK proper motion survey (µ > 40 mas yr⁻¹, V < 20). Additionally, the mission is targeting low-mass, high proper motion stars associated with the local (d < 500 pc) Galactic halo population also selected from SUPERBLINK. K2 campaigns 0 through 8 monitored a total of 26,518 of these cool main-sequence stars. We used the auto-correlation function to search for fast rotators by identifying short-period photometric modulations in the K2 light curves. We identified 481 candidate fast rotators with rotation periods <4 days that show light-curve modulations consistent with starspots. Their kinematics show low average transverse velocities, suggesting that they are part of the young disk population. A subset (13) of the fast rotators is found among those targets with colors and kinematics consistent with the local Galactic halo population and may represent stars spun up by tidal interactions in close binary systems. We further demonstrate that the M dwarf fast rotators selected from the K2 light curves are significantly more likely to have UV excess and discuss the potential of the K2 mission to identify new nearby young GKM dwarfs on the basis of their fast rotation rates. Finally, we discuss the possible use of local halo stars as fiducial, non-variable sources in the Kepler fields.

Key words: stars: activity – stars: low-mass – stars: Population II – stars: rotation – surveys

Supporting material: machine-readable tables

1. Introduction

Stars with convective interiors like the Sun have active magnetic fields that produce relatively cool spots on their surfaces, which appear darker than the surrounding photosphere. As the star rotates, the disk-integrated brightness of the star changes as spots come in and out of view. Using time series analysis, we can determine the star’s rotation rate from the modulation of the light curve over time (McQuillan et al. 2013). In recent years, a vast amount of high-precision photometric data from Kepler and K2 has facilitated the search for exoplanets. An additional benefit of these high-precision, long-term data sets is the ability to determine rotation rates from photometric modulation due to starspots (Rappaport et al. 2014).

A star’s rotation rate is generally well-correlated with its age, a phenomenon that has been empirically demonstrated since the 1970s (Skumanich 1972; Barnes 2007; Mamajek & Hillenbrand 2008). The rotation–age relationship, also known as gyrochronology appears to be relatively reliable for solar-type stars, though it possibly breaks down in the low-mass regime due to changes in the rotational braking mechanism produced by magnetic fields (Reiners & Basri 2008). However, the rule that fast rotation indicates relative youth (i.e., stellar ages <1 Gyr) still holds true in general for early- to mid-type M dwarfs (Newton et al. 2016).

The identification of nearby young M dwarfs is an outstanding problem in stellar astronomy. Nearby (d < 100 pc) young stars are typically identified by moving group membership; proper motion and radial velocity measurements are used to associate a low-mass dwarf with known groups of young (usually more massive) stars. Kinematic data can indicate youth in two ways. In the more general case, where stellar radial velocities are unavailable, proper motions combined with photometric distances may suggest that a star is “kinematically young” by placing it among the young disk population (<2–5 Gyr). On the other hand, if a star has proper motion, distance, and radial velocity data available, we can calculate UVW space velocities and determine group membership (Gagné et al. 2014). Identification of group membership generally indicates a much younger age (<100 Myr) as moving groups tend to disperse on a relatively short timescale.

New members to moving groups are determined by combining UVW velocities with a secondary youth indicator, such as strong X-ray flux, UV excess, or Hα emission. Young M dwarfs have strong magnetic fields making them chromospherically active and producing bright X-ray emission (Fleming et al. 1995). Many nearby, young M dwarfs are indeed detected as ROSAT sources. Active M dwarfs can also show strong UV emission (Ansdell et al. 2015), and many are detected in the GALEX survey. If a cool M dwarf is detected in the X-ray or UV, it can safely be designated as young (Shkolnik et al. 2012). These data are difficult to obtain for most M dwarfs due to their low luminosities at all wavelengths, unless they are relatively nearby (d < 100 pc). This has led to the suggestion that many M dwarfs may be missing from surveys of nearby moving group members because their X-ray or UV brightness is below survey detection limits (Schlieder et al. 2011).

The current method for identifying and confirming young, nearby stars requires that a candidate has both a proper motion consistent with any one of the known moving groups in

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addition to having detected flux in the X-ray and/or UV. The standard procedure then requires one to obtain a spectrum of the candidate and identify other activity features such as a strong Hα in emission. However, stars that do not meet both criteria (kinematics + X-ray/UV detection) are generally not considered to show enough evidence of youth, and are typically not considered for follow-up spectroscopic observations.

Lists of confirmed moving group members have fewer M dwarfs than one would expect, compared with the large numbers of M dwarfs normally found among field stars. A possible explanation for the small number of M dwarfs is that we fail to identify them because our criteria are too strict. Perhaps some young M dwarfs have X-ray or UV emission that is not bright enough to be detected in current surveys; for example, the limiting magnitude of GALEX is NUV ∼ 20.5. There could be an advantage in finding an alternative or additional diagnostic for young stars, e.g., fast rotation. We investigate the potential for using rapid rotation as a youth indicator in the identification of nearby young moving group members based on the hypothesis that young M dwarfs should have rapid rotation even if no clear chromospheric activity (X-ray, UV excess) is detected. With the photometric data available from K2, we have the potential to determine youth via rotation for hundreds of M dwarfs.

In this paper, we present our data selection and reduction in Section 2, data analysis in Section 3, and a discussion of our results in Sections 4–6. We present our conclusions in Section 7.

2. Data Acquisition and Reduction

The current version of the SUPERBLINK proper motion catalog lists stars with proper motions μ > 40 mas yr⁻¹ and visual magnitudes V < 20 over the entire sky north of decl. = −30; this area includes all fields observable in K2 (Lépine 2005; Lépine & Gaidos 2011). Lists of nearby stars with estimated distances d < 100 pc were assembled from this catalog, and proposed as targets of interest in the first calls for K2 targets. Several thousand SUPERBLINK stars were thus deliberately selected for K2 monitoring as part of programs aimed at monitoring nearby M dwarfs (Crossfield et al. 2016), as well as stars with large transverse motions, i.e., Galactic halo candidates. Additional SUPERBLINK stars were selected as targets for K2 after having been proposed by other teams based on different selection criteria whether or not they were known to be high proper motion stars by those teams. We have cross-matched the SUPERBLINK catalog with the final target lists for K2 campaigns 0–8. This was done by checking the coordinates in the SUPERBLINK catalog against the coordinates provided in the K2 target lists available online (http://keplerscience.arc.nasa.gov/K2/). We used a search radius of 5 arcsec to find matches that identified 26,518 high proper motion SUPERBLINK stars monitored by Kepler in the initial K2 campaigns. For reference, the complete list of SUPERBLINK stars monitored by Kepler is provided in the Appendix.

Figure 1 plots the positions on the sky of these 26,518 SUPERBLINK-K2 (hereafter SBK2) targets from K2 campaigns 0–8. The black points represent all SBK2 targets, the red circles indicate the fast rotators identified in the present study (see Section 4, below). The figure shows that there are more SUPERBLINK stars in campaigns 1, 5, 6, and 8 compared to 0, 2, 3, 4, and 7. There are a few reasons for the varying levels of targets per field. Fewer targets were observed in C0, as the mission was still being tested; SUPERBLINK stars were not selected in half of the C4 field for reasons that remain unclear; and fields C2 and C7 contained a lower number of targets overall, as these fields lie near the Galactic plane. Ultimately, SUPERBLINK stars were monitored in each campaign due in large part to the recent increased interest in M-dwarfs among the exoplanet community. Table 1 lists the total number of K2 targets and the number of long cadence observed SBK2 targets per campaign.

We used light curves generated by the k2phot photometric pipeline, which is publicly available on GitHub.⁶ The light curves are also available on the ExoFOP.⁷ The reduction corrects for the periodic drift of star images on the K2 CCD due to roll due around the telescope boresight. This data reduction was specifically designed to work with the TERRA exoplanet transit algorithm (Petigura et al. 2013).

We made two modifications to the k2phot light curves in order to eliminate long-term variations in the signals (including instrumental effects) and focus on the detection of short-period modulations expected from stars with short rotation periods. First, we detrended the time series by fitting a third-order polynomial to the data and subtracting off the fit. Next, we calculated the mean value of the flux over the entire K2 light curve, then subtracted that value to obtain a time series of the residuals with arbitrary flux units, f. Next, we rejected all points that deviated f > 3% or f < −30% from the mean in order to exclude instrumental artifacts and intrinsic bursts such as flares. We chose a deep threshold for rejection, as we did not want to remove any potential eclipses that could be investigated in future work. We kept an account of all points that were rejected and flagged these points as possible flare events (outliers above the mean) or eclipses (outliers below the mean). Many of these rejections appear to be spurious spikes (possibly instrumental artifacts in many cases) with most light curves showing ∼10 of these spurious events. We then ran these “cleaned” light curves through our cross-correlation algorithm (which does not require uniform sampling—see below) to identify periodic signals.

3. Identification of Periodic and Quasi-periodic Modulations

Lomb–Scargle periodograms are widely used to analyze time series data to find rotation periods of stars (Scargle 1982). The strength of Lomb–Scargle analysis is that it does not require the signal to be evenly sampled. However, the signal to be detected must be very nearly periodic over the entire time series. Before Kepler, this was the preferred method to search for rotation signals in stellar light curves because most data sets were irregularly sampled over the course of a few nights of observations (McQuillan et al. 2013). A potential drawback of the method is that rotation modulations of most stars are not strictly periodic because starspot patterns change and flares or transit events occur.

Now, with publicly available K2 data, we can explore more options for time series analysis. McQuillan et al. (2013) thoroughly demonstrated that the auto-correlation function (ACF) is more powerful when used with Kepler data because it is a measure of the self-similarity of the light curve over characteristic timescales and does not require the signal to be strictly repeating. In this paper, we adopt a similar procedure to

⁶ https://github.com/petigura/k2phot (commit a0d507).
⁷ https://exofop.ipac.caltech.edu/
identify stellar fast rotators in the $K2$ data and estimate their rotation periods.

Assuming a lag $k$ in the evenly sampled time-series, we define the auto-correlation coefficient, $r_k$, to be

$$r_k = \frac{\sum_{i=1}^{N-k} (f_i - \bar{f})(f_{i+k} - \bar{f})}{\sum_{i=1}^{N-k} (f_i - \bar{f})^2}, \quad (1)$$

where $\bar{f}$ is the mean flux value, $f_i$ is the flux value at the $i$th point in the time series, $f_{i+k}$ is the flux value at the $i+k$th value in the time series, and $N$ is the total number of sample points. The ACF itself is all coefficients, $r_k$, plotted against their respective $k$ values multiplied by the cadence, $c$, which provides a time delay rather than a pixel lag. In our analysis, we search for modulations with periods that have up to half the length of the time series. The “rotation period” of a star is determined from the characteristic timescale of the variations in the $K2$ light curve from

$$P_{\text{rot}} = k_{\text{max}} \times c, \quad (2)$$

where $k_{\text{max}}$ is the location of the first peak in the auto-correlation function, $r_k$. In general, a strictly periodic and infinitely repeating signal will also display significant peaks at lags of $2k_{\text{max}}, 3k_{\text{max}}, \ldots, nk_{\text{max}}$ all being aliases of the fundamental period. A recurrent signal that changes its fundamental pattern over time, on the other hand, will have alias peaks that are weaker than the first, and they may not peak at exact integer values of the fundamental period. Determining

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**Figure 1.** Positions of SBK2 targets in campaigns 0–8. The black points represent all SBK2 targets, the red circles represent the fast rotators ($P_{\text{rot}} \leq 4$ days) identified in our search.
the location of the first peak proves to be difficult using a simple search for the first local maximum. This is because the ACF typically also displays high frequency, low amplitude signals that produce many hundreds of local maxima. For K2 light curves, a simple box-smoothing of the ACF is generally found to be insufficient in removing the high frequency signal, as the size of the box would have to differ for each target so that the intrinsic signal would not be degraded by the smoothing. Optimally, the size of the box would need to correspond to the fundamental frequency of the ACF, i.e., the rotation period of the star, a value that is not known a priori.

As an alternative method to identify the astronomically relevant signals, we have adopted the use of the Fast Fourier Transform (FFT) of the ACF. The advantage is that the fundamental frequency of the signal with at least a few of its aliases in the ACF will present itself as a relatively strong signal in the FFT. We thus compute the FFT of all the ACF from the K2 light curves and search for maxima in those FFT.

Since the signal we are after may not be strictly repeating, the aliases in the ACF may also not be evenly spaced, and the period extracted from the FFT generally only yields an approximate estimate of the first peak in the ACF. In addition, we find that the FFT has limited accuracy in measuring the periods from low-frequency signals. We therefore use the period identified in the FFT as an initial guess to identify the fundamental first peak in the ACF. We then perform a search for local maxima in the ACF using a parabola fit around the initial guess. We perform a fit of a section of the ACF that is centered on the location of the initial guess for the first peak with a width of one-half of the period corresponding to that fundamental first peak. We use the three coefficients $a_0$, $b_0$, and $c_0$ returned from the polynomial fit ($a_0 x^2 + b_0 x + c_0$) to calculate the center, i.e., the effective stellar rotation period $P_{\text{rot},0}$ associated with the modulation; the peak, i.e., amplitude of the ACF, $A_0$; and the parabola opening, $B_0$. These three values are calculated via the following equations.

$$P_{\text{rot},0} = -\frac{b_0}{2a_0} \quad (3)$$

$$A_0 = c_0 - \frac{b_0^2}{4a_0} \quad (4)$$

$$B_0 = a_0 P_{\text{rot},0}^2 \quad (5)$$

In addition, we also locate the first four aliases in the ACF based on the initial guess, and perform similar second-order polynomial fits to estimate the amplitudes and parabola openings of those peaks and their associated effective rotation periods. Thus for each alias $k$, we find the coefficients $a_k$, $b_k$, and $c_k$, and compute

$$P_{\text{rot},k} = -\frac{b_k}{2a_k} \quad (6)$$

### Table 1

| Field | K2 | SBK2 |
|-------|----|------|
| 0     | 7757 | 574  |
| 1     | 21647 | 5885 |
| 2     | 13351 | 1359 |
| 3     | 16348 | 1798 |
| 4     | 8634  | 2112 |
| 5     | 25137 | 3676 |
| 6     | 28288 | 5123 |
| 7     | 13260 | 1733 |
| 8     | 23564 | 4258 |

Figure 2. Parameters $A$ and $B$ calculated from the ACF used to reject false positive rotation signals. The top panel indicates the box rejection of targets with $P_{\text{rot}} \sim 0.22$ days and $P_{\text{rot}} \sim 1.75$ days with $A \leq 0.4$. The middle panel indicates the rejection of any star with $B < 2$. These selection criteria were determined after careful “by-eye” examination of hundreds of K2 light curves. The bottom panel plots the amplitude of the light curve against the stellar rotation period. There does not appear to be correlation between amplitude and rotation period.

The Astronomical Journal, 155:23 (16pp), 2018 January
Saylor et al.
Finally, we calculate the average values of these parameters from the fundamental peak and its first four aliases:

\[
A_k = c_k - \frac{b_k^2}{4d_k}
\]

\[
B_k = a_k P_{\text{rot},k}^2.
\]

Finally, we calculate the average values of these parameters from the fundamental peak and its first four aliases:

\[
P_{\text{rot}} = \frac{1}{5} \sum_{k=1}^{5} P_{\text{rot},k}
\]

\[
A = \frac{1}{5} \sum_{k=1}^{5} A_k
\]

\[
B = \frac{1}{5} \sum_{k=1}^{5} B_k.
\]

Values of the \(A\) and \(B\) parameters calculated for all the stars with detected modulations are shown in Figure 2. A first look of these parameters revealed the appearance of a systematic false positive at \(P_{\text{rot}} \sim 0.22\) days and \(P_{\text{rot}} \sim 1.75\) days. This systematic false positive appears in all campaigns although some are affected more than others. After trial and error, we determined that the best way to ensure we do not select these false positives for the final sample was to reject all targets with measured periods within \(\pm 0.08\) days of the values above, and with \(A \leq 0.4\). This rejection criterion is shown in the top panel of Figure 2. The rejected targets are in black points, while the targets that pass this selection criterion are plotted in red points. Examples of targets that pass and fail this rejection are shown in Figures 3 and 4.

After we make these box rejections, we then impose the following selection criteria.

\[
0.0 < P_{\text{rot}} \leq 4.0
\]

\[
A > 0.0 \quad \forall k = 0, 5
\]

\[
B > 2.0.
\]

The first criterion simply defines our pre-determined goal of identifying modulations from fast rotators. The second criterion requires that the fundamental peak and its first four aliases all have a positive amplitude, which essentially requires that any signal should have a minimal number of well-defined aliases, as one would expect from a modulation that persists for at least a few cycles before changing significantly. The third selection criterion is a requirement that the fundamental peak and its first four aliases be the dominant signals in the ACF, i.e., have widths that are comparable with the spacing between them. The middle panel of Figure 2 shows the cutoff in \(\log B\) versus \(P_{\text{rot}}\) space. The specific values of \(B\) that are associated with “clean”
signals in the ACF are subjective, but is based on the visual inspection of several hundreds of ACF from K2 light curves. A few typical examples are shown in Figures 5 and 6.

In general, we find that ACF with recovered values of $B > 2$ correspond to light curves in which a periodic modulation is noticeable on a “by-eye” inspection of the light curve, and for which we have a good level of confidence. ACF with $0 < B < 2$, on the other hand, corresponds to extremely noisy light curves that appear to be dominated with stochastic signals, and for which an intrinsic modulation is not readily apparent upon visual inspection, see Figure 7. Finally, ACF with recovered values of $1 < B < 2$ correspond to light curves in which a by-eye examination suggests a possible weak modulation, but we cannot be certain about it. We therefore place a higher confidence on those targets with $B > 2$, and only allow these targets into the final sample; these stars are the ones plotted as candidate fast rotations in Figures 1 and 2 (red symbols). Our method of peak selection differs from earlier studies, but it yields results that are comparable to previous analyses (McQuillan et al. 2014; Armstrong et al. 2016).

4. Identification of Fast Rotators

Young (<150 Myr), early-type M dwarfs typically have rotation periods $P_{\text{rot}} < 4$ days (Mamajek & Hillenbrand 2008). We have thus focused our analysis on the identification of SBK2 stars with these rotation rates.

Fast rotators are identified from our combined ACF and FFT analysis as described above, with the FFT identifying regular peaks in the ACF corresponding to a recurrent signal and its aliases, and with individual fits to these peaks used to compute the associated stellar rotation period and assess the quality of the identification. This combined ACF and FFT algorithm identified 481 candidate fast rotators in the SUPERBLINK stars monitored in K2 campaigns 0–8.

Figure 8 shows a histogram of the distribution of candidate fast rotators as a function of their assumed, estimated rotation period, $P_{\text{rot}}$. The number of detected fast rotators decreases as the rotation period increases, with most objects having estimated rotation periods $P_{\text{rot}} < 1.5$ days. There may be several explanations for this. The distribution may reflect the true statistics of fast rotators, as defined by the physical mechanisms responsible for their slow down. On the other hand, slower rotators have smaller spots, and thus their modulations would have lower intrinsic amplitudes, which would make them harder to identify amidst the instrumental noise. If this is true, then the identification of stars with rotation periods $P_{\text{rot}} \gtrsim 2$ days might therefore be a significant challenge using K2 data. In future work, we would like to develop an algorithm that can pick out more stars with rotation periods
\( P_{\text{rot}} > 2 \) days, and especially stars with \( P_{\text{rot}} > 4 \) days, for which we did not look here.

Figure 9 shows the fraction of fast rotators identified in each magnitude bin. The trend indicates an increase in detection of fast rotators at fainter magnitudes, which is counterintuitive because one would expect rotation modulations to be harder to detect in fainter stars. However, this occurs because the fainter targets are comprised mainly of M dwarfs, while the brighter targets are largely FGK dwarfs (see Figure 10). The age–activity relationship presented by West et al. (2008) indicates that M stars remain active longer than FGK stars. Therefore, late-type stars will persist as rapid rotators longer than early-type stars making it more likely to find a rapid rotator in a sample dominated by M dwarfs like the one we present here.

Finally, the trend in Figure 9 reveals a sharp downturn at \( V = 18 \), which suggests that \( V = 18 \) is the magnitude limit for detecting modulations from spots in K2 data. This limit is due to the light curves becoming too noisy to detect a repeating signal.

The complete list of SBK2 targets identified as fast rotators can be found in Table 2. The first 20 lines of the table are shown in the print version; the complete list is available in the electronic version of the paper.

Columns 1 and 2 give the identification number of the star in the SUPERBLINK and EPIC catalogs, respectively. Columns 3 and 4 list the J2000 R.A. and decl., respectively. Columns 5 and 6 list the SUPERBLINK catalog proper motion in the direction of R.A. and decl., respectively, both in units of seconds of arc per year. Column 7 lists NUV magnitude from GALEX, when available. Column 8 lists \( V \) magnitudes from SUPERBLINK. Column 9 lists \( V - J \) color using 2MASS infrared magnitudes, \( J \). Columns 10 and 11 list the rotation period and uncertainty in rotation period calculated in this work. Columns 12 and 13 list the \( A \) and \( B \) values discussed in Section 3 that were used to differentiate between false positive and real detections. Column 14 is a measure of the amplitude of the intrinsic variability of the star, \( \sigma \), computed by taking the standard deviation of the signal after our detrending procedure. Column 15 is the K2 field corresponding to the target.

5. Kinematic Analysis of the Fast Rotators

5.1. Reduced Proper Motions

We utilize the SUPERBLINK proper motions to produce a reduced proper motion (RPM) diagram of all the SUPERBLINK stars monitored by K2 (Figure 10). The black solid line represents a “by eye” boundary separating the loci of the main-sequence disk and main-sequence halo stars, consistent with the metallicity analysis of Lépine et al. (2007). The black dashed line represents a “by-eye” division between the halo stars and the white dwarf population. The fast rotator candidates identified in our analysis are plotted as large red circles, with all other stars shown as small black dots. Strikingly, the vast majority of the fast rotator candidates are found within the locus.
of the disk stars, with only 13 candidates falling within the locus of halo stars. In addition, the M dwarf \((V - J > 2.7)\) fast rotators as a group are “elevated” (i.e., they have lower RPM values on average) within the locus of the disk stars compared to stars of similar colors. In the RPM diagram, this either means that these rapidly rotating M dwarfs tend to have brighter absolute magnitude at a given color or that they tend to have lower average transverse motions. A low average motion is consistent with youth because nearby star-forming regions and young moving groups have relatively low transverse motions relative to the Sun. A higher absolute magnitude is also consistent with youth because very young (<100 Myr) M dwarfs are not fully contracted onto the main sequence (Baraffe & Chabrier 1996). This feature means young M dwarfs are larger and more luminous for their color compared to the main sequence; therefore, they are larger and more luminous compared to ZAMS stars of the same mass. Either one or a combination of both of these factors results in a smaller RPM value in young, local stars. That the fast rotators show the same expected trends suggests that these fast rotators are indeed part of the local young population.

Of the 26,518 SBK2 stars, 5201 are halo objects based on their location in the RPM diagram, thus representing about 19% of the sample. Of the 481 rapid rotators we identify, only 13 have RPMs consistent with halo objects, which is less than 3% of the fast rotators identified. The identification of any fast rotator among stars associated with the halo population is at first glance surprising, because these stars are mostly relatively old (\(\gtrsim 10\) Gyr). One would expect that such old stars could be fast rotators only in the presence of a close companion, where the rotation rate is driven by tidal interactions. According to the data on nearby binaries and multiples presented in Raghavan et al. (2010), we would expect to find \(\sim 0.4\)% of stars in our sample to be interacting binary stars; this is based on the observation that only two binaries with orbital periods \(<5\) days are found among the 454 local stars that were surveyed in their study. For our subset of halo stars, we would thus expect \(\sim 0.4\)% of 5,201 stars to be close binaries and potentially interacting, which would be about 21 objects. The 13 candidate halo fast rotators we identify thus come reasonably close (within a factor 2) of the predicted number. The slightly lower than expected value may indicate that the binary fraction is different for the local halo population, compared to the nearby G stars surveyed in the Raghavan study. Alternatively, we may be missing some close binary stars that may not be sufficiently interacting or that have inclinations that make it difficult to detect rotation modulations. We are currently planning follow-up spectroscopic observations of some of these stars, as this small subset of halo stars is of special interest. Further analysis will be presented in an associated paper (D. Saylor et al. 2017, in preparation).

Figure 6. Two examples of light curves with \(B\) values close to the limit of our selection cutoff \((B > 2.0)\). EPIC 212396917 (top) has a clear recurrent signal in its light curve, while EPIC 212395381 (bottom) is relatively noisier with no clearly identifiable pattern. While their auto-correlation functions (right panels) appear to be similar at first glance, EPIC 212395381 has peaks of lower amplitude, which places its values of \(A\) and \(B\) outside of our selection limit.
In any case, the much lower detection rate of fast rotators among the halo stars provides a convincing validation of our ACF analysis. Indeed extrinsic signals such as instrumental artifacts in the \textit{K2} light curves should be affecting all light curves equally regardless of what the disk/halo status of the star is. The very fact that the great majority of our candidate fast rotators are identified among “disk” stars shows that these modulations must be intrinsic signals, and thus most likely genuine modulations in those stars. In the worst case, if we assume that all 13 candidate fast rotators identified among the halo stars are false positives, this suggests a false positive detection rate of 0.05% for all the stars in our SBK2 database. If this false positive rate were applied to the subset of disk stars, this means that approximately 66 of the fast rotators in the disk population might be false positives, or 14% of all the candidate fast rotators identified in our study.

In addition, the fact that the halo stars are generally non-variable suggests that these stars, as a group, may be ideally suited for use as “calibration” sources to refine the reduction of \textit{K2} photometric data.

5.2. Velocity-space Projections

Most stars in the present sample do not have parallax measurements as of yet. Therefore, to evaluate the space motion of our stars, we combine proper motions with photometric distances derived from \textit{V} magnitudes and \textit{V}−\textit{J} colors. We first identify 11,809 stars from the entire (all-sky) SUPERBLINK catalog with distances \( d < 100 \text{ pc} \) that currently do have measured trigonometric parallaxes (which includes parallaxes from the \textit{HIPPARCOS} and \textit{TGAS} catalogs) and calculate their absolute magnitudes \( M_V \). We then determine the relationship between \( M_V \) versus \( V−J \) to use as a photometric distance calibration. Because the mathematical relationship between \( M_V \) and \( V−J \) is complex and varies with the \( V−J \) color, we divide the stars into six \( V−J \) bins, and fit a relationship for each one of the bins using a polynomial of the order of one. After a first pass, we eliminate any star that deviates from the fit by ±1.5 mag. We then fit a polynomial of the order of one to the remaining calibration stars. We repeat this process a total of three times. The best-fit linear equations for each of the magnitude bins are

\begin{align}
M_V &= 1.26(V − J) + 1.67 \quad (V − J \leq 0.7) \\
M_V &= 4.02(V − J) − 0.26 \quad (0.7 < V − J \leq 1.5) \\
M_V &= 2.06(V − J) + 2.77 \quad (1.5 < V − J \leq 3.0) \\
M_V &= 2.47(V − J) + 1.51 \quad (3.0 < V − J \leq 4.0) \\
M_V &= 2.40(V − J) + 1.75 \quad (4.0 < V − J \leq 5.0) \\
M_V &= 1.94(V − J) + 4.08 \quad (5.0 < V − J \leq 6.0)
\end{align}
Figure 8. Distribution of the rotation periods identified in this work. We find fewer targets with $P_{\text{rot}} > 1.5$ days. This may be intrinsic to the population of young stars we study here or a systematic trend in the data. In future work, we would like to investigate these possibilities and improve our pipeline to find rotation rates up to four days.

Figure 9. Fraction of rapidly rotating M dwarfs as a function of magnitude. At fainter magnitudes, the fraction of fast rotators increases because the fainter magnitudes are comprised mainly of M dwarfs as indicated by Figure 10. The drop off at $V = 18$ is indicative of the K2 detection limit for fast rotators. This limit is due to light curves that are too noisy to detect a repeating signal.

The top panel of Figure 11 shows all 11,809 calibration stars as black dots, the stars that pass the cuts are overplotted as blue dots, and the derived fit. The bottom panel shows the difference between the derived magnitude and the actual magnitude of the calibration stars that passed both cuts to the initial polynomial fits. We find that the typical error on the photometric distances, $d_{\text{phot}}$, are 15% of the distance, or $\pm 1$ in distance modulus.

We multiply the photometric distances by the total proper motion, $\mu$, of each star to obtain a transverse velocity, from $v_T = 4.74 \mu d_{\text{phot}}$. Figure 12 shows a frequency histogram of those velocity space projections. The rapid rotators are shown on the top panel in red while all SBK2 stars are shown on the bottom panel in black. The rapid rotators appear to be more abundant at lower velocities and their distribution peaks at a lower velocity than the SBK2 stars as a whole (see Table 4). In fact, the median transverse motion of the fast rotators is $33 \text{ km s}^{-1}$, with a mean absolute deviation (MAD) of $19 \text{ km s}^{-1}$. For all the other stars, the median transverse motion is $60 \text{ km s}^{-1}$, with an MAD of $38 \text{ km s}^{-1}$, which implies that the fast rotators peak at a transverse velocity of about half that of the slow rotators. We believe this indicates that the population of rapid rotators is fundamentally different from the general population of stars, i.e., young thin disk stars versus older thick disk and halo stars. A two-sided KS-test returns a $p$-value of $10^{-26}$, which implies that the fast rotators peak at a transverse velocity of about half that of the slow rotators. We believe this indicates that the population of rapid rotators is fundamentally different from the general population of SBK2 stars.

We further combine these photometric distances with the measured proper motions to create kinematics plots. Although we do not have radial velocity data, the combination of proper motion vectors and distances are sufficient to create 2D projections of the space motions in the plane of the sky. We plot these 2D velocity projections in Figure 13 with individual plots for each one of the K2 campaign fields, since each field has a different plane of projection. The axes plot the projected velocity vectors $(v_U, v_V) = (4.74 \mu_U d_{\text{phot}}, 4.74 \mu_V d_{\text{phot}})$, where $\mu_U$ and $\mu_V$ are the components of proper motion in Galactic coordinates, which are multiplied by the photometric distances derived from the procedure described above. The velocity components are given in units of kilometers per second. The black box in each panel shows the approximate location in velocity space of most known nearby, young moving groups (NYMGs), using the generic velocities $U = -10.5 \text{ km s}^{-1}$, $V = -19.5 \text{ km s}^{-1}$, and $W = -7.5 \text{ km s}^{-1}$. The field of Campaign 4 targeted the Hyades and Pleiades; the projected
| SB          | EPIC     | \( \alpha \) (J2000) | \( \delta \) (J2000) | \( \rho_{\alpha} \) (mas yr\(^{-1}\)) | \( \rho_{\delta} \) (mas yr\(^{-1}\)) | NUV         | V         | \( V - J \) (mag) | \( P_{\text{rot}} \) (days) | \( \sigma_{P\text{rot}} \) (days) | \( A^\alpha \) | \( B^\beta \) | \( \sigma^\gamma \) | Field |
|-------------|----------|------------------------|----------------------|-------------------------------|-------------------------------|-------------|-----------|----------------|----------------|----------------|----------|----------|-----------|-------|
| PM P00389+0828 | 220574720 | 9.746918               | 8.478116             | 0.1000                        | -0.0471                       | 18.97       | 10.02     | 2.11           | 1.25            | 0.002          | 0.65     | 12.1     | 0.019     | 8     |
| PM P00421+0509 | 220422705 | 10.525499              | 5.156477             | 0.0152                        | -0.0103                       | 12.34       | 12.38     | -0.15          | 3.78            | 0.095          | 0.22     | 3.6      | 0.002     | 8     |
| PM P00440+0932 | 220623236 | 11.005507              | 9.549399             | 0.0232                        | -0.0468                       | 13.16       | 10.18     | 1.73           | 0.39            | 0.001          | 0.69     | 12.2     | 0.012     | 8     |
| PM P00452+0423 | 220383711 | 11.307917              | 4.383321             | 0.0428                        | -0.0199                       | 99.99       | 18.89     | 4.92           | 3.99            | 0.012          | 0.24     | 3.9      | 0.009     | 8     |
| PM P00460+0757 | 220552625 | 11.524994              | 7.957099             | 0.1190                        | -0.0204                       | 20.97       | 17.80     | 5.00           | 1.07            | 0.000          | 0.50     | 8.2      | 0.006     | 8     |
| PM P00499+0708 | 220516443 | 12.488429              | 7.143973             | 0.1830                        | -0.0152                       | 12.34       | 12.38     | -0.15          | 3.78            | 0.095          | 0.22     | 3.6      | 0.002     | 8     |
| PM P00502+0837 | 220581451 | 12.573019              | 8.626148             | 0.0596                        | -0.0303                       | 99.99       | 18.89     | 4.92           | 3.99            | 0.012          | 0.24     | 3.9      | 0.009     | 8     |
| PM P00523+0638 | 220494537 | 13.078835              | 6.640716             | -0.0459                       | -0.0360                       | 99.99       | 17.85     | 4.60           | 0.51            | 0.003          | 0.28     | 3.5      | 0.004     | 8     |
| PM P00526+0337W | 220346833 | 13.155402              | 3.631029             | -0.0247                       | -0.0469                       | 99.99       | 18.19     | 4.70           | 1.37            | 0.001          | 0.28     | 4.1      | 0.007     | 8     |
| PM P00532+1056 | 220680367 | 13.305914              | 10.938226            | 0.0379                        | -0.0365                       | 99.99       | 15.03     | 3.12           | 0.74            | 0.004          | 0.76     | 10.7     | 0.026     | 8     |
| PM P00532+0017 | 220208154 | 13.316236              | 0.289406             | 0.0513                        | -0.0749                       | 23.71       | 15.52     | 3.13           | 1.64            | 0.000          | 0.78     | 14.4     | 0.020     | 8     |
| PM P00535+0725 | 220529150 | 13.396629              | 7.471817             | 0.0590                        | -0.0317                       | 99.99       | 17.09     | 4.40           | 0.81            | 0.000          | 0.26     | 4.5      | 0.014     | 8     |
| PM P00551+0011 | 220205547 | 13.796958              | 0.193448             | 0.0393                        | -0.0631                       | 99.99       | 19.20     | 4.90           | 0.85            | 0.001          | 0.41     | 6.6      | 0.017     | 8     |
| PM P00552+0531 | 220441862 | 13.822223              | 5.524729             | 0.0476                        | -0.0246                       | 99.99       | 16.53     | 3.70           | 2.57            | 0.003          | 0.62     | 10.6     | 0.016     | 8     |
| PM P00553+0235 | 220298113 | 13.829959              | 2.589331             | -0.0866                       | -0.1565                       | 23.52       | 16.03     | 3.88           | 2.94            | 0.008          | 0.42     | 7.4      | 0.009     | 8     |
| PM P00560+0249W | 220308656 | 14.003282              | 8.224686             | -0.0738                       | -0.0792                       | 21.69       | 13.44     | 3.60           | 0.67            | 0.024          | 0.27     | 4.8      | 0.013     | 8     |
| PM P00570+0223 | 220288486 | 14.252249              | 2.391407             | -0.0920                       | -0.0909                       | 21.75       | 15.30     | 4.52           | 0.58            | 0.003          | 0.26     | 4.0      | 0.005     | 8     |
| PM P00577+0805 | 220585888 | 14.434575              | 8.097114             | -0.0127                       | 0.0659                        | 99.99       | 16.69     | 5.10           | 0.32            | 0.001          | 0.20     | 2.9      | 0.002     | 8     |
| PM P00578+0440 | 220398184 | 14.472344              | 4.680145             | 0.0857                        | 0.0042                        | 22.57       | 14.63     | 3.31           | 1.24            | 0.003          | 0.10     | 3.7      | 0.057     | 8     |
| PM P00583+1203 | 220720015 | 14.586460              | 12.056598            | -0.0332                       | -0.0360                       | 99.99       | 16.69     | 4.53           | 3.96            | 0.476          | 0.66     | 5.9      | 0.010     | 8     |

Notes.

\(^a\) Average correlation value for the first five maxima in the auto-correlation function.

\(^b\) Parameter indicating the dominance of the auto-correlation peak (see the text).

\(^c\) Standard deviation in the light curve after detrending, showing the amplitude of the variability signal.

(This table is available in its entirety in machine-readable form.)
velocity of those two clusters are represented by green and magenta boxes, respectively. For Hyades, we use the velocities \( U = -40 \text{ km s}^{-1}, V = -18 \text{ km s}^{-1}, \) and \( W = -3 \text{ km s}^{-1} \), and for the Pleiades, \( U = -7 \text{ km s}^{-1}, V = -27 \text{ km s}^{-1}, \) and \( W = -13 \text{ km s}^{-1} \).

A surprising result is the fact that most of the fast rotators we identify do not generally fall within these boxes, and thus do not appear to have kinematics consistent with the known NYMGs. While it is clear that the stars have low projected velocities consistent with the thin disk population, see Figure 12, the velocity space distribution varies considerably between fields. Some fields show considerable spread of their fast rotators (e.g., campaign fields 3, 7, and 8), while others show evidence of significant levels of clumping (fields 4, 5, and 6). If it is true that young stars form in clusters or loose associations, then the more scattered objects in velocity space might be stars that have been ejected from their parent cluster/association, while the objects that form clumps in velocity space may be the still comoving remnants of these groups. Ejected objects would be scattered throughout space and show up to some level in all K2 fields, while the more compact remnants (NYMGs) would be apparent only in some fields. An alternative explanation could be due to the fact that the calculated photometric distances used in these diagrams assume that the star is settled on the main sequence, which would result in significant uncertainty in the photometric distance for M dwarfs that are very young and still contracting. Indeed, Figure 10 does suggest that some of these stars are elevated above the main sequence. Therefore, our distances for the fast rotators are potentially underestimated, which would mean that our velocities are overestimated. A revised distance calibration might move our targets more in line with the velocities of the NYMG.

![Figure 11](image1.png)

**Figure 11.** Color–magnitude diagram used to derive photometric distances of SBK2 stars. All 11,809 calibration stars are plotted as black dots, and the stars that pass the cuts made to the initial polynomial fits are overplotted as blue dots. The bottom panel shows the difference between the derived magnitude and the actual magnitude of the calibration stars used to derive the fit. We find that the typical error on the photometric distances is 15% of the distance, or ±1 in distance modulus. The equations of fit are listed in Section 5.2.

![Figure 12](image2.png)

**Figure 12.** Frequency histograms of 2D velocity projections for the fast rotators (top) and all SBK2 stars (bottom). There are more fast rotators at low velocity and their overall distribution peaks at a lower velocity compared to the general population of stars, see Section 5.2. A two-sided KS test of these distributions produces a KS statistic of 0.43 and a p-value of \( 10^{-76} \), indicating that they are drawn from different populations.

Tables 3 and 4 list the median and mean average deviation (MAD) of the 2D velocity space projections of the fast and slow rotators, respectively, for each K2 field analyzed in this work. The average ratio of the MAD for the fast rotators compared to the entire SBK2 sample is 0.43 in the Galactic latitude direction and 0.45 in the Galactic longitude direction. This fraction implies that the fast rotator distribution of velocities is 60% smaller than the general population of targets we analyzed despite the fact that we are potentially overestimating their transverse velocities. This
tighter distribution of velocities is consistent with the young, thin disk. We therefore conclude that the fast rotators are drawn from a younger population.

6. Stars with UV Excess

We cross-matched all SBK2 sources with the GALEX catalog of UV sources to investigate whether fast rotators would also normally be detected as chromospherically active stars from excess UV emission. Figure 14 is a color–color diagram for all SBK2 stars with a counterpart in the GALEX source catalog. We utilize GALEX NUV fluxes (when available) as well as V and J magnitudes. The black points are all SBK2 targets with GALEX counterparts; the red circles are the fast rotators identified in this work. We define a star to be an M dwarf if it has $V - J > 2.7$, following Lépine et al. (2013). We further define an M dwarf to be “active” if it has $NUV - V < 8$, indicative of a significant UV excess. Using these criteria, we identify a total of 124 “active M dwarfs” in the SBK2 sample. Of these, we find that 25 are also identified as fast rotators, which represents ~20% of the “active M dwarf” subset. By comparison, there are 15,745 SBK2 stars that have M dwarf colors, and of these only 328 are fast rotators, or a fast rotator rate of just 2%. These statistics indicate that the M
The Astronomical Journal, 155:23 (16pp), 2018 January

Saylor et al.

Figure 14. NUV − V vs. V − J for SBK2 targets. Black points are all SBK2 stars, while red circles are the rapid rotators with GALEX magnitudes. We find that the M dwarfs identified as fast rotators have a 20% chance of showing UV excess, see Table 5.

Table 3

| Field | \(\langle v \rangle_{med}^{\text{AD}}\) (km s\(^{-1}\)) | MAD\(_{16}^{\text{AD}}\) (km s\(^{-1}\)) | \(\langle v \rangle_{med}^{\text{VL}}\) (km s\(^{-1}\)) | MAD\(_{16}^{\text{VL}}\) (km s\(^{-1}\)) |
|-------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| 0     | 35                              | 26                              | −6                              | 24                              |
| 1     | −8                              | 37                              | −24                             | 23                              |
| 2     | −27                             | 39                              | −7                              | 18                              |
| 3     | 0                               | 28                              | −27                             | 33                              |
| 4     | 28                              | 29                              | 3                               | 21                              |
| 5     | −5                              | 40                              | −30                             | 40                              |
| 6     | −38                             | 43                              | −10                             | 50                              |
| 7     | −26                             | 40                              | −18                             | 21                              |
| 8     | 35                              | 65                              | −22                             | 41                              |

Approximately 95% of the rapid rotators we identify do not fit the criterion for UV excess. Part of this is due to the patchy coverage of GALEX. In particular, GALEX did not observe many regions close to the Galactic plane due to high field density. Of the fields we analyzed, C0 and C7 fall directly on the Galactic plane. Campaigns C2 and C4 lie near the Galactic plane, while C1, C3, C5, C6, and C8 are well within the coverage of the GALEX survey. Table 5 presents a breakdown of the number of SBK2 M dwarfs with UV excess per field and the number of those stars that are identified as fast rotators.

Table 4

| Field | \(\langle v \rangle_{med}^{\text{AD}}\) (km s\(^{-1}\)) | MAD\(_{16}^{\text{AD}}\) (km s\(^{-1}\)) | \(\langle v \rangle_{med}^{\text{VL}}\) (km s\(^{-1}\)) | MAD\(_{16}^{\text{VL}}\) (km s\(^{-1}\)) |
|-------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| 0     | 37                              | 42                              | −11                             | 30                              |
| 1     | −10                             | 107                             | −70                             | 94                              |
| 2     | −35                             | 40                              | −6                              | 29                              |
| 3     | −14                             | 56                              | −37                             | 51                              |
| 4     | 81                              | 106                             | −9                              | 70                              |
| 5     | 78                              | 119                             | −39                             | 88                              |
| 6     | −80                             | 108                             | −35                             | 101                             |
| 7     | −53                             | 74                              | −16                             | 55                              |
| 8     | 67                              | 111                             | −57                             | 103                             |

Table 5 indicates that most of the fast rotator M dwarfs we identify are not in the low Galactic latitude fields. Of the fields that are well covered by GALEX, we still find that only ~20% of the SBK2 M dwarfs show evidence of UV excess from GALEX data. Therefore, it would appear likely that many of the rapid rotators in our sample do have some level of UV excess from chromospheric activity, but GALEX was unable to detect these targets, possibly due to the intrinsic faintness of those M dwarfs. We believe that this is strong evidence that the search for rapid rotators in fields observed with Kepler and K2 can identify young stars that lack a UV detection, which can significantly expand the search for nearby young M dwarfs.

An interesting pattern that emerges in Figure 14 is the fact that most of the M dwarf fast rotators have NUV − V > 6. That is, the majority of M dwarfs with larger UV excesses (NUV − V < 6) are not identified as fast rotators in our study. This is consistent with the observation that most M dwarfs with very large NUV excesses are actually low-mass stars with white dwarf companions. The white dwarf is responsible for the large NUV excess, but these systems are of course relatively older, which means one would not expect the M dwarf component to be a fast rotator, unless the rotation of the M dwarf is driven by tidal forces in a tight system.

The technique we describe in this paper could prove especially useful once data from the upcoming TESS mission becomes available. These data will make it possible to expand the search for young M dwarfs over much of the sky, especially if most of the known nearby M dwarfs are being targeted by TESS.

7. Conclusions

We have searched the first nine K2 campaigns for SUPERB-LINK high proper motion stars with rotation periods \(P_{rot} < 4\) days. According to gyrochronolgy, this should correspond to an age of \(\lesssim 150\) Myr. We developed a data analysis pipeline that
Table 6
SUPERBLINK Stars Observed in K2 Campaigns 0–8

| SB           | EPIC    | α (J2000) | δ (J2000) | pmα (mas yr⁻¹) | pmδ (mas yr⁻¹) | NUV | V | V − J | Field |
|--------------|---------|-----------|-----------|----------------|----------------|-----|---|------|-------|
| PM 100341+0436 | 220394397 | 8.539754  | 4.601908  | 0.0464         | −0.0254        | 99.99 | 17.59  | 3.89  | 8     |
| PM 100348+0433 | 220392429 | 8.712526  | 4.563131  | 0.0604         | −0.0018        | 99.99 | 12.14  | 1.66  | 8     |
| PM 100349+0422N | 220383386 | 8.739845  | 4.381468  | 0.1073         | −0.1734        | 22.38 | 8.97   | 1.42  | 8     |
| PM 100351+0406 | 220370126 | 8.780957  | 4.108527  | 0.0016         | −0.0665        | 99.99 | 17.14  | 4.12  | 8     |
| PM 100351+0358 | 220363792 | 8.785554  | 3.978688  | 0.1203         | 0.0205         | 99.99 | 16.73  | 3.90  | 8     |
| PM 100352+0356 | 220361750 | 8.810661  | 3.937430  | 0.0798         | 0.0370         | 99.99 | 11.73  | 1.70  | 8     |
| PM 100352+0400 | 220365159 | 8.818637  | 4.007222  | −0.0292        | −0.0424        | 99.99 | 13.46  | 1.67  | 8     |
| PM 100353+0442 | 220399282 | 8.836354  | 4.701310  | −0.0324        | −0.0224        | 99.99 | 15.00  | 1.56  | 8     |
| PM 100355+0432 | 220391351 | 8.876101  | 4.540965  | 0.0862         | −0.0393        | 99.99 | 19.62  | 3.25  | 8     |
| PM 100356+0383 | 220396177 | 8.902689  | 4.639234  | 0.0368         | −0.0082        | 99.99 | 13.00  | 1.47  | 8     |
| PM 100357+0357 | 220362983 | 8.929224  | 3.963239  | −0.0322        | −0.1250        | 18.43 | 18.88  | 0.02  | 8     |
| PM 100357+0445 | 220402286 | 8.939465  | 4.760565  | 0.0368         | −0.0136        | 99.99 | 15.59  | 3.00  | 8     |
| PM 100357+0439 | 220396738 | 8.941160  | 4.650753  | 0.1505         | 0.0357         | 99.99 | 20.40  | 3.67  | 8     |
| PM 100357+0440 | 220397535 | 8.942800  | 4.667059  | 0.1691         | 0.1022         | 99.99 | 19.39  | 4.83  | 8     |
| PM 100358+0354 | 220360455 | 8.954550  | 3.910664  | 0.0486         | 0.0076         | 99.99 | 16.52  | 2.18  | 8     |
| PM 100359+0352 | 220358904 | 8.983678  | 3.878616  | 0.1117         | −0.0655        | 99.99 | 16.40  | 3.92  | 8     |
| PM 100359+0442 | 220399472 | 8.999878  | 4.704960  | 0.0705         | 0.0224         | 99.99 | 14.95  | 4.21  | 8     |
| PM 100361+0457 | 220412119 | 9.037066  | 4.952855  | −0.0379        | −0.0339        | 99.99 | 13.72  | 2.11  | 8     |
| PM 100363+0349 | 220355964 | 9.076753  | 3.820655  | −0.0270        | −0.0714        | 99.99 | 14.93  | 2.53  | 8     |
| PM 100363+0342 | 220350324 | 9.096736  | 3.704963  | 0.0557         | −0.0044        | 99.99 | 11.99  | 1.71  | 8     |

(This table is available in its entirety in machine-readable form.)

makes use of an auto-correlation function (ACF) combined with an FFT to identify modulation in the K2 light curves, eliminate obvious instrumental signals, and estimate the timescale of the intrinsic modulation. In most cases the variability appears to be consistent with starspots on a fast-rotating star, so the characteristic timescale modulations are assumed to be estimates of the stellar rotation period. This combined ACF and FFT algorithm identifies 481 probable fast rotators in the first nine campaign fields of the K2 mission (C0–C8).

Based on their location in an RPM diagram, we determine that nearly all the fast rotators are consistent with the thin disk population. However, we also identify 13 rapid rotators with colors and/or kinematics consistent with the old halo population. We believe that these stars may be tidally interacting binary systems. The second paper in this series will discuss this hypothesis.

More generally, the RPM diagram shows that the fast rotators tend to have relatively low RPMs at a given color compared to normal field stars. This either indicates that the stars have low transverse motions or that they are elevated above the ZAMS (i.e., overluminous) or both. In either case, this trend suggests that they are part of a younger field population. A frequency distribution of the transverse motions, estimated using photometric distances, clearly shows that there are more fast rotators at lower velocities than the general population of SBK2 targets and that the distribution peaks at a lower transverse velocity. Two-dimensional plots of the transverse motion vectors in the plane of the sky further shows significant differences in the kinematics of fast rotators in the different K2 campaign fields, along with indications of significant velocity-space clustering in campaigns 2, 4, and 5. This is consistent with the idea that young field stars are part of various collections of young moving groups, resulting from the slow dispersion of loosely bound stellar associations. Further study of these stars’ distances and radial velocities is needed to determine group membership.

A color–color plot of NUV–optical–IR magnitudes (NUV − V, V − J) indicates that a significant fraction (20%) of the fast rotators we identify also have NUV excess detected in the GALEX survey. This indication of chromospheric activity further confirms that these stars are young. However, we find that in K2 fields with good GALEX coverage, ~95% of the fast rotator M dwarf candidates are not detected in GALEX; this suggests that the absence of a detected UV excess is not sufficient to rule out youth in a local field M dwarf, and that starspot modulation may be more efficient in identifying nearby young, low-mass stars. We therefore conclude that the K2 data, along with upcoming data from the NASA TESS mission, can be used most effectively as a way to identify the population of young M dwarfs near the Sun.

The TESS mission should obtain light curves for most nearby M dwarfs unlike Kepler and K2, which do not cover much of the sky. The technique we describe in this paper could be used to search for young M dwarfs independent of NUV coverage.

This material is based on work supported by the National Science Foundation under grant No. AST 09-08419, the National Aeronautics and Space Administration under grant Nos. NNX15AV65G, NNX16AI63G, and NNX16AI62G issued through the SMD/Astrophysics Division as part of the K2 Guest Observer Program.

Appendix

List of SUPERBLINK Stars in Kepler Campaigns C0–C8

The complete list of 26,518 SBK2 targets can be found in Table 6. The first 20 lines of the table are shown in the print.
version; the complete list is available in the electronic version of the paper.

Columns 1 and 2 give the identification number of the star in the SUPERBLINK and EPIC catalogs, respectively. Columns 3 and 4 list the J2000 R.A. and decl., respectively. Columns 5 and 6 list the SUPERBLINK catalog proper motion in the direction of R.A. and decl., respectively, both in units of seconds of arc per year. Column 7 lists NUV magnitude from *GALEX*, when available. Column 8 lists $V$ magnitudes from SUPERBLINK. Column 9 lists $V - J$ color using 2MASS infrared magnitudes, $J$. Column 10 is the K2 field corresponding to the target.

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**References**

Ansdell, M., Gaidos, E., Mann, A. W., et al. 2015, *ApJ*, 798, 41  
Armstrong, D. J., Kirk, J., Lam, K. W. F., et al. 2016, *MNRAS*, 456, 2260  
Baraffe, I., & Chabrier, G. 1996, *ApJ*, 461, L51  
Barnes, S. A. 2007, *ApJ*, 669, 1167

Crossfield, I. J. M., Ciardi, D. R., Petigura, E. A., et al. 2016, *ApJS*, 226, 7  
Crossfield, I. J. M., Petigura, E., Schlieder, J. E., et al. 2015, *ApJ*, 804, 10  
Fleming, T. A., Schnitt, J. H. M. M., & Giampapa, M. S. 1995, *ApJ*, 450, 401  
Gagné, J., Lafrenière, D., Doyon, R., Malo, L., & Artigau, É. 2014, *ApJ*, 783, 121  
Lépine, S. 2005, *AJ*, 130, 1247  
Lépine, S., & Gaidos, E. 2011, *AJ*, 142, 138  
Lépine, S., Hilton, E. J., Mann, A. W., et al. 2013, *AJ*, 145, 102  
Lépine, S., Rich, R. M., & Shara, M. M. 2007, *ApJ*, 669, 1235  
Mamajek, E. E., & Hillenbrand, L. A. 2008, *ApJ*, 687, 1264  
McQuillan, A., Mazeh, T., & Aigrain, S. 2013, *ApJ*, 775, L11  
McQuillan, A., Mazeh, T., & Aigrain, S. 2014, *ApJS*, 211, 24  
Newton, E. R., Irwin, J., Charbonneau, D., et al. 2016, *ApJ*, 821, 93  
Petigura, E. A., Marcy, G. W., & Howard, A. W. 2013, *ApJ*, 770, 69  
Petigura, E. A., Schlieder, J. E., Crossfield, I. J. M., et al. 2015, *ApJ*, 811, 102  
Raghavan, D., McAlister, H. A., Henry, T. J., et al. 2010, *ApJS*, 190, 1  
Rebull, L. M., Stauffer, J. R., Bouvier, J., et al. 2016, *AJ*, 152, 114  
Reiners, A., & Basri, G. 2008, *ApJ*, 684, 1390  
Scargle, J. D. 1982, *ApJ*, 263, 835  
Schlieder, J. E., Lepine, S., Rice, E., & Simon, M. 2011, *BAAS*, 43, 307.05  
Shkolnik, E. L., Anglada-Escudé, G., Liu, M. C., et al. 2012, *ApJ*, 758, 56  
Skumanich, A. 1972, *ApJ*, 171, 565  
Vanderburg, A., & Johnson, J. A. 2014, *PASP*, 126, 948  
West, A. A., Hawley, S. L., Bohanski, J. J., et al. 2008, *AJ*, 135, 785