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Using Flare Rates to search for Stellar Activity Cycles

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Recording the prevalence and duration of stellar activity cycles gives insight into the magnetic dynamo puzzle. For the sun, this cycle spans approximately 11 years. Assuming this cycle represents a typical stellar cycle, we'll need many years of observations to be able to find cyclic magnetic activity in other stars. Currently, finding these cycles requires precise flux measurements (e.g. Kopp et al. 2016), chromospheric emission line monitoring campaigns (e.g. Duncan et al. 1991), or starspot tracking (e.g. Messina & Guinan 2002; Montet et al. 2017). However, these all have challenges: flux measurements aren't nearly precise enough, monitoring campaigns are expensive, and starspot statistics are difficult to see in butterfly diagrams (Morris et al. 2019) or sunspots aren't visible for distant stars.

Data from the Sun suggests that flares may be a good measure for tracking this magnetic activity cycle. Flare rates have been observed to vary by factor of $\sim$10 between solar "maximum" and "minimum" (e.g. Veronig et al. 2002; Aschwanden & Freeland 2012). Flares are bursts of light across the EM spectrum (e.g. see Hawley et al. 2003) produced during a magnetic re-connection event, so the rate and that these flares are produced and their brightness is directly related to the surface magnetic activity of a star. Additionally, since flares are easily detectable at long distance, and can be surveyed for many stars simultaneously using wide-field photometric surveys, flares are a promising avenue for tracing stellar activity cycles.

Here we briefly explore this idea, looking for variations in the rate of white light flares from stars in the Kepler mission (Borucki et al. 2010). Kepler provides up to 4 years of observation for each star, so although we don't expect to see cyclic behavior, we search for coherent variations in flare rate that may indicate these field stars are undergoing activity cycles. We examined a sample of 347 flare stars from Davenport et al. (2019), which were selected as having measured photometric rotation periods from Kepler, at least 100 candidate flare events, and at least 10 flare events with energies above the estimated 68% detection recovery floor of their automated pipeline.

We search for coherent variations in flare rate by computing the total flare-luminosity relative to the total luminosity through the Kepler bandpass, or fractional flare luminosity (FFL):

$$\frac{L_{fl}}{L_{Kp}} = \frac{\xi_{tot}}{t_{exp}} \tag{1}$$

where ξ_{tot} is the sum of the equivalent-duration for each flare event and t_{exp} is the total exposure time of the observation. This has been used to compare flare rates between stars (Lurie et al. 2015) but we compare flare rates between different times for a single star by applying it to each quarter of data from Davenport et al. (2019). We then apply an MCMC fit to try to highlight any sort of trend, indicating a change in flare rate.

To compliment trends in FFL space, we compute the flare frequency distribution (FFD), the standard view of flare activity (e.g. Lacy et al. 1976; Davenport et al. 2019). The FFD compares the cumulative occurrence frequency to the event energy. Here we use the "equivalent duration" (the sum of the fractional flux) for each flare, which can be simply converted to energies by multiplying by the stellar Luminosity, as Hunt-Walker et al. (2012) outline. We color code each quarter in the FFD diagram to match that in the FFL.

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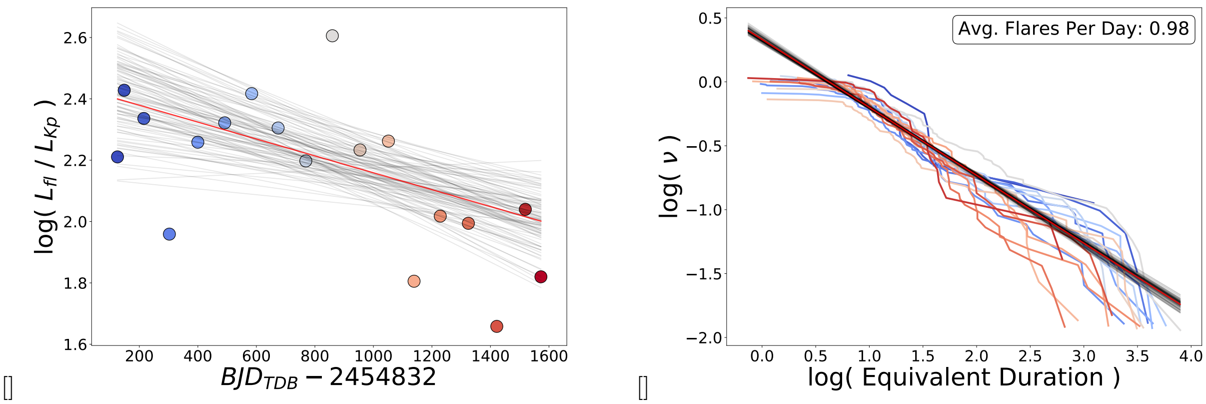

Figure 1. Left: Our candidate star, KIC 8507979, shows a slow decline of ∼0.5 dex in fractional flare luminosity (L_{fl}/L_{Kp}) over time. Points are color-coded blue-to-red according to the observing Quarter throughout the Kepler mission. Uncertainties in L_{fl}/L_{Kp} are smaller than the symbol sizes, as explored by Lurie et al. (2015). **Right:** Cumulative flare frequency distribution for each quarter showing a small gradient in flare rate over time. Line color for each quarter matches points in the left panel. Best MCMC fit of (-0.53±0.01)log(ED) + (0.33±0.02).

In Figure 1 we demonstrate this search for our best candidate, KIC 8507979, which has an average of ∼1 flare per day with energy over 10^{30} erg. This star showed a decline in flare frequency, with a best MCMC fit of (-2.73±1.08)e-4 * log(ED) + 2.43±0.11 suggesting a decrease of roughly 0.0003 flares per day. This decline in flare rate agrees with the FFD plot which shows a color gradient in flare rate over time, most noticeable for flares with equivalent duration ≥ 1.5.

Extrapolating this 4 year decline in flare rate would result in a change similar to our sun of ∼1 dex over 11 years. Conveniently, the upcoming data release of TESS Cycle 14 provides an opportunity to further investigate this candidate and other stars. The TESS data set overlaps the Kepler field and provides a 10 year baseline of observation. With 10 years of data, analyzing changes in flare rate will be less vulnerable to noise and we hope applying this FFL measure will find coherent variations in more stars and confirm the variation in our candidate.

Software: Python, IPython (Perez & Granger 2007), NumPy (Walt et al. 2011), Matplotlib (Hunter 2007), SciPy (Jones et al. 2001–), Pandas (McKinney 2010), emcee, (Foreman-Mackey et al. 2017)

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