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Using Flare Rates to Search for Stellar Activity Cycles

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Measuring the prevalence and duration of activity cycles gives insight into the origin of stellar magnetic dynamos. Traditional techniques for detecting activity cycles include: monitoring integrated flux measurements (Kopp et al. 2016), chromospheric emission lines (Duncan et al. 1991), and starspot tracking (Messina & Guinan 2002; Montet et al. 2017). However, these techniques face challenges such as photometric precision, or limited spectroscopic sample sizes. Flares, however, are easily detectable for stars even out to kpc distances, and can be surveyed for many stars simultaneously using wide-field photometric surveys. Encouragingly, the Sun's flare rate varies by a factor of 10 between solar maximum and minimum (e.g. Veronig et al. 2002; Aschwanden & Freeland 2012).

Here we briefly explore this idea, searching for variations in flare rates from stars in the Kepler mission (Borucki et al. 2010). Kepler provides up to 4 years of nearly continuous optical light curves, which allow us to search for coherent variations in flare rate that may indicate stars are undergoing activity cycles. We examined a sample of 347 flare stars from Davenport et al. (2019), which were selected as having measured Kepler rotation periods, 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 activity by computing the fractional luminosity emitted in flares, $L_{fl}/L_{Kp} \equiv \xi_{tot}/t_{exp}$ (Lurie et al. 2015). Here ξ_{tot} is the sum of the "equivalent duration" for each flare event (Hunt-Walker et al. 2012), and t_{exp} is the total exposure time of the observation. We compute $\log L_{fl}/L_{Kp}$ over each quarter and apply a Markov Chain Monte Carlo (MCMC) routine to fit a linear model to $\log L_{fl}/L_{Kp}$ over time, looking for stars with significant slopes (i.e. changes in flare activity level) [1].

In Figure 1 we show our best candidate for flare activity variation, KIC 8507979, a dM3e with a rotation period of 1.2 days. This star emits on average 0.82 flare(s) per

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[1] https://github.com/mscoggs/flare_cycles

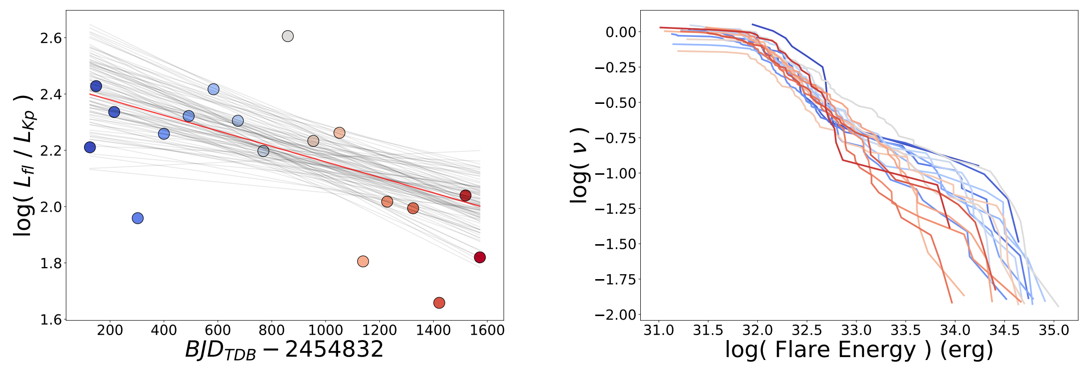

Figure 1. **Left:** KIC 8507979 shows a decline of ∼0.5 dex in L_{fl}/L_{Kp} over 4 years. Point color (blue to red) corresponds to Kepler Quarter. Uncertainties in L_{fl}/L_{Kp} are smaller than the symbol sizes (Lurie et al. 2015). Our MCMC fit is shown (red), with 100 draws from the posterior distribution (grey). **Right:** Cumulative flare frequency distribution for each quarter showing a gradient in flare rate over time. Line color for each quarter matches points in the left panel.

day with energy over 10^{32} erg over the 18 Kepler quarters. A decline in flare activity is seen, with a MCMC best fit of $\log L_{fl}/L_{Kp} = (-9.96{\pm}3.94){\times}10^{-2}{\times}t_{years}{+}2.43{\pm}0.11$.

We also show the flare frequency distribution, the standard figure for flare activity (e.g. Lacy et al. 1976; Davenport et al. 2019), for each quarter. The decline in flare activity found with L_{fl}/L_{Kp} can be seen here as a color gradient, most visible for high energy flares.

While the flare census from KIC 8507979's Kepler light curve doesn't show unambiguous evidence for a stellar activity cycle, the variation of ∼0.1 dex per year is consistent with cyclic behavior over a decade or longer timescale. Fortunately, Sectors 14 and 15 from the Transiting Exoplanet Survey Satellite (TESS; Ricker et al. 2015) will revisit the original Kepler field with comparable light curve sampling (30 min cadence here). Though TESS has a considerably smaller aperture than Kepler (i.e. shallower photometric depth), bright flares will still be detectable with TESS for many of the active Kepler stars. This Kepler–TESS overlap will provide an initial 10-year observing baseline. We anticipate flare activity variations will be an exciting new avenue for discovering and characterizing magnetic activity cycles.

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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REFERENCES

Aschwanden, M. J., & Freeland, S. L. 2012, ApJ, 754, 112

Borucki, W. J., Koch, D., Basri, G., et al. 2010, Science, 327, 977

Davenport, J. R. A., Covey, K. R., Clarke, R. W., et al. 2019, ApJ, 871, 241

Duncan, D. K., Vaughan, A. H., Wilson, O. C., et al. 1991, ApJS, 76, 47

Foreman-Mackey, D., Agol, E., Ambikasaran, S., & Angus, R. 2017, Astronomical Journal, 154

Hunt-Walker, N. M., Hilton, E. J., Kowalski, A. F., Hawley, S. L., & Matthews, J. M. 2012, PASP, 124, 545

Hunter, J. D. 2007, Computing in Science & Engineering, 9, 90

Jones, E., Oliphant, T., Peterson, P., et al. 2001–, SciPy: Open source scientific tools for Python, ,

Kopp, G., Krivova, N., Wu, C., & Lean, J. 2016, Solar Physics

Lacy, C. H., Moffett, T. J., & Evans, D. S. 1976, ApJ

Lurie, J. C., Davenport, J. R. A., Hawley, S. L., et al. 2015, ApJ, 800, 14

McKinney, W. 2010, in Proceedings of the 9th Python in Science Conference, ed. S. van der Walt & J. Millman, 51 – 56

Messina, S., & Guinan, E. F. 2002, A&A, 393, 225

Montet, B. T., Tovar, G., & Foreman-Mackey, D. 2017, ArXiv e-prints

Perez, F., & Granger, B. 2007, IEEE, 9

Ricker, G. R., Winn, J. N., Vanderspek, R., et al. 2015, Journal of Astronomical Telescopes, Instruments, and Systems, 1, 014003

Veronig, A., Temmer, M., Hanslmeier, A., Otruba, W., & Messerotti, M. 2002, A&A, 382, 1070

Walt, S., Colbert , C., & Varoquaux, G. 2011, Computing in Science & Engineering, 13