Investigating the Flare Activity of the Spotted Kepler Star KIC 5110407

Rachael M. Roettenbacher[1], **John D. Monnier**[1], **& Robert O. Harmon**[2]

[1]*Department of Astronomy, University of Michigan, 500 Church Street, Ann Arbor, MI 48019, USA*

[2]*Department of Physics and Astronomy, Ohio Wesleyan University, 61 S. Sandusky St., Delaware, OH 43015, USA*

Abstract. With four years of precise, nearly-continuous photometry from the *Kepler* satellite, we use a light-curve inversion algorithm to reconstruct the stellar surface of KIC 5110407, a rapidly-rotating, spotted star. While the evolving starspots showed no indication of periodicity, the flares serendipitously observed in the light curve of KIC 5110407 showed potential evidence for an activity cycle. Additionally, the full sample of detected flares does not show a correlation with the location of starspots; however, we find a possible connection for the strongest flares occurring when the largest starspot groups faced *Kepler*. With the analysis of our complete data set and archival *Kepler* data, we further investigate individual systems for periodic flare activity and correlations to starspot location.

1. Introduction

We use the high-precision, high-cadence photometric light curves of the *Kepler* satellite to observe the structure and evolution of rapidly-evolving surface features on continuously observed targets. By modeling individual rotation cycles, we are able to observe the growth and motion of starspots across stellar surfaces. With this information we gain an understanding of the differential rotation, the phenomenon of equatorial stellar material rotating more rapidly than the polar material, and the surface structures at the time of flares.

To model the stellar surface we use a constrained non-linear inversion algorithm called Light-curve Inversion (LI Harmon & Crews 2000) which makes no *a priori* assumptions of spot shape, number, or size (input parameters are spot and photospheric temperatures and limb darkening coefficients). Applying LI to seven quarters of *Kepler* data, we observed spot evolution and differential rotation (see Roettenbacher et al. 2013). The Roettenbacher et al. (2013) analysis of the surface reconstructions of K-type star KIC 5110407 show spot evolution and indications of differential rotation ($P_{\rm rot} = 3.4693$ days).

2. Flares

While modeling the starspots of KIC 5110407, we removed the flares present in the *Kepler* photometry. Although problematic for inverting the light curves to study starspots, the flares provide a complementary look into stellar activity. In our analysis of the flares, we considered flare strength and timing.

As reported in Roettenbacher et al. (2013), the flares of KIC 5110407 showed no overall correlation with location between their timing and the spot features facing *Kepler* with the possible exception of the brightest. For the two strongest flares observed in Q2-9, the large spot structures were also facing *Kepler*.

For follow-up using the complete *Kepler* light curve of KIC 5110407, we measured the phase difference between the occurrence of the flare and the light curve minimum. Figure 1 shows the strength of each flare (in percent flux above the stellar flux) plotted against the phase difference between the minimum of the light curve and the time of the flare. The small flares ($< 5\%$) show no correlation in their timing. These flares could be associated with the spots observed on KIC 110407, unresolved spots below our resolution, or the spotless photosphere. The strongest flares are correlated with the position of the largest starspots facing *Kepler*.

In Figure 2, we plot the number of flares in each *Kepler* quarter. The error bars account only for Poisson statistics ($\sigma_{N_{\rm flare}} = \sqrt{N}$). The quarters with no flares are all quarters for which KIC 5110407 was not observed (in the cases of Q6, 10, and 14, the star fell on a detector that previously stopped functioning). If the enhanced activity seen in Q5 and 11 is an indicator of the presence of a magnetic activity cycle, we expected to see another peak in Q17. Unfortunately, in Q17, *Kepler* experienced a failure that ended data-taking operations after one-third of the quarter. In what exists of Q17 data, two flares were detected. Here we extrapolate the flare rate for the entire quarter. Although the rate of flares in Q17 is promising, we cannot verify the existence of an activity cycle in the flares of KIC 5110407.

3. Conclusions and Future Work

We analyzed the flares of KIC 5110407 observed by the *Kepler* satellite. We determined that the largest flares occurred when the largest starspot structures faced *Kepler* indicating a correlation. The smaller spots occurred at any phase. We also identified a potential activity cycle by counting the number of flares in each quarter of data. Unfortunately, the *Kepler* satellite stopped operating at the point which would confirm our predicted cycle.

Our method for activity cycle detection can be applied to other active stars, such as those in the *Kepler* data archive, focusing on shorter rotation periods, which likely have shorter activity cycles (e.g. Vida et al. 2014; Savanov 2012). By observing and modeling more cool stars with rapidly-evolving spot structures and frequent flares, we aim to better understand the connection between starspot and flare cycles. In turn, this will allow for connections between activity, age, and spectral type.

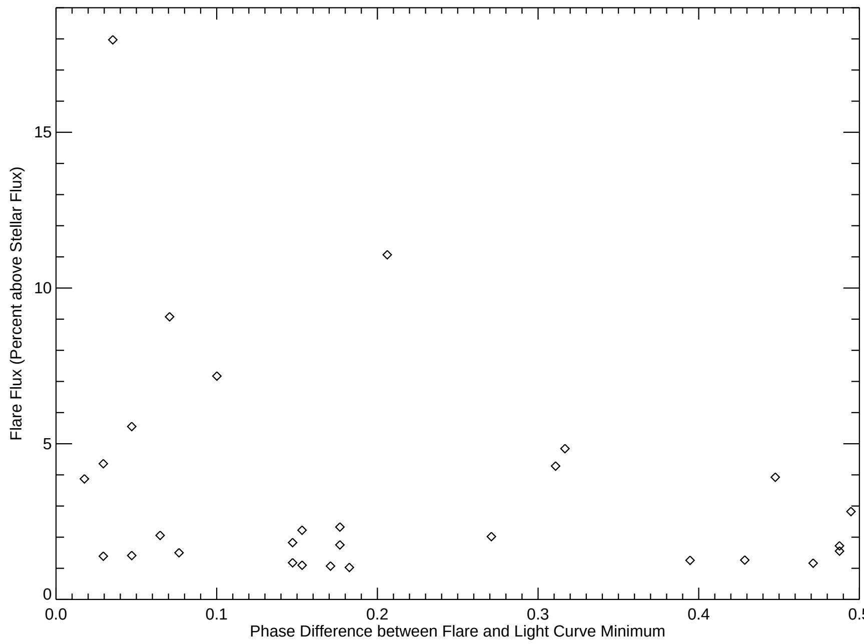

Figure .1: Flare strength plotted agains the phase difference between the minimum of the light curve and the peak of the flare. The small flares (percent of flux above the stellar flux < 5%) show no correlation to the presence of large spot structures. The strongest flares are correlated with the largest starspots.

Acknowledgements. We gratefully acknowledge support from the Kepler Guest Observer Program (NASA grant NNX13AC17G).

References

Harmon, R. O., & Crews, L. J. 2000, AJ, 120, 3274

Roettenbacher, R. M., Monnier, J. D., Harmon, R. O., Barclay, T., & Still, M. 2013, ApJ, 767, 60

Savanov, I. S. 2012, Astronomy Reports, 56, 716

Vida, K., Oláh, K., & Szabó, R. 2014, MNRAS, 441, 2744

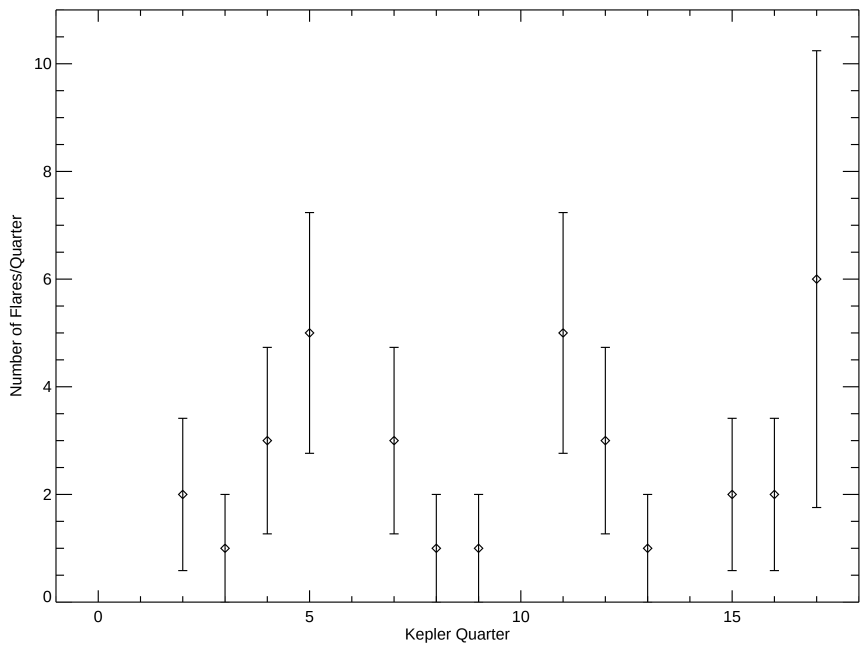

Figure .2: Distribution of flares of KIC 5110407 during each *Kepler* quarter. The quarters with no detections are all quarters for which *Kepler* did not observe KIC 5110407. A potential activity cycle can be noted, but the failure of *Kepler* in Q17 prohibits the confirmation of a cycle.