Characterizing Four Subsets of *Kepler* O'Connell Effect Binaries

Matthew Knote[1]

Advisors: Dr. Eric Perlman and Dr. Saida Caballero-Nieves

Florida Institute of Technology

Department of Aerospace, Physics, and Space Sciences

[1]mknote2015@my.fit.edu

Temporally Varying Systems

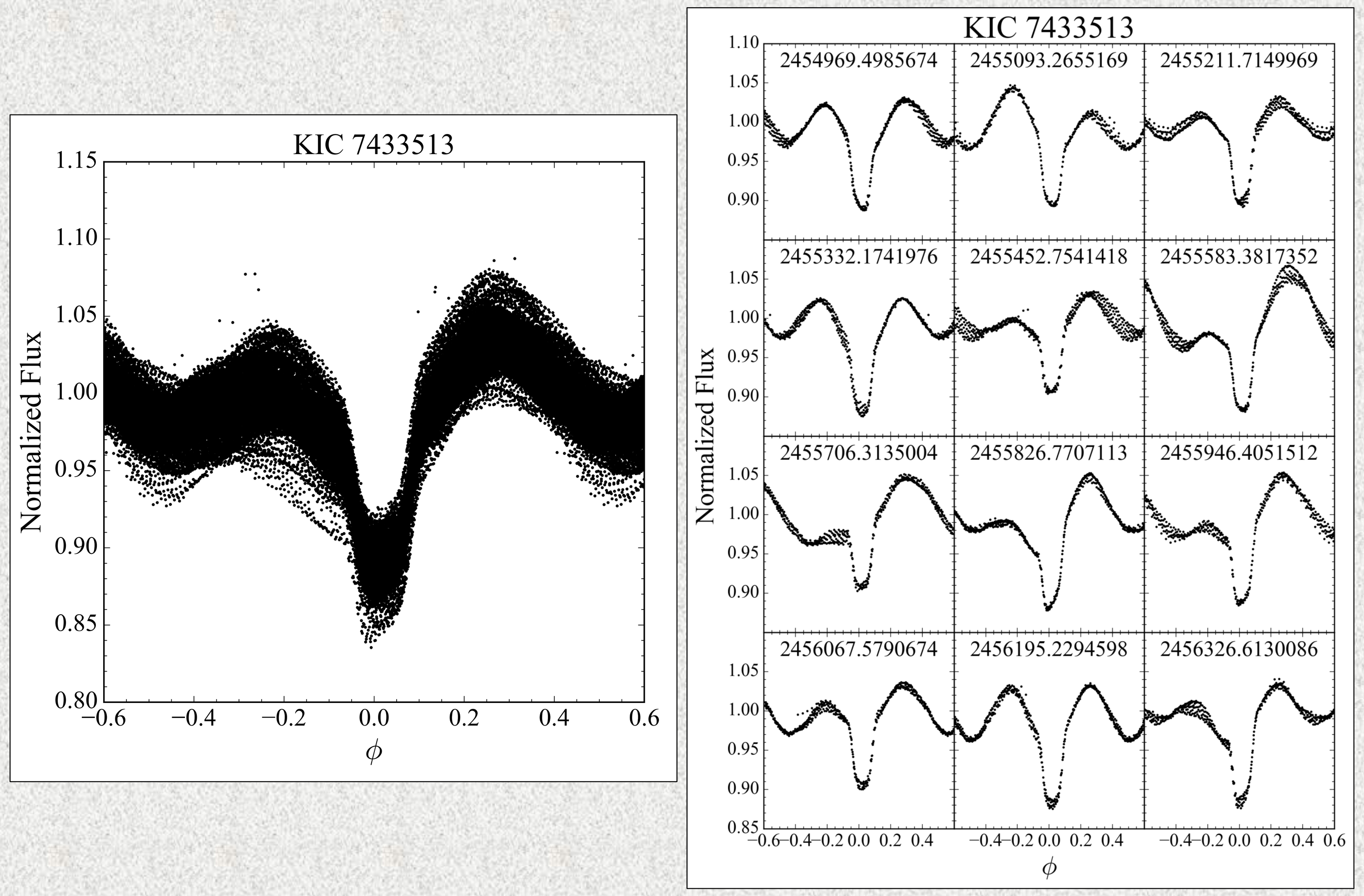

Figure 1: The left panel shows KIC 7433513's *Kepler* data, which shows the significant data scatter due to the system's temporal variation. The right panel shows 10-day intervals of data separated by a few months, demonstrating the rapidly changing nature of the system. The number in each subpanel is the BJD of that time-slice's midpoint.

Concave-Up Systems

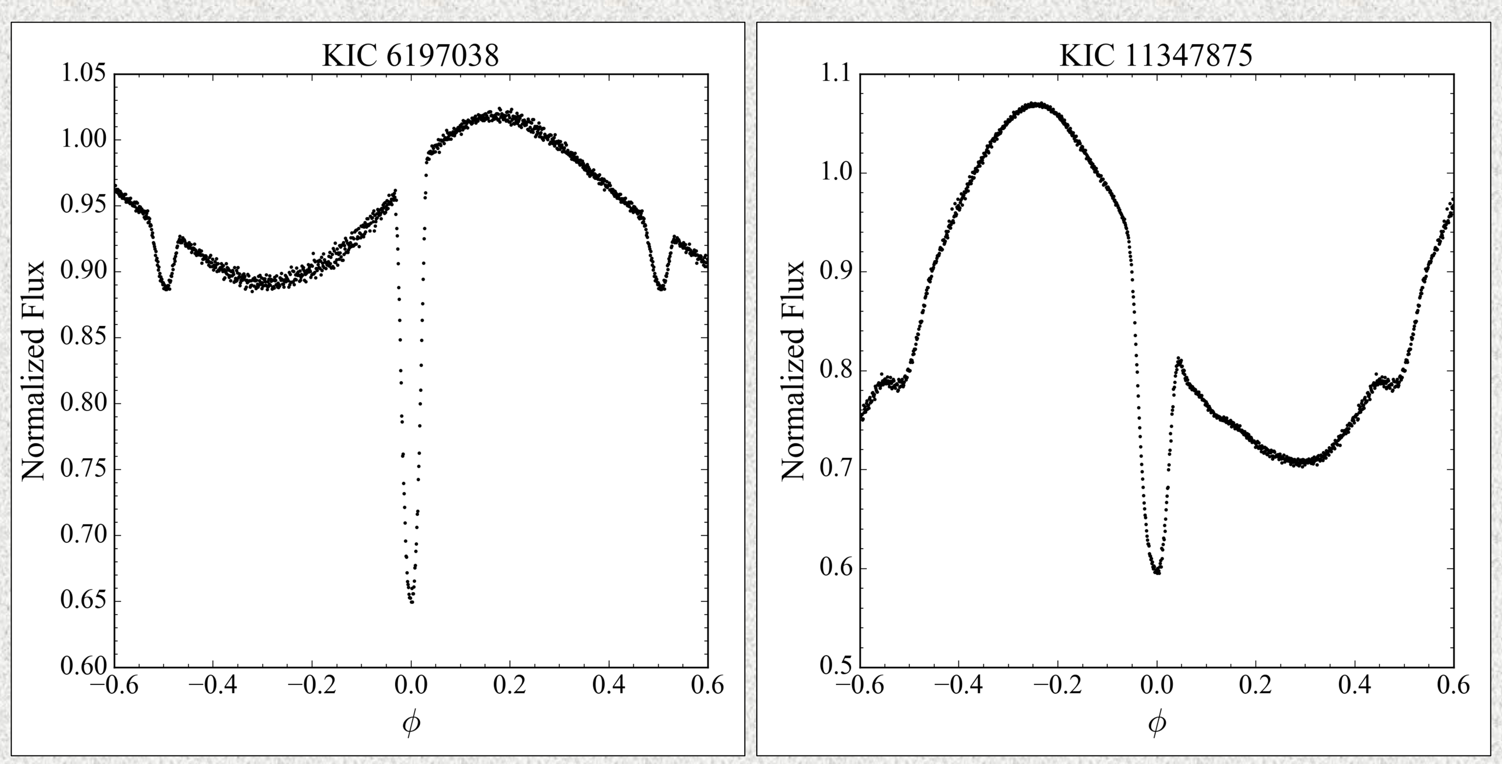

Figure 3: The left panel shows KIC 6197038's average *Kepler* data, which shows its concave-up region before the primary eclipse. The right panel shows KIC 11347875's average *Kepler* data, which shows its concave-up region after the primary eclipse.

Acknowledgements

This material is based upon work supported by the National Aeronautics and Space Administration under Grant No. 80NSSC19K1021 issued through the NNH18ZDA001N Astrophysics Data Analysis Program (ADAP). This paper includes data collected by the *Kepler* mission. Funding for the *Kepler* mission is provided by the NASA Science Mission directorate.

Background

The O'Connell effect (O'Connell 1951; Milone 1968) is a phenomenon in eclipsing binaries where one maximum is brighter than the other. The O'Connell effect's causes are poorly understood, but two leading theories are starspots and mass transfer (Wilsey & Beaky 2009). To better understand the O'Connell effect, we studied 258 eclipsing binaries observed by the *Kepler* space telescope that display it. We selected these targets from the *Kepler* Eclipsing Binary Catalog (Kirk et al. 2016). During our study, we found four subsets of systems that were unique for reasons beyond showing the O'Connell effect. These four subsets include systems with strong temporal variation, those with an asymmetric minimum, those with a concave-up region, and a white dwarf. We describe each subset in the next few paragraphs. Systems can belong to multiple subsets.

Temporally Varying Systems (TV): These 59 systems have light curves that change significantly and rapidly. KIC 7433513 is one such system, and Figure 1 shows its complete *Kepler* data (left panel) and 10-day intervals separated by a few months (right panel). These systems are among the cooler of our sample, with the hottest estimated at 5,760 K. Our leading hypothesis is that the variations are caused by starspots on one or both components. Kunt & Dal (2017) described one such system, KIC 7885570, as an RS Canum Venaticorum variable, consistent with our hypothesis.

Asymmetric Minima Systems (AM): About 25 systems show an asymmetric eclipse minimum. Figure 2 shows averaged light curves of KIC 9164694 (left panel) and KIC 9717924 (right panel), which display an asymmetric primary and secondary minimum, respectively. These systems are among the hotter of our systems, with over half having a temperature above 5,000 K. All systems with an asymmetric minimum exhibit total eclipses. Our leading hypothesis is that the changing aspect of a feature like a starspot causes the asymmetry. The flux change caused by the changing aspect is quite small, only being detectable during the nearly flux-constant period of totality.

Concave-Up Systems (CU): Around 9 systems show a concave-up region of their light curve, giving them the appearance of a sinusoid. Figure 3 shows the averaged light curves of KIC 6197038 (left panel) and KIC 11347875 (right panel), and the concave-up region before and after the primary eclipse, respectively, is plainly visible. All of these systems have a temperature below 5,100 K, a period greater than about 0.7 days, and show many flares. We have no leading hypothesis for this phenomenon, but enormous starspots on one or both components may be responsible.

The White Dwarf (WD): KIC 10544976 is the only white dwarf in our sample. Almenara et al. (2012) found that the binary consists of a DA white dwarf primary and an M4 V secondary in an 8.4-hour orbit. Figure 4 shows KIC 10544976's averaged (left panel) and *Kepler* (right panel) light curves, and the system displays a sharp primary eclipse, no secondary eclipse, and numerous flares. The flux difference before and after the primary eclipse may be due to starspots on the red dwarf.

Results

We used the Kolmogorov–Smirnov test (K–S test; Kolmogorov 1933; Smirnov 1948) to compare the characteristic distributions between the first three subsets discussed above and our entire sample. This test cannot be run for the WD subset because it only has one system. The characteristics we compared were the O'Connell effect size, the eclipse depth, temperature, absolute magnitude, distance, and period. Our analysis revealed several differences between these distributions.

The eclipse depth distributions for the TV subset strongly differ from our sample's. TV systems have shallower eclipses, with only 8% having an eclipse depth greater than 0.2 (in normalized flux), compared to 49% of the full sample. TV systems generally have a longer period, too, with 27% having a period of over a day, compared to 17% of the full sample. The absolute magnitude and period distributions differ for the AM subset. AM systems are brighter on average, with 88% being brighter than the Sun compared to 59% of the full sample. AM systems also have a longer period, with 44% having a period over a day. The temperature, absolute magnitude, and period distributions differ for the CU subset. CU systems are cooler, with 11% having a temperature above 5,000 K compared to 66% of the full sample. CU systems have a longer period, with 67% having a period over a day. Finally, CU systems are fainter, with only 33% being brighter than the Sun.

Asymmetric Minima Systems

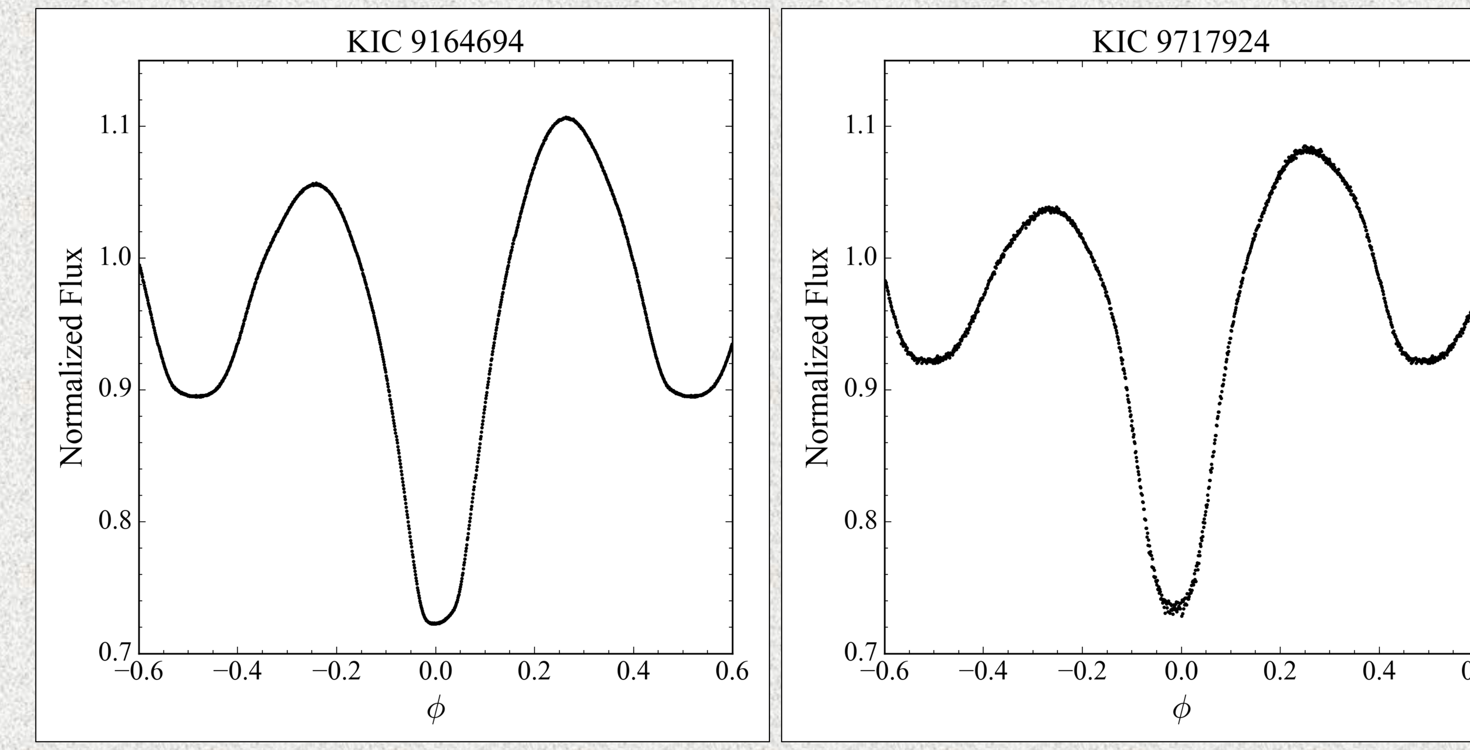

Figure 2: The left panel shows KIC 9164694's average *Kepler* data, which shows its asymmetric primary eclipse. The right panel shows KIC 9717924's average *Kepler* data, which shows its asymmetric secondary eclipse.

The White Dwarf

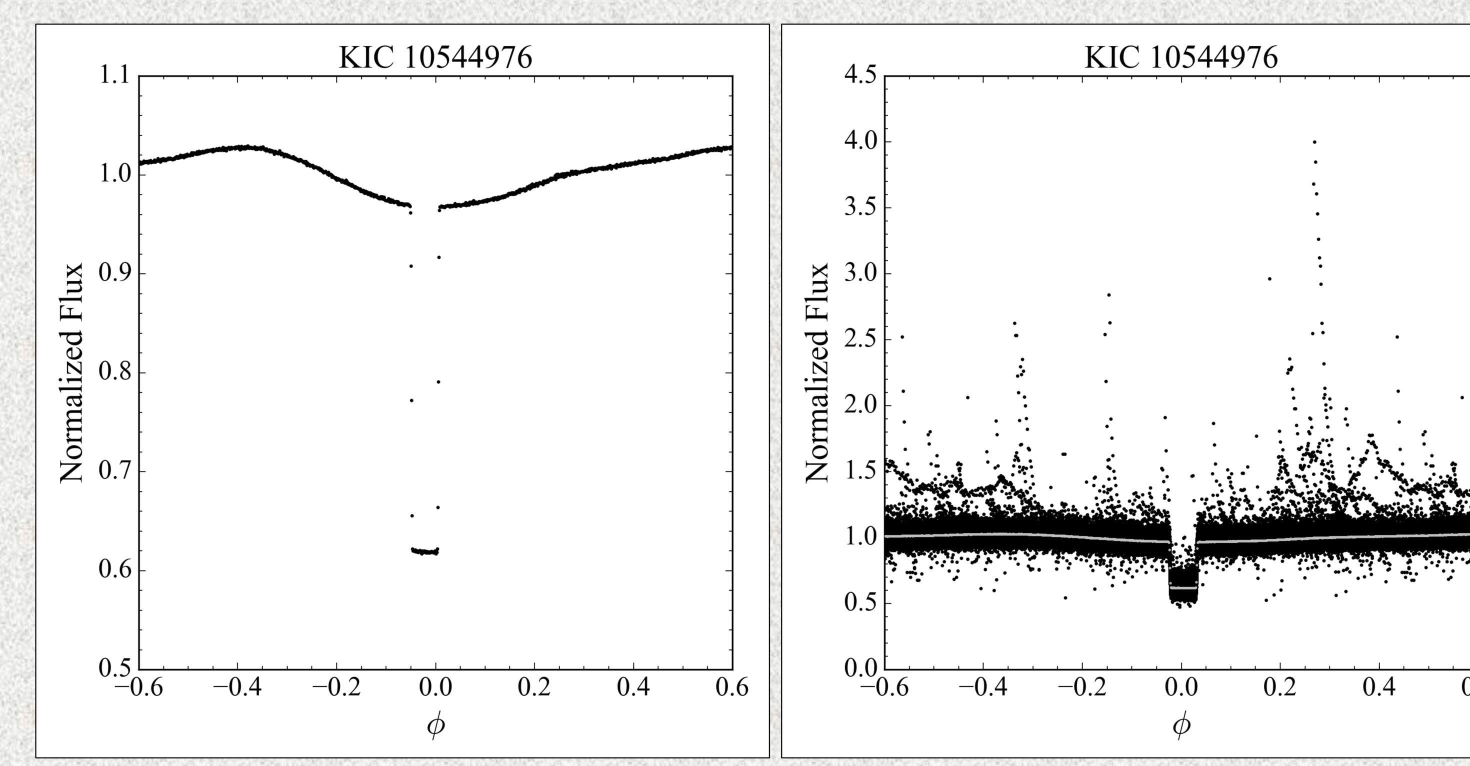

Figure 4: The left panel shows KIC 10544976's average *Kepler* data, which shows its very sharp primary eclipse and lack of secondary eclipse. The right panel shows KIC 10544976's *Kepler* data, which shows multiple flares from the red dwarf. The average light curve is shown in grey in the right panel.

References

Kirk, B., Conroy, K., Prša, A., et al. 2016, AJ, 151, 68

Kolmogorov, A. 1933, Giornale dell'Istituto Italiano degli Attuari, 4, 83

Kunt, M., & Dal, H. A. 2017, AcA, 67, 345

Milone, E. E. 1968, AJ, 73, 708

O'Connell, D. J. K. 1951, Publ. of the Riverview College Observatory, 2, 85

Smirnov, N. 1948, The annals of mathematical statistics, 19, 279

Wilsey, N. J., & Beaky, M. M. 2009, Society for Astro. Sci. An. Symp., 28, 107