Searching for Color Changes During Outburst

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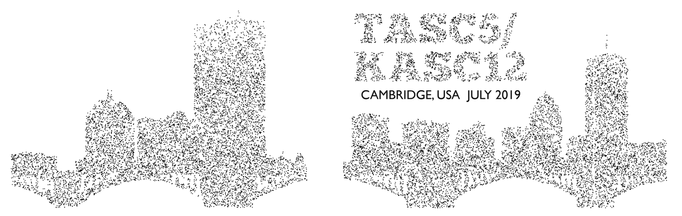


Introduction

- Observations from *Kepler* and *K2* have revealed pulsating hydrogen-atmosphere white dwarfs (ZZ Cetis) that undergo outburst-like phenomena where their irregular mean flux increases of order 2% up to 15% over the course of 4 to 25 hours and repeating on the order of days
- These outbursting ZZ Cetis, or "outbursters", are all characteristically similar with T_{eff} ~ 11000 K, and as such are only observed near to the cool edge of the DA instability strip (Bell 2016) (see Figure 5)
- These outbursts, which have been observed in ~15 ZZ Cetis, are theorized to be a consequence of nonlinear three-mode resonant coupling (Wu & Goldreich 2001; Luan & Goldreich 2018)
- The Panoramic Survey Telescope and Rapid Response System, or Pan-STARRS (PS1), simultaneously observed the same field of view with *K2* during its Campaigns 16 and 17. Campaign 16 included over 80 days of observation of one previously confirmed outburster along with a newly identified one, EPIC 211629697 and EPIC 211968416, respectively
- PS1 observed each star in four different color filters - g_{P1}, r_{P1}, i_{P1}, z_{P1} (see Figure 1 below) - with 30 second integrations (Dotson 2018).

Research Goal

Our primary objective is to measure changes in the surface temperature of the images in outburst relative to those of quiescent pulsations as evidenced by changes in the color of the star. Determining how the colors change may be a vehicle to uncovering the mysterious physics driving these phenomena .

Methods

- Data acquisition: using an example python notebook written by Scott Fleming [5], we queried the PS1 catalogue for cutout-frames of the two outursters. We generated short-cadence K2 lightcurves by first downloading the raw Target Pixel Files from the Mikulski Archive for Space Telescopes (MAST) and then extracting light curves using the Pyke and Lightkurve tools to perform aperture photometry with custom-defined aperture masks.
- For the two outbursters, we produced smoothed short cadence *K2* light curves by convolving them with a kernel box width of 100. This minimized point-to-point scatter while maintaining the temporal extent of outburst events, allowing us to identify which PS1 images were taken during outbursts
- The procedure was then repeated using the original, un-smoothed short cadence light curves for the two outbursters to determine whether measurement occurred relative to the pulsation phases, e.g. a peak or trough
- To add a control to the experiment, we added 3 DAVs (EPICs 211494257, 212090116, 251809152) and 2 non-variable DAs (EPICs 212182185 & 212168788), all bright white dwarfs also in Campaign 16.
- Standard aperture photometry was then performed using the photutils tools in python on the PS1 images and magnitudes were obtained for all seven objects
- After acquiring all the short cadence *K2* data for all seven objects, the normalized fluxes were converted to magnitudes and normalized to the object's calculated K_{p1}, where $K_{p1} \equiv 25.3 - 2.5\log_{10}(\text{median of counts})$, a highly accurate approximation for K_p (Lund et al. 2018).
- We then proceeded to plot color-magnitude diagrams for each object, using the nearest Kp magnitude and PS1 magnitude difference against the Kp magnitude for the g_{p1}, r_{p1}, and i_{p1} filters
- Here, the Kp magnitudes were obtained by binning around the nearest 7 data points in time to reduce point-to-point scatter

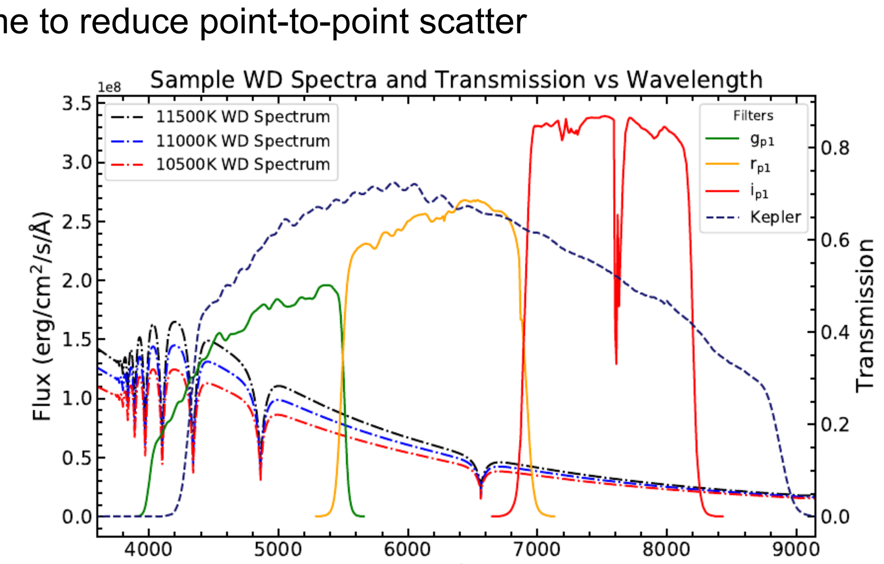
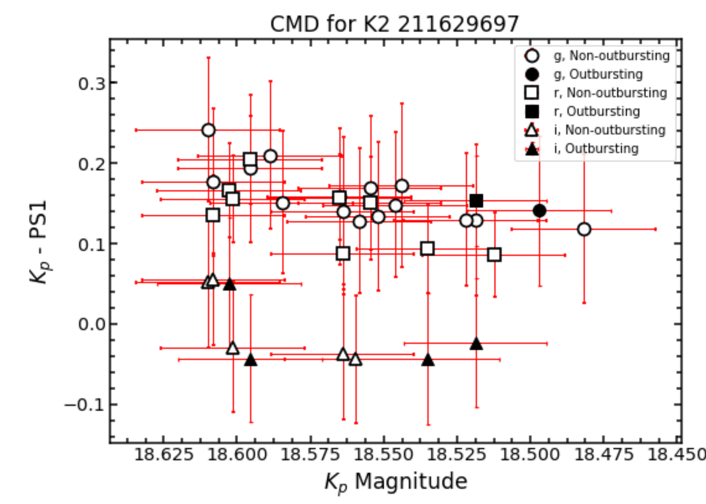
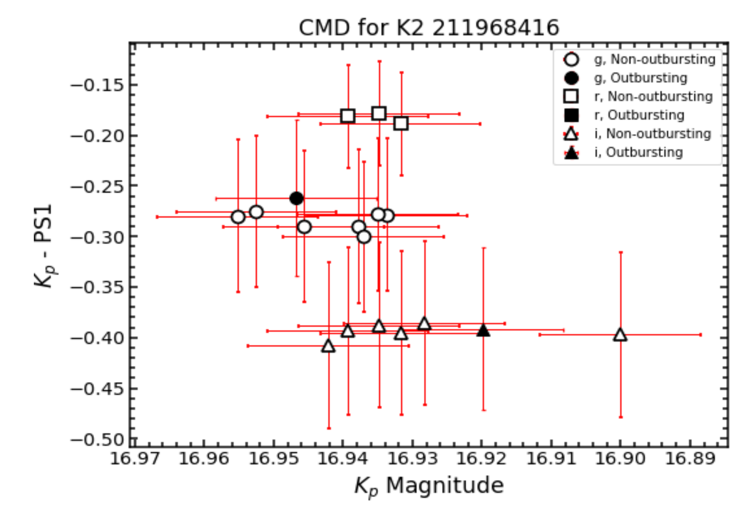


Figure 1: Reference for relevant filter transmissions.

Figures





Figures 2, 3 (above): CMDs for both outbursters.

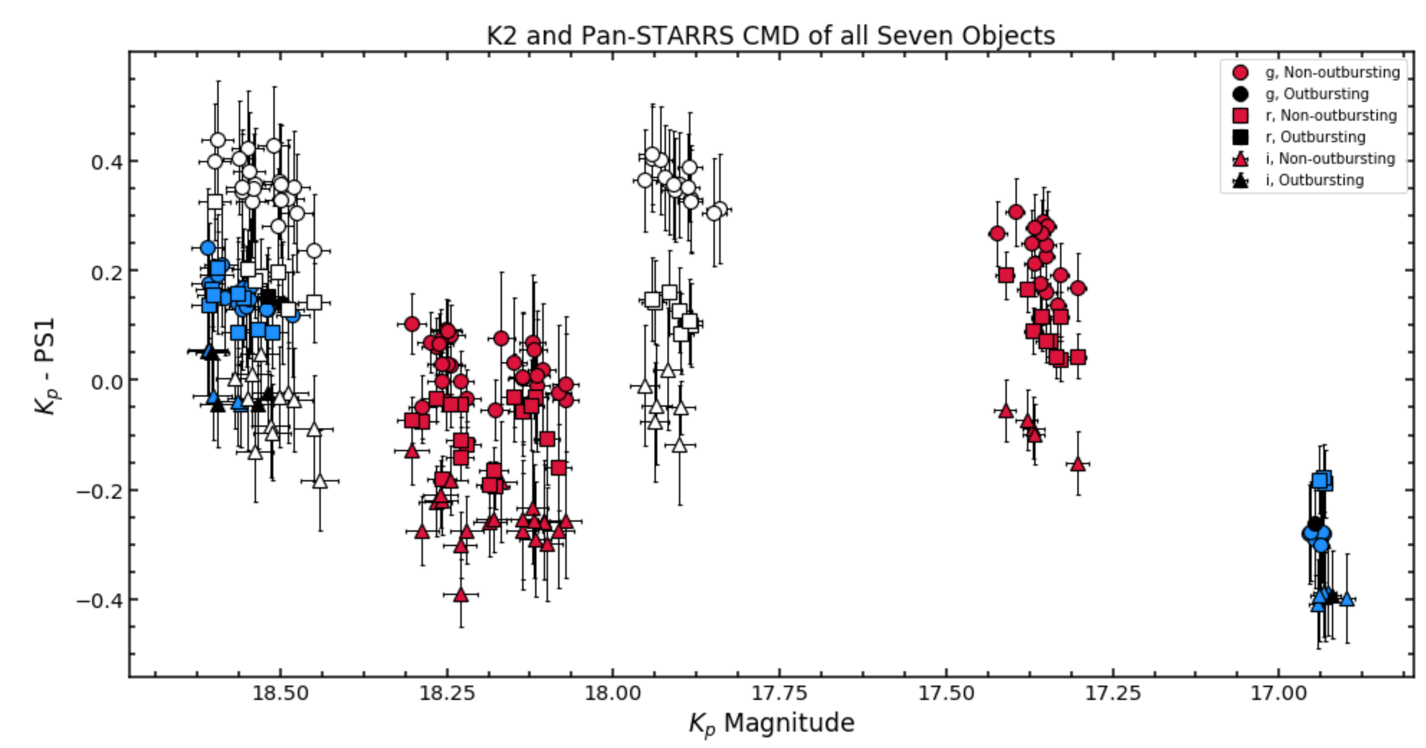


Figure 4 (above): CMD of seven objects. Here blue indicates an outburster, red are ZZ Cetis, and white are non-variable, the dashed lines show the DA instability strip.

Figure 5 (below): Plot of log(g) vs Teff for various pulsating, outbursting, and on-variable white dwarfs. This study's objects are the star shaped points, and the yellow two are the outbursters.

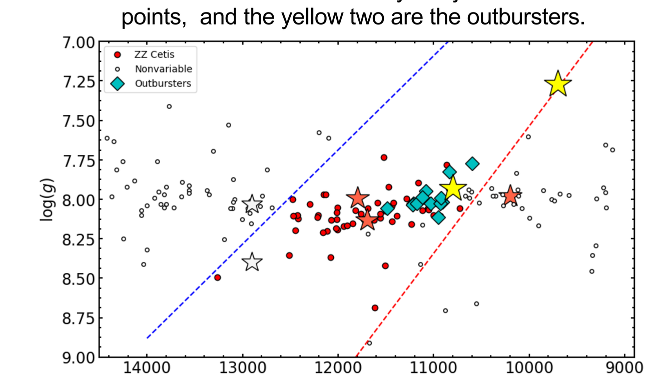
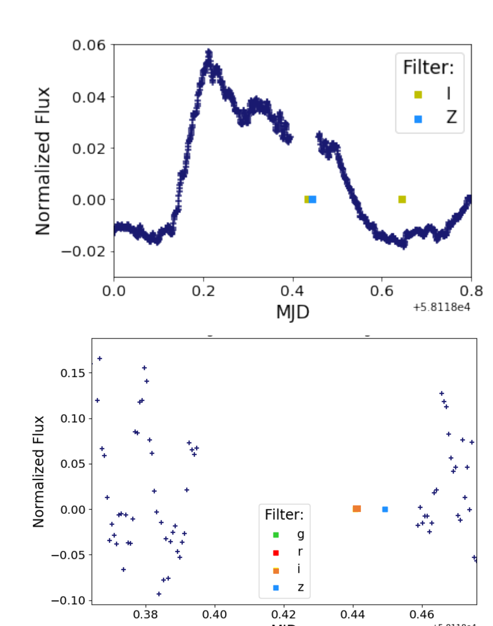
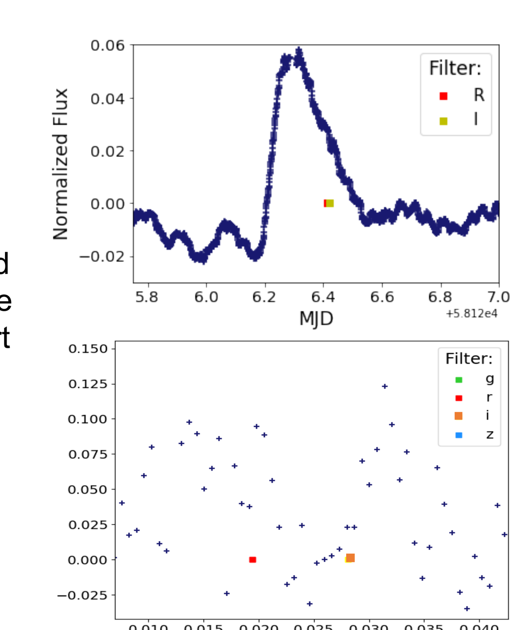


Table 1 (below): Table of properties for all seven objects.

Kepler ID	Object Type	T_{eff} (K)	log(g)	Kp Magnitude
211629697	Outburster	10800	7.93	18.39
211968416	Outburster	9700	7.27	17.00
211494257	DAV	11800	7.99	17.22
212090116	DAV	10200	7.98	18.20
251809152	DAV	11700	8.13	18.30
212168788	DA	12900	8.03	18.29
212182185	DA	12900	8.40	17.72

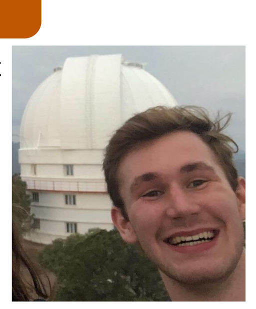


Figures 5, 6 (left, right): Magnified outburst peaks with PS1 images from the smoothed light curves above, and then the same magnified unaltered short cadence data to show what phase of pulsation the image falls.



About the Author

Joseph Guidry is a third-year astronomy and physics undergraduate at the University of Texas at Austin. Always looking up at the night sky, I plan to study observational astronomy in grad school with the goal of obtaining my PhD. I also love to explore the natural world, cook Louisiana creole cuisine, and try my hand at photography.



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Results

Unfortunately, the first data release of Pan-STARRS was not designed to cater to single epoch analysis, given the systematic error where sky coverage does not necessarily cover the entire imaged region. As a result, many frames had to be neglected because they contained no usable data or the target lied in a region that did not receive signal.

Still, from the smoothed light curves, for EPIC 211629697 we found 6 PS1 images taken during outbursts that were usable: 1 in g_{p1} and r_{p1}, and 4 in i_{p1}. From analyzing the short cadence light curves we also identified that all of these outbursts probably fell in the troughs of pulsations, while two were in a data gap.

For EPIC 211968416 there were only 2 images taken during outburst that were usable: 1 each in g_{p1} and i_{p1}. Similarly, the i one also fell in a trough, but the g is inconclusive. Thus, these findings may explain why we are not seeing significant increases in temperature in the CMDs.

Due to inherent unequal amounts of images in each filter and further losses in the amount of usable images, we could not generate color – color plots as originally intended. However, plotting the results on these CMDs still demonstrates the expectation that in both quiescence and outburst stages the star is brightest in g. The fact that the non-variable and variable DAs are behaving similarly in color space is alarming, though, and begs the need for an improved analysis.

Future Work

We can make the most of these data by optimizing the aperture photometry to include as many "low risk" companion stars as stars, allowing us to recover some lost data. This can be done by using edge detection algorithms to identify regions to avoid when selecting stars. We have begun development of an automated reduction pipeline to incorporate this into our aperture photometry, inspired by some of the techniques found in Fulton et al. 2014 [6].

Ultimately, due to the lack of high-quality data, we will have to design a model of outbursting DAVs convolved to the three PS1 filters. From this model we would attain thousands of data points from various quiescent pulsation phases and from outburst events that would allow us to generate true color – color plots and directly test our findings from the improved analysis.

Acknowledgments

I graciously acknowledge the financial support from JJ Hermes and the Wootton Center for Astrophysical Plasma Properties which allowed me to participate at TASC5/KASC12, where this work was originally presented. I extend gratitude to the FRI program and the White Dwarfs stream for their truly incredible passion for research and mentorship. I also thank TIDES for being so accommodating during such stressful times to still hold this forum.

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