



2017-08-18

Observing KELT Candidate Objects in the Search for Transiting Exoplanets

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Martinez, Maria, "Observing KELT Candidate Objects in the Search for Transiting Exoplanets" (2017). *All Student Publications*. 212. <https://scholarsarchive.byu.edu/studentpub/212>

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Observing KELT Candidate Objects in the Search for Transiting Exoplanets

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August 18, 2017

Abstract

The main goal of this project was to learn how to participate and be a part of a real observational team. We worked with the KELT exoplanet search project. While working with the KELT project we hoped to be able to confirm a candidate object as a planet. However, trying to discover a transiting planet was not our main goal for the summer. In addition, we also set out to learn how to work in an observatory, operate telescopes, and process data. The different objects we observed throughout the summer were not all determined to be transiting exoplanets, but we were able to observe eclipsing binary systems. We also had the opportunity to work with data of a candidate object that was recently confirmed to be a transiting exoplanet. This recently discovered planet was designated as KELT-21b.

Contents

1	Introduction	2
2	Methods	2
3	Results	3
4	Discussion	6
5	Future Work	8
6	References	8

1 Introduction

The search for transiting exoplanets has increased over the years. Since the first transiting planet was discovered in 1995 the search for these planets has become a very interesting field of study. A transiting exoplanet is similar to an eclipse but instead of blocking an entire celestial body from view a transiting planet conceals a small fraction of the light from its parent star. The Kilodegree Extremely Little Telescope (KELT) is used to observe these celestial objects. KELT is a ground-based observation system formed of two small robotic telescopes that are surveying exoplanets. There are two KELT's, one is KELT North located at Winer Observatory in Arizona and the other one is KELT South located at the South African Astronomical Observatory. The location of these two telescopes is important because it aids astronomers with being able to achieve complete coverage of the sky over the course of the year. The goal of this project is to discover transiting planets with extreme physical properties. By extreme physical properties we mean very large and massive planets. Since KELT conducts ground-based observations planets with extreme physical properties are easier for it to detect.

The KELT team has built an extensive network of partners from other observatories all over the world. The West Mountain Observatory, which is where we did most of our observations this summer, is one of the many observatories that conducts follow up observations on KELT candidate objects. For our observations we used the 0.91m telescope located in the West Mountain Observatory. We also used differential photometry in order to measure the brightness of the different candidate objects. Apart from trying to find transiting planets we also did support observations of selected binary stars. The observations we do for eclipsing binary systems can help researchers better characterize host stars and determine the physical properties for the newly discovered planets.

Conducting follow up observations of the different candidate objects detected by KELT is important because in many cases these objects may not always be confirmed to be an exoplanet. Often times some of the objects detected turn out to be false positives. For example, some of the false positive objects are at times confirmed to be eclipsing binaries. Studying these eclipsing binaries is also significant. From the light curves of eclipsing binaries, we can determine the mass and size of the individual stars.

2 Methods

We used the West Mountain Observatory to carry out our observations for the different candidate objects we were assigned. We mostly used the 0.91m telescope to carry out most of our observations. Before being able to observe we had to first set up the online software that we use to track our object of interest. There is an online program in which we put the information of the object we want to observe. For example, we put in the name of the object, the right ascension and declination that way the telescope knows what object we are interested in observing. We also had to make sure to choose the different filters in which we want to observe in. Then, we have to choose the exposure time for each filter. Once all of this information is logged on we can run the program and the telescope is able locate the object. Once the telescope has found the object we just wait and observe the object until all of the images in the different filters have been taken.

When we are done making observations we then gather all of the data taken of the specific object and begin to calibrate the raw images we took. In order to do this, we use the software system Image Reduction and Analysis Facilities (IRAF) to reduce and analyze the data we obtained. In IRAF we calibrate our images by applying the zero, dark and flat frames onto the images of the object we observed. Once we are done applying these frames to all of our images we are ready to move on to creating light curves for the object.

In order to create light curve plots we used the software AstroImageJ. First, we have to upload the images of our objects onto AstroImageJ. After our calibrated images are in this program we are able place apertures on our images. We place apertures around the target object and around a few comparison stars. As we run all of our images into AstroImageJ we begin to see a plot for our object. The program creates a graph that demonstrates how the brightness of an object varies with time. Once we have the light curve we can begin to analyze the candidate object.

3 Results

We constructed light curves for KELT-21 which was recently determined to have a transiting exoplanet known as KELT-21b. The brightness of KELT-21 was measured using three different filters. With these light curves we are able to see the transit taking place due to the small dips in brightness for the host star KELT-21.

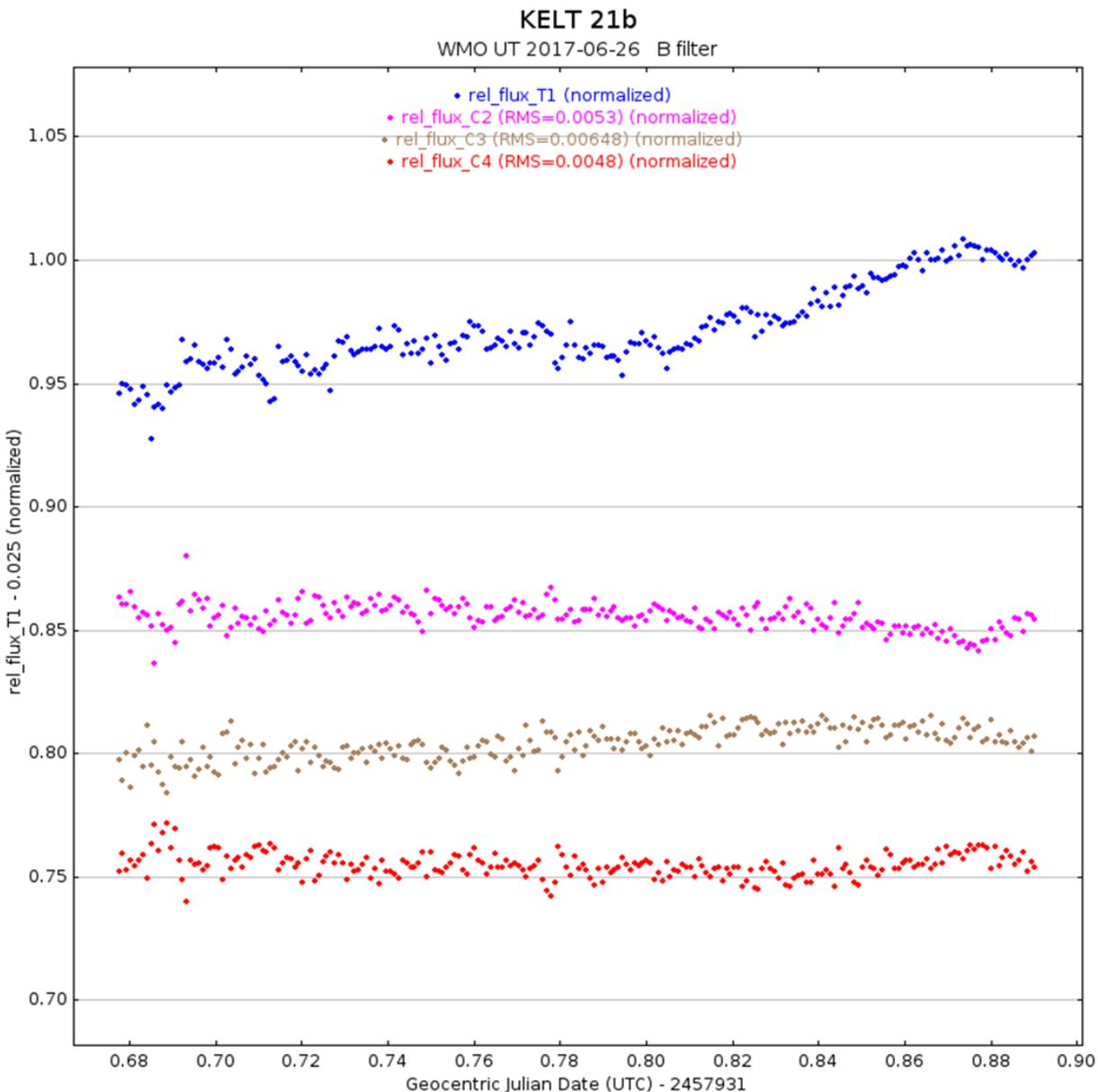


Figure 1: Light curve of KELT-21 in the B-filer.

In figure 1 the blue curve represents the brightness of KELT-21. The other three relatively flat lines represent comparison stars. The B-filter only detects blue light and filters out any other light coming from the star. For this filter it is a bit more difficult to see when the transit begins. We are not too sure why this is, we think that with better detrending we might be able to get a better curve. During the night KELT-21 was observed there were clouds present in the beginning of the night and as the night progressed the clouds did clear out. However, we believe that the blue light was scattered since shorter wavelengths tend to be

scattered more than longer wavelengths the clouds present during the start of our observations might have hindered the blue light from passing through. As the night progressed the sky did clear up so in the graph we are able to see when the transit ends. From the graph we can still see that there was certainly something transiting in front of KELT-21. Its increase in brightness towards the end of the night proves that there was something blocking off some of its brightness.

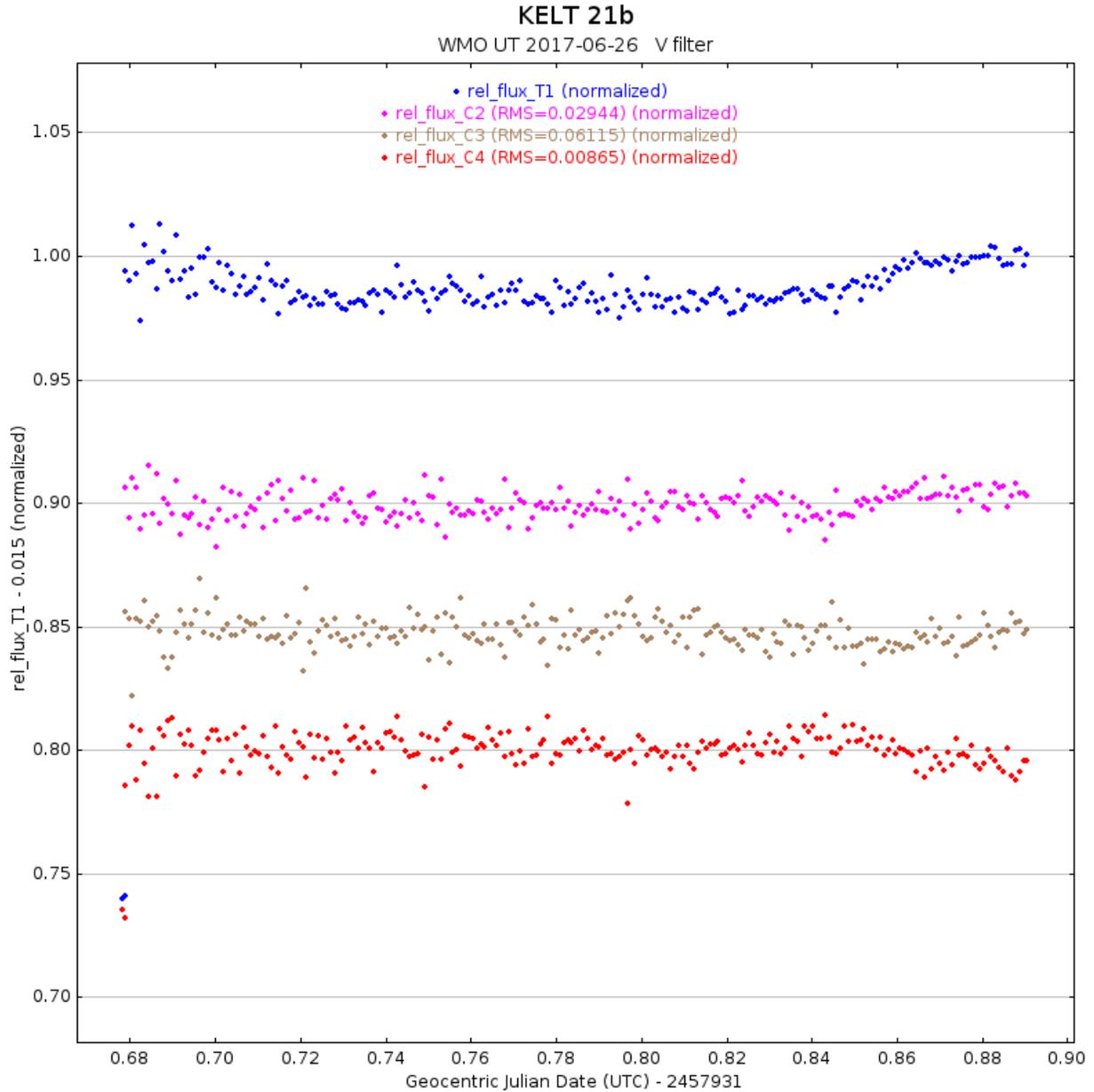


Figure 2: Light curve of KELT-21 in the V-filter.

In figure 2 a light curve of KELT-21 is again shown but for the V filter. The V-filter detects visual light so yellow-green light. In this filter we can clearly see the entire transit take place. The graph shows when the transit begins and when it ends. In the beginning of the transit the data points are a bit more scattered but again that was due to the clouds present at the start of the night. As the night went on the sky did clear up so the data points towards the end are more close together and tighter. Although the dip in brightness is not very sharp we still notice that there is something passing in front of KELT-21 because when compared to

the other stars on the graph their brightness remains pretty much constant as the night progresses. Again, this demonstrates that KELT-21 has a transit.

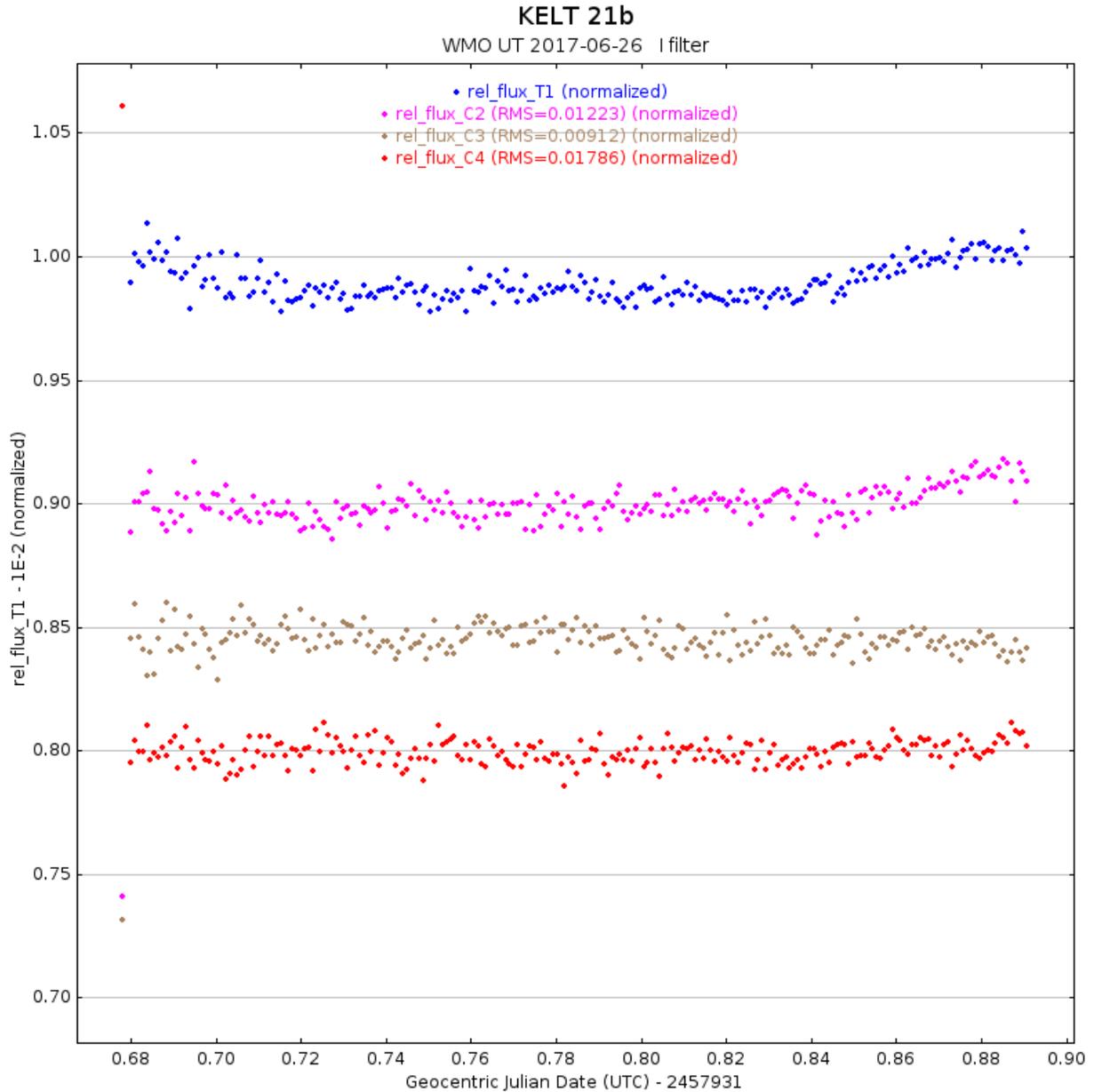


Figure 3: Light curve of KELT-21 in the I-filter.

Figure 3 shows the light curve of KELT-21 in the I-filter. The I-filter detects infrared light. Again from the light curve in this filter we can see the entire transit take place. As in the V-filter, during the beginning of the night the data points are more scattered but as the night goes on the data points get much tighter. With this we can confirm that KELT-21 indeed has an object transiting around it.

The graph in figure 4 demonstrates a light curve of an eclipsing binary system of M stars orbiting each other. The predicted ingress was a bit off; from the graph you can see how by the time we began to observe the binary system the eclipse was already close to occurring. In the case of the predicted egress, the time that the eclipse was predicted to end was also off by quite a bit. It actually ended earlier than what was predicted. However, from the light curve we can still see the dip in brightness of one of the M stars.

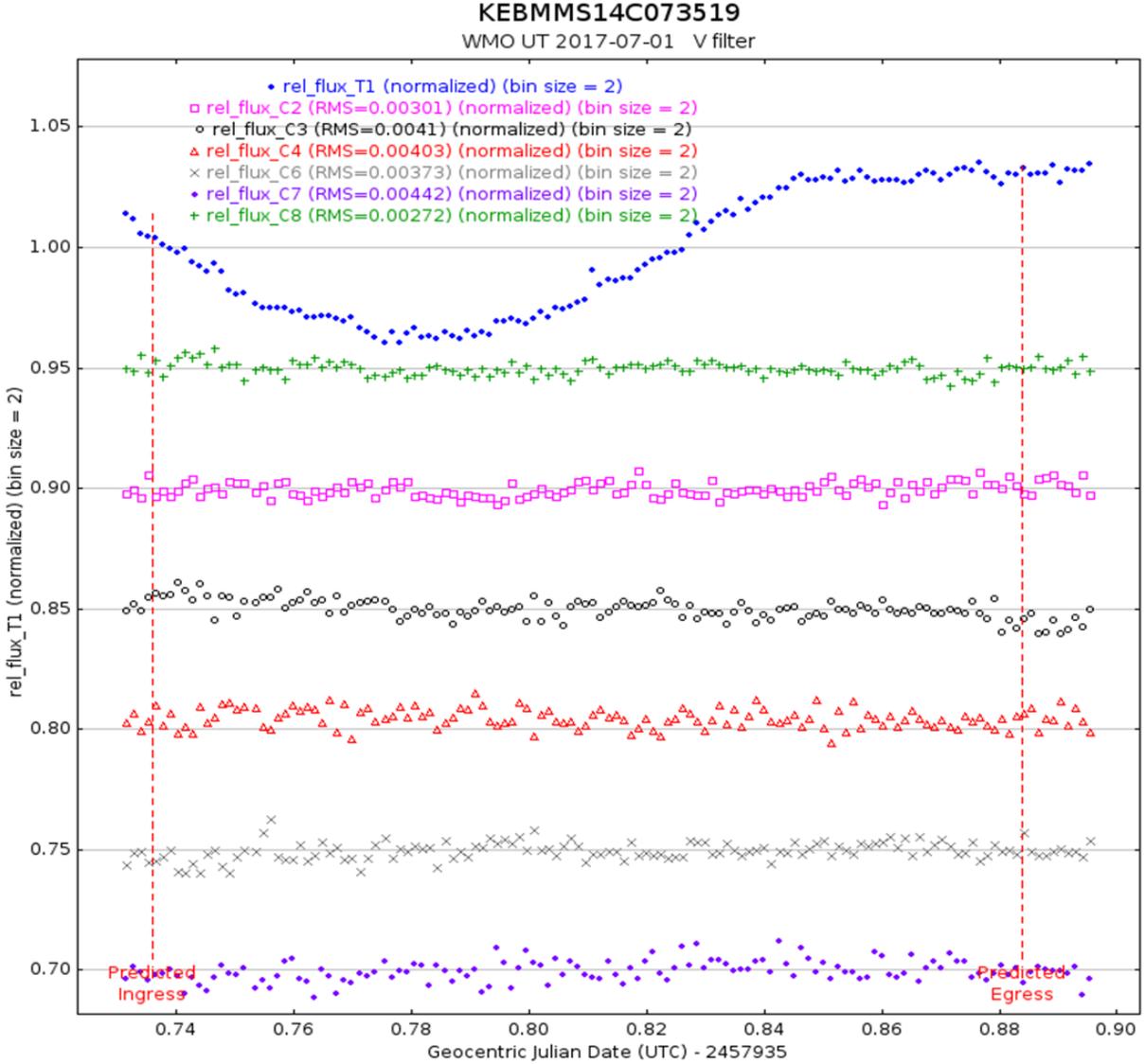


Figure 4: Light curve of a binary system in the V-filter.

4 Discussion

When taking observations, it is important to be very cautious because there are different errors that can occur. For example, when we gathered and processed the data for one of the KELT candidate objects we tried to create a light curve for it but we were not successful. We realized that the target object was off centered in all of the images we took during our observations. This meant that something went wrong while we were observing. Although we do not know the exact source of our error we learned to be more careful when observing by checking that the telescope is tracking the correct object and that we input the correct information on to the online program. This error prevented us from being able to analyze the object further because without having an actual graph for the object there is not much we can say in regards to it. The object was too close to the edge of the image that it was impossible to get a proper plot for its brightness.

Once we are done with all of our observations we moved on to calibrating the images we gathered. Before we can perform any significant scientific analysis with the images we took we have to first calibrate them. In order to do this, we had to apply the zero, dark, and flat frames on to the raw images of the object. Applying these frames help get rid of any electronic or instrumental signature that may be present in the

images we obtained. The zero frames are taken with a zero length exposure and no light on the CCD chip. For the zero frame a bias level is applied to the CCD, this gives the CCD a reference signal to read from. This helps us obtain better measurement of an objects brightness, we just have to make sure to subtract the bias signal from the measurements taken for our specific object. The dark frames remove any thermal noise or dark current within the CCD chip. To reduce the effects of thermal noise and dark current the CCDs we use are cooled to very low temperatures. The dark frames are made by taking an exposure with the shutter to the CCD closed. This helps to ensure that there is no light reaching the CCD and that the only signal being recorded is from the dark current. In addition, the flat frames are used to account for the fact that the sensitivity of the individual pixels on the CCD are not created equal. It is also used to correct for any problems in the optical path such as dust on a filter or the camera. In order to take flat frames, we have to make sure to have an even illuminated surface. When it comes to taking flat frames there are different ways in which the frames can be taken. The way in which we took are frames was by doing sky flats. For sky flats we have to make sure that the sky is completely clear because we want it to be uniformly bright. The sky flat frames were made by taking exposure of the evening sky. When the zero, dark, and flat frames have all been taken we can then apply them on to our raw images. These frames help remove anything from our data that was caused by the telescope and CCD chip that way the only signal we have in our data is of the object we are observing.

When we finished calibrating all of our raw images we were now able to create light curves for the candidate objects like the ones shown in figures 1-4. These light curves where created by using the online software AstroImageJ. Light curves help reveal a significant amount of information about the object observed. In figures 1-3 we can clearly see that there is a transit taking place for KELT-21. By comparing KELT-21 to other stars in the same field we can see that KELT-21s brightness was blocked by an object passing in front of it. Therefore, we see a dip in brightness for KELT-21 and for the other comparison stars their brightness remains constant throughout the night. The light curves for the comparisons stars remain relatively flat. After further investigation it was confirmed that the star KELT-21 has an exoplanet (KELT-21b) orbiting around it.

Before being able to determine with certainty that a candidate object is in fact a planet there are further studies that have to be made. However, by looking at the light curve of an object we can somewhat tell if the object is a planet or not. If the candidate object was observed using different filters we can construct a light curve plot for the object in each filter and analyze how the brightness varies from filter to filter. For example, if the dip in brightness is the same in each filter then we can infer that the object will most likely be a transiting planet. Since planets do not put out any radiation they should block out an equal amount of light in each filter. However, when it comes to binary system their light curves are not the same in each filter. If a cooler star were passing in front of a hotter star the cooler star would block out more blue light than red light; therefore, the dip in brightness will appear deeper in the B-filter where as in the I-filter the dip will not appear as deep. In figures 1-3 we can see how KLET-21 has the same dip in brightness for all three filters. This demonstrates that KELT-21b is blocking off the same amount of light in each filter which means that it is not emitting any light of its own. Another characteristic that we can look at to see if an object is a planet or not is the shape of its light curve. If the dip in brightness is small and has a flat bottom, then that can also be a clue that it is a planet. Once again, in figures 1-3 we can see that the dip for KELT-21 is small and it has a flat bottom that remains constant as the transit is occurring. Seeing this reinforces the idea that KELT-21 has a planet transiting it. If we compare the light curves in figures 1-3 with the light curve in figure 4 we see that there is a major difference. The dip in brightness in figure 4 is deeper than the dip in figures 1-3 because in figure 4 we are seeing a light curve plot for an eclipsing binary. From the graph we can also see that this eclipsing binary does not have a flat bottom. These are just a few characteristics that help us determine if a candidate object is most likely a planet or a false positive such as an eclipsing binary.

Unfortunately, not all of the candidate objects we do follow up observations on turn out to be a transiting planet. As mentioned above the light curve shown in figure 4 is a result of an eclipsing binary not a transiting planet. This binary system is made up of two M stars orbiting a common point in space. From the light curves of binary systems, we can determine the mass and size of each individual star. Further studies on these systems is important because the work that is done on binary systems is applied to determine the basic properties of transiting planets found around similar stars. The more information we have in regards to stars in a binary system the better it will be for us to determine certain properties of exoplanets orbiting

similar stars.

5 Future Work

The search for transiting exoplanets is still an ongoing research project. There are two new space telescopes that are scheduled for launch in 2018. One of these telescopes is the James Webb Space Telescope. This telescope will observe in the infrared; therefore, it will cover longer wavelengths with improved sensitivity. The main goal for this telescope is to study the formation and evolution of galaxies and understand the formation of stars and planetary systems. The other telescope that will be launched is the Transiting Exoplanet Survey Satellite. This telescope is very similar to KELT; the main difference is that TESS will be in space. The objective of TESS is to survey bright stars near earth for transiting planets. TESS will monitor the brightness of more than 200,000 stars for a period of two years and detect temporary drops of brightness caused by a transiting planet. With TESS researchers hope to better measure the planet masses, sizes, densities, and atmospheric properties.

6 References

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