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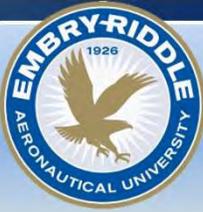
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Utilizing the O-C Method to Determine Third-Body Existence in Eclipsing Binary Systems

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Abstract

Previous studies on the subject of eclipsing binaries (EBs) within the Kepler field have been adequately determined the period, distance, and other stellar parameters of these systems (Borkovits, et al. 2015). Additionally, with the use of Observed-minus-Calculated (O-C) plots, variation in the timing of timing of eclipses can be easily detected. The eclipse timing shifts may be caused by dynamical effects or by light-travel time effects (LTTE) caused by the existence of a third body. The following research was conducted on ten binaries within the Kepler "K2" Campaign 5 field whose light curves (LCs) showed evidence of eclipses with periods shorter than ten days. The timings of the eclipses were then investigated using the O-C method to search for variations and, if so, to deduce the cause of such variations and to determine the parameters of the binary.

Method

In a search of the light curves of K2 Campaign 5 targets, we found ten possible eclipsing binary systems (EPIC numbers 211307207, 211309989, 211345799, 211371463, 211431013, 211536223, 211744153, 211920612, 211972200, 211980250). The light curves were created using Period 04 (Lenz, P., Breger, M. 2005), and the Balicentric Julian Date (BJD) Corrected Flux data was then analyzed to determine the number and timing of primary and secondary eclipses.

The BJD Corrected Flux data points around each light curve minimum were separated and fit with a second-order polynomial using a least squares method. The absolute minima of the polynomials were used to determine the eclipse timings for primary and secondary eclipses. These were combined, with the previously calculated minima of each polynomial serving as the computed (O) value. The Calculated (C) value was found by applying the equation $C = O_o + n*T$. Where n = the eclipse number, T = the averaged period, and O_o= the timing of the initial eclipse during the K2 observation period. After calculating the O and C values for each of the primary and secondary eclipses, the O-C was applied and plotted vs the O values. The resulting plot served as the initial data set for further calculations. In the event that the O-C plot was linear with nonzero slope, the period value was corrected by applying the equation $T_{adj} = P + \frac{\Delta P}{P}T$, where $\frac{\Delta P}{P}$ = the slope of the linear fit line (Otani, 2015). After each primary and secondary plot were corrected as necessary, the data points were then combined onto one graph. The curves were normalized, and any linear slope was removed to more accurately determine the period of any existing third body. Period 04 was once again utilized to determine an accurate frequency, amplitude, and period of the curve in addition to absolute uncertainties. This data was then used in Kepler-based equations (Fig. 5) to determine physical parameters of the possible third body and the binary pair.
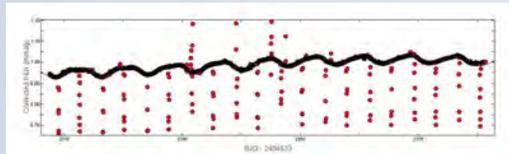

Figure 1. Example of light curve for EPIC 211309989 created in Period 04 using K2 data (red circles). The solid curve is the fitted light curve with all the frequencies and adjusted residuals.
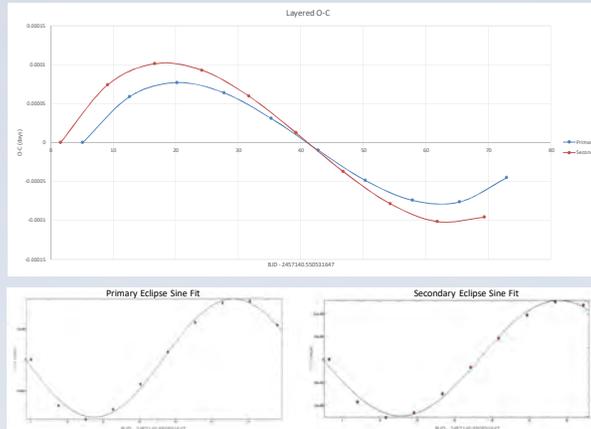
O-C Analysis

Figure 3. TOP: As shown above, the O-C curves for the primary and secondary eclipse timings for EPIC 21139989 agree in magnitude and phase for both curves. The periodicity of the curves suggest a third body in the system. However, less than one cycle of O-C variation was obtained during the K2 observation time span. Follow-up observations would be required to confirm existence of third component. BOTTOM: The separate O-C plots for the primary and secondary eclipses with the best fit sinusoidal curve.
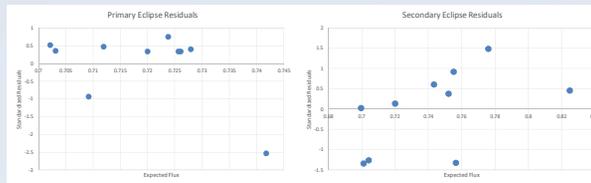

Figure 4. The residuals for the expected minima of each eclipse of EPIC 21139989 suggest that the second order polynomial used to determine the period timing was fairly accurate, with a standard deviation for the primary eclipse residuals of 0.01011 and a standard deviation for the secondary eclipse residuals of 0.00983.

Results

Third Body Parameters (days)		
Frequency	0.0110532	6.45E-05
Period	90.471845	6.448E-05
Amplitude	9.4797907	0.0983365

Table 1. Output from Period 04 analysis of EPIC 21139989. The uncertainties of each value are listed in the right column.

$$f(m) = 4\pi^2(a_{12}\sin i')^3/GT^2$$
$$= (M_3 \sin i')^3/(M_1 + M_2 + M_3)^2$$

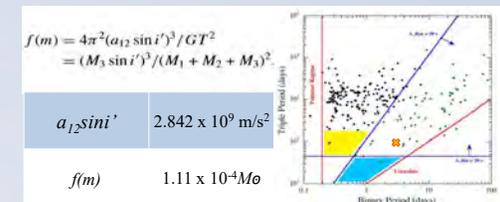|	
$a_{12}\sin i'$	2.842×10^9 m/s²
$f(m)$	$1.11 \times 10^{-4} M_\odot$

Figure 5. LEFT: The equation used to find the mass fraction of the possible third body, where $a_{12}\sin i'$ = A (semi-magnitude of O-C oscillation) x c (speed of light). Listed in the table are the calculated values, to include the mass function. RIGHT: The period of EPIC 21139989's possible third body compared to 222 other triple systems found in the Kepler field (Borkovits et al. 2015). The orange X marks the location of the possible third body on the chart, with the shaded cyan region indicates where dynamical delays are detectable, and the shaded yellow region indicating where LTTE are detectable.

References

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Acknowledgments