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Proposal Attachment - Latex Template *proposal*
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Using Ground-Based Observations to Help Identify False Positive and False Alarm Exoplanetary Transits from the Kepler Mission

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Scientific Justification *Be sure to include overall significance to astronomy. For standard proposals limit text to one page with figures, captions and references on no more than two additional pages.*

The Kepler Mission is a spaced-based project launched in 2009 that surveyed the Cygnus-Lyra region of the sky in search of Earth-like and large exoplanets orbiting in their Sun-like host's habitable zone (Borucki (2016)). Kepler detected such objects via the transit method, in which an exoplanet eclipses its host star, temporarily dimming the apparent brightness of the star, thus creating a "dip" in the star's light-curve. However, the observation of a transiting object does not necessarily entail a positive exoplanet detection. Eclipsing Binary (EB) and Background Eclipsing Binary (BGEB) transits are common causes of false positives (FPWG (2017)). EB false positives occur when a stellar companion eclipses the target star and BGEB false positives are a result of a background EB blending with an unresolved target star (Adams et al. (2012)). Both types of binaries fabricate exoplanet-like light-curves of target stars. Additionally, false alarms in which no transit was observed are possible. False alarms may be caused by stellar variability and instrumental errors which can alter a star's light-curve (FPWG (2017)).

A Kepler Object of Interest (KOI) is an observed planetary candidate that may have produced a false positive or a false alarm. The False Positive Working Group (FPWG) consists of astronomers dedicated to revising KOI observations and identifying false positives and false alarms (FPWG (2017)). The vetting process includes data analysis of Kepler's observations and ground-based observation results that support false positive or false alarm claims (FPWG (2017)). A KOI becomes a Certified False Positive (CFP) when FPWG determines that there is enough evidence that their transit-like light-curve was not a result of an exoplanet.

Information regarding FPWG's examination of KOIs and the targets themselves are found in the NASA Exoplanet Archive's KOI and CFP Tables, respectively. Successfully vetted KOIs are labeled 'CERTIFIED FALSE POSITIVE' or 'CERTIFIED FALSE ALARM' in the CFP Table. If FPWG determines that there is not sufficient evidence to declare a KOI a false positive or false alarm, it is given the disposition, 'POSSIBLE PLANET'. Similarly, if the examination of a KOI presents ambiguous results, it is labeled 'DATA INCONCLUSIVE'.

The Kepler Space Telescope has been defunct since 2018. Given that space-based detections are no longer taking place, ground-based observations are essential for re-examining 'DATA INCONCLUSIVE' and 'POSSIBLE PLANET' KOIs since they may provide additional data that can certify a target as a false positive or false alarm. Therefore, we propose new ground-based observations and analyses of previously examined KOIs with these dispositions. The classification of such invalid observations are needed in the growing exoplanetary field of astronomy since it prevents scientists from observing non-planetary targets. Overall, the primary purpose of this project is to gather additional observational data of previously examined KOIs that may finalize the certification of false positive and false alarm claims.

References

Adams, E. R., Ciardi, D. R., Dupree, A. K., et al. 2012, AJ, 144, 42

Borucki, W. 2016, Reports on Projects in Physics, 79

FPWG. 2017, KSCI

Luque, R., Serrano, L. M., Molaverdikhani, K., et al. 2021, Astronomy amp; Astrophysics, 645, A41

Experimental Design *Describe your overall observational program. How will these observations contribute toward the accomplishment of the goals outlined in the science justification?*

Observations will take place over the course of a year using Las Cumbres Observatory's (LCO) Sinistro imager on the 1-meter telescopes at McDonald Observatory in Texas, USA, and Teide Observatory in Tenerife. It is necessary to observe at both locations because most KOIs have transiting periods longer than twelve hours and thus, observing targets with alternating observatories with significantly different timezones will maximize the amount of data collected. Since the majority of our targets lack evidence to be certified as a false positive or false alarm detection, it is vital to make each observation as continuous as possible to diminish the gaps in targets' light-curve, thus providing more informative results.

We ask to use LCO's 1-meter telescopes due to Sinistro's extensive set of filters, which cover the majority of Kepler's bandpass (400-1100 nm). Specifically, we will use its Johnson-Bessel B, V, and R filters and its Sloan Digital Sky Survey (SDSS) s', g', i', and z' filters. Additionally, this imager is able to detect changes in relative flux as small as 0.001 (Luque et al. (2021)). Such sensitivity is necessary to carry out observations of Earth-sized exoplanets since they block a very small percentage of their host star along our line-of-sight. Additionally, given that our targets are dim, we will take 90-second exposures to capture sufficient signal.

The NASA Exoplanet Archive will be used for target selection. We want to observe KOIs in the CFP Table that possess 'POSSIBLE PLANET' and 'DATA INCONCLUSIVE', dispositions. The Archive will also provide the date and time of each transit. We ask to observe over the course of a year, as limitations like weather conditions and transit frequency require a big timeframe to collect enough data to meet our goals. Nevertheless, we will take measures that optimize our observations by only observing targets with orbiting periods less than seven days.

Our data will be analyzed via photometry of the target stars and examination of their light-curve. Observational flags and comments on the KOI and CFP Tables that predict the type of false positive or false alarm a specific KOI may be will determine the type of analysis we must perform. For example, for possible false alarms due to stellar variability, we will observe at non-transiting times and perform photometry on the target star in search of periodic changes in magnitude. We will simply search for a standard planetary transit-like light-curve for false alarm candidates thought to be results of instrumental errors. The light-curve examinations for EB and BGEB candidates will consist of searching for patterns that indicate that the transiting object is self-luminous and stellar-like. One way of detecting a self-luminous object is by calculating its albedo,

$$A_{obs} = D\frac{a^2}{R_p^2} \tag{1}$$

where D is the depth percentage, R_p is the object's inferred radius, and a is the semi-major axis. If $A_{obs} \geq 1$, the transiting object is self-luminous. Other stellar indicators include depth variations in the light-curve within the transit and a transit depth percentage corresponding to a radius greater than 3 $R_\oplus$. If a target lacks observational flags and comments, we will test for all false positive and false alarm causes described in this letter.