**Searching for L5 Earth Trojans with DECam.** Larissa Markwardt*[1], D. W. Gerdes[1,2], R. Malhotra[3], J. C. Becker[4,1], S. J. Hamilton[2], F. C. Adams[1,2] [1]Department of Astronomy, University of Michigan, [2]Department of Physics, University of Michigan, [3]Lunar and Planetary Laboratory, The University of Arizona, [4]Division of Geological and Planetary Sciences, California Institute of Technology.
* lmmarkwa@umich.edu

**Introduction:** Most of the major planets in the Solar System support populations of co-orbiting bodies, known as Trojans, at their L4 and L5 Lagrange points. In contrast, Earth has only one known co-orbiting companion, 2010 TK7. There have been several dedicated searches, such as [1] and [2], but no additional Earth Trojans (ETs) have been found. Upper limits from these surveys suggest there could still be hundreds of undiscovered ETs. Characterization of this population can give a unique insight into our Solar System and its dynamical history. Numerical simulations suggest that these objects could have stable orbits and be undisturbed remnants from the primordial Solar System. They may also be the population of "missing" asteroids responsible for asymmetric cratering on the Moon's surface [3]. They are also attractive targets for spacecraft missions due to their small $\Delta v$.

**2018 DECam Survey:** Our survey utilized the VR filter on the Dark Energy Camera (DECam) located on the 4-meter Blanco telescope at the Cerro Tololo Inter-American Observatory. The sky coverage for this survey is shown in Fig. 1. We observed shortly after sunset on the night of June 16, 2018. Our survey consisted of 8 fields, covering an area of 24 sq. deg. towards Earth's L5 point.

We found 27 new objects. None were ET candidates (in this survey defined to be objects which moved∼1degree / day).

**Upper Limits:** To place an upper limit on the ET population, we generated a population of simulated ETs, injected them into our data set, and ran these images through our detection pipeline to measure our recovery rate. We then used this rate and our constraint of a non-detection to calculate upper limits as a function of H (Fig. 2). If we assume the ET population follows a power law with $\alpha = 0.46$ for $H < 20.39$ and $\alpha = 0.7$ for $H > 20.39$ (chosen because they give the most conservative upper limits), we can also extrapolate from our faintest upper limit (dotted line in Figs. 2 and 3) to place more stringent limits on the bright end of the distribution (Fig. 3). Under these assumptions, our survey gives the strictest limits on this population, $N_{ET}=18$ for $H=19.7$ (compared to 32 and 81).

**2019 DECam Survey:** In 2019 we conducted another search for L5 ETs with DECam, which is a significant improvement over our 2018 search. This new survey is comprised of 8 hours of observations, rather than 1 hour, and has twice the coverage of the L5 cloud. Using a Shift and Stack algorithm, we expect to detect objects ~2 magnitudes fainter than our previous survey. We also spread these observations across 8 nights in order to fit orbits to our candidates, which was not possible with our previous dataset. This survey will be the most complete survey of Earth's L5 point to date. We will present the latest results from this survey.

**Summary and Conclusions:** In our 2018 survey, we found no ET candidates. For standard assumptions, we calculate upper limits to a 90% confidence limit on the L5 population of $N_{ET}<1$ for magnitude $H<15.5$, $N_{ET}=60-85$ for $H<19.7$, and $N_{ET}=97$ for $H=20.4$. This latter magnitude limit corresponds to Trojans ∼300 m in size for albedo 0.15. At $H=19.7$, these upper limits are consistent with previous L4 Earth Trojan constraints and significantly improve L5 constraints.

After our 2018 DECam Survey, the existence/characterization of primordial ETs is still an open question. Numerical simulations have suggested that the current paucity of ETs may be due to the disruption of small objects due to the Yarkovsky effect [4]. Broader and deeper searches are needed to further constrain the ET population and to test the limits of this effect.

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**References:** [1] Cambioni, S., et al. (2018) *LPSC XLIX,* Abstract #2083. [2] Whiteley, R. J. and Tholen, D. J. (1998) *Icarus*, 136, 154-167. [3] Ito, T. and

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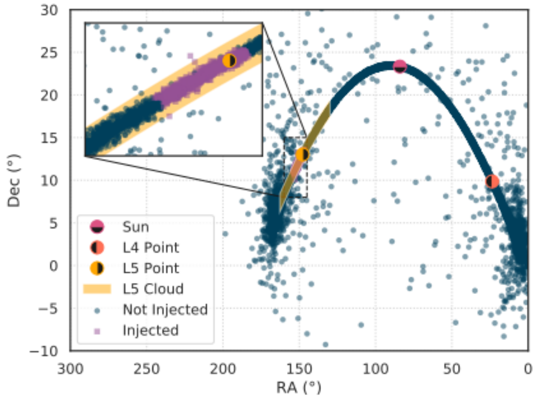


Figure 1: Survey coverage of synthetic ET population. The Lagrange points and the Sun are plotted as half-filled dots for reference. The yellow shaded area represents the L5 cloud. Synthetic ETs that were injected into our images are plotted as purple squares, while those that were not are blue circles. These injected points essentially depict the area covered by our survey. These objects make up 24% of the ETs in the L5 cloud.

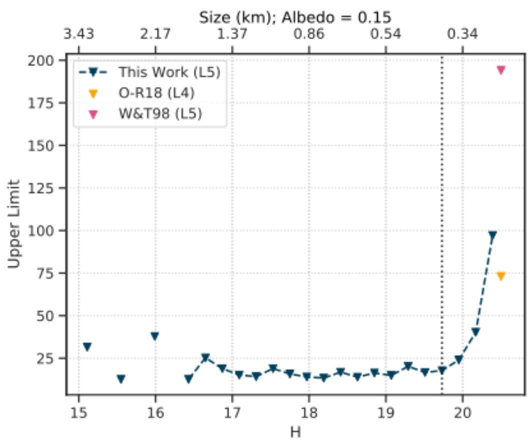


Figure 2: Calculated upper limits on the ET population. The yellow triangle depicts the upper limit calculated for L4 ETs by [1], while the pink triangle is the upper limit extrapolated from the [2] results by [1]. For the faintest bin, *H*=20.4, we calculate an upper limit of 98 ETs. Our recovery rates are flat at the bright end because all of these bins had nearly 100% recovery rates leading to a constant upper limit (~15) for those magnitudes. The most stringent upper limit is 18 ETs with *H* = 19.7 (dotted line).

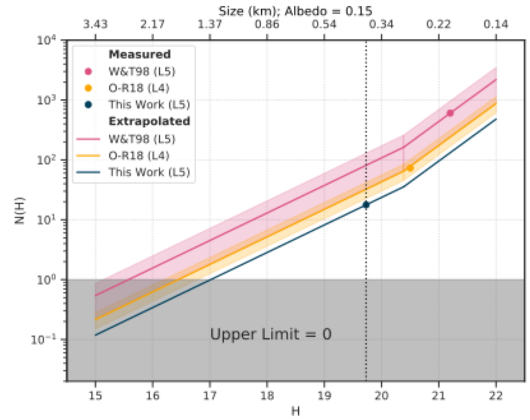


Figure 3: Extrapolated upper limits (lines) based on the measured upper limit (dots). The results for this work are in blue, [1] in yellow, and the upper limit calculated by [1] based on the results in [2] are in pink. The dotted line represents the point used for extrapolation for the results in this work, *H*=19.7. The grey region depicts where *N(H)* <1. The slope of the power law we use is α=0.46 for H<20.39 and α=0.7 for H>20.39, which gave the most conservative upper limits. Under these assumptions, the results from this work give the most stringent upper limit on the ET population.