LATEST RESULTS FROM DECAM SEARCH FOR L5 EARTH TROJANS. Larissa Markwardt*[1], G. Gowman[1,2], D. W. Gerdes[1,2], R. Malhotra[3], 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.
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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. While there have been several dedicated searches, such as [1], [2], and [3], no additional Earth Trojans (ETs) have been found. However, the upper limits from these surveys suggest there could still be hundreds yet to be discovered.

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 orbits which are stable on order the age of the Earth, meaning stable ETs may be undisturbed remnants from the primordial Solar System. ETs may also be the population of "missing" asteroids responsible for asymmetric cratering on the Moon's surface [4]. Additionally, ETs are attractive targets for spacecraft missions due to their small Δv.

Despite the valuable information that could be encoded in the ET population, it is also possible that there are no ETs left to find, especially ones that are stable and/or primordial. Since numerical simulations show that objects *can* be stably captured into the 1:1 resonance with the Earth, we would expect a disrupting force to destabilize any primordial co-orbitals in order to explain a current paucity of ETs. One such explanation is that small objects in this population were destabilized due to the Yarkovsky effect [5]. However, broader and deeper searches are needed to study the faintest end of the ET size distribution in order to test the limits of this effect.

2018 DECam Survey: In 2018, we conducted one of the most recent ground-based surveys for ETs using the VR filter on the Dark Energy Camera (DECam) located on the 4-meter Blanco telescope at the Cerro Tololo Inter-American Observatory [3]. We observed for one hour 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. While we did find some previously unknown main-belt asteroids, there were no ET candidates (in this survey defined to be objects which moved ∼1degree / day; see Fig. 2).

While we were able to place the most stringent upper limits on the ET population with this survey, it had some significant limitations. For one, while we covered a larger area on the sky as compared to other surveys, our limiting magnitude was not as faint (V~21.5). Additionally, we only had observations from one night; this arc was sufficient to measure the speeds of candidates, but not to constrain their orbits, limiting our ability to reliably classify objects.

Shift-and-Stack: In most astronomical cases, fainter limiting magnitudes are reached by simply observing targets for a longer exposure time. Unfortunately, this method does not work for most small bodies in the Solar System; in long exposures, the large rate of motion of these bodies causes them to streak in the image and become *more difficult* to detect. One solution is the Shift-and-Stack technique, where a series of short exposures are taken to avoid any streaking of Solar System objects. These individual exposures are then shifted by the rate of motion of the target. When the shifted images are then co-added, the target object is instead a point source while background stars are streaked (see Fig. 1).

The key drawback of this technique as a discovery tool is that the speeds of unknown targets are also not known a priori, so one must stack over a range of possible speeds to find candidates. However, Trojans are ideal populations for this method as their speeds are all very similar, nearly the speed of their associated planet. Figure 2, shows the rates of motion for synthetic ETs, and they are well constrained to ∼1 degree / day. Therefore, the range of speeds to stack over is significantly reduced as well as the necessary computational resources.

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.

Based on the results from our previous survey and our expected limiting magnitude, we estimate that this survey will be by far most complete survey of Earth's L5 point to date (see Fig. 3). If we do not find any ET candidates in this survey, we should be able to rule out the existence of any ETs larger than ~400m. This limit will also be sufficient to test the Yarkovsky effect on faint end of this population. *We will present the latest results from this survey.*

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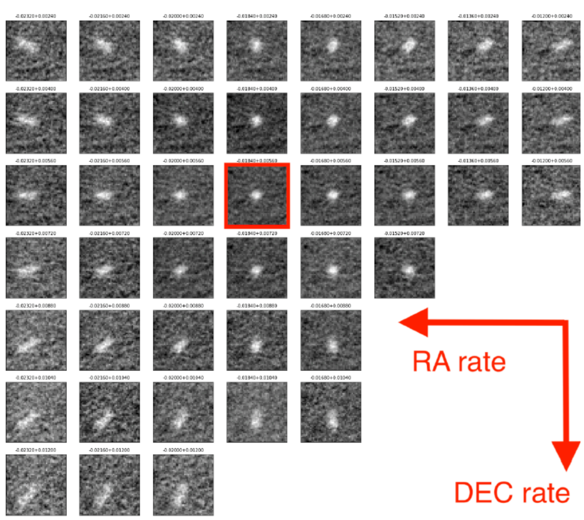

Figure 1: Demonstration of Shift-and-Stack algorithm. This object is a previously unknown Trans-Neptunian Object detected by our Shift-and-Stack pipeline at V~25 and SNR~30. Note, that the object only has a point source PSF near its rate of motion and smears in a predictable pattern when stacked at different speeds.

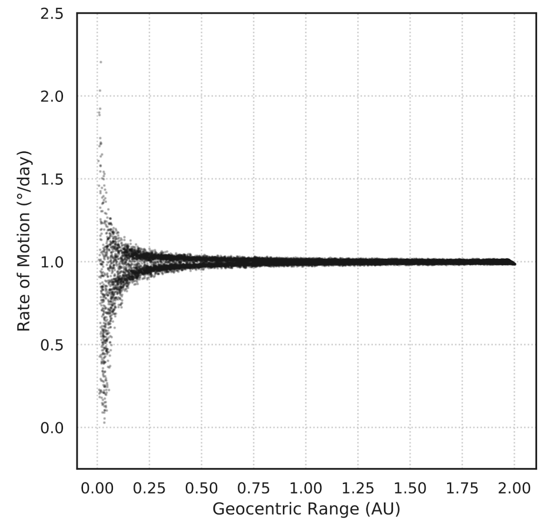

Figure 2: Rates of motion for a synthetic set of ETs. Other than at very small geocentric ranges, all of these ETs have a rate of nearly 1 degree / day. Therefore, the grid of rates necessary for Shift-and-Stack in significantly smaller than for other Solar System populations.

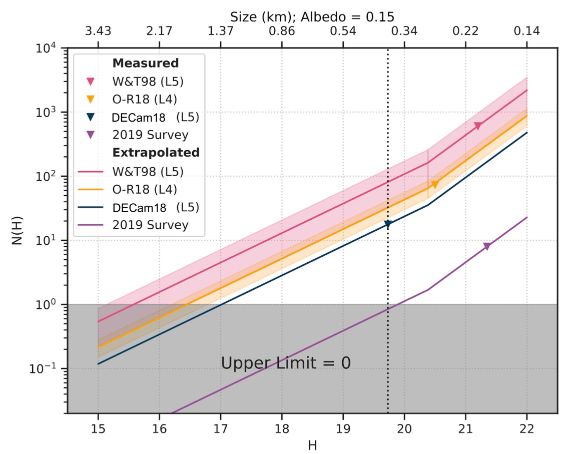

Figure 3: Extrapolated upper limits (lines) based on the measured upper limit (triangles). The results from [3] are in blue, [1] in yellow, and the upper limit calculated by [1] based on the results in [2] are in pink. The purple line shows *predicated* upper limits based on the limiting magnitude of our 2019 survey assuming we do not find any ET candidates. The dotted line represents the point used for extrapolation, 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. The 2019 survey upper limits would be a clear improvement over previous searches.