AN UPPER LIMIT ON EARTH'S TROJAN ASTEROID POPULATION FROM OSIRIS-REX. S. Cambioni*[1], R. Malhotra[1], C. W. Hergenrother[1], B. Rizk[1], J. N. Kidd[1], C. Drouet d'Aubigny[1], S. R. Chesley[2], F. Shelly[1], E. Christensen[1], D. Farnocchia[2], and D. S. Lauretta[1].
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Introduction: In February 2017, the OSIRIS-REx (Origins, Spectral Interpretation, Resource Identification, and Security Regolith Explorer) spacecraft conducted a survey of the Sun-Earth L4 region for Earth Trojan (ET) asteroids (Earth Trojan Asteroid Survey, ETAS) using the OCAMS MapCam, the onboard survey imager [1]. The existence and size of a primordial population of ETs remains poorly constrained, and represents a major gap in our inventory of small bodies in near-Earth space. The discovery of a surviving primordial ET population would provide important constraints on cosmochemical and dynamical theories of the formation and dynamical history of Earth and of the inner solar system [2].

Exploiting the fact that OSIRIS-REx essentially flew through the L4 point between launch and its Earth-Gravity assist maneuver, the MapCam surveyed a region comprised of a mosaic of nine 4x4° patches of sky near opposition. It obtained images over ten dates between February 9 and February 20, 2017. A custom pipeline built on top of the Catalina Sky Survey (CSS) pipeline processed the images for asteroid detection [3]. The software detected 16 previously known Main Belt Asteroids (MBAs), but no Earth Trojan (ET)-like objects. Using the data for the known MBAs, we computed the sensitivity curve and the limiting magnitude of the survey. The Earth-Trojan null result was used to set an upper limit for the ET population around L4 at the magnitude threshold of the survey.

Sensitivity curve: We derived the sensitivity curve by comparing the detected MBAs to the catalogued minor planets known to be in the sky region surveyed by OSIRIS-REx. We queried the JPL Horizons online solar system data and ephemerides service to identify the objects in the Field of View (FOV) of the OCAMS camera at the epoch of the observations, from the point of view of the spacecraft [4]. These queries used an automatic pipeline to input key acquisition information: heliocentric J2000 ecliptic/equinox spacecraft position and pointing, right ascension and declination of the field of view, and epoch. The retrieved objects were validated visually, after being matched to the survey astrometry computed by the customized CSS pipeline. The ratio between the number of MBAs detected (by the CSS pipeline) and the set of catalogued known objects (by JPL Horizons) as a function of visual magnitude provides the sensitivity curve of the survey. The limiting visual magnitude of the survey – estimated to be V = 13.8 – is identified as the magnitude at which the sensitivity drops to 50%.

Simulations of ETs around L4 and L5: Minor planets can share the orbit of Earth in a dynamically stable state if they remain near the triangular Lagrangian points, L4 and L5, leading or trailing a planet by ~ 60 degrees in longitude [5]. To remain in libration about L4 or L5, the Jacobi constant of the minor planets must lie between the value for L4/L5 and the value for the Lagrangian point L3. Controlled by this constraint, we generated a synthetic population of librating ETs by randomizing the semi-major axis between 0.99 and 1.01 AU; we randomized the eccentricity and inclination within the intervals [0, 0.1] and [0, 5] degrees, respectively, and the angular variables within the range [0, 360] degrees. The expectation that primordial L4 and L5 objects in low eccentricity low-inclination orbits are little perturbed over timescales comparable to the age of Earth motivated the choice of the range of semi-major axis, eccentricity and inclination [6,7] . The L4 (leading) and L5 (trailing) populations are distinguishable by requiring the mean longitude with respect to Earth position to be within the ranges [0, 180] degrees and [180, 360] degrees, respectively. We mapped the spatial distribution of the above synthetic population into a 3D grid in spherical coordinates (heliocentric distance, ecliptic longitude, ecliptic latitude). A normalized spatial density distribution of the ET-like objects resulted, describing how ETs are expected to occupy the space around L4 (or L5) as an object number density within the volume's cells.

In order to compute the upper limit of the number of ETs in the L4 (or L5) region that could have escaped detection at the magnitude threshold of our survey, we imposed the constraint that the number of ETs of magnitude equal to the limiting magnitude of the survey, within the FOV, must be unity. This procedure was equivalent to scaling the normalized density distribution such that the integral of the scaled distribution, over the FOV, was also unity. The integral over the entire space of the scaled distribution provided the upper limit for the overall population.

Iteration (Monte Carlo Simulation). We repeated the above steps (generation of the synthetic population, creation and scaling of the normalized density function, computation of the total population) a large number of times (~100) to get good statistics of the upper limit of the total population at the limiting magnitude.

Results: From the null result of ETAS, the upper limit for the population of ETs around L4 was estimated to be 73 ± 22 members of visual magnitude V = 13.8, corresponding to absolute magnitude H = 20.5. This absolute magnitude corresponds to objects with diameter ~ 470 m for C-type asteroids and ~ 210 m for S-type asteroids. This is consistent with the expected ET population based on plausible assumptions about the dynamical evolution of the primordial small body population in the inner solar system, which is about a few hundreds ETs of diameter bigger than 300 m [8]. We assumed that the overall surveyed sky region was observed by OSIRIS-REx at the mid-epoch of the observation window in order to simplify the observational context when converting the visual magnitude to absolute magnitude. This allowed us to conveniently translate the point of observation from the spacecraft to a Sun-centered system, while introducing an error which is well mitigated by the iterative generation of the synthetic population and consequent estimation of the upper limit (Monte Carlo approach).

Comparison with previous surveys: To date, the only published ground-based observational campaign dedicated to the search of ETs resulted in no detection of ETs. It was performed on 1994 May 5–7 and July 6–8 UT at the University of Hawaii 2.24-m telescope [9]. The observers imaged mainly the sky region around L5; the observation of L4 was affected by bad weather conditions. The total surveyed region was about 0.35 deg^2. The sensitivity of the survey was estimated by matching detected Kuiper Belt Objects (KBOs) to the known objects in the sky region. The null result suggested that one object could have escaped detection at the limiting magnitude R = 22.8.

Applying our method to this survey (limiting it to the L5 region) yields an upper limit for the population of ETs around L5 of 604 ± 358 members of absolute magnitude H = 21.2 (which corresponds to R = 22.8 when filter and phase correction are applied). The size of the population drops to 194 ± 116 members of absolute magnitude H = 20.5 if a slope parameter equal to 0.7, consistent with a population of small bodies in collisional equilibrium, is assumed. This population estimate (194 ± 116 members of absolute magnitude H = 20.5) is for L5, whereas our result (73 ± 22 members of absolute magnitude H = 20.5) is for L4. We nevertheless can compare the findings from the two surveys under the assumption that there is no difference between the L4 and L5 populations. The symmetry of the dynamical properties of the two populations, which does not distinguish them in the absence of additional information, supports this assumption. The lower value of the result from ETAS seems more informative than that from the 1994 survey, but the large uncertainty of the latter (probably due to the difficulties in fitting the normalized distribution to the observable in such a small sky region) does not allow us to claim a statistically significant difference between the two measurements (figure 1).

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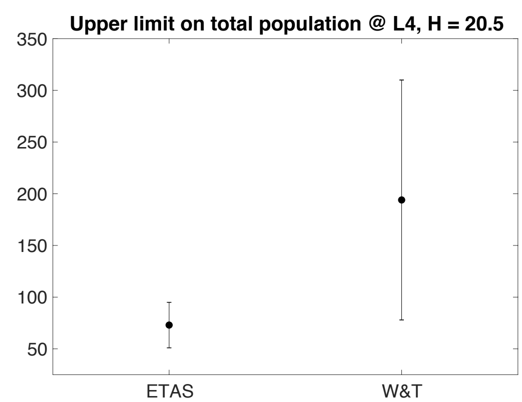

Figure 1. Comparison between the result from ETAS and the result from the 1994 survey [9] (labeled W&T) for the upper limit of the L4 population of ETs of absolute magnitude H = 20.5. The 1-σ errorbars are also reported. The large uncertainty of the W&T result does not allow to claim a statistically significant difference between the two measurements.