Photometric Colors of the Brightest Members of the Jupiter L5 Trojan Cloud

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Abstract

The L5 Jupiter Trojan asteroids are minor bodies that orbit 60 degrees behind Jupiter. Because these orbits are stable over the lifetime of the Solar System, the properties of these objects may inform us about the conditions under which the Solar System formed. We present $BVR_{KC}I_{KC}$ photometry for the 42 intrinsically brightest and presumably largest members of the L5 Jupiter Trojans. We define a new principal color component a_T^* that is indicative of taxonomic types relevant to the Jupiter Trojan asteroids. **We find that 76% of the largest L5 Jupiter Trojans are consistent with a D-type classification, while 24% show shallower slopes more consistent with X-type and C-Type classifications.** Such a breakdown is consistent with other surveys and will help to place the Trojans in the larger context of the Solar System.

Keywords: Trojan Asteroids, Photometry, Asteroids, Composition

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1. Introduction

Two large groups of minor bodies share their orbits with Jupiter, swarming about the L4 and L5 Lagrangian points. These orbits are stable over the lifetime of the Solar System (Marzari et al., 2003). The members of these two groups have been largely named for the classical heroes of the Trojan war, and their names have thus been (mostly) divided by Lagrange point. The “Greek” camp is located at the L4 point, preceding Jupiter in its orbit, while the “Trojans” inhabit the L5 position 60 degrees behind Jupiter.

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36 As of April 2015 there are 4026 Greeks and 2161 Trojans recorded in the
 37 Minor Planet Center (MPC) database². Unlike many of the other >600,000
 38 objects listed³ in the MPC, the minor bodies in these two camps are restricted in
 39 eccentricity and therefore only experience limited mixing with other populations.
 40 Thus, these two camps remain isolated from other minor body populations,
 41 potentially resulting in pristine examples of asteroids originally present in, or
 42 captured into, the region during the initial formation and shakedown of the
 43 Solar System.

44 The very existence of the Greek and Trojan populations puts tight con-
 45 straints on any Solar System formation models. To be considered plausible, any
 46 model of Solar System formation, planetary migration, or dynamical evolution
 47 must allow for the capture and long-term stability of large numbers of Greek
 48 and Trojan asteroids around the Jovian Lagrange points. The theory known
 49 as the Nice Model (Tsiganis et al., 2005), for instance, uses numerical simu-
 50 lations to suggest that giant planet migration may have played a pivotal role
 51 in not only Solar System formation in general, but also the specific formation
 52 for the Trojan clouds as a dynamical group. **Morbidelli et al. (2005) pro-**
 53 **pose that no primordial Jupiter Trojans would have survived the 1:2**
 54 **resonant period between Jupiter and Saturn described in the Nice**
 55 **Model. Thus, Nesvorný et al. (2013) have suggested that the current**
 56 **distributions of Jupiter Trojans can be recreated by rapid changes in**
 57 **Jupiter’s orbit due to its scattering of an ice giant. The rapid changes**
 58 **in the locations of Jupiter’s Lagrange points may have swept up local**
 59 **planetesimals displaced during the earlier instability.** Such an influx
 60 of objects could explain the relatively high range of orbital inclinations (up to
 61 $\sim 40^\circ$) for members of the Greek and Trojan clouds. Compositional character-
 62 ization is necessary to determine the ultimate source or sources of these minor
 63 bodies and to help confirm or constrain such simulations. Emery et al. (2011),
 64 for example, show a potential bimodality present in the near-infrared spectra of
 65 Trojans that might imply the clouds were sourced from two disparate regions
 66 of the Solar System.

67 In this paper we present Johnson-Kron-Cousins $BVR_{KC}I_{KC}$ (hereafter sim-
 68 ply $BVRI$) photometric and color data for 42 members of the Trojan swarm.
 69 Due to the featureless spectra observed for Trojans (Emery et al., 2011), we can
 70 use these broadband photometric data to create a method for further taxonomic
 71 classification of this intermediate population. With such a methodology, we can
 72 bridge the gap between the small bodies of the inner and outer Solar System
 73 by performing comparisons in both directions. Ultimately, through visible color
 74 comparisons of the largest objects in the Greek and Trojan camps, we hope
 75 to achieve a greater understanding of the relationship between the two Jupiter
 76 swarms and their evolutionary place in the Solar System.

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²http://www.minorplanetcenter.net/iau/lists/t_jupitertrojans.html

³<http://www.minorplanetcenter.net/iau/lists/ArchiveStatistics.html>

77 2. Trojan Photometry in the Literature

78 Several Trojan photometric surveys that span a range of wavelengths and
79 sample sizes exist in the literature. Such efforts provide vital context upon
80 which this work expands.

81 Karlsson et al. (2009) present (*U*)*BVRI* photometry for 27 Jupiter Trojans
82 (H ranging from 9.8 to 12.8) in an effort to examine a size-slope ratio for these
83 objects compared to previous work on outer Main Belt objects. Two of these
84 objects, 4791 (Iphidamas) and 5130 (Ilioneus), are also in the dataset presented
85 in this work.

86 The most recent Sloan Digital Sky Survey (SDSS) Moving Object Catalogue
87 (MOC) (Abazajian et al. (2009) and Ivezić et al. (2002)) contains some data on
88 as many as five hundred unique Greeks and Trojans, about three hundred of
89 which belong to the L5 cloud. Hasselmann et al. (2011) have used these data
90 to determine possible taxonomies for 343 Greeks and Trojans. However, due to
91 incomplete spatial and temporal coverage, only 13 of these objects overlap with
92 the largest 42 Trojans examined in this work.

93 The Wide-field Infrared Survey Explorer (WISE) observed large portions of
94 the Trojan clouds at 3.4, 4.6, 12, and 22 μm . 754 known objects from the L5
95 camp have enough data for thermal fits (Grav et al., 2011) which are important
96 for determining albedos and sizes for these objects. While geometric albedos
97 have been shown to be unrelated to taxonomic type (Emery et al., 2011), **Grav**
98 **et al. (2012) are able to differentiate between redder D-types and less-**
99 **red Trojans using the 3.4 μm albedo due to the difference in spectral**
100 **slopes in the vis-NIR.** Updated thermal models for the 42 objects discussed
101 here are also presented by Grav et al. (2012).

102 Most of the largest Jupiter Greeks and Trojans have **published** rotation
103 periods (Mottola et al., 2011), with concerted efforts ongoing to extend that
104 dataset down to fainter objects (French et al., 2015). These surveys also provide
105 separate data on the origins and evolution of the Trojan swarm by providing
106 information regarding collisional histories for these objects.

107 3. Survey of Jupiter Greeks and Trojans - The Sample

108 The data presented here are part of a larger project to characterize members
109 of both of Jupiter's Lagrangian camps with optical photometry. In addition to
110 the *BVRI* photometric colors presented here for the L5 Trojans, photometry is
111 being obtained for the L4 Greek population to be reported in a future publica-
112 tion, and light curves for many smaller Trojans are being obtained by French
113 et al. This is part of an initiative to better characterize the observable prop-
114 erties of the Greek and Trojan asteroids so that connections between the inner
115 and outer Solar System, as well as Solar System formation processes, might be
116 better understood.

117 For our complete photometric sample, we are obtaining *BVRI* colors for

all Jupiter Greeks and Trojans with an absolute magnitude⁴ $H \leq 10$, which corresponds to an effective diameter of about 60 km. The sample includes 113 objects; 71 of which are in the Greek camp and the remaining 42 in the Trojan camp. This initial cut-off of $H \leq 10$ was chosen for two primary reasons: (1) The known sample should be complete down to this limit (Szabó et al. (2007), Karlsson (2010)), so we can be sure that our sample is unbiased and readily compared to other samples of similarly sized objects in other populations. (2) $H = 10$ results in a V apparent magnitude between 17 and 18 for Jupiter Trojans. This is well within the faintness limits ($\text{mag} \sim 20$) of the 1 meter class telescopes to which we have ready access, thus making a good sample for this project. This sample was chosen in early 2010, meaning that some objects have updated values for H . Thus, five objects are now known to be slightly fainter than $H = 10.0$. The most recent values are given in Table 3.

4. Observations and Data Reduction

4.1. Observations

A total of 132 photometric observations have been made for 42 different L5 Trojans. As outlined in Table 1, the vast majority of these observations (106 of them) were made at the Cerro Tololo Inter-American Observatory (CTIO) 1.0-m telescope in Chile. Eighteen of the remaining observations were made at the CTIO 0.9-m, and the final eight were acquired with the Lowell 42-in. telescope in the Northern Hemisphere. These data were gathered over six observing runs from September 2010 to November 2011. Individual observations are given in the Data Appendix in Section 11.

Standard stars from Landolt’s equatorial sample (Landolt, 2009) and Graham’s E-fields (Graham, 1982) were used to calibrate the photometry. Standard stars were chosen of a sufficiently faint magnitude to minimize errors due to shutter speed, and calibration images were taken at a range of airmasses similar to those at which our targets were observed to correct for atmospheric extinction. Integration times were less than 600 seconds for most targets, so non-sidereal tracking was unnecessary because these objects have an apparent motion of about $0''.3/\text{min}$. Targets were specifically observed at times during which crowding by background stars could be best avoided. All observations reported here were made on photometric nights using Johnson-Cousins $BVRI$ filters with typical seeing of $2''$ or better, with individual exposure times ranging from 60 to 900 seconds.

4.1.1. CTIO 1.0-m

Observations were made using the Cerro Tololo Inter-American Observatory (CTIO) Small and Moderate Aperture Research Telescope System (SMARTS)

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⁴The absolute magnitude of a Solar System object is the apparent V magnitude an object would have if it were located at one AU from both the observer and the Sun and viewed at a 0 degree phase angle. This parameter is effectively a combined measure of size and albedo.

156 1.0-m through time allocated by the National Optical Astronomy Observatory
 157 (NOAO). Photometry was obtained with this telescope during 11 nights between
 158 June and November 2011.

159 Images taken using the Y4KCam on the CTIO/SMARTS 1.0-m were typ-
 160 ically binned in 2×2 pixels (to $0''.578/\text{pixel}$) to reduce readout time. Images
 161 were taken in the Johnson-Cousins *BVRI* filters. Details about the transmis-
 162 sion curves for these filters can be seen in Figure 5. In the *I* band, fringing
 163 could be readily observed for some long integration frames. The fringe pat-
 164 tern was removed during the data reduction process by median combining the
 165 worst affected images. This pattern was scaled to be at the same level as the
 166 background fringes and then subtracted from the corresponding image.

167 4.1.2. CTIO 0.9-m

168 Photometric observations of Trojans using the CTIO/SMARTS 0.9-m tele-
 169 scope were made on five nights between September 2010 and October 2012.
 170 Many of these observations were made using time on nights primarily dedicated
 171 to the REsearch Consortium On Nearby Stars (RECONS⁵) effort to discover
 172 and characterize stars within 25 pc (Henry et al., 2006). Thus, for several tar-
 173 gets taken using the 0.9-m, the *B* filter was neglected (leaving Johnson-Cousins
 174 *VRI*) because it did not fit into the larger RECONS observing plan, and signifi-
 175 cant time would be lost on *B* standards for relatively few frames. No binning was
 176 used for frames taken using the 0.9-m Tek2k camera, which has a $0''.401/\text{pixel}$
 177 scale. At the 0.9m, observations were made both in full chip mode (field $13.7'$ on
 178 a side) and using the central quarter of the chip ($6.8'$ on a side).

179 4.1.3. Lowell 42-in.

180 The Lowell 42-in. Hall Telescope was used for observing eight Jupiter Trojans
 181 on the nights of November 25 and 26, 2010. These observations were made pos-
 182 sible through Georgia State University’s partnership with Lowell Observatory.
 183 NASACam was used with Johnson-Cousins *BVRI* filters. This instrument is
 184 also subject to fringing in the *I* filter, which was easily removed by subtracting
 185 a scaled fringe map made from median combining the worst affected frames.
 186 We used 3×3 binning ($0''.981/\text{pixel}$) for these objects.

187 4.2. Data Reduction

188 On most nights, sky flats were taken. On nights when the CTIO 0.9-m was
 189 used, dome flats were acquired. These flats, in conjunction with nightly bias
 190 frames, were used to process the data. As mentioned, for some *I* images on the
 191 1.0-m and the 42-in. fringe removal was necessary. Aperture photometry was
 192 used to calculate instrumental magnitudes. These instrumental magnitudes are
 193 converted into apparent magnitudes using transformation equations created us-
 194 ing the standards discussed above. The pipeline and methodology are described
 195 in detail in Jao et al. (2005) and Winters et al. (2011).

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⁵www.recons.org

196 The primary sources of error in the photometry are the Poisson noise in cal-
 197 culating the fluxes and the error in calculating nightly extinction curves using
 198 the standard star observations. At the telescope, a signal to noise (S/N) ratio
 199 of about 150 in counts was considered ideal because this generally results in a
 200 magnitude error of about ~ 0.03 magnitudes. This level of precision is essential
 201 to being able to differentiate taxonomies in the visible wavelengths. Unfortu-
 202 nately, this quality of data was not always achieved, particularly for faint targets
 203 when the sky background was high. Figure 1 shows that when combined, these
 204 sources of error translate into a typical uncertainty of ~ 0.03 mag for V , R , and
 205 I filters with slightly higher errors of ~ 0.05 mag in B due to the faintness of
 206 objects in this filter. The resulting errors in color are characterized in Table 2.

207 Phase effects were found to be negligible for this sample due to the small
 208 phase angles for Trojans in general and these observations specifically. **Jupiter**
 209 **Trojans are never observed from Earth at phase angles more than**
 210 **about 12° . The phase angle for each observation is listed in Section**
 211 **11, and no correlation between phase and color is detectable for this**
 212 **sample.** Szabó et al. (2007) calculate an offset of $\sim 0.005 \pm 0.001 \frac{mag}{deg}$ for
 213 $g - r$ and $r - i$ colors. We also examined color variation due to phase effects
 214 for Jupiter Trojans using observations from the SDSS MOC. We calculated the
 215 slope of color versus phase for each of the 226 known Jupiter Trojans that had
 216 more than a single observation in the MOC. We then calculated a weighted
 217 mean of these slope values to find the average phase reddening for a Trojan
 218 body. We found a value of $-0.001 \pm 0.004 \frac{mag}{deg}$ for $g - r$ and $0.003 \pm 0.004 \frac{mag}{deg}$ for
 219 $r - i$. Both of these corrections are consistent with $0 \frac{mag}{deg}$, a finding consistent
 220 with lab results for dark asteroids (French and Veverka, 1983), and were thus
 221 ignored for this sample.

222 An additional source of error present in the color calculations is the vari-
 223 ation in the reflected flux of the asteroids due to their rotations. Thus, when
 224 calculating colors based on observations taken at different times through two
 225 different filters, an additional, unknown error is present. Table 2 shows that
 226 for some objects with either relatively fast rotation periods or particularly large
 227 lightcurve amplitudes, this error could be as much as that of the Poisson and
 228 extinction errors. A comparison of photometric errors with and without rota-
 229 tional errors in each color can be seen in Figure 2. For each observation, the
 230 worst case of this error has been estimated by using the largest amplitude and
 231 best period reported for each object in the NASA PDS Lightcurve Database
 232 (Harris et al., 2012) to estimate the largest possible variation in color due to
 233 the time between exposures with different filters. An estimated period and am-
 234 plitude, based on the statistics for other Trojans of similar size, were used for
 235 objects that had none available in the database. These error estimates were
 236 calculated by assuming that photometric observations were made during the
 237 period of highest change in bolometric brightness due to rotation as well as
 238 during a viewing geometry coinciding with the largest amplitude ever observed
 239 for that particular object. Thus, such errors will typically be much smaller than
 240 those estimated here. A summary of the results is shown in Table 2. Future

241 observational procedure has been changed to account for this effect by including
 242 additional observations to track changes in brightness independent of color.

243 5. Results

244 The photometry presented here represents the most complete sample to date
 245 of *BVRI* photometry for the L5 Jupiter Trojans with $H < 10$. Each object was
 246 observed at least twice, and Figure 3 shows each color calculated for each ob-
 247 servation reported in the Data Appendix in Section 11. Figure 4 shows the
 248 clustering of individual observations around a single weighted mean, which was
 249 calculated for each color for each object with results for each object given in Ta-
 250 ble 3. Certain objects such as 3317 (Paris) and 2357 (Phereclos) were observed
 251 with significantly higher frequency (11 and 7 observations respectively) as part
 252 of an effort to more completely characterize these objects through light curve
 253 and phase curve examinations; all photometric observations for these objects are
 254 included here for completeness. More in-depth examination of these individual
 255 Trojans will be presented in a future work. Furthermore, these targets offer an
 256 independent test of the consistency of our methods over time and over varying
 257 telescopes and instruments. The general uniformity in the measurements for
 258 these targets can be seen by the relatively low errors (0.014 to 0.010 mag for
 259 Paris and 0.019 to 0.012 mag for Phereclos) for the mean color values given in
 260 Table 3. Because these values include standard deviations, these data assure us
 261 of consistent measurements in all conditions.

262 6. Analysis

263 For diagnostic and classification purposes, a principal color component such
 264 as a^* defined by Ivezić et al. (2001) can prove extremely useful because it com-
 265 bines multiple photometric colors into a single parameter. However, this prin-
 266 cipal component is ill-suited for this survey for multiple reasons. First, it is
 267 defined by Ivezić et al. (2001) using *ugriz* filters. Fortunately, Moskovitz (2012)
 268 provides a conversion to the Johnson-Cousins *BVRI* filter set used here:

$$a^* = 0.908 \cdot (B - V) + 0.409 \cdot (R_C - I_C) - 0.856 \quad (1)$$

269 However, even with this conversion to the desired filter set, a^* remains less
 270 than ideal. Originally, it was designed using a clear separation of Main Belt
 271 objects in color-color space. It is fundamentally a rotation in $g^* - r^*$ versus
 272 $r^* - i^*$ space to maximize this Main Belt separation, which effectively maximizes
 273 the separation between the C and S-Complex asteroids that largely populate this
 274 portion of the Solar System. However, because numerous surveys (see DeMeo
 275 and Carry (2013)) have failed to find any S-Complex objects in either Trojan
 276 camp, such a criterion as separating C-type from S-type asteroids is not ideal
 277 for these camps. Instead, we have calculated a new principal component for the
 278 Trojan camps (a_T^*) that maximizes the separation between the D-Complex and
 279 X-Complex objects that dominate the Trojan swarms.

Here we use the standard spectra for Bus-DeMeo taxonomy (DeMeo et al., 2009) shown in Figure 5 to determine photometric regions within which D-type, X-type, and C-type objects should be most concentrated, as shown for our data in Figure 6. Comparing these regions to the photometric data gathered in this survey and previous taxonomic classifications in the literature (Neese (2010), and Hasselmann et al. (2011)) we determined the color space and transformation that result in the clearest taxonomic separations while also minimizing regional overlap. We found that $B - R$ and $V - I$ colors provide the clearest divisions between classes. With a transformation and shift within this space designed to minimize overlap between the D-type and X-type objects, we calculate a_T^* :

$$a_T^* = 0.152 \cdot (B - R_C) + 0.988 \cdot (V - I_C) - 1.01 \quad (2)$$

This principal component is similar to the color index t^* computed by Szabó et al. (2007) in that it maximises separation of the Trojan population into distinct groups. However, a_T^* also considers Main Belt taxonomy in an attempt to readily extend the scheme into the Trojan population. A comparison between a^* and a_T^* is shown in Figure 7 along with the regions determined using the 1-sigma regions for Bus-DeMeo standard taxonomic spectra converted to photometric $BVRI$ colors. The a_T^* values were calculated for the mean photometry of each Trojan and are given in Table 3 along with the related taxonomy. The linear shift of a_T^* is conceived to place the majority of D-type objects at an a_T^* greater than 0 while X-type and C-type objects predominantly have negative a_T^* values. C-type objects typically show an a_T^* less than -0.11 , which is directly between the Bus-DeMeo 1-sigma values for X-type and C-type asteroids. A “flat,” perfectly reflected, solar spectrum (using solar colors presented by Ramírez et al. (2012)) would have an a_T^* of -0.16 . This new principal color component shows significantly less overlap in the taxonomies present in the L4 and L5 swarms than a^* and could prove to be a much more precise method of estimating taxonomic classifications for photometric surveys within this region of the Solar System.

Though more rigorous taxonomic classification can be done via spectroscopic analysis, the featureless Trojan spectra allow us to differentiate D-like objects from X-like and C-like objects by using photometry and the resultant a_T^* as a proxy for the spectral slope.

This principal component may now be compared to other physical and orbital parameters associated with these objects in order to explore potential trends that might explain the origin and evolution of the swarms. Roig et al. (2008) found a correlation of inclination, absolute magnitude, and slope among Jupiter Trojans in the SDSS MOC. They claim that both swarms trend towards redder objects being larger and having higher orbital inclinations. As all of the objects in this survey are relatively large compared to most of the objects in the MOC, we examine if this trend holds true for inclination. Figure 8 shows a_T^* as a function of inclination for both the L5 Trojans presented here and the MOC4 sample. Only known L5 Jupiter Trojans with quality *griz* photometric data were used for the MOC4 sample, **resulting in 232 objects**. The Lupton

2005 conversion equations (eq. 3 through 6) from the SDSS website⁶ were used to calculate a_T^* .

$$B = g + 0.3130 * (g - r) + 0.2271 \quad (3)$$

$$V = g - 0.5784 * (g - r) - 0.0038 \quad (4)$$

$$R = r - 0.2936 * (r - i) - 0.1439 \quad (5)$$

$$I = i - 0.3780 * (i - z) - 0.3974 \quad (6)$$

The lack of high inclination, less red objects apparent in the MOC4 sample is not obvious in the larger objects used for this survey, and in fact, as can be seen from Figure 9, no real distinction can be made between the color distributions of high and low inclination Trojans used in this survey. A cutoff of 11° was used to separate high inclination objects from low inclination objects because this value cuts the population roughly in half. The two-sample Kolmogorov-Smirnov test (KS test) gives the probability that two samples could be randomly drawn from the same parent sample by evaluating the maximum difference between the cumulative distribution functions of each sample and accounting for sample size. **This statistic indicates a small probability (5.4%) that the high and low inclination populations in the MOC4 data are drawn from the same underlying color distribution. However, the same statistical test finds no such distinction for the sample provided in this work (labelled "TRO" in Figure 9). The high and low inclination populations are statistically indistinguishable from each other. Furthermore, no statistical difference is found between the high and low TRO populations and the equivalent population from the MOC4 sample.** This discrepancy suggests the potential that low number statistics may be the dominating factor, rather than a fundamental physical difference between the large objects presented here and the primarily smaller objects sampled by the MOC4.

Both Roig et al. (2008) and Wong et al. (2014) tentatively hypothesize that older redder D-types that dominate the higher inclinations in the MOC4 sample are less likely to experience collisions than the more recently resurfaced or disrupted less red, X- and C-type objects in the lower inclination Trojan orbits. Szabó et al. (2007) **suggest that a dynamical effect** could increase weathering effects on the higher inclination objects. The similar color distributions for large high and low inclination L5 Trojans shown here could be indicative of a lack of disruptive events among large objects regardless of inclination.

7. Discussion

Using the a_T^* principal component described in the previous section, we have classified all 42 of the Jupiter Trojans presented in this sample. Of these large

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⁶<http://classic.sdss.org/dr4/algorithms/sdssUBVRITransform.html#Lupton2005>

objects, we have found 32 to have a_T^* consistent with D-type asteroids, 5 consistent with X-type objects, and 3 consistent with C-types. We found 2 objects to be indeterminate between the D and X regions. This leads to a population that is 76% D-type, 12% X-type, 7% C-type, and 5% intermediate DX-type objects. This fractional distribution is similar to the distribution presented by DeMeo and Carry (2013) with a slightly larger ratio of D's to X's.

Emery et al. (2011) and Wong et al. (2014) have shown a lopsided bimodality within the Greek and Trojan populations that they have designated as Red (R) and Less Red (LR) groups. These two groups have a ratio of about 2.2 to 1 in favor of the R group for objects with $H < 12.3$. When the Wong et al. (2014) sample is limited to include only objects brighter than H of 10, the ratio is in good agreement with the 3.2 to 1 ratio of red D-type asteroids to less red DX, X, and C-type asteroids we derive here. The demographics represented by the Bus-DeMeo taxonomies for the Main Belt can now be extended into the Greek and Trojan clouds, and it is possible that the bimodality of the Centaur and KBO populations (Peixinho et al., 2012) might have a presence of some form as far in as Jupiter's orbit.

8. Conclusions and Future Work

We present photometric observations for the 42 largest Jupiter Trojans, each at multiple epochs. Using measured $BVRI$ colors we define a new principal component a_T^* . We used this parameter to classify these objects using a proxy for the Bus-DeMeo taxonomic scheme. **We find 76% of the largest L5 Jupiter Trojans to be consistent with D-type classification and that 24% have less-red slopes more consistent with X-type and C-type classifications.** We also look for color trends with inclination similar to those found by Roig et al. (2008). We find no appreciable difference in color distributions between high and low inclination objects.

As a continuation of this project, a similar work focused on the L4 Greek camp is under way. With the additional 71 objects from this cloud, a total of 113 Jupiter Greeks and Trojans can be examined for population bimodality, such as that seen by Emery et al. (2011) and Wong et al. (2014) and taxonomic distribution using methods similar to Hasselmann et al. (2011) and DeMeo and Carry (2013). Further extending this examination to smaller objects and expanding the overall completeness within the Trojan clouds are also important. This examination should help us to understand exactly what role the Greeks and Trojans play in Solar System formation as a whole. If the bimodality seen by Emery et al. (2011) is real, and represents two distinct parent populations, understanding the origins of these populations and their eventual fate could be vital to fully understanding the taxonomic, and presumably compositional, gradient that exists in the Main Belt (DeMeo and Carry, 2013). A thorough understanding of Jupiter's Greek and Trojan asteroids is necessary to understanding the formation of this region of the Solar System.

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503 9. Figures

Figure 1: Calculated photometric brightnesses versus total calculated errors. In general, increased errors for faint objects are somewhat reduced by longer exposure times. However, increased exposure time will eventually increase the error due to ever increasing sky background, especially for moving objects. The observations in the *R* and *I* filters at about 0.06 mag error are primarily the result of poorer than normal standard star correction for the night of November 10, 2012.

Figure 2: Errors in color measurements from purely photometric sources (Poisson noise and atmospheric extinction corrections) versus total error including potential rotational variation as described in Section 4.2. The time between filters is the primary contribution to this error due to rotation. Thus, because most observations were made in *IRVB* order, $B - I$ colors on average show the largest increase in error due to rotation. The gray line shows a one-to-one correspondence representative of no increase in error due to rotation.

Figure 3: L5 Jupiter Trojan Photometry. Symbol size is inversely proportional to the error for each data point. Both the smallest error and the mean error are shown in the lower right corner of each plot. The data shown in 3(a) are also shown in Fig. 4, in addition to the mean values for individual Jupiter Trojans.

Figure 4: Photometry for 42 Trojans. A mean value was calculated for each Trojan, weighted by the individual errors, and plotted in black. Individual observations are plotted in red and connected to their mean values.

Figure 5: Three standard spectra of the Bus-DeMeo taxonomy presented in DeMeo et al. (2009). The standard spectra are normalized at $0.55\mu m$ and offset from each other by an arbitrary amount. The variation in possible spectra that should be considered within each taxonomic group is depicted via the 1σ range shown as a solid colored region associated with each taxonomy. The three spectra shown here were chosen as representative of the Jupiter Greeks and Trojans because numerous surveys (e.g. DeMeo and Carry (2013)) have failed to find evidence of other types within the camps. The spectra are restricted to the visible range and overlaid above the transmission curves for the Johnson-Cousins $BVRI$ filters used for this project (specifically as reported for the 1.0-m). The relative slopes and variations of these standards allow us to calculate the regions in color space where such objects would appear.

Figure 6: The taxonomic classifications for the brightest L5 Trojans are shown here at their mean color values. Red data points correspond to redder, D-type objects, green correspond to X-type and magenta correspond to C-type classifications as defined by Neese (2010) and Hasselmann et al. (2011). Ellipses designate the 1σ definitions for Bus-DeMeo taxonomies converted into BVR I colors. The yellow asterisk shows the position of solar colors (Ramírez et al., 2012), or the equivalent of a flat asteroid spectrum.

Figure 7: Mean photometric values are plotted, converted into the a^* (equation 1) and a_T^* (equation 2) parameters. The boxes show the regions dictated by the dispersion of the Bus-DeMeo standard spectra, while the colored data show the objects with taxonomies previously determined by Neese (2010) and Hasselmann et al. (2011). Red data points correspond to D-type objects, green correspond to X-type and magenta correspond to C-type classifications. The a_T^* regional demarcations of taxonomy are shown as horizontal lines with the D/X dividing line being set to 0, and the X/C line near -0.11 to be half way between the X and C regions. The black diagonal line shows a one-to-one relationship between a^* and a_T^* . The yellow asterisk shows the position of the Sun in principal component space, or the equivalent of a flat asteroid spectrum. **Only 4709 (Ennomos) is blue relative to solar.** Note: The taxonomy of the outlier green X-type object (7352) with a_T^* above 0 was calculated by Hasselmann et al. (2011) as an XL at a 47% confidence level. This particular object is of interest as an extremely long rotator with a period of 648 hours (Stephens et al., 2014).

Figure 8: Principal component a_T^* (equation 2) plotted for converted SDSS MOC4 L5 Trojans (small black points) as well as the photometric data presented for Trojans in this work (larger dots with red error bars) against the orbital inclination in degrees for these objects. Fewer high inclination, less-red X-type and C-type objects with a_T^* less than 0 are seen among the MOC4 objects than among the Trojans observed here.

Figure 9: Histograms of the SDSS MOC4 L5 Trojans (MOC) and the larger L5 Trojans observed for this work (TRO), both shown in Figure 8, divided into roughly equal populations at an inclination of 11° . The MOC population is clearly differentiated, with low inclination objects (black, solid line) having a significantly disparate color distribution to that of high inclination objects (red, dashed line). The low (blue, dotted line) and high (green, dash-dot line) inclination TRO populations are indistinguishable both from each other and also from their respective MOC populations.

Table 1: Telescopes used for observing Trojans

Telescope	Site	Instrument	Filters	Number of observations
1.0-m	CTIO	Y4KCam CCD	BVR_CI_C	106
0.9-m	CTIO	Tek2K CCD	BVR_CI_C	18
42-in.	Lowell	NASA42 CCD	BVR_CI_C	8

Table 2: Comparison of Errors for Photometric Observations

Color	Poisson Error (Mag)		Extinction Error (Mag)		Rotational Error (Mag)		Total Error (Mag)
	Max	Median	Max	Median	Max	Median	Median
B-V	0.16	0.05	0.11	0.03	0.07	0.02	0.06
B-R	0.15	0.05	0.12	0.02	0.13	0.04	0.07
B-I	0.22	0.06	0.13	0.03	0.20	0.05	0.08
V-R	0.12	0.03	0.08	0.02	0.07	0.01	0.04
V-I	0.22	0.04	0.09	0.03	0.16	0.03	0.05
R-I	0.22	0.03	0.10	0.03	0.12	0.02	0.04

This table gives a breakdown of the maximum and median values calculated for each individual source of error considered for all photometric color calculations as well as the median total error for each color.

Table 3: Individual Object Data for 42 Jupiter Trojans

Object	Number of obs.	H ^a (mag)	$\overline{B - R}$ (mag)	$\overline{V - I}$ (mag)	a_T^* (mag)	Tax. (Lit.)	Tax. (Here)
617(Patroclus)	3	8.19	1.13 ± 0.018	0.83 ± 0.020	-0.02 ± 0.019	P ^b	X
884(Priamus)	6	8.81	1.20 ± 0.017	0.91 ± 0.012	0.07 ± 0.016	D ^{bc}	D
1172(Aneas)	3	8.33	1.25 ± 0.023	0.99 ± 0.017	0.16 ± 0.022	D ^b	D
1173(Anchises)	4	8.89	1.08 ± 0.020	0.78 ± 0.015	-0.07 ± 0.020	P ^b	X
1208(Troilus)	4	8.99	1.10 ± 0.020	0.72 ± 0.013	-0.13 ± 0.020	C ^b	C
1867(Deiphobus)	3	8.30	1.22 ± 0.025	0.93 ± 0.022	0.10 ± 0.025	D ^{bc}	D
2207(Antenor)	4	8.89	1.22 ± 0.027	0.92 ± 0.023	0.09 ± 0.027	D ^b	D
2223(Sarpedon)	3	9.41	1.14 ± 0.044	0.88 ± 0.036	0.03 ± 0.044	D ^b	D
2241(Alcathous)	3	8.64	1.22 ± 0.027	0.94 ± 0.021	0.11 ± 0.027	D ^b	D
2357(Phereclos)	7	8.94	1.22 ± 0.019	0.96 ± 0.012	0.13 ± 0.018	D ^{bc}	D
2363(Cebriones)	2	9.11	1.22 ± 0.074	0.91 ± 0.036	0.07 ± 0.073	D ^b	D
2674(Pandarus)	2	9.10	1.19 ± 0.036	0.95 ± 0.022	0.11 ± 0.036	D ^{bc}	D
2893(Peiroos)	3	9.23	1.18 ± 0.023	0.95 ± 0.017	0.11 ± 0.023	D ^b	D
2895(Memnon)	2	9.90	1.06 ± 0.055	0.71 ± 0.044	-0.15 ± 0.055	–	C
3240(Laocoon)	2	10.10	1.10 ± 0.034	0.87 ± 0.027	0.01 ± 0.033	D ^c	DX
3317(Paris)	11	8.40	1.22 ± 0.014	0.95 ± 0.010	0.11 ± 0.014	D ^b	D
3451(Mentor)	5	8.40	1.11 ± 0.019	0.78 ± 0.015	-0.07 ± 0.018	X ^c	X
3708	2	9.20	1.21 ± 0.024	0.98 ± 0.023	0.14 ± 0.024	–	D
4348(Poulydamas)	2	9.20	1.04 ± 0.041	0.83 ± 0.032	-0.03 ± 0.041	–	X
4708(Polydorus)	3	9.90	1.27 ± 0.045	0.95 ± 0.030	0.12 ± 0.045	D ^c	D
4709(Ennomos)	5	8.60	1.02 ± 0.023	0.67 ± 0.018	-0.19 ± 0.023	–	C
4715	2	9.60	1.11 ± 0.041	0.85 ± 0.027	0.00 ± 0.041	–	DX
4722(Agelaos)	2	9.90	1.20 ± 0.050	0.90 ± 0.031	0.06 ± 0.050	–	D
4791(Iphidamas)	3	9.90	1.20 ± 0.059	1.04 ± 0.039	0.19 ± 0.058	–	D
4792(Lykaon)	3	10.00	1.24 ± 0.054	0.95 ± 0.029	0.12 ± 0.054	D ^c	D
4828(Misenus)	2	10.30	1.08 ± 0.068	0.91 ± 0.044	0.05 ± 0.068	–	D
4832(Palinurus)	2	9.80	1.31 ± 0.055	1.00 ± 0.039	0.17 ± 0.054	D ^c	D
4867(Polites)	2	9.60	1.16 ± 0.046	1.00 ± 0.027	0.16 ± 0.046	–	D
5119	2	10.10	1.12 ± 0.042	0.92 ± 0.030	0.07 ± 0.042	–	D
5120(Bitias)	2	9.50	1.23 ± 0.048	0.78 ± 0.034	-0.05 ± 0.048	–	X
5130(Ilioneus)	2	9.60	1.30 ± 0.068	0.96 ± 0.035	0.13 ± 0.067	–	D
5144(Achates)	6	8.90	1.21 ± 0.014	0.92 ± 0.013	0.09 ± 0.014	–	D
5511(Cloanthus)	3	10.10	1.19 ± 0.053	0.89 ± 0.039	0.05 ± 0.053	–	D
5638(Deikoon)	2	10.00	1.17 ± 0.051	0.90 ± 0.035	0.06 ± 0.051	D ^c	D
5648	2	9.60	1.21 ± 0.031	0.91 ± 0.033	0.08 ± 0.031	D ^b	D
7352	2	9.80	1.13 ± 0.040	0.89 ± 0.032	0.04 ± 0.040	XL ^c	D
12929	4	9.90	1.28 ± 0.046	0.88 ± 0.029	0.05 ± 0.046	–	D
16070	2	9.80	1.24 ± 0.051	0.91 ± 0.043	0.08 ± 0.051	D ^c	D
22180	2	9.80	1.21 ± 0.057	0.94 ± 0.032	0.10 ± 0.057	–	D
32496	3	9.80	1.22 ± 0.047	0.93 ± 0.030	0.09 ± 0.047	–	D
34746	2	9.70	1.12 ± 0.043	0.95 ± 0.029	0.10 ± 0.043	–	D
76867	3	10.10	1.23 ± 0.070	0.97 ± 0.038	0.13 ± 0.069	–	D

^a http://www.minorplanetcenter.net/iau/lists/t_jupitertrojans.html^b Neese (2010)^c Hasselmann et al. (2011)

Table 4: Photometry Data

Object	Telescope ^a	Date (UT)	α ($^{\circ}$)	V (mag)	B-V (mag)	V-R (mag)	V-I (mag)
617(Patroclus)	1.0m	2011 June 24	9.6	15.10 ± 0.021	0.74 ± 0.035	0.40 ± 0.028	0.82 ± 0.043
617(Patroclus)	1.0m	2011 Aug. 10	6.0	14.81 ± 0.017	0.66 ± 0.026	0.45 ± 0.025	0.85 ± 0.028
617(Patroclus)	1.0m	2011 Nov. 13	12.4	15.58 ± 0.023	0.72 ± 0.042	0.42 ± 0.031	0.80 ± 0.050
884(Priamus)	0.9m	2010 Oct. 23	12.3	16.10 ± 0.012	0.76 ± 0.031	0.43 ± 0.018	0.92 ± 0.018
884(Priamus)	42in	2010 Nov. 26	11.0	16.25 ± 0.015	0.74 ± 0.082	0.48 ± 0.030	1.00 ± 0.043
884(Priamus)	1.0m	2011 June 24	11.9	16.10 ± 0.020	0.73 ± 0.034	0.48 ± 0.029	0.94 ± 0.039
884(Priamus)	1.0m	2011 Aug. 10	6.7	15.69 ± 0.017	0.73 ± 0.028	0.46 ± 0.026	0.87 ± 0.030
884(Priamus)	1.0m	2011 Aug. 11	6.5	15.61 ± 0.021	0.80 ± 0.041	0.40 ± 0.032	0.86 ± 0.038
884(Priamus)	1.0m	2011 Nov. 13	10.7	16.06 ± 0.024	0.76 ± 0.046	0.47 ± 0.033	0.88 ± 0.055
1172(Aneas)	1.0m	2011 June 22	12.2	15.58 ± 0.026	0.98 ± 0.078	0.46 ± 0.036	1.13 ± 0.040
1172(Aneas)	1.0m	2011 Aug. 10	7.6	15.11 ± 0.017	0.79 ± 0.028	0.45 ± 0.026	0.93 ± 0.029
1172(Aneas)	1.0m	2011 Nov. 14	11.0	15.48 ± 0.021	0.75 ± 0.032	0.46 ± 0.029	0.98 ± 0.035
1173(Anchises)	1.0m	2011 June 22	8.4	16.06 ± 0.017	0.71 ± 0.041	0.40 ± 0.028	0.80 ± 0.036
1173(Anchises)	1.0m	2011 Aug. 10	2.5	15.25 ± 0.019	0.72 ± 0.030	0.35 ± 0.028	0.77 ± 0.030
1173(Anchises)	1.0m	2011 Aug. 13	3.2	15.25 ± 0.019	0.70 ± 0.034	0.38 ± 0.025	0.78 ± 0.031
1173(Anchises)	1.0m	2011 Nov. 13	12.1	16.61 ± 0.024	0.65 ± 0.045	0.42 ± 0.035	0.75 ± 0.058
1208(Troilus)	0.9m	2010 Oct. 23	11.7	16.51 ± 0.012	0.74 ± 0.033	0.35 ± 0.017	0.69 ± 0.019
1208(Troilus)	1.0m	2011 Aug. 10	8.7	15.96 ± 0.015	0.70 ± 0.028	0.37 ± 0.025	0.72 ± 0.030
1208(Troilus)	1.0m	2011 Nov. 16	11.9	16.54 ± 0.019	0.72 ± 0.036	0.39 ± 0.030	0.83 ± 0.038
1208(Troilus)	0.9m	2012 Sept. 29	5.5	15.76 ± 0.026	0.83 ± 0.060	0.39 ± 0.035	0.76 ± 0.041
1867(Deiphobus)	1.0m	2011 June 24	10.2	15.68 ± 0.019	0.78 ± 0.032	0.44 ± 0.027	0.90 ± 0.038
1867(Deiphobus)	1.0m	2011 Aug. 9	4.9	15.40 ± 0.026	0.74 ± 0.037	0.51 ± 0.071	0.98 ± 0.070
1867(Deiphobus)	1.0m	2011 Nov. 14	11.4	16.23 ± 0.022	0.76 ± 0.034	0.44 ± 0.031	0.95 ± 0.039
2207(Antenor)	1.0m	2011 June 24	10.2	16.51 ± 0.020	0.77 ± 0.037	0.46 ± 0.030	1.06 ± 0.049
2207(Antenor)	1.0m	2011 Aug. 9	3.3	16.07 ± 0.024	0.75 ± 0.035	0.48 ± 0.071	0.95 ± 0.069
2207(Antenor)	1.0m	2011 Aug. 11	2.9	16.00 ± 0.024	0.81 ± 0.048	0.42 ± 0.036	0.88 ± 0.041
2207(Antenor)	1.0m	2011 Nov. 13	10.9	16.72 ± 0.029	0.76 ± 0.055	0.44 ± 0.039	0.81 ± 0.059
2223(Sarpedon)	42in	2010 Nov. 25	10.1	17.09 ± 0.049	0.79 ± 0.114	0.47 ± 0.088	0.98 ± 0.104
2223(Sarpedon)	1.0m	2011 Aug. 9	6.4	16.42 ± 0.024	0.80 ± 0.038	0.43 ± 0.072	0.88 ± 0.072
2223(Sarpedon)	1.0m	2011 Aug. 11	6.2	16.34 ± 0.031	0.64 ± 0.055	0.42 ± 0.042	0.85 ± 0.052
2241(Alcathous)	1.0m	2011 June 24	8.5	16.06 ± 0.019	0.76 ± 0.034	0.54 ± 0.027	0.95 ± 0.042
2241(Alcathous)	1.0m	2011 Aug. 10	3.0	15.79 ± 0.022	0.75 ± 0.037	0.47 ± 0.031	0.95 ± 0.034
2241(Alcathous)	1.0m	2011 Aug. 13	3.0	15.98 ± 0.046	0.47 ± 0.076	0.46 ± 0.063	0.92 ± 0.068
2357(Phereclos)	0.9m	2010 Oct. 22	11.3	16.56 ± 0.017	0.67 ± 0.047	0.42 ± 0.027	0.91 ± 0.039
2357(Phereclos)	1.0m	2011 June 24	10.8	16.53 ± 0.020	0.71 ± 0.038	0.46 ± 0.030	1.03 ± 0.043
2357(Phereclos)	1.0m	2011 Aug. 10	4.6	16.02 ± 0.019	0.77 ± 0.033	0.44 ± 0.028	0.90 ± 0.032
2357(Phereclos)	1.0m	2011 Aug. 11	4.4	16.05 ± 0.024	0.69 ± 0.046	0.48 ± 0.036	0.93 ± 0.041

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Table 4 – continued from previous page

Object	Telescope ^a	Date (UT)	α ($^{\circ}$)	V (mag)	B-V (mag)	V-R (mag)	V-I (mag)
2357(Phereclos)	1.0m	2011 Nov. 14	10.7	16.59 ± 0.023	0.71 ± 0.037	0.51 ± 0.032	1.05 ± 0.041
2357(Phereclos)	0.9m	2012 Sept. 29	1.3	16.06 ± 0.033	1.82 ± 0.145	0.52 ± 0.045	1.05 ± 0.055
2357(Phereclos)	0.9m	2012 Oct. 4	0.3	16.11 ± 0.020	0.87 ± 0.045	0.47 ± 0.026	0.95 ± 0.035
2363(Cebriones)	42in	2010 Nov. 25	10.9	16.70 ± 0.048	0.76 ± 0.110	0.48 ± 0.086	0.92 ± 0.101
2363(Cebriones)	42in	2010 Nov. 26	10.9	16.74 ± 0.016	0.72 ± 0.083	0.49 ± 0.032	0.91 ± 0.048
2674(Pandarus)	0.9m	2010 Oct. 22	11.1	16.95 ± 0.023	0.81 ± 0.067	0.46 ± 0.035	1.02 ± 0.043
2674(Pandarus)	1.0m	2011 Aug. 10	4.0	16.32 ± 0.022	0.73 ± 0.038	0.43 ± 0.033	0.89 ± 0.037
2893(Peiroos)	1.0m	2011 June 24	8.8	16.11 ± 0.019	0.73 ± 0.033	0.46 ± 0.028	0.92 ± 0.041
2893(Peiroos)	1.0m	2011 Aug. 10	1.9	15.62 ± 0.022	0.67 ± 0.033	0.49 ± 0.030	0.99 ± 0.035
2893(Peiroos)	0.9m	2012 Oct. 4	5.2	15.96 ± 0.018	0.76 ± 0.043	0.46 ± 0.024	0.93 ± 0.033
2895(Memnon)	1.0m	2011 Aug. 9	2.4	16.95 ± 0.031	0.65 ± 0.052	0.40 ± 0.076	0.72 ± 0.083
2895(Memnon)	1.0m	2011 Aug. 11	2.1	16.87 ± 0.036	0.70 ± 0.066	0.36 ± 0.050	0.71 ± 0.061
3240(Laocoon)	1.0m	2011 June 27	9.4	17.16 ± 0.019	0.69 ± 0.036	0.43 ± 0.031	0.89 ± 0.050
3240(Laocoon)	1.0m	2011 Aug. 10	0.4	16.43 ± 0.016	0.64 ± 0.037	0.43 ± 0.031	0.85 ± 0.035
3317(Paris)	0.9m	2010 Oct. 22	12.4	15.71 ± 0.013	0.75 ± 0.030	0.44 ± 0.030	0.90 ± 0.022
3317(Paris)	0.9m	2010 Oct. 23	12.5	15.80 ± 0.016	0.73 ± 0.037	0.49 ± 0.022	0.94 ± 0.022
3317(Paris)	42in	2010 Nov. 25	10.9	15.83 ± 0.048	0.78 ± 0.109	0.41 ± 0.084	0.92 ± 0.097
3317(Paris)	42in	2010 Nov. 26	10.8	15.97 ± 0.022	0.72 ± 0.088	0.49 ± 0.041	0.97 ± 0.054
3317(Paris)	1.0m	2011 June 24	11.9	15.85 ± 0.020	0.73 ± 0.032	0.47 ± 0.027	0.93 ± 0.036
3317(Paris)	1.0m	2011 Aug. 9	6.5	15.40 ± 0.024	0.73 ± 0.037	0.52 ± 0.071	0.97 ± 0.068
3317(Paris)	1.0m	2011 Aug. 10	6.3	15.35 ± 0.015	0.74 ± 0.025	0.46 ± 0.024	0.92 ± 0.028
3317(Paris)	1.0m	2011 Aug. 11	6.2	15.34 ± 0.019	0.75 ± 0.037	0.45 ± 0.030	0.95 ± 0.035
3317(Paris)	1.0m	2011 Nov. 13	11.3	15.89 ± 0.026	0.69 ± 0.046	0.55 ± 0.034	0.97 ± 0.052
3317(Paris)	0.9m	2012 Sept. 29	6.1	16.01 ± 0.026	3.09 ± 0.395	0.59 ± 0.034	1.11 ± 0.041
3317(Paris)	0.9m	2012 Oct. 4	5.8	15.70 ± 0.021	0.83 ± 0.042	0.45 ± 0.026	1.09 ± 0.038
3451(Mentor)	1.0m	2011 June 24	12.2	15.94 ± 0.020	0.72 ± 0.033	0.40 ± 0.027	0.81 ± 0.038
3451(Mentor)	1.0m	2011 Aug. 10	7.3	15.45 ± 0.015	0.70 ± 0.026	0.41 ± 0.025	0.77 ± 0.032
3451(Mentor)	1.0m	2011 Aug. 11	7.2	15.68 ± 0.022	0.71 ± 0.041	0.39 ± 0.033	0.78 ± 0.038
3451(Mentor)	1.0m	2011 Nov. 13	10.8	15.67 ± 0.025	0.76 ± 0.045	0.34 ± 0.034	0.77 ± 0.052
3451(Mentor)	0.9m	2012 Sept. 29	4.7	15.32 ± 0.024	0.75 ± 0.054	0.38 ± 0.034	0.77 ± 0.040
3708	1.0m	2011 June 27	9.1	16.22 ± 0.017	0.74 ± 0.026	0.47 ± 0.025	1.01 ± 0.036
3708	1.0m	2011 Aug. 10	1.8	15.82 ± 0.023	0.70 ± 0.036	0.50 ± 0.032	0.96 ± 0.035
4348(Poulydamas)	1.0m	2011 June 22	8.5	17.08 ± 0.024	0.65 ± 0.046	0.40 ± 0.039	0.85 ± 0.057
4348(Poulydamas)	1.0m	2011 Aug. 10	2.3	16.51 ± 0.036	0.63 ± 0.059	0.41 ± 0.049	0.82 ± 0.051
4708(Polydorus)	1.0m	2011 June 24	6.2	17.38 ± 0.021	0.76 ± 0.043	0.46 ± 0.037	0.96 ± 0.061
4708(Polydorus)	1.0m	2011 Aug. 9	3.0	17.18 ± 0.046	0.73 ± 0.080	0.58 ± 0.085	1.00 ± 0.091
4708(Polydorus)	1.0m	2011 Aug. 13	3.8	17.15 ± 0.043	0.83 ± 0.089	0.52 ± 0.056	0.91 ± 0.063
4709(Ennomos)	42in	2010 Nov. 26	10.3	16.49 ± 0.016	0.70 ± 0.082	0.34 ± 0.031	0.69 ± 0.045
4709(Ennomos)	1.0m	2011 June 22	11.4	15.92 ± 0.018	0.63 ± 0.038	0.34 ± 0.029	0.65 ± 0.039
4709(Ennomos)	1.0m	2011 Aug. 11	7.9	16.01 ± 0.027	0.67 ± 0.051	0.36 ± 0.039	0.66 ± 0.044
4709(Ennomos)	1.0m	2011 Aug. 9	8.1	16.06 ± 0.028	0.68 ± 0.042	0.36 ± 0.073	0.74 ± 0.072
4709(Ennomos)	1.0m	2011 Nov. 14	10.6	16.03 ± 0.021	0.69 ± 0.033	0.36 ± 0.030	0.68 ± 0.038

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Table 4 – continued from previous page

Object	Telescope ^a	Date (UT)	α ($^{\circ}$)	V (mag)	B-V (mag)	V-R (mag)	V-I (mag)
4715	0.9m	2010 Oct. 23	11.0	17.43 ± 0.029	0.61 ± 0.061	0.40 ± 0.038	0.83 ± 0.038
4715	1.0m	2011 Aug. 10	3.3	16.88 ± 0.030	0.75 ± 0.054	0.45 ± 0.043	0.88 ± 0.046
4722(Agelaos)	1.0m	2011 June 22	7.8	17.41 ± 0.021	0.71 ± 0.048	0.51 ± 0.037	0.89 ± 0.056
4722(Agelaos)	1.0m	2011 Aug. 13	3.5	17.03 ± 0.043	0.66 ± 0.079	0.49 ± 0.056	0.92 ± 0.064
4791(Iphidamas)	1.0m	2011 June 24	7.6	17.79 ± 0.022	0.74 ± 0.052	0.43 ± 0.041	0.96 ± 0.070
4791(Iphidamas)	1.0m	2011 Aug. 9	4.9	18.06 ± 0.085	0.60 ± 0.140	0.78 ± 0.118	1.15 ± 0.127
4791(Iphidamas)	1.0m	2011 Aug. 11	5.1	18.04 ± 0.094	0.06 ± 0.129	1.04 ± 0.121	1.20 ± 0.136
4792(Lykaon)	1.0m	2011 June 27	8.8	17.25 ± 0.017	NaN $\pm$ NaN	0.47 ± 0.030	0.98 ± 0.051
4792(Lykaon)	1.0m	2011 Aug. 9	2.4	15.32 ± 0.023	0.71 ± 0.038	0.48 ± 0.071	0.80 ± 0.073
4792(Lykaon)	1.0m	2011 Aug. 11	2.4	16.66 ± 0.033	0.94 ± 0.072	0.35 ± 0.048	1.01 ± 0.054
4828(Misenus)	1.0m	2011 June 24	8.0	18.23 ± 0.026	0.67 ± 0.063	0.43 ± 0.050	0.99 ± 0.091
4828(Misenus)	1.0m	2011 Aug. 10	2.2	17.82 ± 0.045	0.67 ± 0.089	0.39 ± 0.068	0.85 ± 0.080
4832(Palinurus)	1.0m	2011 Aug. 9	3.1	16.59 ± 0.031	0.77 ± 0.088	0.59 ± 0.074	1.04 ± 0.073
4832(Palinurus)	1.0m	2011 Aug. 11	2.7	16.50 ± 0.031	0.88 ± 0.060	0.42 ± 0.043	0.97 ± 0.048
4867(Polites)	0.9m	2010 Oct. 23	11.2	17.83 ± 0.037	0.64 ± 0.089	0.54 ± 0.047	1.07 ± 0.048
4867(Polites)	1.0m	2011 Aug. 10	3.4	16.97 ± 0.031	0.67 ± 0.052	0.48 ± 0.041	0.94 ± 0.047
5119	1.0m	2011 June 24	10.8	17.60 ± 0.023	0.63 ± 0.048	0.46 ± 0.038	1.06 ± 0.059
5119	1.0m	2011 Aug. 10	2.2	16.89 ± 0.029	0.72 ± 0.052	0.42 ± 0.040	0.81 ± 0.055
5120(Bitias)	1.0m	2011 June 22	10.1	17.44 ± 0.026	0.82 ± 0.055	0.42 ± 0.041	0.76 ± 0.059
5120(Bitias)	1.0m	2011 Aug. 10	2.9	16.84 ± 0.039	0.74 ± 0.070	0.48 ± 0.051	0.80 ± 0.056
5130(Ilioneus)	1.0m	2011 Aug. 11	5.3	16.82 ± 0.070	1.09 ± 0.135	0.29 ± 0.112	0.97 ± 0.104
5130(Ilioneus)	0.9m	2012 Oct. 4	7.9	17.18 ± 0.019	0.79 ± 0.057	0.49 ± 0.034	0.96 ± 0.057
5144(Achates)	1.0m	2011 June 24	12.2	15.06 ± 0.019	0.74 ± 0.030	0.49 ± 0.026	0.97 ± 0.035
5144(Achates)	1.0m	2011 Aug. 10	0.9	14.48 ± 0.018	0.79 ± 0.029	0.45 ± 0.026	0.88 ± 0.030
5144(Achates)	1.0m	2011 Aug. 10	0.9	14.52 ± 0.017	0.73 ± 0.025	0.46 ± 0.025	0.91 ± 0.027
5144(Achates)	1.0m	2011 Aug. 11	0.6	14.46 ± 0.019	0.74 ± 0.038	0.44 ± 0.030	0.94 ± 0.034
5144(Achates)	1.0m	2011 Aug. 11	0.6	14.46 ± 0.019	0.76 ± 0.036	0.44 ± 0.029	0.91 ± 0.034
5144(Achates)	1.0m	2011 Aug. 11	0.6	14.49 ± 0.021	0.75 ± 0.040	0.46 ± 0.031	0.95 ± 0.035
5511(Cloanthus)	1.0m	2011 Aug. 9	7.0	17.08 ± 0.026	0.77 ± 0.044	0.53 ± 0.073	1.00 ± 0.077
5511(Cloanthus)	1.0m	2011 Aug. 11	6.7	17.46 ± 0.045	0.77 ± 0.088	0.41 ± 0.059	0.80 ± 0.071
5511(Cloanthus)	1.0m	2011 Nov. 14	10.9	18.06 ± 0.043	0.52 ± 0.092	0.51 ± 0.061	0.88 ± 0.099
5638(Deikoon)	1.0m	2011 June 27	9.1	17.86 ± 0.021	0.79 ± 0.045	0.46 ± 0.039	1.01 ± 0.064
5638(Deikoon)	1.0m	2011 Aug. 10	1.2	17.43 ± 0.043	0.66 ± 0.075	0.39 ± 0.060	0.78 ± 0.068
5648	1.0m	2011 June 22	8.0	16.65 ± 0.015	0.72 ± 0.051	0.48 ± 0.041	0.88 ± 0.160
5648	1.0m	2011 June 27	7.3	16.46 ± 0.017	0.73 ± 0.027	0.48 ± 0.026	0.92 ± 0.039
7352	1.0m	2011 June 27	7.5	17.36 ± 0.019	0.79 ± 0.037	0.40 ± 0.032	0.91 ± 0.053
7352	1.0m	2011 Aug. 10	1.4	16.90 ± 0.038	0.53 ± 0.061	0.52 ± 0.051	0.86 ± 0.060
12929	42in	2010 Nov. 26	11.1	17.68 ± 0.021	0.89 ± 0.092	0.48 ± 0.045	0.78 ± 0.077
12929	1.0m	2011 Aug. 9	9.1	17.41 ± 0.034	0.78 ± 0.065	0.48 ± 0.079	0.89 ± 0.086
12929	1.0m	2011 Aug. 11	8.9	17.38 ± 0.039	0.91 ± 0.098	0.41 ± 0.057	0.89 ± 0.075
12929	1.0m	2011 Nov. 14	10.1	17.49 ± 0.024	0.75 ± 0.049	0.48 ± 0.042	0.95 ± 0.069
16070	1.0m	2011 Aug. 9	6.0	16.53 ± 0.030	0.75 ± 0.046	0.57 ± 0.074	0.93 ± 0.073

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Table 4 – continued from previous page

Object	Telescope ^a	Date (UT)	α ($^{\circ}$)	V (mag)	B-V (mag)	V-R (mag)	V-I (mag)
16070	1.0m	2011 Aug. 11	5.7	16.44 ± 0.037	0.79 ± 0.066	0.38 ± 0.052	0.90 ± 0.053
22180	0.9m	2012 Oct. 4	8.3	17.44 ± 0.020	0.78 ± 0.055	0.43 ± 0.035	0.88 ± 0.058
22180	1.0m	2011 June 27	7.5	17.93 ± 0.024	0.76 ± 0.069	0.45 ± 0.041	1.02 ± 0.065
32496	1.0m	2011 Aug. 9	9.0	17.42 ± 0.030	0.79 ± 0.047	0.45 ± 0.075	0.98 ± 0.079
32496	1.0m	2011 Aug. 11	8.9	17.47 ± 0.038	0.75 ± 0.080	0.43 ± 0.054	0.91 ± 0.064
32496	1.0m	2011 Nov. 16	11.4	17.66 ± 0.030	0.73 ± 0.063	0.50 ± 0.045	0.91 ± 0.058
34746	1.0m	2011 June 22	7.8	17.25 ± 0.020	0.66 ± 0.046	0.43 ± 0.036	0.96 ± 0.055
34746	1.0m	2011 Aug. 10	4.8	16.95 ± 0.032	0.69 ± 0.057	0.46 ± 0.044	0.94 ± 0.051
76867	1.0m	2011 Aug. 9	6.7	17.70 ± 0.039	0.63 ± 0.071	0.47 ± 0.082	0.92 ± 0.092
76867	1.0m	2011 Aug. 11	6.7	18.09 ± 0.070	0.60 ± 0.134	0.49 ± 0.089	1.02 ± 0.099
76867	0.9m	2012 Oct. 4	5.8	17.73 ± 0.036	1.20 ± 0.127	0.44 ± 0.054	0.96 ± 0.077

^a The three telescopes used to acquire these data were the CTIO/SMARTS 0.9-m and 1.0-m as well as the Lowell 42-in. telescopes.