SPECTRO-PHOTOMETRY OF DYNAMICALLY ASSOCAITED ASTEROID PAIRS. N. A. Moskovitz[1], [1]Carnegie Institution of Washington, Department of Terrestrial Magnetism, 5241 Broad Branch Road, Washington DC 20015, nmoskovitz@dtm.ciw.edu.

Introduction: Analysis of the osculating orbital elements of Main Belt asteroids has recently revealed over 80 pairs of asteroids that reside in nearly identical heliocentric orbits [1,2]. These objects are distinct from binary asteroids as they are not on bound orbits around a common center of mass. Backwards integration of these pair's heliocentric orbits suggests they may have separated recently into an unbound state, in some cases less than 20 kyr ago [3,4].

One formation scenario for these pairs, which is supported by studies of their rotational properties [4], suggests that their parent asteroids were spun up to a critical frequency by the YORP effect, i.e. a change in angular momentum due to anisotropic emission of thermal photons. At this critical frequency the parent fissioned into a proto-binary system, which would eventually disrupt under its own internal dynamics, thus forming an unbound asteroid pair. Over time these pairs can drift sufficiently far apart in orbital element space that their prior association can no longer be inferred. The components of known pairs are typically a few km in size and consist of a primary and secondary (defined as the largest and smallest components respectively).

There remain several unaddressed questions regarding the formation and evolution of these asteroid pairs. For instance, the relationship between pairs and bound multi-component systems is unclear. In addition, little is known about their compositions/taxonomic types. If they formed by rotational fission then the components of a given pair should be compositionally similar. On the other hand, collisional formation might result in compositionally distinct components. Formation by rotational fissioning should be largely independent of composition, resulting in a population of pairs that is representative of all Main Belt asteroids.

Observations: We have conducted a visible wavelength spectro-photometric survey of a sample of asteroid pairs to address the origin of these objects. Targets were selected primarily based on observability on the dates that our telescope runs were scheduled.

During observing runs in 2010 we used the SITe2K CCD at the DuPont 2.5m telescope and the IMACS instrument on the Magellan Baade 6.5m telescope, both located at Las Campanas Observatory in Chile. Typically BVRI photometry was obtained for each individual object. In a few cases the targets were sufficiently bright that visible wavelength (0.5-0.9 micron) spectra were obtained with IMACS operating in its low-resolution grism mode. In addition, *ugriz* photometry was retrieved for several primaries and secondaries contained in the Sloan Digital Sky Survey Moving Object Catalog (SDSS MOC) [5]. In total we obtained data on 53 individual asteroids, with both the primary and secondary observed for 16 systems. Data reduction employed standard IRAF and IDL routines. The data for one complete pair (asteroids 17288 and 203489) are shown in Figure 1. These data have been solar-corrected and thus provide a rough indication of the reflectance spectra of these asteroids.

Analysis: A principle component color was computed for each asteroid [5]:

$$PC1 = 0.91\cdot(B - V) + 0.41\cdot(R_C - I_C) - 0.29.$$

This color redefines the $(B - V)$ and $(R_C - I_C)$ color space to maximize the difference between C- and S-complex asteroids, thus allowing coarse taxonomic assignment. Multiple observations of individual asteroids, both within and across nights, suggest that the maximum systematic uncertainty on our PC1 values is ±0.1. The statistical errors on our photometry are less than this for all observations.

We first compare PC1 colors of the observed primary and secondary components (Fig. 2). This figure only presents our BVRI observations for 11 complete pairs; no SDSS or spectroscopic data are included. The components for a majority (10/11) of these pairs have the same PC1 colors within the uncertainties of our photometry.

To estimate the significance of this result we select a set of 11 pseudo-pairs from the SDSS MOC and record how many of these fall outside of the region bounded by the systematic errors in Figure 2. Pseudo-primaries are selected at random; pseudo-secondaries are defined as the next nearest object in orbital element space. The random selection of 11 pseudo-pairs is repeated 10,000 times. In only 2% of these trials do 10 out of 11 pairs fall within the bounded region in Figure 2. This suggests it is unlikely at the 98% level that our PC1 measurements are a random result.

We also compare the PC1 colors of all asteroids observed here to the distribution of PC1 colors of Main Belt asteroids from the SDSS MOC (Fig. 3). The PC1 distribution of the pairs shows a similar bimodality to that of the MOC, which is indicative of the color separation of C- and S-complex asteroids.

Discussion: The general similarity of colors between primary and secondary components (Fig. 2) argues in favor of a common origin for these pairs. However the pair 69142/127502 lies well outside of the region bounded by our systematic uncertainties (lower right point in Figure 2). This pair has colors indicative of an S-type primary and a C-type secondary. The origin of such a system is unclear. Future observations are needed to investigate this pair in more detail.

The PC1 distribution of pairs is similar to that of Main Belt asteroids (Fig. 3). There appears to be no bias towards a single taxonomic class. This strongly suggests that formation of pairs is independent of composition, and instead depends solely on the mechanical properties of the parent bodies. This is consistent with the findings of [4]. These results are most consistent with pair formation via rotational fissioning and/or binary disruption. It is expected that collisional formation would produce at least some primaries and secondaries with disparate colors. It is unclear how a collisional formation scenario would influence the taxonomic distribution of pairs in Figure 3.

Future work will involve the inclusion of both SDSS and spectroscopic data in Figure 2 to provide a larger sample size. This will ultimately enable a more robust statistical analysis in the comparison of primary and secondary colors.

References: [1] Vokrouhlicky D. and Nesvorny D. (2008) *AJ, 136,* 280-290. [2] Pravec P. and Vokrouhlicky D. (2009) *Icarus, 204,* 580-588. [3] Vokrouhlicky D. and Nesvorny D. (2009) *AJ, 137,* 111-117. [4] Pravec P. et al. (2010) *Nature, 466*, 1085-1088. [5] Ivezic Z. et al. (2001) *AJ, 122*, 2749-2784.

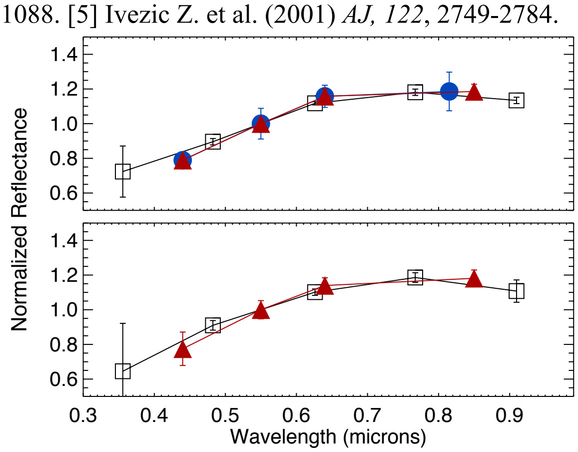

Figure 1: Spectro-photometry of asteroid pair primary 17288 (top) and secondary 203489 (bottom). SDSS *ugriz* photometry is shown as open squares. BVRI photometry from IMACS/Magellan is shown as red triangles and from DuPont as blue circles. The data are normalized at 0.55 microns. The repeat observations of each object are fully consistent within the error bars. The reflectance profiles of these two objects are nearly identical, suggesting a common origin for the pair.

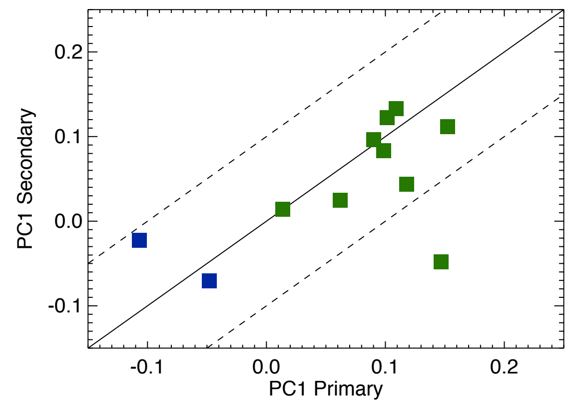

Figure 2: Comparison of PC1 colors for the primary and secondary components in 11 pair systems. The solid line has a slope of one, representing a perfect match of primary and secondary colors. The dashed lines represent estimates on the systematic uncertainties (±0.1) of our observations. The colors indicate a rough taxonomic assignment of C- (blue) or S-type (green). The majority of the points fall within the region bounded by the estimated uncertainties, suggesting a common origin for most pairs.

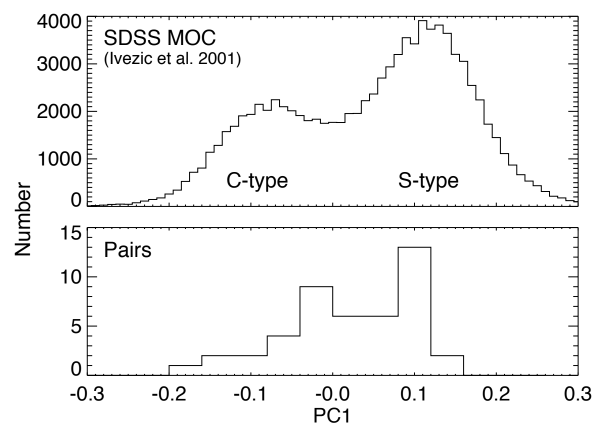

Figure 3: Histograms of PC1 values for all objects within the SDSS Moving Object Catalog (MOC, top) and for all pairs observed in this study (bottom). The apparent bi-modality is attributed to the color differences between C- and S-type asteroids. The similarity of these distributions suggests that the pair formation mechanism is independent of composition.