NEAR-INFRARED SPECTROSCOPY OF TROJAN ASTEROIDS. J.P. Emery[1], D.P. Cruikshank[2], R.H. Brown[3], D.M. Burr[4] [1]NASA Ames / SETI Institute (jemery@mail.arc.nasa.gov), [2]NASA Ames Research Center, [3]University of Arizona, [4]Carl Sagan Center at the SETI Institute.

Introduction: Few objects are as enigmatic as the Jovian Trojan asteroids. Generally classified as a subset of asteroids that happens to orbit the Sun beyond the Main Belt, the Trojan swarms are actually estimated to be nearly as populous as the Main Belt itself. This is a very significant population of minor bodies in its own right. They fit neatly into a paradigm in which macromolecular organic solids were a significant condensate in the solar nebula and now darken the surfaces of distant asteroids, but no direct evidence for organics (i.e., absorption features) have yet been detected. In fact, the only features detected in spectra of Trojan surfaces are due to fine-grained silicates, whose mineralogy may be closer to that of comet grains than typical asteroids. Comparisons with comets are not uncommon for Trojans, given the similarly dark, spectrally red surfaces among the two groups. Trojans continue to refuse, however, to exhibit other similarities to comets, such as comae, tails, the 2.39 μm band seen in comet P/Borrelley, or exposures of volatiles at their surfaces, despite the activity of several other objects at comparable and even more extreme distances.

Despite their frustrating resistance to yield their secrets, the Trojan asteroids lie at the crux of several of the most important and most vigorously investigated aspects of planetary science. For example, dynamical models of the formation of the Kuiper Belt and migration of giant planets make specific predictions about the origin, and therefore interior composition, of Trojan asteroids. Similarly, models for the formation of cometary silicates include diagnostic predictions for the abundance of organics. Models are never the last word, of course, and further observations of the Trojans to determine the surface composition will provide direct tests of these and other hypotheses.

Physical Properties: The first Trojan asteroid was discovered in 1906. There are now ~2080 known Trojans, with an estimated 5.9×10^5 larger than 1km [1,2] (compared to $\sim 6.7 \times 10^5$ for the Main Belt). An explosion of interest in physical studies of asteroids in the 1970s that has endured to the present day benefited the Trojans as well. They were found to have very low albedos [e.g., 3], which has been confirmed by more recent work [4,5], and the extremely high lightcurve amplitude (and therefore extreme shape) of 624 Hektor was quickly uncovered [6]. Despite this early exciting result, lightcurves have been measured for relatively few Trojans, although a study by [7] concluded that Trojans with diameters < 90 km are fragments, while larger objects are primordial. This is in agreement with a change in slope of the size frequency distribution, suggesting a similar interpretation [1,2].

Reflectance spectroscopy in the visible failed to discover any absorption features, but revealed red spectral slopes, comparable to outer belt D-type asteroids [8]. The low albedo and red slope were modeled by mixtures of (hydrated) silicates, carbon black and complex organics [8]. This result was incorporated into a solar nebula condensation sequence that included low-temperature silicates and organics in the middle and outer belt, and increasing organic content causing red slopes farther out, with some possible water ice past ~ 3.5 or 4 AU [9]. This model contains the inherent assumption that the Trojan asteroids formed near 5 AU. Continued visible spectroscopy through the present has continued to show featureless spectra with spectral slopes that range from neutral (gray) to moderately red [e.g. 10,11,12,13]. No ultra-red slopes comparable to many Centaurs and KBOs have been detected among the Trojans. Near-infrared spectroscopy has also failed to detect any clear absorptions, including no evidence for H_2O, no 1 and 2 μm silicate bands, and no absorptions from organics or hydrated minerals [e.g., 14,15,16,17]. [18] and [19] note that vis-NIR spectra can be modeled without the use of organics (just silicates and amorphous carbon), and [19] suggest that the absence of absorptions in the 3-4 μm range strongly limits the type and abundance of organics possible on these surfaces.

Discrete mineralogical features attributed to fine-grained (~few μm), anhydrous silicates were recently detected in mid-IR thermal emission spectra of three Trojans using the Spitzer Space Telescope. The mineralogy may resemble that of cometary silicates, and the spectral shape indicates that the surfaces are either very porous or that the grains are imbedded in a matrix that is relatively transparent in the mid-IR [20].

Density estimates more directly inform us of internal composition. The discovery and follow-up astrometry of a Trojan binary (617 Patroclus) have yielded a density of 0.8 ± 0.2 g/cm^3 [21]. Such a low density implies both significant bulk porosity and a relatively significant ice fraction in the interior. However, there is no spectral evidence for ice or organics at the surface of this object. On the other hand, the density of 624 Hektor (derived both from its extreme shape and the orbit of a recently discovered moonlet) is ~2.5 g/cm^3, which is consistent with an ice-free, silicate dominated body [22,23].

Dynamical context: Dynamical models of the origin and evolution of the Jupiter Trojans are equally intriguing. [23] showed that the Trojan swarms are stable over >4.5 Gyr against gravitational perturbations from the other giant planets, though the region of stability is decreasing, and the overall diffusion of objects is out of, rather than into, stable librating orbits. Gas drag in the early nebula could reverse that trend, capturing objects. [24] found that a growing Jupiter would naturally capture objects into the Lagrange points without the need for substantial gas remaining after giant planet formation. In these scenarios, capture of objects already orbiting near Jupiter is most likely, though small fractions could come from scattering from the Main Belt or Kuiper Belt. Such scattering would be less likely before the giant planets fully formed, so the [24] mechanism would probably result in a more homogeneous population of mid-solar nebula objects than the gas drag model. More recently, [25] suggested a migrating giant planet model which predicts that, as Jupiter and Saturn pass through a mutual 2:1 resonance, the Jupiter Trojan swarms are first emptied of their initial residents, then repopulated with material primarily originating in the Kuiper Belt. In this scenario, the final Trojans pass through a high-eccentricity phase which brings them close to the Sun, devolatilizing their surfaces. According to this model, the Trojans' bulk interior composition should then reflect the diversity of the Kuiper Belt, with only a small fraction of objects from the inner or middle solar nebula.

Current observations: We have measured new near-infrared spectra of 34 Trojans at the IRTF using SpeX and 7 at the MMT on Mt. Hopkins, Arizona using FSPEC. We specifically targeted smaller Trojan asteroids than we previously observed. These smaller objects are statistically more likely to have suffered a surface-resetting impact recently, and may therefore show exposures of internal composition. A few sample spectra are shown in Figure 1.

The new spectra are mostly featureless to within the level of the noise in the spectra. We do note a somewhat surprising diversity of spectral slopes. This diversity is manifest mostly as a larger number of objects with nearly neutral spectral slopes than expected. As yet, no Trojan asteroid exhibits the ultra-red spectral slopes seen among the Centaurs and TNOs.

Several objects exhibit a possible broad absorption feature near 2 μm. This feature is most prominent in the spectrum of 4060 Deipylos. Its occurence seems robust for this object, as it is present is two spectra measured a year apart. The feature is too broad to be due to water ice, however. The most likely candidate is silicate material, but the spectrum shows no accompanying feature at 1 μm that would be expected for pyroxenes. We will present results of ongoing analysis of this possible feature.

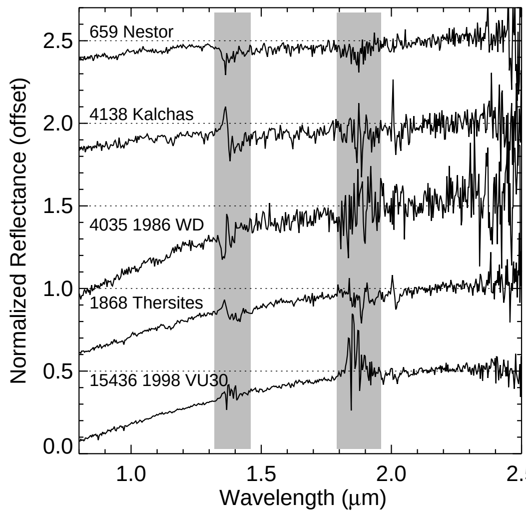

Figure 1. Near-infrared spectra of several Trojans, normalized at 2.2 μm and offset for clarity. The gray areas mark regions of strong telluric absorption.

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