JUPITER TROJAN ASTEROID SIMULANT K. Šļumba[1,2,*], D. T. Britt[1,2], and K. L. Donaldson Hanna[1], [1]Department of Physics, University of Central Florida, 4111 Libra Dr., PSB430, Orlando, FL 32816, USA, [2] Exolith Lab, 532 South Econ Cir, Oviedo, FL 32765, *karlis.slumba@knights.ucf.edu

Introduction: Jupiter Trojans are among the least explored bodies in the Solar System, but that is going to change during this decade with the NASA Lucy mission flying by 5 Trojan systems: 3548 Eurybates, 15094 Polymele, 11351 Leucus, 21900 Orus and 617 Patroclus. So far, we have observed Trojans only remotely and observations reveal low albedo, cold objects with orbits that are moderately inclined and elliptic. Visible and near infrared (VNIR) spectra shows no diagnostic absorption features, only variations in spectral slope [1]. Thermal infrared (TIR) emission spectra shows some features that suggest the existence of iron rich olivine materials on the surface [2,3].

What is Known about Trojan Composition?

VNIR. Observations reveal dark objects (albedo 0.03-0.06) with no spectral details apart from spectral slope that can be red or less red [1]. It is unknown whether these two populations arise from different surface ages, size effects [4], or different accretion regions (which would suggest different starting compositions) [5]. Numerous mixture models have been used to analyze the spectra [1,5], including Hapke modeling [6] and Shkuratov modeling [7]. These modeling results do not give unique solutions for composition, the best that can be said is that the Trojans are composed of largely silicates with a significant amount of opaque materials. Organics and amorphous carbon are likely the opaque component and the cause for the low albedo and lack of spectral features. If there was a significant amount of H_2O ice on the surface of Trojans, it should be detected. However, the Trojan surfaces are likely not water-bearing or aqueously altered as their spectra would show sharp 3μm OH absorption from hydrated minerals [8]. Modeling has shown that H_2O is not stable on Trojan surfaces and slowly sublimates away from depths on the scale of few meters [9]. For some of the less red Trojans, weak absorption in 3μm region is found, and it may be linked to N-H stretch features in organics [10]. This is suggested by linking 3μm absorption feature of comet 67P to ammonium bearing salts [11]. Unlike H_2O, organics may not be as apparent in spectra, and their spectral signatures may not be detected because they are masked by opaques and as hypothesized, even by H_2S [4].

TIR. Thermal emission spectra reveal cold objects (T=120K), that appear as surprisingly optically thin materials, similar to cometary comae [2]. As discussed in [2], the 10-micron phenomena could be explained in several ways: (a) The Trojans having a coma or dust exosphere with particles constantly being moved around, as explained with patched charge model [12]. (b) Porosity on the surface might be extremely high. (c) The surface might consist of dark silicate grains embedded in transparent matrix. Much of the TIR lab work is done with silicates like olivine and KBr (potassium bromide salt) as a matrix, and this indeed has helped in explaining the spectra [13–16]. Recently it has been shown in [3,17] that salt or extreme porosity might not be necessary to explain emission spectra. Correct mineralogy, particle size, and lunar-like porosities might be enough to explain the observed features. T-Matrix and Hapke modeling suggest that highly porous, micrometer scale minerals olivine and some troilite could explain TIR emission spectra in the 8-13.5μm range [3].

Modeling. One of the most important physical properties that can sometimes be approximated from remote observations is density. Observations of the orbits of the eclipsing binary Patroclus system gives $1.08 \pm 0.33\ g\ cm^{-3}$ [18] or $0.81 \pm 0.16\ g\ cm^{-3}$ for the system [19]. The same system from rotation limit and YORP modelling gives 0.9 $\mathrm{g\ cm^{-3}}$ [20] and from stellar occultation 0.88 $\mathrm{g\ cm^{-3}}$ [21]. Density measurements are consistent with values around 0.9 $\mathrm{g\ cm^{-3}}$, with some exceptions like Hector, which might have a contact binary shape that is sensitive to shape model and can return values as high as $2.43 \pm 0.35\ g\ cm^{-3}$ [22]. For comparison, comet 67P/Churyumov-Gerasimenko density was measured at $0.532 \pm 0.007\ \mathrm{g\ cm^{-3}}$ [23]. Densities of rubble piles near Earth asteroids (NEAs) Bennu and Ryugu are around $1.19\ \mathrm{g\ cm^{-3}}$ [24,25]. Density of KBO's smaller than 650km in diameter average $0.82 \pm 0.11\ \mathrm{g\ cm^{-3}}$ [26]. It is shown with Nice and streaming instability models, that Trojans may come from the same population as KBO's during giant planet migration [27]. On the other hand color distribution regression analysis suggests that Jupiter and Neptune Trojans come from the same population that is distinct from KBOs [28]. Trojan composition may be similar to comets, with variations in the proportions of silicate dust, organics and ice. Explosion of comet 17P Holmes have shown that they have more internal cohesion than previously thought [29]. This, together with abundance of volatiles, indicates that comets are probably not rubble piles, but may have accretional structures that are stronger but almost equally porous as rubble piles.

Thermal properties. Thermal inertia measurements from eclipsing binary Trojans gives 5-35 $Js^{-\frac{1}{2}}K^{-1}m^{-2}$[18]. Clearly porous, space weathered, probably dusty Trojan surfaces show orders of magnitude lower thermal inertia than coherent bedrock. It has been shown that thermal properties of the meteorites are strongly dependent on porosity, temperature, and mineralogy [30]. This dependence on mineralogy forbids us to make any conclusions from thermal properties alone.

No meteorites. A lot can be learned from meteorites, but they have a strong bias in their delivery to Earth. For a piece of a Jupiter Trojan asteroid to hit the Earth, it would first need to be dynamically perturbed into Earth-crossing orbit, however the dynamic path for Trojans to hit the Earth has low probability [31,32]. In addition, Trojan material is likely too fragile to survive passage through Earth's atmosphere at the higher velocities than regular NEAs. Unaltered Trojan material is probably not readily available to us. Knowing how meteorite forming minerals form and transform aqueously or with heat, can help to decipher the original unaltered composition which may provide insights into Trojan mineralogy.

Comets: Spectral properties and Solar System evolution models suggest that comets might be made from the same material as Trojans [2]. In-situ observations of comet 67P by ESA Rosetta spacecraft revealed dark and dusty surface that has similar spectra to Trojans [33]. NASA Stardust sample return from coma brought material that is unlike any meteorites [34]. Simulant of comet 67P was developed by [35], but was not particularly successful in reproducing the spectral properties, their spectra did not have consistent slope. They hypothesized, that it might be due to presence of H bearing organics on cometary and Trojan surfaces.

Development: Many high fidelity simulants of the Moon, asteroids, planets and their moons have been developed at the University of Central Florida and are being made in Exolith Lab [36–38]. Already accumulated expertise in UCF and Exolith Lab will be used in the development of Trojan simulants. The goal is to make high fidelity simulant as defined by [36]. Focus will be on mineralogy, while keeping eye on having realistic cosmic element abundances [36]. Geotechnical properties like porosity, grain size, compressibility, hardness, cohesion and abrasivity must be reasonable, as explained in [38]. Geotechnical as well as thermal and optical properties of the simulant will be tested in the lab. VNIR and TIR spectra of the simulant should be consistent with the Trojan spectra. Although, the simulant is not expected to have perfect spectral agreement with the Trojans, because there might be some unknown physical effects in play. The development process will be documented, and recipes will be published and freely available for anyone who wishes to improve upon or change them.

Conclusions: Properties of the body must be constrained before making any simulant. We will be able to improve our Trojan simulant when we have more knowledge, for example when the NASA Lucy spacecraft provides us with closer look at Trojans [39]. Trojans might be among the most primitive bodies in the Solar System that can tell us about the formation and evolution of the early Solar System.

Acknowledgements: K. Šļumba is thankful to Fulbright scholarship that helps him study in the USA.

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