STRUCTURE AND COMPOSITION OF THE SURFACES OF TROJAN ASTEROIDS FROM REFLECTION AND EMISSION SPECTROSCOPY. Joshua. P. Emery,[1] Dale. P. Cruikshank,[2] and Jeffrey Van Cleve[3] *[1]NASA Ames / SETI Institute (jemery@mail.arc.nasa.gov), [2]NASA Ames Research Center (Dale.P.Cruikshank@nasa.gov), [3] Ball Aerospace (jvanclev@ball.com).*

Introduction: The orbits of Trojan asteroids (~5.2 AU – beyond the Main Belt) place them in the transition region between the rocky inner and icy outer Solar System. Most Trojans were traditionally thought to have originated in this region [3], although other locations of origin are possible [e.g., 4,5,6]. Possible connections between Trojans and other groups of objects (Jupiter family comets, irregular satellites, Centaurs, KBOs) are also important, but only poorly understood [4,6,7,9]. The compositions of Trojans thereby hold important clues concerning conditions in this critical transition region, and the solar nebula as a whole. We discuss emission and reflection spectra of three Trojans (624 Hektor, 911 Agamemnon, and 1172 Aneas) and implications for surface structure and composition.

Vis-NIR Reflectance Spectroscopy: Reflectance studies of Trojans in the visible and NIR (0.8 – 4.0 μm) reveal dark surfaces with mild to very red spectral slopes, but no distinct absorption features (Fig. 1) [e.g., 10, and refs therein]. These spectra can be adequately modeled with a combination of silicates and carbon or can include small amounts of organics [11,12].

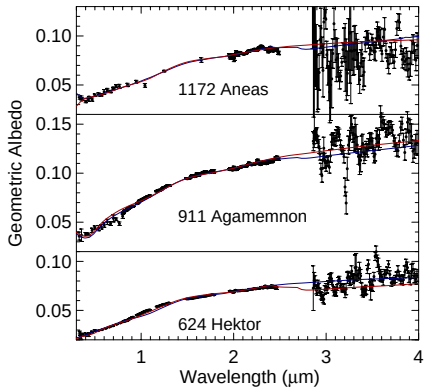

Figure 1. Vis-NIR reflectance spectra of Trojans. Blue are silicate models, red include some organics.

Thermal Emission Spectroscopy: Silicate spectra in the mid-IR (~5–40 μm) are dominated by Si-O fundamentals, and other minerals also have diagnostic bands [e.g., 13,14]. The infrared spectrograph (IRS) on Spitzer operates over the range 5.2 – 38 μm [18].

Current data: The spectral energy distribution (SED) recorded by IRS is dominated by the thermal continuum. Emissivity spectra, which accentuate spectral features, are created by dividing the measured SED by the modeled thermal continuum (Fig. 2) [19].

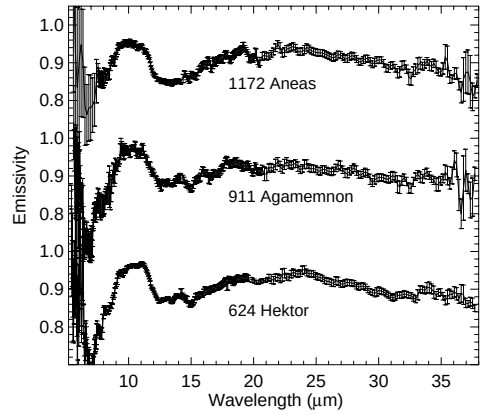

Figure 2. Mid-IR emissivity spectra of Trojans.

Analysis: The Trojans have a similar spectral shape to some carbonaceous meteorites and fine-grained silicates (Fig. 3): a 10-μm plateau is followed by a broad rise near 20-25 μm. Upon closer inspection, several differences are apparent: the 10-μm plateau is narrower for the Trojans, their spectra do not rise as sharply near 15 μm. No minerals in available spectral libraries resolve these differences, nor do linear mixtures of up to five components. Such analysis is limited by the available libraries (e.g., minerals, grain size, type of reflectance) and the simplifying assumption of linear mixing.

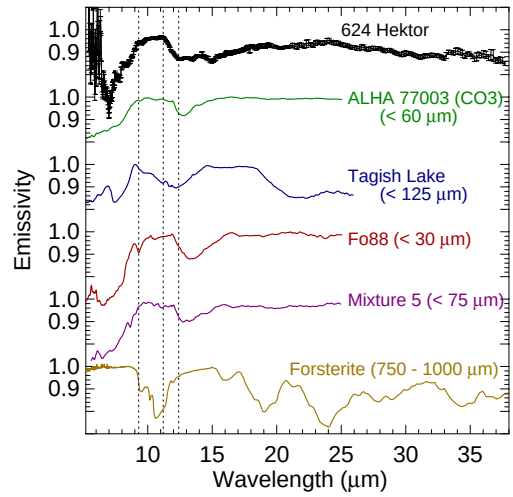

Figure 3. Emissivity spectra of meteorites, minerals, and mixtures. Sources: ALHA 77003 [20], Tagish Lake [21], Fo88 [13], mixture 5 is 63% Fo92 + 28% enstatite + 4% muscovite + 2% pyrophyllite + 3% calcite [13], Forsterite [14].

The 10-μm plateau in spectra of cometary comae are similar width to those in the Trojan data, and possible double peaks near 18 and 24 μm also align (Fig. 4). Emissivity features from surfaces, where scattering is very important, should not generally be compared to those from extended, optically thin comae, where scattering is negligible. Nevertheless, the Trojan spectra do resemble those of cometary comae.

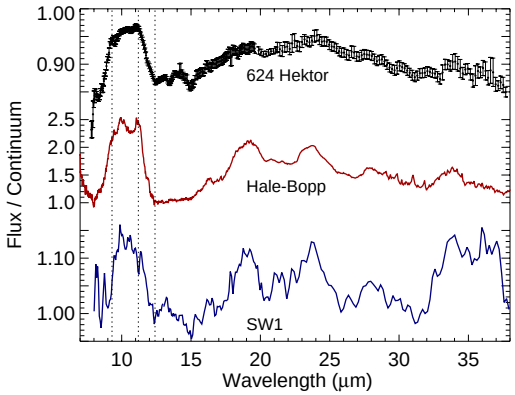

Figure 4. Emission features in comets Hale-Bopp [22] and Schwassmann-Wachmann 1 (SW1) [23].

In an effort to overcome some of the shortcomings associated with comparisons to spectral libraries, we also use Mie and Hapke scattering theories to calculate emissivity spectra of minerals and mixtures from measured optical constants. Neither amorphous silicates nor organic materials match the Trojan data (Fig. 5). Granular (salt and pepper) mixtures of the available materials have the same faults as meteorites, minerals, and linear mixtures from above. Furthermore, the specific mixtures that fit the vis-NIR reflectance data do not match the mid-IR thermal data. Intraparticle mixtures, in which one material is dispersed throughout a matrix of the other, show more promise. In the example shown, with HCN polymer as the matrix material and forsterite the secondary component, the 10-μm plateau is narrowed similar to cometary comae and the Trojan data. HCN polymer (and other organics) is relatively transparent near 10 μm, so the resulting spectrum is similar to that of an optically thin, extended source of the embedded composition. Matrix materials that are more opaque near 10 μm (e.g., graphite) do not produce similar results when combined with silicates.

Discussion: We can imagine three hypotheses for why the Trojan data may resemble comet data. The first is that Trojans themselves have comae. Recent deep imaging of Hektor in the optical revealed no indication of a coma (D. Jewitt, pers. comm.). Furthermore, the amount of extended emission required to create the observed spectral features would be detected

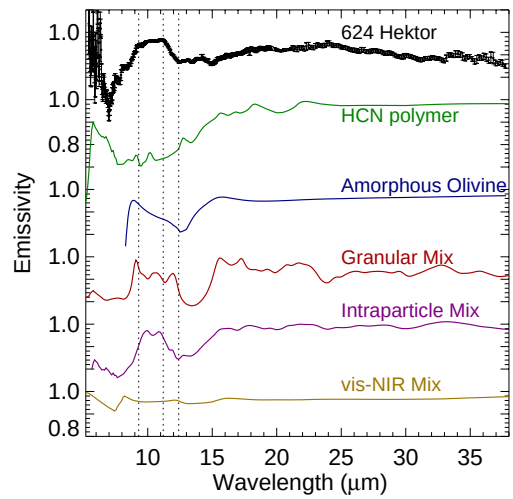

Figure 5. Hapke-Mie models of minerals/mixtures.

in the peak-up images and the 2-D spectral images, as it was for SW1 [23]. We therefore consider a coma around the Trojans to be very unlikely. The second possibility is that a fine-grained, low density regolith with a "fairy-castle" structure emits in a manner similar to an extended coma. We do not really know if emission from such a surface would mimic an extended coma. Additional laboratory studies exploring the dependence of the emissivity on surface structure would help to test this idea. The third hypothesis is that fine-grained silicates are imbedded in a matrix of material that is relatively transparent in the mid-IR. We can begin to test this hypothesis using the Hapke-Mie hybrid model along with Maxwell-Garnett theory, but libraries of optical constants are limited. More laboratory studies of mixtures and derivations of optical constants would help test this hypothesis.

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