A Spitzer-based classification of TNOs. J. R. Cooper[1], C. M. Dalle Ore[1,2], and J. P. Emery[3], [1]SETI Institute, Mountain View, CA 94043, USA, [2]NASA Ames Research Center, Moffett Field, CA 94035, USA, [3]Earth and Planetary Sciences Dept, University of Tennessee, Knoxville, TN 37919, USA

Introduction: The outer reaches of the Solar System are residence to the icy bodies known as trans-Neptunian objects (TNOs). Characteristics such as low albedo and size have left this field relatively unexplored and in turn, encouraged the pursuit of these far-orbiting objects. A database of 48 objects was used by Fulchignoni et al. [1] to cluster, model, and analyze the various spectra into classified taxa. The dataset adopted by that group [1] was used as a baseline for photometric colors to which Dalle Ore et al. [2] provided the significance of adding albedo measurements taken from Stansberry et al. [3]. To further the classification accuracy, two near-infrared color bands from the Spitzer Space Telescope, centered at 3.55 and 4.50 µm, were supplemented with the previous 7-filter photometry. The 9-band compilation produced altered results from the previous studies. The addition of Spitzer data will hopefully aid in distinguishing varying compositional properties of icy objects. We present a redefined taxonomy that may uncover clues to evolutionary trends of the TNO population.

Data: We analyze a sample of 48 objects; each TNO has 9 corresponding geometric albedo wavelengths denoted as B, V, R, I, J, H, K, S1, and S2 (centered at 0.44, 0.55, 0.7, 0.9, 1.25, 1.62, 2.2, 3.55, and 4.5 µm, respectively).

Clustering and Plotting. Analysis of the data was completed through a clustering technique and a K-means partitioning algorithm developed by Marzo et al. [4][5][6] and Calinski and Harabasz [7], respectively. The best-fit number of clusters for the data is 10 as shown below in Figure 1; prior studies involving a smaller number of wavelengths and larger datasets yielded a lower amount of classes, such as [1] which presented 4 taxa and [2] that reproduced 7.

Taxa 3 and 8 each emerge with a distinguished shape in Figure 1; the first is composed of one object, (90482) Orcus, with 2 separate Spitzer observations. DeMeo et al. [8] confirmed the presence of H_2O ice in crystalline form as shown by the 1.65 µm absorption feature, which supports the elevated albedo at shorter wavelengths for taxon 3. Taxon 8 contains 4 objects with 2 Spitzer observations each. The members are (15784), a scattered-disk object, (19308), (52872), a Jupiter-coupled object that does not contain water ice [8], and (54598) Bienor, a Centaur. The only distinguishable correlation that can be determined at this time is that there is a low albedo at all wavelengths for this taxon. Another taxon that is not stand out as much as the aforementioned two is number 4; this is TNO (90377) Sedna. Emery et al. [9] established the presence of CH_4 ice and proposed further inspection for H_2O ice, indicating the presence of organic materials on the surface. The presence of ices might be the cause of the large albedo values between 1 and 3 µm in Figure 1.

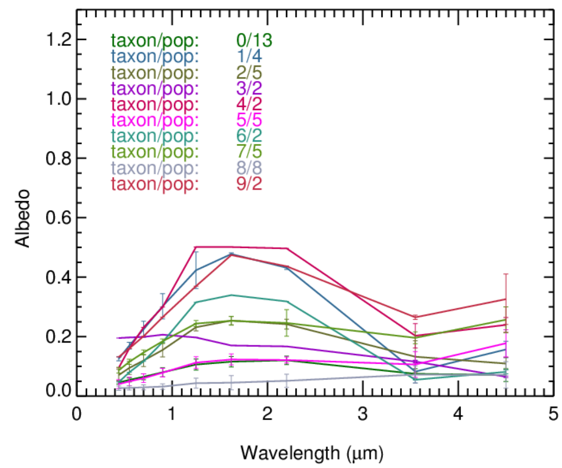

Figure 1: Albedo vs Wavelength for the dataset. Error bars show the spread of each taxon. Taxa 3 and 8 (purple and grey) do not follow the common shape of the dataset. This may be due to compositional differences in the surface of the objects.

Modeling Results. The culmination of the clustering tool produces a centroid per taxon that can be useful in determining how similar the spectra are between the objects. In other words, it is the average of all the spectra in each taxon and the radius of each centroid is the standard deviation. Combinations of H_20, amorphous carbon, CH_4, olivine, serpentine, ice tholin II, hydrogenated amorphous carbon, Triton tholin, Titan tholin, and pyroxene produce models that can be fitted to each taxon, shown below in Figure 2 for two of taxa.

Taxon 4 has 274 possible models that are comprised of 6 different mixtures of H_20, CH_4, Triton and Titan tholins, and amorphous carbon; this is in agreement with [9]. However, the spread of the centroid is unusually large when compared to others within this taxonomy; this may be due in part to the variability in Sedna's spectra that were classified into the taxa. Therefore, more models can fit into the dotted line envelope.

Occasionally, mixtures of the aforementioned compounds cannot be modeled to a taxon; when this occurs, the dashed color line has a slope of 0 at a color magnitude of 0. This is exemplified in taxon 6 in the lower graph of Figure 2; it is also present in centroid models for taxa 0, 1, 7, and 9. In order to expand the currently available database, models of different compounds will have to be completed and further research on our taxa can be accomplished.

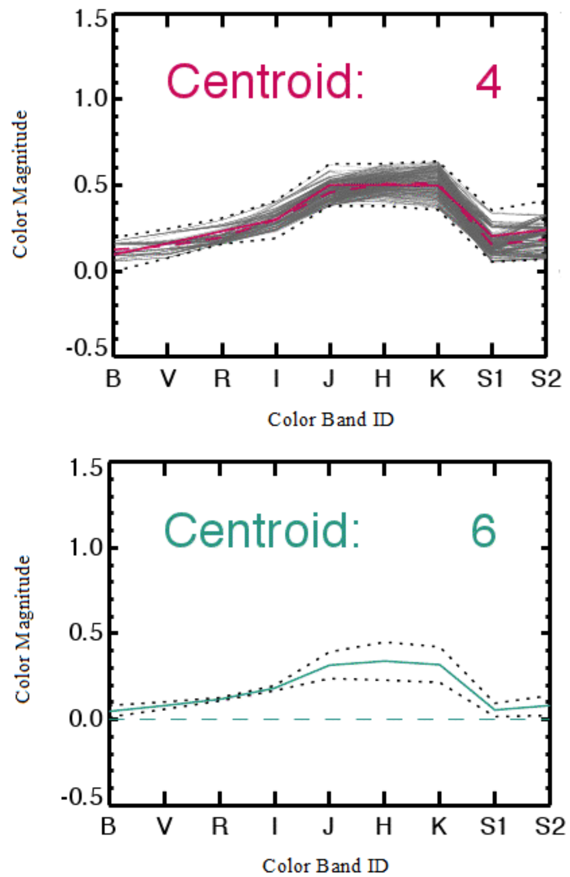

Figure 2: Color magnitude ranges from -.05 to 1.5 on the vertical and all 9 of the color bands are plotted on the horizontal axis. This is the model for taxa 4 (top) and 6 (bottom). Dotted lines show the spread for each taxon and the solid color line is the average spectral line from the taxonomy plot. The grey lines shown only in the top graph represent the 274 models for the specific taxon. The flat dashed line at a color magnitude of 0 in the lower graph corresponds to 0 models fitted to the taxon.

Taxon 3, which is composed solely of Orcus, has a significant amount of water ice in each of the 134 models; this is in accordance with [8]. Finally, taxon 8, which had a peculiar collection of objects, produced 1120 models in 5 mixtures. Amorphous carbon and various tholins create some of these combinations; these 2 categories of compounds vary in color from a red hue to darker tones due to the irradiation of the ices as discussed in [2]. Therefore, the geometric albedo will be lower as seen in Figure 1.

Conclusions: With the inclusion of 2 Spitzer bands at 3.55 and 4.5 µm, an increased number of classes are defined within our adopted population of 48 objects and allow us to introduce a revised TNO taxonomy. A few of the taxa can be compared with previous publications of specific objects and are later confirmed by our work. The modeling resulted in 5 taxa with compositional representations and 5 that were left without. However, the lack of modeling only is an indication of our need to further develop our data-base of geometric albedos.

At this time, our results are very preliminary, but confirm that there is much more to be studied about TNOs, both from the theoretical and the observational standpoint. Future missions will hopefully investigate some of their unknown properties.

References: [1] Fulchignoni M., Belskaya I., Barucci M. A., de Sanctis M. C., Doressoundiram A. (2008) *The Solar System Beyond Neptune*, 181.
[2] Dalle Ore C. M., Dalle Ore, L. V., Cruikshank D. P., Pinilla-Alonso N., Emery J. P., Marzo G. A. (in prep)
[3] Stansberry J. A., Grundy W. M., Brown M. L., Cruikshank D. P., Spencer J. R., Trilling D. E., Margot J.-L. (2008) *The Solar System Beyond Neptune*, 592, 161-179.
[4] Marzo G. A., Roush T. L., Blanco A., Fonti S., Orofino V. (2006) *Journal of Geophysical Research*, 111, CiteID E03002.
[5] Marzo G. A., Roush T. L., Blanco A., Fonti S., Orofino V. (2008) *Journal of Geophysical Research*, Volume 113, CiteID E12009.
[6] Marzo G. A., Roush T. L., Hogan R. C. (2009) *Journal of Geophysical Research*, Volume 114, CiteID E08001.
[7] Calinski J. and Harabasz R. B. (1974) *Communications in Statistics*, 3, 1-27.
[8] DeMeo F. E., Barucci M. A., Merlin F., Guilbert-Lepoutre A., Alvarez-Candal A., Delsanti A., Fornasier S., de Bergh C. (2010) *Astronomy and Astrophysics*, Volume 521, id.A35.
[9] Emery J. P., Dalle Ore C. M., Cruikshank D. P., Fernández Y. R., Trilling D.E., and Stansberry J. A. (2007) *Astronomy and Astrophysics*, 466, 395-398.