Taxonomies and Albedos of Near-Earth Asteroids

Kate Napier[1], Dr. Jessie Dotson[2], Dr. Diane Wooden[2]

[1]Georgia Institute of Technology Atlanta, Georgia (email: knapier3@gatech.edu), [2]Ames Research Center- SSA Moffett Field, California

Abstract

Characterizing near-Earth asteroids (NEAs) can help to assess the risk of possible impactors. Over many decades, asteroids have been spectrally classified into numerous taxonomic systems, most notably those of Tholen, Bus, and Bus-DeMeo. By mapping these various taxonomic systems to broader categories called complexes, it is easier to study the relationship between classifications and other physical parameters. There has recently been an increase in the number of objects with measured albedos which is advantageous for characterization because the albedo and absolute magnitude can be used to determine diameter. Knowing an asteroid's diameter helps us better understand dangers they may pose.

History of Taxonomies

Whereas diameter and albedo measurements are difficult to acquire, taxonomies are relatively easy to obtain because they can use lower-resolution spectra. In the 1980s, Tholen developed a taxonomy system that grouped asteroids based on spectral characteristics. The Bus system expanded upon the Tholen system by incorporating more data from CCD spectra. The Bus-DeMeo taxonomy system is an extension of the Bus system and uses visible and near-IR data.

Table 1. Taxonomic Systems and Classes

Taxonomic System	Classes
Tholen	14 classes A, B, C, D, E, F, G, M, P, Q, R, S, T, V With albedo: E, M, P Others: I, K, U, X
Bus	26 classes A, B, C, Cb, Cg, Cgh, Ch, D, K, L, Ld, O, Q, R, S, Sa, Sk, Sl, Sq, Sr, T, V, X, Xc, Xe, Xk
Bus-DeMeo	24 classes A, B, C, Cb, Cg, Cgh, Ch, D, K, L, O, Q, R, S, Sa, Sq, Sr, Sv, T, V, X, Xc, Xe, Xk

Bus-DeMeo eliminates Sl, Sk, and Ld and defines Sv. In addition, Bus-DeMeo adds a "w" notation to represent taxonomies with similar spectral features but different slopes.

Spectroscopic Classes

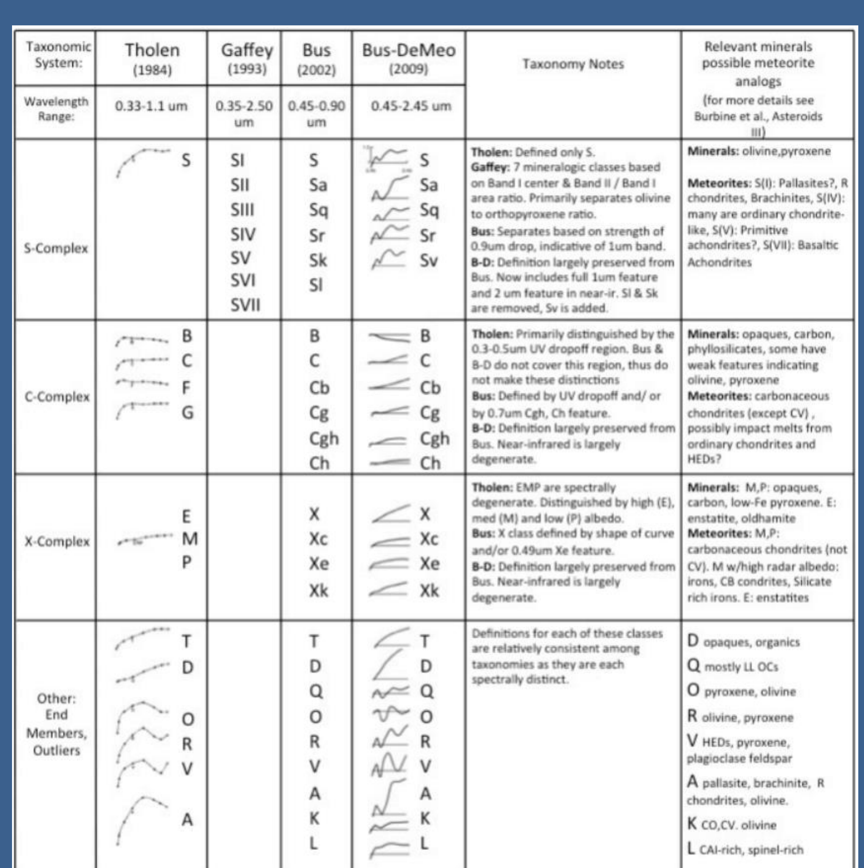

Figure 1. Comparison of various taxonomies.

An asteroid's surface composition can be known by its spectra because distinct spectral features are indicative of certain elements. Using visible and infrared data, asteroids are broadly classified into three main groups: S-type, C-type, and X-type.

Motivation and Method

With an increasing number of NEAs being discovered, there is a need to uniformly classify and compare them. We combined albedo values, thermally derived diameter values, and taxonomy classifications from the literature to make this dataset. We developed a set of rules to classify objects with multiple measurements for a single parameter. The measurement listed is based on the highest S/N and the most IR bands. We mapped taxonomies to complexes and complexes to prime complexes.

Table 2. Bus to Bus-DeMeo

Bus	Bus-DeMeo
Ld	D:
Sk	S*
Sl	S
Sq	S*
Sq:	S*
Sr	S
S(IV)	S*
U	NA (Non-Assignment also is a carat without taxonomy, e.g., Table 2 of Thomas et al. 2014)

Bus taxonomies are mapped to the corresponding Bus-DeMeo taxonomies.

Table 3. Symbols

Symbol	Meaning
&	Complex; when a letter is prepended by &, it refers to the complex of taxonomies (which might include numerous specific taxonomies).
$	Complex Prime; when a letter is prepended by $, it refers to the roll up of complexes to their primary complexes of either S, X, or C.
/	Two taxonomy assignments because on boundary of two principal components.
;	Separator between multiple taxonomy assignments.
:	Uncertainty in taxonomy assignment (e.g., Binzel et al. 2004). Not used in the manner of DeMeo et al. 2014 where specifically Q: means uncertain between Sq and Q, and S: means not Sq and not Sr.
^	Spectrum shows excess thermal emission. Object cannot be formally classified (without some uncertainty) due to the presence of a thermal tail (Thomas et al. 2014 Table 2).
*	Three or more taxonomy assignments; or, placed on more than one principal component boundary; a Bus taxonomy excluded from naming in the Bus-DeMeo system thus incorporating it into a less specific group of taxonomic assignments.

Various symbols are used to modify the primary taxonomies.

Table 4. Complex

Complex	Taxonomies Included
&S	S, Sa, Sk, Sl, Sr, Sw, Srw, Svw, S*, S:, S/Sq, S/Sr, Sv/Sr
&Q	Q, Sq, Sq/Q, Sqw
&K	K
&L	L
&A	A
&L	L
&V	V,V:
&C	C, Cb, Cg, Ch, Cgh, C:, C*, C/Cb, C/Ch, C/Ch/^
&B	B
&D	D, T, D:
&X	X, Xc, Xk, Xe, E, M, P, E/M, M/P, P/M, T, X:, X*, X/E, Xc/C, Xe/E, Xk:
&X/C	C/X, X/C
&U	U (Unknown); C/X/T

The Bus-DeMeo taxonomies are grouped into complexes based on work by DeMeo et al 2009 and Demeo & Carry 2013.

Table 5. Complex to ComplexPrime

ComplexPrime	Complexes Included
$S	&S, &Q, &K, &L, &A, &V
$C	&C, &B
$X	&X, &D
&X/C	&X/C
$U	&U (Unknown)

Complexes are grouped into ComplexPrime, a classification based on broad compositional groups.

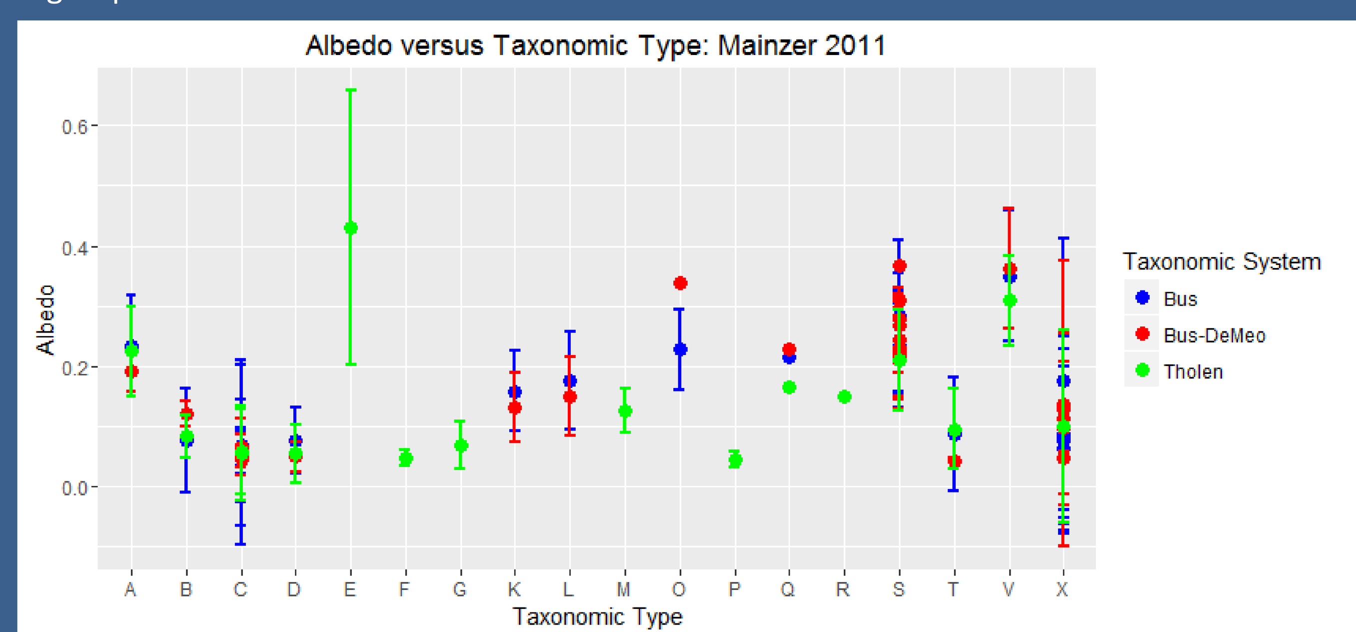

Figure 2. Albedo/ Taxonomic Type relationship for the objects listed in Mainzer et al. (2011) in various taxonomic systems.
The majority (~98%) of the albedo measurements are for main-belt asteroids (MBAs). Albedo varies by taxonomy. Although the Bus and Bus-DeMeo albedos are similar, the Tholen ones are different.

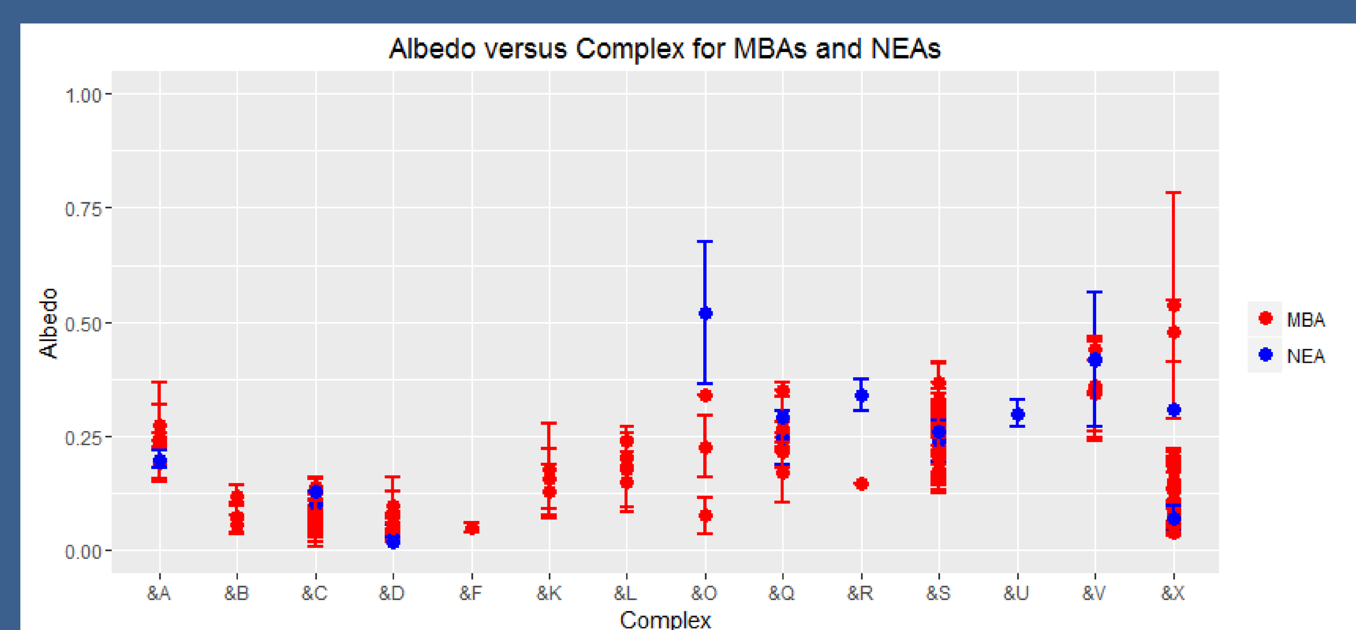

Figure 3. Albedo/ Complex relationship for main-belt asteroids (MBAs) and near-Earth asteroids. It is unclear if the properties for MBAs represent those for NEAs.
The references for MBA albedos include DeMeo & Carry (2013), Mainzer (2011), Mainzer (2012), and Warner (2009). The references for NEA albedos include Stuart & Binzel (2004) and Thomas (2011).

Preliminary Analysis

Our dataset:
Number of NEOs with taxonomy = 833
Number of NEOs with diameter = 1188
Number of NEOs with taxonomy & diameter = 336

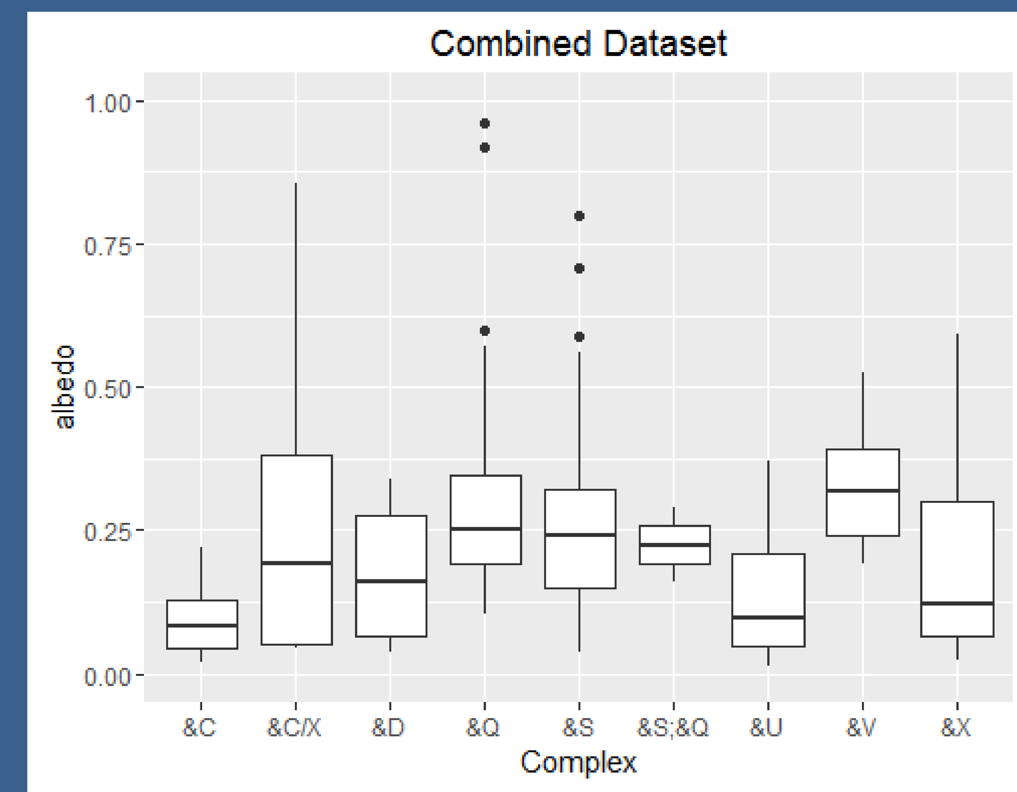

Figure 4. Albedo/ Complex relationship for our dataset. The complexes included have at least five objects in them.

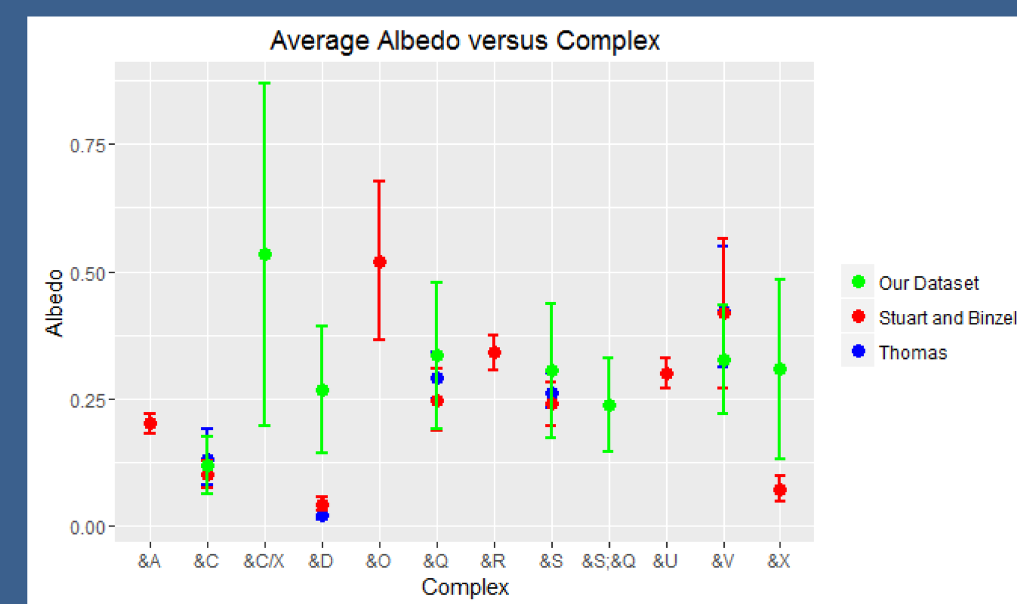

Figure 5. Albedo/ Complex relationship comparing the average of our dataset with those from Stuart & Binzel (2004) and Thomas et al. (2011). Whereas the Stuart & Binzel data is debiased, our dataset and the Thomas et al. data are not debiased. Our average albedos tend to be higher than those reported in the literature.

Future Work

Addressing biases:
- Our dataset is brighter than the known population.
- Closer objects are under-represented.
- Albedos from infrared data are significantly lower than those from optical data.

In August 2016, the results of our research will be available via a searchable interface to the public at neoproperties.nasa.org. Currently the properties listed, including diameter and taxonomy, can be calculated from remote sensing. In the future, the website will be expanded to include the connections between meteorite and asteroid physical properties.

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