A SIMPLE LOOK AT C-COMPLEX ASTEROIDS IN THE SLOAN DIGITAL SKY SURVEY

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Background: The distribution of hydrated minerals (defined here for simplicity as minerals containing either water or hydroxyl) in the asteroid belt has been of great interest for some time. The 3-µm spectral region is diagnostic for hydrated minerals on asteroidal bodies, but it is difficult to obtain data on main-belt objects smaller than ~50 km. Therefore, effort has been put forth to find a “proxy band”, easier to detect than the 3-µm band but correlated to it. Vilas and coauthors [1-4] showed that a broad, shallow absorption centered near 0.7 µm, attributed to iron in phyllosilicates, is present in the spectrum of many C-complex asteroids and was correlated with the presence/absence of the 3-µm band. Further work [5] established that the presence of the 0.7-µm band was diagnostic for the presence of the 3-µm band, though objects without the shorter-wavelength band had a roughly 50% chance of also having the 3-µm band. The Bus spectral taxonomy [6] incorporates the 0.7-µm band, dividing the C complex into Ch and Cgh (which have the band) and C, Cb and Cg (which don’t). For study of an individual object, use of the proxy band alone still potentially carries large uncertainties. For a very large survey, however, it holds great promise.

The Sloan Digital Sky Survey (SDSS) is such a survey. Spectrophotometry of an unprecedented number of asteroids has been performed so far through the course of an ongoing all-sky survey. Large-scale structure in the asteroid belt is easily seen in the dataset [7]. While the information in a particular spectrum may be relatively limited compared to higher resolution, focused studies, the ginormous number of available SDSS spectra provides the opportunity to use the 0.7-µm proxy band on an unprecedentedly large number of objects.

Approach: Vilas [8] converted the SDSS magnitudes to the filter bandpasses used in the Eight Color Asteroid Survey (ECAS) where the formula presented in [3] was used to determine the presence or absence of the 0.7-µm band. She found the results inconclusive.

In the present work, it was decided to use as simple an approach as possible and work in the SDSS filter system. For this preliminary study, a straight line continuum through the r’, i’, and z’, filters (0.62, 0.75, and 0.89 µm, respectively) was assumed.

The full set of 204,305 asteroids in the 3rd SDSS Moving Object Catalog release was winnowed down by selecting only known objects with measured C-like color indices. The resulting set contains 4301 observations of 3594 individual objects. As a first look, observational uncertainties were ignored. Figure 1 shows spectral data for two example asteroids, comparing SDSS to SMASS and showing good (or at least decent) agreement. Objects with i’ points below the continuum were classified as Ch, those above as C (though they may actually be assigned to other classes if higher-resolution data were available).

Figure 1: Solid lines show SMASS spectra of objects with (top, offset) and without (bottom) a 0.7-µm band associated with hydrated minerals. Points show SDSS data for the same objects, error bars omitted. Dotted lines show the continua calculated for each object.

Results: When duplicate observations of an asteroid are removed and the appropriate average for that asteroid included, 44% of the 3594 objects are classified as Ch. Figure 2 shows the fraction of Ch objects as a function of H magnitude, overlayed on a histogram of Ch and C+Ch objects. Looking at the SDSS data, there is a possible increase in the fraction of Ch objects with decreasing size, perhaps leveling off for objects smaller than ~7 km. The red points show the equivalent data for C (and Cg,Cb,B) and Ch (and Cgh) asteroids in the SMASS and S3OS2 surveys [9,10]. These two groupings are consistent with the SDSS data in the region of overlap (save for stray points due to very small sample sizes), though the trend is for more Ch objects at sizes larger than 20-25 km. It remains to be seen how to accomodate both of these trends, though taking all the data sets together suggests little change in Ch fraction with size from 1-20 km.

Figure 3 is similar to Figure 2, but with semi-major axis as the independent variable. No large excursions outside the uncertainties are visible, though objects near the 3:1 resonance (~2.5 AU) perhaps have a lower probability of being Ch, and those near 2.95 AU a
higher one. As a whole, the belt between ~2.5-3.0 AU has a higher fraction of Ch objects than the regions inside and outside that distance, however it is not clear that the difference is statistically significant.

A second simple case was also investigated, where observations whose error bars at $i'$ were large enough to cross the continuum (from above or below) were classified as “U” (uncertain) and removed from the sample set. Over 50% of the observations are removed based on this criterion, but the remaining objects have an overall Ch fraction of 44%, indistinguishable from the previous case.

It is worth noting that the fraction of C-class asteroids with a 0.7-μm band found in this work is consistent with previous findings by others [4]. In addition, the fraction of C-class asteroids with a 3-μm band has been seen to be ~60-65% [11,12], gratifyingly (if perhaps surprisingly) consistent with the ~70% inferred from this work using the assumption that all of the Ch objects have 3-μm bands (as found by [5]).

Figure 2: Histograms show the number of objects vs. H magnitude and use the left axis, symbols the fraction of Ch vs H magnitude and use the right axis. Red closed symbols are from the SMASS and S3OS2 surveys, open symbols from SDSS. The overlap between SMASS/S3OS2 and SDSS is good, except in bins with few objects. Using both datasets, the fraction of Ch asteroids remains fairly constant for H=11.5-18 (~1-20 km), though there is evidence for in increase in Ch fraction for larger objects (as well as a possible trend from 1-7 km in the SDSS data and >20 km in the non-SDSS data).

Caveats and Future Work: While useful as a first look, it is clear that the simplistic approach taken here is not the final word. It can be shown that Ch objects with a particular spectral shape can be misclassified as C by this means and vice versa.

A next step following this approach could involve using additional parameters such as $u'-b'$ color to improve confidence in a Ch classification (and/or identify problem cases) [13]. Alternately (and ideally), a PCA or neural-net approach could be used, as has been used on other subsets of the SDSS data, to do a more robust study of the C-complex asteroids. That work is, so to speak, in the works.

Conclusions: A simple test to identify the 0.7-μm band on C-complex asteroids suggests that it exists on roughly 45% of the members of that group. This fraction seems to be consistent over the 1-7 km diameter range (if not to larger objects). While large, believable variations are not seen with semi-major axis, there appears to be a possible surfeit of Ch objects from 2.5-3.0 AU relative to other parts of the main belt. Although the specific technique used in this study may not be ideally robust, the SDSS data set shows promise for more sophisticated studies.

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Figure 3: Similar to Figure 2, but vs. semi-major axis. There is little large-scale variation seen, but the 2.5-3 AU region has a 5% higher rate of Ch objects than surrounding areas in the main belt.