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The Cost-Effective and Efficient Asteroid Taxonomy for Classification Using Johnson-Cousins BVRI Colors

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Abstract

It is a tradition that taxonomic classes of asteroids are grouped and divided into broad complexes based on visual and near-infrared spectroscopy: silicates (S), carbonaceous (C), featureless (X), Vestoids (V), and the end-members that do not fit well within the S, C, X and V complexes. The extension of the scheme was recently established using the SDSS 4th Moving Object Catalog (MOC 4). However, the boundaries of each major complex and their subclasses have been inevitably ill-defined. Further, there are only few studies on asteroid taxonomy in Johnson-Cousins photometric bands by using a small number of objects with non-negligible measurement uncertainties although these bands are most commonly used. In this paper, we present our results on a novel taxonomic classification system of asteroids using archived data. We determine the class centers and boundaries of each taxonomy complex in a statistically robust way. Our tests of two different clustering methods reveal well-defined taxonomy complexes in the three dimensional Johnson-Cousins color spaces, confirming that our new scheme is very effective.

1. Introduction

To date, different taxonomy classes of asteroids have been characterized by spectral slopes shortward of 0.75 μm and the absorption band at 1 μm using ~10^3 spectra [1][2][3]. In the meantime, we witnessed an explosion of observation data with ~10^5 photometric colors attributed to large-scale surveys such as Sloan Digital Sky Survey (SDSS) [4]. This resulted in an extended taxonomic classification of asteroids to the SDSS Moving Object Catalogue 4 (MOC4) [5]. The class boundaries of each taxonomic complex and the subclass are somewhat ambiguously defined by the extended scheme in the traditional two dimensional plane which comprises the spectral slope and 1-μm absorption depth, or their corresponding 2-D-colors. We present a new solution to the long-standing issue with this classical approach for taxonomical classification of asteroids.

2. Datasets

We make use of ~400 visual-NIR reflectance spectra [6] and ~4200 MOC4 [5] photometric colors which are converted to Johnson-Cousins system for objects with photometric errors < 0.05 mag, and galactic latitude |b| > 15 deg. at the time of observations. In addition, ~1400 Johnson-Cousins band colors are estimated from the SMASS (Small Main-belt Asteroid Spectroscopic Survey) database [2].

3. From 2-D spectra to 3-D colors

We establish a three dimensional coordinate system for asteroid taxonomy taking 1) Johnson-Cousins (B-V) color for spectral slope, 2) (R-I) color for the depth of the 1-μm band, and 3) (B-V) + (B-R) + (B-I) colors as the third axis roughly corresponds to the total area of the, normalized at Johnson-Cousins B-band center.

4. 3-D Clustering method

We utilize two clustering methods to identify major taxonomic types in the 3-dimensional color space. Our methods describe the distribution of asteroid colors as mixtures of 3-D Gaussian distributions. The method 1 estimates properties of these Gaussian mixtures in terms of an Infinite Gaussian Mixture model [7], [8] without any prior information of known asteroid types and their colors in the input data. In the meanwhile, the method 2 uses the DeMeo & Carry dataset [6] with known taxonomy types as well as the synthetic color distribution in the 3-D color space, assuming that we have a sufficient number of sample asteroids for the known taxonomy types in the input data. The cluster membership is accurately determined by distance from the centers of found mixture in the 3-D Johnson-Cousins color space, as well as the probability of assignment to the found mixture components.

5. Future works

This classification scheme is considered to be the cost-effective, efficient, and reliable method of asteroid taxonomy. We plan to test our 3-D clustering techniques to further revise estimation of each complex and subclass boundaries. To achieve this, we will collect more photometric and spectroscopic data to increase the size of the reference input data (i. e., samples with known types in the 3-D color space). Furthermore, in the years to come, we will extend the work to prepare in advance for the "LSST-GAIA era", using the LSST pass bands and the GAIA low resolution spectra.

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