Surface composition of Hungary asteroids from the analysis of the Sloan Digital Sky Survey colors

M. C. Assandri1 and R. Gil-Hutton2,1

1 Universidad Nacional de San Juan, Av. Ignacio de la Roza 590 oeste, 5400 Rivadavia-San Juan, Argentina
e-mail: mcanada@casleo.gov.ar
2 Complejo Astronómico El Leoncito – CONICET, Av. España 1512 sur, J5402DSP San Juan, Argentina

Received 11 February 2008 / Accepted 18 May 2008

ABSTRACT

Aims. We present the results of a taxonomic classification defined using multiband photometry of Hungary asteroids. The aim of this work is to analyze the compositional diversity of this population.

Methods. Photometric observations of 334 Hungary asteroids were taken from the Moving Object Catalog of the Sloan Digital Sky Survey. By means of least squares fitting, a linear function was found to describe the flux data of the Sloan observations and the slope of each spectrum. Each spectrum was then normalized to 6230 Å. The taxonomic type of each object was found by calculating the dissimilarities between the individual spectra and the mean spectra representing the different classes.

Results. We found that a large number of objects in our Hungarias sample are X-types as expected (59% of the sample), but we also found a large number of C-type (26%), and S-type (9%) asteroids and a small number of objects belonging to other taxonomic types. The C-types are not formed originally in this region of the inner main belt, and their presence in this zone could be an indication that there is a dynamical mechanism that is responsible for transporting objects from the main belt to the inner Solar System.

Key words. minor planets, asteroids – solar system: general

1. Introduction

The Hungary dynamical group is composed of high-inclination asteroids orbiting at about 1.9 AU, just inside the inner edge of the asteroid main belt. They occupy a region that has complex dynamics which is surrounded by the 5:1 and 4:1 mean motion resonances with Jupiter and the ν5 and ν16 secular resonances, (Scholl et al. 1986). According to their location in the inner asteroid belt, the members of this group might be the sources of the asteroids that must be replenishing the short-living Mars-crosser population (Michel et al. 2000). The Hungarias are currently clustered in the orbital element space due to long-term dynamical processes, but Williams (1989, 1992) and Lamaitre (1994) identified some dynamical clustering in the proper elements space, possibly indicating the presence of families.

The location of the Hungary group in the inner edge of the main belt would seem to favor a mineralogy associated with E- or M-type taxonomical classes, especially considering that 6 of the 13 E-types classified by Tholen (1989) are in this region. These taxonomic types were originally introduced into the Tholen taxonomy (Tholen 1984), were described as being spectrally degenerate, and could be subdivided based on albedo only. The superficial mineralogies implied by each of these types are considerably different: enstatite or other iron-free silicates for the E-type, and metal with possibly traces of silicates or metal plus enstatite for the M-type (Gaffey et al. 1989). These two types were included in the X-class of the taxonomy proposed by Bus & Binzel (2002b) due to their spectral similarity.

Several works have shed light on the diverse characteristics of the X-class spectra: a 3 μm band in the spectra of M- and E-type asteroids (Rivkin et al. 1995, 2000); absorption bands in the visible spectra of the surface of E-type asteroids (Burbine et al. 1998; Carvano et al. 2001; Fornasier & Lazzarin 2001); absorption bands in the spectra of M-type asteroids (Busarev 1998; Hardersen et al. 2005); small absorption bands in the near-infrared (Clark et al. 2004a), and mineralogical differences between E-type asteroids (Clark et al. 2004b). It is noteworthy that the SMASSII spectra revealed variations in the diverse X-class spectra, allowing them to be divided into several subclasses based solely on spectral features (Bus 1999; Bus & Binzel 2002b).

Carvano et al. (2001) completed a spectroscopic survey of asteroids in the Hungary group. They observed 29 objects and found that 18 showed a slightly red featureless spectrum that was classified as X-type; they also found 8 S-type, 2 C-type, and 1 A-type asteroids. Since the albedo is a valid criterion for subclassifying X-type objects and one of the most important techniques to determine asteroid albedos is polarimetry, Gil-Hutton et al. (2007) performed a extensive polarimetric observing program of Hungary asteroids. They measured the albedo of 18 Hungarias and found that several asteroids do not have polarimetric properties compatible with E-type objects. This results suggests that the compositional distribution in the group is not as peculiar as has been assumed and the number of high albedo asteroids is not as high as expected.

Both Carvano et al. (2001) and Gil-Hutton et al. (2007), studied small samples of asteroids but reached similar conclusions about the compositional distribution of Hungary asteroids. A compositional analysis of a statistically significant number of members of this group would provide invaluable data for assessing the reality of the dynamical grouping and existence of collisional families, and help to develop a more robust understanding of the transport mechanisms operating between the main belt and planet-crossing orbits.

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Impotent sources of data about Hungaria asteroids are large photometric surveys, such as the Sloan Digital Sky Survey (SDSS). A sub-product of the SDSS is the Moving Objects Catalog (MOC), which in its third release provides five band photometry for 43,424 asteroids of which 15,472 have been observed twice or more (Ivezić et al. 2001; Juric et al. 2002). For analyzing the surface composition of asteroids and performing a taxonomic classification, multiband photometry is not as precise as spectroscopy, but the amount of data that the SDSS-MOC provides contrast significantly with the approximately 2,500 objects observed by major spectroscopic surveys that provide publicly available data sets; such as the SMASS (Xu et al. 1995; Bus & Binzel 2002a) and the S3OS² (Lazzaro et al. 2004). While these spectroscopic surveys reached an average absolute magnitude of $H \sim 11$, the SDSS-MOC increased this value to $H \sim 15$, providing taxonomic information for a large population of very small asteroids, for which spectroscopic observations can only be obtained using very large telescopes.

In this paper, we search for photometric data of Hungarian asteroids in the SDSS-MOC to identify the spectral characteristics of members of this group and to distinguish between objects belonging to different taxonomic classes. However, we note that due to the approximation only that few band photometry can provide a spectroscopic classification, this analysis provides only an indication of the taxonomic type of an asteroid. In the following section, we describe the methodology applied to search the database. In Sect. 3 we present the results, and in Sect. 4 we discuss them and outline the conclusions.

2. Methodology

The SDSS photometry is based on the $u$, $g$, $r$, $i$, $z$ system of filters (Fukugita et al. 1996; Stoughton et al. 2002), with band centers at $\lambda_u \approx 3540 \, \text{Å}$, $\lambda_g \approx 4770 \, \text{Å}$, $\lambda_r \approx 6230 \, \text{Å}$, $\lambda_i \approx 7630 \, \text{Å}$, and $\lambda_z \approx 9130 \, \text{Å}$, and bandwidths of $\Delta \lambda_u \approx 570 \, \text{Å}$, $\Delta \lambda_g \approx 1380 \, \text{Å}$, $\Delta \lambda_r \approx 1380 \, \text{Å}$, $\Delta \lambda_i \approx 1350 \, \text{Å}$, and $\Delta \lambda_z \approx 1350 \, \text{Å}$. The photometric observations are performed almost simultaneously in the five filters. Each entry in the MOC corresponds to a single observation of a moving object and provides the apparent magnitudes $u$, $g$, $r$, $i$, $z$ with their corresponding errors. Of the 204,305 entries contained in the third release of the MOC, we only considered 67,637 observations that are effectively linked to known asteroids (Juric et al. 2002). These observations corresponded to 43,424 unique bodies. We then selected only candidates in the Hungaria region, i.e. with semimajor axes in the range $1.77 \, \text{AU} < a < 2.06 \, \text{AU}$, inclinations between $16^\circ$ and $30^\circ$, and perihelion distances larger than 1.66 AU.

To analyze these observations, we computed the reflectance flux or albedo $F(l)$ at each band center using the observed colors corrected by the solar contribution, $C_{r-s} = (u-r) - 1.77$, $C_{g-r} = (g-r) - 0.45$, $C_{r-i} = (r-i) - 0.10$, and $C_r - z = (r-z) - 0.14$, where the values of the solar colors were taken from Ivezić et al. (2001). The albedos at each band center, normalized to the albedo at the $r$ band, were defined to be $F_u = 10^{-0.4Cu}$, $F_g = 10^{-0.4Cg}$, $F_r = 10^{-0.4Cr}$, $F_i = 10^{-0.4Ci}$, and $F_z = 10^{-0.4Cz}$.

To estimate the relative errors $\Delta F/F$, we used a second order approach $\Delta F/F = 0.9210\Delta C \times (1 + 0.4605\Delta C)$, where $\Delta C$ are the color errors computed to be the root mean squared sum of the corresponding magnitude errors. In the case of $F_r$, its error was estimated to be $\Delta F_r = \sqrt{2}\Delta r$. We then discarded data of “bad” observations, i.e. observations for which $\Delta F/F$ was larger than 10% in the $g$, $r$, $i$, and $z$ bands, and larger than 20% in the $u$ band.

3. Results

Using our selection method, we obtained a final sample of 395 observations corresponding to 334 Hungaria asteroids (2 objects with four observations, 3 with three, and 49 with two observations). The spectra derived from these observations increase the size of the spectroscopic database of Hungarian asteroids tenfold.

The taxonomic type of each object was found by calculating the dissimilarities between the individual spectra and the mean spectra representing the different classes. For this purpose, the dissimilarity is defined as the Euclidean distance:

$$d_i^2 = \frac{\sum_k^n (P_{ik} - P_{0k})^2 (\sigma_{ik}^2 + \sigma_{dk}^2)^{-1}}{\sum_k^n (\sigma_{ik}^2 + \sigma_{dk}^2)^{-1}},$$

where $d_i$ is the distance between the $i$th and a mean spectrum, $P$ and $P_0$ represent the individual channel making up the individual and mean spectrum, $\sigma$ is the error in the channel, and the total number of channels is $n$. The mean spectra of each taxonomic class were obtained from Table 3 of Bus & Binzel (2002b), resampled and convolved with the SDSS filter set. Since the SDSS $u$ filter has a central wavelength that is shorter than those considered by the Bus & Binzel taxonomy, this filter is not used to find the spectral dissimilarity. Although using this method we would be able to assign each asteroid to one of the 26 taxonomic types proposed by Bus & Binzel (2002b), we instead define broader subclasses of asteroids to limit the uncertainty caused by using photometry to complete out classification. We propose five classes to classify the asteroids in our sample: a broad X-class (including X, Xe, Xc and Xk types), a broad D-class (including D, T, K, L and Ld types), a broad C-class (including C, Cb, Cg, Ch, CgH and B types), a broad S-class (including S, Sk, Sq, Sl, Sa and Sr types), and a broad O-class (excluding O, R and Q classes), which have 188, 13, 82, 27, and 7 objects, respectively.

Only five of the 334 Hungarian asteroids from our sample were previously observed spectroscopically: (1727) Mette, (3169) Ostro, (3447) Burckhalter, (4116) Elachi and (13111) Papacomas. Table 1 summarizes the taxonomic classification proposed for these objects by different authors, and Tables 2 to 6 list our sample separated into the broad taxonomic classes proposed in this work.

A group of 16 objects from our sample cannot be classified using this methodology because the photometric data provided by the SDSS-MOC result in a dissimilarity too large for a correct taxonomic classification.

4. Discussion

We have analyzed the spectral characteristics of a sample of Hungarian asteroids based on photometric data obtained from the SDSS-MOC. We have determined the taxonomic types of 318 objects using broad taxonomic classes to estimate their classification. We have applied a method that cannot provide a taxonomic classification as rigorous as that provided by spectroscopic data, but which provides a good measure of the spectral characteristics of an object and enables some distinction to be made between the proposed broad classes.

Even though only 5 objects in our sample were previously observed spectroscopically, in almost all cases there are a good agreement with our results. The only exception is the asteroid (3169) Ostro: this object was previously classified into four different taxonomic types by several authors and there is no consensus opinion about its classification (see Table 1). This peculiar
object was observed by Descamps et al. (2007), who obtained its lightcurve and measured a flux variation that could be explained by assuming a tightly bound binary or a contact binary, similar to the Trojan asteroid (624) Hektor. Due to the different taxonomic types proposed for this object, it is impossible to define a taxonomic class for (3169) Ostro and spectra at different rotational phases will be required to improve our understanding of its behavior.

As expected, we found a large number of broad X-class asteroids (~9%), which is a taxonomic class typical of objects in the inner asteroid belt; we also however detected a non negligible number (~26%) of broad C-type asteroids, whose presence in this region is not easy to explain. If we compare the osculating element histograms for the broad X- and C-class groups (Fig. 1), they show a similar shape, imply that the two populations are mixed together and occupy the same region of space. Since the broad C-types objects could be primitive objects similar in surface composition to carbonaceous chondritic meteorites that could have undergone little or no heating (Gradie et al. 1982; Bell et al. 1989), the inner asteroid belt is not the place where objects with broad C-type spectrum were formed and there must be a mechanism responsible for their presence in this region.

An interesting possibility to explain the excess of C-type objects in the Hungaria region is a space weathering effect. Lazzarini et al. (2006) showed that the spectral slope of a fresh X-type object could be confused with that of a C-type with an old surface, so if the slopes obtained for objects classified in these taxonomic types are similar and the C-types that we found are fragments and not C-types. To determine if this scenario is valid, a catastrophic disruption of a X-type object, being fresh X-type asteroid was observed by Descamps et al. (2007), who obtained a comparison between the mean spectra of the classified objects (Fig. 1), they show a similar shape, imply that the two populations are mixed together and occupy the same region of space. Since the broad C-types objects could be primitive objects similar in surface composition to carbonaceous chondritic meteorites that could have undergone little or no heating (Gradie et al. 1982; Bell et al. 1989), the inner asteroid belt is not the place where objects with broad C-type spectrum were formed and there must be a mechanism responsible for their presence in this region.

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seen that the dissimilarity method can detect the UV absorption band shortward of 5500 Å for C-types and the occasional shallow absorption feature longward of 8500 Å, which is characteristic of X-types spectra (Bus & Binzel 2002b). We conclude that the method used to classified these objects can therefore distinguish well between those two broad taxonomic classes.

On the other hand, to test for an excess of C-types among the smaller objects it is possible to compare between the absolute magnitude histograms of objects classified in the broad C- and X-class. Those histograms are shown in Fig. 3, and were compared using a Kolmogorov-Smirnov test, which indicate that both distributions are similar at a 95% level imply that there is no preference for the smaller objects to be classified as C-types.

A more interesting possibility is a transport mechanism. In the Solar System the existence of asteroids in Mars-crossing orbits (Michel et al. 2000) and near-Earth asteroids (Gladman et al. 2000) is strong evidence of a dynamical process of transport from the asteroid belt to the inner Solar System. A possible scenario to explain the presence of broad C-type asteroids in the Hungaria region is that suggested by Gladman et al. (1997) and Migliorini et al. (1998). These authors found that the bodies injected by collisions into the main resonances of the asteroid belt could not sustain the observed population of large diameter Earth-crossers, but that was instead necessary to take into account an important contribution of Mars-crossers to the multikilometer Earth-crosser population. Michel et al. (2000) found in their simulations that several objects arriving at the inner asteroid belt from the intermediate asteroid belt \((a > 2.1\) AU) that become a Mars-crosser, could increase their inclinations and evolve temporarily as a Hungaria asteroid. It would then be possible to find objects placed temporarily in the Hungaria region with short dynamical lifetimes (Michel et al. 2000) that are not original members of the group. If this dynamical scenario is true, it could explain the presence of objects classified in this work as broad D- or O-classes in the Hungaria zone which are not taxonomic types usually found in the inner asteroid belt.
An important point to consider is that in the Hungaria region we have found a large number of broad C-type objects than S-types. If the proposed transport mechanism is at work, the number of C- and S-type objects must be almost identical since the transport process has no preference for one taxonomic type or the other. It is not easy to explain this large difference in the number of objects, but it is possible that a relatively large C-type object coming from the intermediate asteroid belt, arrived at the Hungaria region and had a disruptive collision, forming a large number of broad C-class objects that we observe today in this zone. In fact, there is a larger number of small C-type objects than S-types for \( H > 15 \), while for the largest objects \( H \leq 15 \) the number of asteroids with similar absolute magnitude is almost identical for both classes (see Fig. 3), which is the expected result following a disruptive process.

Acknowledgements. The authors wish to thank A. Rivkin for his comments and suggestions which help to improve the original manuscript, and acknowledge the partial financial support by CICITCA, Universidad Nacional de San Juan, through a research grant.

References

Bus, S. J., & Binzel, R. P. 2002b, Icarus, 158, 146
Busarev, V. V. 1998, Icarus, 131, 32
Fornasier, S., & Lazzarin, M. 2001, Icarus, 152, 127
Gradie, J., & Tedesco, E. F. 1982, Science, 216, 1405
Hardersen, P. S., Gaffey, M. J., & Abell, P. A. 2005, Icarus, 175, 141
Tholen, D. J. 1984, Asteroid taxonomy from cluster analysis of photometry, Ph.D. dissertation, Univ. of Arizona, Tucson