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Taxonomy of asteroids in the Cybele region from the analysis of the Sloan Digital Sky Survey colors

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ABSTRACT

In this paper we search for photometric data of asteroids in the outer region of the Hecuba gap in the Moving Object Catalogue of the Sloan Digital Sky Survey to find the spectrophotometric characteristics of small members of this group. We found that the correlation between size and spectral slope previously identified for Cybele asteroids is correct only for large objects ($H_V < 12$) but it is not supported by data obtained for the small ones. This result argues against the scenario suggesting that D-type objects are more fragile than P-types, favoring disruptive collisions of precursors of the first type and resulting in a larger fraction of the smaller body population being collisional fragments from a few large D-type precursors. A statistical comparison of the spectral slope histograms of Cybeles and Hildas showed that it is not possible to reject the hypothesis that both samples were obtained from the same population at a confident limit of 90%. This result could be indicative of certain homogeneity in the taxonomic distributions of the outer belt populations due to a similar original composition and/or a similar resurfacing processes of these distant bodies. Despite the intrinsic limitations of the five band photometry of the Sloan Digital Sky Survey, the analysis presented is based mainly in the detection of spectral slopes thus providing sufficient indication of the taxonomic type of these asteroids and making us confident about our conclusions.

1. Introduction

The asteroids in the outer asteroid belt with semimajor axis $a > 3.3$ AU are objects with low albedo whose colors varies from gray to red and are usually classified as C-, P-, or D-type (Gradie et al., 1989). These objects fall into three main groups: the Cybeles in the external region of the Hecuba gap (i.e., the 2:1 mean motion resonance with Jupiter) between 3.3 and 3.7 AU, the Hildas in the 3:2 mean motion resonance with Jupiter at 4.0 AU, and the Trojans around the L_4 and L_5 equilibrium points of Jupiter.

Since these outer belt asteroids have experienced less heating and should be of more primitive composition than objects in the main belt, there has been considerable interest in studying them due to their possible relation with dormant comets (Licandro et al., 2008) and to know more about the chemical evolution of the asteroid population as a whole. Most of the Cybeles asteroids are P- or D-type (Lagerkvist et al., 2005) in the Tholen taxonomical classification (Tholen, 1984). P- and D-type asteroids appear to be anhydrous (Jones et al., 1990; Rivkin et al., 2002). The red color of these asteroids are usually associated with the presence or complex organics on their surfaces (Gaffey et al., 1989; Vilas et al., 1994), but organics have yet to be identified spectroscopically (Emery and Brown, 2003, 2004) while fine grained anhydrous silicates on the surface of D–P-type Trojan asteroids were detected by its thermal emission (Emery et al., 2006). However, P- and D-type asteroids may contain significant amounts of hydrosilicates without showing any detectable absorption bands if their surfaces are rich in opaque phases (Cruikshank et al., 2001). The hydration band near 3 μm has been reported only for a few inner main belt D- and P-types (Rivkin et al., 2002; Kanno et al., 2003), and Carvano et al. (2003) point out that inner belt D-type objects often have concave spectral shapes and higher albedos compared to the outer belt D-types, suggesting that they may be compositionally different. The lack of specific spectral features prevent a unique compositional interpretation, at present the general outline for the composition of these asteroids is a mixture of organics, anhydrous silicates, opaque material and ice (Bell et al., 1989; Gaffey et al., 1989; Vilas et al., 1994). It is very difficult to define the composition of these objects since no analogous meteorites for P-type asteroids have been found and there is only one analogous meteorite for D-types: the Tagish Lake carbonaceous chondrite (Hiroi et al., 2001).

The first attempt to study outer belt asteroid composition by CCD spectroscopy was made by Vilas and Smith (1985), but further

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investigations on Cybele asteroids composition have been carried out by Lagerkvist et al. (2005). These authors found that the D-type Cybeles tend to be smaller than P- and C-type objects, which is a behavior similar to that proposed by Dahlgren and Lagerkvist (1995) and Dahlgren et al. (1997) for Hildas, and suggested that the space weathering, compositional differences, or a contribution of both factors could be the most probable scenarios to explain this trend.

The results of Lagerkvist et al. (2005) were obtained using reflectance spectra of 20 Cybele asteroids with absolute magnitude $H_V < 11.9$, which means diameters larger than 20 km assuming a mean albedo of 0.05. This sample corresponds only to the large end of the size distribution. It is therefore desirable to obtain spectra for smaller objects to test if the relation between spectral slope and asteroid size also exists at smaller sizes.

It is possible to search for data of asteroids in the Cybele region using large photometric surveys, like the Sloan Digital Sky Survey (SDSS). A sub-product of this survey 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, 2001; Jurić et al., 2002). Multi-band photometry is not as precise as spectroscopy for determining the surface composition of asteroids, however the amount of data of the SDSS–MOC significantly contrast with the only ~2300 asteroids observed by the major spectroscopic surveys presently available: the SMASS (Xu et al., 1995; Bus and Binzel, 2002a) and the S^3OS^2 (Lazzaro et al., 2004). Moreover, while these spectroscopic surveys reached an average absolute magnitude of $H_V \simeq 11$, the SDSS–MOC pushed this value to $H_V \simeq 15—16$, providing taxonomic information for a large population of small asteroids for which spectroscopic observations can only be obtained using very large telescopes.

In this paper we used the photometric data of asteroids in the Cybele region in the SDSS–MOC to constrain the spectral characteristics of small members of this group. Since the spectral differences between these dark objects in the outer belt are mainly in their spectral slope, we expect to distinguish to which taxonomic class an object belongs. However, we must note that due to the intrinsic limitations of the few band photometry, this analysis provides only a good indication of the taxonomic type. In the following section we introduce the methodology applied to search the database. In Section 3 we present the results, and in Section 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 $\lambda_u \simeq 3540$Å, $\lambda_g \simeq 4770$Å, $\lambda_r \simeq 6230$Å, $\lambda_i \simeq 7630$Å, and $\lambda_z \simeq 9130$Å, and bandwidths of $\Delta\lambda_u \sim 570$Å, $\Delta\lambda_g \sim 1380$Å, $\Delta\lambda_r \sim 1380$Å, $\Delta\lambda_i \sim 1530$Å, and $\Delta\lambda_z \sim 1350$ 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 (Jurić et al., 2002). These observations correspond to 43,424 individual bodies. From this sample we only select objects in the Cybele region, i.e., asteroids with semimajor axis in the range 3.34–3.70 AU, eccentricities smaller than 0.3, inclinations smaller than 25°, and far from the external limit of the empirical region used by Roig et al. (2002) to study the dynamics of resonant objects in the Hecuba gap.

In order to analyze these observations, we compute the relative reflectance $F(\lambda)$ at each band center using the observed colors corrected by the solar contribution, $C_{u-r} = (u - r) - 1.77$, $C_{g-r} = (g - r) - 0.45$, $C_{r-i} = (r - i) - 0.10$, and $C_{r-z} = (r - z) - 0.14$, where the values of the solar colors were taken from Ivezić (2001). The relative reflectance at each band center, normalized to the relative reflectance at the r band, were defined as $F_u = 10^{-0.4C_{u-r}}$, $F_g = 10^{-0.4C_{g-r}}$, $F_i = 10^{-0.4C_{r-i}}$, and $F_z = 10^{-0.4C_{r-z}}$.

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 ΔC are the color errors computed as the root squared sum of the magnitude errors. In the case of F_r, its error was estimated as $\Delta C_r = \sqrt{2}\Delta r$. Then, we proceeded to discard what we consider as "bad" observations, i.e., those observations for which $\Delta F/F$ was larger than 10% at g, r, i, and z bands, and larger than 20% at u band. The spectral slopes were obtained as a linear fit to the relative reflectance at g, r, i, and z bands.

3. Results

Using our selection method we ended up with a final sample of 124 observations corresponding to 89 asteroids in the Cybele region with absolute magnitudes $H_V < 15.7$, 15 of them with two observations in the SDSS, 7 with three, and 2 with four. The spectrophotometric data obtained from these observations double the database of Cybele asteroid taxonomy and increase by three magnitudes the magnitude limit.

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

$$d_i^2 = \frac{\sum_{k=1}^{n} (P_{ik} - P_{ok})^2 (\sigma_{ik}^2 + \sigma_{ok}^2)^{-1}}{\sum_{k=1}^{n} (\sigma_{ik}^2 + \sigma_{ok}^2)^{-1}}, \tag{1}$$

where d_i is the distance between the ith and a mean spectrum, P and P_o represents the individual channels making up the individual and mean spectrum, σ and σ_o are the errors in the channel, and the total number of channels is n. The mean spectra for each taxonomic class were obtained from Bus and Binzel (2002b). Although it is possible to use this method to select for each object in our sample any one of the 26 taxonomic types proposed by Bus and Binzel (2002b), it is advisable to group related taxonomic types in a broader class to circumvent the limitations of the few band photometry. Thus, the asteroids in our final sample were taxonomically classified using the dissimilarity criterion and the (Bus and Binzel, 2002b) taxonomy, and then assigned to a broad class clustering taxonomic types with similar characteristics and with similar limits for the spectral slope than those proposed by Dahlgren and Lagerkvist (1995). As we only have the spectrophotometric information, we propose differentiate only three broad classes: a broad D-class (including D, T, K, L, and Ld types of Bus and Binzel (2002b), spectral slopes $S' \geqslant 6\%/1000$ Å), a broad X-class (including X, Xe, Xc, and Xk types, $2\%/1000$ Å $\leqslant S' < 6\%/1000$ Å), and a broad C-class (including C, Cb, Cg, Ch, Cgh, and B types, $S' < 2\%/1000$ Å), with 26, 34, and 23 members, respectively. Notice that P-type asteroids in Tholen (1984) classification are X-class in this squeme. The absolute magnitude, semimajor axis, eccentricity, inclination, Tisserand parameter, number of SDSS observations, and spectral slope for these objects are listed in Tables 1–3.

The asteroids (11589) 1994 WG, (11616) 1996 BQ_2, (34649) 2000 WB_{103}, (62483) 2000 SG_{221}, (71627) 2000 EY_{66}, and 2001 QT_{232}, do not fit in these broad classes since the classification method assigned (71627) to the O-class and the other five objects to the S-class of Bus and Binzel (2002b). Their SDSS normalized relative reflectance are shown in Fig. 1 in order to show that the method we used correctly classificate the asteroids by spectral classes. Notice that the absorption band longward of 7500 Å, typical of these taxonomic classes, is clearly seen for the six objects. The presence of O- and S-class asteroids in this region is not

Table 1
List of candidate broad D-class Cybele asteroids.

Asteroid		H	a (AU)	e	i (°)	Tiss.	No. obs.	S' (%/1000 Å)
1328	Devota	10.31	3.492	0.14545	5.77	3.11	4	10 ± 1
2311	El Leoncito	10.52	3.634	0.05233	6.64	3.09	1	9 ± 1
3622	Ilinsky	11.40	3.390	0.03508	4.95	3.14	2	10 ± 1
4169	Celsius	10.90	3.390	0.17584	10.18	3.10	1	8 ± 1
4423	Golden	11.30	3.393	0.09551	19.30	3.06	1	6 ± 1
5495	Rumyantsev	11.10	3.421	0.04069	9.20	3.13	1	9 ± 1
6039	Parmenides	11.30	3.408	0.06413	13.16	3.11	1	11 ± 1
8988	1979 MA4	12.90	3.419	0.19685	4.13	3.11	1	12 ± 1
13832	1999 XR13	10.50	3.370	0.11492	16.16	3.09	1	10 ± 1
14330	1981 EG21	13.40	3.390	0.08860	5.98	3.14	1	8 ± 2
21867	1999 TQ251	12.60	3.364	0.05731	17.48	3.09	1	9 ± 1
29071	5048 T-3	12.90	3.383	0.12997	14.99	3.09	2	7 ± 1
32185	2000 ND23	12.90	3.380	0.04254	11.59	3.12	1	8 ± 1
34750	2001 QB97	13.60	3.380	0.09383	10.81	3.12	2	11 ± 1
37291	2001 AP26	13.80	3.427	0.05183	8.90	3.12	1	9 ± 1
42068	2000 YA133	13.20	3.431	0.07897	8.66	3.12	1	9 ± 1
56975	2000 SP161	13.70	3.362	0.08286	9.86	3.13	1	9 ± 1
60934	2000 JL51	14.50	3.358	0.07109	2.83	3.15	2	9 ± 2
61102	2000 LM30	13.50	3.382	0.13394	15.87	3.08	3	8 ± 1
63554	2001 QA8	14.40	3.365	0.05896	7.14	3.14	2	9 ± 1
77735	2001 OJ76	14.00	3.525	0.09593	12.25	3.08	1	8 ± 1
	1999 XS112	12.92	3.413	0.16328	19.20	3.04	1	12 ± 1
	2000 SR325	15.73	3.455	0.34971	12.67	3.00	1	10 ± 1
	2001 VU95	16.13	3.436	0.33941	12.11	3.02	1	12 ± 1
	2002 PF111	13.56	3.456	0.08092	10.62	3.11	2	7 ± 2
	2003 SJ56	14.23	3.383	0.01209	13.34	3.11	1	10 ± 1

Table 2
List of candidate broad X-class Cybele asteroids.

Asteroid		H	a (AU)	e	i (°)	Tiss.	No. obs.	S' (%/1000 Å)
260	Huberta	8.97	3.442	0.12374	6.45	3.12	3	3 ± 1
1177	Gonnessia	9.30	3.349	0.02600	15.10	3.11	1	2 ± 1
1556	Wingolfia	10.55	3.418	0.11784	15.77	3.08	3	4 ± 1
4014	Heizman	12.00	3.423	0.03331	1.10	3.14	1	5 ± 1
4158	Santini	11.40	3.399	0.02009	6.20	3.14	1	3 ± 1
6924	Fukui	11.20	3.388	0.09790	12.21	3.11	2	4 ± 1
10257	Garecynthia	12.50	3.456	0.08694	4.95	3.13	1	6 ± 1
10379	Lake Placid	13.20	3.502	0.02745	6.53	3.12	1	5 ± 1
10653	Witsen	12.50	3.648	0.01501	3.31	3.10	1	5 ± 1
18150	2000 OC60	12.30	3.443	0.09619	12.78	3.10	1	4 ± 1
18959	2000 QG129	13.40	3.503	0.06247	9.32	3.11	1	3 ± 1
24550	2001 DM71	14.70	3.381	0.04346	1.72	3.15	1	4 ± 1
26607	2000 FA33	13.10	3.395	0.04932	16.46	3.09	2	3 ± 1
27719	1989 SR3	12.90	3.409	0.05509	3.56	3.14	1	5 ± 1
42767	1998 SJ150	13.50	3.429	0.03027	11.44	3.11	2	5 ± 2
45709	2000 FR36	13.40	3.371	0.01808	12.67	3.12	3	6 ± 2
47114	1999 CP61	12.30	3.386	0.09985	9.95	3.12	1	3 ± 1
51309	2000 KN62	14.00	3.400	0.02834	12.18	3.12	1	4 ± 1
59903	1999 RO148	13.60	3.396	0.08707	15.60	3.09	1	3 ± 1
61820	2000 QV191	13.70	3.499	0.10524	11.11	3.09	1	2 ± 1
62744	2000 UX1	13.70	3.358	0.02814	9.28	3.14	1	4 ± 1
63283	2001 DA46	14.60	3.362	0.05667	4.54	3.15	1	4 ± 2
90277	2003 DS7	13.60	3.393	0.08716	9.16	3.13	1	2 ± 2
	1999 VL85	13.03	3.519	0.05683	19.26	3.04	1	4 ± 1
	2001 EF8	13.49	3.460	0.00464	8.05	3.12	1	6 ± 1
	2001 TG219	14.37	3.554	0.12084	6.84	3.10	2	3 ± 2
	2001 TS196	13.80	3.423	0.18961	16.18	3.06	1	3 ± 1
	2001 TX145	14.68	3.389	0.01718	6.43	3.14	1	6 ± 1
	2001 YK112	14.25	3.477	0.06406	9.35	3.11	1	4 ± 1
	2002 BW12	13.87	3.526	0.02577	9.32	3.11	1	3 ± 1
	2002 RL200	12.78	3.494	0.09193	8.89	3.11	1	3 ± 1
	2003 BF38	13.60	3.561	0.07301	19.03	3.03	1	3 ± 1
	2003 EZ55	14.81	3.453	0.07597	11.43	3.11	1	5 ± 1
	2004 BS19	13.62	3.442	0.04046	10.71	3.11	1	4 ± 1

unexpected, since the number of S-type objects near the inner side of the Hecuba gap is low but not zero (Mothé-Diniz et al., 2003). The presence of these objects in the Cybele region could be the result of a dynamical mechanism acting on objects in the inner border of the gap, like migration due to Yarkovsky effect, or resonance perturbations on unstable asteroids inside the Hecuba gap.

Only 6 of the 89 asteroids selected in our sample have been previously observed spectroscopically: (260) Huberta, (1177)

Table 3
List of candidate broad C-class Cybele asteroids.

Asteroid		H	a (AU)	e	i (°)	Tiss.	No. obs.	S' (%/1000 Å)
25792	2000 CZ62	13.00	3.408	0.06242	8.11	3.13	2	2 ± 1
27189	1999 CF51	12.60	3.385	0.03343	9.26	3.13	1	1 ± 1
45637	2000 EW12	13.80	3.374	0.09689	9.48	3.13	2	1 ± 1
51199	2000 JA4	13.80	3.447	0.06702	16.03	3.08	2	1 ± 2
68497	2001 UZ33	14.60	3.385	0.13942	9.40	3.12	1	0 ± 1
83452	2001 SG62	14.20	3.424	0.16208	17.00	3.06	2	1 ± 2
83738	2001 TA126	14.50	3.417	0.14023	17.29	3.07	1	1 ± 1
84873	2003 BW55	14.10	3.412	0.06674	10.62	3.12	1	1 ± 1
	2000 GN138	13.68	3.427	0.06374	14.63	3.09	1	0 ± 1
	2000 SH339	13.31	3.423	0.17035	18.32	3.05	1	1 ± 1
	2000 SY173	14.11	3.395	0.18665	15.50	3.07	1	2 ± 1
	2001 DS69	14.59	3.385	0.09954	8.11	3.13	1	−2 ± 1
	2001 MQ7	14.15	3.414	0.10055	17.02	3.08	1	1 ± 1
	2001 XP263	14.23	3.500	0.08093	17.29	3.06	1	1 ± 1
	2002 AC95	13.87	3.386	0.08448	13.19	3.11	1	0 ± 1
	2002 CF107	13.46	3.498	0.08053	9.95	3.10	1	1 ± 2
	2002 JH1	13.95	3.442	0.11134	15.88	3.08	1	2 ± 2
	2002 KA	13.66	3.403	0.11052	17.26	3.07	1	1 ± 1
	2002 UO38	13.45	3.427	0.00723	17.04	3.08	1	2 ± 1
	2003 FE70	15.13	3.470	0.02414	9.87	3.11	1	1 ± 2
	2003 SO206	14.30	3.544	0.05257	12.39	3.09	4	2 ± 3
	2003 UX263	14.46	3.431	0.18015	9.22	3.10	3	1 ± 1
	2004 BA42	13.37	3.563	0.00495	19.01	3.04	1	1 ± 1

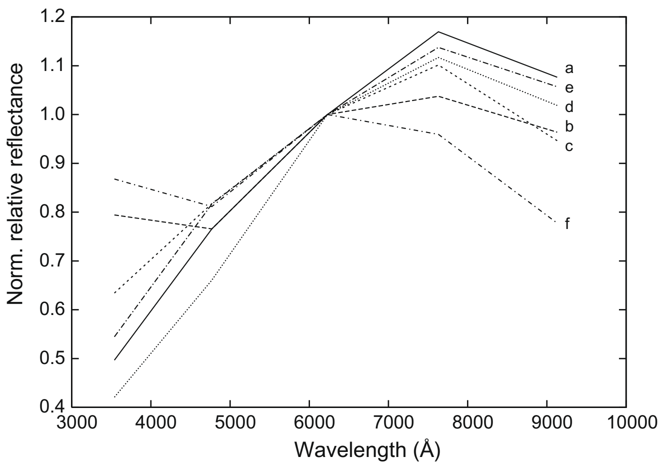

Fig. 1. SDSS normalized relative reflectance of the O- and S-class asteroids identified: (a) (11616) 1996 BQ_2; (b) (62483) 2000 SG_{221}; (c) 2001 QT_{232}; (d) (11589) 1994 WG; (e) (34649) 2000 WB_{103}; and (f) (71627) 2000 EY_{66}. The last one has been classified in the O-class, and the other five in the S-class of Bus and Binzel (2002b). The relative reflectance is normalized to 6230 Å. Notice that the absorption band longward of 7500 Å, typical of O- and S-class asteroids, is clearly seen, showing that the method we used correctly classificate the asteroids by spectral classes.

Gonnessia, (1328) Devota, and (1556) Wingolfia, classified by Lazzaro et al. (2004) as X-, X-, D-, and X-type, respectively, and (4014) Heizman and (4168) Santini classified by Lagerkvist et al. (2005) as PD- and X-type, respectively, which agree very well with the classification using SDSS data.

4. Discussion

Fig. 2 shows a histogram of the SDSS spectral slopes for Cybele asteroids. The fraction of broad X-type objects (41%) is slightly larger than the fraction of D-type ones (31%). The broad C-class appears at smaller slopes (<2%/1000 Å). Since the number of broad X-class objects in the Cybele region is similar to the number of broad D-class asteroids, it does not verify for the small asteroids sampled by the SDSS the correlation between size and spectral slope, or asteroid taxonomy, suggested by Lagerkvist et al. (2005). These authors argued that for the Cybeles the D-type asteroids are significantly more numerous at smaller diameters than P-types (X-class), while the X-class dominates at larger sizes.

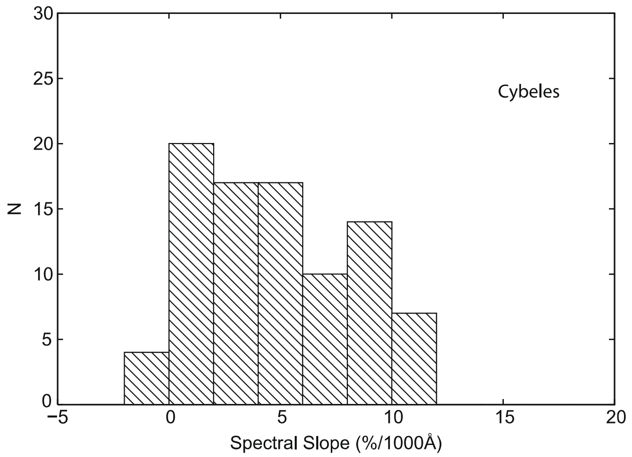

Fig. 2. Histogram of the SDSS spectral slopes for Cybele asteroids. The typical slopes for the broad C-, X-, and D-classes are less than 2, between 2 and 6, and larger than 6%/1000 Å, respectively.

We searched for correlations between semimajor axis, eccentricity, inclination, and Tisserand parameter with the spectral slope, but we did not find any significant relation among them. The only important case to mention is the relation of the spectral slope with absolute magnitude. In Fig. 3, we show a plot of the spectral slope as a function of the absolute magnitude for Cybele asteroids, including spectroscopic results taken from the literature. Assuming that the albedo for these objects is constant, the abscissa in the plot is a direct measurement of their sizes. The correlation with spectral slope claimed by Lagerkvist et al. (2005) is observed only for large objects with $H_V < 11.5$—12. The small objects with $H_V > 12$, which are objects of the SDSS sample, are not concentrated at any preferential spectral slope and are distributed among D-, X- or C-classes. This result presents strong evidence against the preferred scenario of Lagerkvist et al. (2005), where they suggest that D-type objects are more fragile than P-types, favoring

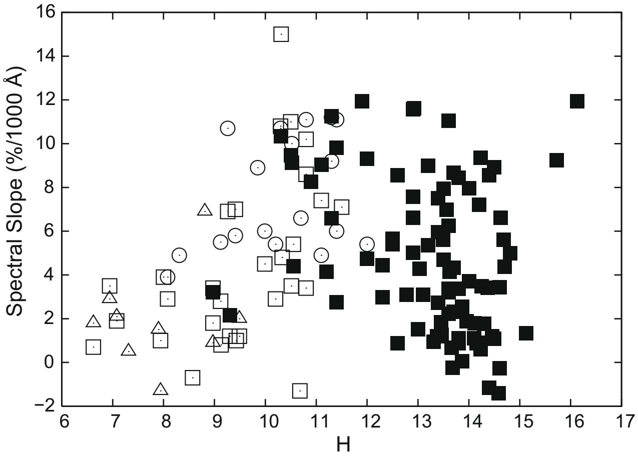

Fig. 3. Spectral slopes in function of the absolute magnitude for Cybele asteroids. Data from the SMASS survey (Bus and Binzel, 2002a) are indicated with triangles, from the S^3OS^2 survey (Lazzaro et al., 2004) with squares, from other campaigns (Lagerkvist et al., 2005; Fitzsimmons et al., 1994) with circles, and the sample obtained from the SDSS with filled squares.

disruptive collisions of precursors of the first type and resulting in a larger fraction of the smaller body population being collisional fragments from a few large D-type precursors.

In order to compare the spectral properties of Cybeles and other outer belt populations we made a statistical comparison using a χ^2 test between the SDSS spectral slope histograms for Cybele asteroids and that for Hilda asteroids obtained by Gil-Hutton and Brunini (2008). The test showed that it is not possible to reject the hypothesis that both samples were obtained from the same population at a confident limit of 90%. The mean S' values of the SDSS slope distributions are 4.78 ± 3.42 and 5.34 ± 3.62 for the Cybeles and the Hildas respectively, so colors at this size ranges are very similar in both populations. This result could be indicative of certain homogeneity in the taxonomic distributions of the outer belt populations due to either a similar original composition or a physical resurfacing processes of these distant bodies.

Also the behavior of the spectral slope of Cybele asteroids for different absolute magnitude is similar to that found by Gil-Hutton and Brunini (2008) for the Hildas, which could also give support to certain homogeneity in the taxonomic distributions observed in the outer belt. In the case of the Hildas, Gil-Hutton and Brunini (2008) explained the behavior of spectral slopes vs. absolute magnitude by a combination of space weathering and a peculiar size distribution resulting from the fact that the Hildas are objects orbiting inside a narrow stable zone in the 3:2 mean motion resonance with Jupiter (Nesvorný and Ferraz-Melo, 1997; Ferraz-Mello et al., 1998), but this process does not work at all for the Cybeles since these objects are not orbiting in a mean motion resonance.

Since it is difficult to find analogous meteorites for these taxonomic types, it is also complex to find differences between the surface composition of objects belonging to these types. Although organics have yet to be identified spectroscopically (see Emery et al. (2006) and reference therein), many authors invoke them to explain the red spectral slopes of those asteroids in the outer belt (Gaffey et al., 1989; Vilas et al., 1994). Andronico et al. (1987) note that not only the color but also the albedo of an organic layer depends on the amount of energy deposited by the particles interacting with the material: a neutral organic layer becomes red at certain low radiation doses, but if the dose increases the organic layer becomes neutral again and the albedo of the layer decreases, becoming darker and darker at higher doses. If this scenario is correct, the Cybele asteroids with $H < 11-12$ are large objects that could survive almost intact the collisional process, but the largest asteroids in this absolute magnitude range become darker and darker since the radiation dose received is very high and the collisional process does not seriously affect their surfaces. On the other hand, the smaller objects in this absolute magnitude range become red because their surfaces are substantially altered by the collisional process that partially destroys the most external layer and excavates underneath fresh material reaching a red color due to an equilibrium between the collisional process and the space weathering. In the case of smaller objects ($H > 12$) the collisional process could fragmented these asteroids exposing fresh and more neutral material, but the fragments obtained spectral slopes depending on the radiation dose received which is proportional to the exposing time. Thus, the range of probable spectral slopes is larger for the smaller objects what is in excellent agreement with Fig. 3.

The results presented in this paper show that the correlation between size and spectral slope suggested by Lagerkvist et al. (2005) for Cybele asteroids is correct only for large objects ($H_V < 12$) but it is not supported by data obtained from the SDSS–MOC for the small ones. Despite the intrinsic limitations of the few band photometry of the SDSS, the analysis presented is based mainly in the detection of spectral slopes providing enough good indication about the taxonomic type of these asteroids and making us confident about our conclusions.

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