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The Hungaria population: A comparison between sub-groups

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ABSTRACT

To investigate if the two sub-groups in proper inclination found in the Hungaria region by Milani et al. (2010) could be characterized by physical parameters of the objects, we analyze two surfaces properties of the asteroids in the zone: the taxonomical distribution, obtained from the SDSS-MOC4, and the albedo distribution, taken from the WISE data. Our analysis suggests that both sub-groups are different. The asteroids with $\sin i_p < 0.4$ exhibit a majority of X-types objects and an excess of high albedo objects. In contrast, the objects with $\sin i_p > 0.4$ show a taxonomical distribution dominated by S-types asteroids and an albedo distribution without high albedo excess. Based on these results we propose that the sub-group in high proper inclination and dominated by S-types could be the primordial population while the high albedo excess observed in the other sub-group could be the consequence of a contamination in this region with a medium-belt object(s) that filled the Hungaria region with fresh X-types after suffering a catastrophic collision.

1. Introduction

The Hungaria 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 with very complex dynamics surrounded by the 5:1 and 4:1 mean motion resonances with Jupiter, and the ν_5 and ν_{16} secular resonances (Scholl and Froeschlé, 1986). As a result of their location in the inner asteroid belt, the members of this group could be the sources of the asteroids that must replenish the short-living Mars-crosser population (Michel et al., 2000; Bottke et al., 2012). The Hungarias are currently clustered in the orbital element space due to long-term dynamical processes, but Williams (1989), Williams (1992) and Lamaitre (1994) identified some dynamical clustering in the proper elements space, possibly indicating the presence of families.

Historically it has been considered that the Hungaria region contained predominantly bright E-type objects because 6 of 13 E-type asteroids classified by Tholen (1984) belong to this region. This assumption has been questioned by the results obtained in spectroscopic and polarimetric surveys performed by Carvano et al. (2001) and Gil-Hutton et al. (2007), respectively, who concluded that this population is not as peculiar as it was previously assumed and has a taxonomical distribution consistent with the inner region of the belt. This result has been confirmed by Assandri and Gil-Hutton (2008) and Cañada-Assandri (2012) using a larger sample and the photometric data from the *Sloan Digital Sky Survey* (SDSS). These authors also found evidences of some dynamical mechanism acting that could bring to this region objects from the external and middle regions of the belt.

Recently Milani et al. (2010), obtained synthetic proper elements for the Hungarias and found that in a plot of proper semimajor axis against proper inclination it is possible to identify a dense core for proper inclinations $20^\circ \lesssim i_p \lesssim 23^\circ$. Around the dense core there is a less dense halo of objects with $\sin i_p > 0.4$ that allow to separate the population in two sub-groups, one with $\sin i_p < 0.4$ and the other with $\sin i_p > 0.4$. The reason for this separation is unclear because the region is dynamically complex, but could be the result of high-order secular resonances operating in the zone (see e.g., Fig. 11 in Milani et al., 2010). It is not clear if exists a relation between these two sub-groups or if they have a common origin and evolution, but the separation of both sub-groups in proper inclination is clear. These authors also found a dynamical family in the low proper inclination sub-group, which could be responsible for the dense core observed, but they can not completely separate it from the background because the large single cluster dominates the population. Previously, Warner et al. (2009) found in this region a family linked to the asteroid (434) Hungaria using pseudo-proper elements, but the inherent difficulties of calculating proper

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elements for high inclination orbits have delayed any confirmation until the work of Milani et al. was published.

The existence of a family in one of these sub-groups is an important fact. A family of asteroids formed as a result of a collision implies a common origing of its members and then it must be expected certain similarity among their physical properties. Two properties that have a strong relation with the object composition are the taxonomy and the albedo. These physical properties are also related each other since objects of the same taxonomic type show similar polarimetric properties, and the polarimetric parameters are directly related with the albedo (Muinonen et al., 2002; Penttilä et al., 2005; Gil-Hutton et al., 2007). Then, if there is an asteroid family superimposed to a background population it is possible to distinguish the family studying the distribution of taxonomic types and/or albedo of its members and compare them with those found for the background. Milani et al. (2010) tried to separate background objects from family members using this method and colors from the SDSS, but they only obtain a statistical result about the distribution of the Hungaria objects in three broad taxonomical classes.

One possibility to do a comparison of the family members with the background objects is to analyze the properties of the asteroids in the two sub-groups separated in proper inclination. It is clear that the core at low proper inclination is dominated by objects belonging to the family, but those in the halo at high proper inclination could be representative of the background population. To perform this type of comparison between these two sub-groups is desirable to have databases as large as possible to maximize the possibility to find some of the objects of interest in it. Two convenient choices to obtain taxonomy and albedos are the last release of the *Sloan Digital Sky Survey* (SDSS) and the infrared catalog of the *Wide-field Infrared Survey Explorer* (WISE), respectively.

The SDSS has a sub-product called the *Moving Objects Catalog* (MOC), which in its fourth release provides five band photometry for 104,449 asteroids (Ivezić et al., 2001; Jurić et al., 2002). In order to analyze the surface composition of asteroids and to perform a taxonomic classification, multiband photometry is not as precise as spectroscopy, but the amount of data of the SDSS-MOC significantly contrast with the only $\sim$2300 asteroids observed by the major spectroscopic surveys presently available: the SMASS (Xu et al., 1995; Bus and Binzel, 2002b) and the S^3OS^2 (Lazzaro et al., 2004). Moreover, while these spectroscopic surveys reached an average absolute magnitude of H$\sim$11, the SDSS-MOC pushed this value to H$\sim$17, providing taxonomic information of a huge population of very small asteroids for which spectroscopic observations can only be assessed using very large telescopes.

On the other hand, WISE is a NASA Medium-class Explorer mission designed to survey the entire sky in four infrared wavelengths. A description of how the mission was organizing before launch and post launch development can be seen in Mainzer et al. (2005), Liu et al. (2008) and Wright et al. (2010), respectively.

In this paper we present a comparison of the taxonomic and albedo distributions for the two sub-groups of Hungaria objects at different proper inclination to test if there are differences in the surface properties of their respective members. In Section 2 we explain the searching mechanisms and data processing applied to each catalog to extract the data, in Section 3 we present the results, and in Section 4 the conclusions.

2. Methodology

The Hungaria asteroids were selected from the *Asteroids Dynamic Site* (AstDyS)[1] considering that these objects have a semimajor axis in the range 1.77 AU $< a <$ 2.06 AU and inclination between 16° and 30°. Nevertheless, to avoid objects strongly affected by Mars we discard of the sample the mars-crossing asteroids, i.e., objects with perihelion distance (q) less than 1.666 AU. Following these criteria we obtain 2693 numbered asteroids and 2652 multi-opposition objects, all of them with synthetic proper elements. This Hungarias sample was divided in two sub-groups taking into account their proper inclination obtaining 384 asteroids with $\sin i_p > 0.4$ (H_U sub-group) and 4961 objects with $\sin i_p < 0.4$ (H_D sub-group). The large difference in the number of objects in both sub-groups is due to the presence of the dense core of the Hungarias that belongs to the H_D sub-group.

The next step is to search for these objects in the SDSS and WISE data to obtain new samples for the H_U and H_D sub-groups that allow a taxonomic and albedo comparison between them. 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 $\lambda_u \sim 3540\,\text{Å}$, $\lambda_g \sim 4770\,\text{Å}$, $\lambda_r \sim 6230\,\text{Å}$, $\lambda_i \sim 7630\,\text{Å}$, and $\lambda_z \sim 9130\,\text{Å}$, and bandwidths of $\Delta\lambda_u \sim 570\,\text{Å}$, $\Delta\lambda_g \sim 1380\,\text{Å}$, $\Delta\lambda_r \sim 1380\,\text{Å}$, $\Delta\lambda_u \sim 1530\,\text{Å}$, and $\Delta\lambda_u \sim 1350\,\text{Å}$. 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 with their corresponding errors. The fourth release of the MOC has 471,569 entries linked with 104,449 know asteroids (Jurić et al., 2002).

In order to obtain a taxonomic classification we first extract the observations of all the Hungaria asteroids in the MOC catalog. Then we compute the reflectance flux at each band center using the observed colors corrected by the solar contribution. Finally, the taxonomic type of each object was found calculating the dissimilarities between the individual spectrum and mean spectra for the different taxonomic types obtained from Table III of Bus and Binzel (2002a). For a complete description of this procedure see Assandri and Gil-Hutton (2008). We prefer to use a dissimilarity method over a principal component analysis because both methods produce similar results, but with the dissimilarity method is possible to assign directly the object to a broad taxonomic class by comparison with a template. This procedure is easier than try to assign a taxonomic type to a region on a principal component plot.

The WISE satellite observed at 3.4 μm, 4.6 μm, 12 μm, and 22 μm, and provides observations of 157, 000 objects including Near-Earth Objects, Main Belt Asteroids, Hungarias, comets, Hildas, Jupiter Trojans, Centaurs, and scattered disk objects (Mainzer et al., 2011). The thermal model used in WISE for the albedo determination is the “Near-Earth Asteroid Thermal Model” (NEATM), proposed by Harris (1998). The objects are modeled as spheres without rotation, with an emissivity of $\epsilon = 0.9$ and a magnitude-phase slope parameter of $G = 0.15$, while the errors of the parameters were obtained from the application of Monte Carlo methods. The effects produced by the object rotation is smoothed along the observation time interval of $\sim$36 h, but it is possible that slow rotators may exhibit bad adjustments. The WISE catalog provides absolute magnitude, diameter, geometric albedo, beaming parameter, fluxes, etc. of each observed body.

Mainzer et al. (2011) noted that WISE exhibits an anomalous concentration of high albedos objects ($p_v > 0.5$) in the region of Hungarias and inner main belt. This could be a consequence of the use of a wrong absolute magnitude (H) because WISE assumes a constant magnitude-phase slope parameter. This problem is perhaps exacerbated by the large phase angle that any object in the inner main belt can reach in comparison with other regions of the belt, producing a large error when the computation process extrapolates the magnitude to zero phase angle. Thus, to avoid contaminating the samples with spurious values we only take into account albedo less than $p_v = 0.5$, which is slightly higher than the highest

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[1] AstDyS website: http://hamilton.dm.unipi.it/cgi-bin/astdys/.