EPSC Abstracts
Vol. 8, EPSC2013-27, 2013
European Planetary Science Congress 2013

A multi-domain approach to asteroid family identification

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Abstract

It has been shown that large families are not limited to what found by hierarchical clustering methods (HCM) in the domain of proper elements (a,e,sin(i)), that seems to be biased to find compact, relatively young clusters, but that there exists an extended population of objects with similar taxonomies and geometric albedo, that can extend to much larger regions in proper elements and frequencies domains: the family ``halo". Numerical simulations can be used to provide estimates of the age of the family halo, that can then be compared with ages of the family obtained with other methods. Determining a good estimate of the possible orbital extension of a family halo is therefore quite important, if one is interested in determining its age and, possibly, the original ejection velocity field. Previous works have identified families halos by an analysis in proper elements domains, or by using Sloan Digital Sky Survey-Moving Object Catalog data, fourth release (SDSS-MOC4) multi-band photometry to infer the asteroid taxonomy, or by a combination of the two methods. The limited number of asteroids for which geometric albedo was known until recently discouraged in the past the extensive use of this additional parameter, which is however of great importance in identifying an asteroid taxonomy. The new availability of geometric albedo data from the Wide-field Infrared Survey Explorer (WISE) mission for about 100,000 asteroids significantly increased the sample of objects for which such information, with some errors, is now known.

In this work we proposed a new method to identify families halos in a multi-domain space composed by proper elements, SDSS-MOC4 (a',i-z) colors, and WISE geometric albedo for the whole main belt (and the Hungaria and Cybele orbital regions [1], [2]). Assuming that most families were created by the breakup of an undifferentiated parent body, they are expected to be homogeneous in colors and albedo. The new method is quite effective in determining objects belonging to a family halo, with low percentages of likely interlopers, and results that are quite consistent in term of taxonomy and geometric albedo of the halo members.

1. Introduction

In this work we tried use of all the new data on surface colors (SDSS-MOC4) and geometric albedo (WISE and NEOWISE) that is currently available to try to find the most possibly accurate determination of all major main belt family halos. For this purpose we determined the main belt asteroids with synthetic proper elements available at the AstDyS site [3] that also have SDSS-MOC4 and WISE albedo data. We then computed the SDSS-MOC4 colors (a', i-z) and their errors. For our sample of 58955 asteroids with SDSS colors, we have for a':

$$a'=C_1\cdot(g-r)+C_2\cdot(r-i)+C_3 \qquad (1)$$

where C_1 = 0.93967, C_2 = 0.34208, and C_3 =-0.6324, respectively. To avoid including data affected by too large uncertainties, we eliminated from our sample asteroids with errors in proper elements, a', (i-z), and p_V that did not satisfied criteria discussed in [1]. We then defined a distance metrics between two asteroids in a multi-domain space as:

$$d_{md}=\sqrt{d^2+C_{SPV}\left[(\delta a')^2+(\delta(i-z))^2+(\delta p_V)^2\right]}$$

where, $\delta a'$ = a'(2)- a'(1) and similar relations hold for δ(i-z) and δp_V. Following the approach of Bus and Binzel (2002) for a similar distance metric of proper elements and SDSS-MOC principal components, C_{SPV} is a weighting factor equal to 10^6, and d is the standard distance metrics in proper element domain defined in [4].

As first halo members, we selected asteroids that belong to the asteroids family, whose spectral type is compatible with that of the other members according to Mothé-Diniz et al. (2005), Nesvorný et al. (2006), Carruba (2009a,b, 2010b) and other authors, and that, of course, also have acceptable SDSS-MOC4 and WISE/NEOWISE data. For families not treated by these authors, we consulted the list of asteroid families available at the AstDyS site, and the Nesvorný (2012) HCM Asteroid Families V2.0, on the Planetary Data System (see reference list in [1]). We then obtained dynamical groups using Eq. (1), for a value of cutoff d_{md} a bit less than the value for which the family halo merges with the local background. We will discuss an application of the method for the inner main belt, but results are available for the whole main belt and the Hungaria and Cybele orbital regions.

2. The inner main belt

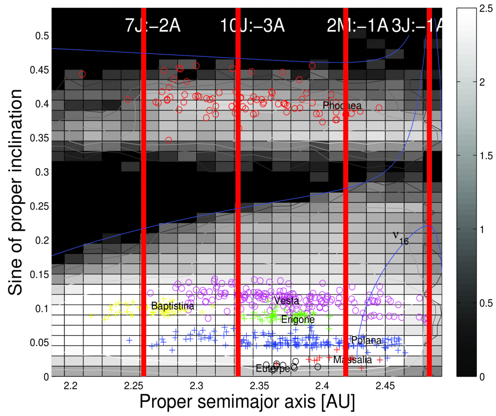

Figure 1: Contour plot of the number density of asteroids in the proper element sample. Superimposed, we display the orbital location of asteroid families in the CX-complex (plus signs), and in the S-complex (circles).

Our results for the inner main belt are summarized in Table 1. In Figure 1 we show a contour plot of the number density of asteroids in the proper element sample. Superimposed, we display the orbital location of asteroids family halos in the CX-complex (plus signs), and in the S-complex (circles). Red lines display the orbital location of mean-motion resonances, and blue lines show the position of secular resonances. Density maps display regions characterized by strong mean-motion or secular resonances by a relatively low number of asteroids per unit bin. Superimposed to the density map, we also show the orbital projection of the halos found in this work shown as plus signs for CX-complex families, and circles for S-complex families.

Family	d_{md} [m/s]	Number of members	Spectral complex	SDSS-MOC4 interlopers	p_V interlopers
Baptistina	250	56	CX	2	47
Vesta	275	161	V	46	26
Erigone	400	57	CX	0	1
Massalia	235	33	S	6	9
Nysa/Polana	280	147	CX	0	1
Euterpe	335	9	S	2	1
Phocaea	> 800	82	S	27	16

The inner main belt is slightly dominated by S-complex asteroids, but with a significant minority of CX-complex bodies. V-type asteroids are mostly concentrated in the Vesta family, but with a significant population outside the dynamical group.

3. Summary and Conclusions

In this work we:

- Introduced a new method to obtain asteroid families and asteroid family halos based on a distance metric in a multi-domain composed of proper elements, SDSS-MOC4 (a',i-z) colors, and WISE geometrical albedo p_V.
- Applied this method to all the major known families in the asteroids' main belt, and in the Cybele and Hungaria orbital regions. Overall, we identified sixty-two asteroid families halos, of which seven were in the inner main belt, thirty-one in the central main belt, nineteen in the outer main belt, three in the Cybele group, and two in the Hungaria region. We confirm the taxonomical analysis performed by Mothé-Diniz et al. (2005), Nesvorný et al. (2006), Carruba (2009a,b), (2010a,b) and other authors (see reference list in [1], [2]), with some small discrepancies for a few minor families in the central main belt.

Acknowledgements

We would like to thank the São Paulo State Science Foundation (FAPESP) that supported this work via the grant 11/19863-3, and the Brazilian National Research Council (CNPq, grant 305453/2011-4).

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