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A STATISTICAL INVESTIGATION OF ASTEROID FAMILIES: PRELIMINARY RESULTS

A. CARUSI and E. MASSARO

The correct identification of asteroid families is a prerequisite for understanding their nature, their orbital evolution and their physical origin. For this reason, a statistical investigation of asteroid families has been carried out, using a new clustering technique developed by A. I. Gavrishin. Proper elements for 2764 asteroids (1810 numbered and 954 Palomar-Leiden-Survey (PLS) asteroids) have been computed. Using these data, the Gavrishin method gives only ten significant classes. Five of them are coincident with the Hirayama families 1, 2, 3, 5, and the Flora group, that cannot be univocally subdivided. The PLS families are recognized. Furthermore many small-sized families reported by several authors lose their statistical relevance.

INTRODUCTION

It is well known that the asteroidal belt doesn't have a uniform structure. A large fraction of the observed objects seem to be clustered in so called "families," first recognized by Hirayama (1919, 1923, 1928). Subsequent searches for families have increased their number from Hirayama's original six to Williams (1975) 104.

Using a new statistical clustering method, recently developed by A. I. Gavrishin (1968, 1974) and adapted for computer techniques by Coradini *et al.* (1976a), we have tried to recognize asteroid families.

A second and quite different method used by us for the searching of families consists in mapping the isodensity curves in (a,e'), (a,i'), and (e',i') planes: families have to correspond with relative density maxima.

The orbital elements of 1,861 numbered asteroids are reported in "Minor Planets Ephemeris" (1976), and recently van Houten *et al.* (1970) have reported the orbital elements of about 1,800 new faint minor planets. Because the orbits of many numbered asteroids have been recalculated, we have determined the proper eccentricity, e', and inclination, i', for all the minor planets with semimajor axis in the range 1.9 - 4.2 A.U. using the tables by Brouwer and van Woerkom (1950). Four point Bessel interpolation has been used for values of a in the center of the range and four point Newton interpolation for values near the minimum and the maximum of the range. To avoid the effects due to the singu-

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PLS minor planets with well determined orbits (class 1) have been taken into consideration.

THE STATISTICAL METHOD

The Gavrishin statistical method used in this analysis has been developed to classify geochemical samples. It has been used with noticeable success in the study of lunar rocks and glasses (Coradini *et al.* 1976b).

In this section we will give only a summary account of it. A detailed description can be found in the quoted references .

The most outstanding characteristic of this statistical procedure is the possibility of an automatic classification in terms of homogeneous taxonomic units. By means of successive transformations the original multivariate distribution has been reduced to an univariate quasi-gaussian distribution with mean value and variance equal to 0 and 1 respectively. If N is the total number of samples, $n_1 < N$ samples, which will form the first class, are selected by a test of appurtenance to a suitably defined normal distribution. The method is afterwards applied to the remaining $N - n_1$ samples to identify the second homogeneous class. By further iterations all the following classes are obtained.

The appurtenance of a sample to a class is based on an hypothesis test where the critical value is represented in terms of a parameter q. The choice of the q value depends on the security level (s.l.) needed : larger the q more general is the classification, for example $q = 3.00$ corresponds to a s.l. of 99.8%.

In the following analysis a value of $q = 1.40$, corresponding to 91.8% s.l., has been used because the first three Hirayama families have been well identified with this value. We have also preferred to use decimal logarithms for e' and i' variables because of smallness of their variation range. This transformation doesn't affect the quality of the results because the method doesn't require any linear relationship among the variables.

The search for families has been done subdividing the entire range of a into five overlapping intervals : (1.90 - 2.50), (2.25 - 2.75), (2.50 - 3.00), (2.75 - 3.25), (3.00 - 4.20). In this way it was possible to note whether or not a "family" recognized in one interval was confirmed in the preceding or in the subsequent one. We have considered as being significant only the confirmed classes excluding those with very few elements, and having a variance better or comparable to that of the first three Hirayama families.

This criterion may seem to be reductive because it doesn't consider as being significant the small sized families, in fact we have noticed that a clear evidence for such families is not supported by the Gavrishin method.

RESULTS

The properties of the recognized families are summarized in Table I. Only ten classes were obtained that fully satisfied our selection criteria. They are indicated by the name of the minor planet with the smallest identification number.

Among the Hirayama families, as reported by Brouwer (1951) and Arnold (1969), four are essentially coincident with ours, and precisely Themis, Eos, Coronis, and Phocaea. Differently from van Houten *et al.* (1970), only few asteroids of the PLS were added to these families.

The new families discovered by van Houten *et al.* (1970) in their survey are essentially confirmed, with the exception of Michela. Noticeable is the fact that Nysa family seems to correspond to the A 74 and B 24 families. The Io family seems to be related to A 69 and A 70, or to B 19 and B 20, and also contains the family recognized by Lindblad and Southworth (1971). Finally Victoria is essentially formed by the families A 77 and B 27.

Particular attention was devoted to the Flora family. It was impossible

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TABLE I

	Name	No. of Elem.	<a>	Range of a	<Log e'>	Range of Log e'		<Log i'>	Range of Log i'		Remarks
1.	Hygiea	41	3.153	3.0726 - 3.2192	-0.863	-0.96738	-0.77448	-1.049	-1.12016	-0.97098	Medea (PLS)
2.	Themis	115	3.142	3.0803 - 3.2138	-0.801	-0.90812	-0.66418	-1.602	-1.76397	-1.38258	Hirayama N1
3.	Eos	82	3.016	3.0003 - 3.0288	-1.136	-1.26059	-1.02993	-0.749	-0.77513	-0.72568	Hirayama N2
4.	Coronis	61	2.875	2.8316 - 2.9182	-1.315	-1.43783	-1.18957	-1.434	-1.45992	-1.39631	Hirayama N3
5.	Io	84	2.646	2.5586 - 2.7377	-0.792	-0.90777	-0.66138	-0.642	-0.71713	-0.56055	Io (PLS), A69-A70, B19-B20
6.	Nysa	82	2.401	2.3380 - 2.4670	-0.764	-0.84436	-0.67233	-1.337	-1.47534	-1.19409	Nysa (PLS), A74, B24
7.	Victoria	28	2.377	2.3295 - 2.4344	-0.699	-0.75183	-0.64015	-0.732	-0.83153	-0.63712	A77, B27
8.	Phocaea	30	2.365	2.3058 - 2.4282	-0.621	-0.86918	-0.50056	-0.353	-0.41125	-0.28943	Hirayama N5
9.	Feronia	29	2.311	2.2518 - 2.3899	-0.1030	-1.0607	-0.96935	-0.930	-1.00371	-0.84488	Vesta (PLS)
10.	Flora	296	2.237	2.1497 - 2.3157	-0.859	-1.04201	-0.71464	-1.133	-1.62178	-0.83690	Hirayama NN 6,7,8,9

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larities of induced oscillations in proximity of 1.94, 2.03, and 2.64, the asteroids very close to these values were rejected.

Proper elements for a total number of 3,606 minor planets (1810 from MPE and 1796 from PLS) were thus obtained, agreeing with van Houten *et al.* (1970)'s proper elements to the fourth decimal point. However in our analysis only 954 to distinguish in a univocal way the four families numbered from 6 to 9 by Brouwer (1951) and Arnold (1969), even though special computation were made to this aim (with different values of q and different ranges of a and e'); several partial classes were obtained, but none appeared in more than computer output, and so did not satisfy our selection criteria. An explanation of this behavior can be found in the presence of a relatively large number of PLA asteroids in the Flora range. Considering only the numbered minor planets, concentrations

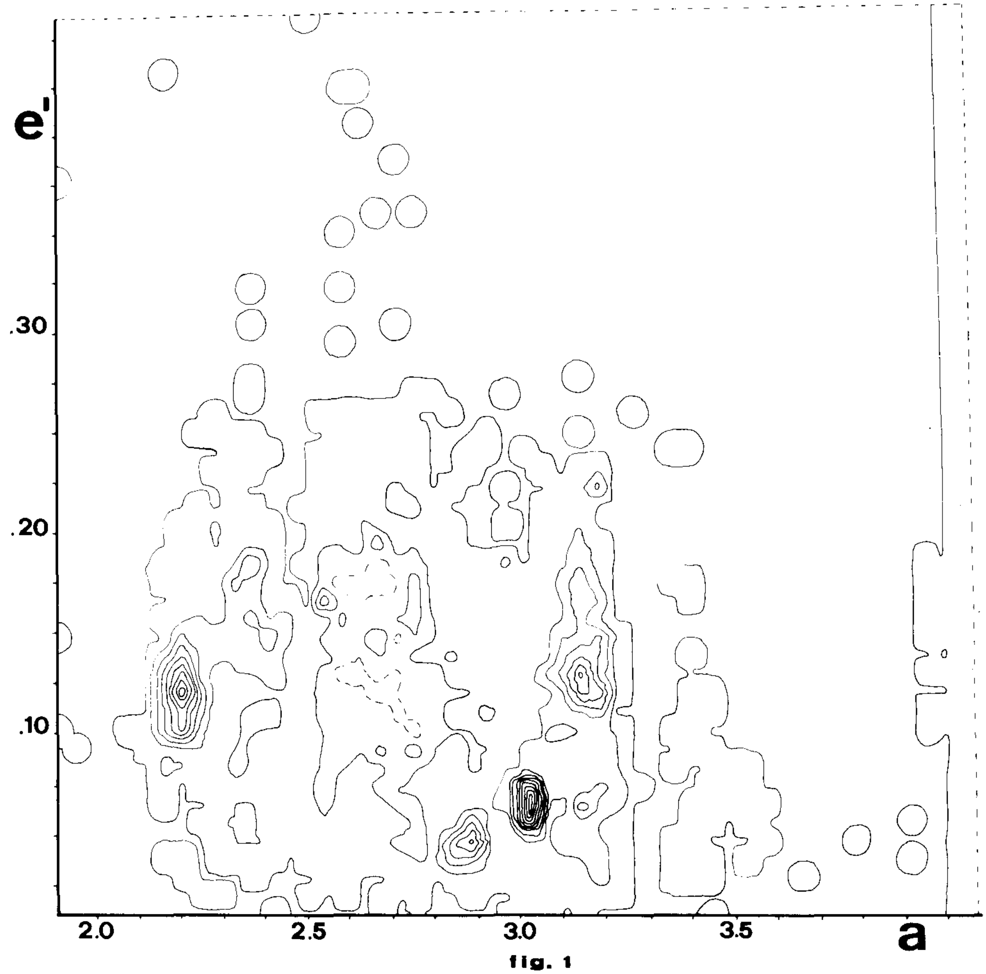

Figure 1. Isodensity curves for numbered asteroid population in the (a,e') plane.

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roughly corresponding to the families 6, 7-8, and 9 were in fact obtained, but when the PLS asteroids were added to them this subdivision disappeared. Also Lindblad and Southworth declare their failure to separate the Flora group into the families 6 through 9, in agreement with our results.

Hirayama family member 4, Maria, has not been separated from the background. In fact it shows a concentration only on a and i' variables, while it is largely scattered in e'. This fact can be verified in Fig. 1 and 2 where the density maps in the (a,e') and (a,i') planes are reported respectively for the population of numbered asteroids. In Fig. 2, in correspondence with Maria, there is a small peak (marked by an asterisk), while no similar peak appears in Fig. 1, so that the reality of this family can be seriously questioned. Similarly the numerous small families reported by the quoted authors cannot be precisely identified and therefore are not included in our list.

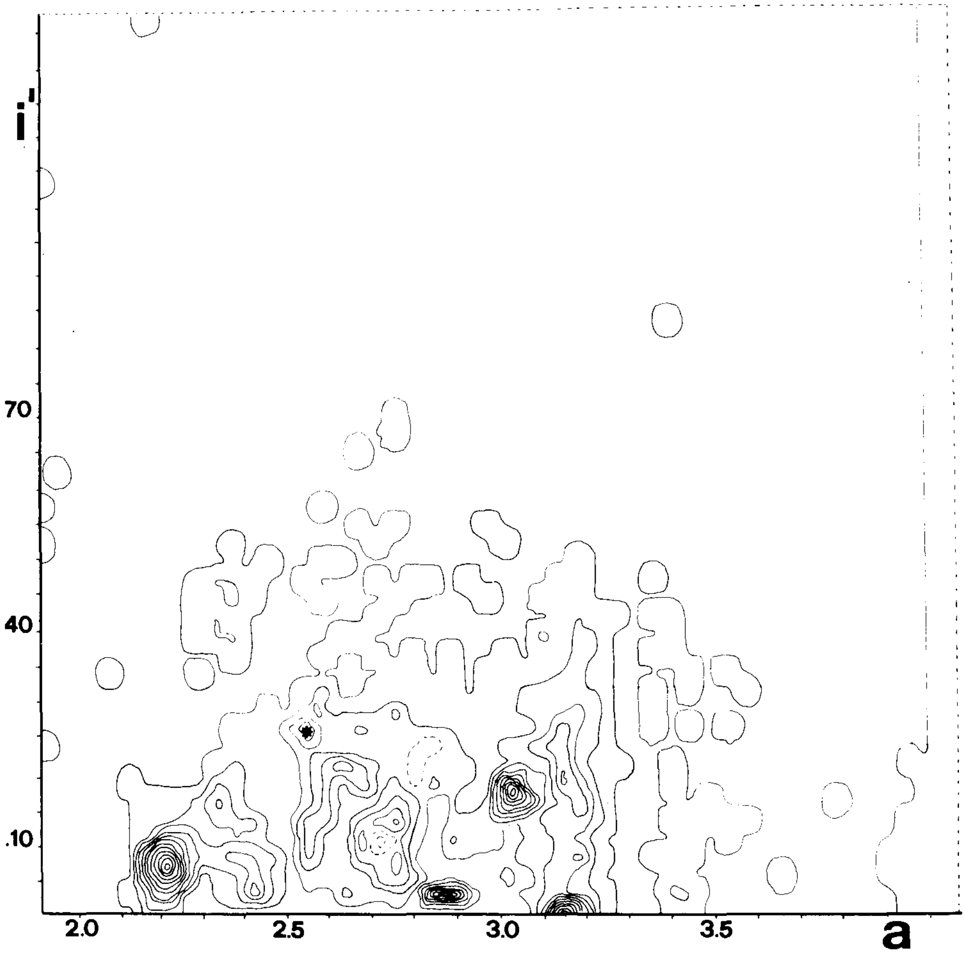

fig. 2

Figure 2. Isodensity curves for numbered asteroid population in the (a,i') plane.

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CONCLUSIONS

1) Using Gavrishin's clustering method we have been able to identify only ten significant asteroid concentrations.

2) This can be confirmed by an inspection of the density maps, which, taking into account only the numbered asteroids, show the existence of four well defined concentrations, *i.e.*, Themis, Eos, Coronis, and Flora.

3) There is no evidence either of Hirayama family number 4 or of Brouwer-Arnold subdivision of the Flora group.

4) The PLS families have been recognized, and some of them correspond to certain known families of the numbered asteroids.

5) Many small sized families, reported by several authors, cannot be separated from the background.

6) Statistical studies, taking into account other variables such as absolute or apparent magnitude, surface composition and albedo, must be performed to minimize selection effects.

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