A STABILITY STUDY OF ASTEROID FAMILIES NEAR THE 3:1 AND 5:2 RESONANCE WITH JUPITER

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Abstract. By using the $D$-criterion Lindblad (1992) has identified 14 asteroid families from a sample of 4100 numbered asteroids with proper elements from Milani and Knežević (1990). Taxonomic types and other physical properties for a significant number of objects in five of the families show strong homogeneity within each family, further strengthening their internal relationship.

To test the hypothesis of a common origin in, e.g., a catastrophic collision event, we have set out to integrate the orbits of the members of the Maria, Dora and Oppavia-Gefion families over some $10^6$ years. The mean distance for the Maria family is close to the 3:1 mean-motion resonance with Jupiter, while the other two families lie close to the 5:2 resonance.

We used a simplified solar system model which included the perturbations by Jupiter and Saturn only and implemented Everhart’s variable stepsize integrator RA15. All close encounters between the family members (within 0.1 AU) were recorded as well. Preliminary results from integrations over $\approx 4 \times 10^5$ years are presented here.

The statistics of close encounters show pronounced peaks for several members within each family, while for others no significant levels above the background of random encounters or even very low frequencies were found. This indicates a subclustering within the families. Quite a lot of very close (<0.005 AU) mutual encounters are found, which suggest that, at least for the larger members in a family, the mutual gravitational interactions could be of some importance for the real orbital evolutions.

The encounter statistics between the Dora and Oppavia family members suggest a possible interrelationship between these two groups.

Key words: Asteroid – families of asteroids – resonances – numerical integrations

1. Introduction

Asteroid families are characterized by almost equal values of the orbital elements $a$, $e$, and $i$ in proper element space. This was first realized by Hirayama (1918) from a then very limited sample of asteroids. Through the development of more accurate theories for the calculation of proper elements during the last 20 years - Yuasa (1973), Williams (1979), Kozai (1979b), Knežević (1986) and Valsecchi et al. (1989) - and the rapidly growing sample of numbered asteroids, a set of 4100 proper elements is nowadays available (Milani and Knežević, 1990). From this sample, Lindblad (1992) identified 14 dynamical families, each with more than 15 members. The $D$-criterion, which was previously used in many meteor stream studies as well as for studying clustering of asteroid and comet orbits (see e.g. Lindblad and Southworth 1971, Lindblad 1985), can be written in the following form for testing orbital similarity in proper elements $a$, $e$, $i$ space

$$D(m, n)^2 = (e_n - e_m)^2 + (q_n - q_m)^2 + (2 \cdot \sin \frac{i_n - i_m}{2})^2$$  (1)
where \( m \) and \( n \) represent two orbits to be compared, and \( q \) is the perihelion distance. The search techniques and selection criteria are described in more detail in Lindblad (1992).

The reality of asteroid families, which have been identified on dynamical grounds, can be checked by studies of the physical properties of the individual members in a family. For most of the larger member in many families such data are available and, indeed, often striking similarities with regard to taxonomic type and albedo are found, which strengthen the hypothesis of a common origin as e.g. emanating from a catastrophic collision event. (For a review on these topics, see e.g. Gradie et al. 1979, Chapman et al. 1989)

The Maria family contains the following numbered asteroids: 170, 472, 575, 616, 695, 714, 727, 787, 875, 879, 897, 1158, 1160, 1215, 1677, 1996, 2151, 2221, 2429, 2638, 2865, 2903, 2962, 3055, 3066, 3158, 3159, 3167, 3332, 3537, 3594, 3786, 3970, 4099, 4104, 4122.

The Oppavia-Gefion family has the following members: 255, 1272, 1433, 1751, 1839, 2373, 2386, 2493, 2559, 2595, 2631, 2801, 2875, 2977, 3724, 3910, 4020.

To the Dora family belong: 668, 1414, 1734, 1795, 1836, 1970, 2598, 2807, 2940, 3563, 3611, 3630, 3775, 3829, 4135, 4220.

Although it is not the purpose of this paper to compare different methods to define asteroid families, a comparison with the selections found by Zappala et al. 1990 and Bendjoya et al. 1991 is interesting. The agreement in membership is comparable for all three studies, yielding identical selections for the Dora family and about 75% in common for the Maria family. The Oppavia-Gefion family as defined by Lindblad (1992) is completely represented within the Leto-family in Bendjoya et al. 1991 and most of the members are in common with the Gefion-family in Zappala et al. 1990.

Data on the physical properties of individual asteroids in each family exist. The Maria family has eight asteroids classified by Tholen (1989) and seven of these are of taxonomic type S and the eight is of type DT. Of the asteroids in this family 13 have albedo determinations (Tedesco, 1989) and all these are characteristic for asteroids of type S.

<table>
<thead>
<tr>
<th>Family name</th>
<th>N</th>
<th>a</th>
<th>e</th>
<th>i</th>
<th>( \bar{D} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maria</td>
<td>36</td>
<td>2.555</td>
<td>0.091</td>
<td>15.0</td>
<td>0.021</td>
</tr>
<tr>
<td>Oppavia-Gefion</td>
<td>17</td>
<td>2.789</td>
<td>0.136</td>
<td>9.1</td>
<td>0.013</td>
</tr>
<tr>
<td>Dora</td>
<td>16</td>
<td>2.787</td>
<td>0.196</td>
<td>7.8</td>
<td>0.007</td>
</tr>
</tbody>
</table>

TABLE I
Mean proper elements \( a, e, i \) and mean values of \( \bar{D} \), taken from Lindblad (1992)