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WHAT MAKES A FAMILY RELIABLE?

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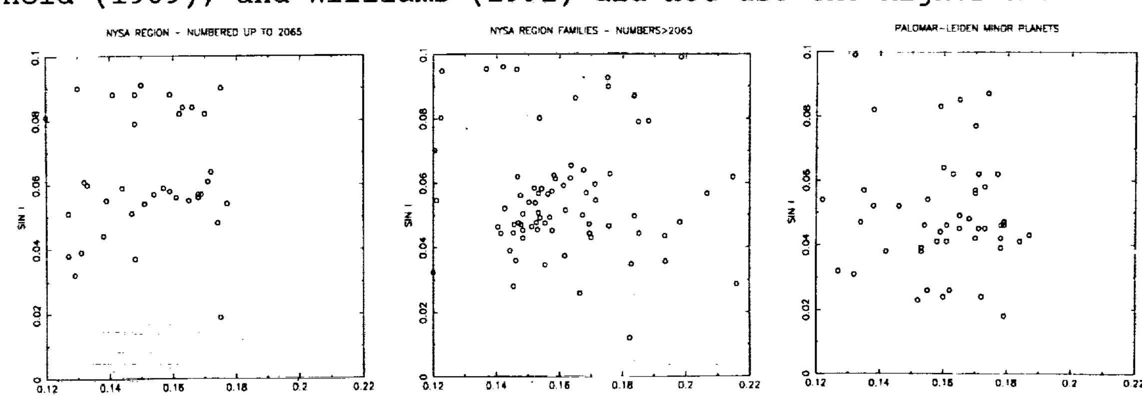
Asteroid families are clusters of asteroids in proper element space which are thought to be fragments from former collisions. Studies of families promise to improve understanding of large collision events and a large event can open up the interior of a former parent body to view. While a variety of searches for families have found the same heavily populated families, and some searches have found the same families of lower population, there is much apparent disagreement between proposed families of lower population of different investigations (Carusi and Valsecchi 1982). Indicators of reliability, factors compromising reliability, an illustration of the influence of different data samples, and a discussion of how several investigations perceived families in the same region of proper element space are given.

Ideally, the asteroids which cluster together to form a proposed family should all come from the same impact event. But the match between the memberships of the proposed family and the surviving fragments of a single impact event may be imperfect and the reliabiliy of a family must be judged by the available data. Several factors contribute to the perception of a family's reliability. Included are high population, a compact size in proper element space, high density, a low background of neighboring objects, neighboring families clearly separate, and reasonable geometry (no pretzels). If available, albedos, colors, spectra, and taxonomic classifications are important, particulary if the family's properties are in contrast to the background. The addition of newly discovered, higher numbered asteroids is an indicator of reliability as is the presence of the family in other data samples, e. g., the Palomar-Leiden (van Houten et al. 1970) or UCAS surveys. The discovery of the same family by different investigators gives further confidence.

Seldom does a family satisfy all of the above properties. Many factors work against reliability. There are more families of low population than high population and low population families are more vulnerable. Some families have larger extent than others and if they are not well populated they will be less evident because of low density. The mapping of the velocities of dispersion from the impact into the scatter of the three proper elements (a, e, sin i) depends upon the unknown location in the orbit at the time of breakup. Thus, families may be elongated or tilted in unpredictable ways which complicates the search procedure. There are examples of crowded or overlapping families. Likely examples of multiple families from a single parent body are known. The background density of asteroids is different in different parts of the belt so that uniform criteria for picking out families need not be optimum criteria. Some considerations depend on properties of families that are not yet well understood. The taxonomy may not be homogeneous in some families because the parent body was differentiated so that interpretation of the taxonomy enters judgement of reliability. A family with a steep size distribution has more members to discover, but there appear to be genuine families with shallow size distributions which do not add many high numbered objects. The background asteroids may not be isolated, they may form low population clumps (unrecognized families) so that it is possible to mistakenly combine disparate clumps into one "family". Structure is common in the well populated families (commonly asymmetries and denser cores) and it cannot be assumed that the less populated families lack structure. Among the less reliable families, additional data will establish reliability or require reconsideration, but some cases, such as overlapping families, will always prove difficult.

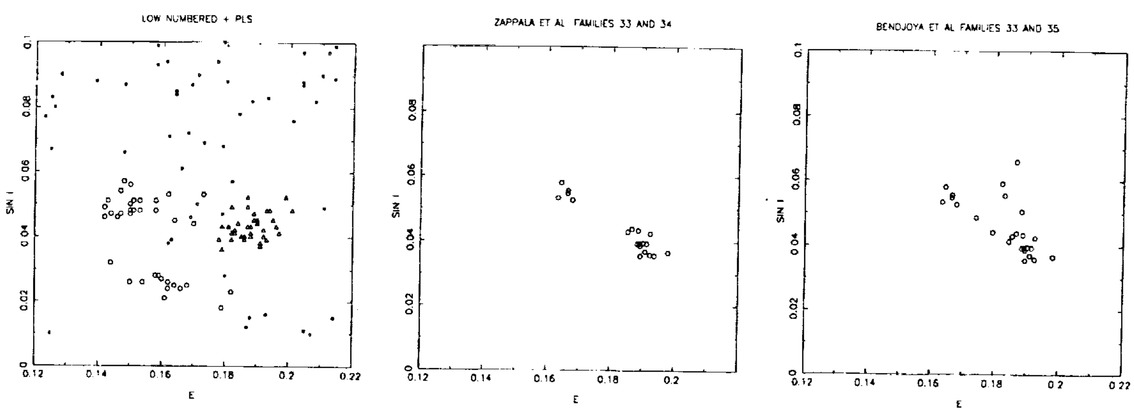
A study of about 1% of the belt's phase space (2.34-2.49 AU, modest e, low sin i) was undertaken to understand why different investigators have proposed different families and to examine how the data sample influences the detection of families. This region includes four major families and two slices, divided at 2.415 AU, were considered. Each slice contains two major families: Mildred and Jutta for the inner slice and Nysa and Hertha for the outer slice. The family names used here will follow Williams (1991).

Three data samples were picked: asteroids with numbers up to 2065, higher numbered objects, and Palomar-Leiden (PLS) objects. These samples are progressively fainter. For the 2.34-2.415 AU slice, the Jutta and Mildred families have a few members among the lower numbered asteroids and they are quite well populated among both samples of fainter asteroids. This is what one might expect for reliable families. The slice from 2.415-2.49 AU is more surprising and is illustrated in Fig. 1. The densest cluster of asteroids for each data sample is in a different location. For the lower numbered asteroids, the cluster slightly to the upper left of center is the Nysa family. The PLS sample shows some Nysa family members, but the Hertha family just below center is more prominent. This is understandable if the size distributions of the two families are different. The plot of higher numbered objects shows a few objects at the location of the Hertha family, a considerable number of objects at the location of the previously recognized Nysa family, and a dense cluster to the left of the former family and below the latter family. I suspect that this cluster is yet another major family, but it is crowded against the Nysa and Hertha families and the figure illustrates that it can be difficult to make a unique division between crowded families. It is evident that the data sample can influence the recognition of families. Brouwer (1951), Arnold (1969), and Williams (1991) did not use the higher numbered



sample and found virtually the same Nysa family. Bendjoya et al. (1991) included part of that Nysa family with the new cluster in a single family. Both Zappala et al. (1990) and Bendjoya et al. also picked out a dense portion within the right side of the Nysa family of Brouwer, Arnold, and Williams as a separate family.

Fig. 2 shows the slice from 2.34-2.415 AU. The first frame shows the lower numbered and PLS asteroids with larger symbols used for the Jutta, Mildred, and Massalia family members given in Williams and Hierath (1987) and Williams (1989). The Jutta family is to the left of center, Mildred family members to the lower right of center are shown with triangles, and the Massalia family lies at low inclination. The second and third frames show the family members proposed by Zappala et al. and Bendjoya et al., but background objects are not shown. Both investigations found a cluster of five members at the right side of the Jutta family (which they both call the Leonce family) and both discover a well populated cluster corresponding to the Mildred family. Most of the family members in the first frame are PLS objects, while most of the family members in the second and third frames are high numbered asteroids so the families have been recognized in different data samples. Bendjoya et al. also include as Mildred family members objects which are well beyond the family boundaries of the other two investigations.



Without higher numbered or PLS asteroids Hirayama, Brouwer, and Arnold could not find the Mildred and Jutta families. Van Houten et al. (1970) put the Nysa, Hertha, Jutta, and Mildred families together into a single "Nysa" family. Lindblad and Southworth (1971), when using a distance criteria intended to match van Houten et al., combined these four families plus the Massalia family into one. For other earlier investigators, table 6 of Carusi and Valsecchi (1982) is useful. Carusi and Massaro's (1978) Nysa family includes parts of the four major families. Kozai's (1979) family 5 has the Jutta family as a major component and his family 15 includes the Nysa family and a considerable amount of other material. Thus we see that some investigations have made families of larger extent by combining, what are considered here to be, several individual families. Thus, different investigators may find the same broad structures, but may partition them into families differently depending on their individual criteria.

The conclusions may be summarized. 1) Many factors influence a family's discovery and the assessment of its reliability. 2) The mean magnitude of different asteroid samples influences the relative prominence of different families and influences which families are found. 3) The criteria of different investigations influences the proposed families and can strongly influence the size of the proposed family in proper element space. 4) Even when different investigations produce very different lists of families, the differences may be understandable as smaller pieces of families or combinations of adjacent families. The proposed families are correlated, not random. 5) Both statistics and geometry are valuable for assessing family reliability. 6) Real asteroid families, meaning collections of fragments from impacts, exist.

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