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# The population of fission clusters inside collisional families

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## Abstract

Asteroid families are groups of objects sharing similar orbits. They are mostly the results of past collisions between two asteroids. Recent studies have shown that some asteroid families can also be the outcome of the spin-up induced fission of a secondary body (fission clusters). In at least four young fission clusters, more than 5% of their members belong to sub-families, that mostly formed after the main fission event. Using family recognition methods based on time-reversal dynamical simulations, machine-learning clustering algorithms, and the exceptional orbit accuracy obtained from *Gaia* observations of Solar System Objects, we identify several sub-clusters within extremely young collisional families. Collisional asteroid families younger than 100 Myr have a higher fraction of detectable fission sub-clusters with respect to older groups. The collisional events that form asteroid families may, therefore, trigger a subsequent cascade of spin-induced formations of fission clusters.

## 1. Introduction

Asteroid families are groups of asteroids mostly identified in domains of proper elements. Large asteroid families are the result of a collision of a projectile on the parent body, that resulted in the ejection of fragments in nearby orbits. Recently, it has been found that asteroid clusters can also form because of the fission of a secondary body. These fission clusters can be found everywhere in the main belt. [3] showed that the asteroid pairs formed by fission belong equally to C-complex or S-complex asteroid taxonomies, suggesting that the formation of asteroid binaries may be driven by mechanical rather than mineralogical properties. Unlike asteroid families, fission clusters are much more compact in proper element domains [3, 4].

Recent studies have shown that a significant fraction of young fission cluster members may be members of sub-families within the primary group. [4], using an approach based on a register of past close encounters of the family members with the parent body (Close Encounter Method, or CEM), recently studied 13 fission clusters with ages up to $\simeq 5$ Myr, the maximum age for which the method can be successfully applied using current asteroid orbital uncertainties. They identified four cases in which multiple fission events occurred, in most cases after the formation of the main cluster. In this work, we will investigate the possibility that sub-families, mostly caused by a fission spin-up, may also occur in young collisional asteroid families.

First, we focused our attention on the youngest known collisional families, for which all members can be studied with methods based on time-reversal dynamical simulations, like CEM, or the backward integration method (BIM). In this method, the difference of the longitudes of pericenter $\varpi$ and node $\Omega$ of family members with respect to those of the alleged parent body are integrated and verified in the past. At the moment of the family formation, the differences should converge to values near zero ([1]). Then, we extended our analysis to older families, and estimated how common is the occurrence of fission clusters in these groups.

## 2. Methods

We used the CEM approach to obtain age estimates for all members of the four young families to which the method can be applied, including all the subsets of each family that was created after the primary event and that includes (secondary groups) or not (tertiary groups) the parent body. We then applied machine-learning clustering techniques such as the K-means algorithm [2] to identify secondary and tertiary families.

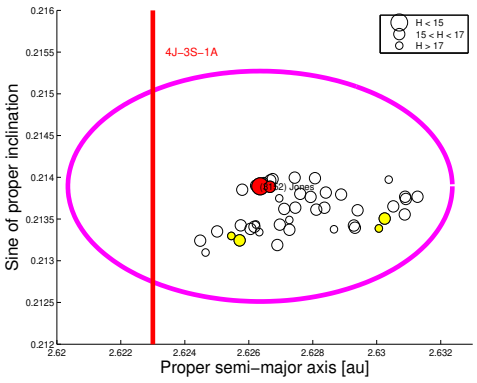


Figure 1: The position in the $(a, \sin(i))$ domain of the members of primary (black circles), secondary (red full circles), and tertiary (yellow full circles) clusters inside the Jones family identified in this work. The vertical line displays the location of a local main mean-motion resonance.

An $(a, \sin(i))$ projection of the orbits of members of the Jones family is shown in figure (1). Overall, we found 3 confirmed fission pairs for the Jones family (6.7% of the total members), none for the Kazuya family, 1 confirmed pair for (108138) 2001 GB11 (6.3% of the total), and 2 for the Lorre family (27.3% of the total). Results for the pairs including (3152) Jones and (280432) (2003 YF106) demonstrate that the age estimates of the fission clusters can be significantly improved using highly precise astrometric data from the ESA *Gaia* mission, when they are available.

## 3. Summary and Conclusions

How do the percentages of fission pairs found for the studied four extremely young families compare with those of older asteroid families? To answer this question, we selected candidate asteroid pairs with a distance in proper element domains of less than $d_d = 5$ m/s, and a mass ratio less than $q = 0.2$ (see [1] for a discussion on the choice of these parameters).

Figure (2) displays the fraction of asteroid families members that are likely to be part of a fission cluster, as a function of the family estimated age. Overall, asteroid families younger than $\simeq 100$ Myr appear to produce a larger quantity of fission clusters than more evolved groups, for which the rate of young fission clusters production induced by spin-up or by collisions on a rapidly rotating primary is never above 5% of the total members. As observed for young fission asteroid families, it is possible that the collisional event that formed the asteroid family may produce fragments on highly rotating states, and therefore trigger, in some cases, a subsequent cascade of formations of fission subfamilies. In this scenario, asteroid families formation would not be a punctual phenomenon, as previously thought, but rather an on-going process.

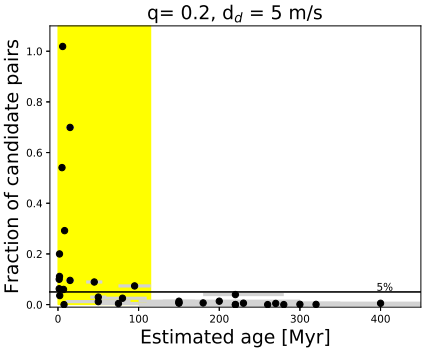


Figure 2: The fraction of the asteroid families members that are likely to be part of fission clusters as a function of the family estimated age. The yellow area shows the region where all families above the 5% threshold level are found.

## Acknowledgements

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