FM1 – A Century of Asteroid Families

Introduction

In 1918, Kiyotsugu Hirayama published a manuscript in the Astronomical Journal titled "Groups of asteroids probably of common origin", opening the field study of asteroid families. The IAU 2018 General Assembly was held on the 100th anniversary of this seminal work. In the intervening century, Hirayama's initial insight that these groups of objects were not random has been supported by countless studies spanning orbital elements, colors, spectral taxonomy, albedo, rotation, impact physics, and dynamical evolution. This wealth of information has become a key aspect in family identification and interpretation, expanding our understanding of family-forming processes.

Asteroid families have provided unique insights into the forces shaping both our Solar System and other planetary systems. Families provide us observable evidence of large-scale catastrophic impacts in the Solar System, giving us the tools to test impact physics on planetary scales. Families also have been critical in revealing the fingerprints left on the Solar System by gravitational mean motion and secular resonances as well as the Yarkovsky effect, the most important non-gravitational force for sculpting the Main Belt of asteroids and supplying new objects into near-Earth space. The quantification and simulation of the Yarkovsky force has enabled age dating of asteroid families, providing us a chronology of the impacts in the inner Solar System. Families allow us to probe the heterogeneity of the protoplanetary disk in the terrestrial planet region, and homogeneity of the parent bodies prior to the family-forming collision. And recently, collisional families have been identified beyond the Main Belt in populations as diverse as the Jovian irregular satellites and the Trans-Neptunian Objects.

Asteroid families are currently undergoing a revolution in understanding due to the combination of a rapid increase in asteroid survey data, and improved computational resources and techniques allowing for detailed simulation of family formation and evolution. Some of the avenues explored in this Focus Meeting included:

- improvements to family classification routines that detect family halos as well as core members;
- simulations probing the internal structure of D$<$ 30km scale family members, formed either from fracturing during impact or reaccretion post-impact;
- the lack of differentiation signatures in the set of known families, and the apparent conflict with the presence of differentiated meteorites in our collections;
- asteroid families formed through mechanisms other than catastrophic disruption (e.g. YORP-induced rotational fission);

This meeting gave the international community the chance to review the history of asteroid family science; highlight some of the major results as well as watershed moments in the field; discuss new work being done; provide predictions for the future of the field in light of the new techniques and data sets that are currently being developed; and celebrate the centennial of the birth of this field. Asteroid families will continue to be a touchstone for Solar System science in their next century, providing insights and test populations for planetary formation models not available in any other way.

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on behalf of the SOC

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The History of Asteroid Family Identification

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Abstract. In this paper the early history of search for asteroid groupings is briefly reviewed. Starting from the first attempts by Kirkwood, who managed to identify a number of asteroid pairs and triples with adjacent orbits, via the similar contributions of Tisserand and Mascart, we arrive to Hirayama and his discovery of asteroid families, marking the beginning of modern asteroid science.

Asteroid families were discovered a century ago by K. Hirayama. The seminal paper of his: "Groups of asteroids probably of common origin" (Hirayama 1918), as well as a series of subsequent papers devoted to asteroid families (Hirayama 1919, 1920, 1922, 1927, 1933), received a lot of attention in the past, and have been thoroughly described in a recent review (Knežević 2016). In the present paper, we shall therefore pay more attention to several almost forgotten attempts to find asteroid groupings that precede the Hirayama's discovery.

The first attempts to find groups of asteroids with similar orbits date back to 1877, when D. Kirkwood, in an article entitled "The asteroids between Mars and Jupiter" (Kirkwood 1877), presented "evidence of a similarity more than accidental between adjacent orbits of the asteroidal group". Among only 172 asteroids known at the time, he found 4 pairs (Fortuna and Eurynome, Fides and Maia, Clotho and Juno, Sirona and Ceres) with striking similarity in the magnitude, form and position of orbits. For an additional pair (Urda and Gerda) he states that the discoverer of these bodies, Dr. Peters, in the American Journal of Science for February 1877, calls attention to coincidences between the elements of their orbits. Kirkwood does not venture (yet) to speculate on the origin of such pairs, stating simply that they must be of common origin.

In 1888 Kirkwood publishes a booklet (Kirkwood 1888) devoted entirely to asteroids, in which he again mentions "adjacent orbits", drawing, however, a special attention to the pair Hilda and Ismene, for which he finds distances, periods, inclinations and eccentricities nearly identical, but longitudes of perihelia different by almost exactly 180°. Wondering whether this indicates that the two objects detached at about the same time from the opposite sides of the solar nebula, he suggests that in general the asteroid pairs with similar orbits originate from single asteroids, which, like comets, "may have been separated by the sun's unequal attraction on their parts".

Finally, in a couple of papers published in astronomical journals (Kirkwood 1890, 1891) he again returns to the topic of similarity of asteroid orbits, proposing in the former paper the three most significant pairs (including a new one – Vera and Semele) and again discussing possible formation by separation/dismemberment; in the latter paper, however, starting from the catalog with about 300 asteroids, he reports on finding of 10 groups (4 triples and 6 pairs) of bodies with similar orbits. Assuming certain characteristics of the solar nebula, he concludes that the disturbing influence of Jupiter could have been sufficient not only to detach the masses of asteroids from the central body, but also to subdivide by unequal attraction on the different parts the newly-formed nebulous planets, until the fragments finally resulted in the existing asteroids.

In his article "La question des petites planètes", F. Tisserand (1891) reports "sans explication" on the three pairs of asteroids with similar orbital elements: (106) Dione and (245) Vera (forming with (86) Semele one of the triples proposed by Kirkwood), (218) Bianea and (246) Asporina, and (84) Klio and (249) Ilse (again a pair which makes part of the Kirkwood's triple with (115) Thyra).

Finally, J. Mascart published two studies (Mascart 1899, 1902) in which he considers pairs of asteroids with similar orbits. In the former paper, he first computes Tisserand invariants for a total of 417 asteroids, identifying subsequently 20 pairs of asteroids with very close values of the invariants and with more or less similar orbital elements. In the latter paper he then analyses in detail the probabilities of these coincidences.

As pointed out by Hirayama (1922), all these attempts to find significant groupings of asteroids failed. Hirayama first rightly cautions against having only two or three asteroids with similar orbits, because this gives rise to a considerable probability that they may be accidentally coincident. Then, explaining the failure to find more asteroids with similar orbits, he attributes it to the "use of actual orbits ... for comparison, whereas these orbits are varied remarkably by the action of the planets", and correctly states that such attempts could be successful only if the separation had occurred very recently. To identify families originated at remoter age, Hirayama asserts that some kind of invariable elements must be used to identify families. Indeed, in the same paper he formally introduces the *proper elements* as such invariable parameters and computes them by means of the Lagrangian linear theory of secular perturbations, stating: "... if there may be noticed a group of the asteroids with the elements approximately common to all, and if at the same time, their number is sufficiently large to be insured from the effect of chance, then we can conclude that they have probably originated from the breaking up of a single asteroid". His success in identifying asteroid families with tens of members marks the end of the pioneer era of the search for asteroid groupings, and the beginning of the modern asteroid science.

References

Hirayama, K. 1918, *Astron. J.*, 31, 185
Hirayama, K. 1919, *Proc. Phys. Mat. Soc. Japan*, III, 1, 52
Hirayama, K. 1920, *Proc. Phys. Mat. Soc. Japan*, III, 2, 236
Hirayama, K. 1922, *Japanese J. Astron. Geo.*, 1, 55
Hirayama, K. 1927, *Japanese J. Astron. Geo.*, 5, 137
Hirayama, K. 1933, *Proc. Imp. Acad. Japan*, 9, 482
Kirkwood, D. 1877, *The Annual Review of the Board of Regents of the Smithsonian Institution for 1876* (Washington: Gov. Print. Office) p. 358
Kirkwood, D. 1888, *The Asteroids or Minor Planets Between Mars and Jupiter* (Philadelphia: J.B.: Lippincot Comp.)
Kirkwood, D. 1890, *Publ. Astron. Soc. Pacific*, 2, 48
Kirkwood, D. 1891, *Publ. Astron. Soc. Pacific*, 3, 95
Knežević, Z. 2016, in: S. R. Chesley, A. Morbidelli, R. Jedicke & D. Farnocchia, (eds.) *Proceedings IAU Symposium 318: Asteroids: New Observations, New Models* (Cambridge: Cambridge Univ. Press), p. 16
Mascart, J. 1899, *Bull. Astron.*, 16, 369
Mascart, J. 1902, *Annales Obs. Paris*, XXIII, F
Tisserand, F. 1891, *Annuaire Pour L'An 1891 publie par Bureau des Longitudes* (Paris: Gauthier-Villars et files) p. B.18