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Formation scenarios of the young Emilkowalski asteroid family

E. Kuznetsov, V. Safronova, A. Perminov, and M. Vasileva

Ural Federal University, 51 Prospekt Lenina, Ekaterinburg, 620000 Russia

Abstract. The scenario of the formation of the young Emilkowalski asteroid family is based on numerical modelling of the evolution of the nominal orbits of the family members. Different variants of the orbital evolution of asteroids are considered depending on the value of the drift velocity of the large semi-major axes of the orbits caused by the influence of the diurnal Yarkovsky effect. On the basis of the analysis of the convergence of the nodes and pericentres of the orbits, estimates of the time of possible formation of all possible pairs among the family members were obtained. On the basis of these estimates, a scenario of family formation was constructed, assuming the destruction of the parent body of asteroid (14627) Emilkowalski as the main mechanism. It is shown that part of the family members could have been formed as a result of cascading disintegration of daughter bodies of the parent asteroid. The constructed scenario of the Emilkowalski family formation can be described as a stage-by-stage destruction of the parent body of asteroid (14627) Emilkowalski with elements of cascading disintegration of some fragments.

Keywords: minor planets; asteroids; individual: (14627) Emilkowalski family

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1 Introduction

The young Emilkowalski asteroid family is located in the central Main Belt: semi-major axis $a = 2.60$ AU, eccentricity $e = 0.15$, inclination $i = 17^{\circ}.75$. Nesvorný and Vokrouhlický (2006) considered Emilkowalski family as a cluster of three asteroids in close heliocentric orbits: (14627) Emilkowalski, (126761) 2002 DW10, and (224559) 2005 WU179. The first estimate of the age of the family at 220 ± 30 kyr (Nesvorný and Vokrouhlický 2006) showed that it is a young family. Pravec et al. (2018) estimated the taxonomic type of asteroid (14627) Emilkowalski based on photometric observations as type D.

Pravec et al. (2018); Fatka et al. (2020) discovered new family members, increasing the number of asteroids in this family to nine. Age estimates of the "main asteroid (14627) Emilkowalski – secondary asteroid" pairs were obtained by Pravec et al. (2018); Fatka et al. (2020). It was shown that at least two decay events of the parent asteroid of this family occurred in the last 5 Myr. This is consistent with the scenario of cascading disintegration of the parent body. Four new members of the Emilkowalski family were discovered by Kuznetsov et al. (2025). Thus, 13 asteroids that are members of the Emilkowalski family are currently known.

In this paper, we consider the young Emilkowalski asteroid family from the point of view of studying the formation process and attempt to reconstruct the chronological sequence of the parent body breakup. For this purpose, we:

1) numerically investigate the dynamical evolution of asteroids based on known nominal orbits, considering the influence of the Yarkovsky effect;
2) estimate the ages of all possible pairs among the asteroids of the family and based on these estimates;
3) construct a basic scenario of the family formation.

2 Modelling the dynamic evolution of asteroids

Numerical simulation of the motion of asteroids of the Emilkowalski family was performed using the `Orbit9` software included in the `OrbFit`[1] software package. When modelling the dynamical evolution, perturbations from eight major planets and the dwarf planet Pluto, the Sun's oblateness, and relativistic effects were considered. The osculating elements of asteroid orbits from the AstDyS catalogue for the epoch MJD 60200 were taken as initial ones. The integration intervals were 5 Myr and 2 Myr.

Different variants of the evolution were considered: without considering the diurnal Yarkovsky effect and with this effect considered. The influence of the diurnal

[1] http://adams.dm.unipi.it/orbfit/

Yarkovsky effect was considered in the form of a constant drift rate da/dt of the semi-major axis of the asteroid's orbit a. The drift rate was estimated either from the known physical and thermophysical parameters of asteroids, or parameters characteristic of the given taxonomic class were used, if all asteroids, as well as the main asteroid of the (14627) Emilkowalski family, are of type D.

Estimation of the drift rate of the semi-major axis da/dt was performed using a modified version of the `Orbit9` software included in the `OrbFit` package (Fenucci and Novaković 2022), which provides the possibility of taking into account the influence of the Yarkovsky effect and the YORP (Yarkovsky–O'Keefe–Radzievskii–Paddack) effect on the basis of setting the dynamic (period of axial rotation and inclination of the rotation axis), physical (density) and thermophysical (heat capacity, thermal conductivity, radiation and absorption coefficients of surface layers) parameters of the asteroid.

The age of the pairs was estimated using a method based on the search for moments of convergence of the nodes and perihelion orbits (synchronous zeroing of the longitude differences of the ascending nodes $\Delta\Omega = 0$ and perihelion arguments $\Delta\omega = 0$) (see, e.g., Kuznetsov et al. 2020). Estimates of the age of pairs T were obtained as the average of $T = (T_\Omega + T_\omega)/2$ moments of zeroing the differences between the longitudes of the ascending nodes T_Ω and the perihelion arguments T_ω. In the following, we used estimates for which the relative moment difference $\delta T = (T_\Omega – T_\omega)/T < 0.1$, which provides the proximity of the zeroing moments of the differences between the longitudes of the ascending nodes and the perihelion arguments necessary for obtaining age estimates. When several evolution variants with different values of the drift rate of the semi-major axis were considered for an asteroid, the interval of possible ages of a pair was estimated.

In addition to estimates of the moments and time intervals corresponding to the convergence of the nodes and perihelion of the orbits at different drift rates of the semi-major axes of the orbits, estimates of the values of the Kholshevnikov metrics ϱ_2 and ϱ_5 (Kholshevnikov et al. 2016) were obtained when constructing the family formation scenario and their differences $\varrho_2 - \varrho_5$ were calculated. The ϱ_2 metric is defined in the five-dimensional space of Keplerian orbital elements a, e, i, Ω, ω (the position of the body in the orbit is not considered). The metric ϱ_5 is defined in the factor space of positional orbit elements a, e, i (at all possible orientations of orbital planes and apsidal lines). A small value of the difference between the metrics ϱ_2–ϱ_5 is a necessary condition for the youth of the pair (Kuznetsov et al. 2020).

3 Scenario for the formation of the Emilkowalski asteroid family

The Emilkowalski family formation scenario was constructed based on a joint analysis of the moments of convergence of the nodes and perihelion orbits and the values of the Kholshevnikov metrics. The construction of the scenario was divided into three stages. At the first stage, the moments of simultaneous convergence of nodes and perihelion orbits were analyzed for cases of asteroid orbits convergence with the orbit of the main asteroid of the (14627) Emilkowalski family. As a result, groups of asteroids corresponding to the sequence of parent body destruction events were identified. At this stage, asteroids whose orbits do not converge with the orbit of (14627) Emilkowalski were excluded from consideration. At the second stage, the proximity of the selected pairs of orbits was analyzed based on estimates of the values of the Kholshevnikov metrics ϱ_2 and ϱ_5, as well as their difference ϱ_2–ϱ_5. It was assumed that the values of metrics and their difference for the subsequent event were smaller than for the previous one. At the third stage, we analyzed the possibility of the formation of family members as a result of cascade fission of fragments of the parental body of the family. Fig. 1 shows the scheme of the constructed scenario, where for each parent body the range of fragment ages in kyr (red font) is indicated in the order of their location on the scheme. For each family member, the number or name and size in meters are given.

Note that the constructed scenario of the Emilkowalski family formation is based on the analysis of the evolution of nominal asteroid orbits. When taking into account the influence of the Yarkovsky effect, the value of the drift rate of the semi-major axis was varied for asteroids for which the direction of the rotation axis is not known. To test the proposed scenario, the probabilistic evolution of all asteroids in the family will be studied, resulting in estimates of the moments of low relative-velocity close encounters of asteroids and the attainment of minima of the Kholshevnikov metric ϱ_2. Based on these data, it is planned to refine the age estimates of the pairs and, if necessary, to correct the developed scenario.

4 Conclusions

A scenario of the formation of the Emilkowalski family was constructed based on the analysis of the evolution of the nominal orbits of asteroids. We used the method of convergence of the nodes and perihelion orbits together with the Kholshevnikov metrics to estimate the age of the pairs. The constructed model shows that the family was formed as a result of cascading destruction of the parent body. It is possible that the family is significantly younger than it was previously thought, with an age of less

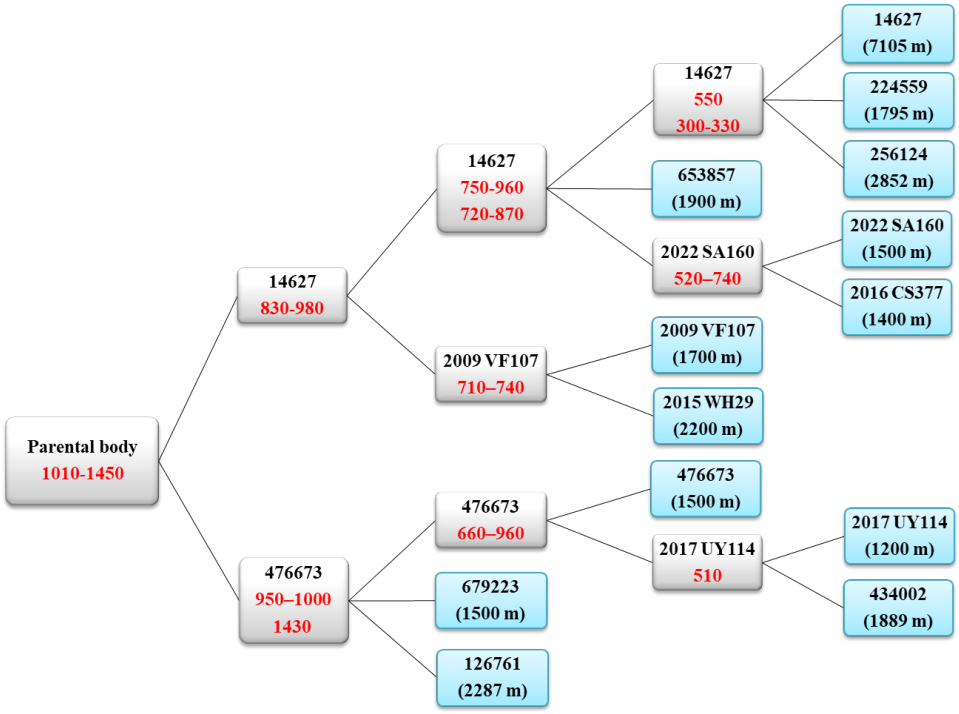

Fig. 1. Emilkowalski family formation scenario.

than 1.5 Myr. We plan to test this conclusion based on the results of a study of the probabilistic evolution.

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References

Fatka P., Pravec P., Vokrouhlický D., 2020, Icarus, 338, id. 113554
Fenucci M. and Novaković B., 2022, Serbian Astronomical Journal, 204, p. 51
Kholshevnikov K.V., Kokhirova G.I., Babadzhanov P.B., et al., 2016, Monthly Notices of the Royal Astronomical Society, 462, 2, p. 2275
Kuznetsov E.D., Rosaev A.E., Plavalova E., et al., 2020, Solar System Research, 54, 3, p. 236
Kuznetsov E.D., Perminov A.S., Vasileva M.A., et al., 2025, Solar System Research, 59, in press
Nesvorný D. and Vokrouhlický D., 2006, The Astronomical Journal, 132, 5, p. 1950
Pravec P., Fatka P., Vokrouhlický D., et al., 2018, Icarus, 304, p. 110