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Second-generation Fragments of a Comet Split in the Making: The Liller Family Comets

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ABSTRACT

Kreutz sungrazers and Kracht, Marsden, and Meyer sunskirters are regarded as second- or third-generation fragments of split comets. First-generation fragments have been observed to form, for example, in the cases of comets 73P/Schwassmann-Wachmann 3, D/1993 F2 (Shoemaker-Levy 9), and 332P/Ikeya-Murakami. Here, we compare relevant orbital correlation properties (the distributions of mutual nodal distances, and the angular separation of perihelia and poles) of the Liller family comets — C/1988 A1 (Liller), C/1996 Q1 (Tabur), C/2015 F3 (SWAN), C/2019 Y1 (ATLAS), and C/2023 V5 (Leonard) — with those of fragments of 332P and some Kreutz sungrazers to show that they are first-generation cometary fragments in the process of producing the second-generation.

Keywords: Comets

INTRODUCTION

Sekanina (1997) argued that comets C/1988 A1 (Liller) and C/1996 Q1 (Tabur) are secondary nuclei or first-generation fragments of a split comet. Sekanina & Kracht (2016) concluded that C/1988 A1, C/1996 Q1, and C/2015 F3 (SWAN) are genetically related, with C/1988 A1 being the main fragment that resulted from a split comet event that took place in 945 BCE. Sekanina (2023) argued that yet another discovery, C/2019 Y1 (ATLAS), belongs to the Liller group. Here, we show that a recent discovery (Beshore et al. 2023), C/2023 V5 (Leonard), is also a Liller family member and argue that it could be a second-generation fragment.

LILLER FAMILY COMETS: DATA

Here, we use publicly available input data from Jet Propulsion Laboratory's Solar System Dynamics Group Small-Body Database (SBDB)[1] and HORIZONS[2] on-line solar system data and ephemeris computation service (Giorgini 2015), which use the new DE440/441 solution (Park et al. 2021). Data retrieval from SBDB used the Python package Astroquery (Ginsburg et al. 2019) and its HorizonsClass[3] and SBDBClass[4] classes. The data collected are referred to epoch JD 2460200.5 (2023-Sep-13.0) TDB (Barycentric Dynamical Time, J2000.0 ecliptic and equinox).

The orbital elements — perihelion distance (q), eccentricity (e), inclination (i), longitude of the ascending node (Ω), and argument of perihelion (ω) — of the Liller family comets are: C/1988 A1 (Liller) has $q = 0.8413360 \pm 0.0000012$ au, $e = 0.996563 \pm 0.000011$, $i = 73.^{\circ}32236 \pm 0.^{\circ}00009$, $\Omega = 31.^{\circ}5153 \pm 0.^{\circ}0002$, and $\omega = 57.^{\circ}38793 \pm 0.^{\circ}00014$; C/1996 Q1 (Tabur) has $q = 0.83980 \pm 0.00002$ au, $e = 0.9986 \pm 0.0002$, $i = 73.^{\circ}3556 \pm 0.^{\circ}0014$, $\Omega = 31.^{\circ}3996 \pm 0.^{\circ}0012$, and $\omega = 57.^{\circ}413 \pm 0.^{\circ}004$; C/2015 F3 (SWAN) has $q = 0.83444 \pm 0.00002$ au, $e = 0.99639 \pm 0.00005$, $i = 73.^{\circ}3864 \pm 0.^{\circ}0003$, $\Omega = 31.^{\circ}6396 \pm 0.^{\circ}0006$, and $\omega = 57.^{\circ}566 \pm 0.^{\circ}002$; C/2019 Y1 (ATLAS) has $q = 0.8378238 \pm 0.0000003$ au, $e =$

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[1] https://ssd.jpl.nasa.gov/sbdb.cgi
[2] https://ssd.jpl.nasa.gov/?horizons
[3] https://astroquery.readthedocs.io/en/latest/jplhorizons/jplhorizons.html
[4] https://astroquery.readthedocs.io/en/latest/jplsbdb/jplsbdb.html

0.996508 ± 0.000002, $i = 73\overset{\circ}{.}34814 \pm 0\overset{\circ}{.}00002$, $\Omega = 31\overset{\circ}{.}36634 \pm 0\overset{\circ}{.}00004$, and $\omega = 57\overset{\circ}{.}49817 \pm 0\overset{\circ}{.}00003$; C/2023 V5 (Leonard) has $q = 0.849 \pm 0.002$ au, $e = 1.026 \pm 0.013$, $i = 73\overset{\circ}{.}9 \pm 0\overset{\circ}{.}3$, $\Omega = 31\overset{\circ}{.}45 \pm 0\overset{\circ}{.}05$, and $\omega = 56\overset{\circ}{.}4 \pm 0\overset{\circ}{.}4$ (values as of 2023-November-22). The orbital elements of C/2023 V5 — in particular, the angular ones — are consistent with those of the other four comets and its MOID with Jupiter is 0.78 au that is the shortest of the group.

EVOLVING FROM FIRST-GENERATION FRAGMENTS

As a way of assessing statistically the evolutionary state of the Liller family comets, we focus on three orbital correlation parameters: the mutual nodal distances between pairs of comets ($\Delta_{\pm}$, + ascending node, − descending node) computed as described by Saillenfest et al. (2017) and the angular separation of perihelia (α_q) and poles ($\alpha_{\rm p}$) evaluated as shown in de la Fuente Marcos & de la Fuente Marcos (2018). In order to investigate the impact of the orbital uncertainties on the computed values of $\Delta_{\pm}$, α_q, and $\alpha_{\rm p}$, we generated sets of orbital elements using data from SBDB as described in de la Fuente Marcos & de la Fuente Marcos (2021). For example, the value of the inclination of a virtual comet was computed using the expression $i_{\rm v} = i + \sigma_i \, r_{\rm k}$, where σ_i is the standard deviation and $r_{\rm k}$ is a (pseudo) random number with normal distribution computed using NumPy (Harris et al. 2020). With the aim of calculating statistically relevant values of $\Delta_{\pm}$, α_q, and $\alpha_{\rm p}$, we computed median and 16th and 84th percentiles from a set of 10^4 pairs of virtual comets for each actual pair.

Figure 1 shows the results of our analyses applied to ten fragments of comet 332P/Ikeya-Murakami (left panels), the Liller family comets (central panels), and four Kreutz sungrazers (right panels). Fragments of 332P are first-generation pieces of a comet and this is clearly seen in the mutual nodal distances that have values as low as 10^{-4} au (top-left panel); for them, the values of α_q and $\alpha_{\rm p}$ are also very small, often $< 1°$ (middle- and bottom-left panels). Significantly larger values are found for the Kreutz sungrazers — the only ones with uncertainties in SBDB, namely C/1880 C1 (Great southern comet), C/1963 R1 (Pereyra), C/2011 N3 (SOHO), and C/2012 E2 (SWAN) — in the right panels. As Kreutz sungrazers are regarded as second- or third-generation fragments of split comets, samples with values intermediate to those of the fragments of 332P and the Kreutz sungrazers can be interpreted as corresponding to a transitional stage in which second-generation fragments are being produced. This is what is observed for the Liller comets in the central panels. On the other hand, the nodal distances that include C/2023 V5, black squares in Fig. 1, have larger values than those of pairs of Liller family comets without C/2023 V5; therefore, C/2023 V5 could be a second-generation fragment.

DISCUSSION AND CONCLUSIONS

Kreutz sungrazers and Kracht, Marsden, and Meyer sunskirters are regarded as second- or third-generation fragments of split comets (Sekanina & Chodas 2005). First-generation fragments have been observed to form, for example, in the cases of comets 73P, D/1993 F2, and 332P. Here, we compared relevant orbital correlation properties (the distributions of $\Delta_{\pm}$, α_q, and $\alpha_{\rm p}$) of Liller family comets with those of the fragments of 332P and some Kreutz sungrazers to show that they are first-generation fragments in the process of producing the second-generation of cometary fragments.

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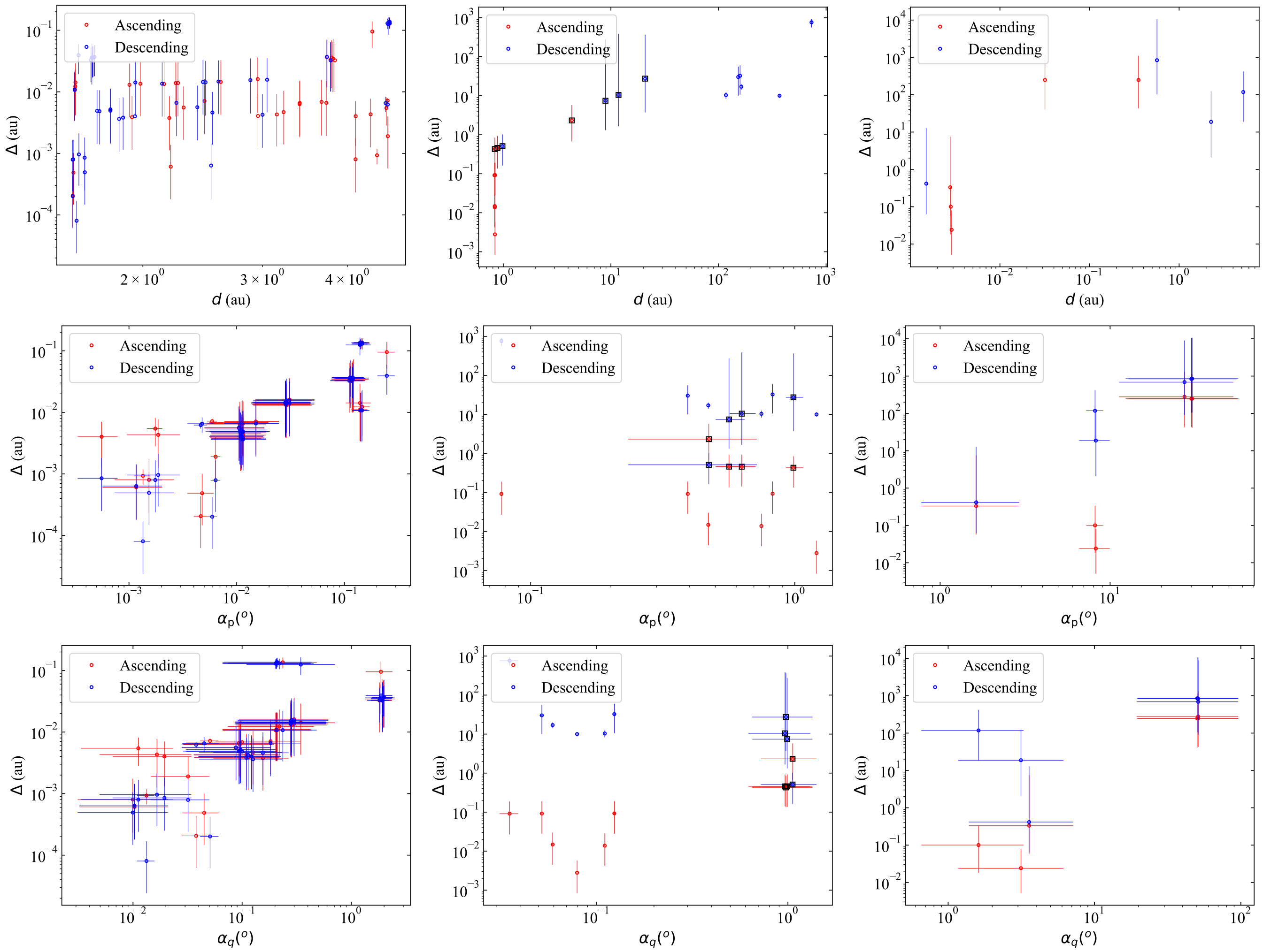

Figure 1. Mutual nodal distances as a function of the distance to the node (top panels), as a function of the angular separation of the orbital poles (middle panels), and as a function of the angular separation of the perihelia (bottom panels) for ten fragments of comet 332P/Ikeya-Murakami (left panels), the Liller family comets (central panels), and four Kreutz sungrazers (right panels). The error bars come from the evaluation of 10^4 sets of synthetic elements compatible with the uncertainties and generated using a Monte Carlo process (see the text for details). The black squares in the central panels correspond to pairs that include C/2023 V5.

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