THE SPLIT COMETS: GRAVITATIONAL INTERACTION BETWEEN THE FRAGMENTS

Z. Sekanina
Harvard-Smithsonian Center for Astrophysics,
Cambridge, Massachusetts, U.S.A.

1. THE APPROACH

The n-body computer program by Schubart and Stumpff (1966) has been slightly modified to study the gravitational interaction between two fragments of a split comet nucleus in the sun's gravitational field. All calculations refer to the orbit of Comet West (1976 VI), the velocity of separation of the fragments is assumed to be equal in magnitude to the velocity of escape from the parent nucleus, and the numerical integration of the relative motion of one fragment (called the companion) with respect to the other (principal fragment) is carried over the period of 200 days from separation. The motion of the companion is modeled as a function of the following circumstances at splitting:

(1) Position of the comet in heliocentric orbit at the time of splitting. Considered are three locations, whose true anomalies are $-90°$, $0°$, and $+90°$, corresponding, respectively, to heliocentric distances of 0.393 A.U. prior to perihelion, 0.197 A.U. (perihelion), and 0.393 A.U. subsequent to perihelion.

(2) The mass of the principal fragment. Two cases are considered: 10^{17} and 10^{15} grams.

(3) The mass ratio of the principal fragment to the companion. Calculations are made for ratios 1:1 and 100:1.

(4) The average bulk density of the fragments. Densities used are 1 and 0.1 g cm^{-3}, same for both fragments.

(5) Direction of separation of the companion from the principal. Considered are six cardinal directions: sunward; forward, i.e., perpendicular to the sunward direction in the orbit plane in the sense of the comet's orbital motion; northward, i.e., in the direction of that orbital pole from which the comet is seen to orbit the sun counterclockwise; and the respective opposite directions: anti-sunward; backward; and southward.

R. L. Duncombe (ed.), Dynamics of the Solar System, 311–314.

(6) Area of separation of the companion on the surface of the parent nucleus. Six basic locations are investigated: subsolar area; leading-side area, oriented in the forward direction from the center of the nucleus; north-pole area; and the areas located opposite these: antisolar area; trailing-side area; and south-pole area.

All possible combinations of the six variables represent a total of 720 patterns. Fortunately, symmetries with respect to the orbit plane reduce the number of independent patterns by 216, and other symmetries that lead to virtually identical patterns reduce the number by additional 240 to leave a total of 264 patterns. Furthermore, the only measurable effect of the mass of the principal fragment is that on the dimensions of the companion's orbit, which scale with the cube root of the mass. This brings the number of patterns under consideration down to 132.

2. THE RESULTS

Computer generated plots of the variations with time of the separation between the fragments, of their relative velocity, and of the angle subtended by the separation and the velocity vectors have been examined for similarity in appearance, separately for each of the three positions in heliocentric orbit. It has been found that the differential gravitational effect of the sun becomes noticeable about 0.5 to 1 day after separation for the breakup taking place at perihelion, and about 1 to 2 days after separation for the breakup at heliocentric distance twice the perihelion distance. It has further been found that the visual aspect of the plots is not affected fundamentally by the bulk density and by the fragment mass ratio, although the outcome of the dynamical solution may so be affected. Consequently, it has been possible to categorize the patterns in terms of only the direction of separation and the area of separation by considering the following eleven standard patterns: separation sunward from (1) subsolar area, (2) leading-side area, (3) north-pole area, (4) trailing-side area; separation forward from (5) subsolar area, (6) leading-side area, (7) north-pole area; separation northward from (8) subsolar area, (9) leading-side area, (10) north-pole area; and (11) separation backward from subsolar area.

For the splitting at true anomaly -90° the calculated patterns can be divided into seven categories. Category 1.1 encompasses separations from the leading-side area sunward, forward, and northward, and from the trailing-side area sunward. The separation distance increases monotonically. The companion escapes along a very strongly hyperbolic orbit; inclination to the comet's orbit plane is zero or very low; prograde motion. Category 1.2 includes separations from the north-pole area sunward and forward. Except for a shallow minimum shortly after perihelion the separation distance increases monotonically. The companion escapes along a high-inclination, strongly hyperbolic orbit; prograde motion. Category 1.3 is a separation forward from the subsolar area. The separation distance increases monotonically at rather a slow rate. The velocity surges at perihelion, then follows a profound decrease and a moderate upswing. The companion escapes along a slightly hyperbolic orbit; zero inclination; retrograde motion. Category 1.4 is a separation northward from the subsolar area. The separation curve has a complicated shape; the velocity curve, after a sudden upswing near perihelion, displays a downward trend. The companion gets gradually into a highly elongated, quasi-stable elliptical orbit with a period ∿240 days; high inclination; retrograde motion. Category 1.5, a separation sunward from the subsolar area, exhibits a separation curve that gradually levels off and a velocity curve with a very deep minimum about 30 days after splitting. The companion gets into a highly elongated, quasi-stable elliptical orbit with a period of 226 days; zero inclination; retrograde motion. Category 1.6, a separation backward from the subsolar area, displays very complicated separation and velocity variations. The companion pursues a retrograde orbit, whose eccentricity is slightly less than unity. The patterns with the bulk density 0.1 g cm^{-3} show the fragments crashing into each other 120 days after breakup for the mass ratio 1:1, 129 days for 100:1. Category 1.7, a separation northward from the north-pole area, results in a crash of the fragments 15 days after breakup regardless of the mass ratio and the density.

For the splitting at perihelion there are five categories of patterns. Category 2.1 is identical in contents with Category 1.1. The companion's motion displays similar but still more vigorous escape characteristics than were those for the Category 1.1 patterns; prograde motion. Category 2.2 encompasses the patterns of Categories 1.3, 1.4 and 1.5. The companion's motion differs from that in Category 2.1 by appreciably milder hyperbolic excess; prograde motion. Category 2.3 is identical in contents with Category 1.6. Escape is still more hesitant than in Category 2.2, and in the case of the high mass ratio combined with the low bulk density the motion becomes elliptical; zero inclination; prograde motion. Category 2.4, equal in contents to Category 1.2, shows the companion in a high-inclination, elliptical, quasi-stable orbit. The eccentricity and the revolution period depend strongly on the mass ratio and on the density; prograde motion. Category 2.5 contains the pattern of Category 1.7 and is again characterized by collision of the fragments, this time 16 days after breakup.

For the splitting at true anomaly +90° we have another five categories. Category 3.1, encompassing Categories 1.3, 1.4, 1.5 and 1.6, has the companion's behavior reminiscent of the one in Category 2.2; prograde motion. Category 3.2 is identical in contents with Category 1.1 except for a separation sunward from the trailing-side area which now makes up Category 3.3. The companion escapes almost exactly radially, the sense of motion being changed from retrograde early after separation to prograde later; zero or low inclination. In Category 3.3 the companion gets into a high-eccentricity elliptical orbit; zero inclination; retrograde motion. Category 3.4 is identical with Category 1.2. The companion's motion is elliptical, somewhat similar to the one in Category 2.4, but less dependent on the mass ratio and the density; high inclination; prograde motion for the separation sunward, retrograde for the forward. Category 3.5, identical with Category 1.7, shows again the two fragments crashing into each other, this time 90 days after separation.

3. FINAL REMARKS

A great variety of the companion's dynamical behavior results from the strong dependence on the circumstances at breakup, particularly on the position of the comet in orbit, on the direction of separation and on the area of separation on the parent nucleus. The calculated patterns vary from zero to very high inclinations, from a prograde to a retrograde sense of motion, and from escape of the companion along very strongly hyperbolic trajectories to its pursuance of periodic, quasi-stable orbits around the principal nucleus terminated in some cases by collision of the fragments. We can state plainly that the velocity of separation as derived from observations of the split comets (Sekanina, 1977, 1978) offers by itself no information on the mass of the comet. The interpretation of the empirically determined time of splitting and the separation velocity, the interaction between the gravitational and the nongravitational perturbations, and the possibility of the existence of binary and multiple comet nuclei are among the most interesting problems that remain to be explored.

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REFERENCES

Schubart, J. and Stumpff, P.: 1966, *Veröffentl. Astron. Rechen-Inst. Heidelberg* No. 18, pp. 1-31.
Sekanina, Z.: 1977, *Astrophys. Letters* 18, pp. 55-59.
Sekanina, Z.: 1978, *Icarus* 33, pp. 64-71.