PART VI

COMETS

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EMPIRICAL DATA ON THE ORIGIN OF "NEW" COMETS

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INTRODUCTION

The different hypotheses proposed so far on the origin of comets have been reviewed in detail last year (Delsemme 1977). In particular, I mentioned why the orbital statistics seem to be consistent with only one hypothesis, namely that comets were accreted at unknown but moderate distances (10 to 1000 A.U.) within the protosolar nebula, and ejected later into a sphere whose radius is some 50,000 A.U., usually called the Oort's cloud. Safronov (1977) and Cameron (1977) have different scenarios to do just that. Even with improvements like that of Dermott and Gold (1978) the choice between these scenarios will remain impossible until we have a convincing model describing the gravitational collapse of an interstellar cloud into a planetary system.

The important point is that the primary source of the long- and short-period comets is unique and cannot be really doubted very much any more: It is supplied by those "new" comets coming straight from the Oort's cloud. In the recent list of original orbits (Marsden et al, 1978), the accumulation of 80 original values of 1/a below 100 (in 10^{-6} AU^{-1} units) leaves little doubt that most of these comets are new. I would however avoid to call all and every one of them "new" (as Marsden et al, do in their Table IV) because of Oort's definition: new comets are those that have never been through the solar system before.

This semantic distinction is important here, because it is unavoidable that a small fraction of the 80 very-long period comets (1/a original < 100 means P > 10^6 years) have already been once or several times through the solar system before, but have come back almost exactly to their previous value of 1/a. This is because of the random nature of the changes in their binding energies introduced by planetary perturbations. Hence these "young" comets cannot be distinguished from the "new" comets by orbital considerations. However, the mere accumulation of orbits below 1/a = 100 demonstrates that a steady state has not been reached by orbital diffusion, which implies that comets decay fast. The physical decay of new comets must be so fast that we can hope (although it has never been done) to separate "new" and "young" comets by using their gross physical properties.

R. L. Duncombe (ed.), Dynamics of the Solar System, 265–271.

PHYSICAL DECAY OF "NEW" COMETS

Oort (1950) had already mentioned that the observed number of "new" comets is approximately five times higher than that which would be expected from the number of other long-period comets. His interpretation was that "they must have a greater capacity for developing gaseous envelopes." Whatever the mechanism, the point is that they decay considerably in not much more than one passage, since some 80% of them seem to have disappeared from the statistics when they should have come back for their second or third passages.

A mere decay of the vaporization rate of the very volatile constituents may be a partial answer, but is unlikely to totally explain the dimming by 3 to 5 magnitudes that is needed to explain the total effect.

In a study of 13 split comets, Stefanik (1966) has shown that they were predominantly "new" comets in the Oort's sense, that ten split without the action of any tidal forces, and that some actually split on their way to their first perihelion passage (Whipple and Stefanik 1966). Repeated splitting is a low-energy fragmentation process from larger bodies that yields an exponent -2/3 in the final mass distribution of the splitted bodies. Most of the grinding processes known in nature also yield this type of mass distribution for the final grains. In particular, collision splitting also yields such a dependence, which is typical of the asteroids. Hartmann (1972,1975) finds that the exponent grows from -2/3 for smaller energies, to -1 for larger fragmentation energies. The existence of a mass distribution law with the exponent -2/3 could therefore be predicted if all comets are derived from "new" comets by a fragmentation process that uses a low-energy, like splitting. However, this does not imply that "new" comets should follow the same distribution, because their size distribution is likely to come from another mechanism, like accretion in the protosolar nebula.

It is therefore submitted here that:

a) the size distribution of "new" comets is likely to be very different from the size distribution of old long-period comets.

b) the size of a comet can be assessed statistically by assuming that its absolute brightness is in proportion to the surface area of the vaporizing nucleus (this is the basic assumption of the vaporization theory of comets, Delsemme and Miller 1971).

We can therefore predict that the distribution of the absolute brightnesses of the quasi-parabolic comets should be bimodal, being the mixture of some 80% (from Oort's remark) of "new" comets, with some 20% of much fainter fragments, that we have called "young" comets (Oort's ratio can of course be considerably biased by the faintness of the "young" comets).

BRIGHTNESS DISTRIBUTION OF "NEW" COMETS

Using the sample of Marsden et al (1978), we exclude first from the 80 orbits those 5 that seem the least reliable (comets 1975 q, 1955 V, 1940 III, 1968 VI and 1959 III), because their osculating orbits have mean errors larger than 100 (in 10^{-6} AU^{-1}). Among the 75 orbits left, we exclude those whose perihelion is too far away (q > 4 AU) to extrapolate an absolute magnitude with any significance (comets 1974 XII, 1975 II,

TABLE I

H_0	Number	Individual Comets
1.1 to 2	1	1914 V.
2.1 to 3	0	
3.1 to 4	5	1889 I, 1890 II, 1905 IV, 1915 II, 1951 I.
4.1 to 5	10	1853 III, 1863 VI, 1886 IX, 1898 VII, 1903 II, 1914 III, 1919 V, 1947 VIII, 1955 VI, 1966 V.
5.1 to 6	17	1886 I, 1892 VI, 1895 IV, 1898 VIII, 1899 I, 1902 III, 1911 IV, 1922 II, 1925 I, 1925 VII, 1942 IV, 1947 I, 1948 V, 1957 III, 1971 V, 1973 XII, 1975 VIII.
6.1 to 7	12	1897 I, 1903 IV, 1904 II, 1907 I, 1912 II, 1917 III, 1921 II, 1941 I, 1946 I, 1948 I, 1954 X, 1975 V.
7.1 to 8	5	1849 II, 1900 I, 1941 VIII, 1944 IV, 1948 II.
8.1 to 9	0	
9.1 to 10	8	1932 VI, 1932 VII, 1952 VI, 1953 II, 1954 XII, 1967 II, 1972 VIII, 1975 XI.
10.1 to 11	1	1937 II.
11.1 to 12	3	1946 V, 1954 V, 1976 XIII.

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1954 VIII, 1972 IX, 1956 I, 1925 VI, 1957 VI and 1936 I). Absolute magnitudes H_0 were determined for 62 of the 67 comets left, mainly from observations published in IAU circulars when available. The actual absolute magnitude deduced from the mean light curve reconstructed from observations when the comet crosses r = 1 A.U. before perihelion was preferred when possible. When the dependence on distance was not known, for comets with q > 1 A.U., the approximation known as H_{10} was used, in particular that given for the 19th century and early 20th century comets by Vsekhvyatsky (1964). When H_{10} varied during the cometary visibility, the value before perihelion was preferred. The results appear in Table I.

DISCUSSION

The expected bimodal distribution is present. However, a first bias is apparent. It is clear that all comets in group 2 ($9.1 < H_o < 12$) were found telescopically during the last 45 years, whereas group 1 ($1.1 < H_o < 8$) corresponds to a span of 130 years, roughly three times longer. The number of comets of the second group in an unbiased sample should probably be larger by a factor of 3. Second, the incompleteness grows fast in magnitudes 10 to 12, and the numbers of objects are too small to make any deduction on the shape of the distribution tail.

The interesting point is of course the gap from 8.1 to 9 already announced by the steady decline from the fifth to the eighth magnitude. If the gap were introduced by a systematic error in the absolute magnitudes of telescopic comets, the shift needed to suppress the bimodal distribution is about 4.0 magnitude, which seems too large to be possible. However, the major argument against a systematic error of that size is that the gap does not exist in the statistics for all long-period comets (Vsekhsvyatsky 1964). Since our very-long period comets are undistinguishable at discovery from other long-period comets, it would be difficult to explain the gap as an artifact coming from observational selection.

In particular, using Vsekhsvyatsky's incompleteness model, since 12 very-long period comets have been observed since the 1930'ies between absolute magnitudes 9 and 12, then at least 12 should have been discovered (instead of zero) between absolute magnitudes 8 and 9; 16 between 7 and 8 (instead of 3); 24 between 6 and 7 (instead of 5). This is a total of 44 missing comets that should have been discovered since the 1930'ies between absolute magnitudes 8 and 9, to fill up the gap with a <u>constant</u> distribution; many more would be needed for a unimodal distribution. The only alternate explanation is that all magnitudes of telescopic comets are biased by 3.5 to 4.0 magnitudes, <u>and</u> that not enough comets of this type are included in Vsekhsvyatsky's statistics to show the bias. It seems easier to believe that the gap is real. We can therefore tentatively identify those 50 brighter comets between magnitudes 1 and 8, as pristine "new" comets, whereas the 12 fainter comets, between magnitudes 9 and 12, would possibly be the fragments of those comets that have split or dimmed during their first passages, and whose orbits have come back by chance in the same energy range as that of "new" comets.

The distribution of the brighter objects seems to be rather narrow, corresponding to objects with a radius of 3 ± 2 km, (that is with a mass between 10^{16} and 10^{18} grams) The shape of their distribution is not known

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with accuracy; however, contrarily to that of the long-period comets, no stretch of the imagination can fit it in with a constant slope on a log-log diagram. It must therefore be explained by a formation mechanism different from a fragmentation process, since in particular it seems to possess a cutoff near magnitude +8. The distribution of the fainter objects is not known at all. Incompleteness could easily hide a constant slope for those faint magnitudes, therefore they might indeed result from the fragmentation of the brighter bodies. It is remarkable that Goldreich and Ward (1973) predict $R = 5\ \xi^{2/3}$ km for the size of the planetesimals accreted from gravitational instabilities in the solar nebula (ξ is smaller than, but near unity). The present results suggest therefore that new comets could be identified with pristine planetesimals, and that they decay very fast, probably by splitting when they come within the inner solar system. Grants of NSF (AST 78-08038) and NASA (NSG-7301, planetary atmosphere program) are gratefully acknowledged.

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DISCUSSION

Van Flandern: I do not object to your interpretation of the data, but offer an alternative one, consistent with the planetary break-up model of cometary origin. In this model, much material is released suddenly into the vacuum of space, and the volatiles are suddenly frozen by the release of temperature and pressure. Such frozen volatiles will adhere only to masses large enough to have self-gravitation, which may explain the lower mass limit you have found. All except a few which are propelled close to the Sun will be somewhat protected from solar radiation by the optical depth of the debris cloud from the break-up. This may explain how they can have been continuously frozen since their origin. Would you care to comment on this alternative explanation of your data?

Delsemme: Your alternative explanation of my data maily demonstrates that you have a bright imagination; I have no quarrel with it. The real problem is to see how your planetary break-up model, which is at variance with the paradigm of recent work on the solar system and its origin, will stand the criticism of the scientific community when it is published. Since you reinterpret many of the observational data in a different way, only the future will tell us whether you have achieved a new paradigm without cracks, able to compete with the classical interpretation.

Kresák: I understand that the bimodality of your magnitude distribution can only be removed by an abrupt change of the discovery probability near $H = 7\text{-}8^m$. Maybe that such a discontinuity is not so unnatural as it appears at first glance. We have a rather complete record of the comets which become brighter than about 10th absolute magnitude, and are discovered in systematic visual searches; and we have a very poor coverage of the fainter comets, which are only detected by chance on plates taken for different purposes. Moreover, it appears that the current total absolute magnitudes of those comets which do not become bright enough for smaller instruments, are systematically underestimated by $2\text{-}3^m$. It would be interesting to see an analogous distribution with the maximum absolute brightness as the parameter, and to look at the circumstances of discovery of the 12 comets forming the low-brightness peak.

Delsemme: If the bimodal distribution of the absolute magnitudes observed for <u>new</u> comets were an effect of observational selection, as proposed by Kresák, it would also show on the larger statistics of long-period comets. It does not. The remarkable fact is that, in spite of a selection effect that must be the same for both groups of comets, the distribution of "new" comets is entirely different from that of the long-period comets. It must mean something: My interpretation is that we see a distribution of pristine planetisimals, mixed up with 20% of broken fragments.

Weissman: I think this is a very important result and should be pursued to the fullest. I see two problems with it, however. First, the observed splitting rates for comets is about 10% for Ooor cloud comets and 4% for older long-period comets. Thus not all comets split on each return. The distribution of magnitudes should thus be a mix of the intrinsic distribution and the fragmentation distribution. Perhaps we simply do not have sufficient statistics to derive this structure in the distribution.

Secondly, Whipple has recently shown that there is no evidence for the existence of cometary groups, with the exception of the sun-grazing comets and a few additional pairs. Thus we do not see many families of fragmentation products. Again the problem may be only observational.

Delsemme: I think Weissman is right when he says that these problems are observational. Not only do we not have enough comets in the faint peak (fragments) of my bimodal distribution, but also this peak is considerably influenced by observational bias. If my interpretation is correct, we should see, when the observational bias is removed, a straight line with almost a -1 slope on a log-log diagram, because these comets must come from a fragmentation process, undistinguishable from that of the long-period comets.