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THE NATURE OF COMETS

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Despite the fact that much scientific interest in comets has prevailed since the days of Newton, the data we have concerning them is exceedingly limited. Just as for other stellar objects, the observations of comets fall under three categories: measures of position, estimates of apparent brightness, and studies of their spectra. We should reasonably expect that most of the existent data would refer to measures of position, as the techniques employed in that field are based on the oldest principles used in astronomy. Fortunately our expectations prove to be correct, but in spite of this, our information concerning the orbits of very long-period comets is so meager that few comets have been sufficiently observed to permit computers to determine their behavior before they reached the immediate vicinity of the sun. The estimation of the brightness variation of comets is a difficult task and hence various results agree poorly. Since the application of spectrographic methods to celestial objects has had only a recent beginning, our information on this aspect of comets is greatly limited also.

When a comet is fairly bright and close to the sun, its two most conspicuous features are the coma and the tail. The tails are usually large and in some comets they extend to a distance equal to that between the earth and the sun. They are transparent, for we can see stars through them without any perceptible dimming of the light. This transparency results from the low density of the matter that constitutes the tail. In some comets, such as Comet Brooks (1911 V) and Comet Morehouse (1908 III), the tail experiences very rapid variations in structure. For a long time it was considered that the pressure of light caused the particles in the tail to move away from the sun. The accelerations observed, however, are larger than those likely to be caused by radiation pressure alone, and consequently we have to call in additional agencies as the cause of the observed motions in the tails. L. Biermann has recently contributed an interesting idea that the observed phenomena in cometary tails can be related to corpuscular radiation emanating from the sun. He finds that the continuous flow of particles leaving the sun exerts sufficient pressure on matter in the tails to produce the high accelerations we observe. Since the material in the tail originates in the nucleus and as we now recognize additional agencies for extracting matter from the nucleus, we conclude that a comet loses a considerable amount of matter on each trip it takes to the neighborhood of the sun.

The coma appears as a hazy, roundish patch of light surrounding the nucleus. From spectrographic studies we know that this halo consists usually of gas and dust particles that are finely divided. The dust particles mostly reflect the sunlight. Because of the transparency of the coma we infer that its material density is fairly low. The coma is sometimes quite large. In Halley's comet the coma attained a size nearly thirty times the earth's radius. The known order of magnitude of cometary masses indicates that the parent nucleus about which the coma exists is too small to exert sufficient gravitational attraction to hold the constituents of the coma together. We therefore conclude that the comae of comets are transient features and that the permanent part of a comet is its small nucleus, which is often invisible.

Some astronomers hold the opinion that the nucleus of a comet is an aggregate of smaller bodies held loosely together. Recently R. A. Lyttleton has even suggested that each of the components will describe an independent orbit about the sun and that they mostly move together without being held by a local central force. It is difficult to believe that such an aggregate can resist breaking up for any length of time, in view of the tidal forces exerted by the sun.

A couple of years ago Fred L. Whipple proposed a comet model whose nucleus is a conglomerate of ices and solids. Some of the external layers of ice would evaporate, leaving a porous crust of meteoritic material which covers up the rest of the nucleus and acts as an insulating layer. When the comet approaches the sun the temperature of the nucleus rises and the hot gases present tend to disrupt the meteoric crust, thus exposing part of the icy interior to intense solar radiation. As a result of the rapid vaporization in these exposed regions, the gases rush out in the form of jets. Most of the jets would be on the sunlit side of the comet, but if the comet rotates about an axis the jet will have a direction asymmetrical with respect to the sun. When a stream of gas leaves the cometary nucleus it has a jet propulsion effect on the comet itself. In other words the comet will experience a retardation or an acceleration of its motion along its orbit depending on the sense of the rotation of the comet. Such effects would change the period of the comet and hence it might arrive ahead or behind its schedule depending on the sign of the acceleration. Whipple thus explains the systematic decrease in period of Encke's comet as due to the expulsion of gas from the nucleus in a direction constantly different from that of the sun. The rotation of a solid nucleus is necessary to explain such phenomena and it gives direct evidence for the unity of cometary nuclei.

We have seen that the numerous forces a comet encounters in the solar neighborhood tend to deprive it of a long life. While comets can survive the effects of material losses over a large number of perihelion passages, it seems obvious that they cannot continue to survive for a length of time equal to the lifetime of the solar system. Since we find no scarcity in the visits of these wanderers, there must be a source which can replenish the stock which has been exhausted by approaches to the vicinity of the planets. We thus enter the domain of interesting speculation concerning these objects.

Nearly eighty percent of the comets we observe have periods greater than a hundred years and the longest periods reach millions of years. The major axes of the orbits of a large majority of these are measured in thousands of astronomical units, while some are as great as 50,000 A.U. (astronomical units) or more. When we consider that the distance to the nearest known star is 270,000 A.U. we realize that the comets in the course of their wanderings may, at aphelion, reach regions where their paths could be affected for extremely long periods of time by our close stellar neighbors.

The question then arises as to whether the comets could have originated in interstellar space before being captured by our sun. Studies based on orbits calculated by Elis Stromgren and his collaborators indicate that this is not likely, because a body captured by the sun, on account of its original motion, would traverse an orbit which has the properties of an hyperbola. It is essential that the orbit determined for the comet apply to the motions it had before it reached the solar vicinity because the comet would be greatly affected by the perturbations of Jupiter and other planets after it arrived within their zone of influence. From a list of about twenty accurately calculated orbits showing the motions of comets outside the solar system not a single hyperbolic orbit was found, a fact that makes it difficult to believe that comets were captured from the interstellar medium.

Such considerations bring us next to a very important investigation carried out by J. H. Oort of the University of Leiden in Holland. He found that a large number of the long-period comets reached distances of the order of 150,000 A.U. when they were farthest from the sun. According to Oort these comets could not have passed the planetary region before because the perturbations of Jupiter alone would have changed the orbits considerably on any previous visit. Hence, he concludes that these comets come originally from distances ranging between thirty and a hundred thousand A.U.

This source of comets extends so far from the planetary domain that we must seriously consider the effect of stellar perturbations on them. The gravitational attractions of the neighboring stars on comets at 100,000 A.U. from the sun change the velocities in such a way that roughly half of them will have values exceeding the velocity of escape from the solar system and thus leave us permanently. At distances of 200,000 A.U. almost all the comets will have escaped so that we can expect the outer fringe of our source of comets to be around 150,000 A.U. As a result of stellar encounters, the orbital inclinations of these comets will have no preference for the plane of the ecliptic, but will be oriented at random. Also, from the number of comets that pass by our neighborhood we can calculate the total number in the shell of comets considered by Oort. This value is close to a hundred billion. We thus see that the comets that come from distances greater than 30,000 A.U. do so as a result of the continual effect of perturbations by neighboring stars.

What happens to most of these new comets when they come close to the planets? The perturbations of Jupiter reach such a magnitude that nearly half will be thrown into short-period orbits. Some, after a few passages, may actually come so close to Jupiter that they will be diverted into Jupiter's family of comets. We thus have a steady source of short-period comets also. However, the deterioration which short-period comets undergo is appreciable and after many returns they remain invisible.

The next stage of Oort's investigation regards the means by which such a cloud of comets could come into existence in the first place. He considers that such large bodies could not have grown in interstellar space, because the gas-density in these regions is low. Oort prefers the view that comets and minor planets originated simultaneously as the result of the breakage of a planet-like body between the orbits of Mars and Jupiter. Some of these fragments might have had circular orbits and some elliptical ones. Those having nearly circular orbits remained stable members of

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the solar system while those in elliptical orbits were subjected to the perturbations of Jupiter and other planets in such a way that they diffused outward. Most of these would have acquired hyperbolic orbits and left the solar system permanently, but a small fraction would have been thrown into orbits with major axes in the neighborhood of fifty to a hundred thousand A.U. These, according to Oort, would constitute the cloud of comets.

Quite recently Lyttleton worked out a theory showing that comets could be produced by the sun's passage through an interstellar cloud at slow speed. This theory does not appear very convincing because an extremely idealized set-up is necessary for the process to operate, a condition that may not be available in actual practice.

Perhaps we may be correct, if we say that today we have gained some insight into the general characteristics of comets. The many recent investigations on the subject have helped greatly. The recognition of solar effects on comets may open a new trend in our approach to the study of both comets and the solar atmosphere. The knowledge of the existence of a surrounding cloud of comets at such large distances from the sun and the effects of stellar perturbations on them is revolutionary. Perhaps, in the not too distant future, some of the features which are puzzling now may become clear and we may get at a better understanding of the exact origin of comets.