Celestial mechanics

Orbital evolution of comets

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A FLAW in our understanding of the orbital evolution of comets is that the number of short-period comets — those with orbital periods less than 200 years, such as comet Halley — is much greater than theory predicts[1]. The discrepancy is enormous; the observed number is two orders of magnitude larger than expected[2]. Relying partly on some newly recognized perturbations acting on comets, Bailey[3], on page 350 of this issue, presents a possible solution to this problem.

In 1950 Oort proposed that the Solar System is surrounded by a spherical cloud containing 10^{11} comets; today it is believed that a typical 'Oort cloud' comet orbits the Sun at a distance of 25,000 astronomical units (AU). Until recently it was thought that the orbits of comets are mainly perturbed by random stars that pass within about one parsec of the Solar System. In the past year, a second, more important perturbation source has been recognized. The relatively smooth gravitational potential of the galactic disk in which the Solar System is embedded is responsible for a tidal effect upon comets that is proportional to the total density of material (stars, gas and dark matter) in the solar neighbourhood. (This is analogous to the orbital precession of the Moon because of the pull of the Sun.)

Both perturbations — from passing stars and galactic tide — gradually alter the orbital angular momentum carrying some comets into the inner Solar System and under the gravitational influence of the outer planets. Those comets that pass within 5 AU of the Sun are observable from the Earth and are called 'new' comets, as they are probably making their first passage through the planetary system. A new comet is recognized by its extremely small orbital energy (in absolute value); after one passage through the inner Solar System the orbital energy is typically increased sixfold. Oort cloud comets that pass within 10 AU of the Sun are either ejected from the Solar System entirely or captured into short-period orbits. However, even using both perturbations, the number of short-period comets derived from this capture process is still a small fraction of the observed number.

A solution to this problem is that the short-period comets come from a source other than the Oort cloud, from a second, closer comet reservoir. Current ideas[4] are that a comet belt extends outwards from the planetary system and departs from the ecliptic to blend in with the spherical outer Oort cloud at about 10,000 AU. Comets at distances between a hundred and a few thousand AU are virtually unperturbed by stars, galactic tides and planets. The comets from the inner region drift into the planetary system with perihelia well outside the detectable limit of 5 AU, and thus no significant flux of observable new comets is produced. (In the case of the outer Oort cloud, the perturbations are stronger and some comets can be directly perturbed into orbits that are observable from the Earth.) As a result of the lack of observable new comets from the inner Oort cloud, the spatial (or energy) distribution is very uncertain, and *ad hoc* assumptions are unavoidable. However, Bailey[1] turns the short-period comet problem around, and demonstrates that the number of short-period comets constrains the choices, allowing one to give a crude determination of the spatial distribution.

Bailey assumes a spherically symmetric cloud with a power-law energy distribution of unknown index. He demonstrates that up to about 30,000 AU the galactic tide perturbs far more comets into the planetary region than stellar encounters do, and hence one can neglect stellar perturbations when calculating the injection rate into the planetary system. This conclusion has been checked independently by numerical experiments[5]. Bailey computes the fraction that will evolve to short-period orbits and multiplies that fraction by the average lifetime of observed comets to derive the expected total number of short-period comets. To explain both the numbers of new and short-period comets, the energy distribution must be fairly steep. For a comet lifetime of 3,000 years and an inner Oort cloud radius of 3,000 AU, 97 per cent of the comet population must be inside 10,000 AU. This conclusion implies that most short-period comets originate in orbits near the cloud's inner boundary, whereas new comets originate at distances greater than 10,000 AU. The short-period comets come from the inner Oort cloud and the new comets from the outer Oort cloud. Furthermore, using entirely analytical methods and without invoking any other perturbations aside from the galactic tide, Bailey is able to derive the correct number of observed short-period comets.

A massive inner cloud has also been invoked to explain biological extinction events on the Earth as a result of comet showers. The related suggestion that large impact craters and extinctions over the past 250 million years occur periodically every 26–30 million years has received much attention, but there are doubts that the claimed periodicities in the data are genuine[6,7]. It is also unlikely that comet showers are responsible for either periodic or random events on such short timescales. Periodic comet shower theories include the proposals of a solar companion (Nemesis)[8,9], a tenth planet (Planet X)[10] and catastrophic encounters with giant molecular clouds during galactic plane crossings[11]. The difficulty with the galactic plane crossing suggestion is that although the Sun does pass through the galactic midplane every 30 million years, the amplitude of its oscillation is small, about 70 parsecs. Giant molecular clouds have a similar scale height, and therefore encounters can occur at all times during the Sun's oscillation, giving no statistically significant periodicity[13]. In fact, despite the Sun's motion, the density of material near the Sun is fairly constant, implying that the comet flux induced by the galactic tide is also fairly uniform. Finally, even random comet showers caused by close stellar encounters are unlikely to explain the crater record because an encounter capable of creating a shower is expected only once every 100 million years[5]. Encounters with giant molecular clouds occur even less frequently, about once every 500 million years. Hence, the crater data may reflect only a few comet showers. This conclusion is supported by identifications of impact material at eight large craters up to 200 million years old; only two of the craters could have been formed by comet impacts, the rest were probably made by asteroids[14].

If Bailey's bold extrapolation of the total comet population is correct, the short-period comet problem is solved; it is satisfying that this problem is soluble using perturbation effects we already understand. However, our theories about the inner region of the Oort cloud are still speculative, and we must proceed carefully, because unlike the situation for the classical Oort cloud, there are no observable new comets that directly sample the proposed inner comet cloud. ☐

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