The Influx of Comets and their Debris

William M. Napier
Armagh Observatory
Armagh, Northern Ireland, United Kingdom

ABSTRACT

The Earth has been bombarded by comets and their debris throughout geological time. Rare giant comets are the most massive bodies to enter the inner planetary system and they are major contributors to the mass budget of the zodiacal cloud, generating large surges of cometary dust onto the Earth. Climatic effects, including severe declines in biodiversity, are then expected, and mass extinctions of life may be caused as much by the trauma of prolonged climatic downturn as by the prompt effects of impact. Cometary debris which may have induced the last ice age, and possibly the progenitor comet itself, are identifiable in the contemporary interplanetary environment.

BOMBARDING THE EARTH

Following the pioneering discovery work of Helin and Shoemaker (1979) and many search programs since, it is now thought that there may be a thousand bodies greater than 1 km diameter in near-Earth orbits, with perhaps another hundred thousand more than 100 m wide. The existence of this population, and the impact megatonnages implied, has widely altered our perceptions of the evolution of life and even human security on the planet.

The existence of fast computers and numerical integration codes has allowed several groups to conduct direct numerical integrations of the known near-Earth objects (NEOs) for simulated times of tens of millions of years. These integrations, along with analytic studies (e.g., Gladman et al., 1997; Migliorini et al., 1998; Farinella et al., chapter 3) have revealed that NEO orbits are controlled by several types of perturbation: a
NEO may undergo a close encounter with Venus, Earth, or Mars; its mean angular motion may become locked into a resonance with that of one of these planets, providing a temporary protection against collision; secular resonances may pump up the eccentricity of a NEO, transporting it from a Mars-crossing orbit to an Earth-crossing one (Michel et al., 1996); this and the so-called Kozai resonance, which amounts to a cycling of the angular momentum vector of an orbit between its components, may yield high-eccentricity, low-perihelion orbits resulting in a NEO falling into the Sun. NEOs are conventionally divided into Apollo asteroids (Earth-crossing), those sunward of the Earth (Atens), and those on the marsward side of Earth (Amors). The division is not dynamically fundamental as there is an exchange of bodies between these regions. Amongst these NEOs, only Apollo/Aten objects have the potential to collide with the Earth. The median impact speed is in the range 15–20 km s$^{-1}$, although a long tail extends up to about 40 km s$^{-1}$. Numerical integrations yield a median lifetime for the known Earth-crossers of about 10 Myr, with ejection from the solar system (12%), planetary impact (21%), or infall to the Sun (67%) as the end-states (Gladman et al., 1997). This sample is however heavily biased towards those NEOs that are most easily discovered; particles randomly placed in NEO orbits typically survive for only ~2 Myr. The known NEOs are thus a transient population, which must be rapidly replenished from one or more reservoirs.

What are the sources of this NEO population? Might there exist reservoirs of which we know little or nothing? Is the current population representative of the hazard, or might the extraterrestrial influx be dominated by rare, atypical objects? And can we assume that the flux and nature of infalling extraterrestrial material are constant through geological time? To answer such questions, we have to look beyond the current, transient NEO system, to the reservoirs that replenish it.

SMALL BODY POPULATIONS

The small bodies that impact Earth come from several sources. Some of these reservoirs are in process of self-destruction through collisional grinding; most (and perhaps all) are dynamically unstable as a result of gravitational influences of planets, stars, massive nebulae, or galactic tides. Dynamical highways connect many of them to each other as well as to the near-Earth environment. The interrelationships between these sources, and the proportions of each that contribute to the extraterrestrial influx, are still uncertain issues. There are even indications that this flux may be substantially due to large but undetected comet populations. The evolution of these small-body reservoirs through geological time will be reflected in the history of dust deposition and impact crater formation on the Earth.

Figure 1 outlines the main classes of known minor body. The 19th-century division into asteroids ("starlike objects") and comets ("hairy stars") is employed. As a taxonomic classification it remains useful even though it is now beginning to fray at the edges: the Edgeworth-Kuiper and Centaur objects are probably in the main icy bodies and thus, constitutionally, comets; many asteroids are in unstable orbits usually associated with active comets; and there are several well-documented cases of comets that have become asteroidal in appearance and the converse.