THE ROLE OF COLLISIONS WITH INTERPLANETARY PARTICLES IN THE PHYSICAL EVOLUTION OF COMETS

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Abstract. Effects of collisions with interplanetary particles are investigated. To this purpose, collision probabilities for comets with different orbital elements are computed. It is found that collisions may have a non-negligible effect on the physical evolution of comets. In this connection, it is shown that under certain conditions collisional lifetimes may be shorter than dynamical or vaporization lifetimes. In particular, collisional lifetimes are on average shorter for comets in retrograde orbits than those for direct ones. It is further suggested that catastrophic collisions may contribute to prevent long-period comets in retrograde orbits from reaching short-period orbits by orbital diffusion. Collisions may also produce irregularities of the nucleus brightness by leaving exposed regions of fresh volatile material and may in this way lead to a 'rejuvenation' of old dusty short-period comets. Catastrophic collision probabilities are too low to account for the observed comet splittings, so other trigger mechanisms should be at work. However, it is shown that collisional mini-bursts (increases in brightness of one magnitude or so) caused by decimeter-sized bodies may occur rather frequently on short-period comets when they pass through the asteroid belt. The burst observed in comet Tempel-2 at \( \sim 3 \) AU in December, 1978 could be an example of such collisional mini-bursts. The systematic observation of periodic comets when they pass through the asteroid belt could give valuable information about the spatial density of decimeter and meter-sized bodies. In particular, collisional effects for comet Halley, for which a continuous surveillance is planned, are evaluated.

1. Introduction

Comets entering the inner planetary region are subject to random collisions with particles of the interplanetary medium. Several dynamical and physical phenomena of comets have been attributed to such collisions as, for example, splittings and bursts (Harwit, 1967, 1968), or sudden anomalies observed in the motion of some short-period comets (Marsden and Sekanina, 1971). The influence of collisions has further been considered by other authors (e.g., Shtejns and Zal'kalne, 1972; Matsuura, 1976; Cintala, 1981). Weissman (1980) concludes that interplanetary matter does not pose a significant collision hazard on long-period comets.

We deem that the problem needs a further discussion to try to define the extent of the influence of impacts on the physical evolution of comets. First, we will compute the spatial density of particles in the interplanetary medium. We will use the generic term 'particle' for centimeter up to subkilometer-sized bodies. The knowledge of the spatial density of particles will allow us to compute the collision probability for any comet. Afterwards, we will evaluate the physical effects of a hypervelocity impact on a comet.

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2. Spatial Distribution of Bodies in the Interplanetary Medium

The study of the interplanetary matter has almost exclusively been limited to the inner planetary region, so we will only consider collisional events at distances smaller than Jupiter's heliocentric distance. Our current knowledge comes from ground-based observations of asteroids and comets, meteoritic influx on Earth, the zodiacal light, crater records in the terrestrial planets and the Moon, and in situ measurements by space probes. A comprehensive review on this subject has been given by Dohnanyi (1972).

We have derived a formula for the spatial density of bodies of mass greater than \( m \), as a function of the heliocentric distance \( r \) and the distance to the ecliptic plane \( z \). We have taken into account the results of Helin and Shoemaker (1979) who quote \( 6.6 \times 10^5 \) asteroids in the main belt, 15,000 Mars-crossers and Mars-grazers, and about 2000 of the kind Apollo, Amor or Atens asteroids. All of these figures refer to a limiting absolute magnitude \( V(1,0) = 18 \). To pass from absolute magnitude to asteroidal radius \( R \), we use the relation given by Zellner and Bowell (1977) in the form

\[
2 \log R = 5.642 - 0.4 V(1,0) - \log p_V, \tag{1}
\]

where \( p_V \) is the geometric albedo. We will adopt an average value of \( p_V = 0.06 \) (Chapman, 1974). Solving Equation (1) for \( V(1,0) = 18 \) we obtain \( R_{18} = 0.675 \) km; and taking an average density for the asteroids of 2.2 gm cm\(^{-3}\) we obtain a mass of \( m_{18} = 2.8 \times 10^{15} \) gm.

Observations and theoretical studies of a population of bodies evolving collisionally indicate that the cumulative number of asteroids \( N(m) \) of mass \( m \) or greater is well represented by a power-law

\[
N(m) \propto m^{-\alpha}, \tag{2}
\]

where \( \alpha = -0.833 \) (Dohnanyi, 1972).

Given the number of asteroids to a limiting mass \( m_{18} \), we can obtain the corresponding number to any limiting mass \( m \) by the relation

\[
N(m) = N(m_{18}) \left( \frac{m}{m_{18}} \right)^\alpha. \tag{3}
\]

Our formula derived for the spatial density of asteroids (in cm\(^{-3}\)) of mass greater than \( m \), at a heliocentric distance \( r \) and a distance \( z \) to the ecliptic plane, is

\[
n(m, r, z) = A m^\alpha \rho(r, z), \tag{4}
\]

where \( A = 8.5 \times 10^{-23} \) and \( \rho(r, z) \) is a function derived empirically characterizing the spatial distribution of asteroids (Figure 1).

A sample of \( 10^5 \) hypothetical asteroids was considered for the computation of \( \rho(r, z) \). The distribution of semimajor axes \( a \) was taken from that given by Zellner and Bowell (1977) for the main-belt asteroids, complemented with \( a \)-distributions for the Mars and Earth-crossers derived from the semi-major axes of the discovered members quoted by Helin and Shoemaker (1979). Watson's distributions for the eccentricities \( e \), and