SWEEPING OF JOVIAN COMMENSURABILITY RESONANCES IN THE EARLY SOLAR SYSTEM AND THE ORIGIN AND EVOLUTION OF THE ASTEROIDS

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There are several features of the asteroid belt that so far remain without adequate explanation. The asteroids' mere existence, as opposed to a well-formed planet in that region, has long been an intriguing problem. In addition, the asteroids exhibit relative velocities that are at least an order of magnitude greater than that which might be expected to be generated by random encounters within a gravitationally interacting swarm of asteroidal masses (1). Since these relative velocities are in excess of the limit for which accretion is possible, the question of interest becomes what was responsible for accelerating the asteroids to their present motions. It has been suggested that the origin and evolution of the asteroids must surely be linked to the obviously important influence of nearby Jupiter which, in some manner, interrupted the process of planetary formation (2). Several mechanisms have been offered including stirring of the asteroids by gravitational encounters with massive, Jupiter scattered planetesimals (3) and the sweeping of secular resonances (4). The present study examines the much more efficient stirring of the asteroids by the sweeping of the low order commensurability resonances as a moderately massive presolar nebula is removed.

It is now widely accepted that, in the collapse of the solar nebula from the interstellar medium, an accretion disk developed as matter flowed toward the accreting central object. Eventually, this accretion disk disappeared at or near the time of the ignition of the central object's T-Tauri phase. The early presence of Jupiter during the accretion disk phase can be inferred by virtue of its solar composition. Thus the gravitational effects of both the accretion disk and an early formed Jupiter were capable of being simultaneously exerted. If the inner planets were, at this time, in the lengthy process of planetesimal accretion, then the gravitational effects of the accretion disk and Jupiter can have a significant impact on the collisional evolution of the asteroids as the nebula is dispersed.

The important aspect of accretion disk, for the present study, is its gravitational influence on the positions of the commensurability resonances of Jupiter. When the disk was still in place it contributed a component to the radial force law which caused significant departures of the force law from Keplerian dependence. As the disk is removed the force law becomes Keplerian and bodies orbiting the central object experience changes in binding energy and hence undergo radial motion. Due to the distributed nature of the accretion disk, the change in the binding energy at Jupiter is greater than that at the asteroid zone. This results in the radial motion of Jupiter being greater than that of the asteroid zone planetesimals. The locations of the commensurability resonances are determined by the period of Jupiter and thus their motions are linked to the motions of Jupiter. Hence, as the disk is removed, the positions of the resonances move at a greater rate than do the asteroid zone planetesimals. This results in a sweeping of these resonances through the asteroid zone material during nebula dispersal.

The low order commensurability resonances are rather efficient at exciting planetesimals to large eccentricities in relatively short timescales. Thus, objects experiencing resonance passage rapidly develop large relative velocities. When enough planetesimals acquire velocities in excess of the limit where accretion is balanced by comminution, destructive collisions dominate and the collisional growth of the planetesimals is halted. For instance, using a moderately massive disk of Cameron (5) and reasonable values of

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T-Tauri mass loss, it is found that each resonance swept at least 0.2 AU in the 10^5 yr. timescale for dispersal of the disk. This implies that, collectively, the 4 main resonances swept over 60% of the asteroid belt and excited eccentricities, judging from numerical experiments (6,7) to values on the order of $e = 0.2$. This results in random velocities on the order of the presently observed 5 km s^{-1} value. Furthermore, these velocities are in excess, by a factor of $\sim$50, of the limit where catastrophic fragmentation begins (8). In this manner, then, the increased collisional velocities resulted in reversing the accretional growth of the planetesimals and eventually produced the fragmentary distribution we now observe as the asteroids. It is also possible that the low mass density of the asteroid belt can be accounted for by ejection of the collisional debris by the enhanced solar wind of the T-Tauri phase.

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