PLANETARY FORMATION SITES - M. Torbett and R. Smoluchowski, Departments of Astronomy and Physics, Univ. of Texas, Austin, TX 78712; R. Greenberg, Planetary Science Institute, Tucson, AZ 85719.

The question of the origin of the present orbital radii of planets is an old one but not much progress has been made since the discovery of the Titius-Bode relationship. Our continuing study of the structure and evolution of the primitive solar nebula suggested that orbital resonances may have played an important role in determining the locations where the swarms of planetesimals eventually condensed to form full-size planets. Of course it is known that several pairs of planets indeed have commensurable orbital periods at present, but the case for control of planet formation by resonances is weakened by the fact that many pairs are not commensurable and that those which are do not necessarily exist at the strongest resonances. If one takes into account, however, the mass loss and mass redistribution which occurred during the evolution of the primitive solar nebula it becomes clear that the positions of resonances were drastically altered during that period. Many different models of the primitive solar nebula and of its history have been proposed but none of these seems to be generally accepted. Therefore we assume, first of all, that the early solar system consisted of a central object of mass M_c surrounded by an accretion disk of mass M_d contained within limits 0.3 and 200 AU. The radial distribution of mass in the disk is assumed to be described by a power law for surface density of the form $\sigma = \sigma_o r^k$, where the index k is an adjustable parameter. Secondly we assume that, as suggested by its nearly solar composition, a proto-Jupiter was the first planet to form while the disk was still in place. The gravitational effects of this early planet produced 2:1 and 1:2 commensurability resonances which influenced the accreting planetesimal swarm. These resonances accelerated the accretional growth and led to the formation of embryos of lunar size and these in turn produced their own 2:1 and 1:2 resonances farther away from Jupiter and so on. The chain of the resulting cascade of resonances is shown in Fig. 1. The redistribution and loss of mass during the transition to present configuration produced a displacement of these planetary embryos so that their final positions were quite different from the original ones. In Fig. 2 we compare the initial positions of the resonances (triangles) with the final ones (squares) and with the actual present positions of the planets (circles). The agreement appears to be comparable to that of the Titius-Bode rule (B's). Reasonable agreement between translated resonances and present planetary positions can be obtained for surface density power index, $k = -1.2$, and for central object and disk mass combinations given by $M_c = 0.41(M_d)^{0.56}$.

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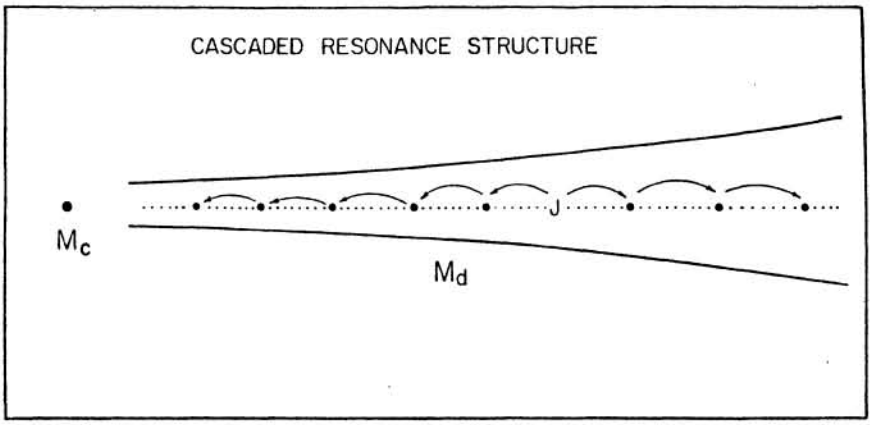

Fig. 1. Cascaded resonance structure in the accretion disk phase of the early solar system. An early-formed Jupiter induces 2:1 and 1:2 resonances on either side of its nebular position which accelerates planetesimal growth by enhancing eccentricities of the planetesimal swarm causing increased collisions resulting in runaway growth of embryos. These objects, in similar manner, themselves trigger accelerated growth at their 2:1 and 1:2 resonances even further interior and exterior to Jupiter. These new objects, in cascade fashion, induce still more objects at the next projected resonance positions. The successive propagation of these 2:1 and 1:2 resonances results in the development of a resonant configuration of planetary embryos.

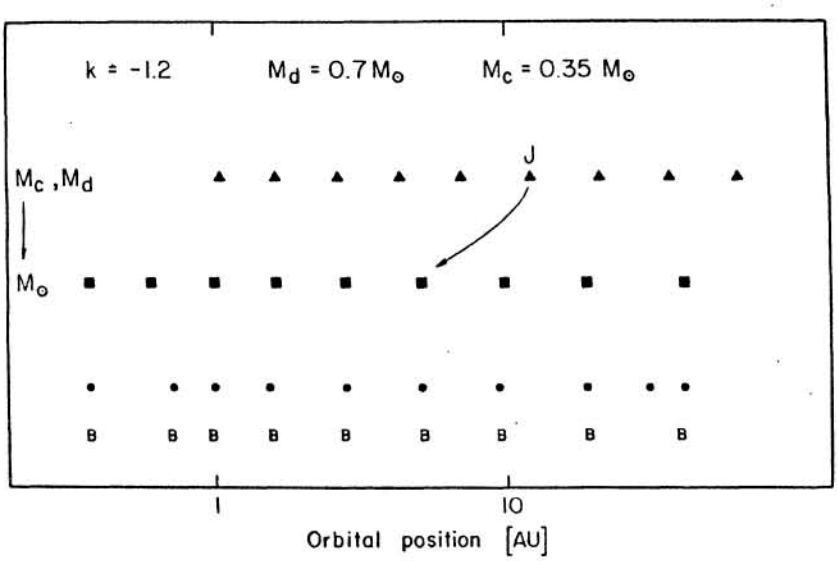

Fig. 2. Radial distribution of cascaded resonances and planetary positions. ▲ = nebular positions of cascaded resonance structure. ■ = positions to which the above structure moves due to the mass evolution of the central object and loss of the accretion disk. ● = present planetary positions. B = positions predicted by Bode's law. Note that the resonance scheme presented here agrees with the actual positions at least as well as does Bode's law. Power index for surface density of the disk, $k = -1.2$; $M_c = 0.35\ M_\odot$, $M_d = 0.7\ M_\odot$, with $0.3 < r < 200$ AU.