PLANETESIMAL SWARMS PERTURBED BY A DISTANT PROTOPLANET; G.R. STEWART, Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO 80309-0392

The early stages of planetary accumulation from a swarm of 10 km diameter planetesimals are most efficiently modeled by calculating the evolution of probability densities which describe the distribution of planetesimal masses and velocities. Recent calculations of this kind for a narrow band of planetesimals at 1 AU from the sun indicate runaway growth of a single 10^{26} g protoplanet in 10^5 years, while the remainder of the swarm remains in bodies smaller than 10^{22} g (1). The subsequent evolution of the swarm is uncertain because the protoplanet produces long range gravitational perturbations that are not accurately modeled by the Fokker-Planck formalism that was used for the early stages. If a population of protoplanets emerges simultaneously in a uniform distribution throughout the terrestrial planet zone, then a statistical random walk treatment of their long range perturbations may be adequate (2,3). However, given the rapid timescale characteristic of runaway growth, it is more likely that the first protoplanets emerged with a highly non-uniform distribution. If such were the case, gravitational perturbations from the few largest protoplanets may have determined the subsequent evolution of the swarm.

The purpose of this abstract is to describe a new computational approach that efficiently models the evolution of a planetesimal swarm that is subjected to the long range gravitational perturbations caused by one or two protoplanets. The separation in semimajor axes between a planetesimal and a protoplanet is assummed to be both a) small enough that Hill's equations may be used to calculate the orbits, and b) larger than three Hill sphere radii of the protoplanet so that analytical approximations can be used to calculat orbit perturbations by a protoplanet. A swarm of 2000 planetesimals is evolved in time steps equal to an orbit period and protoplanet perturbations are only calculated for the orbit period containing a conjunction with a protoplanet. Gravitational perturbations by other planetesimals are only calculated every N time steps, where $N>10$ but must be substantially less than the relaxation time for mutual gravitational encounters between planetesimals. These mutual perturbations between planetesimals are modeled with a Monte Carlo procedure that assumes a model distribution of "background" planetesimals that is periodically updated to reflect the evolution of the 2000 test bodies.

A significant advantage of this code is the ability to run simulations exceeding a thousand years in only a few minutes on a VAX-11; simulations of 10^5 yrs are possible with longer runs. Trial runs with just one protoplanet show the rapid development of gaps near resonance locations even when the theoretical forced eccentricity is roughly comparable to the average eccentricity due to mutual planetesimal encounters. Pertubations by the protoplanet can produce eccentricities that substantially exceed values predicted by Goldreich and Tremaine's analytic theory (4), but these large eccentricities only occur for the few planetesimals that are located in the immediate vicinity of a resonance. Over longer time scales, mutual planetesimal perturbations tend to redistribute this kinetic energy to broader regions of the swarm. Future runs with two protoplanets present are expected to stir the planetesimal swarm more effectively.

Important questions that these calculations can eventually answer are: Over what range in semimajor axes can a given protoplanet stir velocities in the surrounding planetesimal swarm so as to inhibit or delay the runaway growth of a neighboring protoplanet? How large must two neighboring protoplanets get before their accretion zones merge? Was a uniform distribution of several hundred lunar-size protoplanets ever achieved in the terrestrial planet zone?

References:
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