FORMATION OF PLANETESIMALS BY GRAVITATIONAL INSTABILITY IN THE DISK'S TURBULENT STRUCTURES: EVIDENCE FROM ASTEROID BELT CONSTRAINTS..

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Abstract: The formation of planetesimals from a dust/gas disk is a long-standing problem. Meter-sized boulders should quickly spiral into the Sun from gas drag, preventing larger planetesimals (diameter D > 1 km) from forming. This planet accretion bottleneck is known as the `meter-size barrier' problem. A possible solution has been proposed by [1], who showed that density fluctuations in a turbulent disk can concentrate boulders of 25--100 cm in size towards local (and temporary) maxima in the gas density distribution. In these situations, the density of solid material in turbulent eddies can become high enough to trigger the formation of massive planetesimals (e.g., up to Ceres-sized objects) by local gravitational instabilities. Although this work does not yet have the ability to make quantitative predictions about the mass distribution of the resulting planetesimals, it does supports the qualitative idea that planetesimals can be `born big'.

Motivated by these results, we conducted coagulation simulations of main-belt asteroids that initially included large planetesimals. We show that our model parameters, including the size-frequency distribution (SFD) of the starting population, can be constrained by what is known about the main belt: (i) the steep slope of the SFD for D > 100 km asteroids; (ii) the turn-over to a shallower slope for D ~ 100 km (note that both (i) and (ii) were relatively unaffected by post-accretion collisional evolution; see [2]); (iii) the primordial existence of roughly 1000 Ceres-size objects at ~2-4 AU, required to account for the main-belt dynamical depletion events [3]; and (iv) the primordial existence of 0.01-0.1 Earth masses planetary embryos, which are needed to explain both the dynamical sculpting of the asteroid belt and the formation of the terrestrial planets [3, 4].

Our new statistical coagulation/fragmentation code was constructed along the lines of previous codes (e.g., [5, 6, 7]). We investigated a wide range of initial planetesimal SFDs that could lead to plausible final SFDs as constrained by (i)--(iv). Our simulations account for eccentricity/inclination excitation due to mutual planetesimal perturbations and turbulence in the disk as well as eccentricity/inclination damping due to dynamical friction, gas drag and mutual collisions.

We find that classical coagulation models starting from km-sized planetesimals produce results that are incompatible with the above constraints. Note that if turbulent excitation of the planetesimals' eccentricities is neglected, we can satisfy (iv) (i.e., make embryos) but still not (i)-(iii).

Successful results can be obtained by assuming that roughly 40% of the solids of a minimal mass solar nebula were originally in planetesimals between 100km and 1000km in size, with a SFD similar to that of present-day main-belt asteroids in this size range. The rest of the mass remained probably in small objects (e.g., meter-sized boulders). These results provide support to models that claim that gravitational instabilities in turbulent disks are needed for planetesimal formation (e.g., [1]). Our work may help to characterize the properties of the turbulence of the solar system's proto-planetary disk.

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