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Protoplanet Spin by Planetesimal Accretion

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In the standard scenario of planet formation, protoplanets or planetary embryos are formed through runaway and oligarchic growth of planetesimals. We investigate the spin parameters of protoplanets using N-body simulations. By N-body simulations we can calculate consistently the orbital, accretionary, and spin evolution of planetesimals. The spin of protoplanets are important for terrestrial planet formation since it affects the accretion condition of protoplanets and determines the spin of terrestrial planets. For the standard model of a planetesimal disk, a Mars-sized protoplanet forms in 0.5 million years around 1 AU. We find that the spin angular velocity of planetesimals decreases as their mass increases. Planetesimals obtain their spin angular momentum on the early stage of accretion where their mass ratio is not so large. Once a runaway-growing planetesimal (protoplanet) becomes large enough, it mainly accretes smaller planetesimals whose collisional angular momentum tends to cancel out since they collide from random directions. Thus the protoplanet increases its mass but not the spin angular momentum, which leads to smaller angler velocity for larger protoplanets. When a protoplanet reaches the isolation mass, its typical spin angular velocity is as high as 10% of the critical angular velocity for rotational instability under the assumption of perfect accretion in collisions. We find that the obliquity of planetesimals is well expressed by an isotropic distribution. During the protoplanet growth, the scale height of the planetesimal system is much larger than the size of planetesimals. Thus, collisions are three-dimensional and isotropic, which leads to the isotropic obliquity distribution. We show the dependence of the spin parameters on the initial planetesimal system parameters. The spin angular velocity increases with the bulk density of planetesimals. The dependence of the spin angular velocity on the planetesimal mass becomes weaker as the initial mass of planetesimals increases. However, these system parameters do not affect the obliquity distribution.