Rapid Giant Planet Formation

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Two mechanisms have been suggested for forming giant planets, core accretion and disk instability. Core accretion is the generally accepted mechanism, but if a disk instability is possible, it will occur well before core accretion can even get started. In order to further study the disk instability mechanism, 3D gravitational hydrodynamical models of protoplanetary disks have been constructed starting from realistic initial temperature and density profiles. The 3D models show that a clump-forming disk instability can occur in marginally unstable disks with masses as low as 0.04 $M_\odot$ inside 10 AU, and perhaps even in somewhat lower disk masses, though the disk mass seems to need to be greater than about 0.01 $M_\odot$ inside 10 AU. Models with doubled radial extent show that the outer boundary conditions have little effect on the results, and imply that clump formation may be limited to an annulus in orbital radius between about 5 AU and 12 AU, with the usual outcome being two multiple-Jupiter-mass clumps in this annulus. These 3D models suggest that a protoplanetary disk with a mass at the high end of the range (0.01 to 0.07 $M_\odot$) considered possible for the minimum mass solar nebula could quickly lead to the formation of two giant gaseous protoplanets, one at about 6 AU and one at 12 AU. The terrestrial and outer planets could then form much later by the usual process of collisional accumulation of solids.