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Radiative Hydrodynamics and the Formation of Gas Giant Planets

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Gas giant planets undoubtedly form from the orbiting gas and dust disks commonly observed around young stars, and there are two principal mechanisms proposed for how this may occur. The core accretion plus gas capture model argues that a solid core forms first and then accretes gas from the surrounding disk once the core becomes massive enough (about 10 Earth masses). The gas accumulation process is comparatively slow but becomes hydrodynamic at later times. The disk instability model alternatively suggests that gas giant planet formation is initiated by gas-phase gravitational instabilities (GIs) that fragment protoplanetary disks into bound gaseous protoplanets rapidly, on disk orbit period time scales. Solid cores then form more slowly by accretion of solid planetesimals and settling. The overall formation time scales for these two mechanisms can differ by orders of magnitude. Both involve multidimensional hydrodynamic flows at some phase, late in the process for core accretion and early on for disk instability. The ability of cores to accrete gas and the ability of GIs to produce bound clumps depend on how rapidly gas can lose energy by radiation. This regulatory process, while important for controlling the time scale for core accretion plus gas capture, turns out to be absolutely critical for disk instability to work at all. For this reason, I will focus in my talk on the use of radiation hydrodynamics simulations to determine whether and where disk instability can actually form gas giant planets in disks. Results remain controversial, but simulations by several different research groups support analytic arguments that disk instability leading to fragmentation probably cannot occur in disks around Sun-like stars at orbit radii of 10's of Earth-Sun distances or less. On the other hand, very recent simulations suggest that very young, rapidly accreting disks with much larger radii (100's of times the Sun-Earth distance) can indeed readily fragment by disk instability into super-Jupiters and brown dwarfs. It is possible that there are two distinct modes of gas giant planet formation in Nature which operate at different times and in different regions of disks around young stars. The application of more radiative hydrodynamics codes with better numerical techniques could play an important role in future theoretical developments.