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Gravitationally unstable protostellar disks

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The position is adopted that involve a simultaneous formation of a star and all planets around it through a gravitational Jeans-type instability of small-amplitude gravity perturbations in a protostellar disk of gas and dust. The angular momentum flux and dynamical heating by growing Jeans-unstable density perturbations (e.g., those produced by a spontaneous disturbance, or, in rare cases, by a satellite system) in the self-gravitating disk are investigated by using the hydrodynamic theory. In such a system, the hydrodynamic turbulence may arise as a result of the instability. The developed turbulence is related to stochastic motions of gaseous elements. The nonaxisymmetric instability leads to turbulent diffusion of the angular momentum radially outward while of the mass radially inward to the growing star. It is shown that in the Jeans-unstable protostellar disk the turbulent diffusion may exceed the ordinary molecular diffusion substantially. The solid observational result is explained: beyond the 10 Myr period, the circumstellar disk mass drops abruptly by a large factor, with rare examples of transition disks detected, such as β Pictoris. Equations are derived to describe the turbulent heating of the disk that results from the buildup of nonresonant Jeans instability. The heating and the mass redistribution bring the disk toward stability—unless some cooling mechanism is available, e.g., by radiation—against all perturbations, including the most unstable nonaxisymmetric ones. As cooling process always exists in the actual systems, the Jeans instability can be considered to be a long-term $\sim 10^6$ yr generating mechanism for fresh, unstable density waves, thereby leading to recurrent short-lived $\sim 10^4$ yr arc-and-lump or spiral patterns in the disks. Certain astronomical implications of the theory are explored as well.