The details of the origin of the presolar nebula from a collapsing, rotating, interstellar cloud are not known. Theoretical attempts at providing an answer have centered on numerical solutions of initial value problems, where the collapse of a given interstellar cloud is followed to see if a single protostar and preplanetary nebula are obtained.

One mechanism that has been proposed is the orbital decay of a multiple system with subsequent ejection of a single protostar and accompanying nebula (1,2). A multiple protostellar system may result from a fragmentation hierarchy consisting of the collapse and fragmentation of a rotating cloud into coorbital subfragments, further collapse and subfragmentation of the fragments themselves, and so on, until the hierarchy is terminated by rising temperatures. If a coorbital three-body system is formed in one of the stages of the hierarchy, the system will decay to a binary and an ejected single object on the time scale of about 100 orbital periods (3). A calculation of the formation of such a three-body system in the framework of a fragmentation hierarchy is shown in Fig. 1 (4).

Here an isothermal cloud has fragmented into a three-body system, with each fragment having a ratio of thermal to gravitational energy of 0.01 and rotational to gravitational energy of 0.04. The fragments collapse on a time scale short compared to their orbital period, and soon enter the nonisothermal regime where the compressional energy is trapped within the cloud.

The further evolution of one of these fragments has now been studied with a computer code capable of describing three-dimensional, self-gravitational, hydrodynamical collapse, including a detailed treatment of the cloud thermodynamics (5). Radiative transfer in the Eddington approximation is included, as well as realistic relations for the pressure, internal energy, and opacity. The Eddington approximation is very good in the collapse phase and through much of the accretion phase of protostellar formation (6).

The initial conditions for the idealized fragment are taken to be a uniform density, uniform rotation 2 M\(_{\odot}\) cloud with the same ratios of energies as the fragments in Fig. 1. The cloud is initially isothermal at 10 K and has an initial density of 2.5 \times 10^{-14} \text{ g cm}^{-3}; nonisothermal effects begin around 10^{-13} \text{ g cm}^{-3}. In order to discern whether or not the cloud is susceptible to further fragmentation itself, the initial model is given a 10\% amplitude binary perturbation in the density.
Even though initially nearly axisymmetric (the density contours in Fig. 2a correspond to 10% changes in density, and to factor of 2 changes in all other plots), the amplitude of the binary perturbation grows rapidly, because of the small thermal energy. By the end of the calculation (Fig. 2d at 0.978 $t_{	ext{ff}} = 413$ yrs), the cloud has fragmented into a binary with each subfragment having a mass of $0.2 M_\odot$, a ratio of thermal to gravitational energy of 0.07, and a ratio of rotational to gravitational energy of 0.1. The subfragments have heated to maximum temperatures of 84 K at their centers.

The further evolution of the binary fragments is crucial: clearly if the binary protostellar system survives, then the presolar nebula could not have been formed in this manner. The binary system, however, may decay into a single central object due to loss of orbital angular momentum through gravitational torques to the rest of the cloud. Other effects such as viscosity or magnetic fields could also be of importance. However, the very low thermal energy of the subfragments compared to their gravitational energy implies that they may be able to remain gravitationally distinct. If so, then the formation of the presolar nebula through a fragmentation hierarchy involving ejection from a multiple protostellar system can be ruled out; such a process may only terminate in sub-solar-mass sized stars.

REFERENCES