

STAR FORMATION DRIVEN BY THERMAL-CHEMICAL INSTABILITY IN A PRE-GALACTIC GAS CLOUD

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The hydrogen molecule would work as an efficient coolant in a pre-galactic medium which is free from heavy elements. It is shown by linear perturbation analysis that molecular reactions lead to a thermal instability of condensation mode (Sabano and Yoshii 1977, Yoshii and Sabano 1979, Silk 1983). In the present paper we study the nonlinear growth of perturbations by a one-dimensional simulation of gas dynamics, which includes molecular reactions as well as an energy equation. We numerically follow the time-evolution of a spherically symmetric perturbation, which is superposed on initially uniform medium under free-fall contraction, by a Lagrangian hydrodynamical programme with an artificial viscosity (Richtmyer and Morton 1967).

Figure 1 shows time-evolutions of perturbations with masses of  $m = 0.1 M_{\odot}$ ,  $1.0 M_{\odot}$ , and  $10 M_{\odot}$  for initial state of  $n_0 = 7.2 \times 10^9 \text{ cm}^{-3}$ ,  $T_0 = 2.2 \times 10^3 \text{ K}$ , and  $f_0 = 4.5 \times 10^{-4}$ , where the linear theory gives a positive growth rate for the instability. Results for the fluctuation with the small mass of  $m = 0.1 M_{\odot}$  show a rapid growth of density contrast driven by chemical reactions, which is a characteristic of thermal instability of the isobaric condensation mode in the limit of short wavelength of perturbation. Results for the larger mass of  $m = 1.0 M_{\odot}$  distinctly show the effect of self-gravitation. After the initial growth of the thermal mode, the central density continues to grow, following gravitational contraction. In the case of the largest mass,  $m = 10 M_{\odot}$ , a density maximum arises in the middle part driven by the expansion of the hot and rarefield phase which is brought about after the phase-change of the instability. The density enhancement grows further, also due to self-gravity, forming a shell structure. Since the thickness of the dense layer exceeds the Jeans length at epoch  $f$ , the layer break into small fragments by gravitational instability. The fragment mass  $m_f$  can be estimated as  $m_f \approx \rho \ell^3 \approx 1.4 M_{\odot}$  with  $\ell$  being the thickness of the layer when it attains the Jeans length.

We note that the Jeans mass in the initial state,  $M_J = 120 M_{\odot}$ , is much reduced after a phase-change caused by the thermal-chemical instability, and even a low-mass fluctuation with  $m = 1.0 M_{\odot}$  eventually turns to be bound by self-gravitation. It is thus concluded that a primordial gas cloud would break into fragments, with masses in the range of normal stars, suggesting that Population III objects can be formed as normal stars (see also a review by Sabano and Yoshii 1984).

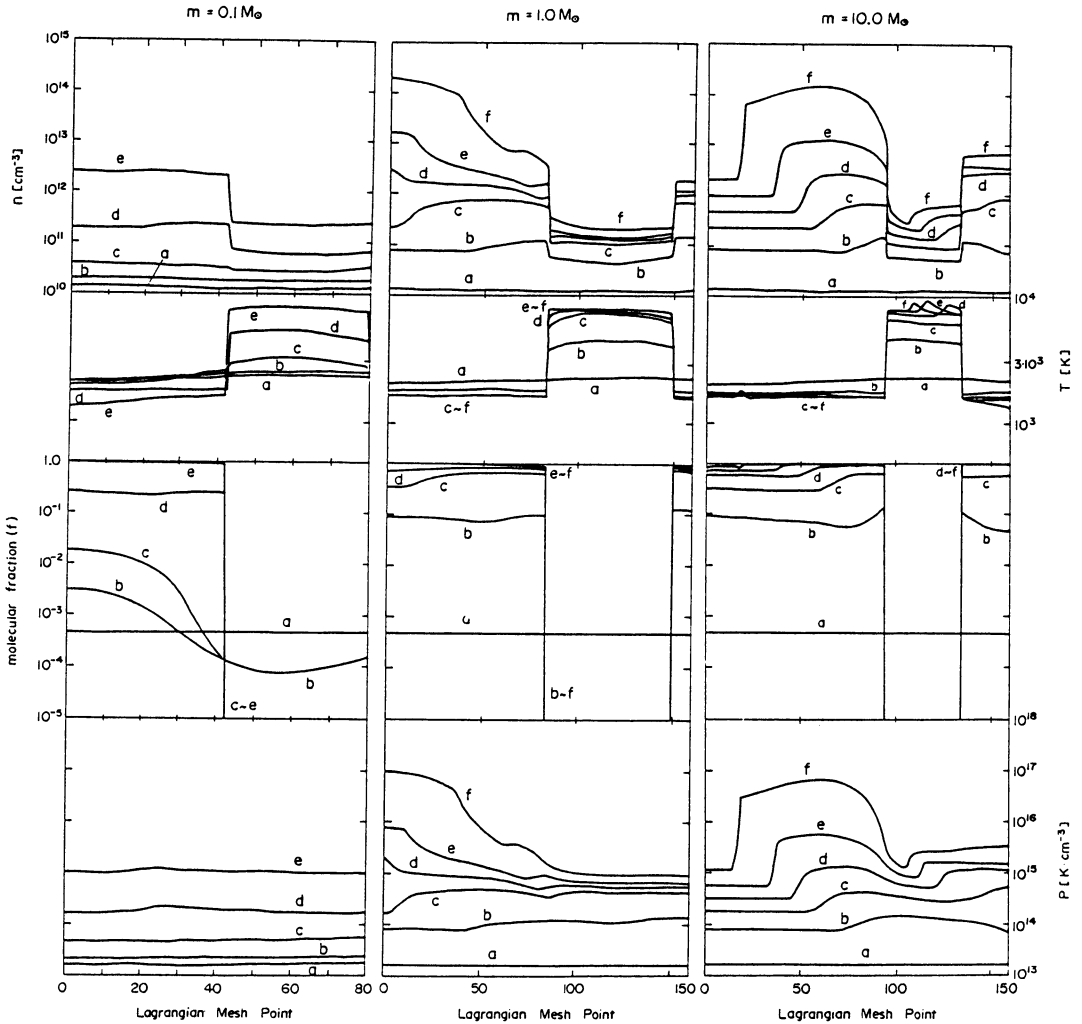


Fig. 1. Time-evolutions of perturbations with masses of  $m = 0.1 M_{\odot}$ ,  $1.0 M_{\odot}$ , and  $10 M_{\odot}$ . The distributions of number density  $n$ , temperature  $T$ , molecular fraction  $f$ , and pressure  $P$  are plotted against Lagrangian mesh points at stages (a)  $t = 0$ , (b) 1.32, (c) 2.9, (d) 4.7, and (e)  $6.4 \times 10^9$  s for  $m = 0.1 M_{\odot}$ , at stages (a)  $t = 0$ , (b) 4.5, (c) 5.8, (d) 6.0, (e) 6.2, and (f)  $6.5 \times 10^9$  s, for  $m = 1.0 M_{\odot}$ , and at stages (a)  $t = 0$ , (b) 4.6, (c) 5.9, (d) 6.6, (e) 7.0, and (f)  $7.3 \times 10^9$  s for  $m = 10 M_{\odot}$ .

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## A SINGLE FRAGMENTATION LAW? THEORETICAL AND OBSERVATIONAL EVIDENCE

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**ABSTRACT.** In the light of the growing interest for the modes of formation of various astronomical objects, a relevant amount of data were collected and treated to obtain mass spectra. Statistical comparisons of the data suggest that a single process drives the formation of the various self-gravitating objects.

Many authors (e.g. Larson 1973,1985, Silk 1977, Zel'dovich 1978) restricted their attention to the formation of a particular single class of objects (i.e. stars and clusters of galaxies), while Reddish, after