EVOLUTION OF ZERO-METAL CLOUDS

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ABSTRACT. Dynamical, chemical and thermal evolution of zero-metal gas clouds has been modeled to study conditions of star formation in the early universe. Numerical results are shown for collapse of a spherical cloud of mass 5×10^5 $M_\odot$. Cooling by H_2 lines and by photons emitted in $H + e^- \rightarrow H^- + h\nu$ maintains collapse until formation of an equilibrium protostellar core with mass 0.03 $M_\odot$. The cooling by photons produced with H- is essential for low-mass star formation. If the cloud is fragmented, the evolution of each piece resembles that of the parent cloud.

1. METHOD

Models for collapse of zero-metal clouds have been constructed with a numerical code based on the work of Bodenheimer 1968. The calculations include self-gravity, internal pressure, H_2 chemistry and radiative cooling with treatment of the spatial and time variation of all physical quantities. Molecular hydrogen is formed by associative attachment of H with H- and by three-body combination. The gas is cooled by rotational and vibrational emission from H_2, with a photon escape probability consistent with the supersonic collapse velocity, and by emission of 0.75 ev photons produced in $H + e^- \rightarrow H^- + h\nu$. The cooling associated with H- formation has not been considered in previous collapse studies.

2. RESULTS AND CONCLUSIONS

Figure 1 shows the evolution of central temperature with density in a 5×10^5 $M_\odot$ cloud of 75 percent hydrogen and 25 percent helium which begins collapse from density 5×10^{-24} gm/cm^3 and temperature 100 K. The temperature first increases sharply, reaching a maximum (point A) when sufficient H_2 is formed that the cooling time equals the compressional heating time. The temperature rise steepens again at B as the H_2 emission becomes optically thick and at C following H_2 dissociation. The onset of cooling by H- photons is abrupt at point D, and subsequent evolution is nearly isothermal until the cloud is opaque to this radiation at E. Without H- cooling the temperature rise would continue along the dotted curve. Point F marks hydrogen ionization and G the

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cessation of collapse in a small core. The core mass is 0.03 $M_\odot$ with the H- cooling and 0.05 $M_\odot$ without. Numerical accretion studies (e.g., Stahler et al. 1985) suggest that the core mass will grow by a factor of at least 10^3 before the formation of a main sequence star. Thus only the models with H- cooling could yield stars of low mass.

The dashed curve in Figure 1 illustrates a calculation by Palla et al. for collapse and cooling of a pure H cloud. Although their numerical results resemble ours, the agreement is likely fortuitous as the physical basis of cooling differs in the two calculations. The Palla et al. model does not include H- cooling, but it has more efficient cooling in the optically thick H_2 lines.

If our cloud model is assumed to fragment during collapse, the evolutionary tracks of the fragments quickly converge to that of the parent cloud. Fragmentation may thus provide multiple centers for collapse, but it should not affect the stellar mass function.

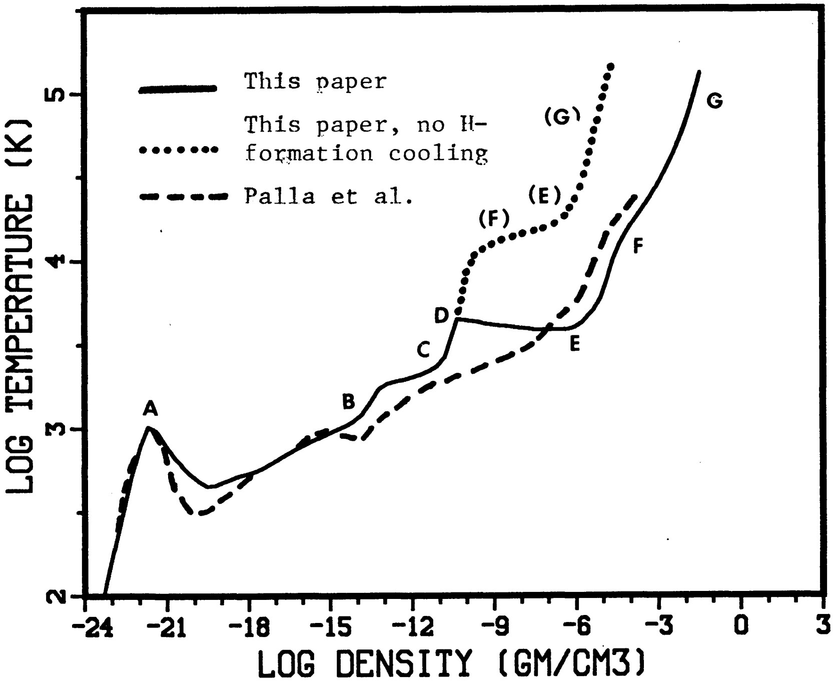

Figure 1. Temperature and density evolution in zero-metal clouds.

REFERENCES

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