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THE EVOLUTION OF POPULATION III OBJECTS

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RESUMEN. Estudiamos el enfriamiento y colapso de las perturbaciones isotérmicas de masa $M \sim M_J$ (masa de Jeans en la era de recombinación) y $M \ll M_J$ tomando en consideración la expansión del Universo, presión, arrastre de fotones, enfriamiento de fotones (calentamiento), fotoionización, ionización por colisiones y la formación y enfriamiento de moléculas de hidrógeno. También estudiamos el efecto de no-esfericidad, rotación y campos magnéticos en el colapso de $M \sim M_J$ debido a perturbaciones residuales que sobreviven para $M \ll M_J$.

ABSTRACT. We study the cooling and collapse of isothermal perturbations of mass $M \sim M_J$ (Jeans mass at recombination era) and $M \ll M_J$ taking into account the expansion of the Universe, pressure, photon-drag, photon-cooling (heating), photoionization, collisional ionization and the formation and cooling of hydrogen molecules. We also study the effect of the nonsphericity, rotation and magnetic fields in the collapse of $M \sim M_J$. The formation of protostars from the fragmentation of clouds of mass $M \sim M_J$ due to the residual perturbations that survive for $M \ll M_J$ is also investigated.

Key words: HYDRODYNAMICS — STARS-POPULATION III

I. INTRODUCTION

A series of problems in astrophysics such as: dark matter, distortion of the cosmic background radiation, pre-galactic enrichment of the Universe, oxygen anomaly (and a possible formation of primordial nitrogen) observed in Pop. III of very low metalicity, galaxy formation can be solved in the context of Pop. III objects.

The Pop. III objects, can in principle have a large range of masses (see e.g. Carr et al. 1984) that is, $M = 0.1\ M_\odot$ (or lower) to $10^8\ M_\odot$.

The Pop. III objects can be formed by isothermal density perturbations (e.g. Peebles and Dicke 1968).

The isothermal density perturbations can be nonlinear for $10^{4-8}\ M_\odot$(or for lower masses) (e.g. Hogan 1978).

We study the evolution of isothermal density perturbations that form Pop. III objects taking into account a series of physical processes not in general considered in previous papers, such as: expansion of the Universe, formation and cooling of H_2 molecules, Lyman α cooling, photon-drag, photon-cooling, photoionization, collisional ionization, aspherical collapse (oblate), rotation and magnetic fields (see de Araujo and Opher 1988, 1989 a,b).

In section II we describe and discuss the calculations performed.

II. CALCULATIONS AND DISCUSSION

We begin the calculations at the recombination era (at a radiation temperature $T_r \sim$ 4000K or redshift $z \sim 1500$).

We study a spectrum of isothermal density perturbations of the form

$$\frac{\delta\rho}{\rho} = \left(\frac{M}{M_o}\right)^{-1/3} (1+z_{rec})^{-1} \qquad (1)$$

(e.g. Gott and Rees 1975) where M_o is the mass scale and z_{rec} is the recombination redshift. We take $M_o = 10^{15}\ M_\odot$ (galactic cluster).

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For the study of the cooling and collapse of clouds of $M \sim M_J$ (Jeans mass at combination era, $M \sim 10^6\ M_\odot$) (see de Araujo and Opher 1988), we assume $\Omega = 0.1$ (Ω is the ratio the present density to the present critical density), $h = 1.0$ (Hubble constant in units 100 s^{-1} Mpc^{-1}). We study clouds with uniform density.

We obtain for spherical clouds:
The minimum mass for collapse: $M_{min} \sim 10^4\ M_\odot$;
The collapse of the clouds is not significantly delayed by internal pressure.
The collapse is not adiabatic.

For aspherical collapse, in particular, an oblate one, we obtain:
The production and cooling due to H_2 molecules decreases with increasing eccentricity (e), for $M/M_\odot = 10^6$, $H_2/H \sim 10^{-3} - 10^{-5}$ for $e = 0 - 0.9$);
The collapse Jeans masses (defined when $e_{final} = 1$) M_{Jc} increases for increasing e, (e.g., for $= 10^6 M_\odot$, $M_{Jc}/M_\odot = 0.3 - 50$ for $e = 0 - 0.9$).

Effects of rotation:
The production and the cooling efficiency of H_2 molecules decreases with rotation;
The M_{Jc} increases with rotation (e.g., for $M = 10^6 M_\odot$ with β (rotational energy/gravitational ergy) $= 0 - 0.1$ gives $T_{mc} = 440 - 640K$ (collapse cloud temperature when $e_{final} = 1$) and $_c/M_\odot = 0.3 - 5$.

For the magnetic field, B, we choose a very simple topology using cylindrical ordinates, with the z-axis in the direction of B. The magnetic field creates a force in the dial direction perpendicular to B.

We obtain, that a field $B = 10^{-6} - 10^{-5}$ G makes an initial spherical cloud of mass $M = {}^6 - 10^8\ M_\odot$ collapse into a disk.

For $M << M_J$ we evaluated the decay of the perturbations during the recombination a. We find; that δ_f/δ_i (where $\delta = \delta\rho/\overline{\rho}$, δ_i(initial) δ at beginning of the recombination and − δ at the end of the recombination) for $M << M_J$ is not in general negligible. For example, r $M/M_J = 10^{-3}$ for $\Omega h^2 = 0.025 - 1.0$ and $\delta_i = 0.01 - 1.0$ we have $\delta_f/\delta_i \sim 0.25 - 0.50$!

De Araujo and Opher (1988) suggest that these fluctuations that persist for $M << M_J$ n fragment the clouds of mass $M_c \sim M_J$. (Note that there is no direct collapse for $M_c < 10^4\ M_\odot$).

We studied the spectrum of isothermal perturbations given by equation (1) for $(\sim M_J)$ and M_S (protostars). We start the calculation, as before, at the beginning of the combination era. We choose $M_c = 10^6 M_\odot$ and $M_S = 10 - 500 M_\odot$. We obtain, e.g., that when $N_s \sim {}^8 - 10^9\ cm^{-3}$ (numerical density of M_S) that $\delta_S \sim 900$ ($\delta_S = \delta\rho_S/\rho_c$, ρ_c − density of M_c) for $= 500 M_\odot$ and $\delta_S = 3.2$ for $M_S = 50\ M_\odot$ at $z \sim 180$ (z − redshift) (de Araujo and Opher 1989a).

In Fig. 1, we show $\hat{v}_{1s}/v_f$

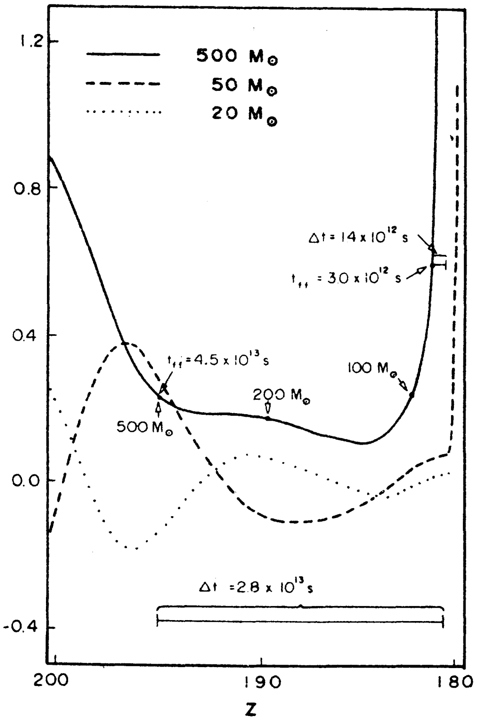

Fig. 1. $\hat{v}_{ls}/v_f$ as a function of redshift z for $M_S = 500$, 50 and 200 $M_\odot$. The Jeans masses are noted on the $M_S = 500\ M_\odot$ curve. The free-fall time (t_{ff}) when $M_S \approx M_J$ is noted on the $M_S = 500 M_\odot$ curve, as well as the time to the collapse of $M_S(\Delta t)$. Also noted: t_{ff} and Δt for $\hat{v}_{ls}/v_f \approx 0.6$ and $z \cong 181$.

where $\hat{v}_{1s}$ is the collapse velocity of M_S if $\delta_S = 0$, $\hat{v}_{1c}$ collapse velocity of M_c, $\overline{r}_s(\overline{r}_c)$ radius of M_S (M_c) and R - scale factor) versus z between z = 200-180 for M_S=500, 50 and 20 $M_\odot$ in order to see how the fragmentation takes place. When M_S becomes greater than the Jeans mass, the gravitational attraction becomes sufficienty strong to compensate the outward pressure.

When the fast collapse starts at $z \cong 181$, one has $\hat{v}_{1s}/v_f \sim 0.6$ for $M_S = 500M_\odot$ which aids its collapse. The same is valid for $50M_\odot$. For $M_S = 20M_\odot$, $\hat{v}_{1s}/v_f$ and δ_S are too small to cause its collapse appreciably before the actual collapse of M_c.

The rest of the M_c cloud can in fact be photoionized by the M_S formed (Tenorio-Tagle). Such photionization inhibits the fragmentation of the rest of the M_c cloud. The M_c cloud is therefore dispersed.

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