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COSMOLOGICAL THERMAL CLUMPS [1]

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Abstract

The formation of structures in the post recombination gaseous medium is commonly explained by gravitational instabilities experienced by primordial density fluctuations. In a self-gravitating collapsing cloud, the temperature tends to increase with contraction. Thus a cooling mechanism is required to lower the pressure against the gravity. The main cooling agent is the molecular hydrogen that is formed during the collapse, but what are the chemical processes inside the collapse ?
We present the evolution of primordial molecules, such as H_2, HD and LiH, in the gravitational collapse of a protocloud. These molecules are formed after the recombination of hydrogen. For two masses of clouds (M=10^9 and 10^{10} $M_\odot$) we obtain an increase of H_2 and LiH abundances, while the behavior of the HD abundance is different. We discuss the role of the chemistry in this context. Finally this chemical approach of a gravitational collapse suggests a strategy for the detection of primordial LiH molecules through experiments devoted to the observations of the Cosmic Microwave Background Radiation anisotropies.

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1/ Introduction

The problem of gravitational collapse offers different fields of studies. In the framework of the gravitational instability theory, each protostructure started as a tiny local overdensity, nevertheless very little is known about proto-clouds at the redshift of the formation. The molecules in such a context have been partially analysed. For example Palla, Stahler, Salpeter [1] examined only the role of molecular hydrogen on protostructure collapsing as primordial star formation. It was suggested by Lepp & Shull [2] that HD and LiH also contribute to the cooling because of their dipole moment. However their abundances are so low compared to that of H_2, that Lahav [3] studied the specific problem of evolution of collapse under the influence of H_2. Nevertheless the study of the chemistry was not considered. Moreover the nuclei from ^7Li to ^{11}B have very recently come to be perceived as very important, because their abundances have been put forward as possible tests of theories of Big Bang nucleosynthesis. Specifically the observation of molecules such as LiH, at primordial levels would determine the primordial abundance of lithium and therefore the degree of inhomogeneity in the Universe before the time of the Big Bang nucleosynthesis.

The purpose of this proceeding is to analyze the evolution of primordial molecules such as H_2, HD and LiH in a gravitational collapse. These molecules are formed after the recombination of hydrogen. From a homologous model of spherical collapse, very similar to the model adopted by Lahav [3], we consider a more complete chemistry of H_2, HD and LiH molecules and study the evolution of their abundances during the collapse of a protocloud. In section 2, we recall the formation of primordial molecules and the different models of primordial nucleosynthesis. In section 3 we describe the evolution equations for a collapsing protostructure with molecules. In section 4 we present and discuss the results.

2/ Formation of primordial molecules

After recombination the chemical species available from nucleosynthesis are H, H^+, D, D^+, He and Li. Puy et al [4] have shown the different routes which lead to molecules formation of H_2, HD and LiH characterizing the primordial molecules. The combinated action of the expansion and the collisional chemistry lead their abundances, after a transient growth, to become almost constant. Therefore the initial abundances of primordial molecules before the collapse of a protocloud are obtained. These calculations are developped for two kinds of primordial nucleosynthesis (standard and inhomogeneous). Recently nuclear astrophysicists have focused in non standard

models, one class of which involving regions of high and low nucleon density. The consequence of the existence of these regions are abundances of light elements more greater than the Standard Big Bang Nucleosynthesis abundances. We have selected this non conventional Inhomogeneous Big Bang Nucleosynthesis model assuming that the Universe is flat with baryons only. In this scenario the fractions D/H and Li/H are higher than in Standard Big Bang Nucleosynthesis model, hence helping to make the effects of the HD and LiH more dramatic.

3/ A simpe model of collapse

We assume that, at some time in the past, there were small deviations from homogeneity in our Universe. These deviations can grow due to gravitational instability over a period of time and , eventually, form structures. As long as these inhomogeneities are small, their evolution can be studied by the classical linear perturbation theory. Once the deviations from the homogeneous Universe become large, the linear theory is no more valid. To study the non linear evolution of perturbations we adopt the following simplified model.

- We assume an isothermal perturbations with the initial mass spectrum given by Gott and Rees [5]. Therefore, these perturbations grow in the linear regime with the expansion of the Universe.
- We follow Peebles [6] for the transition between the linear regime and the non-linear regime by introducing the turn around point at the redshift z_{ta}, corresponding to the maximum radius of the perturbation r_{ta} at the density of matter ρ_{ta} and the temperature T_{ta} (see Puy & Signore [7] for a more complete description).
- We follow Puy et al [4] in order to obtain the temperature of the matter $T_m(z_{ta})$ and the temperature of the radiation $T_r(z_{ta})$ during the expansion of the Universe at $z = z_{ta}$.

This simple model is due to Lahav [3], but, in our case, we also consider the chemistry of primordial molecules. Thus the problem is the equations of evolution during the collapsing phase, coupled with the chemistry. These equations are given in Puy & Signore [7].

4/ Results and discussions

We have choosen two characteristic cloud masses: M=10^9 $M_\odot$ and M=10^{10} $M_\odot$ which correspond to the turn around redshift $z_{ta} \sim 55$ and $z_{ta} \sim 25$ respectively.

10^9 $M_\odot$ protoclouds (figure 1a,1b)

Figure 1a shows the evolution of a 10^9 $M_\odot$ cloud. The decreasing tempera-

ture is due to the molecular cooling with the primordial chemistry. Let us only notic that we give the ratio T/T_{ad} of the temperature of the collapsing cloud to the adiabatic temperature (i.e. the temperature of the collapsing cloud without the primordial chemistry). Figure 1b show an increase of the abundances of the H_2 and LiH molecules and a decrease for the abundance of HD. During the collapse the density increases which leads to an efficiency of collisions. Because the formation of H_2 and LiH is only due to collisional formation, the abundances for these molecules are going to increase naturally. Their destruction is essentially radiative but at the turn around redshift, the radiation is low and therefore negligible. For HD the situation is different. This molecule is destructed by collision with H^+ and is formed mainly from H_2 through the collisional reaction with D. During the collapse, for this mass range, the temperature of the cloud is greater than the activation temperature of the destruction reaction. The reaction rates of the destruction and of the formation have roughly the same order of magnitude (see Puy & Signore [7]). However, because the ions H^+ are more abundant than the H_2 molecule, it results that the net contribution is a destruction of HD molecules.

10^{10} $M_\odot$ primordial clouds (figure 2a, 2b)

Figure 2a shows a slight decrease of the temperature, in fact at the turn around redshift $z_{ta} = 25$, the matter temperature is low ($T_{ta} \sim 25$K), the molecular cooling is small, the collisions are inefficient. Nevertheless at the beginning of collapse, we have a small chemical heating (more efficient at this low temperature). On Figure 2b, we remark the typical increases of the H_2 and LiH abundances. Concerning the molecules HD, the evolution is in two steps. The first step, which corresponds to an increase, is only due to the HD formation. In fact at the beginning of the collapse the temperature is too low to initiate the reaction of destruction. Nevertheless when the temperature is sufficient, this reaction is effective and products a destruction of HD.

For this range of protocloud masses, H_2 and LiH abundances increase while HD molecules seem to be almost destructed during the collapse phase of these protoclouds. Nevertheless, this simple model of collapse does not consider the opacity effects of these molecules (which could be important at the end of the collapse phase). The treatment of these questions -which must be analyzed through a thermal approach of these two phases- is in preparation. In conclusion, this work shows an important modification of the chemical abundances during the gravitational collapse of a protocloud. Let us only remark that this point can be crucial for the estimation of the amplitude

of possible secondary Cosmic Microwave Background (CMB) anisotropies: In effect the Doppler mechanism (a doppler-induced anisotropy in the 3K radiation, due to the motion of protoclouds) can be one of the most efficient and the most probable mechanism for the formation of secondary CMB fluctuations. Signore et al [8] analyzed a strategy for the detection of primordial LiH molecules through experiments devoted to the observations of the CMB anisotropies. Therewith primary CMB anisotropies at intermediate scales ($< 5^o$) could be erased by resonant molecular scattering at low frequencies ($\lambda > 3.3$mm). In particular the blurring of primary anisotropies by resonant lines of LiH may occur. Thus the search for primary anisotropies at these angular scales will be interesting: the future projects such as the long duration ballooning BOOMERANG [9] (Balloon observations of millimetric extragalactic radiation and geomagnetics), or the experiment SAMBA [10] -on board the ESA satellite- could offer a beginning of answer; it would also be important to check wether the CMB anisotropies are erased at the radiofrequencies where scattering starts to be important; in this context, the experiment COBRAS [10] -also on board the medium ESA mission- would be well adapted. Moreover the IRAM 30m telescope (Pico Veleta, Spain), with a 12.5 arcsec FWHM (Full Width at Half Maximum) beam at 1.3mm, is well suited for the search of the secondary anisotropies (at small angular scales) induced by the same molecules that scatter the CMB photons. Finally, let us also notice that all the above searches can be seen as a propaedeutic to the search for primordial molecules ,which is one of the scientific objectives of the cornerstone project FIRST [11] (Far Infra-Red and Submillimeter Space Telescope) of the *HORIZON 2000* plan of ESA.

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Figure 2a

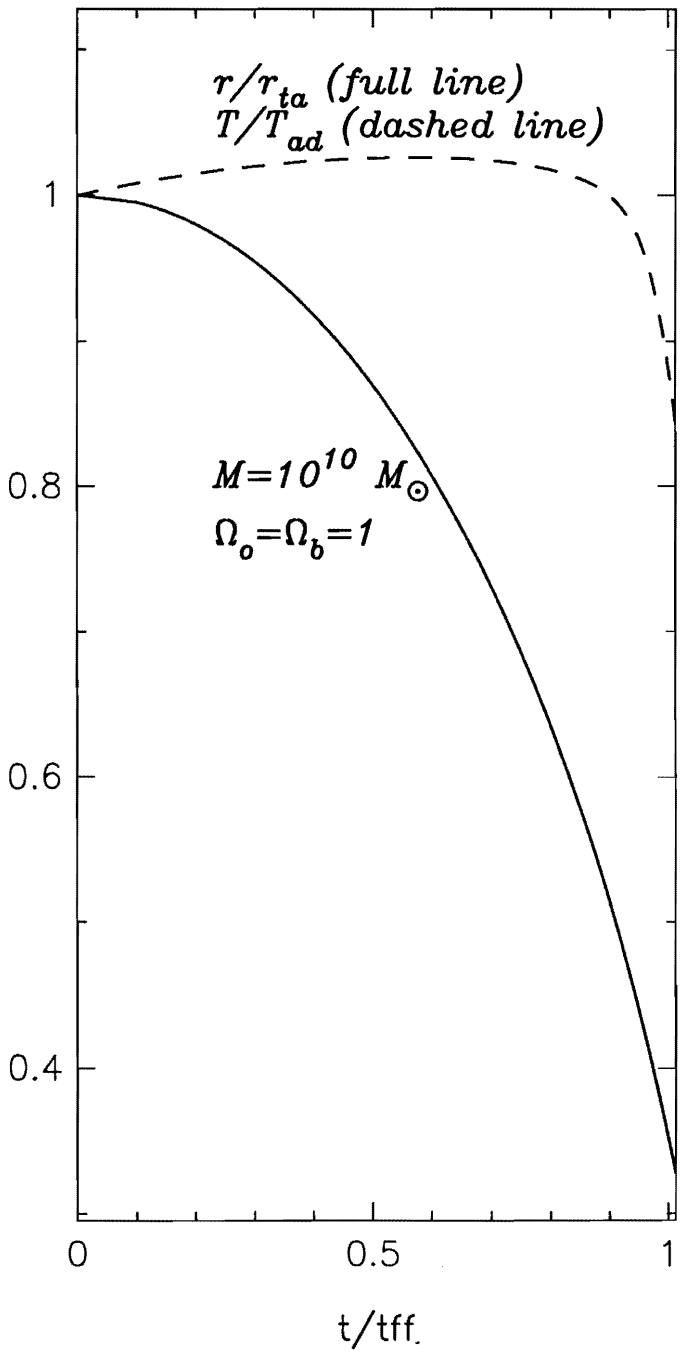

Figure 2b

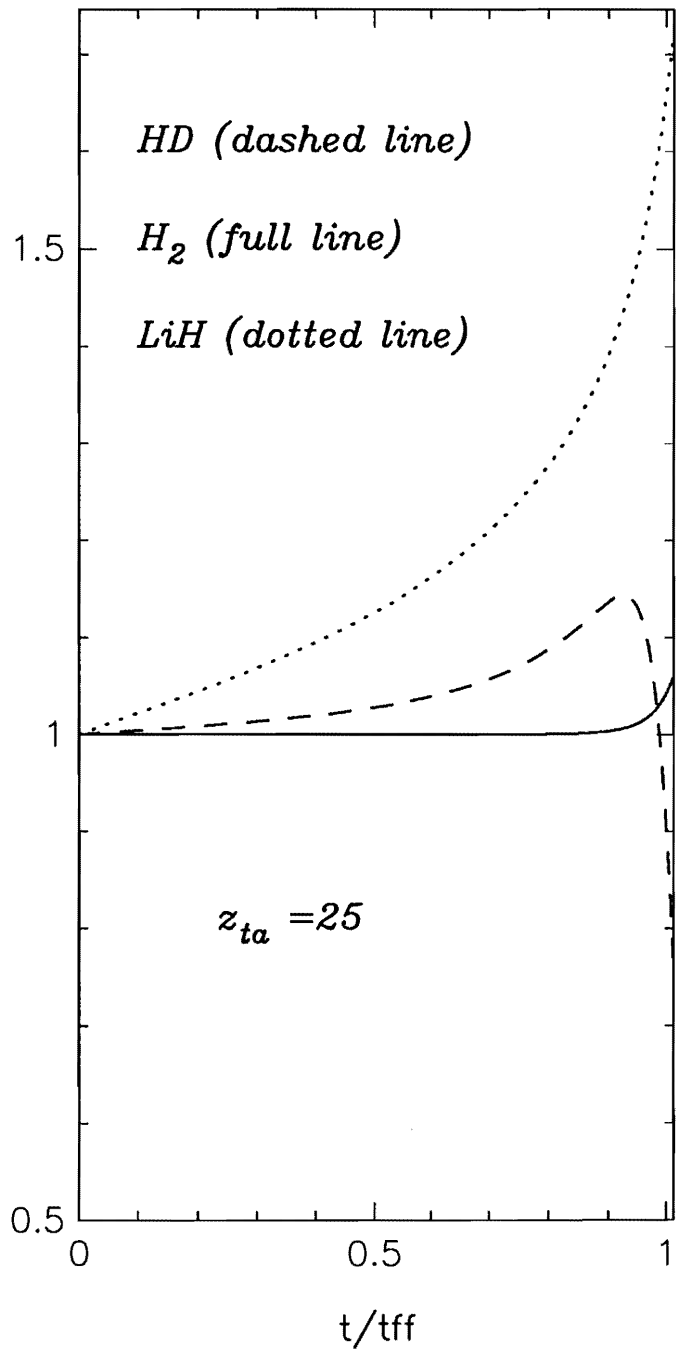

Figure 1a

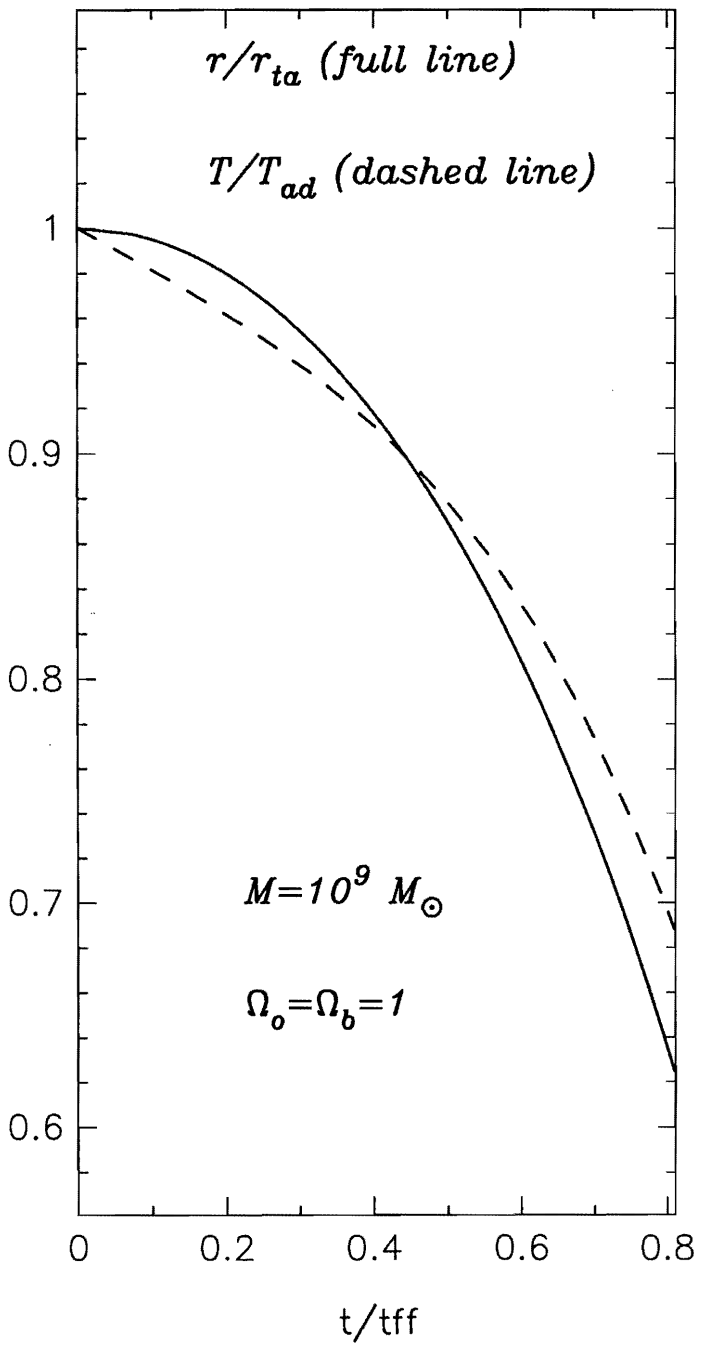
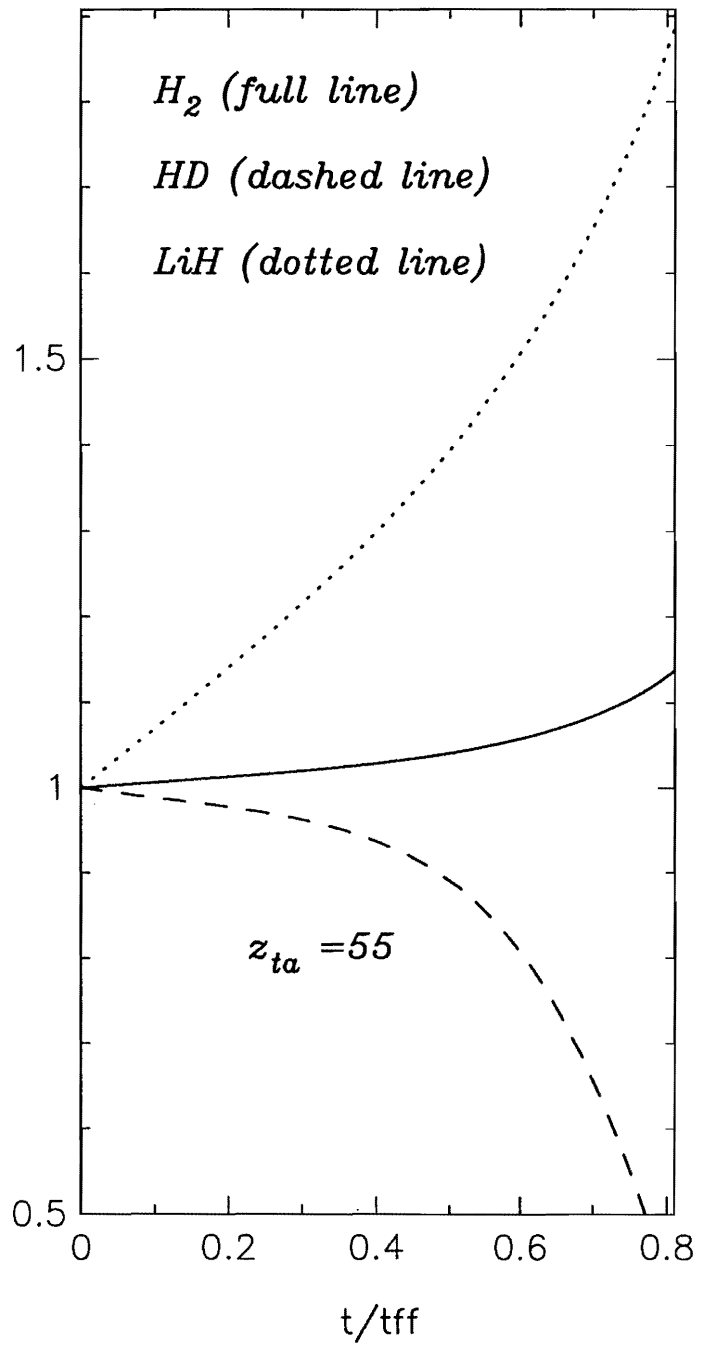
Figure 1b