Revised Primordial Chemistry of the early Universe

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During the dark age (the period between the recombination epoch, \( z \approx 300 - 1000 \), and the formation of the first stars at \( z = 6 - 30 \)), molecules form from neutral and charged atomic species, and open new channels of radioactive exchange. Matter cooling and heating in the collapsing first structures is directly dependent on the quantity and nature of these first molecules, in particular \( \text{H}_2 \). We calculate with the best available data the chemical reactions taking place around the dark age, in the average expanding matter as well as in linear density fluctuations [1].

Revised Primordial Chemistry

The standard Big Bang nucleosynthesis model for the Universe produces mainly hydrogen, helium and lithium and their isotopes. Once these primordial nuclei come in order to form the corresponding atoms, the standard Big Bang chemistry (SBBC) may start. It is the first chemistry of the elements hydrogen, helium, lithium and their respective isotopic forms. We use the thermochemical network developped by [2], [3], [4] and [5], with an extensive improvement in dealing numerical integration errors, and paying attention to the sensitivity of results on the initial conditions. Indeed the coupled chemical and thermal system contains stiff differential equations [1].

Molecular Evolution in Different Cosmological Models

SBBC is relative to a flat Universe with \( \Omega_{\text{m}} = 0.7, \Omega_{\Lambda} = 0.0444 \) and \( H_0 = 71 \text{ km s}^{-1} \text{ Mpc}^{-1} \) with an initial helium mass fraction \( X_\text{He} = 0.2848 \). \( \text{H}_2 \) and HD abundances are relatively insensitive to cosmological parameters (i.e. \( \Omega_{\text{m}}, H_0 \)), making it a poor diagnostic of cosmological models at \( z > 10 \).

Differential Chemistry in fluctuations

Structure formation initiates from the growth of small positive density fluctuations, void formation from small negative density fluctuations. We are currently analyzing in the linear regime the revised differential chemistry for models with different initial density fluctuations \( \delta_i \) and different comoving wavenumber \( k \), allowing us to quantify the differential growth of molecular abundances as function of initial perturbation amplitudes and types [6]. Overall the sensitivity of abundances is high on density fluctuations already in the linear regime.

Conclusion

Molecules are the main factor determining gas cooling in the first non-linear baryonic structures, thus they play a central role in the fragmentation process leading to the first stars [6]. Already in the linear regime, chemistry is sensitive to density perturbations. Initial relative density fluctuations as small as \( 10^{-6} - 10^{-5} \) lead to relative abundance variations of several percents. Larger variations are expected in the non-linear phases such as collapses, but then more detailed calculations are required.

In contrast, chemistry is insensitive to cosmological parameters in the range allowed by the WMAP error bars, therefore molecular abundances will not be useful for constraining these parameters.

References