Brane cosmologies help out the BBN-CMB crisis

<table>
<thead>
<tr>
<th>著者（英）</th>
<th>Nobuo TERASAWA</th>
</tr>
</thead>
<tbody>
<tr>
<td>雑誌名</td>
<td>Bulletin of Saitama Gakuen University. Faculty of Management</td>
</tr>
<tr>
<td>卷</td>
<td>3</td>
</tr>
<tr>
<td>頁</td>
<td>125-128</td>
</tr>
<tr>
<td>年</td>
<td>2003-12-01</td>
</tr>
<tr>
<td>URL</td>
<td><a href="http://id.nii.ac.jp/1354/00001008/">http://id.nii.ac.jp/1354/00001008/</a></td>
</tr>
</tbody>
</table>
Brane cosmologies help out the BBN-CMB crisis?

The Institute of Physical and Chemical Research

TERASAWA, Nobuo

Both Big Bang Nucleosynthesis (BBN) and Cosmic Microwave Background (CMB) are the sensitive probes to the cosmological models and can bound the parameters of the universe and the cosmological models. Improved precision in the measurements of the temperature fluctuation spectrum of CMB by the Wilkinson Microwave Anisotropy Probe (WMAP) enabled us to render considerably tight bounds on the cosmological parameters. Although the WMAP results are essentially consistent with the BBN predictions, the baryon/photon ratio inferred from CMB gives the helium-4 abundance slightly higher than the primordial helium-4 abundance deduced from the observations of HII regions. Dark radiation term included in the Randall-Sundrum type-II brane model, on the other hand, can be negative and decrease the cosmic expansion rate. We show that a parameter space consistent with the helium-4 abundance do exist in the RS-II brane model.

Standard Big Bang Nucleosynthesis (SBBN) theory predicts the primordial abundances of light nuclei, deuterium, helium-3, helium-4 and lithium-7 synthesized in the early universe. We can constrain the number of species of light neutrinos and the baryon/photon ratio (\(\eta\)) comparing the abundances of the light elements predicted by SBBN with the primordial abundances inferred from the observations. The abundances of the four light elements are consistent for the rather range of \(\eta\) and this fact is one of the successful predictions of Big Bang Cosmology.

The fluctuation spectrum of Cosmic Microwave Background contains information on the universe of at the time of last scattering hundreds thousand years after the epoch of nucleosynthesis. The power spectrum of CMB temperature anisotropies observed by WMAP offered significantly tight bounds on the baryon-to-photon ratio from the first and second acoustic peaks. The CMB constraints on \(\eta\) is completely independent of the constraints by BBN based on different physics.

Constraints on \(\eta\) thus derived from quite different observational data are surprisingly consistent with each other at the first glance. Rigorous comparison of these constraints, however, reveals a slight discrepancy. If we adopt \(\eta\) inferred from the CMB anisotropy

Key words: cosmology, nucleosynthesis, microwave background, brane
by WMAP as the input, SBBN predicts somewhat larger value for the primordial helium-4 abundance. Although low helium-4 abundances can be easily justified by astrophysics in the course of the evolution of the universe, it is almost impossible to decrease the helium-4 abundances in large scales as HII regions. This small discrepancy between the CMB results and BBN results may suggest new physics working in the early stages of the universe.

The brane cosmologies proposed by Hořava and Witten\(^{10}\) to explain the large gap between the energy scale of gravity and the energy scales of other fundamental interactions, have attractive aspects as the low energy phenomenology of the universe. In brane cosmologies, the observable universe is a brane embedded in a higher-dimensional bulk. Ordinary matter fields are confined to a three-dimensional brane, corresponding to our universe, while gravity alone propagates in a higher-dimensional bulk space. Randall and Sundram\(^{15}\) realized that the case of one extra dimension is very special and the effective four-dimensional Planck scale is independent of the size of the extra dimension. Among a set of models with a non-compactified extra dimension proposed by them, the type-II Randall Sundram model, in which brane has positive tension and the bulk contains a negative cosmological constant, is especially interesting. This model contains a dark radiation term, which can be negative, and the expansion rate of the universe during the nuleosynthesis can be smaller. Hence the helium-4 abundance can be consistent with the primordial abundance inferred from observations for higher \(\eta\) value deduced from the CMB fluctuation power spectrum.

The friedman equation in the RS-II brane model takes the form

\[
\left(\frac{\dot{a}}{a}\right)^2 = \frac{1}{3M_{pl}^2} \rho - \frac{\kappa}{a^2} + \frac{\Lambda_i}{3} + \frac{1}{36M_{pl}^2} \rho^2 + \frac{C}{a^4} \tag{1}
\]

where \(a\) is the scale factor, \(M_{pl} = (8\pi G_0)^{-1/2}\) is the 4-dimensional Planck mass, \(\kappa = 0, \pm 1\) is the curvature index, \(\Lambda_i\) is the 4-dimensional cosmological constant, \(M_5\) is the 5-dimensional Planck mass, and \(C\) is a integration constant whose term is sometimes called dark energy since it scales as \(a^{-4}\). Since the second term and the third term are negligible in the early universe, the parameters of the model, which is constrained from nucleosynthesis, are \(M_5\) and \(C\). We define \(\Delta N\nu = (C/a^4)\) (3M_{pl}/\rho_\nu) in order to parametrize the dark energy with a single two-component massless neutrino (\(\nu\)).

The number of massless neutrino species (\(N\nu\)) is fixed to 3, and the lifetime of neutron free decay is set to \(\tau = 885.7\, s\). The baryon-to-photon ratio inferred from the CMB observations with WMAP\(^{11}\) is \(\eta = (6.14 \pm 0.25) \times 10^{-10}\). The SBBN predict the primordial helium-4 abundance for this range of \(\eta\):

\[
\begin{align*}
Y_{B} = 0.248 \pm 0.001. \tag{2}
\end{align*}
\]

On the other hand, the inference of the primordial helium-4 abundance from metal-poor HII regions is\(^{56}\)
$$Y_p = 0.238 \pm 0.005. \quad (3)$$

Consistency is marginal (\(\sim 5\%\)) and it may suggest necessity of new physics.

The dark radiation term in the RS-II model can be negative and effectively acts as to decrease the number of species of massless neutrinos. On the other hand, the 5-dimensional Planck mass term accelerate the expansion of the universe and acts as to increase the helium-4 abundance. Therefore the helium-4 abundance is controlled by the competition between these two parameters and we may be able to find the space where the helium-4 abundance can be consistent with the WMAP CMB result. We show the consistent region on the \(M_\nu-\Delta N_\nu\) plane in Fig. 1.

The predicted abundances other than helium-4 are rather insensitive to the values of the parameter of the model, \(M_\nu\) and \(\Delta N_\nu\). The deuterium abundance is predicted to

$$\frac{D}{H} = (2.79 \pm 0.21) \times 10^{-5}. \quad (4)$$

This value is compared with the deuterium abundance observed in Lyman-\(\alpha\) absorption line systems\(^5\). \(\frac{D}{H} = (2.78 \pm 0.29) \times 10^{-5}\). The agreement is thus excellent.

The predicted lithium-7 abundance is

$$\frac{{}^7\text{Li}}{H} = (4.09 \pm 0.70) \times 10^{-10}. \quad (5)$$

This result clearly contradicts with the primordial abundance inferred from the so-called Spite Plateau\(^6\). \(\frac{{}^7\text{Li}}{H} = (1.32 \pm 0.25) \times 10^{-10}\)

In conclusion, we found a parameter space in the RS-II model, which is consistent with the helium-4 abundance predicted by BBN
and the baryon-to-photon ratio inferred from the CMB fluctuation spectrum with WMAP. The deuterium abundance is in excellent agreement with the observed value in Lyman-\(\alpha\) absorption line systems in the ranges of the parameters. However, the predicted lithium-7 abundance is inconsistent with the primordial abundance deduced from the Spite plateau. The discrepancy is unacceptably large and suggest that we cannot expect the role of savior against brane cosmologies.

References