Big Bang Nucleosynthesis in a non-thermal plasma

Youngshin Kwon

(Korea Aerospace University)

in collaboration with Dukjae Jang, Kyujin Kwak and Myung-Ki Cheoun

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Periodic table



History of the Universe



Primordial abundances

Standard BBN

Function of baryon-to-photon ratio η

<u> CMB - constraint on η</u>

ESA and Planck collaboration

Primordial abundances

Observation of metal-poor stars (MPS)

Lithium problem

Observed lithium abundance is smaller than the SBBN prediction by a factor of 3. ⁷Li/H in MPS < ⁷Li/H in SBBN

Spite plateau value: $^{7}Li/H = (1.1 \sim 1.5) \times 10^{-10}$



Standard BBN



Standard BBN

Predominant inputs in the BBN model: Thermonuclear reaction rates

$$N_A \langle \sigma v \rangle = N_A \left(\frac{8}{\pi \mu \left(k_B T \right)^3} \right)^{\frac{1}{2}} \int_0^\infty E \, \sigma(E) \left(\exp \left(-\frac{E}{k_B T} \right) \right) \mathrm{d}E$$
Maxwell-Boltzmann (MB) distribution

Thermal equilibrium property of ideal gas?

But the Universe was a plasma of nuclei, electrons, and photons.

Their velocity distribution could be very different from MB distribution.

Thermonuclear reaction rate

$$N_A \langle \sigma v \rangle = N_A \left(\frac{8}{\pi \mu \left(k_B T \right)^3} \right)^{\frac{1}{2}} \int_0^\infty E \, \sigma(E) \exp\left(-\frac{E}{k_B T} \right) \, \mathrm{d}E$$
Maxwell-Boltzmann (MB) distribution
Non-Maxwellian distribution
$$N_A \langle \sigma v \rangle = N_A \left(\frac{8}{\pi \mu \left(k_B T \right)^3} \right)^{\frac{1}{2}} \int_0^\infty E \, \sigma(E) \left(B_q \left(1 - (q-1) \frac{E}{k_B T} \right)^{\frac{1}{q-1}} \mathrm{d}E \right) \, \mathrm{d}E$$
Trailie' statistics

Isallis' statistics

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BIG BANG NUCLEOSYNTHESIS WITH A NON-MAXWELLIAN DISTRIBUTION

C. A. BERTULANI^{1,2}, J. FUQUA², AND M. S. HUSSEIN^{3,4} ¹ GSI Helmholtzzentrum für Schwerionenforschung, D-64291 Darmstadt, Germany ² Texas A&M University-Commerce, Commerce, TX 75429-3011, USA ³ Instituto de Estudos Avançados, Universidade de São Paulo, C.P. 72.012, 05508-970 São Paulo, Brazil ⁴ Instituto de Física, Universidade de São Paulo, C. P. 66318, 05389-970 São Paulo, Brazil *Received 2012 May 17; accepted 2013 February 13; published 2013 March 25*

ABSTRACT

The abundances of light elements based on the big bang nucleosynthesis model are calculated using the Tsallis non-extensive statistics. The impact of the variation of the non-extensive parameter q from the unity value is compared to observations and to the abundance yields from the standard big bang model. We find large differences between the reaction rates and the abundance of light elements calculated with the extensive and the non-extensive statistics. We found that the observations are consistent with a non-extensive parameter $q = 1^{+0.05}_{-0.12}$, indicating that a large deviation from the Boltzmann–Gibbs statistics (q = 1) is highly unlikely.

Key words: plasmas - primordial nucleosynthesis - stars: a

Online-only material: color figures









History of the Universe



$$\frac{dy}{dx} = y \quad \Rightarrow \quad y = e^x \quad \Rightarrow \quad y = \ln x$$

$$\frac{dy}{dx} = y^q \Rightarrow y = (1 + (1 - q)x)^{\frac{1}{1 - q}} \Rightarrow y = \frac{x^{1 - q} - 1}{1 - q}$$

Boltzmann-Gibbs entropy

$$S_{BG} = -\sum_{i=1}^{W} p_i \ln p_i = \sum_{i=1}^{W} p_i \ln \frac{1}{p_i} = \left\langle \ln \frac{1}{p_i} \right\rangle$$

Non-extensive Tsallis entropy

$$S_q \equiv \left\langle \ln_q \frac{1}{p_i} \right\rangle = \sum_{i=1}^W p_i \ln_q \frac{1}{p_i} = \frac{1 - \sum_{i=1}^W p_i^q}{q - 1}$$



E

Thermonuclear reaction rate

$$N_A \langle \sigma v \rangle = N_A \left(\frac{8}{\pi \mu \left(k_B T \right)^3} \right)^{\frac{1}{2}} \int_0^\infty E \, \sigma(E) \, B_q \left(1 - (q-1) \frac{E}{k_B T} \right)^{\frac{1}{q-1}} \mathrm{d}E$$



Thermonuclear reaction rate

Gamow energy distribution of ²H(d,p)³H







HaPhy meeting, PKNU, 2017



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We consider the non-Maxwellian (Tsallis) distribution as velocity distributions of the particles in the BBN plasma, especially q<1.

In the practical calculation of reaction rates, the integral range should be treated more carefully.

THANK YOU for your attention