Relativistic particle scattering and Big Bang Nucleosynthesis

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Intro to “Big Bang Nucleosynthesis” (BBN)

Time (post big bang) 1 sec → 3 mins

Energy 10 MeV → 0.01 MeV

Temperature 100 GK → 0.1 GK

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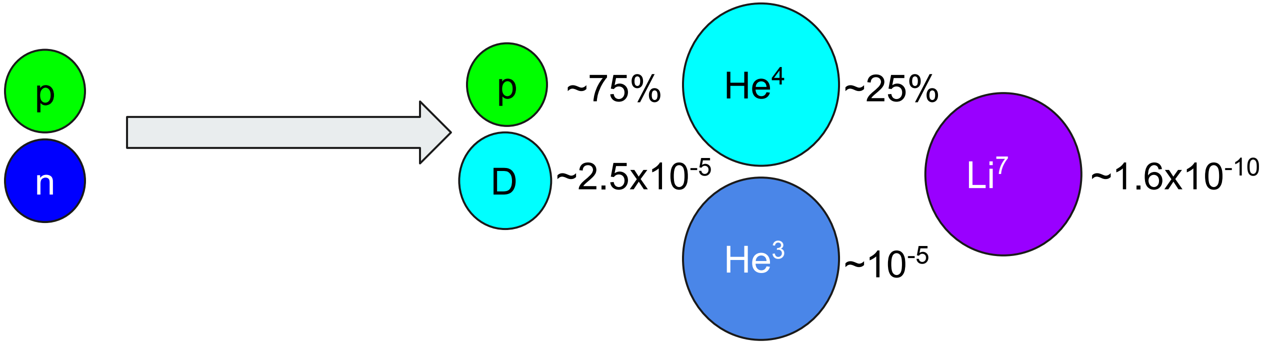
Synthesis of nuclei:



p

n

p ~75%

D ~2.5x10^{-5}

He^4 ~25%

He^3 ~10^{-5}

Li^7 ~1.6x10^{-10}

“BBN Yields”

Motivation

Cosmological Lithium problem: Abundance of ^{7}Li predicted = **3** x ^{7}Li observed
(4.5x10^{-10}) (1.6x10^{-10})

Possible that particle/astrophysical/Nuclear/thermal physics processes not understood.

Reaction rates between two species

$$n_1 n_2 < \sigma(v)v >= n_1 n_2 \int v\sigma(v)f(v)dv$$

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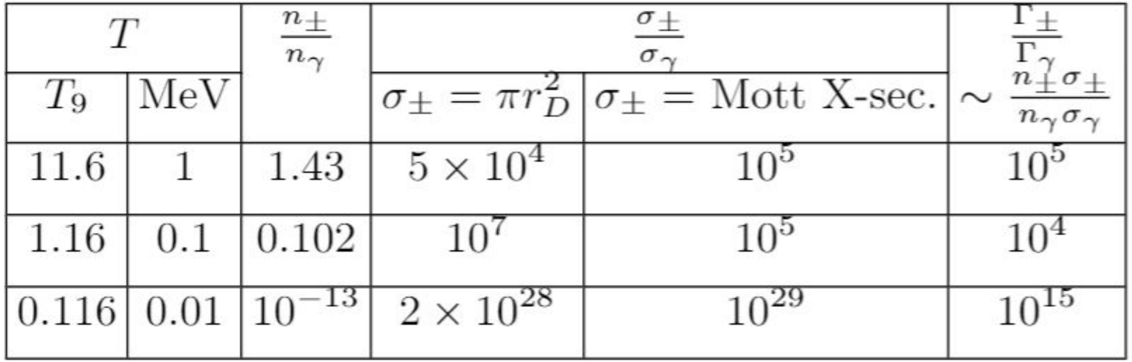
$f(v)$: Distribution of the relative velocities of the two nuclei.

Traditionally assumed to be Maxwell-Boltzmann distribution, obtained by approximating Fermi-Dirac.

Thermalization of (charged) nuclei

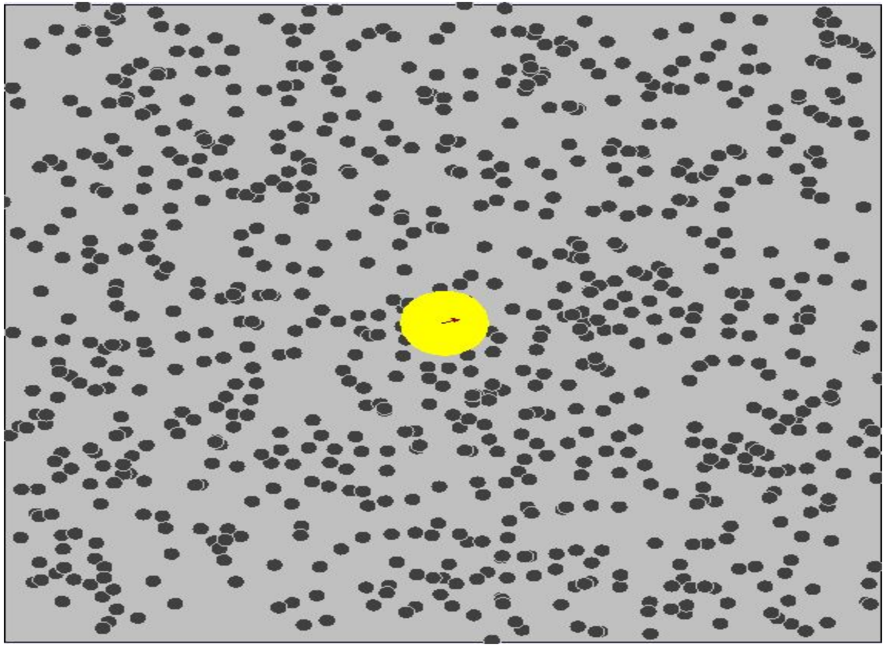
- At BBN, Nuclei are surrounded by e^+e^- and photons.
- Nuclei thermalize by interacting with e^+e^-
- $f(v)$ should be influenced by these interactions
- e^+e^- are relativistic during BBN and hence follow Maxwell-Jüttner distribution (i.e. relativistic Maxwell -Boltzmann distribution)



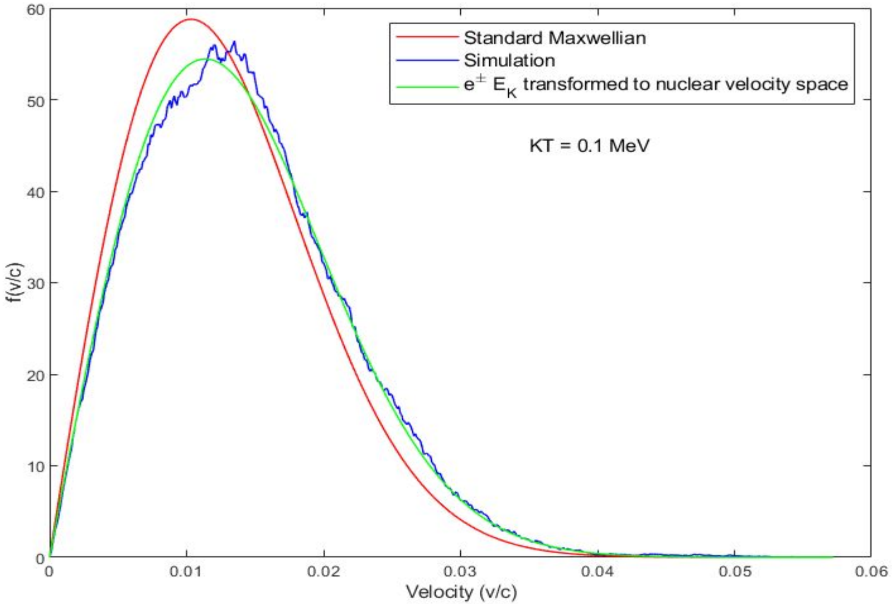
T		$\frac{n_\pm}{n_\gamma}$	$\frac{\sigma_\pm}{\sigma_\gamma}$		$\frac{\Gamma_\pm}{\Gamma_\gamma}$
T_9	MeV		$\sigma_\pm = \pi r_D^2$	$\sigma_\pm =$ Mott X-sec.	$\sim \frac{n_\pm \sigma_\pm}{n_\gamma \sigma_\gamma}$
11.6	1	1.43	5×10^4	10^5	10^5
1.16	0.1	0.102	10^7	10^5	10^4
0.116	0.01	10^{-13}	2×10^{28}	10^{29}	10^{15}

Simulated thermalization with e^+e^-

Nuclei doing random walks by scattering off e^+e^-



Simulated thermalization with e^+e^-



Velocity distribution for Nuclei (Simulation) compared with classical M-B and e^+e^- M-J(transformed to n v-space).

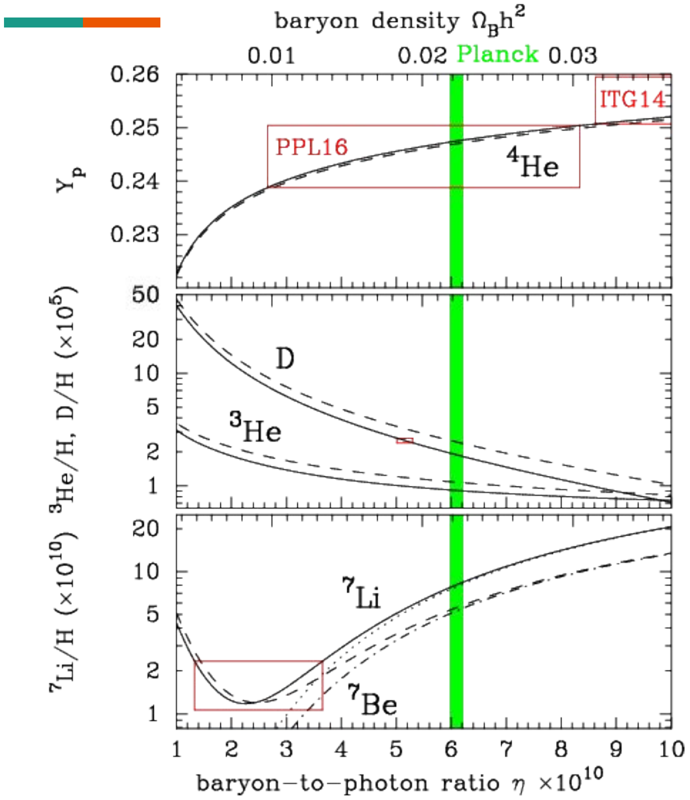
Energy distribution for Nuclei

= Energy distribution of e^+e^-

= Maxwell-Jüttner distribution

Transform this M-J distribution to v-space($f(v)$), update reaction rates and BBN yields.

BBN Yields



Unfortunately, this doesn't solve the Li^7 problem, it worsen's it. But, it is a correction to be accounted for.

Deuterium and Lithium disagree with observational constraints.

"Relativistic Electron Scattering and Big Bang Nucleosynthesis" Sasankan, Kedia, Kusakabe, Mathews [Submitted]

Summary

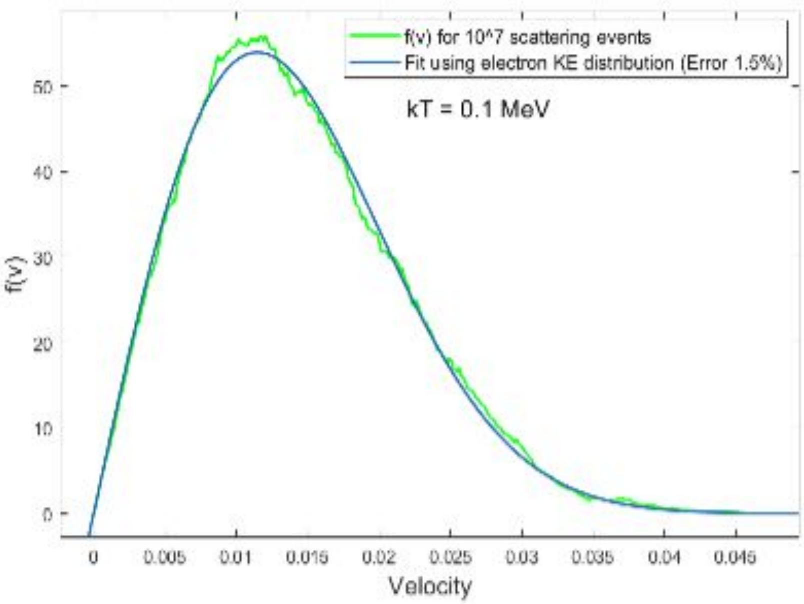
^{7}Li problem → Our research begins:
Question: How does a nucleus thermalize?

- Interacts with surroundings
  - Mostly e^+e^-, γ
  - Interacts with e^+e^-
- e^+e^- follow M-Jüttner, not M-Boltzmann
- Simulate thermalization with e^+e^-
- Observed distribution $\boldsymbol{f_{Nulcei}(E) = f_{e+e-}(E)}$ **= M-Jüttner distribution**
  ⇒ obtain $f(v)$ ⇒ update reaction rates ⇒ update BBN yields.

Lithium Problem is probably really a BBN problem

Thank you!

Velocity profile



Maxwell-Jüttner distribution

$$f(\gamma) = \left(\frac{\gamma^2 v m_e}{kTK_2(m_e c^2/kT)}\right)\frac{1}{\exp\left[(E_T \pm \mu)/kT\right]+1}$$

Relative velocity dist. in terms of nuclear velocity dist.

$$f^{\mathrm{rel}}(\boldsymbol{v};T) \;=\; \int d\boldsymbol{V}\left[f(\boldsymbol{v}_1)f(\boldsymbol{v}_2)\right]_{\boldsymbol{v}}$$

“Relativistic Electron Scattering and Big Bang Nucleosynthesis” Sasankan, Kedia, Kusakabe, Mathews, PRL[Submitted]. ArXiv preprint : https://arxiv.org/abs/1810.05976