Constraining Majoron from Big-Bang Nucleosynthesis

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Abstract

We estimate the Big-Bang nucleosynthesis (BBN) constraint on the Majoron in the mass range between $1\,\mathrm{MeV}$ to $10\,\mathrm{GeV}$ which dominantly decays into the standard model neutrinos. We find that due to the decay of Majoron, deuterium and helium abundances are enhanced, while the constraint from the deuterium is stronger than that from the helium. $^7\mathrm{Li}$ abundance gets decreased as a consequence of additional neutrons, produced due to the Majoron induced enhanced $p \to n$ conversion, but the parameter range that fits the observed $^7\mathrm{Li}$ abundance is excluded by the deuterium constraint. We also estimate other cosmological constraints and compare them with the BBN bound.

Effect of Majoron on BBN

We consider $\mathscr{L} \supset -\dfrac{ig_{\alpha\beta}}{2}\bar{\nu}_\alpha \gamma_5 \nu_\beta J$ and the free parameters are $Y_J^{(0)}, m_J, \tau_J$. The injected ν from the decay of Majoron can have the following effects.

- Injected neutrinos ($\nu_{\rm nt}$) enhance $p \to n$ conversion and as a result, the abundance of n will increase. $\nu_{\rm nt}$ also scatters with other light elements.
- Injected neutrinos can heat-up the background neutrinos and it will change the equilibrium value of n/p ratio as well as the neutron freeze-out temperature.
- Modify the Hubble parameter

Boltzmann Equation

$$\frac{dX_A}{dt} = \Gamma_{\rm SBBN} + \sum_B \left(X_B\, \delta\Gamma_{B\to A} - X_A\, \delta\Gamma_{A\to B}\right)$$

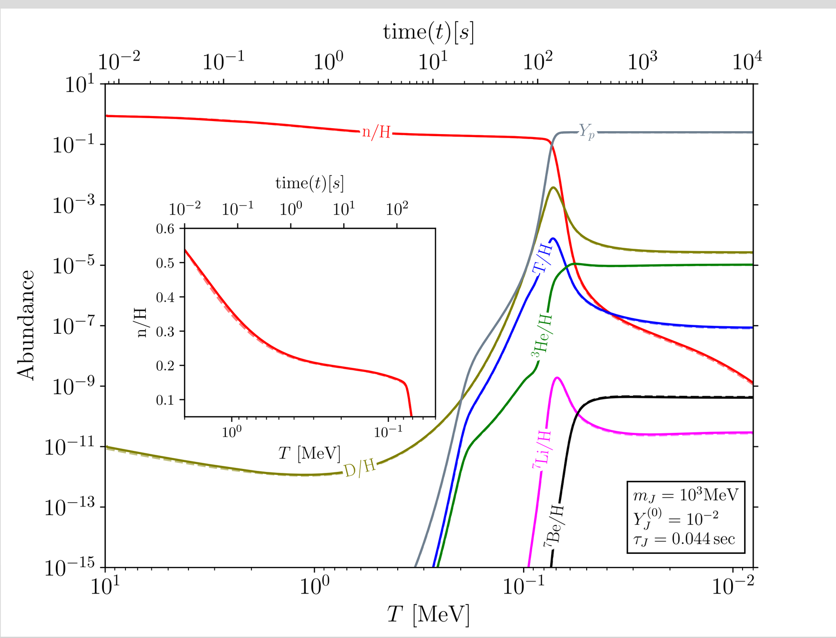
$$\delta\Gamma_{A\to B} = \frac{1}{2\pi^2}\int_0^{m_J/2} dE_{\nu_{\rm nt}} f_{\nu_{\rm nt}} E^2_{\nu_{\rm nt}} \sigma_{\nu_{\rm nt}A\to B} + \left(\Gamma'_{A\to B} - \Gamma^{\rm SBBN}_{A\to B}\right)$$

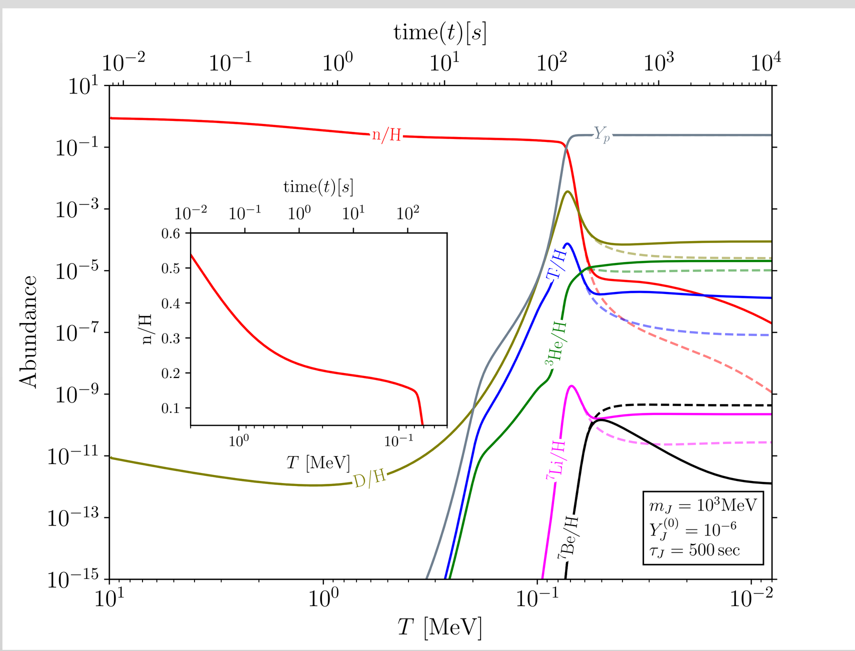
$f_{\nu_{\rm nt}}$ is the non-thermal neutrino momentum distribution function

The last term contributes only when $A, B = n, p$

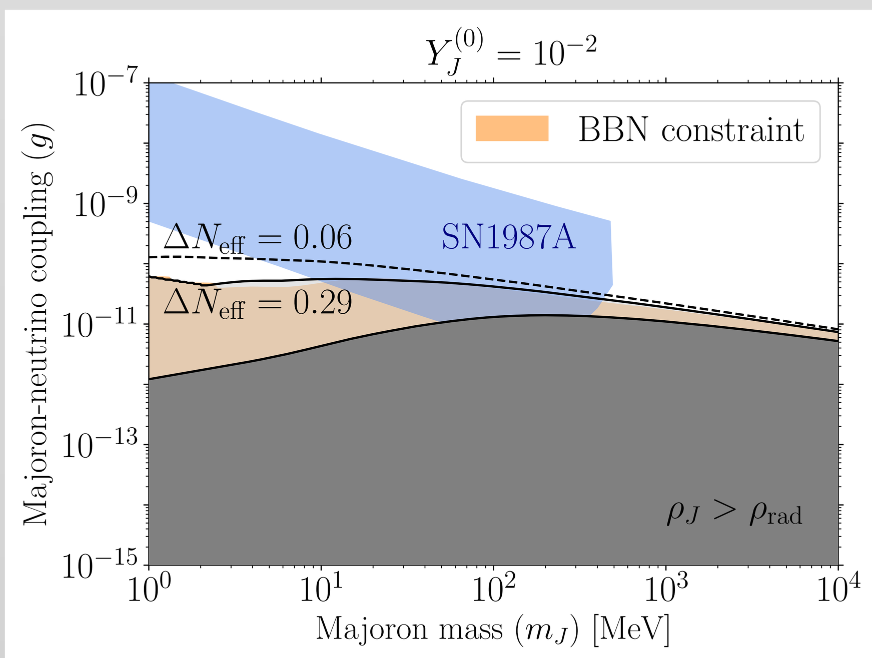
$\Gamma'_{A\to B}$ for $A, B = n, p$ is the modified rate due to background ν heating

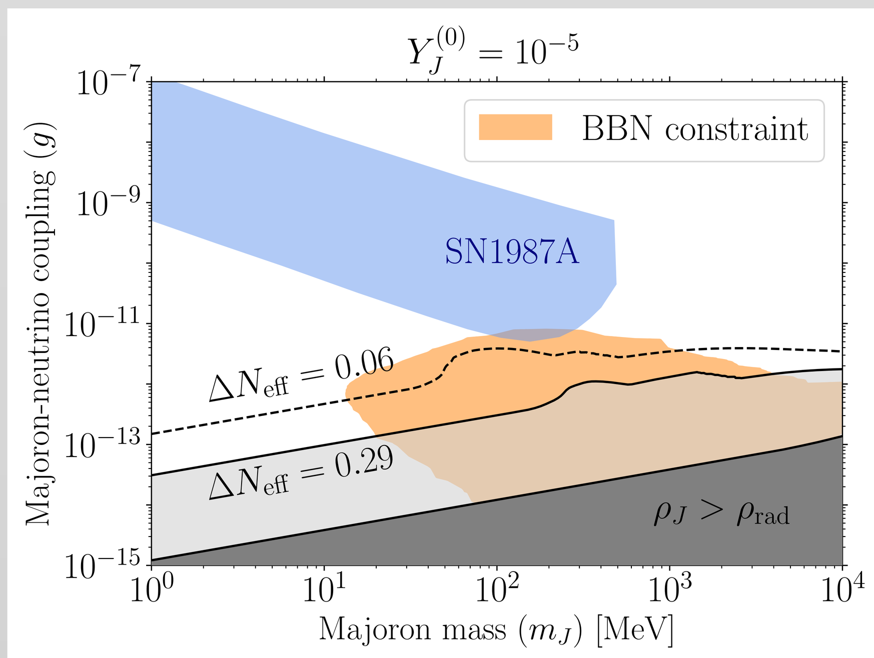
Evolution in presence of Majoron



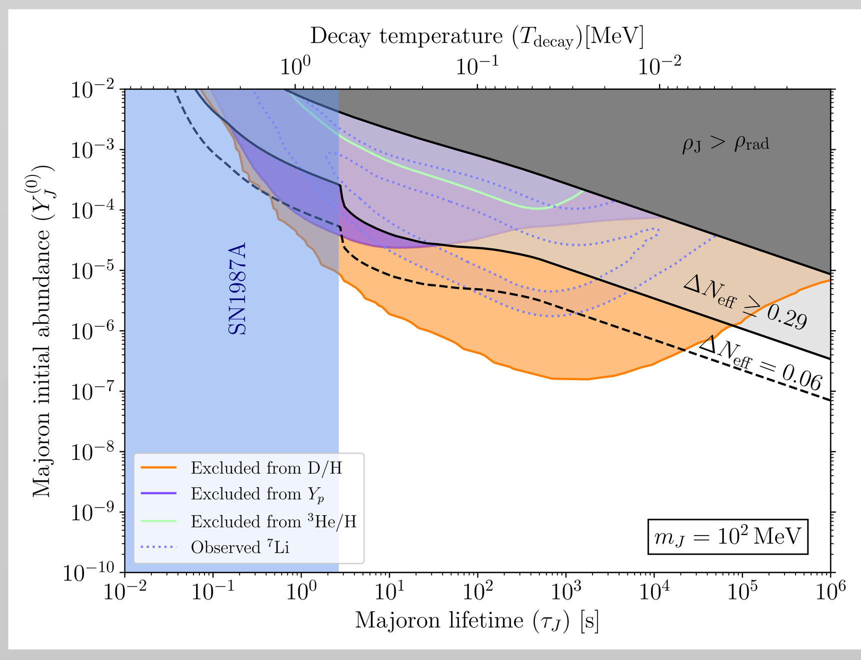


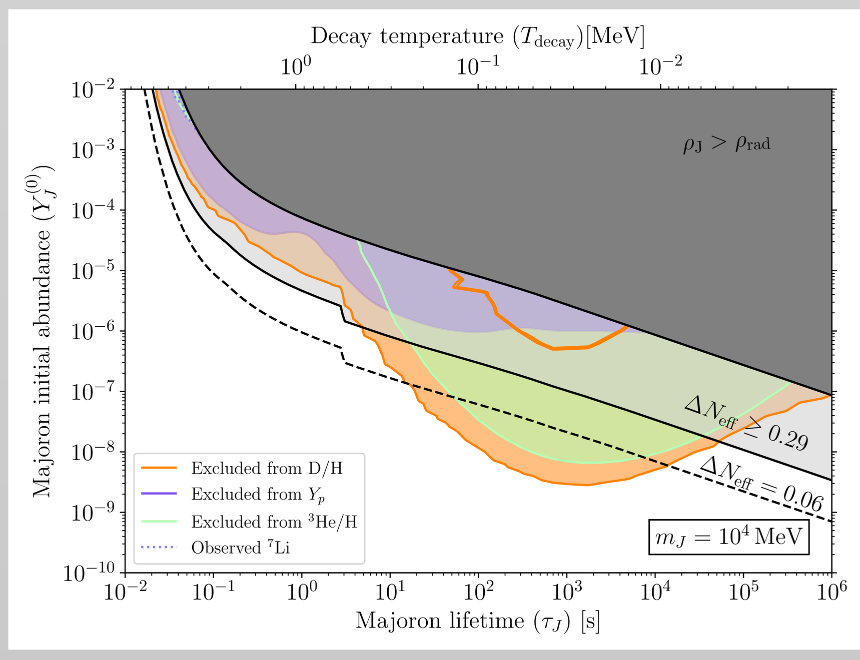
Constraints on $m_J - g$ plane





Constraints on $\tau_J - Y_J^{(0)}$ plane





Summary

We show that non-thermally produced Majoron can have significant impact on the BBN observables and we provide stringent constraint from BBN for small Majoron-Neutrino coupling.

For Majoron abundance $Y_J^{(0)} = 10^{-2}$, BBN constraint is comparable to the $\Delta N_{\rm eff}$ constraint. However, for $Y_J^{(0)} = 10^{-5}$, BBN constraint is stronger than $\Delta N_{\rm eff}$ constraint.

Acknowledgement

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Reference

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