Probing Long-Lived Heavy Neutral Leptons in Cosmology

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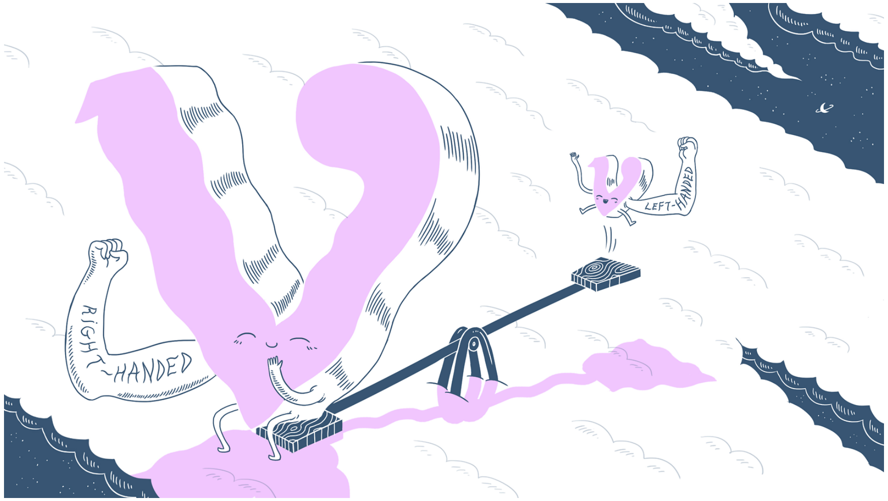
Outlines

1. Heavy Neutral Leptons & Seesaw Mechanism
2. HNL-ALP Interaction
3. Big Bang Nucleosynthesis
4. HNL and ALP Populations
5. Conclusion

Heavy Neutral Lepton & Seesaw Mechanism

Motivation:Massless SM neutrinos
HNLs give mass to light active neutrinos



Dirac mass by **Right-Handed Neutrinos**:

$$\mathscr{L}_{Dirac} = -Y_\nu \bar{L} \cdot H \nu_R + \text{h.c.}$$

Majorana Right-Handed Neutrinos:

$$\mathscr{L}_{Majorana} = -Y_\nu \bar{N} L \cdot H - 1/2 \bar{N}^c M_R N + \text{ h.c.}$$

$$\mathscr{M}_\nu = \begin{pmatrix} 0 & m_D \\ m_D & M_R \end{pmatrix} = U \begin{pmatrix} m_\nu & 0 \\ 0 & m_N \end{pmatrix} U^T$$

Light Neutrino Mass:

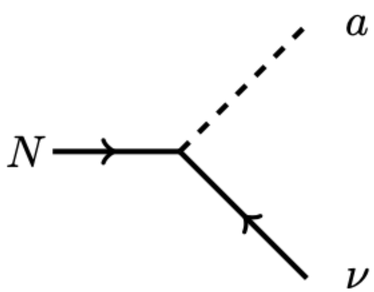
$$m_\nu \simeq \frac{m_D^2}{M_R} \simeq \frac{(1)^2}{10^{10}} \text{GeV} = 0.1\text{eV}$$

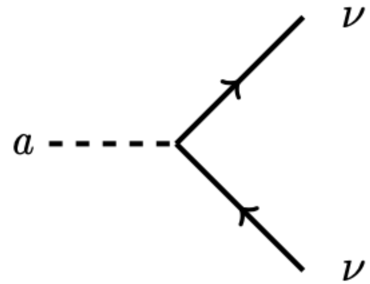
$$|V_{eN}|^2 \simeq \frac{m_\nu}{M_R}$$ Active-Sterile mixing

HNL and Axion Like Particle (ALP)

$$\mathscr{L}_{aN} = \frac{C_{aN}}{f_a}\left(\partial_\mu a\right)\bar{N}\gamma^\mu\gamma_5 N = -\frac{2iC_{aN}}{f_a}m_N a\bar{N}\gamma_5 N = -\frac{2iC_{aN}U_{\nu N}}{f_a}m_N a\bar{N}\gamma_5\nu$$

HNL-ALP interaction



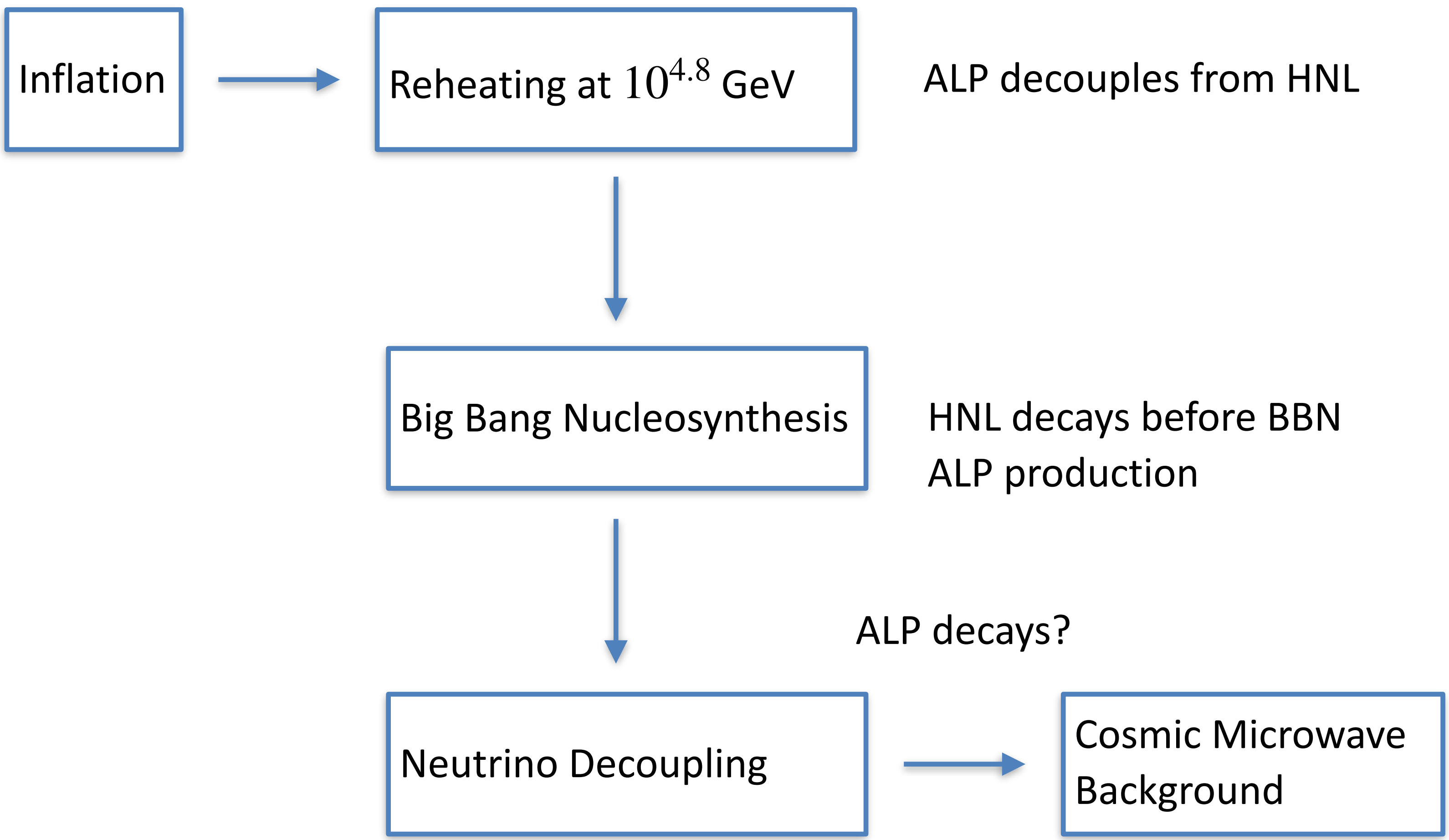


$$\tau_N = \frac{1}{\Gamma_{Na\nu}} \simeq \frac{8\pi f_a^2}{U_{\nu N}^2 m_N^3} = 1\text{sec} \times 8\pi \times \left(\frac{\mathrm{f_a}}{1\mathrm{TeV}}\right)^2 \times \left(\frac{10^{-7}}{\mathrm{U}_{\nu\mathrm{N}}}\right)^2 \times \left(\frac{100\mathrm{MeV}}{\mathrm{m_N}}\right)^3$$

GeV HNL can survive for 0.1s

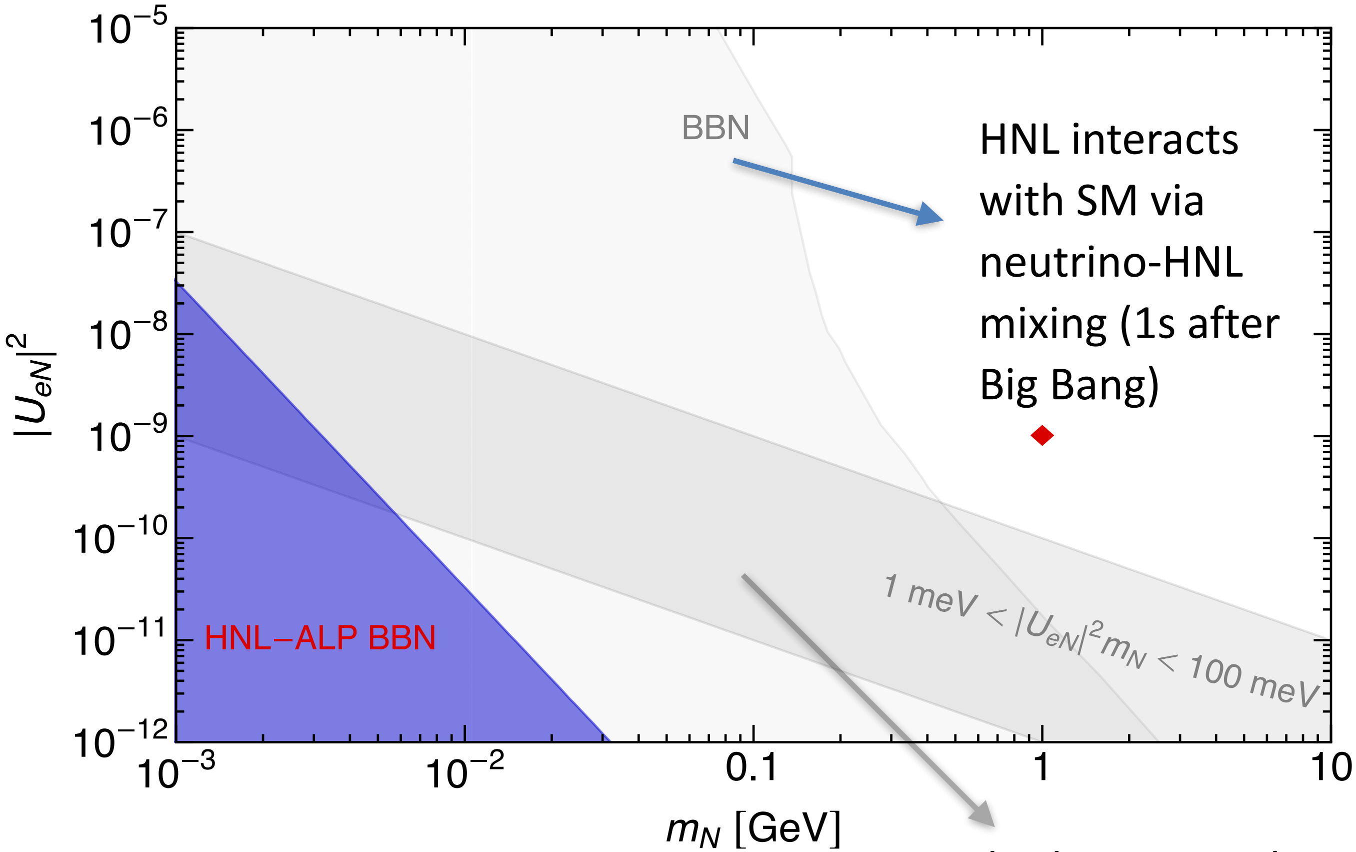
$$\boxed{f_a = 10^3\ \text{GeV},\ |V_{eN}|^2 = 10^{-9}}$$

Thermal History



Big Bang Nucleosynthesis

$f_a = 10^3$ GeV
$m_a =$ eV - MeV



Standard Seesaw relation limit by $|V_{eN}|^2 = m_\nu / m_N$

Benchmarks: 1 GeV at $|V_{eN}|^2 = 10^{-9}$

Conclusion

1. Neutrino mass from light HNL can be achieved by non-standard seesaw mechanisms
2. BBN limits on HNL mass can be relaxed by exotic interactions
3. ALPs can be produced by “Freeze-In” from HNL decay
4. Long-Lived HNL can be probed by beam dump experiments

Thanks for listening

Any Questions?