Neutrino Magnetic Moment in Cosmology

Shao-Ping Li (李少平)

Institute of High Energy Physics, CAS

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S.Li & Xun-Jie Xu, arXiv:2211.04669

Neutrino Magnetic Moment (NMM)

Left-handed neutrinos in SM are massive, right-handed/chirality-flipping counterparts exist

Effective chirality-flipping interaction from unknown UV model

$$\mathcal{L} \supset \mu_\nu \overline{\nu_L} \sigma^{\alpha\beta} \nu_R \partial_\alpha A_\beta + \text{h.c.}$$

Why bother ourselves with NMM? → windows for new physics related to neutrino masses, dark matter, leptogenesis,…

Just add right-handed Dirac neutrinos to the SM K. Fujikawa & R. Shrock, PRL,1980

$$\mu_\nu \sim 10^{-20} \mu_B \qquad \mu_B = e/2m_e \approx 0.296 \text{ MeV}^{-1}$$

could be much larger in new physics, how large can it be from a model-independent view?

NMM bounds

Current bounds from laboratories and astrophysics

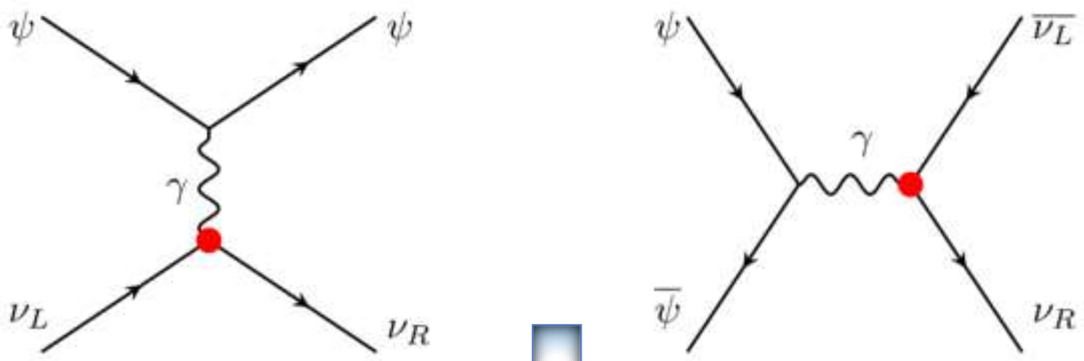
Experiments/Observations	Upper Limit
XENONnT ($\nu + e^-$ scatt.)	$6.3 \times 10^{-12} \mu_B$
LZ ($\nu + e^-$ scatt.)	$6.2 \times 10^{-12} \mu_B$
Borexino ($\nu + e^-$ scatt.)	$28 \times 10^{-12} \mu_B$
Astrophysics (red giant)	$2.2 \times 10^{-12} \mu_B$ $1.5 \times 10^{-12} \mu_B$

How about the cosmology?

NMM in Cosmology

Basic assumption: right-handed neutrinos are light (below 1MeV)

$$\mathcal{L} \supset \mu_\nu \overline{\nu_L} \sigma^{\alpha\beta} \nu_R \partial_\alpha A_\beta + \text{h.c.}$$



Thermalize right-handed neutrinos at high temperatures

Thermally averaged $\nu_L \to \nu_R$ rate	$\langle \sigma v n \rangle / \alpha \mu_\nu^2 T^3$
Zero-T QFT + m_γ cut + $e^\pm$ plasma + Boltzmann statistics	2.26
Finite-T QFT + $e^\pm$ plasma + HTL approximation	1.84
Finite-T QFT + $e^\pm$ plasma + full quantum statistics	1.53
Finite-T QFT + $\psi\overline{\psi}$ plasma + full quantum statistics	6.47

This work

NMM in Cosmology

Once $\nu_L \to \nu_R$ rate becomes smaller than the expansion of the universe, ν_R decouple

Relation between NMM and decoupling temperature

$$\mu_\nu \approx 1.8 \times 10^{-12} \left(\frac{100\ \text{GeV}}{T_{\text{dec}}}\right)^{1/2} \mu_B$$

Any extra radiation during Big Bang Nucleosynthesis or Cosmic Microwave Background is constrained by the effective neutrino number

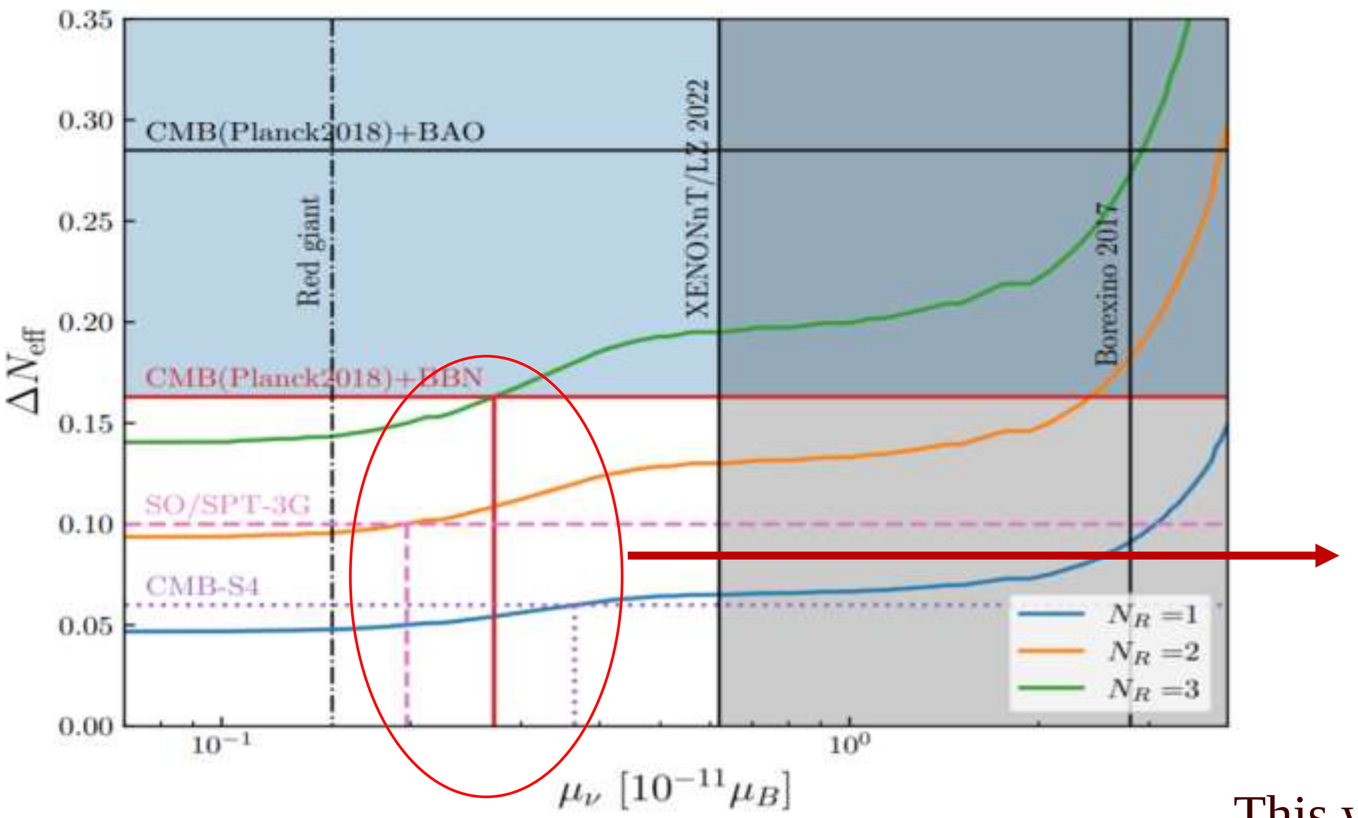
$$\Delta N_{\text{eff}} = N_R \left[\frac{4}{43} g_*(T_{\text{dec}})\right]^{-4/3}$$

$$N_{\text{eff}} = 2.99 \pm 0.17\,, \quad (\text{CMB+BAO})$$

$$N_{\text{eff}} = 2.830 \pm 0.189\,, \quad (\text{CMB+BBN})$$

$$N_{\text{eff}}^{\text{SM}} = 3.044 - 3.046$$

Upper bounds of NMM in Cosmology



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BBN+CMB for $N_R = 3$	$2.7 \times 10^{-12}\mu_B$
SO for $N_R = 2$ (future)	$2.0 \times 10^{-12}\mu_B$
CMB-S4 for $N_R = 1$ (future)	$3.7 \times 10^{-12}\mu_B$

This work

Summary

If right-handed neutrinos are light and thermalized in the early universe, we can constrain the NMM in a model-independent way

Finite-temperature corrections are important in neutrino chirality-flipping rate

The BBN, CMB and their combination give a NMM bound stronger than current laboratory experiments and compatible with astrophysical bounds.

Thanks