Poster of WIN2023, July 3rd, Zhuhai, China

Neutrino Magnetic Moment in Cosmology

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Question?

How large can neutrino magnetic moment (NMM) be in cosmology?

Answer!

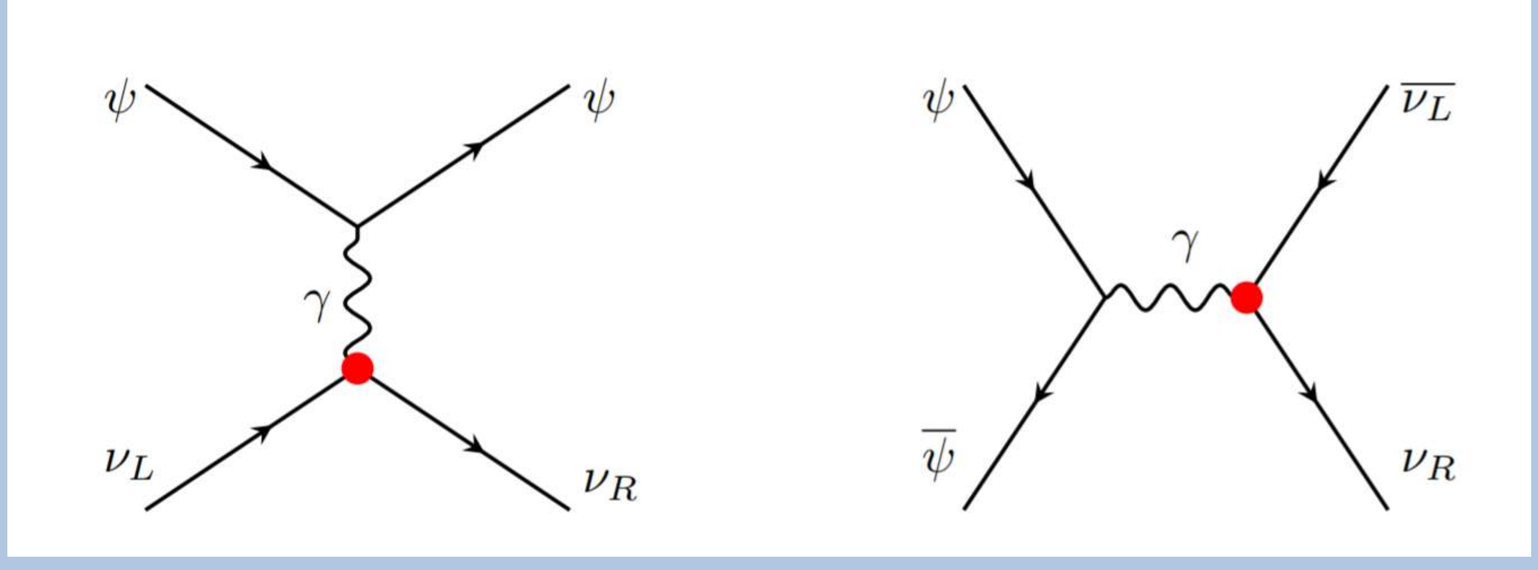
$$\text{BBN+CMB}: \quad \mu_\nu < 2.7\times 10^{-12}\mu_B \quad (\text{for } N_R = 3)$$

Why & How?

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

Light right-handed neutrino

Collisions @ QED plasma



Collision rates @ cubic temperature

Important finite-temperature correction

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

Stronger than Hubble rate

Later decoupling

Right-handed neutrinos thermalized

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

Later decoupling

Faster expansion at BBN & CMB

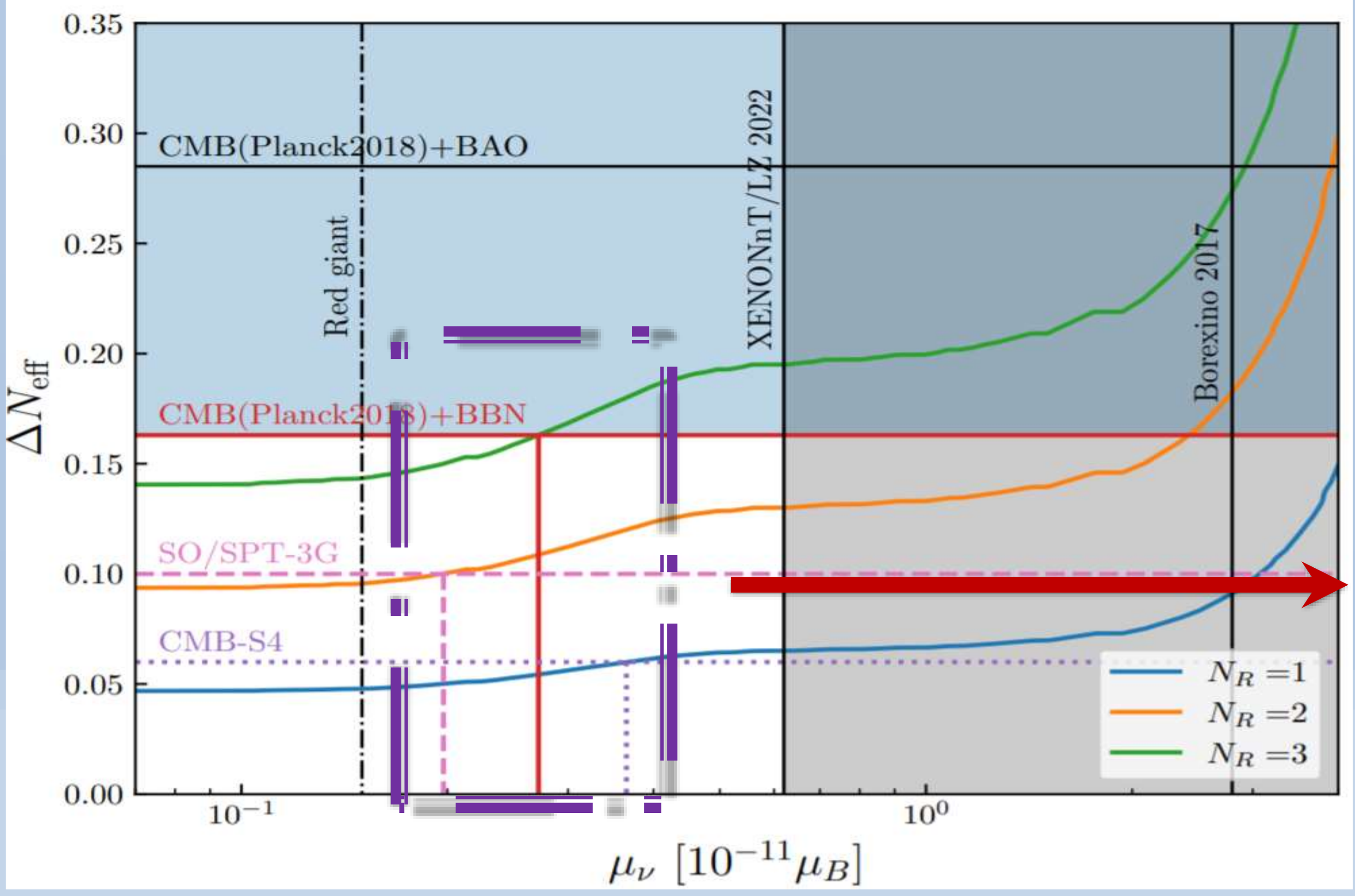
$$\Delta N_\text{eff} = N_R\left[\frac{4}{43}g_*(T_\text{dec})\right]^{-4/3}$$

Strong constraints from BBN & CMB

$$N_\text{eff} = 2.99\pm 0.17\,, \quad (\text{CMB+BAO})$$
$$N_\text{eff} = 2.830\pm 0.189\,, \quad (\text{CMB+BBN})$$

Upper limit on NMM

Upper limit on NMM @ cosmology



This work

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)	$2.2\times 10^{-12}\mu_B$ $1.5\times 10^{-12}\mu_B$
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)	$3.7\times 10^{-12}\mu_B$