Implications of Cosmological Measurements of $N_{\text{eff}}$ for Light Relics

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Light Thermal Relics in Cosmology

- Radiation energy density: \( \rho_r = \left[ 1 + \frac{7}{8} \left( \frac{4}{11} \right)^{4/3} N_{\text{eff}} \right] \rho_\gamma \), \( N_{\text{eff}}^{\text{SM}} = 3.045 \)

- Any thermalized relativistic degree of freedom will contribute to

\[
N_{\text{eff}} = N_{\text{eff}}^{\text{SM}} + \Delta N_{\text{eff}}
\]

as a function of their decoupling/freeze-out temperature \( T_F \):

\[
\Delta N_{\text{eff}}(T_F) = 0.027 g_{*,X} \left( \frac{g_{*,\text{SM}}}{g_{*,(T_F)}} \right)^{4/3} \gamma^{-4/3}
\]

\( g_{*,x} = 1, \frac{4}{7}, 2, \ldots \) for spin-0, \( \frac{1}{2}, 1, \ldots \)
\( g_{*,\text{SM}} = 106.75 \)

Effective number of relativistic degrees of freedom at \( T_F \)

Entropy production

Detailed discussion e.g. in arXiv:1810.02800.
Light Thermal Relics in Cosmology

Assumptions: negligible entropy production, minimal extension of the Standard Model.
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Planck + BAO + BBN

CMB-S4

CMB, CMB + LSS/21cm

See e.g. arXiv:1903.04763

Assumptions: negligible entropy production, minimal extension of the Standard Model.
Broad and Sensitive Probe of New Physics

Example: Photon-axion couplings

and many other use cases!

See e.g. arXiv:1303.5379, 1505.05192, 1604.08614, 1701.08750, 1709.07882, 1808.07430, 2001.01490, ...
Thank you!

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