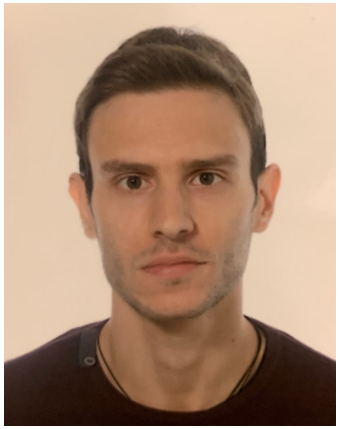
Contributions to $N_{\rm eff}$ from freeze-in production of light relics

Based on **arXiv:2405.xxxxx** with
Luca Caloni, M. Lattanzi, M. Gerbino



INFN FERRARA
Istituto Nazionale di Fisica Nucleare
Sezione di Ferrara

Contributions to $N_{\rm eff}$ from light relics in equilibrium

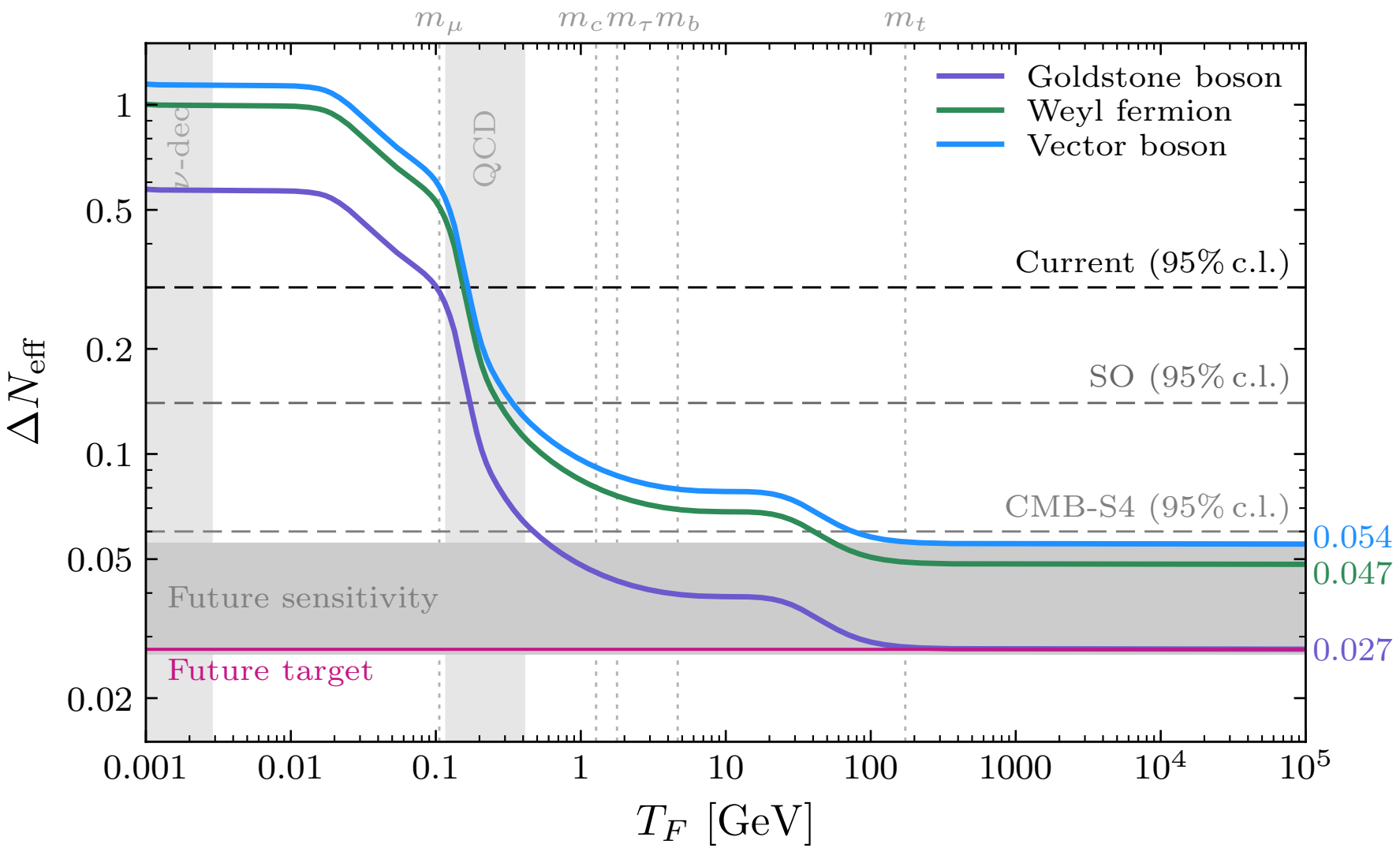


Figure: ▸ arXiv:2203.07943

Boltzmann equation for tracking out-of-equilibrium species

$$\frac{dY_\phi}{d\log x} = \left(1 - \frac{1}{3}\frac{d\log g_{*s}}{d\log x}\right)\frac{\Gamma_\phi(x)}{H(x)}\left[Y_\phi^{\rm eq} - \left(\frac{Y_\phi}{Y_\phi^{\rm eq}}\right)^{\ell-1} Y_\phi\right]$$

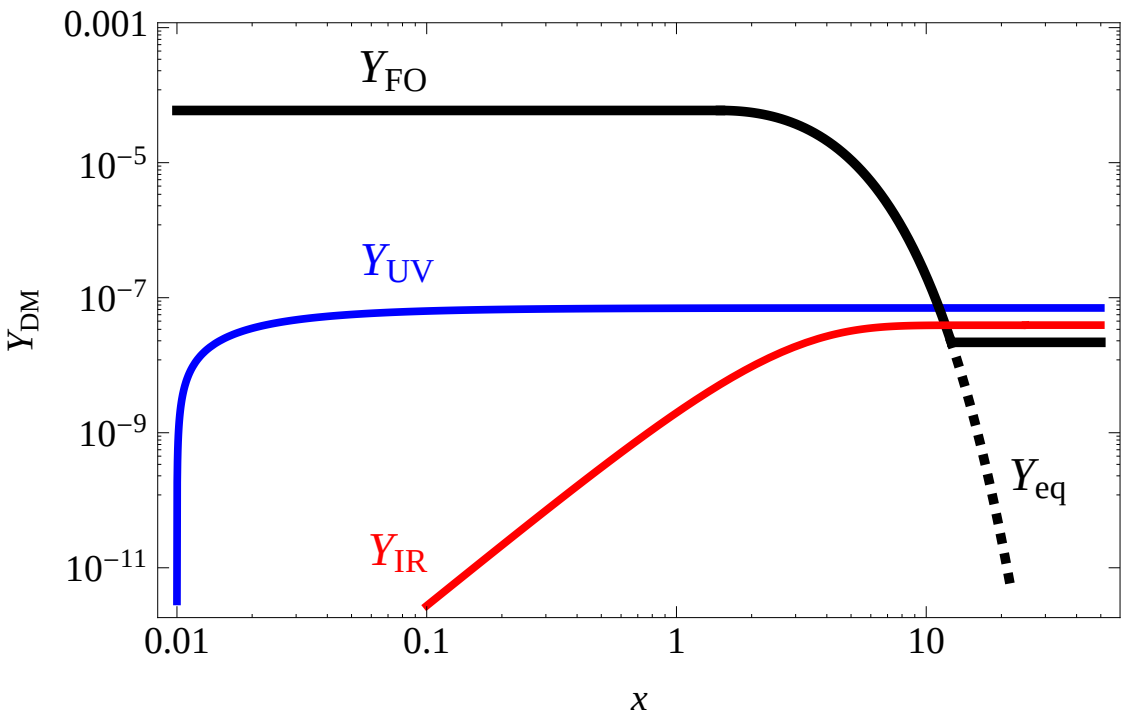


Figure: ▸ arXiv:1410.6157

Freeze-out $\Gamma_\phi(T_F) \simeq H(T_F)$

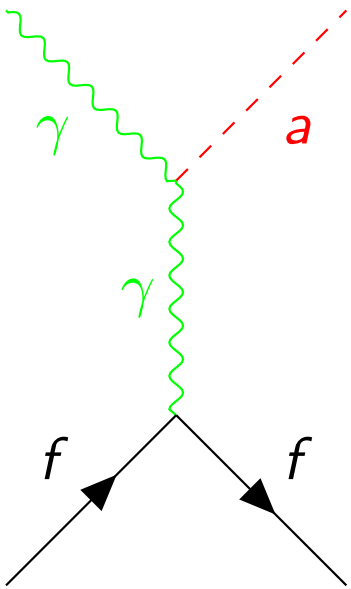
$$\Delta N_{\rm eff}^{\rm FO} \propto \left(\frac{106.75}{g_{*s}^{\rm SM}(T_F)}\right)^{4/3}$$

UV freeze-in Y_ϕ never in equilibrium for dimension $4+n$ suppressed interactions

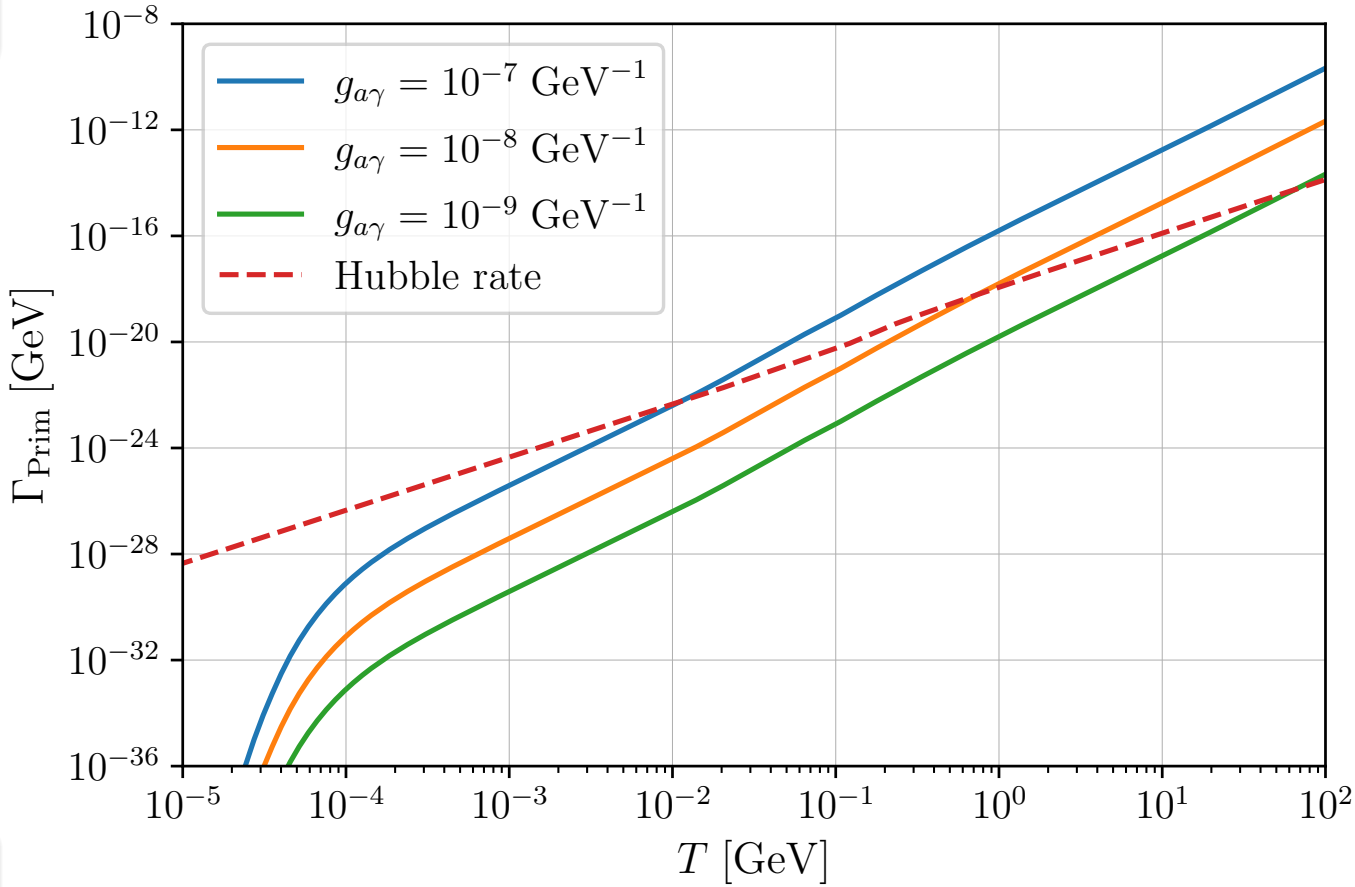
$$\Delta N_{\rm eff}^{\rm UV} \propto \left(\frac{M_{\rm Pl}\, T_{\rm reh}^{2n-1}}{\Lambda^{2n}}\right)^{4/3}$$

Thermal ALP production through the Primakoff effect

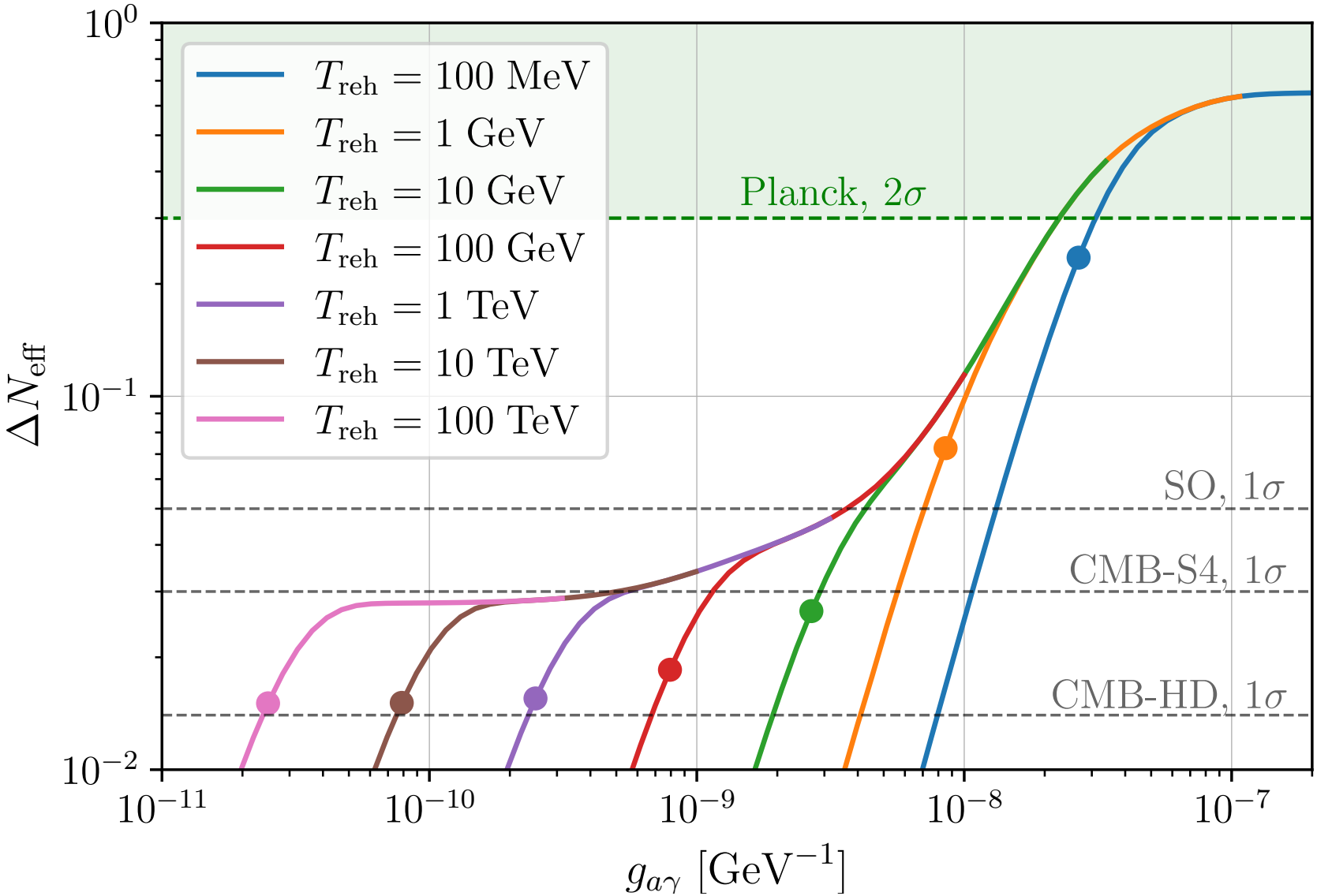
$$\mathcal{L}_{a\gamma} = \frac{1}{4} g_{a\gamma}\, a F_{\mu\nu} \tilde{F}^{\mu\nu}$$



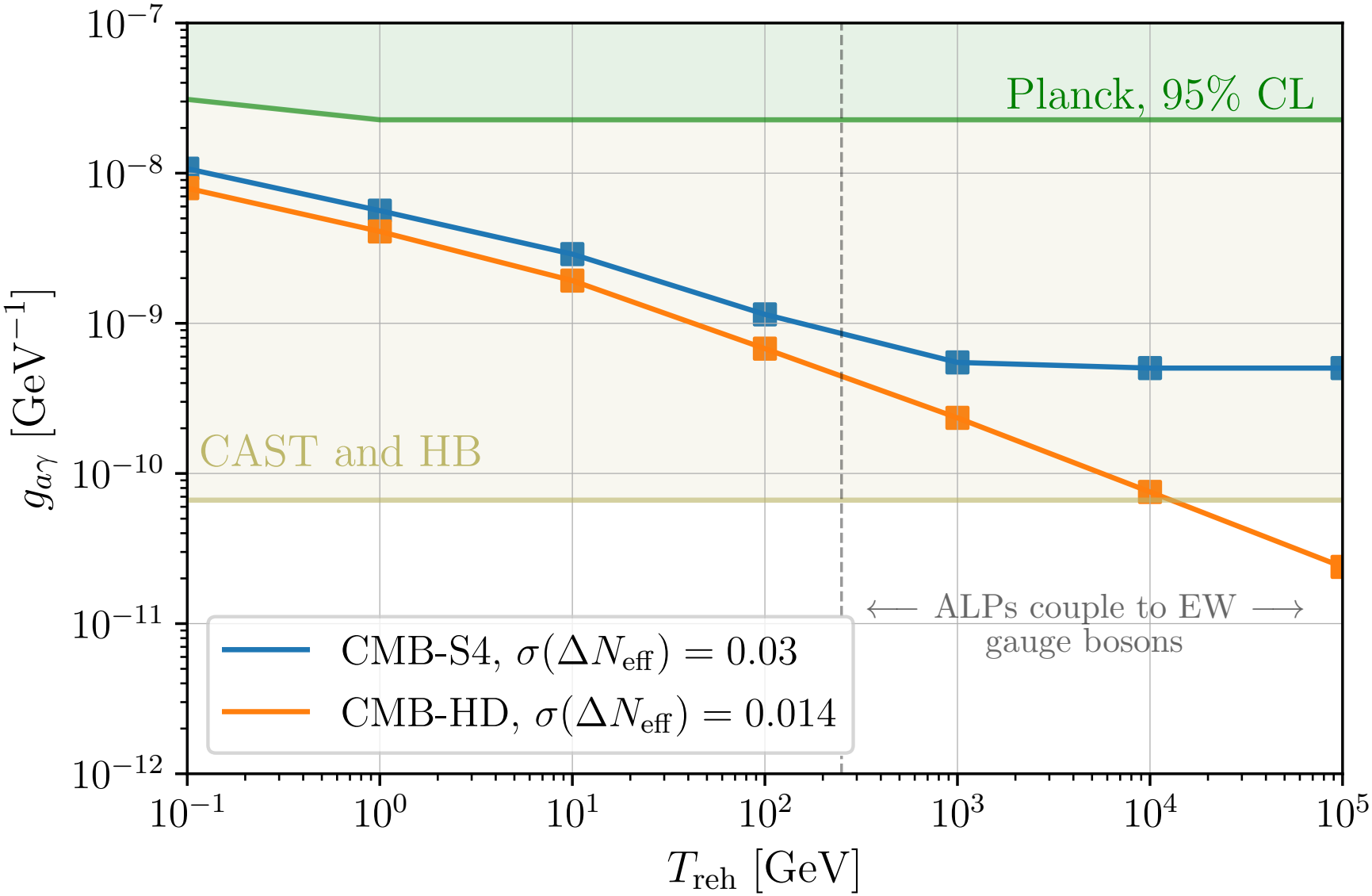
$$\Gamma_{\mathrm{Prim}} \propto \alpha_{\mathrm{em}} g_{a\gamma}^2\, T^3$$



ALP freeze-in probed by next-generation CMB observations



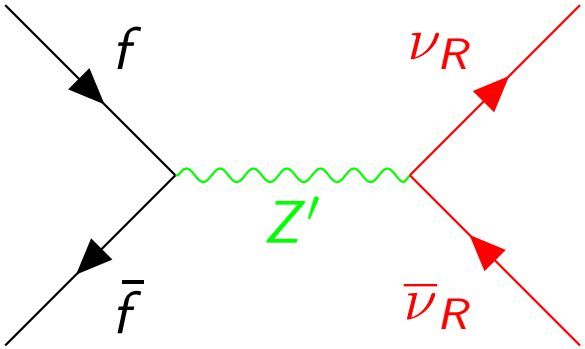
Need $T_{\rm reh} \gtrsim 10\,\text{TeV}$ for $g_{a\gamma}$ below lab and astro constraints



UV freeze-in production of light ν_R in gauged $B-L$ model

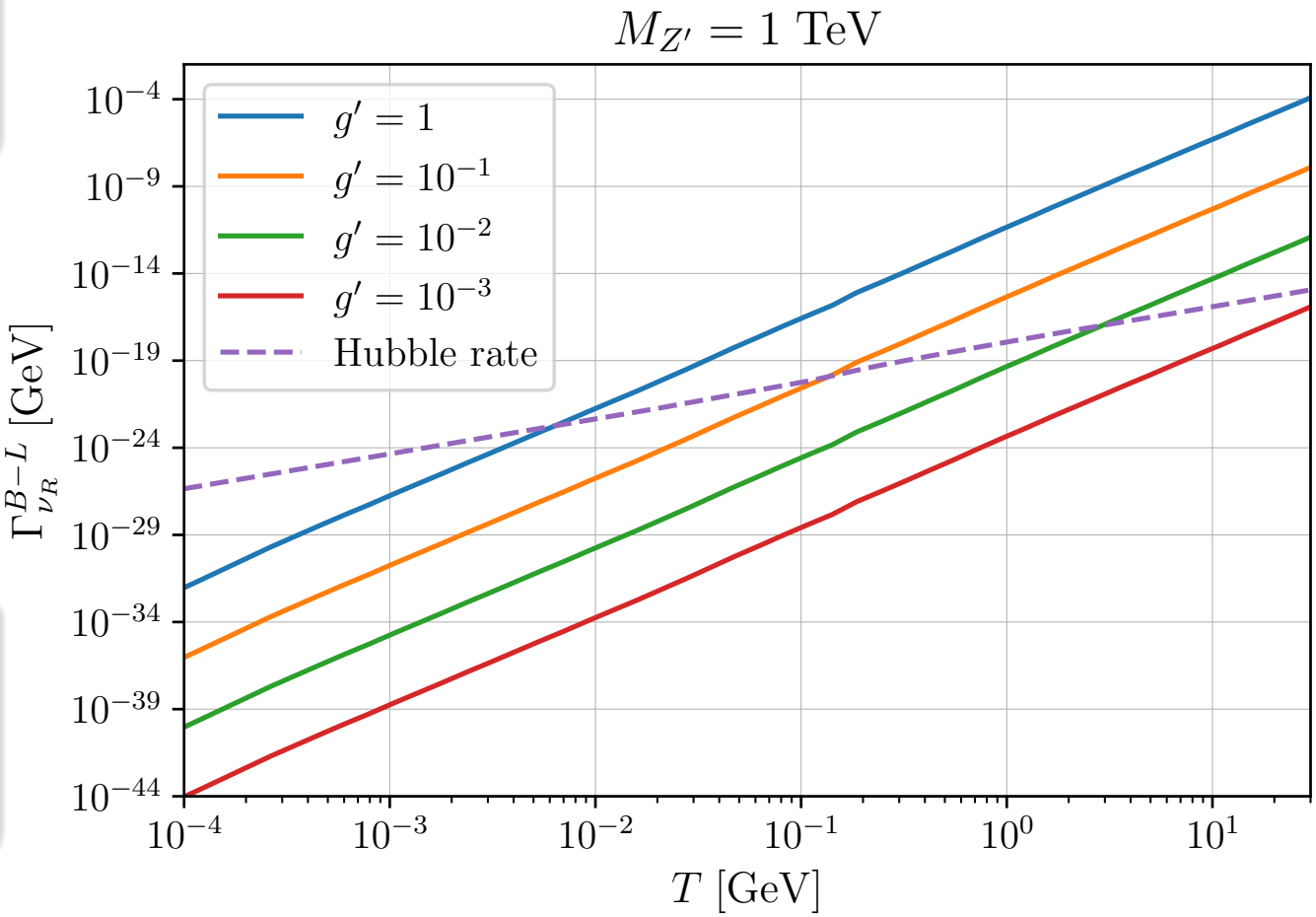
New gauge boson Z'

$$\mathcal{L} = g' Q_{B-L} Z'_\mu \bar{f} \gamma^\mu f$$

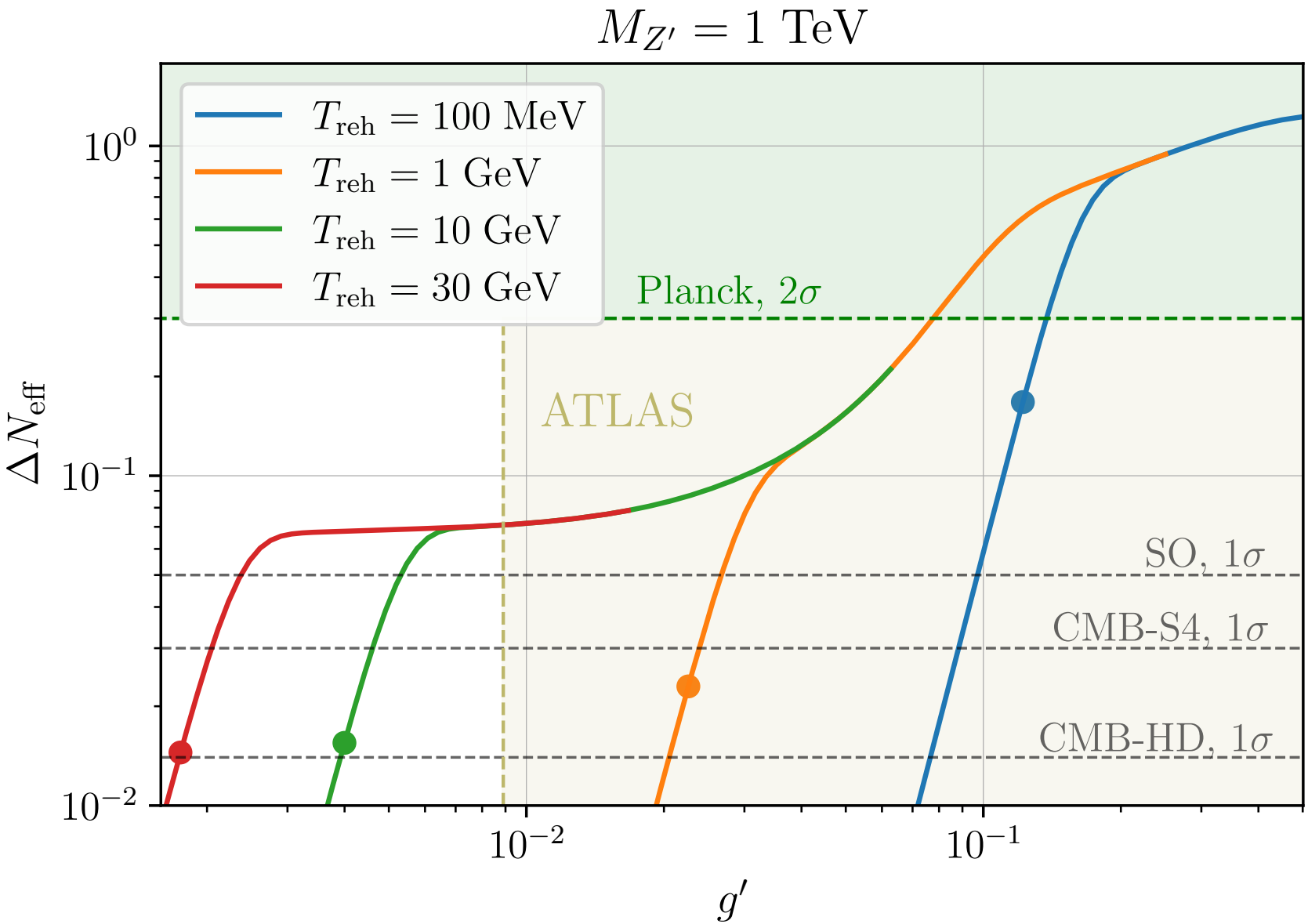


Consider $T_{\rm reh} \ll M_{Z'}$

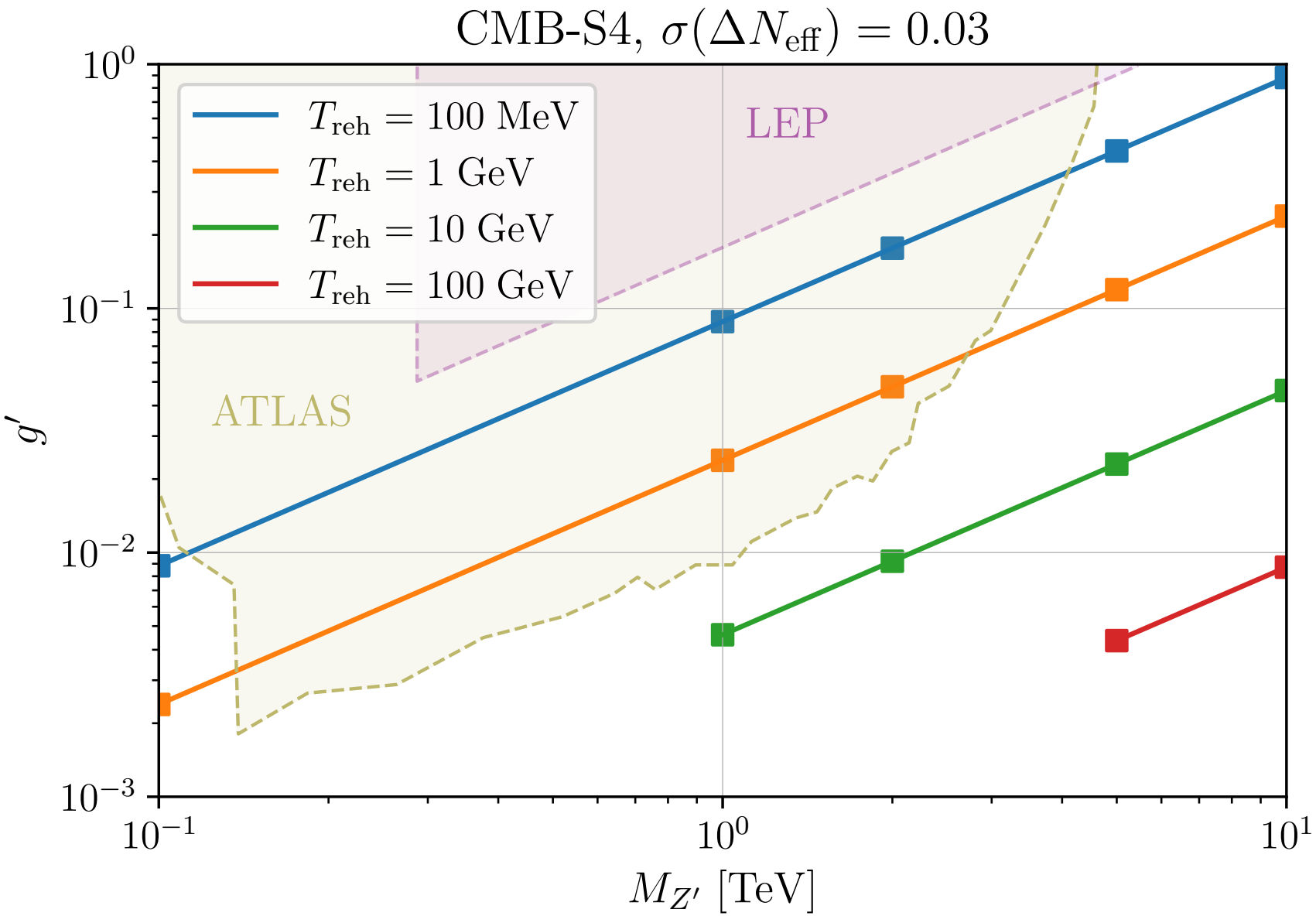
$$\Gamma^{B-L}_{\nu_R} \propto \frac{g'^4}{M^4_{Z'}} T^5$$



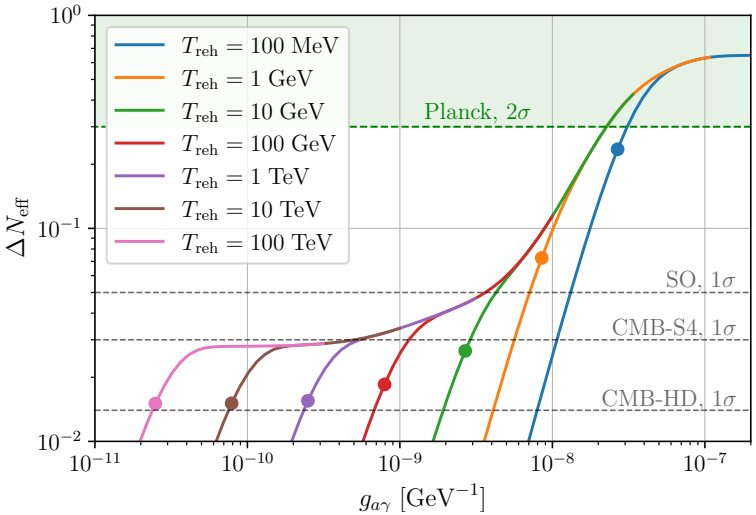
Next-gen CMB observations probe UV freeze-in of ν_R

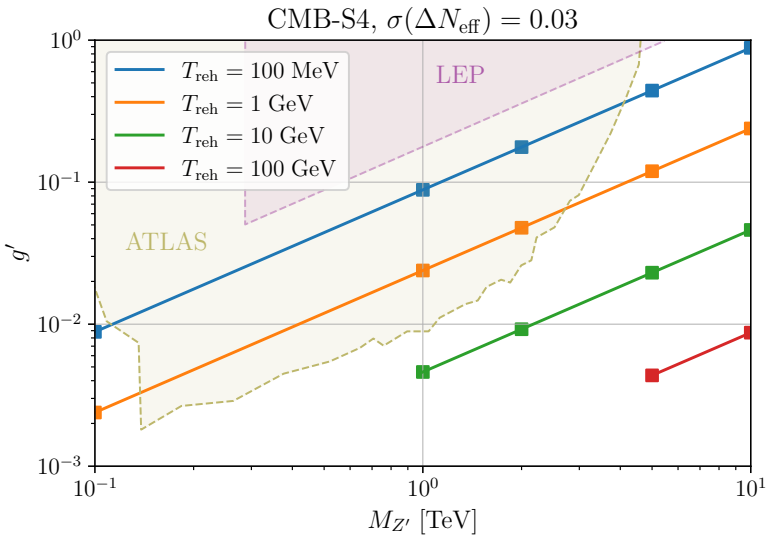


$\Delta N_{\rm eff}$ sensitive to larger $M_{Z'}$ and smaller g' than colliders



UV freeze-in of light relics is a target for CMB experiments





Sensitivity depends on scenario, $T_{\rm reh}$

- $g_{a\gamma} \lesssim$ Planck/100 for ALPs produced at $T_{\rm reh} \gtrsim 1\,\text{TeV}$
- $g' \lesssim$ Planck/3 for ν_R with $T_{\rm reh} \sim 1\,\text{GeV}$ and $M_{Z'} \gtrsim 5\,\text{TeV}$
- $g' \lesssim$ ATLAS/10 for ν_R with $T_{\rm reh} \sim 60\,\text{GeV}$ and $M_{Z'} \simeq 2\,\text{TeV}$

More light relics and BSM scenarios

- Massless **dark photons**
- $f\bar{f} \to \nu_R \bar{\nu}_R$ induced by $\langle r_\nu^2 \rangle_R$
- Production through decays requires more detailed treatment

Next-gen CMB observations probe UV freeze-in of ν_R