Saxion Cosmology

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Saxion Cosmology

What is the Saxion?

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The Strong CP Problem

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- The θ-vacuum term is CP-violating

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- Measurements of the electric dipole moment of the neutron yield the constraint

$$|\bar{\theta}| < 10^{-11}$$

The Peccei - Quinn solution

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$$\mathcal{L}_{\mathrm{PQ}} = \frac{g^2}{32\pi^2 f_{\mathrm{PQ}}} a G^b_{\mu\nu} \widetilde{G}^{b\,\mu\nu}$$

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- Axion acquires mass and restores CP

Supersymmetric Axions

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- → Saxion s (1 bosonic dof)

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  - SUSY breaking: saxion gets massive ~ $m_{3/2}$

Saxion Couplings

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$$A = (s + ia)/\sqrt{2} + \sqrt{2}\theta\tilde{a} + \theta^2 F$$ [Strumia, '10]

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$$\mathcal{L}_{\rm PQ} = \frac{\alpha_s}{8\pi f_{\rm PQ}} \Big[s \left(G^b_{\mu\nu} G^{b\,\mu\nu} - 2D^b D^b - 2i\bar{\tilde{g}}^b \gamma^\mu D_\mu \tilde{g}^b \right)$$
$$+ a \left(G^b_{\mu\nu} \widetilde{G}^{b\,\mu\nu} + 2\bar{\tilde{g}}^b \gamma^\mu \gamma^5 D_\mu \tilde{g}^b \right)$$
$$+ i\bar{\tilde{a}} \frac{[\gamma^\mu, \gamma^\nu]}{2} \tilde{g}^b G^b_{\mu\nu} + 2\bar{\tilde{a}} D^b \tilde{g}^b \Big]$$

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$$f_{\rm PQ} \gtrsim 6 \times 10^8 \ {\rm GeV}$$

[Raffelt,'08]

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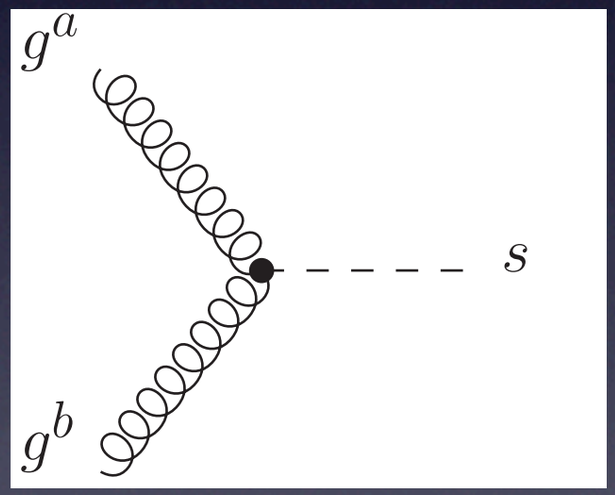
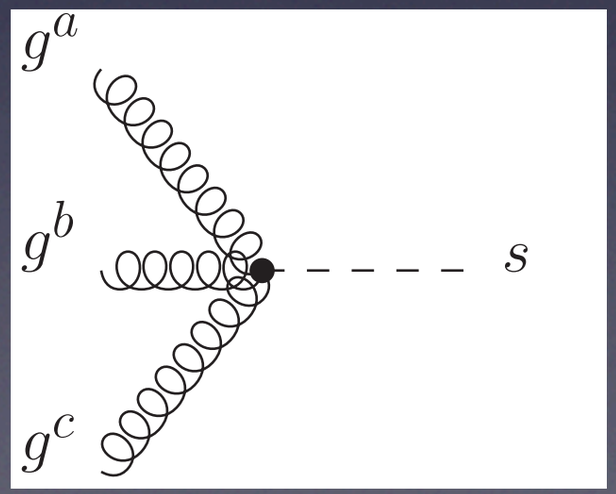
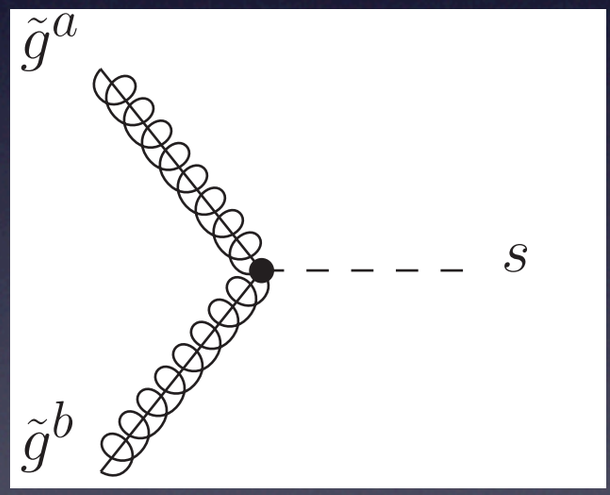
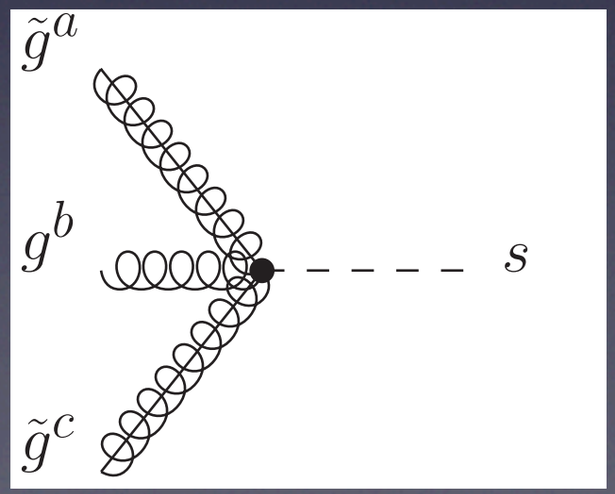
- Coupling to gluons and gluinos:









Saxion Couplings

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- Interaction from the kinetic term:

$$|\partial_\mu \Phi|^2 = \left(1 + \frac{\sqrt{2}x}{f_{\rm PQ}} s\right) \left[\frac{1}{2}(\partial_\mu a)^2 + \frac{1}{2}(\partial_\mu s)^2\right] + \dots$$

[Chun, Lukas, '95]

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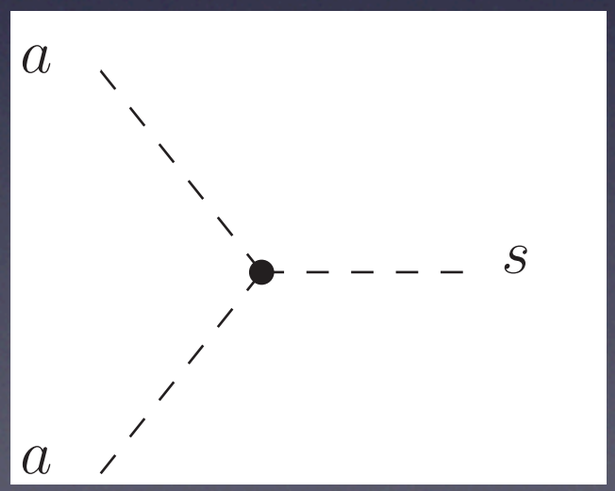
[Chun, Lukas, '95]

- Important for saxion decay:



Saxion Cosmology

Where does it come from?

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Thermal Saxions

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Thermal Saxions

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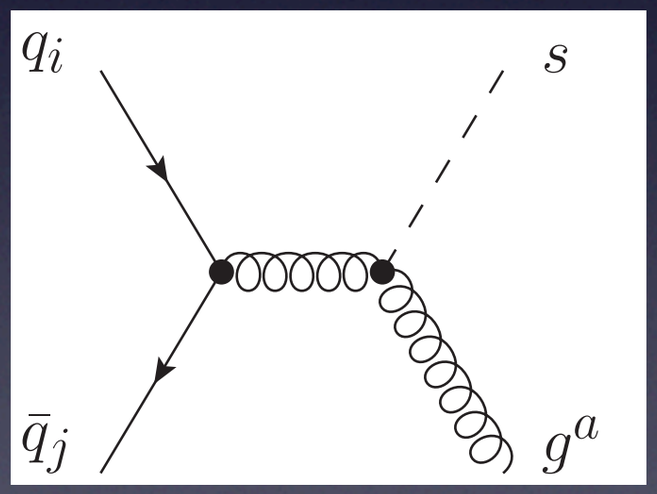
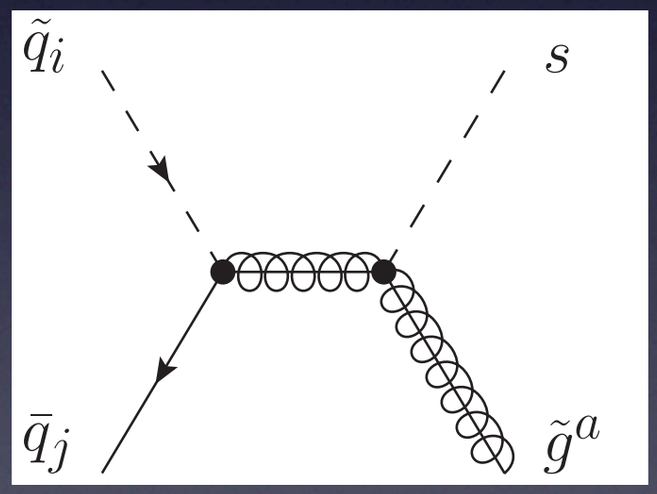
- If they do not, still production via scattering

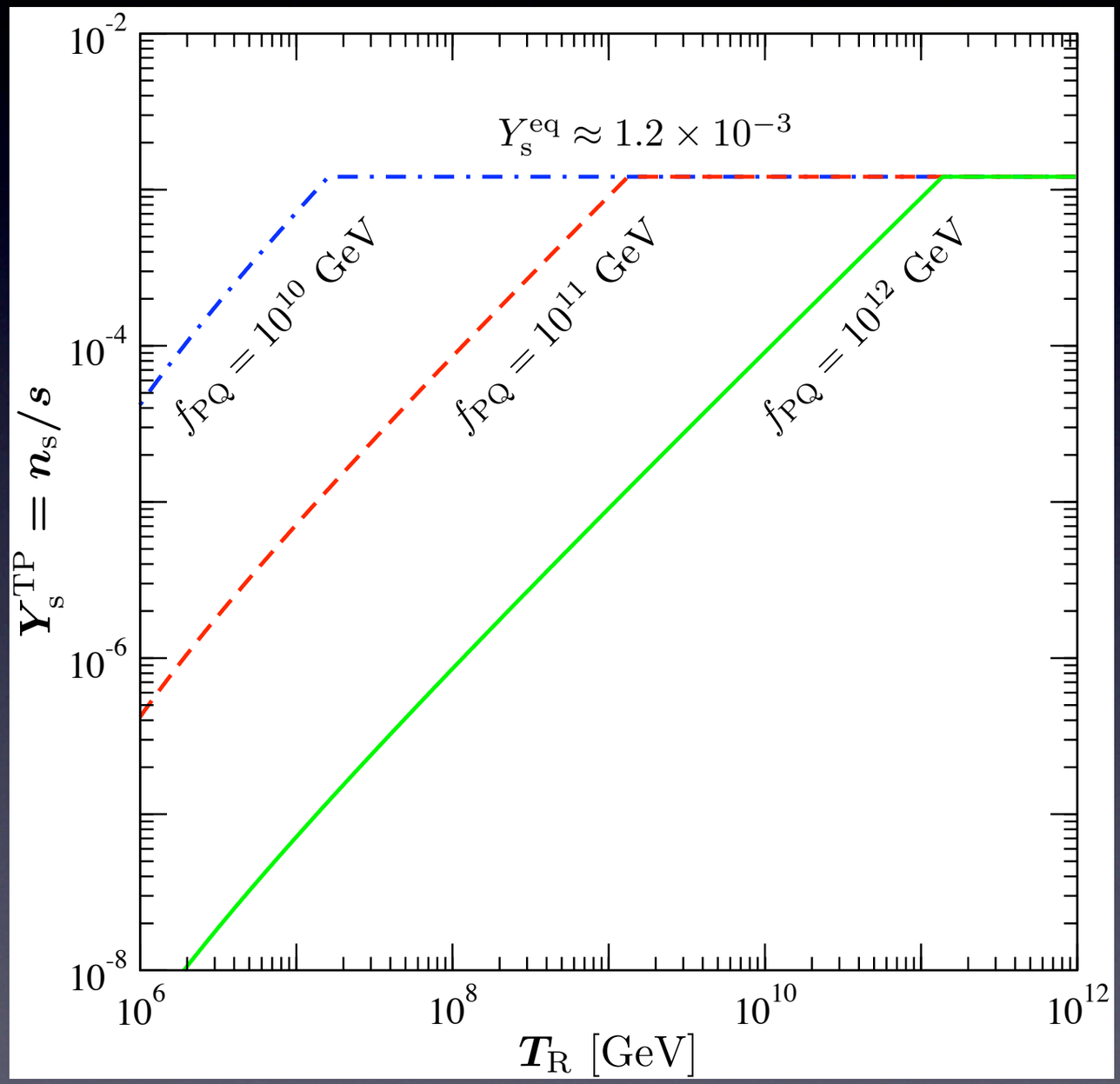




$$Y_s^{\rm TP} = 13.1 g_s^6 \ln\left(\frac{1.02}{g_s}\right)\left(\frac{10^{10}\ {\rm GeV}}{f_{\rm PQ}}\right)^2\left(\frac{T_{\rm R}}{10^{10}\ {\rm GeV}}\right)$$

[P.G.,Steffen, in prep.]

Saxion Yield



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Saxions from Coherent Oscillations

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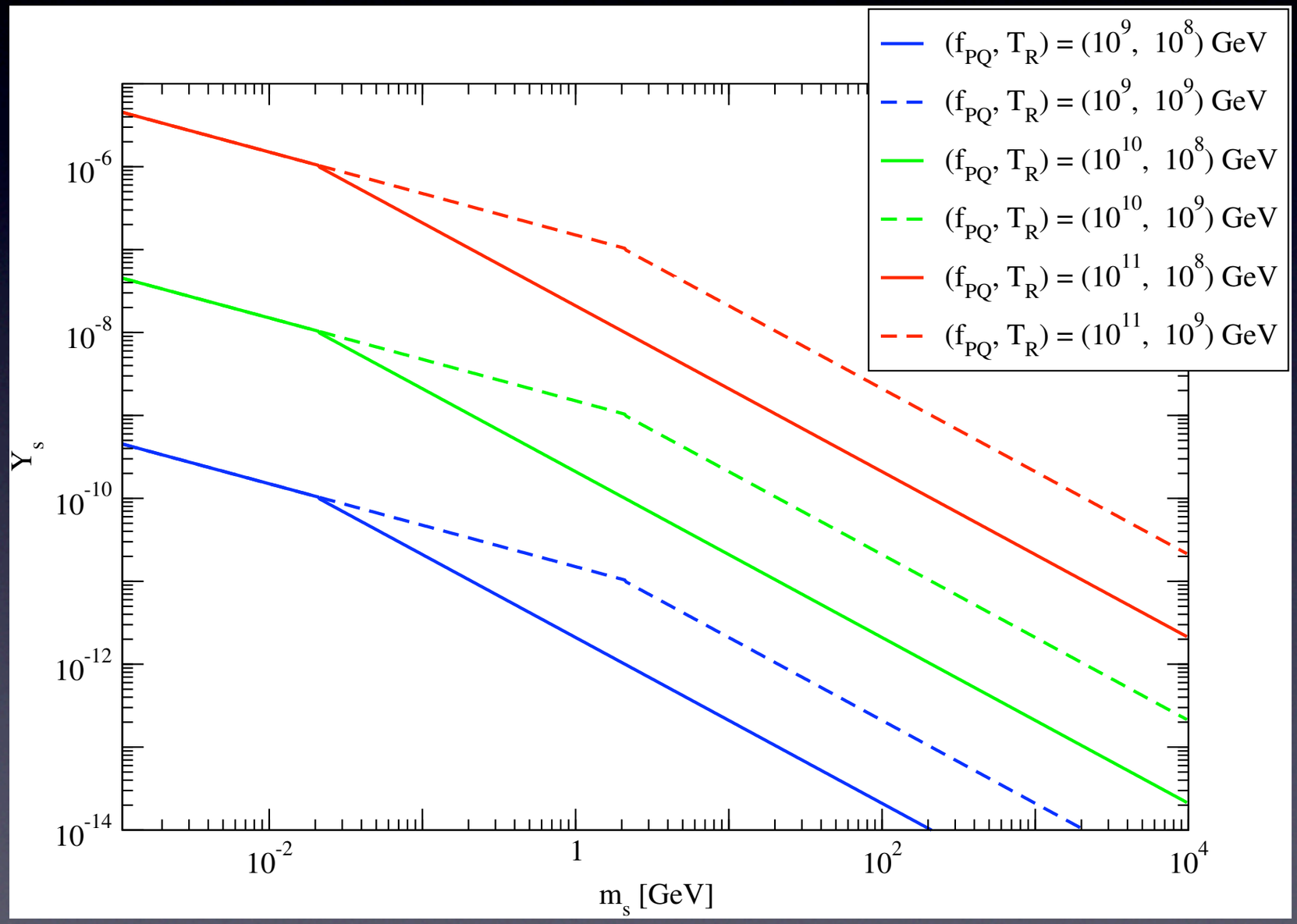

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$$\Gamma_s \propto \frac{m_s^3}{f_{\rm PQ}^2}$$

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$$\Gamma_{s\to aa} = \frac{x^2 m_s^3}{64\pi f_{\mathrm{PQ}}^2}$$

- Decay into gluons

$$\Gamma_{s\to gg} = \frac{\alpha_s^2 m_s^3}{32\pi^3 f_{\mathrm{PQ}}^2}$$

What does it do to the Universe?

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Axions from Saxion Decay

[Chun,Lukas,'84; Kawasaki,Nakayama,Senami,'08; P.G.,Steffen, in prep.]

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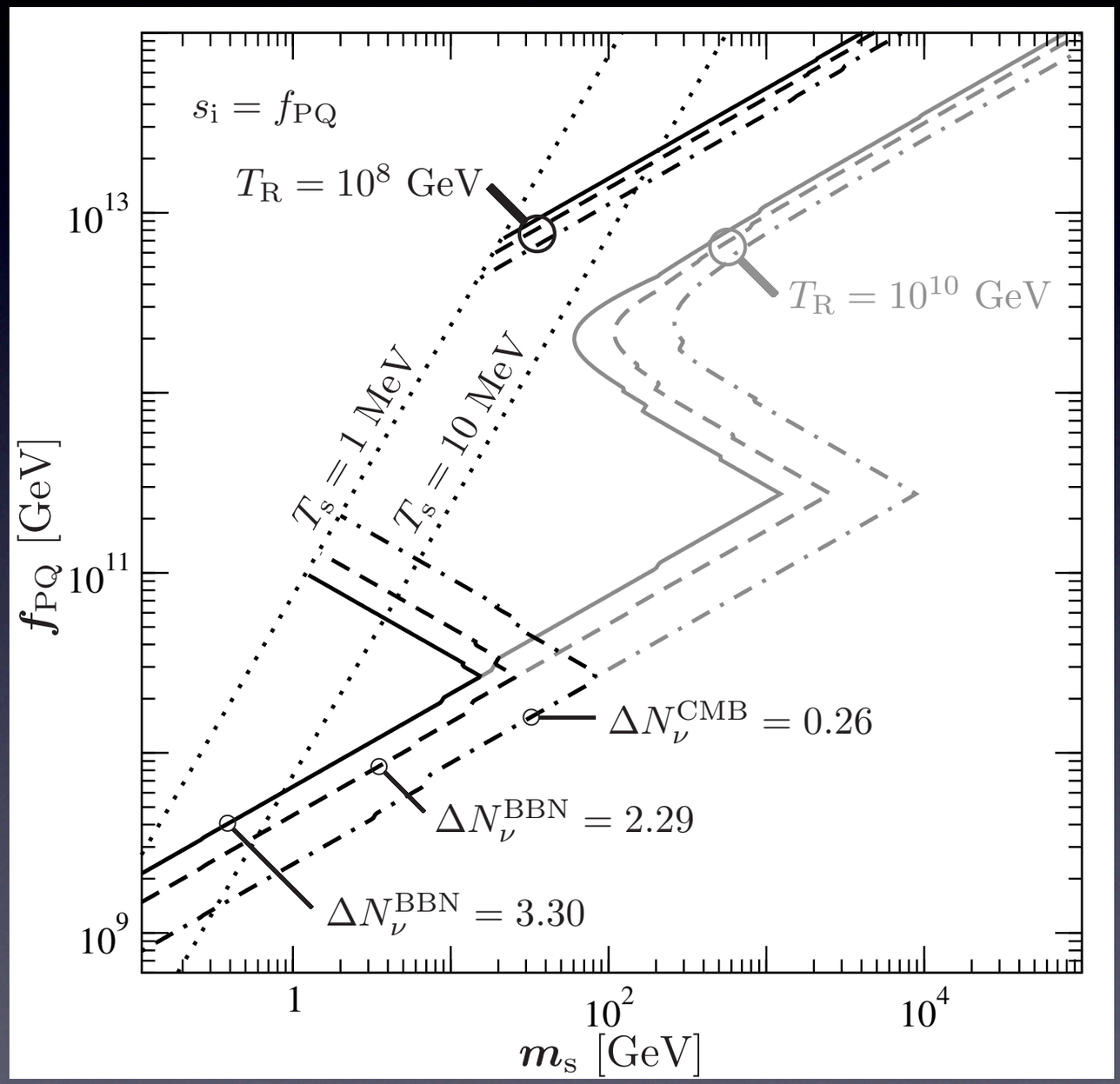
- Focus on decay before BBN

- Axions contribute to relativistic energy density → ΔN_ν

$$\rho_{\rm rad}(T) = \left[1 + \frac{7}{8} N_\nu \left(\frac{T_\nu}{T_\gamma}\right)^4\right] \rho_\gamma(T_\gamma),$$

Extra Radiation



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Saxion Cosmology

What do we learn?

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Conclusions

- PQ mechanism introduces the axion
- SUSY provides flat direction for the saxion
- Cosmology of saxion depends on decay channels
- Decay may affect BBN, blackbody of CMB, X(γ)-ray, reionization, entropy, ΔN_ν
- Extra radiation might be hint towards saxions

No Axions from Saxion Decay

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  - For $m_s < 4.5$ MeV: no constraint from BBN

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- Additional photons may distort blackbody spectrum of CMB
- Contribution to X(γ)-ray spectrum (high energy)
- Source of reionization (low energy)

No Axions from Saxion Decay

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- But: Saxion can be quite heavy, so can dominate

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