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Late cosmology constraints on thermal relic axions and axion-like particles

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*In collaboration with Steen Hannestad, Georg Raffelt & **Javier Redondo***

Based on JCAP 1102 (2011) 003 & ArXiv:1107.xxxx

Outline

- Again axions and ALPs
- Very brief review of astrophysical and cosmological bounds
- Have cosmologically unstable axions and ALPs left some traces in cosmological observables?
- New bounds from N_{eff} and BBN

Again axions...

I am sure you already know what is an axion, just I want to stress that we considered mainly the coupling to photons.

$$\mathcal{L}_a^{\rm eff} = \frac{1}{2}\partial_\mu a \partial^\mu a - \frac{1}{2} m_a^2 a^2 + a\frac{g_{a\gamma}}{4} F_{\mu\nu}\tilde{F}^{\mu\nu} + a\frac{C_\psi m_\psi}{f_a}\bar{\psi}\gamma_5\psi$$

$$m_a = \frac{\sqrt{m_u m_d}}{m_u + m_d}\frac{f_\pi m_\pi}{f_a} \simeq 6 \text{ eV}\left(\frac{10^6 \text{ GeV}}{f_a}\right)$$

$$g_{a\gamma} = \frac{\alpha}{2\pi f_a}\left(\frac{E}{N} - 1.9\right) \equiv \frac{\alpha}{2\pi f_a} 1.9\,\delta$$

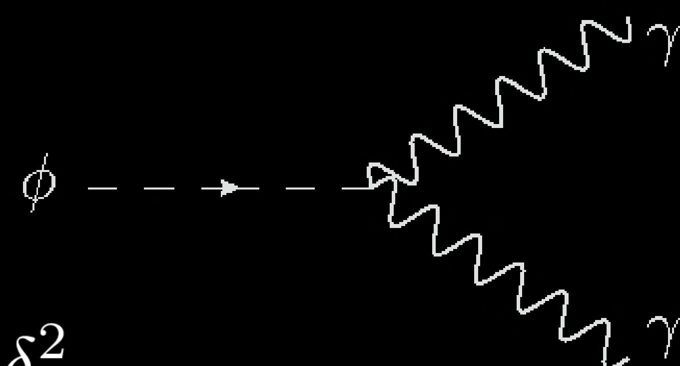
Again axions...

The axion is excluded by precision cosmological data for $m_a > 0.7$ eV ($f_a < 8.6\text{x}10^6$ GeV)
[Hannestad, Mirizzi, Raffelt & Wong (2010)]

However, this is valid only for cosmologically stable axions!!!

$$\Gamma_{a\gamma\gamma} = \tau^{-1} = \frac{m_a^3 g_{a\gamma}^2}{64\pi}$$

$$\simeq 1.1 \times 10^{-24}\ \mathrm{s}^{-1} \left(\frac{m_a}{\mathrm{eV}}\right)^5 \delta^2$$



...and their relatives

The axion can be generalized: axion-like particles (ALPs) are pseudo Goldostone Bosons of eventual spontaneously broken global symmetries that could be present beyond the SM.

$$\mathcal{L}_{\phi}^{\text{eff}} = \frac{1}{2}\partial_{\mu}\phi\partial^{\mu}\phi - \frac{1}{2}m^2\phi^2 + \frac{\phi}{4M}F_{\mu\nu}\tilde{F}^{\mu\nu} + ...$$

Roughly speaking we leave *m* and *g*=1/*M* as independent variables

...and their relatives

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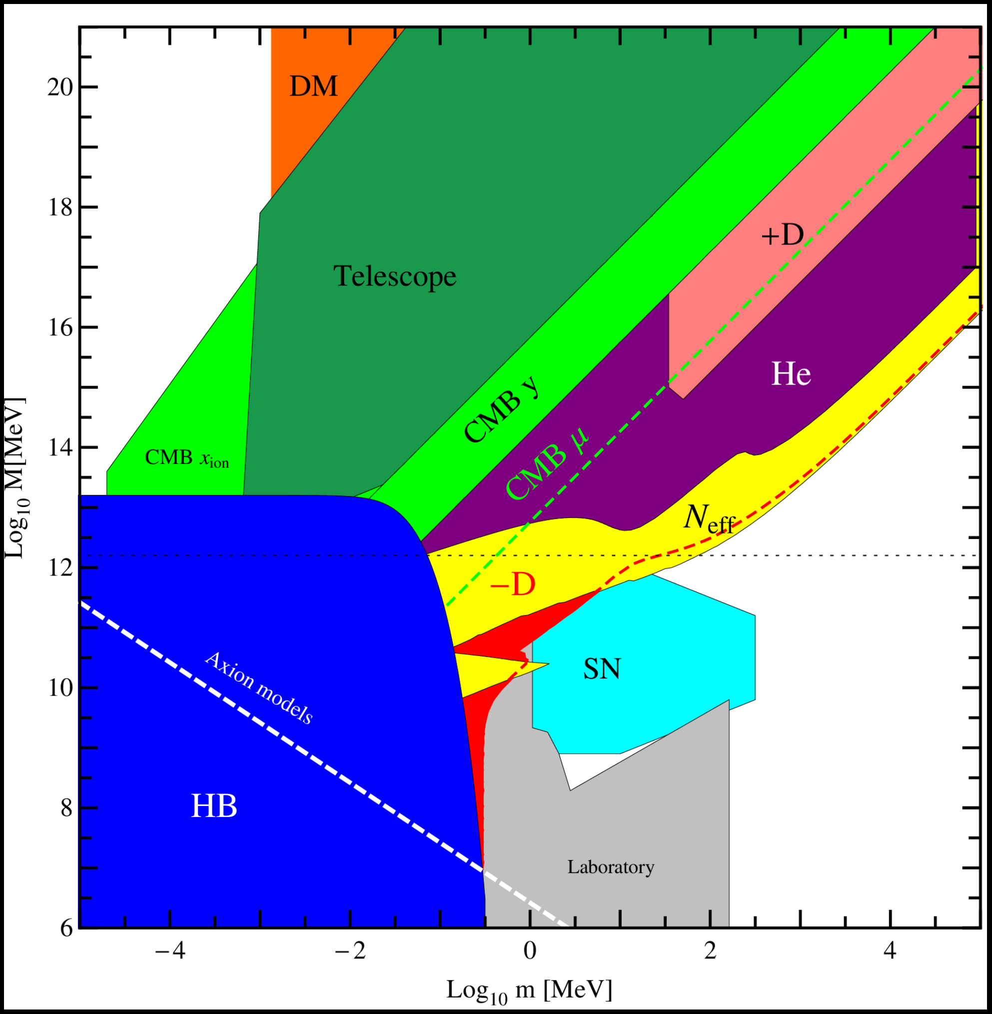
Astrophysical & Cosmological bounds



[D.C & Redondo (2011)]

Late cosmology bounds

The decay of axions and ALPs would produce some entropy which would affect T_ν and η_B that we measure through CMB

Two limit situation:

- LTE

$$\frac{g_{*S}(T_f)}{g_{*S}(T_i)} = \frac{2+7/2}{2+7/2+1} = \frac{11}{13}$$

- A(LP) domination

$$\frac{S_f}{S_i} = 1.83 \, \langle g_{*S}^{1/3} \rangle^{3/4} \frac{m Y_\phi(T_\mathrm{d})}{\sqrt{m_\mathrm{Pl} \Gamma_{\phi\to\gamma\gamma}}}$$

[Kolb & Turner (1990)]

Bound from $N_{\rm eff} = \frac{\rho_\nu}{\frac{7}{8}\left(\frac{4}{11}\right)^{4/3}\rho_\gamma}$

$$N_{\rm eff} > \begin{cases} 2.70 & \text{at } 68\% \text{ C.L.} \\ 2.39 & \text{at } 95\% \text{ C.L.} \\ 2.11 & \text{at } 99\% \text{ C.L.} \end{cases}$$

[D.C., Hannestad, Raffelt & Redondo (2010)]

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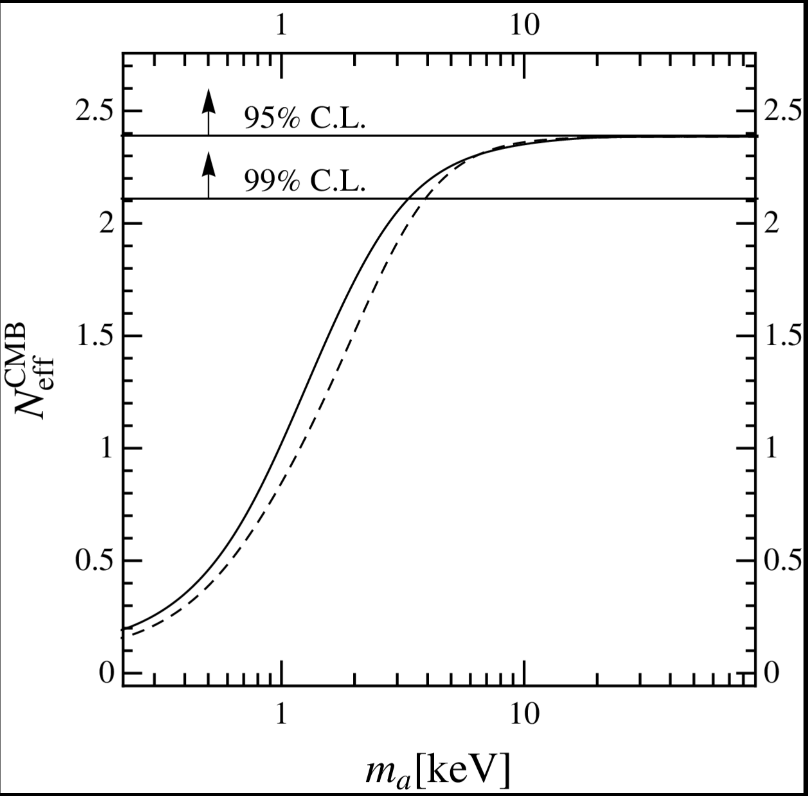
The Solid line is for the hadronic axion



The dashed one includes coupling with electrons (C_e=1/6)

[D.C., Hannestad, Raffelt & Redondo (2010)]

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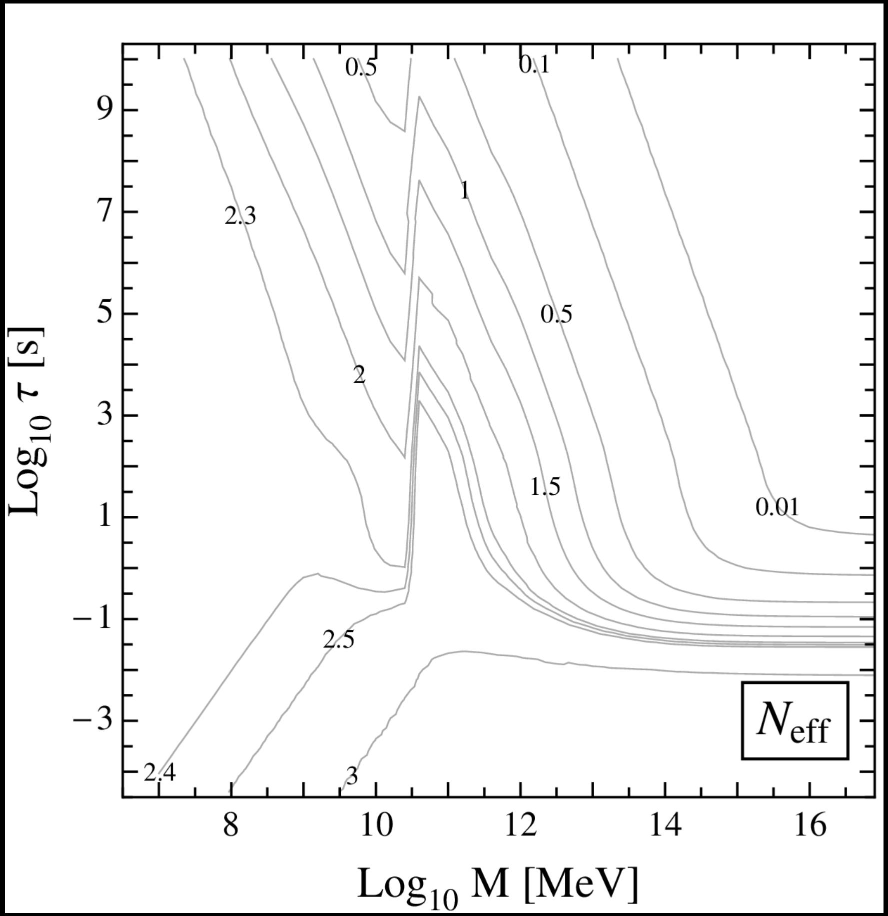
Increasing lifetime



Increasing abundance

[D.C. & Redondo (2011)]

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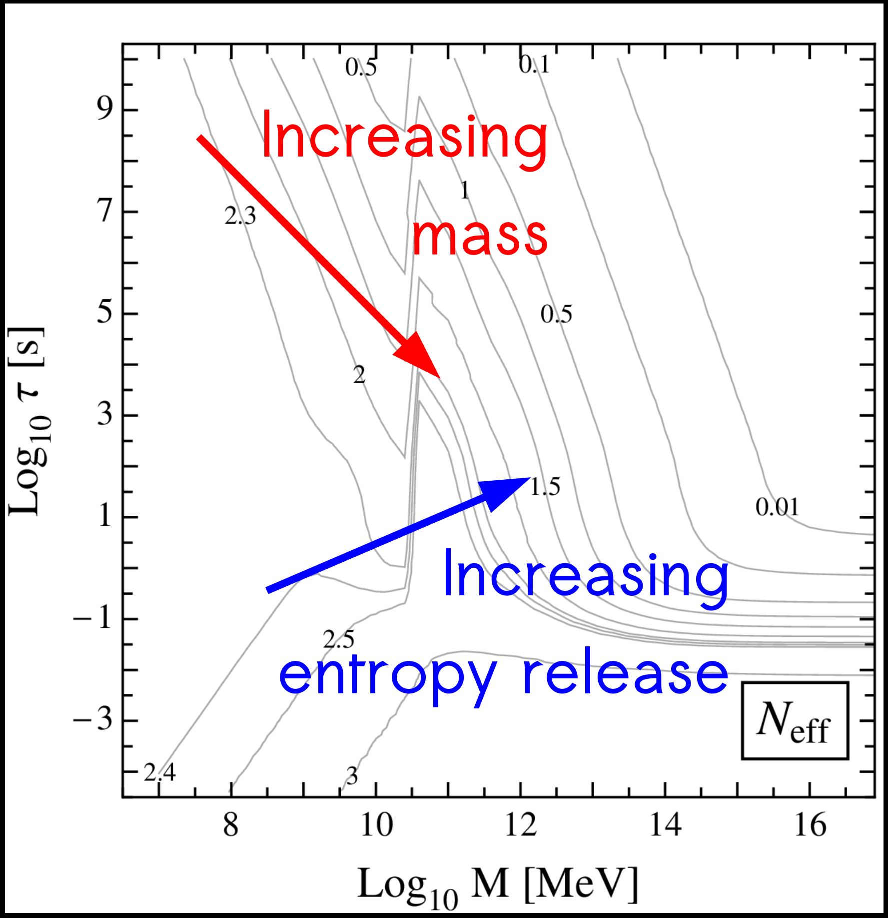

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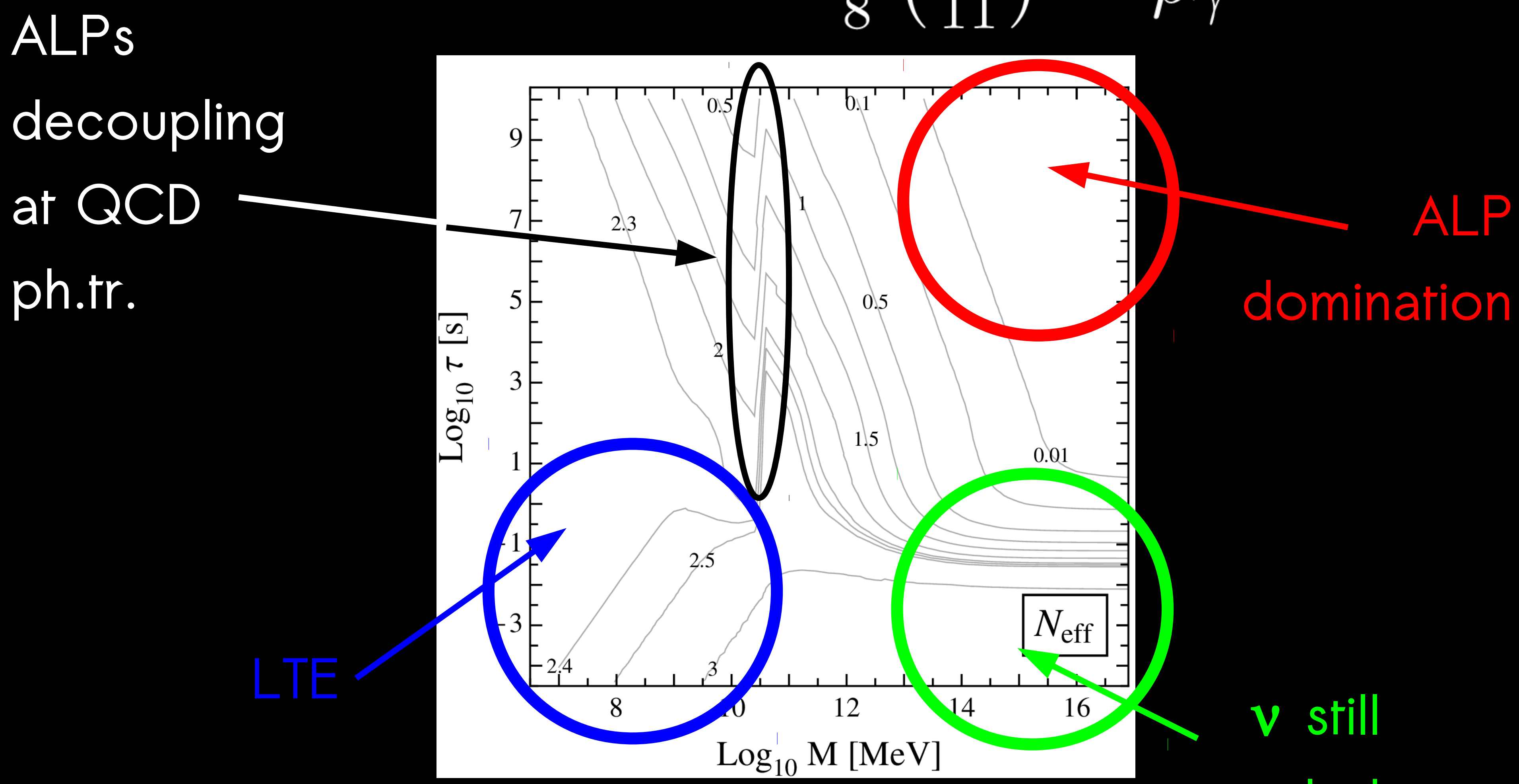


[D.C. & Redondo (2011)]

Bound from BBN

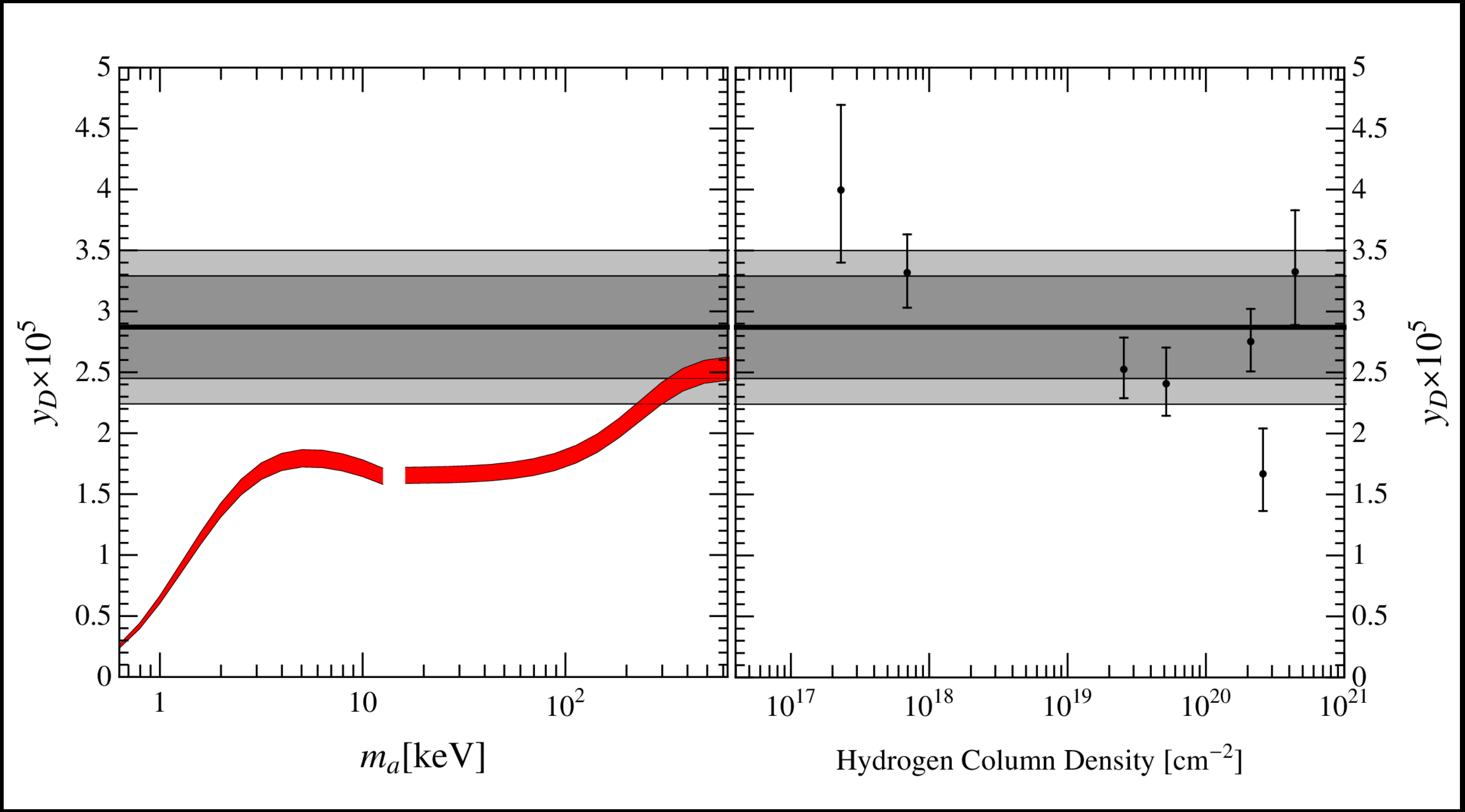
Axions and ALPs can have two effects on BBN:

- Before the decay they increase the energy budget of the universe respect to the standard cosmology → faster expansion (earlier freezing-out of the reactions)

- Decaying they dilute the baryons → estimates of η at CMB and BBN agree, is there room for axion decay in between or does BBN disfavours high η?

Bound from BBN 1: D

$(D/H)_p > 2.1\text{x}10^{-5}$ (95% C.L.)



[D.C., Hannestad, Raffelt & Redondo (2010)]

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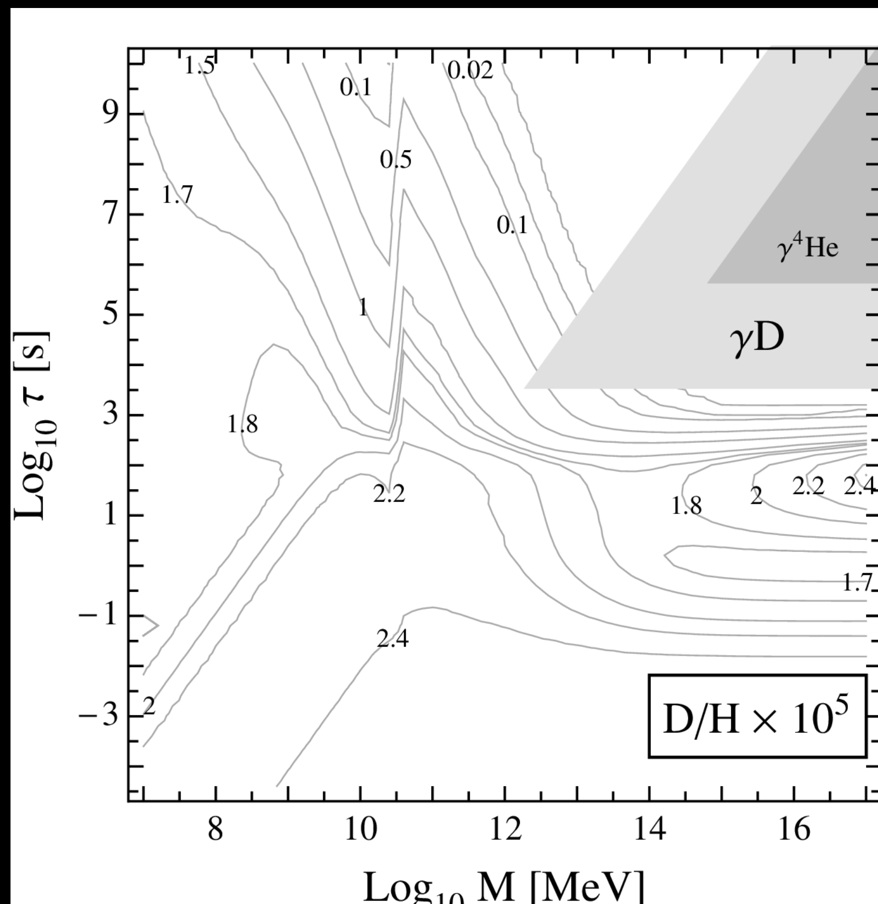

[D.C. & Redondo (2011)]

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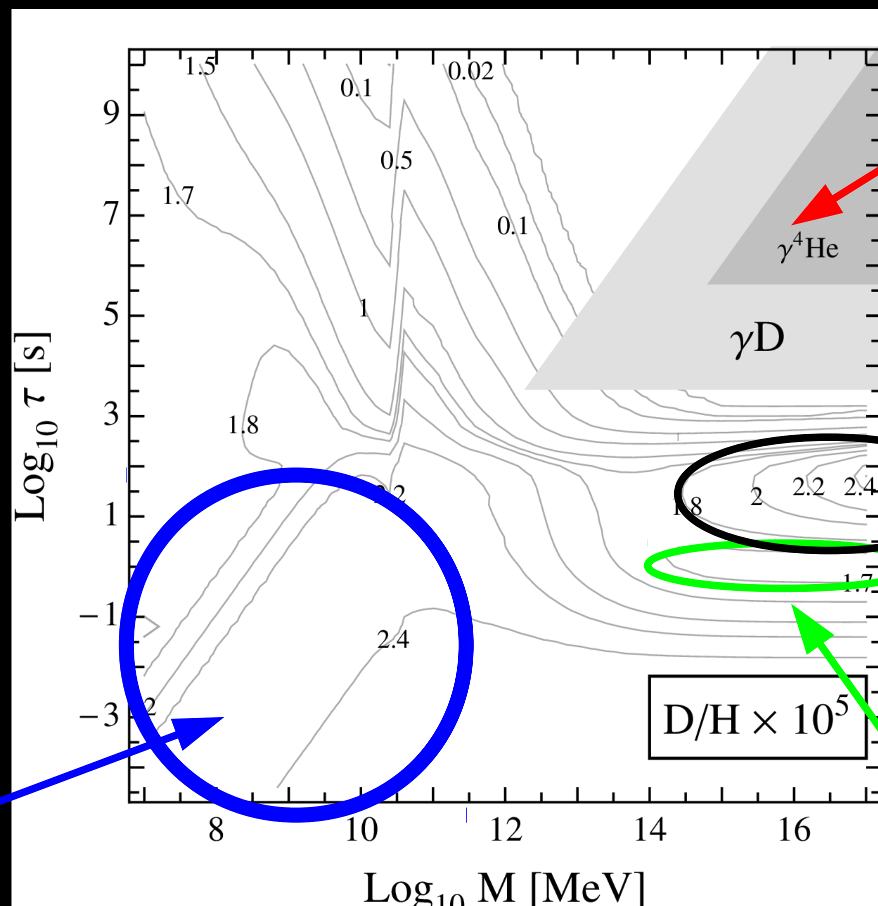
ALP late domination + D-He photo-dissociation

ALP domination during *n*/*p* freeze-out: more *n* around



LTE

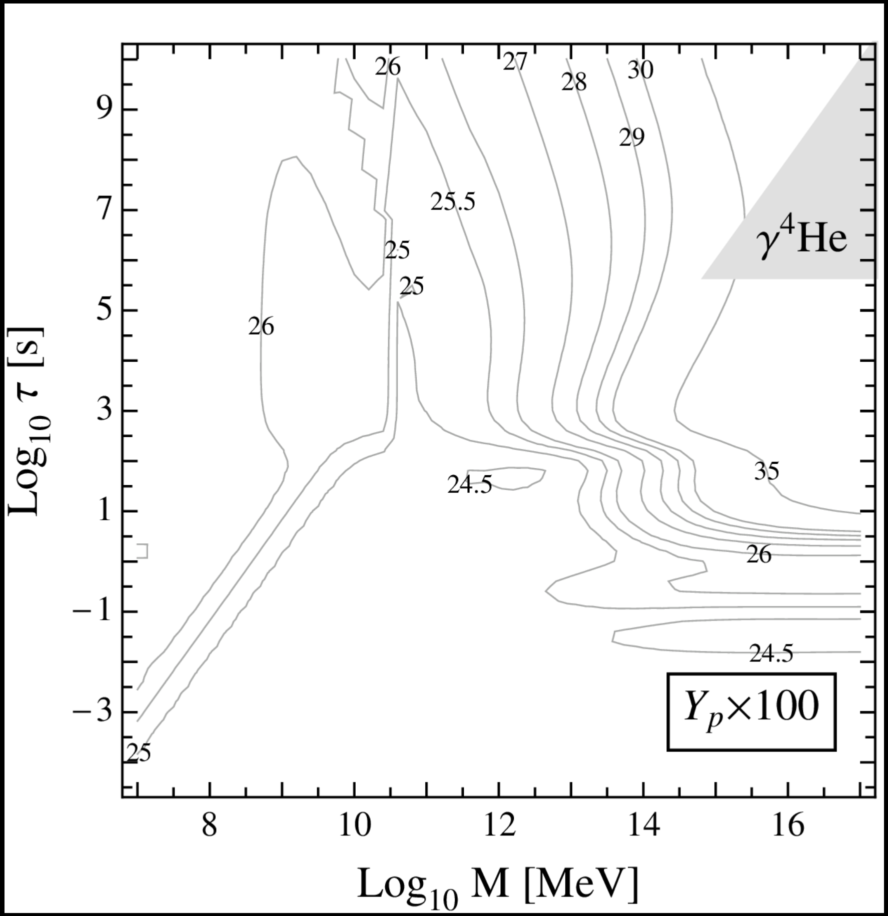
ALPs decay before BBN: low N_{eff}

[D.C. & Redondo (2011)]

Bound from BBN 2: He

Higher ρ fixes higher n/p

Higher η makes D bottleneck opening earlier, thus less time for n to decay



$Y_p < 0.2631$ (95% C.L.)

[D.C. & Redondo (2011)]

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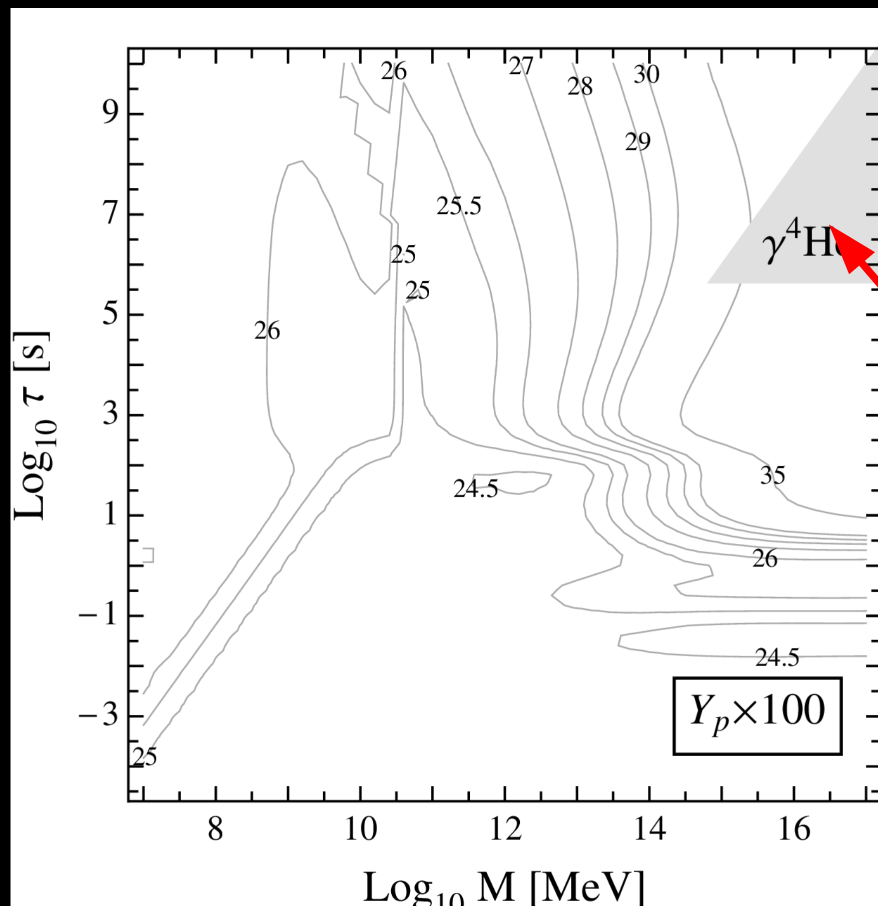

$Y_p < 0.2631$
(95% C.L.)

He photo-dissociation

[D.C. & Redondo (2011)]

Summary

- Axions and axion-like particles can be cosmologically unstable
- Their decay would leave some traces in the history of the universe
- New cosmological bounds from N_{eff} and *BBN*