HEPHY
Institute of High Energy Physics

A light particle solution to the cosmic ^{7}Li problem

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The cosmological ^{7}Li problem

Given the WMAP/Planck measurement of $\eta = (6.10 \pm 0.04)\times10^{-10}$, SBBN explains (very!) successfully the abundances of light elements in the universe...

...but seems to fail when it comes to the ^{7}Li abundance :

$$^{7}Li/H|_{obs} = (1.6 \pm 0.3)\times10^{-10}$$

Value inferred from Pop II stars (low metallicity).

$$^{7}Li/H|_{SBBN} = (4.68 \pm 0.67)\times10^{-10}$$

Predicted abundance too large by factor 2 – 5.

Cosmological Lithium Problem

Solutions include :

- Pop II stars not a good tracer of primordial ^{7}Li
  Harder than it sounds if treated seriously
- Inject photons
  Works, cf e.g. arXiv:1006.4172, arXiv:1502.01250
- Inject catalysts
  Works, cf e.g. hep-ph/0703096, arXiv:0711.4866, arXiv:1403.4156
- Inject extra neutrons
  Basically excluded, overproduces D

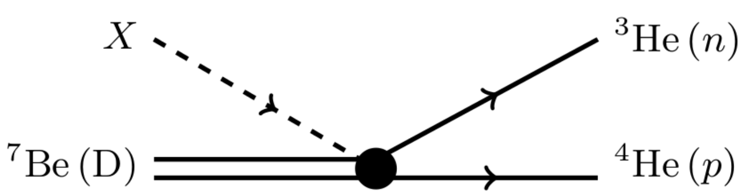
A new solution to the ^{7}Li problem

One of the main problems of injecting extra neutrons : D overproduction.

But what if we instead “borrow” some of the already existing ones ?

The main idea :

- ^{7}Li is mainly formed through $^3He + ^4He \rightarrow ^7Be + \gamma$, followed by $^7Be + n \rightarrow p + ^7Li$.
- The bulk of this production takes place around T ~ [60, 40] keV and the reaction is *slow*.
- During the same period, ^{3}He, ^{4}He and D formation is *fast*.
- Inject some particles that break up ^{7}Be *as well as*, potentially, D.



- ^{7}Be destroyed by X particles *and* by borrowed neutrons from D dissociation.
- D formation remains faster than τ_n down to 10 keV. If X is injected early enough, then...

...even if we destroy some D, it may reform, unlike ^{7}Be!

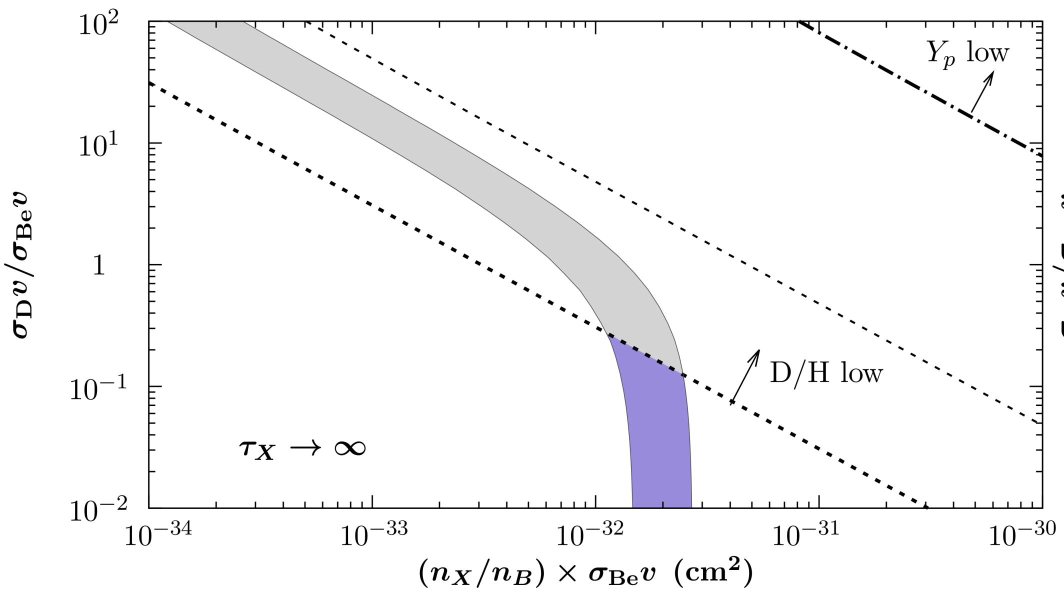
Ingredients and D/^{4}He constraints

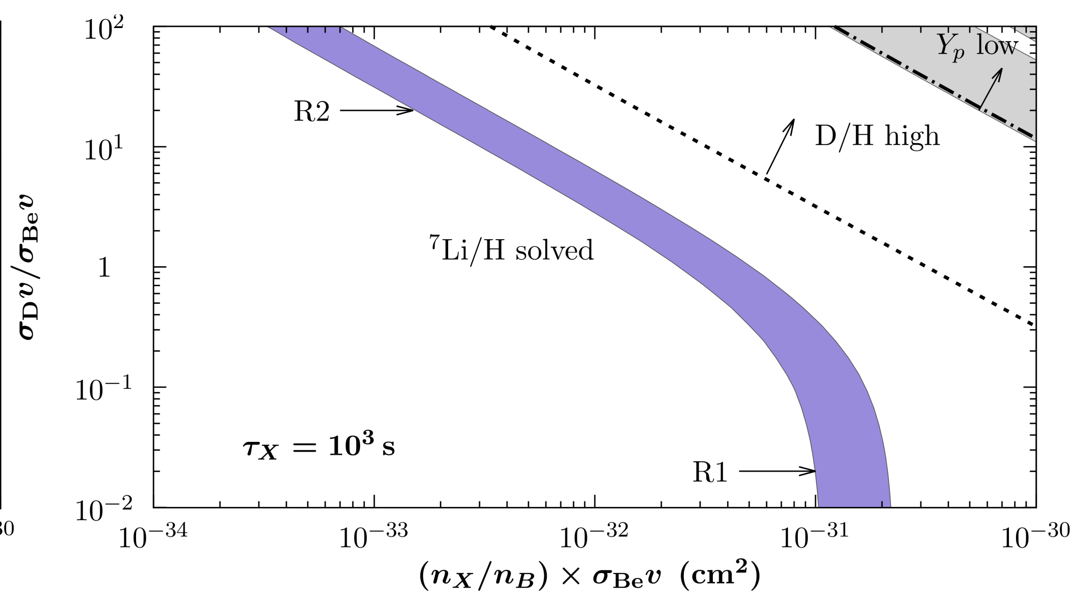
Some requirements must be met for the previous to work :

- The X particles must interact quite weakly, in order to avoid inverse reactions.
- Then, we need large-ish densities. A good condition is

$$n_b \lesssim n_X < \frac{T}{E_X} \times n_\gamma$$

- To avoid ^{4}He destruction, we must further have m_X (or E_X) < 20 MeV.
- Take as free parameters : $\{m_X, \tau_X, n_X/n_b, \sigma_{\rm Be}v, \sigma_{\rm D}v\}$

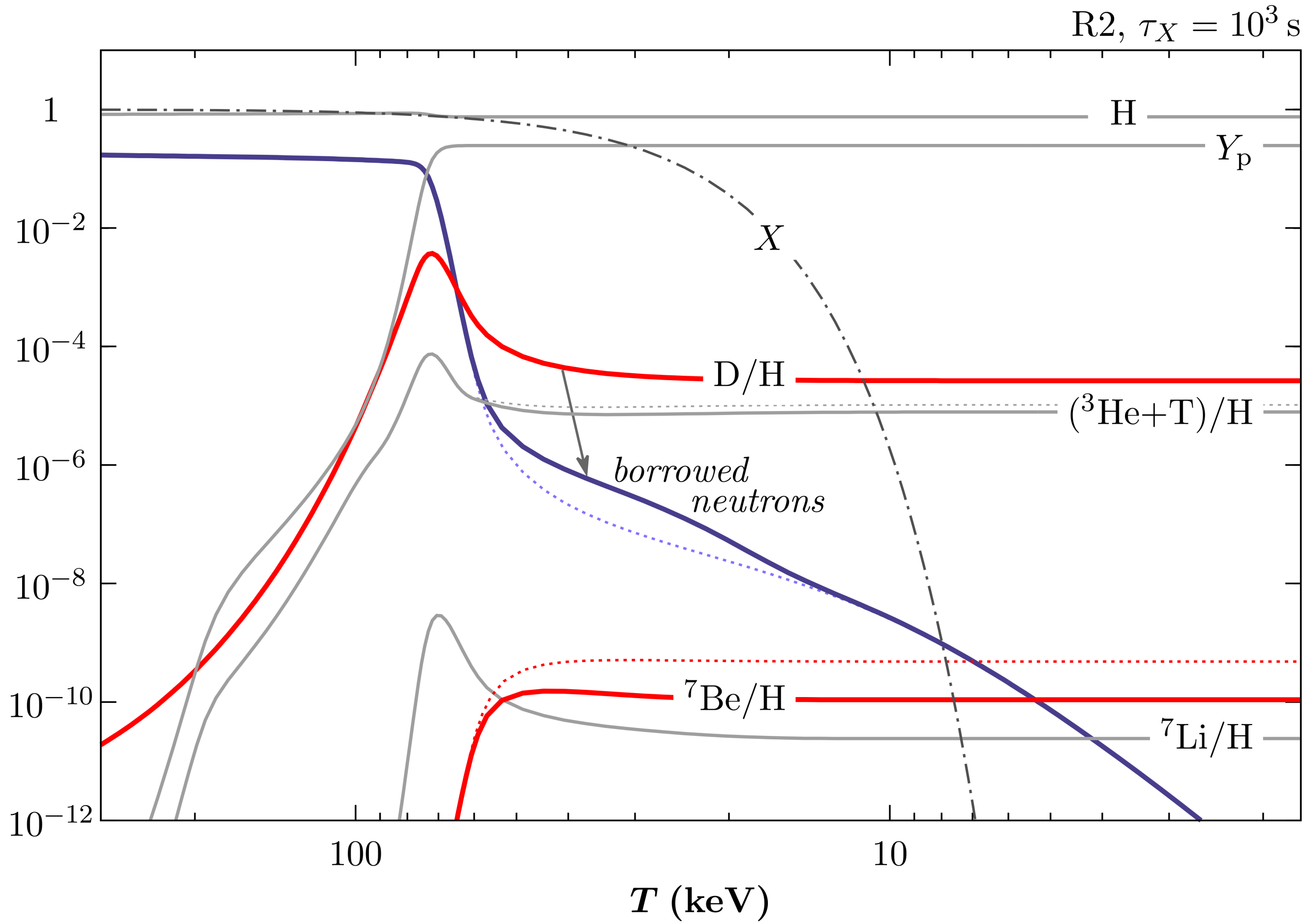




NB: Of course, the two cross sections aren't really independent parameters.

Elemental abundance evolution

An illustration of the mechanism in action :



- Direct ^{7}Be destruction.
- Indirect ^{7}Be destruction from D dissociation – induced n's.

^{7}Li can be reduced to its observed abundance.

NB: example actually dominated by D + X → p + n

Model realizations

As a proof of principle, we consider two scenarios :

Scenario A : Heavy ALP

- X is non-relativistic, m_X ~ [1.6, 20] MeV.
- Assume a toy Lagrangian as

$$\mathcal{L}_{aq} = \frac{\partial_\mu a}{f_d} \bar{d} \gamma^\mu \gamma^5 d$$

- X breaks up D and ^{7}Be and decays into SM/BSM radiation that redshifts away.

Scenario B : Light ALP

- A quasi-massless X arises from the decay of some (frozen-in?) progenitor particle X_p, with m_{X_p} ~ [3.2, 40] MeV

$$\mathcal{L}_{XX_p} = A X_p \left(H^\dagger H\right) + B X_p a^2 + \mathcal{L}_{aq}$$

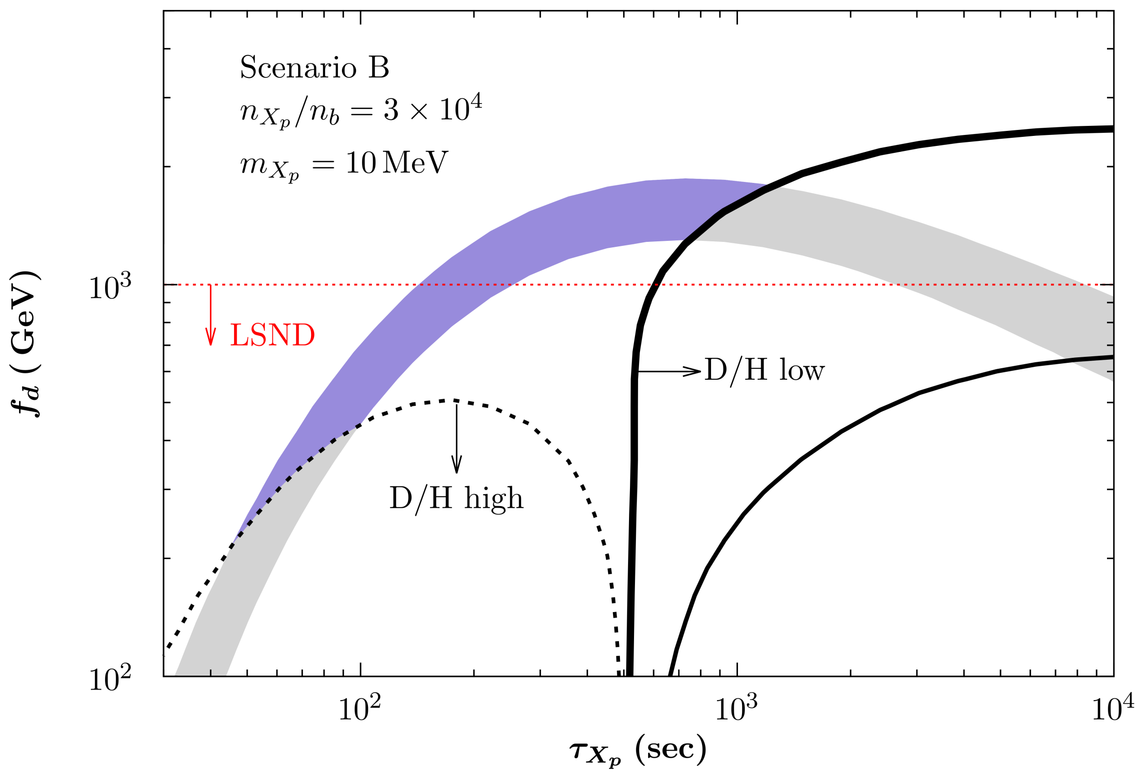
- X breaks up D and ^{7}Be as previously, and eventually redshifts away itself.
- Note that to avoid hot DM constraints, X must be very light : $m_X < 1$ eV.

Overall verdict :

- Both scenarios work, scenario B is easier to realize.
- Moreover : scenario B can be tested in beam dumps e.g. through $p + a \to \gamma + p$

Summary and conclusions

- We proposed a new solution to the cosmological ^{7}Li problem based on new, E/M-neutral light particles that interact non-negligibly with nucleons.



- We pointed out that even if we momentarily decrease the amount of D in the universe, if this is done early enough (but not too early) it can reform to its observed abundance.

- Moreover, the neutrons released from D dissociation can *themselves* play a role in the reduction of ^{7}Li.

Idea of *borrowed* neutrons.

- Especially if very light particles are involved (scenario B), non-negligible parts of the parameter space are testable @ intensity frontier experiments.

- The ^{7}Li problem has been around for quite a while but its particle physics solutions are far from being exhausted! Model building under construction...