Title: BBN and strongly interacting relics

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Abstract:

Outline

- Introduction
- Strongly Interacting Relics
- How Squarks Hadronise
- How Mesinos Can Affect BBN
- Upper Bounds On Y_m
- Possible Impact On Lithium
- Conclusion

Introduction

- We look at new thermal channels that are created when one introduces strongly interacting relics.
- It has already been shown that charged relics are able to open up new channels at temperatures of T=5-30keV
- What about strongly interacting particles?

arXiv:hep-ph/0605215v4

Examples Of Strongly Interacting Relics

- Long lived gluinos (To get the lowest energy hadrons, lattice QCD is needed.)
- Long lived exotic quarks
- Long lived scalar quarks
- …

- We will focus on long lived scalar quarks, with gauge quantum numbers of up and down quarks.
- One way of creating a long lifetime can be achieved in models where the squark is the NLSP to the gravitino.

How do squarks hadronise?

Naively they would bind with quarks and anti-quarks in a way that forms a light stable meson like object.

- Anti-Stop $\overline{\tilde{t}}\, d, \overline{\tilde{t}}\, u$
- Stop

$$\tilde{t}\,\bar{d}, \tilde{t}\,\bar{u} + p, n \rightarrow \tilde{t}\, du$$

- Anti-Sbottom $\overline{\tilde{b}}\, d, \overline{\tilde{b}}\, u$
- Sbottom

$$\tilde{b}\,\bar{d}, \tilde{b}\,\bar{u} + p, n \rightarrow \tilde{b}\, du$$

If the stop hadrons behave like charm or down hadrons then they will interact with the ambient protons and neutrons to form an isospin singles that won't contribute to the neutron fraction X_n.

See the discussion in Diaz-Cruz et. al. for more details.

arXiv:hep-ph/0701229v1

The Expected Mesino Mass Differences

- If the squark of interest is the stop then we expect the mesinos to have similar mass differences as the D mesons, and form an isospin doublet.

$$M^{-} = \overline{\tilde{t}}\, d$$

$$M^{\circ} = \overline{\tilde{t}}\, u$$

$$m_{-} - m_{o} \approx 4.5 MeV$$

- If the squark of interest is the sbottom then we expect the mesinos to have similar mass differences as the B mesons.

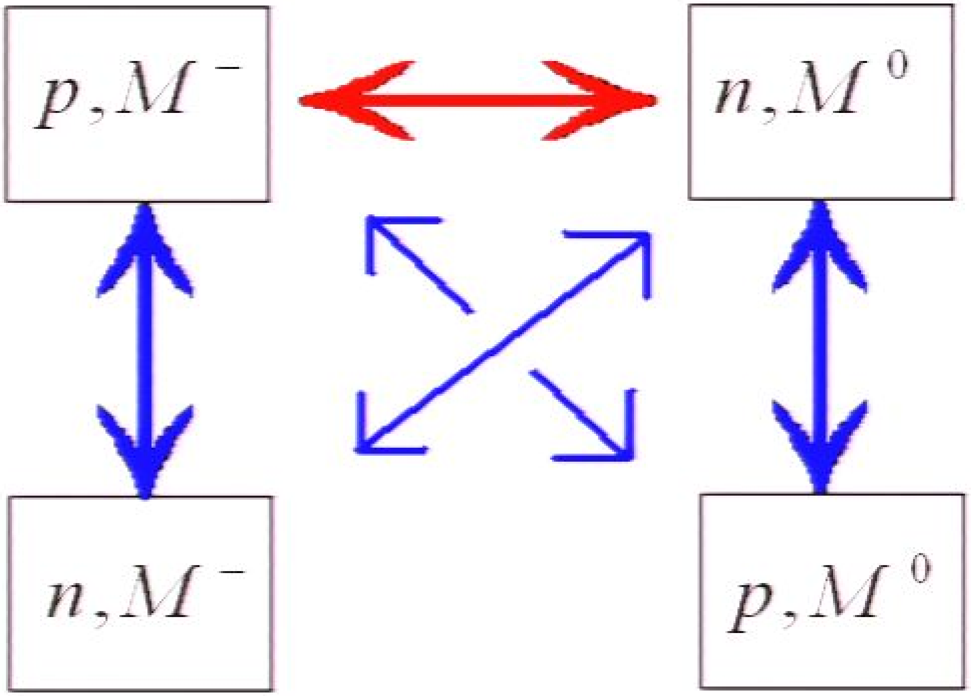
$$M^{+} = \overline{\tilde{b}}\, u$$

$$M^{o} = \overline{\tilde{b}}\, d$$

$$m_{o} - m_{+} \approx 0.33 \pm 0.28 MeV$$

Note: It is not known if the M^0 is stable against beta decay.

How Could Mesinos affect He Abundance



p, M^-

n, M^0

n, M^-

p, M^0

Blue is for Weak rate **Red is for Strong rate**

$\left\langle \sigma_{strong} v \right\rangle n_M$ Can be comparable to the expansion rate.

Mesino Feynman Rules

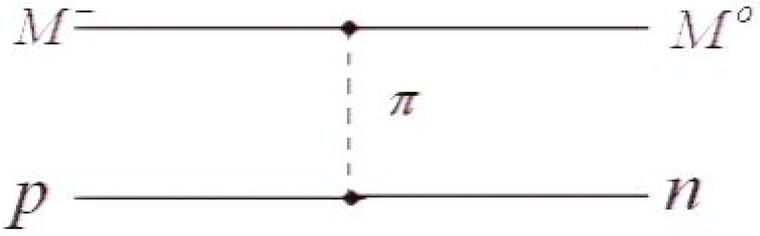
- Because the scalar quarks have no spin, the mesinos are fermions and we expect them to behave similarly to nucleons.
- Their beta decay should progress in the same manner as a neutron decay except with an amplitude given by:

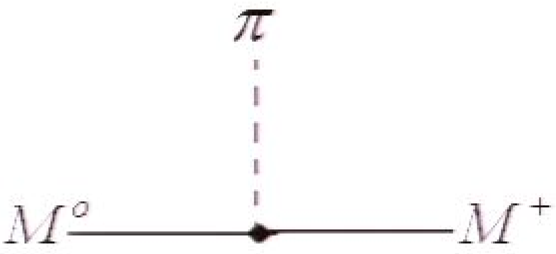
$$G_F^2 \frac{1+3\tilde{g}_A^2}{2\pi^3}$$

Instead of

$$G_F^2 \frac{1+3g_A^2}{2\pi^3}$$

As with low momentum nucleon-nucleon interactions we can get a low momentum approximation of the nucleon-mesino cross section using one pion exchange.





$$= g_{MM\pi} = \frac{\widetilde{g}_A}{f_\pi} m_M$$

Where: $\widetilde{g}_A \approx 1,\ f_\pi = 92\ MeV$

Note: This is just a first order approximation to give us an idea about the behavior of the system.

Relic Abundance

- If we assume no asymmetry between the squark and anti-squark, it is possible to calculate the relic abundance of these particles through various decay channels.

$$\Omega_{\tilde{q}} h^2 = 1.07 \times 10^9 \frac{m_{\tilde{q}}}{T_{fr}} \frac{1}{GeV \sqrt{g_*} m_{Pl} \sigma_0}$$

$$\sigma_0 = \left\langle \sigma_{\bar{\tilde{q}}\tilde{q}} v \right\rangle$$

As an approximation we calculated the abundance of the relics if their dominant decay channel is to two gluons and found the fraction to be:

$$Y_{\bar{\tilde{q}}} = Y_M \equiv \frac{n_{\tilde{q}}}{n_B} \approx \frac{m_{\tilde{q}}}{TeV} \cdot 4.6 \times 10^{-4}$$

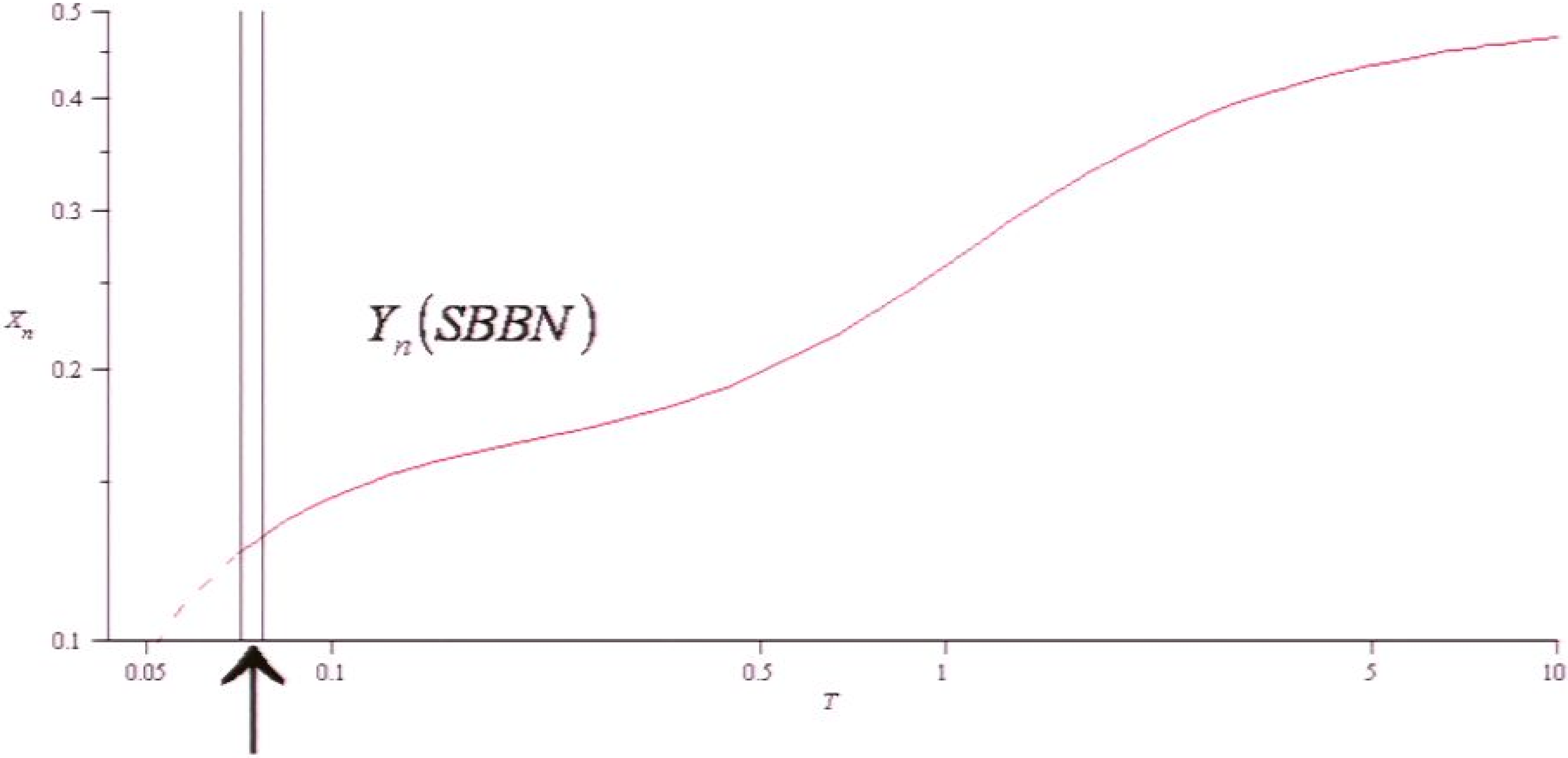
Kang et. al. estimate the squark relic abundance taking into consideration the depletion of squarks below the QCD phase transition due to the formation of squark anti-squark hadrons.

Depending on the cross section, the mesino fraction could be as low as:

$$Y_M = 10^{-7}$$

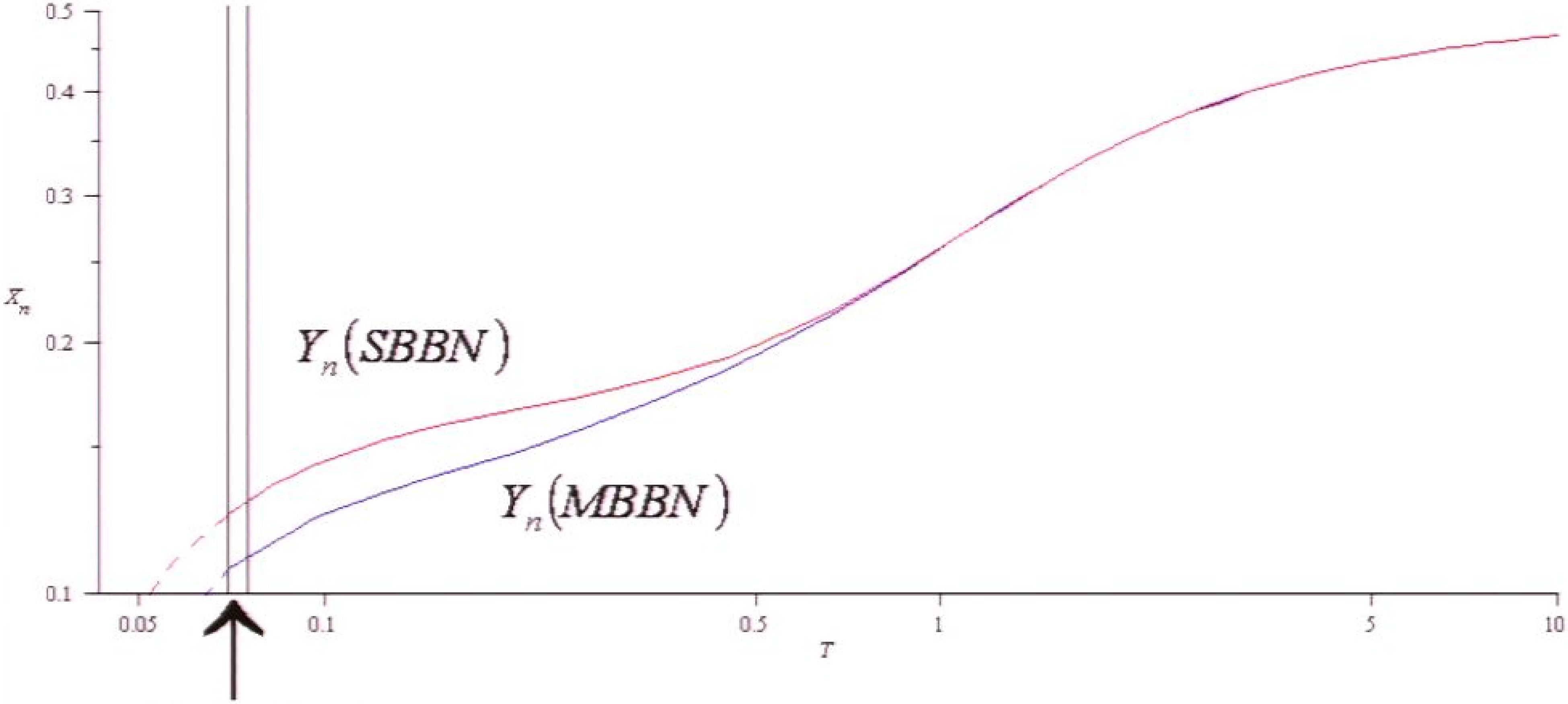
arXiv:hep-ph/0611322v1

He production without catalysis.



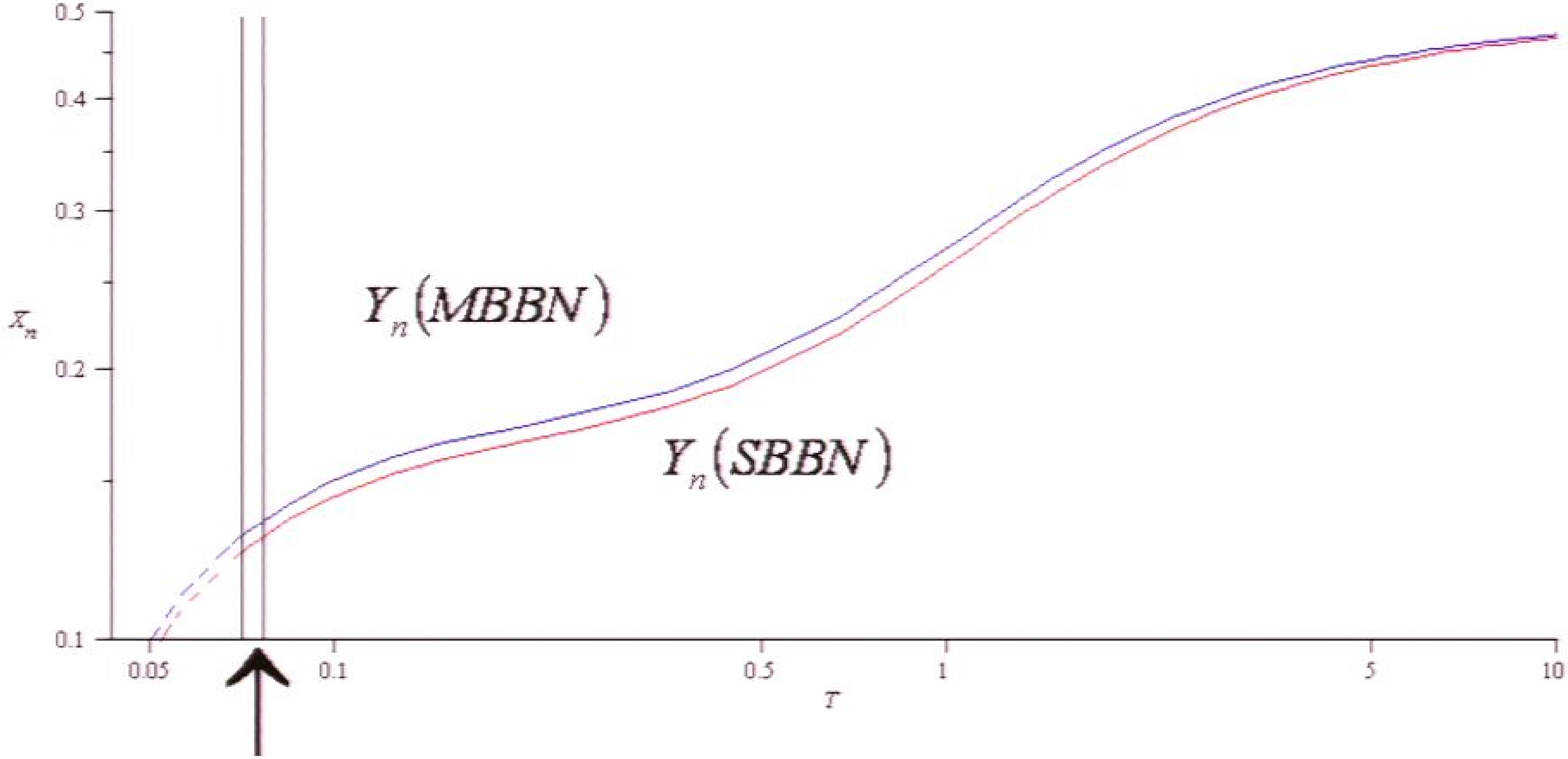
He synthesis

The He curve is depleted at freeze out when: $m_e < m_- - m_o < 1.294 MeV$



He synthesis

In the large mass difference behavior is slightly different.



He synthesis

Cartoon of the low mass, sbottom case.

$$\begin{tikzcd}
 & M^{+}_{\tilde{b}} & M^{0}_{\tilde{b}} \arrow[l, "Weak"'] \\
p \arrow[r, "Weak"'] & n \arrow[r, "Strong"'] & p
\end{tikzcd}$$

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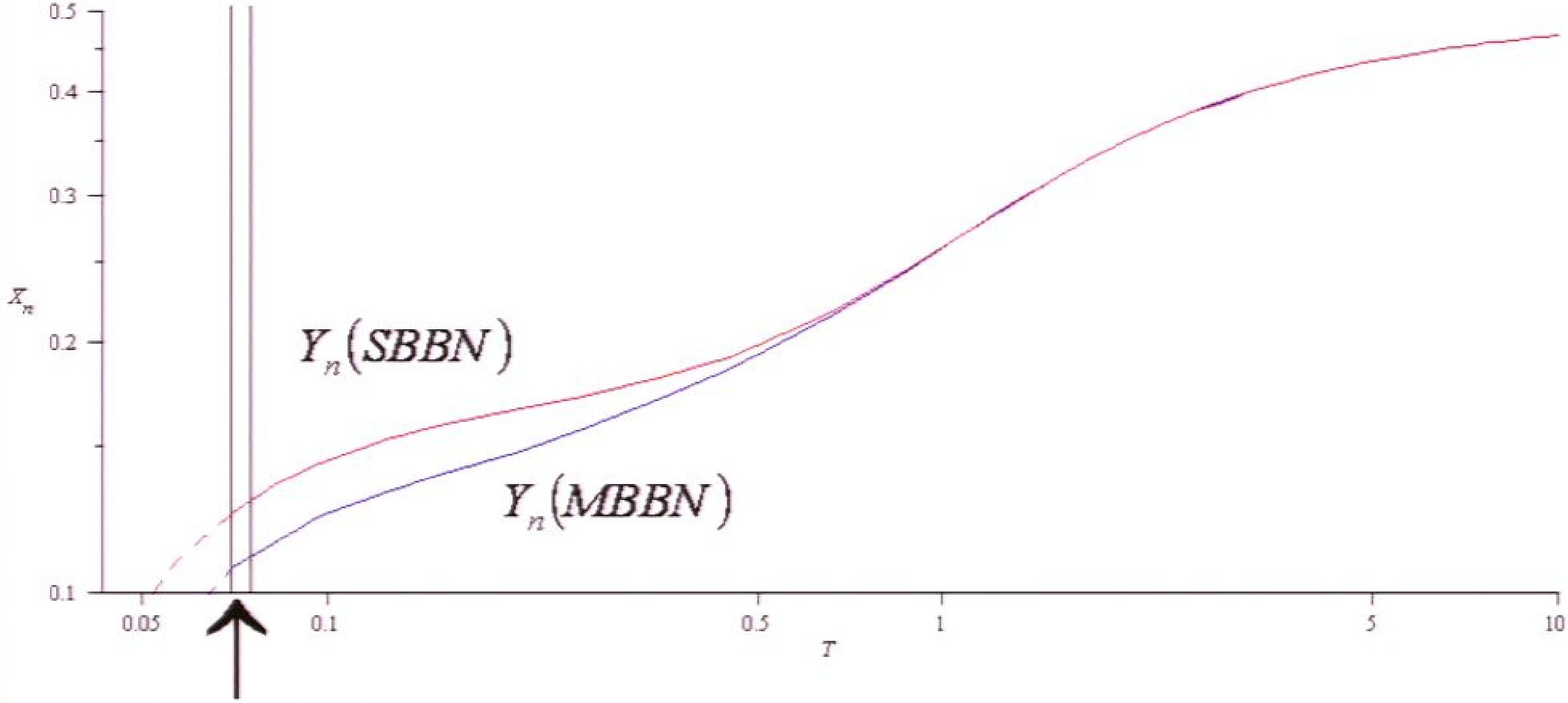

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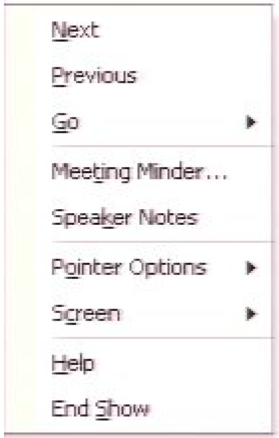

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It is possible to calculate an upper bound on the concentration of mesinos by seeing what concentration would cause an observable shift in the Helium mass fraction.

The current experimental measurement of the mass fraction of Helium four (including systematics) is in the range: [0.230,0.267].

Assuming all the neutrons available at He synthesis are all converted into ^{4}He this means the fraction X_n must be between:[0.115,0.134] at Helium synthesis.

Therefore if the shift between the catalyzed and uncatalyzed abundance cannot be greater than 0.019

PDG Review of BBN by Fields and Sarkar

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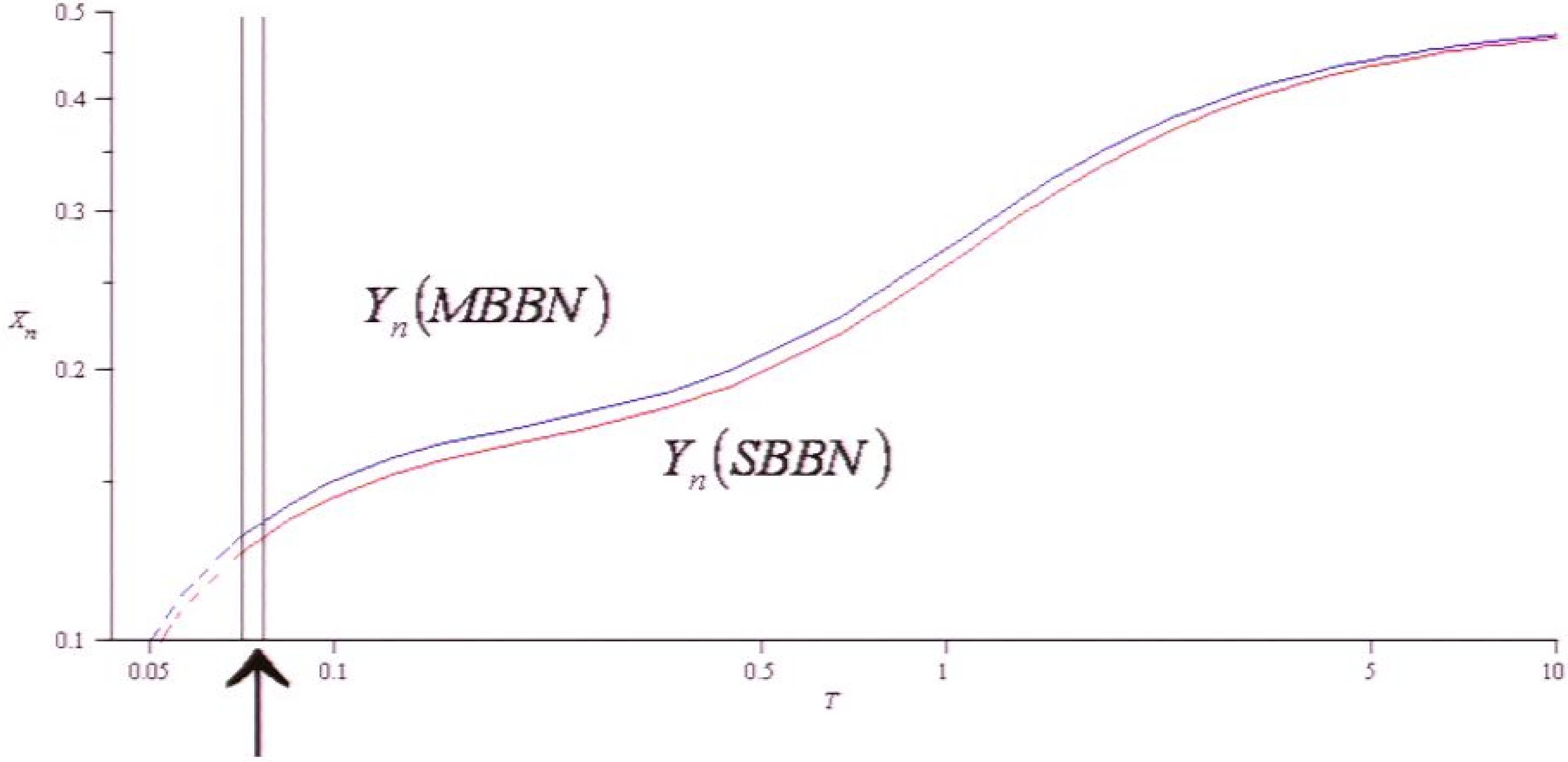

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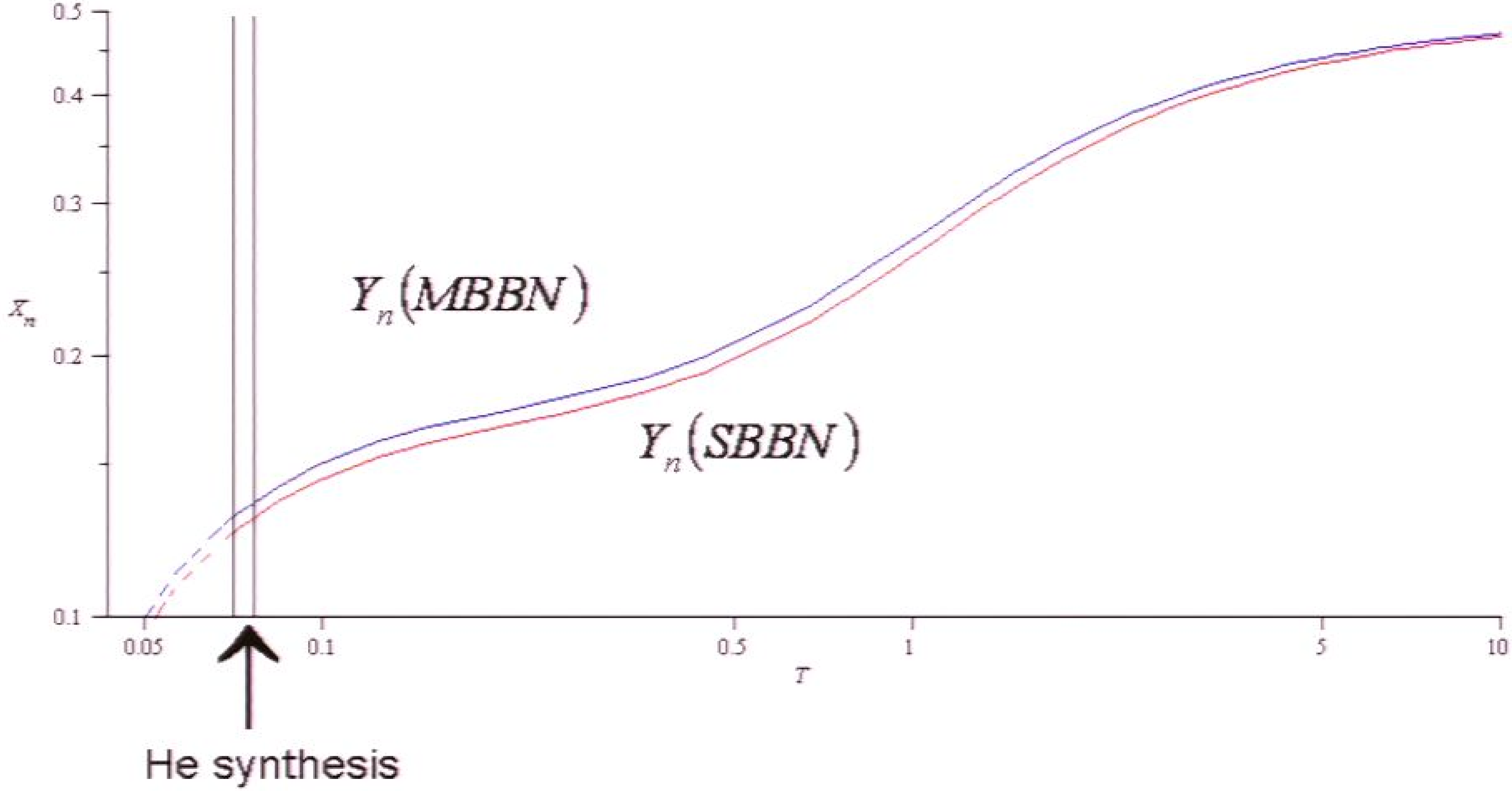

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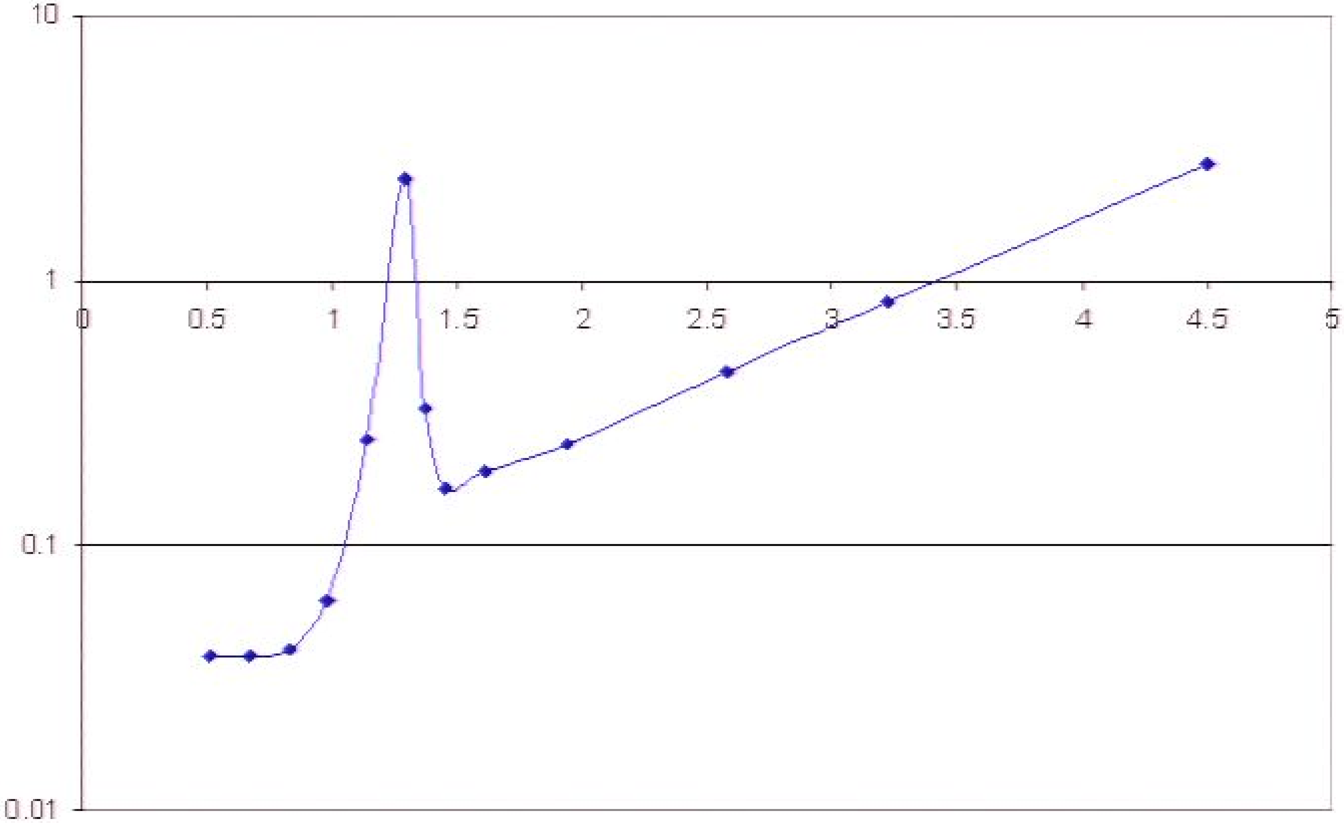
Using this criteria we get the following plot:

Maximum

Value of

Y_M



$m_- - m_o$

- The low Δm_M bound is $Y_M < 3.8 \times 10^{-2}$
- There is little sensitivity to Y_M at large Δm_M.
- While this is much larger than the expectd relic abundance, there are scenarios with sqark asymmetry that can be ruled out.

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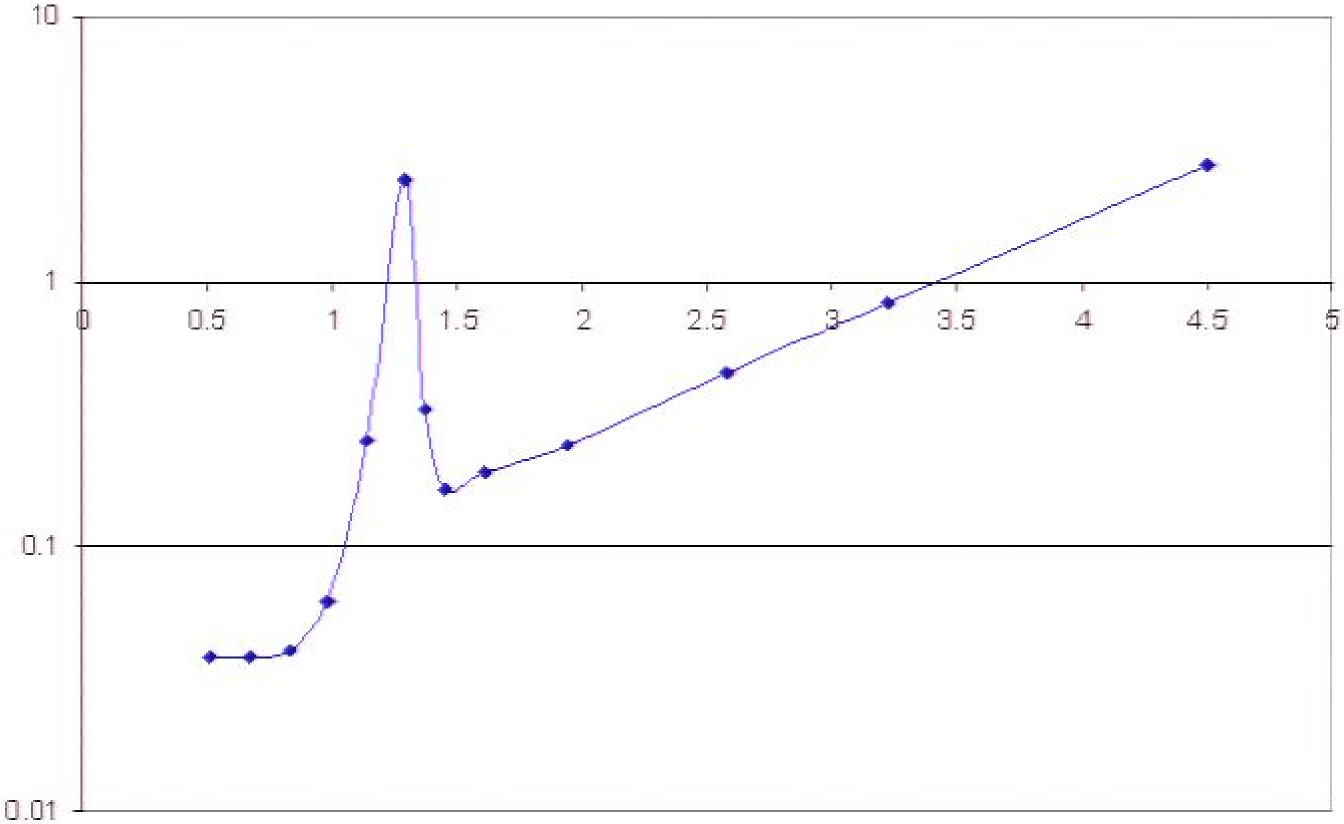

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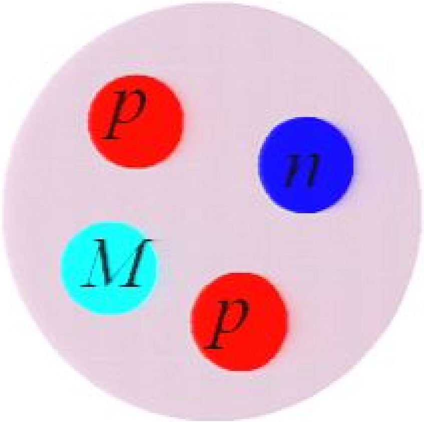
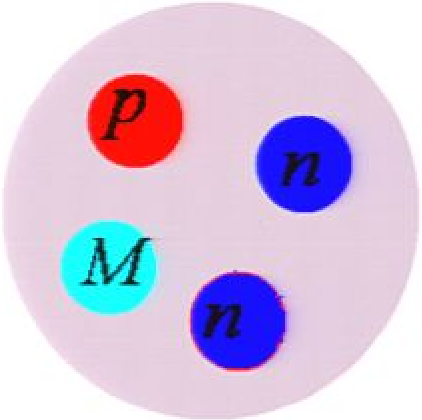
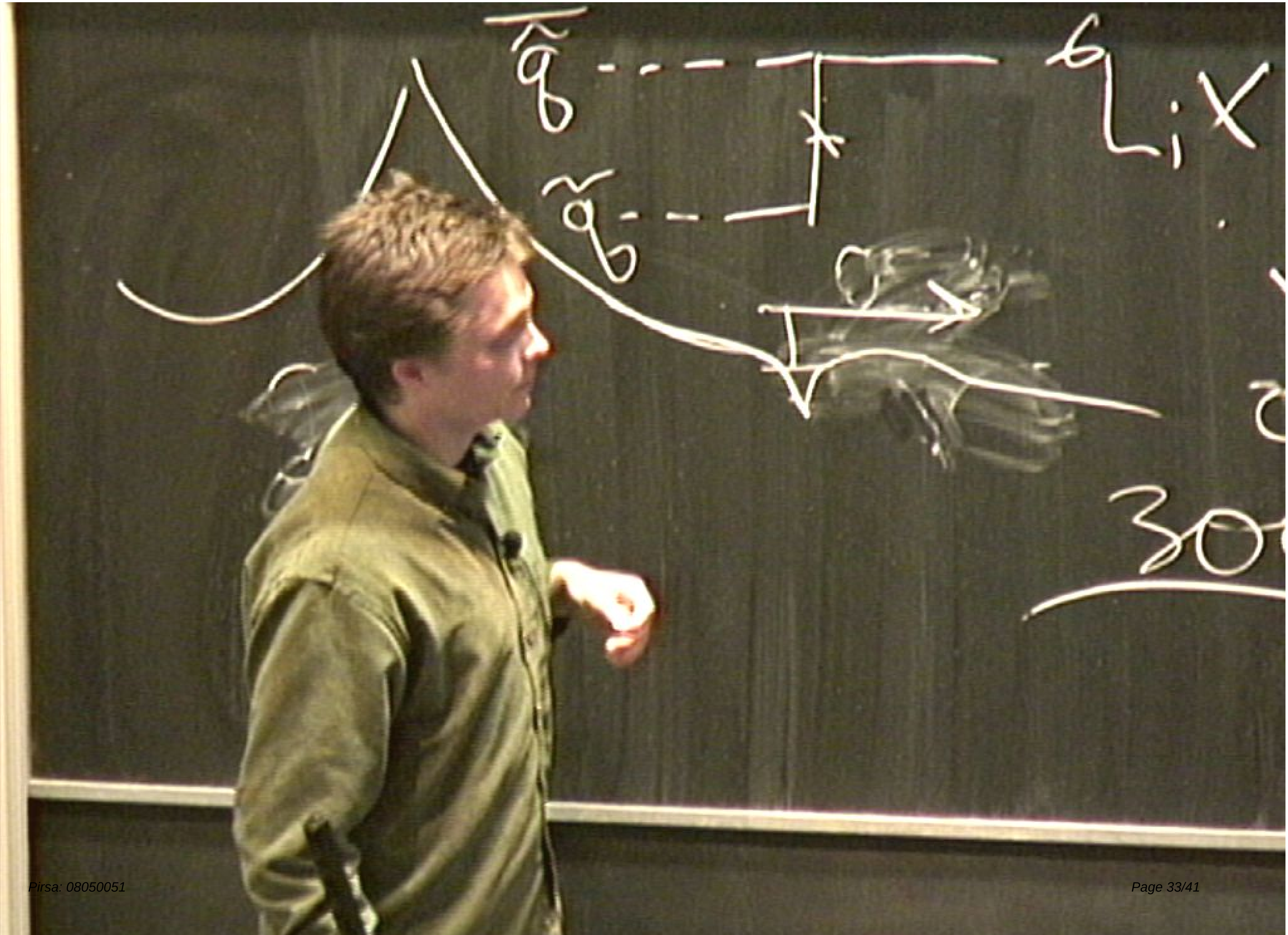
Effect on ^{7}Li and ^{6}Li (Speculative)

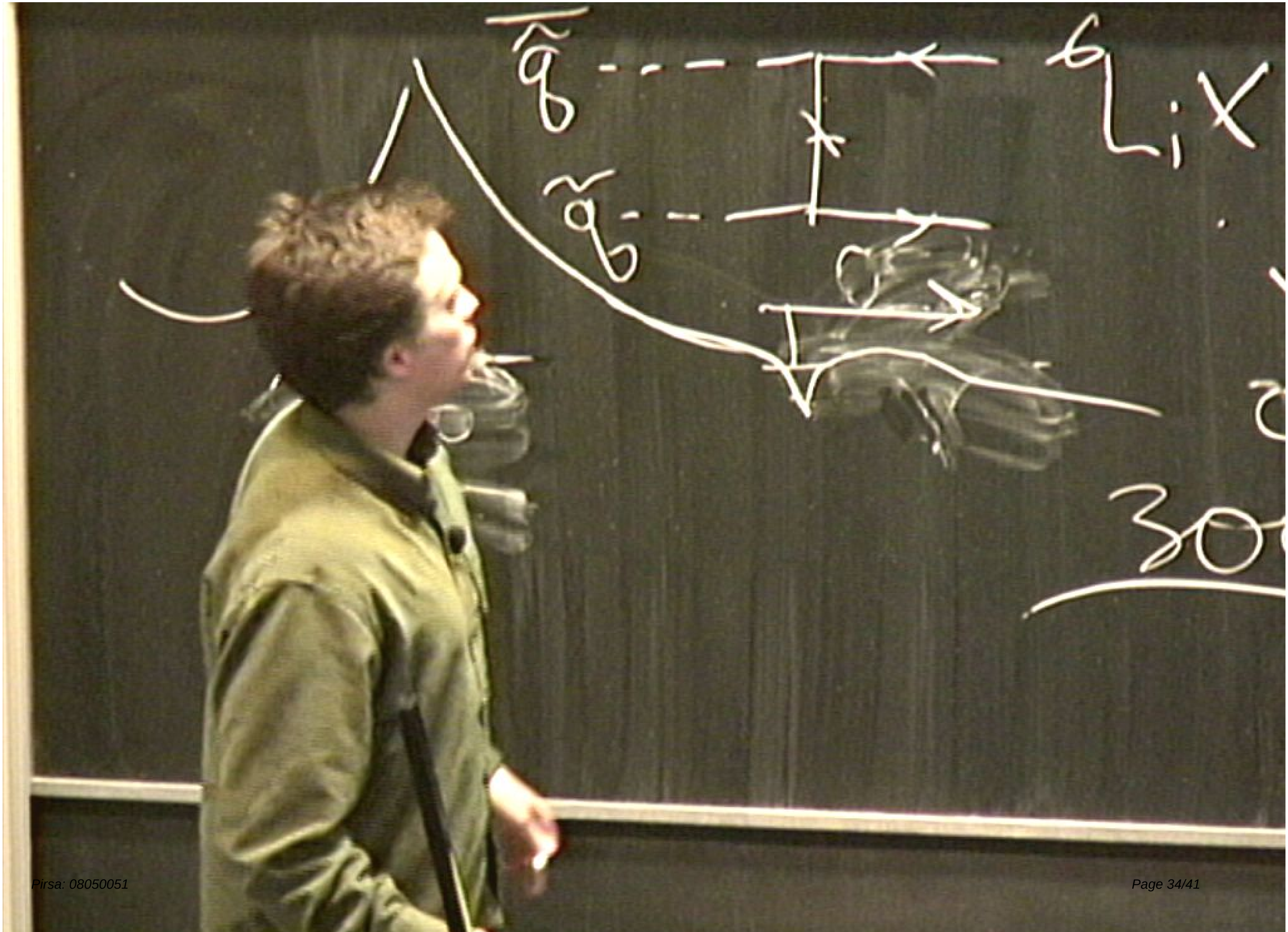
Depending on how the Mesinos behave, we can expect different impacts on the Lithium abundances. The two cases we will deal with are:

- Mesinos remain free of the nuclei.
- Mesinos bind with protons and neutrons into Helium like nuclei.






$\tilde{q}$
$\tilde{q}$
q_L
i
X
300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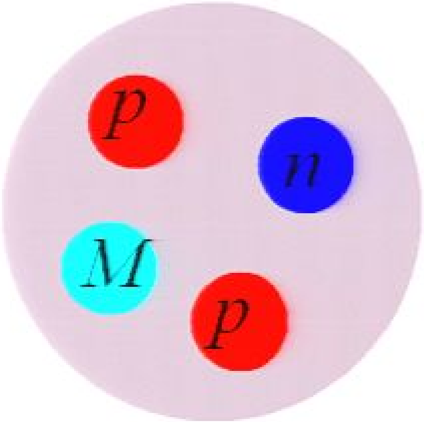
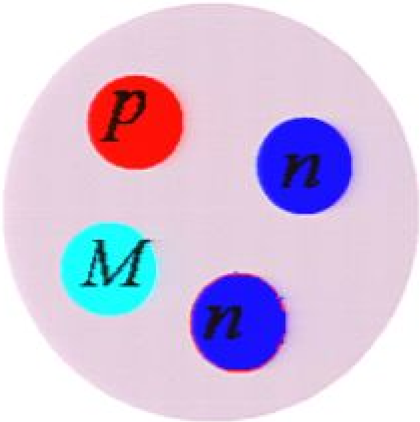




Free Mesonsinos

- Stop mesinos will not help catalyze any reactions since they will all beta decay to the M^0 state and stay there.
- Sbottom mesinos however are much more interesting. Their expected mass separation can make them stable w.r.t beta decay. It is therefore posible for them to continue to catalyze BBN.

Reaction of interest

$$^{7}Be + n \rightarrow {}^{7}Li + p$$

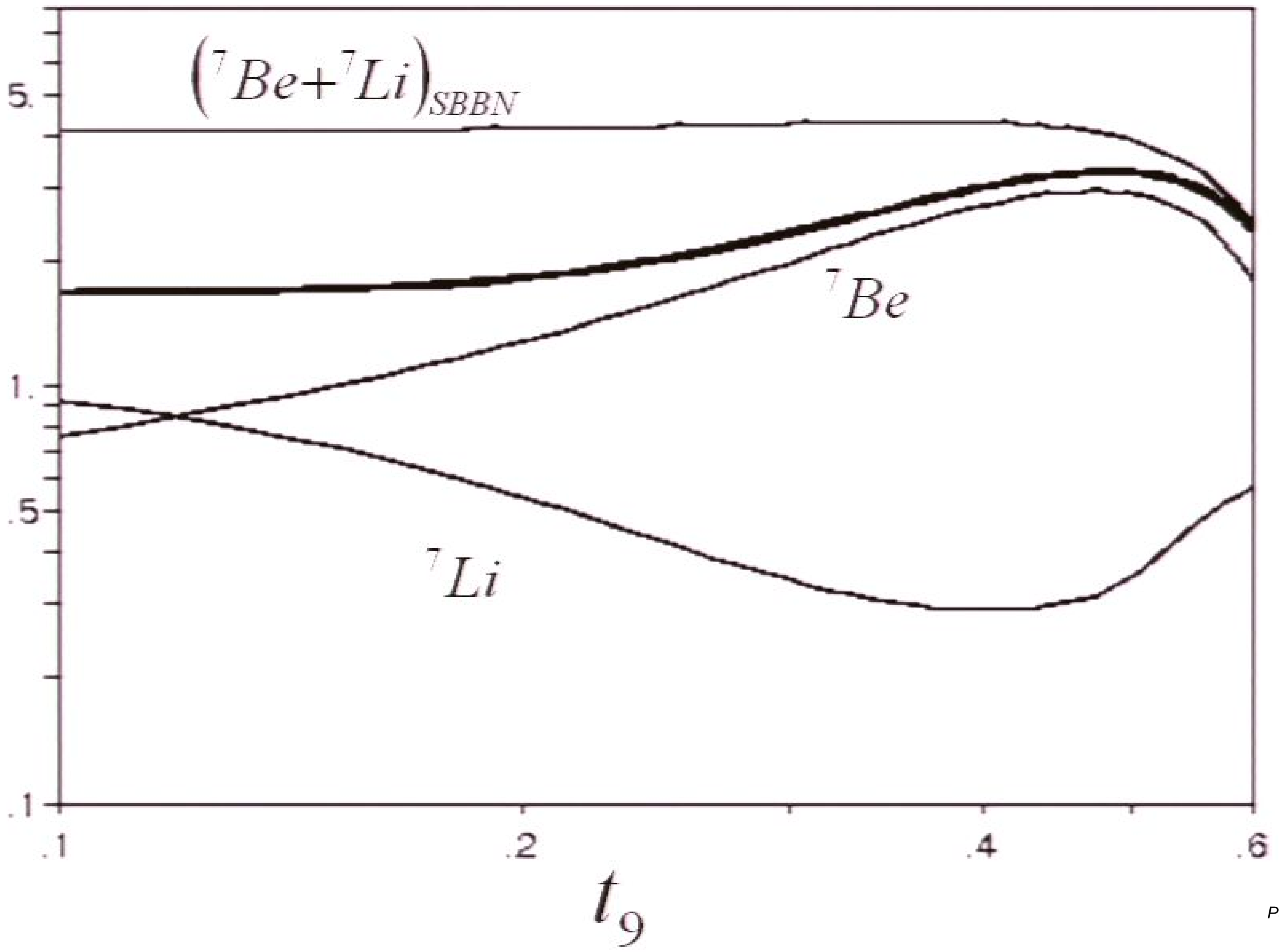
$$^{7}Be + M^{0} \rightarrow {}^{7}Li + M^{+}$$

In the sbottom case, the M^0 behaves similarly to the neutrons. Meaning the Lithium abundance will be affected in a similar way as if the number of free neutrons is given by:

$$n_n^{eff} \rightarrow n_n + Y_{M^0} \frac{\langle \sigma_M v \rangle}{\langle \sigma_n v \rangle}$$

Notice that because the strong interaction freezes out long after the weak rate, nearly all the mesinos will be in the M^0 state.

$$Y_{M^0}\,\frac{\langle \sigma_M v\rangle}{\langle \sigma_n v\rangle} \cong 3\times 10^{-7}$$



Bound Mesons

- Nothing is keeping these particles from binding to the nucleons in order to create exotic nuclei.
- Since the isospin and spin of these mesons is the same as that of nucleons, we can guess that most of the mesons will be locked into ^{4}He like nuclei.
- After the squark decay we believe there will be a recoil of the Tritium or Helium-3 that remains. The typical energy should be on the order of the binding energy or about 15MeV.

$$T + {}^{4}He \rightarrow {}^{6}Li + n$$

$$ {}^{3}He + {}^{4}He \rightarrow {}^{6}Li + p$$

These reactions require 4.8MeV and 3.5Mev respectively in order to proceed. The ${}^{3}He$ and T released by squark decay may have enough energy to initiate these reactions. Given an efficiency of 10^{-4} one could produce 10^{-11}Li from $Y_M = 10^{-7}$.

Conclusion

- In the low mass splitting limit we have found that the concentration of mesinos cannot be more than, $Y_M = 3.8\times 10^{-2}$ without violating experimental bounds.
- Even with small abundances the mesinos can have a large effect on the ^{6}Li and ^{7}Li abundances. However this can depend sensitively on their nuclear properties.
- Suffice it to say a lot more work remains to be done.