Vacuum Stability of Singlet Dark Matter Models

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Pheno, 2010.05.11

MG, Y. Li, H. Patel and M. J. Ramsey-Musolf, JHEP 1001 (2010) 053 [0910.3167]

Outline

* Motivation for scalar singlets
* The real scalar singlet potential & parameters
* Explanation of vacuum stability analysis
* Constraining scalar singlet dark matter

Vacuum stability analysis restricts **mass, self-interaction**, and **new physics scale** in a real scalar singlet model of dark matter

Why study scalar singlets?

* Dark matter candidate if stable
* Mixing with the Higgs
* Play a role in electroweak phase transition
* Arise in MSSM extensions
* They are simple!

Real Scalar Singlet

$$V = m^2 H^\dagger H + \frac{\lambda}{6}\left(H^\dagger H\right)^2 + a_2 S^2 H^\dagger H + \frac{b_2}{2} S^2 + \frac{b_4}{4} S^4$$

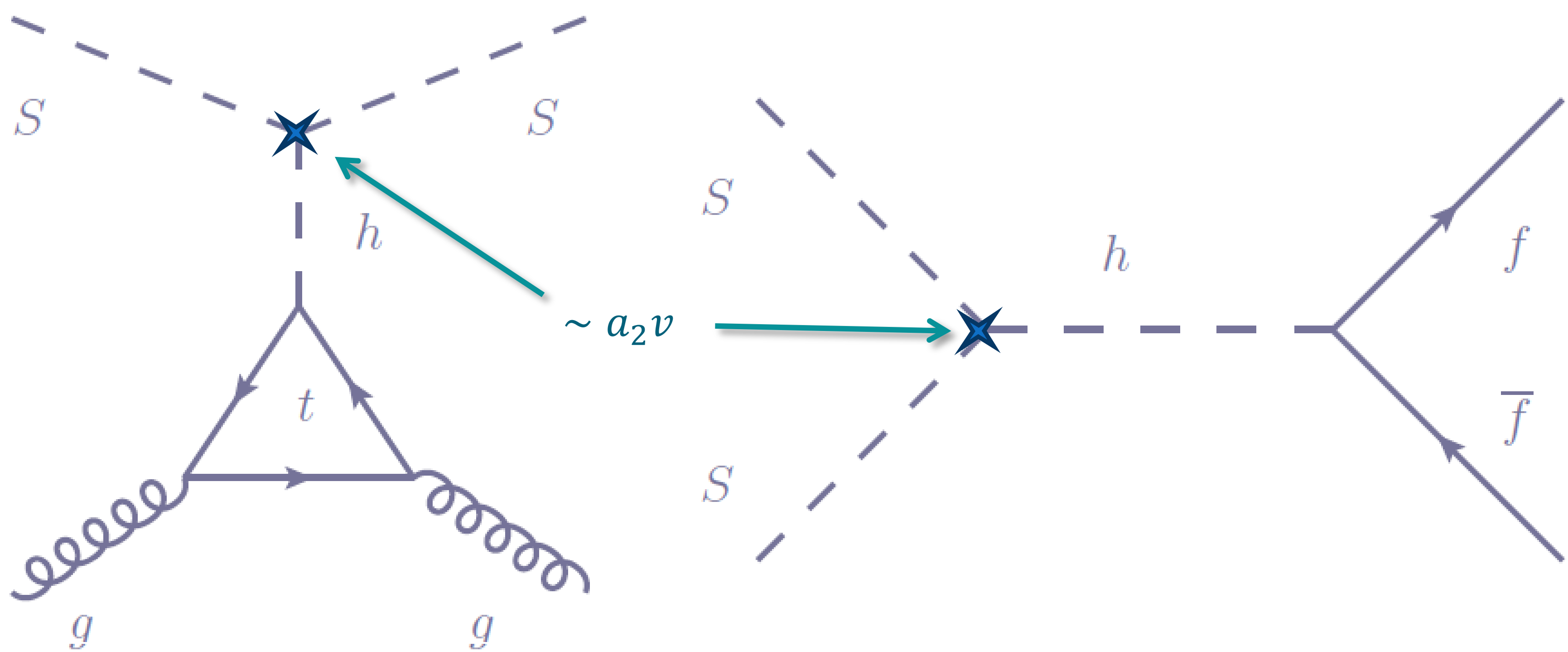
* $\mathbb{Z}_2$ symmetry
* Minimum at $\langle h \rangle = v = 246\ GeV, \langle S \rangle = 0$
* $\Rightarrow$ the singlet is a stable dark matter candidate

Parameters

- $m_h^2 = \lambda v^2/3$ (no mixing between the Higgs and singlet)
- $m_S^2 = b_2 + a_2 v^2$ (small m_S and moderate $a_2 \Rightarrow b_2 < 0$)
- a_2 determines both direct detection cross section and relic density

$\sigma_{dd} \sim a_2^2$	$\Omega_S \sim \frac{1}{\sigma_{ann}} \sim \frac{1}{a_2^2}$

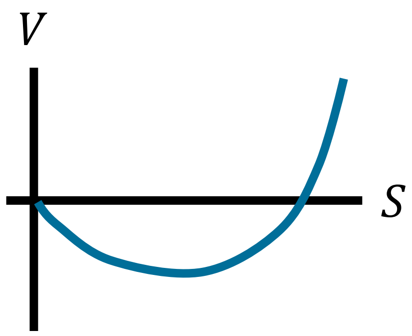
Diagrams



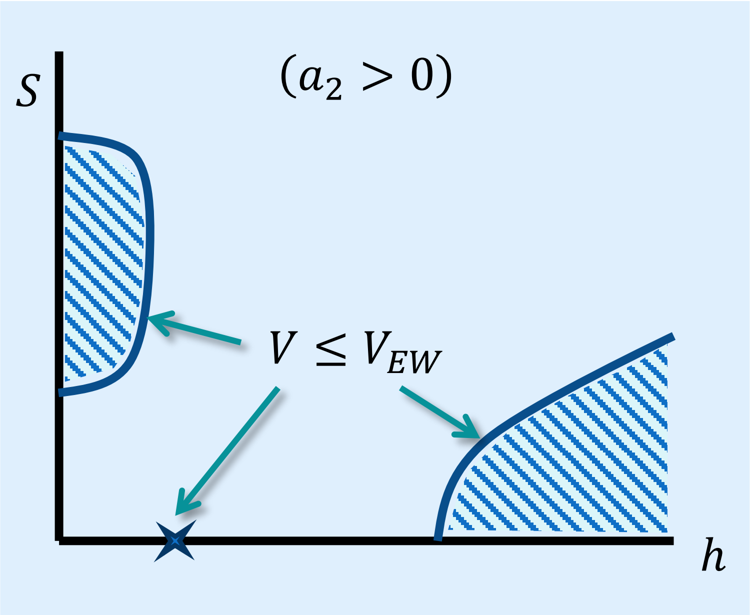
Vacuum Stability

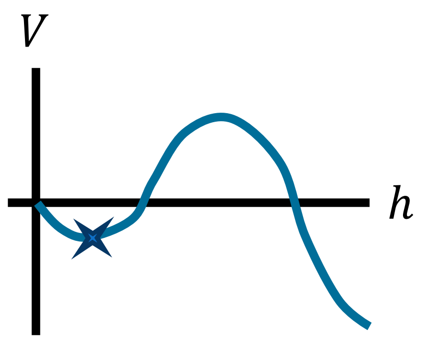
* RG-improved one-loop effective potential is a function of the two fields, h and S
* Require that $\langle h \rangle = v, \langle S \rangle = 0$ be the global minimum below new physics scale Λ
* Choose parameters to avoid:
  * Second minimum along h axis due to running of λ
  * Deeper minimum along S axis when $b_2 < 0$
  * Runaway direction caused by negative a_2

Cartoons



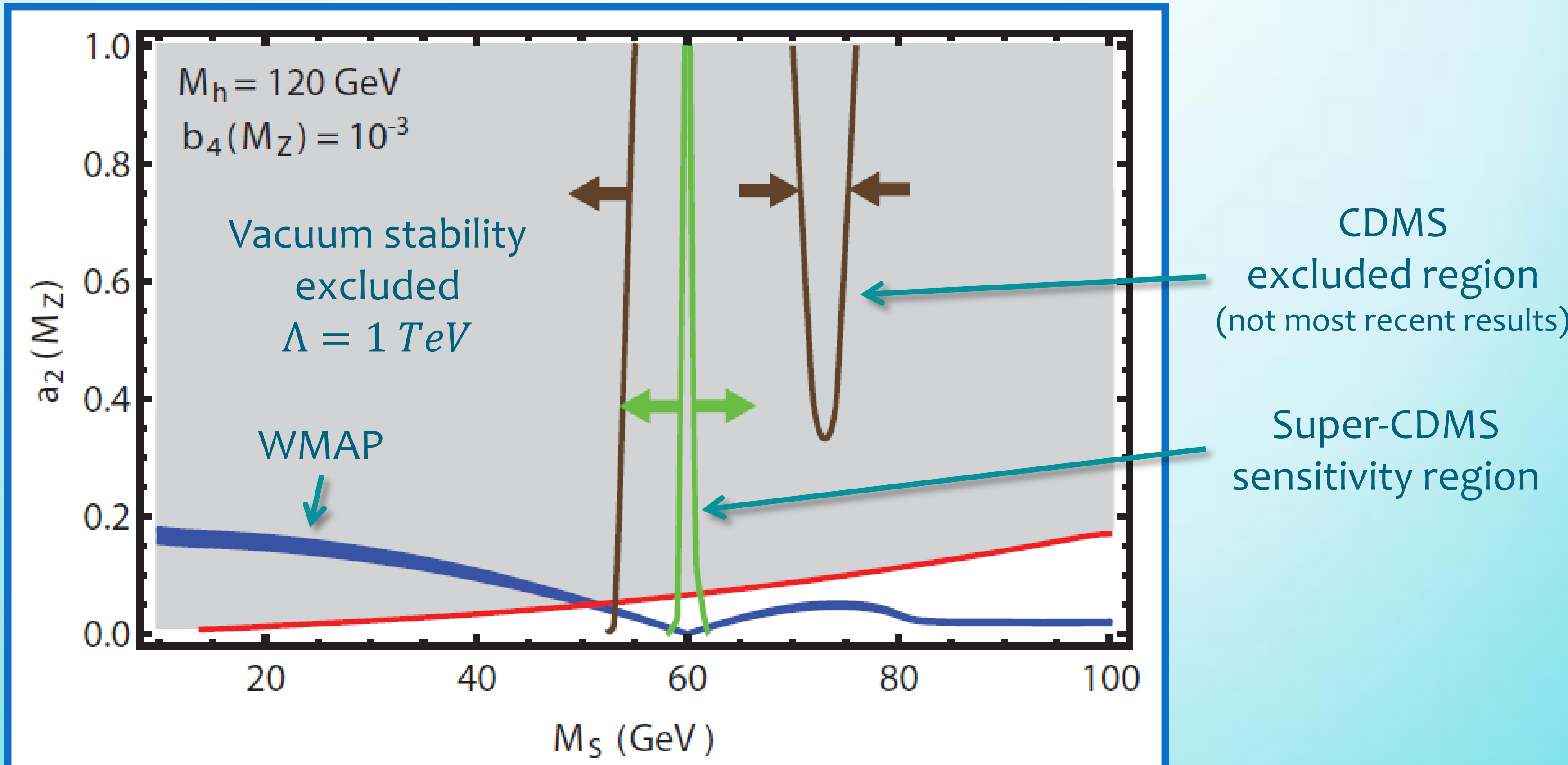
$b_2 < 0$





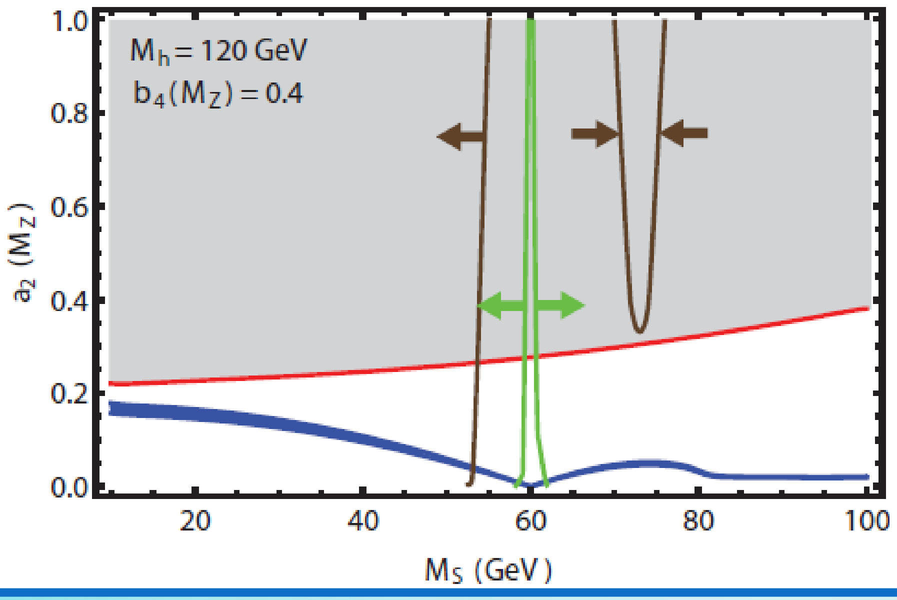
$\beta_\lambda \sim 4\lambda^2 - 36y_t^4$
$+12a_2^2 + \cdots$

Dark Matter

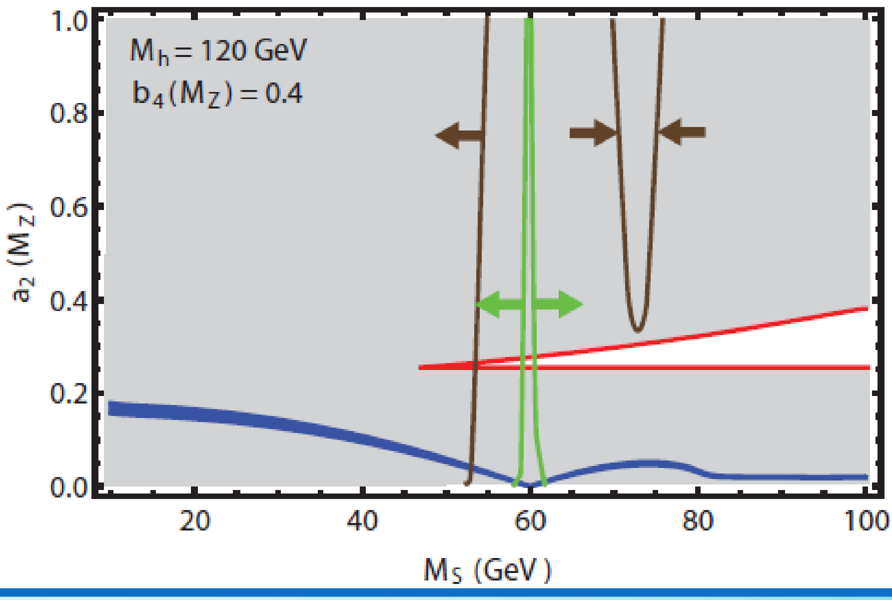


M. Gonderinger, Pheno 2010

More Dark Matter

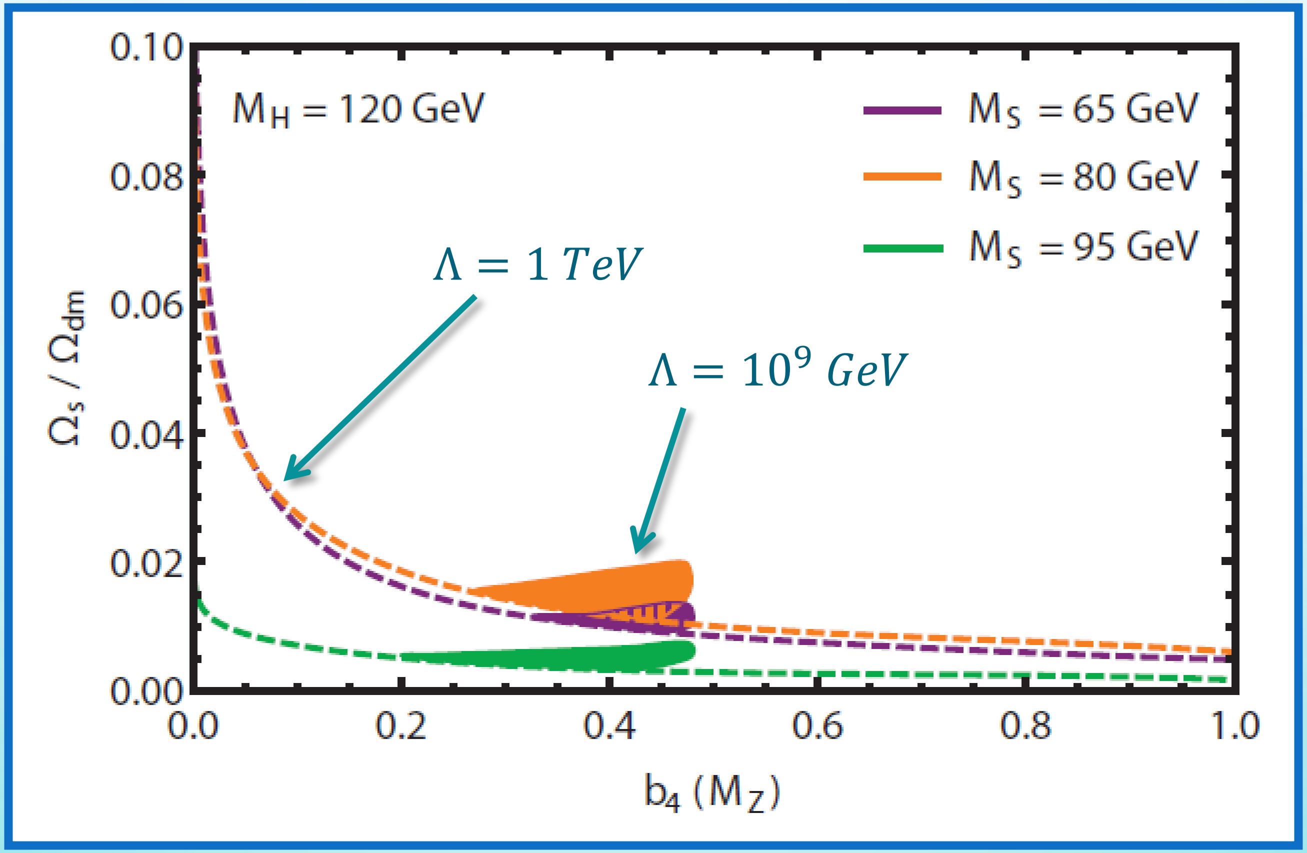


$\Lambda = 1\ TeV$



$\Lambda = 10^9\ GeV$

Even More Dark Matter



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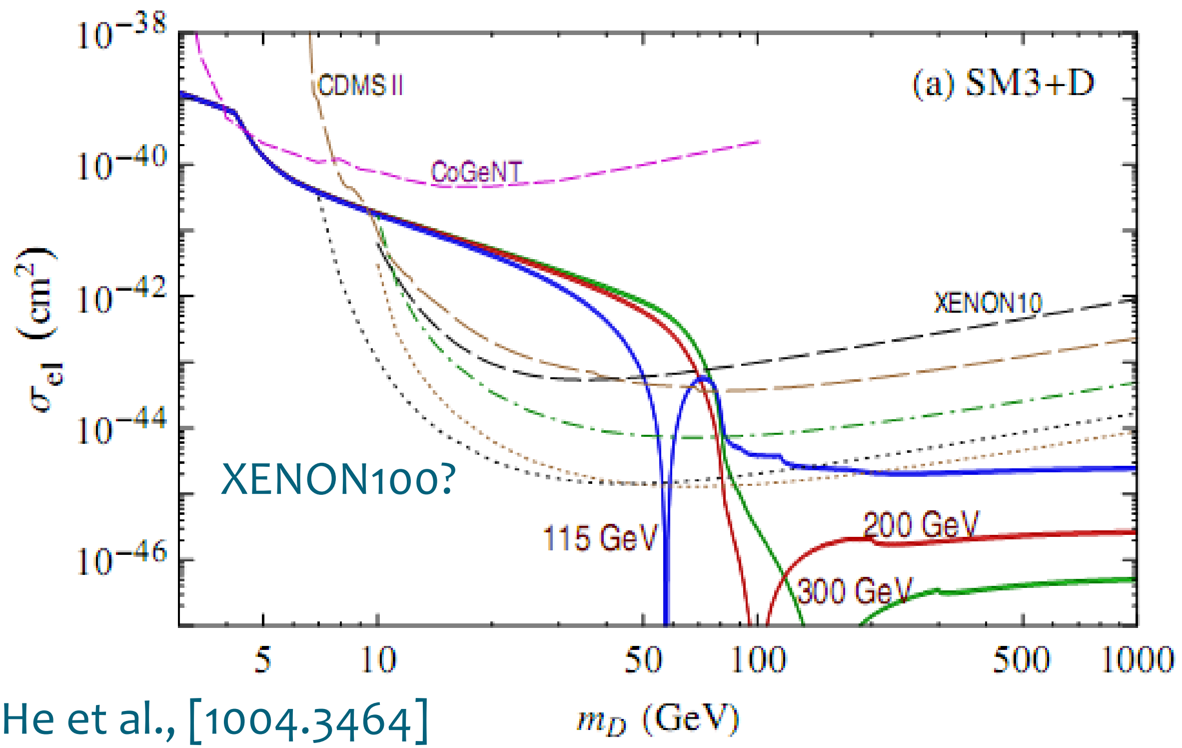
OMG Dark Matter



He et al., [1004.3464]

Hope

* Can the real scalar singlet be a very light ($m_S < 10\ GeV$) dark matter particle?
* Possibly, but vacuum stability requires…
  * a low new physics scale Λ (a_2 is small)
  * a large self-interaction b_4 (b_2 is negative)
* A more thorough analysis is necessary for this small m_S region (including most recent experimental limits)

Summary

Direct detection + relic density

+

Vacuum stability analysis

→

Constrain mass, self-interaction, new physics scale

For the Future

* Vacuum stability is a generally interesting analysis
  * Complex scalar singlet?
  * Finite temperature electroweak phase transition?
  * Metastable vacuum and tunneling?
  * Non-zero singlet vev?
  * Higgs phenomenology?

Many thanks!