Anomalies and parities for quintessential and ultra-light axions

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27 Aug- 7 Sep, 2023

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Dark energy source from a new confining force [248]

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Arion Hotel, Corfu, 1 Sep 2023

If we consider the potential energy which is of order

$$(???\times 10^{-3}\ \mathrm{eV})^4$$

We may consider the potential energy of a pseudo-Goldstone boson with the breaking term of this order.

Breaking must be of this order

Dark Energy in the Universe

$$c.c=(3\times10^{-3}\ \mathrm{eV})^4$$

Why is c.c. this value?

Even anthropic principle is added!!

Quintessential axions require

- The decay constant is near the Planck scale
- QA mass is near 10^{-32} eV

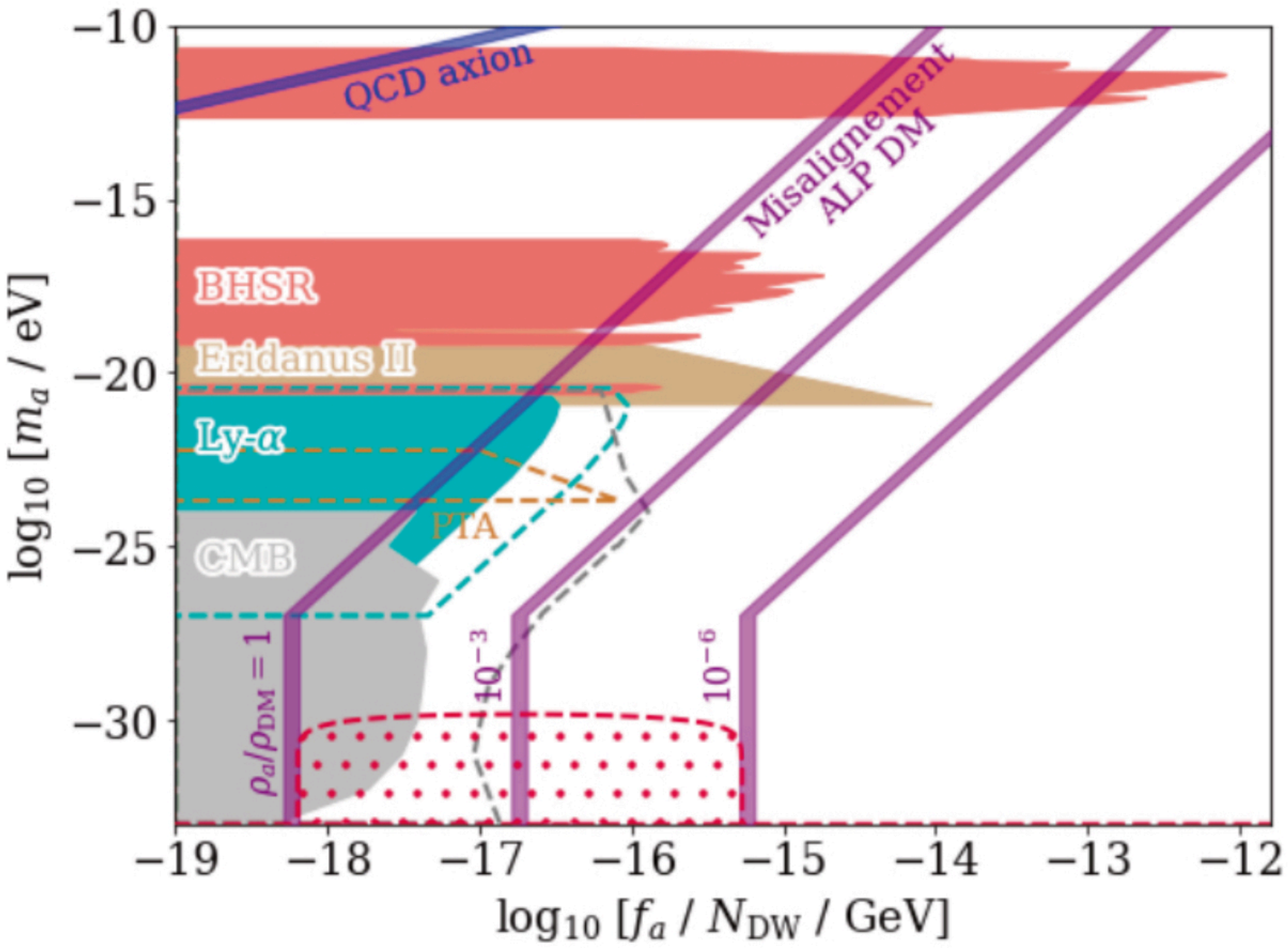


FIG. 5: A summary of the axion scale $f_a/N_{\rm DW}$ versus axion mass from gravitational probes [18]. The shaded regions are excluded by the existing constraints, while the dashed lines show the sensitivities of future experiments. $f_a/N_{\rm DW}$ is identified as the field VEV $\langle a \rangle$ for ALP DM or DE.

Another parameter to mention is the confining force for SUSY breaking around

$$\Lambda = 10^{13}\ \text{GeV}$$

Quark condensates from confining force

$$\langle \overline{Q}_L T^{a\,i}_j Q_L \rangle = \Lambda^3 e^{i\Pi^{a\,i}_j/f}$$

confining scale

Goldstone boson

confining scale

Mesons from light quarks in QCD

pi/K mesons and eta'

Octet
+singlet

f=250 MeV

New Confining Force Example

H. P. Nilles, Phys. Lett. B115, 193 (1982):
Dynamically Broken Supergravity and the Hierarchy Problem

S. Ferrara, L. Girardello, H. P. Nilles, Phys. Lett. B125, 457 (1982):
Breakdown of Local Supersymmetry Through Gauge Fermion Condensates

$$m_{3/2} = mu^3/M^2 = \text{TeV}$$

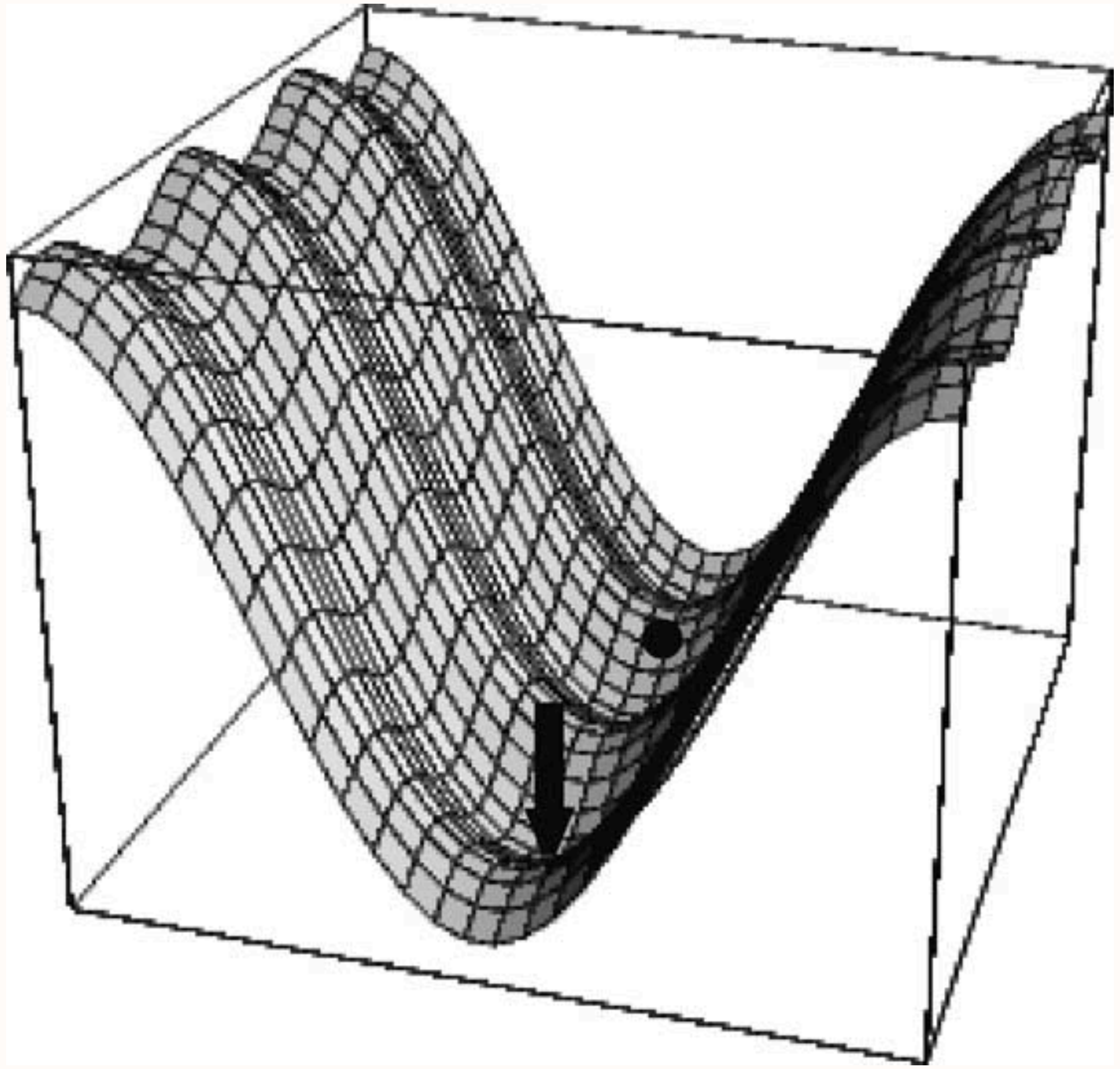
$$\Lambda = 10^{13}\ \text{GeV}$$

Quintessential axion as a pseudoscalar

First introduced in,

JEK+Nilles, PLB 553, 1 (2003):

A quintessential axion



$$\lambda_h^4 \equiv m_Q^n m_{\tilde{G}}^N \Lambda_h^{4-n-N}, \tag{4}$$

where $\Lambda_h \simeq 10^{13}$ GeV is the hidden sector scale and $m_{\tilde{G}}$ is the hidden sector gaugino mass.

Let us now discuss some illustrative examples for the conditions between m_Q, n and N needed to account for the $(0.003\ \mathrm{eV})^4$ dark energy, assuming $m_{\tilde{G}} \simeq 1$ TeV,

$$\left(\frac{m_Q}{\Lambda_h}\right)^n \sim \begin{cases} 10^{-68}, & \text{for } SU(3)_h, \\ 10^{-58}, & \text{for } SU(4)_h, \\ 10^{-48}, & \text{for } SU(5)_h. \end{cases} \tag{5}$$

For $N = 4$, we obtain $m_Q \simeq 10^{-45}$ GeV, 10^{-16} GeV, and 10^{-7} GeV, respectively, for $n = 1, 2,$ and 3.

M. Bronstein, Phys. Z. Sowjetunion 3 (1933) 73;
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R. Caldwell, R. Dave, P.J. Steinhardt, Phys. Rev. Lett. 80 (1998) 1582;
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C. Kolda, D.H. Lyth, Phys. Lett. B 458 (1999) 197;
T. Chiba, Phys. Rev. D 60 (1999) 083508;
P. Brax, J. Martin, Phys. Lett. B 468 (1999) 40;
A. Masiero, M. Pietroni, F. Rosati, Phys. Rev. D 61 (2000) 023504;
M.C. Bento, O. Bertolami, Gen. Relativ. Gravit. 31 (1999) 1461;
F. Perrotta, C. Baccigalupi, S. Matarrase, Phys. Rev. D 61 (2000) 023507;
A. Arbey, J. Lesgourgues, P. Salati, Phys. Rev. D 65 (2002) 083514.

Not by ex-quark mass, but by the scale itself. Then, we have another reason for introducing a new confining source. Mesons have the adjoint representation of $SU(N)_A$

$$\mathrm{SU}(N)_A \subset \mathrm{SU}(N)\times\mathrm{SU}(N)$$

Condensate is parametrized by and f,

$$\langle \overline{Q}_L T^{a\,i}_{j} Q_L \rangle = \Lambda^3 e^{i\Pi^{a\,i}_{j}/f}$$

	Representation under $\mathcal{G} \equiv$SU($\mathcal{N}$)	SU$(N)_L$	$\mathbf{Z}_{12}$
Q_L	$\mathcal{N}$	$\mathbf{N}$	$+1$
$\overline{Q}_L$	$\overline{\mathcal{N}}$	$\overline{\mathbf{N}}$	$+1$
σ	$\mathbf{1}$	$\mathbf{1}$	$+7$

$$\frac{1}{M^9}\overline{Q}_L \mathcal{C}^{-1} Q_L \sigma^{10},$$

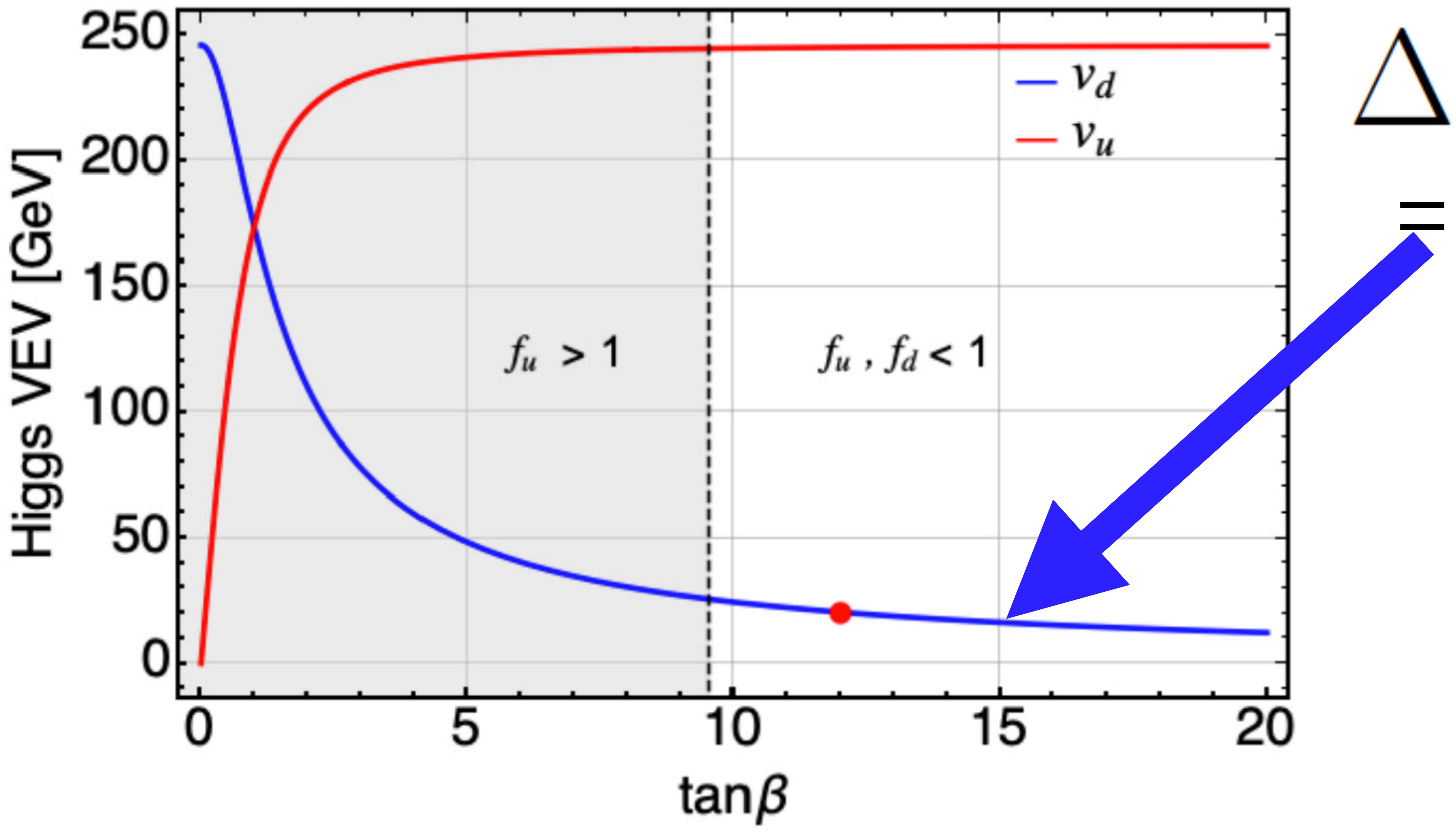
$$\Lambda \simeq 2.9 \times 10^6\,\mathrm{GeV}$$

With SUSY

$$\Delta W = \frac{1}{M^{n+3}} \overline{Q}_L Q_L \left(H_u H_d\right)^2 \sigma^n.$$

Then, condensation of the hidden sector quark Q leads to the following VEVs from Eq. (7),

$$\frac{1}{M^{n+3}} \Lambda^3 (v_u v_d)^2 V^n = \frac{1}{M^{n+3}} \Lambda^3 \frac{v_d^4}{\cos\beta^4} V^n \simeq (0.003\,\mathrm{eV})^4$$



ΔV $=(0.003\mathrm{eV})^4$

FIG. 1: Potential generated by Yukawa terms breaking $\mathrm{U}(1)_{\mathrm{DE}}$. At the intersection of the blue curve and the $f_u = 1$ line, v_d is 25.6 GeV.

Model

	Representation under $\mathcal{G} \equiv$SU($\mathcal{N}$)	SU(2)$_W \times$U(1)$_Y$	$\mathbf{Z}_{6R}$
Q_L	$\mathcal{N}$	$\mathbf{1}$	$+1$
$\overline{Q}_L$	$\overline{\mathcal{N}}$	$\mathbf{1}$	-1
H_u	$\mathbf{1}$	$\mathbf{2}_{+1/2}$	$+3$
H_d	$\mathbf{1}$	$\mathbf{2}_{-1/2}$	$+2$
σ	$\mathbf{1}$	$\mathbf{1}$	$+4$
S	$\mathbf{1}$	$\mathbf{1}$	$+5$

TABLE II: $\mathbf{Z}_{6R}$ quantum numbers of relevant chiral superfileds appearing

Here, we write W terms having $U(1)_R$ quantum number 2 modulo 6. SUSY conditions are

$$W = -\alpha\sigma S^2 + \frac{\varepsilon}{M}S^4 - \frac{x}{M^2}\sigma S^2 Q_L\overline{Q}_L + \cdots$$

$$\frac{\partial W}{\partial\sigma} :\to Q_L\overline{Q}_L = -\frac{\alpha M^2}{x}$$

$$\frac{\partial W}{\partial S} :\to (x\frac{Q_L\overline{Q}_L}{M^2} + \alpha)\sigma = \frac{2\varepsilon}{M}S^2.$$

No acceptable solution.

So we add SUSY breaking effects parametrized by deltas. Then minima occur at

$$-\alpha S^2 - \frac{x}{M^2} S^2 Q_L \overline{Q}_L + \delta_1 \Lambda^2 = 0,$$

$$-\alpha S\sigma - \frac{x}{M^2} S Q_L \overline{Q}_L \sigma + \delta_1 \Lambda^2 \sigma / S = 0,$$

$$2\alpha\sigma S^2 + 2\frac{\varepsilon}{M} S^4 + (\frac{\delta_2 S - 2\delta_1 \sigma}{2})\Lambda^2 = 0.$$

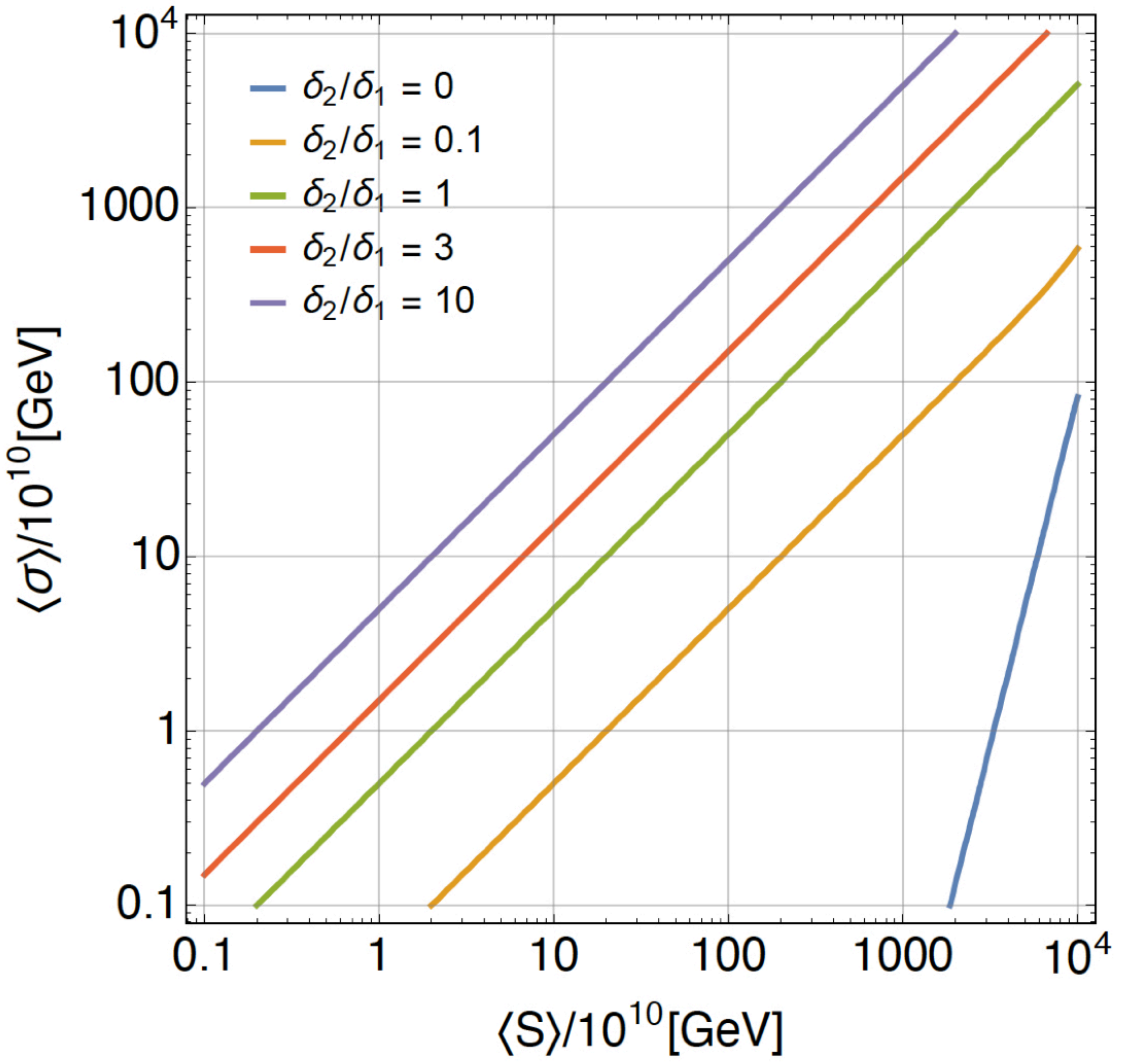


FIG. 2: Solutions of σ and S satisfying Eq. (2).

But f is near the Planck scale. Not at the confining scale.

In SUSY, condensation of scalar ex-quarks do not break SUSY. This scale can be nearer to the Planck scale.

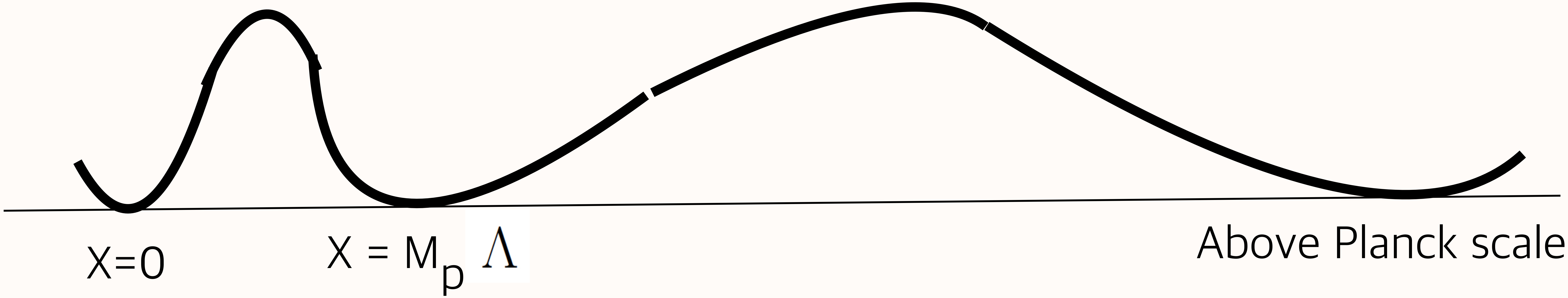
$$\overline{Q}_L Q_L \equiv X.$$

Nonzero X does not break supersymmetry. If we consider a potential in terms of X,

$$W = \Lambda X - \frac{1}{2M_{\mathrm{P}}} X^2 + \cdots .$$

$$V = \left(\Lambda - \frac{1}{M_{\mathrm{P}}} X \right)^2 + \cdots .$$

So, $f = \sqrt{X}$ is expected at a median of Λ and M_{P}.



For SUSY breaking effects to the SM superpartners, we need the mu term

$$W_\mu = \frac{(10^{10}\ \mathrm{GeV})^2}{M} H_u H_d$$

J. E. Kim and H. P. Nilles, The problem and the strong CP problem, Phys. Lett.B 138 (1984) 150 [doi:10.1016/0370-2693(84)91890-2].

But, there should be no HuHd and HuHdS terms.

$$W_\mu = \frac{\sigma\, S}{M} H_u H_d$$

With <sigma> and <S> VEVs around 10^{10} GeV, we have a needed mu term.

Conclusion

I reviewed a new theory on the quintessential axion.

Thanks for attention