Techni-Dilaton as Dark Matter

Deog Ki Hong

Pusan National University

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Based on arXiv:1101.5326 and arXiv:1107.xxxx
with K. Y. Choi and S. Matsuzaki

Introduction

- Higgs holds a key to BSM, since it is sensitive to short distance phyics.
- But, we have not found Higgs yet. Current mass bound is

$$114\ \mathrm{GeV} \lesssim m_H \lesssim 157\ \mathrm{GeV}$$

- Technicolor theory introduces a new strong dynamics at TeV scale to break EW symmetry dynamically. (Weinberg '76, Susskind '79)

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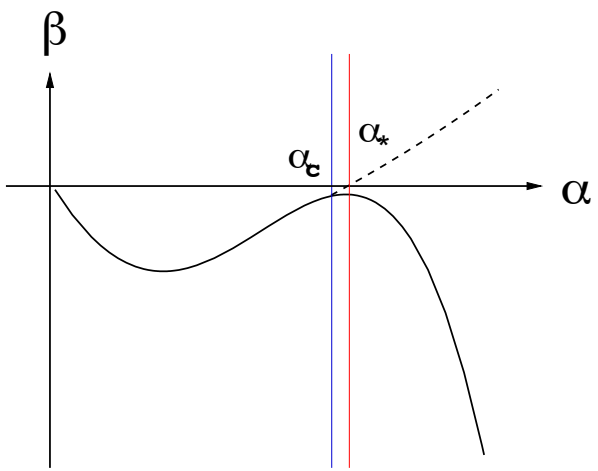
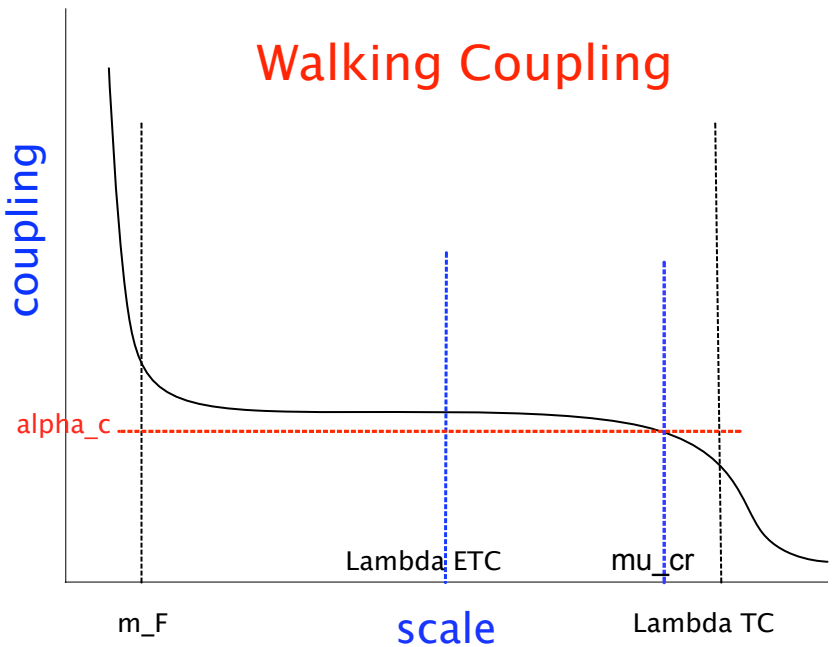
Introduction

- Modern TC is called "Walking Technicolor" (Holdom '81, Yamawaki et al '86, Appelquist et al '86)





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- As a candidate for physics BSM, it will be nice if TC explains dark matter as well.
- Indeed, I will show that WTC can have very light dilaton, techni-dilaton as Nambu-Goldstone bosons, associated with spontaneously broken (approximate) scale symmetry, which can be a good candidate for DM. (Cf. Techni-baryons)

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Review of WTC

- Introduce new strong dynamics in addition to SM, which is confined and breaks chiral symmetry:

$$SU(3)_c \times SU(2)_L \times U(1)_Y \times G_{\rm TC}$$

- Introduce new particles, N_F techniquarks, which transform as

$$Q_L^{\rm TC} \sim (3, 2, y_L, r), \quad Q_R^{\rm TC} \sim (3, 2, y_R, r)$$

- such that theory is anomaly-free, (asymptotically free) and has a (quasi) IR fixed point.

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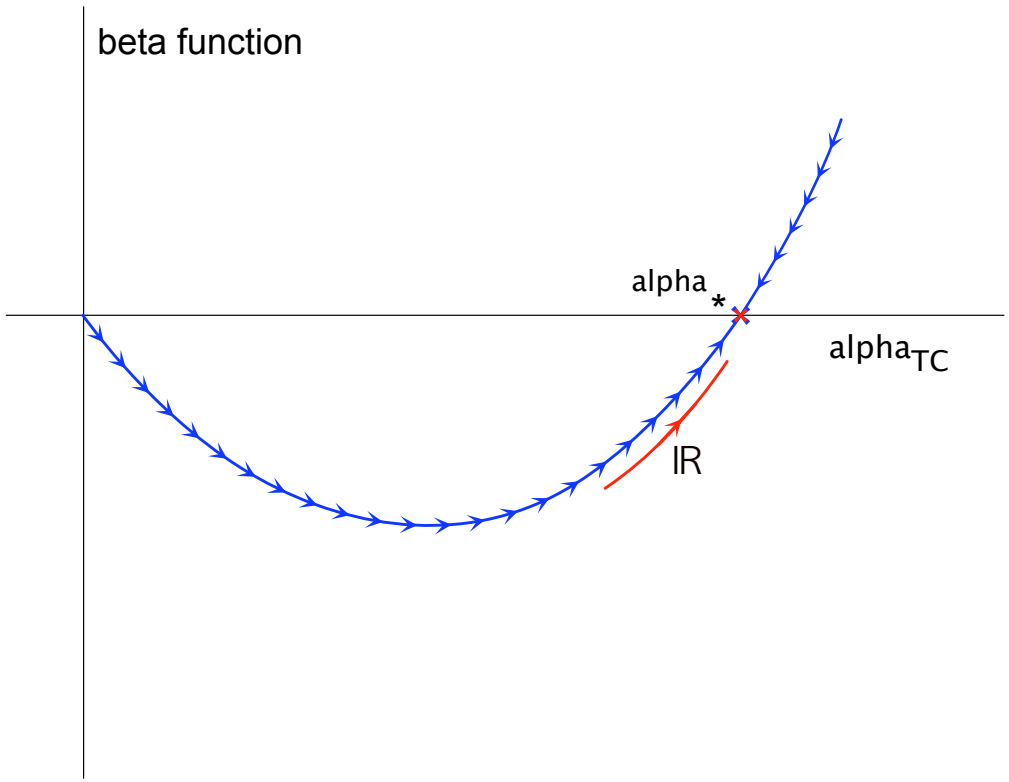


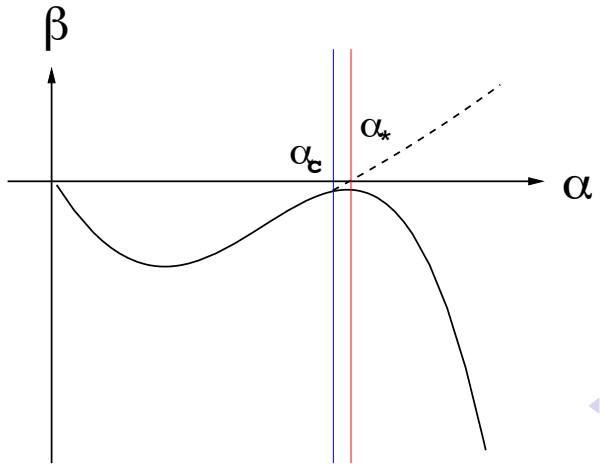
- TC has $SU(N_F)_L \times SU(N_F)_R$ chiral symmetry. (We may need techni-leptons to be anomaly-free.)

Review of WTC

- We assume that chiral symmetry is spontaneously broken by TC interactions: the critical coupling for χSB, $\alpha_c < \alpha_*$.

$$\alpha_c \approx \frac{\pi}{3C_2(r)}$$

- We assume that $\alpha_c \approx \alpha_*$ to have walking behavior.
- Once techni-fermions get dynamical mass, they decouple for $E < m_F$ and coupling runs quickly and confines technicolor.



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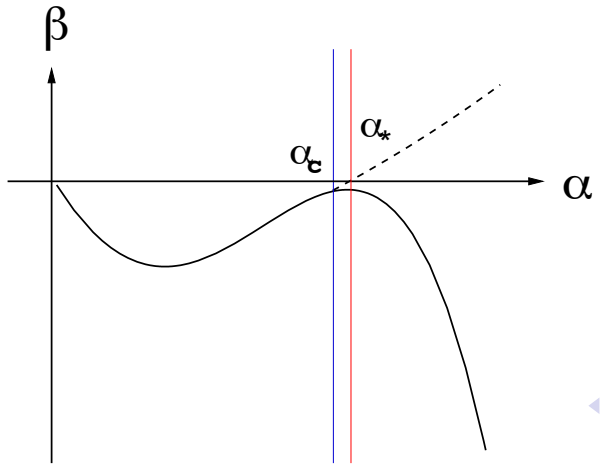

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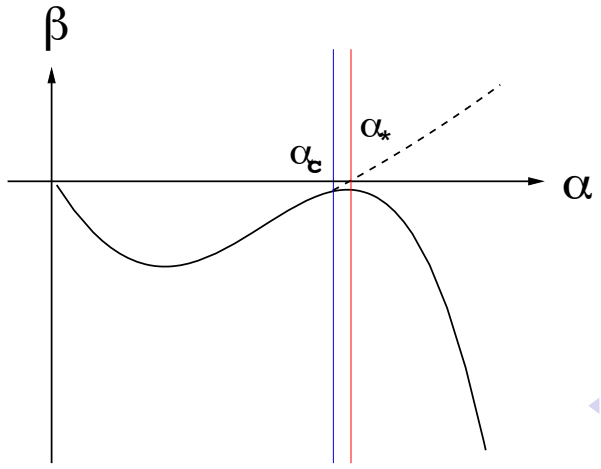

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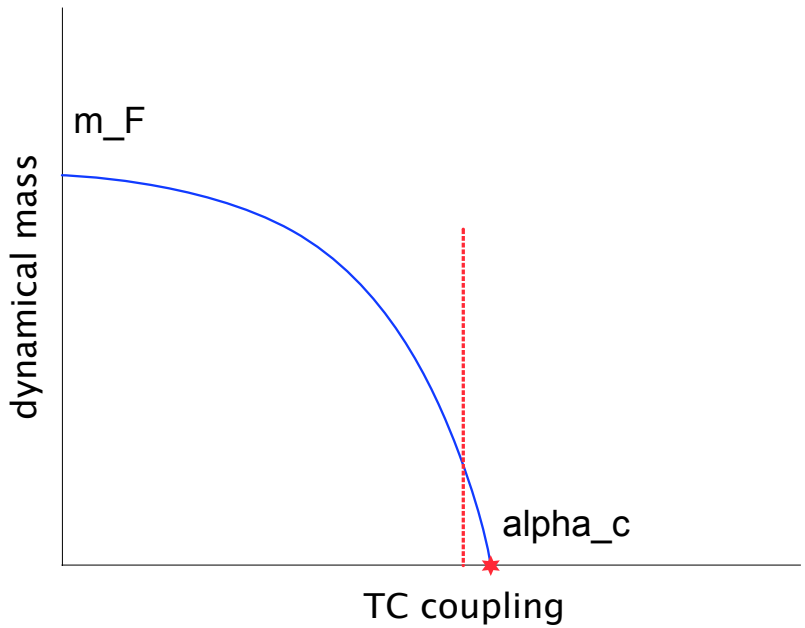

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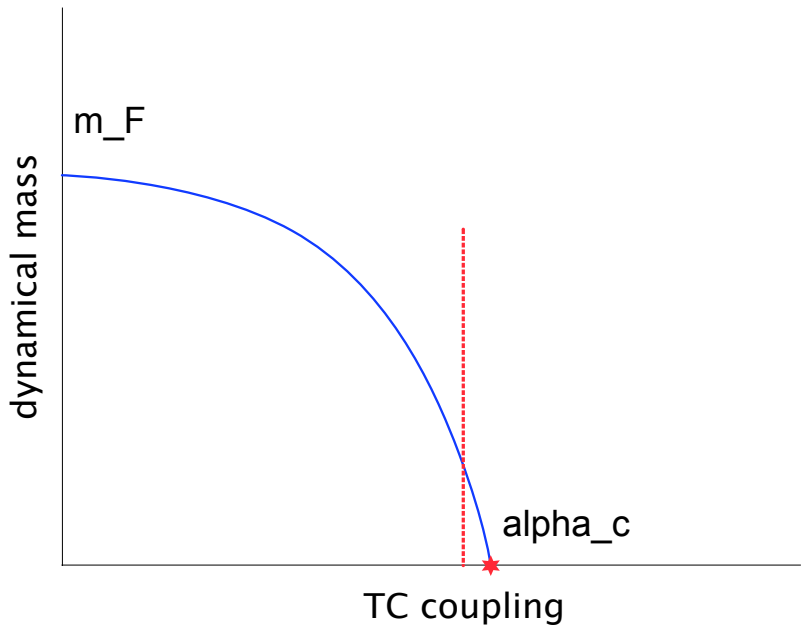

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Very light techni-dilaton

- If $\alpha_* \approx \alpha_c$, theory exhibits walking behavior and is almost scale-invariant for a wide range of scale.
- Dilation current, $D^\mu = x_\nu \theta^{\mu\nu}$, is conserved up to scale-anomaly:

$$\langle \partial_\mu D^\mu \rangle = -\frac{\beta(\alpha)}{\alpha^2} \left\langle \alpha G^a_{\mu\nu} G^{a\mu\nu} \right\rangle^{TC}_{\alpha \approx \alpha_*} \approx 0 \,.$$

- At some scale $\mu_{cr} \ll \Lambda_{TC}$, the coupling walks to cross the critical coupling $\alpha(\mu_{cr}) = \alpha_c$ and the theory undergoes a chiral phase transition:

$$0 \neq \left\langle \bar{Q}_L Q_R \right\rangle\Big|_{\mu_{cr}} \approx \mu^3_{cr} \,.$$

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- Techni-dilaton arises as pseudo Nambu-Goldstone boson, associated with spontaneously broken (approximate) scale symmetry.

$$\langle 0 | D^\mu | \sigma \rangle = i F_{TD} p^\mu e^{-ip\cdot x}$$

- By PCDC

$$\langle \partial_\mu D^\mu \rangle = F_{TD} m_{TD}^2 \langle \sigma \rangle = F_{TD}^2 m_{TD}^2 .$$

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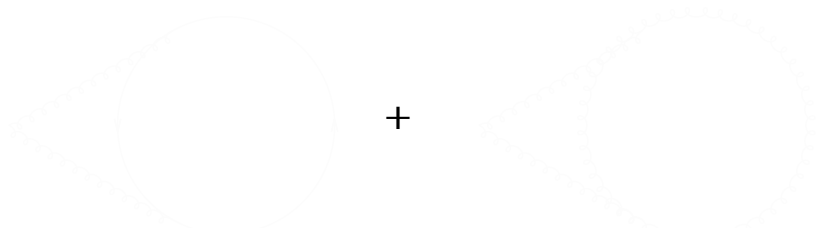
$$\langle \partial_\mu D^\mu \rangle = \langle \theta^\mu_\mu \rangle \sim m_F^4$$



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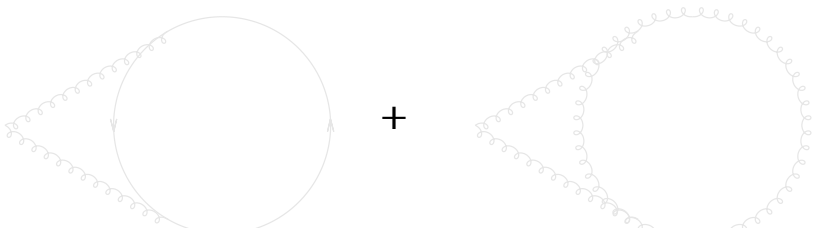

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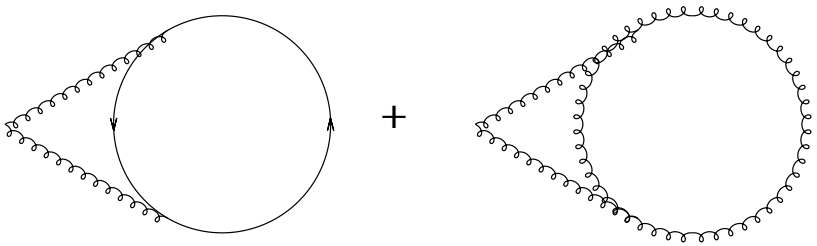

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- We therefore find

$$F_{TD}^2 m_{TD}^2 \approx \frac{16 N_{TC} N_F}{\pi^4} m_F^4 \,.$$

- SD analysis by Hashimoto and Yamawaki shows as $\alpha \to \alpha_c$

$$\frac{m_F}{F_{TD}} \to 0 \,.$$

- Since $\left(\frac{m_{TD}}{m_F}\right)^2 \sim \left(\frac{m_F}{F_{TD}}\right)^2$, TD is very light and decoupled:

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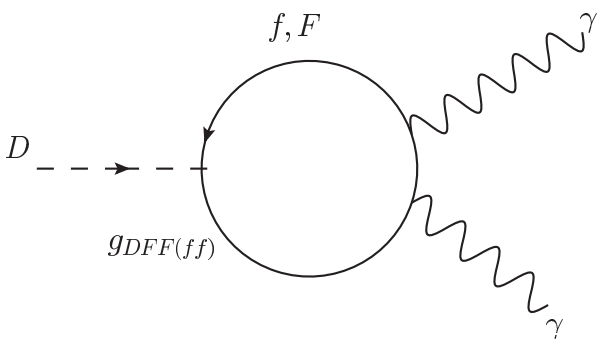
Dark matter TD

- Decay of very light TD



$$\Gamma(\sigma \to \gamma\gamma) \simeq \frac{\alpha_{em}^2}{36\pi^3} \frac{m_{TD}^3}{F_{TD}^2} |\mathcal{C}|^2$$

$$\tau_{\rm TD} \simeq 10^{17}\,{\rm sec}\,(N_{\rm TC} N_{\rm F}) \left(\frac{16}{\mathcal{C}}\right)^2 \left(\frac{10\,{\rm keV}}{m_{\rm TD}}\right)^5 \left(\frac{m_F}{10^3\,{\rm GeV}}\right)^4$$

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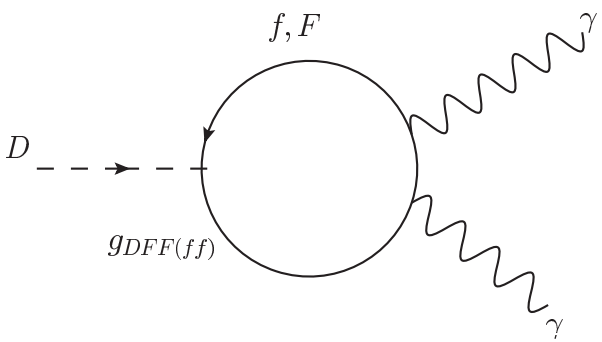

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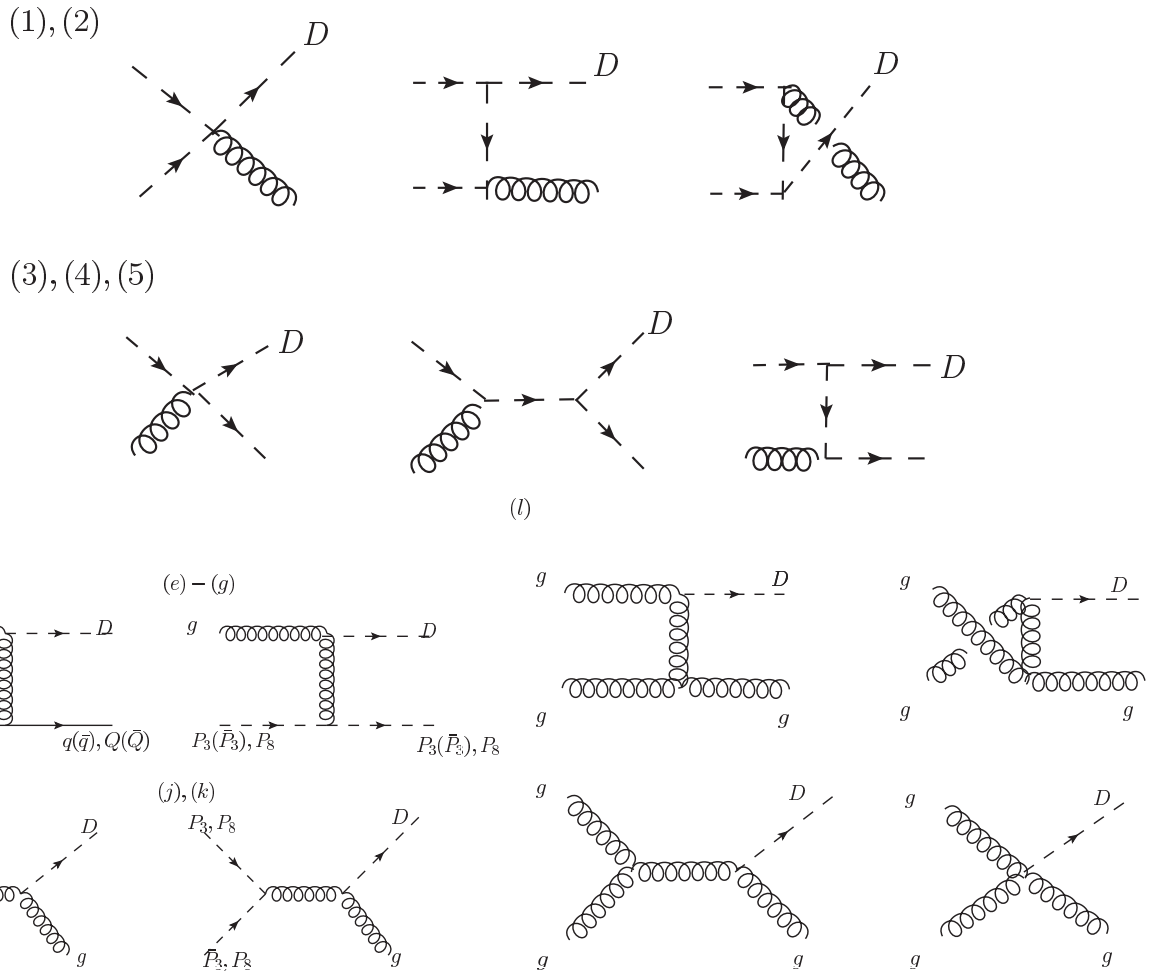
- Thermal production of TD



Dark matter TD

- The Boltzmann equation for the TD number density $n_{\rm TD}$

$$\frac{dn_{\rm TD}}{dt} + 3Hn_{\rm TD} = \sum_{i,j} \langle \sigma(i + j \to D + \cdots) v \rangle n_i n_j$$

where H is the Hubble parameter $H(T) = (\frac{\pi^2}{30} g_* T^4 / 3M_P^2)^{1/2}$.

$$\Omega_{\rm TD}^{\rm tp} h^2 \simeq \left(\frac{\mu_{\rm cr}}{10^8 {\rm GeV}}\right) \left(\frac{m_{\rm TD}}{\rm keV}\right) \left(\frac{200}{g_*(\mu_{\rm cr})}\right)^{3/2} \left(\frac{10^{11} {\rm GeV}}{F_{\rm TD}}\right)^2 \times \begin{cases} 4.4 \times 10^{-1} & \text{for} \quad N_{\rm TC} = 2 \\ 2.6 \times 10^{-2} & \text{for} \quad N_{\rm TC} = 3 \end{cases},$$

Dark matter TD

Contour plot of $\Omega_{TD}^{tp} h^2$ for $\mu_{cr} = 10^{-3} F_{TD}$.

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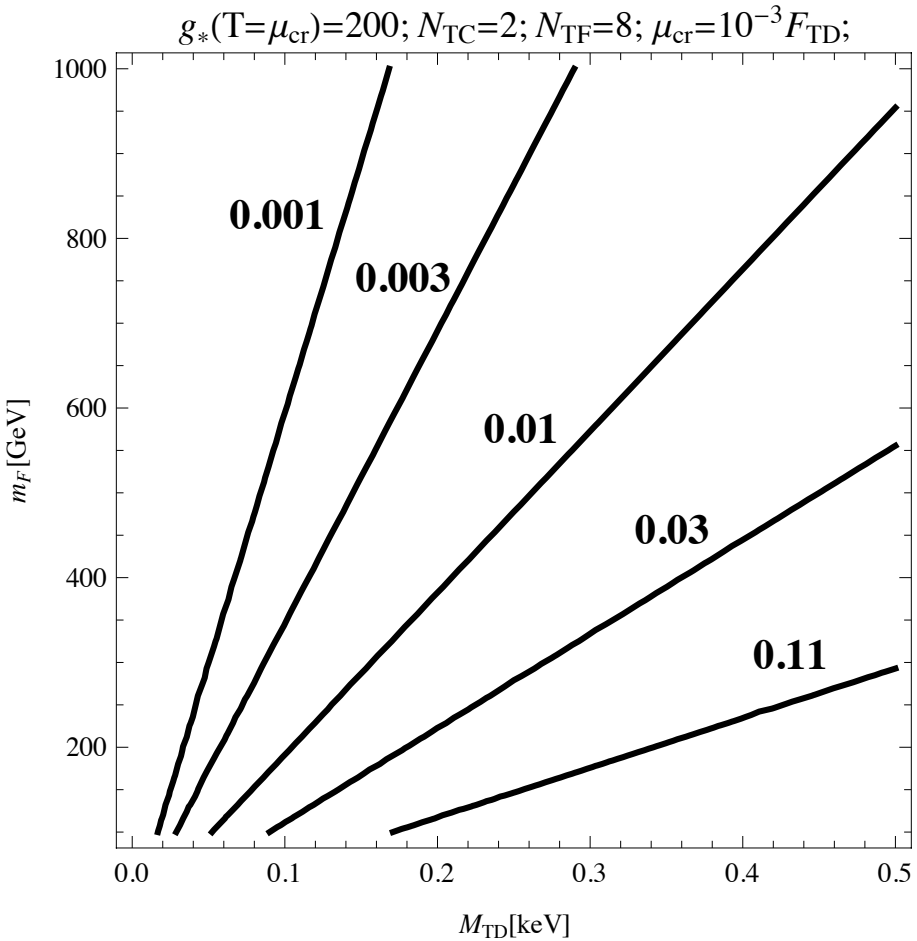

Dark matter TD

- Non-thermal production of TD due to mis-alignment. TD potential is determined by scale anomaly (Schechter '80):

$$\frac{V(\sigma_D)}{F_{\rm TD}^2 m_{\rm TD}^2} \simeq \left(\frac{\sigma_D}{2F_{\rm TD}}\right)^2 \left[\log\left(\frac{2\sigma_D}{F_{\rm TD}}\right)^2 - 1\right]$$

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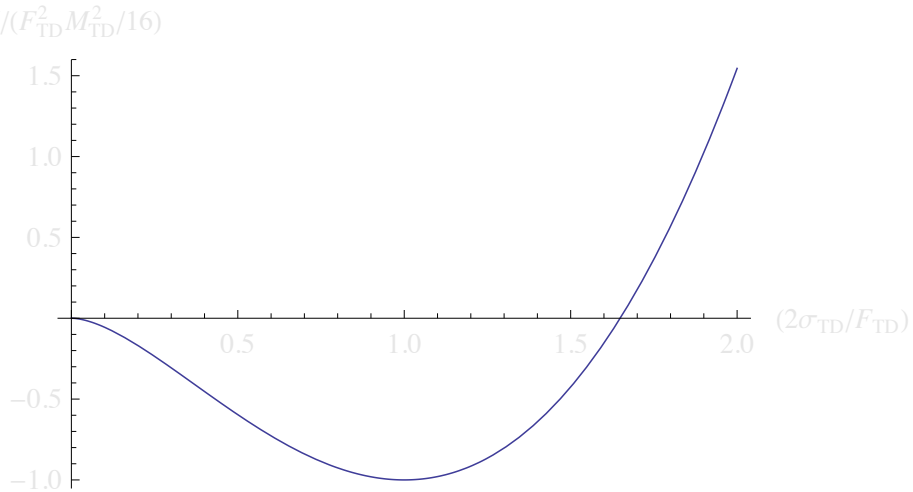

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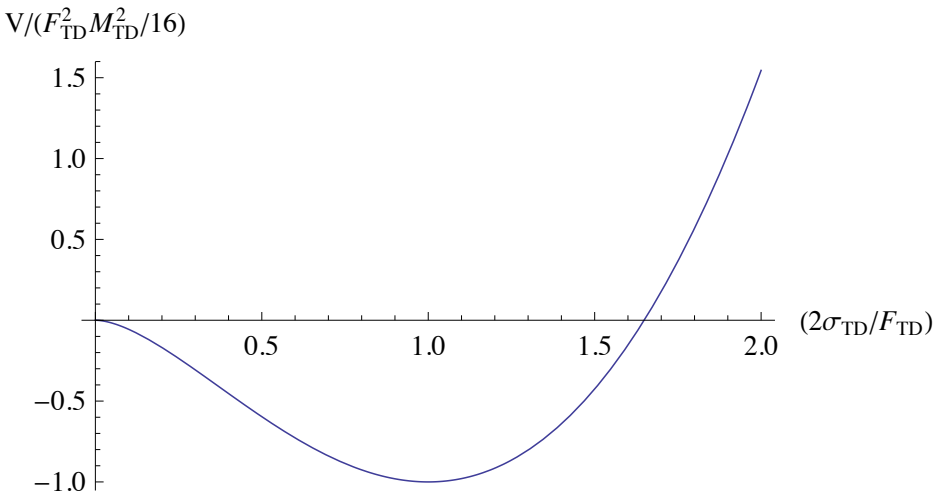

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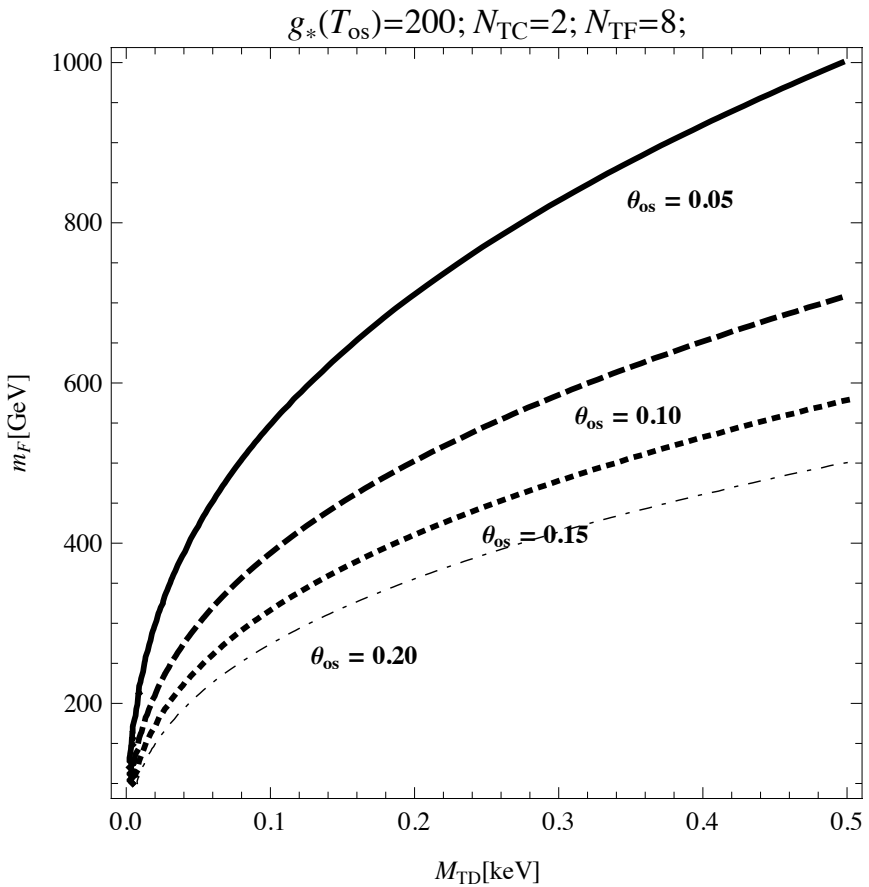

Conclusion

- WTC predicts very light technidilaton (TD) due to spontaneously broken (approximate) scale symmetry.
- If the critical coupling, α_c, for chiral symmetry breaking is very close to the (quasi) Banks-Zaks IR fixed point of WTC, large hierarchy is dynamically generated:

$$m_F \approx \Lambda_{TC}\, e^{-\frac{\pi\alpha_c}{\sqrt{\alpha-\alpha_c}}}\,.$$

- By PCDC we have $m_{TD} \ll m_F \ll F_{TD}$.
- TD can be a good candidate for dark matter.
- Cosmological and astrophysical constraints require

$$0.01\ \mathrm{eV} \lesssim m_{TD} \lesssim 500\ \mathrm{eV}$$

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