From the Higgs Mechanism to Dark matter and the Cosmological Constant

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Outline

- Motivations,
- Composite/Holograpic Higgs models,
- Holographic Dark Matter $(\mathcal{H}DM)$ [a]
  - $SU(3)$ and $SO(5)$ models
  - Constraints from Relic Density
  - Search for dark matter
- Discrete Higgs and the Comological Constant [b]
- Conclusions

[a] J.L. Diaz-Cruz, Phys.Rev.Lett.100:221802,2008.

[b] P. Amore, A. Aranda, J.L. Diaz-Cruz, arXiv:0808.0028 [hep-ph]

1.1 Introduction: The Higgs sector

- Something is needed to generate SM masses (= The Higgs sector),
- Minimal SM contains one Higgs doublet ($\rightarrow h$),
- EWPT favors a light Higgs boson, i.e. $m_h \leq 180$ GeV $\simeq m_W$.
- LHC is expected to find the SM Higgs boson or some of its extensions.
- Stability of Higgs mass $\rightarrow$ Hierarchy problem.

$$M_h^2 = M_{h0}^2 + \frac{c}{16\pi^2}\Lambda_{new}^2 \qquad (1)$$

- Open problems of SM $\rightarrow$ Physics Beyond the SM.

1.2 Proposals to solve hierarchy problem

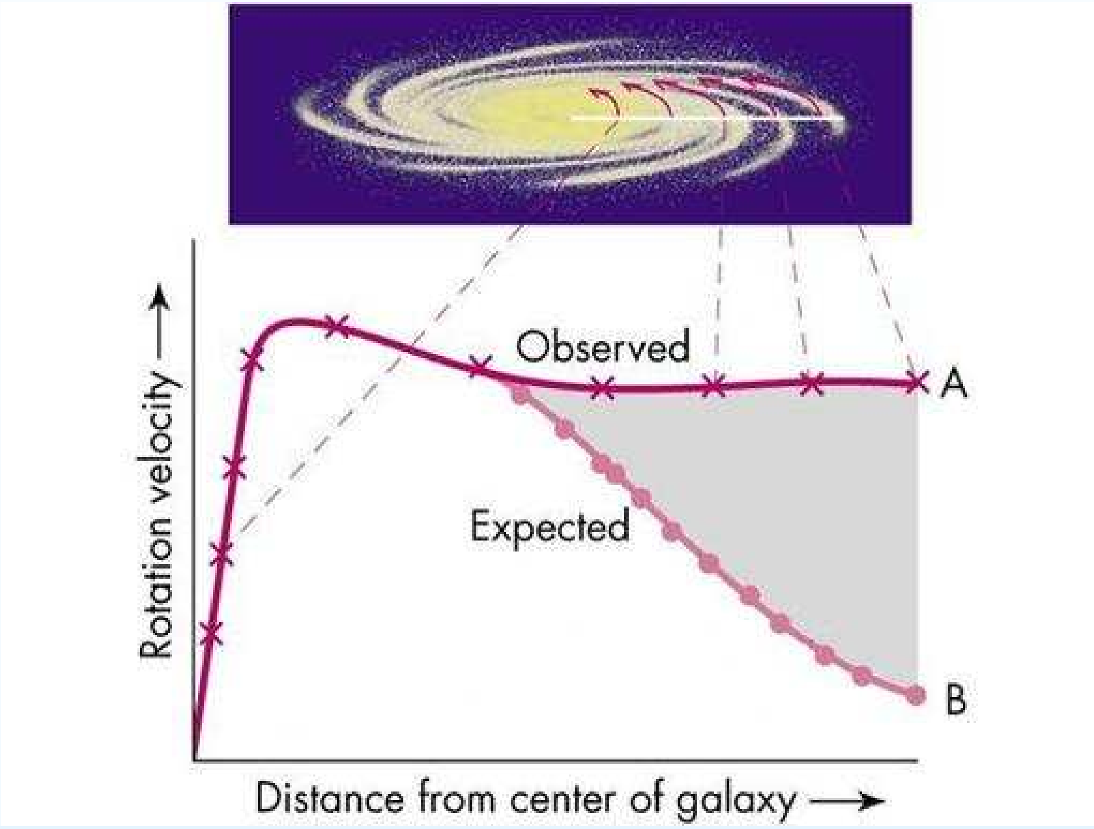
- Accidental cancellation,

$$\lambda = y_t^2 - \frac{1}{8}[3g^2 + g'^2] \tag{2}$$

- New Strongly interacting scenarios (TC, Composite Higgs, TopC),
- Supersymmetry,
- Extra dimensions,
- Salsa

1.3 Why we need Dark matter (DM)?

Rotation curves of galaxies are not explained by “bright” matter, i.e.

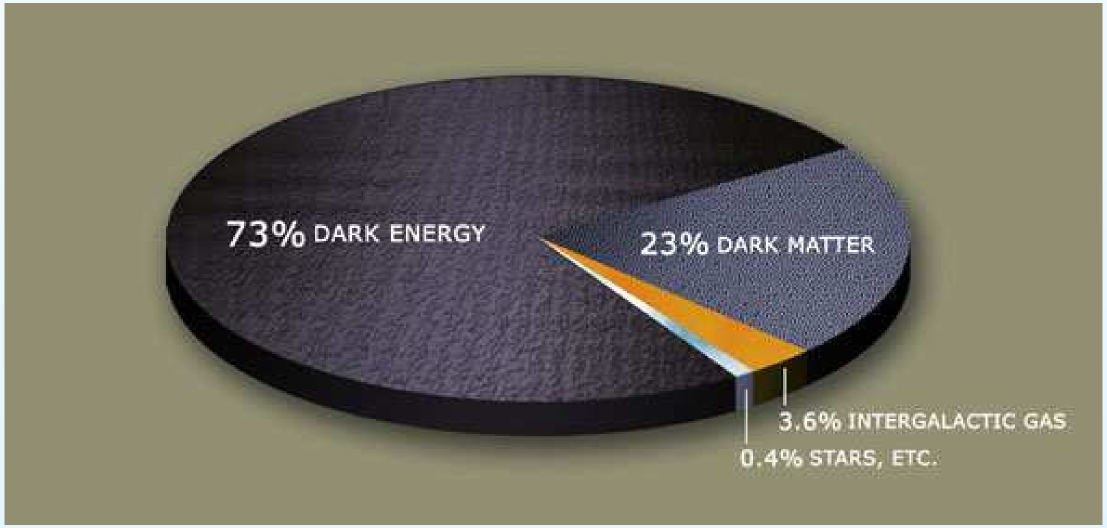


More matter (Dark) is needed.

1.4 How much Dark matter (DM)?

Other evidence:

- Dynamics of galaxie clusters,
- Flatness of the universe, i.e. $\Omega = \frac{\rho_m}{\rho_c} = 1$,
- CMB radiation spectrum,



1.5 What is Dark Matter??

- The relics density of DM can be estimated as:

(3)
$$\Omega h^2 \simeq \frac{3 \times 10^{-27}\, cm^3/s}{<\sigma v>}$$

- To get $O(10-20)\,\%$ DM, for $M_X \simeq O(m_W)$ one needs σ of weak strength (A coincidence?),
- Thus, most viable DM is a weakly interacting particle (WIMP),
- Many models of Physics BSM predict stable neutral particles that could play the role of WIMPS.

1.6 WIPM candidates

- SUSY: R-parity $\longrightarrow$ Lightest SUSY particle (LSP) is stable
  - Neutralino,
  - Gravitino,
  - Sneutrino.
- Little Higgs: Lightest T-odd particle (LTP),
- Universal XD: Lightest KK-particle (LKP)
- Other BSM scenarios: LOP, LZP,.., etc.

Here, we study the viability of a DM candidate within the context of Composite (Holographic) Higgs models.

1.6 Is there a connection DM-Higgs??

- Higgs boson and WIMP masses of O(EW scale), suggest that there could be a connection between them.
- Within the Holographic models, the composite Higgs arises as a PGB,
- The Higgs boson role is similar to the pion ($\pi^{0,\pm}$), which is a PGB of χSB,
- But in ordinary Hadron Physics, we know that there is also a heavier stable baryon (the proton),
- Thus, we can look for a similar “Baryonic” state (but neutral), which would play the role of dark matter.

2.1 Holograhic Higgs models (HHM)

- Composite Higgs models were proposed in early 80's. (Georgi et al $\rightarrow$ Higgs as a PGB)
- HHM [a] are composite Higgs models, which admit a dual description:
- From 4D perspective there are bound states of conformal sector, and Higgs arises as PGB.
- From 5D perspective HHM can be interpreted as GH unified models.
- 5D helps to calculate Higgs properties.

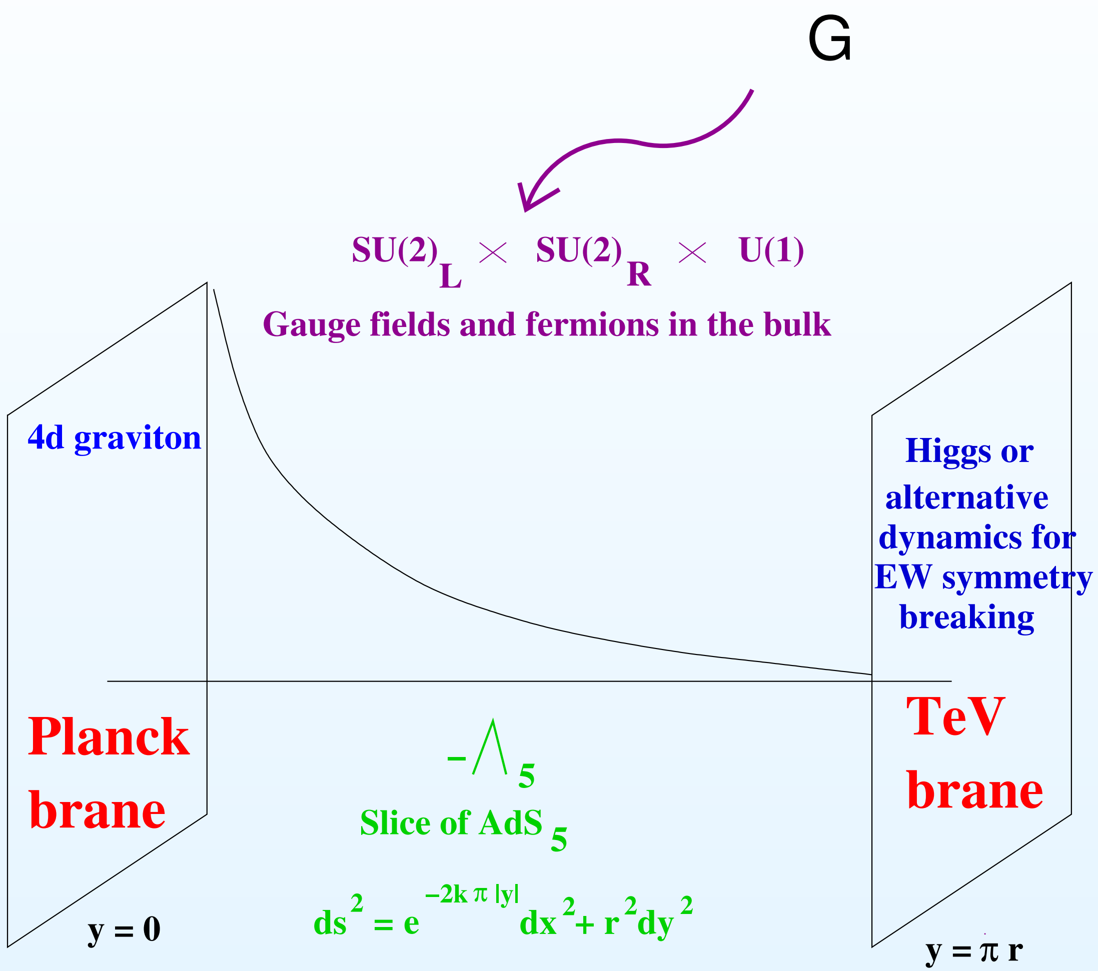
[a] 1) R. Contino, Y. Nomura and A. Pomarol, Nucl. Phys. B **671**, 148 (2003). [arXiv:hep-ph/0306259].

2) K. Agashe, R. Contino and A. Pomarol, Nucl. Phys. B **719**, 165 (2005). [arXiv:hep-ph/0412089].

2.2 Holograhic Higgs models: 4D

- HHM contains: SM and strong sectors:
- SM sector includes gauge and most SM fermions (g denotes SM couplings),
- Strongly int. sector has global symmetry G ($\to g_*$ and scale M_R),
- Global symmetry G breaks $\to H$. Higgs doublet arises as PGB ($\to f_\pi$) and $M_R \simeq 4\pi f_\pi$,
- Higgs potential vanishes at tree-level because of G,
- SM interactions induce the Higgs potential and EWSB,
- Corrs. to EW observables depends on $\epsilon = \frac{v}{f_\pi} \leq 1$,

2.3 5D Randall-Sundrum SM



2.4 Holographic Higgs models: 5D RS-SM

- RS is defined on 5D AdS, with two branes: Planck and TeV.
- Hierarchy problem is solved if Higgs doublet lives in TeV (IR) brane,
- Gauge bosons can live in the bulk,
- Most SM fermions also live in the bulk,
- Top quark (b?) lives near TeV brane (at $z = L_1 \simeq 1/TeV$).
- The Higgs mass is calculable,

$$m_h^2 \simeq \frac{1}{16\pi^2} \frac{c}{L_1^2}, \tag{4}$$

- Higher-dims. operators affect Higgs properties, and could be tested at LHC/ILC.

3.1 Holographic DM models

- In hadron/QCD physics: meson (pion) arises as a PGB of chiral symmetry, while a Baryon state (proton) is stable,
- We propose that a similar state (X^0) appears ($L\mathcal{H}P$) in $\mathcal{H}HM$.
- X^0 is stable because of an assumed conserved quantum number (Dark number) [a],
- The expected mass of X^0 is $M_{X^0} \simeq M_R = O(TeV)$,
- Effective Lagrangian includes ren. and non-ren. operators.

[a] A similar state has been found by Pomarol and A. Wulzer, arXiv:0712.3276 [hep-th], using the Skyrme model in 5D AdS

3.2 Holographic DM quantum numbers

- Simplest HHM contains $G = SU(3) \times U(1)_X$, with
- SM quarks and leptons appear in complete multiplets of $SU(3)$, while X-charge is choosen to satisfy:

$$Y = \frac{T_8}{\sqrt{3}} + X, \tag{5}$$

- Holographic Dark Matter ($\mathcal{H}DM$) X^0 must also appear in multiplets of $SU(3)$ (table 2)
  - Active HDM
  - Sterile HDM
- More realistic models with $\mathcal{H}DM$ within $G = SO(5) \times U(1)_x$, are also contained in table 2.

3.3 Holographic DM ($\mathcal{H}DM$) models

$U(1)_X$	G-multiplets	H-multiplets
$+\frac{1}{3}$	$\mathbf{3}^*$: $\Psi_1 = (N_1^0, C_1^+, N_2^0)$	$\mathbf{2}^*$: $\psi_1 = (N_1^0, C_1^+)$
		LHP: 1) $X^0 = N_1^0$ (Active) 2) $X^0 = N_2^0$ (Sterile)
$+\frac{2}{3}$	$\mathbf{3}^*$: $\Psi_2 = (N_3^0, C_2^+, C_3^+)$	$\mathbf{2}^*$: $\psi_2 = (N_3^0, C_2^+)$
LHP:		3) $X^0 = N_3^0$ (Active)
0	$\mathbf{8}$: $\Psi_3 =$full octet mult.	$\mathbf{3_{Y=0}}$: $\psi_3 = (C_4^+, N_4^0, C_5^-)$
LHP:		4) $X^0 = N_4^0$ (Active)
1	$\mathbf{8}$: $\Psi_4 =$full octet mult.	$\mathbf{3_{Y=1}}$: $\psi_4 = (C_1^{++}, C_6^+, N_5^0)$
LHP:		5) $X^0 = N_5^0$ (Active)

Table 1: LHP candidates within the $SU(3) \times U(1)_X$ models

4.1 Relic Density Constraints: Active DM models

- The relic density can be written as [a]:

$$\Omega_X h^2 = \frac{2.57 \times 10^{-10}}{< \sigma v >} = \frac{2.57 \times 10^{-10} M_X^2}{C_{T,Y}} \quad (6)$$

  $C_{T,Y}$ depends on isospin (T) and hypercharge (Y) of LHP.

- Numerical values of $C_{T,Y}$ for the lowest-dim. reprs. are: $C_{1/2,1/2} = 0.004$, $C_{1,0} = 0.01$, $C_{1,1} = 0.011$.
- Current data, $\Omega_X h^2 = 0.11 \pm 0.066$ (WMAP^2), [b] implies $M_X = 1.3$ TeV models 1,3, and $M_X = 2.1$ $(M_X = 2.2)$ TeV for models 4(5), respectively.

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[a] 3) M. Cirelli, N. Fornengo and A. Strumia, Nucl. Phys. B **753**, 178 (2006). [arXiv:hep-ph/0512090]

[b] 4) D. N. Spergel *et al.* [WMAP Collaboration], Astrophys. J. Suppl. **170**, 377 (2007). [arXiv:astro-ph/0603449]

4.2 Search for $\mathcal{H}DM$

- CDMS^3 limits on direct DM search, are based on the nucleon-LHP scattering [a],
- The cross section can be expressed as: $\sigma_{T,Y} = \frac{G_F^2}{2\pi} f_N Y^2$, where f_N depends on the type of nucleus used in the reaction.
- Models with $Y \neq 0$ are severely constrained, unless one introduces a suppresion mechanism.
- For model 1, the cross-section for $DM + N \rightarrow DM + N$ can then be written as: $\sigma = \frac{G_F^2}{2\pi} f_N \eta'^2$.
- CDMS bounds requires then $|\eta'|^2 \leq 10^{-2} - 10^{-4}$, which seems reasonable.
- DM model 3 (with $Y = 0$) automatically satisfies this bound.

[a] 5) D. S. Akerib *et al.* [CDMS Collaboration], PRL **96**, 011302 (2006)

4.3 Sterile $\mathcal{H}DM$

The couplings of X^0 with the SM gauge and Higgs bosons, arise from the higher-dimensional operators, which include:

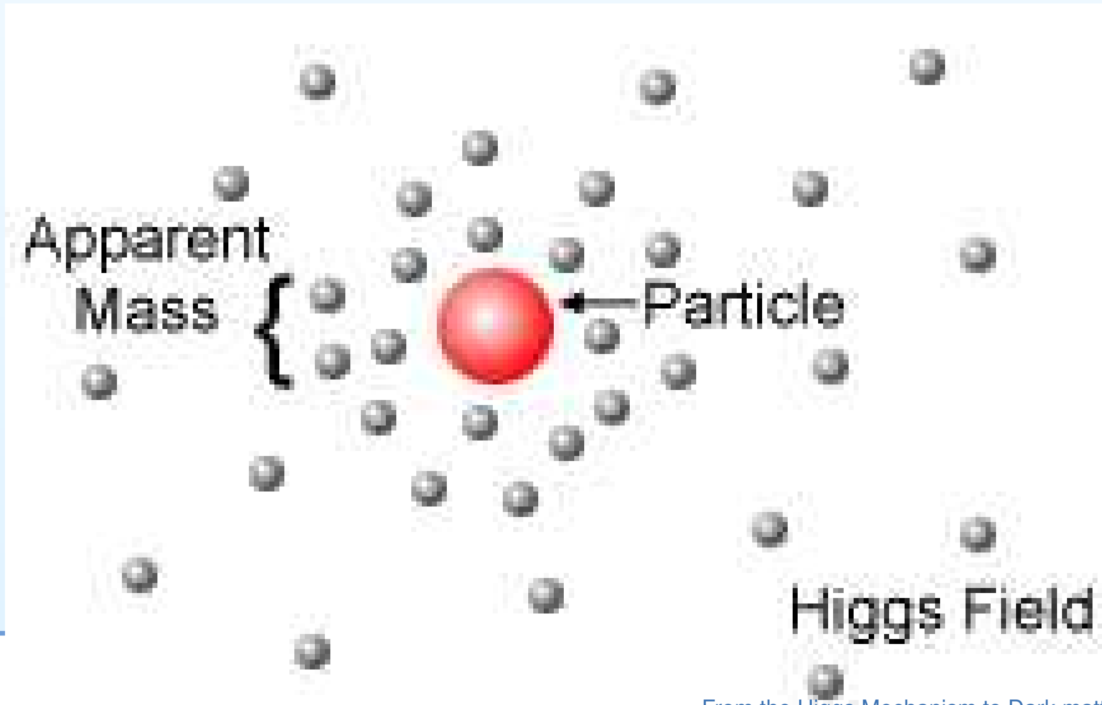
- 4-fermion operators, e.g.
  $O^1_{FX} = \frac{1}{2}(\bar{F}\gamma^\mu F)(\bar{X}\gamma_\mu X)$, $O^1_{fX} = \frac{1}{2}(\bar{f}\gamma^\mu f)(\bar{X}\gamma_\mu X)$,
  $O^V_{FX} = \frac{1}{2}(\bar{F}\gamma^\mu X)(\bar{X}\gamma_\mu F)$, $O^V_{fX} = \frac{1}{2}(\bar{f}\gamma^\mu X)(\bar{X}\gamma_\mu f)$,
  $O^S_{FX} = \frac{1}{2}(\bar{F}X)(\bar{X}F)$, $O^S_{fX} = \frac{1}{2}(\bar{f}X)(\bar{X}f)$,
- Fermion-scalar operator: $O_{X\phi} = (\Phi^\dagger\Phi)(\bar{X}X)$,
- Fermion-vector-scalar operator: $O_{DX} = (\Phi^\dagger D^\mu\Phi)(\bar{X}\gamma_\mu X)$.
  where $F(f)$ denote the SM fermion doublet (singlet).

4.4 Sterile $\mathcal{H}DM$: Analysis based on O_{DX}

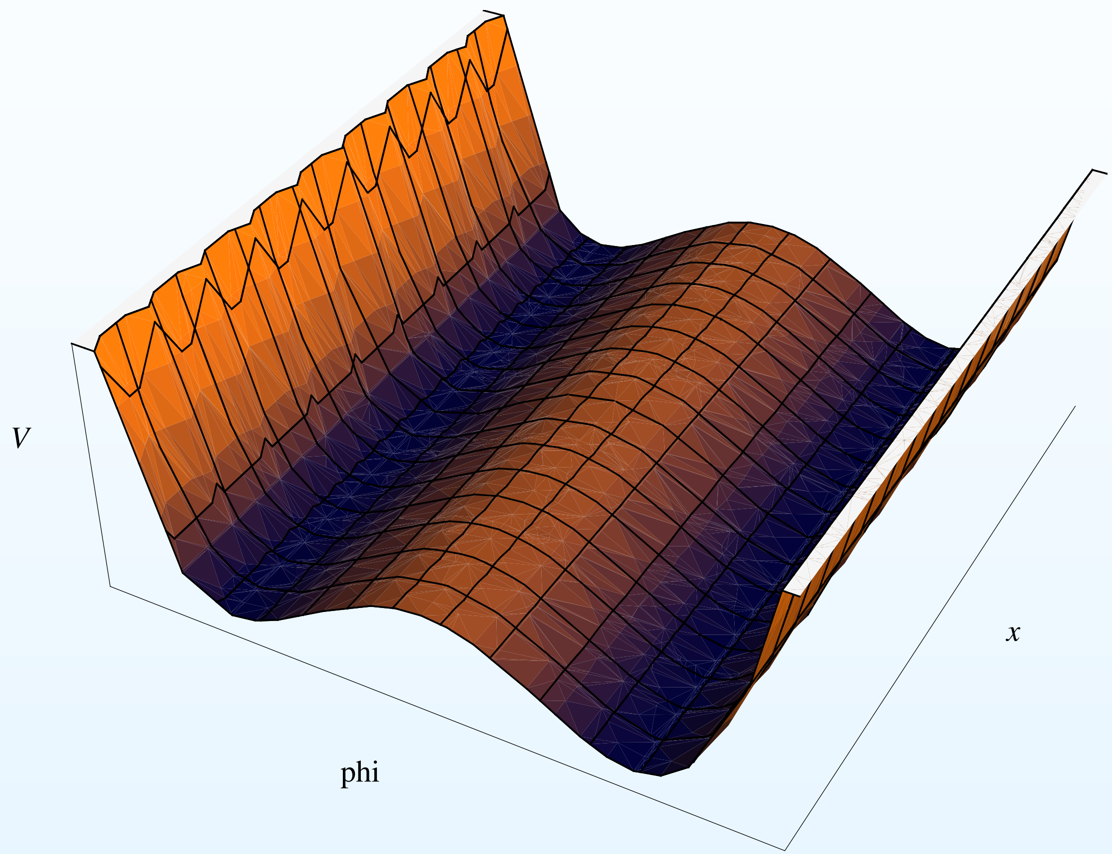
- The operator O_{DX}, induces an effective vertex ZX^0X^0: $\Gamma_{ZXX} = \frac{g}{2c_W}\eta\gamma^\mu$, with $\eta = 2c_x g c_w v^2/M_R^2$, and c_x being the coefficient of O_{DX}.
- Then, WMAP data on $\Omega_X h^2$ implies: $M_X \simeq 0.8\eta$ TeV. Thus, for M_X of order TeV, one has $\eta \geq 1$.
- The nucleon-LHP cross-section, satisfies the current limits, provided that the factor η satisfies $|\eta|^2 \leq 10^{-2} - 10^{-4}$,
- Given these results, the sterile dark matter candidate (Model 2) seems disfavored.

5.1 Discrete Higgs and Λ

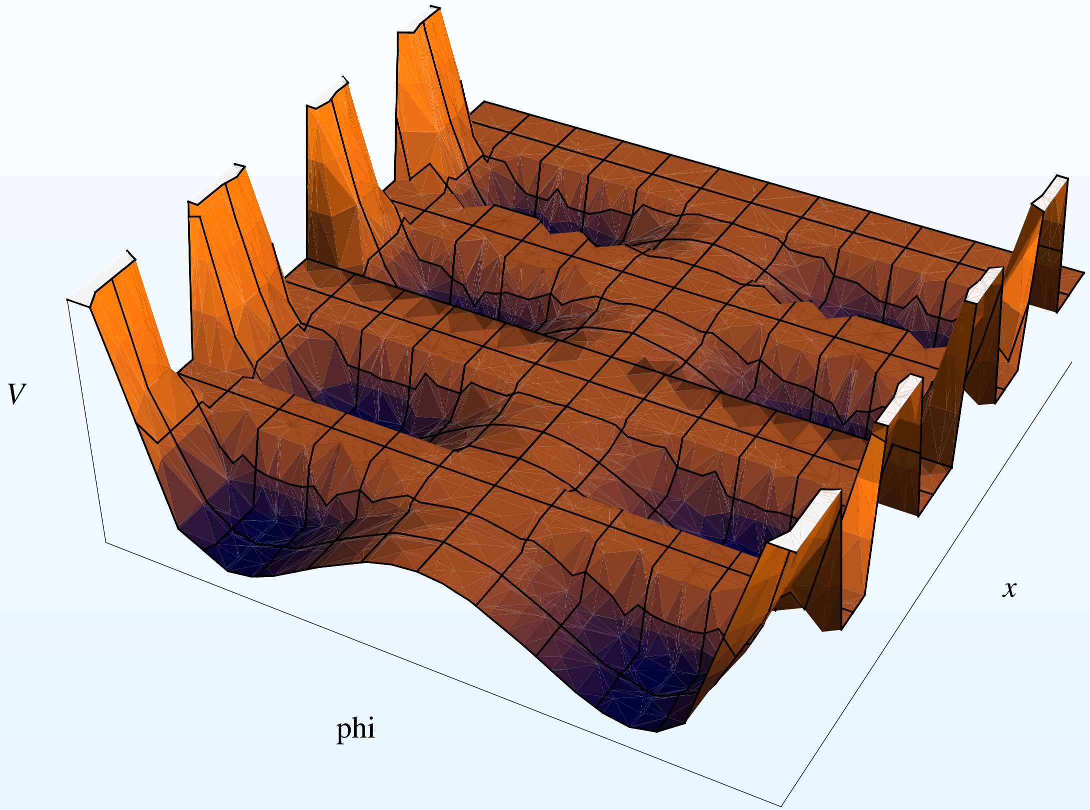
- EWSB contributes to the cosmological constant: $\Lambda_{EW} \simeq \lambda v^4 = 10^9\ GeV^4$,
- However, the meassured values is: $\Lambda \simeq 10^{-47}\ GeV^4$,
- χSB and quantum fluctuations contribute to Λ too,
- We propose that the vaccuum contains “droplets” of vev, whose size and density can be adjustet to explain Λ_{EW},



5.2a SM Higgs Mechanism



5.2b Discrete Higgs model



5.3 Discrete Higgs and Λ_{EW}

- Assume that size and density of the droplest is constant. Let r_d, τ_d, ρ_d be the radius, volume and density of such droplets,
- The contribution of droplets to vacuum density is: $\Lambda_{DEW} \simeq \rho_d \tau_d \Lambda_{EW}$,
- The distance betwen droplets (l_d) should be smaller than shortest distance being tested, i.e. $l_d \leq 10^{-15}$ cm.
- Therefore: $\rho_d \tau_d \simeq r_d^3 / l_d^3 \simeq 10^{-56}$, which means r_d is of order of the Planck distance!!.
- Higgs couplings with fermions and gauge bosons will decreasse with energy. (Could they be testeed at LHC?).

6. Conclusions

- DM candidate can be identified within Holographic Higgs models,
- Two possiblities: Active and sterile $\mathcal{H}DM$,
- Active Holographic Dark Matter is viable, with $M \simeq O(1)$ TeV,
- Sterile $\mathcal{H}DM$ seems disfavored, but complete analysis needed.
- More work also needed to study signatures of active HDM. e.g. $X^0 X^0 \rightarrow X^+ X^-$ at AGNs (contribution to UHECR?).
- Discrete Higgs can explain smallness of EWSB constribution to Λ.