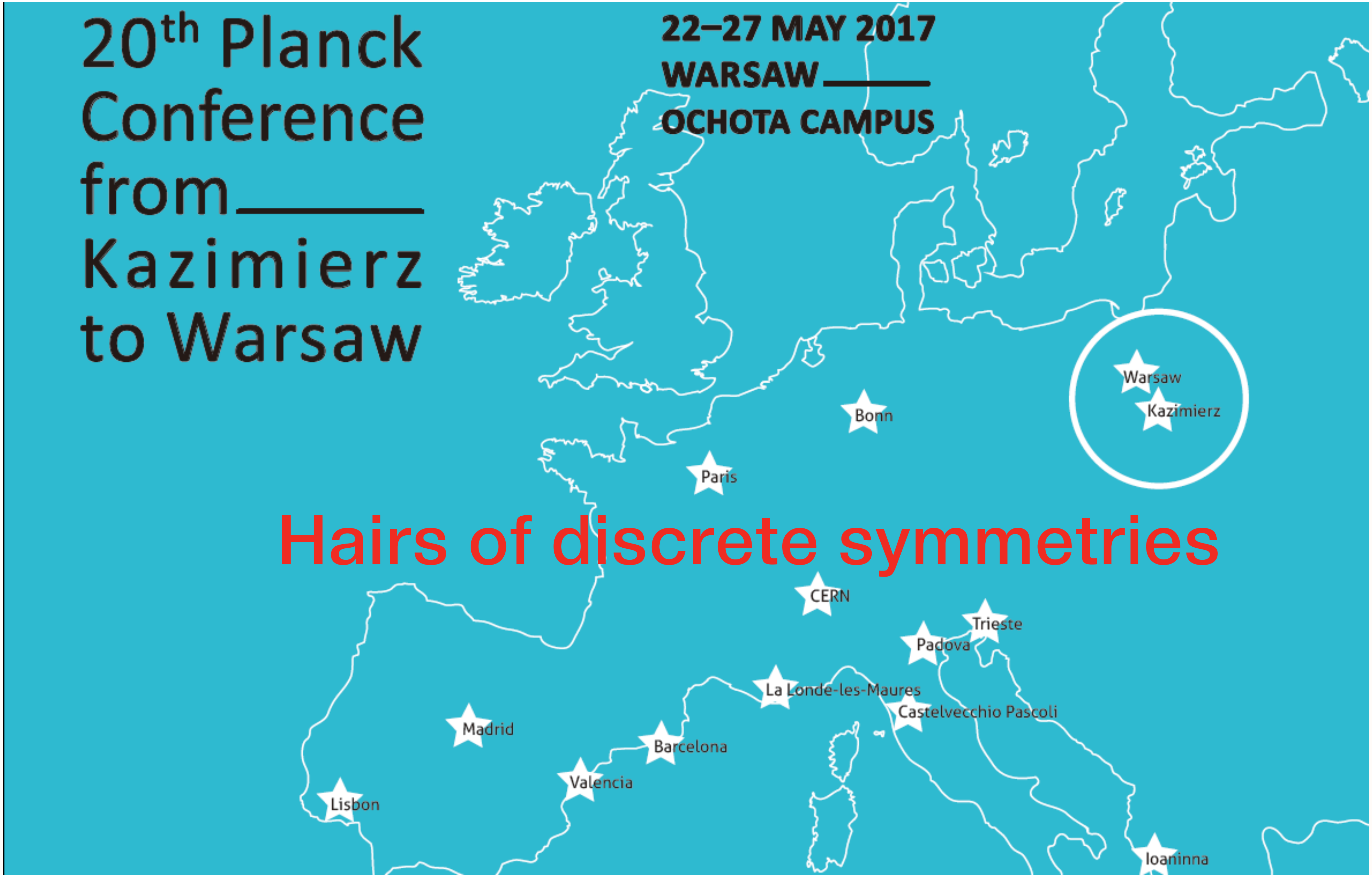
Hairs of discrete symmetries



Hairs of discrete symmetries

(Top-down and bottom-up models)

Jihn E. Kim

Kyung Hee University,
CAPP, IBS,
Seoul National Univ.

Warsaw, 26 May 2017

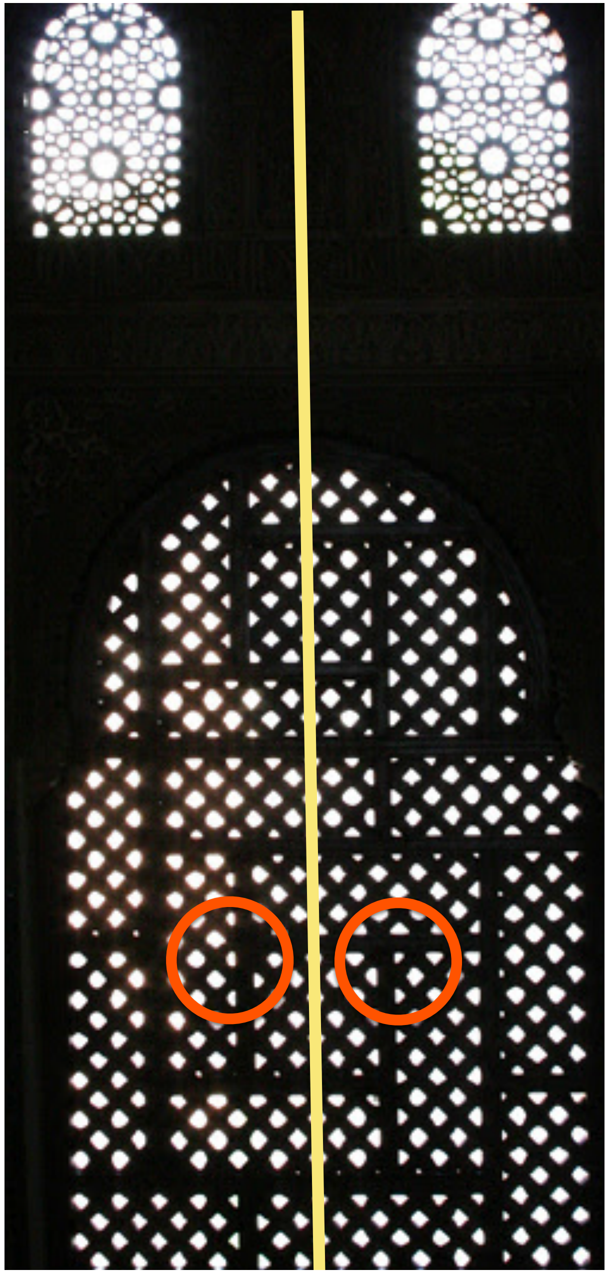
arXiv:1703.05389 [hep-th]

1. Discrete gauge symmetries


Search has begun with symmetry principles

Symmetry is beautiful: a framework, beginning with Gross' grand design.

Parity: Slightly broken!



From top-down approach:

Discrete symmetries are better to be subgroups of gauge symmetries such that spontaneous breaking of the gauge symmetries to those discrete groups do not lead to any unsatisfactory behavior. [Krauss-Wilzek (1989)]

This defines 'discrete gauge symmetries'

Discrete gauge symmetries have been used practically in most model buildings afterwards.

From top-down view of electroweak scale:

Chiral representations at the GUT scale are the key in obtaining the SM at low energy. The choice of 200 GeV as a low energy scale depended on the details of parameters.

At this conference many other reasons were given for the scale of the SM.

The SM is a chiral model.

$$\begin{array}{ccc} & \begin{pmatrix}\nu\\ e\end{pmatrix}_L, & e^c_L \\ Y= & \dfrac{-1}{2} & +1 \end{array}$$

Tr Y=0,

$$\mathrm{Tr}\,Y^3 = 2\left(-\frac{1}{2}\right)^3 + (+1)^3 = +\frac{3}{4}$$

Lepton part alone cannot give a chiral model.
Factionally charged quarks are needed.

$$\begin{array}{cccc} & \begin{pmatrix}u\\ d\end{pmatrix}_L, & u^c_L, & d^c_L \\ Y= & \dfrac{+1}{6} & \dfrac{-2}{3} & \dfrac{+1}{3} \end{array}$$

Tr Y=0,

$$\mathrm{Tr}\,Y^3 = 6\left(+\frac{1}{6}\right)^3 + 3\left(-\frac{2}{3}\right)^3 + 3\left(+\frac{1}{3}\right)^3 = -\frac{3}{4}$$

The Han-Nambu model also works. The color was first introduced. The problem was known in the paper of Okubo's Omega minus particle prediction.

$$\mathrm{SU}(3): \ \text{Vectorlike representations, hence not allowed,}$$
$$\mathrm{SU}(2)\times\mathrm{SU}(2): \ \text{No chiral theory with even number of doublets,}$$
$$\mathrm{U}(1)\times\mathrm{U}(1)': \ \text{Six conditions for the absence of anomalies, } \{\mathrm{Tr}Y, \mathrm{Tr}Y', \mathrm{Tr}Y^3, \mathrm{Tr}Y'^3, \mathrm{Tr}YY'^2, \mathrm{Tr}Y^2Y'\} = 0$$

$$\mathrm{SU}(2)\times\mathrm{U}(1): \ \text{Two conditions with doublets and singlets, } \{\mathrm{Tr}Y, \mathrm{Tr}Y^3\} = 0.$$

$$\sum_{i=1}^{4N} Q_i^3 = \left(\sum_{i=1}^{4N} Q_i\right)\left(\sum_{i=1}^{4N} Q_i^2 - \sum_{i\neq j}^{4N} Q_iQ_j\right) + 3\sum_{i\neq j\neq k}^{4N} Q_iQ_jQ_k = 0.$$

$$\sum_{i=1}^{4N} Q_i = 0, \qquad \sum_{i=1}^{4N} Q_i^3 = \left(\sum_{i=1}^{4N} Q_i\right)\left(\sum_{i=1}^{4N} Q_i^2 - \sum_{i\neq j}^{4N} Q_iQ_j\right) + 3\sum_{i\neq j\neq k}^{4N} Q_iQ_jQ_k = 0.$$

There is a chiral model.

$$Q=\frac{1}{2}: \quad \ell_i=\begin{pmatrix} E_i \\ N_i \end{pmatrix}_{\frac{+1}{2}}, \quad \begin{matrix} E^c_{i\,,-1} \\ N^c_{i\,,0} \end{matrix}, \quad (i=1,2,3)$$

$$Q=-\frac{3}{2}: \ \mathcal{L}=\begin{pmatrix} \mathcal{E} \\ \mathcal{F} \end{pmatrix}_{\frac{-3}{2}}, \quad \begin{matrix} \mathcal{E}^c_{,+1} \\ \mathcal{F}^c_{,+2} \end{matrix}$$

$$\operatorname{Tr} Q^3 = 3\left[2\left(\frac{+1}{2}\right)^3 + (-1)^3\right] \qquad \frac{-9}{4}$$

$$+\,2\left(\frac{-3}{2}\right)^3 + (+1)^3 + (+2)^3 \qquad \frac{-27+4+32}{4}$$

Three families and the new chiral model appear together in string compactification (orbifold Z(12-I)).

A hope to detect this new chiral representation, at LHC:

Kim, arXiv:1703.10925 [hep-ph]

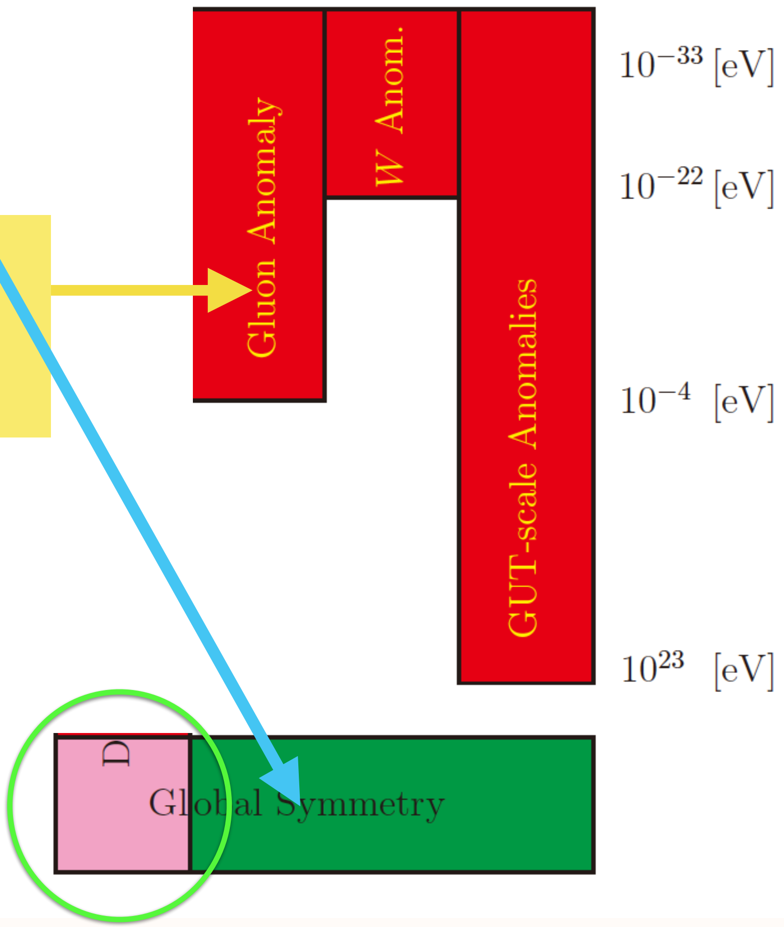
2. Approximate global symmetries

After the Brout-Englert-Higgs-Guralnik-Hagen-Kibble mechanism has been accepted, we do not talk about approximate gauge symmetries. But, even now we use the word, "approximate global symmetries".

If the discrete symmetries are subgroups of gauge groups, then we do not talk about approximate discrete symmetries. But, if a discrete symmetry is a subgroup of global symmetries, then we can talk about approximate discrete symmetries.

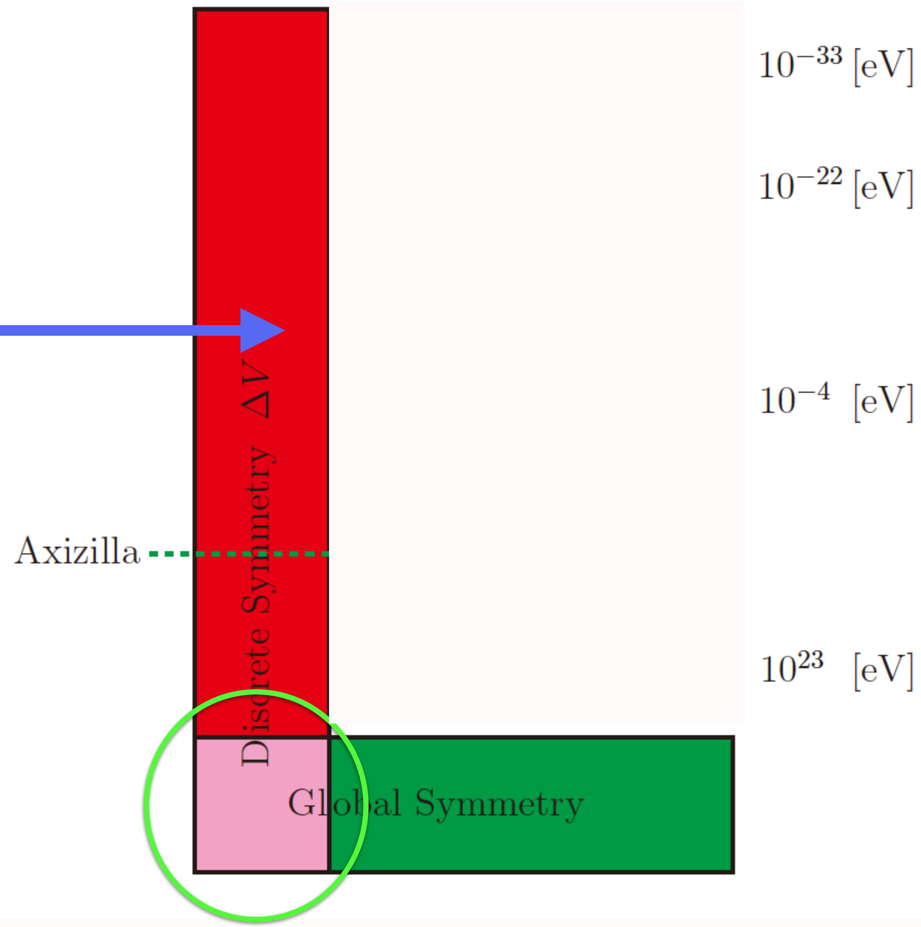
From the exact global symmetry.

This anomaly breaks the PQ symmetry.



VEV of scalar phi gives the f_a scale.

Except the anomalous U(1), any global symmetry does not have anomalies from string theory. So, this V is present.



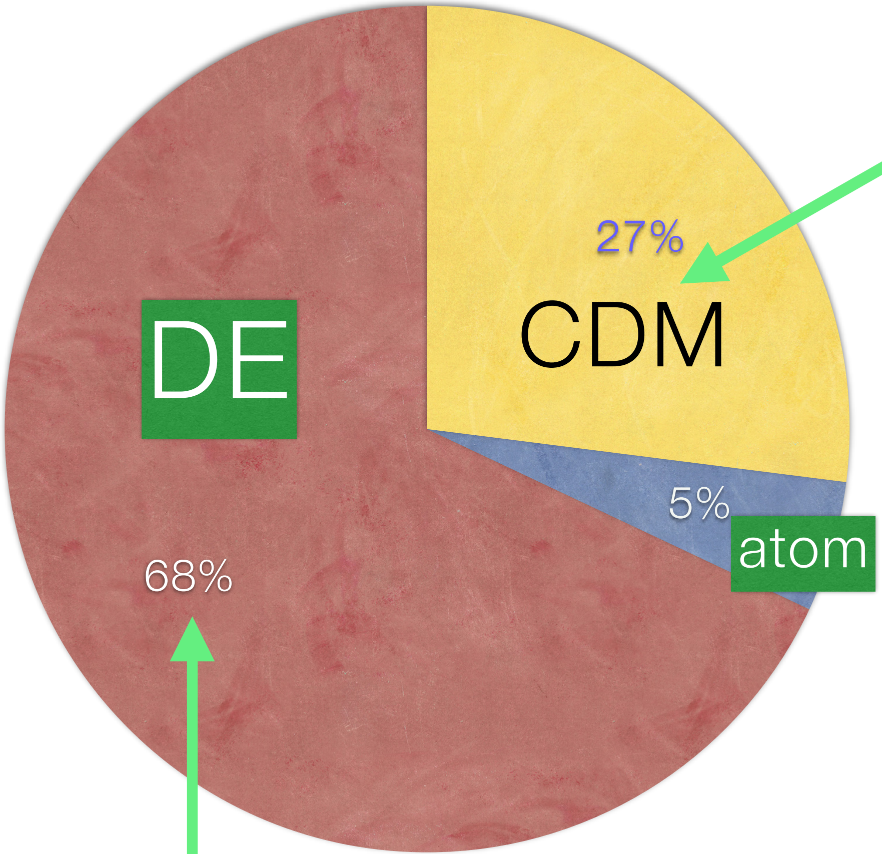
Quintessential axion

ULA

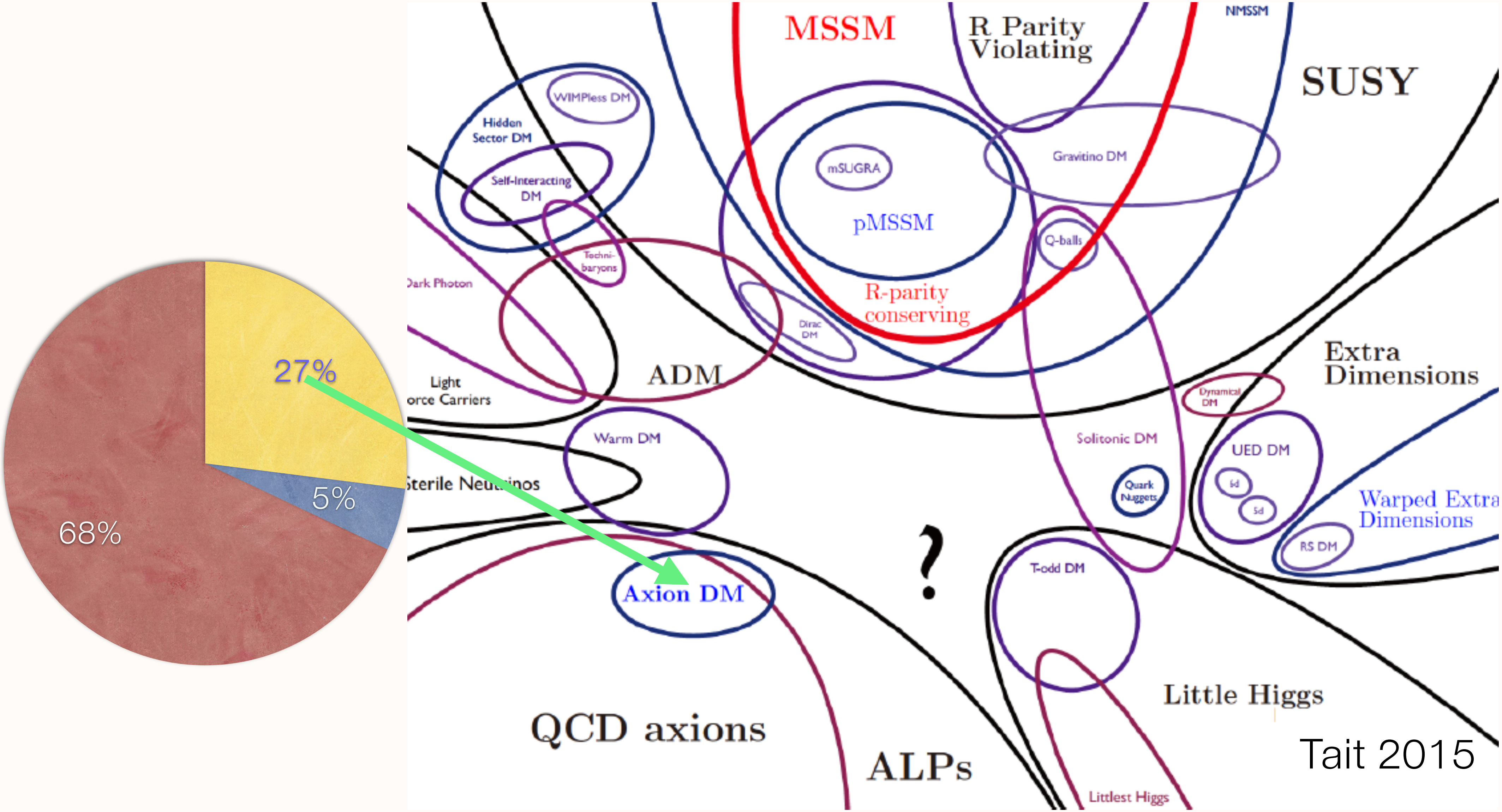
ALPs

Still the question is at what level? If one allows the discrete symmetry from string.

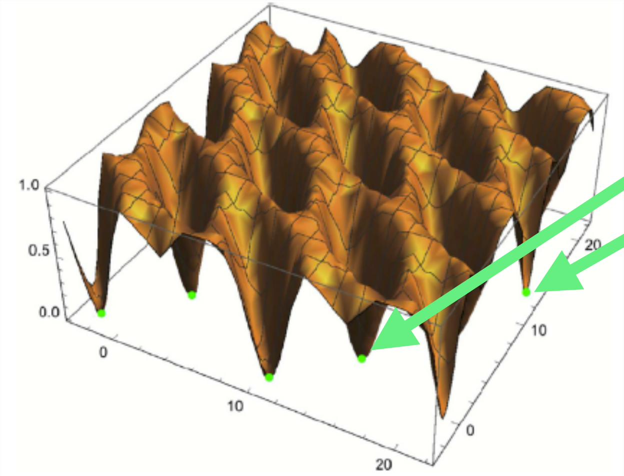
Detection of “invisible” axion CDM by cavity detectors: CAPP, IBS



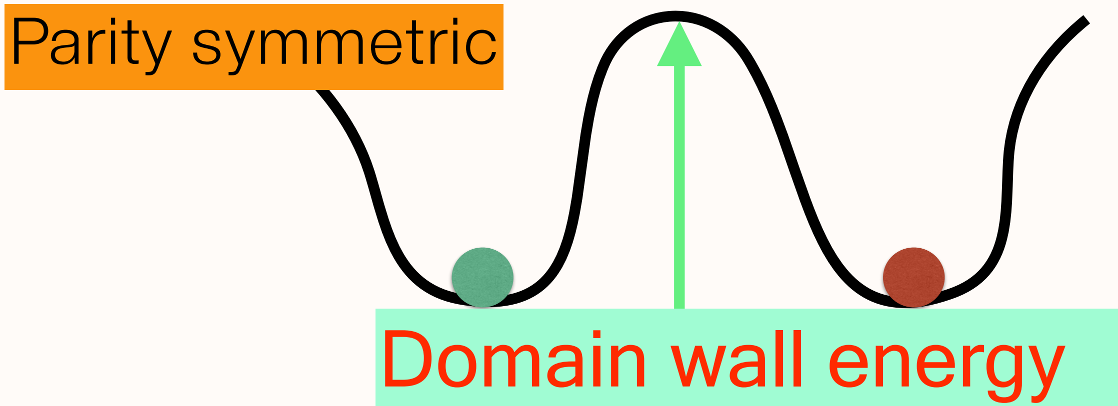
Quintessential axion


27%
5%
68%
MSSM
R Parity Violating
NMSSM
SUSY
WIMPless DM
Hidden Sector DM
Self-Interacting DM
Techni-baryons
Dark Photon
Light Force Carriers
ADM
mSUGRA
pMSSM
Gravitino DM
Q-balls
R-parity conserving
Dirac DM
Extra Dimensions
Dynamical DM
Warm DM
Sterile Neutrinos
Solitonic DM
UED DM
Quark Nuggets
Warped Extra Dimensions
RS DM
Axion DM
?
T-odd DM
Little Higgs
QCD axions
ALPs
Littlest Higgs
Tait 2015

2. Discrete symmetries and domain walls

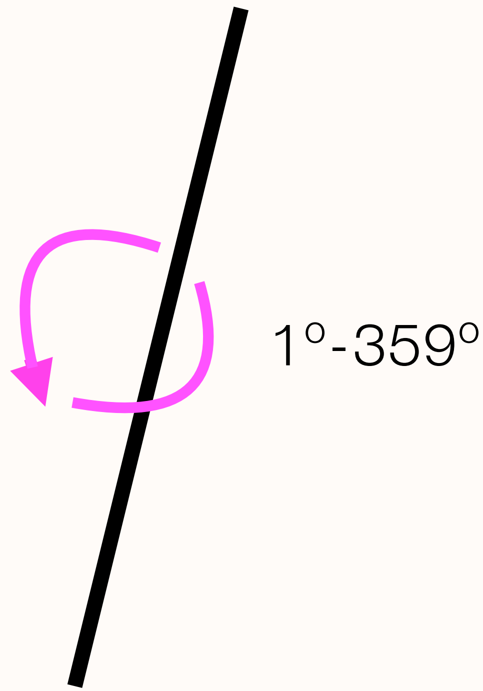


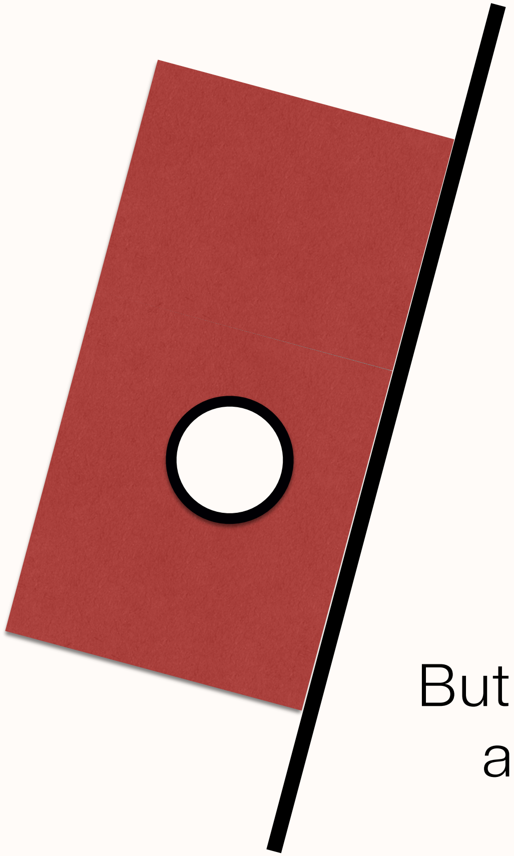
Vacua settle in the evolving Universe lead to domain walls. Basically, the discrete symmetry is not assumed to be broken. Spontaneous breaking of the discrete symmetry is in the evolving Universe.



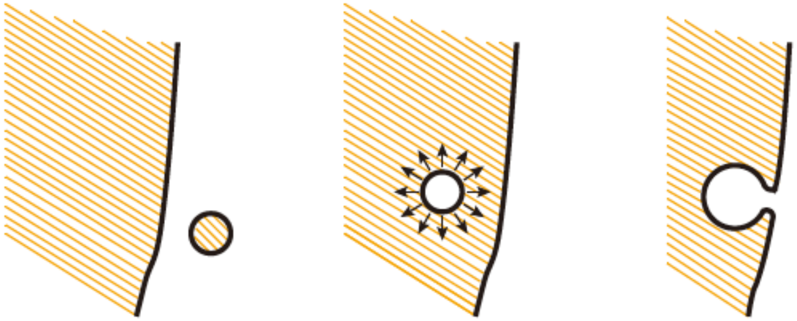
[Zeldovich-Kobzarev-Okun (1974)]

Z_N models, N=2,3, …, lead to domain walls. If Z_N arises from a subgroup of U(1) creating strings and broken by anomaly, we can think of N domain walls, going around the string 360 degrees,



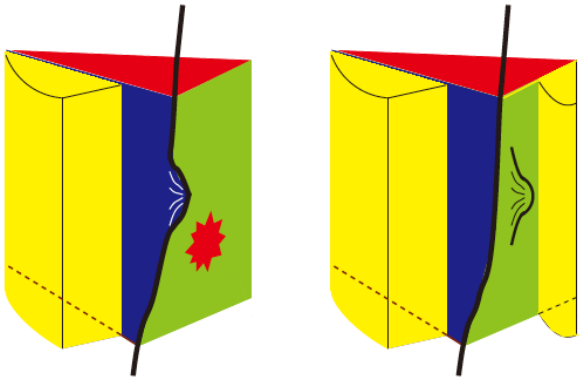


But, NDW=1 does not have
a serious cosmological
DW problem.



(a) (b) (c)

N=1



(a) (b)

N=2

But, NDW>1 have serious cosmological DW problems. [Sikivie (1982)]

Sakikawa (Tokyo group) talk at Patras 2017, with NDW=1:

Estimates of ξ and ϵ may differ by an order of magnitude.
Accordingly, the prediction for the PQ scale is ambiguous.

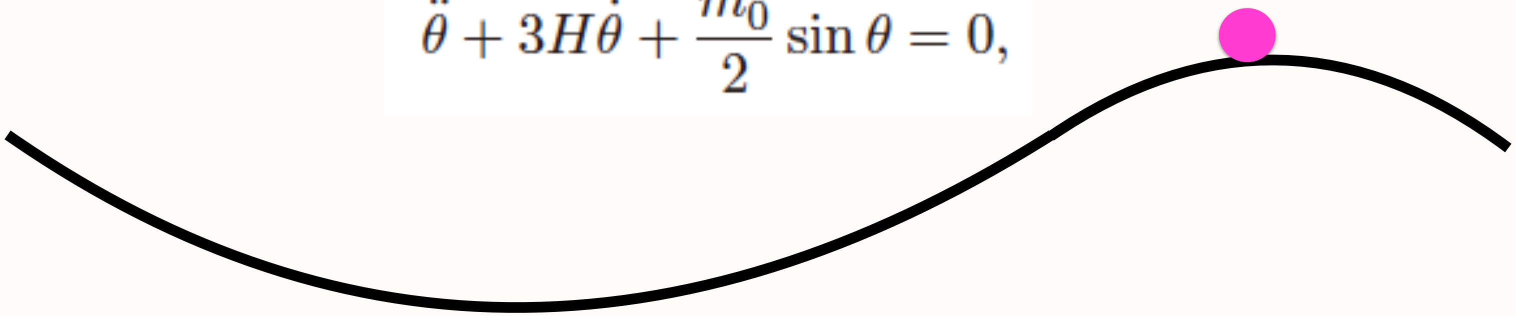
$$\Omega_a = \Omega_{\rm CDM} \Rightarrow 7 \times 10^9\ {\rm GeV} \lesssim F_a \lesssim 3 \times 10^{12}\ {\rm GeV}\ \ (?)$$

Median: $5\text{x}10^{11}$ GeV

Roughly, 10^{11} GeV gives about 20% of axion dark matter with axion mass around 0.6x 10^{-4} eV.

Lattice calculation of temperature dependence between 100 MeV to 1 GeV got interest at the Patras conference. Here, I point out the axion bottle neck problem.

$$\ddot{\theta} + 3H\dot{\theta} + \frac{m_0^2}{2}\sin\theta = 0,$$



Anharmonic effect: Stays there long time until T is sufficiently lowered.

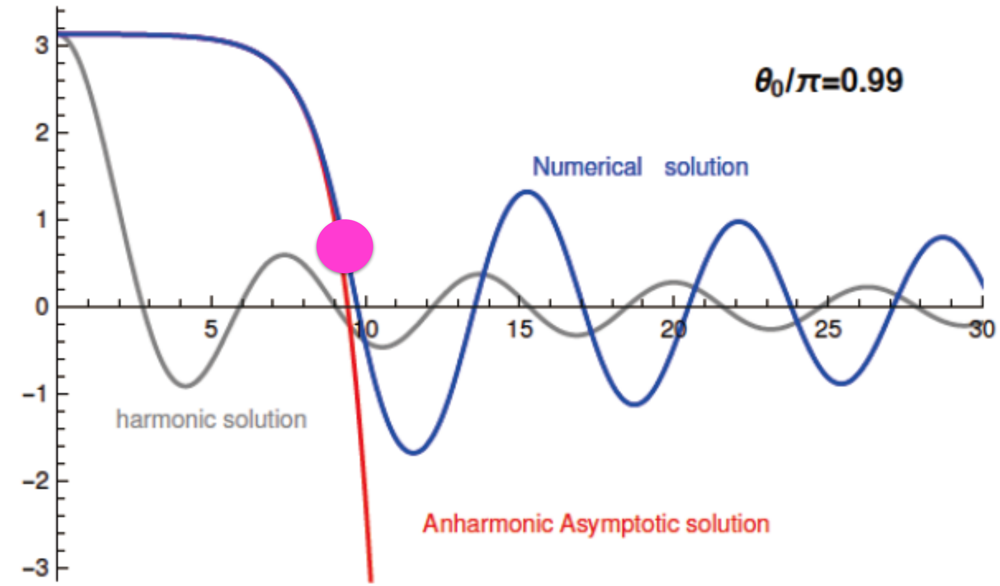
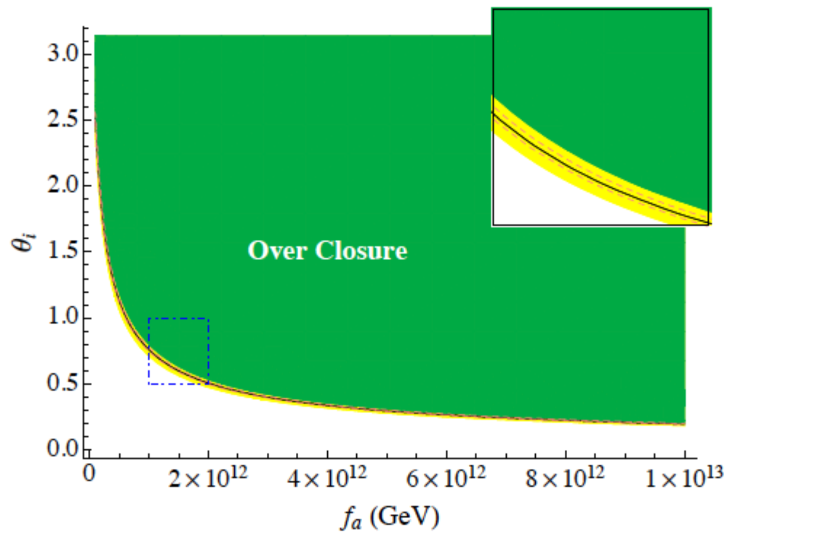


Figure 6.2: The numerical solution (blue) in the anharmonic regime
0.99π [6].

m_0 = T dependent.

Bae-Huh-K, 0806.0497 [hep-ph]
K, RMP 82, 557 (2010)



m_0 = constant, T=0 value. More than one period. For T-dependent mass, more time is needed.

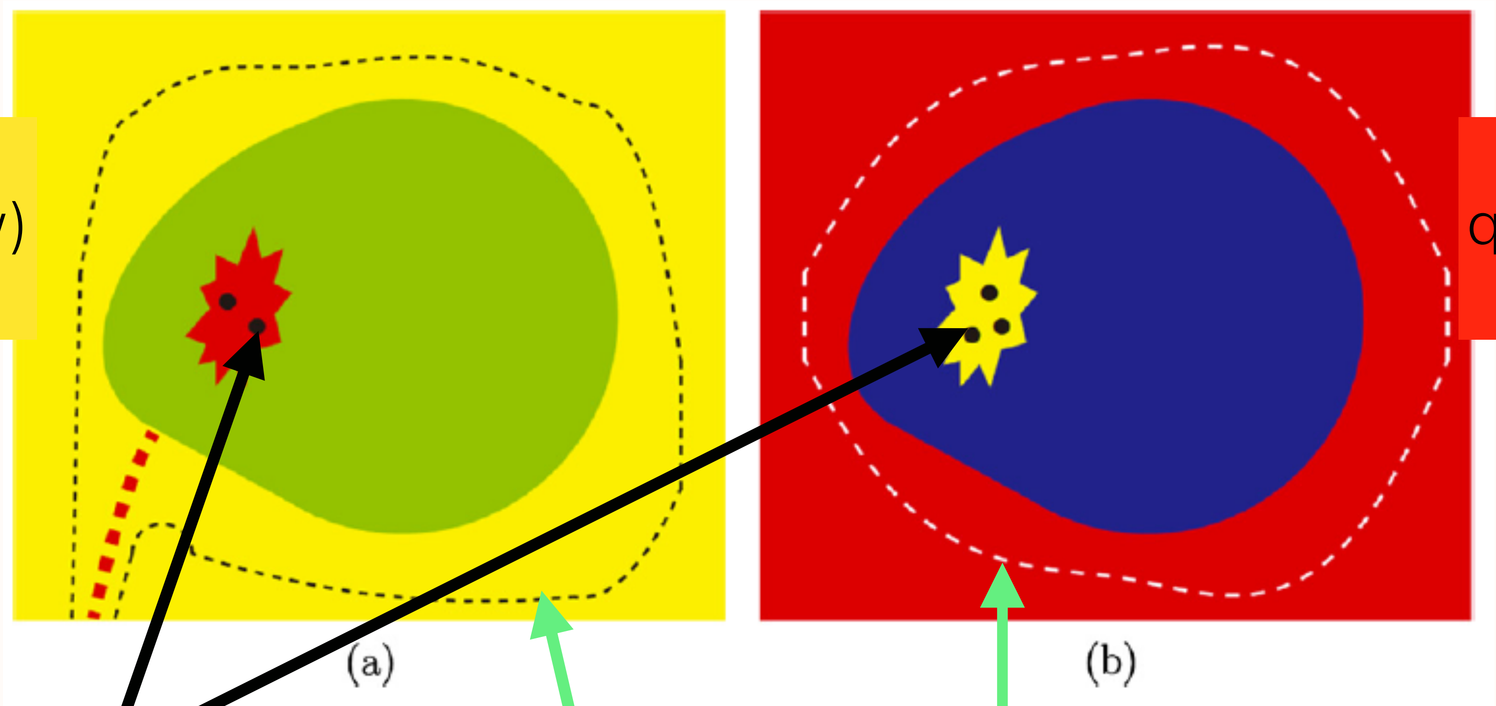
3. DW boundaries : Hairs

Charge inside a ball:

vacuum charge

$$q = \frac{1}{2i} \int d^3x \, (\Phi^* \partial_t \Phi - \Phi \partial_t \Phi^*).$$

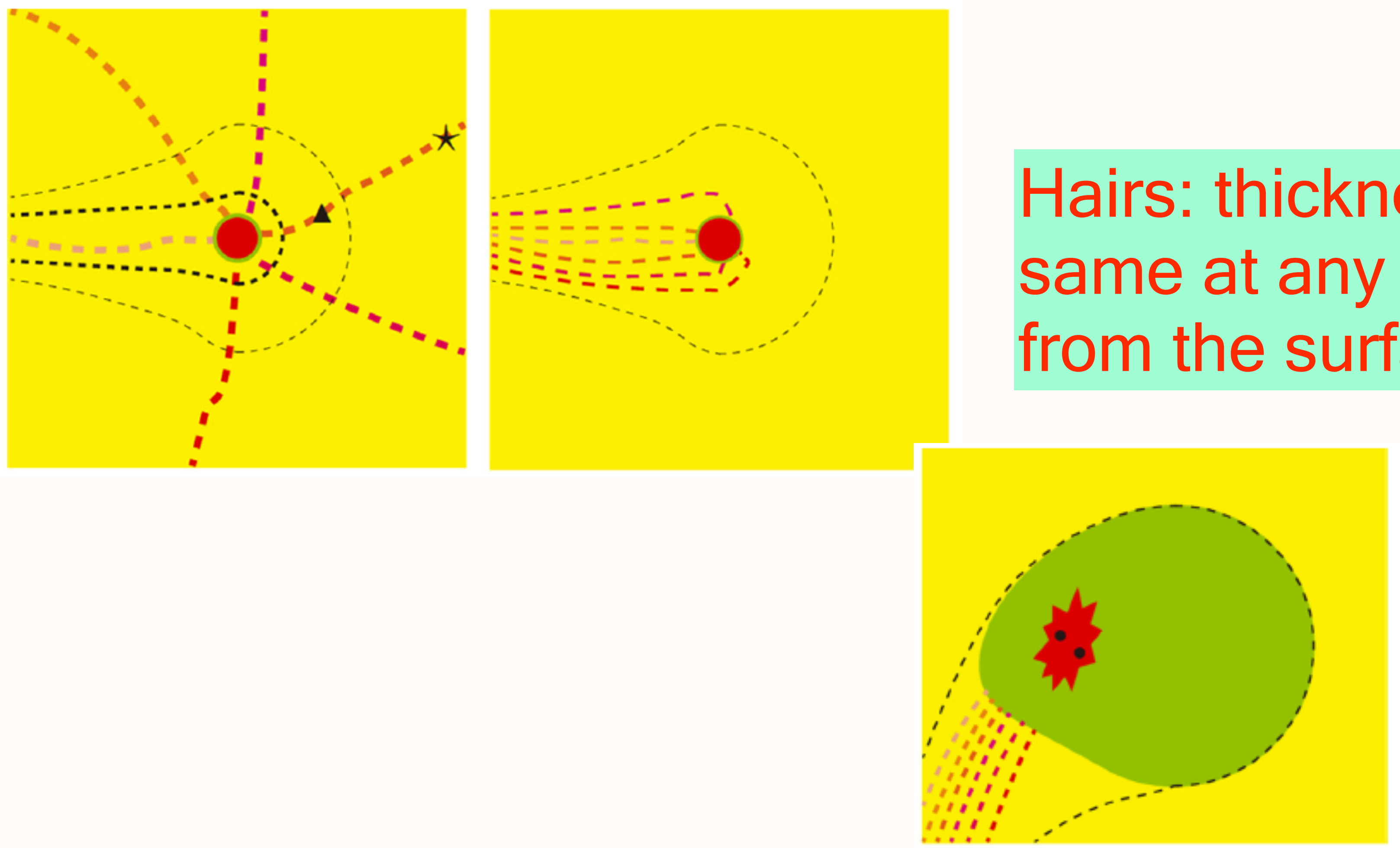
In the q=0(yellow) vac.



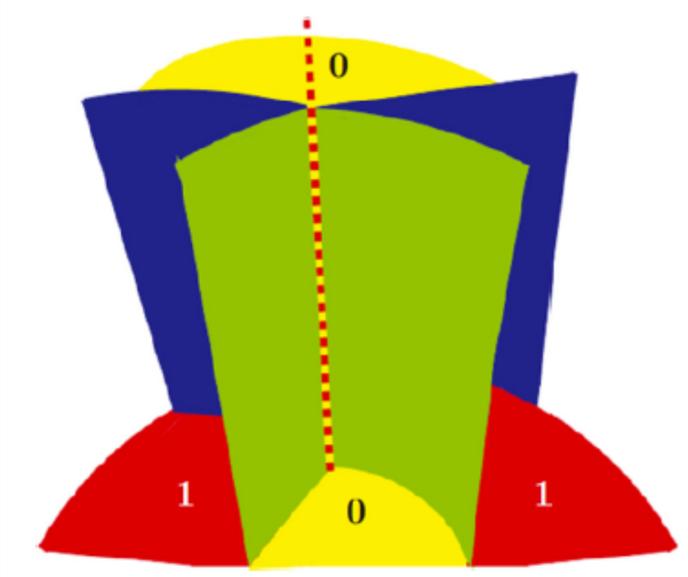
In the q=1(red) vac.

Particles

q evaluated for all contributions inside the closed boundary



Hairs: thickness is the same at any distance from the surface.



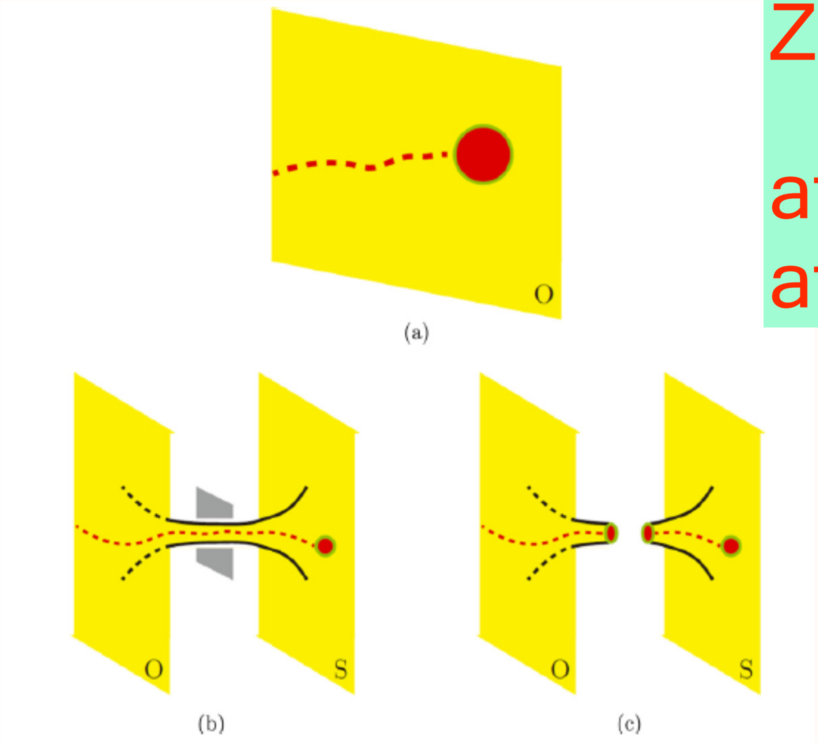
$$j^{\theta\varphi}(\theta,\varphi) = \frac{1}{r^2}\delta(\cos\theta - \cos\theta_0)\delta(\varphi - \varphi_0).$$

The surface integral over the closed surface gives 1, the charge inside the surface.

Boundary of domain walls looks like a hair.

1703.05389 [hep-th]

Bottom-up approach:



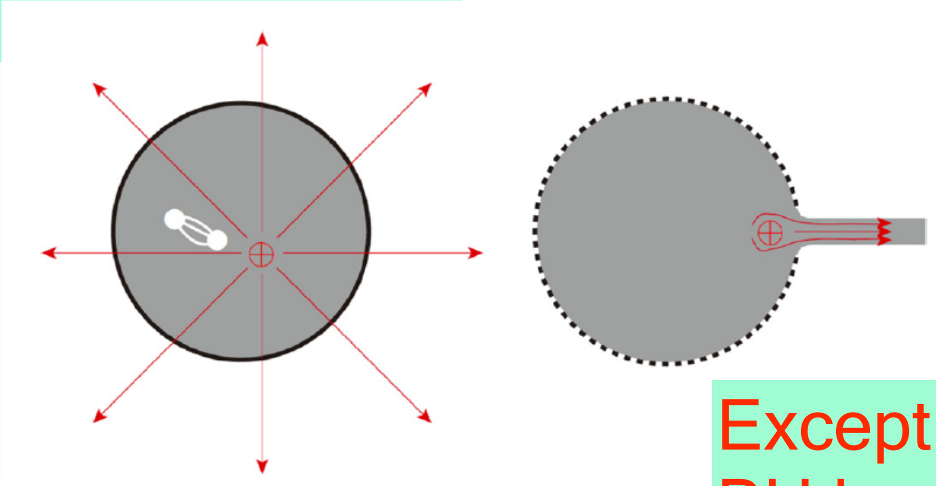
Z2 tadpole ends:

at head or
at horizon

Wormholes do not
break the discrete
symmetry.

Blackhole hairs

It must be applicable to BH also:



$$r_+ = \frac{1}{2}\left(r_S + \sqrt{r_S^2 - 4r_Q^2}\right)$$

Reissner-Norstroem BH radius:
E cannot end inside the horizon.
But mass took into account this.
So, the field energy outside horizon must be subtracted.

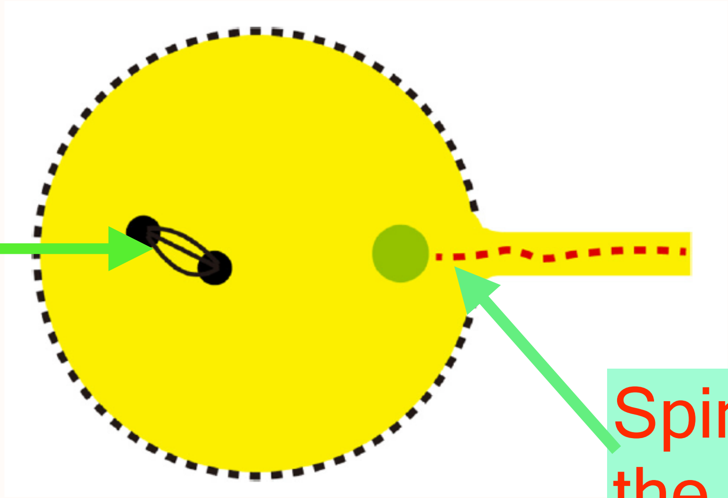
Except a tiny hole, the BH horizon makes sense.

The bundle of flux lines is like our hair.

With discrete symmetry:

Spin 2 graviton respects the horizon

Spin 1 photon discussed above



Spin 0 boson depends on the vacuum structure, a tadpole.

It gives a hair also near the BH.

5. Conclusion

1. Symmetries.

2. Domain walls.

3. Intersection of DW boundaries: hairs