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PASCOS 2016: 22nd International
Symposium on **P**articles, **S**trings and
Cosmology



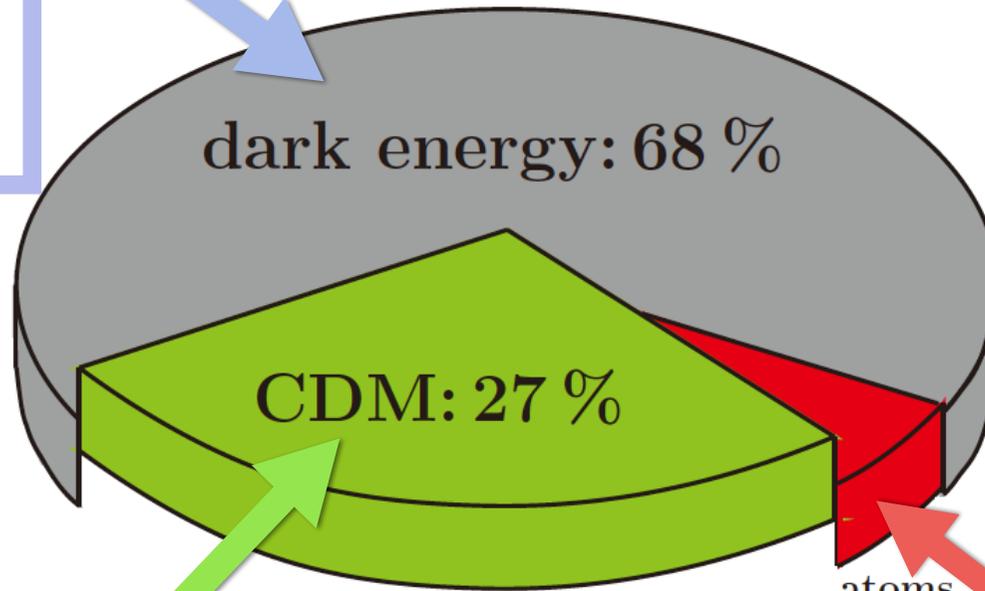
A Summary on DM/DE and Cosmology

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CC is still viable, but $w < -1$
seems preferred
Horndeski theory
[Tsujiikawa]

Quintessence
Quintessential axions,
DES [Soares-Santos]



WIMP
[Penning, Boehm, Gondolo, Serfass, Wulf]

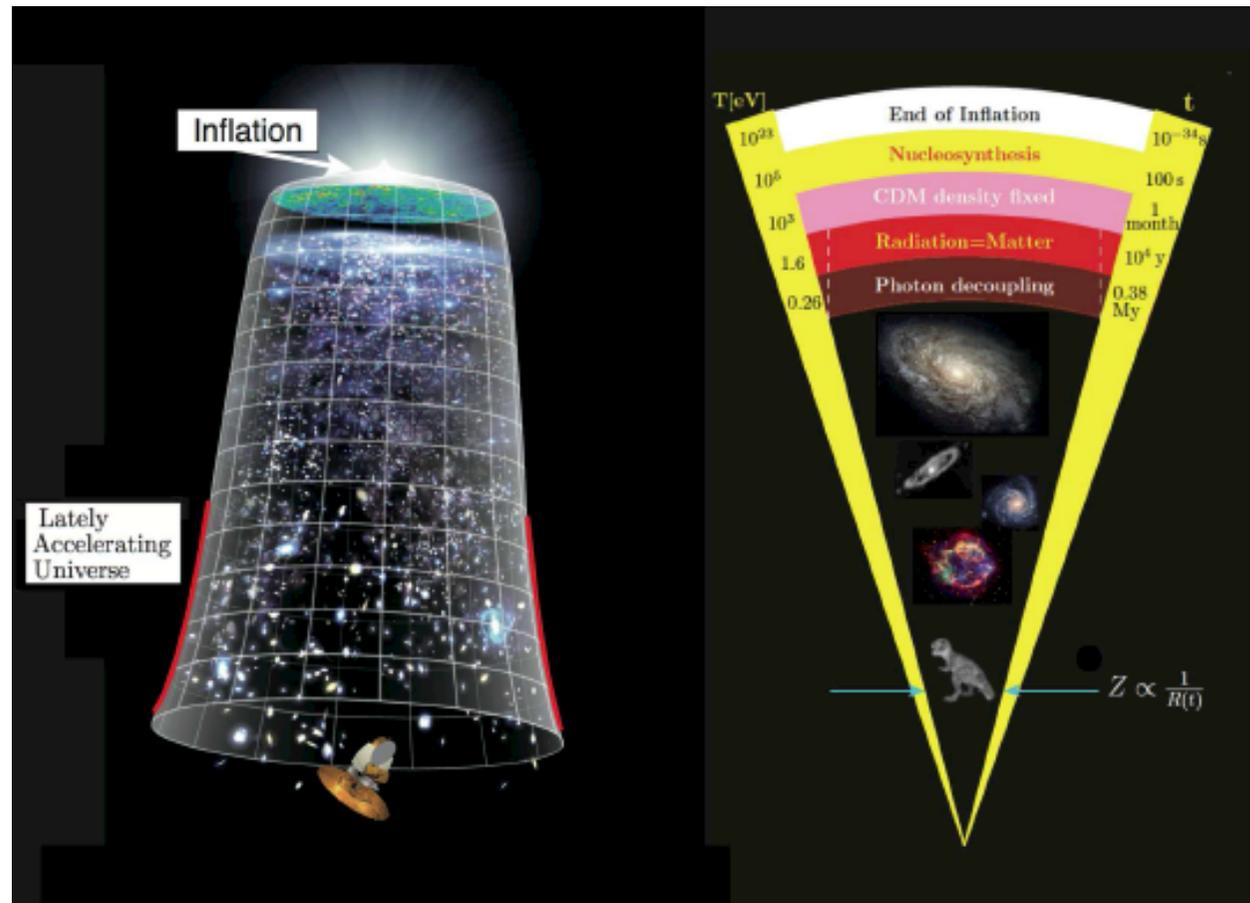
BCM
Axions [Gondolo]

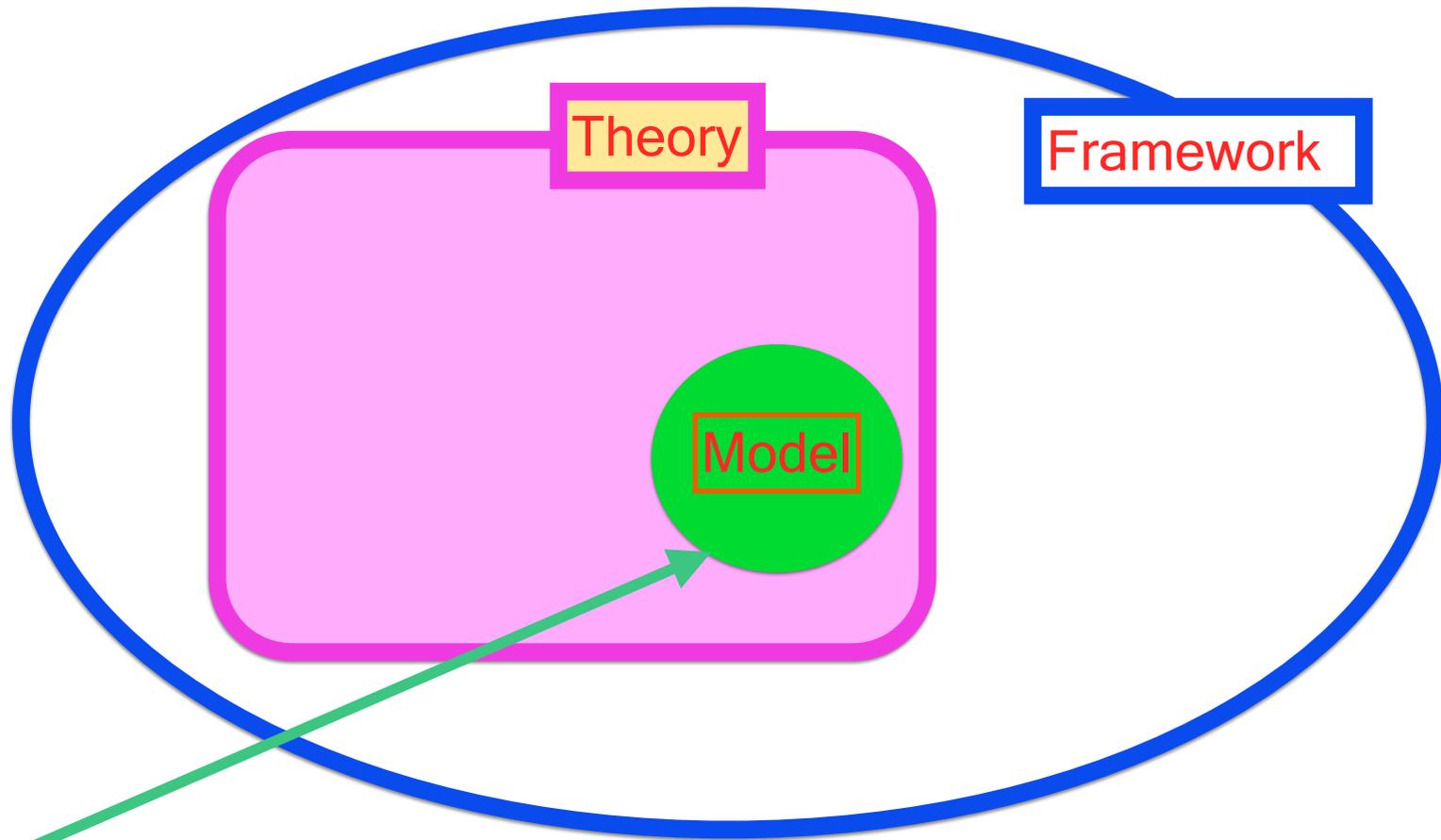
atoms

Chiral fields at GUT scale
SU(5), SU(7) GUTs
Heterotic string [Gross]

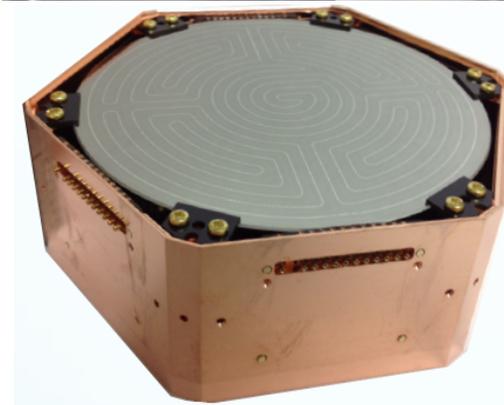
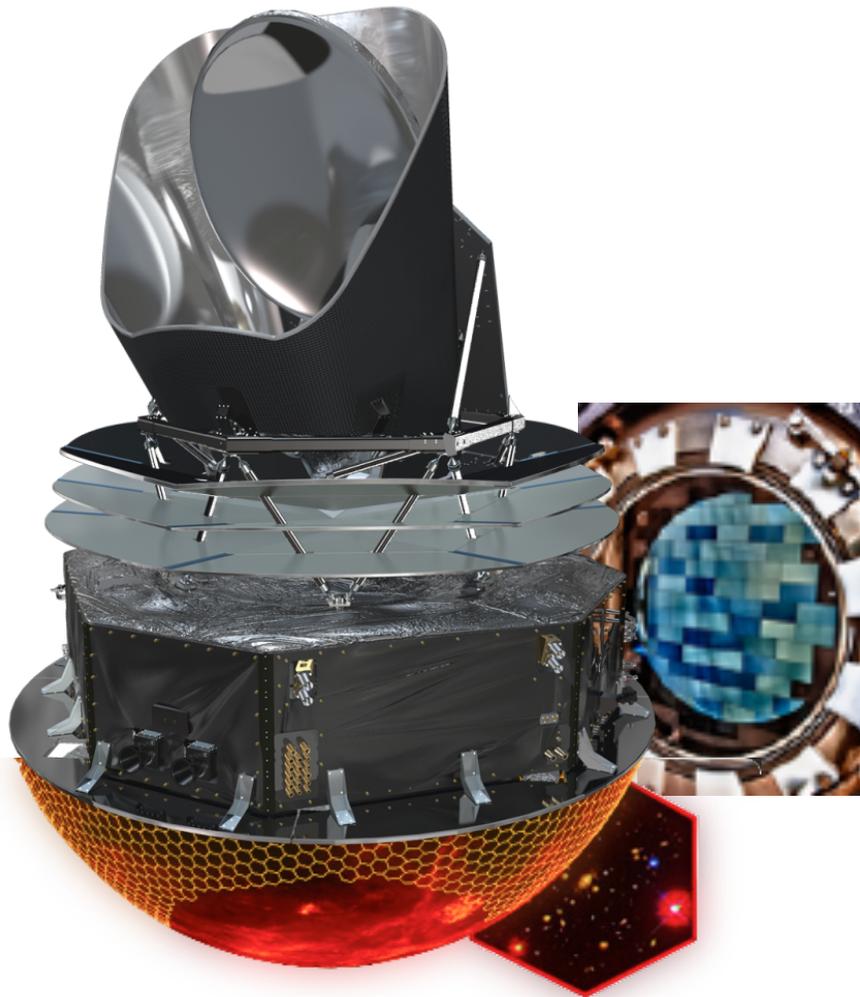
CP violation
Baryogenesis, Leptogenesis

All these must be discussed in the evolving Universe:





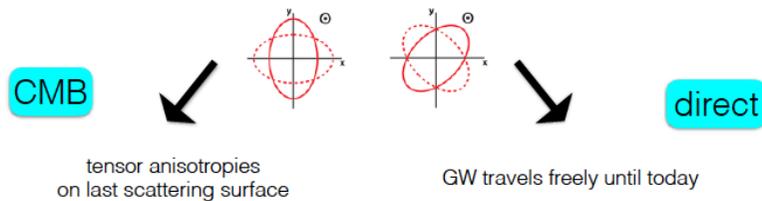
“Model” is a working example. Even though the design is fantastic, without a model example, some will say that it is a religion.
Efforts to find a working model is our job toward THEORY/Framework.



CAPP



Gravity waves-observed[Video] and hoped looked even for (pseudoscalar) inflation [Dombcke]

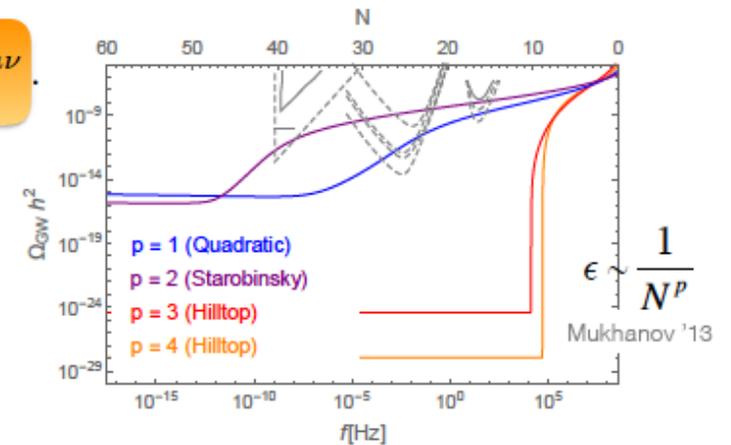


a generic coupling for a pseudoscalar inflaton:

$$\mathcal{L} = -\frac{1}{2}\partial_\mu\phi\partial^\mu\phi - \frac{1}{4}F_{\mu\nu}F^{\mu\nu} - V(\phi) - \frac{\alpha}{4\Lambda}\phi F_{\mu\nu}\tilde{F}^{\mu\nu}$$

$$\xi = \frac{\alpha\dot{\phi}}{2\Lambda H}$$

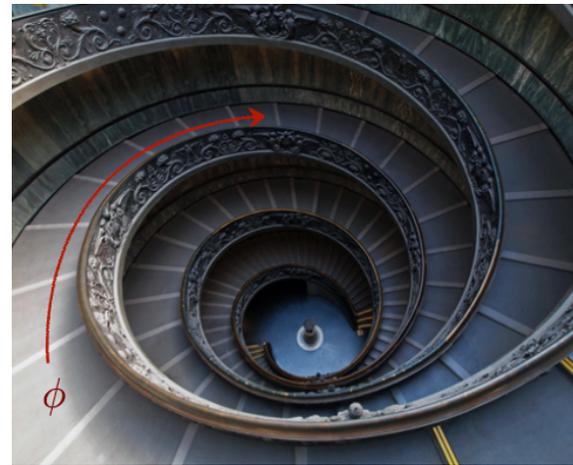
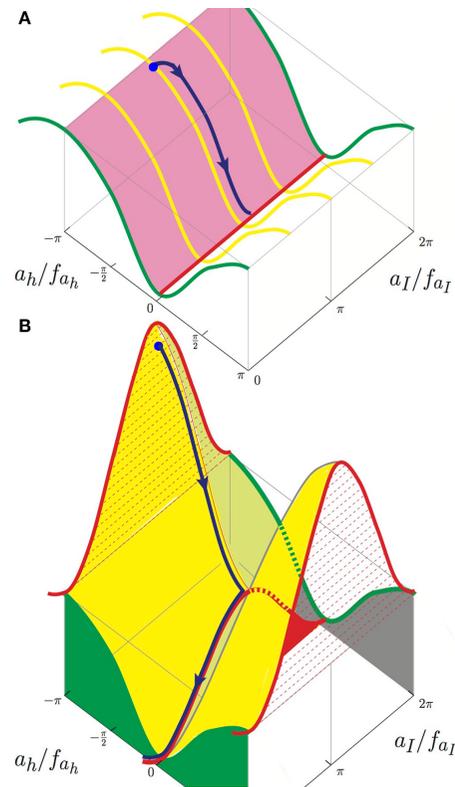
$$\Omega_{\text{GW}} = \frac{1}{12}\left(\frac{H}{\pi M_p}\right)^2 (1 + 4.3 \times 10^{(-7)}) \frac{H^2}{M_p^2 \xi^6} e^{4\pi\xi}$$



DES experiment, in Chile, is trying to see DE [Soares-Santos]

DE/Cosmology: Inflation ideas from string: Natural inflation, aligned inflation, and axion monodromy, to understand large f_a from f_i values smaller than M_P .

[Shiu]



The fine-tuning problem of the SM:
Introduced SUSY/SUGRA, and fine-tuning
degrees, even a few percent [Tata]. But, it is in the
SUGRA theory.

However, if we had a theory of soft-parameters that predicted $A_0 = -1.6m_0$ and $m_{H_u}^2 = 1.64m_0^2$ and $m_{1/2} \simeq 0.4m_0$, this underlying theory would not be fine-tuned. We do not have such a theory today!!!!

Correlation	Δ_{BG}
None	3168
$A_0 = -1.6m_0, m_{H_u}^2 = 1.64m_0^2$	257
$m_{1/2} = 0.4m_0$	15.4
Δ_{EW}	11.3

Intrinsically, there exists a much more serious fine-tuning here. The gravitino mass is defined with $CC=0$. In any SUGRA model discussing MSSM and NMSSM assumes this fine-tuning.

Devils' (Weinberg, Witten, Gross, ...) question:



Isn't it a fine-tuning of order 1 out of 10^{120} ?



- ▶ In SUGRA, the cosmological constant (CC) needs to vanish in the true vacuum:

$$\langle V \rangle = |\langle F \rangle|^2 - 3 e^{\langle K \rangle} |\langle W \rangle|^2 \stackrel{!}{=} 0$$

- ▶ E.g., in the Polonyi model, constant in the superpotential: $w \rightarrow w_0 = (2 - \sqrt{3}) \mu^2$.

[Schmidt]



Should we solve the CC problem first,
before discussing the electroweak fine-
tuning problem?

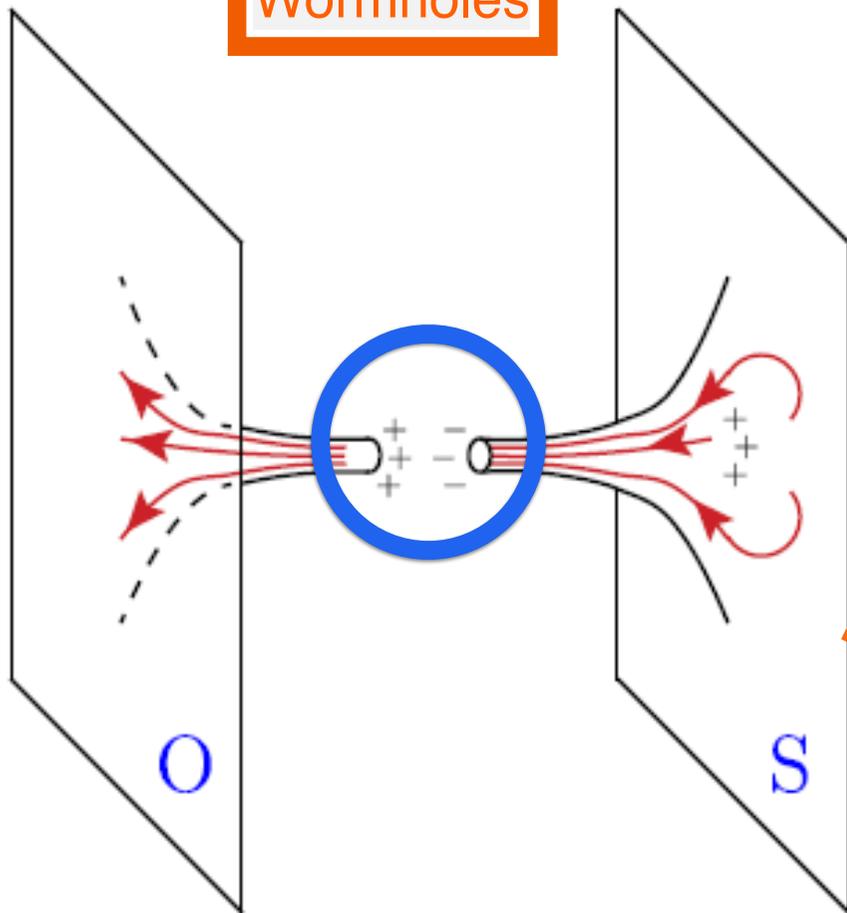
These two problems are in **the same theory.**

Can there be an example, or at least a hope for a solution of the CC problem?

Keep an eye on: Maybe, Hawking's probability argument in Euclidian quantum gravity can be an understanding toward the CC problem [Baum (1983); Hawking (1984). See, also, Duff (1989), Wu(2008)]. Immediately required strategy is a set-up for a parameter for the variable CC in SUGRA.

Nobody has presented an argument so far in SUGRA.

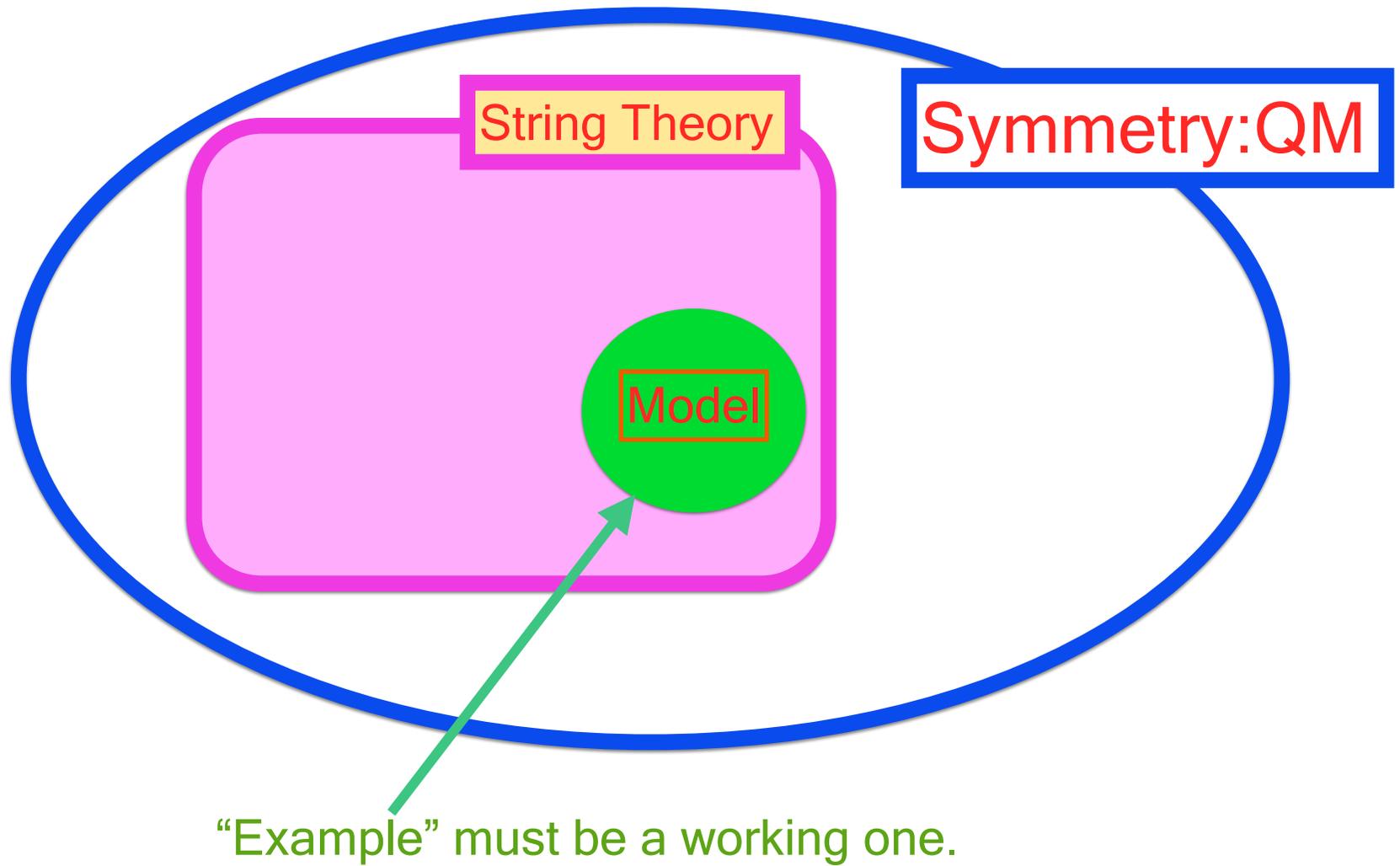
Wormholes



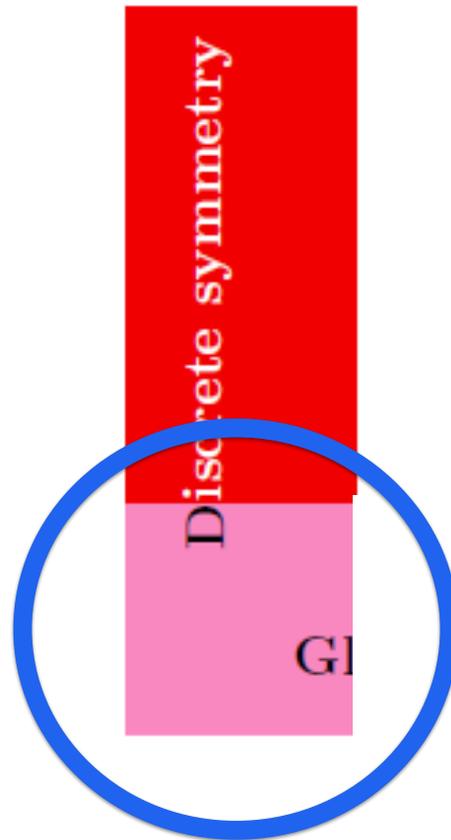
For PQ,
Barr-Seckel,
Kamionkowski-MarchRussel,
Holdom et al.
Exclude terms up to dim 8.

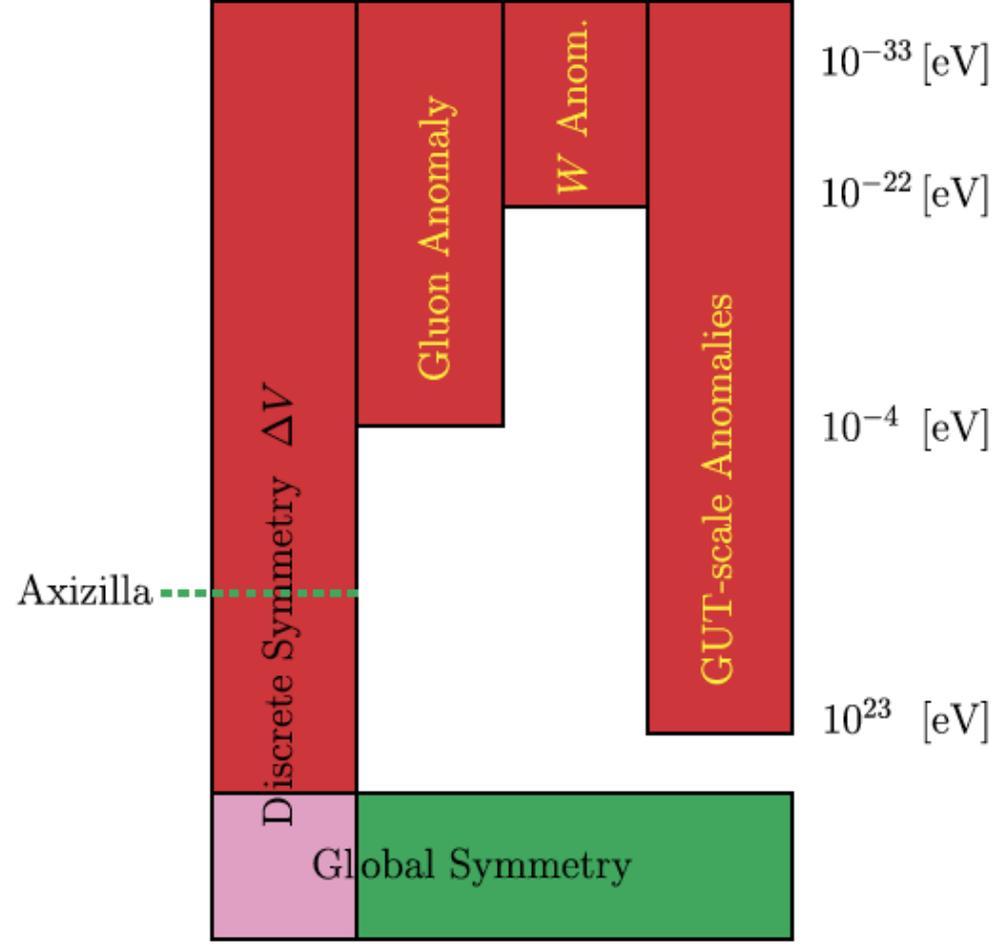
The example of acc symm.





Discrete symmetry





family number is not a symmetry of Lagrangian like charge

[Bernstein]

Family unification and gauge forces are unified into a simple group. Not a direct product of (Gauge group) x (Family group): a real unification of all forces.

[JEK]

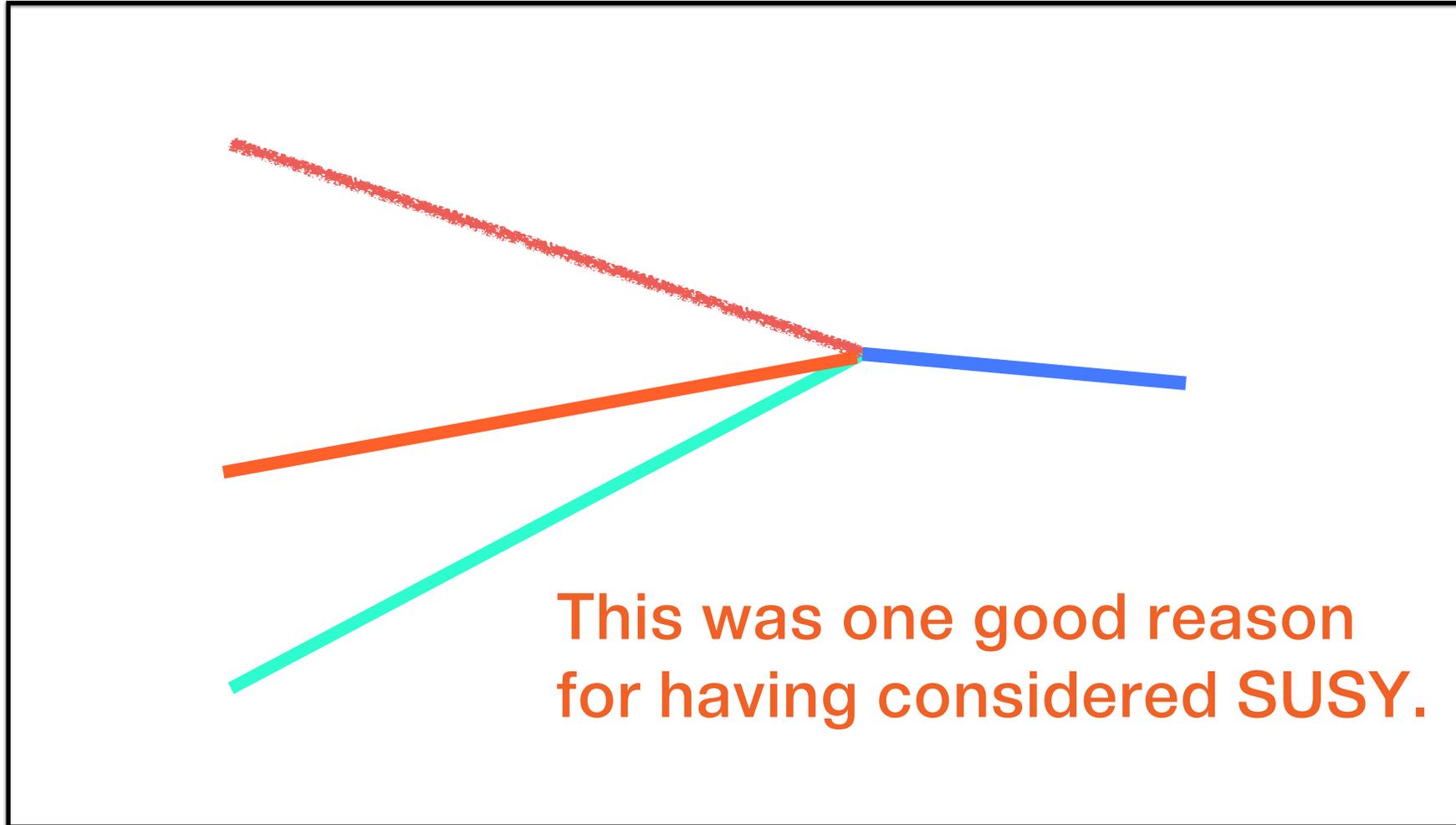
In UGUTFs, after Higgsing, we want to have 3 left-handed families,

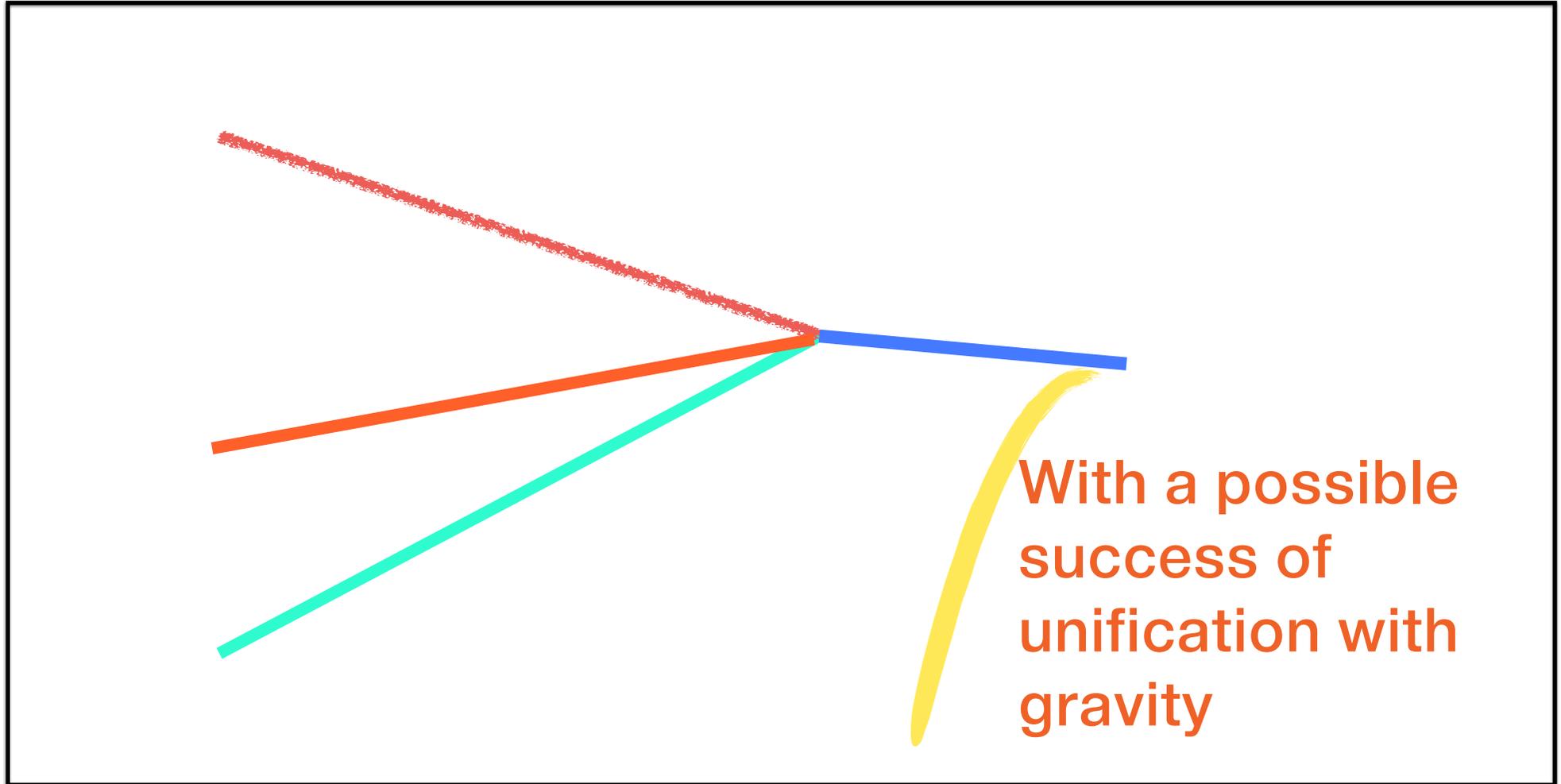
$$\begin{pmatrix} \nu_e \\ e \end{pmatrix}_L, \begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix}_L, \begin{pmatrix} \nu_\tau \\ \tau \end{pmatrix}_L,$$

$$\begin{pmatrix} u \\ d \end{pmatrix}_L, \begin{pmatrix} c \\ s \end{pmatrix}_L, \begin{pmatrix} t \\ b \end{pmatrix}_L$$

and

$$\sin^2 \theta_W = \frac{3}{8}$$

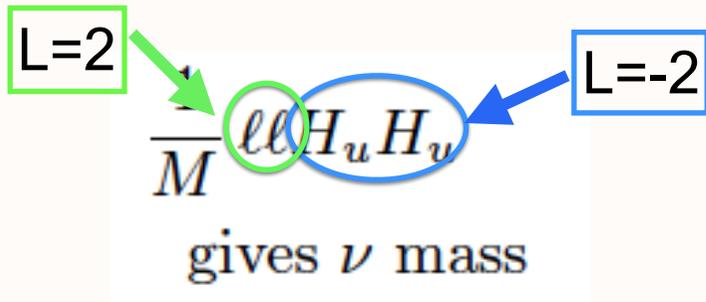




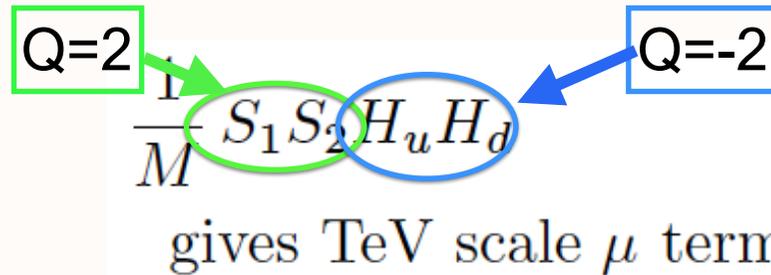
**Effective models
with SM spectrum
plus singlets**

[Gondolo] tried for WIMP.

Summarized by
Weinberg operator:
 [13.08.1979, Received]



Kim-Nilles SUSY operator:
 [24.11.1983, Received]



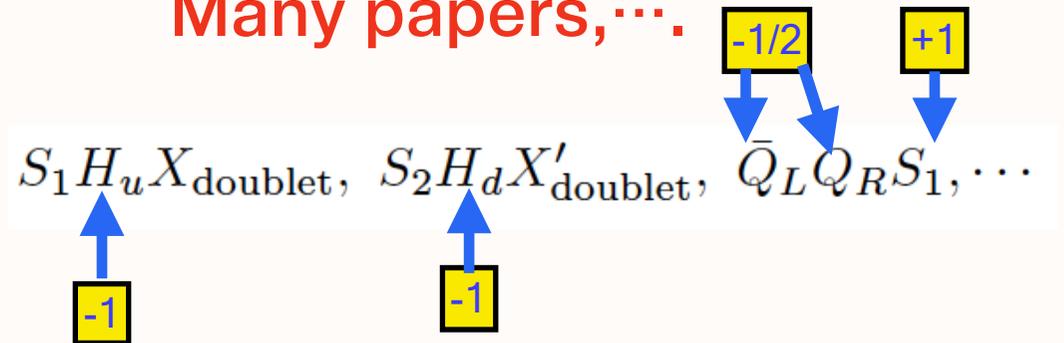
We neglected SH_uH_d since the VEV of S at intermediate scale is too large for $SU(2)$ breaking.

Realized in seesaw:
 Minkowski [13.04.1977, Published],
 Yanagida [13-14 Feb 79, Conf. talk]

.....

$$\ell_L H_u N_R$$

Realized in string comp.:
 Many papers, ...



Summarized by
Weinberg operator:
[13.08.1979, Received]

$$\frac{1}{M} \ell \ell H_u H_d$$

gives ν mass

Kim-Nilles SUSY operator:
[24.11.1983, Received]

$$\frac{1}{M} S_1 S_2 H_u H_d$$

gives TeV scale μ term

Do we really need
RENORMALIZABLE
ONES at present low
energy world?

Definition of symmetries:

$$\frac{1}{M} \ell \ell H_u H_u$$

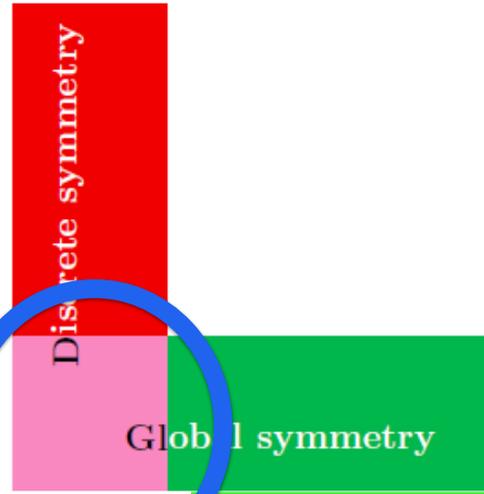
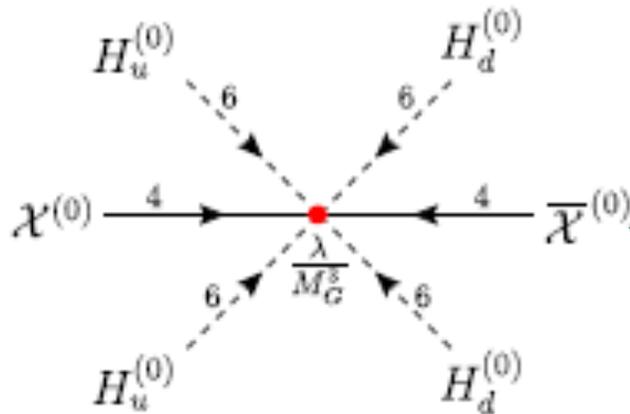
gives ν mass

$$\frac{1}{M} S_1 S_2 H_u H_d$$

gives TeV scale μ term

For effective neutrino mass and μ term, these are sufficient. But, for cosmological effects, the underlying models are needed.

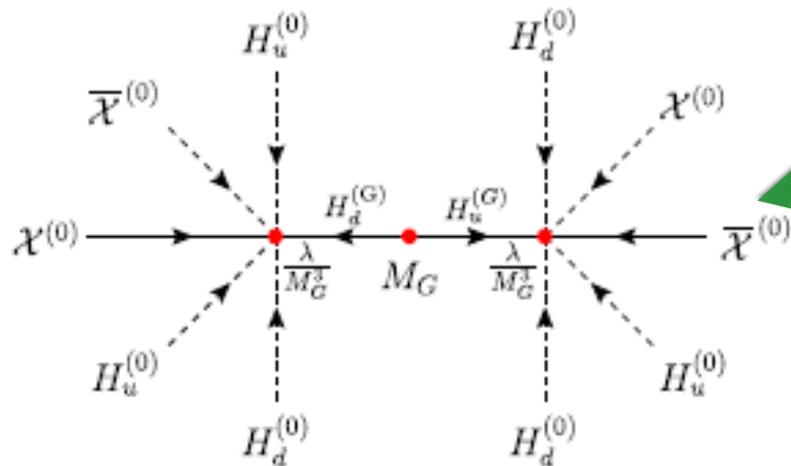
Example:



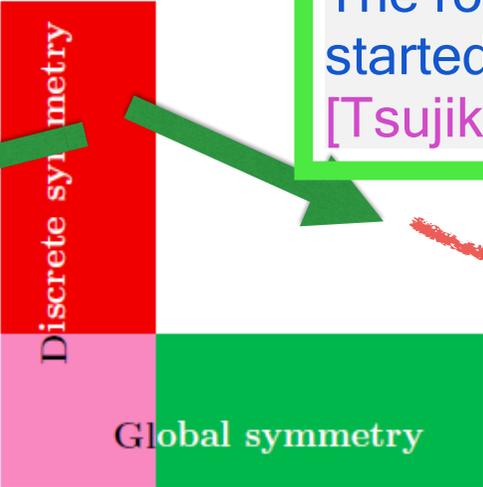
Constructed so that there is no QCD anomaly

Definition of ONE global symmetry with a sufficiently high dimensional operator





The rolling has not started yet, CC: [TsujiKawa]



A sufficiently high dimensional operator def: next order term is very small! 10^{-47} GeV^4 .
 Magic of discrete symmetry.
 $Z(10_R)$ example.



Beyond SM

Neutrinoless double-beta decay:

$$|m| < 0.061 - 0.165 \text{ eV} \text{ [Lubashevskiy]}$$

MEG decay:

$$\text{BR}(\mu^+ \rightarrow e^+ \gamma) < 4.2 \times 10^{-13} \text{ [Signorelli]}$$

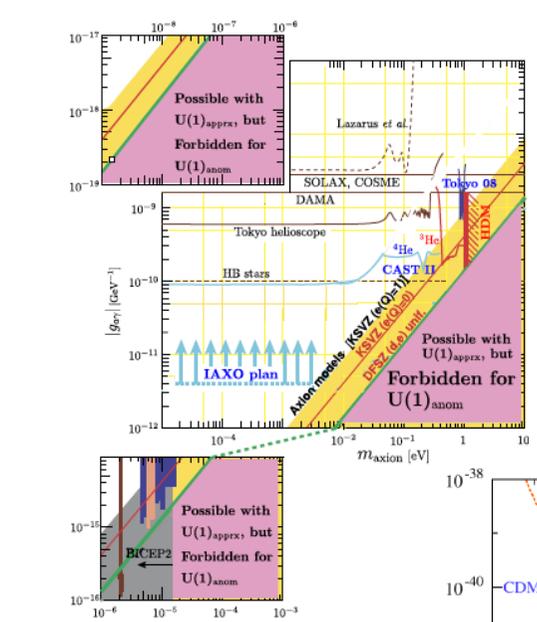
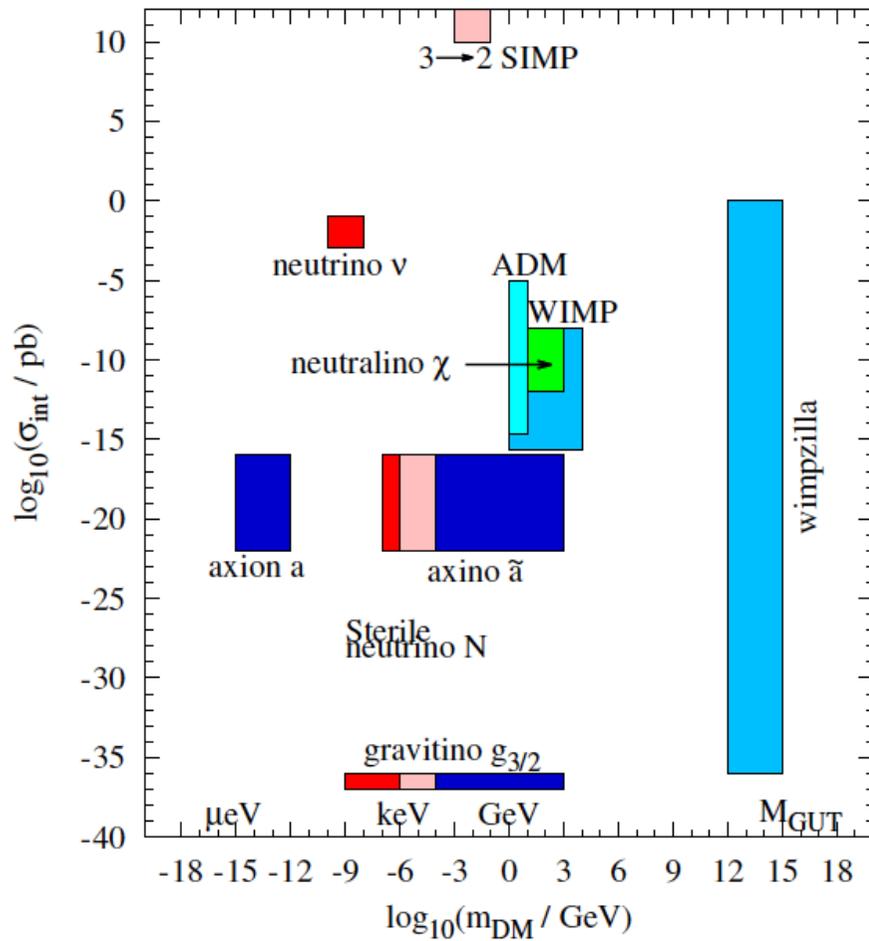
If neutrino
magnetic
moment(s)
observed :

Current terrestrial limit [J-M Frere]:

$$|\mu_{\nu_e}| < 2.9 \times 10^{-11} \mu_B,$$

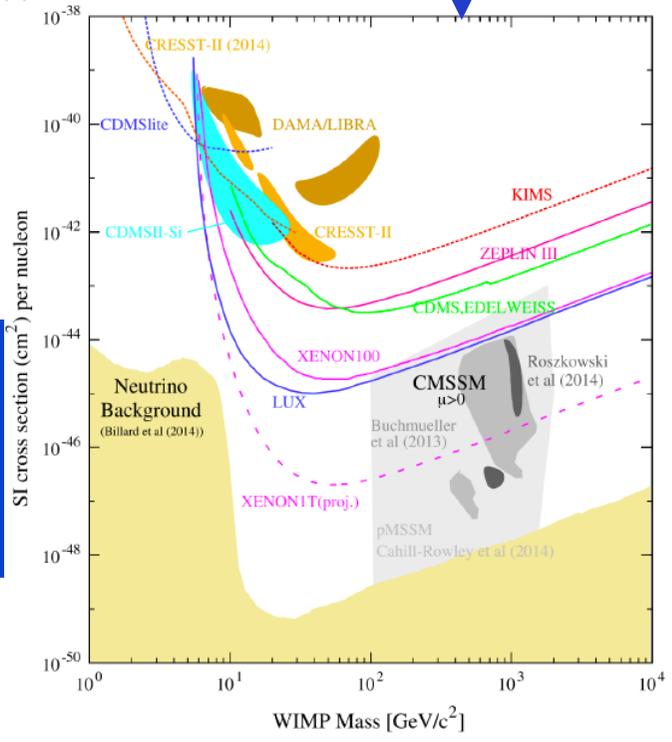
$$|\mu_{\nu_\mu}| < 6.8 \times 10^{-10} \mu_B,$$

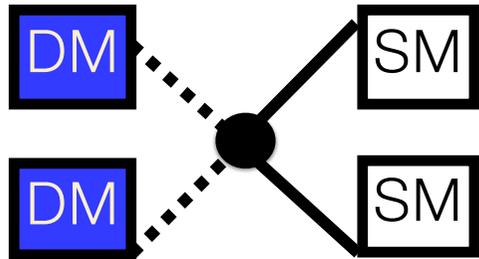
$$|\mu_{\nu_\tau}| < 3.9 \times 10^{-7} \mu_B.$$



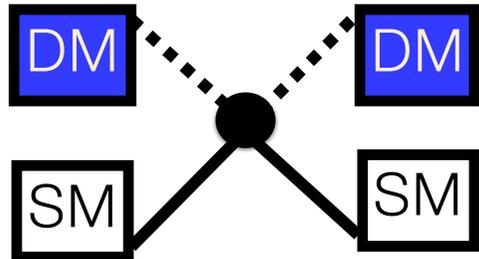
(Exact) Discrete symmetry

Approximate global symmetry

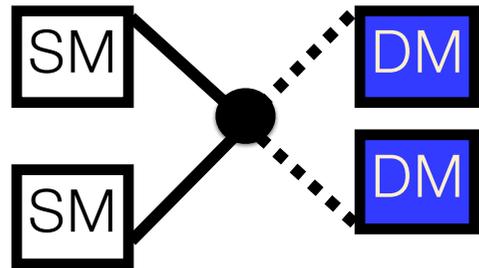




Indirect

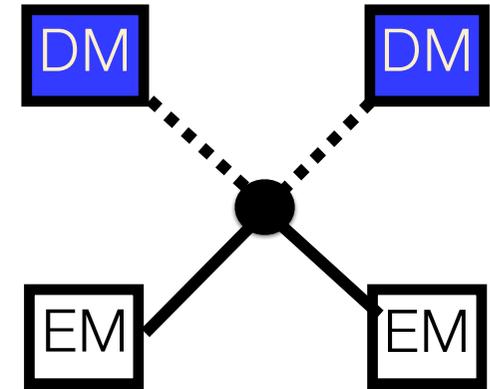


Direct
(Cosmological effect
[Boehm])



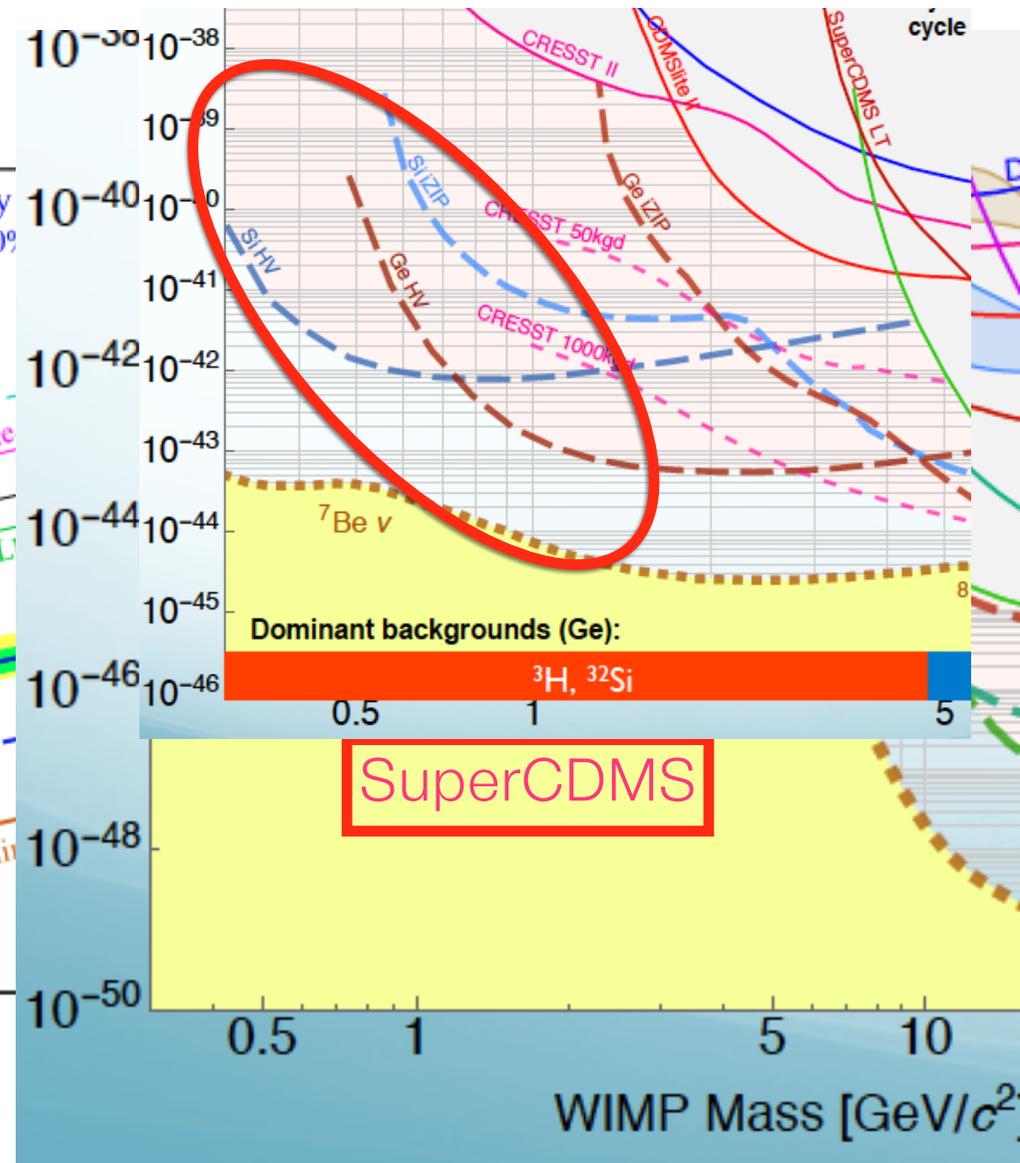
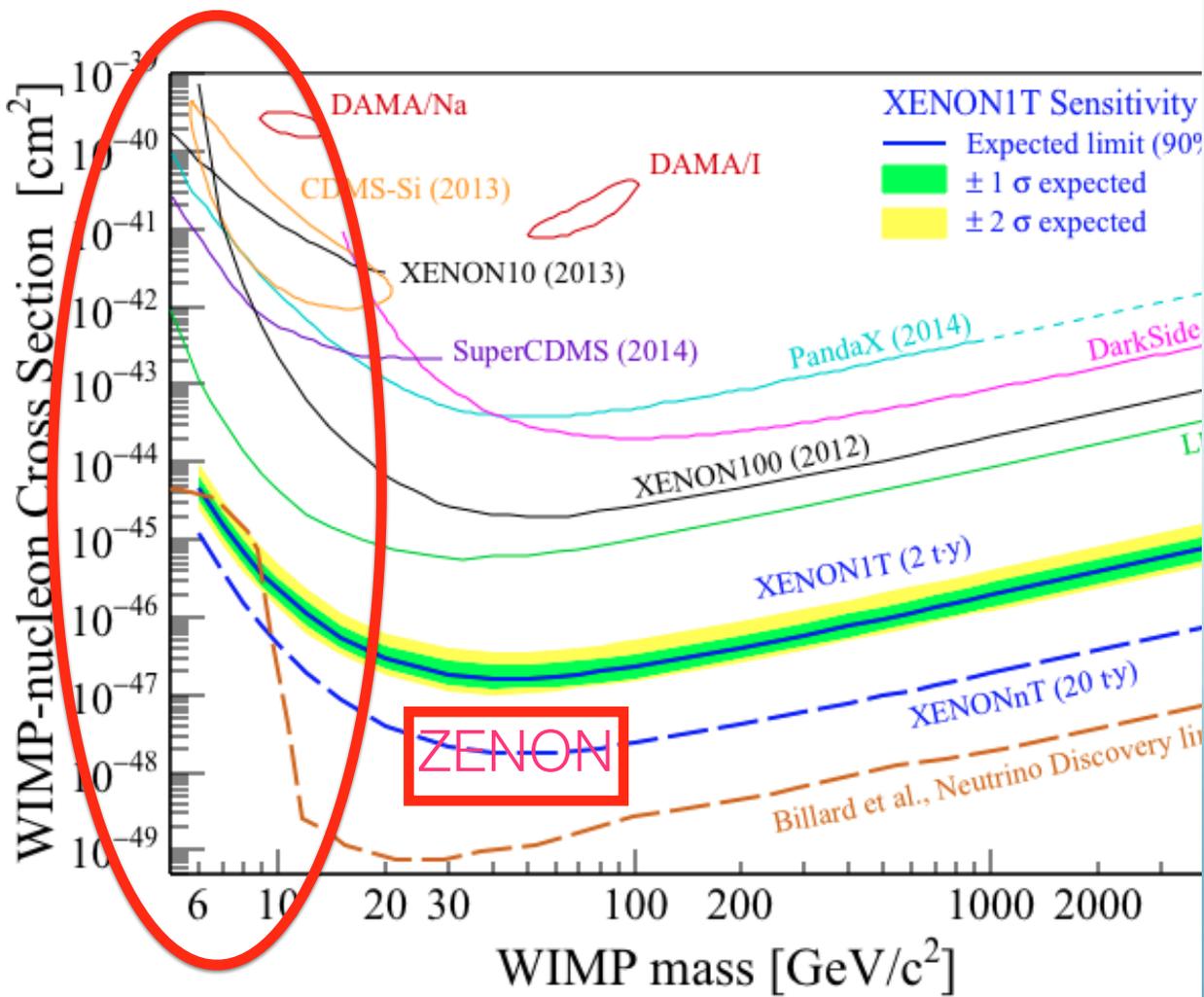
Collider
[Penning]

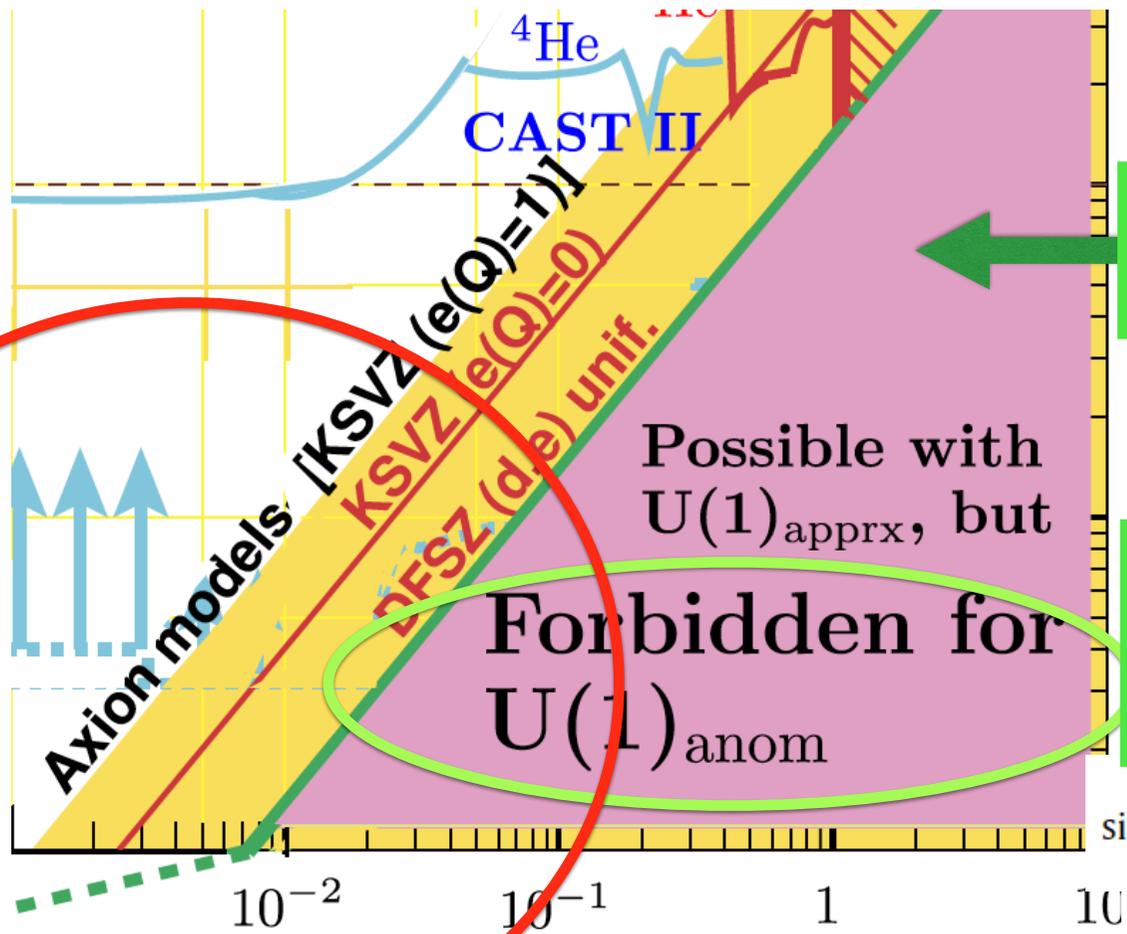
WIMP



(Cosmological effect
[Gondolo])

Axion

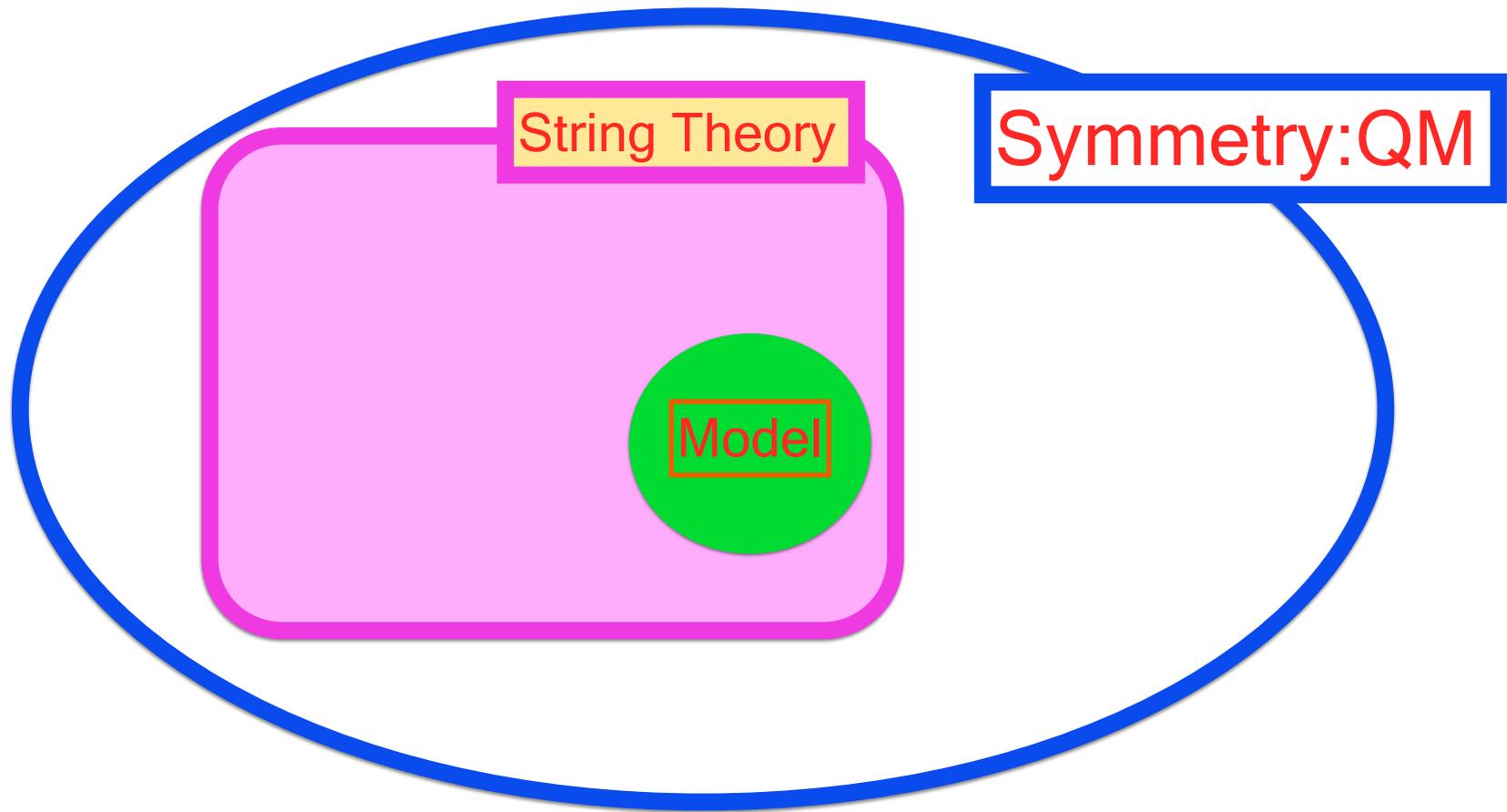




Allowed if an approximate global symmetry is PQ.

from superstring: only possible with MI axion removed.

$$\sin^2 \theta_W = \frac{e^2}{g_2^2} = \frac{\text{Tr}(T_3)^2}{\text{Tr}(Q_{em})^2} = \frac{1/2}{3a^2 + 1 + \sum_i b_i^2}$$



If technicolor worked, we are satisfied because the framework(theory) is simple. Complexity of calculation is of human problem.

In this sense,
models with MINIMAL
something is not
compelling.

It works only if the
framework is consistent.

But an example in the other way:

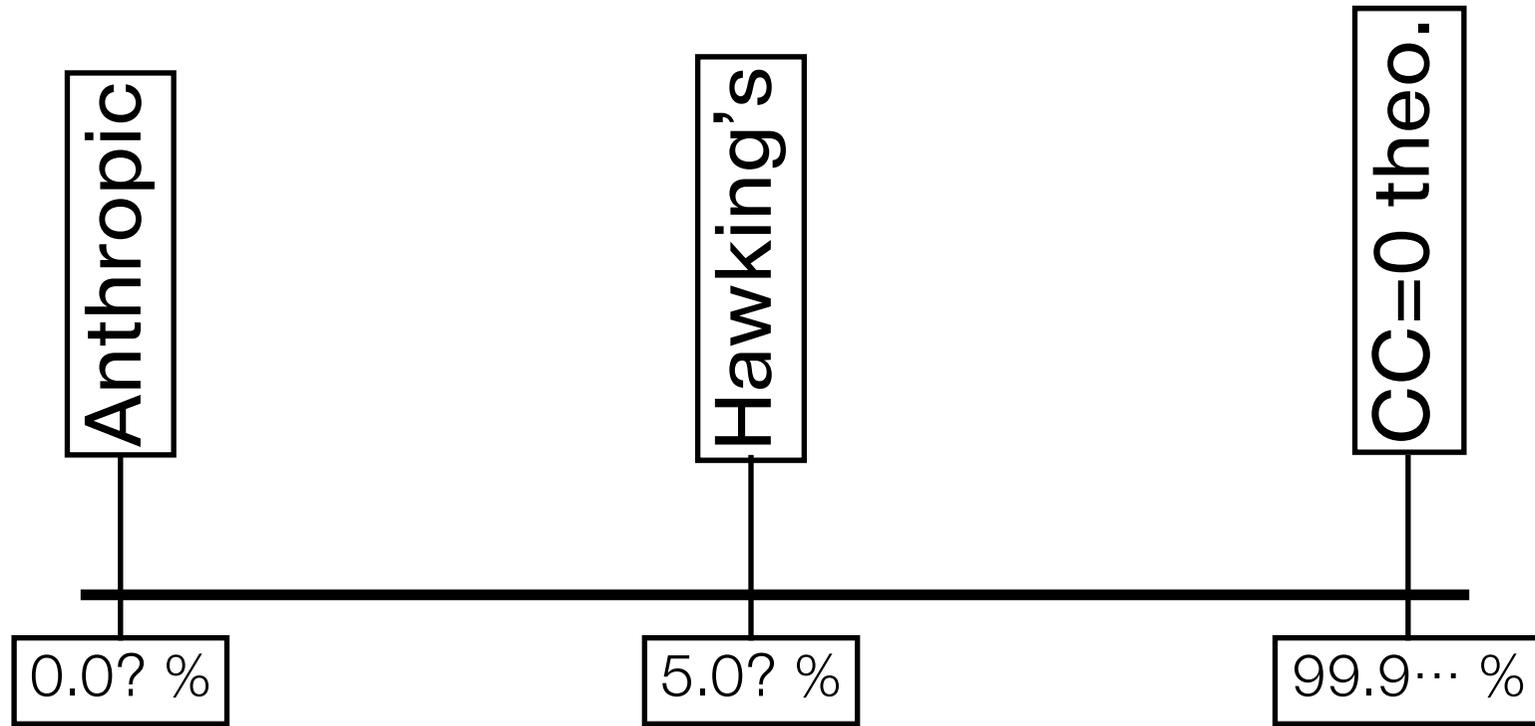
Fermi's beta decay with 34 couplings.

In early 1957, Marshak and Sudarshan noted that V-A structure of weak interaction could explain all but four crucial experiments, and suggested that these four experiments should be redone.

Reduced the number 34 to one G_F . It succeeded because the framework was consistent, and we all follow the SM, succeeding this V-A theory.

Are there another one coupling theory in the market?:

Out of many possible BCM, axion is simple: one parameter the decay constant f_a because of the anomaly and the Adler-Bardeen theorem.



Poll on Science of CC

**Let us aim high at the
framework level.**

**But there must be working examples
with this framework.**

**To prove working examples,
exp and th must go together.**