Quantum Field Theory after "Revolution"

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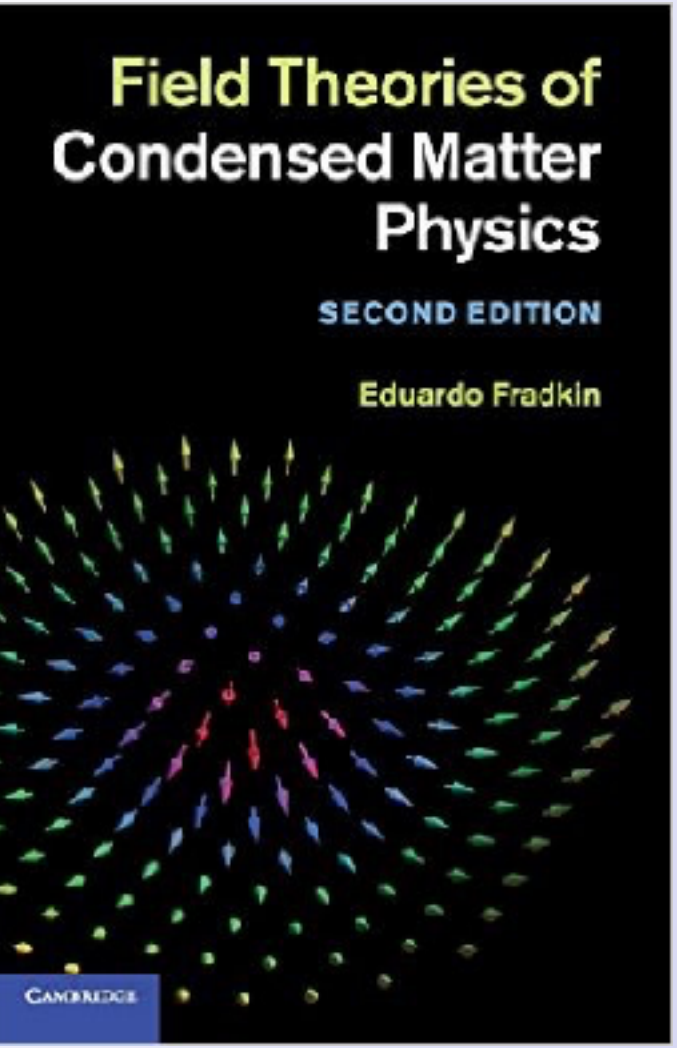
M. Shifman

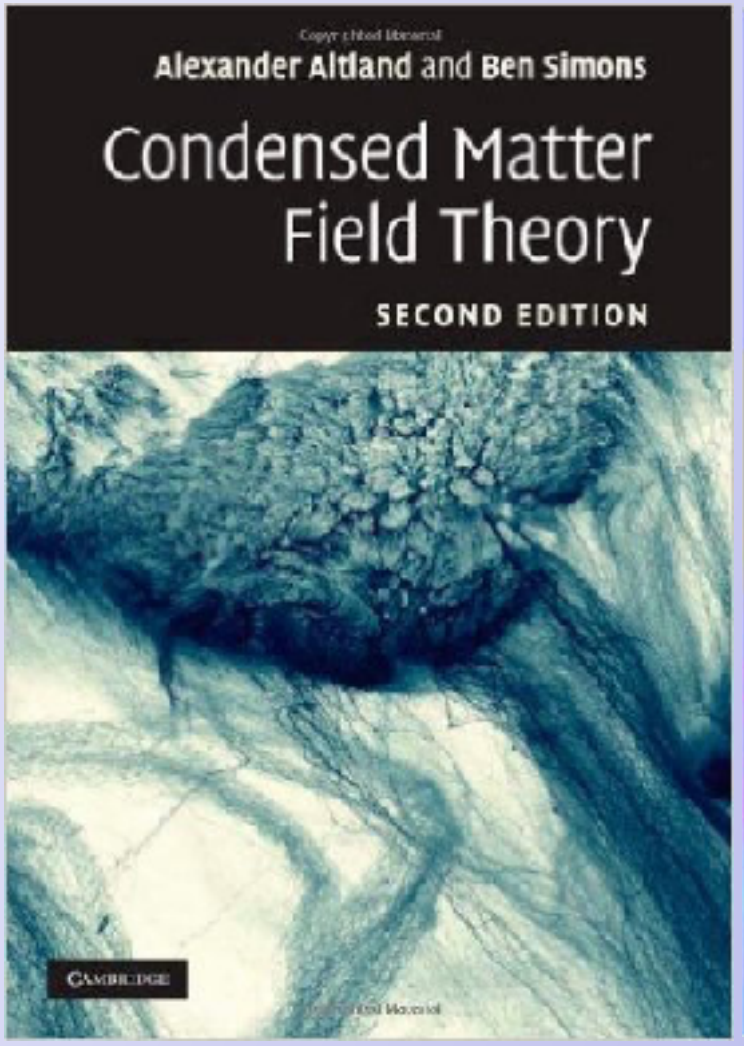
W.I. Fine Theoretical Physics Institute, University of Minnesota

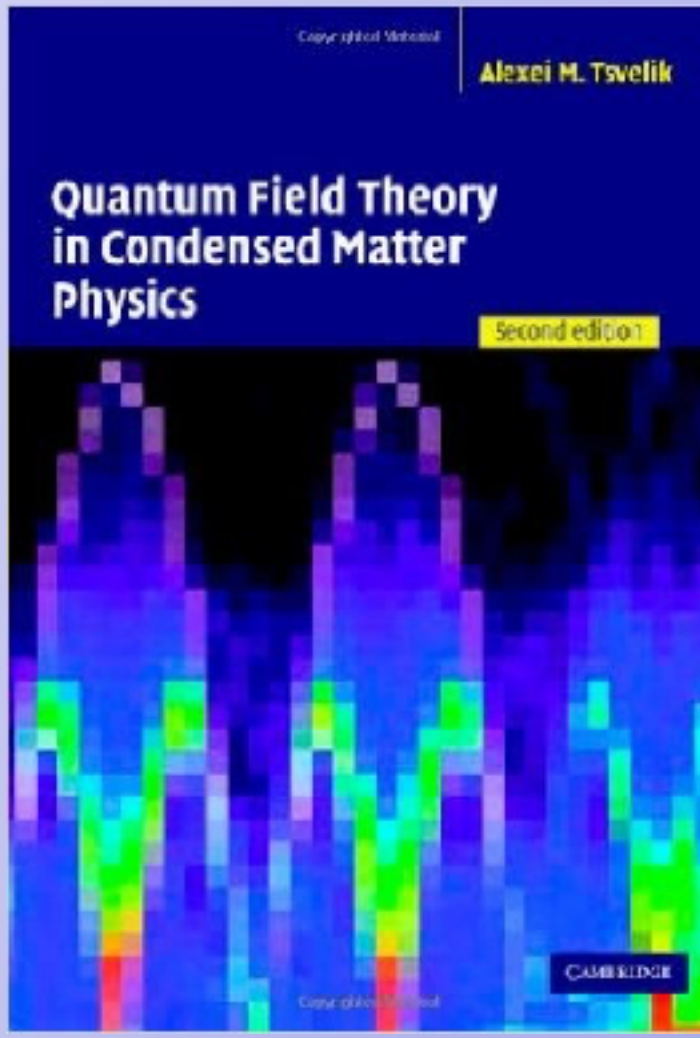
✶ Our today's understanding of Nature at the fundamental level is based on Quantum Field Theory (QFT) which is 90 years old

✶ So far there is no direct evidence calling for going beyond QFT!

Modern condensed matter physics is based on Quantum Field Theory

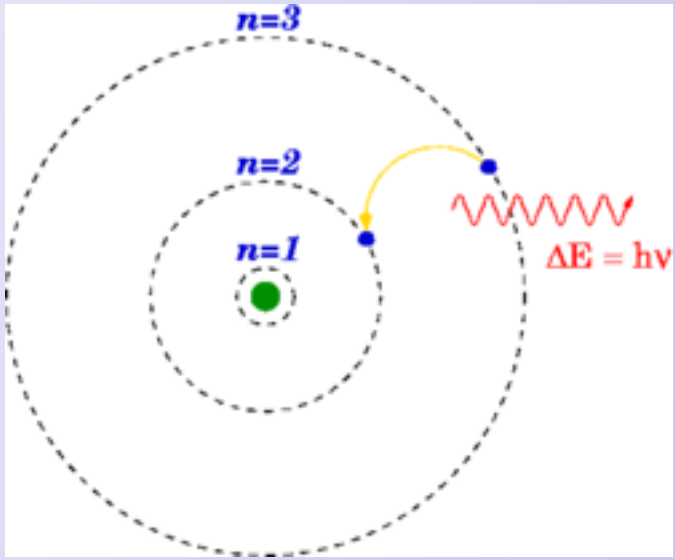






* QFT = quantum mechanics (QM) + relativity

* * In 1926 relativity meant photons



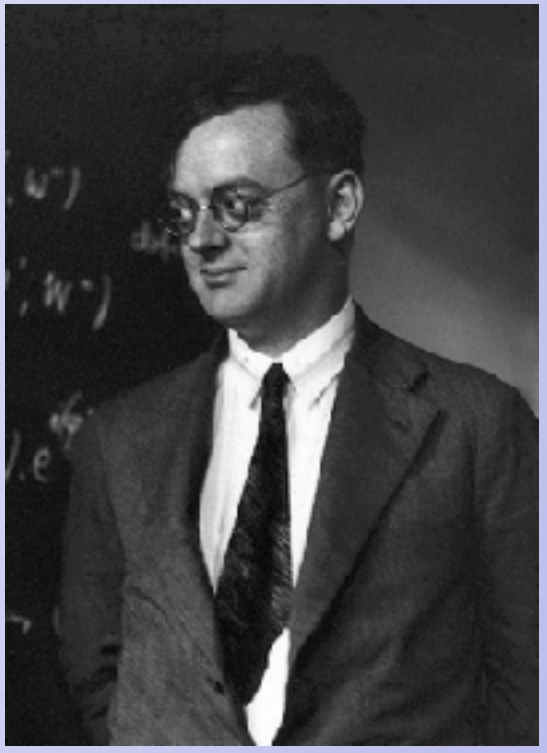
Physicists knew about electromagnetic field. First application of QM to fields came in founding paper of QM itself (1926). Born, Heisenberg, and Jordan considered electromagnetic field in empty space, in the absence of any electric charges or currents.

✷ If quantum mechanics was a revolution, QFT was a humble child

Born, Heisenberg, and Jordan canonically quantized γ field using creation & annihilation operators

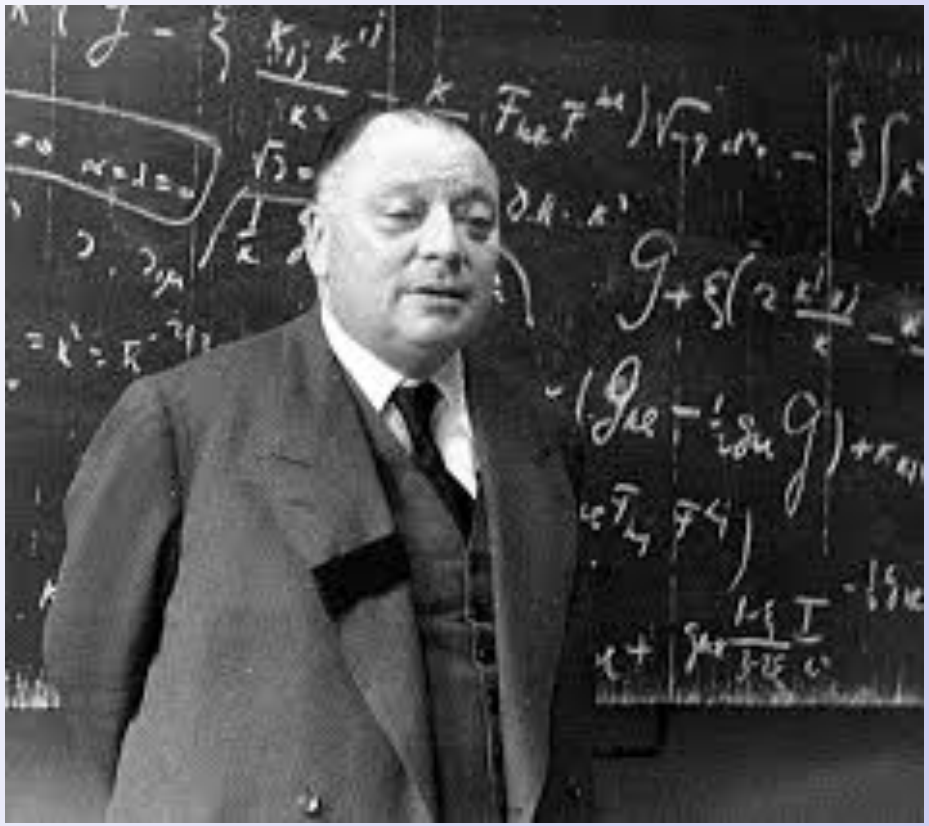
✷ ✷"Practical" QED with electrons: 1927, P. Dirac





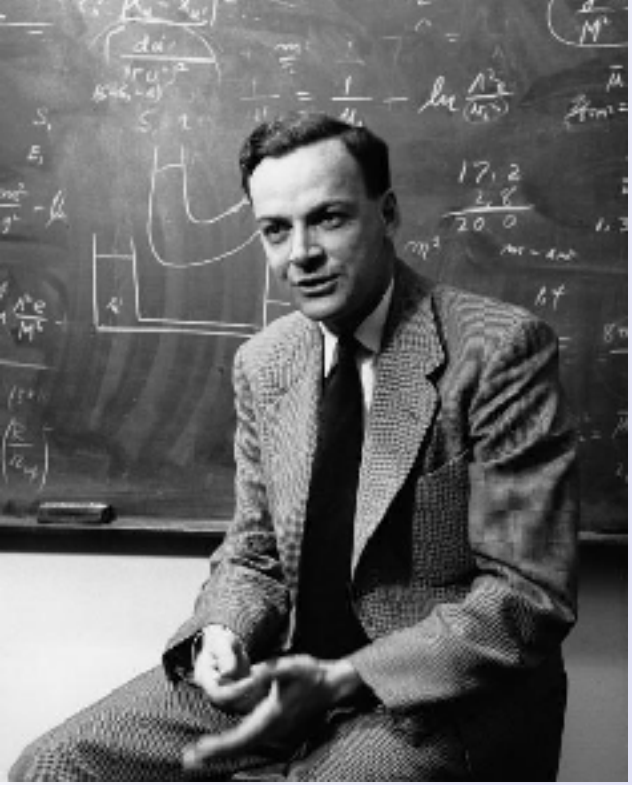

✷ Final touches (1929-30): Heisenberg and Pauli ➔

"Material particles could be understood as the quanta o various fields, in just the same way that the photon is the quantum of the electromagnetic field..."



Subsequent 18 years: struggle with ∞ ∞ ∞. Mysterious holy grail searches.

QED remained the only respectable QFT till 1970s!



Renormalizablity: 1948-51; Feynman et al.

✷

Awe before renormalizable QFT (QED,...)

✷

(1953-54: Landau's zero charge)

$M_{uv} = \infty$

Landau: QFT is DEAD!

Landau: QFT is DEAD!

Landau: QFT is DEAD!

Revolutions of mid-1950-mid-1970s

Yang-Mills; fall 1954

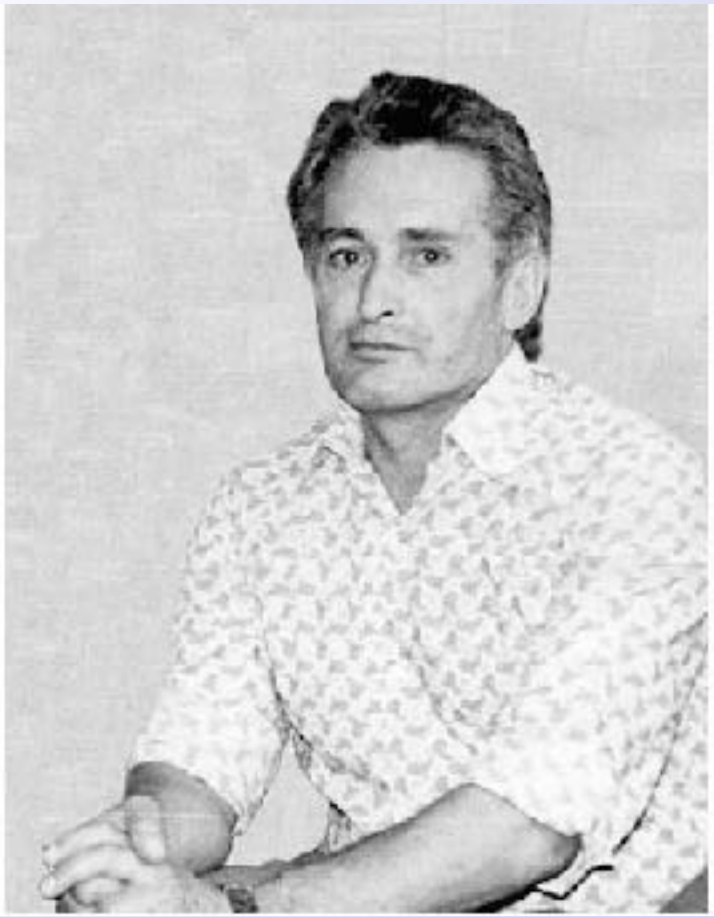
C. N. Yang (1922 -) and Robert Mills (1927 - 1999) at Stony Brook in 1999.

Pauli studied Yang-Mills first, before Yang-Mills, see letter to Pais, "Meson Nucleon Interaction and Differential Geometry" (written "to see what it looks like," on July 22-25 1953).

$$\{\bar{Q}_{\dot{\alpha}}, Q_{\beta}\} = 2\sigma^{\mu}_{\dot{\alpha}\beta} P_{\mu}$$

Superalgebra and 4D SUSY Theories

1970; Golfand and Likhtman



N=1 SUSY without central extensions

(Defying Coleman-Mandula theorem)

точный вид гамильтониана в представлении взаимодействия, можно восстановить по нему лагранжиан в гейзенберговском представлении:

$$L(x) = (\partial_\alpha \phi^* - igA_\alpha \phi^*)(\partial_\alpha \phi + igA_\alpha \phi) - m^2 \phi^* \phi + (\partial_\alpha \omega^* - igA_\alpha \omega^*) \times$$

$$\times (\partial_\alpha \omega + igA_\alpha \omega) - m^2 \omega^* \omega + \frac{i}{2} \psi_1 \gamma_\alpha \overleftrightarrow{\partial}_\alpha \psi_1 - m \bar{\psi}_1 \psi_1 - g \psi_1 \gamma_\alpha \psi_1 A_\alpha +$$

$$+ \frac{i}{2} \bar{\psi}_2 \gamma_\alpha \overleftrightarrow{\partial}_\alpha \psi_2 - \mu \bar{\psi}_2 \psi_2 - \frac{1}{2} (\partial_\beta A_\alpha)^2 + \frac{\mu^2}{2} A_\alpha A_\alpha + \frac{1}{2} (\partial_\alpha \chi)^2 - \frac{\mu^2}{2} \chi^2 +$$

$$+ g\mu(\phi^* \phi - \omega \omega^*) \chi - \frac{g^2}{2} (\phi^* \phi - \omega^* \omega)^2 + \sqrt{2} g (\bar{\psi}_1 \bar{s} \psi_2 \phi + \bar{\psi}_2 \bar{s} \psi_1 \phi^*) -$$

$$- \sqrt{2} g (\psi_1^c \bar{s} \psi_2 \omega^* + \bar{\psi}_2 \bar{s} \psi_1^c \omega) . \qquad (7)$$

Таким образом, получена модель взаимодействия квантованных полей с несохранением четности, инвариантная относительно алгебры (1).

Физический институт
им. П.Н.Лебедева
Академии наук СССР

Поступила в редакцию
10 марта 1971 г.

Литература

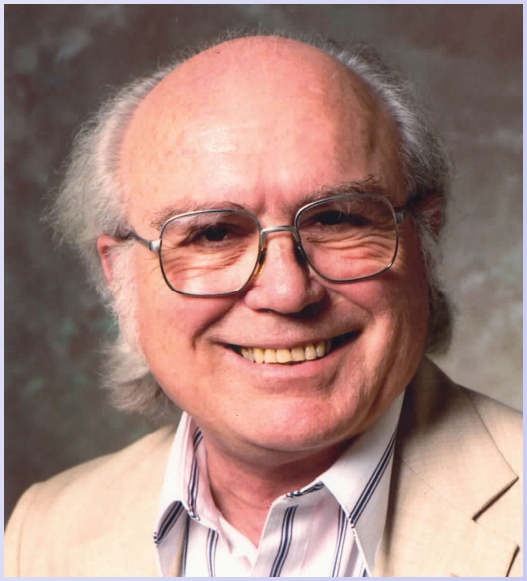
[1] С.Швебер. Введение в релятивистскую квантовую теорию поля. ИИЛ, 1963.

JETP Letters 1971:

SQED with photon mass and massive matter

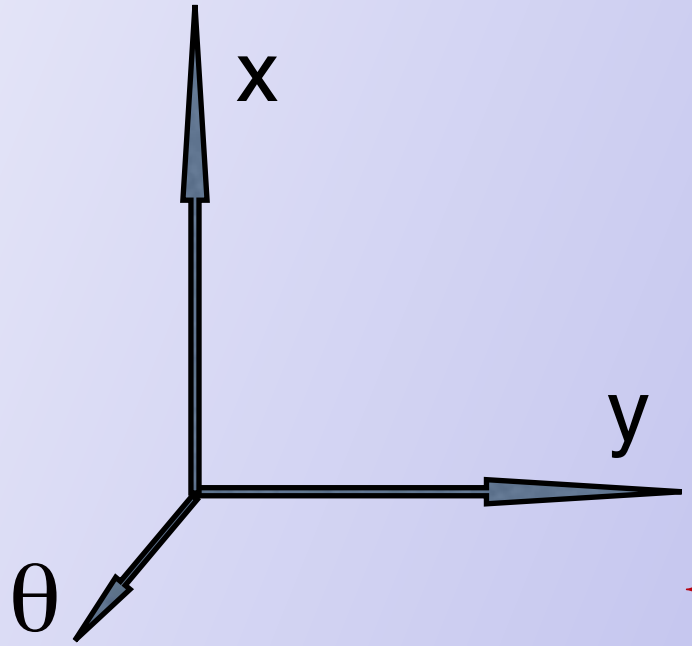
(Couple of typos)

1973 and later



Wess & Zumino, 73

$$\theta^2 = 0$$



Superspace

Salam and
Strathdee, 1975

"fermion" direction
of the superspace

$\longrightarrow$

In 1+3 dimensions

$$\{t, x, y, z\} \longrightarrow \{t, x, y, z;\ \theta^i_\alpha\}$$

New QFT born after the revolution

Dramatic Conceptual Changes

- Infinities are not an issue, $M_{uv} \neq \infty$

  Renormalizable QFT are singled out technically; no need in UV completion

- Asymptotic freedom makes QFT self-consistent

  Landau pole evaded

  Wilson's renormalization group (RG) flow logic

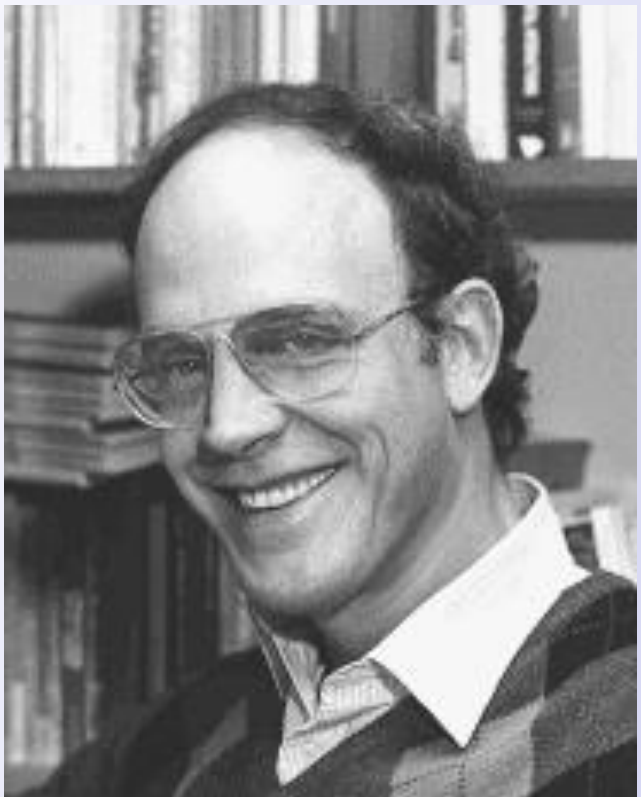
- Uniqueness of vacuum gone

  Multiple vacua, highly complicated vacua, not reducible to harmonic oscillations

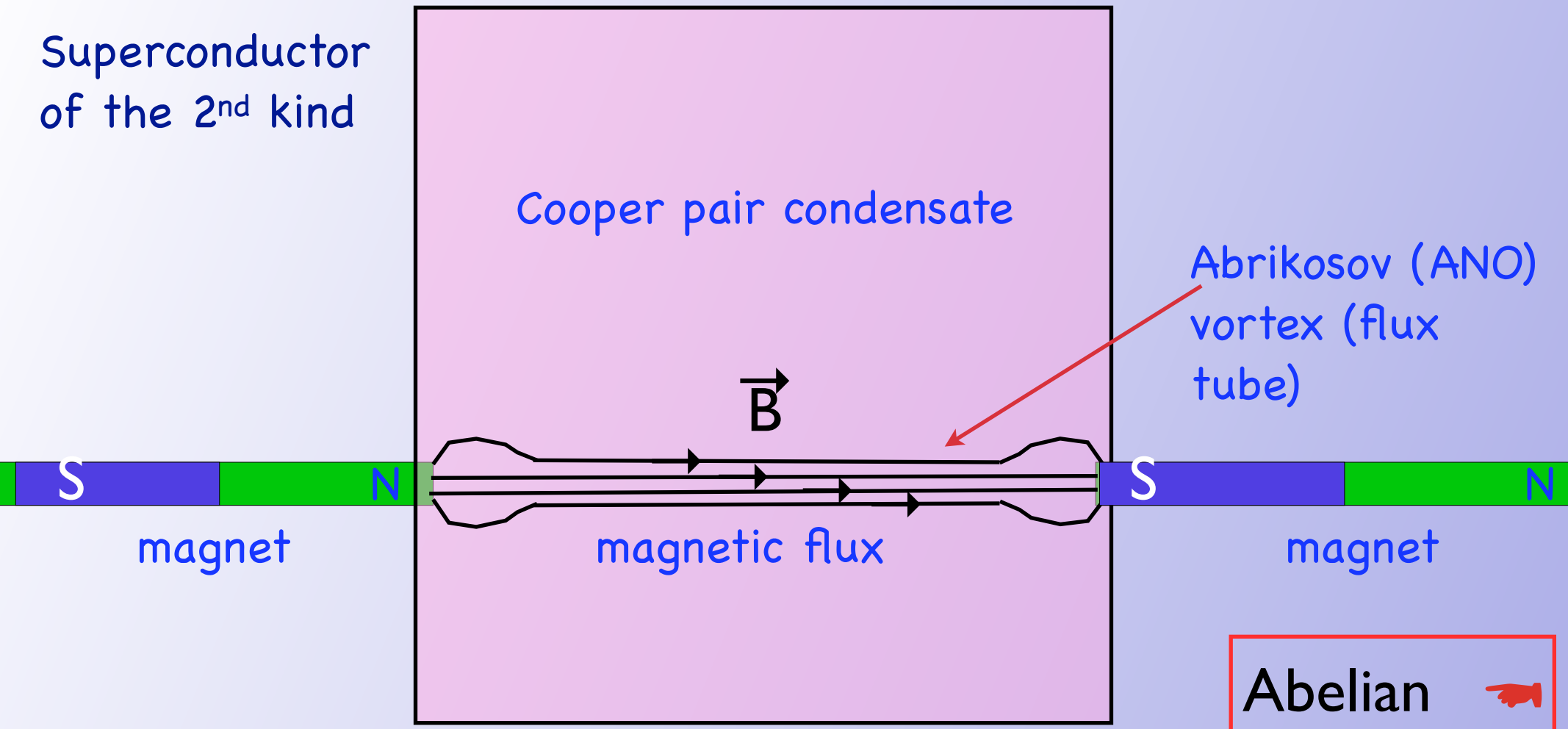
- Logic: Asymptotically free QFT is given by a local L at M_{uv} where couplings are small. Use Wilson flow.

  If Higgs does not stop RG flow, arrive at strong coupling in IR

- Strong coupling in YM ➜ Confinement, conformality or other phases unknown previously



What is confinement? (Example)



Abelian ☚

☞ The Meissner effect: 1930s, 1960s

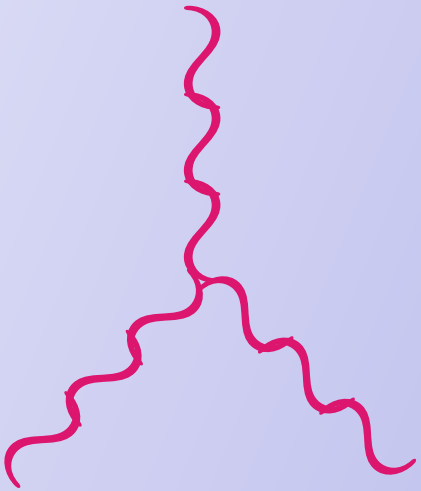
DUAL MEISSNER EFFECT (Nambu-'t Hooft-Mandelstam, ~1975)

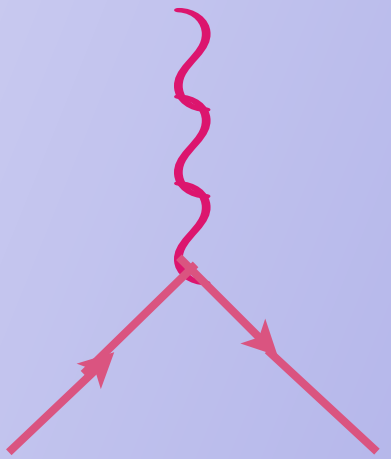
Here comes power of supersymmetry

$$L = -\frac{1}{4g^2} G^a_{\mu\nu} G^{\mu\nu\, a} + \frac{i}{2} \bar{\lambda} \not{D} \lambda$$

gluino

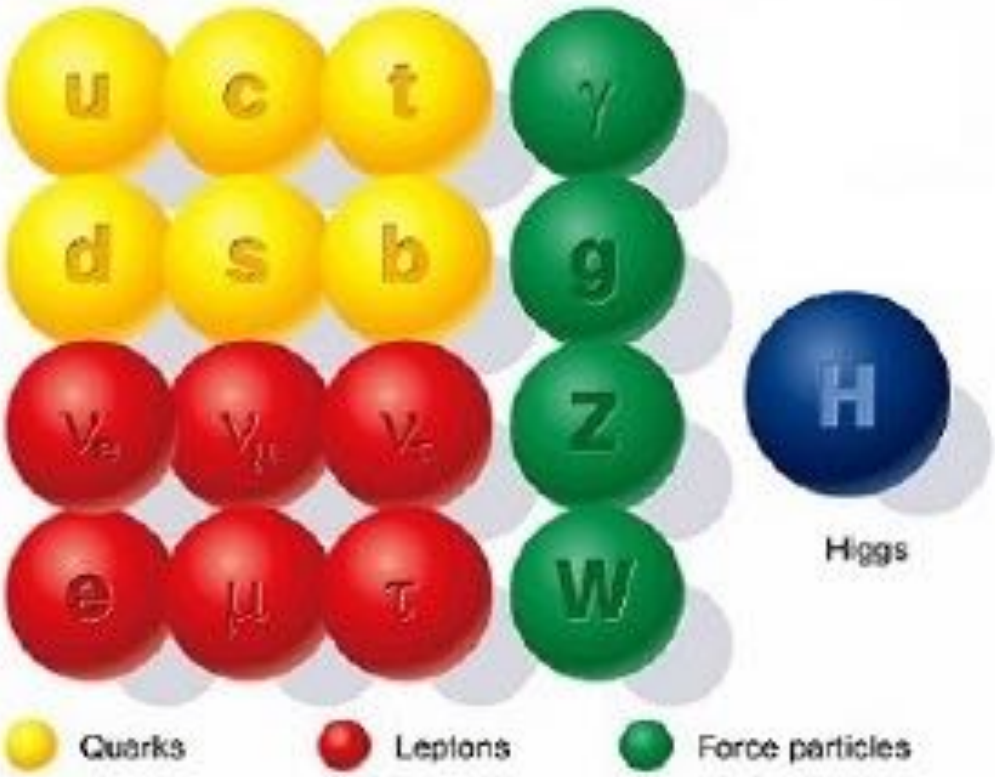
gluon

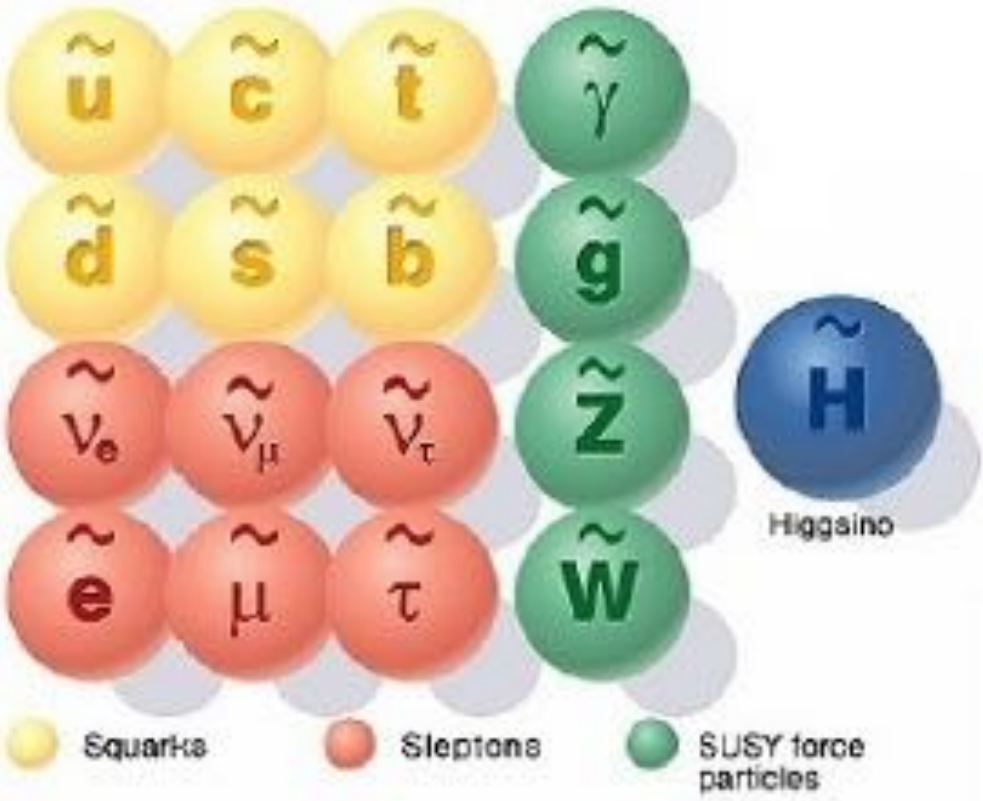




Pure SUSY Yang-Mills = supersymmetric gluodynamics

SUPERSYMMETRY





Standard particles

SUSY particles

☺ First demonstration of the dual Meissner effect: Seiberg & Witten, 1994 ☺

- gluons+complex scalar superpartner
- two gluinos
- Georgi-Glashow model built in

SU(2) $\rightarrow$U(1), monopoles →

Monopoles become light if $|\varphi^3| \lesssim \Lambda$ → At two points, massless!

N=1 deform. forces M condensatition →

U(1) broken, electric flux tube formed →

Exact results in QFT are possible!

Gauge symmetry is a redundancy!!

Hence, Seiberg dualities !!!

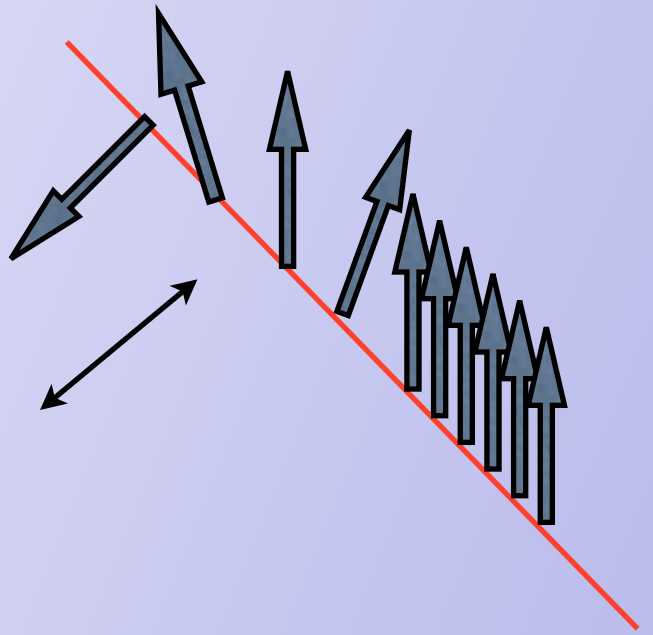
$SU(N)_{gauge}$, N_f flavors =

$SU(N_f-N)_{gauge}$, N_f flavors

NSVZ β function: Conformal Window

Gluino condensate: order parameter (N vacua)

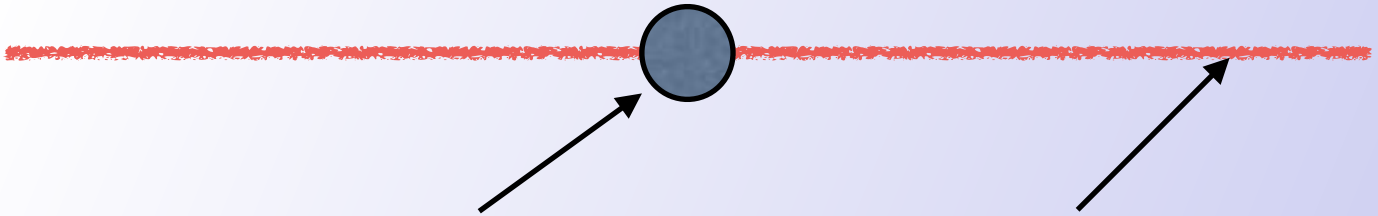
"Non-Abelian" string is formed if all non-Abelian degrees of freedom participate in dynamics at the scale of string formation



2003: Hanany, Tong
Auzzi et al.
Yung + M.S.

classically gapless excitation

SU(2)/U(1) = CP(1)~O(3) sigma model



- Kinks appear on soliton vortex strings
- Kink = Confined Monopole

2D kink mass =4D monopole mass!!!

4D ↔ 2D Correspondence

☛ World-sheet theory ↔ strongly coupled bulk theory inside

Dewar flask

QFT approaches 90 with very recent discoveries:

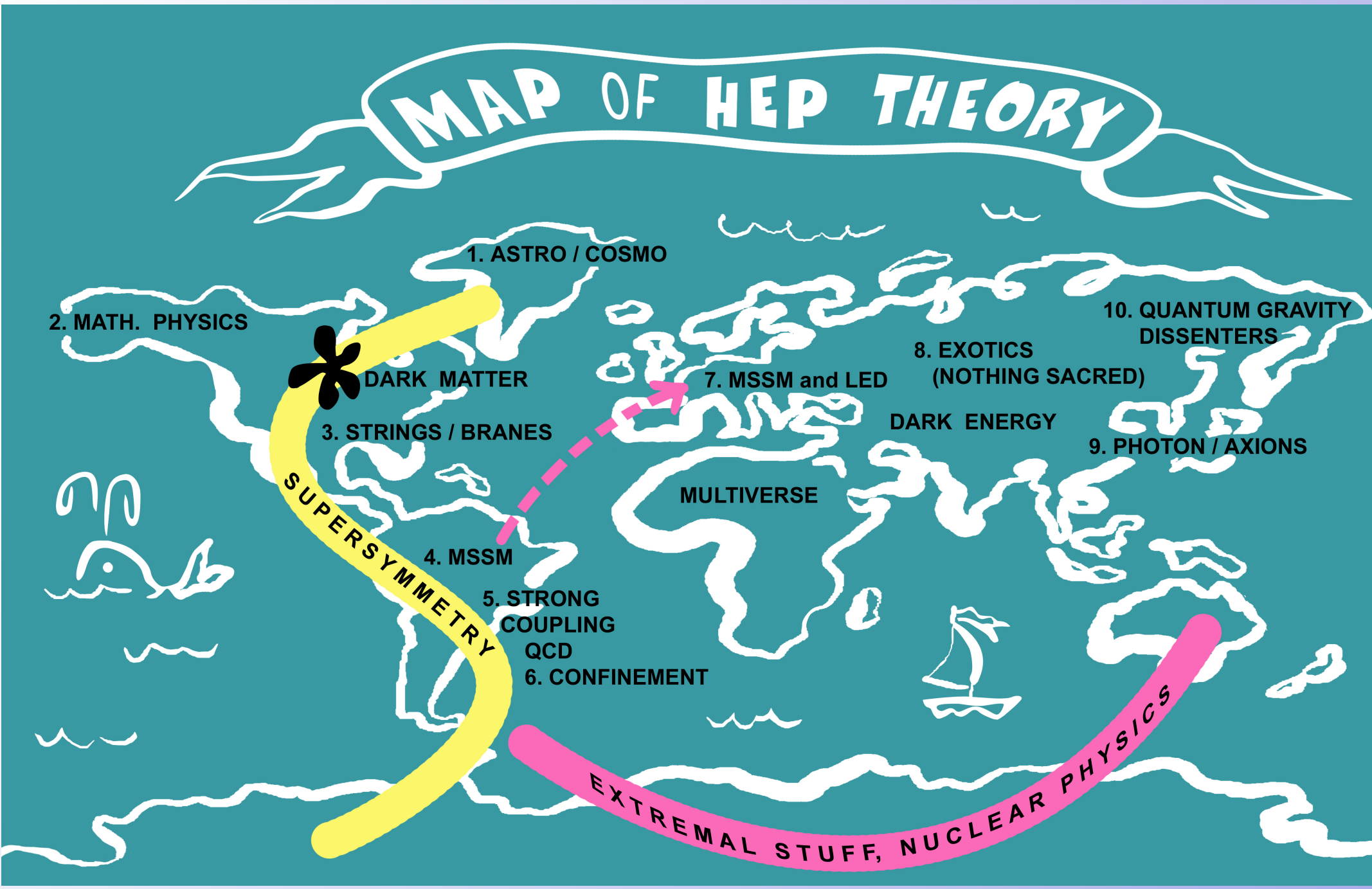
1) 1-form anomalies and their consequences;
2) Unexpected suppression of the vacuum energy density in non-SUSY;
3) Prolifertion of methods at strong coupling,
4) ……

Instead of conclusions

☛ With new understanding and reformulation QFTs thrive. New theories and new phases are being discovered!!!

A treasure trove of novel ideas, methods, solutions. Rejuvenation!

Thank you!


MAP OF HEP THEORY
1. ASTRO / COSMO
2. MATH. PHYSICS
DARK MATTER
3. STRINGS / BRANES
SUPERSYMMETRY
4. MSSM
5. STRONG
COUPLING
QCD
6. CONFINEMENT
7. MSSM and LED
MULTIVERSE
8. EXOTICS
(NOTHING SACRED)
DARK ENERGY
9. PHOTON / AXIONS
10. QUANTUM GRAVITY
DISSENTERS
EXTREMAL STUFF, NUCLEAR PHYSICS