

June 29, 2016

Solitons, Supersymmetry & Strings

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“From the Vacuum
to the Universe”

Kitzbühel,

6/27 - 7/1, 2016



Giant Swirl
Phenomenon, Crater
Lake National Park,
Oregon

Sixty years ago young Alexei Abrikosov in a student work predicted T2 superconductors and Abrikosov vortices....



Landau was not quite happy with this work, and it was not immediately published.

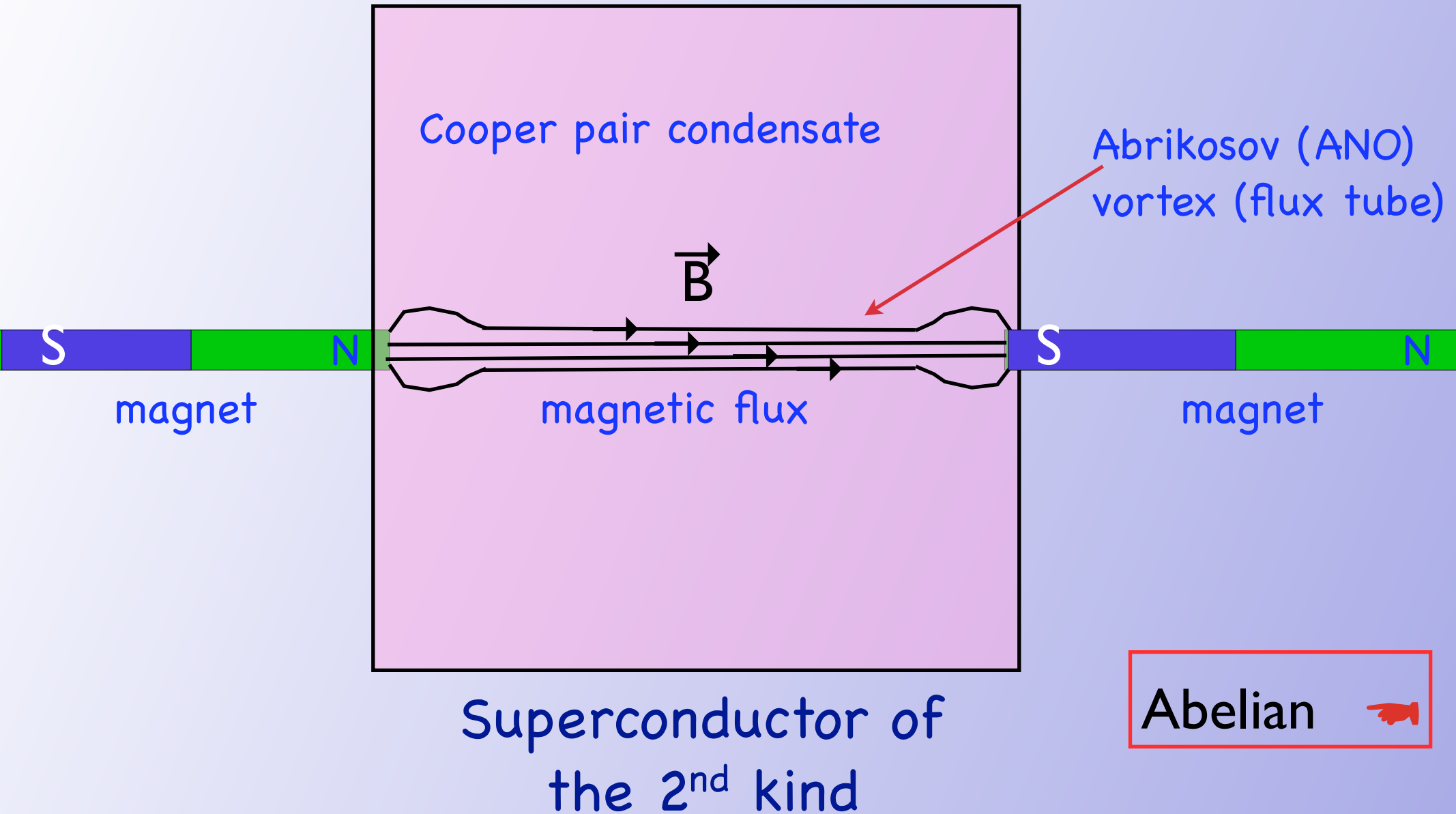
Was published 2 or 3 years later (1957)....

10 Dec 2003 Stockholm

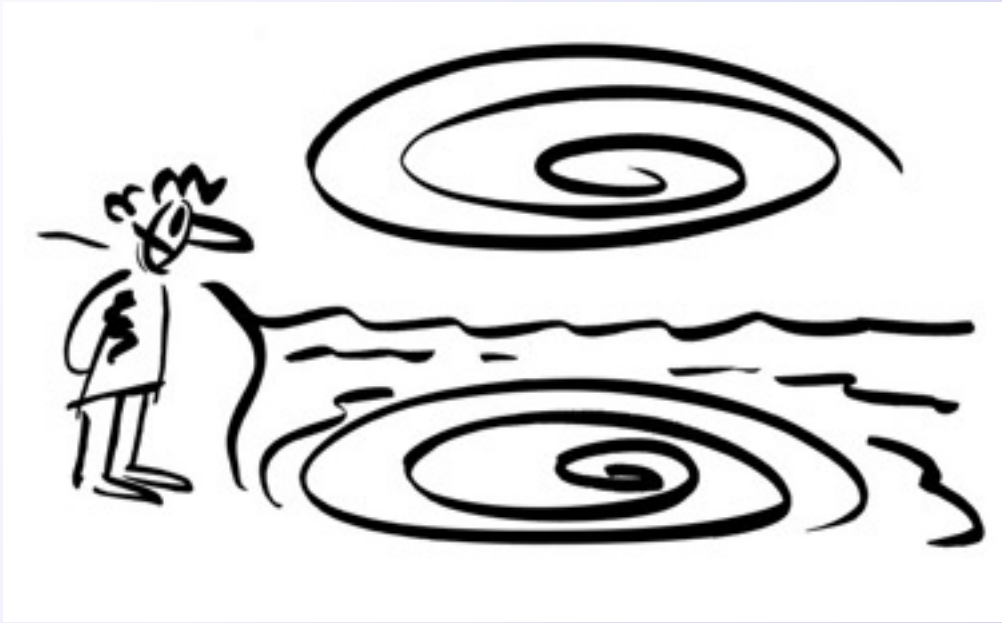
Physics Nobel Prize 2003



👉 The Meissner effect! 1930s

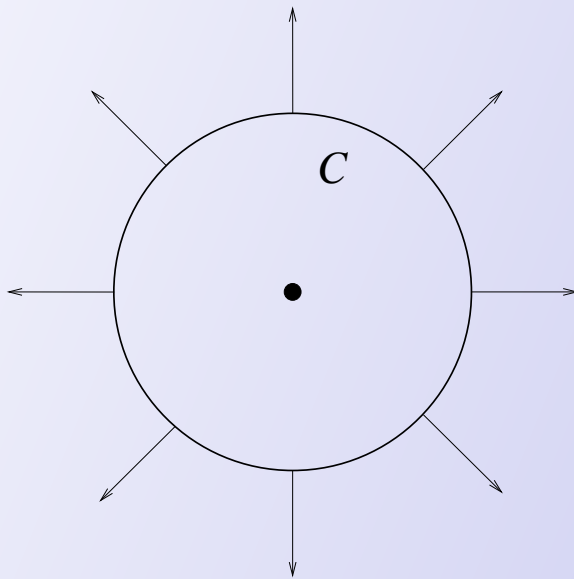


$$\mathcal{L} = -\frac{1}{4e^2} F_{\mu\nu}^2 + |\mathcal{D}^\mu \phi|^2 - U(\phi)$$



ψ complex

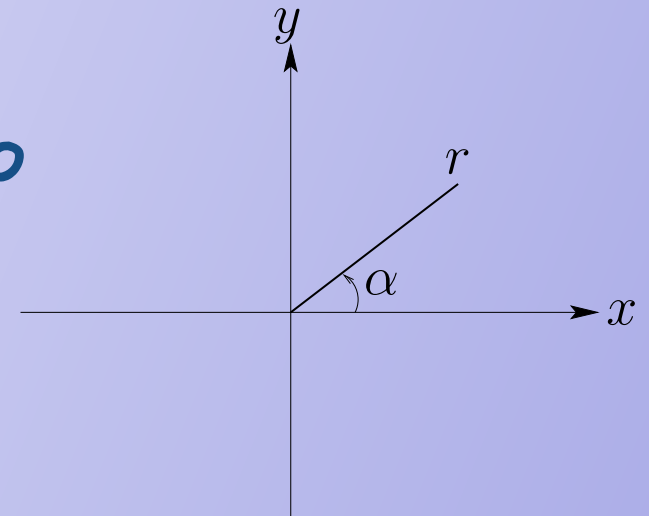
$$U(\phi) = \lambda (|\phi|^2 - v^2)^2$$



$$\varphi = v e^{i\alpha} \text{ at } r \rightarrow \infty$$

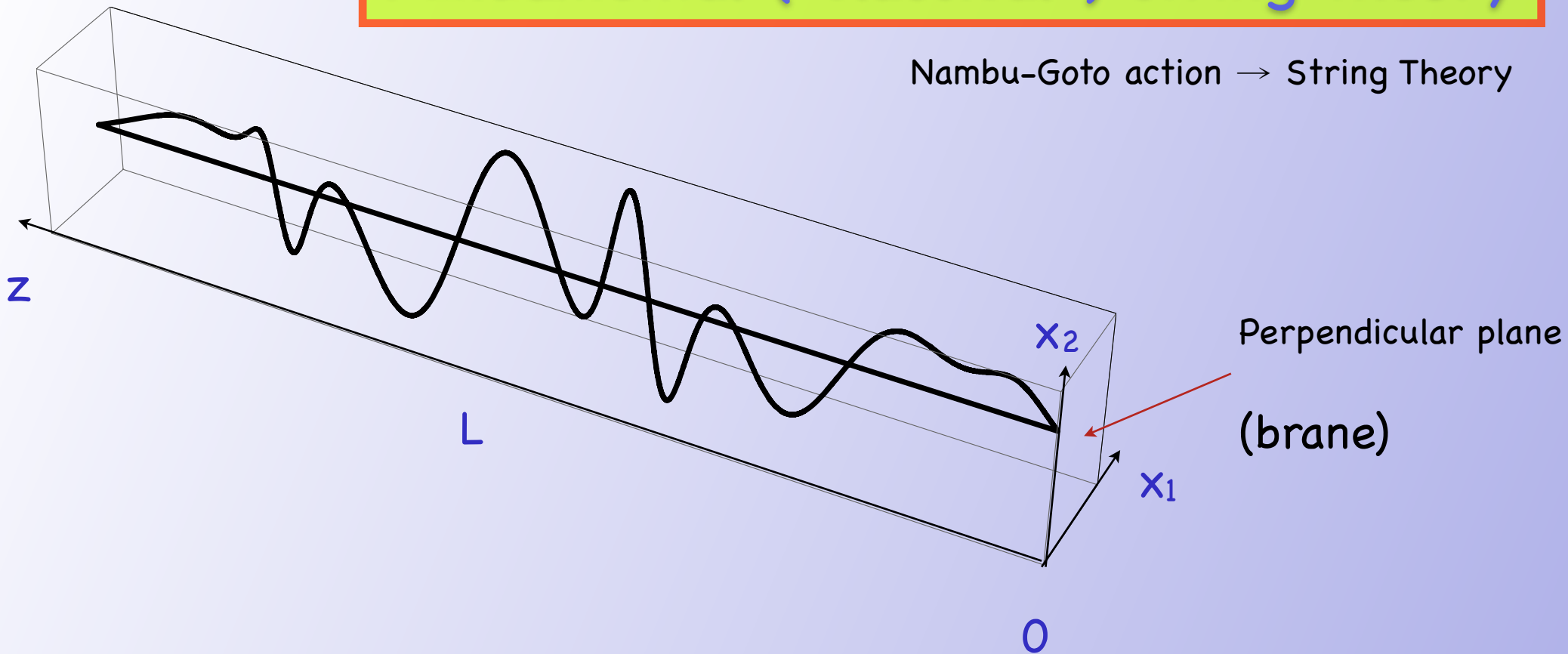
or

$$\varphi = v e^{i(n)\alpha}$$



Fundamental ("classical") string theory

Nambu-Goto action \rightarrow String Theory



Infinitely thin string, fully defined by its coordinates

Quantization possible in 10 dimensions

Sir Thomas Walter Bannerman "Tom" Kibble (1970s)

Edward Witten (1985)

Implementation in QFT: Start with the ANO string, with Higgsed U(1) form "another QED";

Add "our" photon and our QED; Then they will shine!

(Witten also suggested to use "fundamental" strings)



- ★ Formed during a symmetry breaking phase transition in early universe
 - ★ At least one cosmic string per Hubble volume
 - ★ Have never been observed!

Contribution to the structure formation in universe at most 10%

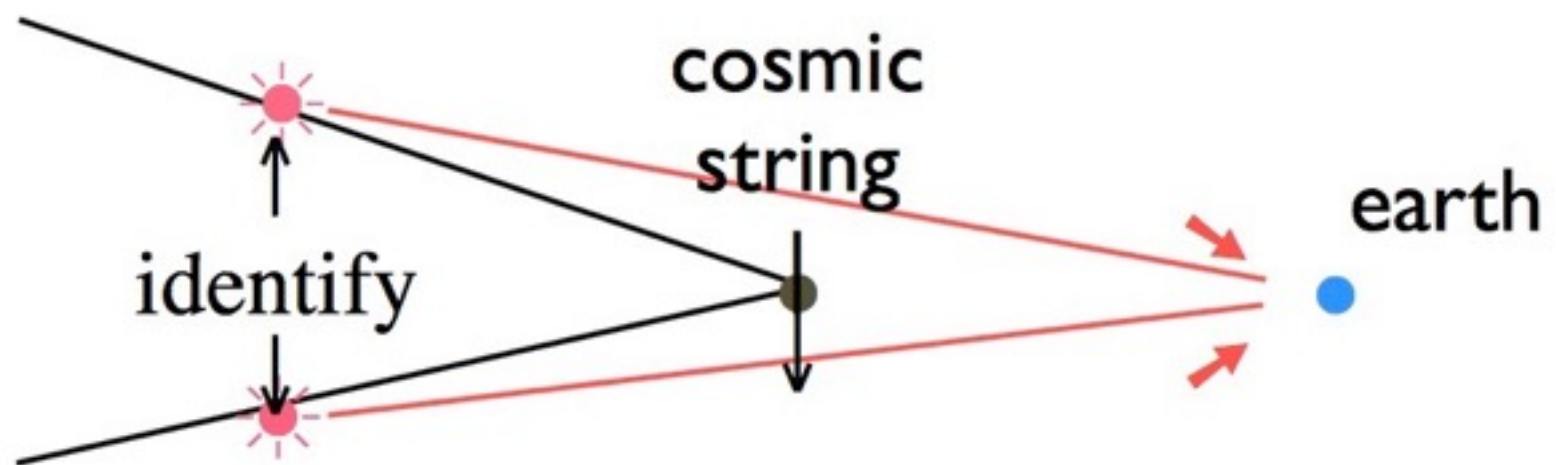
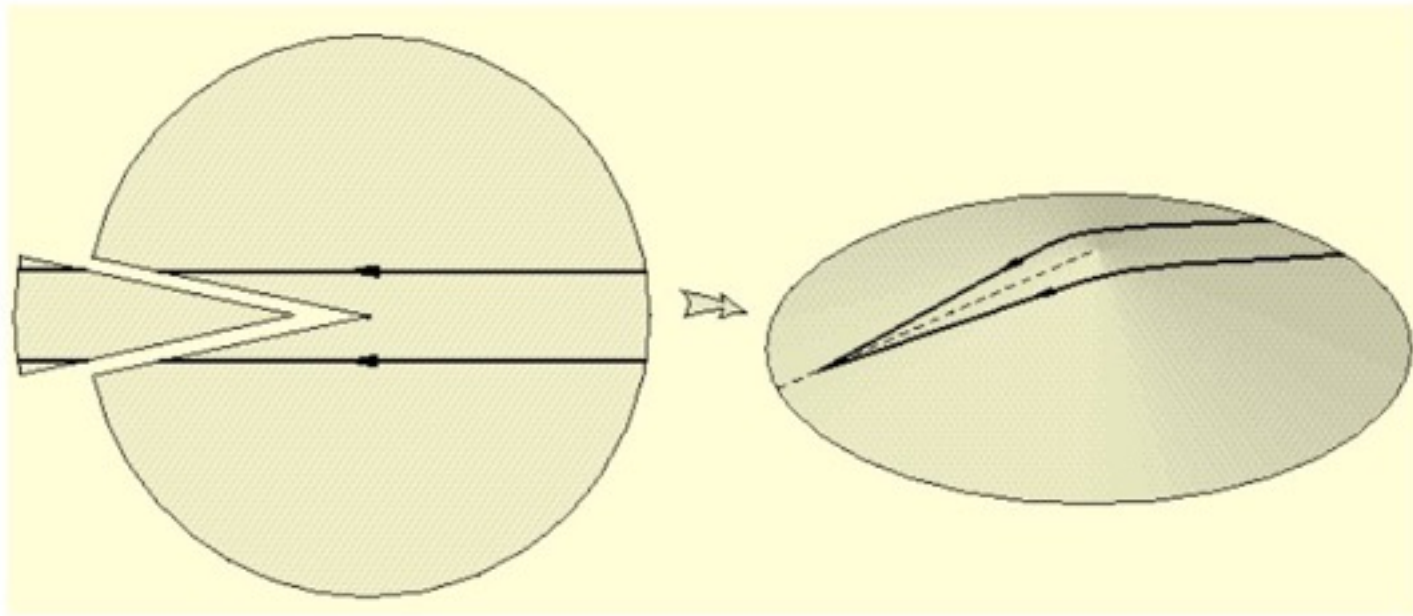
They shine!

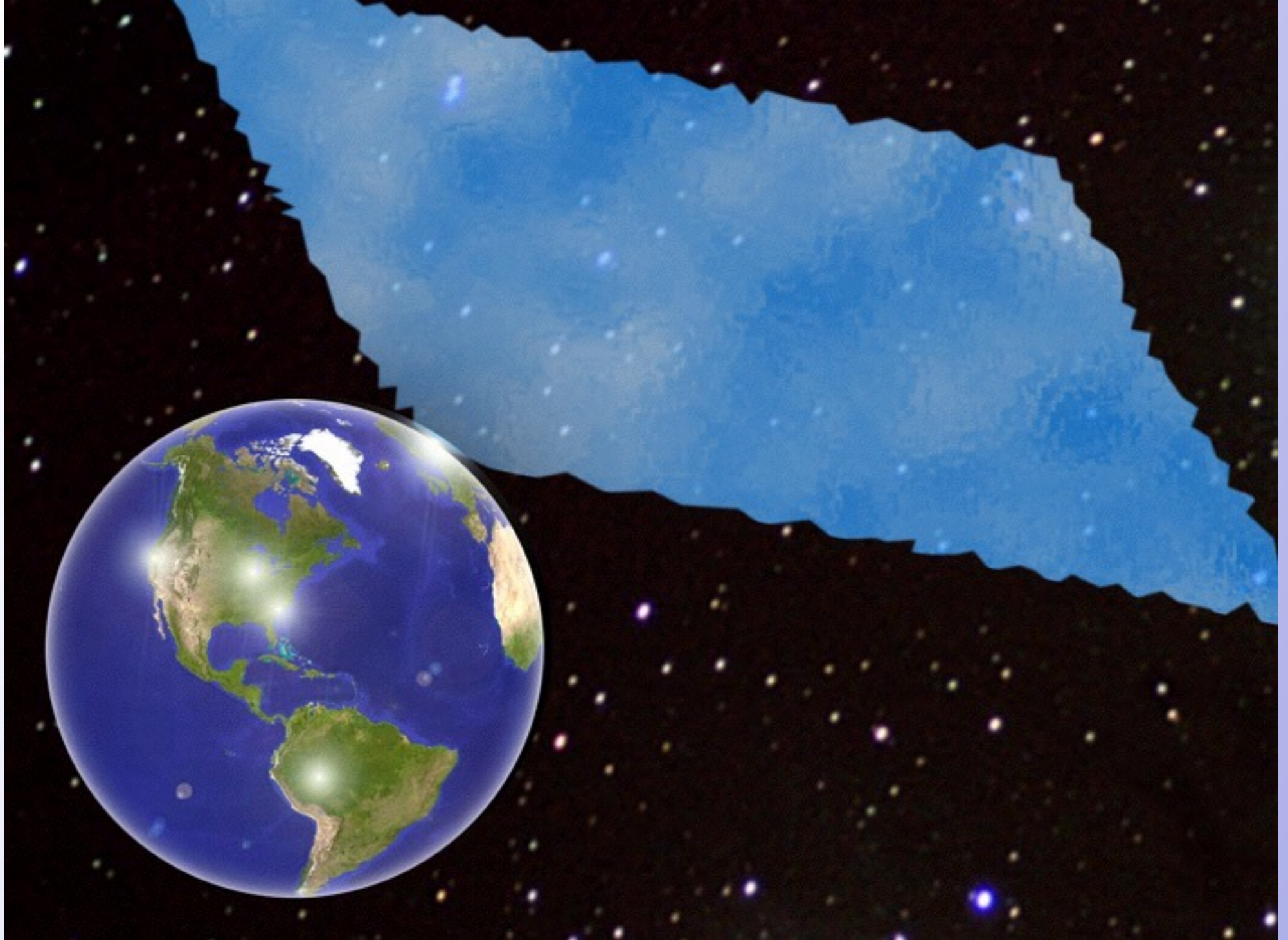
They double gravitational image!

$$\alpha = 2\pi - 8\pi GT_{\text{string}}$$

cosmic string lensing

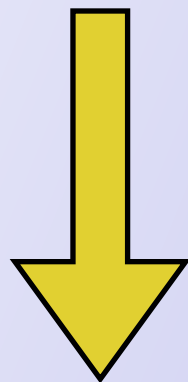
cosmic string introduces a deficit angle





Side remark: Domain wall Gravity REPULSION

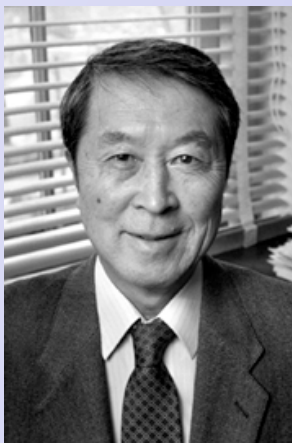
Dual Meissner effect for confinement conjectured



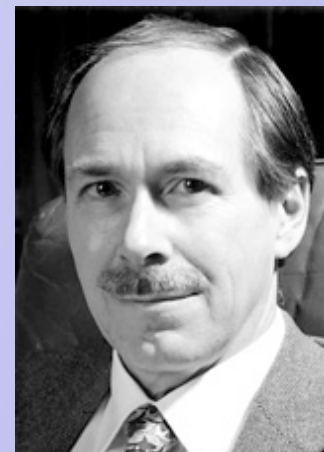
1970s



Mandelstam



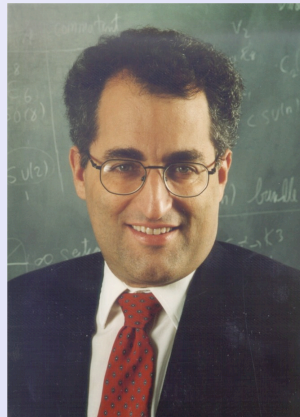
Nambu



't Hooft



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



$\mathcal{N}=2$ (extended) SUSY \rightarrow SU(2) \rightarrow U(1), monopoles \rightarrow

Monopoles become light \rightarrow $\mathcal{N}=1$ deform. forces M condensation \rightarrow

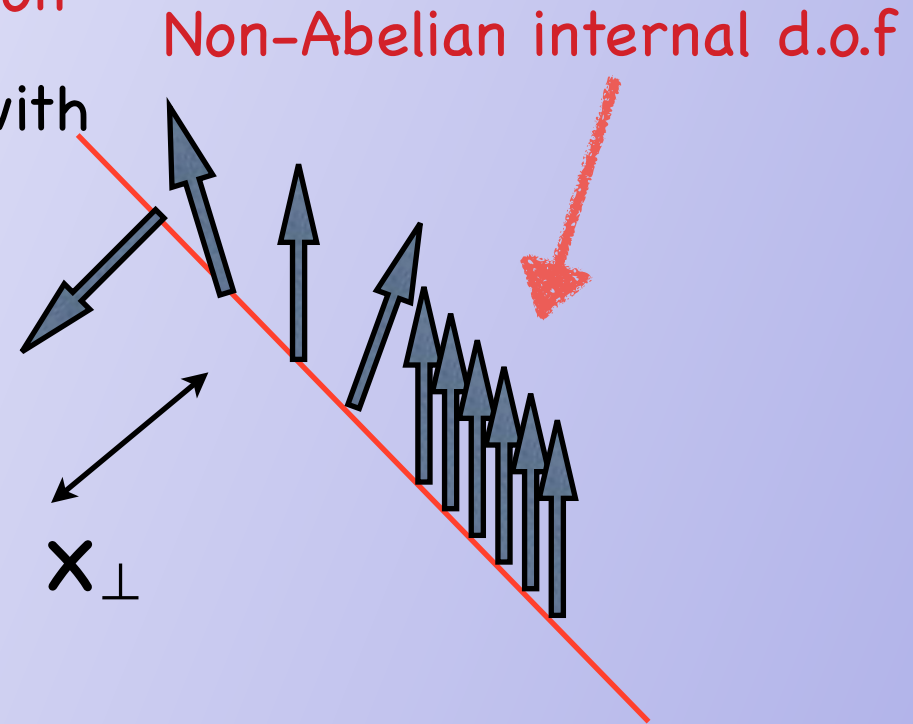
U(1) broken, electric flux tube formed \rightarrow

☹ ☹ Abelian ... (Abrikosov)

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

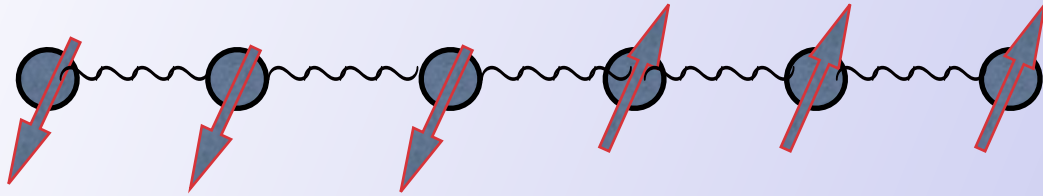
Original discovery in $\mathcal{N}=2$ 4D SYM with $N_f=N_c$ and $N=2$

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

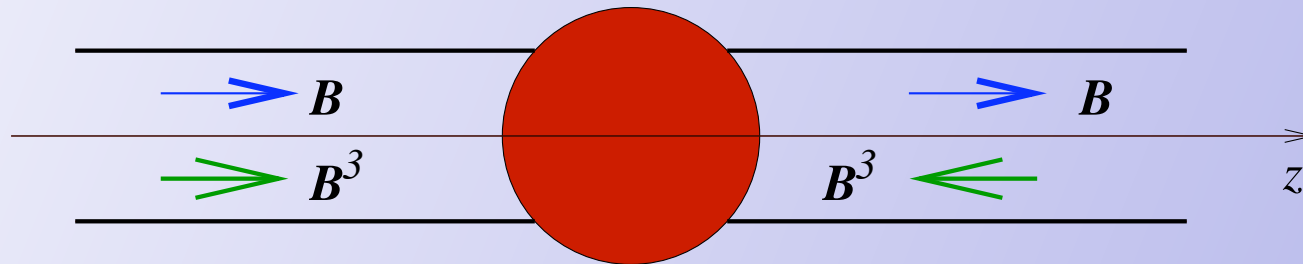


classically gapless excitation

$SU(2)/U(1) = CP(1) \sim O(3)$ sigma model



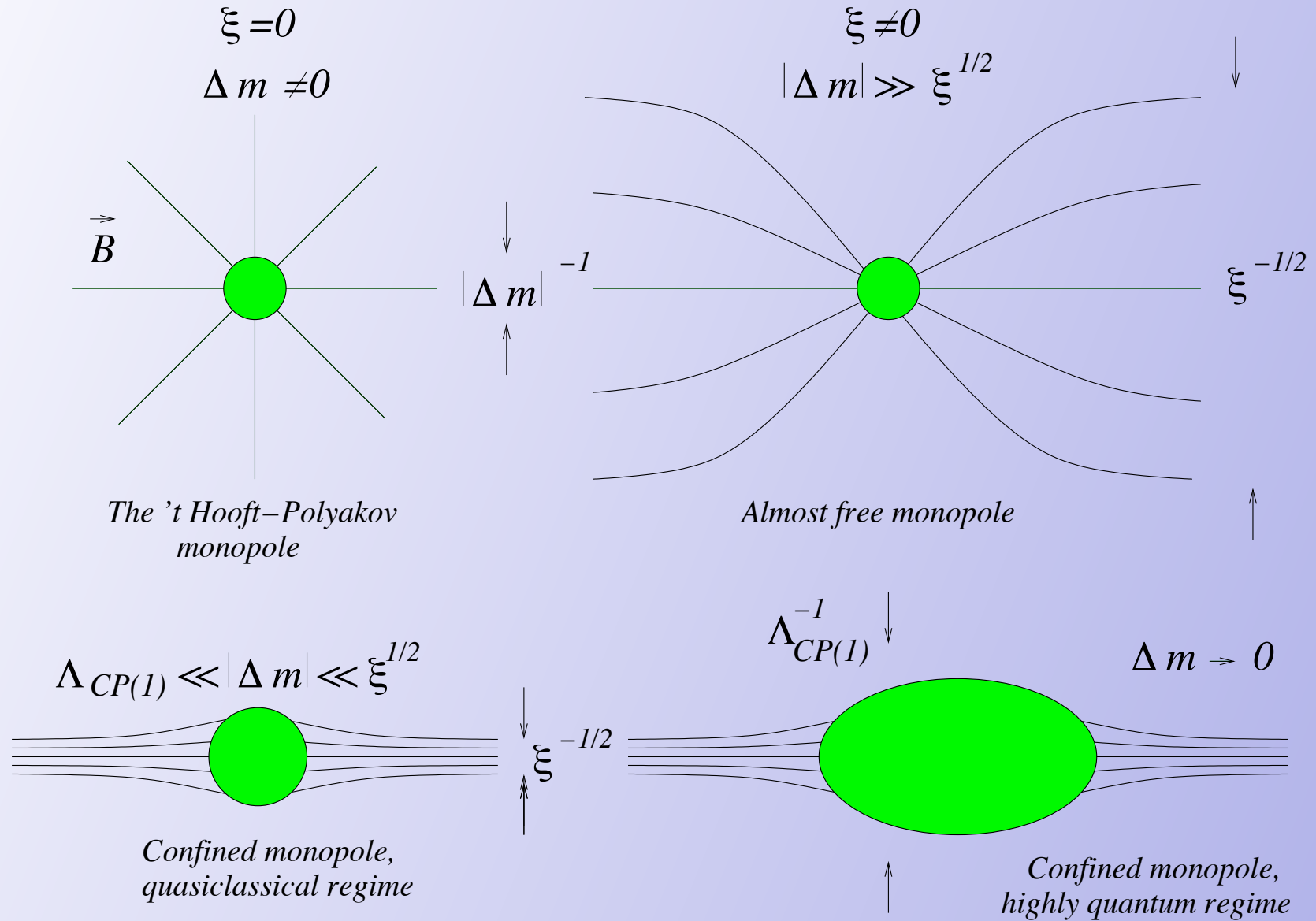
Z_2 string junction = kink



Yung + M.S.
Hanany, Tong

*Kinks are confined in 4D (attached to strings).
Why?

SUSY rules!



Ten-dimensional critical string as a soliton in four-dimensional super-Yang-Mills theory

4D bulk, $N=2$ Yang-Mills

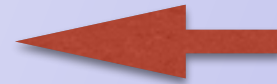
with N_f flavors and N colors;

$U(N)$ gauge group

8 supercharges;

supports 1/2 BPS

"non-Abelian" vortices



For long time

$N_f = N$

\Rightarrow AF $CP(N-1)$

UV incomplete


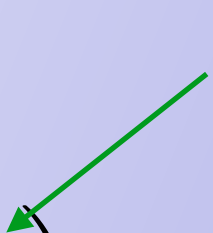
H.D.

If $N_f = 2N$, then

bulk theory CONFORMAL

Verification:

Virasoro central charge (including ghosts) = 0


$$c_{\text{Vir}} = \frac{3}{2} \left(D + \frac{2}{3} c_{\text{WCP}} - 10 \right),$$


$$c(\text{WCP}(N, N)) = 3(N + N - 1)$$



$N=2$

Conclusion:

10D critical string IS reincarnation of a BPS soliton
in 4D $N=2$ super-Yang-Mills with $U(2)$ gauge and
four quark flavors!