Defect Operators in Non-Abelian Gauge Theory

First general meeting of the Fellini program
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Itamar Yaakov

Sezione di Milano-Bicocca

Phases of gauge theories in the Standard Model
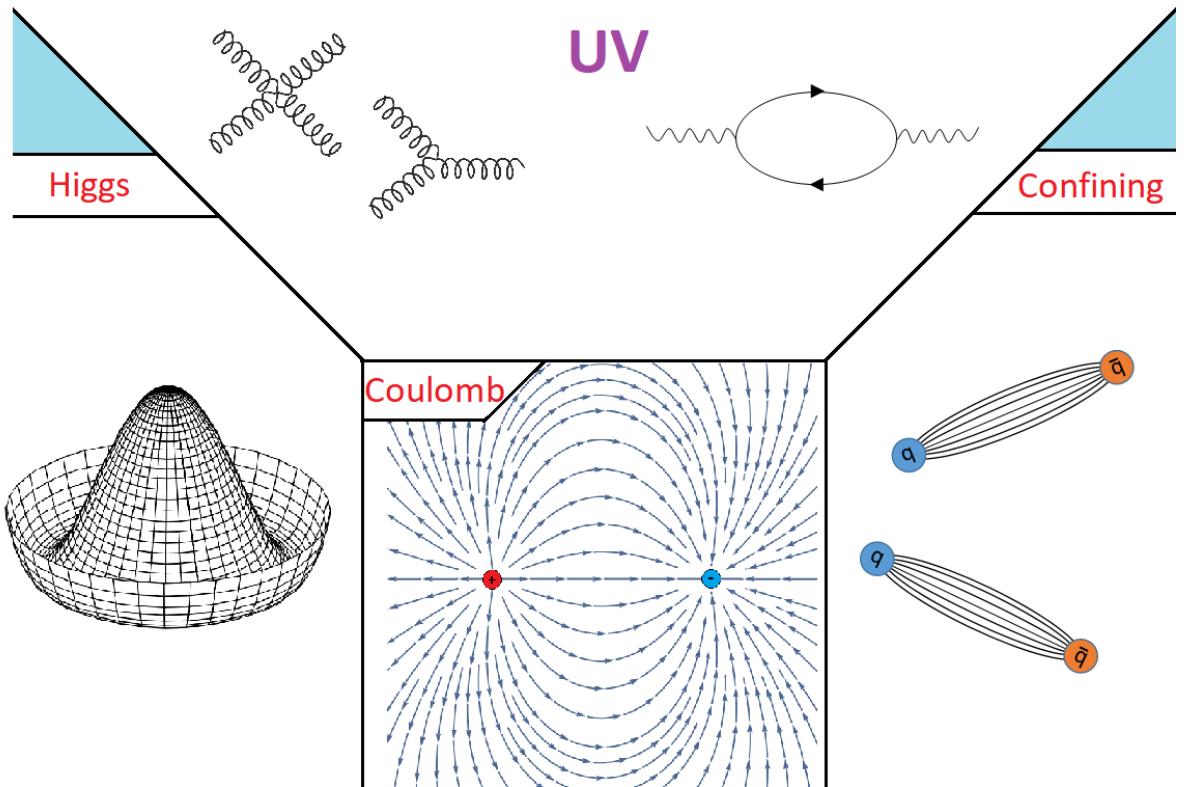
Electric Magnetic duality

Classical electromagnetism is symmetric under the exchange

$$\vec{E} \to \vec{B}, \qquad \vec{B} \to -\vec{E},$$

▶ electric and magnetic sources are exchanged.

▶ for Yang-Mills, a similar "duality" was proposed by
Montonen and Olive (1977), but it doesn't quite work.

The Mandelstam - 't Hooft conjecture

The Higgs and "confining" phases of Yang-Mills are dual to
each other! The Coulomb phase is self-dual.

▶ the confining phase is a result of "monopole
condensation", but no (non-singular) classical monopole
solutions exist in Yang-Mills.

▶ quarks are confined due to the dual Meissner effect: dual
to the situation in a superconductor.

Supersymmetry makes everything simpler!

$\mathcal{N} = 4$ Super-Yang-Mills is the
harmonic oscillator of the 21st century!

▶ EM duality is much better
understood in supersymmetric
theories.

▶ A version of monopole
condensation was demonstrated
by Seiberg and Witten (1994).

▶ Importing ideas from models in
other dimensions, or even from
string theory, has been very
useful.

Defect operators

Supersymmetric theories in 2 and 3 spacetime dimensions offer a compelling story

1. A variety of phases, Non-abelian Coulomb phases, confining phases, some of which can be attributed to condensation of composite particles ("quasi-particles") such as vortices.

2. Dualities at long distances between very different looking gauge theories, with the exchange of quasi-particles (e.g. vortices) with ordinary quanta.

3. Symmetry, even supersymmetry, enhancement at long distances.

4. Exchange ordinary local operators with local **defect operators**: a prescription for creating a quasi-particle.

All have been observed to occur in 4 spacetime dimensions, except #4. Why?

I proposed to "study local defect operators in non-abelian gauge theory in four dimensions, with and without supersymmetry"

▶ Motivated by lower dimensional examples as well as the general picture of electric-magnetic duality.

▶ Accessible through supersymmetric models, with a great deal of relevant recent progress.

▶ The simplest constructions have been ruled out (Kapustin (2005)), but there is still room for some creativity.

▶ A plethora of possible applications to both physics and mathematics (via TQFT).

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The project

Progress and
prospects

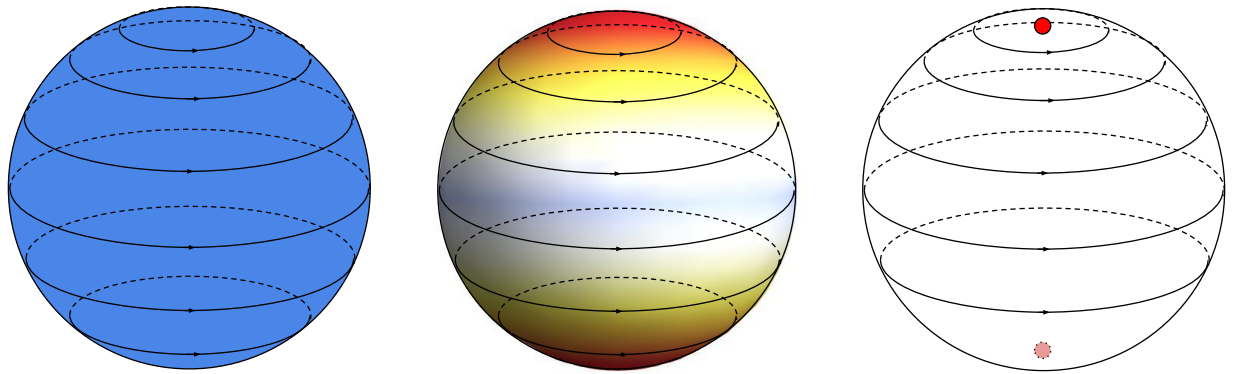**Supersymmetric localization**: an exact version of the saddle point approximation

Figure: All three yield the same result for the Euler number.

▶ Exact results for gauge theories, even at strong coupling!
▶ Supersymmetric defect operators are compatible.

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Progress so far

Before submitting the proposal

▶ preliminary identification for a defect configuration (the "meron"): i.e. the thing which has possibly been missed in previous investigations.

In collaboration with Alberto Zaffaroni at Milano-Bicocca

▶ set up an analogy between the situation in 4 and 3 dimensions (including a fun connection to black hole microstate counting).

▶ proved a mathematical relationship between the topological index (ground state counting) and the superconformal index (operator counting) so I can interpret the meron as an operator (unpublished).

In progress: proving that meron states are **required** by 3d mirror symmetry (3d EM duality). A convincing result if you are a string theorist.

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Future research targets

▶ Compare the moduli space of meron-like solutions to the spectrum of 't Hooft lines.

▶ Quantize merons and deduce the quantum numbers of the meron operator.

▶ Search for connections between merons and global symmetry (or supersymmetry) enhancement.

▶ Investigate possible applications to confinement.

Secondment, mentoring, and outreach

▶ Secondment details will depend on progress and collaborations in the next year or so.

▶ I am mentoring a student on an ITN fellowship at University of Parma: collaboration on Lattice and 2d YM.

▶ I have not had the chance to do any outreach.