# Vacuum defects in YM theories

(comments)

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(presentation uses draft Adriano Di Giacomo + V. Z)

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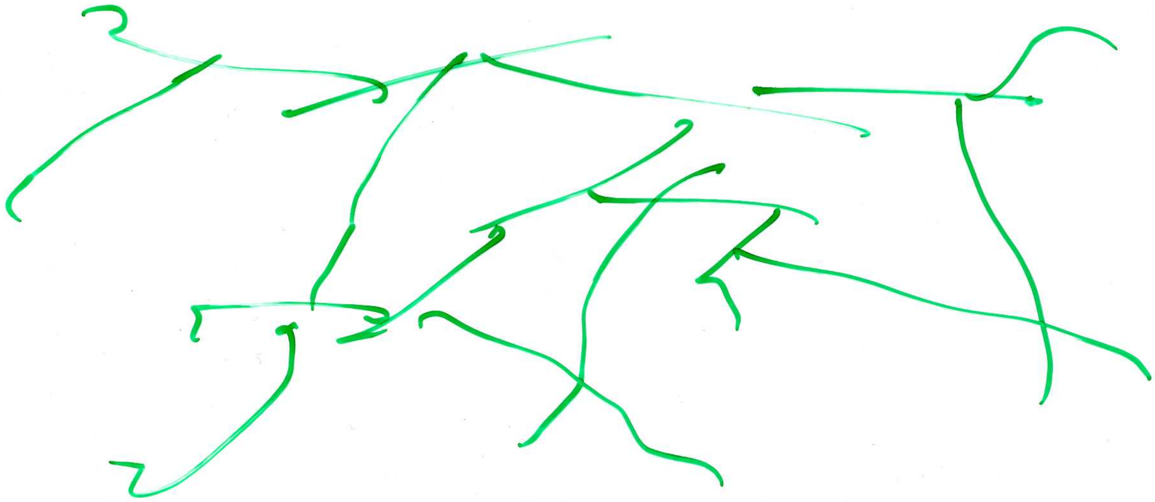
# Outline:

- comments on data, not a theory

- pieces of theory:
- strong UV/IR conneetion exhibited by the data is in no contradiction with YM
- there are phenomenological applications

# Observations:

Confining fields are rather like cracks



Thin, of lattice spacing size

Singular fields

Non-trivial dependences on

$$(\Lambda_{QCD} \cdot a)^{\kappa_i}$$

$\kappa_i$ integer (?) , $i = 1 \ldots 9$

# Chronology (approximate)

## of UV sensitive defects

2001 - 2002 — 1d, 2d defects ≈ ITEP (to be discussed)

2004 — 3d defects (chiral) Ph. de Forcrand

2005 — confining and chiral defects correlated (ITEP)

2006 — further indices

2007 — claim that confining string shrinks to a line with $a \to 0$ ("young ITEP")

## Abelian example

Higgs-field language commonly known

Confining string tension

$$\sigma \sim \langle \varphi \rangle$$

## No-Higgs language

Polyakov '75

Pure gauge field

$$\mathcal{L} = \frac{1}{4e^2} F_{\mu\nu}^2$$

+ plus condition: Dirac string costs no action

Dirac monopoles

$$\vec{H} \sim \frac{1}{e} \frac{\vec{r}}{r^3}$$

Modified eqns of motion:

$$\partial_\mu F_{\mu\nu} = 0 \qquad \partial_\mu \tilde{F}_{\mu\nu} = j_\nu^{mon}$$

$$\partial_\nu j_\nu^{mon} = 0$$

# Back to Higgs

Trading singular gauge fields for a new degree of freedom (scalar)

Radiative mass of monopole

$$\cancel{L} \quad M = \frac{\text{const}}{e^2} \frac{1}{a}$$

Classical action (Euclidean)

$$S = M(a) \cdot \ell$$ length of trajectory

Propagator

$$D(x, y, M) = \sum_{\text{paths}} \exp(-S_{cl})$$

scalar-particle propagator with mass

$$m^2_{phys} = \frac{\text{const}}{a} \left( M(a) - \frac{\ln 7}{a} \right)$$

# Fine tuning

$$M_{crit} = \frac{const}{a\, e^2_{crit}} = \frac{\ln 7}{a}$$

If $e^2 > e^2_{crit}$

$$m^2_{phys} < 0$$

and we are back to the Higgs language

In terms of trajectories:

infinite cluster ($\ell = \infty$) appears

$$\langle |\varphi|^2 \rangle = const\, \rho_{mon} \cdot a$$

$$\langle \varphi \rangle^2 = const\, \rho^{perc}_{mon} \cdot a$$

Interesting case

$$e^2 = e^2_{crit} + \epsilon$$

$$\epsilon \sim m^2_{phys} \cdot a^2 \ll 1 \quad \text{fine tuning.}$$

# Non - Abelian case

"Dual superconductor":

$$D_\mu G_{\mu\nu} = 0, \quad D_\mu \tilde{G}^a_{\mu\nu} \neq 0$$

Monopoles are not good:

(*) $D_\mu \tilde{G}_{\mu\nu} = j^a_\nu \Rightarrow D_\mu G_{\mu\nu} \neq 0$

(**) if $j^a_{\nu, mon} \to \varphi^a$

then $\langle \varphi^a \rangle \neq 0$ no good

(***) $\langle |\varphi^a|^2 \rangle \sim \frac{1}{Q^2}$ contradicts A.F.

Either abandon the idea altogether

**or** look for other defects

# Fields living on surface

Gukov, Witten '06

consider $\int d\sigma_{\mu\nu} G^a_{\mu\nu}$

can be rotated to Abelian direction:

$$(d\sigma_{\mu\nu} G^a_{\mu\nu})(x) \Rightarrow d\sigma_{\mu\nu} G^{(3)}_{\mu\nu}$$

plus fixation of sign:

$$(d\sigma_{\mu\nu} G^{(3)}_{\mu\nu})(x) \cdot (d\sigma_{\mu\nu} G^{(3)}_{\mu\nu})(y) > 0$$

Can also be added $\int d\sigma_{\mu\nu} \tilde{G}^{(3)}_{\mu\nu}$

In other words:

- non-Abelian fields living on a surface are in fact Abelian

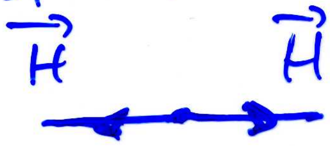
- surface with

$$G^2(x) > 0\ , \quad G\tilde{G}(x) \neq 0$$

is a perfectly non-Abelian object ("defect")

# Non-Abelian "monopoles"

Cannot fix sign $G^3(x) \cdot G^3(y) > 0$ if there exist 1 d defects. In time slice:

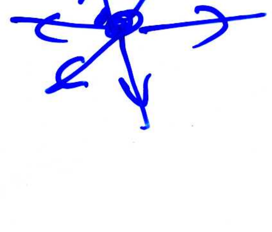



Such defects can be called monopoles

They belong to the surface and their field is confined to the surface as consequence of non-Abelian symmetry

They are line-like 

while Abelian monopoles are spherically-symmetric

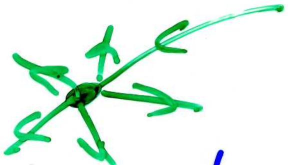


# "Open strings"

If the surface has a boundary (line) it should have invariant meaning as well

The only candidate:
't Hooft line (or $Z_2$ monopole)

No quantization condition



in- and out- fluxes are not equal

(we shall see later, what replaces the quantization condition)

# Fine tuning

is needed for defects to become dynamical degrees of freedom

$$S_{\text{surface}} \sim \frac{\text{Area}}{a^2}$$

$$(\text{Entropy})_{\text{surface}} \sim \frac{\text{Area}}{a^2}$$

The coefficient is not known explicitly (analog of "$\ln 7/a$" in 1d case)

Fine tuning is necessary for the "dual-superconductor" model of confinement to work

# Lattice vortices

defined as closed surfaces in vacuum which can be open on external 't Hooft line (find negative plaquettes)

Properties:

- Action $\simeq$ const $\frac{\text{Area}}{a^2}$
- Area = const $\Lambda^2_{QCD} \cdot V_{total}$
- percolate through vacuum ("tachyonic mode")
- $G^2(x) \neq 0$ only on the surface
- strong correlation with $G\tilde{G}$

All evidence numerical (approximate)
Fits well the classification scheme

# Lattice monopoles

Defined through maximal Abelian projection:

$$A_\mu^a(x) \to A_\mu^3(x) \text{ "closest" to } A_\mu^a(x)$$

reason: defects are intrinsically Abelian, probably survive Abelian projecton

Properties:

- Action $\approx \ell \cdot \frac{\ln 7}{a}$
- total length $\sim \Lambda_{QCD}^3 V_{total}$
- fall on the vortices (defined independently)
- non-Abelian field is aligned with the surfaces

Fits the classification scheme well

# Consistency with AF

For elementary scalar

$$\langle |\varphi_M|^2 \rangle \sim \rho_{mon}^{tot} \cdot a \sim \frac{1}{a^2}$$

Not allowed in YM by AF

For non-Abelian "monopoles":

$$\langle |\varphi_M|^2 \rangle \sim \rho_{mon}^{tot} \cdot a \sim \Lambda_{QCD}^2$$

since monopoles live on 2d defects

+ a few other checks (not many)

# Applications

(*) (never tried)

YM By itself produces

$$S_{mon} \sim \frac{\ln 7}{a} \cdot (\text{length})$$

$$\langle |\varphi_M|^2 \rangle \sim \Lambda^2_{QCD}$$

Similar to what is needed in SM

Probably, a version of technicolor

(**) Quadratic power correction (well studied)

$$\langle G^2 \rangle_{p.th.} \sim \frac{1}{a^4}$$

$$\langle G^2 \rangle_{vortices} \sim \frac{\Lambda^2_{QCD}}{a^2}$$

Translation to $Q\bar{Q}$ potential at short dist.

$$\langle G^2 \rangle \sim \frac{1}{a^4} \Rightarrow V_{Q\bar{Q}} \sim \frac{1}{r}$$

$$\langle G^2 \rangle \sim \frac{\Lambda^2_{QCD}}{a^2} \Rightarrow V_{Q\bar{Q}} \sim \Lambda^2_{QCD} \cdot r$$

(***) Magnetic component of YM plasma

M. Chernodub
V. Z. '06

See in simulations that magnetic defects are released into plasma

(****) Identify 2d defects with the magnetic string of the dual formulation

A. Gorsky
V. Z. '07

# Mystery of fine tuning

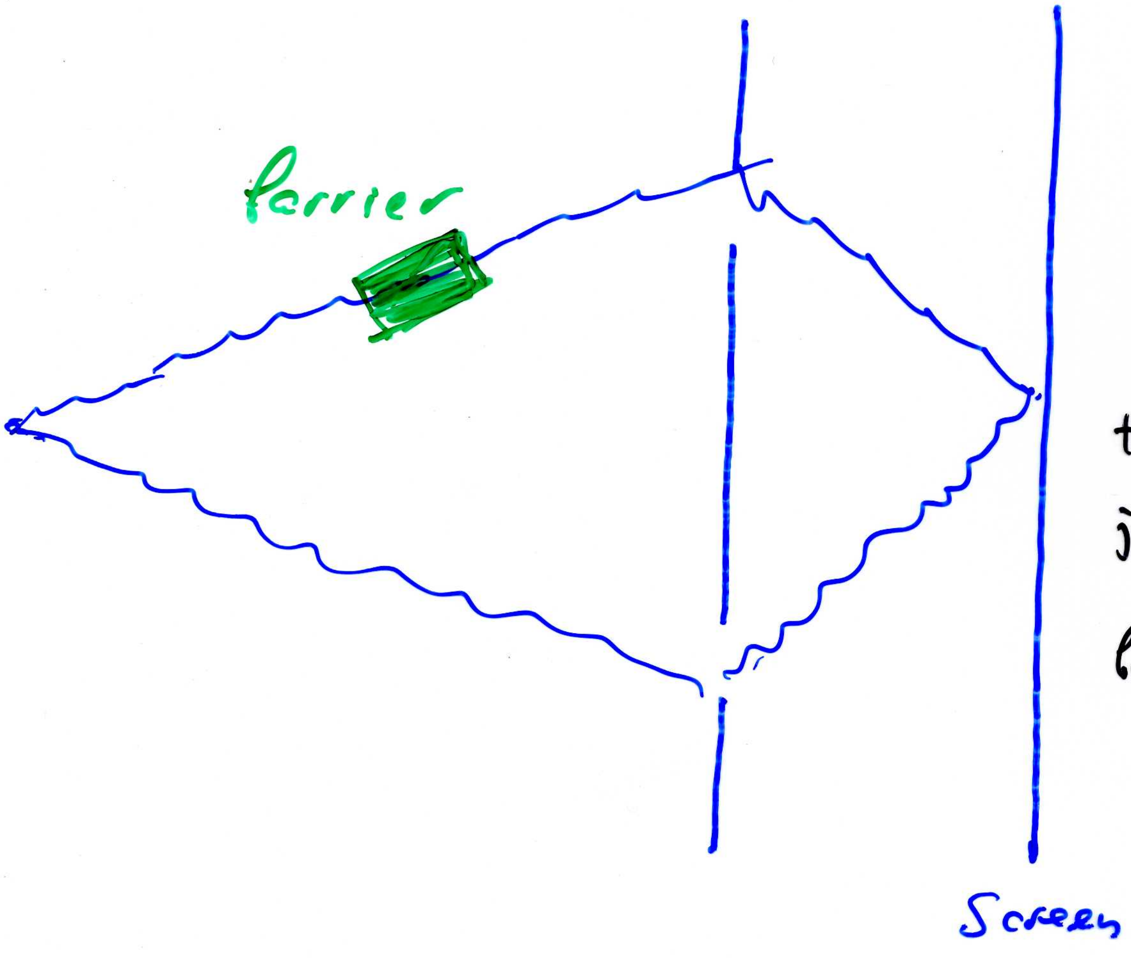
Hypothesis:

$$\underset{\text{(poor resolution)}}{\text{Quasiclassics}} \equiv \underset{\text{(fine resolution)}}{\text{Fine tuning}}$$

lattice spacing $a \equiv$ resolution

Berkeley experiment:

Two-slit experiment + barrier




$\Delta t_{\text{barrier}} \simeq 0$

trajectories jump sharply but rarely

## Conclusions

- non-Abelian inv. provides classification of singular fields

- lattice data fits well

- plus exhibits fine tuning

- because of fine tuning singular non-pert. fields are consistent with asymptotic freedom