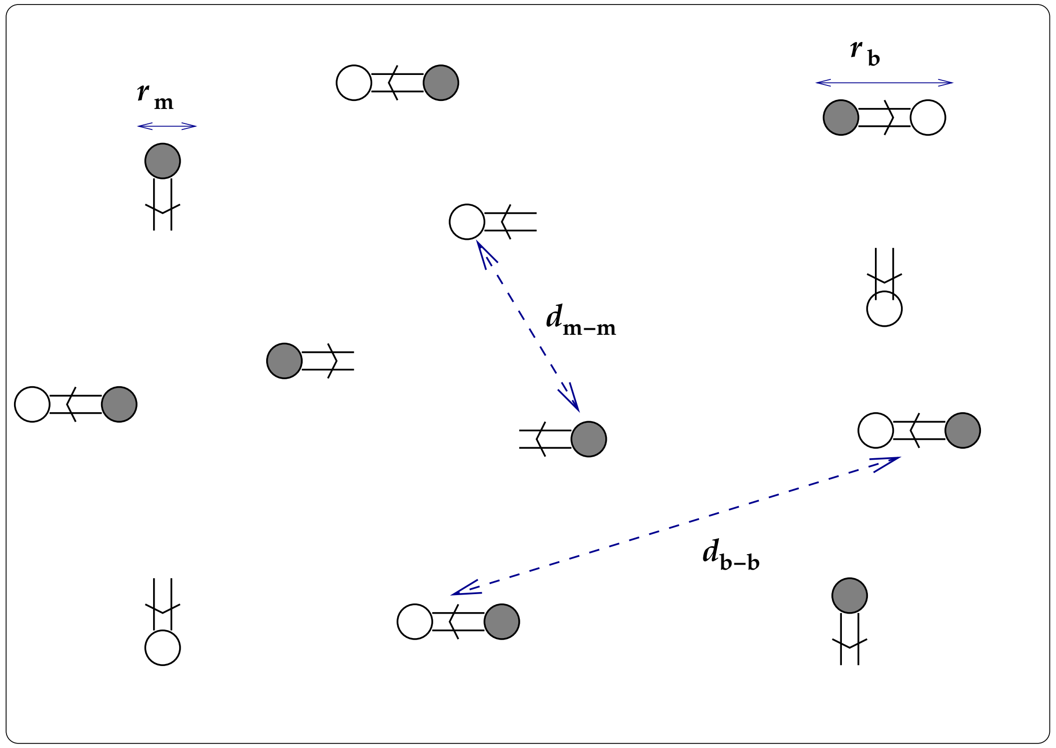
Supersymmetry and neutral bions: hints about deconfinement?

Erich Poppitz

U of Toronto



works with

Thomas Schäfer Mithat Ünsal NCSU 1205.0290 1212.1238

Mohamed Anber Toronto -> Lausanne Brett Teeple Toronto 1406.1199

will also mention work with Tin Sulejmanpasic Regensburg -> NCSU 1307.1317

[see also Thomas Schäfer's talk]

summary of main claims:

$R^3 x S^1$ compactifications of SYM* (with soft breaking mass) exhibit a semiclassically calculable phase transition which appears continuously connected to the thermal deconfinement transition in pure YM - in particular, same "universality" class for all gauge groups

reveal novel topological molecules responsible for center stability - "neutral bions"
(within a theoretically controlled setting, not a model!)

possible lessons for YM deconfinement models?
(Shuryak et al work)

$R^3 x S^1$ compactifications of SYM*

early remarks in Unsal, Yaffe 1006.2101
Schaefer, Unsal, EP 1205.0290, 1212.1238
Anber 1302.2641;
Sulejmanpasic, EP 1307.1317;
Anber, Teeple, EP 1406.1199

DEFINITIONS:

1

super YM = "SYM" = YM + massless quark, an adjoint Weyl "gaugino"

fields: gauge bosons + gauginos Z_(2 N) chiral symmetry for SU(N)
[Z_(2 c_2) chiral symmetry for arbitrary G (cover group)]

2

SYM* = SYM + mass for the adjoint quark, i.e. with a "gaugino mass" m

supersymmetry and chiral symmetry explicitly broken by m

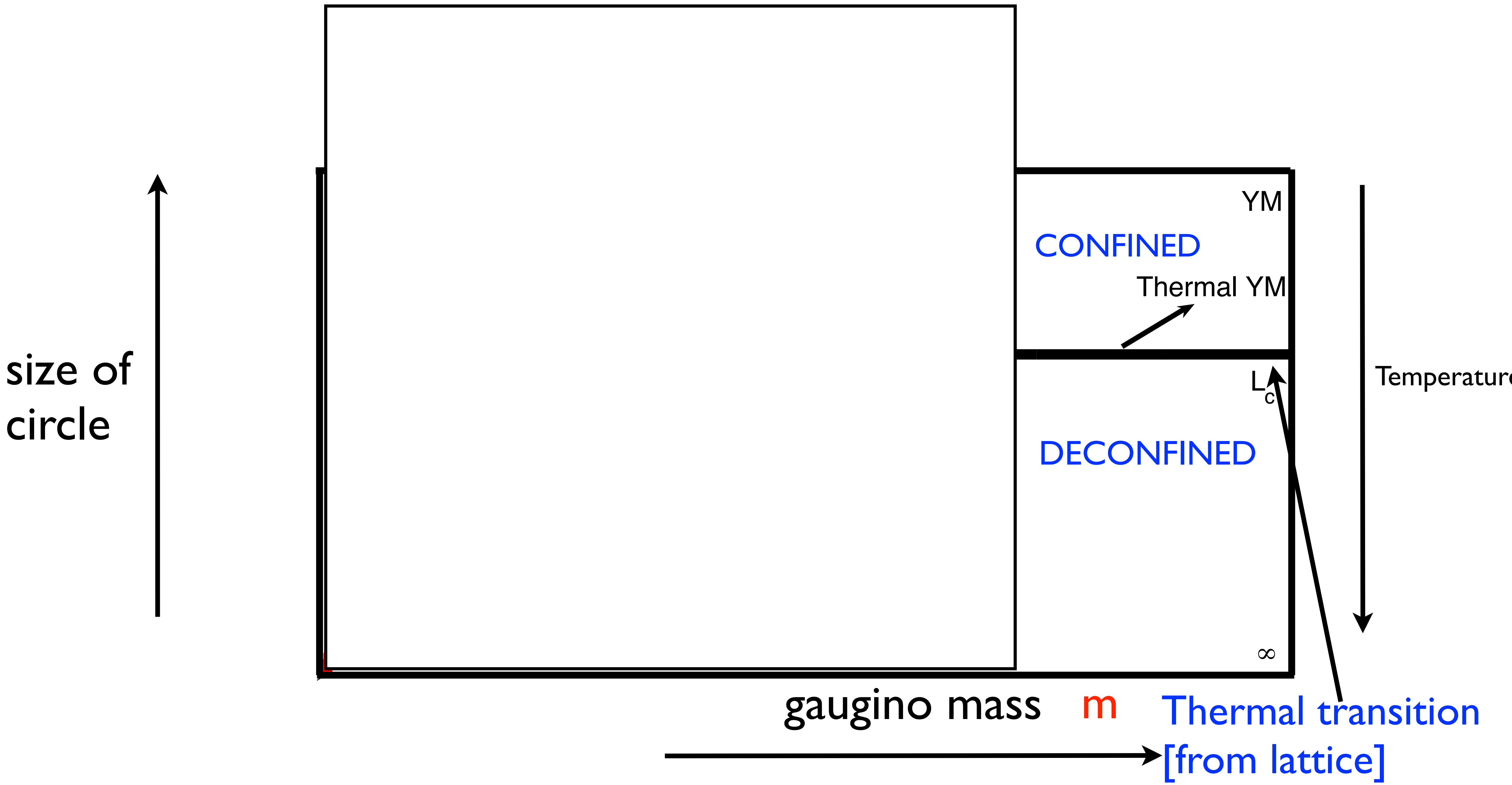
we study SYM* on $\mathbb{R}^3 \times S^1_L$ with periodic (supersymmetric, non-thermal) boundary condition for gaugino

there are only two parameters to vary: L and m

the theory is asymptotically free with a strong scale Λ

$$\frac{m}{\Lambda} \qquad \Lambda L$$

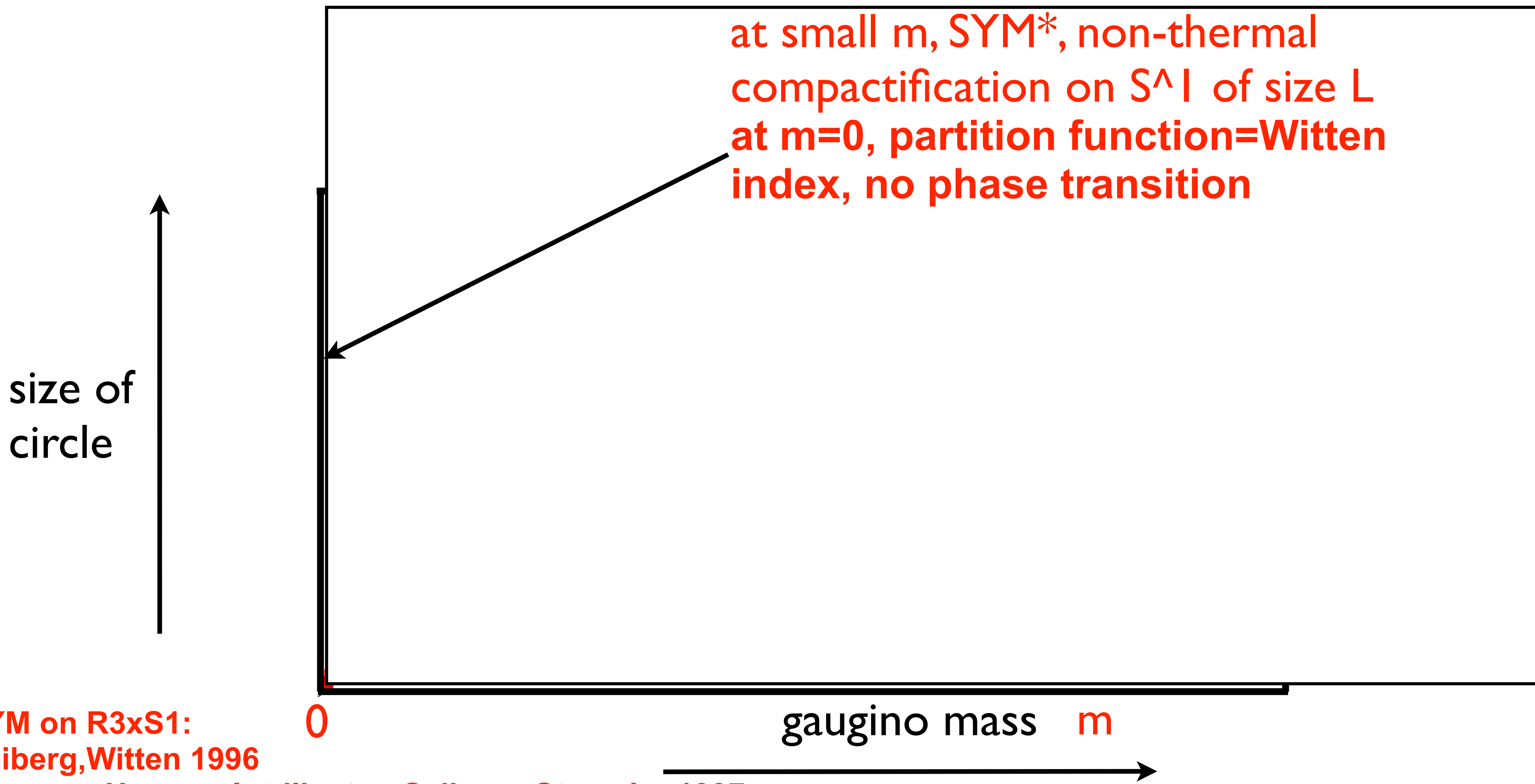
$R^3 x S^1$ compactifications of SYM*



$R^3 x S^1$ compactifications of SYM*

SYM on R3xS1:
Seiberg,Witten 1996
Aharony, Hanany, Intriligator, Seiberg, Strassler 1997
Davies, Hollowood, Khoze 1999
important relevant details of instanton calculation only recent
EP, Schaefer, Unsal, 2012 + Anber,EP,Teeple2014

$R^3 x S^1$ compactifications of SYM*



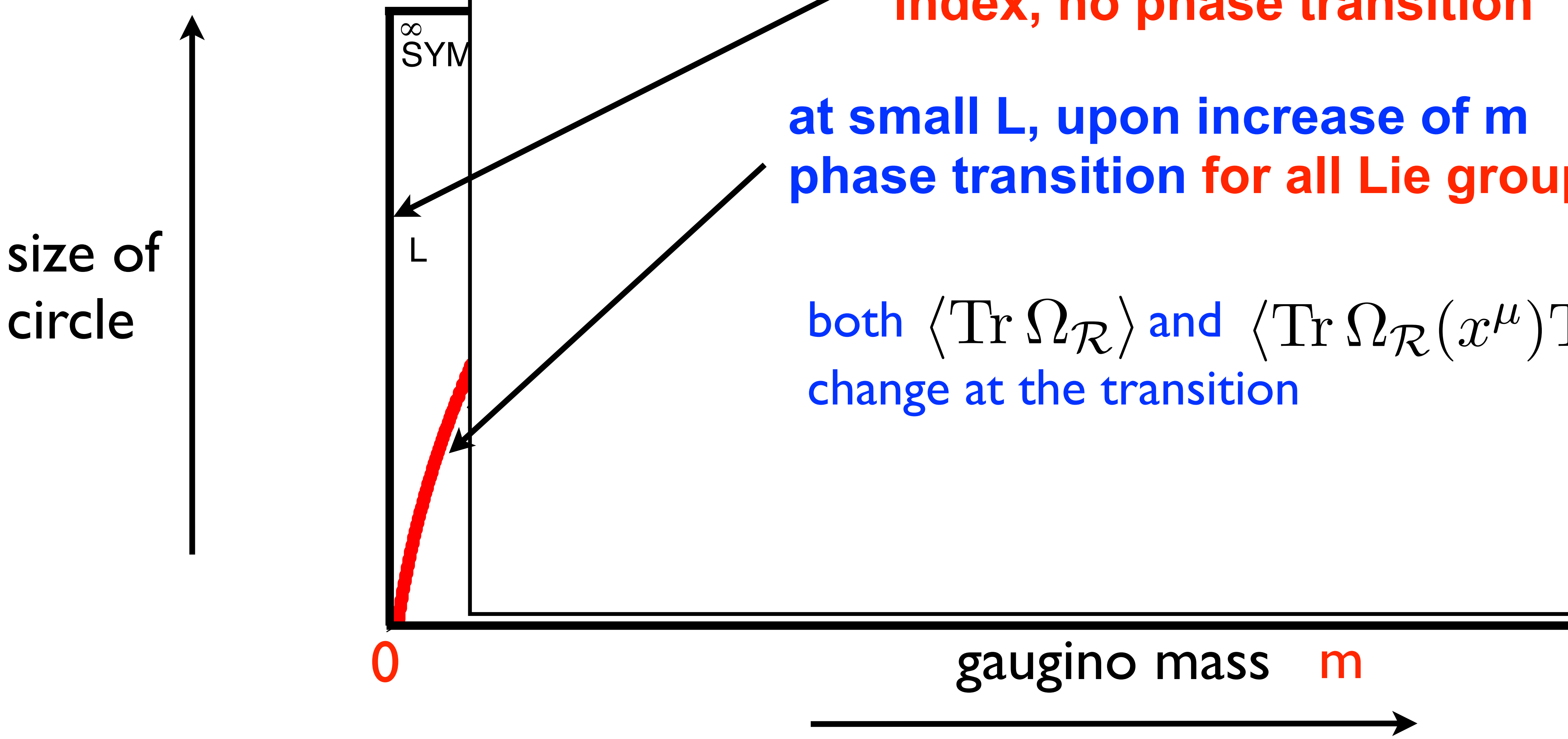
SYM on R3xS1:
Seiberg,Witten 1996
Aharony, Hanany, Intriligator, Seiberg, Strassler 1997
Davies, Hollowood, Khoze 1999
important relevant details of instanton calculation only recent
EP, Schaefer, Unsal, 2012 + Anber,EP,Teeple2014

$R^3 \times S^1$ compactifications of SYM*

at small m, SYM*, non-thermal compactification on S^1 of size L
at m=0, partition function=Witten index, no phase transition

at small L, upon increase of m phase transition for all Lie groups

both $\langle \mathrm{Tr}\, \Omega_{\mathcal{R}} \rangle$ and $\langle \mathrm{Tr}\, \Omega_{\mathcal{R}}(x^\mu)\, \mathrm{Tr}\, \Omega^\dagger_{\mathcal{R}}(0) \rangle$ change at the transition



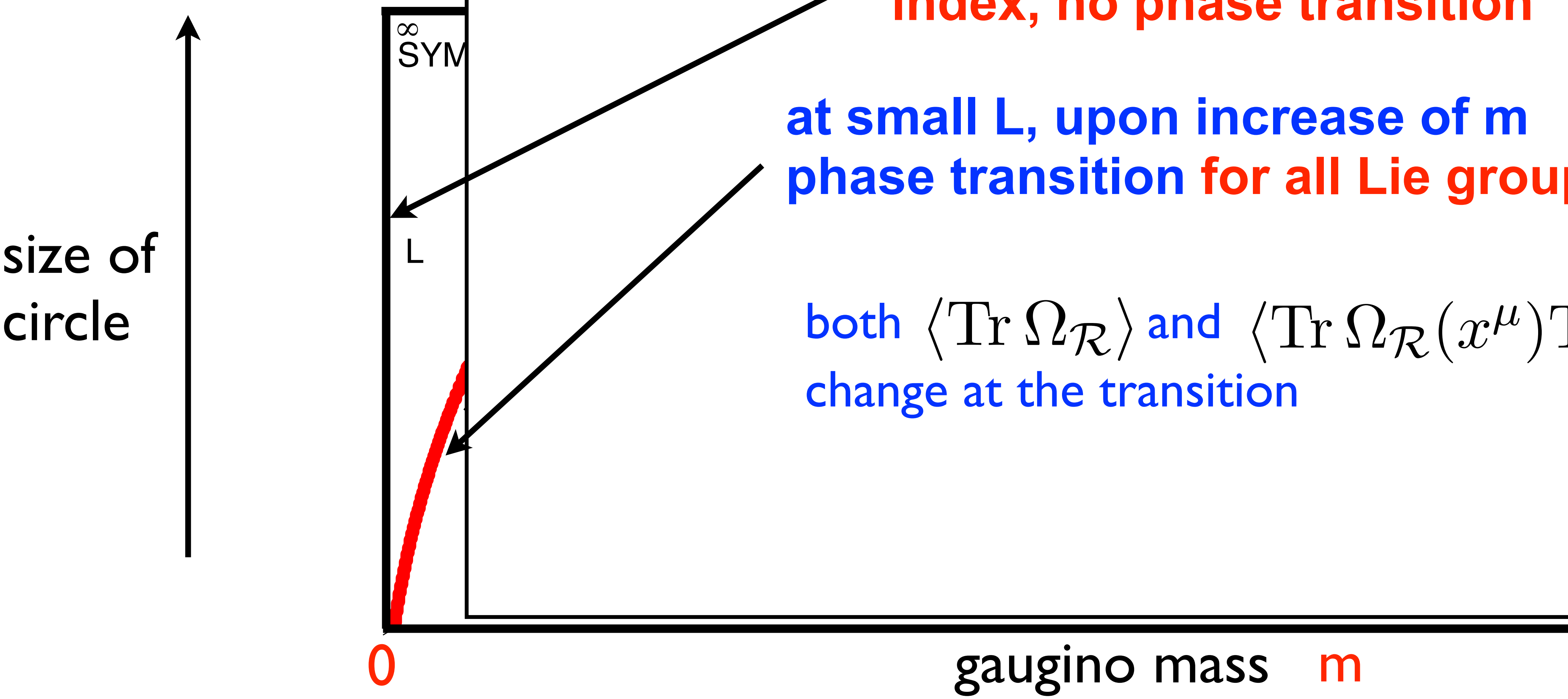
$R^3 \times S^1$ compactifications of SYM*

at small m, SYM*, non-thermal compactification on S^1 of size L

at m=0, partition function=Witten index, no phase transition

at small L, upon increase of m phase transition for all Lie groups

both $\langle \mathrm{Tr}\, \Omega_{\mathcal{R}} \rangle$ and $\langle \mathrm{Tr}\, \Omega_{\mathcal{R}}(x^\mu) \mathrm{Tr}\, \Omega^\dagger_{\mathcal{R}}(0) \rangle$ change at the transition



Semiclassical calculability is the most interesting feature of this small-m,L transition: not a model but under theoretical control!

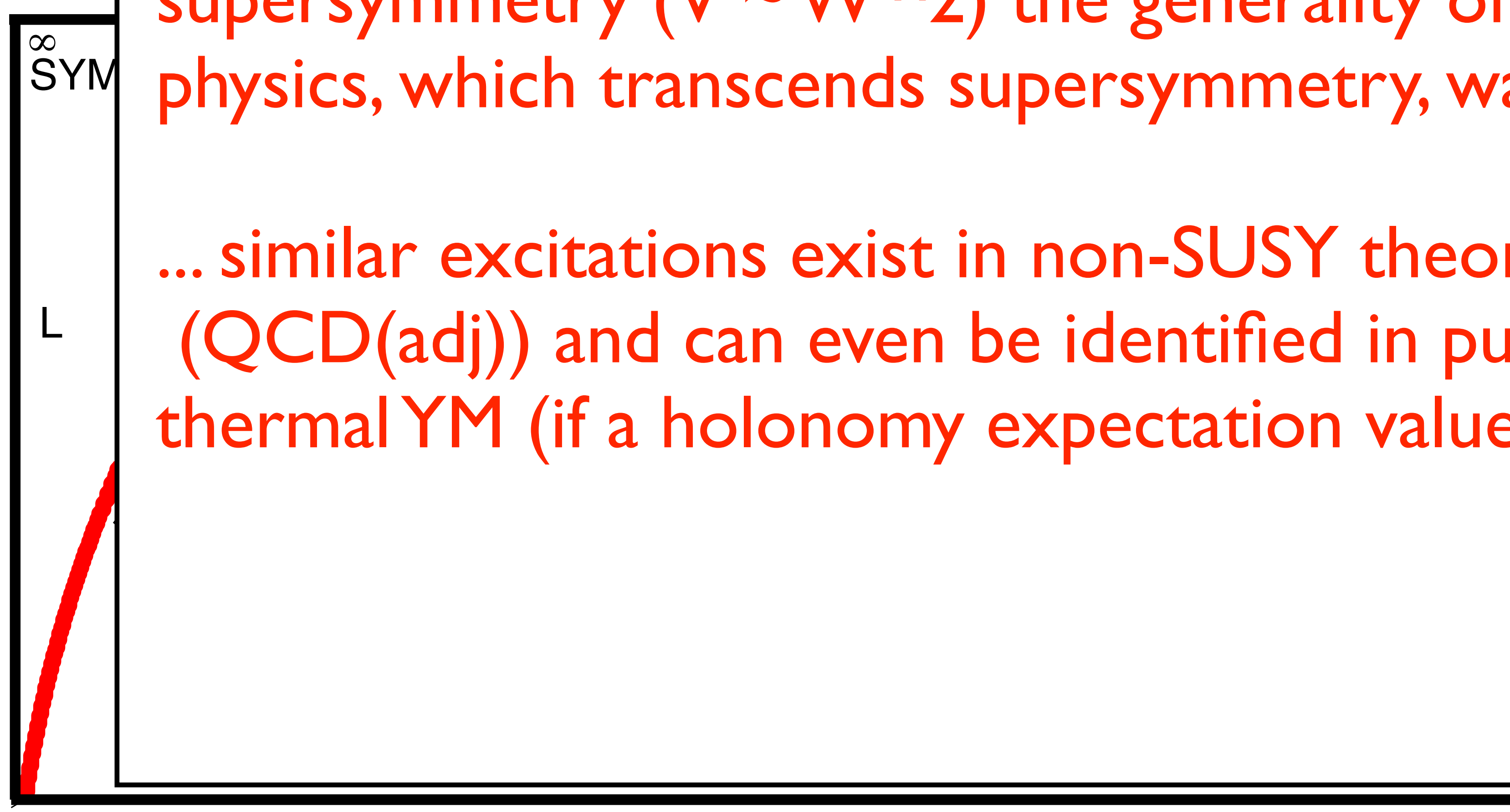
A host of novel topological excitations: "magnetic bions"(Unsal 2007) and "neutral bions" (EP Unsal 2012, Argyres Unsal 2012...) whose raison d'etre runs deep... are responsible for confinement and potential for S^1 holonomy (& center stability, where present)

$R^3 \times S^1$ compactifications of SYM*

…these effects were already in the 1990's papers I mentioned, but because they relied so much on supersymmetry (V ~ W'^2) the generality of the physics, which transcends supersymmetry, was missed!

… similar excitations exist in non-SUSY theories (QCD(adj)) and can even be identified in pure thermal YM (if a holonomy expectation value is assumed)

size of circle



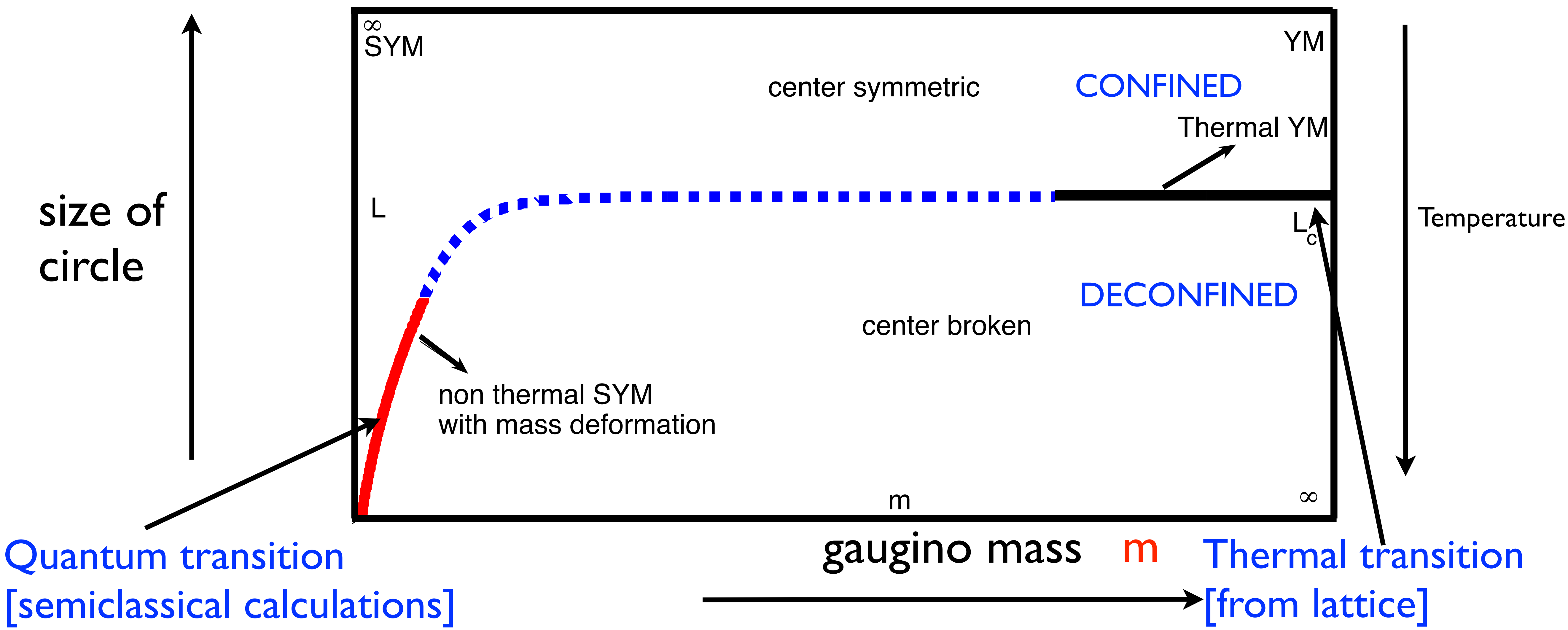
0 gaugino mass m

Semiclassical calculability is the most interesting feature of this small-m,L transition: not a model but under theoretical control!

A host of novel topological excitations: "magnetic bions"(Unsal 2007) and "neutral bions" (EP Unsal 2012, Argyres Unsal 2012...) whose raison d'etre runs deep... are responsible for confinement and potential for S^1 holonomy (& center stability, where present)

$R^3 x S^1$ compactifications of SYM*

The complete phase diagram?

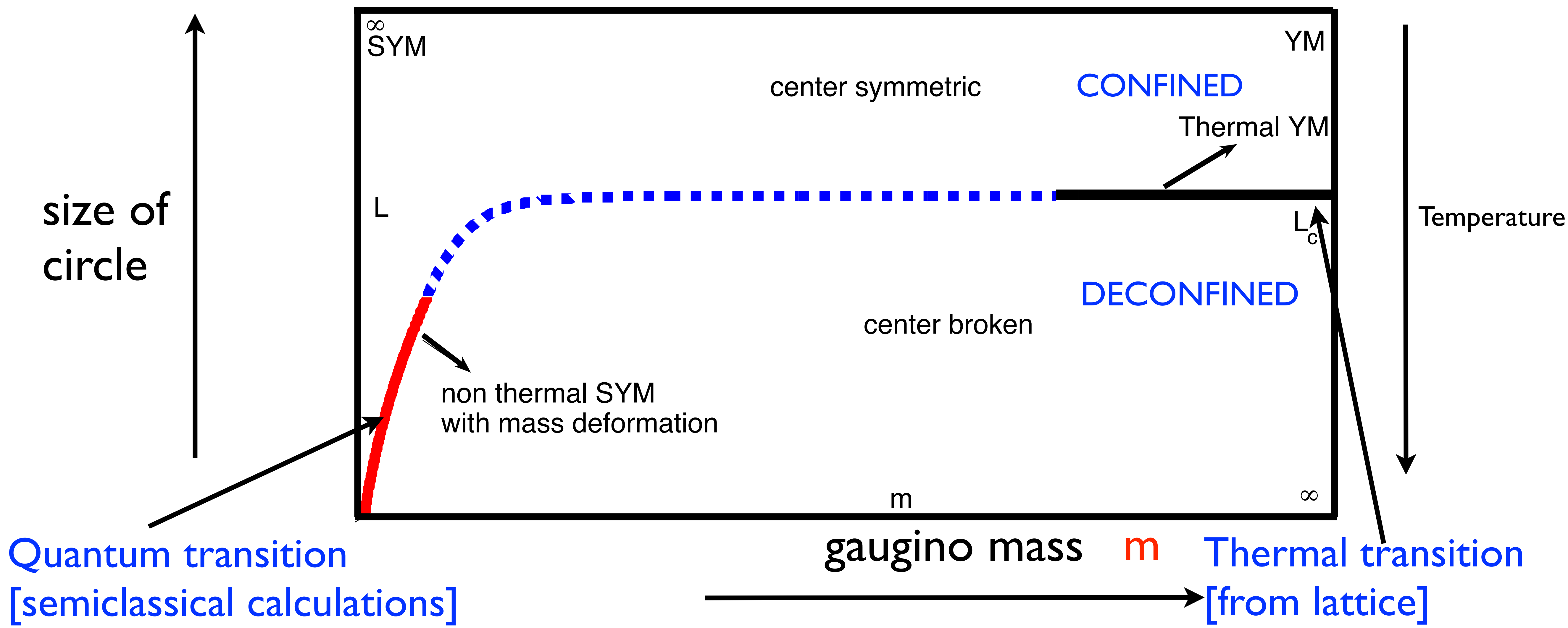


$R^3 x S^1$ compactifications of SYM*

Comparing the behavior of

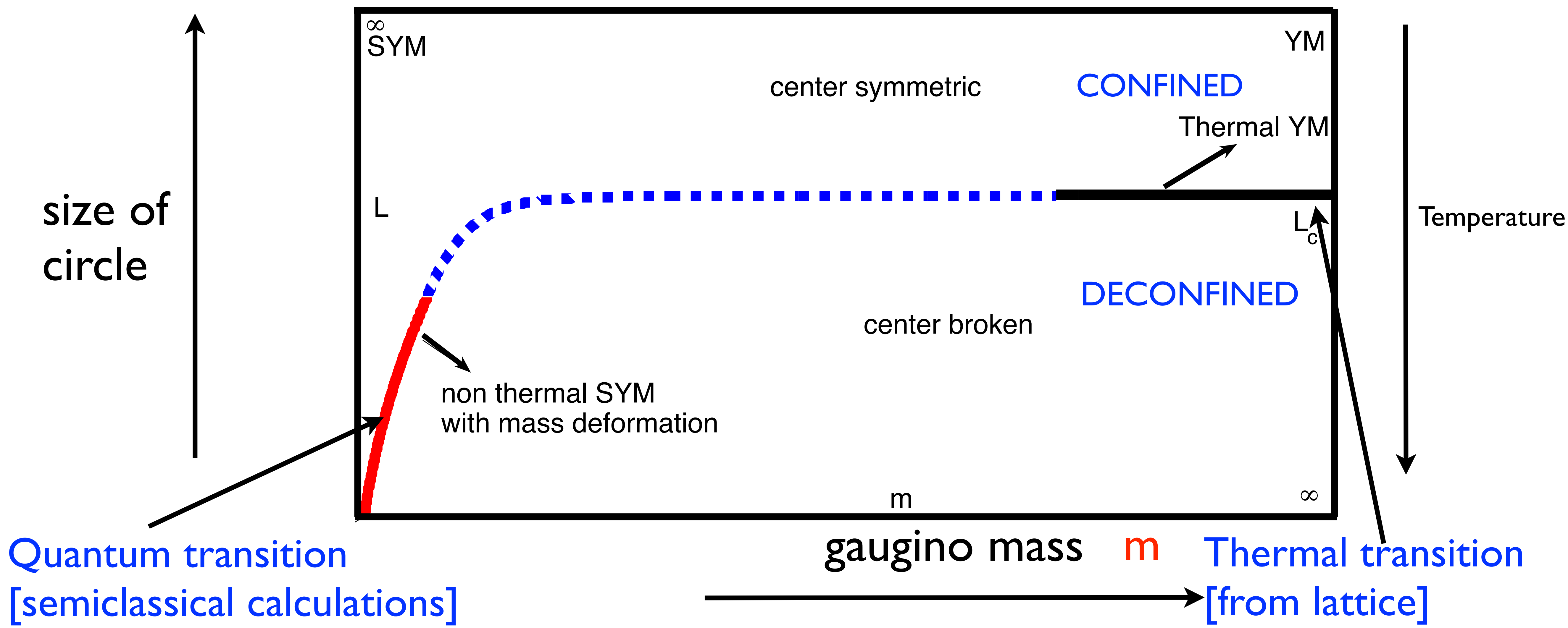
$\langle \mathrm{Tr}\, \Omega_{\mathcal{R}} \rangle$, $\langle \mathrm{Tr}\, \Omega_{\mathcal{R}}(x^\mu) \mathrm{Tr}\, \Omega^\dagger_{\mathcal{R}}(0) \rangle$ **(and other quantities)**

at the two transitions, we find striking similarities...



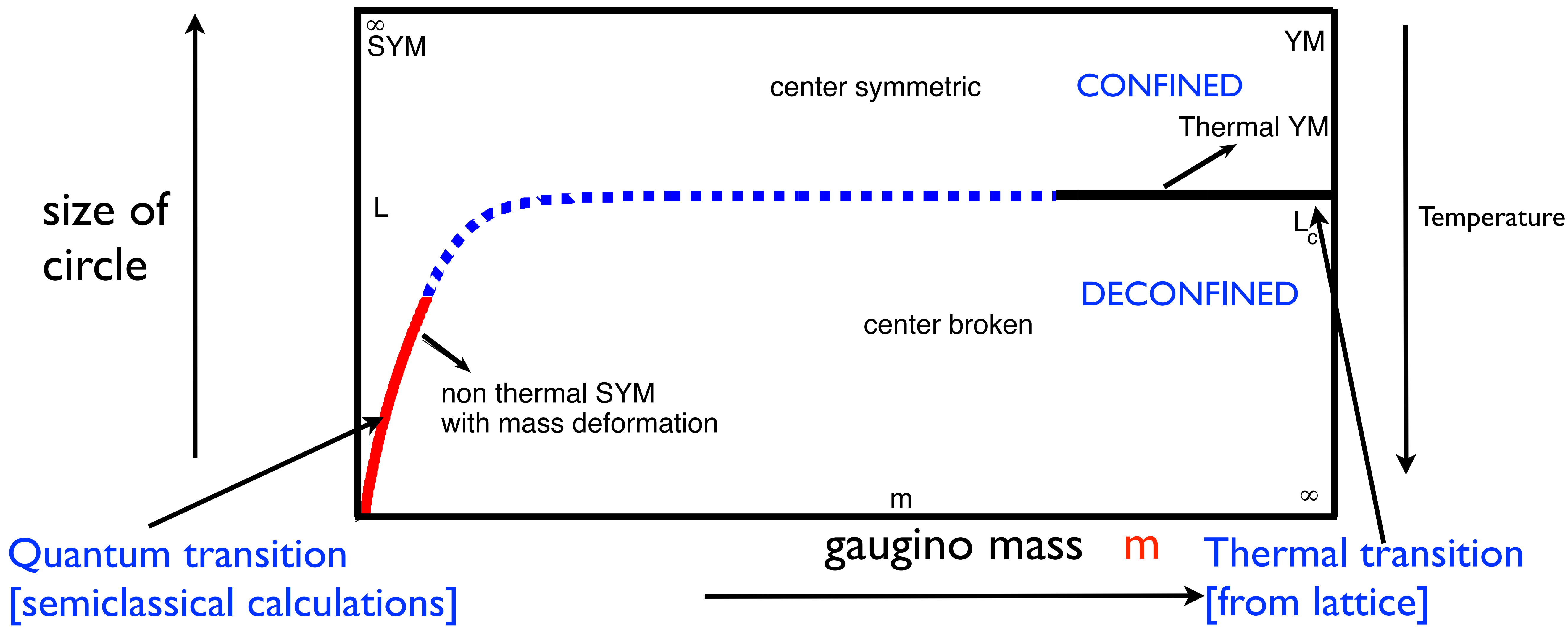
$R^3 \times S^1$ compactifications of SYM*

"continuity conjecture" = this phase diagram



$R^3 x S^1$ compactifications of SYM*

"continuity conjecture" = this phase diagram



Next:

Evidence? - calculable SYM* vs lattice

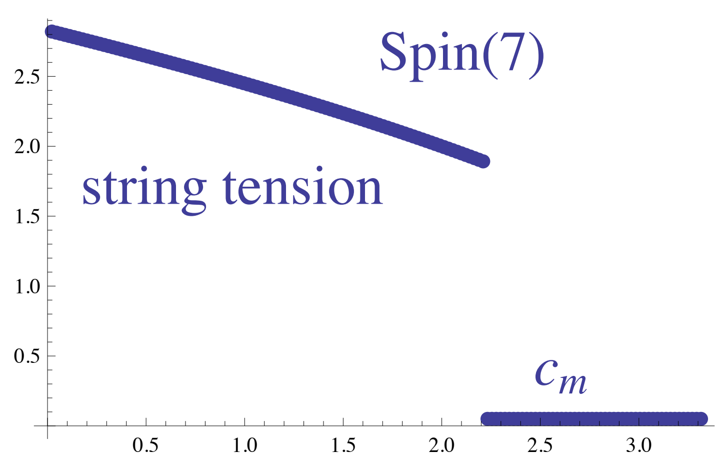
$$C = \frac{m}{L^2\Lambda^3}$$

Evidence? - calculable SYM vs lattice*

Both discontinuities - of the trace of Polyakov loop or of its two point function - are seen also in the semiclassical SYM* quantum transition

For all theories with nontrivial center: SU(N), Sp(2N), Spin(N), E_6, E_7 we have for c<c* = O(1)

$$\langle \mathrm{Tr}\,\Omega(x) \mathrm{Tr}\,\Omega^\dagger(0)\rangle\Big|_{r \gg m_0^{-1}} \simeq e^{-\frac{\hat\sigma m_0}{R} rR} \equiv e^{-\sigma\, rR}$$ and ~ constant at c>c*



⟵ e.g., probes in the spinor of SO(7) string tension discontinuously changes

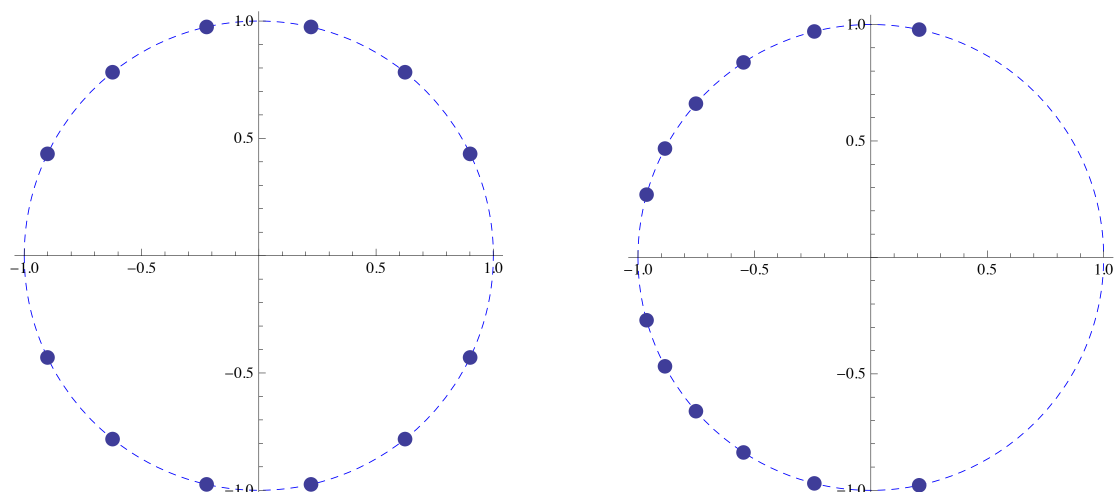
calculable transition is continuous only for SU(2), as known from lattice

Evidence? - calculable SYM vs lattice*

Both discontinuities - of the trace of Polyakov loop or of its two point function - are seen also in the semiclassical SYM* quantum transition

For the trace of the Polyakov loop, for all groups with a center, a discontinuous center-breaking transition,

e.g., eigenvalues of Polyakov loop in fundamental of Sp(12) (Z_2 center)



$\mathrm{Tr}\langle\Omega\rangle = 0$ $\mathrm{Tr}\langle\Omega\rangle \neq 0$

c<c* c>c*

Lattice only SU(N) and Sp(4)

Sp(4) lattice study, Pepe et al 2007,
motivated by "Z2 universality"
still discontinuous transition!

Evidence? - calculable SYM vs lattice*

For all theories without center: G_2, F_4, E_8, also a first order transition

Lattice only G_2 ⟷ SYM*: all transitions discontinuous

$$\langle \mathrm{Tr}\,\Omega(x)\mathrm{Tr}\,\Omega^\dagger(y)\rangle = \begin{cases} 0.0056\left(\frac{g^2}{4\pi}\right)^2 \\ 0.0056\left(\frac{g^2}{4\pi}\right)^2 \\ 11.3\left(\frac{g^2}{4\pi^2}\right)^2 \end{cases}$$

c=0 value (SYM)
below transition
above transition

numbers from Anber, EP, Teeple 1406.1199

SYM* jump of Polyakov loop trace: $\langle \mathrm{Tr}\Omega \rangle$ $\quad \frac{g^2}{4\pi}0.0746$ $\quad \frac{g^2}{4\pi}3.437$

lattice jump of Polyakov loop trace:

[Pepe, Wiese 2006;
Cossu, Pica et al. 2007]

careful study of FSS, 1st order!

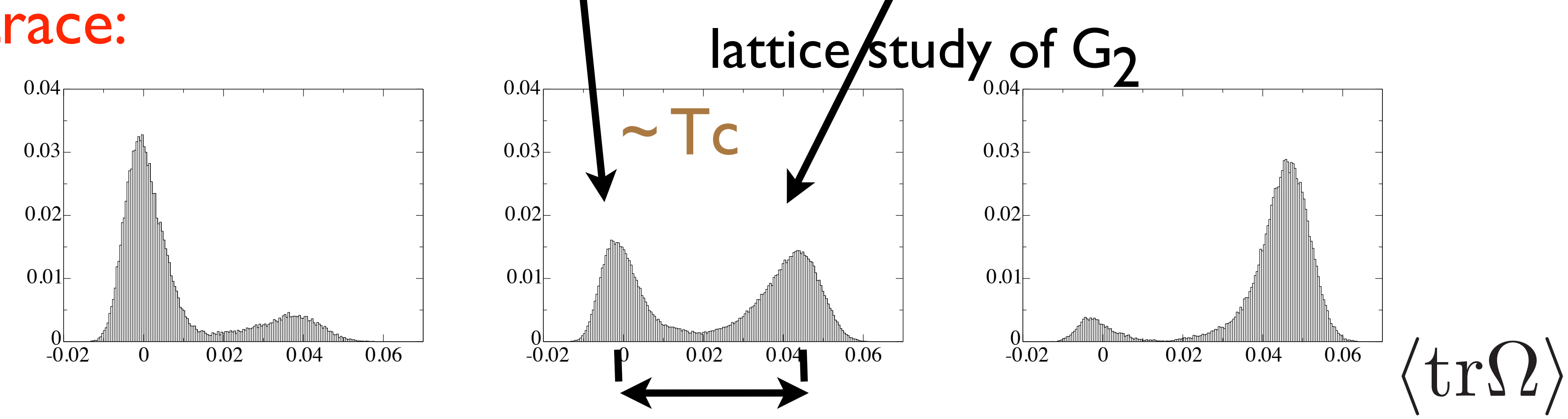
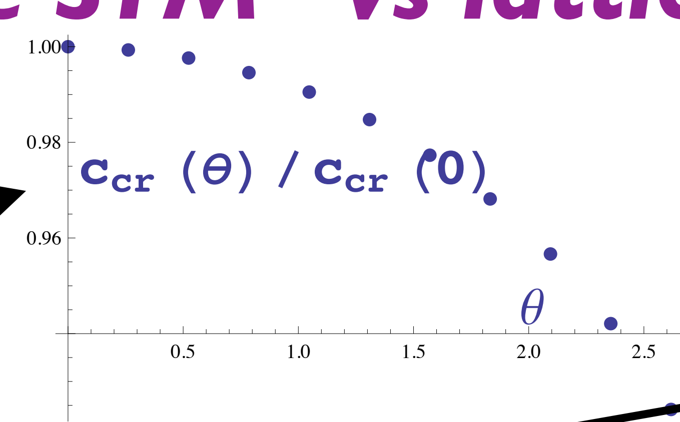
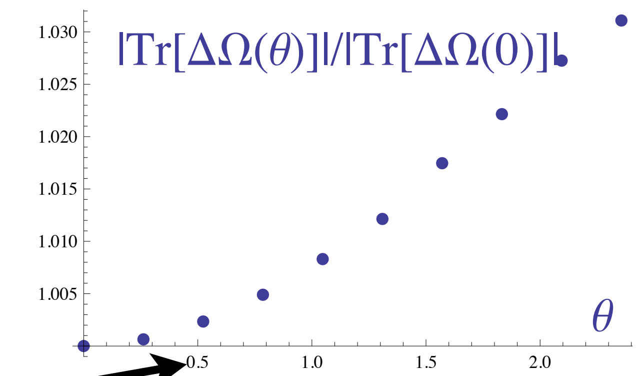


Figure 4: Polyakov loop probability distributions in the region of the deconfinement

[it does not make sense to compare numerical values - very different regimes]

Evidence? - calculable SYM vs lattice*





Theta-angle dependence of:

-critical temperature

-discontinuty of Polyakov loop [lattice prompted by Anber SYM* 2013] **- predictions!**

-string tension [decreases with theta increase]

each qualitatively agrees with lattice (recent progress in tools).

string tension: Del Debbio et al 2006

Tc and gap: D'Elia et al 2012/3

Curious about quarks?

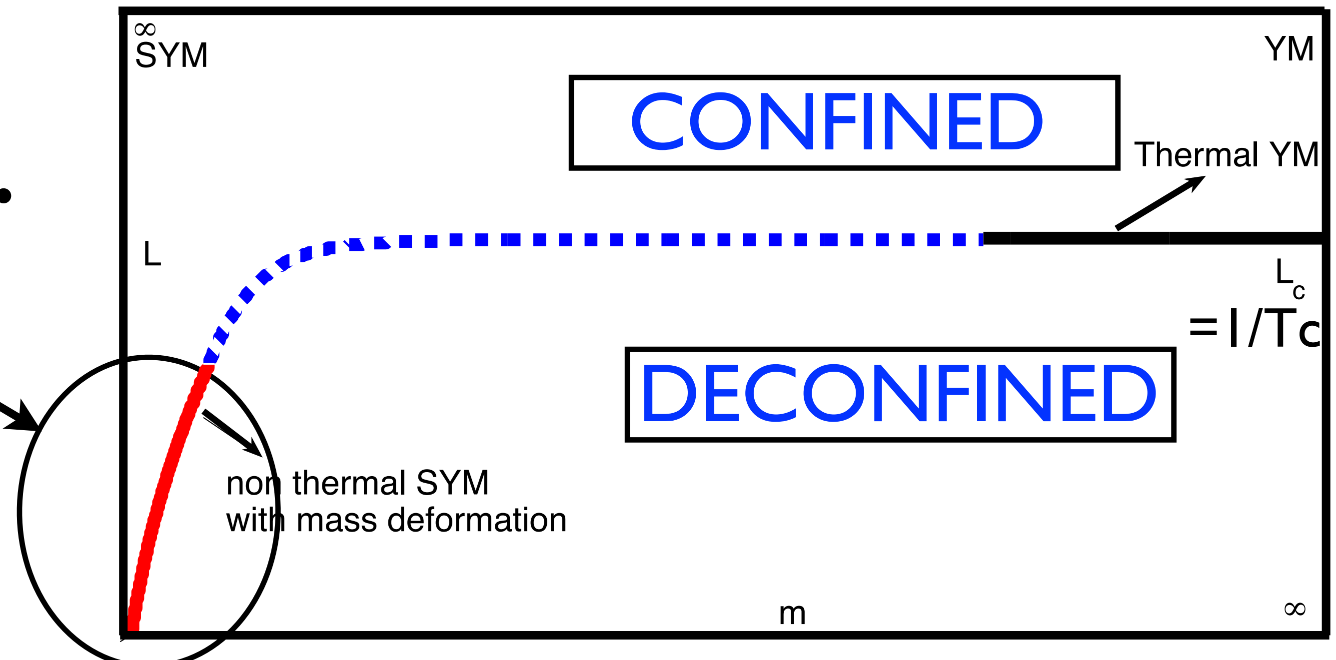
... a weak-coupling controlled semiclassical description of non-abelian chiral symmetry breaking has not been achieved (no surprise!)

... but if one adds massive quarks to SYM* you can see two things that agree with what lattice with massive quarks sees - Polyakov loop crossover and string breaking at distances ~ 2/mass [Tin Sulejmanpasic EP 1307.1317]

Novel topological excitations and their role.

before asking: Why this seems to work the way it does?

I will now tell you how this part of the phase diagram comes about.

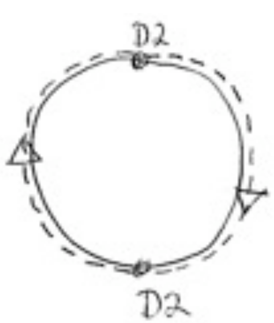


monopole-instantons:

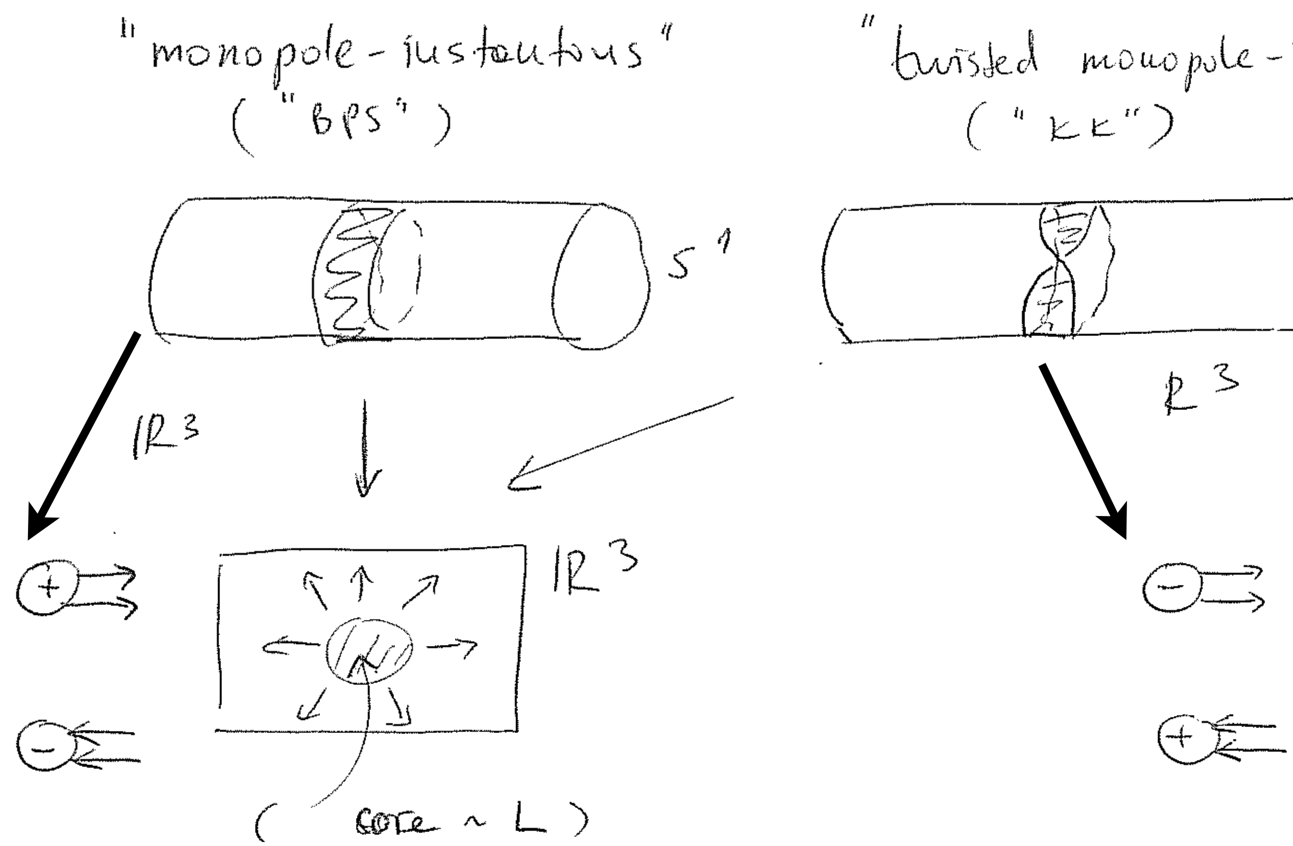
"BPS" and twisted "KK"

do not call them DYONS, please! **[they aren't!]**

[P.Yi, K. Lee, hep-th 9702107]



[Kraan, van Baal, hep-th 9805168]



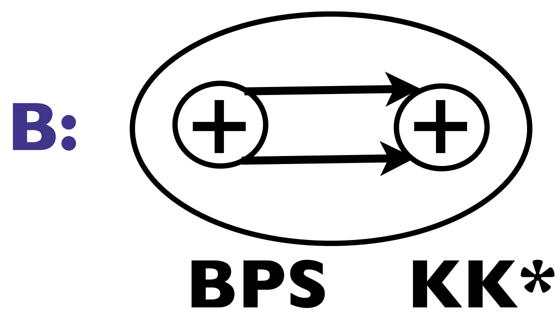
BPS

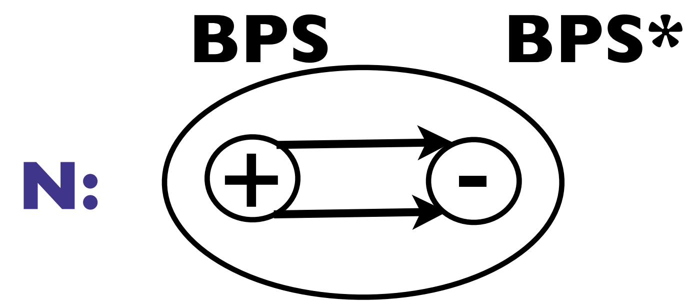
BPS*

KK

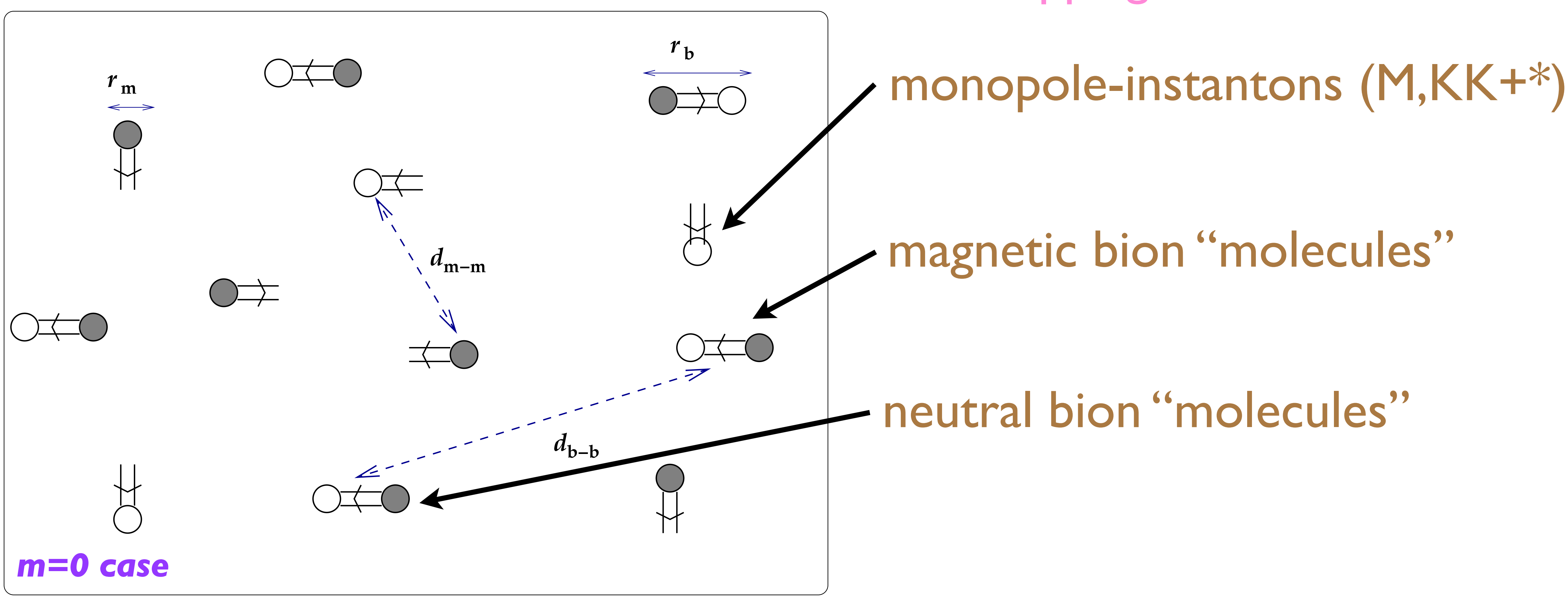
KK*

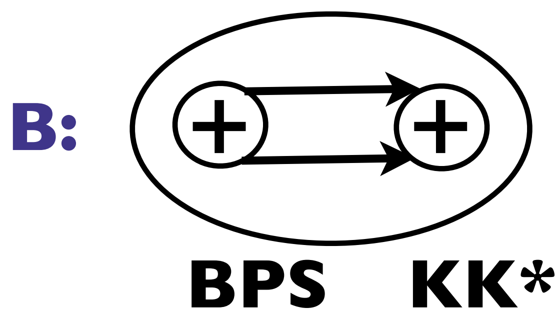
these main "players", as they interact, can form "molecules" - "correlated tunneling events"

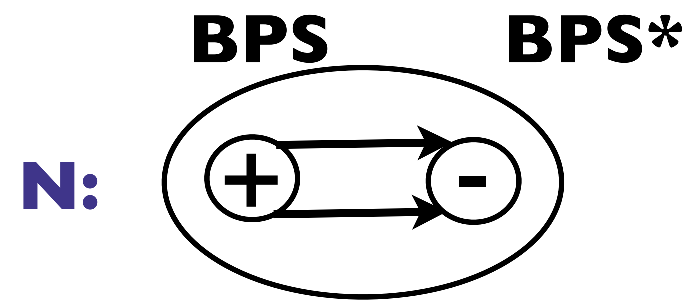




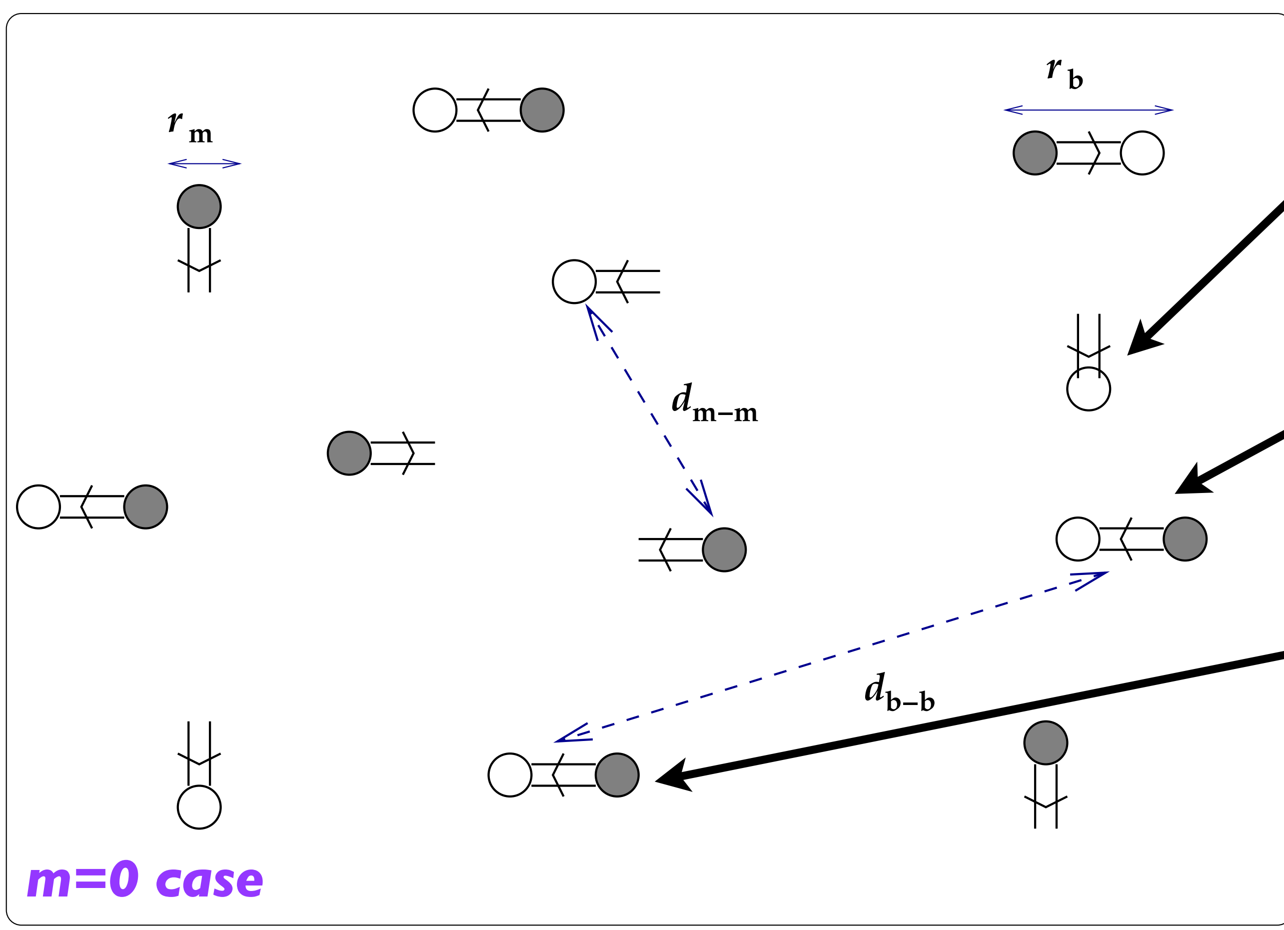
interesting dynamics is all nonperturbative: vacuum of the theory is a dilute 3d "gas" of "molecules" interacting via long-range forces due to (dual) photon, scalar modulus, and fermion zero-mode hopping







interesting dynamics is all nonperturbative: vacuum of the theory is a dilute 3d "gas" of "molecules" interacting via long-range forces due to (dual) photon, scalar modulus, and fermion zero-mode hopping



monopole-instantons (M,KK+*)

the ones with arrows: fermion zero modes carry magnetic charge 1

magnetic bion "molecules"

carry magnetic charge 2

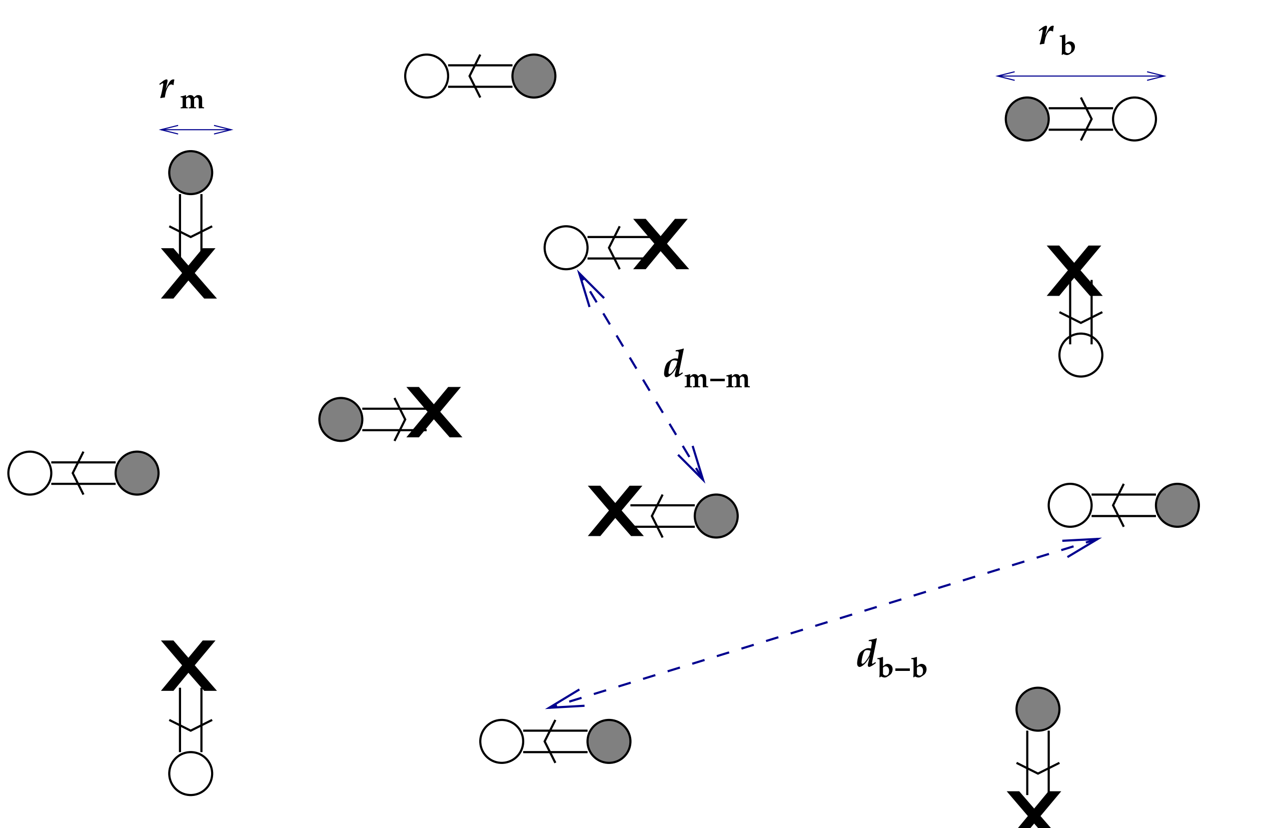
[mass gap; breaking discrete chiral symmetry]

neutral bion "molecules"

carry scalar (modulus) charge 2

[Z2 center symmetry stabilization]

[aside: BB*~renormalons? ..."resurgence"]



m>0 case: breaks chiral symmetry, yields:

1. extra nonperturbative contributions from monopole-instantons (no fermion zero modes)

2. extra perturbative Gross-Pisarski-Yaffe-like contribution (small since m is small)

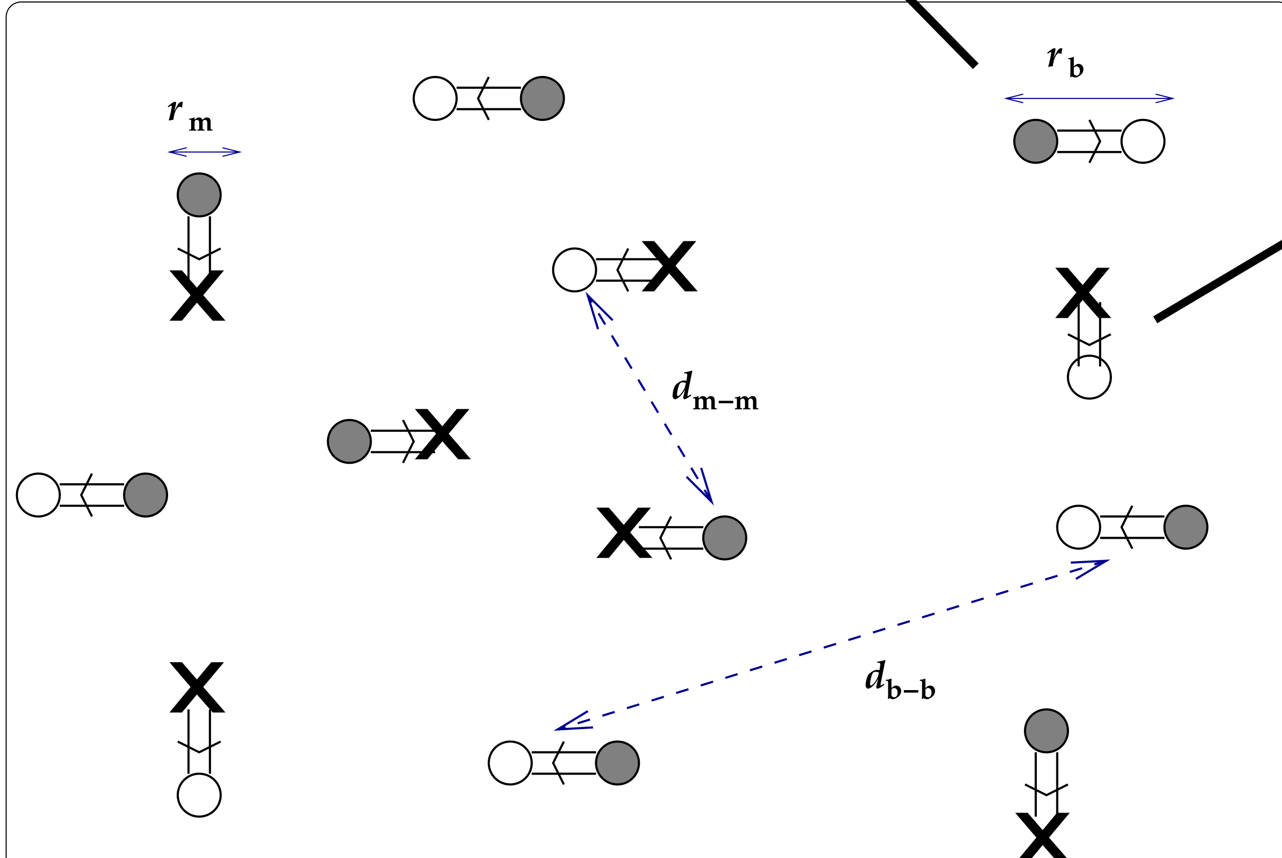
small SUSY breaking "m" allows us to have perturbative and nonperturbative contributions compete while under theoretical control, resulting in a center-breaking transition as $\frac{m}{L^2\Lambda^3}$ becomes O(1) (2nd order for SU(2); 1st for SU(N)...)

=8, so if at m>5Λ decoupled, as quarks in QCD, $1/L_c = \Lambda\sqrt{8\Lambda/m}$ → $T_c \simeq \Lambda$

For a general gauge group, holonomy potential looks like this (using co-roots and dual Katz labels):

$$\sum_{a=0,b=0}^{r} k_a^* k_b^* \boldsymbol{\alpha}_a^* \cdot \boldsymbol{\alpha}_b^* e^{-(\boldsymbol{\alpha}_a^* + \boldsymbol{\alpha}_b^*)\cdot \boldsymbol{b}} \cos\left((\boldsymbol{\alpha}_a^* - \boldsymbol{\alpha}_b^*)\cdot \boldsymbol{\sigma}'\right) - c_m \sum_{a=0}^{r} k_a^* e^{-\boldsymbol{\alpha}_a^*\cdot \boldsymbol{b}} \cos\left(\boldsymbol{\alpha}_a^* \cdot \boldsymbol{\sigma}' + \frac{\theta + 2\pi u}{c_2}\right)$$

$$C = \frac{m}{L^2\Lambda^3} = C_m$$



m>0 case: breaks chiral symmetry, yields:

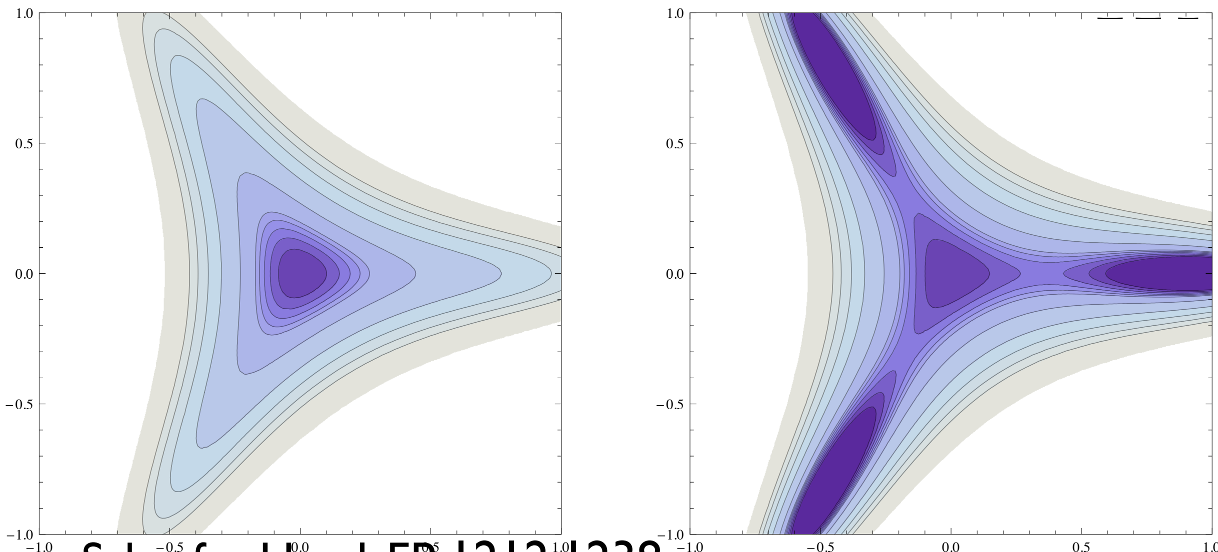
1. extra nonperturbative contributions from monopole-instantons (no fermion zero modes)

2. extra perturbative Gross-Pisarski-Yaffe-like contribution (small since m is small)

small SUSY breaking "m" allows us to have perturbative and nonperturbative contributions compete while under theoretical control, resulting in a center-breaking transition as $\frac{m}{L^2\Lambda^3}$ becomes O(1) (2nd order for SU(2); 1st for SU(N)...)

=8, so if at m>5Λ decoupled, as quarks in QCD, $1/L_c = \Lambda\sqrt{8\Lambda/m}$ → $T_c \simeq \Lambda$

also instead of formulae, plot of potential due to "neutral bions" for SU(3):
Z3-symmetric vs Z3-breaking as $\frac{m}{L^2\Lambda^3}$ = c ***increases*** (deviation of Ω EVs from Z3)



Schaefer, Unsal, EP 1212.1238

c<c*   c>c*

Summary:

- ***a calculable (quantum) phase transition in SYM* appears continuously connected to thermal deconfinement in YM***
- ***novel topological molecules relevant for center stability***

-due to calculability these are unambiguously identified: no gauge dependence, no model dependence
-topology clearly relevant, as seen in, e.g. theta-dependence... how in FRG?

Now, the big question:
Why this seems to work the way it does?

Honestly, I do not know for sure.

Why this seems to work the way it does?

Honestly, I do not know for sure. Some thoughts:

Same objects that were identified in SYM also exist in pure thermal YM.
What is lost is the theoretical control - but not all are bothered ... the(ir) logic:

1. Lattice data show that the Tr(Polyakov loop) is not =1 immediately after the transition, but is quite a bit smaller (and nonzero, of course).

2. Assuming semiclassics applies, this would mean that <A_4> is nonzero, eigenvalues are not on top of each other, so theory can still be thought as abelianized.

3. Then all the monopoles, KK monopoles pictured above exist. These nonperturbative fluctuations are important for the dynamics, hence model the vacuum as a liquid thereof (not dilute gas).

4. Use some lattice measurements (caloron densities) to fix the density of the BPS and KK monopole-instantons (now a model parameter). Try to compute something to compare with other data.

Shuryak, Sulejmanpasic 2013:
instanton-liquid type model of the pure YM deconfinement transition, incorporating "molecular" contributions (neutral bions! - use "excluded volume" not SUSY or BZJ prescription... from old instanton-liquid model of T=0 QCD vacuum***). The model gives order-of-magnitude agreement with lattice measurements of electric and magnetic masses.***
EP: OK, it is a model; but the lattice data is poor (and gauge dependent)

Why this seems to work the way it does?

Honestly, I do not know for sure.

For the future:

Same objects that were identified in SYM also exist in pure thermal YM, assuming ... see comments on previous page

- perhaps these models/data can be improved? [steps in Shuryak et al 1408.]

Lattice can test the entire phase diagram, using present-day technology, at least sufficiently far from semiclassical regime (that's hard on the lattice).
Since m is nonzero, no need to take chiral limit for gaugino, so easier than SYM.

Find something that blatantly contradicts continuity.

Finally, is this "Resurgence in action"?

- wild (but fascinating!) dreams of Unsal et al