Polyakov-loop potential from a massive extension of the background field gauge

Urko Reinosa*

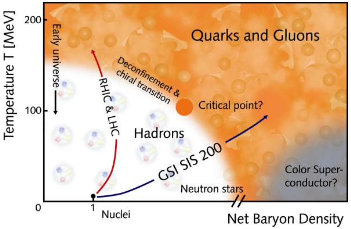
(Work in collaboration with J. Serreau, M. Tissier, N. Wschebor)

*Centre de Physique Théorique, Ecole Polytechnique, CNRS, Palaiseau, France

SEWM, Lausanne, July 2014

Motivation

Semi-analytical approaches to strongly interacting matter



Need for semi-analytical methods to investigate infrared properties of QCD or related theories.

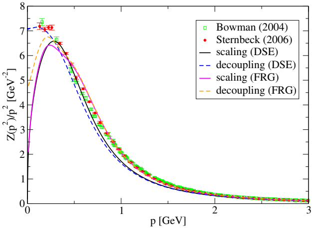
These approaches (SD-eq, fRG, . . .) usually require gauge fixing:

Ex: Landau gauge action

$$S = \int_x \left\{ \frac{1}{4} F^a_{\mu\nu} F^a_{\mu\nu} + \partial_\mu \bar{c}^a (D_\mu c)^a + i h^a \partial_\mu A^a_\mu \right\}$$

Valid only in the UV where the Gribov ambiguity is expected not to play a role.

$\Rightarrow$ Some additional imput is needed in the IR.



Fischer et. al., Annals Phys. 324 (2009).

Extended Landau gauge (eLG)

Alternative approach: find phenomenologically (and hopefully theoretically) motivated actions that could take into account the existence of Gribov copies.

A candidate for such an action is the extended Landau gauge (eLG) action

$$S = \int_x \left\{ \frac{1}{4} F^a_{\mu\nu} F^a_{\mu\nu} + \partial_\mu \bar{c}^a (D_\mu c)^a + i h^a \partial_\mu A^a_\mu + \frac{1}{2} m^2 A^a_\mu A^a_\mu \right\}$$

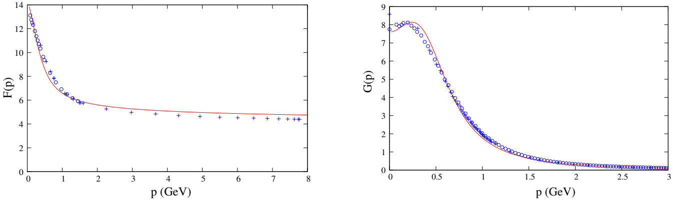
Extended Landau gauge (eLG)

Alternative approach: find phenomenologically (and hopefully theoretically) motivated actions that could take into account the existence of Gribov copies.

A candidate for such an action is the extended Landau gauge (eLG) action

$$S = \int_x \left\{ \frac{1}{4} F^a_{\mu\nu} F^a_{\mu\nu} + \partial_\mu \bar{c}^a (D_\mu c)^a + i h^a \partial_\mu A^a_\mu + \frac{1}{2} m^2 A^a_\mu A^a_\mu \right\}$$

- It is perturbatively renormalizable.
- A perturbative, calculation of the $T = 0$ propagators and vertices reproduces lattice data!



Tissier, Wschebor, Phys.Rev. D84 (2011);
Peláez, Tissier, Wschebor, Phys.Rev. D88 (2013) and arXiv:1407.2005.

- It could result from a gauge fixing procedure which averages over Gribov copies.
  (Serreau, Tissier, Phys.Lett. B712 (2012); Serreau, Tissier, Tresmontant, arXiv:1307.6019).

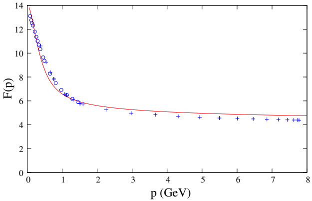
Extended Landau gauge (eLG)

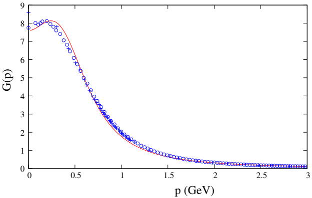
Alternative approach: find phenomenologically (and hopefully theoretically) motivated actions that could take into account the existence of Gribov copies.

A candidate for such an action is the extended Landau gauge (eLG) action

$$S = \int_x \left\{ \frac{1}{4} F^a_{\mu\nu} F^a_{\mu\nu} + \partial_\mu \bar{c}^a (D_\mu c)^a + i h^a \partial_\mu A^a_\mu + \frac{1}{2} m^2 A^a_\mu A^a_\mu \right\}$$

- It is perturbatively renormalizable. Extra parameter: for SU(3), $m \approx 510\,\mathrm{MeV}$.
- A perturbative, calculation of the $T = 0$ propagators and vertices reproduces lattice data!



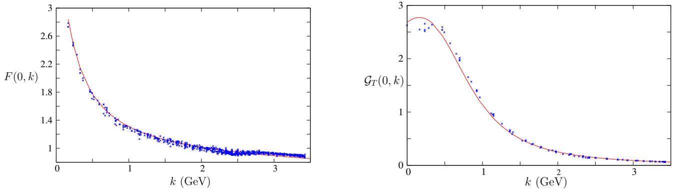


Tissier, Wschebor, Phys.Rev. D84 (2011);
Peláez, Tissier, Wschebor, Phys.Rev. D88 (2013) and arXiv:1407.2005.

- It could result from a gauge fixing procedure which averages over Gribov copies.
  (Serreau, Tissier, Phys.Lett. B712 (2012); Serreau, Tissier, Tresmontant, arXiv:1307.6019).

Tests at finite temperature

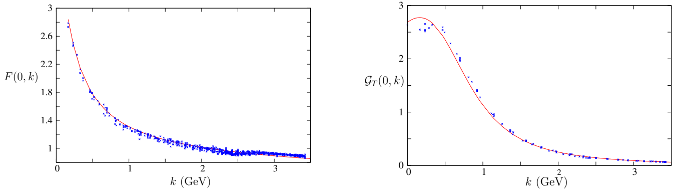
One loop, finite *T*, eLG ghost and chromo-magnetic propagators agree well with lattice results:



UR, J. Serreau, M. Tissier and N. Wschebor, to appear in PRD.

Tests at finite temperature

One loop, finite T, eLG ghost and chromo-magnetic propagators agree well with lattice results:



UR, J. Serreau, M. Tissier and N. Wschebor, to appear in PRD.

The eLG fails in reproducing the lattice chromo-electric propagator in the vicinity of the confinement/deconfinement phase transition:

- could signal a failure of the eLG model
  → but similar limitations are observed in other approaches.
- could signal limitations of the use of the LG
  → explore "more appropriate" gauges and test whether the corresponding (IR) extended gauge models are capable to describe the phase transition.

Polyakov loop and center-symmetry breaking

Free-energy F for having an isolated static quark located somewhere

$$e^{-\beta F} = \frac{1}{N}\left\langle \mathrm{tr}\, P\, e^{ig\int_0^\beta d\tau A_0(\tau)} \right\rangle \equiv \langle L \rangle \quad \text{with} \quad A_0 = A_0^a t^a \ (a = 1, \ldots, N)$$

The Yang-Mills action at finite T is invariant under twisted or center (gauge) transformations

$$U(\beta, \vec{x}) = U(0, \vec{x})\, V \quad \text{with} \quad V \in SU(N)_{\text{center}} = \left\{ e^{i2\pi k/N} \mathbb{1} | k = 0, \ldots, N-1 \right\}$$

Under a center transformation $\langle L \rangle \to \langle L \rangle\, e^{i2\pi k/N}$:

- if center-symmetry is broken $\langle L \rangle \neq 0$ and $F < \infty$ (deconfined phase);
- if center-symmetry is restored $\langle L \rangle = 0$ and $F = \infty$ (confined phase);

Polyakov loop and center-symmetry breaking

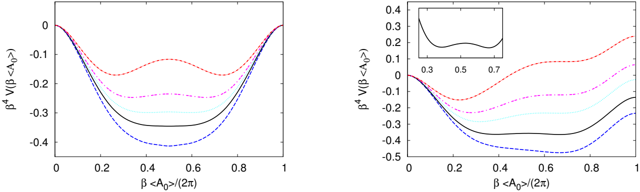
Free-energy F for having an isolated static quark located somewhere

$$e^{-\beta F} = \frac{1}{N}\left\langle \mathrm{tr}\, P\, e^{ig\int_0^\beta d\tau A_0(\tau)} \right\rangle \equiv \langle L \rangle \quad \text{with} \quad A_0 = A_0^a t^a \;\; (a = 1, \ldots, N)$$

The Yang-Mills action at finite T is invariant under twisted or center (gauge) transformations

$$U(\beta, \vec{x}) = U(0, \vec{x})\, V \quad \text{with} \quad V \in SU(N)_{\mathrm{center}} = \left\{ e^{i2\pi k/N}\mathbb{1} \,|\, k = 0, \ldots, N-1 \right\}$$

The lattice predicts a 2nd/1st order breaking of center-symmetry in the SU(2)/SU(3) case.
Confirmed by the functional renormalization group:



J. Braun, H. Gies and J.M. Pawlowski, Phys.Lett. B684 (2010).

Polyakov loop and center-symmetry breaking

Free-energy F for having an isolated static quark located somewhere

$$e^{-\beta F} = \frac{1}{N}\left\langle \mathrm{tr}\, P\, e^{ig\int_0^\beta d\tau A_0(\tau)}\right\rangle \equiv \langle L\rangle \quad \text{with} \quad A_0 = A_0^a t^a \ (a = 1, \ldots, N)$$

The Yang-Mills action at finite T is invariant under twisted or center (gauge) transformations

$$U(\beta, \vec{x}) = U(0, \vec{x})\, V \quad \text{with} \quad V \in SU(N)_{\text{center}} = \left\{ e^{i2\pi k/N}\mathbb{1} \,|\, k = 0, \ldots, N-1 \right\}$$

The lattice predicts a 2nd/1st order breaking of center-symmetry in the SU(2)/SU(3) case. Confirmed by the functional renormalization group:

Can this physics be captured perturbatively?

Extended background field gauge

The extended background field gauge

Choose a background $\bar{A}^a_\mu$. Fix the gauge according to $(\bar{D}_\mu(A_\mu - \bar{A}_\mu))^a = 0$.
In the limit $\xi \to 0$, one obtains the Landau-deWitt gauge:

$$S_{\bar{A}}[A] = \int_x \left\{ \frac{1}{4} F^a_{\mu\nu} F^a_{\mu\nu} + (\bar{D}_\mu \bar{c})^a (D_\mu c)^a + ih^a (\bar{D}_\mu (A_\mu - \bar{A}_\mu))^a \right\}$$

Why to consider such a gauge? From $S_{\bar{A}}[A]$, it is possible to construct $\tilde{\Gamma}[\bar{A}]$ such that

- the physics is obtained at the absolute minimum of $\tilde{\Gamma}[\bar{A}]$;
- center-symmetry is manifest because $\tilde{\Gamma}[\bar{A}^U] = \tilde{\Gamma}[\bar{A}]$.

The extended background field gauge

Choose a background $\bar{A}_\mu^a$. Fix the gauge according to $(\bar{D}_\mu(A_\mu - \bar{A}_\mu))^a = 0$.
In the limit $\xi \to 0$, one obtains the Landau-deWitt gauge:

$$S_{\bar{A}}[A] = \int_x \left\{ \frac{1}{4} F_{\mu\nu}^a F_{\mu\nu}^a + (\bar{D}_\mu \bar{c})^a (D_\mu c)^a + ih^a (\bar{D}_\mu (A_\mu - \bar{A}_\mu))^a \right\}$$

Why to consider such a gauge? From $S_{\bar{A}}[A]$, it is possible to construct $\tilde{\Gamma}[\bar{A}]$ such that

- the physics is obtained at the absolute minimum of $\tilde{\Gamma}[\bar{A}]$;
- center-symmetry is manifest because $\tilde{\Gamma}[\bar{A}^U] = \tilde{\Gamma}[\bar{A}]$.

We upgrade the bakground field gauge to the extended background field gauge (eBFG):

$$S_{\bar{A}}[A] = \int_x \left\{ \frac{1}{4} F_{\mu\nu}^a F_{\mu\nu}^a + (\bar{D}_\mu \bar{c})^a (D_\mu c)^a + ih^a (\bar{D}_\mu (A_\mu - \bar{A}_\mu))^a + \frac{1}{2} m^2 (A_\mu^a - \bar{A}_\mu^a)(A_\mu^a - \bar{A}_\mu^a) \right\}$$

The mass term does not break center symmetry!

Feynman rules?

Feynman rules: simplifying remarks

We are interested in thermodynamical properties:

$\Rightarrow$ uniform background: $\bar{A}_\mu^a(\tau, \vec{x}) = \bar{A}_\mu^a$.

$\Rightarrow$ effective potential: $\gamma(\bar{A}) = \tilde{\Gamma}[\bar{A}]/(\beta V)$.

We are interested in the Polyakov loop:

$\Rightarrow$ temporal background $\bar{A}_\mu^a = \bar{A}_0^a \delta_{\mu 0}$.

One can always choose $\bar{A}_0$ in the Cartan sub-algebra:

$\Rightarrow$ SU(2): $\bar{A}_0 = \bar{A}_0^3 \frac{\sigma^3}{2}$

$\Rightarrow$ SU(3): $\bar{A}_0 = \bar{A}_0^3 \frac{\lambda^3}{2} + \bar{A}_0^8 \frac{\lambda^8}{2}$

...

The only role of the background is to lift the usual degeneracy between the three color directions.

Feynman rules: modes

Ex.: SU(2) ghost propagator:

$$\text{eLG:}\quad \begin{cases} G^{11}(K) = \frac{1}{K^2} \\ G^{22}(K) = G^{11}(K) \\ G^{33}(K) = G^{11}(K) \end{cases} \quad \rightarrow \quad \text{eBFG:}\quad \begin{cases} G^{0}(K) = \frac{1}{K^2} \\ G^{+}(K) = \frac{1}{K_+^2} \\ G^{-}(K) = \frac{1}{K_-^2} \end{cases}$$

$$\boxed{K_\sigma = (\omega_n + \sigma g \bar{A}_0^3, \vec{k})}$$

SU(2) gluon propagator:

$$\text{eLG:}\quad \begin{cases} G^{11}_{\mu\nu}(K) = \frac{P^\perp_{\mu\nu}(K)}{K^2+m^2} + \frac{\xi P^\parallel_{\mu\nu}(K)}{K^2+\xi m^2} \\ G^{22}_{\mu\nu}(K) = G^{11}_{\mu\nu}(K) \\ G^{33}_{\mu\nu}(K) = G^{11}_{\mu\nu}(K) \end{cases} \quad \rightarrow \quad \text{eBFG:}\quad \begin{cases} G^{0}_{\mu\nu}(K) = \frac{P^\perp_{\mu\nu}(K)}{K^2+m^2} + \frac{\xi P^\parallel_{\mu\nu}(K)}{K^2+\xi m^2} \\ G^{+}_{\mu\nu}(K) = \frac{P^\perp_{\mu\nu}(K_+)}{K_+^2+m^2} + \frac{\xi P^\parallel_{\mu\nu}(K_+)}{K_+^2+\xi m^2} \\ G^{-}_{\mu\nu}(K) = \frac{P^\perp_{\mu\nu}(K_-)}{K_-^2+m^2} + \frac{\xi P^\parallel_{\mu\nu}(K_-)}{K_-^2+\xi m^2} \end{cases}$$

Feynman rules: modes

Ex.: SU(2) ghost propagator:

$$\text{eLG:}\quad \begin{cases} G^{11}(K) = \frac{1}{K^2} \\ G^{22}(K) = G^{11}(K) \\ G^{33}(K) = G^{11}(K) \end{cases} \quad \rightarrow \quad \text{eBFG:}\quad \begin{cases} G^{0}(K) = \frac{1}{K^2} \\ G^{+}(K) = \frac{1}{K_+^2} \\ G^{-}(K) = \frac{1}{K_-^2} \end{cases}$$

$$\boxed{K_\sigma = (\omega_n + \sigma g \bar{A}_0^3, \vec{k})}$$

SU(2) gluon propagator:

$$\text{eLG:}\quad \begin{cases} G^{11}_{\mu\nu}(K) = \frac{P^\perp_{\mu\nu}(K)}{K^2+m^2} + \frac{\xi P^\parallel_{\mu\nu}(K)}{K^2+\xi m^2} \\ G^{22}_{\mu\nu}(K) = G^{11}_{\mu\nu}(K) \\ G^{33}_{\mu\nu}(K) = G^{11}_{\mu\nu}(K) \end{cases} \quad \rightarrow \quad \text{eBFG:}\quad \begin{cases} G^{0}_{\mu\nu}(K) = \frac{P^\perp_{\mu\nu}(K)}{K^2+m^2} + \frac{\xi P^\parallel_{\mu\nu}(K)}{K^2+\xi m^2} \\ G^{+}_{\mu\nu}(K) = \frac{P^\perp_{\mu\nu}(K_+)}{K_+^2+m^2} + \frac{\xi P^\parallel_{\mu\nu}(K_+)}{K_+^2+\xi m^2} \\ G^{-}_{\mu\nu}(K) = \frac{P^\perp_{\mu\nu}(K_-)}{K_-^2+m^2} + \frac{\xi P^\parallel_{\mu\nu}(K_-)}{K_-^2+\xi m^2} \end{cases}$$

For each charge eigenstate, we have:

3 massive transverse gluons, 1 massless longitudinal gluon ($\xi \rightarrow 0$), 2 massless ghosts.

Polyakov-loop potential and center-symmetry breaking

Background as an order parameter

To discuss center-symmetry breaking from $\gamma(\bar{A})$, it is first necessary to identify $\bar{A}$ as an order parameter for center-symmetry breaking.

At LO, the path ordering in $\langle L\rangle$ does not play a role

$$\langle L\rangle = \frac{1}{N}\left\langle \mathrm{tr}\, P\, e^{-ig\int_0^\beta d\tau\,(\bar{A}_0+a_0(\tau))}\right\rangle = \underbrace{\frac{1}{N}\mathrm{tr}\, e^{-i\beta g\bar{A}_0}}_{\equiv\langle L\rangle_{\mathrm{lo}}} + \mathcal{O}(g^2)$$

SU(2): $\bar{A}_0 = \bar{A}_0^3\frac{\sigma^3}{2}$

$$\langle L\rangle_{\mathrm{lo}} = \cos\left(\frac{\beta g\bar{A}_0^3}{2}\right) \quad\Rightarrow\quad \boxed{\langle L\rangle_{\mathrm{lo}} = 0 \quad \mathrm{iff} \quad r_3 \equiv \beta g\bar{A}_0^3 = \pi\;[2\pi]}$$

The background plays the role of an order parameter for center-symmetry breaking!

LO Polyakov-loop potential: SU(2) case

Only the charged modes contribute to the background dependence of the potential

$$\gamma(\bar{A}_0^3) = 3T\int_q \ln\left(1 + e^{-2\beta\varepsilon_q} - 2e^{-\beta\varepsilon_q}\cos(\underbrace{\beta g\bar{A}_0^3}_{\equiv r_3})\right) - T\int_q \ln\left(1 + e^{-2\beta q} - e^{-\beta q}\cos(\beta g\bar{A}_0^3)\right)$$

LO Polyakov-loop potential: SU(2) case

Only the charged modes contribute to the background dependence of the potential

$$\gamma(\bar{A}_0^3) = 3T\int_q \ln\Big(1 + e^{-2\beta\varepsilon_q} - 2e^{-\beta\varepsilon_q}\cos(\underbrace{\beta g\bar{A}_0^3}_{\equiv r_3})\Big) - T\int_q \ln\Big(1 + e^{-2\beta q} - e^{-\beta q}\cos(\beta g\bar{A}_0^3)\Big)$$

Symmetries:

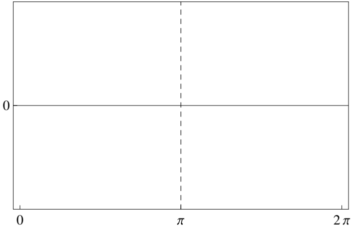
Center symmetry: $\gamma(r_3) = \gamma(r_3 + 2\pi)$

$\Rightarrow$ we can restrict to $[0, 2\pi]$

Center + C-symmetry:

$\gamma(\pi + \delta r_3) = \gamma(-\pi - \delta r_3) = \gamma(\pi - \delta r_3)$

$\Rightarrow \begin{cases} \text{we can restrict to } r_3 \in [0,\pi] \\ 0 \text{ and } \pi \text{ are extrema} \end{cases}$



LO Polyakov-loop potential: SU(2) case

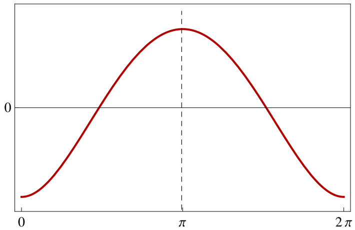
Only the charged modes contribute to the background dependence of the potential

$$\gamma(\bar{A}_0^3) = 3T\int_q \ln\Big(1 + e^{-2\beta\varepsilon_q} - 2e^{-\beta\varepsilon_q}\cos(\underbrace{\beta g\bar{A}_0^3}_{\equiv r_3})\Big) - T\int_q \ln\Big(1 + e^{-2\beta q} - e^{-\beta q}\cos(\beta g\bar{A}_0^3)\Big)$$

Thermal asymptotic behavior:

$$T \gg m,\ \underbrace{2T\int_q \ln(1 + e^{-2\beta q} - e^{-\beta q}\cos(r_3))}_{\equiv\gamma_{\rm Weiss}(r_3)}$$

$$T \ll m,\ \underbrace{-T\int_q \ln(1 + e^{-2\beta q} - e^{-\beta q}\cos(r_3))}_{=-\frac{1}{2}\gamma_{\rm Weiss}(r_3)}$$



$$\gamma_{\rm Weiss}(r_3) = \frac{(r_3-\pi)^4}{24\pi^2} - \frac{(r_3-\pi)^2}{12} + \frac{7\pi^2}{360}$$

LO Polyakov-loop potential: SU(2) case

Only the charged modes contribute to the background dependence of the potential

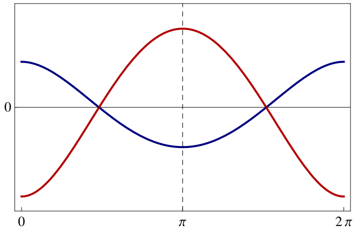
$$\gamma(\bar{A}_0^3) = 3T\int_q \ln\Big(1 + e^{-2\beta\varepsilon_q} - 2e^{-\beta\varepsilon_q}\cos(\underbrace{\beta g\bar{A}_0^3}_{\equiv r_3})\Big) - T\int_q \ln\Big(1 + e^{-2\beta q} - e^{-\beta q}\cos(\beta g\bar{A}_0^3)\Big)$$

Thermal asymptotic behavior:

$$T \gg m,\ \underbrace{2T\int_q \ln(1 + e^{-2\beta q} - e^{-\beta q}\cos(r_3))}_{\equiv\gamma_{\rm Weiss}(r_3)}$$

$$T \ll m,\ \underbrace{-T\int_q \ln(1 + e^{-2\beta q} - e^{-\beta q}\cos(r_3))}_{=-\frac{1}{2}\gamma_{\rm Weiss}(r_3)}$$

$$\boxed{\gamma_{\rm Weiss}(r_3) = \frac{(r_3-\pi)^4}{24\pi^2} - \frac{(r_3-\pi)^2}{12} + \frac{7\pi^2}{360}}$$



reverted Weiss potential!
(ghost dominate at low T;
as in the fRG approach)

LO Polyakov-loop potential: SU(2) case

Only the charged modes contribute to the background dependence of the potential

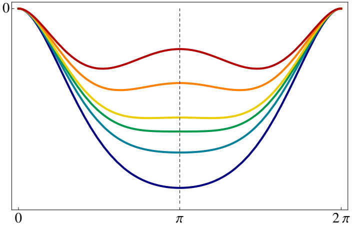
$$\gamma(\bar{A}_0^3) = 3T\int_q \ln\Big(1+e^{-2\beta\varepsilon_q}-2e^{-\beta\varepsilon_q}\cos(\underbrace{\beta g\bar{A}_0^3}_{\equiv r_3})\Big) - T\int_q \ln\Big(1+e^{-2\beta q}-e^{-\beta q}\cos(\beta g\bar{A}_0^3)\Big)$$

Thermal asymptotic behavior:

$$T\gg m,\ \underbrace{2T\int_q \ln(1+e^{-2\beta q}-e^{-\beta q}\cos(r_3))}_{\equiv\gamma_{\rm Weiss}(r_3)}$$

$$T\ll m,\ \underbrace{-T\int_q \ln(1+e^{-2\beta q}-e^{-\beta q}\cos(r_3))}_{=-\frac{1}{2}\gamma_{\rm Weiss}(r_3)}$$

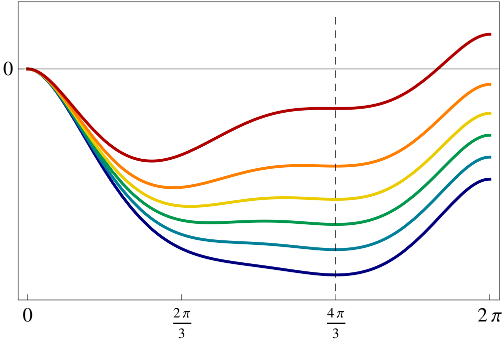
$$\gamma_{\rm Weiss}(r_3)=\frac{(r_3-\pi)^4}{24\pi^2}-\frac{(r_3-\pi)^2}{12}+\frac{7\pi^2}{360}$$



2nd order phase transition!

LO Polyakov-loop potential: SU(3) case

We obtain a mildly first order phase transition in agreement with lattice or fRG results.

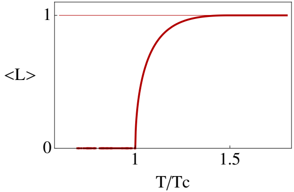


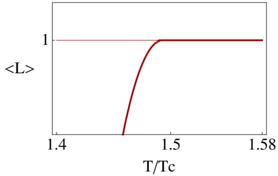
We obtain $T_c/m \simeq 0.363$ and since $m \simeq 510\,\text{MeV}$, we obtain $T_c \simeq 185\,\text{MeV}$.

Still far from the lattice ($T_c \simeq 295\,\text{MeV}$) or from fRG results ($T_c \simeq 284\,\text{MeV}$).

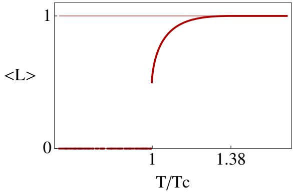
LO artifacts

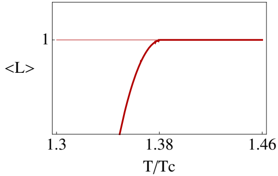
The Polyakov loop reaches its limiting value at a finite temperature $T_a/T_c = 1.5$:





Similar conclusion for SU(3) again with $T_a/T_c = 1.38$:



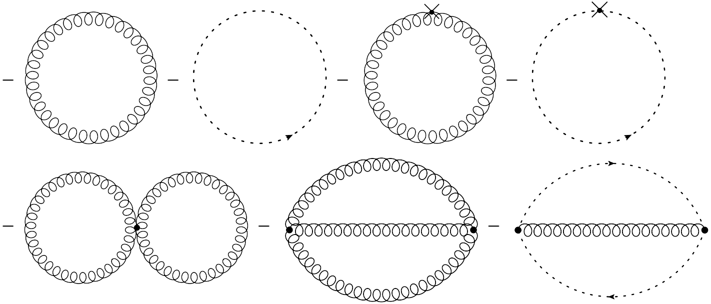


Additional singularity in thermodynamical observables in the range $[T_c, 2T_c]$.

Next-to-leading order results

NLO Polyakov-loop potential

$\gamma_{\mathrm{nlo}}(\bar{A}) =$



(with background-dependent propagators and background-dependent derivative vertices)

Summary of NLO results

→ At NLO, $\bar{A}$ plays the role of an order parameter. We find $\langle L\rangle_{\rm nlo} = (1 + ag^2\beta m) \times \langle L\rangle_{\rm lo}$ with

$$a = \frac{3}{32\pi} + \sin^2\left(\frac{r_3}{2}\right)\int\frac{d^3q}{(2\pi m)^3}\left[\frac{1}{\cosh(\beta q) - \cos(r_3)} - \frac{q^2}{\varepsilon_q^2}\frac{1}{\cosh(\beta\varepsilon_q) - \cos(r_3)}\right]$$

Since $a > 0$, it follows that $\langle L\rangle_{\rm nlo} = 0 \;\text{ iff }\; \langle L\rangle_{\rm lo} = 0 \;\text{ iff }\; r_3 = \pi\,[2\pi]$.

→ The NLO Polyakov loop potential is UV finite.

→ Our “predictions” concerning the orders of the SU(2)/SU(3) transitions remain the same.

→ We obtain improved values for T_c in the SU(3) case:

	order	LO	NLO	FRG*	Lattice**
SU(3)	1st	185 MeV	256 MeV (prelim.)	284 MeV	295 MeV

* Braun et. al, Phys.Lett. B684 (2010) ** Aouane et. al, Phys.Rev. D85 (2012).

→ The LO artifact seems to be lifted or at least pushed to temperatures above $3\,T_c$: we do not find additional thermodynamical singularities in the range $[\,T_c, 3\,T_c]$.

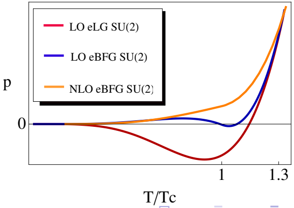
Conclusions and Outlook

- A perturbative one-loop calculation of the Polyakov-loop potential within the extended BFG allows to capture the physics of center-symmetry breaking.
- Our approach allows for a systematic determination of higher order corrections.
- Two-loop corrections are important to reach a value of the transition temperature comparable to that obtained on the lattice or with an fRG approach and to get rid of certain artifacts of the one-loop calculation.

* * * * *

- eBFG propagators (in progress).
- Include quarks and chemical potential (in progress).
- ...
- Solid theoretical justification of extended massive gauges?

- Thermodynamics: meaningful (monotonically increasing) pressure?



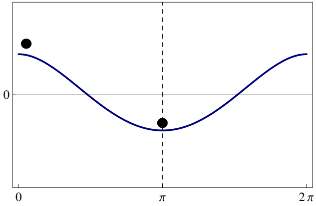
(more) Propaganda

And please, visit the posters by:

- Marcela Peláez;
- Gergely Markó;
- Andréas Tresmontant.

eLG from the perspective of the eBFG

The loop expansion in the eLG looks like an expansion around an instable point.



$p = -\gamma(r_{\rm min})$

eLG: $r_3 = 0$ (max)

eBFG: $r_3 = \pi$ (min)

eLG for $T \ll m$:

$$p = T^4 \int_q \ln\left(1 - e^{-q}\right) + T^4 \int_q \ln\left(1 + e^{-2q} - 2e^{-q}\cos(r_3)\right) = 3T^4 \int_q \ln\left(1 - e^{-q}\right) < 0$$

eBFG for $T \ll m$:

$$p \;=\; T^4 \int_q \ln\left(1 - e^{-q}\right) + T^4 \int_q \ln\left(1 + e^{-q}\right)^2 = -\frac{3}{4} T^4 \int_q \ln\left(1 - e^{-q}\right) > 0$$

Effective change of nature of the degrees of freedom in the presence of the background!

LO Polyakov-loop potential: SU(3) case

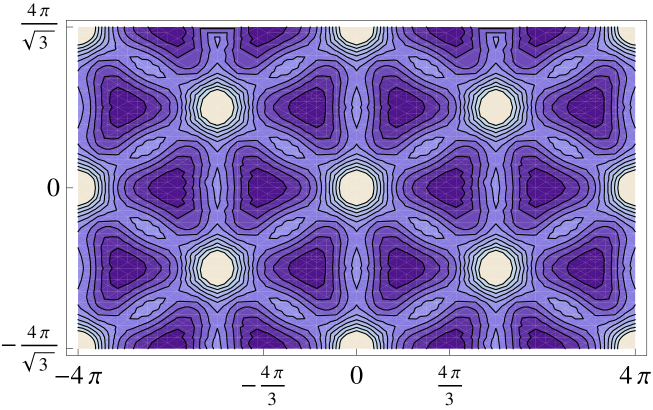
Each charged mode contributes as in the SU(2) case but with its own Q_3 and Q_8 charges:

$$\gamma_{su(3)}(r_3, r_8) = \gamma_{su(2)}(r_3) + \gamma_{su(2)}\left(\frac{r_3 + r_8\sqrt{3}}{2}\right) + \gamma_{su(2)}\left(\frac{-r_3 + r_8\sqrt{3}}{2}\right)$$

LO Polyakov-loop potential: SU(3) case

Each charged mode contributes as in the SU(2) case but with its own Q_3 and Q_8 charges:

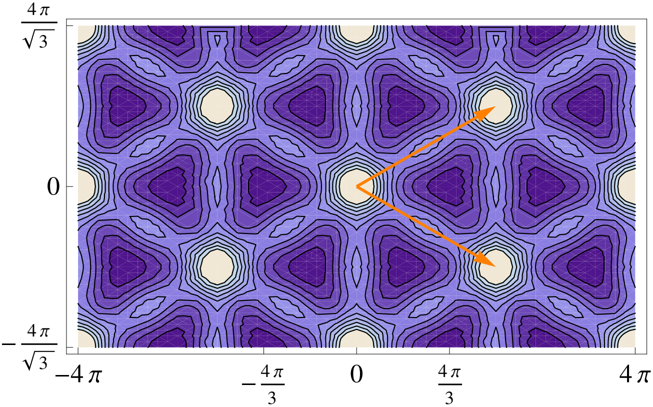
$$\gamma_{su(3)}(r_3, r_8) = \gamma_{su(2)}(r_3) + \gamma_{su(2)}\left(\frac{r_3 + r_8\sqrt{3}}{2}\right) + \gamma_{su(2)}\left(\frac{-r_3 + r_8\sqrt{3}}{2}\right)$$



LO Polyakov-loop potential: SU(3) case

Each charged mode contributes as in the SU(2) case but with its own Q_3 and Q_8 charges:

$$\gamma_{su(3)}(r_3, r_8) = \gamma_{su(2)}(r_3) + \gamma_{su(2)}\left(\frac{r_3 + r_8\sqrt{3}}{2}\right) + \gamma_{su(2)}\left(\frac{-r_3 + r_8\sqrt{3}}{2}\right)$$

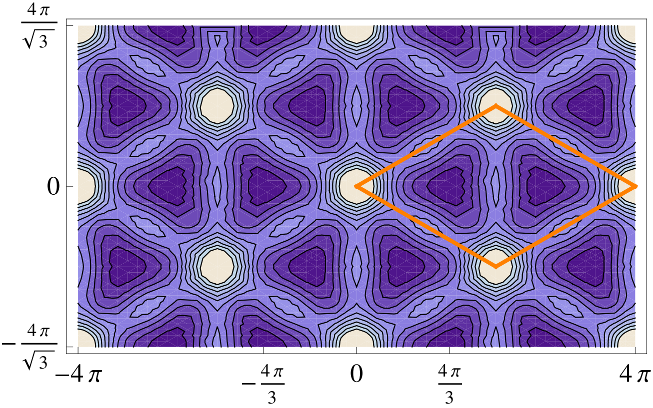


Center-symmetry

LO Polyakov-loop potential: SU(3) case

Each charged mode contributes as in the SU(2) case but with its own Q_3 and Q_8 charges:

$$\gamma_{su(3)}(r_3, r_8) = \gamma_{su(2)}(r_3) + \gamma_{su(2)}\left(\frac{r_3 + r_8\sqrt{3}}{2}\right) + \gamma_{su(2)}\left(\frac{-r_3 + r_8\sqrt{3}}{2}\right)$$

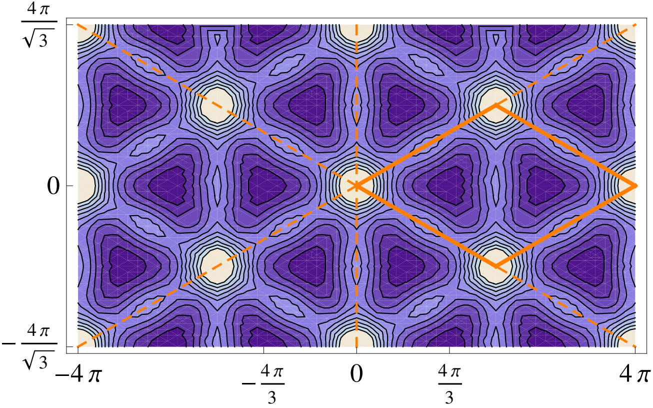


Center-symmetry

LO Polyakov-loop potential: SU(3) case

Each charged mode contributes as in the SU(2) case but with its own Q_3 and Q_8 charges:

$$\gamma_{su(3)}(r_3, r_8) = \gamma_{su(2)}(r_3) + \gamma_{su(2)}\left(\frac{r_3 + r_8\sqrt{3}}{2}\right) + \gamma_{su(2)}\left(\frac{-r_3 + r_8\sqrt{3}}{2}\right)$$

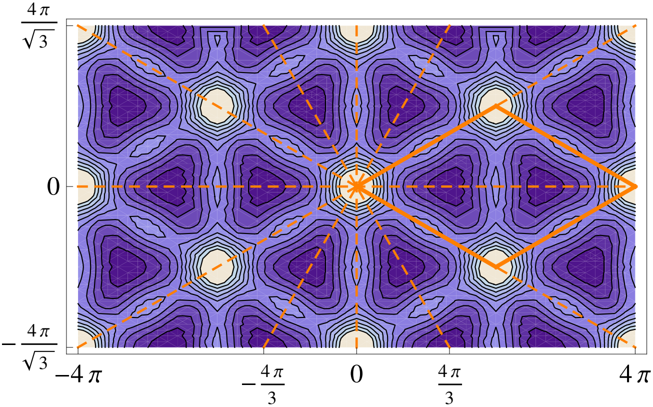


Center-symmetry + Color invariance

LO Polyakov-loop potential: SU(3) case

Each charged mode contributes as in the SU(2) case but with its own Q_3 and Q_8 charges:

$$\gamma_{su(3)}(r_3, r_8) = \gamma_{su(2)}(r_3) + \gamma_{su(2)}\left(\frac{r_3 + r_8\sqrt{3}}{2}\right) + \gamma_{su(2)}\left(\frac{-r_3 + r_8\sqrt{3}}{2}\right)$$

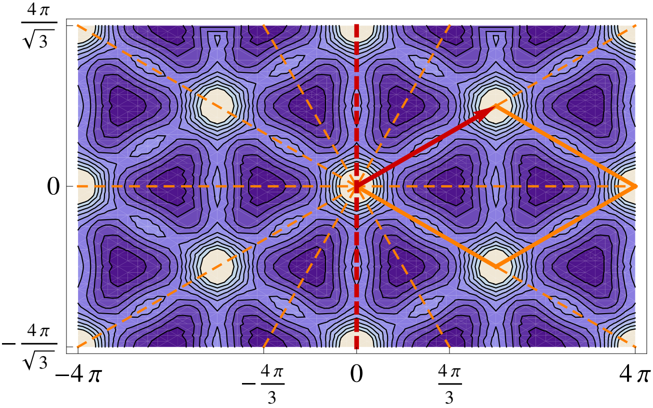


Center-symmetry + Color invariance + C-symmetry

LO Polyakov-loop potential: SU(3) case

Each charged mode contributes as in the SU(2) case but with its own Q_3 and Q_8 charges:

$$\gamma_{su(3)}(r_3, r_8) = \gamma_{su(2)}(r_3) + \gamma_{su(2)}\left(\frac{r_3 + r_8\sqrt{3}}{2}\right) + \gamma_{su(2)}\left(\frac{-r_3 + r_8\sqrt{3}}{2}\right)$$

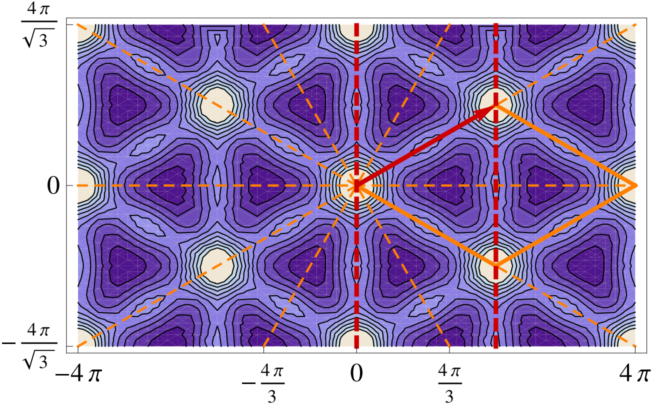


Center-symmetry + Color invariance + C-symmetry

LO Polyakov-loop potential: SU(3) case

Each charged mode contributes as in the SU(2) case but with its own Q_3 and Q_8 charges:

$$\gamma_{su(3)}(r_3, r_8) = \gamma_{su(2)}(r_3) + \gamma_{su(2)}\left(\frac{r_3 + r_8\sqrt{3}}{2}\right) + \gamma_{su(2)}\left(\frac{-r_3 + r_8\sqrt{3}}{2}\right)$$

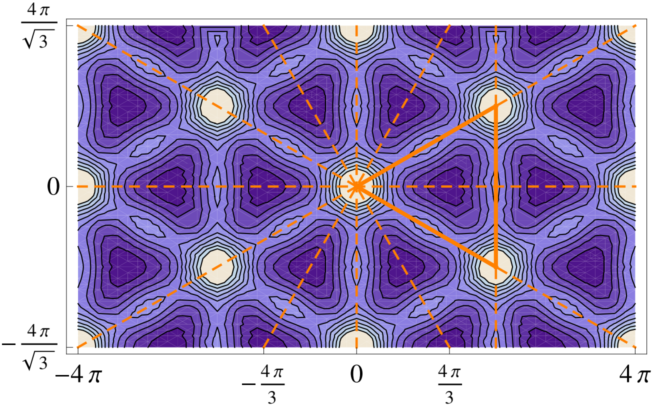


Center-symmetry + Color invariance + C-symmetry

LO Polyakov-loop potential: SU(3) case

Each charged mode contributes as in the SU(2) case but with its own Q_3 and Q_8 charges:

$$\gamma_{su(3)}(r_3, r_8) = \gamma_{su(2)}(r_3) + \gamma_{su(2)}\left(\frac{r_3 + r_8\sqrt{3}}{2}\right) + \gamma_{su(2)}\left(\frac{-r_3 + r_8\sqrt{3}}{2}\right)$$

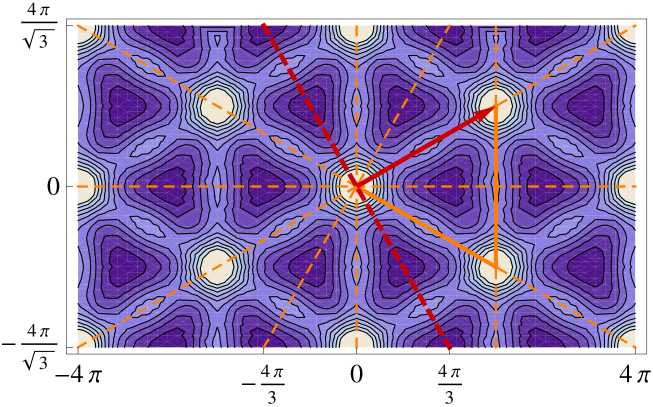


Center-symmetry + Color invariance + C-symmetry

LO Polyakov-loop potential: SU(3) case

Each charged mode contributes as in the SU(2) case but with its own Q_3 and Q_8 charges:

$$\gamma_{su(3)}(r_3, r_8) = \gamma_{su(2)}(r_3) + \gamma_{su(2)}\left(\frac{r_3 + r_8\sqrt{3}}{2}\right) + \gamma_{su(2)}\left(\frac{-r_3 + r_8\sqrt{3}}{2}\right)$$

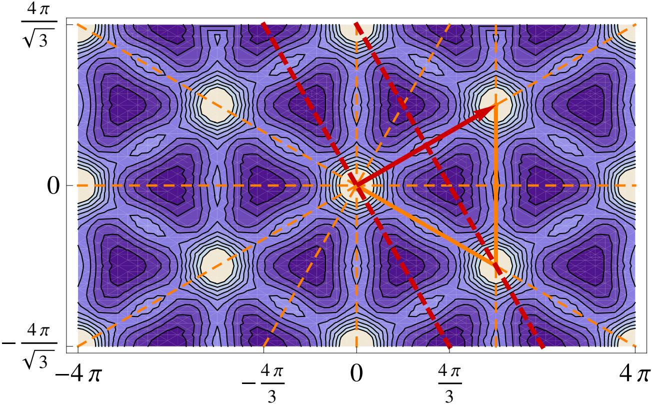


Center-symmetry + Color invariance + C-symmetry

LO Polyakov-loop potential: SU(3) case

Each charged mode contributes as in the SU(2) case but with its own Q_3 and Q_8 charges:

$$\gamma_{su(3)}(r_3, r_8) = \gamma_{su(2)}(r_3) + \gamma_{su(2)}\left(\frac{r_3 + r_8\sqrt{3}}{2}\right) + \gamma_{su(2)}\left(\frac{-r_3 + r_8\sqrt{3}}{2}\right)$$

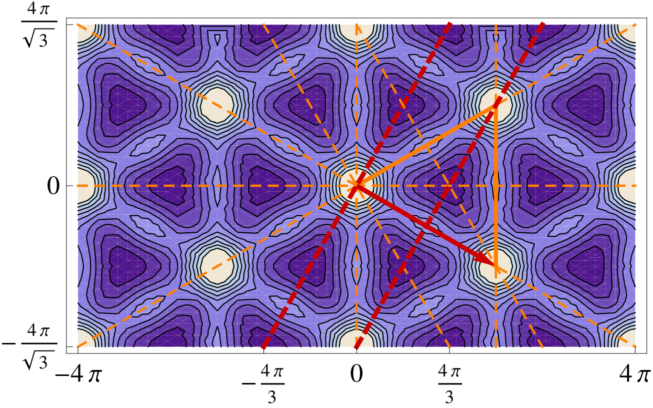


Center-symmetry + Color invariance + C-symmetry

LO Polyakov-loop potential: SU(3) case

Each charged mode contributes as in the SU(2) case but with its own Q_3 and Q_8 charges:

$$\gamma_{su(3)}(r_3, r_8) = \gamma_{su(2)}(r_3) + \gamma_{su(2)}\left(\frac{r_3 + r_8\sqrt{3}}{2}\right) + \gamma_{su(2)}\left(\frac{-r_3 + r_8\sqrt{3}}{2}\right)$$

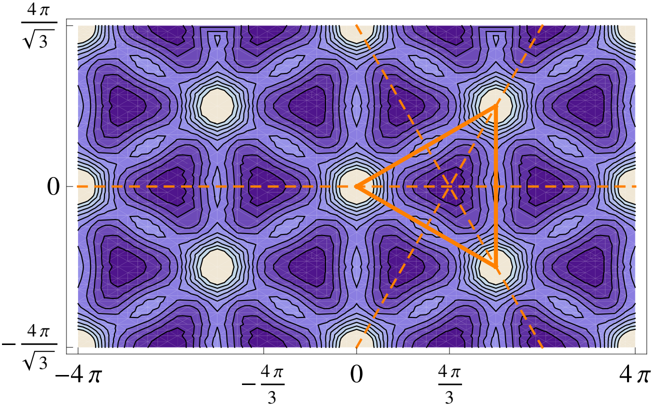


Center-symmetry + Color invariance + C-symmetry

LO Polyakov-loop potential: SU(3) case

Each charged mode contributes as in the SU(2) case but with its own Q_3 and Q_8 charges:

$$\gamma_{su(3)}(r_3, r_8) = \gamma_{su(2)}(r_3) + \gamma_{su(2)}\left(\frac{r_3 + r_8\sqrt{3}}{2}\right) + \gamma_{su(2)}\left(\frac{-r_3 + r_8\sqrt{3}}{2}\right)$$

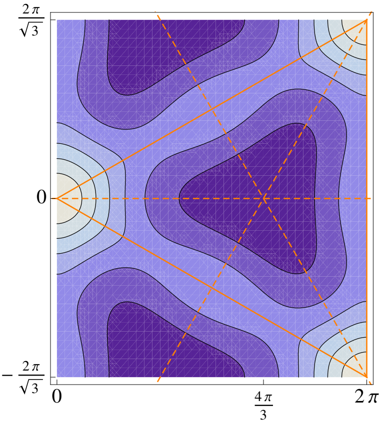


Center-symmetry + Color invariance + C-symmetry

LO Polyakov-loop potential: SU(3) case

Each charged mode contributes as in the SU(2) case but with its own Q_3 and Q_8 charges:

$$\gamma_{su(3)}(r_3, r_8) = \gamma_{su(2)}(r_3) + \gamma_{su(2)}\left(\frac{r_3 + r_8\sqrt{3}}{2}\right) + \gamma_{su(2)}\left(\frac{-r_3 + r_8\sqrt{3}}{2}\right)$$



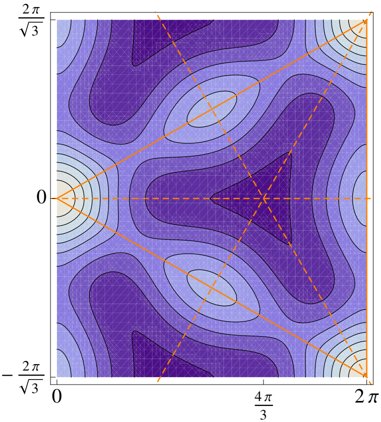
$(4\pi/3, 0)$

is always an extremum!

LO Polyakov-loop potential: SU(3) case

Each charged mode contributes as in the SU(2) case but with its own Q_3 and Q_8 charges:

$$\gamma_{su(3)}(r_3, r_8) = \gamma_{su(2)}(r_3) + \gamma_{su(2)}\left(\frac{r_3 + r_8\sqrt{3}}{2}\right) + \gamma_{su(2)}\left(\frac{-r_3 + r_8\sqrt{3}}{2}\right)$$



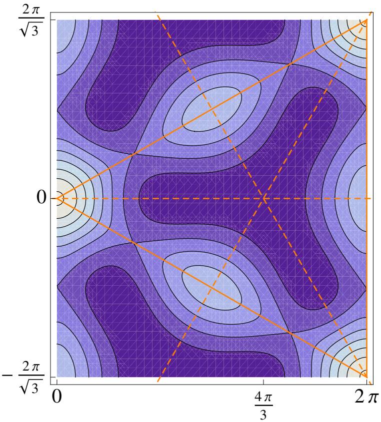
$(4\pi/3, 0)$

is always an extremum!

LO Polyakov-loop potential: SU(3) case

Each charged mode contributes as in the SU(2) case but with its own Q_3 and Q_8 charges:

$$\gamma_{su(3)}(r_3, r_8) = \gamma_{su(2)}(r_3) + \gamma_{su(2)}\left(\frac{r_3 + r_8\sqrt{3}}{2}\right) + \gamma_{su(2)}\left(\frac{-r_3 + r_8\sqrt{3}}{2}\right)$$



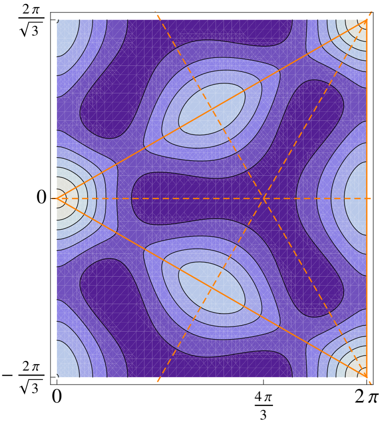
$(4\pi/3, 0)$

is always an extremum!

LO Polyakov-loop potential: SU(3) case

Each charged mode contributes as in the SU(2) case but with its own Q_3 and Q_8 charges:

$$\gamma_{su(3)}(r_3, r_8) = \gamma_{su(2)}(r_3) + \gamma_{su(2)}\left(\frac{r_3 + r_8\sqrt{3}}{2}\right) + \gamma_{su(2)}\left(\frac{-r_3 + r_8\sqrt{3}}{2}\right)$$



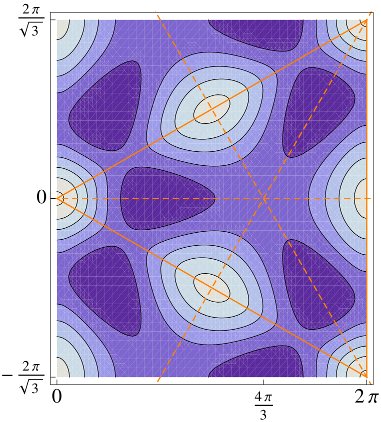
$(4\pi/3, 0)$

is always an extremum!

LO Polyakov-loop potential: SU(3) case

Each charged mode contributes as in the SU(2) case but with its own Q_3 and Q_8 charges:

$$\gamma_{su(3)}(r_3, r_8) = \gamma_{su(2)}(r_3) + \gamma_{su(2)}\left(\frac{r_3 + r_8\sqrt{3}}{2}\right) + \gamma_{su(2)}\left(\frac{-r_3 + r_8\sqrt{3}}{2}\right)$$

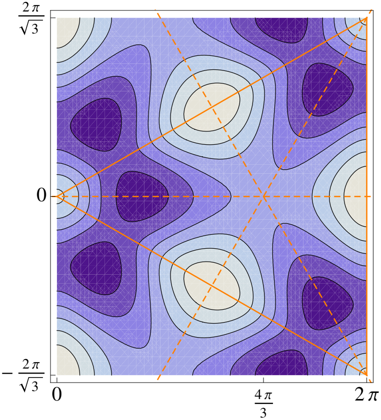


$(4\pi/3, 0)$
is always an extremum!

LO Polyakov-loop potential: SU(3) case

Each charged mode contributes as in the SU(2) case but with its own Q_3 and Q_8 charges:

$$\gamma_{su(3)}(r_3, r_8) = \gamma_{su(2)}(r_3) + \gamma_{su(2)}\left(\frac{r_3 + r_8\sqrt{3}}{2}\right) + \gamma_{su(2)}\left(\frac{-r_3 + r_8\sqrt{3}}{2}\right)$$



$(4\pi/3, 0)$
is always an extremum!