Conformal or Confining

Elisabetta Pallante
U. of Groningen
The Netherlands

rijksuniversiteit groningen / faculteit wiskunde en natuurwetenschappen

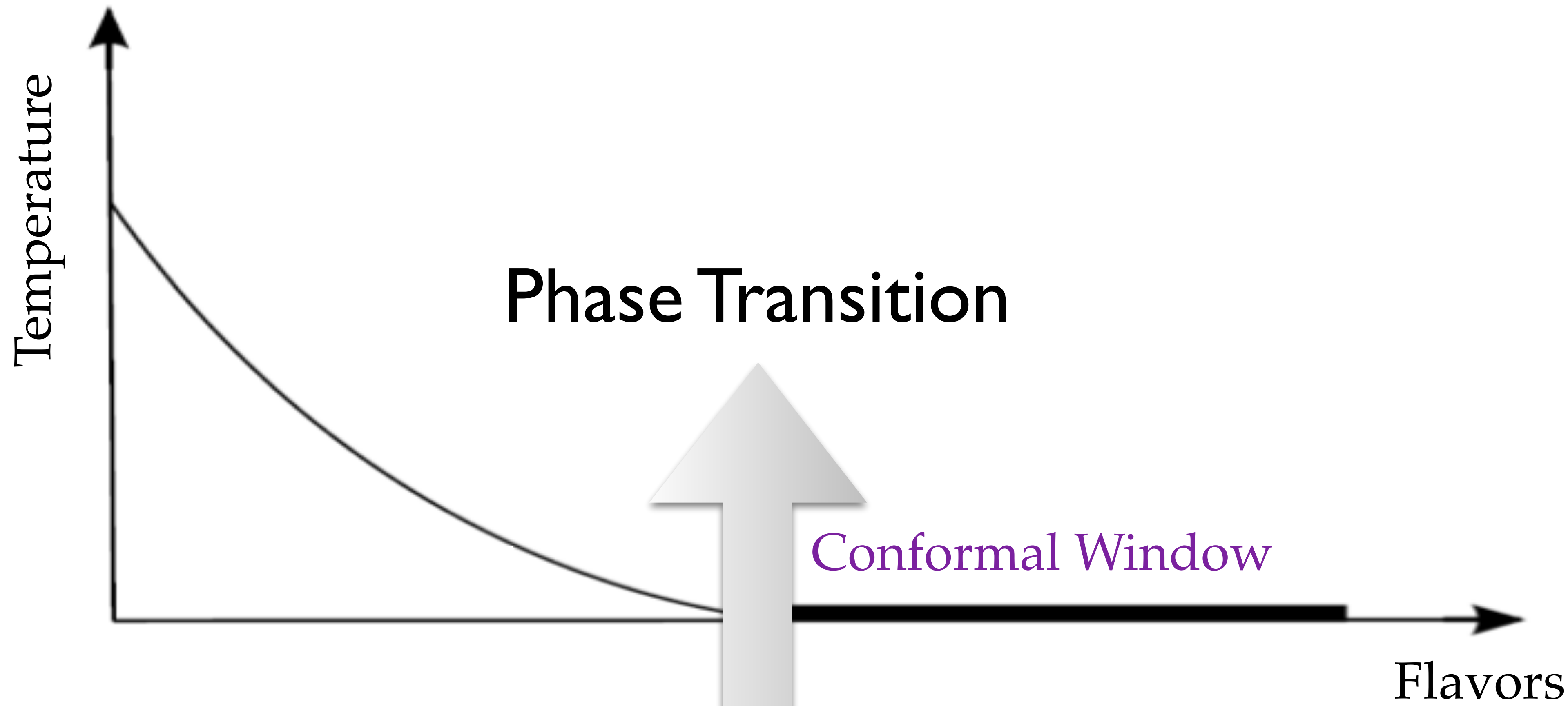
Powered by SURF SARA

Outline

BASED ON NUNES DA SILVA, EP, ROBROEK ARXIV:1506.06396

Given Yang-Mills plus N_f massless flavors (any representation)

- Question: How far is the complete theory from perturbation theory or large-N ?
  I) Interplay of confinement and chiral symmetry
  II) Consequences of removing supersymmetry
- Numerical study of the lower edge of the CW
- Theoretical analysis of the scalar glueball anomalous dimension



QCD	CFTs
Asymptotic Freedom = Confinement	Live at a nontrivial IRFP ≠ QCD (UV and IR)

Very relevant result
[Bochicchio NPB875 2013]

Question

How far is the complete theory from perturbation theory or large-N ?

Lattice study

One step towards the answer:

Identify the lower edge of the CW with a lattice formulation of the theory (Euclidean action for YM+N_f)

Strategy:

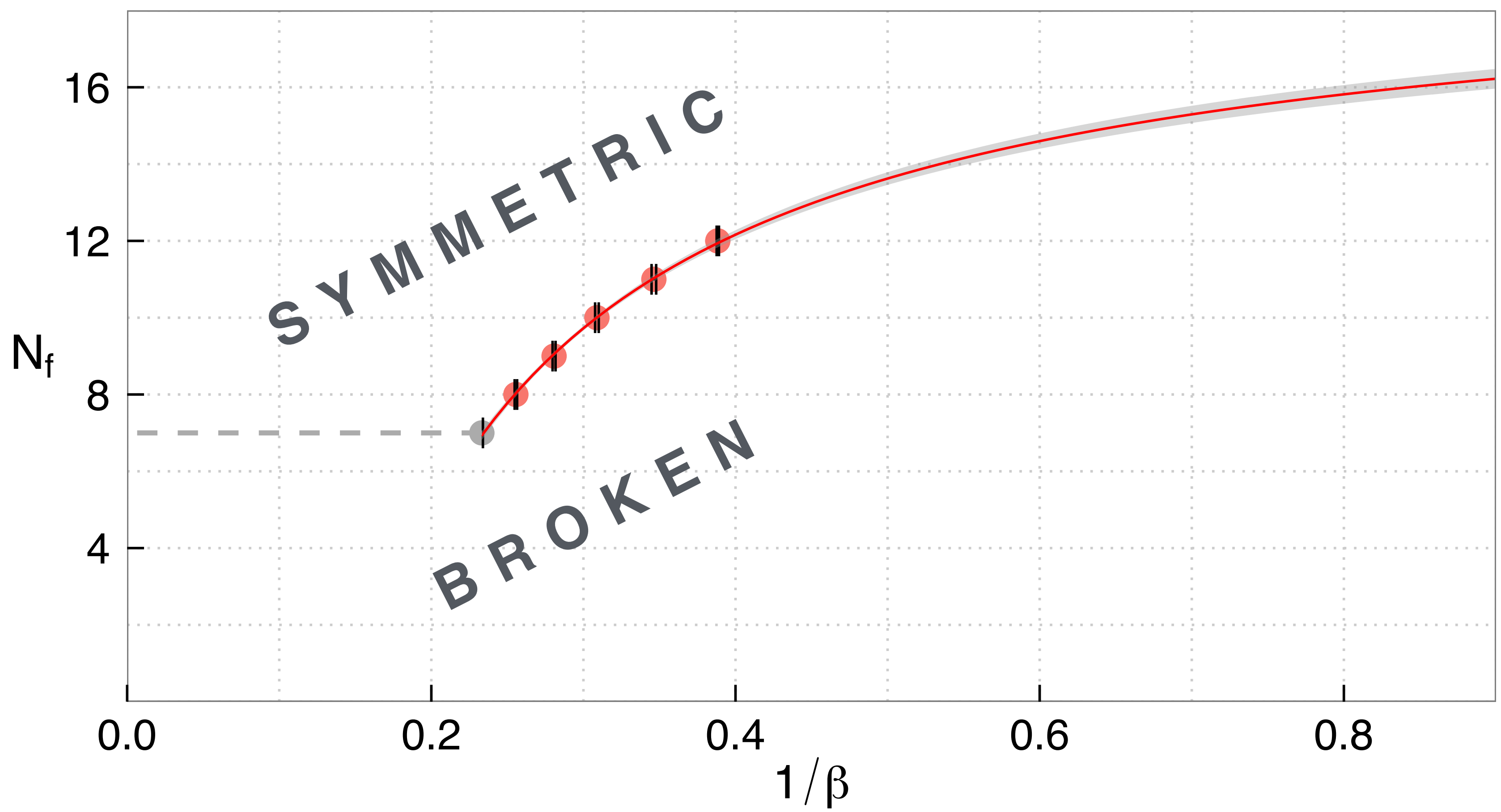
Use observable(s) that undergo a phase transition — other observables are likely to change smoothly across the endpoint

This study:

SU(3) + N_f in the fundamental
Order parameter of chiral symmetry breaking (χSB)
(Chiral symmetry restored if conformal symmetry realized)

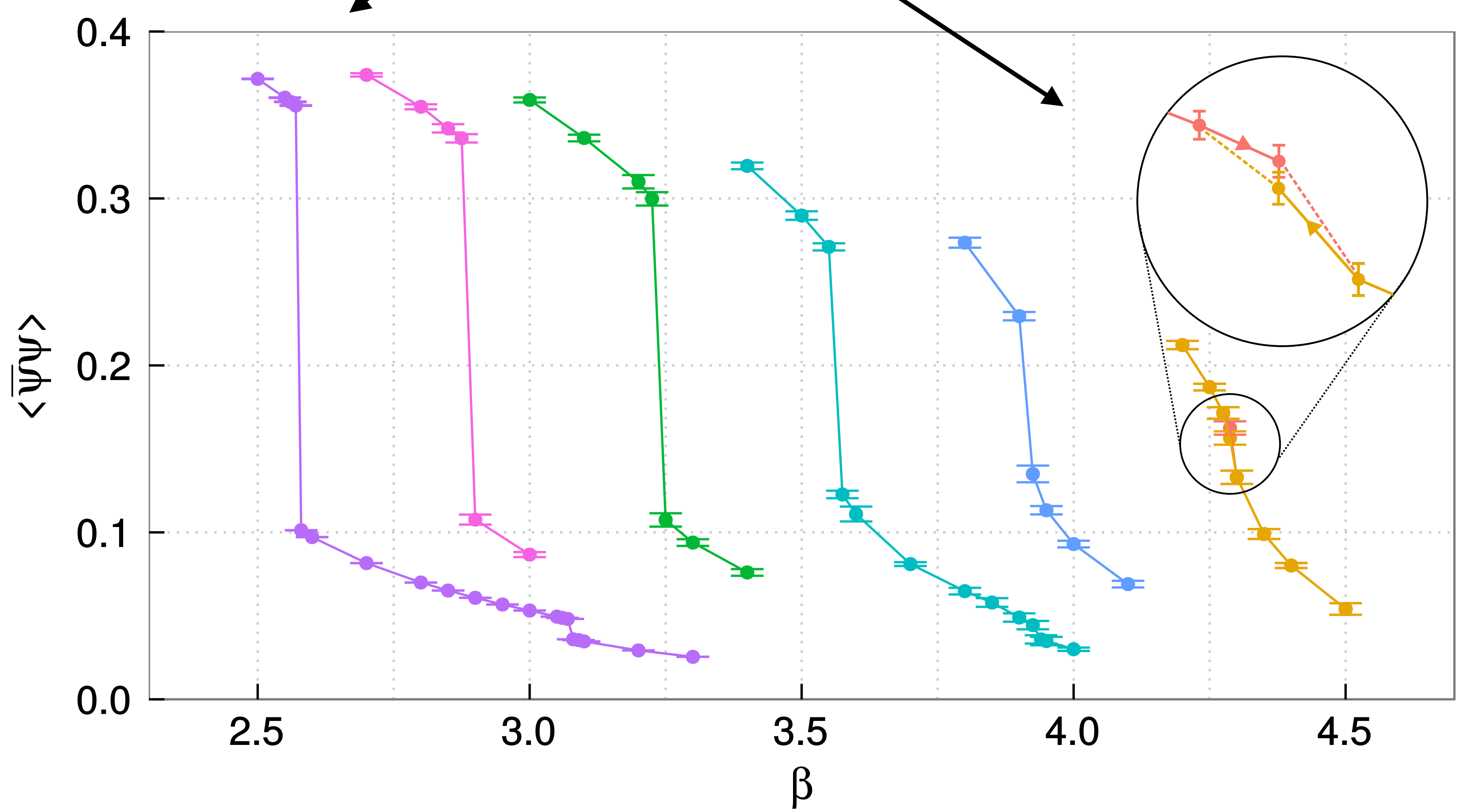
Line of bulk (T=0) chiral symmetry breaking phase transitions for $N_f \searrow N_f^c$

[arXiv:1506.06396]



The N_f dependence of the line is a leading order effect <u>separating phases with different symmetries</u>: larger N_f implies enhanced screening

Sequence N_f = 12,…,7 : am=0.01 V=16c32, 12c24



NB: Exotic phase does not touch chiral symmetry (edge displayed for N_f =12, 9)
Expected to merge with bulk line at the endpoint in the massless limit.

Interpretation

Results consistent with a lower edge below $N_f = 8$ and close to $N_f = 7$

- Not far from two-loop perturbation theory $N_f^c \gtrsim 8$
- In better agreement with four-loop perturbation theory $7 < N_f^c < 8$
- Remarkably, in agreement with large-N QCD in the Veneziano limit

Lower edge at $N_f/N = 5/2$ [Bochicchio 2013 arXiv:1312:1350]

where quantum instability of glueball kinetic term sets in

NB agreement between an observable sensitive to confinement and an observable sensitive to chiral symmetry breaking

Scalar glueball operator anomalous dimension

Trace anomaly of QCD

$$T^\mu_\mu = \frac{\beta(\alpha)}{16\pi\alpha^2}\,\mathrm{Tr}(G^2) + \text{fermion mass contribution}$$

$$\beta(\alpha) \equiv \frac{d\alpha(\mu)}{d\ln\mu} \qquad \alpha \equiv \frac{g^2}{4\pi}$$

Scaling of a quantum operator

$$\frac{dO}{d\ln\mu} = d_O O \qquad O(\mu) \sim \mu^{d_O} \qquad\qquad d_O = d_c + \gamma_O$$

Non renormalization of T^μ_μ implies $d_{T^\mu_\mu} = 4 \text{ in } d = 4$

$$d_G = 4 - \beta'(\alpha) + \frac{2}{\alpha}\beta(\alpha) \qquad\qquad \boxed{\gamma_G = -\beta'(\alpha^*) \text{ IRFP}}$$

Perturbation Theory

	$n=2$		$n=3$		$n=4$	
N_f	$\alpha_{\mathrm{IR},n}$	$\beta'(\alpha_{\mathrm{IR},n})$	$\alpha_{\mathrm{IR},n}$	$\beta'(\alpha_{\mathrm{IR},n})$	$\alpha_{\mathrm{IR},n}$	$\beta'(\alpha_{\mathrm{IR},n})$
6	-	-	12.992	84.646	-	-
7	-	-	2.453	5.956	-	-
8	-	-	1.464	2.654	1.552	1.784
9	5.237	4.169	1.027	1.472	1.070	1.460
10	2.21	1.522	0.764	0.869	0.815	0.851
11	1.23	0.706	0.578	0.513	0.626	0.496
12	0.754	0.360	0.435	0.296	0.470	0.281

Two loops: $\alpha_{\mathrm{IR},2} = -b_1/b_2$ $\beta'(\alpha_{\mathrm{IR},2}) = -b_1^2/b_2$

Endpoint zero* is where b_2 changes sign, i.e., $\alpha_{\mathrm{IR},2} \to \infty$

* Zero is necessary but not sufficient condition

Compare with large-N QCD beta-function in the Veneziano limit

[Bochicchio '13]

$$\boxed{\beta(g) = \frac{g^3\, c(g)}{1 - \frac{4}{(4\pi)^2} g^2} \quad \begin{matrix} \longrightarrow \text{zero} \\ \longrightarrow \text{pole} \end{matrix}}$$

c(g) contains an anomalous dimension term not present in SQCD

Condition for zero at endpoint is renormalisation scheme independent

What is the fate of the IRFP at the lower edge of the conformal window?
(RG point of view)

Plausible picture

SQCD	$N_c + 2 \leq N_f \leq 3N_c/2$ free magnetic phase	cusp in RG flow may occur
QCD	no such phase	no cusp (differentiable flow)

It also suggests that the two-loop singularity (b_2=0) is an artifact of n-loop truncated perturbation theory.

Fate of IRFP coupling

[Luescher Weisz 02
Luescher Weisz 04
Bochicchio 13]

Learn from (large-N) Yang-Mills:
A RG scheme should exist where the coupling saturates

$$V(r) = \sigma r - \frac{g^2_{phys}(1/r)}{4\pi r}$$

breaks conformal symmetry

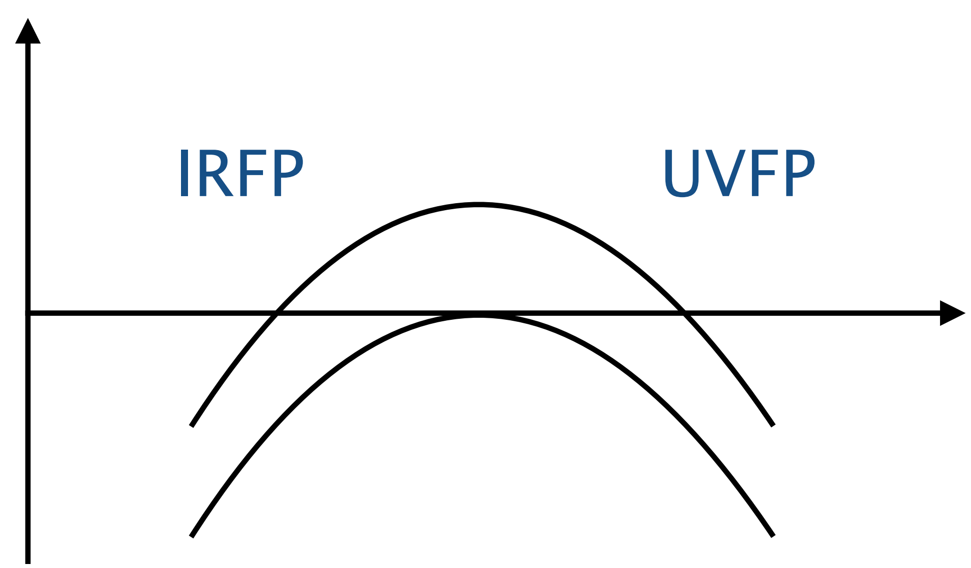
Zeros in a beta-function can occur also below the conformal window

Fate of the anomalous dimension for $N_f \searrow N_f^c$

- Perturbation theory predicts an increasing $|\gamma_G|$ $(|\beta'(\alpha_*|)$
- The large-N QCD beta-function in the Veneziano limit reproduces the two-loop result up to $O(1/N^2)$, but plausibly cures singularities.

UV-IR fixed point merging and γ_G

$$\beta(\alpha, N_f) = (N_f - N_f^c) - (\alpha - \alpha^c)^2$$



[Kaplan et al 2009]

$\beta'(\alpha^c) = 0$, a local maximum at N_f^c

Its magnitude decreases for $N_f \searrow N_f^c$

Conclusions I

- A numerical study of the chiral properties of QCD is consistent with the lower edge of the conformal window below Nf=8 and close to Nf=7
- This is in agreement with perturbation theory and, remarkably, with a recent large-N+Veneziano limit prediction based on the properties of glueball dynamics
- In the end the complete theory may just be close to perturbation theory and large-N.

Conclusions II

- Best observables to probe the lower edge:
  n-point functions sensitive to string tension (confinement)
  n-point functions sensitive to chiral symmetry
  topological quantities

- The scalar glueball anomalous dimension discriminates between different mechanisms for the loss of conformality