Novel phase in SU(3) lattice gauge theories with many light fermions

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arXiv:1111.2317**v2** and work in progress
with Anqi Cheng, Anna Hasenfratz and Greg Petropolous

Goals, methods and results

Goals

- Understand strongly-coupled systems beyond QCD
- Potential applications beyond the standard model

Methods

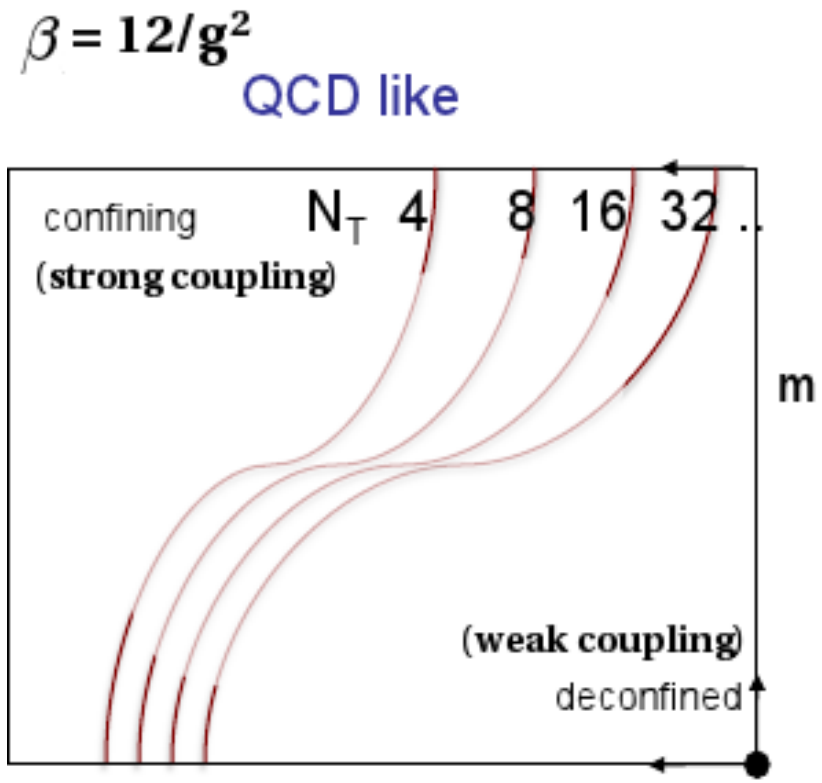
- Lattice gauge theory with highly-improved lattice action
- $N_f = 12$ staggered fermions in the fundamental rep.
- Explore phase transitions on relatively small (cheap!) volumes, **believed to** identify IR-conformal vs. confining systems

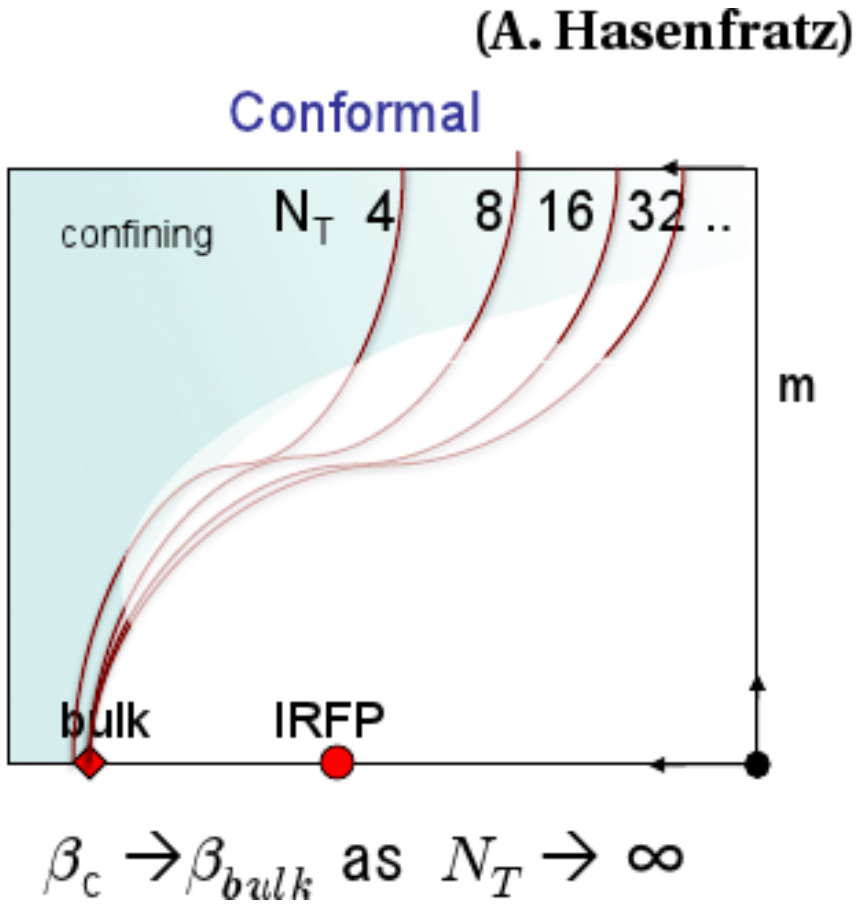
Results

- Novel phase: confining but chirally symmetric, single-site shift symmetry spontaneously broken ("$\not{S}^4$")
- Most likely pure lattice phase $\Longrightarrow$ **doesn't identify conformality**

Qualitative expectations for the lattice phase diagram

(gauge coupling–fermion mass)

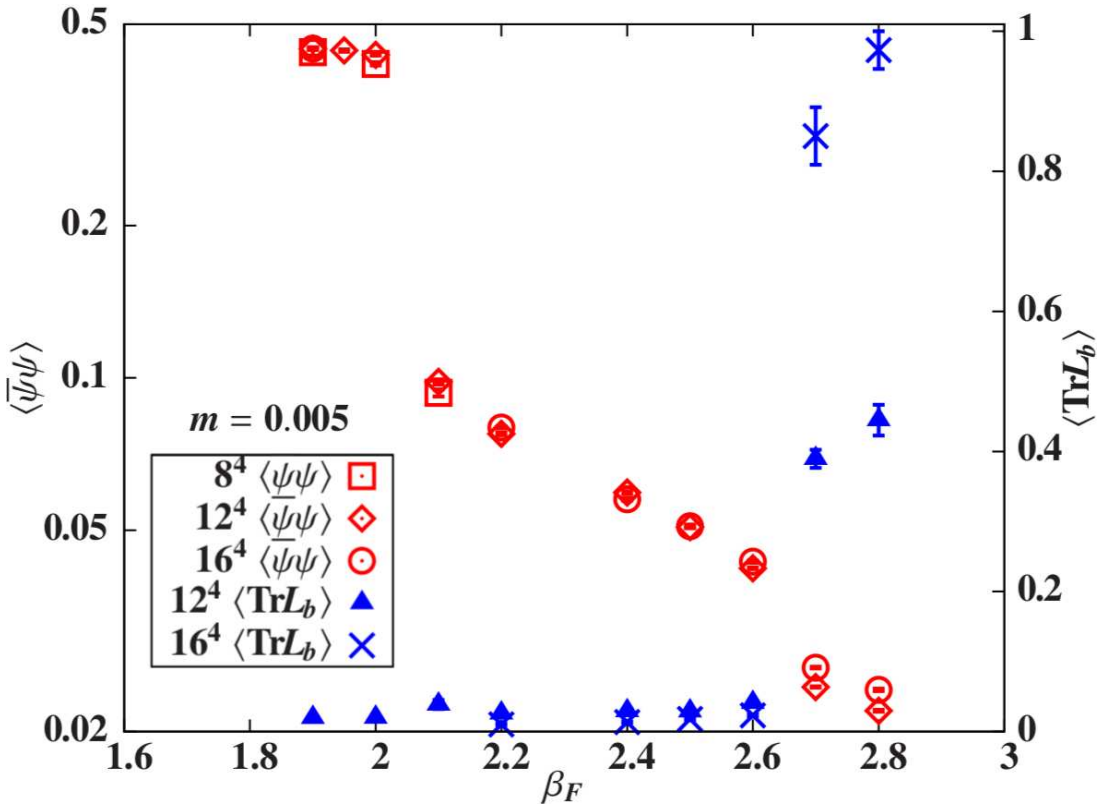




- Hope for clear distinction between QCD-like and conformal cases
- Cheaper than other methods: smaller volumes, lower statistics

We observe **two** first-order bulk transitions

- Chiral condensate $\langle\overline{\psi}\psi\rangle$ (red) related to chiral symmetry
- Blocked Polyakov loop $\langle \mathrm{Tr} L_b\rangle$ (blue) related to confinement

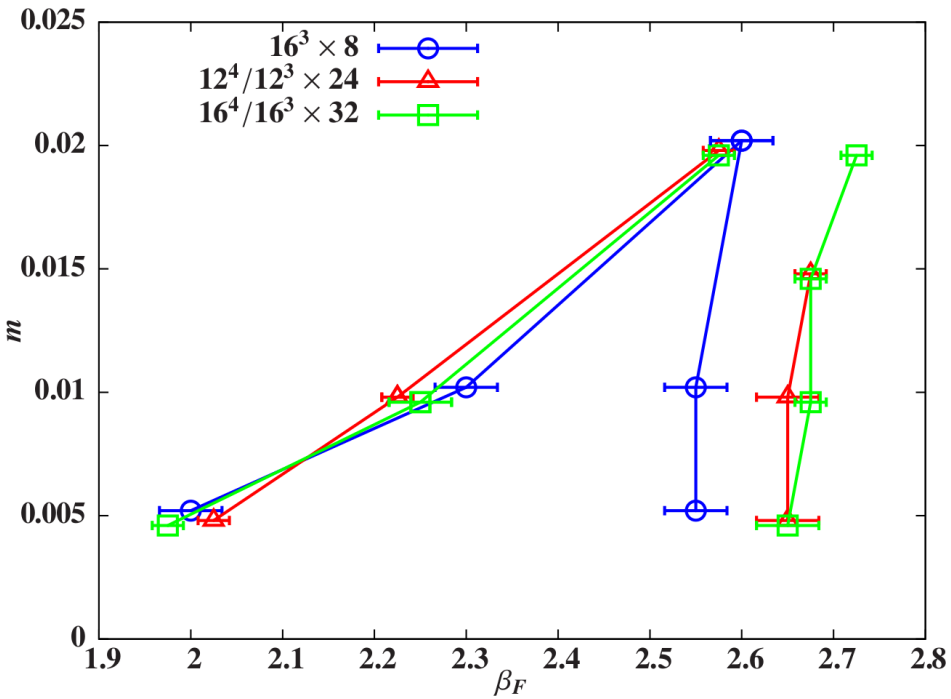


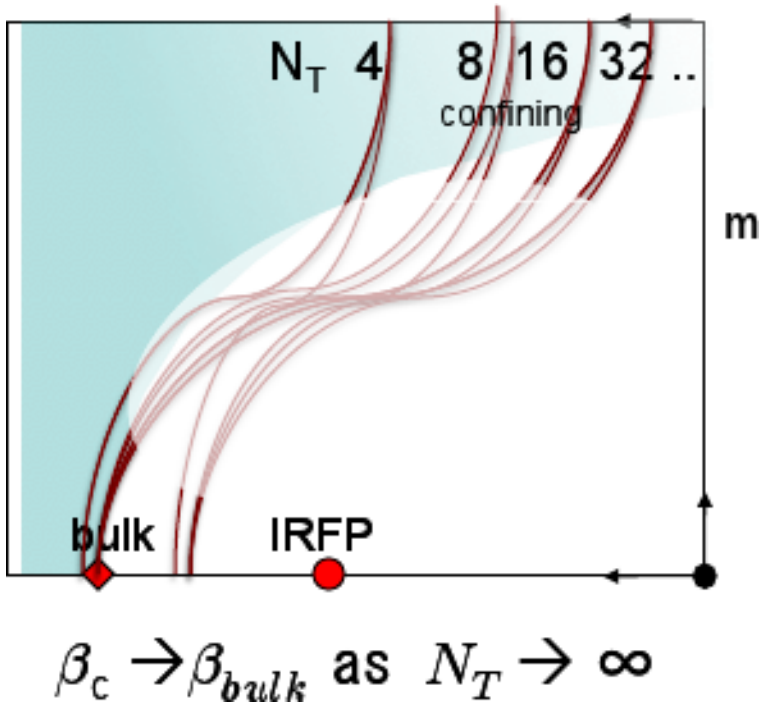
Two jumps in $\langle\overline{\psi}\psi\rangle$ observed by two other groups with different actions

$\Longrightarrow$ robust feature of staggered fermions

Twelve-flavor phase diagram (gauge coupling–fermion mass)

Finite-temperature transitions converge to two bulk transitions which merge as the fermion mass increases





Bulk transition $\Longrightarrow$ IR conformality in the continuum?

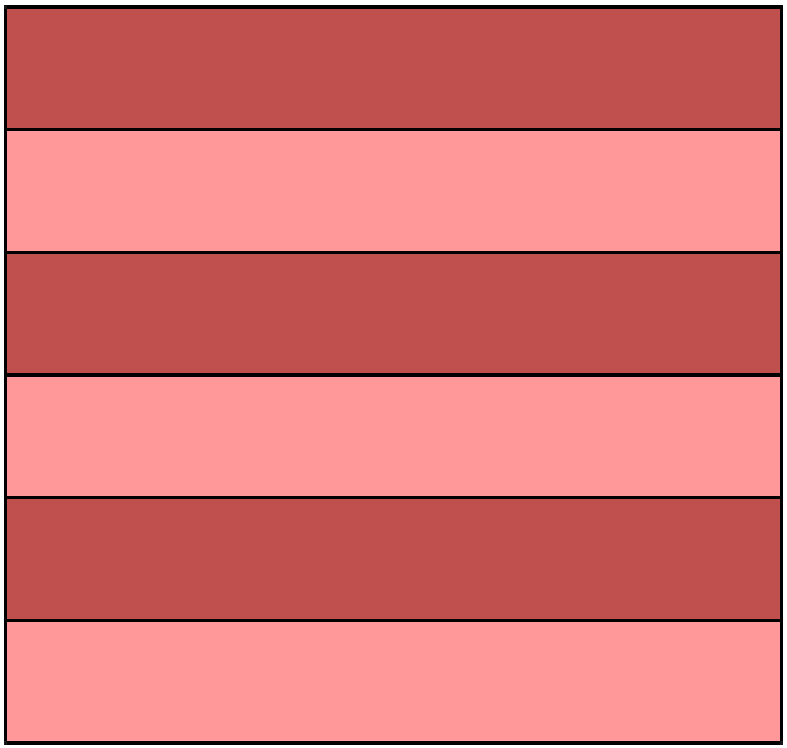
If the intermediate phase has no continuum limit, **this does not follow**

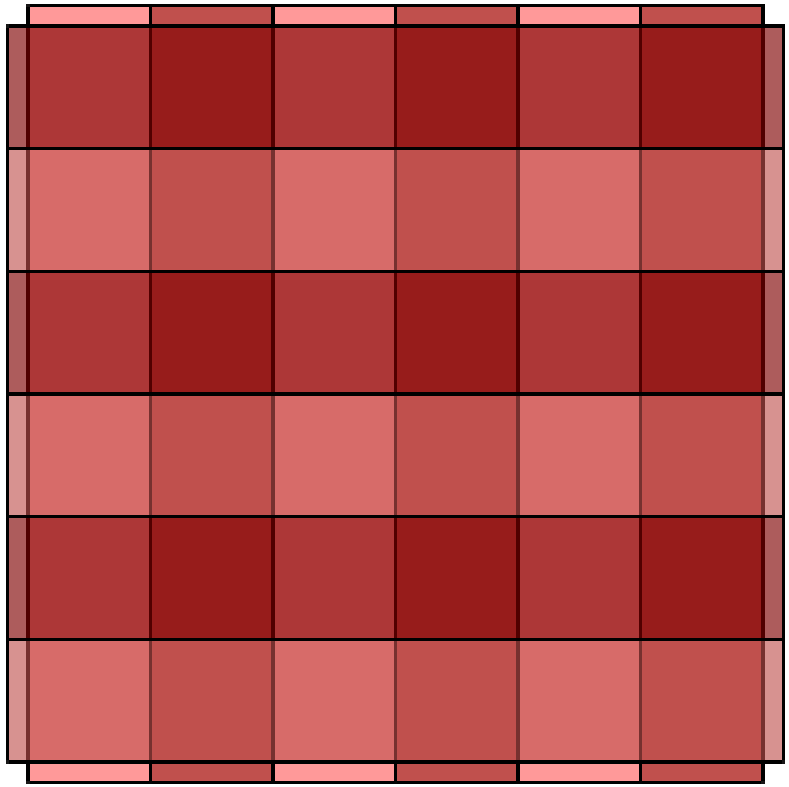
Rest of the talk: what is this novel phase?

The phase breaks single-site shift symmetry ($\not{S}^4$)

Staggered lattice actions possess exact single-site shift symmetry which is spontaneously broken in the intermediate phase

Observables alternate between slices in one or more directions





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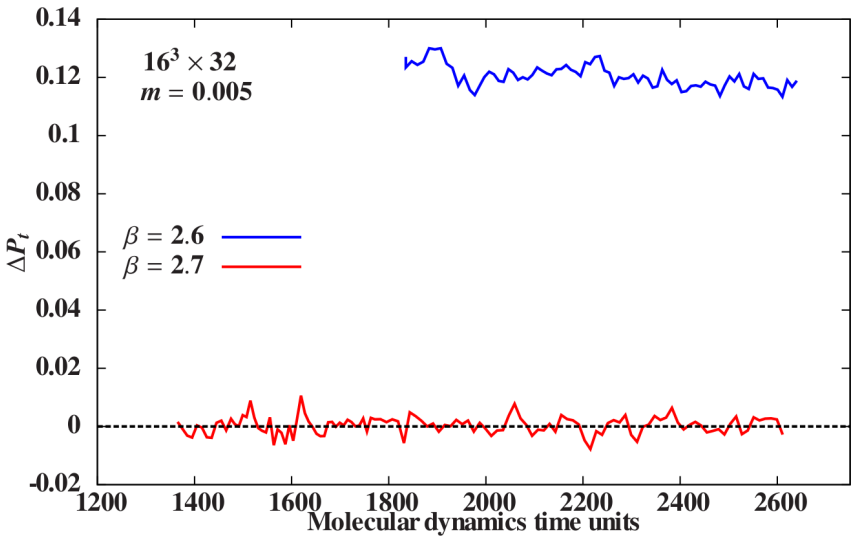
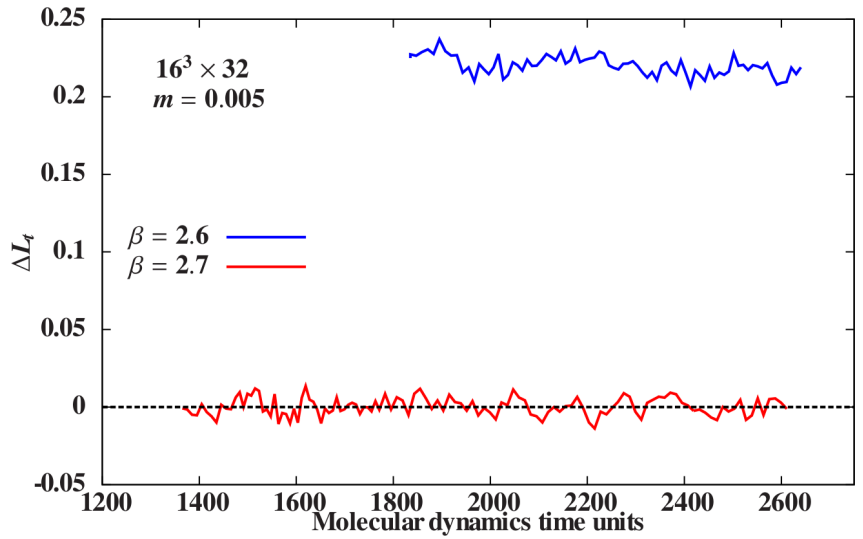
Order parameters (any or all μ)

$$\Delta P_\mu = \langle \mathrm{ReTr}\,\Box_n - \mathrm{ReTr}\,\Box_{n+\mu} \rangle_{n_\mu \mathrm{even}}$$

$$\Delta L_\mu = \left\langle \alpha_{\mu,n} \overline{\chi}_n U_{\mu,n} \chi_{n+\mu} - \alpha_{\mu,n+\mu} \overline{\chi}_{n+\mu} U_{\mu,n+\mu} \chi_{n+2\mu} \right\rangle_{n_\mu \mathrm{even}}$$





$\not{S}^4$ has never been seen before, but is clear in our data

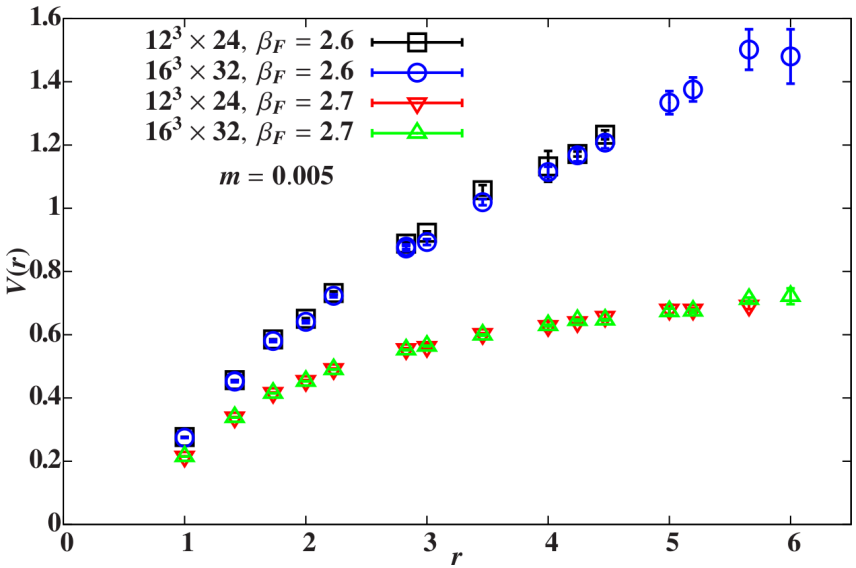
The $\not{S}^4$ phase is confining but chirally symmetric

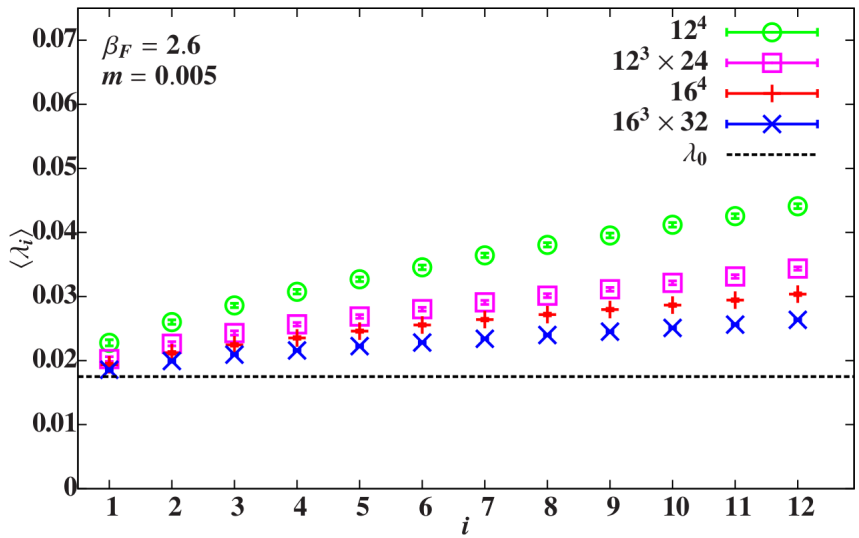
Confinement:

- (Blocked) Polyakov loop is small
- Potential has clear linear term, small Sommer parameter $r_0 \approx 3$

Chiral symmetry:

- Meson spectrum is parity-doubled and volume-independent
- Dirac eigenvalue distribution has "soft edge" $\lambda_0 = 0.0175(5)$





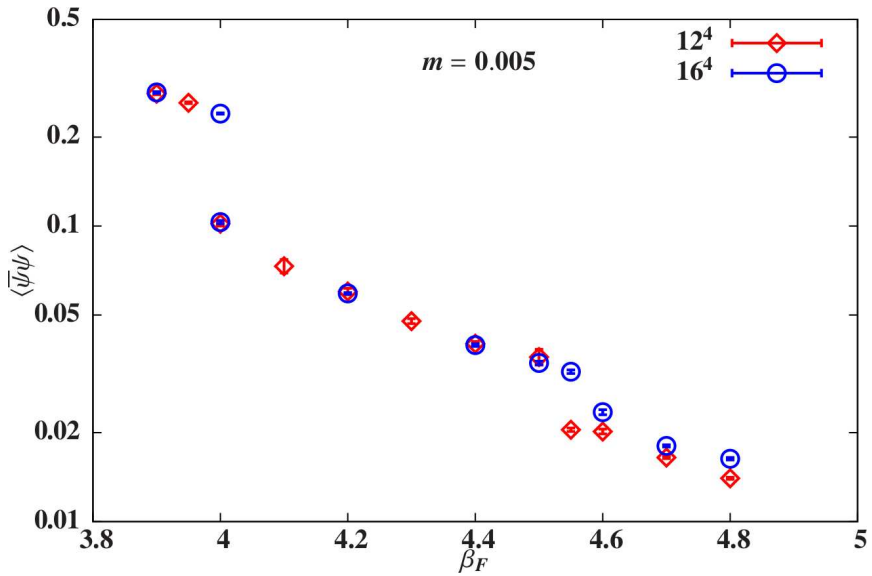
$\not{S}^4$ phase seems to have no continuum limit

- Confining but chirally symmetric phases are forbidden by the continuum 't Hooft anomaly matching condition
- The $\not{S}^4$ phase is bounded by first-order phase transitions

Could this be a staggered Aoki-like phase? (work in progress)

$\not{S}^4$ phase does not imply conformality

Also appears for $N_f = 8$, believed to be confining and chirally broken



(work in progress)

Recapitulation

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Thank you!

Thank you!

Collaborators

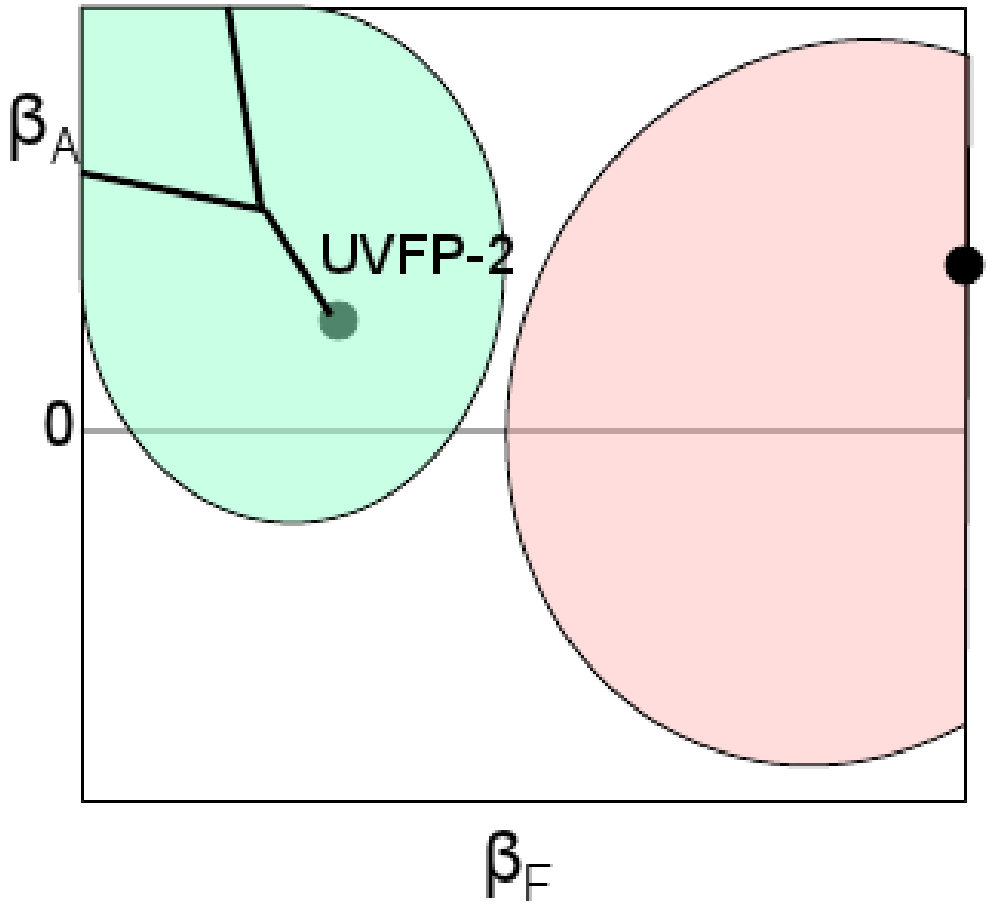
Anqi Cheng, Anna Hasenfratz, Greg Petropolous

Funding and computing resources

USQCD

Backup: spurious UV fixed point from lattice artifacts

We add a negative adjoint plaquette term to the gauge action
to avoid a well-known spurious UV fixed point



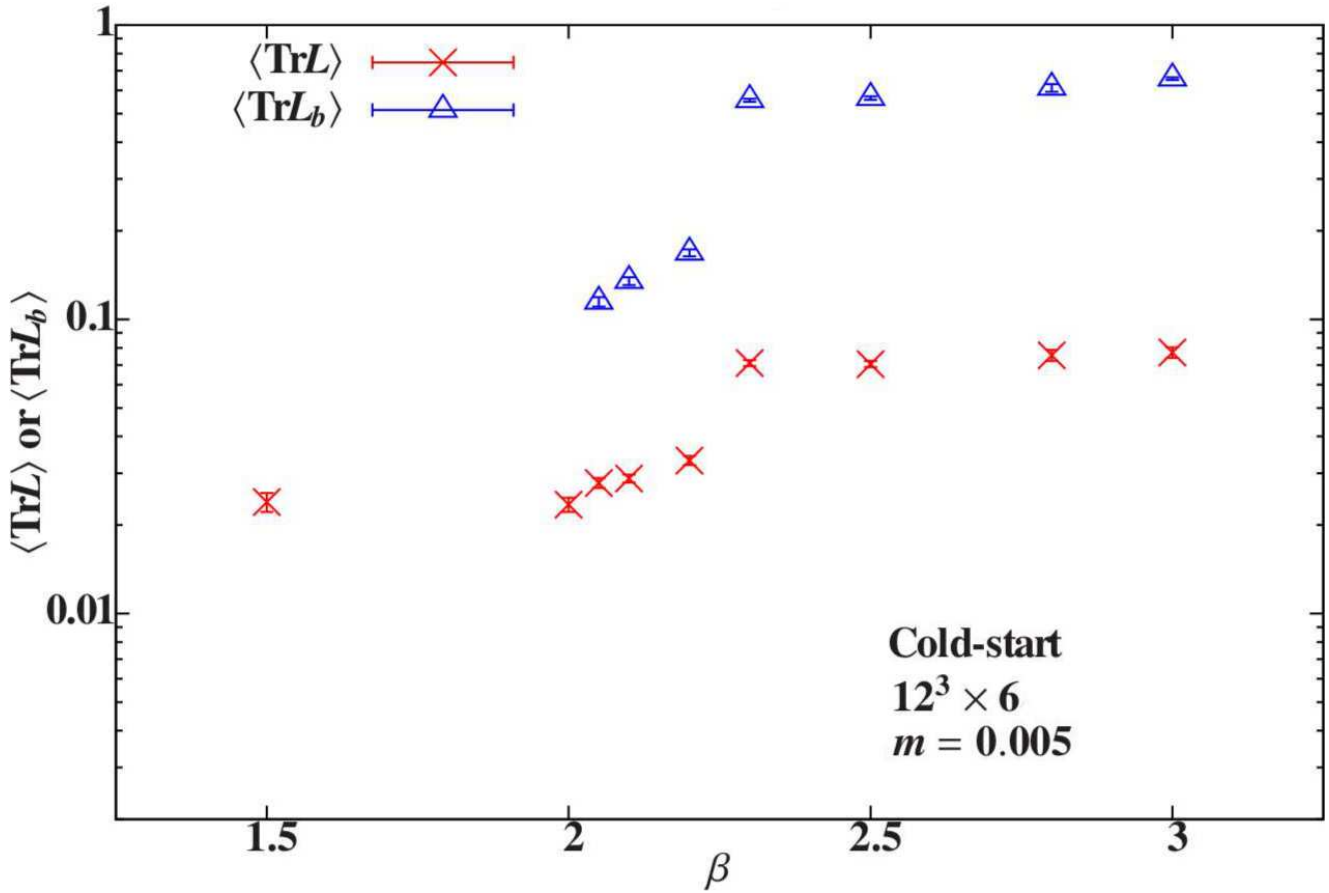
(A. Hasenfratz)

Gaussian
FP

Between the basins of attraction
is a no-man's land

Backup: Blocked and unblocked Polyakov loops

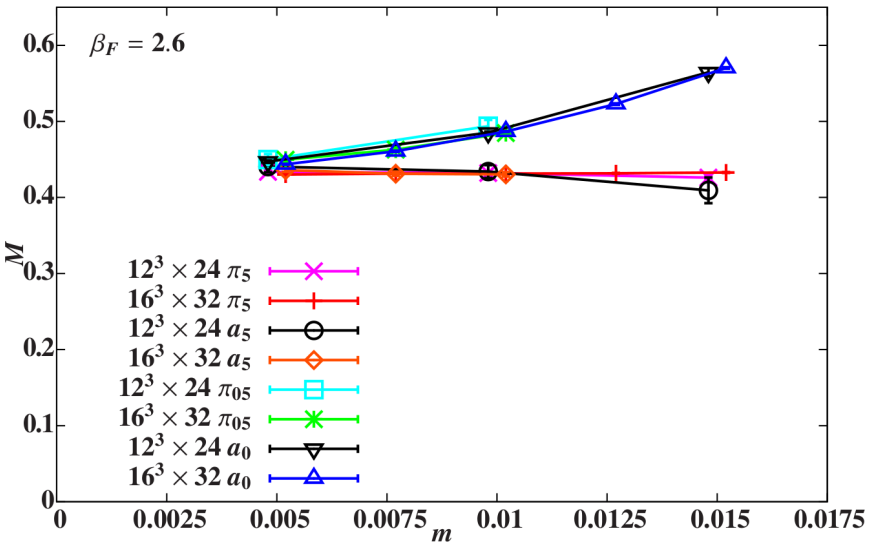
Blocked and unblocked Polyakov loops show the same discontinuity
Blocking simply amplifies the signal, making it easier to see



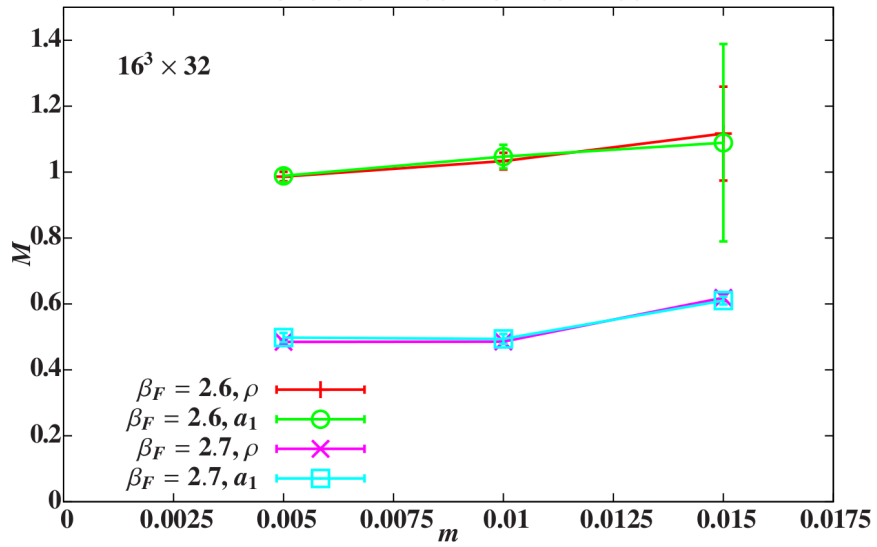
Backup: parity doubling in the $\not{S}^4$ meson spectrum

In the $\not{S}^4$ phase,
meson spectrum is parity-doubled and volume-independent
Goldstone pion possesses a scalar parity partner "a_5"
(forbidden in QCD-like systems!)

Scalars and pseudoscalars



Vector and axial

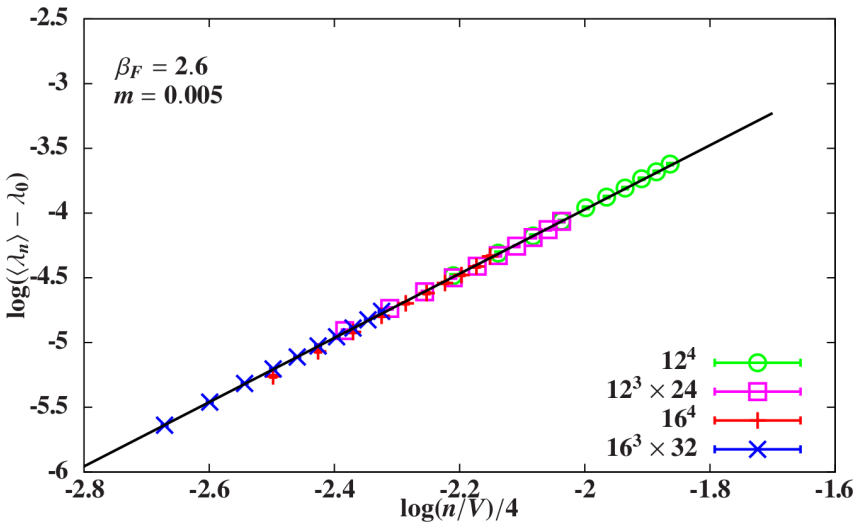


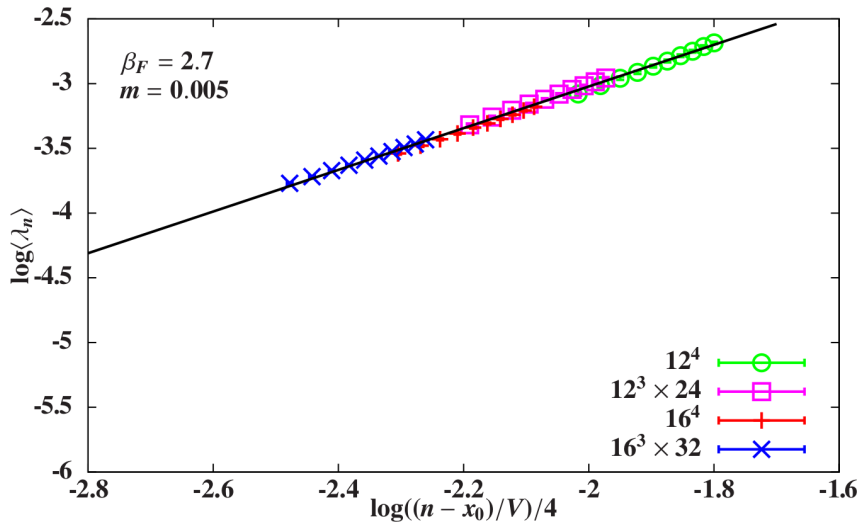
Backup: Volume scaling of Dirac eigenvalues

Scaling of Dirac eigenvalues predicts mass anomalous dimension γ_m

$$\rho(\lambda) \propto (\lambda - \lambda_0)^{\alpha} \qquad \Longrightarrow \qquad \lambda_n - \lambda_0 \propto \left(\frac{n - x_0}{V}\right)^{\frac{1}{1+\alpha}} \left[1 + \mathcal{O}\left(V^{-1}\right)\right]$$

$$y_m = 1 + \gamma_m = \frac{D}{1+\alpha}$$





In weak-coupling phase (right), $\gamma_m = 0.61(5)$