Lattice supersymmetry with exascale computing

Simon Catterall

Syracuse University

Motivation

- SUSY plays a key role in many theories of BSM physics
  - Understanding soft SUSY breaking in MSSM in terms of strongly coupled high scale SQCD
  - Extra dims models
  - SUSY technicolor
  - AdSCFT duals, strings
- Many aspects are inherently non-perturbative eg dynamical SUSY breaking, gaugino condensation – lattice natural tool.

Problems, solutions

- SUSY broken. Large amount fine tuning in general.
- But, some cases evaded/reduced:
  - 4D $\mathcal{N}=1$ SYM: chiral symmetry prohibits gaugino mass. Hence DWF/overlap good approach.
  - 4D $\mathcal{N}=4$ SYM: supersymmetric lattice action. (new ideas twisting, orbifolding, Kähler-Dirac fermions). Also, fine tuning using DWF action may be feasible ...
  - Deformations of these eg super QCD, Strassler mass deformation of $\mathcal{N}=4$, AdSCFT duals ...

Why DWF good for $\mathcal{N} = 1$

- Good chiral properties - no fine tuning $a \to 0$
- Positive definite Pfaffian cf Wilson
- No doublers

But more expensive ..

$\mathcal{N} = 1$ SYM using DWF

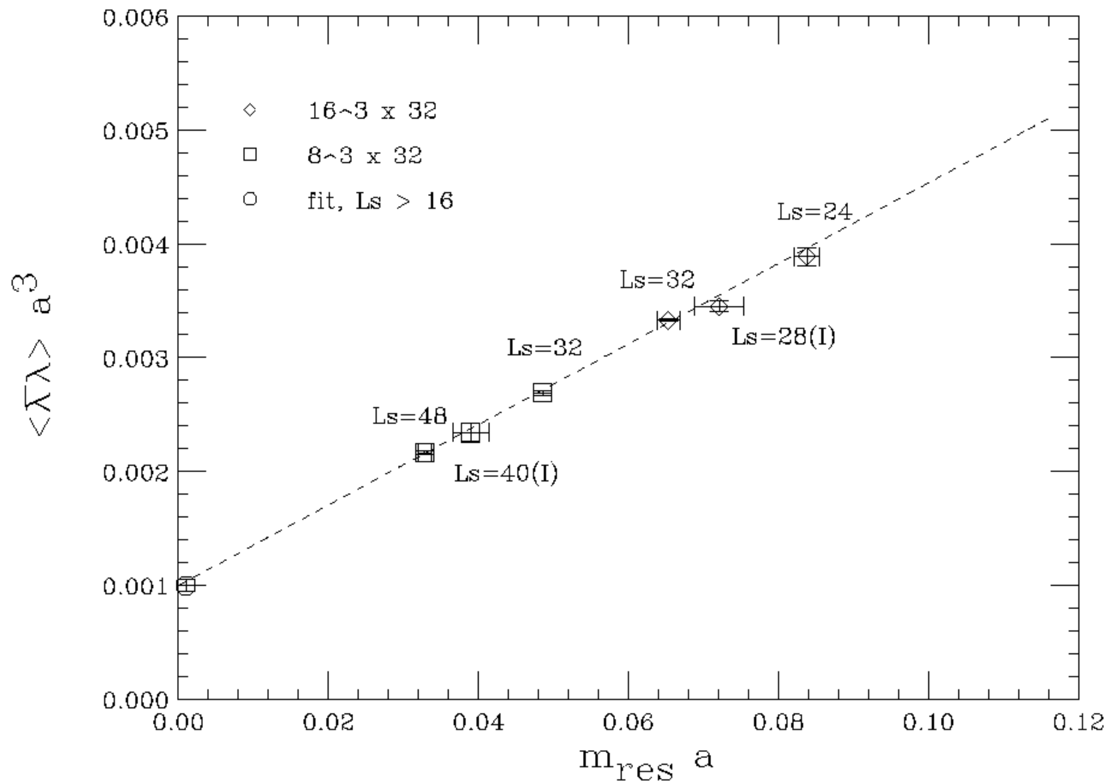
- Fleming, Kogut, Vranas in 2000: $8^4 \times L_s$ lattices, $\beta = 2.3$, $L_s = 12 - 24$
- In 2008 S.C,Brower,Fleming,Giedt,Vranas arXiv:0807.2032, arXiv:0810.5746 ($16^3 \times 32 \times L_s$ with $L_s = 16 - 64$, $\beta = 2.3, 2.4$), (1Tflopyear)
- Also M. Endres arXiv:0810.0431, ($8^4/16^3 \times 32$ $L_s = 16 - 28$ $\beta = 2.3, 2.35, 2.4$)
- Both groups use hacked CPS code for SU(2). Run on BG/L (RPI or Brookhaven).

Results so far

Broad agreement between 2 groups. Show:

- Confining as expected - static potential, string tension.
- Finite volume effects under control.
- Estimate cut-off effects now.
- Much better extrapolations to chiral limit - measure residual mass
- Strong evidence for nonzero $< \bar{\lambda}\lambda >$ as $a \rightarrow 0$.

Condensate



$\beta = 2.4$

To do

- Large $m_{\rm res} = \frac{\rho(0)}{L_s} + \ldots$ – Need larger L_s Or better DWFs (möbius ?,..)
- Non-perturbative renormalization to give physical condensate.
- Spectrum ? Interpolating operators known. But 1 Majorana fermion – disconnected diagrams. Hard.
- $32^3 \times 64$ with $L_s = 64 - 128$ at 3 β's would need approx 100-1000 Tflopyear.
- Calculation of spectrum hard – like η' in QCD. Compare with conjectured low energy effective actions

Super QCD - I

- MSSM weakly coupled. But soft SUSY breaking ops typically generated by strongly coupled SQCD like sector at high scales.
- Ingredients: add chiral multiplets (scalar+fermion in fundamental)
- DWF eliminates need to tune fermion masses (Giedt et al. arXiv:0806.0013)
- Fine tuning Yukawas - swap for scalar kinetic terms. Flavor symmetries imply single m_ϕ^2
- Quartic ops still an issue - $n = (2 - \mathrm{few})$ such ops. depending on N_f, N_c.

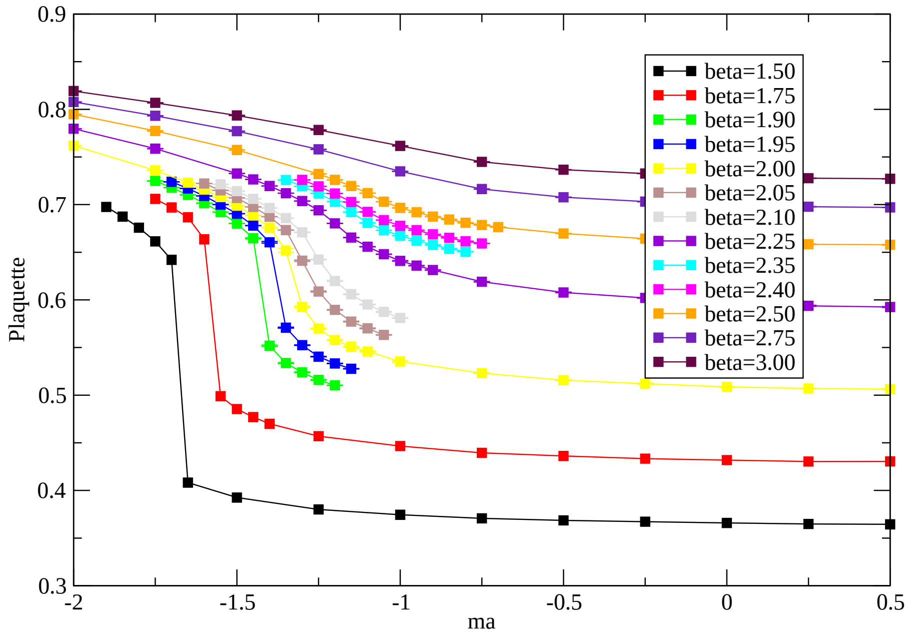
Super QCD - II

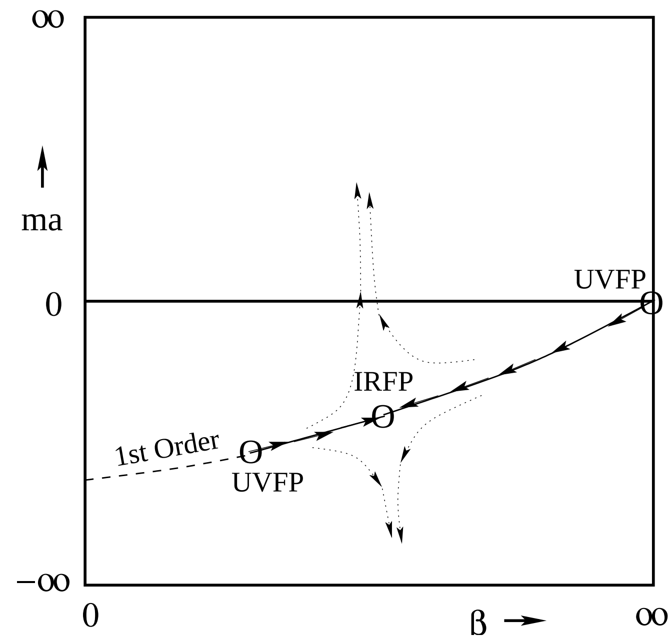
- Find SUSY pt by requiring $< \partial_\mu S_\mu(x) \Theta^i(0) >= 0$ for set of set ops Θ^i with $i \geq n$ number of ops.
- If we want to use multicanonical reweighting techniques need say 10 simulation pts for each fine tuned coupling.
- Implies need $10^{2-\mathrm{few}}$ more CPU than current $\mathcal{N} = 1$ DWF simulations. Hence 10000-100000 Tflopyear if $n = 4$ i.e Exascale !
- Note: can adapt to give approach to $\mathcal{N} = 4$ SYM independent of supersymmetric lattice formulations.

Another use of adjoints

- SU(2) with 2 flavors of adjoint fermion – candidate for walking technicolor model.
- Wilson simulations indicate intriguing phase diagram
- Simulations used 4 months of 1 rack of BG/L at 100Gflops i.e 0.1 Tflopyear calc.
- Next generation ? 32^4 Wilson needs >100 Tflopyear. Survey other gauge groups eg $SU(3)$, other reps eg symmetric/antisymmetric - see Fleming/Kuti talks ...
- Move to overlap/DWF simulations – perhaps 1000 Tflopyear

Phase diagram SU(2)+2adj





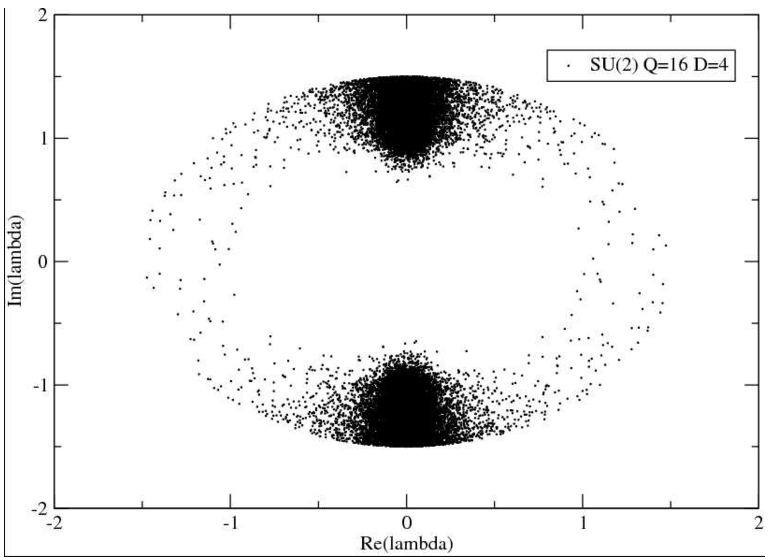
Consistent with conformal phase (confirmed by Edinburgh/Swansea and Helsinki groups (32^4 lattices))

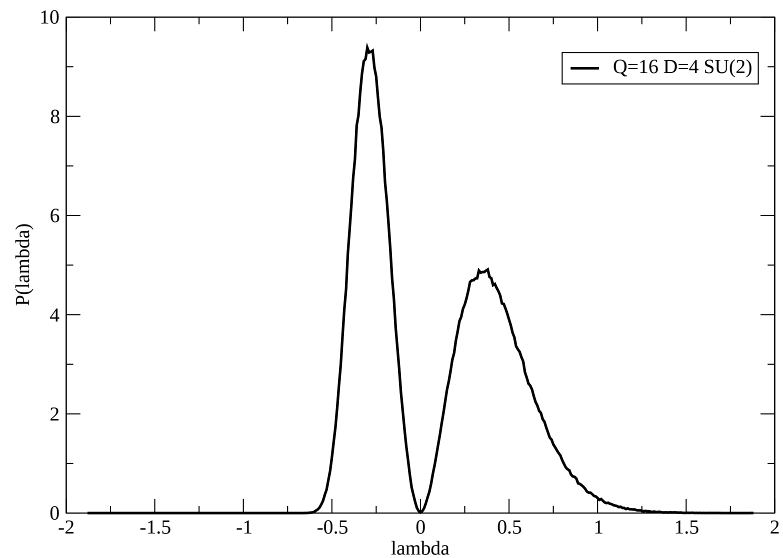
$\mathcal{N} = 4$ SYM using SUSY lattices

- Unique lattice formulation preserves $1/16$ supersymmetries (arXiv:0712.2532, arXiv:0503039)
- Fields distributed over links of A_4^* lattice. Nonstandard gauge transformation properties - dramatic reduction in counterterms ...
- Fermionic action – mapped to (reduced) staggered action.
- Complex Wilson links.
- RHMC alg. use absolute value of Pfaffian first sims: arXiv:0811.1203

$\mathcal{N} = 4$ SYM in four dimensions

Supersymmetry good to O(1)%:$S_B/S_B^{\text{exact}} = 0.98$
Pfaffian phase small $< \cos(\alpha) >= 0.98(1)$





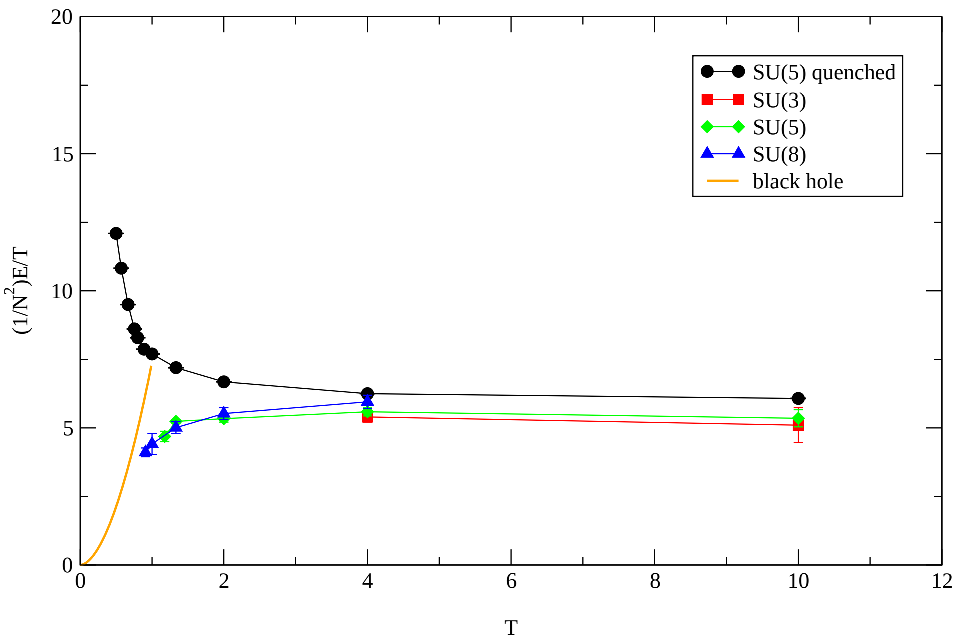
Prelim results and projections

- Exploratory simulations done $SU(2)$ on 3^4. (6^4 staggered) Single core: 50 s per trajectory.
- Estimate $t_{\rm CPU} \sim (V \times (N^2-1))^{1.5}$. Thus 16^4 for $N=3$ trajectory cost: 500 secs using 10^4 cores.
- MDP based code in development. Better options ?
- Thus, for 10^4 configs requires 10-100Tflopyear calc.

Gravity duals

- Large number of examples of conjectured dualities between (supersymmetric) YM and gravity/string theories.
- YM always strongly coupled – lattice useful tool.
- Some may be relevant to phenomenology eg. mass deformations of $\mathcal{N} = 4$.
- Simplest example studied so far: SYMQM at large N and black hole solution in type IIa SUGRA. eg. S.C and Wiseman arXiv:0803.4273, Nishimura et al. arXiv:0810.2884, arXiv:0811.2081 (Schwarzschild radius)
- Large N and massless fermions requires significant resources perhaps 1-10Tflopyear per project

Blackholes from YM



Energy vs temperature for 1D YM system.

$3 \leq N \leq 12$. Lattice $5 \leq L \leq 20$

Black hole prediction shown (no fit)

Summary

- Current $\mathcal{N} = 1$ SYM simulations require approx 10 Tflopyear for condensate. Significantly more for spectrum (disconnected graphs) 100-1000 Tflopyear
- Super QCD requires fine tuning of $n = 2 + \text{few}$ scalar ops. With multicanonical reweighting bosonic ops. need 1000-10000 Tflopyear
- $\mathcal{N} = 4$ simulations possible. Two approaches:
  - Treat like super QCD – fine tuning/reweighting. Similar estimates 1000-10000 Tflopyear
  - Use actions with exact SUSY. No/less fine tuning but possible sign problem, exotic lattices, massless fermions, ... Parallel simulations beginning.
  - Lots of applications to AdSCFT-like duals