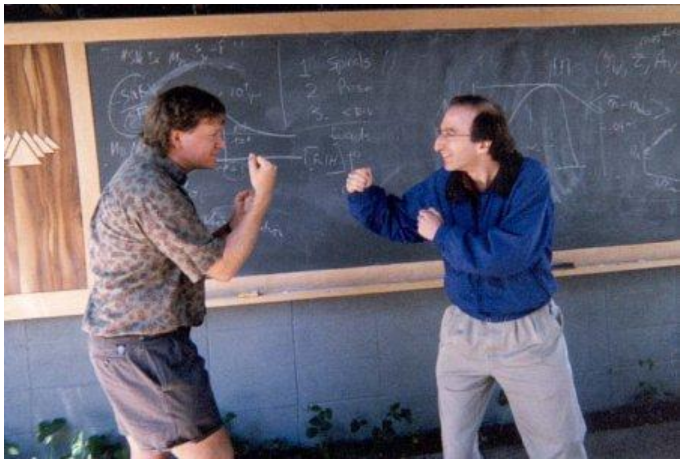
A Less Prickly Cactus

LASSP Theory Pizza Talks, July 19th, 2012

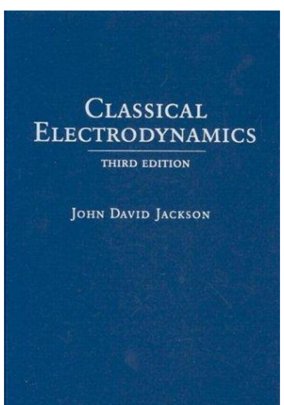
Zach(tus) Lamberty

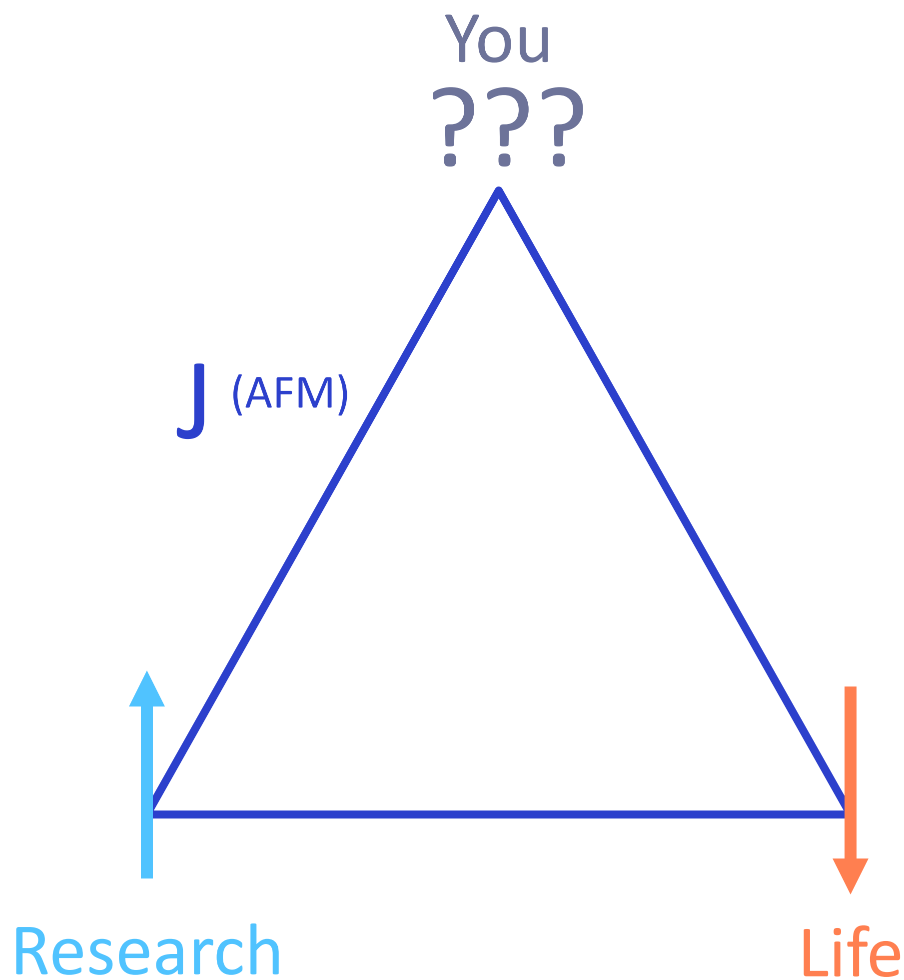
So Frustrating…

- What is frustration?



Brian Schmidt v. Saul Perlmutter, picture by Nicholas Suntzeff

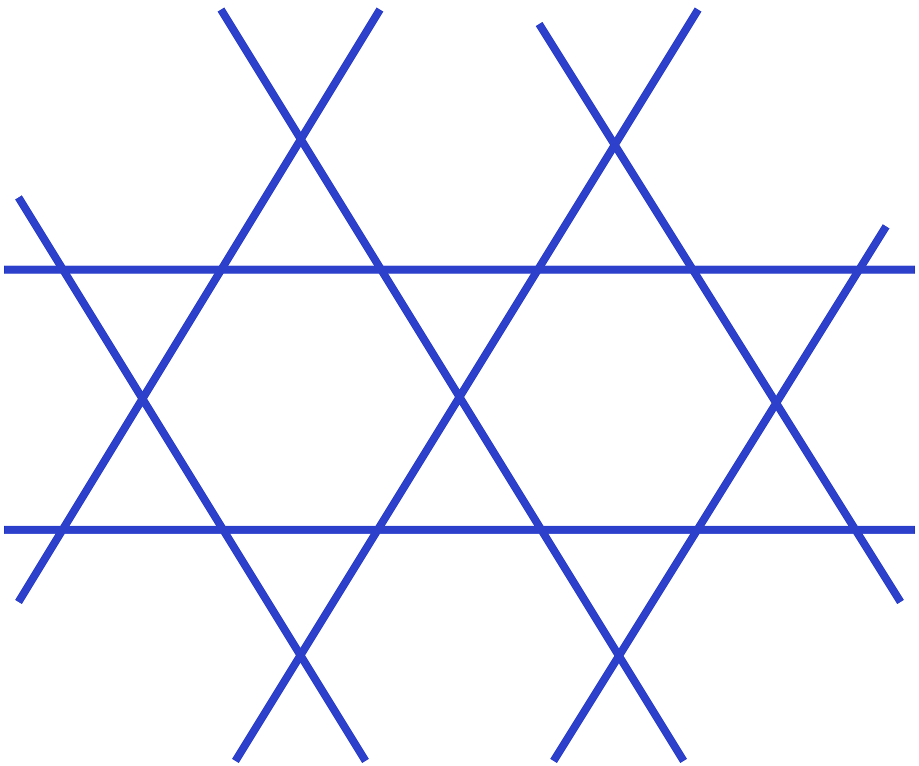




So Frustrating…

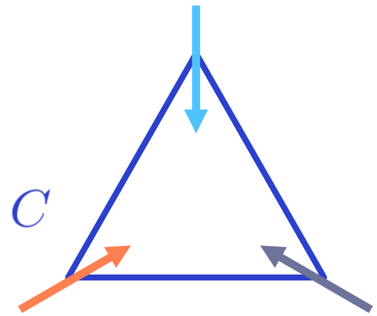
- Why study it?
  - Lots of lattices
  - Weird stuff
    - *Macroscopic* ground state degeneracies
    - "Accidental" symmetries
    - Quantum Spin Liquid state (avoids magnetic ordering down to T = 0)
    - Fractional / anyonic excitations
    - Ground states robust to local perturbation ("Topological" states)
    - Order by disorder effects
  - Some real materials: S = 3/2 and 5/2 Jarosites, S = 1/2 Herbertsmithite, S = 3/2 BSZCGO

Kagome!



- Classical Heisenberg AFM ordered

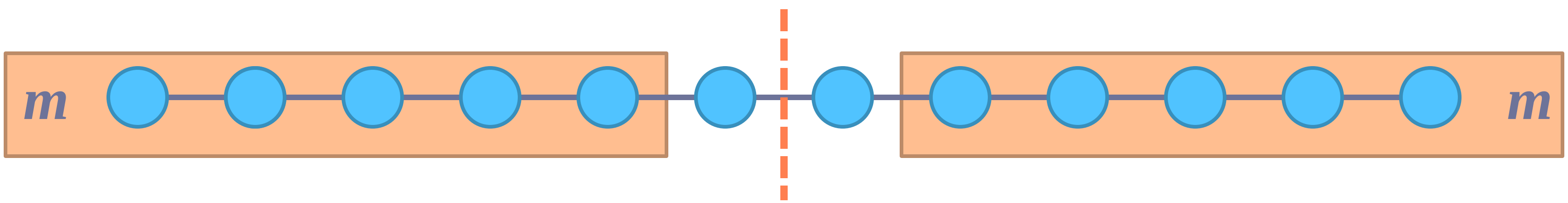
$$H = J\sum_{\langle i,j\rangle} S_i \cdot S_j$$
$$= \frac{J}{2}\sum_{\Delta}\sum_{i\in\Delta} S_i + C$$



- Quantum S = 1/2
  - No LRO in spin-spin correlation
  - Rapid decay in higher-order correlations
  - Very small or no spin gap
  - Gapless singlet sector
- Quantum S = 1
  - Large spin gap
- Quantum S = 3/2
  - Very small or no spin gap
- Not a lot of intuition for any "medium" S, especially S > 1/2!

Kagome!

- Want large lattice sizes and S > 1/2
  - ED exponentially difficult (State of the art: 48 sites)
  - No good way to choose variational wave function for QMC (which also has the sign problem)
  - Density Matrix Renormalization Group methods…

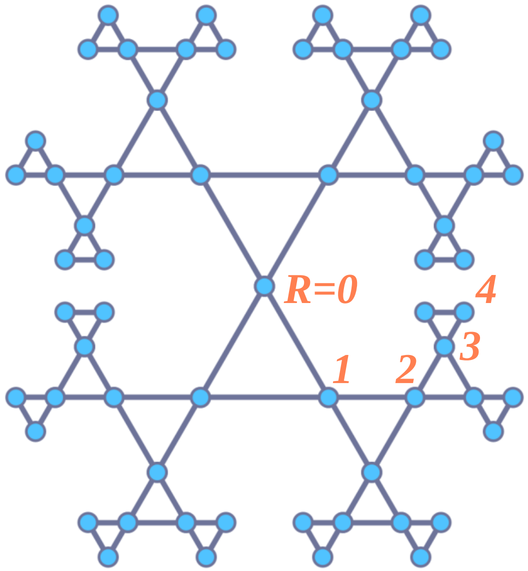


  …abhor loops!

  - DMRG State of the Art: 726-site cylinder, 108-site taurus

Husimi is dreamy

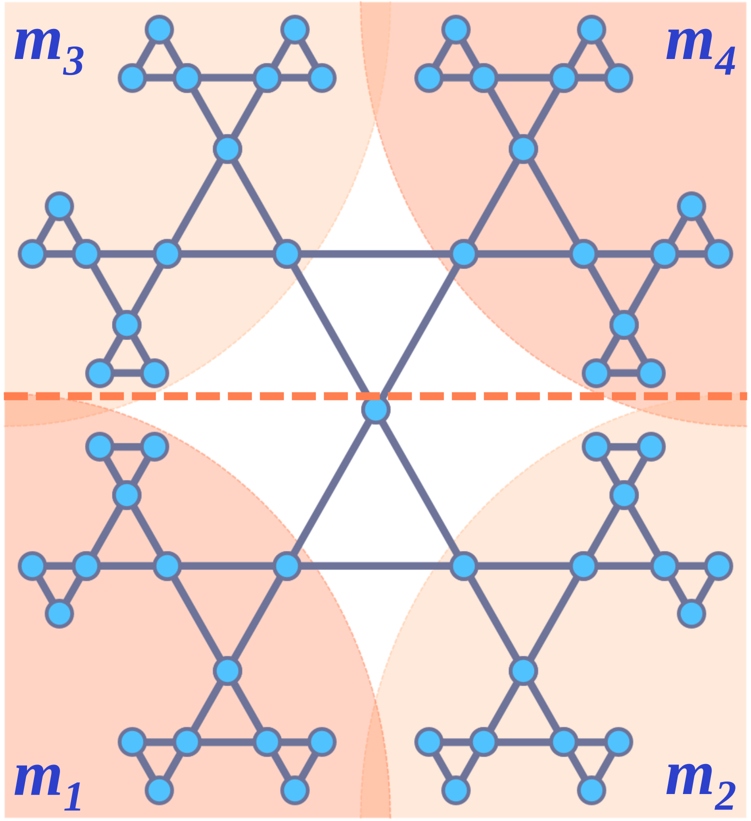
- The Husimi Cactus is locally the same, but loopless!



- Should capture "local" physics
  - Coplanar order, spin disorder, VBS states
- Will miss "loop" physics
  - Coloring selection, spin-loop tunneling, spin liquid flux patterns

Husimi is dreamy

- $O(m^4)$ infinite DMRG algorithm:



- Largest simulations: 210000 sites, 20 – 30 kept states

“Large” spin results

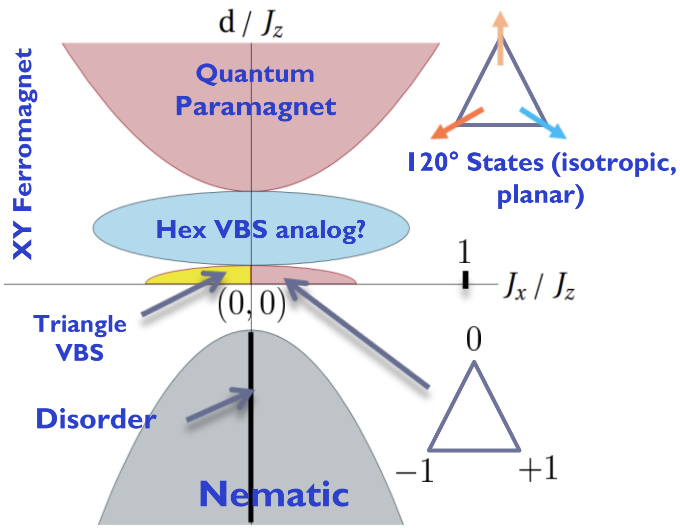
- Slow down, enjoy the view

$$H = \sum_{\langle i,j \rangle} \left(\frac{J_x}{2} \left(S_i^+ S_j^- + S_i^- S_j^+ \right) + J_z S_i^z S_j^z \right) + d \sum_i \left(S_z^i \right)^2$$

Heisenberg Anisotropy

On-site easy axis anisotropy

- Proposed phase diagram (based on Kagome)



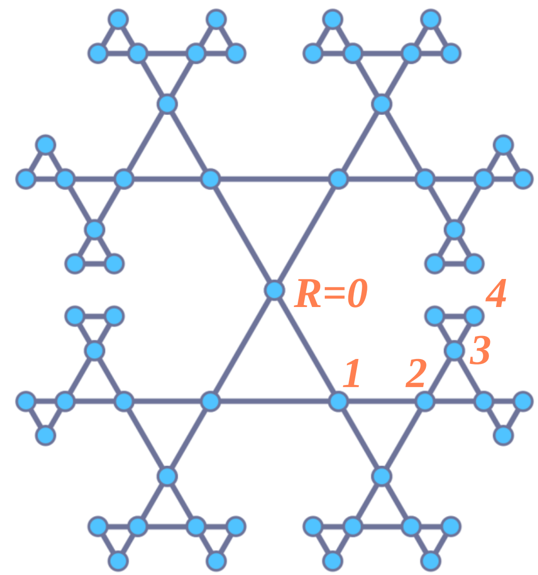
“Large” spin results

- Our primary diagnostic tools are spin-spin correlations

$$\langle S_i \cdot S_{i+R} \rangle$$

$$\langle S_i^z S_{i+R}^z \rangle$$

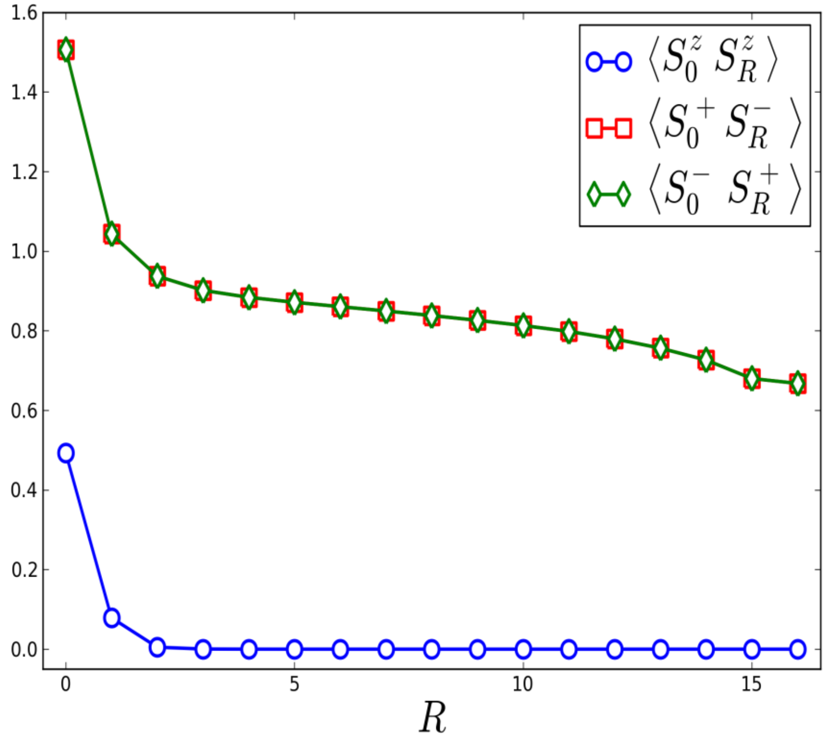
$$\langle S_i^{\pm} S_{i+R}^{\mp} \rangle$$



$$C(i, i+r) \propto \begin{cases} 1/R^0, & \text{ferromagnet} \\ \left(-\dfrac{1}{2}\right)^R, & \text{3-coloring} \end{cases}$$

"Large" spin results

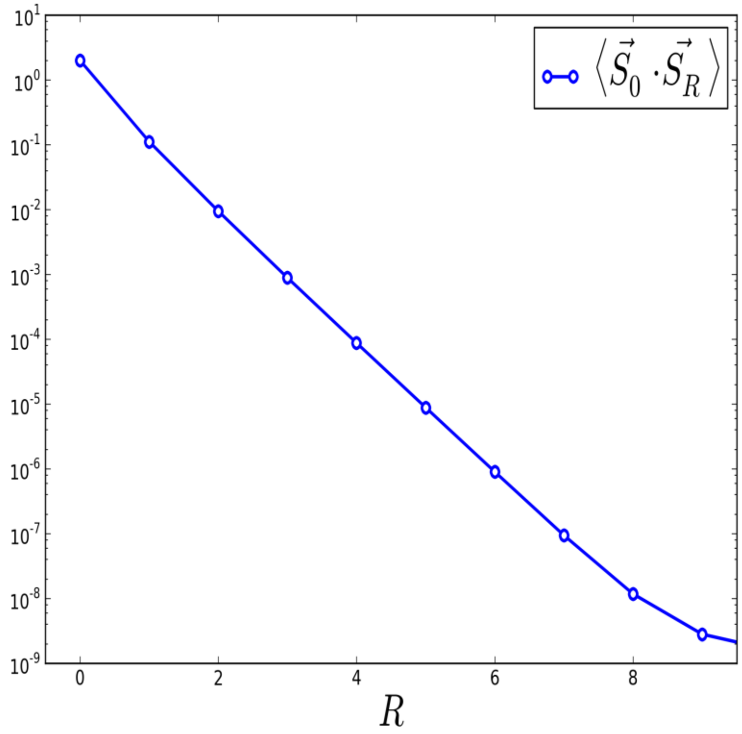
- Test case: XY Ferromagnet (J_x / J_z large and negative)



- z-axis correlation decay to zero rapidly
- In-plane correlations decay to a non-zero constant

“Large” spin results

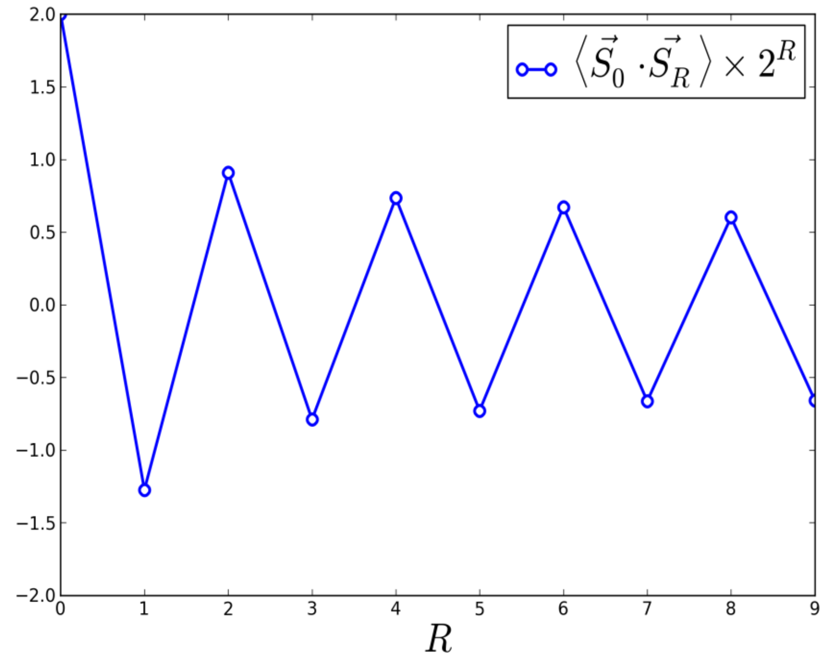
- Disordered quantum paramagnet (large d/J_z)



- Exponentially decaying spin-spin correlations, as expected

"Large" spin results

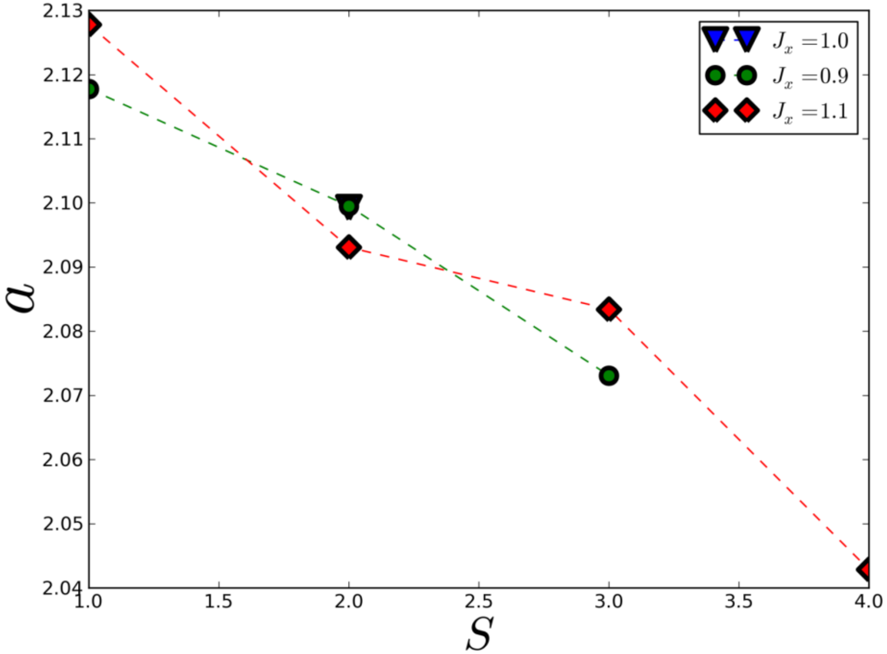
- 120-degree states and 3-color ordering

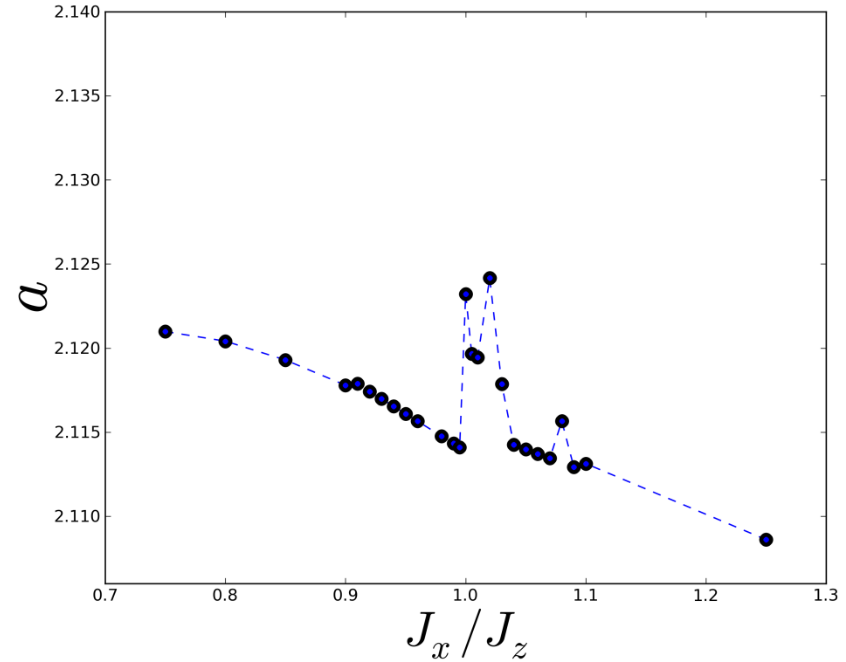


- The closer the decay is to $(-1/2)^R$, the closer the state is to being 3-color-ordered

"Large" spin results

- Scaling at the Isotropic Point $J_x = J_z$ for $S \geq 1$





- Qualitative agreement for larger S values
- Some difficulties near the Isotropic Heisenberg point